KDP-2

KLEIN'S DESIGN PROGRAM - 2

REFERENCE MANUAL

VERSION 5.00

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INTRODUCTORY SECTION

INTRO1-GENERAL INFORMATION - This program is an advanced, interactive optical design and analysis program. It is used in the design and analysis of all forms of optical systems. All titles and some data in tables are shown in **BOLD BLUE**. The entire text is 9pt. Times New Roman.

INSTALLATION - For information concerning installation on your computer, please refer to the installation instructions provided separately.

GETTING STARTED - This manual is the "PROGRAM REFERENCE MANUAL" accessible from the program Help menu. It completely describes all features and commands. There are two separate "TUTORIAL" manuals, also available in PDF form from the Help menu. There are also "prompting" guides available in the program HELP menu.

CASE SENSITIVITY - All program textual command input is case insensitive. Input may be in upper or lower case. All input is converted to upper case before it is processed. The basic input mode of this program is textual. Menus are provided for the more commonly used features.

COMMANDS - All program commands and some command-like auxilliary words are indicated in this manual in **BOLD RED** text.

EXAMPLES - All program examples are indicated in this manual in **BOLD GREEN** text.

GRAPHICAL USER INTERFACE - The program Graphical User Interface is intended to be used by both new users and experienced users, occasional users and regular users, amatuer users and professional users. It provides a powerful sub-set of the command driven capabilities of the program in an intuitive format. It is not intended as a replacement for the command interface and certainly is not a replacement for the macro and scripting capabilities inherent in the command interface. The user is wise to enjoy the GUI and as the occasion permits, explore the command interface. Switching between the two interfaces is as simple as moving the cursor to the command line at the bottom of the main program window and issuing a command followed by the ENTER key.

USER INTERFACE - After installation, a shortcut to the program icon can be made and placed on DESKTOP. When it is double clicked, the program loads and begins to run. The user will see the program output window, below which appears a one line "command box" with a command history option via mouse or up and down arrow keys. All typed input to the program is enetered in that input box. All textual output, which is intended to be displayed to the screen, will be placed in the main output window. This output window automatically scrolls as more and more output is placed in it. At any time, output may be selected with the mouse or by use of the "select all" menu option and copied into the CLIPBOARD or printed. The output window scrolling capacity is only limited by computer memory. The output window history can be cleared at any time issuing the "CLS" command. The selection of some of the menu items causes various program documentation documents to be opened and displayed using Adobe Acrobat Reader. There are command prompting guides, a tutorial, a reference manual and a list of new features in each previous program release dating back to version 4.00in the HELP menu. Hardcopy text output is performed either by copying text from the output window and pasting it into a word processor or by using the "OUTPUT LP" and "PRINT" commands described in the CMD section of this manual. (the "OUTPUT LP" and "PRINT" commands are only available in the distribution of the program which is under full user support). All others will need to copy and paste using the CLIPBOARD. Text output may also be printed using the "PRINT" option in the File Menu.Whenever a command generates screen graphics, those graphics are displayed in a separate window. This window may be moved, re-sized, minimized, maximized or copied into the CLIPBOARD using standard windows techniques. Graphics hardcopy and file output is available via the "GRAOUT" command described in the GRAPHICS section of this manual.

PROGRAM CAPACITIES - The fully supported version of the program, supports lens databases of up to 500 surfaces, 999 macros, each of which may have 1024 macro lines, and 75 alternate lens configurations. These limits can easily be extended should the user require greater capacity.

PROGRAM ORGANIZATION - This program has a command-driven user interface. This choice of interface provides maximum user freedom, speed and control over program execution. Some of the more common program operations are supported in the GUI interface. Program commands may be issued and executed in an immediate interactive mode from the keyboard, they may be strung together in an input data file and read from within the running program or they may be composed into internal macro programs using the built-in macro programming language and editor. Macros can be stored on disk and executed from within the running program at any time. Macro programs (macros and macro functions) can call other macro programs in nests up to 20 levels deep. Once created, these macros look and feel exactly like hard coded program commands. There are also special macro specific commands which enable a macro to be much more than just a string of program commands. Full details are given in the MACRO section of this manual.

ORGANIZATION OF COMMAND INPUT - Program command input is performed through a succession of text commands, each of which may consist of up to 140 characters, including blanks. All program commands will have one of the following formats:

1)   Command Word
2)   Command Word + Qualifier Word
3)   Command Word + Alphanumeric String
4)   Command Word + Qualifier Word + Alphanumeric String
5)   Command Word + from 1 to 5 Numeric Words
6)   Command Word + from 1 to 5 Numeric Word + Alphanumeric String
7)   Command Word + Qualifier Word + from 1 to 5 Numeric Words
8)   Command Word + Qualifier Word + from 1 to 5 Numeric Words + Alphanumeric String
9)   Command Word + ? (special interrogator character)
10)   Command Word + Qualifier Word + ? (special interrogator character)

All commands MUST ALWAYS begin with a COMMAND WORD.

COMMAND AND QUALIFIER WORDS - Command and qualifier words may consist of up to eight alphanumeric or other special characters, except the characters ";" and ",". The use of ";" will be covered later. The comma "," and the blank " " are used as special command delimiters and may not be part of the input, except when they appear as part of an alphanumeric string once that string has begun. The command word is always the first entry on a command line. Macro names follow the same rules as command words, being limited to 8 characters. The command words and qualifier words may begin with any allowed character. The qualifier word, if specified, always follows a command word. The first character in a command word, qualifier word or macro name may not be a digit (0 through 9), a plus "+" or minus "-" sign, a question mark "?" or a decimal point ".". Leading blanks are discarded.

NUMERIC WORDS (NUMERIC INPUT - Up to five numeric words may be used in a single program command, though many commands do not use all five words. Each numeric word may be represented by no more than 23 characters, including a decimal point and an "E" or "D" representing exponential notation. Input is otherwise free format. All numeric words are stored internally in double precision. Numeric data is held internally and transferred in a D23.15 format whenever it is written to or read from disk in an ASCII format. If explicit exponential notation is not used, a plus or minus sign can be used to indicate the start of an exponent. If exponential notation is used, a plus sign is optional. A blank following a "D" or "E" is treated as a plus sign. The exponent may contain one to three digits but must not have a magnitude greater than 300. A decimal point may occur anywhere prior to the start of an exponent. In the absence of a decimal point, an implied decimal point is understood to follow the rightmost digit before the exponent. Leading plus signs are optional.

SPECIAL CHARACTER (" ; ") - The semicolon " ; " character is used as a virtual carriage return. It allows for up to 20 program commands to be issued per 140-character input line. This character can be issued from any program level, including from within the macro editor. It is **ALWAYS** executed immediately. The semicolon is not available as part of string input. Use a comma instead.

THE ALPHANUMERIC STRING - Alphanumeric string input can consist of up to eighty (80) alphanumeric or special characters, excluding ";". Alphanumeric strings may be input as upper or lower case. In the case of the comment and message commands ("C" and "M"), the case of the input is remembered. For all other program commands, program input is automatically converted to upper case before being processed by the main program input parser.

SEPARATORS - A command word and a qualifier word may be separated from one another by one to eight blank spaces. A command word or a command word/qualifier word pair may be separated from the first numeric word by either one to eight blank spaces, a comma or a comma and one to eight blank spaces. Default numeric input is always indicated by no numeric input word or by a succession of commas. The formal rule for separating a command word or a command word/qualifier word combination from a following alphanumeric string is to use a blank space or a comma following the command word or command word/qualifier word pair. This space or comma is then followed by the alphanumeric string. The result of using ,, to specify default input varies from command to command.

COMMAND EXAMPLES
1) **WRITE** - (Command Word)
2) **WRITE ALL** - (Command Word + Qualifier Word)
3) **SET , 25.4** - (Command Word + Numeric Word #1)
4) **SET A 25.4** - (Command Word + Qualifier Word + Numeric Word #1)
5) **M, THE ANSWER IS WRONG** - (Command Word + Alphanumeric String)
6) **NSUB DV , 12.3 , 4.5 , 6.0,,,** - (Command Word + Qualifier Word + Numeric Input with default values for numeric words 4 and 5)

COMMAND DESCRIPTIONS - Program commands are always shown in upper case. Each command is presented in a command shadowed box followed by a complete description of that command, its use and its effects. In a textual reference, commands are delimited by double quotation marks. For example, the command which lists all of the surface data in the current lens would be denoted in text by "RTG ALL". Minimum use of command shorthand will be used in this manual to denote required versus optional input. If a particular input to a command is optional, that fact is simply stated in the description which follows the command box. An attempt has been made to write this manual in simple, plain Engish.

INTRODUCTORY SECTION

PROGRAM PROMPT - When operating in the command interface mode,the program screen prompt is a three-character string followed by a colon ":". At this prompt, commands may be typed in followed by the press of the <ENTER> key. The three-character string preceding the colon indicates the current program level. The program levels corresponding to the various prompts are listed in the following table.

PROMPT CHARACTER STRING	PROGRAM LEVEL
CMD	MAIN or COMMAND
SPE	SPECTRAL ANALYSIS
MAC	MACRO INPUT
MED	MACRO EDIT (MEDIT)
LEN	LENS INPUT
ULN	LENS UPDATE
SPS	SPECIAL SURFACE (SPSRF)
USP	UPDATE SPECIAL SURFACE
FIT	SPECIAL FUNCTION FITTING
CFG	CONFIGS INPUT
UCF	UPDATE CONFIGS
MER	MERIT FUNTION INPUT
UMR	UPDATE MERIT FUNCTION
VAR	VARIABLES INPUT
UVB	UPDATE VARIABLES
TVB	TOLERANCE VARIABLES INPUT
UTV	UPDATE TOLERANCE VARIABLES
CMP	COMPENSATION VARIABLES INPUT
UCP	COMPENSATION VARIABLES UPDATE
TOP	TOLERANCE OPERAND INPUT
UTP	TOLERANCE OPERAND UPDATE
FOC	FOCRIT (FOCUS CRITERIA) INPUT
UFC	FOCRIT UPDATE

PROGRAM ORGANIZATIONAL STRUCTURE - The organizational structure of the program is conceptually very simple. When the program begins running, a prompt symbol will be displayed on the computer screen. At this prompt, you enter a program command and press the <RETURN> or <ENTER> key on the keyboard. Depending on the nature of the command issued, some action will be taken by the program. This action may or may not result in output. When the program begins, it is always at the CMD level. This is the main, or top, level of the program. Beneath this level are sub-levels which are used to manage the lens data, optimization files, tolerancing, macro programming, etc. The organizational flow of the program is best understood by examining the figure below. Solid lines represent paths along which the user travels while using the program. Dashed lines represent internal automatic data flow during program operation.

INTRODUCTORY SECTION

Program Road Map

PROGRAM ROAD MAP

CMD LEVEL

INTERACTIVE AND BATCH I/O
ACCESS TO ALL OTHER LEVELS
TRACE RAYS, CALC. ABERRATIONS

3rd, 5th, 7th ORDER ANALYSIS
EXECUTE MACROS
EXTERNAL DATA TRANSFER

LENS LIBRARY
OPTIMIZATION
INTERACTIVE GRAPHICS

LINK TO OTHER CODES
SENSITIVITY ANALYSIS

LENS DATA BASE LEVEL

LENS INPUT AND MODIFICATION,
SOLVES, PIKUPS, GLASSES, TILTS,
DECENTERS, REFRACTIVE AND
REFLECTIVE SURFACES

SPECIAL SURFACES

DEFINE NON-STANDARD SURFACES,
DIFFRACTION GRATINGS, HOES, FIT
SURFACES TO MEASURED DATA

SPECIAL DATA FITTING

FIT DATA TO VARIOUS FUNCTIONAL
FORMS, DATA SMOOTHING

OTHER LENS CONFIGURATIONS

DEFINE ALTERNATE CONFIGURATIONS
OF EACH LENS SYSTEM FOR
OPTIMIZATION AND ANALYSIS

OPTIMIZATION AND TOLERANCING

SET UP VARIABLE LISTS, DEFINE MERIT
FUNCTIONS, DEFINE TOLERANCE
MODELS

FUTURE ADDITIONS

GLOBAL SURFACE INPUT, GLOBAL
OPTIMIZATION, NON-SEQUENTIAL
RAY TRACING AND DETAILED STRAY
LIGHT ANALYSIS

MACRO FILE

CREATE, EDIT AND FILE MACROS AND
MACRO FUNCTIONS FOR LATER USE
FROM THE TASK LEVEL. USER CAN
CREATE NEW PROGRAM COMMANDS

SPECTRAL AND NARCISSUS ANALYSIS

CALCULATE SPECTRAL WEIGHTING
FACTORS, TRANSMISSION ANALYSIS

PROGRAM DISK DIRECTORY STRUCTURE - During the program installation process, the root or main directory is created on the target disk drive. A default root directory name is supplied if you do not specify one. Several sub-directories are created beneath the main directory. These directories house the following classes of files:

DIRECTORY NAME	FILE CLASSES STORED
\LIBSPO	All the files associated with ray spot diagrams.
\LIBAUT	All the files associated with the optimization process.
\LIBGLA	All of the optical material glass catalogs are stored here in binary and ASCII format. Located here are the .EXE files which rebuild a binary glass catalog file from the ASCII version. This allows the user to update the glass catalogs. The procedure for doing this update is described in the file GLAUP.DOC which is also stored in this directory.
\LIBLxx (These are the directory names of the manufacturer lens libraries.)	All the files associated with the lens manufacturer lenses are stored in these directories.

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PROGRAM FILES - The following files are stored in the main program directory or in one of its sub-directories:

PRINTER.TXT	Printer file created by the program.
PUNCHFILE.DAT	Auxiliary data transfer file created by the program.
CARDTEXT.DAT	Auxiliary data transfer file created by the program.
EDITTEXT.DAT	Editor file used with a DOS editor and the "EDIT" command.
DEFAULTS.DAT	A user-created file containing program commands which the user wishes to run automatically when the program starts. The commands included in the default version of this file are: "OUT TP" and "IN TP" .
TAB.DAT	Table Writer file
DATA.DAT	Functional fitting data file
SPD.DAT, LSF.DAT	MTF, Line Spread Function files
RAYS.DAT, FIELDS.DAT	Field and ray definition files
AUTO.DAT, AUTO2.DAT	Optimization save files
OPDDAT.DAT	OPD fitting files
APMAP.DAT	Pupil apodization file
FOOT1.DAT	Beam footprint file

BATCH MODE OPERATION - The program is primarily intended to be used in an interactive setting. There are; however, situations where the program may need to be run in a BATCH mode. To do this, prepare an ASCII file named BATCH.DAT which contains all of the program commands which are to be executed. Place it in the main program directory. Include an "EXIT" statement as the last entry in this file. Next, either type "PRG BATCH" at the DOS command prompt or at the RUN line. The program will execute all of the commands in the BATCH.DAT file.

THE PROGRAM AS A SUBROUTINE - In some special situations, the program may be available as a callable subroutine. If you don't have the program in that form, then you probably are not going to get the program in that form. When the program is callable as a subroutine, all screen input and output operations are turned off. Graphics output is limited in that no program manipulation of the NEUTRAL.DAT file is possible via the VIE and GRAOUT commands. No operating system commands can be executed in this mode from inside the program. All such actions are to be programmed by the user in non-program related subroutines. When the program is run as a subroutine, it automatically runs in the above described BATCH mode.

OPTICAL DEFINITIONS - The following section has been asked for by several users. It is intended to provide a short review of the "optical definitions" assumed by the program.

Local Optical Axes - The program assumes, at the origin or "vertex" of every surface in a lens prescription, that there exists a right handed rectangular "local" coordinate system. In the absence of surface tilts and decentrations, the positive local Z-axis is perpendicular to the surface and points to the right. The positive Y-axis is "up" and the positive X-axis is "into" the page or screen.

Sequential Database - The pth of rays traced through lens database sequential. From surface 0, "the object surface" to "surface 1" to "surface 2" and to each next surface and then to the final surface in the database. The relative positions of each surface may be established in either a "local" sense or a "global" sense. Most of the time, the "local" sense is the easiest way to establish these relationships. In the "local" sense, surface 1 is positioned relative to surface 0, surface 2 relative to surface 1 and so on. The relative position of a "following" surface is established with a "thickness" or TH specification and by decentration and surface tilt commands relative to the previous surface.

Surface Tilts - A following surface may be reoriented with repect to the previous surface by assigning surface tilts. When this is done, the order in which the tilts are applied is generally ALPHA (about the X-axis), then BETA about the new Y-axis and then GAMMA about the new Z-axis. There are exceptions. The angular sign conventions are such that ALPHA and BETA are left-handed positive and GAMMA is right-handed positive. Figures illustrating these conventions can be found in the Lens Database section of this manual This sign convention agrees with CODE-V and ACCOS-V. In ZEMAX, the ALPHA and BETA sign conventions are right-handed positive.

Paraxial Optical Axis - Paraxial optical ray tracing is the result of a linearization of the trigonometric ray tracing equations in which the SINE and TANGENT of all angles is replace by their angular value in radians and the COSINE is replace by 1.0. The paraxial ray trace ignores surface decentrations and tilts. The paraxial optical axis therefore passes through the center of all lens database surfaces.

Real Optical Axis - The real optical axis has more than one definition depending upon program ray trace settings.

If real ray aiming is turned off with the AIMRAY OFF command (not the default condition), then the real ray optical axis is defined by the path of the ray which originates at the center of the object surface (generally surface 0) and passes through the center of surface 1. The path of this ray, through the rest of the surfaces is considered to be the "gut ray" and defines the optical axis of the system.

If real ray aiming is turned on with the AIMRAY ON command (the default condition), then:

If there is no clear aperture assigned to the "reference surface", the real optical axis is defined by the path of the ray which originates at the center of the object surface (generally surface 0) and passes through the center of the "reference surface". The ray is iteratively aimed during this process. The path of this ray, through the rest of the surfaces is considered to be the "gut ray" and defines the optical axis of the system. The reference surface (see the REFS command) may be assigned to be any surface betweem the object surface and the image surface. In almost all cases, it should be the same surface defined to be the aperture stop (see the ASTOP command).

If there is a clear aperture assigned to the "reference surface", the real optical axis is defined by the path of the ray which originates at the center of the object surface (generally surface 0) and passes through the center of the clear aperture assigned to the "reference surface". The ray is iteratively aimed during this process. This clear aperture may even be decentered and tilted and the ray will still go through the center of the clear aperture. The path of this ray, through the rest of the surfaces is considered to be the "gut ray" and defines the optical axis of the system. The reference surface (see the REFS command) may be assigned to be any surface betweem the object surface and the image surface. In almost all cases, it should be the same surface defined to be the aperture stop (see the ASTOP command).

Real Ray Trace - Real single trigonometric rays are traced with the paradigm of reference object heights (or angles) and reference aperture heights (see the SCY, SCX, SAY and SAX commands). These are single X and Y values are stored with the lens. To specify a location in the object surface from which rays originate, the FOB (Fractional OBject height) command is used to establish a starting point relative to the reference object height (or angle) values. FOB input values may be of any value and are not limited to lie betweem -1 and 1. The RAY command is then used to specify the relative position in the reference surface, vie the reference aperture heights through which a ray will pass (if ray aiming is on) or the relative position in surface 1 if ray aiming is off.

Reflections - Every time a ray strikes and interacts with a reflector, the ray's local n-direction cosine is essentially reversed and the sign of the refractive index is reversed. This is common practice in all optical design programs.

UTILITY (CMD)-GENERAL INFORMATION - The main program level is known as the CMD level. The program is at the CMD level when it begins to execute. Commands entered at this level from the keyboard are executed in an immediate mode. All commands issued from the keyboard are known as CMD level commands, except those commands which cause the program to enter a level other than the CMD level. Commands such as "MACRO" or "MEDIT" or "LENS" are, therefore, not considered to be CMD level commands. The following commands are CMD level commands. They may be issued from the keyboard, from input files like CARDTEXT.DAT and EDITTEXT.DAT or they may be included in, and issued from, a macro or macro function.

GENERAL CMD LEVEL COMMANDS - The first part of the CMD section deals with commands which do not relate directly to the optical system being modeled. They are general commands which control overall program behavior.

SPECIAL ASSISTANCE COMMANDS - Special assistance commands can be issued at any time and from any program level. The only instance in which they will not be immediately executed is when they are entered as part of a macro definition. They will, however, be executed when the macro is executed. Only some of these commands may be included as part of a macro.

C , (comment - up to 69 characters in length) - The "C", or comment, command is provided for macro documentation. It performs no other operation and produces no output. Comment commands within a macro are not processed during macro execution. The comment command may be included in a macro and used to document features of that macro. When the comment command followed by a comment is issued from the CMD level and when "ECHO ON" is set, the comment command and comment are echoed to the terminal display.

M , (message - up to 69 characters in length) - If the input included with the "M" command is an alphanumeric string message, that string is sent to the current output device. The message command may be used in order to produce any desired text output. The message command may be included in a macro.

"?" - The "?" command generates a message as to the type of input the program next expects. It is a universal command valid from all program levels. For example, at the CMD level, "?" produces the message "READY FOR CMD LEVEL INPUT". "?" may not occur in a macro since it is always processed immediately after it is issued. In some cases, issuing a command followed by a "?" or by a space and a "?" will generate an output of additional information about that command. This command is not supported in the "THE PROGRAM AS A SUBROUTINE" mode.

GETTING HELP - There are no commands, other than "?", for requesting program help. All "HELP" features are accessed from the program "HELP" menu.

"PROGSIZE" - The "PROGSIZE" command displays the number of lens surfaces per lens, the number of lines per macro and the maximum number of macros allowed in the current program. This command is not supported in the "THE PROGRAM AS A SUBROUTINE" mode.

"blank input" - "blank input generated using a carriage return via the RETURN key, when it is the only input on a command line (no multiple commands stacked on a line), produces a message specifying the name of the current program level. When given as part of a stacked command line, no output is produced. The "blank input" command may not occur as an instruction in a macro since it is always processed immediately after it is issued. This command is not supported in the "THE PROGRAM AS A SUBROUTINE" mode.

EJECT - If the default output device is defined to be LP (PRINTER.TXT), "EJECT" sends a page eject to the file PRINTER.TXT which causes the printer to position itself at the top of the next page when the file PRINTER.TXT is finally printed. "EJECT" may be used in a macro.

ECHO ON or **ECHO OFF** - When the program is first begun, the echo feature is off. If it is set to on, then each input command will be echoed to the current output device. "ECHO ON" and "ECHO OFF" may also be used in a macro . The program default is "ON". It causes the command issued with the keyboard to be echoed to the output window appended to a ">" character. This command is not supported in the "THE PROGRAM AS A SUBROUTINE" mode.

EXIT or EXI - The "EXIT" or "EXI" command terminates program execution, closes all open files and returns control to the computer operating system. "EXIT" or "EXI" may be used in a macro. This command causes immediate exit from the program. If the dialog close program or exit menu items are selected, the program will prompt the user for an exit confirmation.

SYS or **SYSTEM (alphanumeric string)** - The "SYS" or "SYSTEM" command causes program execution to be temporarily suspended and the operating system command in the alphanumeric string to be executed. If no string is issued, no action is taken. This command is not supported in the "THE PROGRAM AS A SUBROUTINE" mode.

WSYS or **WSYSTEM** - The "WSYS" or "WSYSTEM" command causes program execution to be temporarily suspended and a process spawned to the operating system. The user may then issue any operating system commands. The user must type "EXIT" to stop the spawned process and return to the program. This command is not supported in the "THE PROGRAM AS A SUBROUTINE" mode.

EDIT (file name) - The "EDIT" command causes program execution to be temporarily suspended. The file with name "file name" is edited using the built-in full screen editor. When the editor command, which would act to file the edited file, is issued, the editor will stop and program execution will resume. If no file name is supplied, the EDITTEXT.DAT file will be opened by default. If the file associated with the "file name" does not exist, it will be created and then opened. This command is not supported in the "THE PROGRAM AS A SUBROUTINE" mode.

DATE - The "DATE" command displays the current date.

TIME - The "TIME" command displays the current time.

STAMPD (ON or OFF) - The "STAMPD" command turns date stamping "on" or "off" whenever the "lens identifier" is displayed in a textual or graphical context. The current date will be appended to the beginning of the "lens identifier" display. Issued with a "?", the current status of date stamping will be displayed. The default is "off".

STAMPT (ON or OFF) - The "STAMPT" command turns time stamping "on" or "off" whenever the "lens identifier" is displayed in a textual or graphical context. The current time will be appended to the beginning of the "lens identifier" display. Issued with a "?", the current status of date stamping will be displayed. The default is "off". If time and date stamping are both "ON", the time will always precede the date.

SETTIMER - The "SETTIMER" command sets the internal program timer to zero.

SEETIMER - The "SEETIMER" command displays the elapsed time, in seconds, since the program timer was set to zero.

LENDIR , (qualifier word) By default when the program begins execution, the lens library is located in the directory LIBLEN which sits just below the directory into which the main program was installed and from which the main program runs. The "LENDIR" command is used to change the current lens library directory to the directory named by the first six characters of the "qualifier word". If this directory exists, then only the internal program pointer, pointing to the lens library directory, is changed. If the directory does not yet exist, it is created. After creation of a new lens library directory, a new lens library must be initialized in this new directory via the "ILF" and "PROCEED" commands. The "LENDIR" command makes it possible to have access to as many user-created lens libraries as desired or to update and modify the manufacturer lens catalogs. The only limitation is available disk space. If "LENDIR" is issued followed by a "?", the name of the current lens library directory will be displayed. The new directory name designated by the "qualifier word" must contain exactly six non-blank characters.

MACDIR or CHGMAC , (qualifier word) - By default when the program begins execution, the macro library is located in the directory LIBMAC which sits just below the directory into which the main program was installed and from which the main program runs. The "MACDIR" command is used to change the current macro library directory to the directory named by the first six characters of the "qualifier word". If this directory exists, then only the internal program pointer, pointing to the macro library directory, is changed. If the directory does not yet exist, it is created. After creation of a new macro library directory, a new macro library must be initialized in this new directory via the "IMF" and "PROCEED" commands. The "MACDIR" command makes it possible to have access to as many macro libraries as desired, only limited by available disk space. If "MACDIR" is issued followed by a "?", the name of the current macro library directory will be displayed. The new directory name designated by the "qualifier word" must contain exactly six non-blank characters.

TRADIR , (qualifier word) - By default when the program begins execution, the transmission file library is located in the directory TRALEN which sits just below the directory into which the main program was installed and from which the main program runs. The "TRADIR" command is used to change the current transmission file library directory to the directory named by the first six characters of the "qualifier word". If this directory exists, then only the internal program pointer, pointing to the transmission file library directory, is changed. If the directory does not yet exist, it is created. After creation of a new transmission file library directory, a new transmission file library must be initialized in this new directory via the "ITF" and "PROCEED" commands. The "TRADIR" command makes it possible to have access to as many transmission file libraries as desired, only limited by available disk space. If "TRADIR" is issued followed by a "?", the name of the current transmission file library directory will be displayed. The new directory name designated by the "qualifier word" must contain exactly six non-blank characters.

PLTDIR , (qualifier word) - By default when the program begins execution, the plot library is located in the directory LIBPLO which sits just below the directory into which the main program was installed and from which the main program runs. The "PLTDIR" command is used to change the current plot library directory to the directory named by the first six characters of the "qualifier word". If this directory exists, then only the internal program pointer, pointing to the plot library directory, is changed. If the directory does not yet exist, it is created. After creation of a new plot library directory, a new plot library must be initialized in this new directory via the "IPF" and "PROCEED" commands. The "PLTDIR" command makes it possible to have access to as many plot libraries as desired, only limited by available disk space.

The new directory name designated by the "qualifier word" must contain exactly six non-blank characters. NOTE: If, each time the program is started, it is desired to go to an alternate lens, macro, transmission file and/or plot file library directory, then any or all or the preceding four commands, including the target directory name, may be included in the DEFAULTS.DAT file in the main program directory.

PRINT (P or L) The "PRINT" command, not to be confused with the SPECT level command of the same name, causes the contents of the current printer file to be printed to the attached printer. The default is a "P" or "portrait" orientation. Issuing the qualifier "L" causes a "landscape" orientation. Output to the printer file is controlled using the "OUTPUT LP" command discussed previously. If no printer file exists, a warning message is issued and no printed output is generated. This command is not supported in the "THE PROGRAM AS A SUBROUTINE" mode.

FUNNAME (alternate name) , i - The "FUNNAME" command causes the macro function desinated by "i" to be given the alternate name "alternate name". "alternate name" is entered as a qualifier word and may be up to eight characters in length. "alternate name" should not be the name of any existing macro or program command or unexpected program behavior will result. To give the macro function FUN03 the alternate name "DOTHIS", the command would be: **FUNNAME DOTHIS , 3.** Macro function alternate names remain in effect until they are changed or until the program execution ends.

REPETITION COMMANDS

DO (qualifier word) , i , j - The "DO" command is a rather special and useful repetition command. It is used in combination with any CMD level command which takes as its argument a current lens surface number for its numeric word #1 input and which does not require explicit numeric word #2 through #5 input. An example of its use would be : **DO RTG 3 5.** This causes repeated "RTG" commands to be issued for surfaces 3, 4 and 5. Another example would be the sequence of commands: **FOB** followed by **RAY 1** followed by **DO PRY 8 20.** These commands trace a ray from relative fractional field position 0.0. The ray will intersect the reference surface at a fractional reference Y-height of 1.0 and fractional reference X-height of 0.0. YZ-plane ray data will then be displayed for this ray at surfaces 8 through 20. The default for "i" is always the current object surface number. The default for "j" is always the current image surface number.

INPUT/OUTPUT REDIRECTION - The following commands act to redirect program input and output:

INPUT TP	INPUT CR	INPUT ED	INPUT PU
OUTPUT TP	OUTPUT CP	OUTPUT ED	OUTPUT PU
REWIND CP	OUTPUT NULL		

In all cases, "IN" and "OUT" may be used as short forms of the words "INPUT" and "OUTPUT". These "INPUT"/"OUTPUT" commands are used to redefine the device from which input is received or to which output is sent. "TP" refers to the keyboard, console, terminal(input) or screen(output). "LP" refers to the disk file PRINTER.TXT. This file is used to direct printer output to the attached printer. "CP" and "CR" refer to a file named CARDTEXT.DAT. This file is useful for storing program data which is to be post-processed by other programs or different sections of the program. This file may be rewound using the "REWIND CP" command. The "REWIND CP" command sets the file pointer back to the beginning of the file CARDTEXT.DAT and allows overwriting of data. "PU" and "ED" refer to two other auxiliary input/output disk files "PUNCH.DAT" and "EDITTEXT.DAT". The EDITTEXT.DAT file is used by the "EDIT" command described earlier. "NULL" refers to the device NUL and is used for hiding output. Input and output redirection become effective with the first input or output command processed following the issuance of the redirection. An output redirection command remains in effect until another redirection command is issued or until the program is exited. The startup default output directions are "INPUT TP" and "OUTPUT TP". Input redirection commands cause the associated targeted files to be read immediately after the "INPUT" command is processed, whether the input redirection command is issued from the keyboard or from within a macro. If there is a desire to output to or input from other data files, simply use the "SYS" command to issue a DOS level copy command in order to copy the desired data to or from one of the standard files described above. Commands read in from the associated file are sequentially processed by the program's command processor until the file has been completely read. The files designated by "LP", "CR"/"CP", "PU" and "ED" are all FORMATTED/SEQUENTIAL ASCII files. All disk files associated with output redirection are kept in the same drive and directory as the main EXE file. **NOTE: "OUT" and "OUTPUT" are not allowed in an input script though they are allowed in MACROS.**

USER SPECIFIED FILENAMES - The "INPUT" or "IN" and "OUTPUT" or "OUT" commands have an alternate syntax which allows the user to specify a file name for output and input.

OUTPUT T (optional file name of up to 12 characters) or
OUTPUT FILE (non-optional file name of up to 12 characters) or

GENERAL COMMAND SECTION

INPUT FILE (non-optional file name of up to 12 characters) - The command "OUTPUT T" without the optional file name reverts to the previous command "OUTPUT TP". If an optional file name is specified, output is sent both to the screen and to the specified file. The "OUTPUT FILE" command sends output to the file specified. A file name is required as part of the input for this command. The "INPUT FILE" command attempts to read valid program commands from the file specified. If invalid program commands are encountered, appropriate error messages are generated.

FILE APPEND/REPLACE - The next two commands allow the user to set the "append/replace" characteristic of the files PRINTER.TXT, EDITTEXT.DAT, PUNCH.DAT and CARDTEXT.DAT.

APPEND - The "APPEND" command sets the files PRINTER.TXT, EDITTEXT.DAT, CARDTEXT.DAT and PUNCH.DAT to be defined as "append" type files. After "APPEND" is issued, then each time one of these files is selected as the output file using the "OUT" or "OUTPUT" command, output will be appended to the bottom of that file.

REPLACE - The "REPLACE" command sets the files PRINTER.TXT, EDITTEXT.DAT, CARDTEXT.DAT and PUNCH.DAT to be defined as "sequential" type files. After "REPLACE" is issued, then each time one of these files is selected as the output file using the "OUT" or "OUTPUT" command, the file will be wiped clean and new output will be placed at the top of the file. "REPLACE" is the program default.

RETRIEVAL OF PROGRAM DATABASE VALUES FOR FURTHER PROCESSING
(THE "GET" COMMAND) - The "GET" command, and the wide range of program database items which it can retrieve, make this program more flexible and powerful than any other optical design and analysis code. Using the "GET" command, most program database items can be quickly retrieved into the ACCUMULATOR (X-register) or into any one of the MAXREG general purpose storage registers. These retrieved values may then be displayed, manipulated interactively at the CMD level or manipulated from within a user-written macro or macro function. The intrinsic speed of macro function execution, together with the power of the "GET" command, gives the optimization and tolerancing operations their great power and flexibility.

GET (database item name) , i , j , k ,, r or
SHOW (database item name) , i , j , k ,, r - The "GET" command retrieves into the ACCUMULATOR (X-register), and optionally into the general purpose storage register designated by "r", the program database item with name = "database item name". The numeric input values "i", "j" and "k" are not always required, and their use will be made clear by referring to the "GET" table starting on the next page. Some data items which are automatically placed into the X-register or accumulator during the execution of specific program commands do not appear in the "GET" list because they do not need to be there. The "GET" command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5". The "SHOW" command, when used with a qualifier word, acts exactly as the "GET" command does except that it issues an automatic "WRITE" command which displays the new contents of the accumulator to the screen. This is the second usage of the "SHOW" command.

GETABLE LENS DATABASE PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
UNITS	(not used)	(not used)	(not used)	Returns value of units: 1 = inches 2 = centimeters 3 = millimeters 4= meters
ISN	(not used)	(not used)	(not used)	Current image surface number
OSN	(not used)	(not used)	(not used)	Current object surface number
REFS	(not used)	(not used)	(not used)	Current reference surface number
ASTOP	(not used)	(not used)	(not used)	Current aperture stop surface number
WV	wavelength number	(not used)	(not used)	Wavelength in microns corresponding to given wavelength number
SPTWT	wavelength number	(not used)	(not used)	Spectral weighting factor for wavelength "i".
CW	(not used)	(not used)	(not used)	Control wavelength number
MODE	(not used)	(not used)	(not used)	Returns value of MODE: 1 = FOCAL 2= UFOCAL 3 = AFOCAL 4 = UAFOCAL
RD	surf #	(not used)	(not used)	Radius of curvature at surface "i"
CV	surf #	(not used)	(not used)	Curvature at surface "i"
TH	surf #	(not used)	(not used)	Thickness at surface "i"

GETABLE LENS DATABASE PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
CC	surf #	(not used)	(not used)	Conic constant at surface "i"
AC	surf #	(not used)	(not used)	2nd order aspheric (plano surfaces only) at surface "i"
AD	surf #	(not used)	(not used)	4th order aspheric at surface "i"
AE	surf #	(not used)	(not used)	6th order aspheric at surface "i"
AF	surf #	(not used)	(not used)	8th order aspheric at surface "i"
AG	surf #	(not used)	(not used)	10th order aspheric at surface "i"
AH	surf #	(not used)	(not used)	12th order aspheric at surface "i"
AI	surf #	(not used)	(not used)	14th order aspheric at surface "i"
AJ	surf #	(not used)	(not used)	16th order aspheric at surface "i"
AK	surf #	(not used)	(not used)	18th order aspheric at surface "i"
AL	surf #	(not used)	(not used)	20th order aspheric at surface "i"
RDTOR	surf #	(not used)	(not used)	Toric radius of curvature at surface "i"
CVTOR	surf #	(not used)	(not used)	Toric curvature at surface "i"
CCTOR	surf #	(not used)	(not used)	Toric conic constant at surface "i"
ADTOR	surf #	(not used)	(not used)	4th order anamorphic coefficient at surface "i"
AETOR	surf #	(not used)	(not used)	6th order anamorphic coefficient at surface "i"
AFTOR	surf #	(not used)	(not used)	8th order anamorphic coefficient at surface "i"
AGTOR	surf #	(not used)	(not used)	10th order anamorphic coefficient at surface "i"
ALPHA	surf #	(not used)	(not used)	ALPHA surface tilt angle (degrees) at surface "i"
BETA	surf #	(not used)	(not used)	BETA surface tilt angle (degrees) at surface "i"
GAMMA	surf #	(not used)	(not used)	GAMMA surface tilt angle (degrees) at surface "i"
TCODE	surf #	(not used)	(not used)	Returns the surface "i" tilt code: 0 = (no tilt) 1 = TILT -1 = RTILT 2 = TILT AUTO 3 = TILT AUTOM 4 = TILT BEN 5 = TILT DAR
VNUM	surf #	(not used)	(not used)	V-number or Abbe number for the MODEL glass at surface "i". It is equal to: $$VNUM = \frac{\left(N_{cw} - 1\right)}{\left(N_{pcw1} - N_{pcw2}\right)}$$ Where: pcw1 and pcw2 are the primary wavelength pair defined in the lens database.
PARTL	surf #	(not used)	(not used)	Partial Dispersion for the MODEL glass at surface "i". It is equal to: $$PARTL = \frac{\left(N_{cw} - N_{pcw2}\right)}{\left(N_{pcw1} - N_{pcw2}\right)}$$ Where: pcw1 and pcw2 are the primary wavelength pair defined in the lens database.

GETABLE LENS DATABASE PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
INDEX	surf #	(not used)	(not used)	Refractive index of MODEL glass at surface "i".
MCODE	surf #	(not used)	(not used)	Returns: 0.0 if surface is surrounded by "AIR" 1.0 if material type is "REFL" 2.0 if material is a catalog glass 3.0 if material type is "MYGLASS" 4.0 if material type is "MODEL" 5.0 if material is "PERFECT" 6.0 if material is "IDEAL" 7.0 if material is "REFLTIRO" 8.0 if material is "REFLTIR"
XD	surf #	(not used)	(not used)	X-surface decentration at surface "i"
YD	surf #	(not used)	(not used)	Y-surface decentration at surface "i"
ZD	surf #	(not used)	(not used)	Z-surface decentration at surface "i"
CLAP	surf #	(not used)	(not used)	Clear aperture semi-diameter at surface "i" for a circular clear.
COBS	surf #	(not used)	(not used)	Obscuration semi-diameter at surface "i" for a circular obscuration
CLAPE	surf #	(not used)	(not used)	Clear aperture erase semi-diameter at surface "i" for a circular clear aperture
COBSE	surf #	(not used)	(not used)	Obscuration erase semi-diameter at surface "i" for a circular obscuration
CLRAD	surf #	(not used)	(not used)	Racetrack radius at surface "i" for a racetrack clear aperture
CORAD	surf #	(not used)	(not used)	Racetrack radius at surface "i" for a racetrack obscuration
CLRADE	surf #	(not used)	(not used)	Racetrack radius at surface "i" for a racetrack clear aperture erase
CORADE	surf #	(not used)	(not used)	Racetrack radius at surface "i" for a racetrack obscuration erase
CLDECX	surf #	(not used)	(not used)	Clear aperture X-decentration
CLDECY	surf #	(not used)	(not used)	Clear aperture Y-decentration
CODECX	surf #	(not used)	(not used)	Obscuration X-decentration
CODECY	surf #	(not used)	(not used)	Obscuration Y-decentration
CLDECXE	surf #	(not used)	(not used)	Clear aperture erase X-decentration
CLDECYE	surf #	(not used)	(not used)	Clear aperture erase Y-decentration
CODECXE	surf #	(not used)	(not used)	Obscuration erase X-decentration
CODECYE	surf #	(not used)	(not used)	Obscuration erase Y-decentration
CLTILT	surf #	(not used)	(not used)	Clear aperture tilt
CLTILTE	surf #	(not used)	(not used)	Clear aperture erase tilt
COTILT	surf #	(not used)	(not used)	Obscuration tilt
COTILTE	surf #	(not used)	(not used)	Obscuration erase tilt
CLAPX	surf #	(not used)	(not used)	Non-circular clear aperture X-dimension
CLAPY	surf #	(not used)	(not used)	Non-circular clear aperture Y-dimension
CLAPXE	surf #	(not used)	(not used)	Non-circular clear aperture erase X-dimension
CLAPYE	surf #	(not used)	(not used)	Non-circular clear aperture erase Y-dimension
COBSX	surf #	(not used)	(not used)	Non-circular obscuration X-dimension
COBSY	surf #	(not used)	(not used)	Non-circular obscuration Y-dimension
COBSXE	surf #	(not used)	(not used)	Non-circular obscuration erase X-dimension

GETABLE LENS DATABASE PARAMETERS				
DATABASE ITEM NAME	**"i"**	**"j"**	**"k"**	**DESCRIPTION**
COBSYE	surf #	(not used)	(not used)	Non-circular obscuration erase Y-dimension
XVERT	surf #	Global ref surf #	(not used)	Global X-coordinate of the vertex of surface "i", referenced to a global origin at surface "j".
YVERT	surf #	Global ref surf #	(not used)	Global Y-coordinate of the vertex of surface "i", referenced to a global origin at surface "j".
ZVERT	surf #	Global ref surf #	(not used)	Global Z-coordinate of the vertex of surface "i", referenced to a global origin at surface "j".
LXVERT	surf #	Global ref surf #	(not used)	Global X-direction cosine of the local X-axis of surface "i", referenced to a global origin at surface "j".
MXVERT	surf #	Global ref surf #	(not used)	Global Y-direction cosine of the local X-axis of surface "i", referenced to a global origin at surface "j".
NXVERT	surf #	Global ref surf #	(not used)	Global Z-direction cosine of the local X-axis of surface "i", referenced to a global origin at surface "j".
LYVERT	surf #	Global ref surf #	(not used)	Global X-direction cosine of the local Y-axis of surface "i", referenced to a global origin at surface "j".
MYVERT	surf #	Global ref surf #	(not used)	Global Y-direction cosine of the local Y-axis of surface "i", referenced to a global origin at surface "j".
NYVERT	surf #	Global ref surf #	(not used)	Global Z-direction cosine of the local Y-axis of surface "i", referenced to a global origin at surface "j".
LZVERT	surf #	Global ref surf #	(not used)	Global X-direction cosine of the local Z-axis of surface "i", referenced to a global origin at surface "j".
MZVERT	surf #	Global ref surf #	(not used)	Global Y-direction cosine of the local Z-axis of surface "i", referenced to a global origin at surface "j".
NZVERT	surf #	Global ref surf #	(not used)	Global Z-direction cosine of the local Z-axis of surface "i", referenced to a global origin at surface "j".
LENGTH or OAL	surf #	surf #	(not used)	Algebraic sum of axial thicknesses from surface "i" to surface "j"
MLENGTH or OPTLEN	surf #	surf #	(not used)	Physical length from surface "i" to surface "j" along a path connecting surface vertices and ignoring tilts and decentrations. This is the sum of the axial thickness multiplied by the refractive index in each space.
ET or ETY	surf #	(not used)	(not used)	Edge thickness from surface "i" to surface "i"+1. Surface tilts and decentrations are ignored. If clear apertures are assigned, they are assumed circular with the YZ-plane value being used. The larger of the values on surface "i" and "i"+1 is used. If no clear apertures are assigned, then the larger of the sums of PY+PCY on surfaces "i" and "i"+1 are used in the calculation. Clear aperture decentrations and tilts are ignored.

GETABLE LENS DATABASE PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
ETX	surf #	(not used)	(not used)	Edge thickness from surface "i" to surface "i"+1. Surface tilts and decentrations are ignored. If clear apertures are assigned, they are assumed circular with the XZ-plane value being used. The larger of the values on surface "i" and "i"+1 is used. If no clear apertures are assigned, then the larger of the sums of PX+PCX on surfaces "i" and "i"+1 are used in the calculation. Clear aperture decentrations and tilts are ignored.
C1 through C96	surf #	(not used)	(not used)	This returns the value of any one of the 96 special surface coefficient values C1 THROUGH C96.
SHAPEFAC	surf #	(not used)	(not used)	This returns the shape factor for the lens element which begins at surface "i" and terminates at surface "i+1". The shape factor is defined by : $$SHAPEFAC = \frac{r_{i+1} + r_i}{r_{i+1} - r_i}$$ where: r is the radius of curvature
INR	surf #	(not used)	(not used)	Returns the current "inr" value associated with the specified surface.
SHRTWAVE	(not used)	(not used)	(not used)	Returns the wavelength, in current lens units, of the shortest wavelength whose spectral weight is non-zero.
SAY	(not used)	(not used)	(not used)	Returns the current "say" value
SAX	(not used)	(not used)	(not used)	Returns the current "sax" value
SCY	(not used)	(not used)	(not used)	Returns the current "scy" value
SCX	(not used)	(not used)	(not used)	Returns the current "scx" value
PIVX	surf #	(not used)	(not used)	X-alternate pivot point at surface "i"
PIVY	surf #	(not used)	(not used)	Y-alternate pivot point at surface "i"
PIVZ	surf #	(not used)	(not used)	Z-alternate pivot point at surface "I"
GRO	surf#	(not used)	(not used)	Linear diffraction grating order
GRS	surf#	(not used)	(not used)	Linear diffraction grating spacing in lens units
GRX	surf#	(not used)	(not used)	Linear diffraction grating x-direction number
GRY	surf#	(not used)	(not used)	Linear diffraction grating y-direction number
GRZ	surf#	(not used)	(not used)	Linear diffraction grating z- direction number
FLDSX	FOV #	(not used)	(not used)	X-value of the "i" th multiple field-of-view position.
FLDSY	FOV #	(not used)	(not used)	Y-value of the "i" th multiple field-of-view position.
WEIGHT	surf #	surf #	(not used)	MASS in Kgs of elements from surface "i" to surface "j". This calculation assumes spherical surfaces and ignores all decenters and tilts. It uses the specific gravity assigned to surfaces with the lens database command "SPGR".
ACT	surf #	actuator #	(not used)	Returns the actuator value between –1.0 and 1.0 for actuator "j" on surface "i" if surface "i" is defined as a deformable surface. If not gettable, 0.0 is returned.
ACTMAX	surf #	(not used)	(not used)	Returns the maximun actuator value on surface "i" if surface "i" is defined as a deformable surface. If not gettable, 0.0 is returned.

GENERAL COMMAND SECTION

GETABLE LENS DATABASE PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
ACTMIN	surf #	(not used)	(not used)	Returns the minumum actuator value on surface "i" if surface "i" is defined as a deformable surface. If not gettable, 0.0 is returned.
ACTMEAN	surf #	(not used)	(not used)	Returns the average of all active actuator values on surface "i" if surface "i" is defined as a deformable surface. If not gettable, 0.0 is returned.
ACTSDEV	surf #	(not used)	(not used)	Returns the standard deviation from the mean of all active actuator values on surface "i" if surface "i" is defined as a deformable surface. If not gettable, 0.0 is returned.
ACTPTOV	surf #	(not used)	(not used)	Returns the peak to valley value for all active actuator values on surface "i" if surface "i" is defined as a deformable surface. If not gettable, 0.0 is returned.
SAG	surf#	x	y	Returns the surface SAG value for surface "i" at local surface coordinates "x" and "y". It also places the L, M and N surface normal direction cosines at "x" and "y" into the Y, Z and T stack registers.

GETABLE PROGRAM OPERATING CONDITION PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
SURTOL	(not used)	(not used)	(not used)	Aspheric/ray intersection tolerance.
AIMTOL	(not used)	(not used)	(not used)	Iterative ray aim to reference surface tolerance.
CAIMTOL	(not used)	(not used)	(not used)	Iterative ray aim to image surface tolerance.
NRAITR	(not used)	(not used)	(not used)	Maximum number of ray iterations for aspheric intersection and reference surface ray aiming.
DELSUR	(not used)	(not used)	(not used)	Derivative increment used for surface normal calculations for non-flat, non-spherical and non-conic surfaces.
PFAC	(not used)	(not used)	(not used)	Current value of PFAC
DINMUL	(not used)	(not used)	(not used)	Current value of DINMUL
DIFTOL	(not used)	(not used)	(not used)	Current value of DIFTOL
MRAYS	(not used)	(not used)	(not used)	Current value of MRAYS

GETABLE GRAPHICS PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
XPEN	(not used)	(not used)	(not used)	Current X-coordinate of the pen
YPEN	(not used)	(not used)	(not used)	Current Y-coordinate of the pen
XPENOL	(not used)	(not used)	(not used)	Previous X-coordinate of the pen
YPENOL	(not used)	(not used)	(not used)	Previous Y-coordinate of the pen
PENSTA	(not used)	(not used)	(not used)	0 = pen "UP", 1 = pen "DOWN"

GETABLE REAL RAY PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
X	surf #	(not used)	(not used)	X-local coordinate at surface "i" of last ray traced
Y	surf #	(not used)	(not used)	Y-local coordinate at surface "i" of last ray traced
Z	surf #	(not used)	(not used)	Z-local coordinate at surface "i" of last ray traced
DX	surf #	(not used)	(not used)	DX at surface "i" of last ray traced
DY	surf #	(not used)	(not used)	DY at surface "i" of last ray traced
DR	surf #	(not used)	(not used)	DR at surface "i" of last ray traced
DRA	surf #	(not used)	(not used)	DRA at surface "i" of last ray traced
XANG	surf #	(not used)	(not used)	XZ-plane slope angle at surface "i" of the last ray traced (radians)
YANG	surf #	(not used)	(not used)	YZ-plane slope angle at surface "i" of the last ray traced (radians)
DCL or K	surf #	(not used)	(not used)	X-direction cosine at surface "i" of the last ray traced (after refraction, reflection or diffraction)
DCM or L	surf #	(not used)	(not used)	Y-direction cosine at surface "i" of the last ray traced (after refraction, reflection or diffraction)
DCN or M	surf #	(not used)	(not used)	Z-direction cosine at surface "i" of the last ray traced (after refraction, reflection or diffraction)
LOLD	surf #	(not used)	(not used)	X-direction cosine at surface "i" of the last ray traced (before refraction, reflection or diffraction)
MOLD	surf #	(not used)	(not used)	Y-direction cosine at surface "i" of the last ray traced (before refraction, reflection or diffraction)
NOLD	surf #	(not used)	(not used)	Z-direction cosine at surface "i" of the last ray traced (before refraction, reflection or diffraction)
LEN	surf #	(not used)	(not used)	Physical length along the current ray from surface "i-1" to surface "i"
OPL	surf #	(not used)	(not used)	Optical path length along the current ray from surface "i-1" to surface "i"
RLEN	surf #	surf #	(not used)	Physical length along the current ray from surface "i" to surface "j"
ORLEN	surf #	surf #	(not used)	Optical path length along the current ray from surface "i" to surface "j"
AII	surf #	(not used)	(not used)	Cosine of the angle of incidence of current ray at surface "i"
AIP	surf #	(not used)	(not used)	Cosine of the angle of refraction, reflection or diffraction of current ray at surface "i"
LN	surf #	(not used)	(not used)	Local surface coordinate system X-direction cosine of the surface normal at surface "i" where the current ray intersects surface "i"
MN	surf #	(not used)	(not used)	Local surface coordinate system Y-direction cosine of the surface normal at surface "i" where the current ray intersects surface "i"
NN	surf #	(not used)	(not used)	Local surface coordinate system Z-direction cosine of the surface normal at surface "i" where the current ray intersects surface "i"
PXPX	surf #	(not used)	(not used)	Derivative, at surface "i", of the X-coordinate of the last chief ray traced with respect to a change in that chief ray's X-coordinate at the current object surface.

GETABLE REAL RAY PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
PXPY	surf #	(not used)	(not used)	Derivative, at surface "i", of the X-coordinate of the last chief ray traced with respect to a change in that chief ray's Y-coordinate at the current object surface.
PYPY	surf #	(not used)	(not used)	Derivative, at surface "i", of the Y-coordinate of the last chief ray traced with respect to a change in that chief ray's Y-coordinate at the current object surface.
PXAPX	surf #	(not used)	(not used)	Derivative, at surface "i", of the XZ-plane radian measure slope angle of the last chief ray traced with respect to a change in that chief ray's X-coordinate at the current object surface.
PXAPY	surf #	(not used)	(not used)	Derivative, at surface "i", of the XZ-plane radian measure slope angle of the last chief ray traced with respect to a change in that chief ray's Y-coordinate at the current object surface.
PYAPX	surf #	(not used)	(not used)	Derivative, at surface "i", of the YZ-plane radian measure slope angle of the last chief ray traced with respect to a change in that chief ray's X-coordinate at the current object surface.
PYAPY	surf #	(not used)	(not used)	Derivative, at surface "i", of the YZ-plane radian measure slope angle of the last chief ray traced with respect to a change in that chief ray's Y-coordinate at the current object surface.
DXDX	surf #	(not used)	(not used)	Derivative, at surface "i", of the X-coordinate of the last ray traced with respect to a change in that ray's X-coordinate at the current reference surface.
DXDY	surf #	(not used)	(not used)	Derivative, at surface "i", of the X-coordinate of the last ray traced with respect to a change in that ray's Y-coordinate at the current reference surface.
DYDX	surf #	(not used)	(not used)	Derivative, at surface "i", of the Y-coordinate of the last ray traced with respect to a change in that ray's X-coordinate at the current reference surface.
DYDY	surf #	(not used)	(not used)	Derivative, at surface "i", of the Y-coordinate of the last ray traced with respect to a change in that ray's Y-coordinate at the current reference surface.
DXADX	surf #	(not used)	(not used)	Derivative, at surface "i", of the XZ-plane radian measure slope angle of the last ray traced with respect to a change in that chief ray's X-coordinate at the current reference surface.
DXADY	surf #	(not used)	(not used)	Derivative, at surface "i", of the XZ-plane radian measure slope angle of the last ray traced with respect to a change in that chief ray's Y-coordinate at the current reference surface.

GETABLE REAL RAY PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
DYADX	surf #	(not used)	(not used)	Derivative, at surface "i", of the YZ-plane radian measure slope angle of the last ray traced with respect to a change in that chief ray's X-coordinate at the current reference surface.
DYADY	surf #	(not used)	(not used)	Derivative, at surface "i", of the YZ-plane slope angle of the last ray traced with respect to a change in that ray's Y-coordinate at the current reference surface.
XREF	surf #	(not used)	(not used)	X-coordinate of the current reference ray at surface "i"
YREF	surf #	(not used)	(not used)	Y-coordinate of the current reference ray at surface "i"
ZREF	surf #	(not used)	(not used)	Z-coordinate of the current reference ray at surface "i"
LREF	surf #	(not used)	(not used)	X-direction cosine of the current reference ray at surface "i" after refraction, reflection or diffraction
MREF	surf #	(not used)	(not used)	Y-direction cosine of the current reference ray at surface "i" after refraction, reflection or diffraction
NREF	surf #	(not used)	(not used)	Z-direction cosine of the current reference ray at surface "i" after refraction, reflection or diffraction
LREFOL	surf #	(not used)	(not used)	X-direction cosine of the current reference ray at surface "i" before refraction, reflection or diffraction
MREFOL	surf #	(not used)	(not used)	Y-direction cosine of the current reference ray at surface "i" before refraction, reflection or diffraction
NREFOL	surf #	(not used)	(not used)	Z-direction cosine of the current reference ray at surface "i" before refraction, reflection or diffraction
LENREF	surf #	(not used)	(not used)	Physical length along the current reference ray from surface "i-1" to surface "i"
OPLREF	surf #	(not used)	(not used)	Optical path length along the current reference ray from surface "i-1" to surface "i"
IREF	surf #	(not used)	(not used)	Cosine of the angle of incidence of the current reference ray at surface "i"
IPREF	surf #	(not used)	(not used)	Cosine of the angle of refraction, reflection or diffraction of the current reference ray at surface "i"
XAREF	surf #	(not used)	(not used)	XZ-plane slope angle of the current reference ray at surface "i", measured in radians
YAREF	surf #	(not used)	(not used)	YZ-plane slope angle of the current reference ray at surface "i", measured in radians
LNREF	surf #	(not used)	(not used)	X-direction cosine of the surface normal at surface "i" where the current reference ray intersects surface "i"
MNREF	surf #	(not used)	(not used)	Y-direction cosine of the surface normal at surface "i" where the current reference ray intersects surface "i"
NNREF	surf #	(not used)	(not used)	Z-direction cosine of the surface normal at surface "i" where the current reference ray intersects surface "i"
GLX	surf #	(not used)	(not used)	Global X-coordinate of the last ray traced at surface "i"

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GETABLE REAL RAY PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
GLY	surf #	(not used)	(not used)	Global Y-coordinate of the last ray traced at surface "i"
GLZ	surf #	(not used)	(not used)	Global Z-coordinate of the last ray traced at surface "i"
GLL	surf #	(not used)	(not used)	Global X-direction cosine of the last ray traced at surface "i" after refraction, reflection or diffraction
GLM	surf #	(not used)	(not used)	Global Y-direction cosine of the last ray traced at surface "i" after refraction, reflection or diffraction
GLN	surf #	(not used)	(not used)	Global Z-direction cosine of the last ray traced at surface "i" after refraction, reflection or diffraction
GLLOLD	surf #	(not used)	(not used)	Global X-direction cosine of the last ray traced at surface "i" before refraction, reflection or diffraction
GLMOLD	surf #	(not used)	(not used)	Global Y-direction cosine of the last ray traced at surface "i" before refraction, reflection or diffraction
GLNOLD	surf #	(not used)	(not used)	Global Z-direction cosine of the last ray traced at surface "i" before refraction, reflection or diffraction
GLLN	surf #	(not used)	(not used)	Global surface normal X-direction cosine at the last ray intersection at surface "i"
GLMN	surf #	(not used)	(not used)	Global surface normal Y-direction cosine at the last ray intersection at surface "i"
GLNN	surf #	(not used)	(not used)	Global surface normal Z-direction cosine at the last ray intersection at surface "i"
VIGY	n	(not used)	(not used)	Upper and lower Y-vignetting factors. These are the largest positive and negative Y values used in "RAY" commands which will not result in a ray blockage by mechanisms other than obscuration. 2n+1 points from 1.0 to -1.0 will be searched in a Y-fan to determine the returned results. The largest positive value is placed in the X-register. The largest negative value is placed in the IX-register. The default for "n" is 10.
VIGX	n	(not used)	(not used)	Same as VIGY except in the XZ-plane or the reference surface.
VIGSY	n	(not used)	(not used)	The value which would have been placed in the X-register by previously described "GET VIGY" command is "gotten" and is subtracted from 1.0 and is then placed in the X-register by the "GET VIGSY" command. The value which would have been placed in the IX-register by the previously described "GET VIGY" command is "gotten" and is added to 1.0 and then is placed in the IX-register.
VIGSX	n	(not used)	(not used)	Same as VIGSY except in the YZ-plane of the reference surface.
RENERGY	surf#	(not used)	(not used)	Ray energy at surface "i" after all coating losses, if coating losses are being taken into account.
NUMHITS	surf #	(not used)	(not used)	The number of times the last ray intersects the designated surface. Used for non-sequential surface groups. For sequential surfaces, 1 is always returned.

GENERAL COMMAND SECTION

GETABLE SPOT DIAGRAM, COMPLEX APERTURE FUNCTION (CAPFN) AND PSF PARAMETERS				
DATABASE ITEM NAME	**"i"**	**"j"**	**"k"**	**DESCRIPTION**
RAYCOD1	(not used)	(not used)	(not used)	Returns the ray failure code for the last ray traced. 0 means the ray did not fail.
RAYCOD2	(not used)	(not used)	(not used)	Returns the last surface number of the last ray traced. Reports final surface number for a successful ray. Reports surface number where ray failed for a failed ray.
CENTX	(not used)	(not used)	(not used)	X- centroid location in the current image surface of the current spot diagram centroid. A spot diagram must exist or an error message will be displayed.
CENTY	(not used)	(not used)	(not used)	Y- centroid location in the current image surface of the current spot diagram centroid. A spot diagram must exist or an error message will be displayed.
RMS	(not used)	(not used)	(not used)	Root Mean Square spot size. In modes FOCAL and UFOCAL units are lens units. In modes AFOCAL and UAFOCAL, units are RADIANS. Calculated about the spot centroid. A spot diagram must exist or an error message will be displayed.
RMSX	(not used)	(not used)	(not used)	Same as RMS, except it considers the X-components of rays in the spot diagram.
RMSASPECT	(not used)	(not used)	(not used)	Returns the ratio of the Y to the X-RMS spot values.
RMSY	(not used)	(not used)	(not used)	Same as RMS, except it considers the Y-components of rays in the spot diagram.
RSS	(not used)	(not used)	(not used)	Root Sum Square spot size. In modes FOCAL and UFOCAL, units are lens units. In modes AFOCAL and UAFOCAL, units are RADIANS. Calculated about the chief ray position. A spot diagram must exist or an error message will be displayed.
RSSX	(not used)	(not used)	(not used)	Same as RSS, except it considers the X-components of rays in the spot diagram.
RSSY	(not used)	(not used)	(not used)	Same as RSS, except it considers the Y-components of rays in the spot diagram.
FCSFT	(not used)	(not used)	(not used)	Spot diagram recommended distance to best spot focus. Full statistics must be "on" and the lens must be in the FOCAL or UFOCAL mode.
FCSFTX	(not used)	(not used)	(not used)	Spot diagram recommended distance to best spot focus (X-components only). Full statistics must be "on" and the lens must be in the FOCAL or UFOCAL mode.
RTOT	(not used)	(not used)	(not used)	Total number of successfully traced rays in last spot diagram.
ITOT	(not used)	(not used)	(not used)	Total intensity on the image surface, includes cosine I effects.

GETABLE SPOT DIAGRAM, COMPLEX APERTURE FUNCTION (CAPFN) AND PSF PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
FCSFTY	(not used)	(not used)	(not used)	Spot diagram recommended distance to best spot focus (Y-components only). Full statistics must be "on" and the lens must be in the FOCAL or UFOCAL mode.
RMSOPD	wavelength # (optional)	(not used)	(not used)	RMSOPD for the current complex aperture function in waves at the control wavelength. A CAPFN must exist or an error message will be displayed. If no wavelength number is issued, the max RMSOPD for all wavelengths is returned. If a wavelength number is issued, only the RMSOPD value for that wavelength is returned.
PSF	i	j	(not used)	Places the "i , j " element of the current diffraction Point Spread Function into the accumulator. This is a "power" value. The PSF is normalized so that the peak value is always 32676.0. "i" counts columns from -x to +x and "j" counts rows from -y to +y in the coordinate system of the reference surface.
RSPHX	(not used)	(not used	(not used)	Returns the X-coordinate of the center of the reference sphere used in CAPFN opd calculations.
RSPHY	(not used)	(not used	(not used)	Returns the Y-coordinate of the center of the reference sphere used in CAPFN opd calculations.
RSPHZ	(not used)	(not used	(not used)	Returns the Z-coordinate of the center of the reference sphere used in CAPFN opd calculations.
SPDTRANS	(not used)	(not used)	(not used)	% optical transmission for the existing spot diagram.
TRANS	(not used)	(not used)	(not used)	% optical transmission for the existing complex aperture function.
PSFSUM	(not used)	(not used)	(not used)	If a PSF exists, the value returned is the summation or integration of the current Point Spread Function lying inside the currently defined "prg"x"prg" grid.
PSFFWHMX	(not used)	(not used)	(not used)	If a PSF exists, the value returned is the "full width half max" x-dimension of the Spread Function lying inside the currently defined "prg"x"prg" grid.
PSFFWHMY	(not used)	(not used)	(not used)	Same as PSFFWHMX except in the y-dimention of the PSF.

GETABLE PARAXIAL RAY PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
PWRX	surf #	surf #	(not used)	XZ-plane paraxial, optical power of optical system from surface "i" to surface "j"
PWRY	surf #	surf #	(not used)	Same as PWRX except in the YZ-plane.
FLCLTHX	surf #	surf #	(not used)	XZ-plane, paraxial, effective focal length at the control wavelength of optical system from surface "i" to surface "j"
FLCLTH or FLCLTHY	surf #	surf #	(not used)	Same as FLCLTHY except in the YZ plane.
PX	surf #	wavelength #	(not used)	XZ-plane, marginal paraxial ray height at surface "i" and at wavelength "j"
PY	surf #	wavelength #	(not used)	Same as PX except in the YZ-plane.
PCX	surf #	wavelength #	(not used)	XZ-plane, chief paraxial ray height at surface "i" and at wavelength "j"

GETABLE PARAXIAL RAY PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
PCY	surf #	wavelength #	(not used)	Same as PCX except in the YZ-plane.
PUX	surf #	wavelength #	(not used)	XZ-plane, marginal paraxial ray tangent at surface "i" and at wavelength "j" after refraction or reflection.
PUY	surf #	wavelength #	(not used)	Same as PUX except in the YZ-plane.
PUCX	surf #	wavelength #	(not used)	XZ-plane, chief paraxial ray tangent at surface "i" and at wavelength "j" after refraction or reflection.
PUCY	surf #	wavelength #	(not used)	Same as PUCX except in the YZ-plane.
PIX	surf #	wavelength #	(not used)	XZ-plane, marginal paraxial ray incident angle tangent at surface "i" and at wavelength "j"
PIY	surf #	wavelength #	(not used)	Same as PIX except in the YZ-plane.
PICX	surf #	wavelength #	(not used)	XZ-plane, chief paraxial ray incident angle tangent at surface "i" and at wavelength "j" before refraction or reflection.
PICY	surf #	wavelength #	(not used)	Same as PICX except in the YZ-plane.
PIXP	surf #	wavelength #	(not used)	XZ-plane, marginal paraxial ray angle of refraction or reflection (tangent) at surface "i" and at wavelength "j"
PIYP	surf #	wavelength #	(not used)	Same as PIXP except in the YZ-plane.
PICXP	surf #	wavelength #	(not used)	XZ-plane, chief paraxial ray angle of refraction or reflection (tangent) at surface "i" and at wavelength "j"
PICYP	surf #	wavelength #	(not used)	Same as PICXP except in the YZ-plane.
PACX	(not used)	(not used)	(not used)	XZ-plane, primary axial chromatic aberration at the final surface.
PACY	(not used)	(not used)	(not used)	Same as PACX except in the YZ-plane.
PLCX	(not used)	(not used)	(not used)	XZ-plane, primary lateral chromatic aberration at the final surface.
PLCY	(not used)	(not used)	(not used)	Same as PLCX except in the YZ-plane.
SACX	(not used)	(not used)	(not used)	XZ-plane, secondary axial chromatic aberration at the final surface.
SACY	(not used)	(not used)	(not used)	Same as SACX except in the YZ-plane.
SLCX	(not used)	(not used)	(not used)	XZ-plane, secondary lateral chromatic aberration at the final surface.
SLCY	(not used)	(not used)	(not used)	Same as SLCX except in the YZ-plane.

GETABLE SPECIAL REAL RAY/PARAXIAL RAY PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
MAGX	(not used)	(not used)	(not used)	XZ-plane magnification. Uses ratio of slope of paraxial chief ray at object surface to slope of paraxial chief ray at image surface if no differential chief ray was traced. If real differential chief ray was traced, uses ratio of slope of differential chief ray at object surface to slope of differential chief ray at image surface.
MAGY	(not used)	(not used)	(not used)	Same as MAGX except in the YZ-plane.
MAGXOR	(not used)	(not used)	(not used)	XZ-plane reference magnification. Uses ratio of slope of paraxial chief ray at object surface to slope of paraxial chief ray at reference surface if no differential chief ray was traced. If real differential chief ray was traced, uses ratio of slope of differential chief ray at object surface to slope of differential chief ray at reference surface.
MAGYOR	(not used)	(not used)	(not used)	Same as MAGXOR except in the YZ-plane.

GETABLE SPECIAL REAL RAY/PARAXIAL RAY PARAMETERS				
DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
FFLX	(not used)	(not used)	(not used)	XZ-plane front focal length. Based upon the paraxial ray trace if no differential chief ray was traced. If real differential chief ray was traced, uses differential ray data.
FFLY	(not used)	(not used)	(not used)	Same as FFLX except in the YZ-plane.
BFLX	(not used)	(not used)	(not used)	XZ-plane back focal length. Based upon the paraxial ray trace if no differential chief ray was traced. If real differential chief ray was traced, uses differential ray data.
BFLY	(not used)	(not used)	(not used)	Same as BFLX except in the YZ-plane.
FFNX	(not used)	(not used)	(not used)	XZ-plane front F-number. Uses the reciprocal of -2 times the slope of paraxial marginal ray at object surface if no differential chief ray was traced. If real differential chief ray was traced, uses the reciprocal of -2 times the slope of differential marginal ray at object surface.
FFNY	(not used)	(not used)	(not used)	Same as FFNX except in the YZ-plane.
EFLX	(not used)	(not used)	(not used)	XZ-plane effective focal length. Based upon the paraxial ray trace if no differential chief ray was traced. If real differential chief ray was traced, uses differential ray data.
EFLY	(not used)	(not used)	(not used)	Same as EFLX except in the YZ-plane.
BFNX	(not used)	(not used)	(not used)	XZ-plane back F-number. Uses the reciprocal of -2 times the slope of paraxial marginal ray at image surface if no differential chief ray was traced. If real differential chief ray was traced, uses the reciprocal of -2 times the slope of differential marginal ray at image surface.
BFNY	(not used)	(not used)	(not used)	Same as BFNX except in the YZ-plane.
ENDIAX	(not used)	(not used)	(not used)	XZ-plane entrance pupil diameter. If no real differential chief rays exists, the value is based upon paraxial ray data. If differential ray data exists, it is used for the calculation.
ENDIAY	(not used)	(not used)	(not used)	Same as ENDIAX except in the YZ-plane.
EXDIAX	(not used)	(not used)	(not used)	XZ-plane exit pupil diameter. If no real differential chief rays exists, the value is based upon paraxial ray data. If differential ray data exists, it is used for the calculation.
EXDIAY	(not used)	(not used)	(not used)	Same as EXDIAX except in the YZ-plane.
ENPOSX	(not used)	(not used)	(not used)	X-coordinate of the center of the entrance pupil. If no real differential ray data exists, value is based upon paraxial ray data and is represented in the coordinate system of surface #1. If differential ray data exists, that data is used in the calculation and the value is represented in the coordinate system of the NEWOBJ+1 surface.
ENPOSY	(not used)	(not used)	(not used)	Same as ENPOSX except the Y-coordinate.
ENPOSZ	(not used)	(not used)	(not used)	Same as ENPOSX except the Z-coordinate.
EXPOSX	(not used)	(not used)	(not used)	X-coordinate of the center of the exit pupil. If no real differential ray data exists, value is based upon paraxial ray data and is represented in the coordinate system of the last surface. If differential ray data exists, that data is used in the calculation and the value is represented in the coordinate system of the NEWIMG surface.

GETABLE SPECIAL REAL RAY/PARAXIAL RAY PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
EXPOSY	(not used)	(not used)	(not used)	Same as EXPOSX except the Y-coordinate.
EXPOSZ	(not used)	(not used)	(not used)	Same as EXPOSX except the Z-coordinate.
FNUMX	(not used)	(not used)	(not used)	Image space F-number. Uses extreme upper and lower real marginal rays in the XZ-plane of the reference surface for the current FOB. Takes vignetting into account automatically. If no chief ray exist, a paxaial value is used instead.
FNUMY	(not used)	(not used)	(not used)	Same as FNUMX except in the YZ-plane.
OBFNUMX	(not used)	(not used)	(not used)	Object space F-number. Uses extreme upper and lower real marginal rays in the XZ-plane of the reference surface for the current FOB. Takes vignetting into account automatically. If no chief ray exist, a paxaial value is used instead.
OBFNUMY	(not used)	(not used)	(not used)	Same as OBFUMBX except in the YX-plane.
ENPDIAX	(not used)	(not used)	(not used)	Entrance pupil diameter. Uses extreme upper and lower real marginal rays in the XZ-plane of the reference surface for the current FOB. Takes vignetting into account automatically. If no chief ray exist, a paxaial value is used instead.
ENPDIAY	(not used)	(not used)	(not used)	Same as ENPDIAX except in the YZ-plane.
EXPDIAX	(not used)	(not used)	(not used)	Exit pupil diameter. Uses extreme upper and lower real marginal rays in the XZ-plane of the reference surface for the current FOB. Takes vignetting into account automatically. If no chief ray exist, a paxaial value is used instead.
EXPDIAY	(not used)	(not used)	(not used)	Same as EXPDIAX except in the YZ-plane.
PUPDIAX	surf #	(not used)	(not used)	XZ-plane. This is 2.0 times the height of the paraxial marginal ray at the position relative to surface "i" at which the paraxial chief ray has zero height.
PUPDIAY	surf #	(not used)	(not used)	Same as PUPDIAX except in the YZ-plane.
PUPDISX	surf #	(not used)	(not used)	XZ-plane. This is the position at which the paraxial chief, in the space folloing surface "i", ray has zero height. It is represented in the coordinate system of surface "i".
PUPDISY	surf #	(not used)	(not used)	Same as PUPDISX except in the YZ-plane.
CHFIMX	surf #	(not used)	(not used)	XZ-plane. This is the height of the paraxial chief ray at the position relative to surface "i" at which the paraxial marginal ray has zero height.
CHFIMY	surf #	(not used)	(not used)	Same as CHFIMX except in the YZ-plane.
GPX	surf #	(optional) y-fob value	(optional) x-fob value	XZ-plane generalized paraxial marginal ray height (at the control wavelength). If no differential ray can be traced, an error message is issued.
GPY	surf #	(optional) y-fob value	(optional) x-fob value	Same as GPUX except in the YZ-plane.
GPUX	surf #	(optional) y-fob value	(optional) x-fob value	XZ-plane generalized paraxial marginal ray slope (at the control wavelength). If no differential ray can be traced, an error message is issued.
GPUY	surf #	(optional) y-fob value	(optional) x-fob value	Same as GPUX except in the YZ-plane.

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GETABLE SPECIAL REAL RAY/PARAXIAL RAY PARAMETERS				
DATABASE ITEM NAME	**"i"**	**"j"**	**"k"**	**DESCRIPTION**
GPCX	surf #	(optional) y-fob value	(optional) x-fob value	XZ-plane generalized paraxial chief ray height (at the control wavelength). If no differential ray can be traced, an error message is issued.
GPCY	surf #	(optional) y-fob value	(optional) x-fob value	Same as GPCX except in the YZ-plane.
GPUCX	surf #	(optional) y-fob value	(optional) x-fob value	XZ-plane generalized paraxial chief ray slope (at the control wavelength). If no differential ray can be traced, an error message is issued.
GPUCY	surf #	(optional) y-fob value	(optional) x-fob value	Same as GPUCX except in the YZ-plane.
DIST	Y-FOB	X-FOB	(not used)	Uses real chief and real chief differential ray traces (at the control wavelength) to calculate percent distortion at the field point designated by the Y and X-FOB input values. Calculation is performed at the control wavelength for the current lens configuration. Value is valid for tilted and decentered systems. All surface types including special surfaces are recognized. See the "DIST" command for a full description of the nature of this calculation.
FISHDIST	Y-FOB	X-FOB	(not used)	This is similar to DIST but does its calculation with the slope angles in radians rather than with the slope tangents. See the "FISHDIST" command for a full description.
XFOC	Y-FOB	X-FOB	(not used)	XFOC returns the distance from the current image surface to the focus position of close XZ-plane marginal differential rays traced about the chief ray specified by the X and Y-FOB values (at the control wavelength). This distance is measured along the local Z-axis of the current image surface in the coordinate system of the current image surface. **This is the X-field curvature. In modes FOCAL and UFOCAL, the units are lens units. In modes AFOCAL and UAFOCAL, the units are diopters. If, in the AFOCAL or UAFOCAL mode, the field curvature is too large to represent, it will be set to 1.0D20.**
YFOC	Y-FOB	X-FOB	(not used)	Same as XFOC but in the YZ-plane. **This is the Y-field curvature. In modes FOCAL and UFOCAL, the units are lens units. In modes AFOCAL and UAFOCAL, the units are diopters. If, in the AFOCAL or UAFOCAL mode, the field curvature is too large to represent, it will be set to 1.0D20.**
AST	Y-FOB	X-FOB	(not used)	AST returns the the astigmatism along the chief ray specified by the X and Y-FOB values (at the control wavelength). It is just the YFOC value minus the XFOC value. **In modes FOCAL and UFOCAL, the units are lens units. In modes AFOCAL and UAFOCAL, the units are diopters. If, in the AFOCAL or UAFOCAL mode, the astigmatism is too large to represent, it will be set to 1.0D20.**

GETABLE SPECIAL REAL RAY/PARAXIAL RAY PARAMETERS				
DATABASE ITEM NAME	**"i"**	**"j"**	**"k"**	**DESCRIPTION**
IMDISX	surf #	(not used)	(not used)	XZ-plane. This is the position at which the paraxial marginal ray, in the space following surface "i", has zero height. It is represented in the coordinate system of surface "i".
IMDISY	surf #	(not used)	(not used)	YZ-plane. This is the position at which the paraxial marginal ray, in the space following surface "i", has zero height. It is represented in the coordinate system of surface "i".

GETABLE 3RD, 5TH and 7TH ORDER ABERRATION PARAMETERS				
DATABASE ITEM NAME	**"i"**	**"j"**	**"k"**	**DESCRIPTION**
SA3	surf #	(not used)	(not used)	YZ-plane, 3rd order SPHERICAL ABERRATION at surface "i" and at the control wavelength.
XSA3	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
CMA3	surf #	(not used)	(not used)	YZ-plane, 3rd order COMA at surface "i" and at the control wavelength.
XCMA3	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
AST3	surf #	(not used)	(not used)	YZ-plane, 3rd order ASTIGMATISM at surface "i" and at the control wavelength.
XAST3	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
DIS3	surf #	(not used)	(not used)	YZ-plane, 3rd order DISTORTION at surface "i" and at the control wavelength.
XDIS3	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PTZ3	surf #	(not used)	(not used)	YZ-plane, 3rd order PETZVAL CURVATURE at surface "i" and at the control wavelength.
XPTZ3	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SA5	surf #	(not used)	(not used)	YZ-plane, 5th order SPHERICAL ABERRATION at surface "i" and at the control wavelength.
XSA5	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
CMA5	surf #	(not used)	(not used)	YZ-plane, 5th order COMA at surface "i" and at the control wavelength.
XCMA5	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
AST5	surf #	(not used)	(not used)	YZ-plane, 5th order ASTIGMATISM at surface "i" and at the control wavelength.
XAST5	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
DIS5	surf #	(not used)	(not used)	YZ-plane, 5th order DISTORTION at surface "i" and at the control wavelength.
XDIS5	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PTZ5	surf #	(not used)	(not used)	YZ-plane, 5th order PETZVAL CURVATURE at surface "i" and at the control wavelength.
XPTZ5	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
TOBSA	surf #	(not used)	(not used)	YZ-plane, 5th order TANGENTIAL OBLIQUE SPHERICAL ABERRATION at surface "i" and at the control wavelength.
XTOBSA	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SOBSA	surf #	(not used)	(not used)	YZ-plane, 5th order SAGITTAL OBLIQUE SPHERICAL ABERRATION at surface "i" and at the control wavelength.
XSOBSA	surf #	(not used)	(not used)	Same as above except in the XZ-plane.

GETABLE 3RD, 5TH and 7TH ORDER ABERRATION PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
ELCMA	surf #	(not used)	(not used)	YZ-plane, 5th order ELLIPTICAL COMA at surface "i" and at the control wavelength.
XELCMA	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
TAS	surf #	(not used)	(not used)	YZ-plane, 5th order TANGENTIAL ASTIGMATISM at surface "i" and at the control wavelength.
XTAS	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SAS	surf #	(not used)	(not used)	YZ-plane, 5th order SAGITTAL ASTIGMATISM at surface "i" and at the control wavelength.
XSAS	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SA7	surf #	(not used)	(not used)	YZ-plane, 7th order SPHERICAL ABERRATION at surface "i" and at the control wavelength.
XSA7	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SA3P	surf #	(not used)	(not used)	YZ-plane, 3rd order SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XSA3P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
CMA3P	surf #	(not used)	(not used)	YZ-plane, 3rd order COMA, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XCMA3P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
AST3P	surf #	(not used)	(not used)	YZ-plane, 3rd order ASTIGMATISM, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XAST3P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
DIS3P	surf #	(not used)	(not used)	YZ-plane, 3rd order DISTORTION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XDIS3P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PTZ3P	surf #	(not used)	(not used)	YZ-plane, 3rd order PETZVAL CURVATURE, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XPTZ3P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SA5P	surf #	(not used)	(not used)	YZ-plane, 5th order SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XSA5P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
CMA5P	surf #	(not used)	(not used)	YZ-plane, 5th order COMA, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XCMA5P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
AST5P	surf #	(not used)	(not used)	YZ-plane, 5th order ASTIGMATISM, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XAST5P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.

GETABLE 3RD, 5TH and 7TH ORDER ABERRATION PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
DIS5P	surf #	(not used)	(not used)	YZ-plane, 5th order DISTORTION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XDIS5P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PTZ5P	surf #	(not used)	(not used)	YZ-plane, 5th order PETZVAL CURVATURE, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XPTZ5P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
TOBSAP	surf #	(not used)	(not used)	YZ-plane, 5th order TANGENTIAL OBLIQUE SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XTOBSAP	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SOBSAP	surf #	(not used)	(not used)	YZ-plane, 5th order SAGITTAL OBLIQUE SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XSOBSAP	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
ELCMAP	surf #	(not used)	(not used)	YZ-plane, 5th order ELLIPTICAL COMA, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the .
XELCMAP	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
TASP	surf #	(not used)	(not used)	YZ-plane, 5th order TANGENTIAL ASTIGMATISM, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XTASP	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SASP	surf #	(not used)	(not used)	YZ-plane, 5th order SAGITTAL ASTIGMATISM, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XSASP	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SA7P	surf #	(not used)	(not used)	YZ-plane, 7th order SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XSA7P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SA3S	surf #	(not used)	(not used)	YZ-plane, 3rd order SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XSA3S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
CMA3S	surf #	(not used)	(not used)	YZ-plane, 3rd order COMA, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XCMA3S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
AST3S	surf #	(not used)	(not used)	YZ-plane, 3rd order ASTIGMATISM, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.

GETABLE 3RD, 5TH and 7TH ORDER ABERRATION PARAMETERS				
DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
XAST3S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
DIS3S	surf #	(not used)	(not used)	YZ-plane, 3rd order DISTORTION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XDIS3S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PTZ3S	surf #	(not used)	(not used)	YZ-plane, 3rd order PETZVAL CURVATURE, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XPTZ3S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SA5S	surf #	(not used)	(not used)	YZ-plane, 5th order SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XSA5S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
CMA5S	surf #	(not used)	(not used)	YZ-plane, 5th order COMA, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XCMA5S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
AST5S	surf #	(not used)	(not used)	YZ-plane, 5th order ASTIGMATISM, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XAST5S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
DIS5S	surf #	(not used)	(not used)	YZ-plane, 5th order DISTORTION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XDIS5S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PTZ5S	surf #	(not used)	(not used)	YZ-plane, 5th order PETZVAL CURVATURE, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XPTZ5S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
TOBSAS	surf #	(not used)	(not used)	YZ-plane, 5th order TANGENTIAL OBLIQUE SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XTOBSAS	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SOBSAS	surf #	(not used)	(not used)	YZ-plane, 5th order SAGITTAL OBLIQUE SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XSOBSAS	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
ELCMAS	surf #	(not used)	(not used)	YZ-plane, 5th order ELLIPTICAL COMA, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XELCMAS	surf #	(not used)	(not used)	Same as above except in the XZ-plane.

GETABLE 3RD, 5TH and 7TH ORDER ABERRATION PARAMETERS				
DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
TASS	surf #	(not used)	(not used)	YZ-plane, 5th order TANGENTIAL ASTIGMATISM, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XTASS	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SASS	surf #	(not used)	(not used)	YZ-plane, 5th order SAGITTAL ASTIGMATISM, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XSASS	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SA7S	surf #	(not used)	(not used)	YZ-plane, 7th order SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength.
XSA7S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SA5I	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order SPHERICAL ABERRATION at surface "i" and at the control wavelength.
XSA5I	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
CMA5I	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order COMA at surface "i" and at the control wavelength.
XCMA5I	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
AST5I	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order ASTIGMATISM at surface "i" and at the control wavelength.
XAST5I	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
DIS5I	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order DISTORTION at surface "i" and at the control wavelength.
XDIS5I	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PTZ5I	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order PETZVAL CURVATURE at surface "i" and at the control wavelength.
XPTZ5I	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
TOBSAI	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order TANGENTIAL OBLIQUE SPHERICAL ABERRATION at surface "i" and at the control wavelength.
XTOBSAI	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SOBSAI	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order SAGITTAL OBLIQUE SPHERICAL ABERRATION at surface "i" and at the control wavelength.
XSOBSAI	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
ELCMAI	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order ELLIPTICAL COMA at surface "i" and at the control wavelength.
XELCMAI	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
TASI	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order TANGENTIAL ASTIGMATISM at surface "i" and at the control wavelength.

GETABLE 3RD, 5TH and 7TH ORDER ABERRATION PARAMETERS				
DATABASE ITEM NAME	**"i"**	**"j"**	**"k"**	**DESCRIPTION**
XTASI	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SASI	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order SAGITTAL ASTIGMATISM at surface "i" and at the control wavelength.
XSASI	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SA7I	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 7th order SPHERICAL ABERRATION at surface "i" and at the control wavelength.
XSA7I	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PSA3	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order SPHERICAL ABERRATION at surface "i" and at the control wavelength.
XPSA3	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PCMA3	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order COMA at surface "i" and at the control wavelength.
PXCMA3	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PAST3	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order ASTIGMATISM at surface "i" and at the control wavelength.
XPAST3	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PDIS3	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order DISTORTION at surface "i" and at the control wavelength.
XPDIS3	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PPTZ3	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order PETZVAL CURVATURE at surface "i" and at the control wavelength.
XPPTZ3	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PSA3P	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES at surface "i".
XPSA3P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PCMA3P	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order COMA, PRIMARY CHROMATIC DIFFERENCES at surface "i".
XPCMA3P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PAST3P	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order ASTIGMATISM, PRIMARY CHROMATIC DIFFERENCES at surface "i"
XPAST3P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PDIS3P	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order DISTORTION, PRIMARY CHROMATIC DIFFERENCES at surface "i".

GETABLE 3RD, 5TH and 7TH ORDER ABERRATION PARAMETERS				
DATABASE ITEM NAME	**"i"**	**"j"**	**"k"**	**DESCRIPTION**
XPDIS3P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PPTZ3P	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order PETZVAL CURVATURE, PRIMARY CHROMATIC DIFFERENCES at surface "i".
XPPTZ3P	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PSA3S	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i".
PXSA3S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PCMA3S	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order COMA, SECONDARY CHROMATIC DIFFERENCES at surface "i".
XPCMA3S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PAST3S	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order ASTIGMATISM, SECONDARY CHROMATIC DIFFERENCES at surface "i".
XPAST3S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PDIS3S	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order DISTORTION, SECONDARY CHROMATIC DIFFERENCES at surface "i".
XPDIS3S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PPTZ3S	surf #	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order PETZVAL CURVATURE, SECONDARY CHROMATIC DIFFERENCES at surface "i".
XPPTZ3S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
PTZCV	surf#	(not used)	(not used)	This is the YZ-plane, third order Petzval curvature. Its value is independent of lens mode.
XPTZCV	surf#	(not used)	(not used)	Same as above except in the XZ-plane.

GETABLE OPTIMIZATION PARAMETERS				
DATABASE ITEM NAME	**"i"**	**"j"**	**"k"**	**DESCRIPTION**
DERIV or MATRIX	variable #	operand #	(not used)	This returns the value of the derivative matrix for variable "i" and operand "j".
OPWT or WT	operand #	(not used)	(not used)	This returns the value of the weighting factor for operand "i".
VARWT or WVFC	variable #	(not used)	(not used)	This returns the value of the weighting factor for variable "i".
VARDNC	variable #	(not used)	(not used)	This returns the "dincr" value used for variable "i".

GENERAL COMMAND SECTION

GETABLE OPTIMIZATION PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
OPTYPE	operand #	(not used)	(not used)	This returns a code which designates the operand type for operand "i": 1 = COR 2 = BYP 3 = HLD 4 = BLO or GTE 5 = BHI or LTE
VB	variable #	(not used)	(not used)	The value of the variable "i" is returned.
VBT	variable #	(not used)	(not used)	The value of the tolerance variable "i" is returned.
LCV	(not used)	(not used)	(not used)	The length of the last change vector is returned.
TV	operand #	(not used)	(not used)	The target value of operand "i" is returned.
OPRD	operand #	(not used)	(not used)	The current value of operand "i" is returned.
FOCRIT	operand #	(not used)	(not used)	The value of focus criteria operand "i" is returned.
KDWA	(not used)	(not used)	(not used)	The number of operands is returned.
NVAR	(not used)	(not used)	(not used)	The number of variables is returned.

GETABLE GAUSSIAN BEAM PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
GBRADX	surf #	z-position default = 0.0	(not used)	This returns the value of the XZ-plane $1/e^2$ semi-diameter of the gaussian beam at a Z-distance "j" from surface "i". The last "FOB" command is used to specify object point and wavelength used. If no "FOB" command was issued, then an on-axis point at the control wavelength is assumed.
GBRADY	surf #	z-position default = 0.0	(not used)	This is the same as GBRADX except that it works in the YZ-plane.
GBDISX	surf #	(not used)	(not used)	This returns the distance from surface "i" to the next XZ-plane beam waist in the image space of surface "i". The last "FOB" command is used to specify object point and wavelength used. If no "FOB" command was issued, then an on-axis point at the control wavelength is assumed.
GBDISY	surf #	(not used)	(not used)	This is the same as GBDISX except that it works in the YZ-plane.
GBRCVX	surf #	z-position default = 0.0	(not used)	This returns the XZ-plane wavefront radius of curvature at a Z-distance "j" from surface "i". in the image space of surface "i". The last "FOB" command is used to specify object point and wavelength used. If no "FOB" command was issued, then an on-axis point at the control wavelength is assumed.

GETABLE GAUSSIAN BEAM PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
GBRCVY	surf #	z-position default = 0.0	(not used)	This is the same as GBRCVX except that it works in the YZ-plane.
GBWAISTX	surf #	(not used)	(not used)	This returns the XZ-plane $1/e^2$ semi-diameter of the beam waist in the image space of surface "i". The last "FOB" command is used to specify object point and wavelength used. If no "FOB" command was issued, then an on-axis point at the control wavelength is assumed.
GBWAISTY	surf #	(not used)	(not used)	This is the same as GBWAISTX except that it works in the YZ-plane.
WRY	(not used)	(not used)	(not used)	Returns the current "wry" value, the starting YZ-plane beam waist semi-diameter.
WRX	(not used)	(not used)	(not used)	Returns the current "wrx" value, the starting XZ-plane beam waist semi-diameter.
BDY	(not used)	(not used)	(not used)	Returns the current "bdy" value, the starting YZ-plane beam divergence half-angle.
BDX	(not used)	(not used)	(not used)	Returns the current "bdx" value, the starting XZ-plane beam divergence half-angle.

GETABLE MISCELLANEOUS PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
GLASSWV1 or GLASSWV2 or GLASSWV3 or GLASSWV4 or GLASSWV5	(not used)	(not used)	(not used)	The first, second, third, fourth or fifth lens independent wavelength used in the glass catalog refractive index calculation when not connected with the "current" lens. Value is in mcron units.
MINREG	(MINREG #)	(not used)	(not used)	The value currently in the MINREG register designated by (MINREG#). Valid inputs are 1 to 100. Default value is 1.
MAXREG	(MAXREG #)	(not used)	(not used)	The value currently in the MAXREG register designated by (MAXREG#). Valid inputs are 1 to 100. Default value is 1.

GETABLE NSS DATABASE PARAMETERS

DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
NSSMEANX	(not used)	(not used)	(not used)	X - mean value of the last NSS spot diagram
NSSMEANY	(not used)	(not used)	(not used)	Y - mean value of the last NSS spot diagram
NSSMEANR	(not used)	(not used)	(not used)	Radial - mean value of the last NSS spot diagram
NSSRMSX	(not used)	(not used)	(not used)	X - RMS value of the last NSS spot diagram
NSSRMSY	(not used)	(not used)	(not used)	Y - RMS value of the last NSS spot diagram
NSSRMSR	(not used)	(not used)	(not used)	Radial - RMD value of the last NSS spot diagram

GETTING RMS SPOT SIZE - The RMS (Root Mean Square) spot diameter and the X and Y-widths of the spot are automatically placed into the X, Y and Z-general purpose storage registers whenever a spot diagram is generated with one of the "SPD" commands. These values are useful in optimization and are just some of the data items which do not need to be explicitly "gotten" with the "GET" command.

OPTIMIZATION SPECIFIC PARAMETERS - Any "gettable" parameters may be used as part of a user-defined merit function during the optimization process. Construction of this user-defined merit function is described in the "OPTIMIZATION" section of this manual.

GENERAL COMMAND SECTION

GETABLE REAL RAY SPECTROMETER CHARACTERISTICS (See explanation below)				
DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
CTSX and CTSY	wavelength #	pixel size (optional)	(not used)	Cross-track Spectral Co-registration Error at wavelength number "i".
SCEX and SCEY	pixel size (optional)	(not used)	(not used)	Spatial Co-registration Error for all defined wavelengths.

The REAL RAY SPECTROMETER CHARACTERISTICS are intended for use in the analysis of imaging spectrometers. These values are only valid for FOCAL or UFOCAL systems. "CTSX" and "CTSY" are measures of a characteristic known as Cross Track Spectral Co-registration Error measured either in the XZ or the YZ-plane of the image surface. "CTSX" is the appropriate choice if the spectral direction at the focal plane lies in the YZ-plane and the spatial direction lies in the XZ-plane. "CTSY" is the appropriate choice if the spectral direction at the focal plane lies in the XZ-plane and the spatial direction lies in the YZ-plane. They are calculated at a specified wavelength. For "CTSX", chief rays are traced at the specified wavelength at the top, middle and bottom of the XZ-plane field of view. CTSX is then the absolute value of the maximum spread of the YZ-plane components of these three rays. For "CTSY", chief rays are traced at the specified wavelength at the top, middle and bottom of the YZ-plane field of view. CTSY is then the absolute value of the maximum spread of the XZ-plane components of these three rays. "SCEX" and "SCEY" are measures of a characteristic known as Spatial co-registration error measured either in the XZ or the YZ-plane of the image surface. They are calculated at every non-zero wavelength. For "SCEX", chief rays are traced at each non-zero wavelength at the top, middle and bottom of the XZ-plane field of view. Three preliminary values (one for each of the three field positions) of SCEX are calculated. Each preliminary value is equal to the maximum spread of the XZ-plane coordinates of the rays traced at the different wavelengths. The preliminary SCEX value with the largest absolute value becomes the final SCEX value. For "SCEY", chief rays are traced at each non-zero wavelength at the top, middle and bottom of the YZ-plane field of view. Three preliminary values (one for each of the three field positions) of SCEY are calculated. Each preliminary value is equal to the maximum spread of the YZ-plane coordinates of the rays traced at the different wavelengths. The preliminary SCEY value with the largest absolute value becomes the final SCEX value. If a square pixel size (in lens units) is input, then CTSX, CTSY, SCEX and SCEY are represented as a percentage of that pixel size. If no pixel size is input, then CTSX, CTSY, SCEX and SCEY will be in lens units. The next page contains a figure which graphically illustrates these spectrometer characteristics.

λ Spectral Direction

Cross Track Spectral Error   (Slit Smile)

Spatial
Direction

Spatial Co-registration Error
(Field of View Smile)
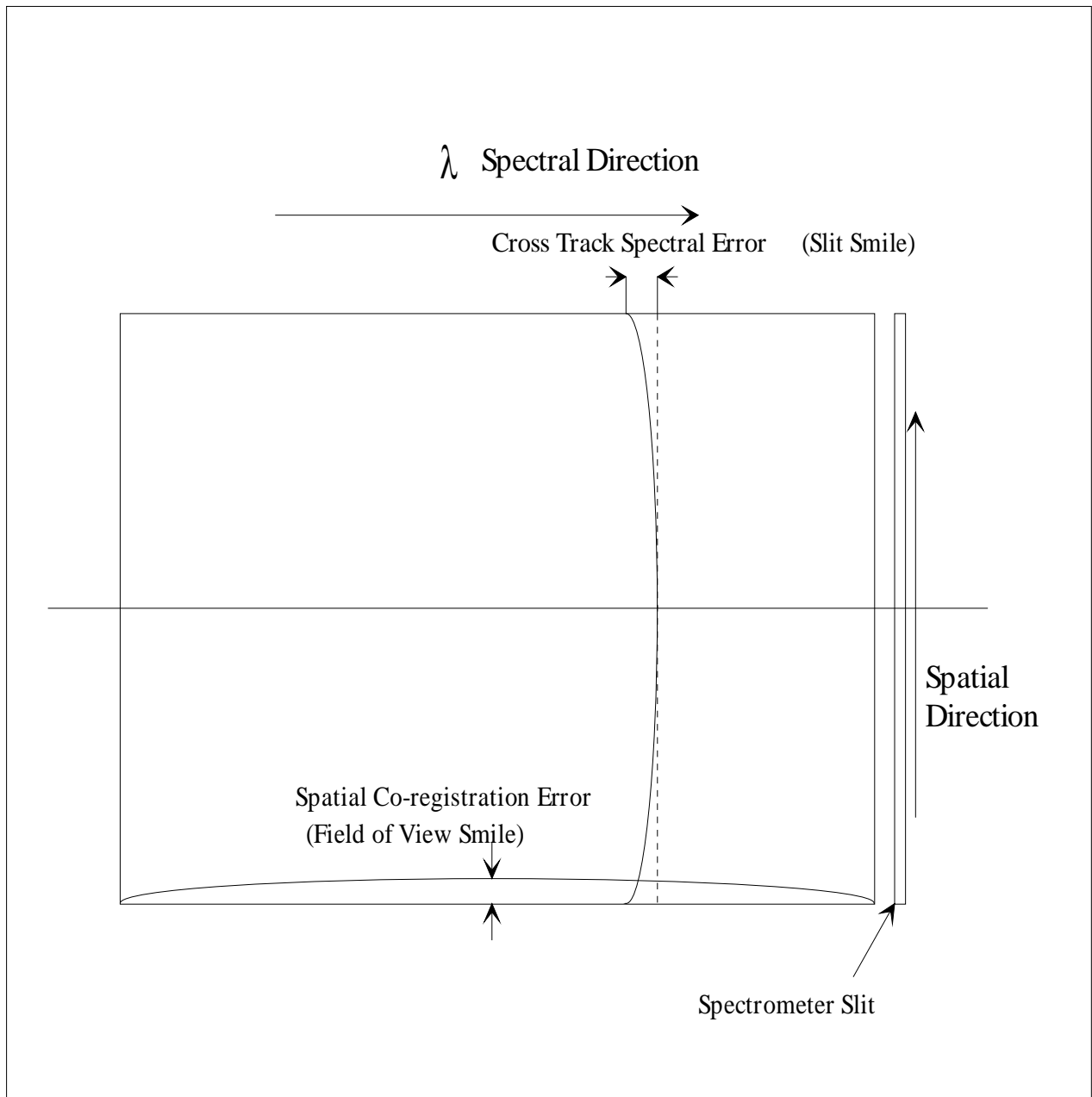
Spectrometer Slit

Spectrometer Characteristics

RETRIEVAL OF ALPHANUMERIC VALUES (THE "AGET" COMMAND) - Using the "AGET" command, many alphanumeric database items can be quickly retrieved into any one of the MAXREG alphanumeric storage registers. These retrieved values may then be displayed, manipulated interactively at the CMD level or manipulated from within a user-written macro or macro function.

AGET (database item name) , i , j , k ,, r or
ASHOW (database item name) , i , j , k ,, r - The "AGET" command retrieves into the alphanumeric storage register designated by "r", the program database item with name = "database item name". The numeric input values "i", "j" and "k" are not always required, and their use will be made clear by referring to the "AGET" table starting on the next page. The default value for "r" is 1 and refers to the "A1" alphanumeric storage register. The "ASHOW" command, when used with a qualifier word, acts exactly as the "AGET" command does except that it also displays the retrieved data to the screen.

GETABLE ALPHANUMERIC PARAMETERS				
DATABASE ITEM NAME	"i"	"j"	"k"	DESCRIPTION
LI	(not used)	(not used)	(not used)	Returns the current Lens Identifier
LIC1	(not used)	(not used)	(not used)	Returns the current first Lens Identifier continuation line
LIC2	(not used)	(not used)	(not used)	Returns the current second Lens Identifier continuation line
LIC3	(not used)	(not used)	(not used)	Returns the current third Lens Identifier continuation line
LIC4	(not used)	(not used)	(not used)	Returns the current fourth Lens Identifier continuation line
CATNAME	surf#	(not used)	(not used)	Glass catalog name at surface "i".
GLANAME	surf#	(not used)	(not used)	Glass name at surface "i"
SURFLBL	surf#	(not used)	(not used)	Surface label at surface "i"

GENERAL OPTICAL ENGINEERING UTILITIES - The following section contains CMD level commands which can best be described as general optical engineering utilities. They are listed here in the order in which they were added to the program.

THIN LENS RELATIONSHIPS

OIF (P) , o , i , f - The "OIF" command calculates either the object distance "o", the image distance "i" or the focal length "f" given any of the other two values. The resultant value will be placed in the X-register and the LASTX register will be updated. If the optional qualifier word "P" is included, output will be displayed at the current output device. The quantities are related by the following equation:

$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$

Two of the three values must be entered with the third represented by default numerical input delimiting commas as appropriate. This command does not refer in any way to the "current" lens in the lens database. Zero input values are disallowed.

XXF (P) , x , x' , f - The "XXF" command calculates either the Newtonian object distance "x", the Newtonian image distance "x'" or the focal length "f" given any of the other two values. The resultant value will be placed in the X-register and the LASTX register will be updated. If the optional qualifier word "P" is included, output will be displayed at the current output device. The quantities are related by the following equation:

$$f^2 = -xx'$$

Two of the three values must be entered with the third represented by default numerical input delimiting commas as appropriate. This command does not refer in any way to the "current" lens in the lens database. Zero input values are disallowed.

XXFF (P) , x , x' , f , f' - The "XXFF" command calculates either the Newtonian object distance "x", the Newtonian image distance "x'" or the first focal length "f" or the second focal length "f'" given any of the other three values. The resultant value will be placed in the X-register and the LASTX register will be updated. If the optional qualifier word "P" is included, output will be displayed at the current output device. The quantities are related by the following equation:

$$ff' = -xx'$$

Three of the four values must be entered with the fourth represented by default numerical input delimiting commas as appropriate. This command does not refer in any way to the "current" lens in the lens database. Zero input values are disallowed.

GENERAL COMMAND SECTION

RADIOMETRIC RELATIONSHIPS

RADUNITS (qualifier word) - The "RADUNITS" command sets the type of radiometric units used for all CMD level radiometric calculations. The "qualifier word" may be either "WATTS" or "PHOTONS". "WATTS" sets radiometric units to WATTS, (CENTIMETERS) ^{2} and DEGREES KELVIN. "PHOTONS" sets the radiometric units to PHOTONS, SECONDS, (CENTIMETERS) ^{2} and DEGREES KELVIN. The radiometric units remain set until changed by the user or until the program stops. The default value assumed for the "qualifier word" when the program starts is "WATTS". Issuing the "RADUNITS" command with no qualifier or with the special interrogator "?" causes the current radiometric units type to be displayed.

WIEN (P) , T - The "WIEN" command calculates either the wavelength of maximum radiant emittance or the wavelength of maximum radiant photon emittance depending on whether the current radiometric units are set to "WATTS" or "PHOTONS". The resultant wavelength value (in micron units) will be placed in the X-register and the LASTX register will be updated. If the optional qualifier word "P" is included, output will be displayed at the current output device. Wien's displacement law in terms of radiant emittance is:

$$\lambda_m T = 2897.8\mu\text{-}^o K$$

Wien's displacement law in terms of radiant photon emittance is:

$$\lambda_m T = 3669.73\mu\text{-}^o K$$

STEFBOLT (P) , T , λupper , λlower - "STEFBOLT" command calculates either the total radiant emittance or the total radiant photon emittance between "λlower" and "λupper". The value calculated depends on whether the current radiometric units are set to "WATTS" or "PHOTONS". "T" must be in degrees Kelvin and "λlower" and "λupper", if entered, must be in micron units. The resultant value will be placed in the X-register and the LASTX register will be updated. If the optional qualifier word "P" is included, output will be displayed at the current output device. The default value for "λlower" is 0.0 microns. The default value for "λupper" is ∞. The units of total radiant emittance are WATTS-CM^2. The units of total radiant photon emittance are PHOTONS-SEC^{-1}-CM^{-2}. The total radiant emittance between "λlower" and "λupper" is:

$$W(T) = \int_{\lambda_{lower}}^{\lambda_{upper}} \frac{c_1}{\lambda^5} \frac{d\lambda}{e^{\frac{c_2}{\lambda T}} - 1}$$

The total radiant photon emittance between "λlower" and "λupper" is:

$$Q(T) = \int_{\lambda_{lower}}^{\lambda_{upper}} \frac{c_1'}{\lambda^4} \frac{d\lambda}{e^{\frac{c_2}{\lambda T}} - 1}$$

$c1 = 37415.0$ WATT-CM^{-2}-MICRON^4
$c1' = 1.88365 \times 10^{23}$ PHOTON-SEC^{-1}-CM^{-2}-MICRON^3
$c2 = 1.4387.9$ MICRON-DEG K

PLANK (P) , T , λ - The "PLANK" command calculates either the radiant emittance or the radiant photon emittance depending on whether the current radiometric units are set to "WATTS" or "PHOTONS". "T" must be in degrees Kelvin and λ must be in microns. The resultant value will be placed in the X-register and the LASTX register will be updated. If the optional qualifier word "P" is included, output will be displayed at the current output device. The units of radiant emittance are WATTS-CM^2-MICRON^{-1}. The units of total radiant photon emittance are PHOTONS-SEC^{-1}-CM^{-2}-MICRON^{-1}. Plank's law in terms of radiant emittance is:

$$W(\lambda, T) = \frac{c_1}{\lambda^5 \left[e^{\frac{c_2}{\lambda T}} - 1 \right]}$$

Plank's law in terms of radiant photon emittance is:

$$Q(\lambda, T) = \frac{c_1'}{\lambda^4 \left[e^{\frac{c_2}{\lambda T}} - 1 \right]}$$

$$c1 = 37415.0 \text{ WATT-CM}^{-2}\text{-MICRON}^4$$
$$c1' = 1.88365 \times 10^{23} \text{ PHOTON-SEC}^{-1}\text{-CM}^{-2}\text{-MICRON}^3$$
$$c2 = 1.4387.9 \text{ MICRON-DEG K}$$

GAUSSIAN BEAM RELATIONSHIPS

RAYLEIGH (w_o) , (λ) - he Rayleigh Range is the distance from a gaussian beam's beam waist to a region which can be considered to be in the "far field" of the beam. The equation used here was taken from "Lasers" by Siegman. The "RAYLEIGH" command calculates the rayleigh range (b) in current lens units for a gaussian beam which has a beam waist diameter "w_0" at the $1/e^2$ point. The wavelength for the calculation is λ. By default, the value of w_0 is 2 times the current "wry" value assigned to the current lens database. The default value for λ is the control wavelength assigned for the current lens database. The value for the Rayleigh Range is displayed and also placed into the X-register. If the optional qualifier word "ACC" is issued, the value display is suppressed.

$$b = \frac{2\pi w_0^2}{\lambda}$$

GRAZING INCIDENCE OPTICS

K0 , cv , κ , Zo - The "K0" command calculates and displays the value of the "K_0" term used in the apo-vertex equations described in "Reflective Optics" by Dietrich Korsch, Academic Press, Inc., 1991. The input values are the base curvature "cv"; which is just the reciprocal of the base radius of curvature "rd", "κ", the conic constant and "Z_0", the distance from the surface vertex to the center of the section of the surface used. A figure illustrating "Z_0" is included as part of the description of the TYPE 18 special surface in the SPECIAL SURFACE section of this manual. The relationship of "K_0" to "cv" , "κ" and "Z_0" is given in the following equation:

$$K_0 = \frac{1}{cv} + \left[(1 + \kappa) \times Z_0 \right]$$

The resultant K_0 value is left in the X-register.

CVG, K_0 , κ , Z_0 - The "CVG" command calculates and displays the value of the surface curvature "cv" term. The input values are the term "K_0", "κ", the conic constant and "Z_0", the distance from the surface vertex to the center of the section of the surface used. The relationship of " cv" to " K_0 " , "κ" and "Z_0" is given in the following equation:

$$cv = \frac{1}{K_0 + \left[(1 + \kappa) \times Z_0 \right]}$$

The resultant curvature value is left in the X-register.

FOCI (R or C) , nw1 , κ - The "FOCI" command calculates and displays the position or positions of the focus or foci of parabolic, hyperbolic and prolate spheroidal shaped optical surfaces relative to the surface's vertex. "nw1" is either the radius of curvature or the curvature depending upon whether the "R" or "C" qualifier word is used. "κ" is the conic constant. "κ" is -1.0 for a parabola, is between -1.0 and 0.0 for a prolate spheroid and is less than -1.0 for a hyperbola. The units are understood to be the units of the radius of curvature as used in the calculation. Negative distances are understood to lie to the left of the surface vertex while positive distances are understood to lie to the right. Surfaces with negative curvatures or radii have their centers of curvature to the left of the surface vertex. Surfaces with positive curvatures or radii have their centers of curvature to the right of the surface vertex. The default qualifier is understood to be "R" for radius of curvature input. The resultant focus or focii location(s) are left in the X or the X and Y-registers.

RHO (R or C) , nw1 , κ , Z - The "RHO" command calculates and displays the distance from the local Z-axis, measured perpendicular to the local Z-axis, of a point which lies a distance "Z" from the surface vertex of a conic surface. "nw1" is either the radius of curvature or the curvature depending upon whether the "R" or "C" qualifier word is used. "κ" is the conic constant. "κ". "Z" is a distance measured from the surface vertex along the local Z-axis. The units are understood to be the units of the radius of curvature and Z-position as used in the calculation. Negative Z-distances are understood to lie to the left of the surface vertex while positive Z-distances are understood to lie to the right. Surfaces with negative curvatures or radii have their centers of curvature to the left of the surface vertex. Surfaces with positive curvatures or radii have their centers of curvature to the right of the surface vertex. The default qualifier is understood to be "R" for radius of curvature input. The resultant RHO value is left in the X-register.

GENERAL COMMAND SECTION

Z0 (R or C) , nw1 , κ , RHO - The "Z0" command calculates and displays the Z-position(s) along a conic's local Z-axis which are also a distance "RHO" from the conic's local Z-axis. "RHO" is measured perpendicular to the conic's local Z-axis. "nw1" is either the radius of curvature or the curvature depending upon whether the "R" or "C" qualifier word is used. "κ" is the conic constant. "κ". "RHO" is the distance measured from the local Z-axis, perpendicular to the local Z-axis, to a point of intersection with the conic. The units are understood to be the units of the radius of curvature and "RHO". Negative Z-distances are understood to lie to the left of the surface vertex while positive Z-distances are understood to lie to the right. Surfaces with negative curvatures or radii have their centers of curvature to the left of the surface vertex. Surfaces with positive curvatures or radii have their centers of curvature to the right of the surface vertex. The default qualifier is understood to be "R" for radius of curvature input. The resultant value(s) are left in the X or the X and Y-registers.

RTOD , r , e - The "RTOD" command calculates and displays "d", the distance from a conic's focus to the nearest dirextrix line measured along the conic's local Z-axis. "r" is the base radius of curvature of the conic and "e" is the conic's eccentricity. Only conics with real eccentricities are supported by this command. A positive "r" value yields a negative "d" value and vice versa. "d" is just "r" divied by "e". "e" must be non-zero.The resultant value is left in the X-register.

DTOR , r , e - The "DTOR" command calculates and displays the conic base radius of curvature "r". "d" is the distance from a conic's focus to the nearest dirextrix line measured along the conic's local Z-axis and "e" is the conic's eccentricity. Only conics with real eccentricities are supported by this command. A positive "d" value yields a negative "r" value and vice versa. "r" is just "d" multiplied by "e". "e" must be non-zero.The resultant value is left in the X-register.

ETOCC , e , iflag - The "ETOCC" command calculates and displays the conic constant "cc",given the conic's eccentricity "e". If "iflag" is set to -1.0, the eccentricity is understood to be imaginary. The conic constant "cc" is just equal to $-e^2$ .The resultant value is left in the X-register.

CCTOE , cc - The "CCTOE" command calculates and displays the conic eccentricity "e",given the conic constant "cc". The conic's eccentricity "e" is just equal to $\sqrt{-cc}$. The resultant value is left in the X-register.

GENERAL PURPOSE COMMANDS - The commands described have their greatest usage inside Macros but may be used from the CMD level in an interactive way as well.

INDIRECT ADDRESSING OF COMMANDS

W1 (qualifier or numeric word #1) through **W5 (qualifier or numeric word #1)** - The "W1" through "W5" commands are special purpose commands which provide a form of indirect addressing for all other program commands that accept numeric input. They act in the following way: If commands "W1" through "W5" are entered with no "qualifier word" and no "numeric word #1", then the current value stored in the "X" or accumulator register will be used as the numeric word #1, #2, #3, #4 or #5, respectively, for the next program command (excluding other "W1" through "W5" commands). If commands "W1" through "W5" are entered with a qualifier word equal to the name of any named storage register, then the current value stored in that named register will be used as the numeric word #1, #2, #3, #4 or #5, respectively, for the next program command (excluding other "W1" through "W5" commands). If commands "W1" through "W5" are entered with numeric word #1 in the range 1 to MAXREG, then the current value stored in the general purpose storage register designated by that numeric word #1 entry will be used as the numeric word #1, #2, #3, #4 or #5, respectively, for the next program command (excluding other "W1" through "W5" commands). The following example will set the new "WV" values to be equal to the old "WV" values divided by 1.5. These are all CMD level command issued one after another from the command line. The "W1" through "W5" commands act like CMD level "NSUB" commands.

```
GET WV 1
STO 1
GET WV 2
STO 2
GET WV 3
STO 3
GET WV 4
STO 4
GET WV 5
STO 5
SET X 1.5
STO DIV 1
STO DIV 2
STO DIV 3
STO DIV 4
STO DIV 5
U L
W1 1
W2 2
W3 3
W4 4
W5 5
WV
EOS
```

PROMPTED INPUT - The program prompt has been discussed in the INTRO section of this manual. In general, the user issues a command from that prompt and the program does something. The next three commands allow the user to cause input to be prompted for. They are CMD level commands but they only have value when issued from within a macro.

PROMPT (character string of up to 20 characters) - The "PROMPT" command allows the user to set up a character string of up to 20 characters which will be used as part of the prompting string for a subsequent issuance of a "PREAD" command. This string will be appended to the string "INPUT ". The default prompt is a single blank space. Once set, the prompt remains set until changed or until the program ends. This command is not supported in the "THE PROGRAM AS A SUBROUTINE" mode.

PREAD The "PREAD" command causes a prompted read from the keyboard to be performed. The prompt "INPUT " followed by the last user defined prompt string will be displayed. The program will pause until input has been issued via the keyboard and the ENTER key has been pressed. The program will wait forever for the press of the ENTER key or until the computer power is interrupted. The input may be anything usable from the keyboard. It will be treated as a character value by the program. Up to 80 characters may be input. From within macros, if string comparisons are made, the lengths of those comparisons will be set by the length of the comparison test string. If, for example, the comparison test string is "END", then only the first three characters of the input string read by the last "PREAD" command will be compared. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5". This command is not supported in the "THE PROGRAM AS A SUBROUTINE" mode.

ATON The "ATON" command causes the first 23 characters of the last value read by the "PREAD" command to be converted to a numeric value. If this conversion process is successful, the numeric value will be stored in the X-register which will be described in the next section. If it can not be converted, a message to that effect will be displayed, the X-register will be left unchanged and an error flag will be set in the program which may be tested using the "BRERR" or "Branch on Read ERRor" command which is described in the MACRO section of this manual.. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

STOAX , i The "STOAX" command causes the last string value read by the "PREAD" command to be stored in alphanumeric storage register "i". The alphanumeric storage registers are discussed later in the CMD section. Valid values for "i" range from 1 to MAXREG. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

ARCL , i The "ARCL" command causes the string value stored in alphanumeric storage register "i" to be recalled so that it may be operated upon by an "ATON" command or so that it may be used in a macro with the "QRSUB" or "CRSUB" commands. The alphanumeric storage registers are discussed later in the CMD section. Valid values for "i" range from 1 to MAXREG. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

ARITHMETIC PROCESSING COMMANDS - There is a set of eight symbolic storage registers available for direct calculation and for calculations within a macro. These registers are named "A", "B", "C", "D", "E", "F", "G" and "H". These registers, along with an accumulator register also called the "X"-register, are known as the primary named registers. There also exists a number of secondary named registers. These secondary registers are used to form the real and imaginary stacks. The secondary named registers are named "Y", "Z", "T", "IX", "IY", "IZ" and "IT". There are also two other special tertiary named registers which keep track of the previous values of the "X" and "IX" registers. They are the "LASTX" and "LASTIX" registers. There also exists a set of MAXREG general purpose registers with their own separate set of manipulation commands. Only the primary and secondary named registers are saved and reloaded by the "SAVE" and "RELOAD" macro processing commands discussed in the MACRO section. When the program begins execution, all registers are initialized to zero. They are **not** automatically re-initialized again at any time during program execution. In the commands which follow, blank entry for "register name" indicates that the register to be used is the accumulator. The accumulator may, however, be called by name if so desired. Its names are "X" or "ACC". "register name" means "X", "Y", "Z", "T", "IX", "IY", "IZ", "IT", "A", "B", "C", "D", "E", "F", "G" and "H". It never refers to the numbered, general purpose registers.

SET (target register name) , (i or source register name) - The "SET" command places either the number "i" into the named target register or it places the value contained in the named source register into the named target register. This command is valid for both the primary and secondary named registers. There is a short cut to setting these registers as well. Enter the target register name with an equal sign appended then a space or comma (necessary) and finally either the numerical value to which the target register is to be set to, or the name of the source register which contains the value which is to be moved to the target register. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

<div align="center">

SET C 25.67
(or)
C= 25.67
(or)
SET A 25.67
(then)
SET C A
(or)
C= A

</div>

PI (register name) - The "PI" command places the value of π in double precision (3.141592653589793D0) into the named register. This command is valid for both the primary and secondary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

MOVE register name - The "MOVE" command moves the number stored in the named register to the accumulator. This command is valid for both the primary and secondary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

LASTX - The "LASTX" command moves the contents of the "LASTX" register into the accumulator. The previous accumulator value is moved to the "LASTX" register. This is a swap operation. This is similar to the "LASTX" key on some calculators. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

LASTIXThe "LASTIX" command moves the contents of the imaginary "LASTIX" register into the "IX" register. The previous "IX" register is moved to the "LASTIX" register. This is a swap operation analogous to "LASTX". This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

INCR (register name) , i - The "INCR" command adds the number "i" to the number in the named register, and the result is placed in the named register, i.e. the named register is incremented by "i". If "i" is not specified, the default value is taken as 1.0. The accumulator is unaffected unless no entry is made for the register name or unless the register "X" or "ACC" is named. This command is valid for both the primary and secondary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

PLUS (register name) - The "PLUS" command adds the number in the named register to the accumulator, and the result is left in the accumulator. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

MINUS (register name) - The "MINUS" command subtracts the number in the named register from the number in the accumulator, and the result is left in the accumulator. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

MPY (register name) - The "MPY" command multiplies the number in the accumulator by the number in the named register, and the result is left in the accumulator. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

DIV (register name) - The "DIV" command divides the number in the accumulator by the number in the named register, and the result is left in the accumulator. This command is only valid for the primary named registers. If the divisor is zero, the accumulator is set to zero. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

SQRT (register name) - The "SQRT" command causes the square root of the number in the named register to be placed in the accumulator. If the argument is zero, the accumulator is set to zero. If the argument is negative, an error message is printed and the accumulator is unchanged. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

SIN (register name) - The "SIN" command causes the sine of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. The value is assumed to be in radian measure. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

COS (register name) - The "COS" command causes the cosine of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. The value is assumed to be in radian measure. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

TAN (register name) - The "TAN" command causes the tangent of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. The value is assumed to be in radian measure. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

SINH (register name) - The "SINH" command causes the hyperbolic sine of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. The value is assumed to be in radian measure. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

COSH (register name) - The "COSH" command causes the hyperbolic cosine of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. The value is assumed to be in radian measure. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

TANH (register name) - The "TANH" command causes the hyperbolic tangent of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. The value is assumed to be in radian measure. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

ASIN (register name) - The "ASIN" command causes the arc-sine (in radians) of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

ACOS (register name) - The "ACOS" command causes the arc-cosine (in radians) of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

ATAN (register name) - The "ATAN" command causes the arc-tangent (in radians) of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

ABS (register name) - The "ABS" command causes the absolute value of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

EXP (register name) - The "EXP" command causes the exponential (e^X) of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. The maximum allowable value for the register value is 88.0. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

LN (register name) - The "LN" command causes the natural logarithm of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. If the register value is less than or equal to 0.0, the accumulator is set to 0.0. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

LOG10 (register name) - The "LOG10" command causes the base 10 logarithm of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. If the register value is less than or equal to 0.0, the accumulator is set to 0.0. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

FACT (register name) - The "FACT" command causes the factorial of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. The argument must be positive and must have a zero fractional part. Arguments larger than 33 are not allowed. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

SGN (register name) - The "SGN" command causes the SIGNUM function of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

Sgn(x) Values		
0	IF	x=0
+1	IF	x>0
-1	IF	x<0

RECIP (register name) The "RECIP" command causes the reciprocal of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. If the argument is zero, the accumulator is set to zero. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

INTGR (register name) - The "INTGR" command causes the integer portion of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. This is truncation and not rounding. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

FRAC (register name) - The "FRAC" command causes the fractional portion of the number in the named register to be placed in the accumulator. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

POW (register name) - The "POW" command causes the number in the accumulator to be raised to the power of the number in the named register, and the result is left in the accumulator. This command is only valid for the primary named registers. If the number in the accumulator and the number in the named register are both zero, the result of this operation is 1.0. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

STORE (register name) - The "STORE" command causes the number in the accumulator to be placed in the named register. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

RAND - The "RAND" command returns a uniform random deviate (uniformly distributed random value) in the range 0.0 to 1.0 to the X-register and a gaussian normally distributed deviate with mean value 0.0 and unit variance 1.0 (normally distributed value with mean 0.0 and one sigma value 1.0) to the Y-register. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

GENERAL COMMAND SECTION

NEWSEED - The random number generator used for all program random number calculations is automatically initialized each time the program starts. The "NEWSEED" command is used to re-initialize this random number generator at any time during program operation.

SEED , (seed value) - The random number generator used for all program random number calculations is automatically initialized each time the program starts and each time the "NEWSEED" command is issued. The "SEED" command is used to re-specify a "user-provided" seed value. The user-supplied "seed" must not be less than 0.001 and not greater than 1.0. The program uses the frist 5 significant figures of the input seed, thus and input seed of 0.1234567 would cause the new seed to be 0.12345. Issued with the interrogator "?", "SEED" displays the new seed value.

MOD , i , j - The "MOD" command causes the MODULO function of the arguments "i" and "j" to be calculated and returned to the accumulator. "i" and "j" are assumed to be floating point numbers. No other registers are involved. If "j" is equal to zero, the modulo is not defined and 0.0 is returned to the accumulator. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

ATAN2, i , j - The "ATAN2" command causes the FORTRAN "ATAN2" function of the arguments "i" and "j" to be calculated and returned (in radians) to the accumulator. No other registers are involved. "i" and "j" are assumed to be floating point numbers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

DTR (register name) - The "DTR" command causes the number in the named register (assumed to be an angular value in decimal degrees) to be converted to radian measure and placed in the accumulator. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

RTD (register name) - The "RTD" command causes the number in the named register (assumed to be an angular value in radians) to be converted to decimal degree measure and placed in the accumulator. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

CHS (register name) - The "CHS" command causes the number in the named register to be moved to the accumulator where its sign is changed. This command is only valid for the primary named registers. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

J1 , x - The "J1" command causes the value of the Bessel function $J_1(x)$, for any real "x" from -1.0D+15 to +1.0D+15, to be calculated and placed in the X-register. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

Whenever the value of the "X" or "IX" registers are changed, the previous values are placed in the "LASTX" or "LASTIX" registers. This behavior is true program wide.

GENERAL PURPOSE REGISTERS - The following commands work only upon the MAXREG general purpose storage registers. These registers are initially set to zero and only changed by the user and by certain commands where specifically documented.

RCL , i - The "RCL" command causes the number stored in register "i" to be recalled into the accumulator. "i" is a positive integer in the range 1 to MAXREG. The register value remains unchanged.

STO , i , (optional value) - If the "(optional value)" is not included, the "STO" command causes the number in the accumulator to be stored into register "i". "i" is a positive integer in the range 1 to MAXREG. If the "(optional vale)" is included, it is stored in the specified register. The accumulator remains unchanged in either case. Qualifier words may also be specified with the "RCL" and "STO" commands. These qualifier words modify the value to be transferred according to the rules below. This is storage register arithmetic similar to that found on some calculators. For division, if the accumulator (X-register) is zero, zero is stored or recalled. The "RCL" and "STO" commands are also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

Qualifier Word	Value Stored or Recalled
PLUS	Register "i" + "ACC"
MINUS	Register "i" - "ACC"
MPY	Register "i" * "ACC"
DIV	Register "i" / "ACC"

MAXVAL - The "MAXVAL" command stores the maximum of all values in the general purpose registers into the "X" register. It also stores the general purpose register number containing this maximum value into the "Y" register. The old "Y" register is copied into the "T" register and the old "X" register is copied into the "Z" register. The value of the "LASTX" register is updated. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

MINVAL - The "MINVAL" command stores the minimum of all values in the general purpose registers into the "X" register. It also stores the general purpose register number containing this minimum value into the "Y" register. The old "Y" register is copied into the "T" register and the old "X" register is copied into the "Z" register. The value of the "LASTX" register is updated. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

SHOW i , j - The "SHOW" command, when issued with no qualifier word input, is used to display the contents of one or more of the general purpose storage registers. If only the first numeric word is input, then the contents of general purpose storage register "i" will be displayed. If "i" and "j" are both input, the contents of registers "i" through "j" will be displayed. This is the first usage of the "SHOW" command. The second usage is described in connection with the "GET" command later in this manual section. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

SAVEREG i , j - The "SAVEREG" command outputs the values of general purpose storage registers "i" through "j" in a format which is readable by the program. Using this command in conjunction with "OUT" and "IN" provides the user with a way of saving and reloading all of the general purpose numeric storage registers from one program session to the next. This is advantageous in cases wherein the general purpose registers are being used as optimization variables or operands or as definition parameters from within the USERSURF.FOR or GOES.FOR subroutines.

CLEARREG i , j - The "CLEARREG" command resets the values of general purpose storage registers "i" through "j" to zero.

USER DEFINED FUNCTIONS

USERFUNC , x , y , z , t , i - The "USERFUNC" command causes the value of a user defined function, defined in the subroutine USERFUNC.FOR to be returned either to general purpose storage register "i", if "i" is explicitly entered or to the accumulator (x-register) is "i" is not explicitly entered. The values "x", "y", "z" and "t" are passed to the function. If these values are not explicitly entered, then the current values in the stack registers "X", "Y", "Z" and "T" will be passed to the function. The user of this command requires access to the program source code and access to the current compiler and graphics package software used to build this program.

USER DEFINED SUBROUTINE

USERSUBR - The "USERSUBR" command causes the user-written subroutine USERSUBR.FOR to be called. Anything may be included in this subroutine. The routine can take numeric, qualifier and string input. The user is 100% responsible for what this routine does.

ALPHANUMERIC REGISTERS - There are MAXREG alphanumeric storage registers. The following commands work only upon these MAXREG alphanumeric storage registers. These registers are initially set to blank and only changed by the user. Within a macro, the QSUB command may be used to modify these commands.

ASTO (qualifier word) (alphanumeric string) - The "ASTO" command causes the full alphanumeric string (up to 80 characters) to be stored in the alphanumeric storage register designated by the qualifier word. The string is later used by other program options, such as optimization and tolerancing, to clarify and annotate output. The valid qualifier words range from "A1" through "A(MAXREG)" and designate alphanumeric registers 1 through MAXREG. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

CLASTO - The "CLASTO" command causes the contents of the MAXREG alphanumeric storage registers to be set to blank character values. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

STOAX , i - The "STOAX" command causes the last string value read by the "PREAD" command to be stored in alphanumeric storage register "i". This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

ARCL , i The "ARCL" command causes the string value stored in alphanumeric storage register "i" to be recalled so that it may be operated upon by an "ATON" command or so that it may be used in a macro with the "QRSUB" or "CRSUB" commands. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

AWRITE , i - The "AWRITE" command causes the string value stored in alphanumeric storage register "i" to be displayed on the current output device. This command is also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

THE STACK REGISTERS - Unlike RPN calculators, there is no automatic stack push in this program. The only way the stack gets "pushed" is if the "ENT", "ENTI" or "ENTC" commands are issued. The secondary and tertiary named registers are used to provide a 4-level complex arithmetic RPN (Reverse Polish Notation) stack made up of the real stack ("X", "Y", "Z" and "T") and the imaginary stack ("IX", "IY", "IZ" and "IT"). The "LASTX" and "LASTIX" registers are provided to track the "X" and "IX" register previous values. All stack register commands are also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5". Values may be entered into these stack registers directly through the "SET" command or the values may be entered into the registers "X" and "IX" and then manipulated using the following commands:

ENT - Each time the "ENT" command is issued, the "Z" register is copied into the "T" register, then the "Y" register is copied into the "Z" register, then the "X" register is copied into the "Y" register. The value of the accumulator ("X" register) is left unchanged. This command pushes the real stack.

ENTI - Each time the "ENTI" command is issued, the "IZ" register is copied into the "IT" register, then the "IY" register is copied into the "IZ" register, then the "IX" register is copied into the "IY" register. The value of the "IX" register is left unchanged. This command pushes the imaginary stack.

ENTC The "ENTC" command is a combination of the "ENT" command and the "ENTI" command. This command pushes the complex stack.

PULL - The "PULL" command is the inverse of the "ENT" command. The "Y" register is copied into the "X" register, then the "Z" register is copied into the "Y" register, then the "T" register is copied into the "Z" register. The "T" register is left unchanged. The "LASTX" register is updated.

IPULL - The "IPULL" command is the inverse of the "ENTI" command. The "IY" register is copied into the "IX" register, then the "IZ" register is copied into the "IY" register, then the "IT" register is copied into the "IZ" register. The "IT" register is left unchanged. The "LASTIX" register is updated.

CPULL - The "CPULL" command is a combination of "PULL" and "IPULL". It operates on the complex stack.

RUP - The "RUP" command rolls up the values in the real stack registers. Each time it is issued, the value in the "X" register moves into the "Y" register, the value in the "Y" register moves to the "Z" register, the value in the "Z" register moves to the "T" register, and the value in the "T" register moves to the "X" register. The "LASTX" register is updated each time.

IRUP - The "IRUP" command rolls up the values in the imaginary stack registers "IX", "IY", "IZ" and "IT" in the same way that "RUP" rolled up the values in the real stack registers. The "LASTIX" register is updated each time.

CRUP - The "CRUP" command rolls up the values in the complex stack registers. It is a combination of the "RUP" and "IRUP" commands.

RDN - The "RDN" command rolls down the values in the real stack registers "X", "Y", "Z" and "T". Each time it is issued, the value in the "X" register moves into the "T" register, the value in the "Y" register moves into the "X" register, the value in the "Z" register moves into the "Y" register and the value in the "T" register moves into the "Z" register. The "LAST" register is updated each time.

IRDN - The "IRDN" command rolls down the values in the imaginary stack registers "IX", "IY", "IZ" and "IT". Each time it is issued, the value in the "IX" register moves into the "IT" register, the value in the "IY" register moves into the "IX" register, the value in the "IZ" register moves into the "IY" register and the value in the "IT" register moves into the "IZ" register. The "LASTIX" register is updated each time.

CRDN - The "CRDN" command is a combination of the "RDN" and "IRDN" commands.

CLSTK - The "CLSTK" command clears the real stack registers "X", "Y", "Z" and "T" to zero. The "LASTX" register is updated.

CLSTKI - The "CLSTKI" command clears the imaginary stack registers "IX", "IY", "IZ" and "IT" to zero. The "LASTIX" register is updated.

CLSTKC - The "CLSTKC" command clears the complex stack registers. It is a combination of the "CLSTK" and "CLSTKI" commands.

CLREG - The "CLREG" command clears to zero all the primary, secondary and tertiary named registers. It also clears the index and test registers which are described in detail in the MACRO section of this manual. Use it carefully!

GENERAL COMMAND SECTION

CLGREG - The "CLGREG" command clears to zero all numeric and alpha-numeric general purpose storage registers. Use it carefully!

CLX and CLIX - The "CLX" and "CLIX" commands clear the "X" and "IX" registers respectively. The "LASTX" and "LASTIX" registers are updated.

X-Y - The "X-Y" command exchanges the values in the "X" and "Y" register. The "LASTX" register is updated.

IX-IY - The "IX-IY" command exchanges values in the "IX" and "IY" registers. The "LASTIX" register is updated.

+ - The "+" command causes the values in the "X" and "Y" registers to be added together with the result left in the "X" register. The "LASTX" register is updated, and the real stack is "pulled" down.

- - The "-" command causes the value in the "X" register to be subtracted from the value in the "Y" stack register with the result left in the "X" register. The "LASTX" register is updated, and the real stack is "pulled" down.

* - The "*" command causes the values in the "X" and "Y" stack registers to be multiplied together with the result left in the "X" register. The "LASTX" register is updated, and the real stack is "pulled" down.

/ - The "/ " command causes the value in the "Y" register to be divided by the value in the "X" register with the result left in the "X" register. The "LASTX" register is updated, and the real stack is "pulled" down. If the contents of the "X" register are equal to 0.0, then no division is performed, a warning is printed and the real stack is left unchanged).

I+ - The "I+" command causes the values in the "IX" and "IY" stack registers to be added together with the result left in the "IX" register. The "LASTIX" register is updated, and the imaginary stack is "pulled" down.

I- The "I-" command causes the value in the "IX" register to be subtracted from the value in the "IY" register with the result left in the "IX" register. The "LASTIX" register is updated and the imaginary stack is "pulled" down.

I* - The "I*" command causes the values in the "IX" and "IY" registers to be multiplied together with the result left in the "IX" register. The "LASTIX" register is updated, and the imaginary stack is "pulled" down.

I/ - The "I/" command causes the value in the "IY" register to be divided by the value in the "IX" stack register with the result left in the "IX" register. The "LASTIX" register is updated, and the imaginary stack is "pulleddown. If the contents of the "IX" register are equal to 0.0, then no division is performed, a warning is printed and the imaginary stack is left unchanged).

C+ - The "C+" command is a combination of ("+") and ("I+").

C- - The "C-" command is a combination of ("-") and ("I-").

C* - The "C*" command is a combination of ("*") and ("I*").

C/ - The "C/" command is a combination of ("/") and ("I/").

Y**X - The "Y**X" command causes the value in the "Y" register to be raised to the power of the value in the "X" register. The result is left in the "X" register, and the real stack is "pulled" down.

IY**IX - The "IY**X" command causes the value in the "IY" register to be raised to the power of the value in the "IX" register. The result is left in the "IX" register, and the imaginary stack is "pulled" down.

CY**CX The "CY**CX" command is a combination of the "Y**X" and the "IY**IX" commands.

P-R - The "P-R" command converts the R(radius) and Ø (angular) values stored in the "X" and "Y" registers from polar to rectangular coordinates. The results are stored in the "X" and "Y" registers, the X-result stored in the "X" register and the Y-result stored in the "Y" register. Ø is assumed to be in decimal degrees.

R-P - The "R-P" command converts the X and Y values stored in the "X" and "Y" registers from rectangular to polar coordinates. The results are stored in the "X" and "Y" registers, the R(radius)-result stored in the "X" register and the Ø (angular)-result stored in the "Y" register. Ø is represented in decimal degrees.

GENERAL COMMAND SECTION

CYL-R - The "CYL-R" command converts the R, Ø and Z values stored in the "X", "Y" and "Z" registers from right-handed cylindrical to rectangular coordinates. The results are stored in the "X", "Y" and "Z" registers, the X-result stored in the "X" register, the Y-result stored in the "Y" register and the Z-result stored in the "Z" register. Ø is assumed to be in decimal degrees.

R-CYL - The "R-CYL" command converts the X, Y and Z values stored in the "X", "Y" and "Z" registers from rectangular to right-handed cylindrical coordinates. The results are stored in the "X", "Y" and "Z" registers, the R-result stored in the "X" register, the Ø-result stored in the "Y" register and the Z-result stored in the "Z" register. Ø is represented in decimal degrees.

SP-R - The "SP-R" command converts the R, Ø and PHI values stored in the "X", "Y" and "Z" registers from right-handed spherical to rectangular coordinates. The results are stored in the "X", "Y" and "Z" registers, the X-result stored in the "X" register, the Y-result stored in the "Y" register and the Z-result stored in the "Z" register. Ø and PHI are assumed to be in decimal degrees.

R-SP - The "R-SP" command converts the X, Y and Z values stored in the "X", "Y" and "Z" registers from rectangular to right-handed spherical coordinates. The results are stored in the "X", "Y" and "Z" registers, the R-result stored in the "X" register, the Ø-result stored in the "Y" register and the PHI-result stored in the "Z" register. Ø and PHI are represented in decimal degrees.

RE-IM - The "RE-IM" command exchanges the real and imaginary stacks. The "LASTX" and "LASTIX" registers are updated. This is an expanded version of the "X-Y" command.

H-HMS - The "H-HMS" command converts the value in the "X" register (assumed to be a value in decimal hours or decimal degrees) to hours-minutes-seconds or degrees-minutes-seconds format. The "LASTX" register is updated.

HMS-H - The "HMS-H" command converts the value in the "X" register (assumed to be a value in hours-minutes-seconds or degrees-minutes-seconds) to decimal hours or decimal degrees format. The "LASTX" register is updated.

VECTOR OPERATIONS - The following commands allow for the input of two, three component vectors and allow for DOT and CROSS products to be formed from them

AVEC , x , y , z - The "AVEC command is used to set the A-vector's components to "x", "y" and "z" Default values are assumed to be zero as long as at least one explicit value is input. Issued with the "?" operator or with no input, the current values of "x", "y" and "z" are displayed.

BVEC , x , y , z - The "BVEC command is used to set the B-vector's components to "x", "y" and "z" Default values are assumed to be zero as long as at least one explicit value is input. Issued with the "?" operator or with no input, the current values of "x", "y" and "z" are displayed.

DOT (N) - The "DOT command causes the vector DOT product of A and B to be computed, placed in the X-register and displayed to the current output device. If the qualifier word "N" is included, the display is suppressed.

CROSS (N) - The "CROSS command causes the vector CROSS product of A and B to be computed. The x-component is placed in the x-register, the y-component is placed in the y-register and the z-component is placed in the z-register. The values are displayed to the current output device. If the qualifier word "N" is included, the display is suppressed.

THE MIN/MAX REGISTERS - Many times it is of use to find the maximum or minimum value of a set of values. The MIN/MAX registers serve this purpose. There are 100 MIN registers and 100 MAX registers (1 to 100). These registers may be reset to any starting value using the commands "RESETMIN" and "RESETMAX"

RESETMIN , n , v - The "RESETMIN command is used to reset the MIN register designated by the integer "n" to value "v". If "n" is not explicitly entered, all 100 MIN registers will be reset. The default value for "v" is +1.0D+300.

RESETMAX , n , v - The "RESETMAX command is used to reset the MAX register designated by the integer "n" to value "v". If "n" is not explicitly entered, all 100 MAX registers will be reset. The default value for "v" is -1.0D+300. Any numeric value in the x-register (or accumulator) may be "tested" against a current value in a NIM or MAX register. If the value in the x-register is tested against a MIN register value and the value in the x-register is numerically less than the value in that MIN register, then the value in the accumulator is copied into that MIN register and becomes the new minimum value. Likewise, if the value in the x-register is tested against a MAX register value and the value in the x-register is numerically greater than the value in that MAX register, then the value in the accumulator is copied into that MAX register and becomes the new maximum value.

STOREMIN , n - The "STOREMIN command is used to test if the current value in the x-register is less than the value in the MIN register designated by "n". The default for "n" is 1, for the first MIN register. If the value in the x-register is less than the value in the referenced MIN register, then the value in the x-register is copied into that MIN register and becomes the new minimum vale.

GENERAL COMMAND SECTION

STOREMAX , n - The "STOREMAX command is used to test if the current value in the x-register is greater than the value in the MAX register designated by "n". The default for "n" is 1, for the first MAX register. If the value in the x-register is greater than the value in the referenced MAX register, then the value in the x-register is copied into that MAX register and becomes the new maximum value. Values in MIN and MAX registers may be copied back into the x-register at any time using the "GET MINREG" and "GET MAXREG" commands described in the "GET" section of this manual section.

UNITS CONVERSIONS - The following commands assume that the value in the X-register is representative of a quantity in "from units". The commands convert this value to specific "to units". These commands ar also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5".

From Units	To Units	Command Name
in	mm	**IN-MM**
in	cm	**IN-CM**
in	m	**IN-M**
mm	in	**MM-IN**
cm	in	**CM-IN**
m	in	**M-IN**

LINEAR, PARABOLIC AND CUBIC INTERPOLATION - The following seven commands give the program the ability to do linear 2-point, parabolic 3-point and cubic 4-point interpolation of data:

X1Y1= , i , j and
X2Y2= , i , j and
X3Y3= , i , j and
X4Y4= , i , j
The "X1Y1=", X2Y2=", "X3Y3=" and "X4Y4=" commands provide for the input of up to four x, y data pairs. These data pairs are remembered until they are changed or until program termination.

INTERP LIN , x - The "INTERP LIN" command causes a linear interpolation between the x1, y1 and x2, y2 data pairs. A new value y is calculated for the value of "x". The new y-value is displayed and also stored in the accumulator. The "LASTX" register is updated.

INTERP LAG , x   or   INTERP PAR , x - The "INTERP LAG" or "INTERP PAR" command causes a 3-point parabolic Lagrangian interpolation among the x1, y1, x2, y2 and x3, y3 data pairs. A new value y is calculated for the value of "x". The new y-value is displayed and also stored in the accumulator. The "LASTX" register is updated.

INTERP CUBIC , x - The "INTERP CUBIC" command causes a 4-point cubic interpolation among the x1,y1, x2,y2, x3,y3 and x4,y4 data pairs. A new value y is calculated for the value of "x". The new y-value is displayed and also stored in the accumulator. The "LASTX" register is updated.

FLAG CONTROLS - The program has 20 user flags which may be set and tested by the user. They are global and are available at the CMD level or from any macro nesting level.

FLAG , f1, f2, f3, f4 , f5 - The "FLAG" command may be used to turn "on" or "off" up to five flags at a time. The absolute value of each flag f_i specifies the flag to be set. If f_i is positive, the flag is set "on". If fi is negative, the flag is set "off". NSUB commands (described in the MACRO section) may be used to modify the "FLAG" command from within a macro. If the "FLAG" command is issued without numeric input (just "FLAG"), then the setting of each flag is printed to the current output device. Output appears as either a "+ 1" for true or "- 1" for false with the status of flags f1 to f5 in the first row, f6 to f10 in the second row, etc. In order to set flags numbers 3, 5 and 6 to on and 17 and 19 to off, issue the command: "FLAG ,3, 5, 6, -17, -19" In order to display the current status of all flags, issue the command: "FLAG" which will yield output of the following form:

-1	-2	3	-4	5
6	-7	-8	-9	-10
-11	-12	-13	-14	-15
-16	17	-18	19	-20

The output shown on the previous page indicates that flags 3, 5 and 6 are the only flags currently set to on. All 20 user flags are initially set off when the program is started.

STATISTICAL COMMANDS - The program has statistical functions similar to some popular hand calculators. All statistical register commands are also operational at all the program sub-levels in order to support the indirect addressing commands "W1" through "W5". The general purpose registers 151 to 200 are used for these calculations. The following commands are available for statistical calculations:

CLSTREG - The "CLSTREG" command clears to zero the general purpose registers 150 to 200.

STADD - The "STADD" command adds the current values in the "X" and "Y" registers to the statistical accumulations being formed in the statistical registers. It also increments the statistical counter by 1.0.

STSUB - The "STSUB" command subtracts the current values in the "X" and "Y" stack registers from the statistical accumulations being formed in the statistical registers and also decrements the statistical counter by 1.0.

MEAN - The "MEAN" command calculates the X-mean value and the Y-mean value of the data in the statistical accumulation registers and leaves the X-mean and the Y-mean values in the "X" and "Y" registers, respectively. The "LASTX" register is updated.

STDEV - The "STDEV" command calculates the X-standard deviation and the Y-standard deviation of the data in the statistical accumulation registers, placing the X-standard deviation value in the "X" register and the Y-standard deviation value in the "Y" register. The "LASTX" register is updated.

REGISTER	151	NUMBER OF DATA POINTS ACCUMULATED
REGISTER	152	SUMMATION OF X-VALUES
REGISTER	153	SUMMATION OF SQUARES OF X-VALUES
REGISTER	154	SUMMATION OF Y-VALUES
REGISTER	155	SUMMATION OF SQUARES OF Y-VALUES
REGISTER	156	SUMMATION OF PRODUCT X*Y
REGISTER	157	SUMMATION OF PRODUCT (X**2)*Y
REGISTER	158	SUMMATION OF PRODUCT X*(Y**2)
REGISTER	159	SUMMATION OF CUBES OF X-VALUES
REGISTER	160	SUMMATION OF CUBES OF Y-VALUES
REGISTERS	161-200	(RESERVED FOR EXPANSION)

DATA OUTPUT COMMANDS

FORMAT (format string) - The "FORMAT" command is used to set up the output format for the "WRITE", "SHOW", "PRIREG", "PSTK", "PSTKI", "PSTKC", "PLSTX" and "PLSTIX" commands. The "format string" can any valid FORTRAN format specification. The program default format is "D23.15". Only output to the screen, to the spool file and to the printer are modified by the "FORMAT" command. Output to all other devices and files is done in a D23.15 format. EXAMPLE: **"FORMAT F11.2"** would cause all output generated by the "WRITE", "SHOW", "PRIREG" and stack output commands to be displayed in an F11.2 format.

WRITE (register name) , (optional alphanumeric label up to 40 characters) - The "WRITE" command generates a line of output which looks like:

label = value stored in the named register

The "WRITE" command is valid for the primary and secondary named registers only. If no register name is given, then the value in the accumulator ("X" register) is printed. If no label is entered and if the output device is the screen or the file PRINTER.TXT, then the register name will be printed in front of the numeric value. Output to the file PRINTER.TXT is specified using the command "OUTPUT LP". For other file output, such as to the file CARDTEXT.DAT using "OUTPUT CP", the labels and/or register names are not printed before the numeric values of the register contents. If the qualifier word "ALL" is used, then the contents of all primary and secondary registers are printed. In the "ALL" option, labels are not available for use. If the "label" is explicitly entered, then the first forty (40) non-blank characters of "label" will be used for the label.

PRIREG - The "PRIREG" command performs the same function as "WRITE ALL" in the foregoing discussion of output using "WRITE".

PRSTK - The "PRSTK" command causes the values in the real stack registers "X", "Y" ,"Z" and "T" to be output. If output goes to the screen or to LP, program supplied labels are used. For other output devices, only the numerical values stored in the real stack registers are printed.

PRSTKI - The "PRSTKI" command causes the values in the imaginary stack registers "IX", "IY", "IZ" and "IT" to be output. If output goes to the screen or to LP, program supplied labels are used. For other output devices, only the numerical values stored in the imaginary stack registers are printed.

PRSTKC - The "PRSTKC" command is a combination of the "PRSTK" and "PRSTKI" commands.

PRLSTX and
PRLSTIX - The "PRLSTX" and "PRLSTIX" commands cause the "LASTX" and "LASTIX" registers to be output. If output is to the terminal or to LP, then a program supplied label is used. For other output devices, only the numerical value stored in the "LASTX" or "LASTIX" register is printed.

LFORMAT (format string) - The line formatting "LFORMAT" command is used to set up the output format for the "LWRITE" command. The "format string" can be any valid FORTRAN format specification which will output up to five numerical values. If the "format string" conflicts with the number of output values listed in the "LWRITE" command, a warning message is issued and no action is taken. This is a very powerful command. All "LWRITE" output is modified by the "LFORMAT" command. There is no default value for the "format string". EXAMPLE: **LFORMAT F11.2,1x,G23.15** would cause all output generated by the "LWRITE 3, 5" command to be output with the (F11.2,2x,G23.15) format. For those not familiar with FORTRAN formatting, see a basic FORTRAN reference text.

LWRITE (A1 through A(MAXREG)) , i1, i2, i3, i4, i5 - The line writing "LWRITE" command generates a line of output of up to five numerical values formatted by the current "LFORMAT" format specification. The values "i1", "i2", "i3", "i4" and "i5" are the numbers of general purpose numerical storage registers. In the example above, the contents of the #3 and #5 general purpose numerical storage registers would be written to the current output device. "LWRITE" also accepts optional qualifier words "A1" through "A(MAXREG)". If one of these qualifier words is issued with the "LWRITE" command, then the numeric output generated by the "LWRITE" command will be preceded by an alphanumeric label which will consist of the current contents of the alphanumeric storage register designated by the qualifier word. If the content of the designated alphanumeric storage register is all blank then no label will be displayed. If, for example, alphanumeric storage register #50 had stored in it the string value "DATA" and general purpose storage registers 1, 2, 3 and 4 had the values 10, 20, 30 and 60 stored in them, then the command "LWRITE A50 , 1 , 2 , 3 , 4" using a previously issued "LFORMAT" statement of

"LFORMAT F6.2,1x,F6.2,1x,F6.2,1x,F6.2

would generate the output:

DATA 10.00 20.00 30.00 60.00

The use of the optional label is a good way to generate new program input commands in an output text file which will later be read into back into the program and executed.

OUTPUT FORMATS - The "FORMAT" and "LFORMAT" commands refer to Fortran format specifications. This next section explains these format specifications for users not familiar with the Fortran language. The "FORMAT" and "LFORMAT" commands can take any of the many format specifications available in Fortran. Only a few of these format specifiers are really needed in order to control output using the "WRITE" and "LWRITE" commands. The "X", "F", "I" and "D" specifiers will be described here. Should the user wish to use other Fortran format specifies, the user should refer to one of the many good Fortran 77 or Fortran 90 reference books available at any good technical bookstore or library. The "X" format specifier is used to add a blank or blanks to output. 5X would generate five blank spaces in the output. This format specifier is only useful with "LWRITE" and "LFORMAT". The "F" format specifier is used to output "fixed" format, non-integer data. The syntax is F#.d where "#" is an integer which specifies the total number of spaces used for the number (including the sign) and "d" is an integer which specifies the number of digits to the right of the decimal point. The value of $-\pi$ output in F7.4 format would be -3.1416. The "I#" format specifier is used to output "integer" format, integer data. "#" specifies the number of spaces used. To output the value 345 in 5 spaces, use the format specifier I5. The output would contain two spaces preceding 345. The "D#.d" format specifier is used to output floating point data in exponential, double precision form. "#" specifies the total number of spaces used, "d" specifies the number of digits to the right of the decimal. If 234.5675431 was output with D10.5 format, the result would be 0.23457D+3.

THE TABLE WRITER - The TABLE WRITER provides the capability for conveniently generating tabulated output of user data. Tables can have up to100 rows and 9 columns. The following commands are used to construct, manipulate and display data tables:

TABLE SETUP - The "TABLE SETUP" command sets the numeric storage area of the current table to 0.0. This is required before table input.
TABLE CLEAR - The "TABLE CLEAR" command sets the numeric storage area of the current table to 0.0. Any existing row and column headings are preserved.

ROWHD (row name), : (row label) and
COLHD (column name), : (row label) and
ROWHD2 (row name), (row label) and
COLHD2 (column name), (row label) - The "ROWHD" and "ROWHD2" commands expect to be given "row names" which range from "R1" through "R100". The "COLHD" and "COLHD2" commands expect to be given column names "C1" through "C9". Each of these commands also expect a 1 to 12-character string input designating the particular "row label" or "column label". "ROWHD" or "COLHD" is used for the first 12-character line of a row or column label. "ROWHD2" or "COLHD2" is used if a second 12-character line is needed for a row or column label.

TABLE PUT , i , j , (numeric value) - The "TABLE PUT" command copies the contents of the accumulator (X-register) to row "i", column "j" of the current table if no numeric value is supplied. If a numeric value is supplied as numeric word #3, that value is loaded into the designated table position.

TABLE GET , i , j - he "TABLE GET" command copies the contents of row "i", column "j" of the current table into the accumulator (X-register). The stack and the LASTX register are updated.

TABLE PRINT1 and
TABLE PRINT2 and
TABLE PRINT3 - The "TABLE PRINT1", "TABLE PRINT2" and "TABLE PRINT3" commands cause the contents of the current table to be displayed on the current output device or to be written to a file.

"TABLE PRINT1" displays the table in a space delimited, 80-column format to the current output device.
"TABLE PRINT2" is used to write the table to a disk file when OUT is not TP or LP (terminal or printer)..
"TABLE PRINT3" outputs the table, without column and row headings, in a comma delimited, D23.15 format when the output file was previously specified with an "OUT FILE (file name)" type of output redirection.

TABLE SAVE and
TABLE RELOAD - The "TABLE SAVE" and "TABLE RELOAD" commands cause the contents of the table to be written to and read from a direct access, unformatted binary file named TAB.DAT.

FINANCIAL COMMAND SECTION

GENERAL INFORMATION - This manual section describes general financial analysis operations which have no connection to optics, optical design or optical analysis except as an adjunct to running a business or for investment purposes. I wrote these for my own use and decided to use the framework of the optical design program to host them. They come with no warranty whatsoever. There are general financial calculations available as well as sophisticated stock market analysis.

STOCK MARKET ANALYSIS - All the the following stock market analysis operations are based upon the analysis of historical stock market data contained in the ASCII file, PROFIT.DAT. Each line of PROFIT.DAT comprises the following data:

SYM (up to 8 characters representing the stock's symbol) , Opening Price , Day's High Price , Day's Low Price , Day's Closing Price , Day's Volume (number of shares traded) , Date (YYYYMMDD format) , Company Descriptor (up to 80 characters)

The assumption is that the data for each stock is always grouped together and within each group, entries are in assending date order. See the PROFSAMP.DAT file for an example. The user can us any methoe to generate the PROFIT.DAT file. The author currently uses the Worden Bros TC2005 program and data service to generate a daily updated PROFIT.DAT file. Trading days are the only days kept track of. Weekends, holidays and other days when no trading is performed are not considered.

ISSUE CONTROL PARAMETERS

PMP (qualifier word) - The "PMP" command displays the current value of the parameter identified by "qualifier word". This command is also described in the CMD section.

PM (qualifier word) , i - The "PM" command is used to set a control parameter, identified by "qualifier word", to the numeric value specified by "i". This command is also described in the CMD section. The table below lists the various control parameters:

QUALIFIER	DESCRIPTION
SHORT	This is the "short" time interval used in "short" moving averages. **Default value = 5 days**
MEDIUM	This is the "medium" time interval used in "medium" moving averages. **Default value = 10 days**
LONG	This is the "long" time interval for "long" moving averages. **Default value = 30 days**
BUYDELAY	This is the "buy delay" time interval used in automatic "buy" alarm routines to help avoid false "buy" alarms. **Default value = 5 days**
SELDELAY	This is the "sell delay" time interval used in automatic "sell" alarm routines to help avoid false "sell" alarms. **Default value = 5 days**
DAYS	This is the number of days to display in a graphical stock plot. It counts back from the last day in the database or the last day to be displayed or analyzed. Minimum number of days is 30. **Default value = 60 days**

If any of the above operating condition qualifier words is issued as a command word rather than a qualifier word, and if they are issued without numeric input, they are then treated as if they had been preceded by the "PMP" command. If they are entered with appropriate numeric input, they are then treated as if they had been preceded by the "PM" command.

PROFIT OPERATING CONDITIONS
LOADPROF (OPTIONAL FILE NAME) - The "LOADPROF" command causes the current PROFIT.DAT file to be read and processed. If an optional file name is entered, that file is loaded. After each stock item (data with the same stock symbol) is processed, All the items are written into an archieval binary file PROFDAT.DAT. A second binary file PROFLIB.PRF is written which remembers the sequential number of each stock in the current database, the stock's symbol, the company descriptor, the starting and ending record number for that symbol and the total number or days for that symbol as saved in PROFDAT.PRF. If the optional file associated with the optional file name exists and it is a single issue file, and automatic "LOADISSU (issue name)" and "PLOTISSU" commands will be issued.

The following data is computed for each stock and is stored in the PDAT.PRF binary files:

For each stock referenced in the PROLIB.DAT file: N records consist each of up to 100, 8-byte, REAL*8 or Double Precision values. Each record represents data associated with one day of stock issue data though some values are based on averages of earlier days values.

Item 1: The day's highest price
Item 2: The days lowest price
Item 3: The day's closing price
Item 4: The short moving average
Item 5: The medium moving average
Item 6: The long moving average
Item 7: The short oscillator
Item 8: The long oscillator
Item 9: The short trend
Item 10: The long trend
Item 11: The spread
Item 12: The days volume (number of shares traded)
Item 13: Date (YYYYMMDD)
Item 14: High price delta
Item 15: Low price delta
Item 16: Closing price delta
Item 17: Short moving average delta
Item 18: Medium moving average delta
Item 19: Long moving average delta
Item 20: Short oscillator delta
Item 21: Long oscillator delta
Item 22: Short trend delta
Item 23: Long trend delta
Item 24: Spread delta
Item 25: Volume delta
Item 26: (NOT IN USE)
Item 27: Second delta of high price
Item 28: Second delta of low price
Item 29: Second delta of closing price
Item 30: Second delta of short moving average
Item 31: Second delta of medium moving average
Item 32: Second delta of long moving average
Item 33: Second delta of short oscillator
Item 34: Second delta of long oscillator
Item 35: Second delta of short trend
Item 36: Second delta of long trend
Item 37: Second delta of spread
Item 38: Second delta of volume
Item 39: (NOT IN USE)
Item 40: Julian day number
Item 41: Julian day number delta
Item 42: Second delta of Julian day number
Item 43: (NOT IN USE)
Item 44: (NOT IN USE)
Item 45: (NOT IN USE)
Item 46: Opening price
Item 47: Issue number in the PROFIT.DAT file (SREC)
Item 48: Sequential entry number in the PROFIT.DAT file (IREC)
Item 49: Sequential entry for the particular isse (JREC)
Item 50: Current total number of entries for current issue
Item 51: Short moving average of the spread
Item 52: Medium moving average of the spread
Item 53: Long moving average of the spread.

Items 54 - 100 (NOT IN USE)

FUNCTIONAL DEFINITIONS
The following is a functional definition of every item tracked in the binary (SYM).PRF files. The actual fortran code is included to avoid any abiguity as to how the calculations are performed

```
C
C       SHORT_TIME, MEDIUM_TIME, LONG_TIME, BUY_DELAY AND
C       SELL_DELAY ARE HANDLED WITH THE PM AND PMP COMMANDS
C       SHORT,MEDIUM,LONG,SELDELAY,BUYDELAY
C
```

```
C          SHORT INTERMEDIATE VARIABLES
           D2=2.0/DBLE(SHORT_TIME+1)
           D2=(ANINT(D2*100))/100
           D1=1.0-D2
C
C          MEDIUM INTERMEDIATE VARIABLES
           D4=2.0/DBLE(MEDIUM_TIME+1)
           D4=(ANINT(D4*100))/100
           D3=1.0-D4
C
C          LONG INTERMEDIATE VARIABLES
           D6=2.0/DBLE(LONG_TIME+1)
           D6=(ANINT(D6*100))/100
           D5=1.0-D6
C
C          J IS THE SEQUENTIAL COUNTER OF DAYS SINCE THE
C          BEGINNING OF AN ISSUES' DATABASE
C
C          ITEMS 1,2,3 AND 13 ARE INPUT NUMBERS
C
C          PRICE HI
C          PROFITDATA(J,1), READ FROM PROFIT.DAT
C
C          PRICE LOW
C          PROFITDATA(J,2), READ FROM PROFIT.DAT
C
C          PRICE CLOSE
C          PROFITDATA(J,3), READ FROM PROFIT.DAT
C
C          VOLUME
C          PROFITDATA(J,12), READ FROM PROFIT.DAT
C
C          SHORT MOVING AVERAGE
           IF(J.GT.SHORT_TIME) THEN
           PROFITDATA(J,4)=
     1     ANINT((D1*PROFITDATA(J-1,4)+
     2     D2*PROFITDATA(J,3)*100))/100
                   ELSE
           IF(J.EQ.1) THEN
           PROFITDATA(J,4)=PROFITDATA(J,3)
                   ELSE
           PROFITDATA(J,4)=((DBLE(J-1)*(PROFITDATA(J,4)))
     1     +PROFITDATA(J,3))/DBLE(J)
                   END IF
                   END IF
C
C          MEDIUM MOVING AVERAGE
           IF(J.GT.MEDIUM_TIME) THEN
           PROFITDATA(J,5)=
     1     ANINT((D3*PROFITDATA(J-1,5)+
     2     D4*PROFITDATA(J,3)*100))/100
                   ELSE
           IF(J.EQ.1) THEN
           PROFITDATA(J,5)=PROFITDATA(J,3)
                   ELSE
           PROFITDATA(J,5)=((DBLE(J-1)*(PROFITDATA(J,5)))
     1     +PROFITDATA(J,3))/DBLE(J)
                   END IF
                   END IF

C
C          LONG MOVING AVERAGE
           IF(J.GT.LONG_TIME) THEN
           PROFITDATA(J,6)=
     1     ANINT((D5*PROFITDATA(J-1,6)+
     2     D6*PROFITDATA(J,3)*100))/100
                   ELSE
           IF(J.EQ.1) THEN
           PROFITDATA(J,6)=PROFITDATA(J,3)
                   ELSE
           PROFITDATA(J,6)=((DBLE(J-1)*(PROFITDATA(J,6)))
     1     +PROFITDATA(J,3))/DBLE(J)
                   END IF
                   END IF
C
C          SHORT TREND
C          SHORT MOVING AVERAGE MINUS LONG MOVING AVERAGE
           PROFITDATA(J,9)=
     1     ANINT((PROFITDATA(J,4)-PROFITDATA(J,6))*100)
C

C          LONG TREND
C          MEDIUM MOVING AVERAGE MINUS LONG MOVING AVERAGE
           PROFITDATA(J,10)=
     1     ANINT((PROFITDATA(J,5)-PROFITDATA(J,6))*100)
C
C          SHORT AND LONG OSCILLATORS ARE RELATED TO THE
C           SHORT AND LONG TRENDS
```

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```
         IF(J.EQ.1) THEN
C        SHORT OSCILLATOR
         PROFITDATA(J,7)=
     1   ANINT((PROFITDATA(J,9))*100)
C
C        LONG OSCILLATOR
         PROFITDATA(J,8)=
     1   ANINT((PROFITDATA(J,10))*100)
                         ELSE
C        SHORT OSCILLATOR
         PROFITDATA(J,7)=
     1   ANINT((PROFITDATA(J,9)-PROFITDATA(J-1,9))*100)
C
C        LONG OSCILLATOR
         PROFITDATA(J,8)=
     1   ANINT((PROFITDATA(J,10)-PROFITDATA(J-1,10))*100)
                         END IF
C
C        SPREAD
C        SHORT TREND MINUS LONG TREND
         PROFITDATA(J,11)=
     1   PROFITDATA(J,9)-PROFITDATA(J,10)
C
C        I ADDED THE SHORT, MEDIUM AND LONG MOVING AVERAGES
C        OF THE SPREAD TO GIVE US SOMETHING FOR AN APPLES TO APPLES
C        TYPE COMPARISON WITH THE SHORT, MEDIUM AND LONG MOVING AVERAGES
C
C        SHORT MOVING AVERAGE OF THE SPREAD
C        (NEED TO BE INTO THE DATA AT LEAST SHORT+LONG DAYS TO BE MEANINGFULL)
         IF(J.GT.SHORT_TIME) THEN
         PROFITDATA(J,51)=
     1   ANINT((D1*PROFITDATA(J-1,51)+
     2   D2*PROFITDATA(J,11)*100))/100
                 ELSE
         IF(J.EQ.1) THEN
         PROFITDATA(J,51)=PROFITDATA(J,11)
                 ELSE
         PROFITDATA(J,51)=((DBLE(J-1)*(PROFITDATA(J,51)))
     1   +PROFITDATA(J,11))/DBLE(J)
                 END IF
                 END IF
C
C        MEDIUM MOVING AVERAGE OR THE SPREAD
C        (NEED TO BE INTO THE DATA AT LEAST MEDIUM+LONG DAYS TO BE MEANINGFULL)
         IF(J.GT.MEDIUM_TIME) THEN
         PROFITDATA(J,52)=
     1   ANINT((D3*PROFITDATA(J-1,52)+
     2   D4*PROFITDATA(J,11)*100))/100
                 ELSE
         IF(J.EQ.1) THEN
         PROFITDATA(J,52)=PROFITDATA(J,11)
                 ELSE
         PROFITDATA(J,52)=((DBLE(J-1)*(PROFITDATA(J,52)))
     1   +PROFITDATA(J,11))/DBLE(J)
                 END IF
                 END IF
C
C        LONG MOVING AVERAGE OF THE SPREAD
C        (NEED TO BE INTO THE DATA AT LEAST LONG+LONG DAYS TO BE MEANINGFULL)
         IF(J.GT.LONG_TIME) THEN
         PROFITDATA(J,53)=
     1   ANINT((D5*PROFITDATA(J-1,53)+
     2   D6*PROFITDATA(J,11)*100))/100
                 ELSE
         IF(J.EQ.1) THEN
         PROFITDATA(J,53)=PROFITDATA(J,11)
                 ELSE
         PROFITDATA(J,53)=((DBLE(J-1)*(PROFITDATA(J,53)))
     1   +PROFITDATA(J,11))/DBLE(J)
                 END IF
                 END IF
C
C        VOLUME STORED IN 12
C
C        JULIAN DAY IN 40
C
C        FIRST DELTA JULIAN DAY IN 41
C
C        DECOND DELTA JULAIN DAY IN 42
C
C        DATE STORED IN 13 AS YYYYMMDD
         IDATE=INT(PROFITDATA(J,13))
         WRITE(ADATE,10) IDATE
 10      FORMAT(I8)
         AYEAR=ADATE(1:4)
         AMONTH=ADATE(5:6)
         ADAY=ADATE(7:8)
```

```
          READ(AYEAR,11) IYEAR
          READ(AMONTH,12) IMONTH
          READ(ADAY,13) IDAY
   11     FORMAT(I4)
   12     FORMAT(I2)
   13     FORMAT(I2)
          JD=JULDAY(IMONTH,IDAY,IYEAR)
          PROFITDATA(J,40)=DBLE(JD)
          IF(J.LT.2) THEN
          PROFITDATA(J,41)=0.0D0
          ELSE
          PROFITDATA(J,41)=PROFITDATA(J,40)-PROFITDATA(J-1,40)
                          END IF
          IF(J.LT.3) THEN
          PROFITDATA(J,41)=0.0D0
          ELSE
          PROFITDATA(J,42)=PROFITDATA(J,41)-PROFITDATA(J-1,41)
                          END IF
C
C         FIRST DELTAS (SLOPES)
C
          IF(J.LT.2) THEN
          PROFITDATA(J,14:25)=0.0
                          ELSE
C         K=14, HI PRICE DELTA
          PROFITDATA(J,14)=PROFITDATA(J,1)-PROFITDATA(J-1,1)
C         K=15, LO PRICE DELTA
          PROFITDATA(J,15)=PROFITDATA(J,2)-PROFITDATA(J-1,2)
C         K=16, CLOSING PRICE DELTA
          PROFITDATA(J,16)=PROFITDATA(J,3)-PROFITDATA(J-1,3)
C         K=17, SHORT MOVING AVERAGE DELTA
          PROFITDATA(J,17)=PROFITDATA(J,4)-PROFITDATA(J-1,4)
C         K=18, MEDIUM MOVING AVERAGE DELTA
          PROFITDATA(J,18)=PROFITDATA(J,5)-PROFITDATA(J-1,5)
C         K=19, LONG MOVING AVERAGE DELTA
          PROFITDATA(J,19)=PROFITDATA(J,6)-PROFITDATA(J-1,6)
C         K=20, SHORT OSCILLATOR DELTA
          PROFITDATA(J,20)=PROFITDATA(J,7)-PROFITDATA(J-1,7)
C         K=21, LONG OSCILLATOR DELTA
          PROFITDATA(J,21)=PROFITDATA(J,8)-PROFITDATA(J-1,8)
C         K=22, SHORT TREND DELTA
          PROFITDATA(J,22)=PROFITDATA(J,9)-PROFITDATA(J-1,9)
C         K=23, LONG TREND DELTA
          PROFITDATA(J,23)=PROFITDATA(J,10)-PROFITDATA(J-1,10)
C         K=24, SPREAD DELTA
          PROFITDATA(J,24)=PROFITDATA(J,11)-PROFITDATA(J-1,11)
C         K=25, VOLUME DELTA
          PROFITDATA(J,25)=PROFITDATA(J,12)-PROFITDATA(J-1,12)
C         K=26, NOT USED
                          END IF
C
C
C         SECOND DELTAS (SLOPES OF SLOPES)
C
           IF(J.LT.3) THEN
          PROFITDATA(J,27:39)=0.0
                          ELSE
C         K=27, HI PRICE DELTA
          PROFITDATA(J,27)=PROFITDATA(J,14)-PROFITDATA(J-1,14)
C         K=28, LO PRICE DELTA
          PROFITDATA(J,28)=PROFITDATA(J,15)-PROFITDATA(J-1,15)
C         K=29, CLOSING PRICE DELTA
          PROFITDATA(J,29)=PROFITDATA(J,16)-PROFITDATA(J-1,16)
C         K=30, SHORT MOVING AVERAGE DELTA
          PROFITDATA(J,30)=PROFITDATA(J,17)-PROFITDATA(J-1,17)
C         K=31, MEDIUM MOVING AVERAGE DELTA
          PROFITDATA(J,31)=PROFITDATA(J,18)-PROFITDATA(J-1,18)
C         K=32, LONG MOVING AVERAGE DELTA
          PROFITDATA(J,32)=PROFITDATA(J,19)-PROFITDATA(J-1,19)
C         K=33, SHORT OSCILLATOR DELTA
          PROFITDATA(J,33)=PROFITDATA(J,20)-PROFITDATA(J-1,20)
C         K=34, LONG OSCILLATOR DELTA
          PROFITDATA(J,34)=PROFITDATA(J,21)-PROFITDATA(J-1,21)
C         K=35, SHORT TREND DELTA
          PROFITDATA(J,35)=PROFITDATA(J,22)-PROFITDATA(J-1,22)
C         K=36, LONG TREND DELTA
          PROFITDATA(J,36)=PROFITDATA(J,23)-PROFITDATA(J-1,23)
C         K=37, SPREAD DELTA
          PROFITDATA(J,37)=PROFITDATA(J,24)-PROFITDATA(J-1,24)
C         K=38, VOLUME DELTA
          PROFITDATA(J,38)=PROFITDATA(J,25)-PROFITDATA(J-1,25)
C         K=39, NOT USED
                          END IF
C
C          K=43 TO 45 NOT YET USED
C
C          K=46 : OPENING PRICE
C          K=47 : SREC (THE ISSUE NUMBER IN THE PROFIT.DAT FILE)
```

FINANCIAL COMMAND SECTION

```
C         K=48 : IREC (SEQUENTIAL ENTRY NUMBER IN THE PROFIT.DAT FILE)
C         K=49 : JREC (SEQUENTIAL ENTRY FOR THE PARTICULAR ISSUE)
C         K=50 : TOTAL NUMBER OF VALID RECORDS FOR STOCK ITEM I, UPDATED EACH TIME A NEW DAY IS PROCESSED
C         K=51 TO 100 NOT YET USED
```

The julian day number is computed with the following Fortran function:

```
      FUNCTION julday(mm,id,iyyy)
      INTEGER julday,id,iyyy,mm,IGREG
      PARAMETER (IGREG=15+31*(10+12*1582))
      INTEGER ja,jm,jy
      jy=iyyy
      if (jy.eq.0) JY=1
      if (jy.lt.0) jy=1
      if (mm.gt.2) then
        jm=mm+1
      else
        jy=jy-1
        jm=mm+13
      endif
      julday=int(365.25*jy)+int(30.6001*jm)+id+1720995
      if (id+31*(mm+12*iyyy).ge.IGREG) then
        ja=int(0.01*jy)
        julday=julday+2-ja+int(0.25*ja)
      endif
      return
      END
      FUNCTION julday1()
      INTEGER julday1,id,iyyy,mm,IGREG
      PARAMETER (IGREG=15+31*(10+12*1582))
      INTEGER ja,jm,jy,dt(10)
      CHARACTER*10 DATE,TIME,ZONE
      INCLUDE 'DATMAI.INC'
      CALL MY_DATE_AND_TIME(DATE,TIME,ZONE,DT)
      IYYY=DT(1)
      MM=DT(2)
      ID=DT(3)
      jy=iyyy
      if (jy.eq.0) jy=1
      if (jy.lt.0) jy=1
      if (mm.gt.2) then
        jm=mm+1
      else
        jy=jy-1
        jm=mm+13
      endif
      julday1=int(365.25*jy)+int(30.6001*jm)+id+1720995
      if (id+31*(mm+12*iyyy).ge.IGREG) then
        ja=int(0.01*jy)
        julday1=julday1+2-ja+int(0.25*ja)
      endif
      return
      END
```

LISTING THE PROCESSED DATA
LISTPROF - After the PROFIT.DAT file has been read and processed by the "LOADPROF" command, the "LISTPROF" command is used to produce a listing of the sequential number assigned to each stock issue, it's symbol and its company descriptor. Output can be directed to any of the usual output devices. The file LISTSAMP.DAT is a listing run after the S&P 500 data base was processed by the "LOADPROF" command.

LOADING AN ISSUE
LOADISSU (stock ticker or , issue number) - After the PROFIT.DAT file has been read and processed by the "LOADPROF" command, the "LOADISSU" command is used to load all of the data in the PROFDAT.DAT binary file associated with the "i" th issue (see the "LISTPROF" command generated listing) into program internal memory where it may be analyzed and or graphically displayed by analysis and graphics display commands.

PLOTTING A LOADED ISSUE
PLOTISSU (plottype) , end date back count - After an issue has been loaded, it may be graphically displayed with the "PLOTISSU" command. The number of days displayed is set using the "DAYS" operating condition setting. The default is 60 days. The minimum is 30 days. The default plot type is a Type 1. "end date back count" is the number of trading day, counted backwards from the last trading date in the database for the issue in question, which will be displayed. The default "end date back count" is 0 days.

Plot Type	Data Displayed
1	Top plot: Closing Price (black - 15) Short Moving Average Price (dark green - 13) Medium Moving Average Price (dark yellow - 9)

	Long Moving Average Price (dark red - 11)
	Bottom plot:
	Spread (black - 15)
	Short Moving Average of Spread (dark green - 13)
	Medium Moving Average of Spread (dark yellow - 9)
	Long Moving Average of Spread (dark red - 11)

LENS DATABASE SECTION

LENS-GENERAL INFORMATION- -The LENS section describes the establishment and manipulation of the lens database. Some of the commands described here are CMD level commands issued at the CMD level. These CMD level commands are described here instead of in the CMD section because they act to modify, or in other ways manipulate, the lens data base. The other commands described here are LENS level and UPDATE LENS level commands which can only be issued at one or both of these levels. Associated with the lens database are two additional optional databases which may be used with, and attached to, the lens database. These databases are the ALTERNATE-CONFIGURATION database and the SPECIAL SURFACE database. These optional databases are operated upon via the CONFIGS, UPDATE CONFIGS, SPSRF and UPDATE SPSRF program levels. Alternate lens configurations are described in the CONFIGS manual section. The special surface database is described in the SPECIAL SURFACES manual section. There can be a maximum of 500 surfaces per lens prescription.

THE LENS DATABASE - The lens database consists of an object surface, a sequence of transmitting, reflecting or diffraction gratting surfaces and an image surface. (Holographic Optical Surfaces and other more complex surface types are modeled using SPECIAL SURFACES definitions). Provision is made for the entry of a number of flat, spherical, conic, aspheric, toroidal and anamorphic surface profiles. Glass catalogs with refractive index interpolation coefficients are provided for most optical materials. These catalog glasses can be called out by name or glass number as appropriate. A right-handed rectangular coordinate system (X, Y, Z) is used throughout the program. Lens surface data is represented in the local coordinate system of each surface. Surface profile equations are expressed in these local coordinate systems. The local coordinate system of a given lens surface becomes the reference coordinate system for the following surface. For systems with no tilts or decenters, the Z-axis is the system optical axis. The "right-handedness" of the coordinate system is strictly observed with respect to spatial coordinates X, Y and Z and associated direction cosines L, M and N. The arithmetic sign convention will be ALPHA and BETA positive "left-handed" and Gamma positive "right-handed". This angle sign convention is attached to a particular lens file and is not global to the program. The lens database is sequential, and surfaces are numbered in the order in which they are encountered by a ray traveling from the object to the image surface. The object surface is initially assumed to be number 0. The object, reference and image surface numbers may be temporarily reassigned during some ray tracing. A general surface number will be denoted by "i". Quantities relating to the space between surfaces "i" and "i+1" will be associated with surface number "i". There is always a "current lens", though the "current lens" might not have any surfaces. When the program ends execution, that "current lens" is automatically stored in the sub-directory \CURLENS in the file named "LENSTEXT.DAT". The next time the program is run, that lens is automatically read into the lens database and is immediately ready for analysis. If tolerance or optimization definitions exist, they will be stored with the lens database whenever that lens database is written to disk. These definitions will then be automatically reloaded when the lens database is from disk.

THE LENS POINTER - The secret to understanding the UPDATE LENS level is the concept of the update lens pointer. For surface dependent UPDATE LENS commands, a surface pointer is used to point to the "current surface". The "CHG" command is used to move this pointer from surface to surface. Surface dependent commands simply act upon this "current surface" rather than requiring the surface number as part of their input syntax. This pointer is quite analogous to the pointer used in the MACRO section for macro editing. Issuing the "?" command at any time in the UPDATE LENS level will display the surface number of the "current surface".

REFRACTIVE INDICES - Most refractive indices in this program are assumed to be measured with respect to the refractive index of air at 760 mm Hg and at 20 degrees Centigrade. Some special catalog materials comprise data measured at other temperatures. If a temperature of measurement is not mentioned in the "GLASSP" output for that particular material, then 760 mm Hg and 20 degrees Centigrade are assumed. When a vacuum must be simulated, use the material "VAC" in the "MATL" catalog. It is the only glass catalog material to have a refractive index less than 1.0 since its refractive index is also represented with respect to air. The user may use the "THERM" and "PRES" commands described later in this section to change refractive indices to correct for other temperatures and pressures.

ZERO OBJECT THICKNESS - The program depends upon a non-zero object surface thickness as part of the initial ray aiming. This in no way limits the systems which may be modeled. For systems in which the object distance is either zero or very small, use a dummy surface at surface 1. Assign a positive object surface thickness to surface 0 and an equal but opposite signed thickness to surface 1 The absolute magnitude of the thickness assigned to surface 0 should not be less than 0.1 lens units or problems may occur when computing OPD. If the object distance desired is, for example, 0.001 lens units, a thickness of 1.001 should be assigned to surface 0 and a thickness of -1.000 should be assigned to surface 1.

CREATING A NEW LENS

LENS - The "LENS" command causes the program to leave the CMD level and enter the LENS input level. The lens database is wiped clean and is ready for lens input. Between "LENS" and "EOS", any LENS input level command may be entered. The "LENS" command also wipes clean any optimization and tolerance definitions which were in effect prior its issuance. If issued with an alphanumeric string, that string becomes the lens identifier.

EOS or **END** - The "EOS" or "END" command, issued from the LENS level, causes the program to return to the CMD level and terminates lens input. The "lens pointer" is left at the current surface, and this current surface automatically becomes the "LAST SURFACE" or image surface of the lens system. The lens database is left in memory and is ready for analysis.

MODIFYING AN EXISTING CURRENT LENS

UPDATE LENS or **U L** - The "UPDATE LENS" command, or its abbreviated form "U L", causes the program to leave the CMD level and enter the UPDATE LENS level. The lens database is opened and is ready for lens modification. Between "UPDATE LENS" or "U L" and "EOS" or "END", any UPDATE LENS level command may be entered.

INS, i , n - The "INS" command, issued from the UPDATE LENS level, causes the insertion of a new surface. If "i" is explicitly entered, the new surface will become the new surface "i". The previous surface "i" will become the new surface "i+1", and all surfaces beyond the new inserted surface will have their surface numbers increased by "1". If "i" is not explicitly entered, "i" is assumed to be the current value of the update lens pointer. New surface insertion at surface 0 is not allowed. All PIKUPs, solves, alternate configuration parameters and special surface definition values will be properly adjusted. The optional second numeric entry "n" is a repetition indicator. Its default value is 1. The "INS" command will be repeated "n" times if "n" is entered explicitly and if it is greater than 1. The new inserted surface(s) will be initialized as a plano surface with zero thickness, a material type of "AIR" and refractive indices all equal to 1.0 or -1.0 depending upon the existing arrangement of reflecting surfaces in the lens. This command is only available at configuration #1 (the main configuration) of a multiple configuration lens.

DEL, i , j The "DEL" command, issued from the UPDATE LENS level, causes the program to delete a surface. If "i" is explicitly entered, the "i"th surface will be deleted. The previous surface "i+1" will become the new surface "i", and all surfaces beyond the deleted surface will have their surface numbers decreased by "1". If "i" is not explicitly input, "i" is assumed to be the current value of the update lens pointer. Surface deletion at surface 0 and at the last or final surface is not allowed. All PIKUPs, solves, alternate configuration parameters and special surface definition values will be properly adjusted. The optional second numeric entry "j" is the last surface to delete in a range of surfaces "i" to "j". Its default value is "i". If PIKUPs, solves, alternate configuration parameters or special surface definition values refer to the deleted surface, they will be deleted as well. This command is only available at configuration #1 (the main configuration) of a multiple configuration lens. Surface insertion and deletion are rather drastic operations upon a lens prescription and these operations can cause optimization operands, tolerance operands and focrit operands which are evaluated for specific surface numbers to take on unpredictable values. After surface insertion or deletion, values for all current operands should be checked before optimization or tolerancing resumes. Surface numbers for optimization and tolerance variables are automatically adjusted after surface insertion and deletion.

CHG, i - The "CHG" command, issued from the UPDATE LENS level, causes the update lens pointer to be positioned at surface "i". Surface "i" is then the "current surface" with respect to all surface dependent UPDATE LENS commands.

EOS or **END** - The command "EOS" or "END", issued from the UPDATE LENS level, causes the program to return to the CMD level and terminates the lens update process. The lens database is left in memory and is ready for analysis. In addition to the closing of the lens database to input or modification, "EOS" or "END", issued at the LENS input and UPDATE LENS levels, causes all PIKUPS and SOLVES to be resolved and causes a new paraxial raytrace to be performed.

ZERO - The command "ZERO", issued from the UPDATE LENS level, causes all of the surfaces in the lens database to be converted to plano surfaces with 0.0 thickness and material type AIR. All lens database items associated with all surfaces are returned to program defaults. This command is intended to be issued at the UPDATE LENS level from within the CONFIGS or UPDATE CONFIGS mode when it is desired to start adding alternate configuration data to a blank lens database as when designing using type 13 special surfaces. This is a very specialized command which should be used with extreme care. The command is only valid for alternate configurations. It has no effect upon the main configuration, configuration #1.

AUTOMATIC MACRO FUNCTION EXECUTION

AUTOFUNC , n - The "AUTOFUNC" command, issued from the LENS or UPDATE LENS program levels, allows the user to specify that during the execution of an "EOS" command from within the LENS and LENS UPDATE program levels, the macro function "n" will be automatically executed. "n" may be set to from 0 to 10. If "n" is set to zero, no macro function will be executed. "n" = 0 is the default. ANYTHING may be done in this macro function including manipulation of all lens database items. Provision has been made to avoid any "infinite looping". This seemingly simple command allows for the establishment of extremely complex and automatic manipulations of the lens database including complex user-defined pickups and solves. It can also be used to execute any other macro, if that macro is called for execution from within the macro function. If the "AUTOFUNC" command is issued followed only by a "?", the current AUTOFUNC setting will be displayed. Issued from the CMD level, the current AUTOFUNC setting is also displayed.

LENS INPUT AND UPDATE LENS LEVEL COMMANDS - Most LENS input and UPDATE LENS level commands are the same. The difference in the operation between the UPDATE LENS level and the LENS input level is in the concept and operation of the update lens pointer system which has already been described. At the LENS input level, only sequential, surface-by-surface input is allowed and no moving pointer is provided. At the LENS input level, you are always at the current surface or "LAST SURFACE" of the lens system. The optical material name used at the final surface of all lens systems is always "LAST SURFACE". This "LAST SURFACE" optical material name is not entered by the user but is automatically supplied by the program.

LENS DATABASE SECTION

NON-SURFACE DEPENDENT COMMANDS - The following program commands are non-surface dependent. They refer to the lens database as a whole:

LI (lens identifier - up to 79 characters in length) - The "LI" command is used to name the current lens in the lens database. This is the first line of identification. It is the name used during lens library storage. If the "LI" command is issued followed only by a "?", the current lens identifier will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels. The lens identifier in used to give lenses in the lens library their labels or names. It is important to assign lens identifiers to every lens which is to be placed in the lens library with the "LIB PUT" command. If this is not done, lenses will only be differentiated by time and date.

The default lens identifier is always "NEW LENS". If the time and/or date stamping option has been turned on using the CMD level commands "STAMPT" and "STAMPD" described in the CMD section of this manual, then time and/or date notations will be appended to the beginning of the lens identifier whenever the lens identifier is displayed in a textual or graphical context.

LIC (lens identifier - up to 79 characters in length) - The "LIC" command continues the information input initiated by the "LI" command. Up to four "LIC" commands may be entered providing a maximum of five lines of lens identification. If more than four "LIC" commands are issued, the last line will be repeatedly overwritten. If the "LIC" command is issued followed only by a "?", the current value of the continued lens identifier will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

INI (designer identifier - up to 70 characters) - The "INI" command is used to store the designer identifier or name with the current lens. Up to 70 characters can be used. If the "INI" command is issued followed only by a "?", the current value of the designer identifier will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

LTYPE (optical design type identifier - up to 5 characters) - The "LTYPE" command is used to store the optical design type identifier with the current lens. Up to 5 characters can be used. If the "LTYPE" command is issued followed only by a "?", the current value of the optical design type identifier will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

WV , λ1 , λ2 , λ3 , λ4 ,λ5 - The "WV" command is the command used to change the first five default wavelengths of the program to user-selected values. "λ1", "λ2", "λ3", "λ4" and "λ5" represent numeric values for the first five wavelengths at which rays may be traced. They must be expressed in micron units (1.0 micron = 1.0×10^{-6} meters). These wavelengths are used for diffraction calculations at gratings, polychromatic OTF calculations and refractive index calculations for catalog glasses. If the "WV" command is issued followed only by a "?", the current value of the five wavelengths will be displayed. "λ1" through "λ5" will always be referred to as wavelength numbers 1 through 5. This command is valid at both the LENS input and the UPDATE LENS levels. In the absence of a "WV" command, the following values are assumed for "λ1" through "λ5"

λ1	λ2	λ3	λ4	λ5
0.58756 μ	0.48613 μ	0.65627 μ	0.43584 μ	0.70652 μ

WV2 , λ6 , λ7 , λ8 , λ9 , λ10 - The "WV2" command is the command used to change the second five default wavelengths of the program to user-selected values. λ6, λ7, λ8, λ9 and λ10 represent numeric values for the second five wavelengths at which rays may be traced. They must be expressed in micron units (1.0 micron = 1.0×10^{-6} meters). These wavelengths are used for diffraction calculations at gratings, polychromatic OTF calculations and refractive index calculations for catalog glasses. If the "WV2" command is issued followed only by a "?", the current value of the five wavelengths will be displayed. "λ6" through "λ10" will always be referred to as wavelength numbers 6 through 10. This command is valid at both the LENS input and the UPDATE LENS levels. In the absence of a "WV2" command, the following values are assumed for "λ6" through "λ10".

λ6	λ7	λ8	λ9	λ10
0.0 μ	0.0 μ	0.0 μ	0.0 μ	0.0 μ

If default entries are made in the "WV" and "WV2" commands, then the wavelengths refered to by these default entries are left unchanged. "WV .25,,.45" causes wavelengths 1 and 3 to be changed while leaving wavelengths 2, 4 and 5 unchanged. Spectral weighting factors for each wavelength are, by default, set to either 1.0 or 0.0 depending upon whether or not the associated wavelength is non-zero or zero. Use the "SPTWT" and "SPTWT2" commands, described later in this section, to modify these spectral weighting factors.

UNITS (qualifier word) - The "UNITS" command sets the linear units to be used for the current lens in the lens database according to the table below:

LENS DATABASE SECTION

"qualifier word"	UNITS
IN or INCH or INCHES	Inches
MM	Millimeters
CM	Centimeters
M	Meters

If no "UNITS" command is issued, the default units are INCHES. If the "UNITS" command is issued followed only by a "?", the name of the current system units will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

PCW , i , j - The "PCW" command defines the primary wavelength pair to be used for all "primary chromatic aberrations", whether they be paraxial or real ray based. Primary chromatic aberrations are always values at wavelength number "i" minus values at wavelength number "j". If the "PCW" command is issued followed only by a "?", the current wavelength numbers of the primary wavelength pair will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels. If no "PCW" command is issued, the default for "i"=2 and "j"=3.

SCW , i , j - The "SCW" command defines the secondary wavelength pair to be used for all "secondary chromatic aberrations", whether they be paraxial or real ray based. Secondary chromatic aberrations are always values at wavelength number "i" minus values at wavelength number "j". If the "SCW" command is issued followed only by a "?", the current wavelength numbers of the secondary wavelength pair will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels. If no "SCW" command is issued, the default for "i"=2 and "j"=1.

CW , i - The "CW" command defines the control or reference wavelength number to be "i". This is the number of the wavelength number used in the paraxial raytrace and is the default wavelength number used in CMD level commands when the wavelength number input in those commands is left as the default value. If this command is issued followed only by a "?", the wavelength number of the current control wavelength will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels. If no "CW" command is issued, the default for "i"=1.

OBJECT HEIGHT COMMANDS - For use by the paraxial solve options, the paraxial ray trace, the calculation of 3rd, 5th and 7th order aberrations of the lens system and the establishment of initial reference heights for trigonometric ray tracing, the program requires that an object height at the object surface be entered. This height may be entered either as a linear measure at the object surface in lens units or as an object space angle in degrees. If used, the object space angle is the angle subtended by the object at surface 0 as seen from surface 1.

SCY , Yo , Y1 - The "SCY" command is used to define the reference object height at the object surface. This reference height of the object will be Yo lens units. This input value assumes a flat object surface. Object coordinates for ray tracing, using the CMD level command "FOB", are expressed as fractions of Yo. Y1 is an optional input value. Y1 will be the height at surface 1 of the paraxial chief ray in the YZ-plane. Y1 implicitly defines a paraxial entrance pupil which would be located at the point where the line joining Yo and Y1 intersects the Z-axis. (This would be at infinity if the system was telecentric in the object space i.e., Y1=Yo). If the object distance is altered at any time, the value of Y1 is adjusted to preserve the location of this implicit entrance pupil. If an aperture stop is explicitly defined within the system by use of an "ASTOP" command, the entry for Y1 is ignored since the program automatically positions the paraxial chief ray so that it passes through the center of the aperture stop. This command is valid at both the LENS input and the UPDATE LENS levels.

SCY FANG , Uo , Y1 - The "SCY FANG" command is used as an alternative definition of object height when it is desired to express the object by the angle which it subtends as seen from surface 1. This object angle will be Uo degrees. Internally, the program calculates Yo from Uo. This input value assumes a flat object surface. Object coordinates for ray tracing, using the CMD level command "FOB", are derived from Uo and expressed as fractions of Uo. Y1 is an optional input value. Y1 will be the height at surface 1 of the paraxial chief ray in the YZ-plane. Y1 implicitly defines a paraxial entrance pupil which would be located at the point where the line joining Yo (derived from Uo) and Y1 intersects the Z-axis. (This would be at infinity if the system is telecentric in the object space i.e., Uo = 0.0). If the object distance is altered at any time, the value of Y1 is adjusted to preserve the location of this implicit entrance pupil. If an aperture stop is explicitly defined within the system by use of an "ASTOP" command, the entry for Y1 is ignored since the program automatically positions the paraxial chief ray so that it passes through the center of the aperture stop. This command is valid at both the LENS input and the UPDATE LENS levels. The use of Uo rather than Yo is usually appropriate for "infinite" object distance cases where the angle of entry to the system is invariant with respect to the ray intersection point on surface 1. Yo, Y1 and Uo are related by the following relation:

$$Y_0 \ = \ Y_1 \ - \ TH_0 * TAN(U_0)$$

THo is the distance from the object surface to surface 1. The above relation implicitly defines the sign convention for Uo. Uo will be negative if TH_0 is positive, Y1 is zero and Yo is positive. During ray tracing, the "FOB" command uses either the Yo or Uo value to determine the object coordinate from which a ray is to be traced depending upon whether "SCY" or "SCY FANG" was used to define the reference object height.

SCX , Xo , X1 and **SCX FANG , Uo , X1** - The "SCX" and "SCX FANG" commands are identical to the "SCY" and "SCY FANG" commands except that they act in the XZ-plane. If no "SCX/SCX FANG" command is explicitly issued, the XZ-plane object height/field angle value takes on the value set by the "SCY/SCY FANG" command. If no "SCY"/"SCY FANG" or "SCX"/"SCX FANG" commands are issued, the default values set by the program are:

SCY	1.0 (LENS UNITS)
SCX	1.0 (LENS UNITS)
SCY FANG	Calculated from SCY
SCX FANG	Calculated from SCX

The "SCY"/"SCY FANG" and "SCX"/"SCX FANG" commands are valid at both the LENS input and the UPDATE LENS levels. If the "SCY", "SCY FANG", "SCX" or "SCX FANG" commands are issued followed only by a "?", the current (Y_0,Y_1), (U_0,Y_1), (X_0,X_1) or (U_0,X_1) values will be displayed. If either "SCY" or "SCX" is set to 0.0, the paraxial raytrace assumes that it is equal to 1.0 so that first order quantities such as EFL, BFL and FFL can be computed correctly. "SCY FANG" and "SCX FANG" U_0 values may be assigned any angular values less than +/- 180 degrees. Additional information regarding the tracing rays from half-angles greater than or equal to 90 degrees are to be found in the CMD section of this manual under the discussion of the "FOB" command.

OBJECT HEIGHT AND ANGLE

The object height is always represented in lens units at the object surface. The corresponding object slope angle is measured counter-clockwise from the current local z-axis to the ray. This means that positive object heights always correspond to negative object angles and vice versa. This should always be kept in mind when tracing chief rays when interpreting ray trace results.
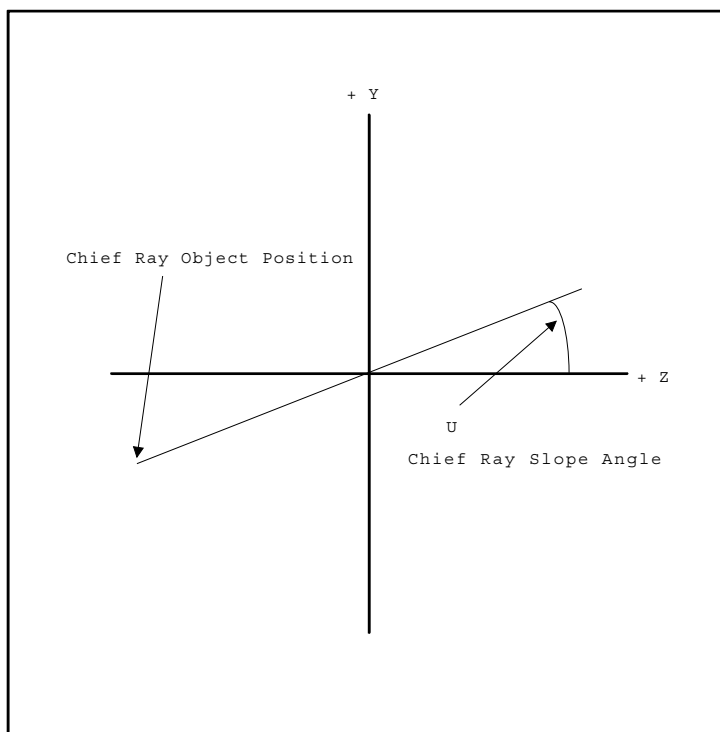
Relationship between object height and object angle

IMAGE HEIGHT COMMANDS - The reference object heights in both the XZ and YZ-planes can, alternately, be specified using either paraxial or real image surface heights or angles (specified in degrees). If real image heights or angles are specified, the object surface starting position of every chief ray traced is iterated until the chief ray strikes the final image surface at a position or angle specified by the last "FOB" command.

PARAXIAL SPECIFICATION

PYIM , Y and **PYIM FANG , U** - The "PYIM" and "PYIM FANG" commands are used to specify that the SCY value should be automatically adjusted so that the image surface Y-paraxial chief ray height will be equal to "Y" or that the image surface Y-paraxial chief ray slope angle will be equal to "U". All real rays use this new adjusted SCY value for their starting point on the object surface.

PYIM , X and **PXIM FANG , U** - The "PXIM" and "PXIM FANG" commands identical to the "PYIM" and "PYIM FANG" commands except that they act in the XZ rather than the YX-plane. These four commands ignore all tilts and decentrations in the lens database.

REAL RAY SPECIFICATION

RYIM , Y and **RYIM FANG , U** - The "RYIM" and "RYIM FANG" commands are used to specify that the all chief rays will have their image surface heights or slope angles specified by "Y" or "U" and by the current fractional values of the current "FOB" command. This is achieved by an iterative ray aiming scheme which automatically adjusts the X and Y-chief rays heights on the object surface.

RXIM , X and **RXIM FANG , U** - The "RXIM" and "RXIM FANG" commands identical to the "RYIM" and "RYIM FANG" commands except that they act in the XZ rather than the YX plane of the image surface.

When "RXIM" and RYIM" are active, a double iterative aiming loop is used to aim the chief rays to the appropriate targets in the reference surface while aiming the chief rays to the appropriate targets in the image plane. The accuracy of image surface ray aiming is set using "CAIMTOL". The default value is 0.001 lens unit. Make CAIMTOL as small as possible before ray aiming failures occur.

REFERENCE APERTURE HEIGHT COMMANDS

SAY (FLOAT or NOFLOAT) , say - The command "SAY", either with no qualifier word or with the qualifier word "NOFLOAT", sets the starting marginal reference ray height at surface 1 for the paraxial axial ray in the YZ-plane. This is equivalent to specifying the semi-diameter of the system entrance pupil. If the position of surface 1 is shifted by the program as a result of an entrance pupil adjustment via the "ASTOP" command, the value of "SAY" will be altered so that the object space slope angle of the marginal ray is maintained at its original value. If the qualifier word "FLOAT" is used and if there is a clear aperture assigned to the aperture stop surface, then the "SAY" value will be continually adjusted so that the YZ-plane marginal paraxial ray height at the aperture stop surface will be kept equal to the YZ-plane dimension of the clear aperture at the aperture stop surface. All clear aperture decentrations and tilts will be ignored. "FLOAT" may not be used if an f-number or exit pupil hold is in effect. If surface #1 is at infinity, the accuracy of the "FLOAT" option may suffer. In cases such as these, use the telecentric stop position option instead of "floating" the "SAY" and "SAX" values. If "FLOAT" is in effect and an "SAY" or "SAX" command is entered with a numeric value, the "FLOAT" condition will be automatically reset to "NOFLOAT"

SAX (FLOAT or NOFLOAT) , sax - The "SAX" command is identical to the "SAY" command but acts in the XZ-plane. If no "SAX" command is explicitly issued, the XZ-plane reference aperture height takes on the value set by the "SAY" command. If no "SAY" or "SAX" commands are issued, the default values set by the program are:

SAY NOFLOAT	1.0 (LENS UNITS)
SAX NOFLOAT	1.0 (LENS UNITS)

If the "SAY" or "SAX" commands are issued followed only by a "?", the current "SAY" or "SAX" values will be displayed. The "SAY" and "SAX" commands are valid at both the LENS input and the UPDATE LENS levels. "FLOAT" is the default qualifier for "SAY" and "SAX".

EPD (FLOAT or NOFLOAT) , epd - The "EPD" command (entrance pupil diameter) is identical to the "SAY" command except that the "EPD" command takes as its numeric input a value twice the magnitude of an "SAY" command input value. The numeric value input with an "EPD" command is divided by 2.0 and then that value is included as input to an automatically generated "SAY" command

NAOY , naoy - - The command "NAOY" sets the starting height at surface 1 for the paraxial axial ray in the XY and YZ-plane in terms of an "object space numerical aperture". This object space numerical aperture is maintained through adjustments to the internal "SAY" value.

NAOX , naox - - The command "NAOX" sets the starting height at surface 1 for the paraxial axial ray in the XZ-plane in terms of an "object space numerical aperture". This object space numerical aperture is maintained through adjustments to the internal "SAX" value. The "NAOY" and "NAOX" commands are valid at both the LENS input and the UPDATE LENS levels. "NAOY" and "NAOX" are not allowed for systems with object distances whose magnitude exceeds 1.0×10^{10} lens units. Systems such as these are considered to have infinite object distances for which no object space numerical aperture can be defined.

FNOY , fnoy - The command "FNOY" sets the starting height at surface 1 for the paraxial axial ray in the XZ and YZ-plane in terms of an "object space f-number". This object space f-number is maintained through adjustments to the internal "SAY" value.

FNOX , fnox - The command "FNOX" sets the starting height at surface 1 for the paraxial axial ray in the XZ-plane in terms of an "object space f-number". This object space f-number is maintained through adjustments to the internal "SAX" value. The "FNOY" and "FNOX" commands are valid at both the LENS input and the UPDATE LENS levels. "FNOY" and "FNOX" are not allowed for systems with object distances whose magnitude exceeds 1.0×10^{10} lens units. Systems such as these are considered to have infinite object distances for which no object space f-number can be defined. "FNOY", "FNOX", "NAOY" and "NAOX" are not compatible with a "FLOAT" of the "SAY" or "SAX" values.

GAUSSIAN BEAM SPECIFICATION COMMANDS - The next four commands are used to establish the starting values of the YZ and XZ-plane gaussian beam plane $1/e^2$ semi-diameters and gaussian beam divergence half-angles. These values are only used during gaussian beam propagation calculations. By default, the $1/e^2$ semi-diameters are set at 1.0 lens unit and the beam divergence half-angles are set to 0.001 radians when a new lens database is created with the "LENS" command. It is the responsibility of the designer to set these values to realistic values prior to any analysis.

WRY, wry - The command "WRY" sets the YZ-plane gaussian beam $1/e^2$ semi-diameter at surface 1 to the value "wry". (Units are "lens units")

WRX, wrx - The command "WRX" sets the XZ-plane gaussian beam $1/e^2$ semi-diameter at surface 1 to the value "wrx". (Units are "lens units")

BDY , bdy - The command "BDY" sets YZ-plane beam divergence half-angle of the gaussian beam at surface 1 to the value "bdy". (Units are "milliradians")

BDX , bdx - The command "BDX" sets XZ-plane beam divergence half-angle of the gaussian beam at surface 1 to the value "bdx". (Units are "milliradians")

BDY TEM00 - The command "BDY TEM00" sets YZ-plane beam divergence half-angle of the gaussian beam at surface 1 to the value which corresponds to a TEM00 mode laser beam. The divergence is computed at the control wavelength.

BDX TEM00 - The command "BDX TEM00" sets XZ-plane beam divergence half-angle of the gaussian beam at surface 1 to the value which corresponds to a TEM00 mode laser beam. The divergence is computed at the control wavelength.If "WRX", "WRY", "BDX" or "BDY" are issued followed by the interrogator "?", their current values will be displayed. These six commands are valid at both the LENS input and the UPDATE LENS levels. The half-angle beam divergence in radians is given by the following equation. R_0 is the $1/e^2$ semi-diameter of the beam at surface 1 and assumes that a true beam waist exists at that surface.

$$\theta = \frac{\lambda}{\pi \times R_0}$$

SURFACE DEPENDENT COMMANDS - Surface dependent LENS input and UPDATE LENS commands act on a specific surface of the lens database. Each omitted command results in specific default input for the specified database item. If no surface shape commands are entered, the surface will be defined as plano (flat). If no tilt or decentration commands are issued, the surface will not be tilted or decentered. Only enough commands to define a surface shape, location and special characteristics need be entered. In the UPDATE LENS level, the order in which commands are issued for a given surface is arbitrary. When in the LENS input level, the program expects the last command for a particular surface to be a command specifying the surface's optical material. The program increments the surface counter automatically when this command is issued. Commands such as "MYGLASS", "MODEL", "AIR", "REFL", "REFLTIRO" or [a reference to a glass catalog glass] are optical material commands. The image surface optical material is always automatically renamed "LAST SURFACE". Dummy surfaces may be used at any location in a lens database. Dummy surfaces are surfaces with identical refractive indices on each side. For the surface shape commands which follow, except where otherwise noted, a default numeric entry will be interpreted as an input of 0.0. Lens surfaces may be REAL or PARAXIAL and lenses may be "thick" or "thin"

MODULAR LENS ELEMENTS - Several other programs provide the user with a way of placing "lens modules" into an optical system. The primary draw back of these implementations is that there is no clear way to relate these "module" lenses to real optical elements. In this program, lens modules are implemented via an extension to the standard optical surface definitions normally found in any optical design program. Through the use of the following two commands "REAL" and "PARAX", any and all optical surfaces can take on a paraxial "flat" profile while still retaining their ability to bend real and paraxial rays by nature of their curvature, conic constant and other surface shape definitions. Thin paraxial lenses may be modeled by setting the material thickness between paraxial surfaces to zero. All surface solves and pikups remain in effect with these paraxial or modular surfaces. When it is desired to convert these surfaces to "thick" and "non-paraxial" surfaces, the element thicknesses are reset to realistic values and the "REAL" command is issued to change the surface type to a "real".

REAL SURFACES - By default, all lens database surfaces in this program are considered to be real surfaces. Real surfaces have as their primary property some dependent longitudinal depth of curvature (surface sag) which can vary with respect to some independent lateral coordinate. This includes real plano-surfaces which have 0.0 surface sag for all lateral coordinate positions. By default all surfaces are real surfaces.

REAL - The "REAL" command is used to re-define a "paraxial" surface as a "real" surface.

LENS DATABASE SECTION

PARAXIAL SURFACES - Paraxial surfaces are lens database surfaces which have no surface sag associated with them even though they may have surface curvature or other surface shape properties such as asphericity. A paraxial surface is designated as such with the command "PARAX". Paraxial surfaces are of primary interest during the initial layout of an optical system when that layout process has progressed beyond the paraxial raytrace phase but may not be ready for the "real" surface phase. When real trigonometric rays are traced through paraxial surfaces, optical path differences should be viewed with extreme caution.

PARAX - The "PARAX" command is used to re-define a "real" surface as a "paraxial" surface.

THICK AND THIN LENSES - Thin lenses are simply lenses for which there is zero axial distance between the two surfaces which bound the lens.

SURFACE SHAPE COMMANDS
SPHERICAL, CONIC, ASPHERIC AND PLANO SURFACES - The non-plano (non-flat) axially symmetric optical surface is characterized by the equation:

$$Z = \frac{c\rho^2}{1 + \sqrt{1 - (\kappa + 1)c^2\rho^2}} + D\rho^4 + E\rho^6 + F\rho^8 + G\rho^{10} + H\rho^{12} + I\rho^{14} + J\rho^{16} + K\rho^{18} + L\rho^{20}$$

where:

$$\rho = \sqrt{x^2 + y^2}$$

c is the vertex curvature, ρ is a radial measure from the Z-axis, κ is the conic constant and D, E, F, G, H, I, J, K and L are the 4th, 6th, 8th, 10th, 12th, 14th, 16th, 18th and 20th order aspheric deformation coefficients.
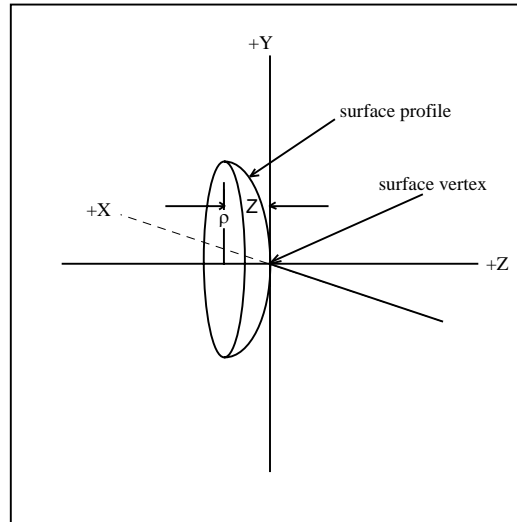
Axially Symmetric Surface Profile

The specific ranges in the value of the conic constant representing specific types of conic surfaces are given in the following table:

CONIC CONSTANT VALUE (κ)	CONIC SURFACE TYPE
$\kappa < -1.0$	HYPERBOLOID
$\kappa = -1.0$	PARABOLOID
$-1.0 < \kappa < 0.0$	PROLATE SPHEROID (ellipsoid of revolution about the major axis)
$\kappa > 0.0$	OBLATE SPHEROID (ellipsoid of revolution about the minor axis)
$\kappa = 0.0$	SPHERE

The plano (flat) axially symmetric optical surface is characterized by the equation:

$$Z = C\rho^2 + D\rho^4 + E\rho^6 + F\rho^8 + G\rho^{10} + H\rho^{12} + I\rho^{14} + J\rho^{16} + K\rho^{18} + L\rho^{20}$$

where:

$$\rho = \sqrt{x^2 + y^2}$$

where ρ is a radial measure from the Z-axis. C, D, E, F, G, H, I, J, K, and L are the 2nd, 4th, 6th, 8th, 10th, 12th, 14th, 16th, 18th and 20th order aspheric deformation coefficients. The 2nd order term plays the role of the conic constant for plano surfaces and provides the **correct** means to model the classical Schmidt corrector plate surface profile. The following commands define the shape of a lens surface in the lens database:

CV , c , κ - The "CV" command is used to enter the vertex curvature of a lens surface "c". A plano surface (flat) is selected by entering 0.0 for "c" or by skipping the "CV" command altogether. Surfaces, by default, are always plano. Remember, "c", the curvature, is just the reciprocal of the radius of curvature "r". "c"=1/"r". If the "CV" command is issued followed only by a "?", the current "c" will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels. The object surface, surface 0, is always assumed to be a plano surface. If issued with an explicit numeric word #2, that value becomes the conic constant if no qualifier word is present.

CC , κ - The "CC" command is used to enter the conic constant "κ" for a surface whose curvature "c" has already been entered. If the "CC" command is issued followed only by a "?", the current "κ" value will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

RD , r , κ - The "RD" command is used to enter the vertex radius of curvature of a lens surface "r". A plano surface is selected by entering 0.0 for "r" or by skipping the "RD" command altogether. Surfaces, by default, are always plano. Remember, "r", the radius of curvature, is just the reciprocal of the curvature "c". "r"=1/"c". If the "RD" command is issued followed only by a "?", the current surface "r" value will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels. The program convention is that "r" = 0.0 is equivalent to "c" = 0.0. Plano surfaces ("c"=0.0) may not be defined as conics since that definition has no meaning mathematically. The conic constant of a plano surface is always equal to 0.0. For low order aspheric deformations of plano surfaces, use the "ASPH" command. If issued with an explicit numeric word #2, that value becomes the conic constant if no qualifier word is present.

ASPH , ad , ae , af , ag , ac The "ASPH" command defines the surface to be aspheric and is used to enter the values of the 4th, 6th, 8th, 10th and 2nd order aspheric deformation coefficients "ad", "ae", "af", "ag" and "ac". The 2nd order aspheric deformation term is only valid for plano surfaces and will be ignored for non-plano surfaces. Default entries leave previously defined values of that value unchanged. If the "ASPH" command is issued followed only by a "?", the current "ad", "ae", "af", "ag" and "ac" values will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

ASPH2 , ah , ai , aj , ak , al - The "ASPH2" command defines the surface to be aspheric and is used to enter the values of the 12th, 14th, 16th, 18h and 20th order aspheric deformation coefficients "ah", "ai", "aj", "ak" and "al". Default entries leave previously defined values of that value unchanged. If the "ASPH2" command is issued followed only by a "?", the current "ah", "ai", "aj", "ak" and "al" values will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

ASPHD , i , j - The "ASPHD" command deletes any existing aspheric definitions from the current surface. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. The "lens pointer" is not modified by this command. Any PIKUPs referring to these deleted definitions will also be deleted. This command is valid at the UPDATE LENS level.

AC through AL , value - The "AC", "AD", "AE", "AF", "AG", "AH", "AI", "AJ", "AK" and "AL" commands are used to enter the values of the 2nd through 20th order aspheric deformation coefficients. "AC" is valid for plano surfaces only. If the surface is not already defined as an aspheric, the these commands will define it as such. If the these commands are issued followed only by a "?", the current value will be displayed. These commands are valid at both the LENS input and the UPDATE LENS levels.

TOROIDAL SURFACES - The next equation characterizes the XZ-plane profile of an X-TORIC surface. An X-TORIC surface is generated by this XZ-plane profile as it is revolved about an axis which is parallel to the X-axis. This axis of revolution lies in the XZ-plane. The surface circular profile is swept out in the YZ-plane with a toric curvature c' = 1/ r'. r' is the toric radius of curvature. The surface is only valid for |Z| < |r'|. If c', D, E, F, G and κ are all equal to 0.0, the surface becomes a cylinder with its axis parallel to the Y-axis. The conic and aspheric deformation terms for the profile of a toric surface are set using previously defined aspheric profile definition commands.

$$Z = \frac{cx^2}{1 + \sqrt{1 - (\kappa + 1)c^2x^2}} + Dx^4 + Ex^6 + Fx^8 + Gx^{10}$$
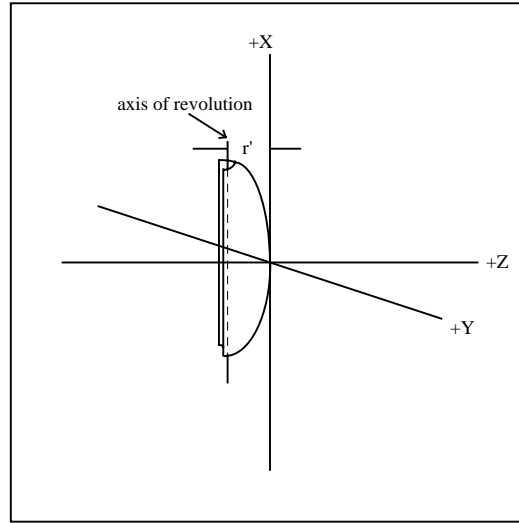
X-Toric Surface Profile

The next equation characterizes the YZ-plane profile of a Y-TORIC surface. A Y-TORIC surface is generated by this YZ-plane profile as it is revolved about an axis which is parallel to the Y-axis. This axis of revolution lies in the YZ-plane. The surface circular profile is swept out in the XZ-plane with a toric curvature c' = 1/ r'. r' is the toric radius of curvature. The surface is only valid for |Z| < |r'|. If c', D, E, F, G and κ are all equal to 0.0, the surface becomes a cylinder with its axis parallel to the X-axis. The conic and aspheric deformation terms for the profile of a toric surface are set using previously defined aspheric profile definition commands.

$$Z = \frac{cy^2}{1 + \sqrt{1 - (\kappa + 1)c^2y^2}} + Dy^4 + Ey^6 + Fy^8 + Gy^{10}$$
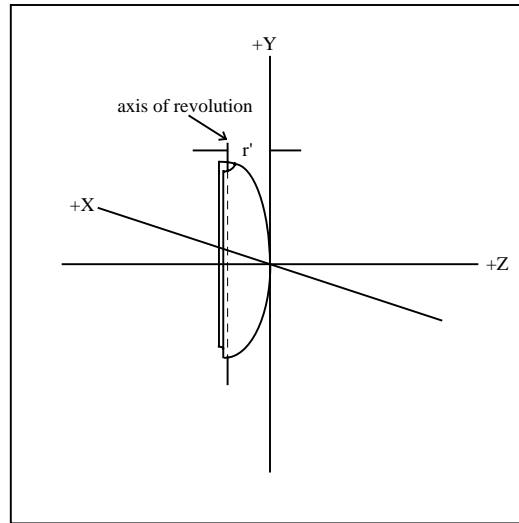
Y-Toric Surface Profile

XTORIC or **YTORIC** - The "XTORIC" and "YTORIC" commands act to define a surface as an X or Y-TORIC surface. One of these commands is required before toric surface shape parameters may be entered. If the "XTORIC" or the "YTORIC" command is issued followed only by a "?", the current toric definition will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

CVTOR , c' - The "CVTOR" command is used to enter the curvature of revolution of an X or a Y-TORIC surface. If "c'" is entered with a zero value, the surface is a cylinder whose axis is parallel to either the Y or the X-axis. If the "CVTOR" command is issued followed only by a "?", the current "c'" value will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

RDTOR , r' - The "RDTOR" command is used to enter the radius of curvature of revolution of an X or a Y-TORIC surface. If "r'" is entered with a zero value, the surface is a cylinder whose axis is parallel to either the Y or the X-axis. As with "r" and"c", "r'" = 0 is equivalent to "c'" = 0. If the "RDTOR" command is issued followed only by a "?", the current "r'" value will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

TORD , i , j - The "TORD" command deletes any existing toric or anamorphic definitions from the current surface. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. The "lens pointer" is not modified by this command. Any PIKUPs referring to these deleted definitions will also be deleted. This command is valid at the UPDATE LENS level.

ANAMORPHIC ASPHERIC SURFACES - Anamorphic aspheric surfaces are similar to toric surfaces, except that both the YZ-plane and the XZ-plane profiles have either conic or conic and aspheric deformation terms added to the base curvatures. The anamorphic aspheric surface shapes are characterized by the next two equations.

1.   If the surface profile is defined as an X-TORIC, then the surface profile is given by:

$$Z = \frac{\left(c_Y y^2 + c_x x^2\right)}{1+\sqrt{1-\left(\kappa_y+1\right)c^2 y^2-\left(\kappa_x+1\right)c^2 x^2}}$$
$$+D_x\left\{\left(1-D_y\right)y^2+\left(1+D_y\right)x^2\right\}^2+E_x\left\{\left(1-E_y\right)y^2+\left(1+E_y\right)x^2\right\}^3$$
$$+F_x\left\{\left(1-F_y\right)y^2+\left(1+F_y\right)x^2\right\}^4+G_x\left\{\left(1-G_y\right)y^2+\left(1+G_y\right)x^2\right\}^5$$

"c_x" is the curvature set with the "CV" or "RD" commands. "κ_x" is the conic constant set with the "CV", "RD" or "CC" commands. The aspheric terms "D_x", "E_x", "F_x" and "G_x" are set using the "ASPH" or "AD", "AE", "AF" and "AG" commands. "c_y" is the curvature of revolution set with the "CVTOR" or "RDTOR" commands. The anamorphic conic and aspheric terms "κ_y", "D_y", "E_y", "F_y" and "G_y" are set with the next five commands. These commands require that the surface already be defined as an X-TORIC.

2.   If the surface profile is defined as a Y-TORIC, then the surface profile is given by:

$$Z = \frac{\left(c_Y y^2 + c_x x^2\right)}{1+\sqrt{1-\left(\kappa_y+1\right)c^2 y^2-\left(\kappa_x+1\right)c^2 x^2}}$$
$$+D_x\left\{\left(1-D_y\right)y^2+\left(1+D_y\right)x^2\right\}^2+E_x\left\{\left(1-E_y\right)y^2+\left(1+E_y\right)x^2\right\}^3$$
$$+F_x\left\{\left(1-F_y\right)y^2+\left(1+F_y\right)x^2\right\}^4+G_x\left\{\left(1-G_y\right)y^2+\left(1+G_y\right)x^2\right\}^5$$

c_y is the curvature set with the "CV" or "RD" commands. κ_y is the conic constant set with the "CV", "RD" or "CC" commands. The aspheric terms D_y, E_y, F_y and G_y are set using the "ASPH" or "AD", "AE", "AF" and "AG" commands. c_x is the curvature of revolution set with the "CVTOR" or "RDTOR" commands. The anamorphic conic and aspheric terms "κ_x", "D_x", "E_x", "F_x" and "G_x" are set with the next five commands. These commands require that the surface already be defined as a Y-TORIC.

CCTOR , cctor - The "CCTOR" command sets the anamorphic conic constant "cctor" for the surface. If the "CCTOR" command is issued followed only by a "?", the current "cctor" value will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

TASPH , adtor , aetor , aftor , agtor - The "TASPH" command defines the surface to be anamorphic aspheric and is used to enter the values of the 4th, 6th, 8th and 10th order anamorphic aspheric deformation coefficients "adtor", "aetor", "aftor" and "agtor". If the "TASPH" command is issued followed only by a "?", the current anamorphic aspheric coefficient values will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

TASPHD , i , j - The "TASPHD" command deletes any existing anamorphic aspheric definitions from the current surface. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. The "lens pointer" is not modified by this command. Any PIKUPs referring to these deleted definitions will also be deleted. This command is valid at the UPDATE LENS level.

ADTOR through AGTOR , value - The "ADTOR" through "AGTOR" commands, set the value of the 4th through 10th order anamorphic deformation coefficient to the supplied "value". If the surface is not already defined as an anamorphic aspheric, these commands perform that task as well. If the commands are issued followed only by a "?", the current anamorphic aspheric coefficient value will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

SURFACE DEPENDENT COMMANDS (cont'd)

DEFORMABLE SURFACES - The Deformable Surface is a surface definition which may be added to any other regular surface definition. It simulates the effect of a rectangular grid of deformable surface actuators, each of which have a deformation influence function which is in general of the form:

$$f(\chi) = A_0 e^{-\left(\frac{\zeta^2}{2}\right)} + A_3 + A_4\chi + A_5\chi^2$$

where:

$$\zeta = \frac{(\chi - A_1)}{A_2}$$

and:

A_0	1.08342
A_1	-0.0069
A_2	0.486
A_2	-0.063
A_2	0.005
A_2	0.005

The "χ" value represents the absolute value of the average distance to each actuator in units of "average actuator spacing". The "average actuator spacing" in "lens units" is computed from the actuator locations input in deformable surface data file described below. Influence function data courtesy of Xinetics Inc., 37 MacArthur Ave., Devens, MA 01432, (978) 772-0352 (April,1998) The "average actuator spacing" in "lens units" is an arithmetic average of the average x-spacing and the average y-spacing based on the x and y-locations of the actuators specified in the deformable mirror surface. In general, the actuators will be on a square grid. The extent of the deformable mirror will be established by the clear aperture assigned to the surface in the lens database.

DEFORM F1 to F10 , n , z-scale factor - The "DEFORM" command, at the LENS or UPDATE LENS levels, is used to specify that a surface is to be defined as a deformable surface. F01 to F10 is a qualifier word that specifies that the ASCII file named DEFORM01.DAT to DEGORM10.DAT holds the actuator locations and normalized actuator extention values for this surface. Normalized actuator extensions can range from -1.0 to 1.0. "n" is the total number of actuators (max. allowable is 3969). "z-scale" is the actuator scale factor representing the physical surface deformation at any actuator location when the normalized actuator extension reaches a value of 1.0. If the "DEFORM" command is issued followed only by a "?", the current deformation input settings will be displayed. If a DEFORMxx.DAT file exists and if it has exactly "n" entries, then this file will be read into the deformable surface array. Actuator numbering (used in optimization) is illustrated in the following figure. Normalized actuator extension entries in the DEFORMxx.DAT file appear with their associated actuator X and Y-positions. The x and y-coordinates of each actuator are assumed to be relative to the center of the clear aperture assgned to the deformable surface. Each line entry in the file consists of the X-actuator location (real value), the Y-actuator location (real value) and the associated normalized actuator extension value (real value).

Example: File DEFORM01.DAT with 9 actuators

```
-4.5 -4.5 0.0        "actuator # 0001"
-4.5,0.0,0.0         "actuator # 0002"
-4.5,4.5,0.0         "actuator # 0003"
0.0, -4.5 0.0        "actuator # 0004"
0.0,0.0,0.0          "actuator # 0005"
0.0,4.5,0.0          "actuator # 0006"
4.5 -4.5 0.0         "actuator # 0007"
4.5,0.0,0.0          "actuator # 0008"
4.5,4.5,0.0          "actuator # 0009"
```

would be appropriate for a mirror with "average actuator spacing" of 4.5 lens units and with a rectangular clear aperture of 9.0 lens units (semi-extent). Deformable surfaces may not assigned special surface characteristics. The 4-digit numbers in parantheses are the variable number designators used when calling out an actuator number to be an optimization variable. (See the OPTIM section for more details).

DELDEFOR - The "DELDEFOR" command, at the LENS or UPDATE LENS levels, is used to delete an existing DEFORM definition at the current surface.

LENS DATABASE SECTION

ARRAY SURFACES - The Array Surface is a surface definition which rides "on top" of plano, spherical, aspheric and amamorphic surface shape definitions and creates a "grid" or array of surfaces whose x and y-extents are equal to the array spacings in x and y. The current surface profile is replicated, centered at each array element center. Any clear aperture or obscuration applies to the entire array and not to one element of the array. Each element has in implicit rectangular clear aperture associated with it equal to the x and y-array spacings.

ARRAY (ODD or EVEN) , dx , dy - The "ARRAY" command defines the current surface to be an array surface with rectangular elements. Each element will have dimensions "dx" by "dy" in lens units. The array is limitless in extent but can be effectively truncated via a clear aperture definition. If the "ODD" qualifier is used, the array has an element centered at the vertex of the surface."ODD" is the default centering if it is not explicitly entered. If the "EVEN" qualifier is used, then the intersection of four adjacent array elements lies at the surface vertex. All surface standard shapes are available for use with array lenses but special surfaces are not currently available for use with this surface type. If the "ARRAY" command is issued followed only by a "?", the current "dx", "dy" and "odd/even" values will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

ARRAYD - The "ARRAYD" command removes any "array" definition at the current surface. This command is available at the This command is valid at both the LENS input and the UPDATE LENS levels.

LENS DATABASE SECTION

SURFACE SEPARATION COMMANDS - For the following surface separation commands, except where otherwise noted, a default numeric entry will be interpreted as an input of 0.0.

TH , t - The "TH" command defines the distance "t" from the origin of the current surface to the origin of the following surface. The distance "t" is measured along the local Z-axis of the current surface before any decentration of the following surface takes place. "t" is positive if the vertex of the next or following surface is along the positive Z-axis of the local coordinate system of the current surface and negative if it is along the local negative Z-axis. The "TH" command is not applicable at the last or image surface. If the "TH" command is issued followed only by a "?", the current "t" value will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels. A non-zero thickness on the "LAST" or image surface has no meaning and is not allowed. Any thickness whose magnitude is greater than $1.0X10^{200}$ lens units will have its magnitude reduced to $1.0X10^{200}$ lens units. This is done to prevent overflow in ray tracing calculations.

SOLVES (Curvature, Separation, Center of Curvature and Clear Aperture) - The concept of the SOLVE is one of the more useful concepts included in optical design software. Depending upon their nature, solves act to automatically maintain either first order optical properties or mechanical properties of an optical system. Solves, as they are implemented in the program, are of four basic types. They are:

SOLVE TYPE	PROPERTY MAINTAINED
CURVATURE SOLVE	Tangent of the slope angle of either the paraxial axial or paraxial chief ray as it leaves a surface is held to a specified value.
CENTER OF CURVATURE SOLVE	Surface curvature so that the center of curvature is located at a specified position. This is a type of curvature solve that does not use paraxial ray trace data as its target.
THICKNESS SOLVE	Height of either the paraxial axial or paraxial chief ray when it arrives at the next surface is held to a specified value.
CLEAR APERTURE SOLVE	Maintains the distance between the current surface and the next surface to a specified value. This is a type of thickness solve that does not use paraxial ray trace data as its target.

THM , tm - The "THM" command defines a mirror thickness which will be used in the calculation of weight and price. The "THM" command is only applicable to mirror surfaces with material type REFL. The distance "tm" is measured along the local Z-axis of the current surface. If the "THM" command is issued followed only by a "?", the current "tm" value will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels.

CURVATURE SOLVES

APY - The "APY" command implements the YZ-plane paraxial axial ray aplanatic solve. The surface curvature in the YZ-plane is adjusted such that the aplanatic condition is satisfied, i.e., i + u = 0 where "i" is the angle of incidence (tangent) for the paraxial axial ray and u is the slope angle (tangent) of that same ray after refraction or reflection. 3rd order spherical aberration, coma and astigmatism contributions at this surface in the YZ-plane will be zero. This command is valid at both the LENS input and the UPDATE LENS levels.

APX - The "APX" command is identical to the "APY" command except that it works in the XZ-plane.

APCY - The "APCY" command implements the YZ-plane paraxial chief ray aplanatic solve. The surface curvature in the YZ-plane is adjusted such that the aplanatic condition is satisfied, i.e., i' + u' = 0 where " i' " is the angle of incidence (tangent) for the paraxial chief ray and " u' " is the slope angle (tangent) of that same ray after refraction or reflection. This command is valid at both the LENS input and the UPDATE LENS levels.

APCX - The "APCX" command is identical to the "APCY" command except that it works in the XZ-plane.

PIY , j - The "PIY" command implements the YZ-plane paraxial axial ray angle of incidence solve. The surface curvature in the YZ-plane is adjusted so that the angle of incidence (tangent) of the paraxial axial ray has the value "j". This command is valid at both the LENS input and the UPDATE LENS levels.

PIX , j - The "PIX" command is identical to the "PIY" command except that it works in the XZ-plane.

PICY , j - The "PICY" command implements the YZ-plane paraxial chief ray angle of incidence solve. The surface curvature in the YZ-plane is adjusted so that the angle of incidence (tangent) of the paraxial chief ray has the value "j". This command is valid at both the LENS input and the UPDATE LENS levels.

PICX , j - The "PICX" command is identical to the "PICY" command except that it works in the XZ-plane.

PUY (qualifier) , j- -The "PUY" command implements the YZ-plane paraxial axial ray slope angle solve. The surface curvature in the YZ-plane is adjusted so that the slope angle (tangent) of the paraxial axial ray after reflection or refraction has the value "j". This command is valid at both the LENS input and the UPDATE LENS levels. The solve is always "remembered" in the lens database as a "PUY" solve without the "qualifier" and with the target value always representing an axial ray slope (tangent). An optional qualifier word is available. If it is used, the meaning of "j" temporarily changes. If the qualifier "FN" is used, "j" is interpreted initially as a YZ-plane f/number. This f/number is converted to and remembered as a target ray slope angle (tangent) by the following relation:

$$\dot{j}_{(angle)} = -\frac{1.0}{2.0 \times j_{(f/number)}}$$

PUX (qualifier) , j - The "PUX" command works exactly as the "PUY" command except that it works in the XZ-plane.

PUCY , j - The "PUCY" command implements the YZ-plane paraxial chief ray slope angle solve. The surface curvature in the YZ-plane is adjusted so that the slope angle (tangent) of the paraxial chief ray after reflection or refraction has the value "j". This command is valid at both the LENS input and the UPDATE LENS levels.

PUCX (qualifier) , j - The "PUCX" command works exactly as the "PUCY" command except that it works in the XZ-plane.

COCY , j - The "COCY" command implements the YZ-plane center of curvature solve. The surface curvature in the YZ-plane is adjusted so its center of curvature is positioned at the origin of surface "j". It is assumed that there are no tilted or decentered surfaces between this surface and surface "j". This command is valid at both the LENS input and the UPDATE LENS levels. If "j" is greater than the number of the surface for which this command is issued, there may be no paraxial thickness solves affecting any intervening thicknesses.

COCX (qualifier) , j - The "COCX" command works exactly as the "COCY" command except that it works in the XZ-plane.

CSD , i , j or **CSD ALL** - The "CSD" command deletes any existing XZ and YZ-plane curvature solves from the current surface. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. If the qualifier word "ALL" is used, curvature solves are deleted from all surfaces. The "lens pointer" is not modified by this command. Solve parameters will be frozen at their current value. This command is valid at the UPDATE LENS level.

CSDX , i , j or **CSDX ALL** - The "CSDX" command deletes any existing XZ-plane curvature solves from the current surface. Solve parameters will be frozen at their current value. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. If the qualifier word "ALL" is used, curvature solves are deleted from all surfaces. The "lens pointer" is not modified by this command. This command is valid at the UPDATE LENS level.

CSDY , i , j or **CSDY ALL** - The "CSDX" command works exactly as the "CSDY" command except that it works in the XZ-plane.

THICKNESS SOLVES - The "TH" command was used to explicitly define the axial thickness "t". Thickness solves on the other hand are used to specify the axial thickness "t" indirectly in terms of a condition which must be satisfied by a specific value of "t".

PY , i - The "PY" command implements the YZ-plane paraxial axial ray height solve. The axial distance to the next surface "t" will be adjusted so that the paraxial axial ray in the YZ-plane has height "i" at the next surface. This command is valid at both the LENS input and the UPDATE LENS levels.

PX , i - The "PX" command works exactly as the "PY" command except that it works in the XZ-plane.

PCY , i - The "PCY" command implements the YZ-plane paraxial chief ray height solve. The axial distance to the next surface "t" will be adjusted so that the paraxial chief ray in the YZ-plane has height "i" at the next surface. This command is valid at both the LENS input and the UPDATE LENS levels.

PCX , i - The "PCX" command works exactly as the "PCY" command except that it works in the XZ-plane.

CAY , i and **CAX , i** - The "CAY" and "CAX" commands implement the YZ-plane and XZ-plane clear aperture solves. The axial distance to the next surface "t" is initially assigned the value "i". If there is a circular clear aperture defined on surface "i", then that clear aperture height is used as the effective aperture height. Any clear aperture decentrations are ignored. If there is no circular clear aperture defined on surface "i", then the effective aperture height will be taken as the sum of the absolute values of the marginal and chief paraxial ray heights at surface "i". Then:

1. The sagitta (sag) Z of the current surface at the effective aperture height is calculated from the equation describing the current surface.
2. The sagitta Z_{+1} of the following surface at the same effective aperture height in the YZ-plan or XZ-plane is calculated.
3. If $Z - Z_{+1} > 0$, the program redefines "t" to be $t = t' + (Z - Z_{+1})$. If $Z - Z_{+1} <$ or $= 0$, the program sets t=t'.

Only surface shapes established through input at the LENS input and UPDATE LENS levels are used in the clear aperture solves. The sagitta calculation used in the "CAY" and "CAX" solve implementations does not take into account surface shapes generated from special surface profile definitions. In the case of toric surfaces, the steepest curvature is used in the calculation. Conic and rotationally symmetric aspheric coefficients are considered in this calculation. The "CAY" and "CAX" commands are valid at both the LENS input and the UPDATE LENS levels.

TSD , i , j or **TSD ALL** - The "TSD" command deletes any existing thickness solves from the current surface. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. If the qualifier word "ALL" is used, thickness solves are deleted from all surfaces. The "lens pointer" is not modified by this command. Solve parameters will be frozen at their current value. This command is valid at the UPDATE LENS level.

PARTING NOTES ON ALL SOLVES:
1: Solves, even those which do not reference paraxial ray data, ignore all tilts and decentrations in the lens system just as the paraxial ray trace does.
2: Chief ray solves are never allowed on the object surface or on surfaces which come before the aperture stop. The aperture stop will be discussed in detail in the description of the "ASTOP" command. Thickness and clear aperture solves are also not allowed on the image surface. Specifically the solve in question are: PCY, PCX, PUCY, PUCX, PICY, PICX, APCY and APCX.
3: YZ-plane marginal ray solves are not allowed before the ASTOP surface if SAY FLOAT is in effect. Specifically the solve in question are: PY, PUY, PIY, CAY, COCY and APY.
4: XZ-plane marginal ray solves are not allowed before the ASTOP surface if SAX FLOAT is in effect. Specifically the solve in question are: PY, PUY, PIY, CAX, COCX and APY.
5: All solves are resolved when the "EOS" or "END" command is issued from the LENS input and the UPDATE LENS levels.
6: Issuing any solve command followed only by a "?" will cause the current solve datum and associated surface parameter values to be displayed.
7: All solves take precedence over optimization and tolerance variable definitions. If there is a conflict, the variable definition is disallowed or deleted.

SURFACE TILT AND DECENTRATION - The terms "preceding surface" and "following surface" refer to two adjacent surfaces in the lens database. Tilt and decentration commands provide a means of positioning a "following surface" relative to the local coordinate system of its "preceding surface". In the absence of tilts and decentrations, the X and Y-axis of a "following surface" are assumed to be parallel to the X and Y-axis of its "preceding surface". The local Z-axis of the surfaces are assumed to be coincident. The origin of a following surface lies a distance "t" from the origin of a "preceding surface" measured along the local Z-axis of its "preceding surface". The local coordinate system of a "preceding surface" is always the reference coordinate system for its "following surface" after tilts and/or decentrations have been applied. Tilts and decentrations are not applicable to the object surface since the local coordinate system of the object surface is the initial reference coordinate system for the lens database. Tilts or decentrations assigned to the object surface are always ignored during real ray tracing. The object surface may either be surface zero or it may be some other surface which has been temporarily assigned as the object surface using the 5th numeric word of the "FOB" command.

DEC , yd , xd , zd or **YD , yd** or **XD , xd** or **ZD , zd** - The "DEC", "YD", "XD" and "ZD" commands define the current surface to be decentered with respect to the local coordinate system of its "preceding surface" by the amounts "yd" in the Y-direction, "xd" in the X-direction and "zd" in the Z-direction. If these commands are issued followed only by a "?", the current "yd", "xd" and/or "zd" values will be displayed. These commands are valid at both the LENS input and the UPDATE LENS levels. The surface vertex of the surface containing these decentrations will be located at coordinates X = "xd", Y = "yd" and z = "zd"+"t" with respect to the coordinate system of the previous surface. If the decentered surface is defined as a "TILT"ed surface and if the associated surface angle rotations ALPHA, BETA and/or GAMMA are non-zero, then these tilt rotations are performed **after** the decentrations are performed. The tilts are performed in the order ALPHA then BETA then GAMMA. If the decentered surface is defined as an "RTILT"ed surface (Reverse Tilt) and if the associated surface angle rotations ALPHA, BETA and/or GAMMA are non-zero, then these tilt rotations are performed **before** the decentrations are performed. The tilts are performed in the reverse sequence order. First, a negative GAMMA rotation is performed; then, a negative BETA rotation is performed; and finally, a negative ALPHA rotation is performed. After these reverse sequence rotations are performed, negative "xd", negative "yd" and a negative "zd" decentrations are made. These decentrations are made in the new coordinate system generated by the rotations. The following three figures illustrate the definitions of the surface angle rotations ALPHA, BETA and GAMMA as they are used in this program. ALPHA and BETA are positive left-handed and GAMMA is positive right-handed.

PIVAXIS VERTEX or **PIVAXIS NORMAL** - This feature only works on surfaces which have either a "TILT", "RTITLT" or "TILT DAR" and also an explicit alternate pivot point defined on them. By default, when the program starts or when a new lens database is started, all surface tilts and decenters are understood to be represented in the local coordinate system of the surface. This system has its origin at the surface vertex. This is the condition represented when the default "PIVAXIS VERTEX" is in effect. If "PIVAXIS NORMAL" is set, then a different coordinate system will be used as the tilt and decenter reference coordinate system. This alternate coordinate system will have its origin on the surface at locations X and Y where X and Y are the X and Y-values of the PIVOT definition currently established at that surface. The reference Z-axis will be parallel to the surface normal at this point. If an unrealistic surface sag exists at this surface at coordinates X and Y then the tilts and decenters will be applied as if "PIVAXIS VERTEX" was in effect.
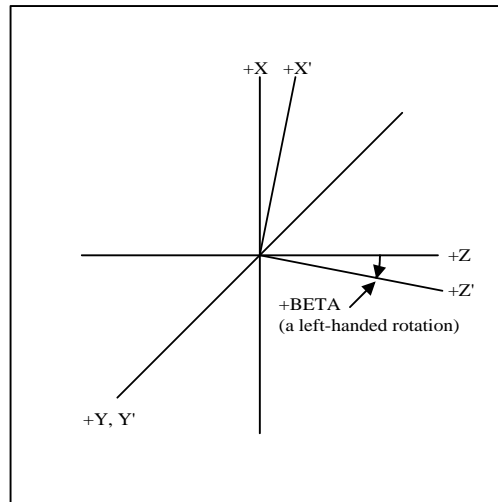
SIGN CONVENTION OF THE SURFACE TILT ANGLES

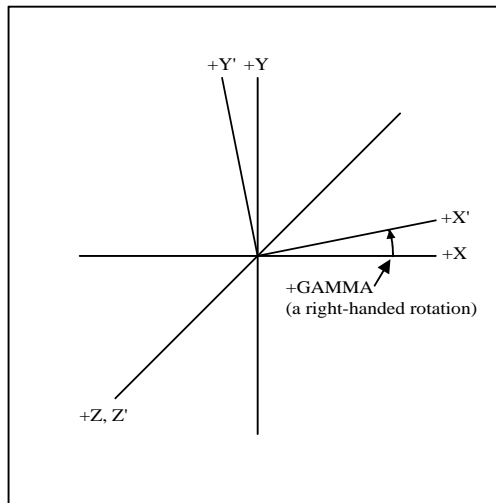**TILT COORDINATE SYSTEM**
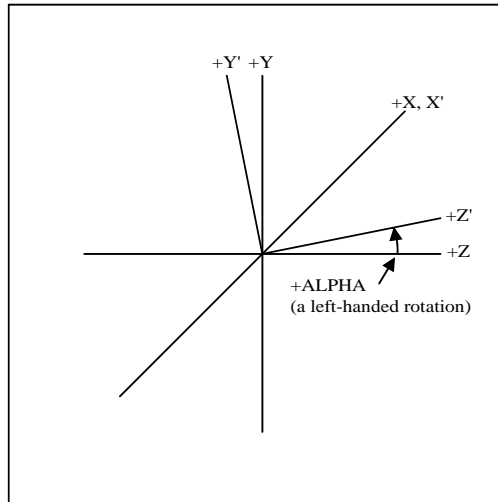
"ALPHA" Definition

The "ALPHA" surface rotation angle defines a rotation about the current X-axis. This rotation follows the **left**-hand rule. The sign convention for "ALPHA" is such that if your **left**-hand fingers point from the original Z-axis toward the new Z'-axis, your **left**-hand thumb points in the direction of the positive X-axis.

"BETA" Definition

The "BETA" surface rotation angle defines a rotation about the current Y-axis. This rotation follows the **left**-hand rule. The sign convention for "BETA" is such that if your **left**-hand fingers point from the original Z-axis toward the new Z'-axis, your **left**-hand thumb points in the direction of the positive Y-axis.

"GAMMA" Definition

The "GAMMA" surface rotation angle defines a rotation about the current Z-axis. This rotation follows the **right**-hand rule. The sign convention for "GAMMA" is such that if your **right**-hand fingers point from the original Y-axis toward the new Y'-axis, your **right**-hand thumb points in the direction of the positive Z-axis.

SURFACE TILT COMMANDS

TILT , alpha , beta , gamma - The "TILT" command causes the local coordinate system of the surface to be tilted by successive surface angle rotations "alpha", "beta" and "gamma". If the surface is decentered, decentrations are performed first. "alpha", "beta", "gamma" are always expressed in degrees. This command is valid at both the LENS input and the UPDATE LENS levels.

RTILT , alpha , beta , gamma - The "RTILT" command (stands for Reverse TILT) causes the local coordinate system of the surface to be tilted by successive surface angle rotations negative "gamma", negative "beta" and then negative "alpha". If the surface is decentered, negative decentrations are performed after the rotations. "gamma", "beta" and "alpha" are always expressed in degrees. The command is the inverse of the "TILT" command. This command is valid at both the LENS input and the UPDATE LENS levels.

TILT AUTO , alpha , beta , gamma - The "TILT AUTO" command automatically tilts and decenters the surface to which it is assigned so as to align the surface Z-axis parallel with the so-called optical axis. The so-called optical axis is defined by a real, non-paraxial reference ray traced from the center of the object surface through the center of the reference surface. The specific inputs of "alpha", "beta" and "gamma" are interpreted as angular offsets to this automatic alignment process. A surface can be held in an offset alignment mode with the optical axis using explicit entries for "alpha", "beta" and "gamma". The default values for "alpha", "beta" and "gamma" are 0.0. With the "TILT AUTO" feature on, every time a reference ray is traced using the "FOB" command, an on-axis reference ray is first traced at the control wavelength, and then the surface with the "TILT AUTO" assigned to it is decentered and tilted so as to remain aligned with this on-axis reference ray. This command is valid at both the LENS input and the UPDATE LENS levels. This auto-alignment will effect the positions and orientations of all following surfaces.

TILT AUTOM , alpha , beta , gamma - The "TILT AUTOM" command is identical to the "TILT AUTO" command, except that the surface Z-axis is aligned anti-parallel to the optical axis. This command is valid at both the LENS input and the UPDATE LENS levels.

TILT AUTOD - The "TILT AUTOD" command removes the automatic tilt and decenter feature from the current surface. The surface will remain tilted and decentered at its current position. This command is valid at both the LENS input and the UPDATE LENS levels. "TILT AUTO" and "TILT AUTOM" commands may only be used on surfaces which follow the system reference surface. If the reference surface position is redefined during ray tracing so that this rule is violated, serious ray trace errors will occur.

ABOUT TILT SIGN CONVERTIONS: When converting a lens system from one which has ALPHA tilts to one which has BETA tilts, or vice versa, remember that in order to maintain correct relationships, a positive ALPHA tilt looks just like a negative BETA tilt a positive BETA tilt looks just like a negative alpha tilt. Study the foregoing figures before replacing BETA tilts with same sign ALPHA tilts or ALPHA tilts with same sign BETA tilts. This is a very common user error. (

TILTD , i , j - The "TILTD" command deletes any existing tilt definitions from the current surface. Any PIKUPs referring to these deleted tilt definitions will also be deleted. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. The "lens pointer" is not modified by this command. Decentrations are not deleted. This command is valid at the UPDATE LENS level. Decentrations may be deleted using the "YD , 0", "XD , 0" or "DEC , 0 , 0" commands.

TILT AUTOD , i , j - The "TILT AUTOD" command deletes any existing TILT AUTO or TILT AUTOM definitions from the current surface. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. The "lens pointer" is not modified by this command. TILT AUTO will be replaced by a simple TILT definition. This command is valid at the UPDATE LENS level.

SPECIAL TILT COMMANDS - The tilt and decenter commands already described are all that are needed to completely describe surface positions and orientations in the optical design and analysis process. The next three commands are special tilt commands. They can be simulated using the previously described tilt commands but at the expense of using extra dummy surfaces containing tilts and decenters.

TILT BEN , alpha , beta - "TILT BEN" may not be placed on the object surface or on surface #1. If you think you need it on surface #1, make surface #1 a dummy surface and put it on surface #2. The "TILT BEN" command is used to model a fold mirror with just one lens database surface. Without the "TILT BEN" command, two tilted surfaces would be required to model a fold mirror. The first tilted surface would be required to model the mirror surface and its tilt. The second "dummy" surface would be required to align the new coordinate system with the optical axis. The "TILT BEN" command causes the program to automatically and internally align the new coordinate system with the optical axis without the use of this second "dummy" surface. If decenters are assigned to a "TILT BEN" surface, the decenters are performed before the tilts. The tilts are performed in the order "alpha", then "beta" and then "gamma". This command is valid at both the LENS input and the UPDATE LENS levels. The program automatically computes a "gamma" rotation and assigns it. This is only done once at the time the "TILT BEN" command is issued. This automatically supplied "gamma" rotation acts to rotate the system surface following the TILT BEN surface so that the central ray will be aligned properly and so that a meridional ray will remain a meridional ray in the surfaces following the TILT BEN surface.

Issued with no numeric input, the "TILT BEN" command converts any existing tilt type to a TILT BEN and leaves existing alpha,beta and gamma values unchanged. The "gamma" angle is computed using the following two equations:

$$\cos(\gamma) = \frac{\cos(\alpha) + \cos(\beta)}{1 + \cos(\alpha)\cos(\beta)}$$

$$\sin(\gamma) = \frac{-\sin(\alpha)\sin(\beta)}{1 + \cos(\alpha)\cos(\beta)}$$

TILT BEND - The "TILT BEND" command is used to convert a "TILT BEN" assignment on the current surface into a simple "TILT" on that surface followed by a new surface with a "TILT" and appropriate tilts and decenters such that the two surfaced work as the single "TILT BEN" originally worked. All appropriate solves and thicknesses are transferred to the new surface. Since "TILT BEND" adds a lens surface, it is best to use "TILT BEND" from the highest surface number to the lowest, when replacing multiple occurrences of "TILT BEN" during the same lens modification session.

TILT DAR , alpha , beta , gamma - "TILT DAR" may not be placed on the object surface or on surface #1. If you think you need it on surface #1, make surface #1 a dummy surface and put it on surface #2. The "TILT DAR" command is used to model a tilted surface without tilting the underlying coordinate system. Without the "TILT DAR" command, two tilted surfaces would be required to model such a geometry. The first tilted surface would be required to model the surface and its tilt. A second "dummy" surface would be required (with a reverse tilt assigned to it) to restore the original coordinate system orientation. The "TILT DAR" command causes the program to automatically and internally restore the original coordinate system without the use of this second "dummy" surface. If decenters are assigned to a "TILT DAR" surface, the decenters are performed before the tilts. The tilts are performed in the order "alpha", then "beta" and then "gamma". The tilts are then removed from the underlying coordinate system in the order "gamma", then "beta" and then "alpha". The decenters are then removed. This command is valid at both the LENS input and the UPDATE LENS levels. If the foregoing tilt commands are issued followed only by "?", the current tilt definition type and associated angles will be displayed. Issued with no numeric input, the "TILT DAR" command converts any existing tilt type to a TILT DAR and leaves existing alpha,beta and gamma values unchanged.

TILT DARD - The "TILT DARD" command is used to convert a "TILT DAR" assignment on the current surface into a simple "TILT". on that surface followed by a new surface with an "RTILT" and appropriate tilts and decenters such that the two surfaced work as the single "TILT DAR" originally worked. All appropriate solves and thicknesses are transferred to the new surface. Since "TILT DARD" adds a lens surface, it is best to use "TILT DARD" from the highest surface number to the lowest, when replacing multiple occurrences of "TILT DAR" during the same lens modification session.

TILT REV , alpha , beta , gamma - "TILT REV" may not be placed on the object surface or on surface #1. If you think you need it on surface #1, make surface #1 a dummy surface and put it on surface #2. The "TILT REV" command works exactly the same as an "RTILT" command except that all rays intersect the surface to which the "TILT REV" command is assigned, before the reverse tilts and decentrations are applied. After ray intersection, "TILT REV" causes the local coordinate system of the surface to which the "TILT REV" is assigned, to be rotated by successive surface angle rotations negative "gamma", negative "beta" and then negative "alpha". If the surface is decentered, negative decentrations are performed after the rotations. "gamma", "beta" and "alpha" are always expressed in degrees. This command is valid at both the LENS input and the UPDATE LENS levels. If the foregoing tilt commands are issued followed only by "?", the current tilt definition type and associated angles will be displayed. Issued with no numeric input, the "TILT REV" command converts any existing tilt type to a TILT REV and leaves existing alpha,beta and gamma values unchanged.

TILT REVD - The "TILT REVD" command is used to convert a "TILT REV" assignment on the current surface into an untilted surface followed by a new surface with an "RTILT". Appropriate tilts and decenters are assigned to the second surface such that the two surfaced work as the single "TILT REV" originally worked. All appropriate solves and thicknesses are transferred to the new surface. Since "TILT REVD" adds a lens surface, it is best to use "TILT REVD" from the highest surface number to the lowest, when replacing multiple occurrences of "TILT REV" during the same lens modification session.

TILT RET , i - "TILT RET" may not be placed on the object surface or on surface #1. If you think you need it on surface #1, make surface #1 a dummy surface and put it on surface #2. The "TILT RET" command is used to automatically relocate the surface to which it is assigned to the location of a previous surface, designated by "i". "i" must be explicitly input by the user. This is done without using any additional dummy surfaces.

TILT RETD - The "TILT RETD" command is used to convert a "TILT RET" assignment on the current surface into a simple "TILT". After this automatic co-location operation, the vertices of the two surfaces will be co-aligned so that the X, Y and Z-axes of the two surface will have identical orientations with respect to one another. This command is valid at both the LENS input and the UPDATE LENS levels. If the foregoing "TILT RET" command is issued followed only by "?", the current tilt definition type and associated angles will be displayed.

SPECIAL "TILT RET" RULES:

1. A "TILT RET" may only be made to a previous surface.

2. No "TILT AUTO" or "TILT AUTOM" commands may appear on surfaces preceding surfaces with "TILT RET"s assigned.

3. A "TILT RET" may not be made to a surface which itself has a "TILT RET" or "TILT RETGO" assigned.

4. All "TILT RET" are resolved sequentially from the object surface to the image surface in one, single resolution pass. Circular return references will be ignored or interpreted incorrectly.

ALTERNATE PIVOT POINTS

PIVOT , pivx , pivy , pivz and **PIVX , pivx** and **PIVY , pivy** and **PIVZ , pivz** - The "PIVOT", "PIVX", "PIVY" and "PIVZ" commands are used to specify alternate pivot points for the "TILT", "TILT DAR" and "RTILT" commands on the current surface. The default pivot point for all tilts is always the origin of the local coordinate system on the surface. This alternate pivot point definition is ignored by "TILT RET", "TILT AUTO", "TILT AUTOM" and "TILT BEN" commands. The "pivx", "pivy" and "pivz" positions are always measured in the local coordinate system of the surface upon which the alternate pivot point assignment is placed. Any explicit surface decentrations are added to the program computed decenters needed to simulate a rotation about an alternate pivot piont.

PIVOTD - The "PIVOTD" command removes any existing pivot assignment on the current surface.

CMD LEVEL TILT UTILITY

VERTS command. Sometimes the position of a following surface, and it's orientation, is not be specified in terms of XD, YD, TH, ALPHA, BETA and GAMMA with respect to the previous surface but will instead be specified by XD, YD, ZD and a set of direction cosines of the X, Y and Z local coordinate axis of the following surface with respect to the previous surface. The "VERTS" command will convert that type of specification into XD, YD, ZD, ALPHA, BETA and GAMMA (assuming a TILT definition is used on the following surface). Before issuing the VERTS command, the following data must be stored in the first 24 general puropse storage registers using the STO (register number) , (value to be stored). The data for both surfaces must, of course, be specified in the same shared coordinate system).

Register 1	X-position of the previous surface
Register 2	Y-position of the previous surface
Register 3	Z-position of the previous surface
Register 4	XL-L-dircos of previous surface's local X-axis
Register 5	XM-M-dircos of previous surface's local X-axis
Register 6	XN-N-dircos of previous surface's local X-axis
Register 7	YL-L-dircos of previous surface's local Y-axis
Register 8	YM-M-dircos of previous surface's local Y-axis
Register 9	YN-N-dircos of previous surface's local Y-axis
Register 10	ZL-L-dircos of previous surface's local Z-axis
Register 11	ZM-M-dircos of previous surface's local Z-axis
Register 12	ZN-N-dircos of previous surface's local Z-axis
Register 13	X-position of the next surface
Register 14	Y-position of the next surface
Register 15	Z-position of the next surface
Register 16	XL-L-dircos of next surface's local X-axis
Register 17	XM-M-dircos of next surface's local X-axis
Register 18	XN-N-dircos of next surface's local X-axis
Register 19	YL-L-dircos of next surface's local Y-axis
Register 20	YM-M-dircos of next surface's local Y-axis
Register 21	YN-N-dircos of next surface's local Y-axis
Register 22	ZL-L-dircos of next surface's local Z-axis
Register 23	ZM-M-dircos of next surface's local Z-axis
Register 24	ZN-N-dircos of next surface's local Z-axis

LENS DATABASE SECTION

GLOBAL COORDINATE SURFACE INPUT - In all of the previous and many following commands, surface locations are specified in the local coordinate system of the previous surface. This section describes a way to specify surface locations in the coordinate system of a "global" surface. It should be remembered that using the "TILT RET" command, the local surface vertex of a surface could be automatically relocated and realigned to the local coordinate system of a previous surface. The program automatically computed and applied decentrations and tilts so as to relocate and realign a surface vertex at this previous surface location and orientation. The following six global coordinate specification commands have been added to the program. They can be applied to any surface which has previously been assigned a "TILT" but are most useful when applied to a surface which has been previously assigned a "TILT RET". After a "TILT RET" has returned and oriented a surface to the "TILT RET" target surface orientation, then the surface can be decentered and tilted with respect to the RET surface local coordinate system. This provides for full "global"-type of surface positioning. It allows the user to have multiple "global"-type coordinate reference surfaces. Remember that the "TILT RET" command is the command which defines the active "global"-type of surface. The following six commands may be used to define this type of "global" surface positioning:

GDX , gdx
GDY , gdy
GDZ , gdz
GALPHA , galpha
GBETA , gbeta
GGAMMA , ggamma

The angles are input in degrees. These six global positioning data items can now also be "picked up", used as optimization or tolerancing variables, gotten using the "GET" command and used as optimization or tolerancing operands.

SINGLE SURFACE PIKUPS - Single surface PIKUP commands are tools used to link a surface parameter (radius, thickness, glass, etc.) of one surface to a corresponding surface parameter of another surface. These PIKUPs are resolved (i.e., values are actually assigned) each time the LENS input or UPDATE LENS levels are exited using the "EOS" or "END" command. Checking is performed to determine if PIKUP and/or solve conflicts exist. Error messages are automatically displayed if disallowed combinations of PIKUPs and solves are attempted. The usual error is an attempt to pick up a surface parameter from a following surface when the picked-up parameter is defined indirectly in terms of other PIKUPs or solves. These nested PIKUPs are not allowed. The general form of the "PIKUP" command is:

PIKUP (parameter name) , j , a , b ,, cfflag - The PIKUP surface parameter value "P" (the eventual value after "EOS" or "END") is related to the corresponding parameter value "P(j)" at surface "j" by the relation:

$$P = aP(j) + b$$

"a" is the user-supplied multiplicative constant and "b" user-supplied is the additive constant. PIKUPs are alway kept properly "up to date", even during tolerancing and optimization. The "cfflag" is normally left blank. If "cfflag" is left blank, then the source value for the pikup will be data from the current lens configuration. If "cfflag" is not left blank, then the source value for the pikup will be data from lens configuration #1, otherwise known as the main configuration. Some PIKUP parameters logically do not use the multiplicative and additive constants. The following table is a list of all 44 parameters that may be picked up:

Parameter Name	Parameter
CV	surface profile curvature (c)
RD	surface profile radius of curvature (r)
CC	surface conic constant (cc)
CVTOR	surface profile toric curvature (c')
RDTOR	surface profile toric radius of curvature (r')
AC	2nd order aspheric coefficient (ac)
AD	4th order aspheric coefficient (ad)
AE	6th order aspheric coefficient (ae)
AF	8th order aspheric coefficient (af)
AG	10th order aspheric coefficient (ag)
AH	12th order aspheric coefficient (ag)
AI	14th order aspheric coefficient (ag)
AJ	16th order aspheric coefficient (ag)
AK	18th order aspheric coefficient (ag)
AL	20th order aspheric coefficient (ag)
ADTOR	4th order anamorphic aspheric coefficient (adtor)
AETOR	6th order anamorphic aspheric coefficient (aetor)

LENS DATABASE SECTION

Parameter Name	Parameter
AFTOR	8th order anamorphic aspheric coefficient (aftor)
AGTOR	10th order anamorphic aspheric coefficient (agtor)
CCTOR	surface toric conic constant (cctor)
XD	X-decentration (xd)
YD	Y-decentration (yd)
ZD	Z-decentration (zd)
ALPHA	tilt angle about the X-axis (alpha)
PRO	complete surface profile (no "a" or "b") (Includes special surface definitions and deformable surface definitions)
NPRO	PRO , cv and aspheric signs reversed (no "a" or "b" input) (Excludes special surface definitions and deformable surface definitions)
GLASS	surface glass definition (no "a" or "b" input)
CLAP	complete surface clear aperture data (no "a" or "b" input)
COBS	complete surface obscuration data (no "a" or "b" input)
BETA	tilt angle about the Y-axis (beta)
GAMMA	tilt angle about the Z-axis (gamma)
TH	axial thickness (t)
THOAL	overall length pikup
PIVX	alternate x-pivot point location for a "TILT"
PIVY	alternate y-pivot point location for a "TILT"
PIVZ	alternate z-pivot point location for a "TILT"
GDX	global coordinate surface x-decenter (used with TILT RET)
GDY	global coordinate surface y-decenter (used with TILT RET)
GDZ	global coordinate surface z-decenter (used with TILT RET)
GALPHA	global coordinate surface alpha tilt (used with TILT RET)
GBETA	global coordinate surface beta tilt (used with TILT RET)
GGAMMA	global coordinate surface gamma tilt (used with TILT RET)
GRT	diffraction grating definition
COATING	coating file number 0=no coating, 1 to 1000 valid coating file numbers

Default conditions for PIKUPS are: Except for "PRO", "NPRO", "CLAP", "COBS", "GLASS", if no entry is made for the multiplicative constant "a", the program assumes a=1.0. If no entry is made for the additive constant "b", it is assumed to be 0.0. The default for "cfflag" is blank. A negative value for the surface number entry "j" may be used to count back from the current surface. Thus, j = -1 denotes the immediately preceding surface. The "PIKUP CVTOR" and "PIKUP RDTOR" commands require both the current surface and the referenced surface "j" to be defined as toric and as the same type of toric (either both Y-TORIC or both X-TORIC) by the time the "EOS" or "END" command is issued. The "PIKUP PRO" and "PIKUP NPRO" commands require both the current surface and the referenced surface "j" to be defined as either the same type of toric or non-toric by the time the "EOS" or "END" command is issued. If these conditions do not exist at the time the "EOS" or "END" command is issued, the "pikup" surface will be redefined so as to be either non-toric or to be the same toric type as the surface being referenced by the PIKUP. The picking up of an aspheric coefficient automatically identifies the "pikup" surface as aspheric. Any undefined coefficients are assumed equal to zero.

SPECIAL PIKUP OPTION

PIKUP (parameter name) , j , a , , 1, cfflag - For any "PIKUP" command requiring entry of the additive constant "b", an option for specifying "b" implicitly is provided. This implicit definition of "b" is selected by entering a "1" in the 4th numeric word of the "PIKUP" command. The explicit entry for "b" may be left in the default input form as shown above or an explicit value may be entered. In either case, the entry for "b" is ignored. A new value for "b" is calculated by the relation:

$$b = P' - aP'(j)$$

where:

$\qquad$ a=(multiplicative constant)

$\qquad$ P'=(parameter value at PIKUP surface)

$\qquad$ P'(j)=(parameter value at surface "j")

P' is the value of the PIKUP parameter at the current PIKUP surface. P'(j) is the value of the PIKUP parameter at referenced surface "j". P' and P'(j) must have already been explicitly defined using other LENS input or UPDATE LENS level commands. After this initial calculation of "b", the surface PIKUP will be reset to a normal PIKUP. This special PIKUP option is an easy way of establishing linear relationships between a parameter on different surfaces. This special PIKUP option applies to all PIKUPs, except "PIKUP PRO", "PIKUP NPRO" and "PIKUP GLASS". If the "PIKUP" commands are issued followed only by a "?", the current value of the associated PIKUP data will be displayed. "PIKUP" commands are valid at both the LENS input and the UPDATE LENS levels.

OVERALL LENGTH PIKUP

PIKUP THOAL , j , k , a , b , cfflag - The "PIKUP THOAL" command is a multiple-surface thickness pikup. It is used to link the thickness on the current surface to the overall length (sum of axial surface thicknesses) from surface "j" to surface "k". The current surface is not allowed to lie in the surface number range "j" to "k". The "PIKUP THOAL" is resolved (i.e., value is actually assigned) each time the LENS input or UPDATE LENS levels are exited using the "EOS" or "END" command. Checking is performed to determine if PIKUP and/or solve conflicts exist. Error messages are automatically displayed if disallowed combinations of PIKUP THOAL, PIKUP TH and solves are attempted. The usual error is an attempt to pick up from a following surface when the picked-up parameter is defined indirectly in terms of other PIKUPs or solves. As before, nested PIKUPs are not allowed.

The PIKUP'd up surface thickness value (the eventual surface thickness value after "EOS" or "END") is set equal to the sum of the axial thicknesses from surface "j" to surface "k" multiplied by the multiplicative constant "a" and then increased by the additive constant "b". "a" is the user-supplied multiplicative constant and "b" is the user-supplied additive constant. The defaults for "a" and "b" are 1.0 and 0.0, respectively. PIKUPs are alway kept properly "up to date", even during tolerancing and optimization. The "cfflag" is normally left blank. If "cfflag" is left blank, then the source value for the pikup will be data from the current lens configuration. If "cfflag" is not left blank, then the source value for the pikup will be data from lens configuration #1, otherwise known as the main configuration. Unlike the single surface pikup commands, there is **no** special pickup option available for use with the "PIKUP THAOL" command. All PIKUPs take precedence over optimization and tolerance variable definitions. If there is a conflict, the variable definition is disallowed or deleted.

PIKUP DELETIONS

PIKD (optional parameter name) , i , j - The "PIKD" command, issued with no optional pikup parameter name, deletes all existing PIKUP definitions from the designated current or designated surface. If an optional pikup parameter name from the list of pikup types is entered, then only that PIKUP is deleted. "PIKD" deletes all PIKUPs from a surface whereas "PIKD RD" deletes the radius PIKUP if one exists. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. This command is valid at the UPDATE LENS level.

CMD LEVEL LINKING - The "LINK" command provides a way of assigning PIKUPS from the CMD level. It is a shortcut method and produces exactly the same result as if the UPDATE LENS level was entered and a traditional PIKUP was assigned. The "LINK" command syntax is:

LINK (parameter name) , i , j , a , b - "i" is the target surface number to which the PIKUP is assigned. "j" is the source surface number from which the PIKUP receives its reference data. "a" and "b" are the multiplicative and additive constants. The "cfflag" parameter of the "PIKUP" command is not supported in the "LINK" command.

LINKD (parameter name) , i , j The "LINKD" command, issued with no optional pikup parameter name, deletes all existing PIKUP definitions from surface "i". It is the CMD level equivalent of the UPDATE LENS command "PIKD". If an optional pikup parameter name from the list of pikup types is entered, then only that PIKUP is deleted. "LINKD" deletes all PIKUPs from a surface whereas "LINKD RD" deletes the radius PIKUP if one exists. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. The "TLINK command provides a way of assigning one time LINK **without PIKUPS** from the CMD level. It is exactly the same as issuing a "LINK" command followed immediately by a "LINKD" command.

TLINK (parameter name) , i , j , a , b - "i" is the target surface number upon which the "TLINK" operates. "j" is the source surface number from which the one time link receives its reference data. "a" and "b" are the multiplicative and additive constants.

LENS DATABASE SECTION

SURFACE NORMALS - The surface normal definition is: If the surface curvature "c" is positive, the surface normal vector is taken as the **inner** normal. If the curvature "c" is negative, the surface normal vector is taken as the **outer** normal. At the surface vertex, the surface normal is along the local positive Z-axis. The above definition of surface normals is **always** used.

BEAM FOOTPRINT CONTROLS - In some very special cases during the generation of beam footprint plotting (see the GRAPHICS section of this manual) it may be desired that the "APE" qualifier word of the "FOOT" command not be used but at the same time it is still desired that surfaces additional to the reference surface be used to control the shape of the beam. In these very special cases, the surfaces which are to be used to control beam shape can be set as foot print blocking surfaces with the LENS INPUT and LENS UPDATE command "FOOTBLOK". There are two different "FOOTBLOK" surface settings available in the program, "YES"/"ON" and "NO"/"OFF". The default setting is "NO"/"OFF".

"FOOTBLOK" was originally only supposed to work in beam footprint ray tracing. It became necessary to be able to selectively shut "off" regular ray aperture and obscuration checking during normal ray tracing when "RAY CAOB" was either issued by the user or by some internal program operation. So now, if "FOOTBLOK" is set to "ON" on a surface and "RAY CAOB" is issued, no aperture or obscuration checking will be done at that surface. This is a case of a double positive equaling a negatuve.

FOOTBLOK ("YES/ON" or "NO/OFF") - The "FOOTBLOK" command establishes the nature of the footprint blocking status of a surface. The footprint blocking setting should only be set to "YES"/"ON" when it is desired to shape a beam with clear apertures and obscuration on surfaces additional to the reference surface and then to show that the shaped beam walks off the surface at which the beam foot print is plotted.

SPECIFIC GRAVITY

SPGR , spgr At the LENS, and UPDATE LENS levels, the "SPGR" command is used to enter the specific gravity, in grams/cc, of the lens material at the current surface. The default value for the specific gravity is 0.0. If the "SPGR" command is issued followed only by a "?", the current value of the "SPGR" setting will be displayed. The "SPGR" command is valid at both the LENS input and the UPDATE LENS levels.

PRICE PER Kg

PRICE , price - At the LENS, and UPDATE LENS levels, the "PRICE" command is used to enter the price, in price units/Kg, of the lens or mirror material at the current surface. The default value for the price is 0.0. If the "PRICE" command is issued followed only by a "?", the current value of the "PRICE" setting will be displayed. The "PRICE" command is valid at both the LENS input and the UPDATE LENS levels.

SURFACE INTERSECTION POINTS - The intersection points of a ray with a surface are distinguished by the fact that at one intersection point, the angle of incidence (angle between ray vector and surface normal vector) is always less than 90 degrees in magnitude, and at the other, the angle is always greater than 90 degrees. The intersection point at which the angle of incidence is less than 90 degrees in magnitude will be called the "first intersection" point. The intersection point at which the angle of incidence is greater than 90 degrees in magnitude will be called the "second intersection" point.

SELECTION OF INTERSECTION POINTS AND "RAY TRAVEL DIRECTION" - he direction of travel of the ray in the local coordinate system determines the standard intersection point. If the ray is traveling in a media which has a positive refractive index, the ray is considered to be traveling in the "positive" direction. If the ray is traveling in a media which has a negative refractive index, the ray direction is considered to be traveling in the "negative" direction.

LENS DATABASE SECTION

APERTURE STOP AND REFERENCE SURFACE

THE APERTURE STOP - The **aperture stop** of a lens system is defined to be that surface at which the paraxial chief ray (in both YZ and XZ-planes) has a height of zero. The paraxial chief ray will be automatically aimed so that this condition is always met (except when the "telecentric" option is being used). The paraxial raytrace ignores all decentrations, tilts, conic constants, aspheric deformations and special surface data.

THE PARAXIAL ENTRANCE PUPIL - The paraxial **entrance pupil** of a lens system is defined to be the paraxial image of the aperture stop as seen from the object surface. This image is formed by all optical elements which lie between the aperture stop and the object surface.

THE PARAXIAL EXIT PUPIL - The paraxial **exit pupil** of a lens system is defined to be the paraxial image of the aperture stop as seen from the image surface. This image is formed by all optical elements which lie between the aperture stop and the image surface.

THE REFERENCE SURFACE - The **reference surface** of a lens is defined to be that surface at which all real trigonometric chief rays will have a height of zero. All real trigonometric chief rays will be automatically aimed so that this condition is always met (except when the "telecentric" option is on). The real chief ray zero height target is defined to be located at the surface vertex if the surface has no clear aperture assigned, and it is located at the center of the clear aperture if a clear aperture is assigned. Decentering and tilting a clear aperture causes the chief ray aiming point to move with respect to the surface vertex. The real trigonometric raytrace considers all parameters in the lens database, the alternate configuration database and the special surface database. The aperture stop and the reference surface may be defined on the same surface or on different surfaces as suits the needs of the designer. **In most cases, they should be placed on the same surface.** The height of the paraxial chief ray at surface 1, adjusted by any tilts and decentration on surface 1, is used as the first aiming point in the iterative, real chief ray aiming process.

ASTOP (qualifier) The "ASTOP" command defines the surface to which it is applied to be the aperture stop for the lens system. The "qualifier word" is used to designate whether or not paraxial entrance and paraxial exit pupil position adjustments are to be performed. If the "ASTOP" command is issued followed only by a "?", the current aperture stop surface number and adjustment conditions will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels. When a paraxial entrance pupil position adjustment is made (qualifier word EN or ENEX), the axial thicknesses of the object surface and surface number 1 are adjusted such that the overall length from the object surface to surface number 2 remains unchanged while, at the same time, surface number 1 is relocated to the position of the system paraxial entrance pupil. When a paraxial exit pupil position adjustment is made (qualifier word EX or ENEX), the axial thicknesses of the (image surface number - 1) surface and the (image surface number -2) surface are adjusted so that the overall length from the (image surface number - 2) surface to the image surface remains unchanged while, at the same time, the (image surface number -1) surface is relocated to the position of the system paraxial exit pupil.

"ASTOP" qualifier	ACTION TAKEN
(no qualifier)	no paraxial pupil position adjustments are made
EN	paraxial entrance pupil position adjustment
EX	paraxial exit pupil position adjustment
ENEX	adjust both paraxial pupil positions

The entrance and exit pupil positions are determined from paraxial raytrace data in the YZ-plane.

REFS , θ - The "REFS" command defines the surface to which it is assigned as the lens system reference surface. The reference surface orientation angle "θ", which is measured positive in degrees from the reference surface local X-axis to the reference surface local Y-axis in a right-handed sense, is used to rotate the reference surface ray aiming point in the reference surface when there is either no clear aperture assigned to the reference surface or when the clear aperture assigned to the reference surface has no decentrations and/or tilts associated with it. The default reference surface number is "1". If the "REFS" command is issued followed only by a "?", the current reference surface number and orientation will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels. If issued from the CMD level, the current reference surface number will be displayed.

LENS DATABASE SECTION

SURFACE LABELS

LABEL , (alphanumeric string) or **LBL , (alphanumeric string)** - The "LABEL" or "LBL" command allows for the definition of a lens surface label of up to 79 alphanumeric characters which will be attached to the current surface and stored with the current lens. This command is valid at both the LENS input and the UPDATE LENS levels.

INR ASSIGNMENTS

INR , inr - The "INR" command is used to assign a reference radius (semi-diameter) value to a surface. This value will be used whenever special surface TYPE 9 or TYPE 10 Zernike polynomial phase surface data is assigned to the surface at the SPSRF or UPDATE SPSRF program level. The "inr" value is used to provide normalization to a unit radius for the Zernike polynomials. If the "INR" command is issued followed only by a "?", the current "inr" value will be displayed. This command is valid at both the LENS input and the UPDATE LENS levels. If no explicit "inr" value is assigned, then the default "inr" value will be:
1. The sum of the absolute values of the x-clear aperture value and the x-clear aperture offset or the sum of the absolute values of the y-clear aperture value and the y-clear aperture offset, whichever sum is larger (if clear apertures are assigned to the surface) ,
2. The sum of the absolute values of the "PX" and "PCX" paraxial ray values at the surface or the sum of the absolute values of the "PY" and "PCY" values at the surface, whichever sum is larger (if no clear apertures are assigned to the surface).

INRD , i , j - The "INRD" command deletes an explicit "inr" assignment on the current surface. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. The "lens pointer" is not modified by this command. This command is valid at the UPDATE LENS level.

DUMMY SURFACES - A dummy surface is usually defined as a surface which has the same optical material in front of it and behind it. In some cases, plotted rays will not be shown going to and from dummy surfaces if the rays are "virtual". Virtual rays are defined in the GRAPHICS section of this manual. Virtual rays can be turned "on" (see GRAPHICS) but then all virtual rays are shown and that can get messy. A virtual ray will be drawn to and from a dummy surface if an explicit clear aperture has been assigned to that dummy surface. If a virtual ray needs to be drawn to and from a dummy surface and a clear aperture can not be assigned to that dummy surface due to other design or analysis considerations, the surface may be "forced" to not be considered a dummy surface by using the following command:

NODUM ("YES/ON" or "NO/OFF") - The "NODUM" command establishes a surface as "not a dummy" if the qualifier words "YES" or "ON" are used with it. The qualifier words "NO" or "OFF" are used to cancel a NODUM YES or NODUM ON assignment. The "NODUM" status is remembered in the lens database and may be displayed using the "DUMOUT" command .

OPTICAL MATERIALS COMMANDS

AIR - The "AIR" command specifies that the material following the current surface will be AIR having a refractive index of 1.0. At the LENS input level, this command also advances the surface counter by "1". Any surface dependent input following an "AIR" command will be associated with the next surface. Entry of multiple "AIR" commands at the LENS input level causes multiple plano "dummy" surfaces to be entered. This command is valid at both the LENS input and the UPDATE LENS levels. "AIR" may also be entered as "GLASS AIR".

REFL - The "REFL" command specifies that the current surface is a mirror surface. The refractive indices of the material following this surface will be of the same magnitude but opposite in sign to the refractive indices of the material preceding it. At the LENS input level, this command also advances the surface counter by "1". Any surface dependent input following an "REFL" command will be associated with the next surface. Entry of multiple "REFL" commands at the LENS input level causes multiple plano mirror surfaces to be entered. This command is valid at both the LENS input and the UPDATE LENS levels. "REFL" may also be entered as "GLASS REFL".

REFLTIRO - The "REFLTIRO" command specifies that the current surface is a mirror surface if and only if a total internal reflection condition exists for the current ray. The refractive index of the material into which the ray would refract, should TIR not exist, is always assumed to be 1.0. If TIR can not occur for a ray, then the ray fails. At the LENS input level, this command also advances the surface counter by "1". Any surface dependent input following an "REFLTIRO" command will be associated with the next surface. Entry of multiple "REFLTIRO" commands at the LENS input level causes multiple plano mirror surfaces to be entered. This command is valid at both the LENS input and the UPDATE LENS levels. "REFLTIRO" may also be entered as "GLASS REFLTIRO".

MYGLASS (glass name) , n1 , n2 , n3 , n4 , n5 - The "MYGLASS" command specifies that the material following the current surface will be made of material "glass name". The refractive indices of this material will be "n1", "n2", "n3", "n4" and "n5" corresponding to the first five program wavelengths. If any of these five numeric values is missing, that refractive index will be set to 1.0. At the LENS input level, this command also advances the surface counter by "1". Any surface dependent input following a "MODEL" command will be associated with the next surface. Entry of multiple glass input commands at the LENS input level causes multiple plano surfaces to be entered. Each of those surfaces will have material type "glass name" in the space following it. When the "MYGLASS" command is used to specify the material type at a particular surface, no refractive index interpolation is performed for that surface if wavelength values are changed!

N1 , n through **N10 , n** - At the UPDATE LENS level, the "N1" through "N10" commands specify that if the current surface material was defined using the "MYGLASS" command, then the refractive index for wavelengths 1, to 10 will be set to the specified value. At the LENS INPUT level, the "N1" through "N10" commands specify that if the previous surface material was defined using the "MYGLASS" command, then the refractive index for wavelengths 1, to 10 will be set to the specified value. A surface's material type must be explicitly defined by a "MYGLASS" command before the refractive indices may be changed using the "N1" through "N10" commands.

(Catalog Name) (Glass Name or Glass Number) - This command specifies that the material following the current surface will be made of material "Glass Name" whose refractive index wavelength interpolation coefficients are stored in the glass catalog and is named "Catalog Name". Refractive indices will be calculated for each wavelength. The program will determine if these indices are to have positive or negative signs depending on the presence of mirrors on other lens surfaces. At the LENS input level, this command also advances the surface counter by "1". Any surface dependent input following this command will be associated with the next surface. Entry of multiple commands of this form at the LENS input level causes multiple plano surfaces to be entered. Each of those surfaces will have material type "Glass Catalog" "Glass Name" in the space following it. This command is valid at both the LENS input and the UPDATE LENS levels. This command is the only exception to the rule that a qualifier word may only have eight alphanumeric characters. "Glass Name" can have up to 13 alphanumeric characters since some catalog glasses have 13 character glass names. If, during optimization, refractive indices are varied as part of the optimization process, glasses defined with this command will be permanently converted to glasses defined by the "MYGLASS" command. Only surfaces whose refractive indices are defined with the "MYGLASS" command may have their refractive indices varied during optimization. The following table lists valid glass catalog names, types of material stored and wavelength regions:

Valid Glass Catalog Name	Type of Material Stored	Wavelength Band
SCHOTT	Schott Optical Glasses	0.3126 μ - 2.3254 μ
SCH2000	Schott Optical Glasses (Post 2000)	0.3126 μ - 2.3254 μ
HOYA	Hoya Optical Glasses	0.365 μ - 1.1 μ
HIKARI	Hikari Optical Glasses NOTE: For Lead and Arsenic free glasses, enter the 6-digit glass code instead of the glass name.	0.365 μ - 1.1 μ
OHARA	Ohara Optical Glasses (except I-LINE glasses)	0.365 μ - 1.1 μ for glasses using the Schott Formula or 0.3126 μ - 2.3254 μ for glasses using the Sellmeier Formula
OHARA	Ohara I-LINE glasses	0.250 μ - 1.1 μ
CHANCE	Chance-Pilkington Optical Glasses	0.365 μ - 1.1 μ
CORNIN	Corning-France Optical Glasses	0.365 μ - 1.1 μ
RUSSIAN	SOVOPTIKS Glasses	0.3126 μ - 2.3254 μ
RADHARD	Assorted radiation hard glasses	varies with material
USER	User Defined Glass Catalog	All (NO RESTRICTIONS)
MATL	Assorted IR, UV, and VIS materials	varies with material
GLCAT or GLASS	Schott,Schott(Post-2000), Hoya, Ohara, Corning-France, Chance-Pilkington, SOVOPTIKS, USER and then MATL specified by glass name or glass number only. After the glass is found, the manufacturer/catalog name replaces the word GLCAT or GLASS in the lens database. This is used when the manufacturer/catalog name is initially unknown.	varies with limits on specific glass catalog referenced (see above list)

LENS DATABASE SECTION

RUSSIAN GLASS NAMES

The following table list equivalent english alphabet names for the glasses in the Russian glass catalog (SOVOPTIKS $_{USA,}$,1983):

Description	English Designation	Russian Designation
Light Crown	LK	*ЛК*
Phosphate Crown	FK	*ФК*
Dense Phosphate Crown	TFK	*ТФК*
Crown	K	*К*
Barium Crown	BK	*БК*
Extra Dense Crown	STK	*СТК*
Special Crown	OK	*ОК*
Crown Flint	KF	*КФ*
Barium Flint	BF	*БФ*
Dense Barium Flint	TBF	*ТБФ*
Light Flint	LF	*ЛФ*
Flint	F	*Ф*
Dense Flint	TF	*ТФ*
Special Flint	OF	*ОФ*
Dense Crown	TK	*ТК*

USER-DEFINED GLASS CATALOG - The user-defined glass catalog, which is referenced by catalog name "USER", is stored in the ASCII file "USER.DAT". It is stored in the same directory into which the main program was installed and from which the main program runs. It is an ASCII file whose entries are free format and are expected to be of the form:

GLASS_NAME , A0 , A1 , A2 , A3 , A4 , A5 "GLASS NAME" is a one to thirteen character, user-defined glass name, and A0 through A5 are the six interpolation coefficients used with the following equation:

$$ n^2 = A_0 + A_1 * \lambda^2 + A_2 * \lambda^{-2} + A_3 * \lambda^{-4} + A_4 * \lambda^{-6} + A_5 * \lambda^{-8} $$

All input in the file USER.DAT should be separated by spaces or commas. If the user only has a table of index versus wavelength, then SPFIT routines (see the SPFIT section of this manual) may be used to determine the coefficients. A sample "USER.DAT" exists in the main program directory. λ is always assumed to be represented in microns. An example of fitting index data and automatic assigning the fitting coefficients to a new user-defined glass type is given in the SPFIT section of the manual.

MODEL GLASSES - Refractive index values may always be varied during optimization when a surface's glass type is specified with the "MYGLASS" command. When this is done, it is the responsibility of the designer to build constraints into the merit function which keep the glass from becoming an unrealistic material. This makes for maximum program flexibility but requires much from the designer. The "MODEL" command makes the process of varying glasses during optimization a much simpler.

MODEL (user supplied name) , Nd , Vd , ΔPartial Dispersion - The "MODEL" command is used to specify a glass in terms of its refractive index at the Fraunhoffer "d" line (0.5875618 micron) and its Abbe-number Vd. After the user specifies these two values, the program automatically determines the refractive index values at all other wavelengths by assuming that the glass is on the "normal" partial dispersion line defined by the two Schott glasses K7 and F2. If the user wishes to have this glass shifted "off" the "normal" dispersion line, then a partial dispersion shift value should be entered as the third numeric word. The partial dispersion shift is assumed to be constant across the entire wavelength band in the lens database. The "Nd" , "Vd" and "ΔPartial Dispersion" (also called "DPART") can be used as optimization and tolerance variables. They are also included in the "GET" list and the lists of pre-defined operands.

INDEX , nd - The "INDEX" command is used to specify or change the refractive index "nd" for a glass which was specified previously using the "MODEL" command.

VNUM , Vd - The "VNUM" command is used to specify or change the Abbe-number "Vd" for a glass which was specified previously using the "MODEL" command.

DPARTL , ΔPartial Dispersion - The "DPARTL" command is used to specify or change the partial dispersion shift value used with a model glass.

LENS DATABASE SECTION

CMD LEVEL GLASS COMMANDS

FINDING REAL GLASSES - After optimization, it is usually necessary to replace the "MODEL" glass with a real glass. This is done with the help of the following CMD level command:

FINDGLASS (catalog name or ALL) , i , n - The "FINDGLASS" command, issued at the CMD program level, searches the SCHOTT, SCH2000, OHARA, HOYA, CHANCE PILKINGTON, CORNING FRANCE, and/or HIKARI glass catalogs for the closest "n" glasses to the MODEL glass on surface "i" and displays them. The valid qualifier words are: "SCHOTT", "SCH2000", "HOYA", "OHARA", "CORNIN", "CHANCE", "HIKARI" or "ALL" (to search all the catalogs).

TOMODEL i - The "TOMODEL" command converts any glass in the SCHOTT, "SCH2000", OHARA, HOYA, CHANCE PILKINGTON, CORNING FRANCE, HIKARI, RUSSIAN and RADHARD glass catalogs into a MODEL glass with the correct values of Nd , Vd , ΔPartial Dispersion. "I" is the surface number.

SURFACE COATINGS

COATING , n - The "COATING" command specifies that the surface coating data designated by coating file number "n" will be associated with the current surface. This command is valid at both the LENS input and the UPDATE LENS levels. Surface coating data is stored in the files COAT0001.DAT THROUGH COAT1000.DAT (file numbers 1 to 1000) which are ASCII files stored in the main program directory. The default coating is an uncoated surface with no losses.

SURFACE COATING DATABASE - The SURFACE COATING database consists of user-generated ASCII files COAT0001.DAT through COAT1000.DAT. These files hold the complete description of all the types of single and multi-layer coatings available for use in the program. Up to 1000 individual coating files may be defined and redefined by the user.

NATURE OF THE COATING DESCRIPTIONS - Unlike most other optical design and analysis codes, the program contains a flexible syntax for describing optical surface coatings in many different ways. Each coating definition consists of a series data lines in an ASCII file which describe the type of coating and its characteristics. All coatings are prepared ahead of time by the user using any text editor. The syntax of every coating definition file begins with the header line which contains a single integer that specifies the coating type. The program currently has 4 coating types availabe. Any of these 4 coating types may be used in any of the 1000 different coating database files.

COATING TYPES - Valid coating types are defined below. Coatings are used for energy throughput calculations when surface coating dependent ray trace options are in are in effect. When performing polarization type calculations, only type 1 (no effect on ploarization) or type 4 coatings will be used.

COATING TYPE 1 – No coating and no coating losses. Transmissions and reflections are 100% efficient. This is the program default and requires no coating definition file. If this type of coating is to be explicitly set in a coating definition file, only one entry, the coating type number 1 is needed as shown below:

1
ABSORB
(ABSORPTION COEFFICIENT FOR WAVELENGTH 1)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 2)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 3)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 4)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 5)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 6)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 7)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 8)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 9)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 10)

"ABSORB" is an optional entry. If used it may be followed by up to 10 entries which are interpreted as the absorption coefficients at the 10 program wavelengths. The absorbtion coefficients are interpreted as belonging to the material into which the ray advances after interacting with the surface to which the coating is attached. Defaults and missing values are assumed to be zero. The ray energy is reduced by the factor:

$$\mathbf{EXP}\left(-\,\mathbf{COEF} \times \mathbf{RPL}\right)$$

where RPL is the ray path length in the absorbing material and COEF is the absorbtion coefficient. The user is responsible for using a COEF value that is correct for the current lens units (INCH, MM, CM or METER).

COATING TYPE 2 - Coating type 2 is an uncoated surface with Fresnel losses. Uncoated transmissive surfaces exhibit simple Fresnel reflection losses. Reflections will experience no energy loss. A coating file used to define a type 2 coating has only one entry as shown below:

2
ABSORB
(ABSORPTION COEFFICIENT FOR WAVELENGTH 1)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 2)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 3)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 4)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 5)

(ABSORPTION COEFFICIENT FOR WAVELENGTH 6)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 7)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 8)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 9)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 10)

"ABSORB" is an optional entry. If used it may be followed by up to 10 entries which are interpreted as the absorption coefficients at the 10 program wavelengths. The absorbtion coefficients are interpreted as belonging to the material into which the ray advances after interacting with the surface to which the coating is attached. Defaults and missing values are assumed to be zero. The ray energy is reduced by the factor:

$$EXP(-COEF \times RPL)$$

where RPL is the ray path length in the absorbing material and COEF is the absorbtion coefficient. The user is responsible for using a COEF value that is correct for the current lens units (INCH, MM, CM or METER).

COATING TYPE 3 - Coating type 3 is a simple "e"% efficient coating where the default value for "e" is 100%. If a "TIR" condition is found, perfect 100% reflection will always occur. If reflection occurs at a surface with a type 3 coating (other than case of TIR), the reflectivity will be assumed to be "e"%. The file entry for this specific coating, if the efficienct were to be 85% is:

3
85
ABSORB
(ABSORPTION COEFFICIENT FOR WAVELENGTH 1)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 2)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 3)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 4)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 5)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 6)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 7)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 8)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 9)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 10)

"ABSORB" is an optional entry. If used it may be followed by up to 10 entries which are interpreted as the absorption coefficients at the 10 program wavelengths. The absorbtion coefficients are interpreted as belonging to the material into which the ray advances after interacting with the surface to which the coating is attached. Defaults and missing values are assumed to be zero. The ray energy is reduced by the factor:

$$EXP(-COEF \times RPL)$$

where RPL is the ray path length in the absorbing material and COEF is the absorbtion coefficient. The user is responsible for using a COEF value that is correct for the current lens units (INCH, MM, CM or METER).

COATING TYPE 4 - Coating type 4 is the program general coating type. The first line in the coating file must be a **4**. The next N lines in the file comprise the user-supplied data for each of the N-layers of the coating. Each line starting at line 2 consists of a user supplied material name (up to 13 characters) followed by 10 real and then 10 imaginary refractive index values and then the layer thickness in microns. In multiple layer coatings, the first layer is the layer farthest from the substrait. As in regular program input, nested commas represent default values which are 1.0 for the real part and 0.0 for the imaginary part of the complex refractive index. As an example, a type 4 coating defined in the ASCII coating file COAT0025.DAT and consisting of a single layer of MGF2 with a complex refractive index at wavelength #1 of (1.38,0.0) and having a thickness of 0.34 microns would be defined using the following two lines in file COAT0025.DAT.

4
MGF2,1.38, , , , , , , , , ,0.0, , , , , , , , , ,0.34
ABSORB
(ABSORPTION COEFFICIENT FOR WAVELENGTH 1)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 2)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 3)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 4)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 5)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 6)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 7)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 8)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 9)
(ABSORPTION COEFFICIENT FOR WAVELENGTH 10)

"ABSORB" is an optional entry. If used it may be followed by up to 10 entries which are interpreted as the absorption coefficients at the 10 program wavelengths. The absorbtion coefficients are interpreted as belonging to the material into which the ray advances after interacting with the surface to which the coating is attached. Defaults and missing values are assumed to be zero. The ray energy is reduced by the factor:

$$\mathrm{EXP}\left(-\,\mathrm{COEF}\times\mathrm{RPL}\right)$$

where RPL is the ray path length in the absorbing material and COEF is the absorbtion coefficient. The user is responsible for using a COEF value that is correct for the current lens units (INCH, MM, CM or METER).

LENS DATABASE SECTION

THE PERFECT LENS

PERFECT - The "PERFECT" command specifies that a surface is to be considered as a "PERFECT" paraxial focusing lens. This property can only be assigned to the surface immediately in front of the final surface of the lens. This PERFECT lens will have a focal length equal to the thickness assigned to it by either the "TH" or "PY" commands. No aberrations are added to the system with this surface. It is used to simulate a focal system when designing afocal systems when it is desired not to use the MODE AFOCAL or MODE UAFOCAL settings in this program. The "PERFECT" command is only recommended when it is desired to simulate the "PERFECT" lens constructs of the other optical design programs which do not support true afocal design and analysis capability.

THE IDEAL LENS

IDEAL, efl - The "IDEAL" command specifies that a surface is to be considered as an "IDEAL" paraxial focusing lens. This property can only be assigned to the surface immediately in front of the final surface of the lens. This IDEAL lens will have a focal length equal to the assigned "efl" value. The axial distance from this "IDEAL" lens to the final surface may be set explicitly, may be set with a "PY" or "PX" solve or may be set during optimization. No aberrations are added to the system with this surface. It is used to simulate a focal system when designing afocal systems when it is desired not to use the MODE AFOCAL or MODE UAFOCAL settings in this program and when the "imput" to the "IDEAL" lens is not from an infinite conjugate position. The "IDEAL" command is only recommended when it is desired to simulate the "IDEAL" lens constructs of the other optical design programs which do not support true afocal design and analysis capability.

DIFFRACTION GRATINGS - Linear diffraction gratings may be placed on plano, spherical, conic, aspheric and anamorphic aspheric surfaces. The grating lines are formed by the intersection of a set of evenly spaced "generating planes" with the current optical surface. These grating surfaces may also be defined as Type-12 HOE special surfaces and in doing so, compound interlaced gratings may be modeled. During lens scaling, none of the grating parameters are scaled. Diffraction gratings are implemented using the following diffraction grating definition commands:

GRT - The "GRT" command is used to specify that the current surface is to be understood to be a linear linear diffraction grating.

GRO , order - The "GRO" command is used to specify or change the order of the diffration grating. A positive order will deflect the ray in the positive X, Y and/or Z direction. "order" need not be an integer though it usually is. (Default value = 0.0)

GRS , spacing - The "GRS" command is used to specify or change line spacing (in lens units) of the diffration grating. (Default value = 0.0)

GRX , x-grating direction number - The "GRX" command is used to specify or change the x-direction number of the grating generating planes. (Default value = 0.0)

GRY , y-grating direction number - The "GRY" command is used to specify or change the y-direction number of the grating generating planes. (Default value = 1.0 if the space ahead of the grating has positive refractive indecies and = -1.0 if the space ahead of the grating has negative refractive indecies.)

GRZ , z-grating direction number - The "GRZ" command is used to specify or change the z-direction number of the grating generating planes. (Default value = 0.0)

The linear diffraction grating special surface may be assigned to any plano, spherical, toroidal, conic, aspheric or anamorphic surface and this surface may also have Special Surface definitions assigned to it. The grating can be thought of as being generated by the intersection, with the surface, of a series of parallel planes. The x, y and z-grating direction numbers are used to specify the orientation of the normal to these planes in the local coordinate system of the surface. There are two sets of direction numbers which can be used to specify the orientation of an infinite plane in space (two anti-parallel normal vectors). The choice of one of these normal vectors over the other has the effect of changing the definition of the diffraction orders from the U. S. standard definition to the European standard definition.

LENS DATABASE SECTION

GRTD - The "GRTD" command is used to delete all diffraction grating data on the current surface.

For grating lines parallel to the local YZ-plane, x, y and z-grating direction numbers = 1.0, 0.0, 0.0 (U.S. standard definition of diffraction orders) For grating lines parallel to the local XZ-plane, x, y and z-grating direction numbers = 0.0, 1.0, 0.0 (U.S. standard definition of diffraction orders) For grating lines parallel to the local XY-plane, x, y and z-grating direction numbers = 0.0, 0.0, 1.0 (U.S. standard definition of diffraction orders) These definitions assume that the space just previous to the grating has positive refractive indices. If the previous space has negative refractive indices, the signs of the grating direction numbers will need to be reversed or the action of the specified diffraction order will be incorrect.

GRATING EFFICIENCY - The efficiency of a ruled diffraction grating is automatically computed when ever the "COATINGS" command is set to "COATINGS ON". In this case, the energy in each ray traced is reduced by the efficiency computed with the following equation:

$$\text{Efficiency} = \frac{\left[\sin\left(\frac{\pi A}{\lambda}\left(\sin^{-1}\left(\frac{m\lambda}{A} - \sin\theta_o\right) - \sin^{-1}\left(\frac{m\lambda_B}{A} - \sin\theta_o\right)\right)\right)\right]^2}{\left[\frac{\pi A}{\lambda}\left(\sin^{-1}\left(\frac{m\lambda}{A} - \sin\theta_o\right) - \sin^{-1}\left(\frac{m\lambda_B}{A} - \sin\theta_o\right)\right)\right]^2}$$

where: λ_B is the blaze wavelength (the program uses the current control wavelength for the blaze wavelength), λ is the wavelength for the current ray being traced, A is the grating line spacing in microns, m is the grating order and is assumed to be the order for which the grating is blazed. θ_o is the angle of incidence for the ray at the grating. This calculation is not meant to replace full diffraction efficiency codes but is meant to give the user a way of estimating system through put in systems with diffraction gratings. This relationship has been computationally verified for metalized, ruled gratings.

CLEAR APERTURE AND OBSCURATION COMMANDS - Clear apertures and obscurations are used to define limits to the extent of an optical surface, generally in directions perpendicular to the local Z-axis at each surface. They play an important role in limiting ray bundles in spot diagrams and in defining diffracting apertures in diffraction-based calculations. Circular, rectangular, elliptical and racetrack shapes may be used in defining these surface limits. All clear aperture and obscuration definitions are centered on the local coordinate systems of their respective surfaces unless explicit aperture/obscuration decentrations and tilts are specified. Besides the commands which allow for explicit clear aperture assignment, there is also an option descibed in the CMD section of this manual which provides for automatic assignment of circular clear apertures based upon limiting ray data. See the command "SETCLAP" in the CMD section for more details.

CLAP , ca , Yd , Xd , (radius to flat) , Δz   - The "CLAP" command specifies that a circular clear aperture is to be assigned to the current surface. The semi-diameter of this clear aperture is to be "ca". It is to be centered at Yd and Xd. All values except Δz are specified in lens units relative to the surface local coordinate system centered at the surface vertex. If there are no clear aperture decenter values assigned and if the surface is concave toward air and if an explicit value for the optional "radius to flat" has been entered and if that "radius to flat" value is less than the "ca" value, then the surface will be drawn with a flattened area on it in all graphical representations of the surface. If "Δz" has been entered along with the "radius to flat" value, then the flattened area will be drawn with its maximum diameter z-position retarded or advanced by the amount Δz. The Δz value is useful when one needs to draw an element as it would be manufactured as in one of the inner elements in the Leitz F/2 Summicron camera lens. By default, the optional "radius to flat" is considered to be equal to "ca" and Δz is considered to be 0.0. This command is valid at both the LENS input and the UPDATE LENS levels.

CLAP RECT , cay , cax , Yd , Xd - The "CLAP RECT" command specifies that a rectangular clear aperture is to be assigned to the current surface. The Y-height of this clear aperture is to be "cay" and the X-height is to be "cax". It is to be centered at Yd and Xd. All four values are specified in lens units relative to the surface local coordinate system centered at the surface vertex. This command is valid at both the LENS input and the UPDATE LENS levels.

CLAP ELIP , cay , cax , Yd , Xd - The "CLAP ELIP" command specifies that an elliptical clear aperture is to be assigned to the current surface. The Y-semi-axis dimension of this clear aperture is to be "cay" and the X-semi-axis dimension is to be "cax". It is to be centered at Yd and Xd. All four values are specified in lens units relative to the surface local coordinate system centered at the surface vertex. This command is valid at both the LENS input and the UPDATE LENS levels.

CLAP RCTK , cay , cax , Yd , Xd , r - The "CLAP RCTK" command specifies that a racetrack clear aperture is to be assigned to the current surface. The Y-height of this clear aperture is to be "cay" and the X-semi-height is to be "cax". It is to be centered at Yd and Xd. The radius of the circles forming the four corners will be "r". All five values are specified in lens units. The first four values are specified relative to the surface local coordinate system centered at the surface vertex. This command is valid at both the LENS input and the UPDATE LENS levels.

CLAP POLY , R , n , Yd , Xd - The "CLAP POLY" command specifies that a regular polygon clear aperture is to be assigned to the current surface. The "R" is the distance from the polygon center out to any corner. "n" specifies the number of sides and can be set to from 3 to 200. It is to be centered at Yd and Xd.All "R", "Yd" and "Xd" are specified in lens units. This command is valid at both the LENS input and the UPDATE LENS levels. Until rotated, a polygon apex always points toward the +y local surface axis direction.

CLAP POLY (CONFORMAL or NONCONFORMAL) - The "CLAP POLY" command can also be used to specify whether or not the polygon clear aperture is to be understood to lie in the tangent plane of the surface (NONCONFORMAL) or if is to be considered to lie in a tangent plane, tangent to the surface and located at the center of the clear aperture (CONFORMAL). If "CONFORMAL" is set, the polygonal clear aperture will lie "in the surface" rather than in the surface tangent plane at the surface vertex. If the polygonal clear aperture is not decentered or if there are no multiple clear apertures defined, then "CONFORMAL" and "NONCONFORMAL" yield the same results. This command is valid at both the LENS input and the UPDATE LENS levels.

CLAP IPOLY , file# , n , Yd , Xd , maxr - The "CLAP IPOLY" command specifies that a irregular polygon clear aperture is to be assigned to the current surface. The "file#" is the number which designates the IPOLYxx.DAT file number which holds from 3 up to a maximum of 200 pairs of x and y coordinated points which defines the irregular**. The order of the x, y pairs must be in a counter-clockwise sense when the local surface z-axis is "facing" the observer.** "n" specifies the number of sides in the irregular polygon. "maxr" specifies the maximum radial semi-dimension and is used in assigning a bounding square around the irregular polygon for some internal program operations. It is to be centered at Yd and Xd.All "maxr", "Yd" and "Xd" are specified in lens units. This command is valid at both the LENS input and the UPDATE LENS levels. All five numeric words are explicitly required. The IPOLYxx.DAT files are free format. Each line has three values: the pont number, the X-value and the Y-value.

CLAP TILT , γ - The "CLAP TILT" command must follow a "CLAP" type of command. It assigns a rotation of "γ" degrees to the existing clear aperture about the center of the clear aperture. This is a rotation of the clear aperture in the local surface XY-plane about an axis which is parallel to the local Z-axis of the surface. This command is valid at both the LENS input and the UPDATE LENS levels.

COBS , obs , Yd , Xd
COBS RECT , obsy , obsx , Yd , Xd
COBS ELIP , obsy , obsx , Yd , Xd
COBS RCTK , obsy , obsx , Yd , Xd , r
COBS POLY , R , n , Yd , Xd
COBS IPOLY , file# , maxr , Yd , Xd
COBS TILT , γ - The preceding five commands act exactly as the corresponding clear aperture commands, except that they assign obscuration with semi-diameter, semi-height or semi-axis dimensions of "obs", "obsx" or "obsy".

CLEAR APERTURE AND OBSCURATION ERASES
CLEAR APERTURE ERASE - If a ray falls within the boundary of a clear aperture erase, and if that ray had been blocked by a clear aperture on that surface, the fact that it was blocked by the clear aperture on that surface is then ignored.

OBSCURATION ERASE - If a ray falls within the boundary of a cobs erase, and if that ray had been blocked by an obscuration on that surface, the fact that it was blocked by the obscuration on that surface is then ignored.
CLAP ERASE , ca , Yd , Xd
CLAP RECTE , cay , cax , Yd , Xd
CLAP ELIPE , cay , cax , Yd , Xd
CLAP RCTKE , cay , cax , Yd , Xd , r
CLAP POLYE , R , n , Yd , Xd , r
CLAP IPOLYE , R , n , Yd , Xd , r
CLAP TILTE , γ
COBS ERASE , obs , Yd , Xd
COBS RECTE , obsy , obsx , Yd , Xd
COBS ELIPE , obsy , obsx , Yd , Xd
COBS RCTKE , obsy , obsx , Yd , Xd , r
COBS POLYE , R , n , Yd , Xd , r
COBS IPOLYE , file# , maxr , Yd , Xd , r
COBS TILTE , γ - The "CLAP TILTE" and "COBS TILTE" commands must follow a "CLAP ERASE" or "COBS ERASE" type of command, respectively. They work in a manner similar to "CLAP TILT" and "COBS TILT". These commands are valid at both the LENS input and the UPDATE LENS levels.

CLAPD , i , j - The "CLAPD" command deletes any existing clear aperture or clear aperture erase definitions from the current surface. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. The "lens pointer" is not modified by this command. Any PIKUPs referring to these deleted definitions will also be deleted. This command is valid at the UPDATE LENS level.

COBSD , i , j - The "COBSD" command deletes any existing obscuration or obscuration erase definitions from the current surface. If "i" and "j" are both explicitly entered, then the command acts on surfaces "i" through "j", inclusively. The "lens pointer" is not modified by this command. Any PIKUPs referring to these deleted definitions will also be deleted. This command is valid at the UPDATE LENS level.
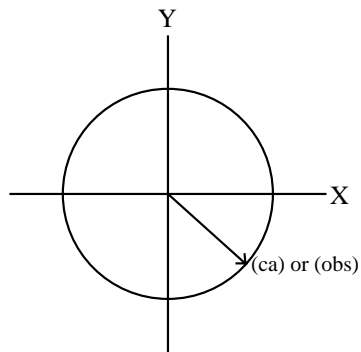
Circular Clear Aperture or Obscuration
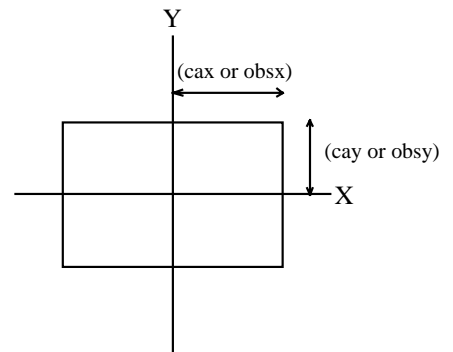
Rectangular Clear Aperture or Obscuration
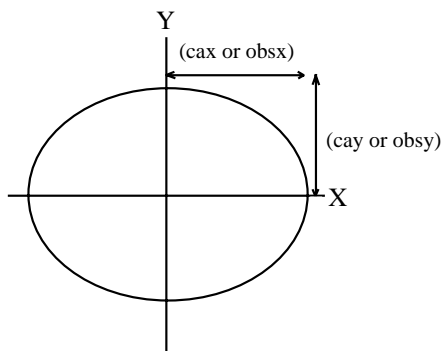
Elliptical Clear Aperture or Obscuration
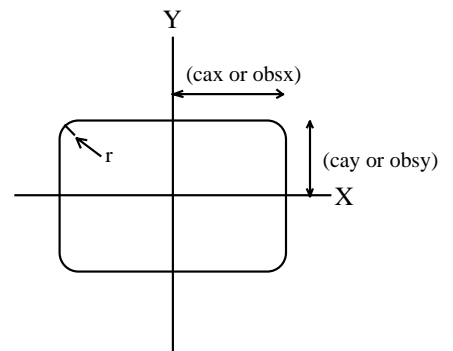
Racetrack Clear Aperture or Obscuration

Clear Apertures and Obscurations
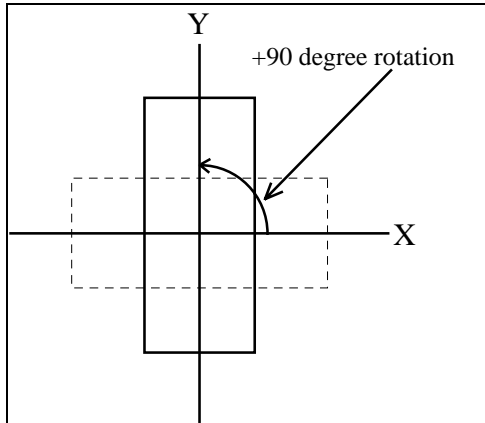
Clear Aperture and Obscuration Tilts
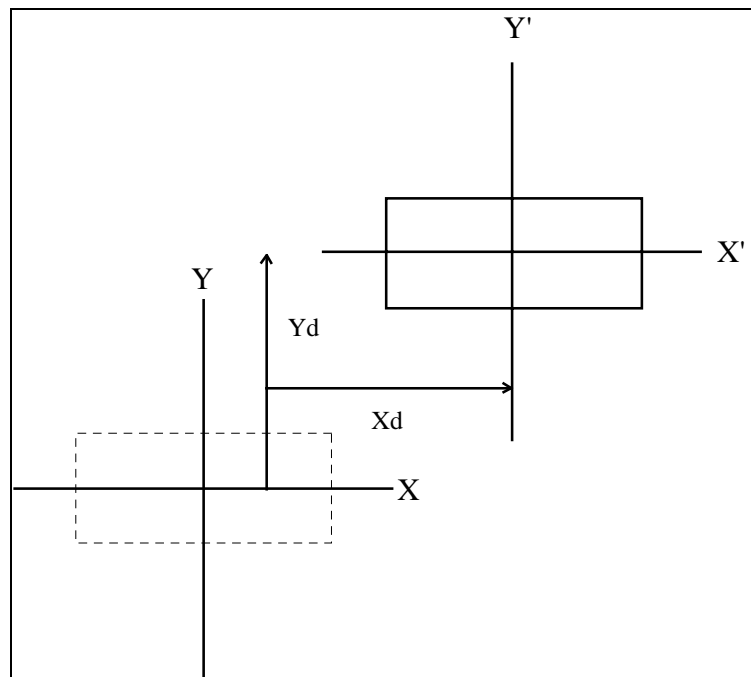
Clear Aperture and Obscuration Decentrations

MULTI-CLEAR APERTURES

MULTCLAP , n , x , y , γ - The "MULTCLAP" command is used to specify that the current clear aperture definition on the current surface is to be repeated on the current surface with new center coordinates "x" and "y" and with an added gamma rotation, in degrees, specified by γ. If the rotation γ is explicitly entered, it is added to any gamma rotation defined with a "CLAP TILT" command. Multiply defined clear apertures are considered "or" type surfaces during ray trace aperture checking and rays only fail if they do not pass through any of the copies of the clear aperture. The maximum allowed number of multiple clear apertures per lens surface is 1000. This command is valid at the LENS INPUT and LENS UPDATE levels.

MULTCLAP DELETE - The "MULTCLAP DELETE" command is used to delete any and all multiple aperture assignments made to the current surface. This command is valid at the LENS INPUT and LENS UPDATE levels.

MULTI-OBSCURATIONS

MULTCOBS , n , x , y , γ - The "MULTCOBS" command is used to specify that the current obscuration definition on the current surface is to be repeated on the current surface with new center coordinates "x" and "y" and with an added gamma rotation, in degrees, specified by γ. If the rotation γ is explicitly entered, it is added to any gamma rotation defined with a "COBS TILT" command. Multiply defined obscurations are considered "or" type surfaces during ray trace obscuration checking and rays fail if they are blocked by any one of the multiply defined apertures. The maximum allowed number of multiple obscurations per lens surface is 1000. This command is valid at the LENS INPUT and LENS UPDATE levels.

MULTCOBS DELETE - The "MULTCOBS DELETE" command is used to delete any and all multiple aperture assignments made to the current surface. This command is valid at the LENS INPUT and LENS UPDATE levels.

SPIDERS

SPIDER , n , W , L - The "SPIDER" command is used to specify that a spider type of support structure is attached to the current surface. "W" is the full width of an individual spider vane. "L" is the full length of the vane. "n" specifies the number of vanes to be evenly distributed in 360 degrees. If "n" is 3, there will be three vanes spaced by 120 degrees each. The first vane is always aligned with the local x-axis of the surface's local coordinate system. Each vane has one end anchored to the origin of the local coordinate system. Explicit input for "n", "W" and "L" is required. A four vane spider is illustrated in the following figure. "n" may range from 1 to 1000.
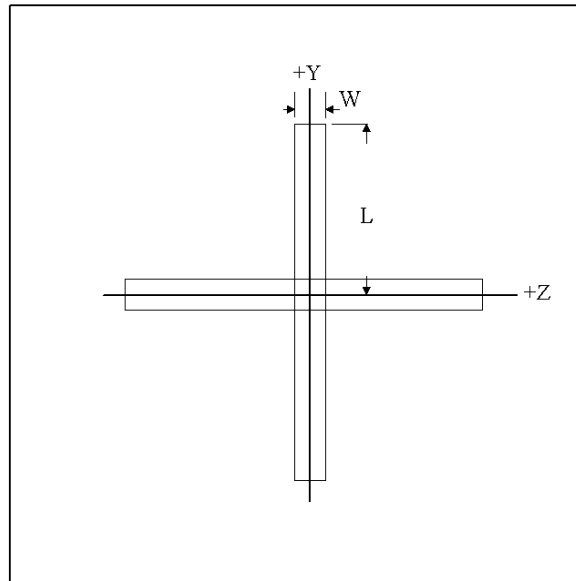
Defining a Spider

Spider definitions use multiple obscurations to define the spider structure. The "SPIDER" command is valid at the LENS INPUT and LENS UPDATE levels.

SPIDER DELETE - The "SPIDER DELETE" command is used to delete a spider previously defined made to the current surface. This command deletes any MULTCOBS definitions on the current surface. This command is valid at the LENS INPUT and LENS UPDATE levels.

LENS DATABASE SECTION

DATA ENTRY CONFLICT RESOLUTIONS - Duplicate datum specifications for the same parameter on the same surface are never allowed. The following table indicates how conflicts are resolved during surface specific data entry:

DATUM ENTRY	SURFACE TYPE SPECIFICATION	PRIOR DATUM ENTRIES DELETED
CV or RD	X-TORIC	CV or RD PIKUP or any XZ-plane curvature solve
	Y-TORIC	CV or RD PIKUP or any YZ-plane curvature solve
	Any axially symmetric surface	CV or RD PIKUP or any curvature solve
CVTOR or RDTOR	X-TORIC	CVTOR or RDTOR PIKUP or any YZ-plane curvature solve
	Y-TORIC	CVTOR or RDTOR PIKUP or any XZ-plane curvature solve
TH	All surface types	TH PIKUP or any curvature solve
PIKUP CV	X-TORIC	RD PIKUP or any XZ-plane curvature solve
	Y-TORIC	RD PIKUP or any YZ-plane curvature solve
	Any axially symmetric surface	RD PIKUP or any curvature solve
PIKUP RD	X-TORIC	CV PIKUP or any XZ-plane curvature solve
	Y-TORIC	CV PIKUP or any YZ-plane curvature solve
	Any axially symmetric surface	CV PIKUP or any curvature solve
PIKUP CVTOR	X-TORIC	RDTOR PIKUP or any YZ-plane curvature solve
	Y-TORIC	RDTOR PIKUP or any XZ-plane curvature solve
PIKUP RDTOR	X-TORIC	CVTOR PIKUP or any YZ-plane curvature solve
	Y-TORIC	CVTOR PIKUP or any XZ-plane curvature solve
PIKUP TH	All surface types	Any thickness solve
Any XZ-plane curvature solve	X-TORIC	CV or RD PIKUP
	Y-TORIC	CVTOR or RDTOR PIKUP
	Any axially symmetric surface	CV or RD PIKUP or any YZ-plane curvature solve
Any YZ-plane curvature solve	X-TORIC	CVTOR or RDTOR PIKUP
	Y-TORIC	CV or RD PIKUP
	Any axially symmetric surface	CV or RD PIKUP or any XZ-plane curvature solve
Any thickness solve	All surface types	TH PIKUP

LENS / CMD LEVEL COMMANDS
THE MODE COMMAND - The "MODE" command is valid from the LENS input level, the UPDATE LENS level and also from the CMD level. It changes the setting for imaging mode which is stored with each lens database.

MODE FOCAL or **MODE UFOCAL** - The commands "MODE FOCAL" and "MODE UFOCAL" place the current lens in "focal mode". Most real ray aberration data will be displayed in transverse linear measure in these modes. First, third and fifth order aberrations and primary and secondary chromatic differences will be displayed in transverse linear measure. If the qualifier "UFOCAL" is specified, these paraxial based aberrations will not be converted to transverse linear measure (i.e., they remain the direct sum of surface contribution coefficients).

MODE AFOCAL or **MODE UAFOCAL** - The commands "MODE AFOCAL" and "MODE UAFOCAL" place the current lens in "afocal mode". Most real ray aberration data will be displayed in angular measure in these modes. The angular measure is either "radians", "degrees" or "tangent" depending on the program angular mode setting. First, third and fifth order aberrations and primary and secondary chromatic differences will be displayed in angular radian measure. If the qualifier "UAFOCAL" is specified, these paraxial based aberrations will not be converted to transverse linear measure (i.e., they remain the direct sum of surface contribution coefficients). If the "MODE" command is issued followed only by a "?", the current mode name will be displayed. The default mode is "FOCAL" when a new lens is created. The default program angular mode for ray data display is degrees.

LENS DATABASE SECTION

The "RADIANS", "DEGREES", "TANGENT" and "ANGMOD" commands described in the "CMD" manual section allow changing and interrogation of this angular mode. Unlike this program, some optical design programs do not support an AFOCAL mode and require the use of a "PERFECT" lens construct to make an afocal system appear as a focal system. If users transitioning from one of these other design codes wish to use a "PERFECT" lens construct rather than design in the native AFOCAL modes of this program, they may do so via use of the "PERFECT" command described later in this section of the manual.

SPECTRAL WEIGHTING FACTORS

SPTWT, W1 , W2 , W3 , W4 , W5 - The "SPTWT" command is valid from the LENS input level, UPDATE LENS level and also from the CMD level. Issuing this command with numeric input resets relative spectral weights for each of the first five wavelengths. The default settings for the first five spectral weights is 1.0. If only some of the spectral weights are input, the others are set to 0.0. If the "SPTWT" command is followed only by a "?", the current value of the associated parameters will be displayed.

SPTWT2, W6, W7 , W8 , W9 , W10 - The "SPTWT2" command is valid from the LENS input level, UPDATE LENS level and also from the CMD level. Issuing this command with numeric input resets relative spectral weights for each of the second five wavelengths. The default settings for the second five spectral weights is 0.0. If only some of the spectral weights are input, the others are set to 0.0. If the "SPTWT2" command is followed only by a "?", the current value of the associated parameters will be displayed. W_i is the weight associated with wavelength number "i". These weights are used in all polychromatic calculations. For example, if a spot diagram is generated, all of the rays at wavelength "i" account for P_i percent of the total rays contributing to the spot. P_i is defined as:

$$P_i = 100.0 \times \left[\frac{W_i}{\left(W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7 + W_8 + W_9 + W_{10} \right)} \right]$$

CMD LEVEL COMMANDS

MAGNIFICATION, F-NUMBER AND EXIT PUPIL ADJUSTMENT - The next three commands are issued from the CMD level only. They adjust thicknesses and paraxial ray heights in order to produce specified lens system magnifications, f-numbers and exit pupil semi-diameters. These requested adjustments are stored with the lens database.

FINITE CONJUGATE MAGNIFICATION COMMANDS

MAGY , M , i , j - The "MAGY" command is used to adjust the transverse, YZ-plane, paraxial, finite conjugate magnification "M" between surfaces "i" and "j" to the specified value "m". The object and the image surfaces are the default values for "i" and "j", respectively. The actual adjustment is made by alteration of the axial thickness of surfaces "i" and "j-1". Positive magnifications are interpreted as "real" imagery and negative magnifications are interpreted as "virtual" imagery. The magnification is defined by the following equation:

$$M = -\frac{PCY_j}{PCY_i}$$

where PCY_i and PCY_j are the paraxial chief ray heights at surfaces "i" and "j". There may be no solves assigned to surfaces "i" through "j". If there are, a warning message will be issued and no adjustment will be performed. The reference object heights should be set using "SCY" and/or "SCX" before the adjustment is performed.

MAGX , M , i , j - The "MAGX" command is identical to the "MAGY" command, except that it works in the XZ-plane using XZ-plane paraxial ray data. The "MAGY" and "MAGX" commands are mutually exclusive since there is only one pair of thicknesses available to use to perform the magnification adjustment.

F-NUMBER COMMANDS

FNBY (HLD or DEL) , f-number - The "FNBY" command, used with no qualifier input, is used to adjust the paraxial axial ray slope in the YZ-plane to produce the "f-number" specified. This adjustment is performed by a change in the paraxial axial ray height at surface 1 with all solves temporarily suspended. This adjusted paraxial axial ray is traced, and each paraxial ray solve datum is reset to the value computed for it during this paraxial ray trace. The "f-number" is changed without altering any thicknesses or curvatures. The lens MODE must be FOCAL or UFOCAL, and the paraxial axial ray at the image surface cannot have a zero slope. A zero slope would imply an afocal system where the "f-number" is not defined. If the qualifier "HLD" is used, the command performs the same functions described above. In addition, a code is set in the lens database which specifies that the "f-number" is to be held at the input value even when manual or automatic changes are made to the lens prescription The use of the "DEL" qualifier word causes any existing "FNBY HLD" conditions in the lens database to be removed.

FNBX (HLD or DEL) , f-number The "FNBX" command is identical to the "FNBY " command, except that it acts in the XZ-plane using XZ-plane paraxial ray trace data. F-number holds may not be used if the "say" or "sax" values are "floating".

EXIT PUPIL SEMI-DIAMETER COMMANDS

ERY and ERX (HLD or DEL) , exit pupil semi-diameter - The "ERY" and "ERX" commands are used to adjust the radius of the exit pupil in the YZ and the XZ-planes to radius "exit pupil semi-diameter". This adjustment is performed by a change in the paraxial axial ray height at surface 1 with all solves temporarily suspended. This adjusted paraxial axial ray is traced, and each paraxial ray solve datum is reset to the value computed for it during this paraxial ray trace. The "exit pupil semi-diameter" is changed without altering any thicknesses or curvatures. The lens MODE must be AFOCAL or UAFOCAL, and the paraxial axial ray at the image surface must have a zero slope. The "HLD" qualifier word causes a code to be set in the lens database which specifies that the "exit pupil radius" is to be held at the input value even when manual or automatic changes are made to the lens prescription. The " DEL" qualifier word causes any existing "HLD" conditions in the lens database to be removed The "ERX", command is identical to the "ERY" command, except that it acts in the XZ-plane using XZ-plane paraxial ray trace data. Exit pupil semi-diameter holds may not be used if the "say" or "sax" values are "floating".

RAY AIMING AND TELECENTRIC COMMANDS

AIMRAY (ON or YES or OFF or NO) The "AIMRAY (ON or YES)" and "AIMRAY (OFF or NO)" commands either activate or deactivate real ray, ray aiming to a specific relative coordinate in the reference surface. When ray aiming is "(OFF or NO)", rays are aimed at next surface after the object surface based only upon the existing paraxial ray trace. It should only be used for diagnosing ray tracing problems. Issued with a "?", the "AIMRAY" command returns a message as to the current setting. This command is "sticky" and remains as set for the current lens until changed by the user. The setting is stored with the current lens in the lens database. The "AIMRAY" command is also described in the "CMD" section.

TEL (ON or YES or OFF or NO) If "TEL ON" is set, then the user must set or must have set the aperture of the system using the "NAOY" and "NAOX" commands. "NAOX" is only needed, if the "noax" value is to be different from the "naoy" value. Whenever "NAOY" is issued, it resets both the "noay" and "noax" values. If this is not done, the ray trace will give strange and incorrect results. Alternatively, the "FNOY" and "FNOX" commands can be used to specify the numerical apertures in terms of object space F-numbers. The "TEL (ON or YES)" and "TEL (OFF or NO)" commands either activate or deactivate real and paraxial ray, telecentric ray aiming. When telecentric ray aiming is "(OFF or NO)", real and paraxial rays are aimed as usual depending upon the location of the reference surface, the aperture stop surface and the current "AIMRAY" setting. When telecentric ray aiming is "(ON or YES)", all chief rays from all object points are aimed so that they are all parallel to the "gut" or central chief ray and to each other and so that they are all perpendicular to surface 0. In this setting, paraxial chief rays will not be aimed at the aperture stop surface and real chief rays will not be aimed toward the reference surface. All non-chief rays will be aimed toward the surface 1 using either the current SAY or SAX values. This telecentric ray aiming will ignore all tilts, decentrations and clear apertures assigned to the surface #1. Issued with a "?", the "TEL" command returns a message as to the current setting. This command is "sticky" and remains as set for the current lens until changed by the user. The setting is stored with the current lens in the lens database. While "TEL" is "(ON or YES)", reassignment of the object, reference and image surface with numeric word #5 of the "FOB" command is not allowed. While "TEL" is "(ON or YES)", the absolute value of the object distances (surface 0 thickness) must be less than 1.0×10^{10} lens units.

APLANATIC RAY AIMING

AIMAPL (ON or YES or OFF or NO) - The "AIMAPL (ON or YES)" and "AIMAPL (OFF or NO)" commands either activate or deactivate real ray, aplanatic ray aiming. When ray aiming is "on" and aplanatic ray aiming is "off", which is the default startup setting for the program, real rays are iteratively aimed to specific relative x and y-coordinates in the reference surface. When ray aiming is "on" and aplanatic ray aiming is also "on", then real rays are aimed at x and y-coordinates in the reference surface which are determined in part by the radius of curvature assigned to the reference surface. Aiming is performed such that if a uniform grid of rays was aimed at the reference surface, that grid of rays would be uniformly spread over the curved surface of the reference surface and would represent uniform angular ray aiming at that surface with respect to the center of curvature of that surface. If aplanatic ray aiming is "on" but the reference surface is a plano surface, then ray aiming will be performed as if aplanatic ray aiming were "off". Aplanatic ray aiming also requires that there be a circular clear aperture assigned to the reference surface and that there be no clear aperture decenters and no clear aperture tilt assigned to that circular clear aperture. The radius of curvature of the reference surface must also be greater than or equal to the semi-diameter of the circular clear aperture assigned to that surface. The figure on the right illustrates non-aplanatic ray aiming. In this case the y-height of the 0.5 ray at the reference surface is exactly 0.5 of the y-height of the 1.0 ray at the reference surface. The figure on the left illustrates aplanatic ray aiming. Here, the angle subtended by the 0.5 ray at the reference surface (measured with respect to the reference surface center of curvature) is exactly 0.5 of the angle subtended by the 1.0 ray at the reference surface (measured with respect to the reference surface center of curvature).
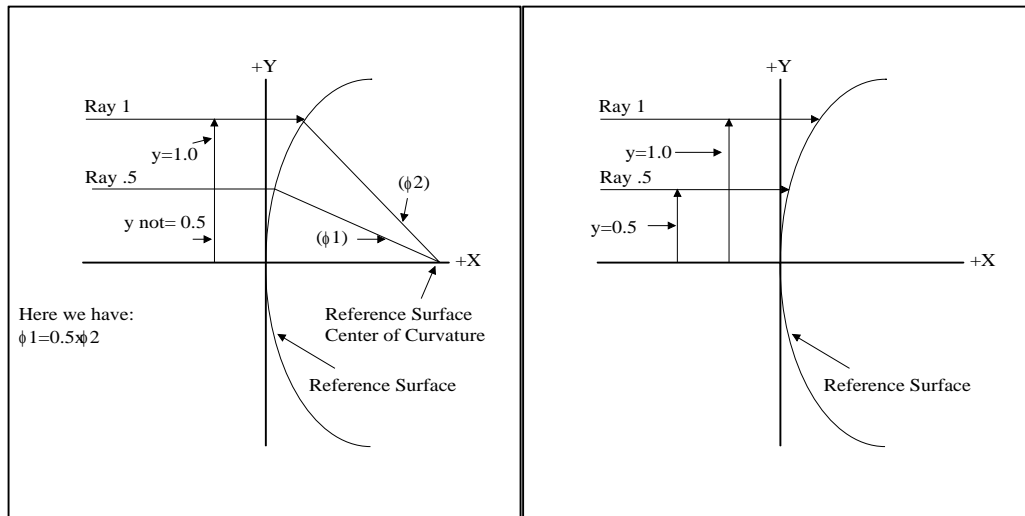
Aplanatic and Non-aplanatic ray aiming

MULTIPLE FOV DEFINITIONS - The multiple field-of-view definition commands are issued from the CMD level only. They are used to specify multiple field-of-view positions which are used by some of the CMD level commands which can generate data at multiple field-of-views. These multiple field-of-view definitions are stored with the lens database.

FLDS MAX , n - The "FLDS MAX" command specifies that there will be "n" fields-of-view active at the current lens database configuration. "n" may be set to from 1 to 10. The multiple field-of-view data will be interpreted as object field of view angles. By default, if none are defined, three field of view positions will be defined at 0.0, 0.7 and 1.0 degrees in the YZ-plane.

FLDS , i , x , y - The "FLDS" command is used to specify the xz and yz-plane input values for the "i" th multiple field of view.

FLDSARE - The "FLDSARE" command is used to display the current multiple field-of-view definitions contained in the current lens database.

ENVIRONMENTAL ANALYSIS COMMANDS

TEMPERATURE - Environmental analysis is performed by modifying the lens database and then calculating optical system metrics such as ray position, paraxial quantities or any other metric which the designer deems appropriate.

THERM (qualifier) , i , j , ΔT , coef The "THERM" command causes certain lens parameters (specified by the qualifier word) to be modified due to a change in temperature. The "qualifier" is selected from the table which follows. "i" is the first surface modified. "j" is the last surface modified. "i" and "j" may be equal if only one surface needs to be modified. "ΔT" is the thermal change in degrees C or K. "coef" is the value of the appropriate coefficient to be used. "ΔT" must be explicitly entered. The "coef" value must also be supplied, except for the eight gases listed in the next table. If "i" and "j" are left blank, the entire lens is modified. If "i" is omitted, the starting surface will be assumed to be the current object surface. If "j" is omitted, the ending surface will be assumed to be the current image surface. After the parameter modifications, all pickups, solves and paraxial datum are updated. The "THERM" command always acts upon the current lens configuration, however, "THERM" commands may be included as part of the multiple configuration definitions. The "THERM GLASS" command causes the current surface glass type to be changed to the "MYGLASS" definition with the new user-defined glass name being the previous glass name. After this occurs, no automatic interpolation of indices with wavelength changes will take place. The "THERM GLASS" and "THERM GAS" commands allows the user to define how the refractive index of a glass or of a gas will be modified by a change in temperature according to the following equation:

$$N = N_{previous} + [coef \times \Delta T]$$

The "THERM (specific gas name)" command allows the user to specify a particular gas to be used in an air space. For each gas, the absolute refractive index minus 1 (n-1) is first calculated at 760 mm of Hg and at 273 degrees Kelvin. This is done as is discussed in Born & Wolf. This value is remembered. This value is then scaled linearly in temperature by the ΔT input by the user. It is assumed that the lens system is initially at 293 degrees Kelvin (room temperature). The difference between the absolute (n-1) and the temperature scaled n-1 is then applied to each of the ten refractive indices. The glass definition is set automatically to "MYGLASS" and the glass name becomes the name of that specific gas. If pikups or solves exist on a surface which act to define the values of lens parameters and if these parameters would be changed by the "THERM" command, then the pikups or solves will be left in place and no lens parameter modification will occur. In this case, a warning message will be displayed.

"qualifier"	PARAMETER(S) MODIFIED	COEFFICIENT USED
SHAPE	RD/CV, RDTOR/CVTOR, AC, AD, AE, AF, AG, AH, AI, AJ, AK, AL, ADTOR, AETOR, AETOR and AFTOR (Toric and non-toric curvatures and aspheric deformations)	Coefficient of linear expansion per degrees C or K. (Must be supplied by the user.)
THICK	TH (surfaces with absolute values of the refractive indices greater 1.1)	Coefficient of linear expansion per degrees C or K. (Must be supplied by the user.)
SPACE	TH (surfaces with absolute values of the refractive indices less than or equal to 1.1)	Coefficient of linear expansion per degrees C or K. (Must be supplied by the user.)
GLASS	N1 through N10 (Refractive indices at all ten wavelengths)	dN/dT (degrees C or K). (Must be supplied by the user.)
GAS	N1 through N10 (Refractive indices on air spaces at all ten wavelengths) (Spaces with refractive indices less than or equal to 1.1)	The operation of this command is explicitly defined in the equation above this table. (The coefficient must be supplied by the user.)
AIR, OXYGEN, NITROGEN, HELIUM, HYDROGEN, ARGON, ETHANE, and METHANE	N1 through N10 (Refractive indices on air spaces at all ten wavelengths) (Spaces with refractive indices greater than 1.1)	(All coefficients are supplied by the program.)

PRESSURE

PRES (qualifier) , i , j , ΔP , coef - The "PRES" command modifies the refractive indices of air spaces due to changes in pressure. The "qualifier" is selected from the table below. "i" is the first surface modified. "j" is the last surface modified. "i" and "j" may be equal if only one surface needs to be modified. "ΔP" is the pressure change in mm of Hg. "coef" is the value of the appropriate coefficient to be used. "ΔP" must be explicitly entered. If the qualifier "GAS" is used, the "coef" value must also be supplied. If "i" and "j" are left blank, the entire lens is modified. If "i" is omitted, the starting surface will be assumed to be the current object surface. If "j" is omitted, the ending surface will be assumed to be the current image surface. After the parameter modifications, all PIKUPS, solves and paraxial datum are updated. The "PRES" command always acts upon the current lens configuration but "PRES" commands may be included as part of the configuration definitions. The "PRES GAS" command allows the user to define how the refractive index of an air space gas will be modified by a change in pressure according to the following equation:

$$N = N_{previous} + \left[coef \times \Delta P \right]$$

The "PRES (specific gas name)" command allows the user to specify a particular gas to be used in an air space. For each gas, the absolute refractive index minus 1 (n-1) is first calculated at 760 mm of Hg and at 273 degrees Kelvin. This is done as is discussed in Born & Wolf. This value is remembered. This value is then scaled linearly in pressure by the ΔP input by the user. It is assumed that the lens system is initially at 760 mm of Hg. The difference between the absolute (n-1) and the pressure scaled n-1 is then applied to each of the ten refractive indices. The glass definition is set automatically to "MYGLASS" and the glass name becomes the name of that specific gas. If pikups or solves exist on a surface which act to define the values of lens parameters and if these parameters would be changed by the "PRES" command, then the pikups or solves will be left in place and no lens parameter modification will occur. In this case, a warning message will be displayed.

"qualifier"	PARAMETER(S) MODIFIED	COEFFICIENT USED
GAS	N1 through N10 (Refractive indices on air spaces at all ten wavelengths) (Spaces with refractive indices less than or equal to 1.1)	The operation of this command is explicitly defined in the equation above this table. (Must be supplied by the user.)
AIR, OXYGEN, NITROGEN, HELIUM, HYDROGEN, ARGON, ETHANE, and METHANE	N1 through N10 (Refractive indices on air spaces at all ten wavelengths) (Spaces with refractive indices greater than 1.1)	(All coefficients are supplied by the program)

SAVE AND RESTORE LENSES - The next four commands describe an alternate way to save lens prescriptions when it is not desired to use the lens library structure.

LENSLOC (6-character directory name) - The "LENSLOC" command, issued with exactly 6 characters, designates the directory name, under the main program directory, wherein lenses will be saved to and retrieved from with the next issuances of "LENSSAVE" and "LENSREST" commands. Issued with a "?", the current LENSLOC directory name will be displayed. The default lens directory name is "LENSES".

LENS DATABASE SECTION

LENSDIR - The "LENSDIR" command is issued in order to list the contents of the current lens storage directory.

LENSSAVE (filename) - The "LENSSAVE" command, issued with a one to eight character file name, causes the current lens to be saved as an ASCII file with the file extension .PRG into the current lens storage directory. If the "LENSSAVE" command is issued with the file name "ABC" for example, the current lens will be saved in the file ABC.PRG in the lens storage directory. Existing optimization and tolerance definitions are automatically saved as well.

LENSREST (filename) - The "LENSREST" command, issued with a one to eight character file name, causes the lens stored in that named ASCII file, in the current lens storage directory, to be restored as the current lens. If the "LENSREST" command is issued with the file name "ABC" for example, then if the file ABC.PRG exists in the current lens storage directory, the lens data in that file will become the lens data for the new current lens. Previously saved optimization and tolerance definitions are automatically reloaded as well.

LSAVE (filename) - The "LSAVE" command works exactly like the LENSSAVE command except that no OPTIMIZATION, TOLERANCING, FIELDS or RAYS data is saved with the lens data.

THE LENS LIBRARY

LENS LIBRARY INITIALIZATION - The lens library is initially created by entering the next CMD level command.

ILF - To avoid accidental destruction of the existing lens library, the "ILF" command performs no file initialization unless it is followed immediately by the command:

PROCEED - If the CMD level command "PROCEED" is not immediately entered following the "ILF" command, then the "ILF" command is ignored and canceled. THIS INITIALIZATION PROCEDURE SHOULD BE USED WITH CAUTION AS LARGE AMOUNTS OF DATA MAY BE LOST IF IT IS USED CARELESSLY. The "ILF" command is intended for a user who has no lens library or for a user who intentionally desires to clean the slate and begin anew with an empty lens library.

LENS LIBRARY COMMANDS - The program lens library routines provide a lens library for the storage and retrieval of optical systems. The lens library serves as permanent optical system data storage. The number of lenses which may be stored is limited to a maximum of 999. Lens data may be entered into the library at any time following lens input or modification. Lens retrieval may be requested at any time at the CMD level. If they exist at the time of lens storage, optimization and tolerance definitions are saved in the lens library along with the lens. If optimization and tolerance definitions were save with a lens, they will be retrieved when the lens is retrieved.

LIB P or **LIB P , i** or **LIB P , i , j** - The "LIB P" command displays a directory listing of all or part of the lens library. Without numeric input, the entire contents of the lens library directory is displayed. If only "i" is entered, only the "i"th lens library directory entry will be displayed. If "i" and "j" are both entered, the lens library directory from entry "i" to entry "j" will be displayed. "i" and "j" may range from 1 to 999. The display consists of the current lens identifier and a time and date stamp.

LIB PUT (Optional string which becomes the new Lens Identifier LI which is used as the new lens library label) or **LIB PUT , i (Optional string which becomes the new Lens Identifier LI which is used as the new lens library label)** - The "LIB PUT" command causes the current lens to be stored in the lens library. If "i" is entered, storage will be attempted in the "i"th lens library storage area. If "i" is not explicitly entered, the current lens will be stored in the first empty lens library location found.

LIB GET or **LIB GET , i**The "LIB GET" command causes the contents of the "i"th lens library location to be retrieved as the new current lens. The old current lens will be lost.

LIB DEL , i or **LIB DEL , i , j** - The "LIB DEL" command causes the "i"th lens library entry to be deleted. If both "i" and "j" are entered, lens library entries from "i" through "j" will be deleted.

LSTAT - The "LSTAT" command generates a display of the current lens library storage status.

MANIPULATING LIBRARIES - The following commands are used to save and restore the contents of the current lens library dircetory. These two next two commands should not be used for saving and restoring the lens library when updating the program. The behavior of these commands in this situation is not reliable and alternate lens libraries will be lost!

LIBSAVE - The command "LIBSAVE" causes the contents of the current lens library directory to be saved in the ASCII file LIBSAV.DAT. This process erases the current contents of the EDITTEXT.DAT file and the previous contents of the LIBSAV.DAT file.

LIBREST - The command "LIBREST" causes the contents of the current LIBSAV.DAT file to be loaded into the current lens library directory. This process erases the current contents of the EDITTEXT.DAT file and the previous contents of the current lens library directory.

LENS DATABASE SECTION

COMMERCIAL LENS MANUFACTURER LIBRARIES - There are a number of lens manufacturers who provide large selections of optical components in finished form. Many times it is useful to be able to insert the optical prescriptions of these components into an existing optical system prescription or to build an entirely new optical system from these "off-the-shelf" components. In order to provide a simple method for selection and retrieval of these prescriptions, the following commands are provided:

LIB PMG or **LIB PES** or **LIB PNC** or **LIB PRO** or **LIB PSH** - These four commands work the same as the "LIB P" command, except that they provide listings of the lens libraries which store optical components from MELLES GRIOT, EDMUND SCIENTIFIC, NEWPORT CORPORATION, ROLYN OPTICS COMPANY and SPINDLER & HOYER.

LIB GETMG , i or **LIB GETES , i** or **LIB GETNC , i** or **LIB GETRO , i** or **LIB GETSH , i** - These four commands work the same as the "LIB GET" command, except that they cause the "i"th lens in the specified lens library to be retrieved as the current lens. The previous current lens will be lost unless it has been previously saved. Using the CMD level command "LENADD", the current lens and the lens being retrieved may be added together. The qualifiers "GETMG", "GETES", "GETNC" "GETRO" and "GETSH" refer to MELLES GRIOT, EDMUND SCIENTIFIC, NEWPORT CORPORATION, ROLYN OPTICS COMPANY and SPINDLER & HOYER. These manufacturer lens libraries are provided only as a convenience to the user and do not constitute a product endorsement.

OPTICAL GLASS CATALOGS

GLASSP - The "GLASSP" command, entered without a qualifier, displays the names of all the currently implemented optical glass libraries.

GLASSP (catalog name) - The "GLASSP" command, entered with a valid glass catalog name, displays the names and/or numbers of all of the current optical glasses in that catalog.

GLASSP (catalog name) (glass name) - The "GLASSP" command, entered with a valid glass catalog name and a valid optical glass name, displays additional information about that glass. The glass name is entered as an alphanumeric string. Issuing the "GLASSP" command with the catalog name "USER" causes the default text editor to open the USER.DAT file.

LENS SCALING COMMANDS

SC , factor , i , j or **WSC , factor , i , j** - The "SC" and "WSC" commands are used to scale the current lens from surface "i" to surface "j" by the "scale factor". If "j" is not input, the ending surface is assumed to be the image surface. The use of "WSC" rather than "SC" results in no scaling of the SCX, SCY, SAX or SAY values.

SC FY , efl , i , j or **WSC FY , efl , i , j** - The "SC FY" and "WSC FY" commands act exactly as the "SC" and "WSC" commands do, except that they act to scale the lens so that the YZ-plane paraxial effective focal length will equal the "efl" value input in numeric word 1. If no efl can be calculated, an error message will be issued and no action will be taken. Only special surface coefficients associated with special surface TYPES 1, 4, 6, 7, 8, 12 and 13 are scaled via these four scaling commands.

LENS OUTPUT AND DISPLAY

LENO - The "LENO" command outputs all data for the current lens and all current multiple configuration and special surface data in a format which is readable as program input. If the output is read by the program, then the "LENO" command should be preceded by "OUTPUT CP", "OUTPUT PU" or OUTPUT ED". If the output is to be printed, then "LENO" should be preceded by "OUTPUT LP". Existing optimization and tolerance definitions are automatically output as well.

LENO NOOPT - The "LENO NOOPT" command outputs all data for the current lens and all current multiple configuration and special surface data in a format which is readable as program input. If the output is read by the program, then the "LENO NOOPT" command should be preceded by "OUTPUT CP", "OUTPUT PU" or OUTPUT ED". If the output is to be printed, then "LENO NOOPT" should be preceded by "OUTPUT LP". Existing optimization and tolerance definitions are NOT output.

LENO RD - The "LENO RD" command outputs all data for the current lens and all current multiple configuration and special surface data in a format which is readable as program input. It works exactly as does "LENO" except for surfaces with non-zero curvatures or toric curvatures. For those surfaces, surface radius or toric radius are output.

LENO REVERSE - The "LENO REVERSE" command outputs the lens data of the current lens in reverse order. Only the main lens configuration is reversed. All PIKUPs, solves, tilts, decentrations and alternate configurations are first removed. Should a configuration, other than the main configuration, need reversal, use the "DEZOOM" command to change the alternate configuration into the main configuration. If a complex set of adjacent reflectors is found, LENO REVERSE will do its best to identify glasses surrounding the reflectors. If it can not resolve the glasses, the glass "GLASS UNKNOWN" with unit refractive indices will be used and the user will need to change that glass to the correct glass by hand with UPDATE LENS commands.

LENS DATABASE SECTION

LENS CONVERSION - No two optical design programs support all the same optical modeling features. Most programs have some commonality of data types although not all command syntax is the same. The following translators, may be used to translate optical prescriptions to and from this program's lens database. Use these translators with caution and check all translated data in the target optical design program. Any errors in these translators should be reported immediately so that they may be fixed. Output may be performed to the screen or to one of the output files via the CMD level command "OUTPUT". CODE-V and ZEMAX database items not translated using the "CV2PRG" and ZMX2PRG" commands will be stored in a file named CONVERT.ERR so that after conversion, the user can see what the translator has not translated.

LENO AC - The "LENO AC" command outputs the lens data of the current lens in a form in which it may be imported into ACCOS-V optical design program. Only the main lens configuration is output. All PIKUPs, solves, and alternate configurations are first removed. Some of this program's features are not supported in ACCOSS-V and it is up to the user to verify the translation accuracy. All glasses are converted to the ACCOS-V "GLASS" command. The decenters and tilts of clear apertures and obscurations are ignored. "CLAP and COBS ERASES" are ignored. Special surface definitions are ignored.

LENO CV - The "LENO CV" command outputs the lens data of the current lens in a form in which it may be imported into CODE-V optical design program. Only the main lens configuration is output. All PIKUPs, solves, and alternate configurations are first removed. Some of this program's features are not supported in CODE-V and it is up to the user to verify the translation accuracy. All glasses are converted to the CODE-V "GLASS" command. The decenters and tilts of clear apertures and obscurations are retained. "CLAP and COBS ERASES" are ignored. Special surface definitions are ignored. "TILT BEN" and "TILT DAR" commands are translated but "TILT RET" and "PIVOT" are ignored.

LENO EXCEL (i , j , glo , cfg) - The "LENO EXCEL" command outputs the lens data of the current lens in a tab delimited file which may be read into Microsoft Excel. Data items which are all default, are omitted. For example, if there are no conics in the surface range requested, no conic column is output. Data is output from surface "i" to surface "j". Defaults for "i" and "j" are surfaces 1 and the image surface. "glo" specifies the global reference surface for global vertex data. The default is surface 1. "cfg" specifies the configuration to output. The default is cfg 1.

CV2PRG filename - The "CV2PRG" command converts the Code V™ sequence file representation of a lens contained in the file named "filename" into the "current" lens. Not all Code V™ lens database features are supported in this translation but most important and common surface shapes, glass types, apertures, obscurations and tilt/decentration modes are supported. A listing of all Code V™ commands not translated can be viewed by opening the file CONVERT.ERR, after the translation is finished.

ZMX2PRG filename - The "ZMX2PRG" command converts the ZEMAX™ ASCII file representation of a lens contained in the file named "filename" into the "current" lens. Not all ZEMAX™ lens database features are supported in this translation but most important and common surface shapes, glass types, apertures, obscurations and tilt/decentration modes are supported. A listing of all ZEMAX™ commands not translated can be viewed by opening the file CONVERT.ERR, after the translation is finished.

COMBINING LENSES

LENADD , i , j , k - The "LENADD" command will add on to the end of the current lens (called the first lens) the lens stored in the lens library block "i" (called the second lens) and the resultant lens will become the new current lens. The lens units must be the same for both lenses. The lens identification, wavelengths, spectral weights, control wavelength and paraxial trace parameters (SAY, SAX, SCY or SCY FANG and SCX or SCX FANG) will continue to be what they were for the first lens. All solves will be removed, but all PIKUPs will remain. The aperture stop will remain that of the first lens unless "j" is non-blank, in which case the aperture stop of the second lens will become the aperture stop for the new lens. The reference surface of the new lens will remain that of the first lens unless "k" is non-blank, in which case the reference surface of the second lens will become the reference surface of the new lens. Any holds on f/# or exit pupil radius will remain with the first lens. The mode will remain with the second lens. All special surface data will remain intact, **but all alternate configurations associated with either lens will be lost**.

DISPLAYING LENS DATA - The following commands generate the display of various items of the lens database. The qualifier words "OB" or "OBJ" cause data to be displayed for the object surface only. If no qualifier word is entered, a line of data is produced for the surface whose number "i" is specified by numeric word #1. If a negative value is entered for "i", the program increases the entered value by adding the number of the image surface. Thus, an entry of -1 may be used to denote the surface immediately preceding the image surface. These commands are also described in the sections with deal with the modification of these specific lens database items.

HEADINGS ON or **HEADINGS OFF** - Headings are always displayed when tabular output is requested via the qualifier "ALL". The "HEADINGS" command with the qualifier words "ON" and "OFF" controls whether or not headings will be displayed for single lines of displayed data. The default setting for "HEADINGS" is "OFF" when the program begins. New users may be more comfortable seeing headings for all data displays. Headings can be set to "ON" after program startup or the line "HEADINGS ON" can be added to the "DEFAULTS.DAT" file before starting the program. If requested program data does not exist, a message to that effect is displayed.

LENS DATABASE SECTION

LENS DATA DISPLAY COMMANDS - The following commands can take "ALL" (all surfaces) or "OBJ" or "OB" (object surface) as qualifier words or they can take numeric wrd #1 input, "i" designating a specific surface for which surface data is to be displayed. Issued with no input, the data for the final surface of the lens will be displayed.

RADIUS,THICKNESS, GLASS DATA

RTG or **CTG** - The "RTG" and "CTG" commands produce output of the surface profile (radius for "RTG" and curvature for "CTG"), the axial thickness to the next surface, the name associated with the optical medium following the surface (e.g., AIR, REFL, MODEL, SCHOTT BK5), the refractive index, N at the control wavelength and the Abbe-number V at the control wavelength and primary wavelength pair. An asterisk (*) will be printed immediately preceding the surface number of all surfaces which contain unusual properties: tilts, decenters, a conic constant, aspheric data, torics or special surface data. For this and other commands which follow, "OB" and "OBJ" refer to surface 0. "ALL" produces a listing for all surfaces in the lens database for which output would be appropriate.

RTGLBL or **CTGLBL** - The "RTGLBL" and "CTGLBL" commands are identical to the "RTG" and "CTG" commands, except that they also display lens database surface label information entered at the LENS or UPDATE LENS levels.

TILT AND DECENTER DATA

TAD - The "TAD" command displays surface decentration and tilt data. A line of output consists of the surface number, the type of tilt condition: TILT, RTILT, TILT A(AUTO) or TILT AM (AUTOM), the decentration values Yd and Xd and tilt values ALPHA, BETA and GAMMA. Decentrations are displayed in lens units and the tilt values are in degrees.

PIVOT - The "PIVOT" CMD level command displays surface alternate pivot data. A line of output consists of the surface number, and the pivot values "pivx", "pivy" and "pivz".

CONIC AND ASPHERIC DATA

ASPH - The "ASPH" command displays any conic constant and 2nd, 4th, 6th, 8th or 10th order aspheric surface terms which may be defined on a surface. The display consists of the surface number, conic constant CC and aspheric coefficients (if present) AC, AD, AE, AF, and AG. The 2nd order term is provided for use on rotationally symmetric surfaces with zero curvature to accurately model Schmidt corrector plates.

ASPH2 - The "ASPH2" command displays any conic constant and 12nd, 14th, 16th, 18th or 20th order aspheric surface terms which may be defined on a surface. The display consists of the surface number, conic constant CC and aspheric coefficients (if present) AH, AI, AJ, AK, and AL.

ARRAY AND DEFORMABLE LENS DATA

ARRAY - The "ARRAY" command, issued at the CMD level, displays current array lens data. The display consists of the array spacing in x and y and whether the array is "odd" or "even". This data, if present, is also automatically displayed whenever an "RTG", "CTG", "RTGLBL" or "CTGLBL" command is issued.

DEFORM - The "DEFORM" level command displays current defomation input settings. The display consists of the file number, array dimension, x and y actuator spacings and z-scale factor.

MIRROR THICKNESS DATA

THM - The "THM" CMD level command displays the mirror thickness values currently assigned to the lens database. Units are always in current lens units.

TORIC AND ANAMORPHIC DATA

TR or **TC** - The "TR" and "TC" CMD level commands display toric radius of revolution (for "TR") or curvature of revolution (for "TC") data for surfaces defined as torics. The display consists of the surface number, the type of toric (X or Y) and the radius of revolution or the curvature of revolution.

TASPH - The "TASPH" CMD level command displays any anamorphic conic constant and 4th, 6th, 8th or 10th order anamorphic aspheric surface terms which may be defined on a surface. The display consists of the surface number, conic constant CCTOR and anamorphic aspheric coefficients (if present) ACTOR, ADTOR, AETOR, AFTOR and AGTOR.

LENS DATABASE SECTION

SOLVE DATA

SLV - The "SLV" command displays any data solves defined on a surface. The display consists of the surface number, the command word name of the solve (e.g., PUCY, PCY), the name of the parameter whose value is determined by the solve (e.g., TH, CV), the current value of that parameter and the "solve target value". The solve target value is the numeric input value associated with the solve. For a PUCY solve, it is the paraxial chief ray angle tangent; for a PCY solve, it is the paraxial chief ray height.

PIKUP DATA

PIK - The "PIK" command displays any PIKUP data defined on a surface. Display consists of the surface number, type of PIKUP (e.g., TH, ALPHA, GLASS), the number of the surface from which data is picked up, the multiplicative constant, A, and additive constant, B. Several lines will be displayed for a single surface if several PIKUPs are present.

APERTURE AND OBSCURATION DATA

CAOB - The "CAOB" command displays clear aperture, obscuration and erase data defined on a surface. Display consists of the surface number, the type of aperture or obscuration (CIRCLE, etc.), the Y and the X dimensions, the aperture decentrations and the aperture rotation angle (if appropriate). An obstruction is identified by "(OB)" following the surface number. Data display is consistent with the clear aperture naming conventions.

SPIDER - The "SPIDER" CMD level command displays spider data defined on a surface. Display consists of the surface number, the type number of vanes and the "W" and "L" values.

REFRACTIVE INDEX DATA

RIN - The "RIN" CMD level command displays the refractive indices of all optical media at each of the first five program wavelengths.

RIN2 - The "RIN2" CMD level command displays the refractive indices of all optical media at each of the second five program wavelengths.

NDEX - The "NDEX" CMD level command displays the glass names and associated refractive indices of all optical media at each of the first five program wavelengths. This command is similar to "RIN" except that materials with all indices equal to 1.0 or -1.0 are omitted.

NDEX2 - The "NDEX2" CMD level command displays the glass names and associated refractive indices of all optical media at each of the second five program wavelengths. This command is similar to "RIN2" except that materials with all indices equal to 1.0 or -1.0 are omitted.

FOOTPRINT SETTING DATA

FOOTBLOK - The "FOOTBLOK" CMD level command displays the nature of surface FOOTBLOK surface setting.

WEIGHT AND PRICE DATA

SPGR - The "SPGR" CMD level command displays the specific gravity values currently assigned to the lens database. Units are always grams per cubic centimeter.

PRICE - The "PRICE" CMD level command displays the price per Kg values currently assigned to the lens database. Units are always grams per cubic centimeter.

DUMMY SURFACE SETTING DATA

DUMOUT - The "DUMOUT" command displays the nature of the forced dummy surface status.

INTERFEROGRAM DATA

INR - The "INR" command displays the "inr" values currently assigned to the lens database.

LENS DATABASE SECTION

GRATING DATA

GRT - The "GRT" CMD level command displays the diffraction grating data for the specified surface or surfaces.

NON-SURACE DEPENDENT DATA DISPLAY

LI - The "LI" command displays the current lens, Lens Identifier.

LIC - The "LIC" command displays the current lens, Lens Identifier Continuation lines.

INI - The "INI" command displays the current lens, Designer Identifier.

LTYPE - The "LTYPE" command displays the current lens, Lens Type Identifier.

ASTOP - The "ASTOP" command displays the surface number of the aperture.

UNITS - The "UNITS" command displays the units (inches, centimeters, millimeters or meters) in which linear lens dimensions are expressed.

CW - The "CW" command displays the wavelength number of the current control wavelength.

PCW - The "PCW" command displays the wavelength numbers to be used for "primary chromatic difference" calculations.

SCW - The "SCW" command displays the wavelength numbers to be used for "secondary chromatic differences".

REF - The "REF" command displays "reference surface data" used for ray tracing in the YZ and XZ-planes. This includes the chief ray reference object height, marginal ray reference height at the reference surface and the object surface, reference surface and image surface numbers. The reference field angle, in degrees, is printed in parentheses following the reference object height. This is the angle subtended by an object of height equal to the reference object height as viewed from the origin of the surface following the object surface. Normally, the object surface is surface number 0. It is possible, however, to redefine object, reference and image surface numbers whenever an object point is defined by an "FOB" command.

SPC - The "SPC" command displays all f-number hold data (FNBY HLD and FNBX HLD) and exit pupil diameter hold data (ERY HLD and ERX HLD) associated with the entire lens.

MODE - The "MODE" command (issued with no qualifier word) displays a message indicating the current lens mode.

SPTWT - The "SPTWT" command (issued with no numeric input) displays the current spectral weights for the first five program wavelengths.

SPTWT2 - The "SPTWT2" command (issued with no numeric input) displays the current spectral weights for the second five program wavelengths.

SAY or **EPD** or **SAX** - The "SAY" and "SAX" commands (issued with no numeric input) display the current SAY and SAX values for the current lens.

WRY or **WRX**The "WRY" and "WRX" commands (issued with no numeric input) display the current WRY and WRX values for the current lens.

BDY or **BDX** - The "BDY" and "BDX" commands (issued with no numeric input) display the current BDY and BDX values for the current lens.

SCY (qualifier) or **SCX (qualifier)** - The "SCY" and "SCX" commands (issued with no numeric input) display the current SCY and SCX values for the current lens. If issued with the qualifier "FANG", the field angle equivalents of SCY and SCX will be displayed

COMPLETE LENS LISTING

LEPRT or LIS , (i) - The "LEPRT" and "LIS" commands , issued with no numeric input, produce a complete listing of the "current lens", lens data. If a surface number "i" is issued with the commands, all surface dependent data for that surface is displayed.

LENS DATABASE SECTION

FULL SCREEN EDITING OF LENS DATA - Lens data for the current lens may be edited using the program full screen editor without leaving the program. By using the "EDIT" command (described in the CMD section), the file EDITTEXT.DAT may be edited using the current program full screen editor. To edit the current lens, simply use the output redirection command "OUTPUT ED" (described in the CMD section) and the "LENO" command (described in this section) to output the current lens data to the EDITTEXT.DAT file. Use the "EDIT" command to edit this file, making any desired changes. After filing the modified "EDITTEXT.DAT" file and leaving the editor, read in the modified EDITTEXT.DAT file using the "INPUT ED" command (described in the CMD section). The changes made during the edit session will be manifested in the new current lens.
NOTE: This method provides full screen edit capability for lens data, but it lacks the sophisticated built-in error checking of the standard lens input and lens update procedures.

PARAMETER CHANGE COMMANDS - Fifty one commands, when issued from the LENS UPDATE LEVEL, may be issued with the optional qualifier words "CENT" or "DELT". If one of these commands is issued with the "CENT" qualifier word, the current lens parameter value referenced by the command will be increased or decreased by the percentage specified by the value of numeric word #1. If one of these commands is issued with the "DELT" qualifier word, the current lens parameter value referenced by the command will be changed by the value of numeric word #1. Additionally, the "CV", "RD", "CVTOR" and "RDTOR" commands may be issued with the qualifier word "DELTFR". "DELTFR" is used to modify the curvature, radius of curvature, toric curvature or toric radius of curvature of a surface to represent a change by a specified number of "fringes". By default, the wavelength used is 0.5461 microns. If no clear aperture is assigned, then the default aperture height used for "DELTFR" is the sum of the absolute values of the paraxial marginal and paraxial chief ray heights in the YZ-plane for the previous paraxial ray trace. If a clear aperture is assigned, then the default aperture height used for "DELTFR" is the larger of the Y and X-clear aperture heights, ignoring clear aperture decentrations and clear aperture tilts. The wavelength in microns may be explicitly entered via an explicit entry for numeric word #2. The clear aperture height in lens units may be explicitly entered via an explicit entry for numeric word #3. Furthermore, the "CV" and "RD commands may be issued with the qualifier word "SAG". "SAG" is used to modify the curvature or radius of curvature of a surface so that it has a specific SAG value (in lens units) given by the value input in numeric word #1. If no clear aperture is assigned the surface, then the default aperture height used for "SAG" is the sum of the absolute values of the paraxial marginal and paraxial chief ray heights in the YZ-plane for the previous paraxial ray trace. If a clear aperture is assigned, then the default aperture height used for "SAG" is the larger of the Y and X-clear aperture heights, ignoring clear aperture decentrations and clear aperture tilts. A temporary clear height in lens units may be explicitly entered via an explicit entry for numeric word #2. The conic constant is used as part of this SAG calculation. The following table lists these thirty-nine commands and the parameter values which will be modified by them:

COMMAND	VALUE MODIFIED
RD or CV	Radius of curvature or curvature only.
RDTOR or CVTOR	Toric radius or curvature or toric curvature
CC	Conic constant
AC	2nd order aspheric coefficient
AD	4th order aspheric coefficient
AE	6th order aspheric coefficient
AF	8th order aspheric coefficient
AG	10th order aspheric coefficient
AH	12th order aspheric coefficient
AI	14th order aspheric coefficient
AJ	16th order aspheric coefficient
AK	18th order aspheric coefficient
AL	20th order aspheric coefficient
CCTOR	Toric conic constant
ADTOR	4th order toric aspheric coefficient
AETOR	6th order toric aspheric coefficient
AFTOR	8th order toric aspheric coefficient
AGTOR	10th order toric aspheric coefficient
TH	Thickness
YD	Y-decenter
XD	X-decenter
COMMAND	**VALUE MODIFIED**
ALPHA	Alpha surface tilt
BETA	Beta surface tilt
GAMMA	Gamma surface tilt
INR	Zernike reference radius
N1	Refractive index at $\lambda 1$

COMMAND	VALUE MODIFIED
N2	Refractive index at $\lambda2$
N3	Refractive index at $\lambda3$
N4	Refractive index at $\lambda4$
N5	Refractive index at $\lambda5$
N6	Refractive index at $\lambda6$
N7	Refractive index at $\lambda7$
N8	Refractive index at $\lambda8$
N9	Refractive index at $\lambda9$
N10	Refractive index at $\lambda10$
SAY	SAY or EPD value
SAX	SAX value
INDEX	index value for a "model" glass
VNUM	V-number for a "model" glass
DPARTL	ΔPartial dispersion for a "model" glass
PIVX	Tilt X-pivot position
PIVY	Tilt Y-pivot position
PIVZ	Tilt Z-pivot position
GDX	global x-decenter (with TILT RET)
GDY	global y-decenter (with TILT RET)
GDZ	global z-decenter (with TILT RET)
GALPHA	global alpha tilt (with TILT RET)
GBETA	global beta tilt (with TILT RET)
GGAMMA	global gamma tilt (with TILT RET)

LENS INDEPENDENT GLASS COMMANDS Up to this point, all of the commands which relate to glass catalog data have connected the glass catalog data to the "current" lens. The next few commands are completely independent of the "current" lens.

GLASSWV (LENS or NSSLENS) , $\lambda1$, $\lambda2$, $\lambda3$, $\lambda4$, $\lambda5$ - The "GLASSWV" command is used to establish five or ten wavelengths at which a glass catalog glass refractive index will be evaluated. In the absence of a "GLASSWV" command, the following values are assumed for "λ_1" to "λ_5":

$\lambda1$	$\lambda2$	$\lambda3$	$\lambda4$	$\lambda5$
0.58756 μ	0.48613 μ	0.65627 μ	0.43584 μ	0.70652 μ
$\lambda6$	$\lambda7$	$\lambda8$	$\lambda9$	$\lambda10$
0.0 μ	0.0 μ	0.0 μ	0.0 μ	0.0 μ

If optional qualifiers are used, numeric input is ignored. If the qualifier word "LENS" is used, then the ten wavelengths are the ten wavelengths in the current lens. If the qualifier "NSSLENS" is used, then the ten wavelengths are the ten wavelengths in the NSS database. λ is always assumed to be represented in microns.

(glass catalog name) , (glass name) - A valid glass catalog name is the command word of this command. Glass names or number codes are the valid qualifier words. This command causes the refractive indices at the ten wavelengths established with the "GLASSWV" command to be placed in the **general purpose storage registers 1 to 10**. These refractive indices may then be recalled, displayed or used in a macro or macro function.

CMD LEVEL CHANGE COMMANDS - The following commands are issued from the CMD level only. They are used to introduce complex surface and element displacements, tilts and re-positionings. They are most useful in examining the effect of optical alignment errors. They are implemented without the use of additional dummy surfaces. Assignment of multiple complex surface or element tilts should be done with care since rotations, in general, do not commute. The following commands are not, in general, compatible with "TILT BEN", "TILT DAR" and "TILT RET". All occurrences of "TILT BEN", "TILT DAR" and "TILT RET" should be removed via the "TILT BEND", "TILT DARD" and "TILT RETD" commands before using "DISP", "STILT", "BTILT", "ROLL" and the associated "PIVOT" commands.

DISP , i , j , Δx , Δy , Δz - The "DISP" command is used to move surfaces "i" through "j" by the amounts Δx, Δy and Δz while leaving all other surfaces in the lens database in their original locations. Displacements are always assumed to be in current lens units.

STILT , i , Δalpha , Δbeta , Δgamma - The "STILT" command is used to rotate surface "i" through angles Δalpha, Abeta and Δgamma while leaving all other surfaces in the lens database in their original locations. Rotations are always assumed to be measured in degrees. The default pivot position for "STILT" is the origin of the local coordinate system of surface "i".

STILT PIVOT , Δx , Δy , Δz - The "STILT PIVOT" command must be issued before an "STILT" command for it to be effective. It specifies an alternate x, y and z-location, specified with respect to the vertex of surface "i", as the pivot point for the next "STILT" command.

STILT PIVAUTO, Δx , Δy , Δz - The "STILT PIVAUTO" command must be issued before an "STILT" command for it to be effective. It specifies that the alternate x, y and z -location of the pivot point to be used in the next "STILT" command will be equal to the x, y and z-intersection of the last chief ray traced with the surface to which the following "STILT" is applied. The automatically calculated pivot location will then be incremented by the Δx, Δy and Δz values, if they are included. If no chief ray data is available, a warning message will be issued and no action will be taken.

ROLL , i , j , Δx , Δy , k - The "ROLL" command is used to "roll" surfaces "i" through "j" by Δx and Δy measured at surface "k". This "roll" is performed internally as a tilt about a pivot point located at the center of curvature of surface "k" where "k" must be set equal to either "i" or "j". If not explicitly entered, "k" is assumed to be equal to "i". This "roll" is performed while leaving all other surfaces in the lens database in their original locations. Rolls are always specified in current lens units of effective decentration at surface "k". For the purposes of determining the pivot point for the roll, it is assumed that there are no x or y displacements or alpha, beta or gamma tilts between surfaces "i" and "j".

BTILT , i , j , Δalpha , Δbeta , Δgamma - The "BTILT" command is used to rotate surfaces "i" though "j" through angles Δalpha, Δbeta and Δgamma while leaving all other surfaces in the lens database in their original locations. The default pivot point for this rotation is located at the vertex of surface "i" unless the command is immediately preceded by a "BTILT PIVOT" command. Rotations are always assumed to be measured in degrees.

BTILT PIVOT , Δx , Δy , Δz - The "BTILT PIVOT" command must be issued before a "BTILT" command for it to be effective. It specifies an alternate x, y and z-location, specified with respect to the vertex of surface "i", will be the pivot point for the next "BTILT" command.

BTILT PIVAUTO , Δx , Δy , Δz - The "BTILT PIVAUTO" command must be issued before a "BTILT" command for it to be effective. It specifies that the alternate x, y and z -location of the pivot point to be used in the next "BTILT" command will be equal to the x, y and z-intersection of the last chief ray traced with the first surface of the lens group to which the following "BTILT" is applied. The automatically calculated pivot location will then be incremented by the Δx, Δy and Δz values, if they are included. If no chief ray data is available, a warning message will be issued and no action will be taken.

FLIP i , j - The "FLIP" command reverses the order in which the lens database surfaces "i" through "j" appear in the current lens database. During the "FLIP" process, all tilts, decenters, solves and pikups are deleted in the surface number range. "FLIP" only acts on the main configuration of the lens so if there are alternate configuration definitions assigned to the surfaces in the surface number range, they are not changed by the "FLIP" command. "FLIP" also does not change any special surface definitions.

HUMAN EYE MODELS - Many times it is important to be able to simulate the aberrations of the human eye when evaluating the performance of an optical system. Two long standing optical models of the human eye have been included in this program. The models are taken from MIL-HDBK-141 and from the Handbook of Optics. The prescriptions are stored in the files HUMEYE01.DAT and HUMEYE02.DAT respectively. They may be retrieved as the current lens using the "INPUT FILE (file name)" command and then manipulated with the "LENADD" command and the lens library commands.

LENS DATABASE GRAPHICS - All graphical displays and representations of the lens database are described in the GRAPHICS section of the manual.

SPECIAL NSS SURFACES

CCR , apex_length , error12_arcsec , error23_arcsec , error31_arcsec - The "CCR" command causes a special type of single surface corner cube reflector to be inserted as new surface "i". This is a "pre-packaged" type of NSS surface which acts and is drawn as a real corner cube reflector but only takes one lens database surface to model. The "apex_length" is the perpendicular distance from the base to the apex. The surface location is at the CCR apex. The "apex_length" is only used to determine the location of the base of the CCR for CAD and plotting purposes and is measured along the local Z-axis. The nominal roof angles are always 90 degrees. The 1-2 lies in the local YZ-plane. The 2-3 edge lies on the +X-side of the local YZ-plane and the 3-1 edge lies on the -X-side of the local YZ-plane. Angle "errors" are entered in arc-sec and is an error applied to the nominal 90 degree roof angles. The reflection mode will set by the use of "REFL" or "REFLTIRO" in the lens database.

ROO , apex_length , error_arcsec - The "ROO" command causes a special type of single surface "roof" type of surface to be inserted as new surface "i". This is a "pre-packaged" type of NSS surface which acts and is drawn as a roof reflector but only takes one lens database surface to model. The "apex_length" is the perpendicular distance from the roof base to the roof apex. The nominal roof angle is always 90 degrees. The "apex_length" is the perpendicular distance from the base to the apex. The surface location is at the ROOF apex. The "apex_length" is only used to determine the location of the base of the roof for CAD and plotting purposes and is measured along the local Z-axis. The "error" is entered in arc-sec and is an error applied to the nominal 90 degree roof angles. The reflection mode will set by the use of "REFL" or "REFLTIRO" in the lens database.

RAY ERROR SURFACE FLAG

RAYERROR , ray error in arc-sec - The "RAYERROR" command designates the current surface to be an imperfectly manufactured surface for which random surface errors such as surface roughness exist. The error is expressed as the one sigma ray angle deviation in arc-seconds. The angular distribution of the error is assumed to be gaussian but the gamma orientation is distributed uniformly. The error is applied to a ray and to its associated differential rays (if they exist). The error is applied after any other ray surface interactions occurr. Issued from the CMD level, this command lists all the non-zero RAYERROR settings in the current lens configuration. If all RAYERROR settings are zero, no output is produced.

ALTERNATE LENS CONFIGURATION SECTION

CONFIGS-GENERAL INFORMATION - The alternate configurations (CONFIGS) section describes the establishment and manipulation of alternate versions or configurations of the lens database. These alternate configurations are stored with the lens database. Some of the commands described here are CMD level commands issued at the CMD level. These CMD level commands are described here instead of in the CMD section because they act to modify, or in other ways manipulate, these alternate configurations. The other commands described here are CONFIGS input level and UPDATE CONFIGS level commands which can only be issued at one or both of these levels. The alternate configuration database provides a way for surface and non-surface dependent lens parameter values as well as special surface parameter values to be set to values different from those values established in the main lens database and the main special surface database . The lens database is described in the LENS manual section. Special surface database is described in the SPECIAL SURFACES manual section.

THE CONFIGS DATABASE - The alternate configuration (CONFIGS) database consists of a sequence of UPDATE LENS, UPDATE SPSRF and CMD level commands which are stored in memory and on disk with the "current lens" data. There can be up to 75 configurations defined in a lens database including the regular lens database which is always the main configuration or configuration #1. This means there can be 74 alternate configurations. In each alternate configuration, there can be up to 2000 individual command entries.

CURRENT AND PERMANENT LENS - There is always a "current lens" which was described in the LENS section. There is also always a lens called the "permanent lens". As long as there are no alternate configurations defined, the "permanent lens" is identical to the "current lens". When alternate configurations are defined, the "current lens" is only identical to the "permanent lens" when the main configuration, designated as CFG 1, is the active configuration. If a configuration other than this main configuration becomes the active configuration, then the UPDATE LENS, UPDATE SPSRF and CMD level commands, which are stored in the alternate configuration database, are applied to the "permanent lens" in order to generate a new "current lens". This new "current lens" is no longer identical to the "permanent lens" but is the result of the commands stored in the alternate configuration database acting or operating upon the "permanent lens". The order in which the alternate configuration commands are applied to the "permanent" lens in order to create the new "current" lens is:

1. Update Lens level commands are applied,
2. then all Update Special Surface level commands are applied,
3. and finally, all CMD level commands are applied.

CREATING A NEW CONFIGS DATABASE

CONFIGS - The "CONFIGS" command causes the program to leave the CMD level and enter the CONFIGS input level. The alternate configuration database is wiped clean and is ready for new input. Between "CONFIGS" and "EOS" or "END", any CONFIGS input level command may be entered. The "CONFIGS" command also wipes clean any optimization and tolerance definitions which were in effect prior its issuance.

EOS or **END** - The "EOS" or "END" command, issued from the CONFIGS level, causes the program to return to the CMD level. The alternate configuration database is left in memory and is ready for analysis.

MODIFYING A CONFIGS DATABASE

UPDATE CONFIGS or **U CF** - The "UPDATE CONFIGS" command, or its abbreviated form "U CF", causes the program to leave the CMD level and enter the UPDATE CONFIGS level. The alternate configuration database is opened and is ready for modification. Between "UPDATE CONFIGS" or "U CF" and "EOS" or "END", any UPDATE CONFIGS level command may be entered.

EOS or **END** - The "EOS" or "END" command, issued from the UPDATE CONFIGS level, causes the program to return to the CMD level. The alternate configuration database is left in memory and is ready for analysis.

CONFIGS AND UPDATE CONFIGS SPECIFIC COMMANDS

CFG , i - The "CFG" command, issued from the CONFIGS or UPDATE CONFIGS level, designates that configuration "i" will be the configuration to which all the following CONFIGS or UPDATE CONFIGS commands are to be applied. Configuration "i" remains the configuration for input until another CFG command is entered or until the CONFIGS or UPDATE CONFIGS levels are exited via the "EOS" or "END" command. Valid values for "i" range from "2" to "75". If this command is not issued, all alternate configuration input will be made to configuration number 2.

CFG - The "CFG" command, issued with no numeric input, simply causes the current configuration number to be displayed.

ALTERNATE LENS CONFIGURATION SECTION

HOW COMMANDS WITHIN CONFIGS WORK - After the CONFIGS or the UPDATE CONFIGS level has been entered and the configuration number for input has been designated, either by way of the "CFG , i" command or by default, then specifying changes to the main lens database and/or the special surface database is trivial. All that need be done is to enter selected CMD, UPDATE LENS or UPDATE SPSRF level commands in exactly the same way as would have been done from outside the CONFIGS level. These commands will be stored and later executed when configurations are switched at the CMD level.

EXAMPLES

EXAMPLE 1 (A CMD LEVEL CHANGE) - The current lens is set up in mode FOCAL. It is desired to define configuration 3 as mode AFOCAL. The following commands are used:

> **UPDATE CONFIGS** (or **CONFIGS**)
> **CFG , 3**
> **MODE AFOCAL**
> **EOS** or **END** (This "EOS" or "END" refers to UPDATE CONFIGS)

The current lens database now has an alternate configuration number 3 attached to it. Using the CMD level command "CFG , 3" switches the lens into configuration 3. The CMD level command "MODE" will display the message "AFOCAL". Switching back to the main configuration with the CMD level command "CFG , 1" returns the lens to configuration number 1. The CMD level command "MODE" will now display the message "FOCAL" as expected.

EXAMPLE 2 (AN UPDATE LENS LEVEL CHANGE) - The current lens has been set up and surface number 5 has a radius of 234.567 lens units. It is desired to have the radius of this surface be 500.00 lens units in configuration 2. The command sequence will be:

> **UPDATE CONFIGS** (or CONFIGS)
> **CFG , 2** (this is optional since CFG 2 is the default)
> **UPDATE LENS** (or **U L**)
> **CHG,5**
> **RD , 500**
> **EOS** or **END** (This "EOS" or "END" refers to "U L")
> **EOS** or **END** (This "EOS" or "END" refers to "UPDATE CONFIGS")

The current lens database now has an alternate configuration number 2 attached to it. Using the CMD level command "CFG , 2" switches the lens into configuration 2. The CMD level command "RTG , 5" will display the radius, thickness and glass at surface 5 with radius = 500. Switching back to the main configuration with the CMD level command "CFG , 1" returns the lens to configuration number 1. The CMD level command "RTG , 5" will now display the radius, thickness and glass at surface 5 with radius = 234.567.

EXAMPLE 3 (AN UPDATE SPSRF LEVEL CHANGE) - The current lens has been set up and surface number 6 has special surface definition assigned to it. Coefficient C2 = 2.34D-5. It is desired to have the C2 coefficient of this surface be = 0 in configuration 10. The command sequence will be:

> **UPDATE CONFIGS** (or **CONFIGS**)
> **CFG , 10**
> **UPDATE SPSRF** (or **U SP**)
> **C2 , 6 , 0**
> **EOS** or **END** (This "EOS" or "END" refers to "U SP")
> **EOS** or **END** (This "EOS" or "END" refers to "UPDATE CONFIGS")

The current lens database now has an alternate configuration number 10 attached to it. Using the CMD level command "CFG , 10" switches the lens into configuration 10. The CMD level command "PRSPR , 6" will display coefficient values at surface 6. C2 will be = 0. Switching back to the main configuration with the CMD level command "CFG , 1" returns the lens to configuration number 1. The CMD level command "PRSPR , 6" will now display the coefficient values at surface 6. C2 will be back to 2.34D-5.

EXAMPLE 4 (EXAMPLES 1, 2 AND 3 ALL TOGETHER) - All of the changes could have been done at once with the following command sequence:

> **UPDATE CONFIGS** (or **CONFIGS**)
> **CFG , 3**
> **MODE AFOCAL**
> **CFG , 2**
> **UPDATE LENS**
> **CHG,5**
> **RD , 500**
> **EOS** or **END** (This "EOS" or "END" refers to "U L")
> **CFG , 10**
> **UPDATE SPSRF**
> **C2 , 6 , 0**
> **EOS** or **END** (This "EOS" or "END" refers to "U SP"
> **EOS** or **END** (This "EOS" or "END" refers to "UPDATE CONFIGS)

ALLOWED COMMANDS WITHIN CONFIGS - All UPDATE LENS commands (except "INS" and "DEL") and all of the UPDATE SPSRF are valid for use in defining alternate configurations. Consult the LENS and SPECIAL SURFACES manual sections for command syntax. The following CMD level commands are also valid within the CONFIGS or UPDATE CONFIGS level:

> MODE (FOCAL, UFOCAL, AFOCAL or UAFOCAL),
> THERM (SHAPE, THICK, SPACE, GLASS, GAS, or specific gas names) , i , j , ΔT , coeff,
> PRES (GAS, or specific gas names) , i , j , ΔP , coeff,
> SPTWT , λ_1, λ_2 , λ_3 , λ_4 , λ_5 and SPTWT2 , λ_6, λ_7 , λ_8 , λ_9 , λ_{10},
> and the first order f-number, exit pupil radius and magnification hold commands:
> FNBX, FNBX HLD, FNBY, FNBY HLD, ERX, ERX HLD, ERY, ERY HLD, MAGX, MAGX,
> HLD, MAGY, MAGY HLD, FLDS MAX, FLDS FRA, FLDS POS, FLDS ANG, FLDS and
> SPSRF (ON or OFF) .,i

CMD LEVEL CONFIGS MANIPULATION

CONFIGS DISPLAY COMMANDS

CF , i - The "CF" command, when issued at the CMD level, causes the "i"th configuration data to be displayed. If "i" is not explicitly entered, all of the alternate configuration data from all currently defined configurations will be displayed. Each item in the alternate configuration database is numbered sequentially within each configuration. These sequential position values are the first items listed in this data display. Should an item need to be removed from the alternate configuration database, the item is referred to by the configuration number and entry number.

REMOVE , i , j , k - The "REMOVE" command can be used to manually delete alternate configuration data items number "j" through the "k" in configuration number "I".

DELCFG , i - The "DELCFG" command deletes the "i"th configuration from the current configuration database attached to the lens.

CFG , i - The "CFG" command, when issued at the CMD level, causes the "i"th configuration to become the "current" configuration represented as a new "current" lens. Only the "current" configuration in the form of the "current" lens can be used in ray trace or other forms of analysis.

DEZOOM , i - The "DEZOOM" command, when issued at the CMD level, causes the "i"th configuration to become the "permanent lens" and the "current" lens. All other alternate configuration data is deleted! The "DEZOOM" command also wipes clean any optimization and tolerance definitions which were in effect prior its issuance.

AUTOMATIC DATA MANAGEMENT - Many items which can be made part of an alternate configuration definition are mutually exclusive. A "TH" definition is mutually exclusive to a "PY" or a "PIKUP TH" definition. Mutually exclusive items will be automatically deleted with the last item entered taking precedence. The exceptions to this rule are the "THERM" and "PRES" commands. Since the user may wish to enter several identical "THERM" and "PRES" commands in order to produce a specific lens configuration, no automatic removal of "THERM" or "PRES" commands will be performed. Only through the use of the "REMOVE" command can individual "THERM" or "PRES" commands be removed from alternate configuration data.

ALTERNATE LENS CONFIGURATION SECTION

HEXAGON/ACCOS-V INPUT - Between the issuance of a CONFIGS or UPDATE CONFIGS command and the EOS or END command, the following HEXAGON/ACCOS-V commands may be entered. They are automatically converted into regular program commands.

(parameter name) , j , v - The "(parameter name)" command (from the following table), when issued at the configs level, causes the parameter on the "j"th surface to take on the value "v".

parameter name	parameter
CV	profile curvature
RD	profile radius
CVR	toric curvature
RDR	toric radius
CC	conic constant
XD	x-decenter
YD	y-decenter
ALPHA	alpha tilt
BETA	beta tilt
GAMMA	gamma tilt
AD	4th order aspheric coefficient
AE	6th order aspheric coefficient
AF	8th order aspheric coefficient
AG	10th order aspheric coefficient
RN	refractive index (this results in a null input)
DF	dispersion factor (this results in a null input)
TH	axial thickness
TEMP	medium temperature (this results in a null input)
GLALPHA	medium thermal expansion coefficient (this results in a null input)

SPECIAL SURFACE SECTION

SPSRF-GENERAL INFORMATION - The special surfaces (SPSRF) section describes the establishment and manipulation of specialized surface definitions which may be attached to the existing lens database surfaces. This special surfaces database is stored with the lens database. Some of the commands described here are CMD level commands issued at the CMD level. These CMD level commands are described here instead of in the CMD section because they act to modify or in other ways manipulate the special surfaces database. The other commands described here are SPSRF input level and UPDATE SPSRF level commands which can only be issued at one or both of these levels. The special surfaces database provides a tool with which to modify, replace or augment the lens database surface profile definitions. Each special surface type is unique unto itself and is described at the end of this section. There is no limit to the maximum number of special surface types which eventually will be contained in the program. By checking the table of contents for this section, it will be clear as to how many special surface types are currently defined. Surfaces which have been defined as Deformable Surfaces in the Lens Input or Lens Update levels may not be defined as Special surfaces.

CREATING A NEW SPSRF DATABASE

SPSRF - The "SPSRF" command causes the program to leave the CMD level and enter the SPSRF input level. The special surfaces database is wiped clean and is ready for new input. Between "SPSRF" and "EOS" or "END", any SPSRF input level command may be entered.

EOS or **END** - The "EOS" or "END"command, issued from the SPSRF level, causes the program to return to the CMD level. The special surfaces database is left in memory and is ready for analysis.

MODIFYING AN SPSRF DATABASE

UPDATE SPSRF or **U SP** - The "UPDATE SPSRF" command, or its abbreviated form "U SP", causes the program to leave the CMD level and enter the UPDATE SPSRF level. The special surfaces database is opened and is ready for modification. Between "UPDATE SPSRF" or "U SP" and "EOS" or "END", any SPSRF level command may be entered.

EOS or **END** - The "EOS" or "END" command, issued from the UPDATE SPSRF level, causes the program to return to the CMD level. The special surface database is left in memory and is ready for analysis.

SPSRF SPECIFIC COMMANDS

SPECIAL or GENL , i , j - The "SPECIAL" or "GENL" command, issued from the SPSRF or UPDATE SPSRF level, designates that the lens database surface "i" will be defined as a type "j" special surface. All coefficient values for surface "i" are initialized to 0.0. Valid values for "j" range from "1" to the current maximum number of special surfaces implemented in the program.

C1 , i , c through **C96 , i , c** - The "C1" through "C96" commands are used to assign coefficient values to any of the 96 special surface coefficients. "i" specifies the surface number and "c" is the coefficient value. Not every surface uses all 96 coefficients.

SPDEL , i - The "SPDEL" command deletes special surface definitions from surface "i".

SPSRF ON , i - The "SPSRF ON" command causes a lens database surface "i", which has a special surface definition, to have that special surface definition considered during CMD level ray tracing and other analysis. "SPSRF ON" is the default condition when a special surfaces definition is applied to a surface.

SPSRF OFF , i - The "SPSRF OFF" command causes a lens database surface "i", which has a special surface definition, **NOT** to have that special surface definition considered during CMD level ray tracing and other analysis.

SPSRF CMD LEVEL COMMANDS

SPSRF ON , i - The "SPSRF ON" command causes a lens database surface "i", which has a special surface definition, to have that special surface definition considered during CMD level ray tracing and other analysis. "SPSRF ON" is the default condition when a special surfaces definition is applied to a surface. This command behaves exactly the same as it does at the SPSRF or UPDATE SPSRF level.

SPSRF OFF , i - The "SPSRF OFF" command causes a lens database surface "i", which has a special surface definition, **NOT** to have that special surface definition considered during CMD level ray tracing and other analysis. This command behaves exactly the same as it does at the SPSRF or UPDATE SPSRF level.

PRSPR ALL or **PRSPR , i** - The "PRSPR" command produces a display of the surface number, the special surface type and the value of the 96 coefficients C1 through C96. "ALL" produces a full listing for the entire lens. Input of the surface number "i" generates output for just surface "i".

SPECIAL SURFACE SECTION

PHASE SURFACES - The special surface TYPES 6, 7, 9, 10 and 15 have similar functional forms to surface TYPES 1, 8, 2, 3 and 14 but represent ray phase changes rather than surface sag changes. These are not to be confused with the diffractive phase terms used with special surface type 12 . TYPE 6, 7, 9, 10, 11, 15 and 20 phase surfaces may only be placed on flat, dummy surfaces. The units of the "phase" are initially evaluated in "waves" at the current "control wavelength". This phase in waves is converted to optical path length in "lens units" by multiplying the phase in waves by the wavelength of the control wavelength measured in the current "lens units". When a ray is traced through a phase surface, the optical path length corresponding to the phase is added to the optical path length of the ray according to the following equation:

$$\mathrm{OPL} = \mathrm{OPL}_{(\mathrm{original})} + \Delta\mathrm{OPL}_{(\mathrm{added})}$$

The changes to the direction cosines of the ray are calculated by taking the derivatives of this added phase term.

$$\Delta\mathrm{L} = -\frac{\partial\big(\Phi(x, y)\big)}{\partial x} \times \lambda_{cw}$$

$$\Delta\mathrm{M} = -\frac{\partial\big(\Phi(x, y)\big)}{\partial y} \times \lambda_{cw}$$

The new direction cosines are just:

$$\mathrm{L}_{new} = \mathrm{L}_{old} + \Delta\mathrm{L}$$

$$\mathrm{M}_{new} = \mathrm{M}_{old} + \Delta\mathrm{M}$$

The N direction cosine is calculated by re-normalization. Phase surfaces deflect a ray but they can not deflect the ray through more than 90 degrees from its original propagation direction. For all special surface types except TYPE 9, TYPE 10 and TYPE 15 phase surfaces, the "x" and "y" arguments in the descriptive equations are just the "x" and "y" ray coordinates at the lens database surface. For special surface TYPE 9, 10 and 15, the "x" and "y" terms in the descriptive equations are the "x" and "y" ray coordinates at the lens database surface, each divided by the "inr" value assigned to that surface. The "inr" value and the "INR" command are fully described in the LENS section of this manual. "inr" provides a way of normalizing the TYPE 9, TYPE 10 and TYPE 15 phase surfaces over a unit radius since that is how Zernike polynomials are defined. Even though TYPE 15 is not a true Zernike polynomial, it is similar enough to one to warrant the use of the "inr" value for coordinate normalization. For TYPE 9, 10 and 15 phase surfaces, the direction cosines are first computed at the "inr" normalized coordinate and then scaled up by the reciprocal of the "inr" value. This correctly adjusts the direction cosine so as to be representative of the phase being added to the ray. The "inr" value at a lens database surface may be explicitly set by the user using the LENS or UPDATE LENS level command "INR". If "inr" is not set explicitly, the default "inr" value will be determined either from existing clear aperture assignments at the surface or from the paraxial ray trace, if no clear apertures are assigned. In general, special surface coefficients are not scaled during a lens scaling operation unless there is explicit mention of coefficient scaling included in the description of that particular special surface type.

ZERNIKE SURFACES - The special surface TYPES 2, 3 and 14 comprise Zernike or Zernike-like polynomials. For these surface deformation special surface types, the "x" and "y" coordinates in the descriptive equations, when used to evaluate the polynomials, are the "x" and "y" ray coordinates at the surface divided by the "inr" value described above. The regular surface "sag" equations for the non-Zernike part of the surface evaluation are just the "x" and "y" ray coordinates at the surface. This normalization is performed automatically by the program.

ZERNREPT , i - The "ZERNREPT" is a CMD level command. It causes a lens database surface "i", which has been previously defined as a type 3 or type 10 special surface to be used as the basis of a 37-tern Fringe Zernike Report. The report displays RMS surface (type 3) or wavefront (type 10) values, based not upon a ray trace, but upon the special surface coefficient values. The calculation is based on the equations in Appendix 2 of "Optical Shop Testing" by Daniel Malacara.

COEFFICIENTS - Many of the special surface coefficients which appear in the following description of specific special surface types will not be set explicitly by the user but will be determined automatically during the optimization process. When this is the intended way in which these special surface coefficients are to achieve a specific value, simple enter these coefficients as variables in the optimization process.

SPECIAL SURFACE SECTION

THE TYPE 1 SPECIAL SURFACE (Polynomial-1) - The TYPE 1 special surface is a rotationally symmetric polynomial defined by the following equation:

$$Z(x,y) = SAG(x,y) + \sum_{n=0}^{39} \left\{ C_{n+9} \left[\sqrt{(x^2 + y^2)} \right]^n \right\}$$

SAG(x,y) is the original surface sag due to radius, conic, aspheric terms, etc. Coefficients C1 to C8 are not used for this surface type as they would cause the surface to be poorly behaved at the surface vertex. Terms with values of n=4, 6, 8 and 10 are already represented by the rotationally symmetric aspheric surface type.

THE TYPE 2 SPECIAL SURFACE (Zernike-1) - The TYPE 2 special surface is a 66-term Zernike polynomial defined by the following equation:

$$Z(x,y) = SAG(x,y) + \sum_{n=1}^{66} C_n Z_n(\rho,\theta)$$

where:

$$\rho = \sqrt{(x^2 + y^2)}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

SAG(x,y) is the original surface sag due to radius, conic, aspheric terms, etc.
(All ambiguities in θ are resolved in the program internals)

and:

$Z_1(\rho,\theta) = 1$ {constant}
$Z_2(\rho,\theta) = \rho \cos(\theta)$ {x-tilt}
$Z_3(\rho,\theta) = \rho \sin(\theta)$ {y-tilt}

$Z_4(\rho,\theta) = \rho^2 \cos(2\theta)$ {0 degree astigmatism}
$Z_5(\rho,\theta) = 2\rho^2 - 1$ {focus + constant}
$Z_6(\rho,\theta) = \rho^2 \sin(2\theta)$ {45 degree astigmatism}

$Z_7(\rho,\theta) = \rho^3 \cos(3\theta)$ {x-clover}
$Z_8(\rho,\theta) = (3\rho^3 - 2\rho) \cos(\theta)$
$Z_9(\rho,\theta) = (3\rho^3 - 2\rho) \sin(\theta)$
$Z_{10}(\rho,\theta) = \rho^3 \sin(3\theta)$ {y-clover}

$Z_{11}(\rho,\theta) = \rho^4 \cos(4\theta)$
$Z_{12}(\rho,\theta) = (4\rho^4 - 3\rho^2) \cos(2\theta)$
$Z_{13}(\rho,\theta) = 6\rho^4 - 6\rho^2 + 1$
$Z_{14}(\rho,\theta) = (4\rho^4 - 3\rho^2) \sin(2\theta)$
$Z_{15}(\rho,\theta) = \rho^4 \sin(4\theta)$

$Z_{16}(\rho,\theta) = \rho^5 \cos(5\theta)$
$Z_{17}(\rho,\theta) = (5\rho^5 - 4\rho^3) \cos(3\theta)$
$Z_{18}(\rho,\theta) = (10\rho^5 - 12\rho^3 + 3\rho) \cos(\theta)$
$Z_{19}(\rho,\theta) = (10\rho^5 - 12\rho^3 + 3\rho) \sin(\theta)$
$Z_{20}(\rho,\theta) = (5\rho^5 - 4\rho^3) \sin(3\theta)$
$Z_{21}(\rho,\theta) = \rho^5 \sin(5\theta)$

$Z_{22}(\rho,\theta) = \rho^6 \cos(6\theta)$
$Z_{23}(\rho,\theta) = (6\rho^6 - 5\rho^4) \cos(4\theta)$
$Z_{24}(\rho,\theta) = (15\rho^6 - 20\rho^4 + 6\rho^2) \cos(2\theta)$
$Z_{25}(\rho,\theta) = 20\rho^6 - 30\rho^4 + 12\rho^2 - 1$
$Z_{26}(\rho,\theta) = (15\rho^6 - 20\rho^4 + 6\rho^2) \sin(2\theta)$
$Z_{27}(\rho,\theta) = (6\rho^6 - 5\rho^4) \sin(4\theta)$
$Z_{28}(\rho,\theta) = \rho^6 \sin(6\theta)$
$Z_{29}(\rho,\theta) = \rho^7 \cos(7\theta)$
$Z_{30}(\rho,\theta) = (7\rho^7 - 6\rho^5) \cos(5\theta)$
$Z_{31}(\rho,\theta) = (21\rho^7 - 30\rho^5 + 10\rho^3) \cos(3\theta)$
$Z_{32}(\rho,\theta) = (35\rho^7 - 60\rho^5 + 30\rho^3 - 4\rho) \cos(\theta)$
$Z_{33}(\rho,\theta) = (35\rho^7 - 60\rho^5 + 30\rho^3 - 4\rho) \sin(\theta)$
$Z_{34}(\rho,\theta) = (21\rho^7 - 30\rho^5 + 10\rho^3) \sin(3\theta)$
$Z_{35}(\rho,\theta) = (7\rho^7 - 6\rho^5) \sin(5\theta)$
$Z_{36}(\rho,\theta) = \rho^7 \sin(7\theta)$

$Z_{37}(\rho,\theta) = \rho^8 \cos(8\theta)$
$Z_{38}(\rho,\theta) = (8\rho^8 - 7\rho^6) \cos(6\theta)$
$Z_{39}(\rho,\theta) = (28\rho^8 - 42\rho^6 + 15\rho^4) \cos(4\theta)$
$Z_{40}(\rho,\theta) = (56\rho^8 - 105\rho^6 + 60\rho^4 - 10\rho^2) \cos(2\theta)$
$Z_{41}(\rho,\theta) = 70\rho^8 - 140\rho^6 + 90\rho^4 - 20\rho^2 + 1$
$Z_{40}(\rho,\theta) = (56\rho^8 - 105\rho^6 + 60\rho^4 - 10\rho^2) \sin(2\theta)$
$Z_{43}(\rho,\theta) = (28\rho^8 - 42\rho^6 + 15\rho^4) \sin(4\theta)$
$Z_{44}(\rho,\theta) = (8\rho^8 - 7\rho^6) \sin(6\theta)$
$Z_{45}(\rho,\theta) = \rho^8 \sin(8\theta)$

$Z_{46}(\rho,\theta) = \rho^9 \cos(9\theta)$
$Z_{47}(\rho,\theta) = (9\rho^9 - 8\rho^7) \cos(7\theta)$
$Z_{48}(\rho,\theta) = (36\rho^9 - 56\rho^7 + 21\rho^5) \cos(5\theta)$
$Z_{49}(\rho,\theta) = (84\rho^9 - 168\rho^7 + 105\rho^5 - 20\rho^3) \cos(3\theta)$
$Z_{50}(\rho,\theta) = (126\rho^9 - 280\rho^7 + 210\rho^5 - 60\rho^3 + 5\rho) \cos(\theta)$
$Z_{51}(\rho,\theta) = (126\rho^9 - 280\rho^7 + 210\rho^5 - 60\rho^3 + 5\rho) \sin(\theta)$
$Z_{52}(\rho,\theta) = (84\rho^9 - 168\rho^7 + 105\rho^5 - 20\rho^3) \sin(3\theta)$
$Z_{53}(\rho,\theta) = (36\rho^9 - 56\rho^7 + 21\rho^5) \sin(5\theta)$
$Z_{54}(\rho,\theta) = (9\rho^9 - 8\rho^7) \sin(7\theta)$
$Z_{55}(\rho,\theta) = \rho^9 \sin(9\theta)$

$Z_{56}(\rho,\theta) = \rho^{10} \cos(10\theta)$
$Z_{57}(\rho,\theta) = (10\rho^{10} - 9\rho^8) \cos(8\theta)$
$Z_{58}(\rho,\theta) = (45\rho^{10} - 72\rho^8 + 28\rho^6) \cos(6\theta)$
$Z_{59}(\rho,\theta) = (120\rho^{10} - 252\rho^8 + 168\rho^6 - 35\rho^4) \cos(4\theta)$
$Z_{60}(\rho,\theta) = (210\rho^{10} - 504\rho^8 + 420\rho^6 - 140\rho^4 + 15\rho^2) \cos(\theta)$
$Z_{61}(\rho,\theta) = 252\rho^{10} - 630\rho^8 + 560\rho^6 - 210\rho^4 + 30\rho^2 - 1$
$Z_{62}(\rho,\theta) = (210\rho^{10} - 504\rho^8 + 420\rho^6 - 140\rho^4 + 15\rho^2) \sin(\theta)$
$Z_{63}(\rho,\theta) = (120\rho^{10} - 252\rho^8 + 168\rho^6 - 35\rho^4) \sin(4\theta)$
$Z_{64}(\rho,\theta) = (45\rho^{10} - 72\rho^8 + 28\rho^6) \sin(6\theta)$
$Z_{65}(\rho,\theta) = (10\rho^{10} - 9\rho^8) \sin(8\theta)$
$Z_{66}(\rho,\theta) = \rho^{10} \sin(10\theta)$

SPECIAL SURFACE SECTION

THE TYPE 3 SPECIAL SURFACE (Zernike-2) - The TYPE 3 special surface is the 37-term Fringe Zernike polynomial defined by the following equation:

$$Z(x,y) = SAG(x,y) + \sum_{n=1}^{30} C_n Z_n(\rho, \theta)$$

where:

$$\rho = \sqrt{(x^2 + y^2)}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

SAG(x,y) is the original surface sag due to radius, conic, aspheric terms, etc.
(All ambiguities in θ are resolved in the program internals) and:

$Z_1(\rho,\theta) = 1$		{constant}
$Z_2(\rho,\theta) = \rho \cos(\theta)$	{x-tilt}	
$Z_3(\rho,\theta) = \rho \sin(\theta)$	{y-tilt}	
$Z_4(\rho,\theta) = 2\rho^2 - 1$		{focus + constant}
$Z_5(\rho,\theta) = \rho^2 \cos(2\theta)$		{0 degree astigmatism}
$Z_6(\rho,\theta) = \rho^2 \sin(2\theta)$		{45 degree astigmatism}
$Z_7(\rho,\theta) = (3\rho^3 - 2\rho) \cos(\theta)$		
$Z_8(\rho,\theta) = (3\rho^3 - 2\rho) \sin(\theta)$		
$Z_9(\rho,\theta) = 6\rho^4 - 6\rho^2 + 1$		
$Z_{10}(\rho,\theta) = \rho^3 \cos(3\theta)$		{x-clover}
$Z_{11}(\rho,\theta) = \rho^3 \sin(3\theta)$		{y-clover}
$Z_{12}(\rho,\theta) = (4\rho^4 - 3\rho^2) \cos(2\theta)$		
$Z_{13}(\rho,\theta) = (4\rho^4 - 3\rho^2) \sin(2\theta)$		
$Z_{14}(\rho,\theta) = (10\rho^5 - 12\rho^3 + 3\rho) \cos(\theta)$		
$Z_{15}(\rho,\theta) = (10\rho^5 - 12\rho^3 + 3\rho) \sin(\theta)$		
$Z_{16}(\rho,\theta) = 20\rho^6 - 30\rho^4 + 12\rho^2 - 1$		
$Z_{17}(\rho,\theta) = \rho^4 \cos(4\theta)$		
$Z_{18}(\rho,\theta) = \rho^4 \sin(4\theta)$		
$Z_{19}(\rho,\theta) = (5\rho^5 - 4\rho^3) \cos(3\theta)$		
$Z_{20}(\rho,\theta) = (5\rho^5 - 4\rho^3) \sin(3\theta)$		
$Z_{21}(\rho,\theta) = (15\rho^6 - 20\rho^4 + 6\rho^2) \cos(2\theta)$		
$Z_{22}(\rho,\theta) = (15\rho^6 - 20\rho^4 + 6\rho^2) \sin(2\theta)$		
$Z_{23}(\rho,\theta) = (35\rho^7 - 60\rho^5 + 30\rho^3 - 4\rho) \cos(\theta)$		
$Z_{24}(\rho,\theta) = (35\rho^7 - 60\rho^5 + 30\rho^3 - 4\rho) \sin(\theta)$		
$Z_{25}(\rho,\theta) = 70\rho^8 - 140\rho^6 + 90\rho^4 - 20\rho^2 + 1$		
$Z_{26}(\rho,\theta) = \rho^5 \cos(5\theta)$		
$Z_{27}(\rho,\theta) = \rho^5 \sin(5\theta)$		
$Z_{28}(\rho,\theta) = (6\rho^6 - 5\rho^4) \cos(4\theta)$		
$Z_{29}(\rho,\theta) = (6\rho^6 - 5\rho^4) \sin(4\theta)$		
$Z_{30}(\rho,\theta) = (21\rho^7 - 30\rho^4 + 10\rho^3) \cos(3\theta)$		
$Z_{31}(\rho,\theta) = (21\rho^7 - 30\rho^4 + 10\rho^3) \sin(3\theta)$		
$Z_{32}(\rho,\theta) = (56\rho^8 - 105\rho^6 + 60\rho^4 - 10\rho^2) \cos(2\theta)$		
$Z_{33}(\rho,\theta) = (56\rho^8 - 105\rho^6 + 60\rho^4 - 10\rho^2) \sin(2\theta)$		
$Z_{34}(\rho,\theta) = (126\rho^9 - 280\rho^7 + 210\rho^5 - 60\rho^3 + 5\rho) \cos(\theta)$		
$Z_{35}(\rho,\theta) = (126\rho^9 - 280\rho^7 + 210\rho^5 - 60\rho^3 + 5\rho) \sin(\theta)$		
$Z_{36}(\rho,\theta) = 252\rho^{10} - 630\rho^8 + 560\rho^6 - 210\rho^4 + 30\rho^2 - 1$		
$Z_{37}(\rho,\theta) = 924\rho^{12} - 2772\rho^{10} + 3150\rho^8 - 1680\rho^6 + 420\rho^4 - 42\rho^2 + 1$		

SPECIAL SURFACE SECTION

THE TYPE 4 SPECIAL SURFACE (Sinusoidal Error Surface) - The TYPE 4 special surface is a 2D Sinusoidal Error Surface. It is used to add to a standard optical surface (flat, sphere, conic, aspheric, cylinder, or anamorphic aspheric) up to five rectangularly distributed, sinusoidal surface perturbations. In the absence of detailed knowledge of surface deformation, this special surface type may be used to simulate manufacturing errors on an optical surface. The SAG of the surface is represented by the following equations:

$$
\begin{aligned}
Z(x,y) = {}& SAG(x,y) \\
& + C_1 \times 0.5 \times CF \times \left[\cos(\omega_{1x} x) \times \cos(\omega_{1y} y)\right] \\
& + C_4 \times 0.5 \times CF \times \left[\cos(\omega_{2x} x) \times \cos(\omega_{2y} y)\right] \\
& + C_7 \times 0.5 \times CF \times \left[\cos(\omega_{3x} x) \times \cos(\omega_{3y} y)\right] \\
& + C_{10} \times 0.5 \times CF \times \left[\cos(\omega_{4x} x) \times \cos(\omega_{4y} y)\right] \\
& + C_{13} \times 0.5 \times CF \times \left[\cos(\omega_{5x} x) \times \cos(\omega_{5y} y)\right]
\end{aligned}
$$

where:

$$\omega_{1x} = \frac{2\pi}{C_2}$$

$$\omega_{1y} = \frac{2\pi}{C_3}$$

$$\omega_{2x} = \frac{2\pi}{C_5}$$

$$\omega_{2y} = \frac{2\pi}{C_6}$$

$$\omega_{3x} = \frac{2\pi}{C_8}$$

$$\omega_{3y} = \frac{2\pi}{C_9}$$

$$\omega_{4x} = \frac{2\pi}{C_{11}}$$

$$\omega_{4y} = \frac{2\pi}{C_{12}}$$

$$\omega_{5x} = \frac{2\pi}{C_{14}}$$

$$\omega_{5y} = \frac{2\pi}{C_{15}}$$

SAG(x,y) is the surface sag before the sinusoidal disturbance is added. C1, C4, C7, C10 and C13 are the peak-to-valley added surface sags in waves referenced to the wavelength of the currently defined reference wavelength. CF is the program supplied conversion factor from waves at the reference wavelength to current lens units. ω_x and ω_y are the spatial frequencies of the disturbance distributions in the local coordinate system of the surface for the five distributions. C2/C3, C5/C6, C8/C9, C11/C12 and C14/C15 are the periods of these five distrbances in the x and y-directions.

SPECIAL SURFACE SECTION

THE TYPE 5 SPECIAL SURFACE (User-Defined #1) - The TYPE 5 special surface is a user-defined surface defined by the following equation:

$$Z(x,y) = SAG(x,y) + (Z - register)$$

The TYPE 5 special surface is a user-defined surface type. The TYPE 5 special surface may use none, any or all of the coefficients C1 to C96. The additional surface sag added to the surface by the TYPE 5 special surface is defined by the user in macro function FUN10. If FUN10 does not exist, the added surface sag, Z, is 0.0. If FUN10 exists, the additional surface sag will be whatever is left in the Z-storage register after FUN10 finishes its execution. FUN10 may not call any other macros or macro functions when used in special surface definitions. The values of the 96 coefficients are passed via general purpose storage registers 301 through 396. The current X-ray coordinate is passed via the X-register and the current Y-ray value is passed via the Y-register. The surface number is passed via the T-register. The LASTX-register remembers the previous value of the X-register as usual.

THE TYPE 6 SPECIAL SURFACE (Polynomial-1 Phase) - The TYPE 6 special surface is a rotationally symmetric polynomial similar to a TYPE 1 surface except that the polynomial represents a variation in phase rather than surface profile. It may only be applied to a flat dummy surface. It is defined by the following equation:

$$\Phi(x,y) = \sum_{n=0}^{39}\left\{ C_{n+9}\left[\sqrt{\left(x^2+y^2\right)}\right]^n\right\}$$

The phase, in terms of OPD with respect to the control wavelength, is added to the phase of the ray being traced. The ray direction cosines are modified appropriately.

THE TYPE 7 SPECIAL SURFACE (Rectangular Polynomial Phase) - The TYPE 7 special surface is a rectangular polynomial similar to a TYPE 8 surface, except that the polynomial represents a variation in phase rather than surface profile. It may only be applied to a flat dummy surface. It is defined by the following equation:

$$\Phi(x,y) = \sum_{n=1}^{91}\left\{ C_n F_n(x,y)\right\}$$

The phase, in terms of OPD with respect to the control wavelength, is added to the phase of the ray being traced. The ray direction cosines are modified appropriately. The terms F1 to F91 are the same as those listed in the TYPE 8 surface description.

THE TYPE 8 SPECIAL SURFACE (Rectangular Polynomial) - The TYPE 8 special surface is a rectangular polynomial surface. It is defined by the following equation:

$$Z(x,y) = SAG(x,y) + \sum_{n=1}^{91}\left\{ C_n F_n(x,y)\right\}$$

where:

SAG(x,y) is the original surface sag due to radius, conic, aspheric terms, etc.

and:

$$F_1(X,Y) = 1$$
$$F_{2,3}(x,y) = x,y$$
$$F_{4,5,6}(x,y) = x^2,xy,y^2$$
$$F_{7,8,9,10}(x,y) = x^3,x^2y,xy^2,y^3$$
$$F_{11,12,13,14,15}(x,y) = x^4,x^3y,x^2y^2,xy^3,y^4$$
$$F_{16,17,18,19,20,21}(x,y) = x^5,x^4y,x^3y^2,x^2y^3,xy^4,y^5$$
$$F_{22,23,24,25,26,27,28}(x,y) = x^6,x^5y,x^4y^2,x^3y^3,x^2y^4,x^1y^5,y^6$$
$$F_{29,30,31,32,33,34,35,36}(x,y) = x^7,x^6y,x^5y^2,x^4y^3,x^3y^4,x^2y^5,xy^6,y^7$$
$$F_{37,38,39,40,41,42,43,44,45}(x,y) = x^8,x^7y,x^6y^2,x^5y^3,x^4y^4,x^3y^5,x^2y^6,xy^7,y^8$$
$$F_{46,47,48,49,50,51,52,53,54,55}(x,y) = x^9,x^8y,x^7y^2,x^6y^3,x^5y^4,x^4y^5,x^3y^6,x^2y^7,xy^8,y^9$$
$$F_{56,57,58,59,60,61,62,63,64,65,66}(x,y) = x^{10},x^9y,x^8y^2,x^7y^3,x^6y^4,x^5y^5,x^4y^6,x^3y^7,x^2y^8,xy^9,y^{10}$$
$$F_{67,68,69,70,71,72,73,74,75,76,77,78}(x,y) = x^{11},x^{10}y,x^9y^2,x^8y^3,x^7y^4,x^6y^5,x^5y^6,x^4y^7,x^3y^8,x^2y^9,xy^{10},y^{11}$$
$$F_{79,80,81,82,83,84,85,86,87,88,89,90,91}(x,y) = x^{12},x^{11}y,x^{10}y^2,x^9y^3,x^8y^4,x^7y^5,x^6y^6,x^5y^7,x^4y^8,x^3y^9,x^2y^{10},xy^{11},y^{12}$$

SPECIAL SURFACE SECTION

THE TYPE 9 SPECIAL SURFACE (Zernike-1 Phase) - The TYPE 9 special surface is a 66-term Zernike polynomial similar to a TYPE 2 surface except that the polynomial represents a variation in phase rather than surface profile. It may only be applied to a flat dummy surface. It is defined by the following equation:

$$\Phi(x,y) = \sum_{n=1}^{66} C_n Z_n(\rho,\theta)$$

where:

$$\rho = \sqrt{(x^2 + y^2)}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

All ambiguities in θ are resolved in the program internals. The phase, in terms of OPD with respect to the control wavelength, is added to the phase of the ray being traced. The ray direction cosines are modified appropriately. The "x" and "y" values used in the TYPE 9 phase surface equations are the "x" and "y" ray coordinates at the surface, each divided by the "inr" value assigned to that surface. The terms Z1 to Z66 are the same as those listed in the TYPE 2 surface description.

THE TYPE 10 SPECIAL SURFACE (Zernike-2 Phase) - The TYPE 10 special surface is a 37-term Fringe Zernike polynomial similar to a TYPE 3 surface except that the polynomial represents a variation in phase rather than surface profile. It may only be applied to a flat dummy surface. It is defined by the following equation:

$$\Phi(x,y) = \sum_{n=1}^{37} C_n Z_n(\rho,\theta)$$

where:

$$\rho = \sqrt{(x^2 + y^2)}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

All ambiguities in θ are resolved in the program internals. The phase, in terms of OPD with respect to the control wavelength, is added to the phase of the ray being traced. The ray direction cosines are modified appropriately. The "x" and "y" values used in the TYPE 10 phase surface equations are the "x" and "y" ray coordinates at the surface, each divided by the "inr" value assigned to that surface. The terms Z1 to Z37 are the same as those listed in the TYPE 3 surface description.

THE TYPE 11 SPECIAL SURFACE (User-Defined Phase) - The TYPE 11 special surface is a user-defined phase surface defined by the following equation:

$$\Phi(x, y) = (IY - register\ )$$

$$\frac{\partial \Phi(x, y)}{\partial X} = (IX - register\ )$$

$$\frac{\partial \Phi(x, y)}{\partial Y} = (IY - register\ )$$

It may only be applied to a flat dummy surface. The TYPE 11 special surface may use none, any or all of the coefficients C_1 to C_{96}. The phase contribution of the TYPE 11 special surface, in terms of OPD with respect to the control wavelength, is defined by the user in macro function FUN09. If FUN09 does not exist, the added phase is 0.0. If FUN09 exists, the additional phase will be whatever is left in the IZ-storage register after FUN09 finishes its execution. The derivatives of the phase with respect to X and Y must be returned in the IX and IY-registers. These derivative values are needed to calculate the change in the ray direction cosine due to the phase change. FUN09 may not call any other macros or macro functions when used in special surface definitions. The values of the 96 coefficients are passed via general purpose storage registers 201 through 296. The current X-ray coordinate is passed via the X-register and the current Y-ray value is passed via the Y-register. The surface number is passed via the T-register. The LASTX-register remembers the previous value of the X-register as usual.

THE TYPE 12 SPECIAL SURFACE (HOE) - The TYPE 12 special surface is a Holographic Optical Element (HOE) with optional phase deformation terms. The HOE diffraction equation used for ray tracing is just::

$$\mathbf{n} \times (\mathbf{r}_o' - \mathbf{r}_r') = \frac{m\lambda'}{\lambda} \mathbf{n} \times (\mathbf{r}_o - \mathbf{r}_r)$$

where:

m	is the order number for diffraction
n	is the surface normal unit vector
$\mathbf{r_o}$	is the unit vector along construction beam 1 (sometimes referred to as the construction object point ray or just the object ray)
$\mathbf{r_r}$	is the unit vector along construction beam 2 (sometimes referred to as the construction reference point ray or just the reference ray)
r'o	is the unit vector along the diffracted ray (sometimes called the image ray)
r'r	is the unit vector along the incident ray (sometimes called the readout ray or reconstruction ray)
λ'	is the end-use or play back wavelength (wavelength at which ray is traced)
λ	is the construction wavelength

Coefficient C1 = order number
Coefficient C2 = construction wavelength in microns
Coefficient C3 = X-coordinate of the source point
Coefficient C4 = Y-coordinate of the source point
Coefficient C5 = Z-coordinate of the source point
Coefficient C6 = +1 if the source is real and -1 if the source is virtual
Coefficient C7 = X-coordinate of the reference point
Coefficient C8 = Y-coordinate of the reference point
Coefficient C9 = Z-coordinate of the reference point
Coefficient C10 = +1 if the reference is real and -1 if the reference is virtual

Coefficient C11 = 0 for no added phase

= 1 (R) for a rotationally symmetric phase polynomial in R starting at R^2 and extending to R^{20} (even powers of R)

= 2 (XY) for a rectangular phase polynomial

= 3 (AXY) same as 2 but uses absolute value of x

= 4 (XAY) same as 2 but uses absolute value of y

= 5 (AXAY) same as 2 but uses absolute value of x and y

= 6 (AR) for a polynomial in absolute value of R starting at $ABS(R)^0$ and extending to $ABS(R)^{20}$

= 7 (U) user-defined phase and phase derivative (macro function FUN09)*

* Phase is returned in the IZ register, the x and y partial derivatives are returned in the IX and IY registers.

During lens scaling, the coefficients C3 , C4 , C5 , C7 , C8 and C9 are scaled by the scale factor. If the source or reference object is defined as real, light will diverge away from it. If the source or reference object is defined as virtual, light will converge toward it. The coordinates of the source and reference objects are always represented in the local coordinate system of the HOE surface. Reflection HOEs should always have the source and reference points on opposite sides of the HOE surface. Unexpected and non-physically real results will occur if:

1. If the source and reference points are on the same side of the HOE and the glass type is REFL;

2. If the source and reference points are on opposite sides of the HOE and the glass type is not REFL;

3. If the source and reference points are located at the HOE surface.

If C11 = 1, the optional rotationally symmetric polynomial phase terms (coefficients 12 through 21) (R-type) which modify the HOE equation are defined by the following equation:

$$\Phi(x, y) = \sum_{n=1}^{10} \left\{ C_{n+11} \left[(x^2 + y^2) \right]^n \right\}$$

The coefficients used for the rotationally symmetric phase terms are coefficients C12 through C31. If C11 = 6, the optional rotationally symmetric polynomial phase terms (AR-type) which modify the HOE equation are defined by the following equation:

$$\Phi(x, y) = \sum_{n=1}^{20} \left\{ C_{n+11} \left[\sqrt{(x^2 + y^2)} \right]^n \right\}$$

The coefficients used for the rotationally symmetric phase terms are coefficients C12 through C31. If C11 = 2, 3, 4 or 5 the optional rectangular polynomial phase terms which modify the HOE equation are defined by the following equation:

$$\Phi(x, y) = \sum_{n=1}^{78} \left\{ C_{n+11} F_n(x, y) \right\}$$

and:

$F_1(X,Y) = 1$

$F_{2,3}(x,y) = x,y$

$F_{4,5,6}(x,y) = x^2,xy,y^2$

$F_{7,8,9,10}(x,y) = x^3,x^2y,xy^2,y^3$

$F_{11,12,13,14,15}(x,y) = x^4,x^3y,x^2y^2,xy^3,y^4$

$F_{16,17,18,19,20,21}(x,y) = x^5,x^4y,x^3y^2,x^2y^3,xy^4,y^5$

$F_{22,23,24,25,26,27,28}(x,y) = x^6,x^5y,x^4y^2,x^3y^3,x^2y^4,x^1y^5,y^6$

$F_{29,30,31,32,33,34,35,36}(x,y) = x^7,x^6y,x^5y^2,x^4y^3,x^3y^4,x^2y^5,xy^6,y^7$

$F_{37,38,39,40,41,42,43,44,45}(x,y) = x^8,x^7y,x^6y^2,x^5y^3,x^4y^4,x^3y^5,x^2y^6,xy^7,y^8$

$F_{46,47,48,49,50,51,52,53,54,55}(x,y) = x^9,x^8y,x^7y^2,x^6y^3,x^5y^4,x^4y^5,x^3y^6,x^2y^7,xy^8,y^9$

$F_{56,57,58,59,60,61,62,63,64,65,66}(x,y) = x^{10},x^9y,x^8y^2,x^7y^3,x^6y^4,x^5y^5,x^4y^6,x^3y^7,x^2y^8,xy^9,y^{10}$

$F_{67,68,69,70,71,72,73,74,75,76,77,78}(x,y) = x^{11},x^{10}y,x^9y^2,x^8y^3,x^7y^4,x^6y^5,x^5y^6,x^4y^7,x^3y^8,x^2y^9,xy^{10},y^{11}$

The coefficients used for the rectangular polynomial phase terms are coefficients C12 through C89. The "x" and "y" terms in the equations are the "x" and "y" ray coordinates at the lens database surface. The phase, in terms of OPD in lens units with respect to the construction wavelength is added to the phase of the ray being traced. The final ray direction cosines are then modified appropriately. For example, if the current lens units are millimeters, then the phase $\Phi(x,y)$ will be in millimeters. Before this phase is added to the phase of the diffracted ray, it is further modified by the following equation:

$$\Delta OPD = \frac{\Phi(x, y) \times m \times \lambda_{playback}}{\lambda_{construction}}$$

"m" is the diffraction order number. λplayback is the wavelength of the ray being traced. When a ray is traced through a diffractive phase surface, the delta optical path length is added to the optical path length of the ray according to the following equation:

$$OPL = OPL_{(original)} + \Delta OPL_{(added)}$$

When C11 is set to 7 and user-defined added phase is in effect, the values of the coefficients #1 through #96 are passed via general purpose storage registers 201 through 296. Coefficients C12 through C96 may be used to pass additional information to the macro function. The current X-ray coordinate is passed via the X-register and the current Y-ray value is passed via the Y-register. The surface number is passed via the T-register. The LASTX-register remembers the previous value of the X-register as usual. All data passing is performed automatically by the program. When using a user-defined phase to model a diffraction grating, the magnitude of the gradient of the phase divded into the HOE construction wavelength (represented in lens units) is equal to the grating spacing in lens units. It is not the intent here to teach HOE theory. Please refer to the paper by W. T. Welford, *Opt. Comm.*, Vol. 14, No.3, pp. 322-323 (1975) for HOE theory and modeling details.

THE TYPE 13 SPECIAL SURFACE (HOE-R) - The TYPE 13 special surface is a Holographic Optical Element-Real Rays (HOE-R). This type of HOE is valid only at the main (config#1) lens configuration. This is superior to the technique in other codes because real ray aiming is used throughout the ray trace process. The HOE diffraction equation used for ray tracing is just:

$$\mathbf{n} \times \left(\mathbf{r}_o' - \mathbf{r}_r'\right) = \frac{m\lambda'}{\lambda}\mathbf{n} \times \left(\mathbf{r}_o - \mathbf{r}_r\right)$$

where:

m	is the order number for diffraction	
n	is the surface normal unit vector	
r$_o$	is the unit vector along construction beam 1 (sometimes referred to as the construction object point ray or just the object ray)	
r$_r$	is the unit vector along construction beam 2 (sometimes referred to as the construction reference point ray or just the reference ray)	
r'$_o$	is the unit vector along the diffracted ray (sometimes called the image ray)	
r'$_r$	is the unit vector along the incident ray (sometimes called the readout ray or reconstruction ray)	
λ'	is the end-use or play back wavelength (wavelength at which ray is traced through HOE)	
λ	is the construction wavelength	

Coefficient C1 = order number
Coefficient C2 = construction wavelength in microns
Coefficient C3 = X-coordinate of the source point (default 0.0)
Coefficient C4 = Y-coordinate of the source point (default 0.0)
Coefficient C5 = Z-coordinate of the source point (default 0.0)
Coefficient C6 = +1 if the source point ray trace is to be interpreted as initially tracing into the +Z direction and is equal to –1 if the source point ray trace is to be interpreted as initially tracing into the –Z direction.
Coefficient C7 = +1 if the source beam is to be considered to be "real" and -1 if it is to be considered "virtual"
Coefficient C8 = X-coordinate of the reference point (default 0.0)
Coefficient C9 = Y-coordinate of the reference point (default 0.0)
Coefficient C10 = Z-coordinate of the reference point (default 0.0)
Coefficient C11 = +1 if the reference point ray trace is to be interpreted as initially tracing into the +Z direction and is equal to –1 if the reference point ray trace is to be interpreted as initially tracing into the –Z direction
Coefficient C12 = +1 if the reference beam is to be considered to be "real" and -1 if it is to be considered "virtual".
Coefficient C13   = alternate lens configuration for the source point definition (source point configuration)
Coefficient C14 = alternate lens configuration for the reference point definition (reference point configuration)
During lens scaling, none of the coefficients are scaled. The coordinates of the source and reference rays are always understood to be represented in the local coordinate system of the HOE-R surface.
Unexpected and non-physically real results will occur if:

1.   If the effective source and reference points are on the same side of the HOE-R and the glass type is REFL;
2. If the effective source and reference points are on opposite sides of the HOE-R and the glass type is not REFL;
3. If the effective source and reference points are located at the HOE-R surface.
During ray tracing, when the ray in the main lens configuration (configuration #1) reaches a HOE-R type of surface, an internal program flag is set at which time the following things happen automatically:

SPECIAL SURFACE SECTION

1. The ray trace data of the ray at the HOE-R surface are remembered. The x, y and z-coordinates of the ray are called X_0, Y_0 and Z_0.

2. A ray is traced from the object point specified by C3, C4 and C5 in the alternate lens configuration specified by C13 to final surface. This ray is aimed such that it strikes the final surface of this alternate configuration at X_0, Y_0 and Z_0. This is the construction ray. Its direction vector is remembered as: $\mathbf{r_o}$. No differential ray data is generated for this ray. Real ray aiming is used. The object distance in this configuration must be greater than zero.

3. A ray is traced from the object point specified by C8, C9 and C10 in the alternate lens configuration specified by C14 to final surface. This ray is aimed such that it strikes the final surface of this alternate configuration at X_0, Y_0 and Z_0. This is the construction ray. Its direction vector is remembered as: $\mathbf{r_r}$. No differential ray data is generated for this ray. Real ray aiming is used. The object distance in this configuration must be greater than zero.

4. The lens is then returned to the main configuration and the original ray is traced through the HOE using the vector data stored in $\mathbf{r_o}$ and $\mathbf{r_r}$. This is done for all rays including differential rays.

The process of generating a HOE "on the fly" must be done with the knowledge that the rays trace more slowly than in a type 12 special surface. The constructional parameters in the CFGs specified in C13 and C13 can be used as optimization variables while the merit function is made up of operand values only calculated in the main CFG. Direction of the traced rays in the two alternate configurations. If coefficient C6 or C11 is positive, the construction or reference rays are assumed to be initially trace in the positive Z direction, "left to right". If the coefficients are negative, the rays are assumed to be initially traced in the negative Z direction, "right to left". This convention keeps the user from needing to set an alternate configuration up "backward". Since the HOE-R surface is represented by the final surfaces in configurations C13 and C14, if there is a curvature or other non-flat definition on the HOE-R surface, it should also be represented in the alternate configurations. It is not the intent here to teach HOE theory. Please refer to the paper by W. T. Welford, *Opt. Comm.*, Vol. 14, No.3, pp. 322-323 (1975) for HOE theory and modeling details.

THE TYPE 14 SPECIAL SURFACE (Aberration Polynomial) - -The TYPE 14 special surface is a 48-term aberration polynomial defined by the following equation:

$$Z(x,y) = SAG(x,y) + \sum_{n=1}^{48} C_n Z_n(\rho,\theta)$$

where:

$$\rho = \sqrt{(x^2 + y^2)}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

SAG(x,y) is the original surface sag due to radius, conic, aspheric terms, etc.
(All ambiguities in θ are resolved in the program internals)

and:

$$
\begin{aligned}
&Z_1(\rho,\theta) = 1 && \{\text{constant}\} \\
&Z_2(\rho,\theta) = \rho\cos(\theta) && \{\text{x-tilt}\} \\
&Z_3(\rho,\theta) = \rho\sin(\theta) && \{\text{y-tilt}\} \\
&Z_4(\rho,\theta) = \rho^2 && \{\text{focus}\} \\
&Z_5(\rho,\theta) = \rho^2\cos(2\theta) && \{\text{0 degree astigmatism (3rd)}\} \\
&Z_6(\rho,\theta) = \rho^2\sin(2\theta) && \{\text{45 degree astigmatism (3rd)}\} \\
&Z_7(\rho,\theta) = \rho^3\cos(\theta) && \{\text{x-coma (3rd)}\} \\
&Z_8(\rho,\theta) = \rho^3\sin(\theta) && \{\text{y-coma (3rd)}\} \\
&Z_9(\rho,\theta) = \rho^3\cos(3\theta) && \{\text{x-clover (3rd)}\} \\
&Z_{10}(\rho,\theta) = \rho^3\sin(3\theta) && \{\text{y-clover (3rd)}\} \\
&Z_{11}(\rho,\theta) = \rho^4 && \{\text{spherical (3rd)}\} \\
&Z_{12}(\rho,\theta) = \rho^4\cos(2\theta) && \{\text{0 degree astigmatism (5th)}\} \\
&Z_{13}(\rho,\theta) = \rho^4\sin(2\theta) && \{\text{45 degree astigmatism (5th)}\} \\
&Z_{14}(\rho,\theta) = \rho^4\cos(4\theta) && \\
&Z_{15}(\rho,\theta) = \rho^4\sin(4\theta) && \\
&Z_{16}(\rho,\theta) = \rho^5\cos(\theta) && \{\text{x-coma (5th)}\} \\
&Z_{17}(\rho,\theta) = \rho^5\sin(\theta) && \{\text{y-coma (5th)}\} \\
&Z_{18}(\rho,\theta) = \rho^5\cos(3\theta) && \{\text{x-clover (5th)}\} \\
&Z_{19}(\rho,\theta) = \rho^5\sin(3\theta) && \{\text{y-clover (5th)}\} \\
&Z_{20}(\rho,\theta) = \rho^5\cos(5\theta) && \\
&Z_{21}(\rho,\theta) = \rho^5\sin(5\theta) &&
\end{aligned}
$$

$$Z_{22}(\rho,\theta) = \rho^6 \qquad\qquad \{\text{spherical (5th)}\}$$
$$Z_{23}(\rho,\theta) = \rho^8 \qquad\qquad \{\text{spherical (7th)}\}$$
$$Z_{24}(\rho,\theta) = \rho^{10} \qquad\qquad \{\text{spherical (9th)}\}$$
$$Z_{25}(\rho,\theta) = \rho^6\cos(2\theta) \qquad\qquad \{\text{0 degree astigmatism (7th)}\}$$
$$Z_{26}(\rho,\theta) = \rho^6\sin(2\theta) \qquad\qquad \{\text{45 degree astigmatism (7th)}\}$$
$$Z_{27}(\rho,\theta) = \rho^6\cos(4\theta)$$
$$Z_{28}(\rho,\theta) = \rho^6\sin(4\theta)$$
$$Z_{29}(\rho,\theta) = \rho^6\cos(6\theta)$$
$$Z_{30}(\rho,\theta) = \rho^6\sin(6\theta)$$
$$Z_{31}(\rho,\theta) = \rho^7\cos(\theta) \qquad\qquad \{\text{x-coma (7th)}\}$$
$$Z_{32}(\rho,\theta) = \rho^7\sin(\theta) \qquad\qquad \{\text{y-coma (7th)}\}$$
$$Z_{33}(\rho,\theta) = \rho^7\cos(3\theta) \qquad\qquad \{\text{x-clover (7th)}\}$$
$$Z_{34}(\rho,\theta) = \rho^7\sin(3\theta) \qquad\qquad \{\text{y-clover (7th)}\}$$
$$Z_{35}(\rho,\theta) = \rho^7\cos(5\theta)$$
$$Z_{36}(\rho,\theta) = \rho^7\sin(5\theta)$$
$$Z_{37}(\rho,\theta) = \rho^7\cos(7\theta)$$
$$Z_{38}(\rho,\theta) = \rho^7\sin(7\theta)$$

$$Z_{39}(\rho,\theta) = \rho^8\cos(2\theta) \qquad\qquad \{\text{0 degree astigmatism (9th)}\}$$
$$Z_{40}(\rho,\theta) = \rho^8\sin(2\theta) \qquad\qquad \{\text{45 degree astigmatism (9th)}\}$$
$$Z_{41}(\rho,\theta) = \rho^8\cos(4\theta)$$
$$Z_{42}(\rho,\theta) = \rho^8\sin(4\theta)$$
$$Z_{43}(\rho,\theta) = \rho^8\cos(6\theta)$$
$$Z_{44}(\rho,\theta) = \rho^8\sin(6\theta)$$
$$Z_{45}(\rho,\theta) = \rho^8\cos(8\theta)$$
$$Z_{46}(\rho,\theta) = \rho^8\sin(8\theta)$$
$$Z_{47}(\rho,\theta) = \rho^{12} \qquad\qquad \{\text{spherical (11th)}\}$$
$$Z_{48}(\rho,\theta) = \rho^{14} \qquad\qquad \{\text{spherical (13th)}\}$$

THE TYPE 15 SPECIAL SURFACE (Aberration Polynomial Phase) - The TYPE 15 special surface is a 48-term aberration polynomial similar to a TYPE 14 surface, except that the polynomial represents a variation in phase rather than surface profile. It may only be applied to a flat dummy surface. It is defined by the following equation:

$$\Phi(x,y) = \sum_{n=1}^{48} C_n Z_n(\rho,\theta)$$

where:

$$\rho = \sqrt{\left(x^2 + y^2\right)}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

All ambiguities in θ are resolved in the program internals. The phase, in terms of OPD with respect to the control wavelength, is added to the phase of the ray being traced. The ray direction cosines are modified appropriately. The terms Z1 to Z48 are the same as those listed in the TYPE 14 surface description.

THE TYPE 16 SPECIAL SURFACE (FRESNEL) - The TYPE 16 special surface is either a rotationally symmetric or a cylindrical FRESNEL surface. In FRESNEL surfaces, fresnel zones are considered to be small. This is not a good approximation to surfaces with large, deep zones as are found in some illumination systems. It is a good approximation for surfaces which have many small, shallow zones.

ROTATIONALLY SYMMETRIC CASE - If the surface upon which a TYPE 16 special surface definition is placed is not defined as a toric surface in the lens database, then base surface profile is considered to be rotationally symmetric about the surface local Z-axis. The profile is determined by the curvature and optionally the conic constant values set in the lens database. The surface profile, therefore, may be a flat, a sphere or a conic. The fresnel zones will be circular with their center at the surface vertex.

CYLINDRICAL CASE - If the surface upon which a TYPE 16 special surface definition is placed is defined as an X or Y-toric surface in the lens database, then base surface profile is considered to be cylindrical. The cylinder orientation and profile are determined by the toric type definition (X or Y-toric), the toric curvature and optionally the toric conic constant set in the lens database. The surface curvature, conic constant and surface aspheric terms will be considered to be equal to zero for all ray tracing. The surface profile, therefore, may be a flat, a cylinder or a conic profile cylinder. The fresnel zone boundaries will be linear rather than circular and they will be parallel to the axis of the cylinder. For a Y-toric, the zone boundaries will be considered to be parallel to the local Y-axis of the surface. For an X-toric, the zone boundaries will be considered to be parallel to the local X-axis of the surface. During the ray trace, the surface curvature and conic constant (rotationally symmetric case) or toric type, toric curvature and toric conic constant (cylinder case) only determine the intersection coordinates of the ray with the surface. After these intersection coordinates are computed, the direction cosines of the surface normal are calculated by assuming that the shape is described by the equation below:

$$Z(x,y) = \frac{c_1\rho^2}{1 + \sqrt{1 - (c_2 + 1)c_1^2\rho^2}} + c_3\rho^4 + c_4\rho^6 + c_5\rho^8 + c_6\rho^{10} + c_7\rho^{12} + c_8\rho^{14} + c_9\rho^{16} + c_{10}\rho^{18} + c_{11}\rho^{20}$$

where:

$$\rho = \sqrt{(x^2 + y^2)}$$

Rotationally Symmetric Case (Non-Toric)

$$\rho = x$$

Y-Toric Surface Profile Cylinder

$$\rho = y$$

X-Toric Surface Profile Cylinder

Coefficient C2 has no effect if coefficient C1 is 0.0. The CMD level "SAG" commands, output only the base surface profile and ignore the special surface coefficients which define the surface slope.

THE TYPE 17 SPECIAL SURFACE (User-Defined #2) -The TYPE 17 special surface is a user-defined surface defined by the following equation:

$$Z(x,y) = Z - \text{register}$$
$$L(x,y) = IX - \text{register}$$
$$M(x,y) = IY - \text{register}$$
$$N(x,y) = IZ - \text{register}$$

The TYPE 17 special surface is a second user-defined surface type. Unlike the TYPE 5 user-defined surface, the TYPE 17 user-defined surface ignores all non-special surface characteristics such as curvature, conic constant, aspheric deformation coefficients, toric definitions or anamorphic coefficients. The TYPE 17 special surface may use none, any or all of the special surface coefficients C1 to C96. The surface sag, Z, is defined by the user in macro function FUN10. If FUN10 does not exist, the sag is 0.0. If FUN10 exists, the surface sag will be whatever is left in the Z-storage register after FUN10 finishes its execution. FUN10 may not call any other macros or macro functions when used in special surface definitions. Unlike other surface types, the user must explicitly define the surface normal direction cosines in the macro function FUN10. The L, M and N direction cosines must be placed in registers IX, IY and IZ. If FUN10 does not exist, these values will be assumed to be 0.0, 0.0 and 1.0 respectively. The values of the 96 coefficients are passed via general purpose storage registers 301 through 396. The current X-ray coordinate is passed via the X-register and the current Y-ray value is passed via the Y-register. The surface number is passed via the T-register. The LASTX-register remembers the previous value of the X-register as usual.

THE TYPE 18 SPECIAL SURFACE (Grazing Incidence Surface) - The TYPE 18 special surface is a grazing incidence optical surface. The TYPE 18 surface assignment causes the ray trace algorithm to be modified so as to minimize any numerical problems which could occur when rays intersect and reflect from a surface at near grazing incidence. The TYPE 18 special surface also provides a capability to represent surface deformations in terms of 15 Fourier-Legendre polynomials. The type 18 special surface can only be assigned to a surface which is spherical or conic in profile and which is a mirror (material defined by the "REFL" command). The TYPE 18 coefficients have the following meaning:

COEFFICIENT	MEANING
C1	Forward, most negative Z-coordinate which corresponds to the location of the entrance edge of the surface clear aperture which is closest to the object surface. This is called Z_1. Negative values lie to the left of the surface vertex and positive values lie to the right. (This value is also used during surface profile and clear aperture plotting).
C2	Rear, most positive Z-coordinate which corresponds to the location of the exit edge of the surface clear aperture which is closest to the image surface. This is called Z_2. Negative values lie to the left of the surface vertex and positive values lie to the right. (This value is also used during surface profile and clear aperture plotting).
C3	Central Z-coordinate which is measured from the surface vertex and acts as the z-offset for ray tracing. This is called Z_0. Negative values lie to the left of the surface vertex and positive values lie to the right.
C4	Fourier-Legendre coefficient #1 (n=0, m=0) COS
C5	Fourier-Legendre coefficient #2 (n=1, m=0) COS
C6	Fourier-Legendre coefficient #3 (n=2, m=0) COS
C7	Fourier-Legendre coefficient #4 (n=0, m=1) COS
C8	Fourier-Legendre coefficient #5 (n=0, m=1) SIN
C9	Fourier-Legendre coefficient #6 (n=1, m=1) SIN
C10	Fourier-Legendre coefficient #7 (n=1, m=1) COS
C11	Fourier-Legendre coefficient #8 (n=2, m=1) SIN
C12	Fourier-Legendre coefficient #9 (n=2, ,m=1) COS
C13	Fourier-Legendre coefficient #10 (n=0, m=2) COS
C14	Fourier-Legendre coefficient #11 (n=0, m=2) SIN
C15	Fourier-Legendre coefficient #12 (n=1, m=2) COS
C16	Fourier-Legendre coefficient #13 (n=1, m=2) SIN
C17	Fourier-Legendre coefficient #14 (n=2, m=2) COS
C18	Fourier-Legendre coefficient #15 (n=2, m=2) SIN

The Fourier-Legendre polynomials are given by:

$$G_{n0} = \sqrt{2n + 1} \times P_n(\zeta)$$

$$G_{nm}^C = \sqrt{2(2n + 1)} \times P_n(\zeta) \times \cos(m\theta)$$

$$G_{nm}^S = \sqrt{2(2n + 1)} \times P_n(\zeta) \times \sin(m\theta)$$

where:

$$\zeta = \frac{2(z - z_0)}{(z_2 - z_1)}$$

and:

$$-1 \leq \zeta \leq 1$$

and when z lies to the left of z_0 then ζ is negative.

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

The first three Legendre polynomials, $P_n(\zeta)$, are:

$$P_0(\zeta) = 1$$

$$P_1(\zeta) = \zeta$$

$$P_2(\zeta) = \frac{(3\zeta^2 - 1)}{2}$$

SPECIAL SURFACE SECTION

The terms used are:

TERM #	n	m	COS or SIN
1	0	0	COS
2	1	0	COS
3	2	0	COS
4	0	1	COS
5	0	1	SIN
6	1	1	COS
7	1	1	SIN
8	2	1	COS
9	2	1	SIN
10	0	2	COS
11	0	2	SIN
12	1	2	COS
13	1	2	SIN
14	2	2	COS
15	2	2	SIN

The technique of using these particular coefficients to model near cylindrical mirror deformations is described in detail by Paul Glenn, "Set of orthonormal surface error descriptors for near cylindrical optics", Optical Engineering ,July/August 1984, Vol. 23, No.4. The following figure illustrates the use of the first three TYPE 18 coefficients and the section of the surface to be used in the ray trace. If rays fall outside the area designated by the coefficients C1 and C2, the ray is considered to have failed for the purposes of spot diagram analysis.
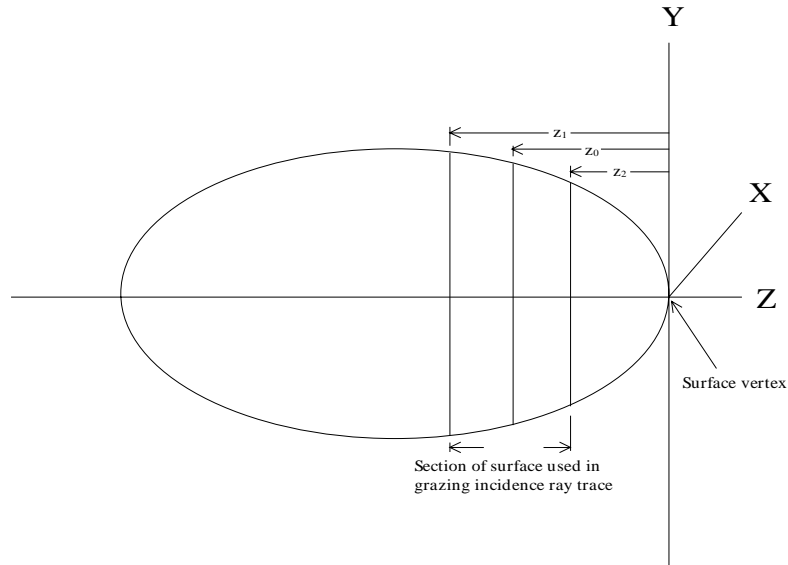
Surface Section in Grazing Ray Trace

The base radius of curvature or the curvature, the conic constant and the vertex position for the grazing incidence surface are set using the lens database commands described in the LENS section of this manual. There are several grazing incidence There are also dedicated grazing incidence CMD level commands in the CMD section of the manual.

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SPECIAL SURFACE SECTION

THE TYPE 19 SPECIAL SURFACE (Apodization Surface) - The TYPE 19 special surface is an grid aperture apodization type of surface which is defined over nxn data points using data stored in a specified ASCII disk file. The special surface coefficients have the following meaning.

COEFFICIENT	MEANING
C1	Integer value, 1 to 10. Designates that the file named APGRIDxx.DAT will be used as the source file for the apodization grid. The xx is replaced by the value of C1. If C1 = 23, then file APGRID23.DAT is used as the source file for the current apodization grid. If the file does not exist, then a single grid value for the entire surface will be assumed and will represent uniform, 100% transmission.
C2	Integer value greater than 0. C2 specifies the dimension "n" of the apodization grid. C2 = 10 would specify a 10 x 10 grid. Default value is 5. Minimum allowed value is 5.
C3	Clear aperture dimension, in current lens units, of the grid semi-extent at the assigned surface. This is equal to ½ of C2 times the x or y-grid point separation. If this input is left out, the default will be to apply the grid over a square area on the surface equal to twice the "inr" value at that surface. The "inr" value and the "INR" command are fully described in the LENS section of this manual.
C4	Scale factor for apodization data. Default value = 1.0

Apodization values are transmittance or reflectance values. There range is always 0.0 (no transmission or reflection) to 1.0 (100% transmission or reflection). The first point on the grid is at the grid point index $n_x=1$ and $n_y = 1$. This grid point will lie at the most negative location in x and y in the local coordinate system of the assigned surface. The final point in the grid, index $n_x=n$, $n_y=n$ will lie at the most positive location in x and y in the local coordinate system of the assigned surface. See the figure on the next page. If rays which have an apodization value assigned to them are blocked by any normal ray blocking (clear apertures, obscurations etc.) then the effective apodization factor for that ray becomes 0.0.

DATA FILE ENTRIES - There must be exactly C2xC2 lines in the file designated by the value C1. If there are not exactly that many lines, an error message will be issued, file input will be ignored and no apodization grid data will be assigned to the surface. Each file entry can be free form and each line consists of two integers and one floating point value. The integers can range from 1 to n and the floating point apodization values can range from 0.0 to 1.0. Any missing grid points in this file will be set to a transmission value of 1.0.

Example: File APGRID01.DAT with a 3x3 grid of apodization data:

1,1,0.1D0
1,2,0.5D0
1,3,0.1D0
2,1,0.5D0
2,2,1.0D0
2,3,0.5D0
3,1,0.1D0
3,2,0.5D0
3,3,0.1D0

SPECIAL SURFACE SECTION

The input values in each line of the file may be separated by spaces or commas. The file will be "list directed" read when the program reads it. Input is always x-index, y-index, apodization factor (integer, integer, double precision).
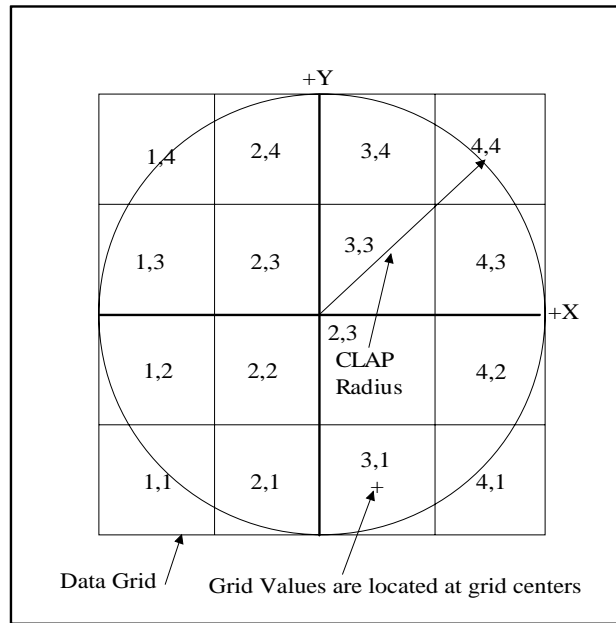
APOD Data Grid/Surface Relationship

The grid datum is always considered to be located at the center of a grid square. The above figure shows the grid counting system and relationship to the surface clear aperture for a 4x4 grid assigned to a surface. Grid square (1,1) is at the lower left. The value anywhere inside a grid square is interpolated from the value at the grid center using slope values which are automatically calculated based on apodization values at surrounding grid squares centers. If a ray falls inside a grid square, an apodization value is assigned to that ray unless the ray is blocked by a clear aperture or obscuration or unless the ray fails for some other reason. Rays which fall on grid square boundaries are assigned to a bordering grid square based upon a random "coin flip".

THE TYPE 20 SPECIAL SURFACE (Grid Phase Surface) - The TYPE 20 special surface is an grid OPD (Optical Path Difference) phase type of surface which is defined over nxn data points using data stored in a specified ASCII disk file. The special surface coefficients have the following meaning. It may only be applied to a flat dummy surface.

COEFFICIENT	MEANING
C1	Integer value, 1 to 10. Designates that the file named PHGRIDxx.DAT will be used as the source file for the phase grid. The xx is replaced by the value of C1. If C1 = 23, then file PHGRID23.DAT is used as the source file for the current phase grid. If the file does not exist, then a single grid value for the entire surface will be assumed and will represent zero phase.
C2	Integer value greater than 0. C2 specifies the dimension "n" of the SAG grid. C2 = 10 would specify a 10 x 10 grid. Default value is 5. Minimum allowed value is 5.
C3	Clear aperture dimension, in current lens units, of the grid semi-extent at the assigned surface. This is equal to ½ of C2 times the x or y-grid point separation. If this input is left out, the default will be to apply the grid over a square area on the surface equal to twice the "inr" value at that surface. The "inr" value and the "INR" command are fully described in the LENS section of this manual.
C4	Phase unit indicator: 0 = OPD phase in fractions of waves of the current reference wavelength. 1 = OPD in current lens units. 2 = OPD in microns.
C5	Scale factor for phase data. Default value = 1.0

The first point on the grid is at the grid point index $n_x=1$ and $n_y = 1$. This grid point will lie at the most negative location in x and y in the local coordinate system of the assigned surface. The final point in the grid, index $n_x=n$, $n_y=n$ will lie at the most positive location in x and y in the local coordinate system of the assigned surface. See the figure on the next page. Rays which are blocked or fail, have no phase term added to them. The phase in adjacent grid squares is used to calculate the "wavefront slope" which is used during the ray trace to "adjust" the direction cosines of the deviated ray.

DATA FILE ENTRIES - There must be exactly C2xC2 lines in the file designated by the value C1. If there are not exactly that many lines, an error message will be issued, file input will be ignored and no phase grid data will be assigned to the surface. Each file entry can be free form and each line consists of two integers and one floating point value. The integers can range from 1 to n and the floating point phase values which can take on any value. Any missing grid points in this file will be set to a phase = 0.0

Example: File PHGRID01.DAT with a 3x3 grid of phase data:

1,1,0.9D0
1,2,1.5D0
1,3,0.1D0
2,1,0.5D0
2,2,-.01D0
2,3,0.5D0
3,1,0.1D0
3,2,0.5D0
3,3,0.1D0

The input values in each line of the file may be separated by spaces or commas. The file will be "list directed" read when the program reads it. Input is always x-index, y-index, phase (integer, integer, double precision). The phase is added to the phase of the ray being traced. The ray direction cosines are modified appropriately in exactly the same manner as is done in other phase surfaces.
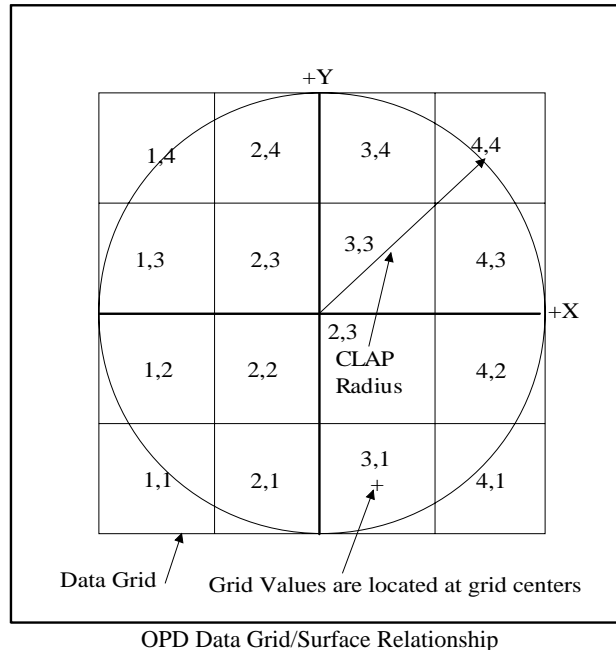
OPD Data Grid/Surface Relationship

The grid datum is always considered to be located at the center of a grid square. The above figure shows the grid counting system and relationship to the surface clear aperture for an 4x4 grid assigned to a surface. Grid square 1,1 is at the lower left. If a ray falls inside a grid square, a phase value is added to that ray unless the ray is blocked by a clear aperture or obscuration or unless the ray fails for some other reason. Rays which fall on grid square boundaries are assigned to a bordering grid square based upon a random "coin flip".

THE TYPE 21 SPECIAL SURFACE (User-defined Subroutine Surface) - The User-defined Subroutine Surface type of special surface, is a special surface definition which may be added to any other regular surface definition. It simulates the effects of complex, generalized surface shapes which are user-defined in the USERSURF.FOR subroutine. By default, the USERSURF.FOR subroutine is just an empty subroutine which does nothing until it is modified to do something, by the user. The USERSURF.FOR special surface subroutine may use any and all of the 96 special surface coefficients plus any of the general purpose storage registers.

THE TYPE 22 SPECIAL SURFACE (Grid SAG Surface) - The TYPE 22 special surface is a grid SAG type of surface which is defined over nxn data points using data stored in a specified ASCII disk file. The SAG value for the grid square in which the current ray lies is added to the SAG of the surface at that x,y due to curvatures, conics or aspheric non-special surface definitions. The added SAG must be represented in the local coordinate system of the surface to which the sag grid file it is being assigned. The SAG values in SAG grid file are assumed to be represented in the same units as the current lens file data.

$$Z(x,y) = SAG(x,y) + SAG_{grid}(x,y)$$

The special surface coefficients have the following meaning.

COEFFICIENT	MEANING
C1	Integer value, 1 to 10. Designates that the file named SGGRIDxx.DAT will be used as the source file for the SAG grid. The xx is replaced by the value of C1. If C1 = 23, then file SGRID23.DAT is used as the source file for the current SAG grid. If the file does not exist, then a single SAG grid value for the entire surface will be assumed and will represent zero SAG.
C2	Integer value greater than 0. C2 specifies the dimension "n" of the SAG grid. C2 = 10 would specify a 10 x 10 grid. Default value is 5. Minimum allowed value is 5.
C3	Clear aperture dimension, in current lens units, of the grid semi-extent at the assigned surface. This is equal to ½ of C2 times the x or y-grid point separation. If this input is left out, the default will be to apply the grid over a square area on the surface equal to twice the "inr" value at that surface. The "inr" value and the "INR" command are fully described in the LENS section of this manual.
C4	Scale factor for sag data. Default value = 1.0

The first point on the grid is at the grid point index $n_x=1$ and $n_y = 1$. This grid point will lie at the most negative location in x and y in the local coordinate system of the assigned surface. The final point in the grid, index $n_x=n$, $n_y=n$ will lie at the most positive location in x and y in the local coordinate system of the assigned surface. See the figure on the next page. The SAG in adjacent grid squares is used to calculate the surface direction cosine contributions from the grid SAG data.

DATA FILE ENTRIES - There must be exactly C2xC2 lines in the file designated by the value C1. If there are not exactly that many lines, an error message will be issued, file input will be ignored and no SAG grid data will be assigned to the surface. Each file entry can be free form and each line consists of two integers and one floating point value. The integers can range from 1 to n and the floating point SAG values can take on any value. Any missing grid points in this file will be set to a SAG = 0.0

Example: File SGGRID01.DAT with a 3x3 grid of SAG data:

1,1,0.9D0
1,2,1.5D0
1,3,0.1D0
2,1,0.5D0
2,2,-.01D0
2,3,0.5D0
3,1,0.1D0
3,2,0.5D0
3,3,0.1D0

The input values in each line of the file may be separated by spaces or commas. The file will be "list directed" read when the program reads it. Input is always x-index, y-index, sag (integer,integer,double precision). The SAG is added to the SAG of the base surface.

SPECIAL SURFACE SECTION
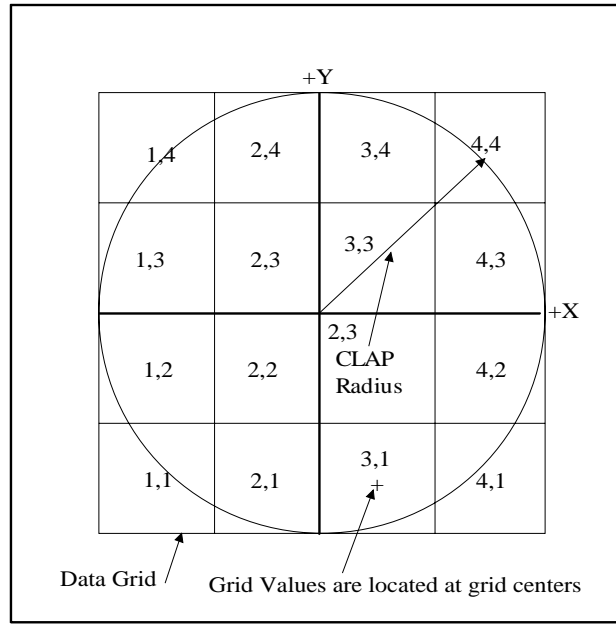
SAG Data Grid/Surface Relationship

The grid datum is always considered to be located at the center of a grid square. The above figure shows the grid counting system and relationship to the surface clear aperture for an 4x4 grid assigned to a surface. Grid square 1,1 is at the lower left. If a ray falls inside a grid square, a SAG value is added to that ray unless the ray is blocked by a clear aperture or obscuration or unless the ray fails for some other reason. Rays which fall on grid square boundaries are assigned to a bordering grid square based upon a random "coin flip".

THE TYPE 23 SPECIAL SURFACE (Cubic Spline) - The TYPE 23 special surface is a rotationally symmetric, normal, cubic spline surface. A normal cubic spline is one which has zero valued second derivatives at its end points. The surface is characterized by from 3 to 94 equally spaced spline input SAG data entries. The resultant surface sag is defined as:

$$Z(x,y) = SAG(x,y) + SAG_{spline}(\rho)$$

$$\rho = \sqrt{x^2 + y^2}$$

SAG(x,y) is the original surface SAG due to radius, conic, aspheric terms, etc. Coefficients C1 and C2 are not used for specifiying surface sag data points. Coefficient C1 is used to specify the number of equally spaced spline SAG data points including the 0,0,0 point at the surface vertex. Coefficient C2 is used to specify the reference radius value over which these data points are to be located. C1 has a default value of 0. If C1 has a value less than 3 at the time that rays are traced, then the cubic spline surface will have no effect during ray tracing. C2, if not input by the user, will be taken as the current "INR" value at that surface. The spline SAG data points are assumed to be arranged in assending radial order with C3 located at the local surface origin and the highest numbered coefficient being the most distant from the local surface origin. The sag value assigned to coefficient C3 Must always be zero or strange things will happen during ray tracing.

FOR EXAMPLE: If C1 is equal to 10, then the program will use coefficients C3 through C12 as the basis of the spline surface definition. The first data point will be located at the surface vertex. The 10th data point will be located at a radial distance equal to the value of C2 from the surface vertex.

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SPECIAL FUNCTION FITTING SECTION

SPFIT-GENERAL INFORMATION - The special function fitting, or SPFIT level, is used for fitting tabular data to predefined functional forms. The coefficients resulting from these data fits may either be displayed or, in some cases, assigned to a special surface functional form attached to a lens surface in the lens database through use of special surface definitions (see the SPSRF section of the manual for details regarding these assignments). All fitting is done using a least squares fitting routine. The resulting normal equations are solved using a single-value decomposition routine which avoids the problem of inverting a singular or near singular matrix.

SPFIT COMMANDS

SPFIT - The "SPFIT" command is issued at the CMD level. It causes the program to enter the SPFIT sub-level where the rest of the SPFIT commands may be issued.

TYPE , i - The "TYPE" command is used when numerical data is to be fit to a functional form without the coefficients of the fit being automatically assigned to a lens database surface. The numerical input value "i" designates the type of functional form to be used for the current fit. The functional forms associated with values of "i" are identified in the table of contents for this section. Detailed descriptions of each functional form are found at the end of this section.

SURF , i - The "SURF" command is used when numerical data is to be fit to a functional form with the coefficients of that fit being automatically assigned to a lens database surface. The numerical input value "i" designates the surface number of the surface to which the fit coefficients are to be assigned. The special surface type, which must already have been assigned to the desired surface using SPSRF program level commands, defines the functional form of the fit. See the SPSRF section for a listing of the current special surface types. Either the "TYPE" command or the "SURF" command must be the first command issued following the "SPFIT" command. Special surface types 2, 3, 7, 8, 9, 10, 14 and 15 may be entered as surface types during fitting. Special surface types 2 and 9 will be fit using functional form TYPE 1. Special surface types 2 and 9 will be fit using functional form 2. Special surface types 3 and 10 will be fit using functional form 3. Special surface types 7 and 8 will be fit using functional form 4. Special surface types 14 and 15 will be fit using functional form 5. When special surface fitting to special surface types 2, 3, 9, 10, 14 and 15, the x and y-inputs to the fit must be relative coordinates on a circle with unit (1.0) radius. The "inr" value associated with the lens database surface will be used to automatically scale these relative coordinates to true physical coordinates on the surface before a ray is traced.

COEF , i , j , value - The "COEF" command is used in order to designate that coefficient number "i" should either be included in the current fit using "j" = 1 or omitted from the current fit "j" = 0. The default "j" value for all coefficients is 0. This command must precede data input and data fitting and should follow either the "TYPE" command or the "SURF" command. For the "data fitting" process, the coefficient "value" will normally not be entered explicitly. Entry of explicit coefficient values, using the "value" entry, is normally performed only when values of a function associated with a predetermined set of coefficients need to be calculated in the absence of an actual "data fit". Although the program has a provision for a total of 96 coefficients, not all coefficients apply to all functional forms or special surface types.

DATA , y , x , fn , wt - The "DATA" command is used to enter data which will be used in the fitting process. The functional value is "fn". It is assumed to be associated with variables "y" and "x". A weighting factor "wt" may be included, if desired. The default value for the "wt" is 1.0. Up to 2000 data entries may be input for fitting.

READ - The "READ" command is used to read data which will be used in the fitting process from the file "DATA.DAT". This file must only be a series of data statements. The file is an ASCII file, and it should be placed in the same directory which contains the "PROGRAM.EXE" file. Misreads due to input errors will cause the read to abort with an error message. The program will be left in the SPFIT level. This "READ" method provides a method of preparing large amounts of data outside the main program which then may be fitted from within the program. The same limit of 2000 data entries applies as in the description of the "DATA" command. The data must be all explicitly input in decimal form including the weights, "wt", even if the weights are all 1.0. A valid line in the file might look like:

<p align="center">DATA 1.23 3.238 4.3 1.0</p>

The data in the file "DATA.DAT" is read as list directed input as a sequence of SPFIT "DATA" commands.

FIT - The "FIT" command is used to initiate the least squares fitting process and the calculation of the coefficients.

LIST - The "LIST" command is used to list the input function, the fitted function and the fitting error. The functional values are tabulated for the set of input data points "y" and "x". The "LIST" command must be entered after the "FIT" command.

COEFS - The "COEFS" command is used to list the resulting coefficients of the current fit, in groups of four.

LISTCOEF - The "LISTCOEF" command is used to list the resulting coefficients of the current fit, one per line in D23.15 format.

EVAL , y , x - The "EVAL" command is used to evaluate the fitted function at the point y = "y" and x = "x". The evaluated functional value is displayed and placed into the accumulation (X-register).

EOS or **END** - The "EOS" or "END" command is used to exit the SPFIT level and return the program to the CMD level. When performing Zernike Polynomial to data which is to be attached to a surface, that surface **MUST NOT** have an elliptical, racetrack, square or rectangular clear aperture assigned to it. The clear aperture must be circular.

FITTING GLASS INDEX DATA - The following two special SPFIT fitting commands are used exclusively in the process of fitting wavelength versus refractive index data to the SCHOTT index interpolation equation and then automatically assigning that data to the user defined glass catalog contained in the file USER.DAT. The USER.DAT file assumes that the user-defined glass is represented by the SCHOTT index interpolation equation:

$$n^2 = A_0 + A_1*\lambda^2 + A_2*\lambda^{-2} + A_3*\lambda^{-4} + A_4*\lambda^{-6} + A_5*\lambda^{-8}$$

Using a TYPE 1 functional form, these six coefficients A0 to A5 are represented by the TYPE 1 function coefficients C9, C11, C1, C3, C5 and C7 respectively. In order to utilize all six coefficients in the fit, at least six unique wavelength/index data pairs will be needed. If fewer than six unique pairs of data are available, then fewer coefficients should be used in the fitting process. Some experimentation may be necessary in determining which sub-set of these six coefficients works best in this reduced data situation.

FITGLASS (glass name) - The "FITGLASS" command is used to initiate the calculation of the index interpolation coefficients and the automatic assignment of these six coefficients to a USER-DEFINED glass, named (glass name) in the file USER.DAT. (glass name) may be any glass name up to 8 characters in length. The "FITGLASS" command, in all other ways, acts as the "FIT" command does. An example of fitting glass data to a user-defined glass type is given at the end of this section.

GDATA , λ , refractive index - The "GDATA" command is used to enter wavelength and refractive index data which will be used in the user-defined index fitting process. "λ" is always the wavelength in microns. Up to 200 data pairs may be input for fitting. The user-defined glass type, which is discussed in the LENS section of this manual, provides a way for the user to enter wavelength/index coefficients for any optical material for which the older SCHOTT type of index interpolation coefficients are known. If the coefficients are not known, but if pairs of wavelength/index values are known, the following procedure (presented as a macro named GLFITTER) can be used to automatically generate a new entry in the user-defined glass catalog data file USER.DAT. In this example, glass data for SCHOTT BK7 glass will be fit to the SCHOTT interpolation equation and then a new user-defined glass named MYBK7 will be automatically added to the file USER.DAT.

User defined glass fitting example:
(This macro may be copied from this manual, saved as an ASCII text file, copied to the EDITTEXT.DAT file and then read into the program with the "INPUT ED" command. These actions will cause the macro GLFITTER to be added to the MACRO library of the program from which it may be run by typing the command "GLFITTER".)

```
MACRO GLFITTER
C, Get into SPFIT
SPFIT
M, Set the function type to #1
TYPE , 1
C, The next six lines set the desired coefficients to "ON" for the fit
COEF,9,1
COEF,11,1
COEF,1,1
COEF,3,1
COEF,5,1
COEF,7,1
C, Enter the wavelength versus index data items
GDATA,0.3126,1.54862
GDATA,0.3341,1.54272
GDATA,0.3650,1.53627
GDATA,0.4047,1.53024
GDATA,0.4358,1.52668
GDATA,0.4800,1.52283
GDATA,0.4861,1.52238
GDATA,0.5461,1.51872
GDATA,0.5876,1.51680
GDATA,0.5893,1.51673
GDATA,0.6328,1.51509
GDATA,0.6438,1.51472
GDATA,0.6563,1.51432
GDATA,0.7065,1.51289
```

To list the new contents of the user-defined glass catalog, simple type GLASSP USER from the CMD level. The USER.DAT file is a simple ASCII file. If a glass needs to be removed from the file, use a text editor to edit and modify the file USER.DAT which is located in the main program directory. When the USER.DAT file is used by the program, the first entry with a given glass name will be used. If duplicate glass names exist, only the first entry with a duplicated name will be available to the ray trace.

THE TYPE 1 FUNCTIONAL FORM - The TYPE 1 functional form and special surface types 1 and 6 are of a rotationally symmetric polynomial form defined by the following equation:

$$fn(x, y) = \sum_{n=-8}^{39} \left\{ C_{n+9} \left[\sqrt{(x^2 + y^2)} \right]^n \right\}$$

Care should be taken when using this functional form for fitting data for which the term

$$\left[\sqrt{(x^2 + y^2)} \right]$$

takes on a zero value. In those cases, do not fit with coefficients C1 through C8.

THE TYPE 2 FUNCTIONAL FORM - The TYPE 2 functional form and special surface types 2 and 9 are of a Zernike polynomial form of 30 terms defined by the following equation:

$$fn(\rho, \theta) = \sum_{n=1}^{30} C_n Z_n(\rho, \theta)$$

where:

$$\rho = \sqrt{(x^2 + y^2)}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

and:

$$Z_1(\rho, \theta) = 1 \quad \text{\{constant\}}$$
$$Z_2(\rho, \theta) = \rho \cos(\theta) \quad \text{\{x-tilt\}}$$
$$Z_3(\rho, \theta) = \rho \sin(\theta) \quad \text{\{y-tilt\}}$$
$$Z_4(\rho, \theta) = \rho^2 \cos(2\theta) \quad \text{\{0 degree astigmatism\}}$$
$$Z_5(\rho, \theta) = 2\rho^2 - 1 \quad \text{\{focus + constant\}}$$
$$Z_6(\rho, \theta) = \rho^2 \sin(2\theta) \quad \text{\{45 degree astigmatism\}}$$
$$Z_7(\rho, \theta) = \rho^3 \cos(3\theta) \quad \text{\{x-clover\}}$$
$$Z_8(\rho, \theta) = (3\rho^3 - 2\rho) \cos(\theta)$$
$$Z_9(\rho, \theta) = (3\rho^3 - 2\rho) \sin(\theta)$$
$$Z_{10}(\rho, \theta) = \rho^3 \sin(3\theta) \quad \text{\{y-clover\}}$$
$$Z_{11}(\rho, \theta) = \rho^4 \cos(4\theta)$$
$$Z_{12}(\rho, \theta) = (4\rho^4 - 3\rho^2) \cos(2\theta)$$
$$Z_{13}(\rho, \theta) = 6\rho^4 - 6\rho^2 + 1$$
$$Z_{14}(\rho, \theta) = (4\rho^4 - 3\rho^2) \sin(2\theta)$$
$$Z_{15}(\rho, \theta) = \rho^4 \sin(4\theta)$$
$$Z_{16}(\rho, \theta) = \rho^5 \cos(5\theta)$$
$$Z_{17}(\rho, \theta) = (5\rho^5 - 4\rho^3) \cos(3\theta)$$
$$Z_{18}(\rho, \theta) = (10\rho^5 - 12\rho^3 + 3\rho) \cos(\theta)$$

$Z_{19}(\rho,\theta) = (10\rho^5 - 12\rho^3 + 3\rho)\sin(\theta)$

$Z_{20}(\rho,\theta) = (5\rho^5 - 4\rho^3)\sin(3\theta)$

$Z_{21}(\rho,\theta) = \rho^5 \sin(5\theta)$

$Z_{22}(\rho,\theta) = \rho^6 \cos(6\theta)$

$Z_{23}(\rho,\theta) = (6\rho^6 - 5\rho^4)\cos(4\theta)$

$Z_{24}(\rho,\theta) = (15\rho^6 - 20\rho^4 + 6\rho^2)\cos(2\theta)$

$Z_{25}(\rho,\theta) = 20\rho^6 - 30\rho^4 + 12\rho^2 - 1$

$Z_{26}(\rho,\theta) = (15\rho^6 - 20\rho^4 + 6\rho^2)\sin(2\theta)$

$Z_{27}(\rho,\theta) = (6\rho^6 - 5\rho^4)\sin(4\theta)$

$Z_{28}(\rho,\theta) = \rho^6 \sin(6\theta)$

$Z_{29}(\rho,\theta) = 70\rho^8 - 140\rho^6 + 90\rho^4 - 20\rho^2 + 1$

$Z_{30}(\rho,\theta) = 252\rho^{10} - 630\rho^8 + 560\rho^6 - 210\rho^4 + 30\rho^2 - 1$

THE TYPE 3 FUNCTIONAL FORM - The TYPE 3 functional form and special surface types 3 and 10 are of a the 37-term Fringe Zernike polynomial form defined by the following equation:

$$fn(\rho,\theta) = \sum_{n=1}^{37} C_n Z_n(\rho,\theta)$$

where:

$$\rho = \sqrt{\left(x^2 + y^2\right)}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

and:

$Z_1(\rho,\theta) = 1$ {constant }

$Z_2(\rho,\theta) = \rho\cos(\theta)$ {x-tilt}

$Z_3(\rho,\theta) = \rho\sin(\theta)$ {y-tilt}

$Z_4(\rho,\theta) = 2\rho^2 - 1$ {focus + constant}

$Z_5(\rho,\theta) = \rho^2\cos(2\theta)$ {0 degree astigmatism}

$Z_6(\rho,\theta) = \rho^2\sin(2\theta)$ {45 degree astigmatism}

$Z_7(\rho,\theta) = (3\rho^3 - 2\rho)\cos(\theta)$

$Z_8(\rho,\theta) = (3\rho^3 - 2\rho)\sin(\theta)$

$Z_9(\rho,\theta) = 6\rho^4 - 6\rho^2 + 1$

$Z_{10}(\rho,\theta) = \rho^3\cos(3\theta)$ {x-clover}

$Z_{11}(\rho,\theta) = \rho^3\sin(3\theta)$ {y-clover}

$Z_{12}(\rho,\theta) = (4\rho^4 - 3\rho^2)\cos(2\theta)$

$Z_{13}(\rho,\theta) = (4\rho^4 - 3\rho^2)\sin(2\theta)$

$Z_{14}(\rho,\theta) = (10\rho^5 - 12\rho^3 + 3\rho)\cos(\theta)$

$Z_{15}(\rho,\theta) = (10\rho^5 - 12\rho^3 + 3\rho)\sin(\theta)$

$Z_{16}(\rho,\theta) = 20\rho^6 - 30\rho^4 + 12\rho^2 - 1$

$Z_{17}(\rho,\theta) = \rho^4\cos(4\theta)$

$Z_{18}(\rho,\theta) = \rho^4\sin(4\theta)$

$Z_{19}(\rho,\theta) = (5\rho^5 - 4\rho^3)\cos(3\theta)$

$Z_{20}(\rho,\theta) = (5\rho^5 - 4\rho^3)\sin(3\theta)$

$Z_{21}(\rho,\theta) = (15\rho^6 - 20\rho^4 + 6\rho^2)\cos(2\theta)$

$Z_{22}(\rho,\theta) = (15\rho^6 - 20\rho^4 + 6\rho^2)\sin(2\theta)$

$Z_{23}(\rho,\theta) = (35\rho^7 - 60\rho^5 + 30\rho^3 - 4\rho)\cos(\theta)$

$Z_{24}(\rho,\theta) = (35\rho^7 - 60\rho^5 + 30\rho^3 - 4\rho)\sin(\theta)$

$Z_{25}(\rho,\theta) = 70\rho^8 - 140\rho^6 + 90\rho^4 - 20\rho^2 + 1$

$Z_{26}(\rho,\theta) = \rho^5\cos(5\theta)$

$Z_{27}(\rho,\theta) = \rho^5\sin(5\theta)$

$Z_{28}(\rho,\theta) = (6\rho^6 - 5\rho^4)\cos(4\theta)$

$Z_{29}(\rho,\theta) = (6\rho^6 - 5\rho^4)\sin(4\theta)$

$Z_{30}(\rho,\theta) = (21\rho^7 - 30\rho^4 + 10\rho^3)\cos(3\theta)$

$Z_{31}(\rho,\theta) = (21\rho^7 - 30\rho^4 + 10\rho^3)\sin(3\theta)$

$Z_{32}(\rho,\theta) = (56\rho^8 - 105\rho^6 + 60\rho^4 - 10\rho^2)\cos(2\theta)$

$Z_{33}(\rho,\theta) = (56\rho^8 - 105\rho^6 + 60\rho^4 - 10\rho^2) \sin(2\theta)$

$Z_{34}(\rho,\theta) = (126\rho^9 - 280\rho^7 + 210\rho^5 - 60\rho^3 + 5\rho) \cos(\theta)$

$Z_{35}(\rho,\theta) = (126\rho^9 - 280\rho^7 + 210\rho^5 - 60\rho^3 + 5\rho) \sin(\theta)$

$Z_{36}(\rho,\theta) = 252\rho^{10} - 630\rho^8 + 560\rho^6 - 210\rho^4 + 30\rho^2 - 1$

$Z_{37}(\rho,\theta) = 924\rho^{12} - 2772\rho^{10} + 3150\rho^8 - 1680\rho^6 + 420\rho^4 - 42\rho^2 + 1$

THE TYPE 4 FUNCTIONAL FORM - The TYPE 4 functional form and special surface types 7 and 8 are of a rectangular polynomial form defined by the following equation:

$$fn(x,y) = \sum_{n=0}^{91} \left\{ C_n F_n(x,y) \right\}$$

where:

$F_1(X,Y) = 1$

$F_{2,3}(x,y) = x,y$

$F_{4,5,6}(x,y) = x^2, xy, y^2$

$F_{7,8,9,10}(x,y) = x^3, x^2y, xy^2, y^3$

$F_{11,12,13,14,15}(x,y) = x^4, x^3y, x^2y^2, xy^3, y^4$

$F_{16,17,18,19,20,21}(x,y) = x^5, x^4y, x^3y^2, x^2y^3, xy^4, y^5$

$F_{22,23,24,25,26,27,28}(x,y) = x^6, x^5y, x^4y^2, x^3y^3, x^2y^4, x^1y^5, y^6$

$F_{29,30,31,32,33,34,35,36}(x,y) = x^7, x^6y, x^5y^2, x^4y^3, x^3y^4, x^2y^5, xy^6, y^7$

$F_{37,38,39,40,41,42,43,44,45}(x,y) = x^8, x^7y, x^6y^2, x^5y^3, x^4y^4, x^3y^5, x^2y^6, xy^7, y^8$

$F_{46,47,48,49,50,51,52,53,54,55}(x,y) = x^9, x^8y, x^7y^2, x^6y^3, x^5y^4, x^4y^5, x^3y^6, x^2y^7, xy^8, y^9$

$F_{56,57,58,59,60,61,62,63,64,65,66}(x,y) = x^{10}, x^9y, x^8y^2, x^7y^3, x^6y^4, x^5y^5, x^4y^6, x^3y^7, x^2y^8, xy^9, y^{10}$

$F_{67,68,69,70,71,72,73,74,75,76,77,78}(x,y) = x^{11}, x^{10}y, x^9y^2, x^8y^3, x^7y^4, x^6y^5, x^5y^6, x^4y^7, x^3y^8, x^2y^9, xy^{10}, y^{11}$

$F_{79,80,81,82,83,84,85,86,87,88,89,90,91}(x,y) = x^{12}, x^{11}y, x^{10}y^2, x^9y^3, x^8y^4, x^7y^5, x^6y^6, x^5y^7, x^4y^8, x^3y^9, x^2y^{10}, xy^{11}, y^{12}$

THE TYPE 5 FUNCTIONAL FORM - The TYPE 5 functional form and special surface types 14 and 15 are of a 48-term aberration polynomial form defined by the following equation:

$$fn(x,y) = \sum_{n=0}^{48} \left\{ C_n Z_n(x,y) \right\}$$

where:

$$\rho = \sqrt{\left(x^2 + y^2\right)}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

and:

$Z_1(\rho,\theta) = 1$ {constant}

$Z_2(\rho,\theta) = \rho \cos(\theta)$ {x-tilt}

$Z_3(\rho,\theta) = \rho \sin(\theta)$ {y-tilt}

$Z_4(\rho,\theta) = \rho^2$ {focus}

$Z_5(\rho,\theta) = \rho^2\cos(2\theta)$ {0 degree astigmatism (3rd)}

$Z_6(\rho,\theta) = \rho^2\sin(2\theta)$ {45 degree astigmatism (3rd)}

$Z_7(\rho,\theta) = \rho^3\cos(\theta)$ {x-coma (3rd)}

$Z_8(\rho,\theta) = \rho^3\sin(\theta)$ {y-coma (3rd)}

$Z_9(\rho,\theta) = \rho^3\cos(3\theta)$ {x-clover (3rd)}

$Z_{10}(\rho,\theta) = \rho^3\sin(3\theta)$ {y-clover (3rd)}

$Z_{11}(\rho,\theta) = \rho^4$ {spherical (3rd)}

$Z_{12}(\rho,\theta) = \rho^4\cos(2\theta)$ {0 degree astigmatism (5th)}

$Z_{13}(\rho,\theta) = \rho^4\sin(2\theta)$ {45 degree astigmatism (5th)}

$Z_{14}(\rho,\theta) = \rho^4\cos(4\theta)$

$Z_{15}(\rho,\theta) = \rho^4\sin(4\theta)$

$Z_{16}(\rho,\theta) = \rho^5\cos(\theta)$

{x-coma (5th)}

$Z_{17}(\rho,\theta) = \rho^5\sin(\theta)$ {y-coma (5th)}

$Z_{18}(\rho,\theta) = \rho^5\cos(3\theta)$ {x-clover (5th)}

$Z_{19}(\rho,\theta) = \rho^5\sin(3\theta)$ {y-clover (5th)}

$Z_{20}(\rho,\theta) = \rho^5\cos(5\theta)$

$Z_{21}(\rho,\theta) = \rho^5\sin(5\theta)$

$Z_{22}(\rho,\theta) = \rho^6$ {spherical (5th)}

$Z_{23}(\rho,\theta) = \rho^8$ {spherical (7th)}

$Z_{24}(\rho,\theta) = \rho^{10}$ {spherical (9th)}

$Z_{25}(\rho,\theta) = \rho^6\cos(2\theta)$ {0 degree astigmatism (7th)}

$Z_{26}(\rho,\theta) = \rho^6\sin(2\theta)$ {45 degree astigmatism (7th)}

$Z_{27}(\rho,\theta) = \rho^6\cos(4\theta)$

$Z_{28}(\rho,\theta) = \rho^6\sin(4\theta)$

$Z_{29}(\rho,\theta) = \rho^6\cos(6\theta)$

$Z_{30}(\rho,\theta) = \rho^6\sin(6\theta)$

$Z_{31}(\rho,\theta) = \rho^7\cos(\theta)$ {x-coma (7th)}

$Z_{32}(\rho,\theta) = \rho^7\sin(\theta)$ {y-coma (7th)}

$Z_{33}(\rho,\theta) = \rho^7\cos(3\theta)$ {x-clover (7th)}

$Z_{34}(\rho,\theta) = \rho^7\sin(3\theta)$ {y-clover (7th)}

$Z_{35}(\rho,\theta) = \rho^7\cos(5\theta)$

$Z_{36}(\rho,\theta) = \rho^7\sin(5\theta)$

$Z_{37}(\rho,\theta) = \rho^7\cos(7\theta)$

$Z_{38}(\rho,\theta) = \rho^7\sin(7\theta)$

$Z_{39}(\rho,\theta) = \rho^8\cos(2\theta)$ {0 degree astigmatism (9th)}

$Z_{40}(\rho,\theta) = \rho^8\sin(2\theta)$ {45 degree astigmatism (9th)}

$Z_{41}(\rho,\theta) = \rho^8\cos(4\theta)$

$Z_{42}(\rho,\theta) = \rho^8\sin(4\theta)$

$Z_{43}(\rho,\theta) = \rho^8\cos(6\theta)$

$Z_{44}(\rho,\theta) = \rho^8\sin(6\theta)$

$Z_{45}(\rho,\theta) = \rho^8\cos(8\theta)$

$Z_{46}(\rho,\theta) = \rho^8\sin(8\theta)$

$Z_{47}(\rho,\theta) = \rho^{12}$ {spherical (11th)}

$Z_{48}(\rho,\theta) = \rho^{14}$ {spherical (13th)}

PARAX-GENERAL INFORMATION - All of the commands and optical system analysis functions described in this section pertain to the so called "paraxial" ray trace, based upon simplifying assumptions with respect to real trigonometric ray tracing equations. The results of a paraxial ray trace can lead to a deep understanding of the nature of a specific optical design. The paraxial ray trace is an absolute necessity when a good starting point design does not already exist. The paraxial ray trace ignores all tilts and decentrations. Its results depend only on curvatures, spacings and optical materials. The paraxial ray trace is "extended" to 3rd, 5th and 7th order aberration analysis. I so doing, conic constants and the 4th, 6th and 8th order aspheric deformation coefficients come into play. All commands described in this section are issued from the CMD program level.

WHEN IS THE TRACE PERFORMED - The paraxial ray trace is performed , at the control wavelength, every time the lens database is modified. The trace is initiated when the "EOS" or "END" command completes a phase of lens modification. The trace is performed each time the lens changes from one alternate configuration to another. The trace is kept up to date with respect to paraxial solves and with respect to surface parameter "PIKUP"s. The trace is also performed at other wavelengths when requests for first order chromatic values are made. When 3rd, 5th and 7th order data is requested, these aberrations are automatically computed from the paraxial ray trace. The paraxial ray trace should be considered to "always" exist. No specific action on the part of the designer is required inorder to have the latest paraxial ray trace data available for analysis, optimization or tolerancing.

ZEROTH ORDER DATA DISPLAYS

WEIGHT (qualifier word) , i , j - The "WEIGHT" command calculates the weight of an element or group of elements based upon the assumptions that all surfaces are centered (no tilts or decenters) and that all surface profiles are either plano or spherical". The calculation uses the specific gravity entered in the lens database using the "SPGR" command. If the qualifier word "ACC" is used, no display occurs but the weight, in Kilograms, is placed in the accumulator (X-register). For mirror surfaces with a non-zero THM assigned, this mirror thickness is used in the calculation.

COST (qualifier word) , i , j - The "COST" command calculates the cost of an element or group of elements based upon weight and price per unit weight. The associated weight calculation is based upon the assumptions that all surfaces are centered (no tilts or decenters) and that all surface profiles are either plano or spherical". The calculation uses the specific gravity and price per Kg, entered in the lens database using the "SPGR" and "PRICE" commands. If the qualifier word "ACC" is used, no display occurs but the COST in "pricing units", is placed in the accumulator (X-register). For mirror surfaces with a non-zero THM assigned, this mirror thickness is used in the calculation.

DISPLAYING FIRST ORDER CONDITIONS

OCDY , i and **OCDX , i** - The "OCDY" and "OCDX" commands display the first order operating conditions of the current lens in either the YZ or the XZ-plane. Specific displayed data is determined by the paraxial raytrace and mode of the lens. "i" designates the wavelength number for which the values are to be calculated. If no "i" value is entered, the control wavelength is used. The default control wavelength number is 1.

LENS MODE and OBJECT POSITION	FIRST VALUE DISPLAYED	SECOND VALUE DISPLAYED	THIRD VALUE DISPLAYED	FOURTH VALUE DISPLAYED	FIFTH VALUE DISPLAYED	SIXTH VALUE DISPLAYED
Focal- Obj. at Inf.	EFL	BFD	F-NUM	LENGTH	GIH	(not used)
Afocal-Obj. at Inf.	EX P DIST	EX P RAD	A-MAG	LENGTH	(not used)	(not used
Focal- Near Obj.	EFL	BFD	IMG F-NUM	LENGTH	OAL	T-MAG
Afocal-Near Obj.	EX P DIST	EX P RAD	(not used)	LENGTH	(not used	(not used

Surface "i" is the final surface in the lens. EFL is the paraxial effective focal length. BFD is the axial distance from surface "i"-1 to surface "i", "i" being the last surface of the lens. LENGTH is the axial distance from surface 1 to "i:-1. OAL is the axial distance from the object surface to surface "i". T-MAG, the tangential magnification, is the ratio of the chief paraxial ray height at surface I to the chief paraxial ray height at the object surface. A-MAG, the afocal magnification, is the ratio of the slope of the paraxial chief ray after it leaves surface "i"-1 to the slope of the paraxial chief ray before it interacts with surface 1. EX P DIST is the axial distance from surface "i"-1 to the paraxial exit pupil. EX P RAD is the semi-diameter of the paraxial exit pupil. F-NUM is the paraxial f-number. IMG F-NUM is the image space paraxial f-number for a non-infinite distant object. GIH, the gaussian image height, is the height of the paraxial chief ray at surface I.

PARAXIAL SECTION

SURFACE DEPENDENT DATA - Many of the following commands generate the display of data which is dependent upon a lens database surface number. This may be entered as a qualifier word or as numeric word #1. The qualifier words "OB" or "OBJ" will cause data to be displayed for the object surface only. The qualifier word "ALL" will generate data for all surfaces and some system totals. If no qualifier word is entered but explicit, non-negative numeric word #1 entry is made, a line of data is produced for the surface whose number "i" is specified by numeric word #1. If no qualifier or numeric entry is made, either final surface data or system total data is displayed depending upon the specific command entered. If a negative value is entered for the surface number, the program increases the entered value by adding the number of the image surface. Thus, an entry of -1 may be used to denote the surface immediately preceding the image surface.

THE ALL COMMAND

ALL (ON or YES or OFF or NO) Any program command which can take surface number input or the qualifier word input "ALL" and has the characteristic behavior that when that command is entered with no input, data for the final lens surface is printed can be impacted by the "ALL" command. If "ALL" is set to "ON", the default behavior of that command will be to assume that the "ALL" qualifier word had been issued with that command. The default setting for "ALL" will be "OFF". If it is desired to have "ALL" always set to "ON", place the "ALL ON" command in the DEFAULTS.DAT file in the main program directory. It will be executed whenever the program is run.

SPECIFIC PARAXIAL RAY DATA

PXTY (ALL or OB or OBJ) or , i and **PXTX (ALL or OB or OBJ) or , i** - The "PXTY" and "PXTX" commands output the YZ or XZ-plane, paraxial marginal ray heights, paraxial marginal ray slopes (tangents), paraxial chief ray heights and paraxial chief ray slopes (tangents). This data may be output for "ALL" surfaces, for the object surface ("OB" or "OBJ") or for surface "i". Output is performed for the current control wavelength.

PITY (ALL or OB or OBJ) or , i and **PITX (ALL or OB or OBJ) or , i** - The "PITY" and "PITX" commands output the YZ or XZ-plane, paraxial marginal ray heights, paraxial marginal ray slope of incidence (tangent), paraxial chief ray heights and paraxial chief ray slope of incidence (tangent). This data may be output for "ALL" surfaces, for the object surface ("OB" or "OBJ") or for surface "i". Output is performed for the current control wavelength.

PRTY (ALL or OB or OBJ) or , i and **PRTX (ALL or OB or OBJ) or , i** - The "PRTY" and "PRTX" commands output the YZ or XZ-plane, paraxial marginal ray heights, paraxial marginal ray exitance slope (tangent), paraxial chief ray heights and paraxial chief ray exitance slope (tangent). This data may be output for "ALL" surfaces, for the object surface ("OB" or "OBJ") or for surface "i". Output is performed for the current control wavelength.

FIRST ORDER CHROMATIC ABERRATIONS

FCHY (ALL or OB or OBJ) or , i and **FCHX (ALL or OB or OBJ) or , i** - These commands display first order chromatic aberrations in the YZ and XZ-plane. Output consists of four values per surface. The primary aberrations are computed for the wavelength pair set by "PCW". The secondary aberrations are computed for the wavelength pair set by "SCW". The display will be converted to transverse or angular units or will be left unconverted (determined by the current lens MODE). Output may be produced at one or all surfaces. All values given for any surface are either always converted or not converted. Issuing any of the following commands with no numeric surface input data "i" causes only the aberration totals to be displayed. Paraxial data in the YZ or XZ-plane is used for aberrations in the YZ and XZ-planes, respectively. All aberrations are calculated at the current control wavelength. Calculations are based on equations described in Mil-Handbook 141.

LENS MODE	ABERRATION TOTALS CONVERSION
UFOCAL	(none)
UAFOCAL	(none)
FOCAL	CONVERSION TO TRANSVERSE MEASURE
AFOCAL	CONVERSION TO ANGULAR MEASURE

ABERRATION TITLE	ABERRATION DESCRIPTION
PACY or PACX	Primary first order axial color
PLCY or PLCX	Primary first order lateral color
SACY or SACX	Secondary first order axial color
SLCY or SLCX	Secondary first order lateral color

CHROMATIC FOCUS SHIFTS

CHRSHIFT The "CHRSHIFT" command generates a table of paraxial focus shifts versus wavelength. For paraxial marginal rays, longitudinal focus shift in microns (FOCAL and UFOCAL systems) or marginal ray angle deviation in micro-radians (AFOCAL and UAFOCAL systems) is tabulated versus wavelength in microns. Shifts (deviations) are with respect to the paraxial marginal ray at the control wavelength. For paraxial chief rays, lateral ray shift in microns (FOCAL and UFOCAL systems) or chief ray angle deviation in micro-radians (AFOCAL and UAFOCAL systems) is tabulated versus wavelength in microns. Shifts (deviations) are with respect to the paraxial chief ray at the control wavelength. After it is generated, graphical display of this data is generated using the "PLTCSHIFT" .

CHROMATIC FOCUS SHIFT PLOTS

PLTCHRSH (optional qualifier) -The "PLTCHRSH" command causes a plot of the paraxial chromatic focus shift data. The default is to plot YZ-plane data. Using the optional qualifier word "X" causes the XZ-plane data to be plotted.

OTHER PARAXIAL DISPLAYS

FIRD (QUIET) , i , j , (λ) - The "FIRD" command displays the YZ-plane, paraxial effective focal length (EFL), back focal length (BFL), front focal length (FFL) and the principle plane positions PP1 and PP2 for the sub-set of the current lens beginning at surface "i" and ending with surface "j". If "λ" is not explicitly entered, then the values are calculated at the current control wavelength for the active lens configuration. If "λ" has been entered explicitly, then "λ" is interpreted as a "temporary" and "new" control wavelength in microns. After the calculation, the original control wavelength is restored. The yz-plane EFL, BFL, FFL, PP1 and PP2 values are placed general purpose storage registers 1 to 5. The xz-plane EFL, BFL, FFL, PP1 and PP2 values are placed general purpose storage registers 6 to 10. Make sure that solves are not in effect which could modify curvatures of thicknesses which would in themselves change the final answer. If the qualifier word "QUIET" is issued, the EFLY, BFLY, FFLY, PPY1. PPY2, EFLX, BFLX, FFLX, PPX1 and PPX2 will be stored in the first ten general purpose storage registers without any screen display.

INVAR - The "INVAR" command displays the YZ and XZ-plane, paraxial optical invarients for the current lens at the control wavelength for the active lens configuration.

DR/FR (qualifier word) , r , D , λ - The "DR/FR" command calculates the exact "delta radius per fringe" for a spherical optical surface whose radius of curvature is "r" lens units. The calculation is performed for a part diameter equal to "D" lens units. The wavelength of fringe interpretation is λ (in microns). In the absence of a qualifier word, the result is displayed at the current output device. If the qualifier word "ACC" is used, no display occurs but resultant delta radius per fringe (in the units of the current lens) is placed in the accumulator (X-register). "r" and "D" must be explicitly entered in lens units. The default value for λ is 0.5461 micron. Consider this a useful "side calculation" as it is not based on lens database values.

OUTFLAT (qualifier word) , m , D , λ The "OUTFLAT" command calculates the exact curvature for a circular optical surface which is "out of flat" by "m" fringes of power. The calculation is performed for a part diameter equal to "D" lens units. The wavelength of fringe interpretation is λ (in microns). In the absence of a qualifier word, the result is displayed at the current output device. If the qualifier word "ACC" is used, no display occurs but curvature (in the inverse units of the current lens) is placed in the accumulator (X-register). "m" and "D" must be explicitly entered. The default value for λ is 0.5461 micron. "m" need not be an integer. Consider this a useful "side calculation" as it is not based on lens database values.

THIRD, FIFTH, SEVENTH ORDER ABERRATIONS - The following commands display transverse or angular measures or unconverted aberration coefficients (determined by the current lens MODE) of the third and fifth order aberrations and seventh order spherical aberration. Output may be produced at one or all surfaces just as was done for the paraxial ray data. All values given for any surface are either always converted or not converted. Issuing any of the following commands with no numeric surface input data "i" causes only the aberration totals to be displayed. Paraxial data in the YZ or XZ-plane is used for aberrations in the YZ and XZ-planes, respectively. All aberrations are calculated at the current control wavelength. All third, fifth and seventh order aberration calculations are based upon the work of Dr. H. A. Buchdahl and we use the equations which first were used in the ORDEALS program at the University of Rochester.

MAB3 (ALL or OB or OBJ) or , i and **XMAB3 (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, third order monochromatic spherical aberration, coma, astigmatism, distortion and Petzval sum. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

MAB5 (ALL or OB or OBJ) or , i and **XMAB5 (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, fifth order monochromatic, intrinsic surface plus transferred spherical aberration, coma, astigmatism, distortion and Petzval sum. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

MABX5 (ALL or OB or OBJ) or , i and **XMAB5 (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, fifth order, extended, monochromatic, tangential oblique spherical aberration (TOBSA), sagittal oblique spherical aberration (SOBSA), elliptical coma (ELCMA), tangential astigmatism (TAS) and sagittal astigmatism (SAS). Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

SA357 (ALL or OB or OBJ) or , i and **XSA357 (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, third, fifth and seventh order, monochromatic, spherical aberrations SA3, SA5 and SA7. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

MAB5I (ALL or OB or OBJ) or , i and **XMAB5I (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, intrinsic surface component of fifth order monochromatic, spherical aberration, coma, astigmatism, distortion and Petzval sum. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals of the intrinsic surface components. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

MABX5I (ALL or OB or OBJ) or , i and **XMABX5I (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, intrinsic surface component of fifth order, extended, monochromatic tangential oblique spherical aberration (TOBSA), sagittal oblique spherical aberration (SOBSA), elliptical coma (ELCMA), tangential astigmatism (TAS) and sagittal astigmatism (SAS). Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

SA357I (ALL or OB or OBJ) or , i and **XSA357I (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, third order spherical aberration, SA3, and the intrinsic surface component of fifth and seventh order, monochromatic spherical aberration, SA5 and SA7. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

MABP3 (ALL or OB or OBJ) or , i and **XMABP3 (ALL or OB or OBJ) or , i** - These commands display the following YZ or XZ-plane, third order monochromatic, exit pupil aberrations: spherical aberration, coma, astigmatism, distortion and Petzval sum. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

THIRD, FIFTH, SEVENTH CHROMATIC VALUES

PCD3 (ALL or OB or OBJ) or , i and **XPCD3 (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, third order chromatic differences of spherical aberration, coma, astigmatism, distortion and Petzval sum. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength. The displayed aberration values are the aberration differences of the third order aberrations at the primary wavelength pair wavelengths. These two wavelengths are set by the "PCW" command. The following commands display primary chromatic differences of the aberrations generated by "MAB5", "XMAB5", "MABX5", XMABX5", "MABP3", "XMABP3", "SA357" AND "XSA357" :
PCD5 (ALL or OB or OBJ) or , i and **XPCD5 (ALL or OB or OBJ) or , i**
PCDX5 (ALL or OB or OBJ) or , i and **XPCDX5 (ALL or OB or OBJ) or , i**
PCDP3 (ALL or OB or OBJ) or , i and **XPCDP3 (ALL or OB or OBJ) or , i**
PCDSA (ALL or OB or OBJ) or , i and **XPCDSA (ALL or OB or OBJ) or , i**

The following commands display secondary chromatic differences of the third, fifth and seventh order aberrations. They use the secondary wavelength pair which can be set using the "SCW" command:
SCD3 (ALL or OB or OBJ) or , i and **XSCD3 (ALL or OB or OBJ) or , i**
SCD5 (ALL or OB or OBJ) or , i and **XSCD5 (ALL or OB or OBJ) or , i**
SCDX5 (ALL or OB or OBJ) or , i and **XSCDX5 (ALL or OB or OBJ) or , i**
SCDP3 (ALL or OB or OBJ) or , i and **XSCDP3 (ALL or OB or OBJ) or , i**
SCDSA (ALL or OB or OBJ) or , i and **XSCDSA (ALL or OB or OBJ) or , i**

If there are solves defined in a lens, then all aberration calculations involving the primary wavelength pair or the secondary wavelength pair are performed using lens data established with solves at the control wavelength only ! The third order coma term is tangential coma. Sagittal coma is 3 times smaller than tangential coma. The third order Petzval sum (PTZ3) is equivalent to what some call the Petzval blur. The Petzval curvature is not output by the above commands but is "GET-able" using the "GET PTZCV" and "GET XPTZCV" commands.

OTHER PLACES FOR PARAXIAL DATA - Paraxial, first order chromatic and 3rd, 5th and 7th order data is also available using the "GET" command described in the PARAX manual section. The same data is available in optimization and tolerancing as described in the OPTIM and TOLER operand listings.

RAY TRACE-GENERAL INFORMATION - All of the commands and optical system analysis functions described in this section pertain to the tracing of real, trigonometric rays through the current lens database. All commands described in this section are issued from the CMD program level.

WHEN IS THE TRACE PERFORMED - Real rays are not "automatically" traced, as was the case in paraxial ray tracing. Real rays are traced at the specific request of the designer using the commands described in this section. These requests may be explicit or implicit as in the act of ray tracing while performing optimization or tolerancing.

SURFACE COATINGS AND RAY TRACING

COATINGS (YES or ON or NO or OFF) - The "COATINGS" command is used to tell the program whether or not to calculate ray energy values based on currently assigned surface coating data and diffraction grating efficiency, in the case of diffraction gratings. When in the "OFF" setting, no ray energy calculations are possible. The default setting is "OFF". If "COATINGS ON" is set, then if there either bare substrate coatings or multiple layer coatings are defined on surfaces, polarization values for these surface will be computed. These polarization values can be explicitly output for single rays and are used appropriately in spot diagram and complex aperture function related calculations.

RAY AIMING - In some optical design and analysis programs, real rays are aimed toward the system entrance pupil. This entrance pupil is the image of the aperture stop produced by all optical elements which lie between the object surface and the aperture stop. Programs which aim rays in this manner either ignore pupil aberrations or they require auxiliary ray calculations to account for any pupil aberrations. In this program, real rays are iteratively aimed at the reference surface. The reference surface is defined to be that surface at which all real chief rays have zero height. The reference surface can be thought of as the real ray equivalent of the aperture stop surface. For a reference surface with no clear aperture assigned, the chief ray aiming point is the vertex of this reference surface. This chief ray aiming point may be shifted from the vertex of the reference surface to any other point on the reference surface and angularly re-oriented by assigning a decentered and tilted clear aperture to the reference surface. All chief rays will then be aimed so as to pass through the center of the clear aperture on the reference surface. If there is a non-zero clear aperture tilt associated with a clear aperture assignment at the reference surface, the ray aiming orientation will be adjusted so that fans of rays are parallel to the defining axes of the reference surface clear aperture rather than parallel to the local coordinate system at the reference surface. If there is a non-zero reference surface orientation angle associated with a non-tilted, non-decentered clear aperture assignment at the reference surface, then the ray aiming orientation will be rotated through that angle. All non-chief rays are then aimed to relative coordinate positions in the reference surface. The reference surface may be assigned to the same surface as the aperture stop definition, but this is not required. The choice of aperture stop and reference surface is completely up to the designer. The designer should always remember, however, that if the aperture stop and the reference surfaces are different surfaces and if they are not images on one another, then strange things may occur during ray aiming and ray aiming convergence might not occur. The ray aiming discussed above may be shut off using the "AIMRAY" command discussed later in this section. When ray aiming is shut off, rays are aimed at the surface following the object surface. This option should be used carefully. It is useful in diagnosing difficult to trace systems.

TRACING A SINGLE RAY - In order to trace a single ray and display the results of the single ray trace, the user does the following:

Specify the location in the object surface from which the ray is traced.

Specify the location in the REFERENCE SURFACE through which the ray will be aimed

Request some display of the data fror that ray

OBJECT POINT SPECIFICATION (FOB COMMAND)

FOB (qualifier word) , Y, X, Z, n, m - The "FOB" command must be issued before any ray can be traced. This is true for single rays, fans, spot diagrams, MTF calculations, etc. This command defines the object point from which subsequent rays will be traced. It stays in effect until another "FOB" command is issued or until it is canceled by some other program option such as "UPDATE LENS". "Y", "X" AND "Z" are the fractional y, x and z-coordinates of the object point measured on the current object surface if the reference object height is set via "SCY" and "SCX" commands. "Y", "X" are the fractional y and x-object space field angles if the reference object height is set via "SCY FANG" and "SCX FANG" commands. Z is represented as a fraction of the current object surface axial thickness. If "Z" is zero, the object point lies on the object surface. "Z" is a fractional measure. It represents the fraction of the thickness assigned to the object surface and is an "off-set". If "Z" is +1.0, then the object point is a positive z-distance from the object surface equal to the axial thickness of the current object surface. If "Z" is -1.0, then the object point is a negative z-distance from the object surface equal to the axial thickness of the current object surface. Z is only used when the reference object height has been set by "SCY" and "SCX" commands. It is ignored with no warning message, if the reference object height has been specified using "SCY FANG" and/or "SCX FANG". Issued with the iterrogator "?", the "FOB" command returns the last "FOB" input data if a chief ray exists. When an object point is defined, the program automatically traces a ray from that object point or field angle to the image plane. This ray passes through the vertex of the reference surface if the reference surface has no clear aperture assigned, or through the center of a clear aperture if one has been assigned. All ray aberrations are calculated with respect to this chief ray which is also known as the "reference ray".

RAY TRACING SECTION

Normally, this reference ray is traced at the control wavelength if "n" is not explicitly input. If "n" is explicitly input, it can be 1 through 10, the reference ray is traced at wavelength number "n". The fifth numeric word entry, "m", is a composite number which defines a temporary reassignment for the object, reference and image surface numbers. If this entry is omitted, the object surface is surface 0, the reference surface is the surface defined as the reference surface in the lens input mode and the image surface is the last surface.

Whenever telecentric ray aiming is in effect, reassignment of the object, reference and image surface with numeric word #5 of the "FOB" command is not allowed. "m" is a nine-digit integer of the form "xxxyyyzzz". "xxx" is the new object surface number, "yyy" is the new reference surface number and "zzz" is the new image surface number. If "m" is explicitly input, all nine digits must be input, even if not all three surfaces are to be reassigned from their original values. The choice of "qualifier word" selects the specific additional output to be displayed as shown in the following table:

Qualifier Word	OUTPUT
(none)	(none)
NULL	(none)
"P"	Yo, Xo, Zo
"PIC" or "PICNH"	Yo, Xo, Zo, Yi, X_i
"PFS" or "PFSNH"	Yo, Xo, Zo, Fy, Fx

The qualifier word "P" causes the reference ray coordinates at the object surface to be displayed. The qualifier words "PIC" and "PICNH" display the reference ray coordinates at the object surface, Yo, X0, Zo, and the Y and X-coordinates of the reference ray at the image surface, Yi, Xi. "PIC" produces header information; "PICNH" produces no header information. The qualifier words "PFS" and "PFSNH" display the reference ray coordinates at the object surface, Yo, Xo, Zo, and the YZ-plane and XZ-plane field sags at the image surface, Fy, Fx. "PFS" produces header information; "PFSNH" produces no header information. Calculation of Fy and Fx is performed by tracing differential rays about the reference ray corresponding to differential displacements in Y and X on the reference surface. Fy locates the intersection of the Y-differential ray with the reference ray. Fx locates the intersection of the X-differential ray with the reference ray. Fy and Fx are distances, measured in the Z direction, from the image surface to each focus. The options "P", "PIC" and "PFS" display information indicating the wavelength and the field angle. The field angle is defined to be the angle between the Z-axis and the reference ray in the object space. "PICNH" and "PFSNH" suppress these headings. The "FOB NULL" is used when it is necessary to trace rays in a situation in which the reference ray fails. In such a case, a non-chief ray may still pass through the lens system. Of course, since there will be no reference ray data, aberrations based upon reference ray calculations will not be possible. The "FOB NULL" command is identical to the usual "FOB" command, except that the tracing of the reference ray is suppressed. This allows a limited subset of ray tracing commands to be performed on "pathological" systems in which the reference ray at some object position cannot be traced. Diffraction analysis commands invoked in this mode use (x,y,z) = (o,o,o) as the center of the reference sphere. The validity of results obtained in this mode depend on the optical system, and no general rules can be given. **IT IS THE RESPONSIBILITY OF THE USER TO VERIFY THE VALIDITY OF RESULTS OBTAINED IN THIS WAY!**

FOBH (qualifier word) , YH, XH, ZH, n - The "FOBH" command is similar to the "FOB" command except that the "YH", "XH" and "ZH" input values are the Y, X and Z-positions of the current object point relative to the origin of the current object surface. They are always represented in current lens units. "n" is the wavelength number. "FOBH" does not take the fifth numeric word of the "FOB" command. All valid "FOB" qualifier words may be used with "FOBH".

FOBA (qualifier word) , Yang , Xang , n - The "FOBA" command is an alternate form of the "FOB" command. If has less power than "FOB" but allows the user to input field of view angles directly in degrees. The user may specify the "Yang", the "Xang" and the wavelength number "n". The defaults are 0.0, 0.0 and "cw", the control wavelength. The command will work whether the reference object height was specified using "SCX" and "SCY" or "SCX FANG" and "SCY FANG". For near objects and systems with internal stops/reference surfaces, the resultant field angles may not be exactly the angles requested due to the non-zero chief ray height on surface (newobj+1) and the less than large object distance. For object distances greater than 1.0×10^{10} lens units, the "FOBA" command should yield exact chief ray angles. All valid "FOB" qualifier words may be used with "FOBH".

RAY TRACING SECTION

THE SINGLE RAY TRACE - Single rays may be traced in an arbitrary order following an "FOB" command. Single ray trace commands generate no display except for the "RAY CAOB" command. Results of these ray traces are displayed using the ray data display commands which are described later in this section.

RAY , Y, X, n , I - "Y" and "X" are the fractional reference surface coordinates and "n" is the wavelength number. If no entry is made for "n", the ray is traced at the control wavelength number. "I" is the starting ray intensity which may be set to any non-zero value less than or equal to 1.0. The default value for "I" is 1.0. If the reference surface has no clear aperture assigned, the actual reference ray coordinates will be calculated based upon the reference aperture height set by the paraxial ray trace. If a clear aperture has been assigned to the reference surface, the actual reference ray coordinates will be calculated based upon the fractional reference aperture height relative to the center of the clear aperture. Whenever an "FOB" command is issued, an automatic "RAY , 0 0" command is also issued. This avoids the neccessity of issuing a "RAY" command in order to trace and display regular ray data for the chief ray.

RAY CAOB , Y , X , n , I , silent - The "RAY CAOB" command works just like the standard "RAY" command, except that it causes checking for ray blockages due to clear apertures, obstructions and erases. If a ray falls outside a clear aperture or within an obscuration, a ray failure message will be generated, saved internally and displayed. In order for this message to be displayed, plotting MUST be turned "OFF". This is done by issuing a "PLOT END" message after plotting is completed. Clear aperture ray blocking is not checked on the current object surface or the current image surface by "RAY CAOB". If "silent" is nonzero, no ray failure message is displayed

Example: To trace a marginal ray from the maximul +Y field of view position, the commands would be:

FOB 1
RAY 1

SINGLE RAY DATA DISPLAY - The following four commands allow the user to change the ray angle output mode for real rays to "degrees", "radians" or "tangents". Paraxial output angles are always expressed as tangents. These commands do not change any input units. The "ANGMODE" command displays the current angular mode. The default angular mode when the program starts is "degrees":

DEG
or
RAD
or
TANGENT
or
ANGMODE

HEADINGS ON or **HEADINGS OFF** - Headings are always displayed when tabular output is requested via the qualifier "ALL". The "HEADINGS" command with the qualifier words "ON" and "OFF" controls whether or not headings will be displayed for single lines of displayed data. The default setting for "HEADINGS" is "OFF" when the program begins. New users may be more comfortable seeing headings for all data displays. Headings can be set to "ON" after program startup or the line "HEADINGS ON" can be added to the "DEFAULTS.DAT" file before starting the program. If requested program data does not exist, a message to that effect is displayed.

SURFACE DEPENDENT DATA - Many of the following commands generate the display of data which is dependent upon a lens database surface number. This may be entered as a qualifier word or as numeric word #1. The qualifier words "OB" or "OBJ" will cause data to be displayed for the object surface only. The qualifier word "ALL" will generate data for all surfaces and some system totals. If no qualifier word is entered but explicit, non-negative numeric word #1 entry is made, a line of data is produced for the surface whose number "i" is specified by numeric word #1. If no qualifier or numeric entry is made, either final surface data or system total data is displayed depending upon the specific command entered. If a negative value is entered for the surface number, the program increases the entered value by adding the number of the image surface. Thus, an entry of -1 may be used to denote the surface immediately preceding the image surface.

THE ALL COMMAND

ALL (ON or YES or OFF or NO) Any program command which can take surface number input or the qualifier word input "ALL" and has the characteristic behavior that when that command is entered with no input, data for the final lens surface is printed can be impacted by the "ALL" command. If "ALL" is set to "ON", the default behavior of that command will be to assume that the "ALL" qualifier word had been issued with that command. The default setting for "ALL" will be "OFF". If it is desired to have "ALL" always set to "ON", place the "ALL ON" command in the DEFAULTS.DAT file in the main program directory. It will be executed whenever the program is run.

RAY TRACING SECTION

SINGLE RAY DATA DISPLAY - The following commands all refer to data related to the last single ray traced:

PRX (ALL or OB or OBJ) or

PRX P , i or

PRX , i - The "PRX" command displays the X-coordinate of the ray at a surface and the ray angle to the Z-axis made by the projection of the ray on the XZ-plane in the space following the surface. For the image surface, angles are with respect to the previous surface. The qualifier "ALL" causes a table of data for all surfaces to be displayed. If no qualifier is entered, single surface data is displayed. If no qualifier or numeric surface number "i" input is entered, the current image surface is assumed. The qualifier "P" causes the wavelength number and relative aperture coordinates in the reference surface to be displayed.

PRY (ALL or OB or OBJ) or

PRY P , i or

PRY , i - "PRY" acts just like "PRX" but displays Y-coordinate and YZ-plane angle projections.

PRXYZ (ALL or OB or OBJ) or

PRXYZ P , i or

PRXYZ , i - "PRXYZ" acts just like "PRX" but displays X, Y and Z-ray coordinates and XZ and YZ-plane angle projections.

PRXYI (ALL or OB or OBJ) or

PRXYI P , i or

PRXYI , i - "PRXYI" acts just like "PRXYZ" with Z replaced by the angle of incidence at the surface.

PRXYIP (ALL or OB or OBJ) or

PRXYIP P , i or

PRXYIP , i - "PRXYIP" acts just like "PRXYZ" with Z replaced by the angle of exitance at the surface.

PRXYD (ALL or OB or OBJ) or

PRXYD P , i or

PRXYD , i - "PRXYD" acts just like "PRXYZ" with Z replaced by the optical path length along the ray in the space preceding the surface.

PRZ (ALL or OB or OBJ) or

PRZ P , i or

PRZ , i - "PRZ" acts like "PRX" but displays the Z-ray coordinate and the optical path length along the ray in the space preceding the surface.

PRR (ALL or OB or OBJ) or

PRR P , i or

PRR , i - "PRR" acts like "PRX" but displays the radial ray coordinate R and the angle from the ray to the Z-axis.
R is defined in the following equation:

$$R = \left(\sqrt{X^2 + Y^2} \right)$$

PRREF (ALL or OB or OBJ) or

PRREF P , i or

PRREF , i - "PRREF" acts like "PRXYZ" but displays the X, Y and Z-coordinates or the current reference ray and the tangents of the X and Y-angles which that ray makes with the Z-axis.

PRLMN (ALL or OB or OBJ) or

PRLMN P , i or

PRLMN , i - "PRLMN" acts like "PRXYZ" but displays the current ray X, Y and Z-coordinates and the L, M and N direction cosines.

OPD - The "OPD" command calculates and displays the optical path difference for the last ray traced both in lens units and in waves (at the wavelength at which the reference ray was traced).

PRFLUX (ALL or OB or OBJ) or

PRFLUX P , i or

PRFLUX , i - "PRFLUX" acts like "PRX" but displays the current relative ray energy or flux. If coatings are assigned to surfaces and if "COATINGS" are set to "ON", the surface coatings will be used to compute ray trasmission or reflection factors which will be used in the relative ray energy calculation.

PRPOL (ALL or OB or OBJ) or

PRPOL P , i or

PRPOL , i - "PRPOL" acts like "PRX" but displays the current ray polarization data. Data includes the parallel and perpendicular reduction factors, phases and the angle between the plane of incidence and the y-vector dirrection of the current chief ray.

PLOTTING SINGLE RAYS - The plotting of single rays as part of an optical system layout is covered in the GRAPHICS section of this manual.

DIFFERENTIAL RAYS - Whenever a single ray is traced while "DIFRAY" and "DIFFOB" are set to "(ON or YES)", close differential rays will be traced along side and near the chief ray traced with the last "FOB" command and along side and near the regular ray traced with the last "RAY" command. If differential ray failures occur, adjust the DIFTOL value up or down until they no longer occur. See the DIFTOL value description in this section under the "PM" command. Differential chief rays are traced from the current object position plus small X and Y-shifts in object position. These rays are traced to the standard aim point in the reference surface unless the "TEL" is set to "ON". If "TEL" is set to "ON", meaning telecentric rays, the chief differential rays are traced parallel to the regular chief ray. Non-chief differential rays are traced from the current object position. These rays are traced to the standard aim point in the reference surface shifted by small X and Y-values. In telecentric systems, the X and Y-shifts are applied at the NEWOBJ+1 surface rather than at the reference surface. All shifts are based upon current reference aperture data and object heights scaled by the current value of DIFTOL. The following commands provide a way of displaying the most recent differential ray data:

PRDIFFXR (ALL or OB or OBJ) or

PRDIFFXR P, i or

PRDIFFXR , i - "PRDIFFXR" acts like "PRX" but displays the X, Y and Z-coordinates and the L, M and N direction cosines of the current differential ray with respect to a differential shift in the starting ray X-coordinate at the object surface.

PRDIFFYR (ALL or OB or OBJ) or

PRDIFFYR P, i or

PRDIFFYR , i - "PRDIFFYR" acts like "PRX" but displays the X, Y and Z-coordinates and the L, M and N direction cosines of the current differential ray with respect to a differential shift in the starting ray Y-coordinate at the object surface.

PRDIFFXM (ALL or OB or OBJ) or

PRDIFFXM P, i or

PRDIFFXM , i - "PRDIFFXM" acts like "PRX" but displays the X, Y and Z-coordinates and the L, M and N direction cosines of the current differential ray with respect to a differential shift in the reference ray X-coordinate at the reference surface.

PRDIFFYM (ALL or OB or OBJ) or

PRDIFFYM P, i or

PRDIFFYM , i - "PRDIFFYM" acts like "PRX" but displays the X, Y and Z-coordinates and the L, M and N direction cosines of the current differential ray with respect to a differential shift in the reference ray Y-coordinate at the reference surface. Whenever an "FOB" command is issued, a "RAY , 0 , 0 , (wavelength number equal to that used in the "FOB" command)" command is automatically issued. As long as these two rays can be traced through the optical system and as long as "DIFFOB" and "DIFRAY" are set to "(ON or YES)", differential rays will be traced. This program behavior is used to generate a set of extremely useful data which we will call "GENERALIZED PARAXIAL RAY TRACE" data. This ray trace, unlike the true paraxial ray trace, takes into account surface tilts, decentrations and aspheric and other surface deformations.

Whenever this generalized paraxial data is requested, appropriate rays will be traced automatically. For this trace, "DIFFOB" and "DIFRAY" will be temporarily turned "(ON or YES)" if they were "(OFF or NO)" and the associated differential ray trace will be used to generate the generalized paraxial ray data. The generalized paraxial ray trace data is generated and displayed using the following two commands:

RAY TRACING SECTION

GENERALIZED PARAXIAL RAY TRACE
GPXTY (ALL or OB or OBJ) or
GPXTY , i , y-fob , x-fob , z-obj. shift , wavelength #
and
GPXTX (ALL or OB or OBJ) or
GPXTX , i , y-fob , x-fob , z-obj. shift , wavelength # - The "GPXTY" and "GPXTX" commands generate and output the YZ or XZ-plane, generalized paraxial marginal ray heights, generalized paraxial marginal ray slopes, generalized paraxial chief ray heights and generalized paraxial chief ray slopes. This data may be output for "ALL" surfaces, for the object surface ("OB" or "OBJ") or for surface "i". Output is performed for the current control wavelength. Generalized paraxial ray data is always generated for the current configuration. Generalized paraxial ray data is never used in solves or for 3rd, 5th and 7th order aberration calculations. Generalized paraxial datum items may be moved to the "X" register using the "GET" command described in the CMD section. All the "GPXTX" and "GPXTY" commands may also take numeric words #2, #3, #4 and #5 input. Numeric words #2 and #3 are Y and X-FOB values which will override the default 0.0, 0.0. When explicit Y and X-FOB values are input, the output generated should no longer be considered a true "generalized paraxial ray trace" which can be compared to the regular paraxial ray trace. Numeric word #4 is used to specify a Z-obj. shift as is used in the "FOB" command. Numeric word #5 is used to specify a wavelength number other than the control wavelength number. Valid entries are 1 to 10. Generalized paraxial data is generated by tracing real chief and marginal rays close to a chief ray and then scaling the resultant data up by the appropriate and current "SCX", "SCY", "SAX" and "SAY" values. For a centered systems with the reference surface assigned to the same surface as the aperture stop, a generalized paraxial ray trace along the optical axis will yield results identical to an ordinary first order paraxial ray trace.

LOCAL COORDINATE INFORMATION - It is extremely important to remember the following general information concerning the nature of non-global coordinate, trigonometric ray tracing as it is implemented here:

Object Surface ray coordinates are represented in the local coordinate system of the Object Surface.

Reference Surface ray coordinates are represented in the local coordinate system of the Reference Surface.

Image Surface ray coordinates are represented in the local coordinate system of the Image Surface.

Ray coordinates at any surface are represented in the local coordinate system of that surface.

Spot diagram, geometrical energy distributions and geometrical MTF calculations are evaluated in the coordinate system of the image surface but the grid of rays is aimed at reference surface coordinates.

If there are rotations which alter the relative orientations of the Object Surface, Reference Surface and Image Surface X and Y-axes, then lines or grids of rays traced so as to line up with local coordinate axes at one surface may not line up with the local coordinate axes at another surface. This fact must be remembered when interpreting ray fans, spot diagrams, energy distibutions and MTF calculations. The user may always use GAMMA rotations on dummy surfaces to insure that vertical and horizontal axes relationships represent the real physical system being designed or modeled. Tilts or decentrations assigned to the object surface are always ignored during real ray tracing.

GLOBAL COORDINATE RAY TRACING - Normally, when a single ray is traced, ray data is generated for the ray with respect to the local coordinate system at each surface. Ray data may also be generated with respect to a "global" coordinate system. If "global" ray trace data is generated, it is generated in addition to the normally produced "local" ray trace data. The same object point definition and ray definition commands "FOB" and "RAY" are used to trace rays for which this "global" ray trace data is to be generated.

GLOBAL , i - The "GLOBAL" command, when issued with integer numeric input, is used to define the surface number whose "local" coordinate system is to be used as the "global" coordinate system for all subsequent "global" ray trace data.

GLOBAL OFF - The "GLOBAL OFF" command shuts off global coordinate ray tracing.

OFFSET DEC , X , Y , Z - The "OFFSET DEC" command is used to define an offset from the vertex of the "global" surface vertex. This new "offset" location will be the origin for all "global" ray trace data. "X", "Y" and "Z" are the X, Y and Z-offsets measured in the local coordinate system of the "global" surface.

OFFSET TILT , ALPHA , BETA , GAMMA - The "OFFSET TILT" command is used to define an angular offset from the orientation of the "global" surface vertex coordinate system. This new "angular offset" will define the "global" coordinate system orientation for all "global" ray trace data. "ALPHA", "BETA" and "GAMMA" are defined in the local coordinate system of the "global" surface. They are input in degrees and are defined in the same sense as the "ALPHA", "BETA" and "GAMMA" tilts in the LENS section. The angular offsets in the "OFFSET TILT" command are considered to be either in the MIXED or in the RIGHT-HANDED directional sense depending upon the current angular setting in the current lens. See the LENS section for more details. If offset tilts and decentrations are entered, the offsets are applied before the tilts in the determination of the location and orientation of the "offset" "global" coordinate system.

RAY TRACING SECTION

GLOBAL - The "GLOBAL" command, when issued with no additional input, is used to display the current status of "global" ray tracing. If "global" ray tracing has been previously set to "on", then the surface number of the surface whose coordinate system is used as the origin for "global" data, as well as any defined "offsets", will be displayed.

VERTEX (ALL or OB or OBJ) or

VERTEX , i - The "VERTEX" command displays "global" surface vertex coordinates X, Y and Z. It also displays "global" surface coordinate system L, M and N direction cosines for each local surface coordinate axis. If the qualifier "ALL" is used, a header is included which is similar to the display produced by the "GLOBAL" command.

PRGLOBAL (ALL or OB or OBJ) or

PRGLOBAL , i - The "PRGLOBAL" command displays "global" ray trace data. The "global" X, Y and Z ray coordinates and the "global" L, M and N ray direction cosines before (LOLD, MOLD and NOLD) and after (L, M and N) surface interaction (reflection, refraction or diffraction) are displayed. If the qualifier "ALL" is used, a header is included which is similar to the display produced by the "GLOBAL" command.

ADDITIONAL RAY COMMANDS

FOBDUMPThe "FOBDUMP" command displays all internal program reference ray data for all surfaces for the last single ray traced. It is intended as a debugging tool when attempting to trace a difficult or poorly understood case of ray trace failure.

RAYDUMPThe "RAYDUMP" command displays all internal program ray data for all surfaces for the last single ray traced. It is intended as a debugging tool when attempting to trace a difficult or poorly understood case of ray trace failure.

DIFFOB (ON or **YES** or **OFF** or **NO)** - The "DIFFOB (ON or YES)" and "DIFFOB (OFF or NO)" commands either activate or deactivate differential reference ray tracing in cases where differential reference ray tracing would normally apply such as in the single ray trace. It should only be used for diagnosing ray tracing problems. Issued with a "?", the "DIFFOB" command returns a message as to its current setting. It only applies to the action taken after a "FOB" command is issued. This command is "sticky" and remains as set until changed by the user or until the program ends.

DIFRAY (ON or **YES** or **OFF** or **NO)** - The "DIFRAY (ON or YES)" and "DIFRAY (OFF or NO)" commands either activate or deactivate differential ray tracing in cases where differential ray tracing would normally apply such as in the single ray trace. It should only be used for diagnosing ray tracing problems. Issued with a "?", the "DIFRAY" command returns a message as to its current setting. This command is "sticky" and remains as set until changed by the user or until the program ends.

AIMRAY (ON or **YES** or **OFF** or **NO)** - The "AIMRAY (ON or YES)" and "AIMRAY (OFF or NO)" commands either activate or deactivate real ray, ray aiming to a specific relative coordinate in the reference surface. When ray aiming is "(OFF or NO)", rays are aimed at next surface after the object surface based only upon the existing paraxial ray trace. It should only be used for diagnosing ray tracing problems. Issued with a "?", the "AIMRAY" command returns a message as to the current setting. This command is "sticky" and remains as set for the current lens until changed by the user. The setting is remembered in the current lens database. This command is also described in the LENS section

AIMRAY OFFSET , x-offset , y-offset , z-offset - The "AIMRAY OFFSET" command is provided in order give the user maximum control over program ray tracing. It will rarely, if ever, be needed. When the program begins aiming a chief ray toward the center of the current reference surface, it uses, as its first guess, paraxial ray trace data at surface NEWOBJ+1, decentrations assigned to the surface NEWOBJ+1 and the numeric input issued with the "FOB" command. In all cases tested, either this "first guess" or the automatic search engine built into the program has been found to be good enough to allow chief ray aiming to proceed successfully. In the unlikely event that the first guess ray coordinate at surface NEWOBJ+1 is not good enough to allow the chief ray to be traced, the "AIMRAY OFFSET" command may be used to introduce a permanent "x-offset", "y-offset" and "z-offset" to the initial surface NEWOBJ+1 ray coordinate. The default "x-offset", "y-offset" and "z-offset" are always zero. The "x-offset", "y-offset" and "z-offset" will be stored with the lens database. These offsets are only used to give the program a different initial starting point when aiming the chief ray. They do not change the chief ray aim point at the reference surface. The command "AIMRAY", when issued with the special interrogator "?", will display the current status of ray aiming as well as the current "x-offset", "x-offset" and "z-offset" values.

GAUSSIAN BEAM PROPAGATION - In this program, gaussian beam propagation is performed in the following way:

First; The user specifies the XZ and YZ-plane gaussian beam $1/e^2$ semi-diameters and gaussian beam divergence half-angles using the "WRX", "WRY", BDX" and "BDY" described in the LENS section of this manual. The user has full control of the $1/e^2$ semi-diameters and divergence half-angles and is responsible for the realism of these starting values. All four values should be explicitly set !

Second; The starting wavefront radius of curvature will be the distance between the wavefront origin position on surface 0 and the center of surface 1 (or the center of the clear aperture assigned to surface 1). The wavefront always originates on surface 0. Specification of a field-of-view position in some of the gaussian beam propagation commands specifies the point on the object that is to be the origin of the wavefront. If the distance from surface 0 to surface 1 is positive, the wavefront will be a diverging wavefront and it will have a negative radius of curvature associated with it. If the user wishes to specify that surface 1 is a true "beam waist", then the distance from the wavefront origin on surface 0 to center of surface 1 (or the center of the clear aperture assigned to surface 1) should be set to a large and nearly infinite value (1.0D+20 is a good choice). This can be done by giving surface 0 a very large axial thickness. This will cause the wavefront to be effectively flat.

Third; The appropriate gaussian beam analysis command is issued or the appropriate value is retrieved using the "GET" command or the appropriate operand is used in optimization or tolerancing.

How the calculation are performed

In many optical design and analysis programs, gaussian beam propagation is based upon a paraxial ray trace. This method is fast and simple but leaves much to be desired. The "paraxial" method can't be used in "decentered" optical system or in systems which contain diffractive optical elements. This program does not use this simplistic "paraxial" method but instead uses the "generalized paraxial ray trace" described earlier in this manual section. In the form of the "generalized paraxial ray trace" used for gaussian beam propagation, the gaussian beam divergence half-angle plays the role of a field angle to define the "generalized paraxial chief rays" and the gaussian beam semi-diameter on surface 1 plays the role of reference aperture height to define "generalized paraxial marginal rays". If surface 1 is not the system "reference surface" then it is temporarily redefined to be the system "reference surface" for all gaussian beam calculations. A field-of-view specification in the gaussian beam analysis commands acts to re-define the reference optical axis of the system for that particular ray trace by defining a new wavefront origin location on surface 0. The ray tracing performed is always exact, real, trigonometric ray tracing. The "generalized paraxial ray trace" is simulated by tracing real rays close to the central reference axis ray. The central reference axis ray is the ray that starts at the specified wavefront origin position on surface 0 and passes through the center of surface 1 (or the center of the clear aperture assigned to surface 1).

BEAM (ALL or OB or OBJ) or BEAM , i , y-fob , x-fob , z-obj. shift , wavelength # - The "BEAM" command generates and outputs the YZ or XZ-plane gaussian beam propagation data. This data consists of:

The gaussian beam $1/e^2$ semi-diameter at each specified surface.

The wavefront radius of curvature after interaction with each specified surface at that surface.

The distance to the next beam waist after interaction with each specified surface.

The gaussian beam $1/e^2$ semi-diameter at the next waist after interaction with each specified surface.

This data may be output for "ALL" surfaces, for the object surface ("OB" or "OBJ") or for surface "i". Output is performed for the current control wavelength. The "BEAM" command may take optional numeric words #2, #3, #4 and #5 input. Numeric words #2 and #3 are Y and X-FOB values which will override the default 0.0, 0.0 values. Y and X-FOB input is used to specify wavefront origin points other than at the center of the object surface. Numeric word #4 is used to specify a Z-obj. shift as is used in the "FOB" command. Numeric word #5 is used to specify a wavelength number other than the control wavelength number. Valid entries are 1 to 10. There are also "GET" options used for retrieving individual gaussian beam properties. These are listed later in this section. There are also predefined gaussian beam operands described in the "OPTIMIZATION" and "TOLERANCING" sections of this manual.

ABERRATION RAY FANS - Ray fans are tabulations of ray aberration versus relative fractional ray position in the reference surface. Each of the following "ray fan" commands must be preceded by an "FOB" command.

XFAN (qualifier word) , Xmin , Xmax , n , m , δ and

YFAN (qualifier word) , Ymin , Ymax , n , m , δ and

PFAN (qualifier word) ,Pmin , Pmax , n , m , δ and

NFAN (qualifier word) , Nmin , Nmax , n , m , δ - The "XFAN", "YFAN", "PFAN" and "NFAN" commands are used to generate and display ray fan data for a set of rays intersecting the reference surface. These sets of rays are traced in fan lines and intersect the reference surface at fractional reference surface coordinates from "X_{min}" to "X_{max}" for "XFAN", "Y_{min}" to "Y_{max}", for "YFAN", "P_{min}" to "P_{max}" for "PFAN" and "N_{min}" to "N_{max}" for "NFAN". There will be "m" rays traced. These "m" rays are evenly spaced along the fan line between the minimum and maximum fan reference surface coordinate limits. If no entry is made for "m", four rays will be traced for an XFAN and nine rays for all other fans. All rays will be traced at wavelength number "n". "δ" is the fan offset shown in the next figure. "δ" allows a fan to be traced "offset" in the reference surface. "δ" is entered as a relative, fractional value of the reference aperture height rather than an offset in lens system units.

"XFAN" traces a ray fan along a line defined by:

$$Y = \delta$$

"YFAN" traces a ray fan along a line defined by:

$$X = \delta$$

"PFAN" traces a ray fan along a +45 degree line defined by:

$$Y = (P + \delta)/\sqrt{2} \, , x = (P - \delta)/\sqrt{2}$$

"NFAN" traces a ray fan along a -45 degree line defined by:

$$Y = -(N - \delta)/\sqrt{2} \, , x = (N + \delta)/\sqrt{2}$$

P and N are relative (fractional) parameters, which measure distance along the "PFAN" or "NFAN" at the reference surface. All fan extents are referenced to the reference aperture height. If a PFAN is traced in a system which has a non-circular clear aperture assigned to it, the maximum extent of the fan when P is +1 or -1 will be set equal to the larger of the two non-equal clear aperture height dimensions.
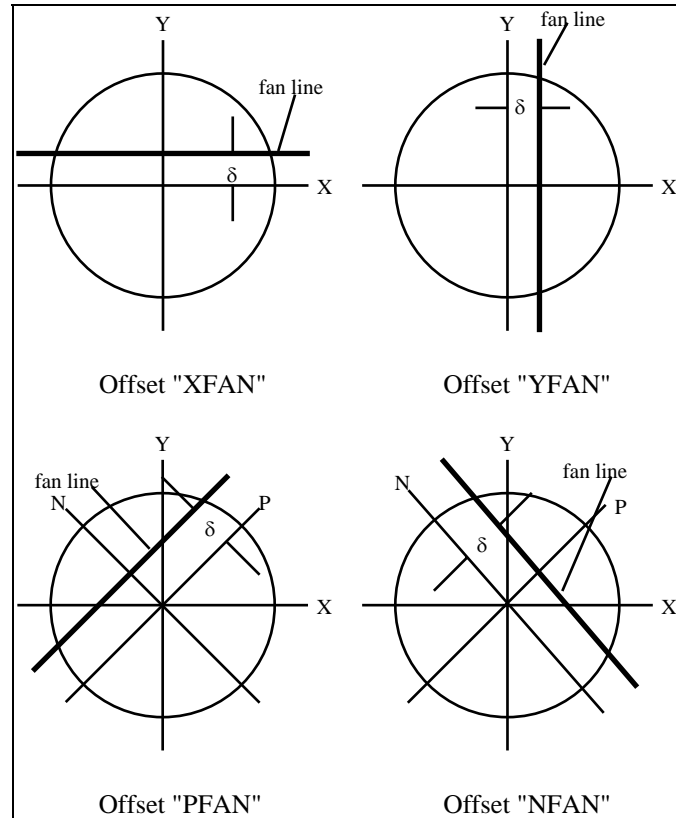
Fan Offset Definition

The transverse ray aberrations DX, DY, DN, DP and DR are displayed in lens units. They are the ray height differences between the ray and the reference ray at the image surface, either in the X, Y or radial coordinate direction. DXA, DYA, DPA, DNA and DRA are the angular equivalents of DX, DY, DP, DN and DR and are always measured in radians. LAX, LAY, LAN and LAP are longitudinal aberration measures. They represent the distance between the image surface and a plane perpendicular to the local Z-axis of the image surface which passes through the intersection point of a fan ray and the chief ray. This distance is measured along the local Z-axis of the image surface. The distance is always displayed in lens units. DTX , DTY, DTP and DTN are differences in the tangents of the ray slope angles of a fan and the chief ray. They are unitless. DR and DRA are defined by the following equation:

$$DR = \left(\sqrt{DX^2 + DY^2} \right)$$

$$DRA = \left(\sqrt{DXA^2 + DYA^2} \right)$$

The primary and secondary chromatic differences, PCDX, PCDY, SCDX, SCDY, PCDP, PCDN, SCDP and SCDN are measured in lens units at the image surface. PCDXA, PCDYA, SCDXA , SCDYA, PCDPA, PCDNA, SCDPA and SCDNA are the angular equivalents of PCDX, PCDY, SCDX, SCDY, PCDP, PCDN, SCDP and SCDN. They are always displayed in radians. The chromatic differences are formed by differencing the transverse ray coordinates (in modes FOCAL and UFOCAL) or the radian measure of the ray-to-optical axis angles (in modes AFOCAL and UAFOCAL) calculated at each wavelength of either the primary or secondary wavelength pairs. The ray datum calculated at the second wavelength of the chromatic wavelength pair is always subtracted from the ray datum calculated at the first wavelength of the chromatic wavelength pair. NFANs and PFANs can be thought of as YFANs which are rotated through either a + or a - 45 degree GAMMA rotation at the reference surface. The output of NFANs and PFANs is also represented in a rotated coordinate system which is located in the plane of the image surface This rotated image plane coordinate system has a +45 degree GAMMA rotation for NFANs and a - 45 degree GAMMA rotation for PFANs. The following table lists output displayed for each combination of fan type, fan qualifier and lens mode:

FAN TYPE	FAN QUALIFIER	MODE	DATA DISPLAYED
YFAN or XFAN	(none)	FOCAL or UFOCAL	DX, DY
PFAN and NFAN	(none)	FOCAL or UFOCAL	DN, DP
YFAN or XFAN	(none)	AFOCAL or UAFOCAL	DXA, DYA
PFAN or NFAN	(none)	AFOCAL or UAFOCAL	DNA, DPA
(all fan types)	OPD	(all modes)	OPD
(all fan types)	LA	FOCAL or UFOCAL	LAX, LAY, DTX, DTY or LAN, LAP, DTN, DTP
(all fan types)	LA	AFOCAL or UAFOCAL	(not functional)
(all fan types)	CD	FOCAL or UFOCAL	PCDX, PCDY, SCDX, SCDY or PCDXN PCDP, SCDN, SCDP
(all fan types)	CD	AFOCAL or UAFOCAL	PCDXA,PCDYA,SCDXA,SCDYA or PCDNA,PCDPA,SCDNA and SCDPA

OPD FANS - OPD (optical path difference) is defined as the optical path length along a given ray minus the optical path length of the reference chief ray which passes through the center of the reference surface. The optical path lengths are measured from the object point to a reference sphere in the image space. This reference sphere represents the "perfect" spherical wave traveling in the direction of the reference ray toward the image surface. The reference sphere is constructed so that its center of curvature coincides with the point of intersection of the reference ray with the image surface. The radius of curvature of the reference sphere is chosen in one of several ways, depending upon the mode of the lens (FOCAL/UFOCAL or AFOCAL/UAFOCAL) and whether or not automatic calculation of the exit pupil position is in effect.

EXPUP (qualifier word) - The "EXPUP" command controls how the radius of curvature of the reference sphere is calculated. It takes one of two qualifier words, "AUTO" or "NOAUTO", and only applies in modes FOCAL and UFOCAL. If the qualifier word "AUTO" is used (this is the default when the program starts and is ALWAYS used during spot diagram OPD calculations), then close real differential rays are traced along the chief ray to determine location of the real exit pupil. The reference sphere radius of curvature is then equal to the distance from this real exit pupil to the intersection of the chief ray with the image surface measured along the chief ray. If the qualifier word "NOAUTO" is used, then the radius of curvature of the reference sphere is computed as follows:

If the surface preceding the image surface has a non-zero thickness, then the radius of curvature of the reference sphere is set equal to that axial thickness.

If the surface preceding the image surface has a zero axial thickness, then the radius of curvature of the reference sphere is set equal to the axial distance from the image surface to the location of the paraxial exit pupil measured along the optical axis. The reference ray is always traced at the wavelength specified in the "FOB" command. The center of curvature and the radius of the reference sphere do **not** change as fans are traced at different wavelengths but only when the object point is redefined with a new "FOB" command.

RAY TRACING SECTION

For afocal systems, the reference "sphere" is not a sphere but is a plane located at the intersection of the reference ray with the image surface. It is perpendicular to the reference ray. In some cases, such as in visual systems, it may be a good idea to place this final surface at the location of the paraxial exit pupil by using an ASTOP EX setting, or at the location of the real ray exit pupil via an optimization based upon where the chief ray crosses the optical axis. Since afocal systems vary so much in their intended use, designer judgement should be used in the selection of the location of the final surface in afocal systems when OPD wavefront performance must be evaluated. For focal systems which have their exit pupil at infinity (telecentric systems), the reference "sphere" is also not a sphere but is a plane perpendicular to the reference ray and located at infinity. Infinity in this case is a value whose magnitude is greater than or equal to 1.0×10^{10} lens units. If reference ray differential ray tracing has been shut off via the "DIFFOB (OFF or NO)" command, the paraxial exit pupil position will be used even if "EXPUP AUTO" was in effect.

ABERRATION FAN PLOTTING

DRAWFAN , (ssi) , dflag - During the design process it is often useful to issue a "FOB" command followed by one of the CMD level fan commands so as to examine the current aberration characteristic of the system being designed. If a "DRAWFAN" command is issued immediately after one of the fan commands, a graphical representation of this "last" fan will be displayed on the screen. This fan plot may be re-displayed on the screen with the "DRAW" command or may be sent to a printer or plotter with the "GRAOUT" command. The optional scale bar length, "ssi", may be entered to specify the scale bar length used in the display. If it is ommitted, the scale bar length will be automatically picked by the program. The rest of the commands described in this section are independent of the last fan displayed using the CMD level fan commands. If "dflag" is explicitly input (any numeric value), the automatic "draw" command will not be issued.

PLT_FAN , (ssi) - This command is identical to "DRAWFAN" except that the fan is not drawn. A seperate "DRAW" command should be issued to draw the plotted fan.

AUTOMATED FAN PLOTS - These commands are provided so that the designer may custom tune the type of plot to be generated. They work best when issued from within a macro. They generate fan plots at three field-of-view positions. In the default mode, the field positions are at 1.0, 0.7 and 0.0 relative Y-field-of-view positions as defined by the "SCY" or "SCY FANG" setting in the current lens file.

FANFIELD (F1 or F2 or F3) , y-fob , x-fob

The CMD level command "FANFIELD" is used to reset the default values of the field positions for the automated fan plots to follow. The settings are "sticky" and stay set until reset or until the program terminates. The valid qualifiers are "F1", "F2" and "F3". The "y-fob" and "x-fob" are fractional object or field positions just like those used with the "FOB" command. The default "y-fob" and "x-fob" values for fields "F1", "F2" and "F3" are: (1.0,0.0), (0.7,0.0) and (0.0,0.0).

FANS (qualifier word) , ssi , dflag

The CMD level command "FANS" causes a one-page, three field-of-view fan plot to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "ssi" is the amount of aberration represented by the vertical axis of the plots. If "ssi" is omitted, the plots will be auto-scaled by the maximum aberration value in the first field of view. Aberration fans will be generated and displayed based upon the current "SPTWT" and "SPTWT2" spectral weight settings in the lens database. The following table lists all of the valid qualifier words (the default qualifier word is "XYFAN") and the types of fans which will be generated by each:

QUALIFIER WORD	TYPE OF FAN GENERATED
XFAN or YFAN	X and Y-components of an X-fan or a Y-fan
XYFAN or YXFAN (XYFAN is the default)	Transverse tangential or sagittal aberrations of X and Y ray fans
NFAN or PFAN	N and P-components of an N-fan or a P-fan
XOPD or YOPD	OPD of an X-fan or a Y-fan
XYOPD	OPD of X and Y ray fans
NOPD or POPD	OPD of an N or a P-fan
XCD or YCD	X and Y-chromatic differences of X or Y-fans
XYCD of YXCD	Chromatic differences (tangential or sagittal components) of X and Y ray fans
NCD or PCD	N and P-chromatic differences of N or P-fans
XLA or YLA	X and Y-components of the longitudinal aberrations of an X or Y-fan
XYLA or YXLA	Longitudinal aberrations (tangential or sagittal) of X and Y ray fans
NLA or PLA	N and P-components of the longitudinal aberrations of an N or P-fan

It will be noticed that the X and Y-fans are not drawn on the same sides on the plots as in some other optical design programs. This is because X comes before Y in the English alphabet and we are using a left to right alphabetical layout for most of the fans in graphical output.

REGULAR RAY FAN COMMANDS - The commands which follow may be used to graphically display ray fans. The plots are sent to NEUTRAL.DAT as usual and may then be displayed to the screen or printed in the usual way. The commands which follow set up parameter values which specify the exact type of plot to be generated. The final command causes the specified plot to be generated and sent to NEUTRAL.DAT. The order of entry of all of these commands, except the last command "PLOTFANS GO", is not important.

PLOTFANS SSI , i - The "PLOTFANS SSI" command sets the aberration plotting scale so that "i" units of the specified aberration are plotted in the vertical height of each fan plot drawn. This command also sets the magnitude of the aberration represented by the aberration scale bar. This bar is drawn in the caption area of the plot. If this command is omitted, the scale bar will be automatically set equal to the maximum aberration value at the first field of view position specified in the next two commands. If this default "ssi" determination yields a zero "ssi" value, "ssi" will be set to 0.001.

PLOTFANS YFOB , yfob1 , yfob2 , yfob3 - The "PLOTFANS YFOB" command sets Y-fractional object heights "yfob1", "yfob2" and "yfob3" for up to three fields of view.

PLOTFANS XFOB , xfob1 , xfob2 , xfob3 - The "PLOTFANS XFOB" command sets X-fractional object heights "xfob1", "xfob2" and "xfob3" for up to three fields of view. The program determines from these two commands whether one, two or three sets of fans will be drawn per fan plot. If these commands are omitted, one set of fans will be drawn using X and Y-fractional object heights both equal to 0.0.

PLOTFANS OFFSET , δ - The "PLOTFANS OFFSET" command sets the fan "offset" to be equal to δ. This "offset" is described in the discussion of ray fans in the CMD section.

PLOTFANS NEWOBJ , i - The "PLOTFANS NEWOBJ" command sets surface "i" to be the new temporary object surface for the next fan plot. The default object surface is surface 0.

PLOTFANS NEWREF , i - The "PLOTFANS NEWREF" command sets surface "i" to be the new temporary reference surface for the next fan plot. The default reference surface is the current reference surface defined in the lens database.

PLOTFANS NEWIMG , i - The "PLOTFANS NEWIMG" command sets surface "i" to be the new temporary image surface for the next fan plot. The default image surface is the last surface of the lens database.

PLOTFANS REFWV , n - The "PLOTFANS REFWV" command sets wavelength number "n" to be the new temporary reference wavelength for the next fan plot. The default reference wavelength is the control wavelength defined in the lens database.

PLOTFANS WV , i , j , k , l , m - The "PLOTFANS WV" command specifies the first five program wavelengths for which fans will be traced and plotted. Each of the "i" through "m" input values can be set to ±1 through ±10. A plus value indicates that a fan will be generated at that wavelength number. A minus indicates that a fan will not be generated at that wavelength number. If this command is omitted, the current state of the spectral weighting factors will be used to determine if a fan will be traced. Fans will be traced, in this default scenario, at each of the program wavelengths for which the spectral weighting factor is non-zero.

PLOTFANS WV2 , i , j , k , l , m - The "PLOTFANS WV2" command specifies the second five program wavelengths for which fans will be traced and plotted. Each of the "i" through "m" input values can be set to ±1 through ±10. A plus value indicates that a fan will be generated at that wavelength number. A minus indicates that a fan will not be generated at that wavelength number. If this command is omitted, the current state of the spectral weighting factors will be used to determine if a fan will be traced. Fans will be traced, in this default scenario, at each of the program wavelengths for which the spectral weighting factor is non-zero.

Primary Chromatic Difference (PCD) fan plots use line style #0 and the color assigned to wavelength #1 in the other types of fan plots. Secondary Chromatic Difference (SCD) fan plots use line style # 1 and the color assigned to wavelength #2 in the other types of fan plots.

PLT(X.or Y or XY or YX or N or P) FAN (qualifier) - The "PLTXFAN", "PLTYFAN", "PLTXYFAN", "PLTYXFAN", "PLTNFAN" and "PLTPFAN" commands specify the type of fan data that will be displayed. "PLTXFAN" will generate plot data for the X and Y-components of an X-fan . "PLTYFAN" will generate plot data for the X and Y-components of a Y-fan. "PLTXYFAN" will generate plot data for the X-component of an X-fan and the Y-component of a Y-fan. "PLTYXFAN" will generate plot data for the Y-component of an X-fan and the X-component of a Y-fan. "PLTNFAN" will generate plot data for the N and P-components of an N-fan. "PLTPFAN" will generate plot data for the N and P-components of a P-fan. If none of the above six commands is explicitly issued, then the default fan type will be that which would have been generated by a "PLTXYFAN" command. The "qualifier" may be (no qualifier) or "OPD" or "LA" or "CD". A more detailed description of aberration fans is contained in the CMD manual section. The qualifier "OPD" used with either the "PLTXYFAN" or the "PLTYXFAN" command, produces identical results.

PLOTFANS RESET - The "PLOTFANS RESET" command resets all fan plotting settings to their original state immediately after a "PLOT NEW" command.

PLOTFANS GO - The "PLOTFANS GO" command causes all plotfan settings, both implicit and explicit, to be used to generate a fanplot. This plot is sent to the NEUTRAL.DAT. Fan plot display is then performed via the "DRAW", or the "GRAOUT " command.

USER-DEFINED FAN PLOTS - The fan plotting commands which have been described so far attempt to give the user a way to generate aberration fan plots in a more or less automated way. The following user-defined fan plotting commands give the user complete control, and responsibility, for the generation of custom aberration fan plots. Before these five following user-defined fan plotting commands are issued, a "PLOT NEW" command should be issued. At anytime during the issuing of any of these user-defined aberration fan plotting commands, the user may issue "DRAW" commands to check on the progress of the user-defined aberration plotting.

PFANAXIS ,(xpos) , (ypos) , (x-extent) , (y-extent) , (clipping) - The "PFANAXIS" command causes an aberration fan axis set to be generated. The axis set will be centered at "xpos" and "ypos". The default values are "xpos"= 5000 and "ypos" = 3500 device independent coordinates. The "x-extent" and "y-extent" set the x and y-extents of the respective axes in device independent units. Extent defaults are "x-extent" = 2500 and "y-extent" = 2000 device independent units. "clipping" set to 0 will cause the fan plots to be clipped outside of a box defined by the axes extents. "clipping" set to 1 will result is no fan plot clipping. The color of the axes will be the current RAY color set using "COLORSET" command and the line style will be the current line style set using the "PLOT LSTYLE" command. "PFANAXIS", issued with the interrogator "?", causes the current "xpos", "ypos", "x-extent", "y-extent" and "clipping" values to be displayed at the current output device.

RAY TRACING SECTION

PFANSSI ssi - The "PFANSSI" command allows the user to explicitly set the "ssi" scale bar for all user-defined fan plotting. If no explicit "ssi" is in effect, one will be computed based upon the first aberration fan plotted with the "PFANCOMP" command. "ssi" is the amount of vertically represented aberration which will be displayed in ("y-extent") device independent units. "PFANSSI" issued with the interrogator "?", causes the current "ssi" value to be displayed at the current output device.

PFANLBL (vertical axis label – up to 21 characters) - The "PFANLBL" command causes the current aberration fan axis set to be labeled. The left and right extremes of the x-axis will be labled –1.0 and 1.0 representing the limits of the reference aperture. The vertical axis will be labled with the optionally input label (up to 21 characters in length). The default label is blank.

PFANCAP (fan caption – up to 40 characters) - The "PFANCAP" command causes the current aberration fan axis set to be captioned with a caption up to 40 characters in length. The caption will be fit beneath the plot, as close to the plot as is practical. The default caption is blank.

PFANCOMP , component number , color number, line style number - The "PFANCOMP" command causes the specified component of the last aberration fan generated to be plotted on the current user-defined fan axis set. Components of the aberration fans are numbered as per the following table. Remember that "LA" fans are only available in the FOCAL and UFOCAL modes. Color numbers range from 1 to 10 and represent the 10 currently assigned colors associated with the WAV1 to WAV10 entries in the "COLORSET" command. Line stype numbers are the numbers associated with the line styles in the "LSTYLE" command. When tracing fans in a macro prior to plotting, the textual output at the screen can be supressed by issuing an "OUT NULL" before and after each "FAN" command.

Fan Type (numeric word #1 value)	Component number 1	Component number 2	Component number 3	Component number 4
Fans (no qualifier)	DX, DXA,DN, DNA	DY, DYA, DP, DPA	(not used)	(not used)
OPD fans	OPD	(not used)	(not used)	(not used)
LA fans	LAX or LAX	LAY or LAP	DTX or DTN	DTY or DTN
CD fans	DCDX or DCDN or DCDXA or DCDNA	DCDY or DCDP or DCDYA or DCDPA	SCDX or SCDN or SCDXA or SCDNA	SCDY or SCDP or SCDYA or SCDPA

This is the end of the user-defined aberration fan plotting capability. Remember, these commands are for users who wish to create and label custom types of aberration plots not normally available in other optical design programs. Any labeling which is desired and which is not described in these above five commands may be added using the commands such as "PLOT NOTE" , "PLOT PEN", "PLOT ACC" etc. which are described earlier in this section. You don't see the action of these commands until you issue a "DRAW" command or until you send the plot to the printer with the "GRAOUT" command.

Example: The following macro is an exaple of user-defined fan plotting:

MACRO TESTIT
C set output to null and generate fan data
OUT NULL
FOB
YFAN OPD , -1 , 1 , 1 , 11
OUT TP
C set output to screen, fan data generated
PLOT NEW
PFANAXIS 4000 , 3000
C center plot at x4000, y=3000
PFANLBL OPD FAN PLOT
PFANCAP OPD Example plot
PFANCOMP 1
DRAW
C generate more fans to plot on this axis set
C or start a new axis set and plot more fans.
EOM

RAY TRACING SECTION

RAY FAILURE CODES - Most of the time when a ray cannot be traced through an optical system, a full descriptive error message is displayed on the screen. There are some instances, however, where these messages would cause too much screen clutter, and in these cases, a shorter message referencing a ray failure code is displayed. This is particularly true during ray fan tracing. The following is a list of ray error codes with their meanings:

MESSAGE: **RAY FAILURE CODE 1 AT SURFACE (I)**
MEANING: Ray was not able to intersect surface I.

MESSAGE: **RAY FAILURE CODE 2 AT SURFACE (I)**
MEANING: Iterative intersection routine for an aspheric, toric or special surface failed to converge for surface (I).

MESSAGE: **RAY FAILURE CODE 3**
MEANING: Ray trace failed to converge to the reference surface aim point.

MESSAGE: **RAY FAILURE CODE 4 AT SURFACE (I)**
MEANING: Total internal reflection occurred at surface (I).

MESSAGE: **RAY FAILURE CODE 5 AT SURFACE (I)**
MEANING: Angle of diffraction at the grating on surface (I) was physically unrealizable.

MESSAGE: **RAY FAILURE CODE 6 AT SURFACE (I)**
MEANING: Ray was blocked by a clear aperture on surface (I).

MESSAGE: **RAY FAILURE CODE 7 AT SURFACE (I)**
MEANING: Ray was blocked by an obscuration on surface (I).

MESSAGE: **RAY FAILURE CODE 8**
MEANING: Chief ray from the current object point could not be traced.

MESSAGE: **RAY FAILURE CODE 9 AT SURFACE (I)**
MEANING: Angle of refraction for the HOE on surface (I) was physically unrealizable.

(ray failur code 10 not currently in use)

MESSAGE: **RAY FAILURE CODE 11 AT SURFACE (I)**
MEANING: Reference ray cannot be traced because current trace wavelength is equal to 0.0 microns.

MESSAGE: **RAY FAILURE CODE 12 AT SURFACE (I)**
MEANING: Ray can not be traced because current trace wavelength is equal to 0.0 microns.

MESSAGE: **RAY FAILURE CODE 13 AT SURFACE (I)**
MEANING: Ray can not be traced because ray missed the grazing incidence surface section between the beginning and ending Z-coordinates defined in special surface coefficients C_1 and C_2.

MESSAGE: **RAY FAILURE CODE 14 AT SURFACE (I)**
MEANING: Illumination ray can not be traced because ray was blocked by a clear aperture.

MESSAGE: **RAY FAILURE CODE 15 AT SURFACE (I)**
MEANING: Ray can not be traced because GRID (apodization, sag or phase) file data was missing for this surface.

RAY FAILURE CODES (cont'd)

MESSAGE: **RAY FAILURE CODE 16 AT SURFACE (I)**
MEANING: Specified object point does not exist because sag on object surface at specified x and y points does not exist.

MESSAGE: **RAY FAILURE CODE 17 AT SURFACE (I)**
MEANING: No DEFORM file exists for the surface or the file has insufficient data.

MESSAGE: **RAY FAILURE CODE 18 AT SURFACE (I)**
MEANING: Ray coordinate lies beyond deformable surface bounds.

MESSAGE: **RAY FAILURE CODE 19 AT SURFACE (I)**
MEANING: Aimed chief ray could not hit defined target point in the image surface.
MESSAGE: **RAY FAILURE CODE 20 AT SURFACE (I)**
MEANING: Ray failed because it could not reflect in a TIR condition. This is related to the "REFLTIRO" command.
MESSAGE: **RAY FAILURE CODE 21 AT SURFACE (I)**
MEANING: Ray failed because it could not be traced in the CONSTRUCTION configuration for a HOE-R, Type 13 special surface.
MESSAGE: **RAY FAILURE CODE 22 AT SURFACE (I)**
MEANING: Ray failed because it could not be traced in the REFERENCE configuration for a HOE-R, Type 13 special surface.
MESSAGE: **RAY FAILURE CODE 23 AT SURFACE (I)**
MEANING: Reference ray could not intersect the NSS surface group.
MESSAGE: **RAY FAILURE CODE 24 AT SURFACE (I)**
MEANING: Ray could not intersect the NSS surface group.
In the source code, the failure code is tracked in RAYCOD(1) and the surface the ray stopped on is tracked with RAYCOD(2).

SPOT DIAGRAM RAY TRACING - Spot diagrams, as used in OPTIMIZATION, are described in the OPTIM section of this manual. Spot diagram ray tracing provides a means to trace one of several different types of ray distributions through the current lens system. Each ray in the distribution is aimed at a specific point in the current reference surface. If the reference surface has no clear aperture assigned to it, a temporary clear aperture will be assigned. This temporary clear aperture will be dimensioned according to the maximum of the current XZ and YZ-plane reference aperture heights. The clear aperture type will be circular. After completion of the spot diagram ray tracing, this temporary clear aperture will be removed. Spot diagram ray tracing is used to analyze geometrical imaging properties of the current lens in its current active configuration and can be used during optimization to optimize the RMS spot dimensions. An "FOB" command must be in effect before spot diagrams can be traced. Spot diagram rays all have equal energy unless ray energies are adjusted using the "APOD" command. The energy weighting scheme, once set, is used in all calculations involving spot diagram data including geometrical optical transfer function calculations described later in this section.

STATS (FULL or MIN) - The "STATS" command causes a sticky switch to be set which determines the amount of statistical data calculated and displayed by some of the "SPD" commands. The program default is "FULL". Output generated by this command will vary depending upon the "MODE" of the current lens and whether "FOB" or "FOB NULL" is in effect. Ray failure statistics are always displayed. Spot diagrams are used both for optical system analysis and for some types of optimization. The default forms of the ray distributions in the spots for these two purposes are different. Spot characteristics for optimization are controlled by commands described in the OPTIMIZATION section of this manual. Spot characteristics for optical system analysis are controlled by the next few commands.

SPOT (RECT, RING, RAND) - The "SPOT" command, issued with one of the three qualifier words ("RECT", "RING" or "RAND"), is used to set the type of grid or ray distribution to be used in spot diagram ray tracing. "RING" is the default type. "RECT" causes a rectangular ray grid to be defined over the reference surface. "RECT" also causes circular clear aperture to be assigned to the reference surface if one has not yet been assigned. The default rectangular grid size is 10X10. "RING" causes circular or elliptical rings of rays to be traced. A temporary circular clear aperture will be assigned to the reference surface if no clear aperture is assigned to that surface. The default spot diagram will contain 33 rays. One ray at the center and eight rays each in rings at fractional reference surface radii 0.5, 0.707, 0.866 and 1.0. The eight rays will be uniformly distributed in each of these rings and all ring angular offsets will be zero. If the reference surface clear aperture is not square or circular, rays will have similar fractional relative but different actual coordinate in X and Y on the reference surface. If the qualifier "RAND" is used, a pseudo-random ray distribution over the reference surface will be traced. If no clear aperture is assigned to the reference surface, a circular clear aperture will be assigned. The randomly distributed rays are distributed over a square area which is just large enough to guarantee that the clear aperture on the reference surface will be filled with rays. This is similar to the area over which the rectangular grid is placed. Issued without a qualifier or with the interrogator "?", the current grid style will be displayed.

RINGS , n - The "RINGS" command is used to specify the number of rings to be used whenever the "SPOT RING" command is in effect. The maximum number of rings is set at 50. In general, these rings will be first defined as circular. Rays will be distributed uniformly around each circular ring and then, if needed, the circular ring will be scaled to the appropriate ellipse. Elliptical rings are used when an elliptical clear aperture has been assigned to the reference surface or when the SAY and SAX values are not equal. The program default for "n" is 4. These four default rings will have fractional aperture heights (relative fractional radius) of 0.5, 0.707, 0.866 and 1.0. Each default ring will have eight equally spaced rays on that ring. Angular offsets will be zero in this default configuration. Issued with no numeric input or with the special interrogator "?", "RINGS" displays the current number of rings that will be used.

RAY TRACING SECTION

RING , i , r , m , θ - The "RING" command is used to specify the relative fractional radius "r" of ring "i", the number of rays "m" to be used in ring "i" and the angular offset "θ" of the first ray in ring "i". The program default value for "r", if "RING" is explicitly issued, is the reciprocal of the total number of rings times the number of the current ring. The maximum value for "r" is always 1.0. The maximum value for "n" is 2500 per ring. The program default is 8 rays per ring. "θ" is the first ray angular offset value measured counter-clockwise from the local X-axis of the reference surface coordinate system toward the local Y-axis of the reference surface coordinate system. The default value for " θ" is 0.0. With this default value in effect, the first ray in the ring will always lie on the local Y-axis of the reference surface coordinate system. Issued with no numeric input or with the special interrogator "?", "RING" displays the current data for each ring. Issued with numeric word #1 input only, "RING" displays the current data for ring "i".

RECT , n - The "RECT" command is used to specify the dimensions of the "n" X "n" rectangular grid of rays to be traced when "SPOT RECT" is in effect. The default value for "n" is 10 and the maximum is 300. Issued with no numeric input or with the special interrogator "?", "RECT" displays the current number value of "n".

RANNUM , n - The "RANNUM" command is used to specify the total number of rays to be traced per wavelength when "SPOT RAND" is in effect. The default value for "n" is 100. There is no maximum. Issued with no numeric input or with the special interrogator "?", "RANNUM" displays the current numeric value of "n". Should the random number generator seed need be reset, use either the "NEWSEED" or "SEED" commands in the RAYTRACE section of the manual.

SPDRESET - The "SPDRESET" command is used to reset all non-optimization related spot diagram parameters to their program default values. Whenever the characteristics of a spot pattern is modified by the user, all characteristics must be reset by the user. If, for example, the user sets the number of rings to 20, then the characteristics of every ring will need to be reset by the user using the "RING" command.

APOD (GAUSS or NONE) , dbloss - The "APOD" command is used to set the state of aperture apodization in spot diadram, complex aperture function and point spread function calculations. The default is "NONE" meaning a uniform apodization. If "GAUSS" is selected, a gaussian apodization will be used such that at the edge of the reference surface aperture, the ray intensity will be reduced by "dbloss" decibles. This apodization will be applied program wide including in tolerance and optimization options. The default for "dbloss" is 0.0 meaning uniform apodization. If the x and y-fractional ray positions in the reference surface are given by "fx" and "fy" then "APX" and "APR" are given by the following equations:

$$APX = -\ln\left(10.0^{-\left(\frac{abs(dbloss)}{10.0}\right)}\right)$$

$$APR = \left(fx^2 + fy^2\right)$$

and the he original ray intensity is reduced by:

$$I = I * e^{-(APX \times APR)}$$

cast in the more familiar optical $1/e^n$ intensity reduction terms, the absolute value of the "dbloss" term is given by:

$$dbloss = 10 * Log_{10}\left(e^{-n}\right)$$

EXAMPLE: You want to trace a gaussian apoadized beam into an optical system such that the $1/e^2$ intensity radius is 2.5 lens units at the reference surface but you want the full gaussian traced into the system to be truncated at an intensity = $1/e^6$ reference surface.

Question: what reference aperture height and dbloss term should be used, so that at a reference surface radius of 2.5 lens units, the intensity will be $1/e^2$?

The dbloss term is simple. It is $10*Log_{10}(e^{-6})$ = -26.0576689142

SPD , (λ#) , fflag , i - The "SPD" command causes a spot diagram to be traced from the field position defined by the last "FOB" command. Rays are traced in either a ring, rectangular or random distribution over the reference surface, depending upon the settings established by the foregoing spot definition commands. The default distribution is a 10x10 rectangular ray grid. Full statistics are printed unless STATS was set to MIN using the "STATS MIN" command. Rays will be traced at every wavelength for which there is a non-zero spectral weight if no explicit wavelength number , (λ#), is entered. If a specific wavelength number is entered, only that wavelength will be used and the spectral weight will be assumed to be 1.0. Ray energies are established in relation to the spectral weights set at each wavelength. RMS spot size and centroid location is computed and displayed along with ray failure statistics. When "STATS FULL" is in effect, distance to best geometrical focus is also displayed. After the spot has been generated, a number of data values may be "gotten" using the "GET" command described later in the RAYTRACE section of this manual. Spot statistics are reported in lens units for modes "FOCAL" and "UFOCAL" and in angular radian measure for modes "AFOCAL" and "UAFOCAL". If "flagg" is not explicitly input or is zero, clear aperture and obscuration checking checks for aperture and obscuration ray blocking from surface 0 to the final surface. If "fflag" has been explicitly issued or is set to "1", then clear aperture and obscuration ray blockages are checked from the final surface to surface 0. This provies support for simulated reverse ray tracing. If the third numeric word "i", is set to a surface number other than the surface number of the final surface, then all calculations performed inside the "MTRACEI GRID" command will use the X,Y and Z coordinates of the rays at surface "i" rather than at the final or NEWIMG surface. All other spot diagram calculations will remain un-affected.

RAY TRACING SECTION

SPD ACC, (λ#) , fflag , i - The "SPD ACC" command works exactly as the "SPD" command does, except that no display of output is performed. The RSM spot values are calculated by these commands. ". If "flagg" is not explicitly input or is zero, clear aperture and obscuration checking checks for aperture and obscuration ray blocking from surface 0 to the final surface. If "fflag" has been explicitly issued or is set to "1", then clear aperture and obscuration ray blockages are checked from the final surface to surface 0. This provies support for simulated reverse ray tracing.

FAIL , i , j and

RAY TRACING SECTION

FAIL ACC , i , j - The "FAIL" and "FAIL ACC" commands either display or store in the X-register (accumulator) the number of "failed" or "blocked" rays in the current spot diagram. A spot diagram must already exist for these commands to be used. If no numeric input is entered for "i" or "j", the total number of failed rays at all surfaces is returned. If only "i" is supplied, the number of failed rays at surface "i" will be returned. If "i" and "j" are both entered, the number of rays which failed at surface "i" through surface "j" will be returned. The RSM spot values are **not** calculated by these commands.

SPD MOVE , δ and

SPD MOVEACC , δ - The "SPD MOVE" and "SPD MOVEACC" commands either display or store in the X-register (accumulator) the RMS spot size after a shift in focus of "δ" lens units. A spot diagram must already exist for these commands to be used. These commands are only applicable in MODE FOCAL and MODE UFOCAL systems. The RSM spot values are calculated by these commands.

SPD ISTAT , i , angle1, angle2 , δangle - The "SPD ISTAT" command generates a new spot diagram with surface "i" as the new current image surface. It then displays a table listing the number of rays, at surface "i", which have angles of incidence which range from "angle1" degrees to just less than "angle1" + "δangle" degrees. "angle1" is then incremented by "δangle". This table continues until "angle1" + "δangle" = "angle2". When this end condition occurs, rays with angles of incidence equal to "angle2" are included in the final value. The rays tabulated are non-zero energy, non-failed rays. The total number of non-zero energy, non-failed rays is also listed.

SPD IPSTAT , i , angle1, angle2 , δangle - The "SPD IPSTAT" command is identical to "SPD ISTAT" except that instead of performing statistics upon the angle of incidence of each ray in the spot diagram, statistics are performed upon the angle of refraction, reflection or diffraction.

SPDSAVE (filename) , wt - The "SPDSAVE" command causes the current spot diagram to be stored in the file "filename".DAT. Before the data is saved, the energy term for each ray will be multiplied by the "wt" factor. The default value for "wt" is 1.0. Any existing spot diagram stored in "filename".DAT is erased. RMS spot values are **not** calculated by this command. If no file name is explicitly entered, the file named "SPOTS.DAT" will be used.

SPDADD (filename) , wt The "SPDADD" command causes the current spot diagram to be stored in the file "filename".DAT and appended to any spot diagram data already stored in that file. Before the data is saved, the energy term for each added ray will be multiplied by the "wt" factor. The default value for "wt" is 1.0. The RMS spot values are **not** calculated by this command. If no file name is explicitly entered, the file named "SPOTS.DAT" will be used.

SPOT DIAGRAM DEPENDENT CALCULATIONS

SPDSTATS (filename) - The "SPDSTATS" command causes the spot diagram data stored in the "saved and summed" spot diagram file "filename".DAT to be statistically analyzed and the results of the analysis to be displayed. This command is useful for creating averaged spot diagrams. The RMS spot values are calculated by this command. If the file name "filename" is not explicitly entered, the file SPOTS.DAT will be used. All "SPD" commands which calculate RMS (Root Mean Square) geometrical spot diameter and the X and Y-RMS spot dimensions cause these values to be automatically placed in the X, Y and Z-general purpose storage registers. A spot diagram must exist before radial energy distributions, expanding slit energy distributions, LSFs and MTFs calculations can be performed. At least 100 non-failing rays per non-zero weighted wavelength should be traced before any of the following commands are issued. The commands described below generate radial and expanding slit edge energy distributions, line spread functions and geometrical optical transfer functions, and these calculations are always based upon the most recent spot diagram.

RAY TRACING SECTION

WRITING A SPOT DIAGRAM

BWRTSPOT (filename) - The "BWRTSPOT" command causes the last current spot diagram to be written to the main program directory as the file named "filename" with the file extension .SPD. The "filename" is input as a qualifier word and may be up to 8 characters long. The data is written as a direct access binary file. The first record is an integer which specifies the number of records in the file not counting record 1 and the last record. This file may later be opened, read and post-processed by a user written program outside of this program. Each record, except the first and the last, consists of the 50 double precision data items kept for each ray in the spot diagram. The last record contains the x, y, z, l, m, n and wavelength number of the chief ray at the object surface. The file may be opened using the following FORTRAN open statement: OPEN (UNIT = {unit number}, ACCESS = DIRECT, FILE = {file name}, FORM = 'UNFORMATTED', RECL = 240, STATUS = 'UNKNOWN'). If there are 100 rays in the spot diagram, there will be 101 records in the file.

AWRTSPOT (filename) - The "AWRTSPOT" command causes the last current spot diagram to be written to the main program directory as the file named "filename" with the file extension .ASC. The "filename" is input as a qualifier word and may be up to 8 characters long. The data is written in ASCII format. The first line contains an integer which specifies the number of rays in the spot diagram. Every following group of 25 lines contain the 50 items stored in a spot diagram for each ray. This file may later be printed or opened, read and post-processed by a user written program outside of this program. If there are 100 rays in a spot diagram, there will be 1301 lines in the file plus the ending seven entries. The last seven entries are the x, y, z, l, m, n and wavelength number of the chief ray at the object surface. The first line holds items 1 and two, the second line items 3 and 4 etc. The twenty-six data items written for each ray in the spot diagram are:

Item Number	Data Description
1	Ray X-coordinate at image surface
2	Ray Y-coordinate at image surface
3	Ray Z-coordinate at image surface
4	(reserved for CAPFN calculations)
5	Ray X-coordinate at reference surface
6	Ray Y-coordinate at reference surface
7	Ray failure code 1
8	Ray failure code 2
9	Ray XZ-slope angle in radians at image surface
10	Ray YZ-slope angle in radians at image surface
11	Ray aperture apodization term
12	Ray Energy term
13	OPL from object to image surface
14	Ray X-coordinate at current Object+1 surface
15	Ray Y-coordinate at current Object+1 surface
16	Ray Wavelength Number (1 to 10)
17	Ray Spectral Weighting Factor
18	Ray Z-coordinate at Object+1 surface
19	L-dir cosine of ray at Object+1 surface in coordinate system of surface Object
20	M-dir cosine of ray at Object+1 surface in coordinate system of surface Object
21	N-dir cosine of ray at Object+1 surface in coordinate system of surface Object
22	L-dir cosine of ray at Image surface in coordinate system of surface Image-1
23	M-dir cosine of ray at Image surface in coordinate system of surface Image-1
24	N-dir cosine of ray at Image surface in coordinate system of surface Image-1
25	Ray angle of incidence at the image surface
26	Ray angle of exitance at image surface
27	X - ray coordinate at Image-1
28	Y - ray coordinate at Image-1
29	Z - ray coordinate at Image-1
30	L - dir cosine before surface interaction at Image-1
31	M - dir cosine before surface interaction at Image-1
32	N - dir cosine before surface interaction at Image-1
33	User for Polychromatic RMSOPD only
34	Ray Energy ingnoring adjustment due to pupil distortion
35	Spectral weight for rays wavelength
36	0 is aimed ray is inside reference surface clap, 1 if outside it.
37-50	(reserved for future use)

WRITING A SUMMED SPOT DIAGRAM

BWRTSUM (tofilename) (fromfilename) - The "BWRTSUM" command causes the summed spot diagram in the file named "fromfilename" in the LIBSPO directory to be written to the main program directory as the file named "tofilename" with the file extension .SPD. The "tofilename" is input as a qualifier word and the "fromfilename" is input as a string. Each may be up to 8 characters long. The data is written as a direct access binary file. The first record is an integer which specifies the number of records in the file not counting record 1. This file may later be opened, read and post-processed by a user written program outside of this program. Each record after record #1 consists of the 50 double precision data items kept for each ray in the spot diagram. The file may be opened using the following FORTRAN open statement: OPEN (UNIT = {unit number}, ACCESS = DIRECT, FILE = {file name}, FORM = 'UNFORMATTED', RECL = 280, STATUS = 'UNKNOWN'). If there are 100 rays in the spot diagram, there will be 101 records in the file. The "tofilename" must be explicitly entered. If the "fromfilename" is not explicitly entered, the file SPOTS.DAT will be used.

AWRTSUM (filename) (fromfilename) - The "AWRTSUM" command causes the summed spot diagram in the file named "fromfilename" in the LIBSPO directory to be written to the main program directory as the file named "tofilename" with the file extension .ASC. The "tofilename" is input as a qualifier word and the "fromfilename" is input as a string. Each may be up to 8 characters long. The data is written in ASCII format. The first line contains an integer which specifies the number of rays in the spot diagram. Every following group of 25 lines contain the 50 data items stored in a spot diagram for each ray. This file may later be printed or opened, read and post-processed by a user written program outside of this program. If there are 100 rays in a spot diagram, there will be 1301 lines in the file. The "tofilename" must be explicitly entered. If the "fromfilename" is not explicitly entered, the file SPOTS.DAT will be used. The twenty-six data items written for each ray in the spot diagram were listed in the preceding table.

SPOT DIAGRAM PLOTS - This is another automated plot routine. All spot diagram plotting routines apply to the most recently generated spot diagram. If no spot diagram exists, a message to that effect is issued and no plot is generated. Each ray in the spot diagram is represented by a small plus sign (+). Rays in each wavelength are assigned a color according to the current wavelength color assignments described at the beginning of this section. All "ssi", "x", "Δx", "Y" and "Δy" dimensions are entered as lens units in modes FOCAL and UFOCAL and in radian units in modes AFOCAL and UAFOCAL.

SPDSSI , ssi - The CMD level command "SPDSSI" is used to set the number lens system units (in the FOCAL and UFOCAL mode) or number of RADIANS (in the AFOCAL or UAFOCAL mode) for the little scale bar at the bottom of the spot diagram plot. The bar is 1.0 inch (25.4 mm) long in the printed version of spot diagram plots. The "ssi" value remains set until a new spot diagram is generated. If no "SPDSSI" command is issued, the "ssi" value will be automatically set so that the maximum extent of the spot diagram spans 3.6 inches (91.44 mm) on the display. The entire "square" in which the spot diagram plots measures 4.0 inches (101.6 mm). If "SPDSSI" is issued with the interrogator "?", the current "ssi" value will be displayed.

DET (ON or OFF) - The CMD level command "DET" issued with the qualifier words "ON" or "OFF" is used to specify whether or not a detector is to be included in the spot diagram plot. The default is "OFF".

DET CIRC , diam , Δx , Δy
The CMD level command "DET" issued with the qualifier word "CIRC" is used to specify that the detector is to be circular with diameter "diam". It is to be offset from its nominal center position by "Δx" and "Δy" in the X and Y-directions, respectively. The defaults for "Δx" and "Δy" are 0.0. "diam" must be explicitly input.

DET RECT ,x , y , Δx , Δy , θ - The CMD level command "DET" issued with the qualifier word "RECT" is used to specify that the detector is to be rectangular with X and Y-dimensions "x" and "y". It is to be offset from its nominal center position by "Δx" and "Δy" in the X and Y-directions, respectively. If is to be rotated "θ" degrees counterclockwise as seen looking from the current object surface toward the detector. The defaults for "Δx", "Δy" and "θ" are 0.0. "x" and "y" must be explicitly. If "DET" is issued followed by the interrogator "?", the full current status of "DET" will be displayed. If the detector shape is not explicitly input, the detector will not be drawn, even if "DET ON" has been issued.

RAY TRACING SECTION

PLTSPD (CHIEF or CENT or SUM or ZERO) , dflag - The CMD level command "PLTSPD" causes a plot of the current spot diagram to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. Solid horizontal and vertical lines intersect at the spot center. The qualifier "CHIEF" causes the chief ray location to be the center of the plot. The qualifier "CENT" causes the spot centroid to be the center of the plot. If the qualifier "CHIEF" is entered, a pair of intersecting dashed lines will mark the spot centroid location. If the qualifier "CENT" is entered, a pair of intersecting dashed lines will mark the chief ray location. The qualifier "ZERO" causes the center of the spot plot to be located at x=0, y=0 on the image surface. Normally the current spot diagram in file SPD.DAT is plotted. The qualifier "SUM" causes the "saved and summed" spot diagram in file SPOTS.DAT to be plotted. This plot is centered the X=0.0, Y=0.0 position in the spot. Spot diagrams are "saved and summed" with the "SPD SAVE" and SPD SAVEADD" commands described in the CMD section of this manual. If the "saved and summed" spot diagram is stored in a file whose name is not SPOTS.DAT, the file will first need to be renamed or copied to the file SPOTS.DAT. A framed window 4.0 inches on a side defines the extent of plotted spot diagram data. Any rays which would be plotted outside this window are not plotted. If the detector would be drawn outside this window, it, too, will be omitted. The spot diagram plot is annotated with the lens identifier, field-of-view position and spot diagram specification data. Spot diagrams are always displayed with the positve y-axis of the final surface local coordinate system pointing up, the positive x-axis of the final surface local coordinate system pointing to the right and the positive z-axis of the final surface local coordinate system pointing toward the observer.

GEOMETRICAL ENERGY DISTRIBUTIONS - In the case of "perfect" geometrical systems, 100.0 percent of the energy will always lie within a spot of radius = 1.0X10-20 units or a slit of semi-width = 1.0X10-20 units (units will either be linear system units or angular radian units).

RED (N) , ΔE , ΔX , ΔY , ΔZ and

RED (N)CENT , ΔE , ΔZ - The "RED" and "RED CENT" commands produce radial energy distributions using the current spot diagram data. "CENT" specifies that the distribution center or reference point will be the spot centroid location. In the absence of "CENT", the chief ray location at the current image surface is used as the distribution center. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units) in modes "FOCAL" and "AFOCAL" and angular offsets (in radians) in modes "AFOCAL" and "UAFOCAL". "ΔZ" is a defocus term which is only applicable in the "FOCAL" and "UFOCAL" modes. If the qualifier words "N" or "NCENT" are used, no output is generated.

RED ACC , E , ΔX , ΔY , ΔZ

and

RED CACC , E , ΔZ - The "RED ACC" and "RED CACC" commands produce no display. "RED ACC" returns to the X-register (accumulator), the radius of the circle which encloses "E" percent energy. All the above comments concerning "ΔX" , "ΔY", and "ΔZ" apply in the same way as for the "RED" and "RED CENT" commands. "RED ACC" centers the distribution at the chief ray; "RED CACC" centers it at the spot centroid location.

ESEDX (N) , ΔE , ΔX , ΔY , ΔZ and
ESEDX (N)CENT , ΔE , ΔZ and
ESEDX ACC , E , ΔX , ΔY , ΔZ and
ESEDX CACC , E , ΔZ and
ESEDY , ΔE , ΔX , ΔY , ΔZ and
ESEDY CENT , ΔE , ΔZ and
ESEDY ACC , E , ΔX , ΔY , ΔZ
ESEDY CACC , E , ΔZ - The preceding eight commands act in exactly the same manner as the four "RED" commands, except that they produce one dimensional, expanding slit edge energy distributions in either the X or the Y-directions at the current image surface. Instead of spot semi-diameters, slit semi-width dimensions are displayed or returned to the X-register (accumulator) when using the "ESED", "ESEDX" and "ESEDY" commands. If the qualifier words "N" or "NCENT" are used, no output is generated.

ESED (N) , ΔE , ΔX , ΔY , ΔZ , θ and
ESED (N)CENT , ΔE , ΔZ , θ and
ESED ACC , E , ΔX , ΔY , ΔZ, θ and
ESED CACC , E , ΔZ , θ - The preceding four commands act in exactly the same manner as the eight "ESEDX" and "ESEDY" commands, except that instead of limiting themselves to the X and Y directions, they can produce expanding slit edge energy distributions at any orientation specified by "θ" (in degrees). "θ" = 0 degrees corresponds to "ESEDX" and "θ" = 90.0 degrees corresponds to "ESEDY". Instead of spot semi-diameters, slit semi-width dimensions are displayed or returned to the X-register (accumulator) when using the "ESED", "ESEDX" and "ESEDY" commands. All offset dimensions for radial and expanding slit energy distributions are represented in the coordinate system of the image surface.

RAY TRACING SECTION

If the qualifier words "N" or "NCENT" are used, no output is generated. After tabular data is generated with the "RED" or the "ESED" commands, it may be graphically displayed using the "PLTRED" and "PLTESED" commands.

SUMMED ENERGY DISTRIBUTIONS-I - In the case of "perfect" geometrical systems, 100.0 percent of the energy from each spot diagram in the summation will always lie within a spot of radius = 1.0X10-20 units or a slit of semi-width = 1.0X10-20 units (units will either be linear system units or angular radian units).

SRED (N) , ΔE , ΔX , ΔY , ΔZ and

SRED (N)CENT , ΔE , ΔZ - The "SRED" and "SRED CENT" commands produce radial energy distributions using the current summed spot diagram data stored in the default summed spot diagram file, SPOTS.DAT. "CENT" specifies that the distribution center or reference point will be the spot centroid location. In the absence of "CENT", the vertex of the current image surface is used as the distribution center. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units) in modes "FOCAL" and "AFOCAL" and angular offsets (in radians) in modes "AFOCAL" and "UAFOCAL". "ΔZ" is a defocus term which is only applicable in the "FOCAL" and "UFOCAL" modes. If the qualifier words "N" or "NCENT" are used, no output is generated.

SRED ACC , E , ΔX , ΔY , ΔZ and

SRED CACC , E , ΔZ - he "SRED ACC" and "SRED CACC" commands produce no display. "SRED ACC" returns to the X-register (accumulator), the radius of the circle which encloses "E" percent energy. All the above comments concerning "ΔX" , "ΔY", and "ΔZ" apply in the same way as for the "SRED" and "SRED CENT" commands. "SRED ACC" centers the distribution at the image surface vertex; "SRED CACC" centers it at the spot centroid location.

SESEDX (N) , ΔE , ΔX , ΔY , ΔZ and

SESEDX (N)CENT , ΔE , ΔZ and

SESEDX ACC , E , ΔX , ΔY , ΔZ and

SESEDX CACC , E , ΔZ and

SESEDY (N) , ΔE , ΔX , ΔY , ΔZ and

SESEDY (N)CENT , ΔE , ΔZ and

SESEDY ACC , E , ΔX , ΔY , ΔZ and

SESEDY CACC , E , ΔZ - The preceding eight commands act in exactly the same manner as the four "SRED" commands, except that they produce one dimensional, expanding slit edge energy distributions in either the X or the Y-directions at the current image surface. Instead of spot semi-diameters, slit semi-width dimensions are displayed or returned to the X-register (accumulator) when using the "SESED", "SESEDX" and "SESEDY" commands. If the qualifier words "N" or "NCENT" are used, no output is generated.

SESED (N), ΔE , ΔX , ΔY , ΔZ , θ and

SESED (N)CENT , ΔE , ΔZ , θ and

SESED ACC , E , ΔX , ΔY , ΔZ, θ and

SESED CACC , E , ΔZ , θ - The preceding four commands act in exactly the same manner as the eight "SESEDX" and "SESEDY" commands, except that instead of limiting themselves to the X and Y directions, they can produce expanding slit edge energy distributions at any orientation specified by "θ" (in degrees). "θ" = 0 degrees corresponds to "ESEDX" and "θ" = 90.0 degrees corresponds to "SESEDY". Instead of spot semi-diameters, slit semi-width dimensions are displayed or returned to the X-register (accumulator) when using the "SESED", "SESEDX" and "SESEDY" commands. All offset dimensions for radial and expanding slit energy distributions are represented in the coordinate system of the image surface. If the qualifier words "N" or "NCENT" are used, no output is generated. After tabular data is generated with the "SRED" or the "SESED" commands, it may be graphically displayed using the "PLTRED" and "PLTESED" commands.

AUTOMATED RED AND ESED PLOTS

PLTRED , dflag , (x-extent) - The "PLTRED" command causes a plot of the current Radial Energy Distribution data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTRED" applies to the most recently generated RED data. If no RED data exists, a message to that effect is issued and no plot is generated. (x-extent) optionally allows the user to specify the number of lens units at the final surface which are represented by the horizontal axis of the energy distribution plot. RED data may be generated using one of the radial energy distribution commands described in the CMD section (geometrical based calculations) or the FOE section (diffraction based calculations) of this manual.

RAY TRACING SECTION

PLTESED , dflag , (x-extent) - The "PLTESED" command causes a plot of the current Expanding Slit Energy Distribution data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTESED" applies to the most recently generated ESED data. If no ESED data exists, a message to that effect is issued and no plot is generated. (x-extent) optionally allows the user to specify the number of lens units at the final surface which are represented by the horizontal axis of the energy distribution plot. ESED data may be generated using one of the expanding slit energy distribution commands described in the CMD section (geometrical based calculations) or the FOE section (diffraction based calculations) of this manual. The following figure illustrates expanding slit orientation as a function of "θ":
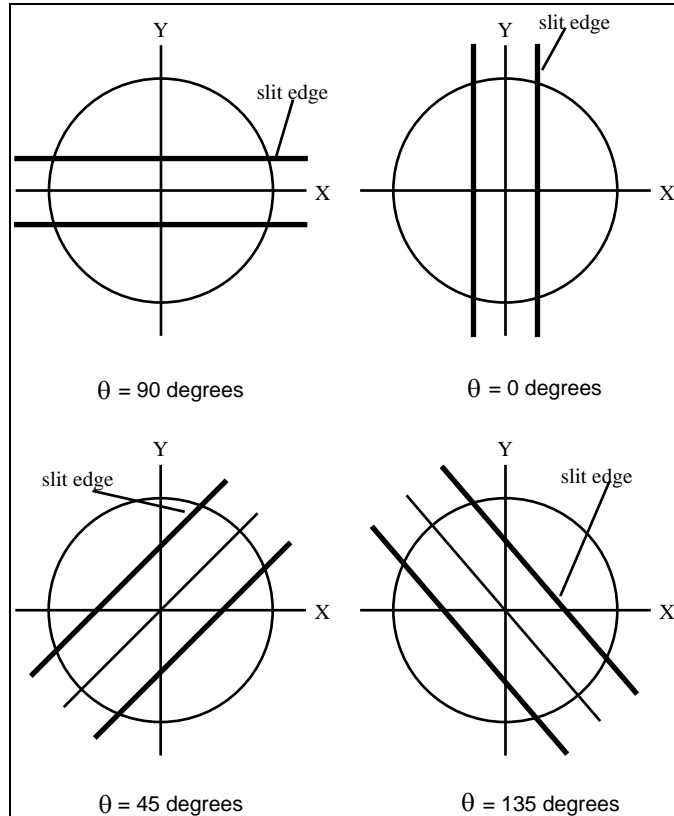
Expanding Slit and Line Spread Function Orientations

SUMMED ENERGY DISTRIBUTIONS-II - This command is only of use from inside macros. Unlike the "SRED", "SESED", "SESEDX" and "SESEDY" commands, it can analyze "summed and saved" spot diagrams which are stored in files which have been given user specified names. The "REDSUM" command uses "summed and saved" spot diagram data which was created by the "SPDSAVE" and "SPDADD" commands. The file read is "filename.DAT. If the file name is not explicitly entered, the file "SPOTS.DAT" will be used.

REDSUM (filename) , E - The "REDSUM" command produces no display but returns to the X-register (accumulator), the radius of the circle which encloses "E" percent energy in the current "summed and saved" spot diagram. No "ΔX" , "ΔY", or "ΔZ" apply in this command. "REDSUM" centers the distribution at the spot centroid.

ENSQUARED ENERGY DISTRIBUTIONS

REDSQ (N), ΔE , ΔX , ΔY , ΔZ and

REDSQ (N)CENT , ΔE , ΔZ - The "REDSQ" and "REDSQ CENT" commands produce ensquared rather than encircled energy distributions using the current spot diagram data. "CENT" specifies that the distribution center or reference point will be the spot centroid location. In the absence of "CENT", the chief ray location at the current image surface is used as the distribution center. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units) in modes "FOCAL" and "AFOCAL" and angular offsets (in radians) in modes "AFOCAL" and "UAFOCAL". "ΔZ" is a defocus term which is only applicable in the "FOCAL" and "UFOCAL" modes. If the qualifier words "N" or "NCENT" are used, no output is generated.

RAY TRACING SECTION

REDSQ ACC , E , ΔX , ΔY , ΔZ and

REDSQ CACC , E , ΔZ - The "REDSQ ACC" and "REDSQ CACC" commands produce no display. "REDSQ ACC" returns to the X-register (accumulator), the length of the side of a square which encloses "E" percent energy. All the above comments concerning "ΔX" , "ΔY", and "ΔZ" apply in the same way as for the "REDSQ" and "REDSQ CENT" commands. "REDSQ ACC" centers the distribution at the chief ray; "SQRED CACC" centers it at the spot centroid location. After tabular data is generated with the "REDSQ" command, it may be graphically displayed using the "PLTRED" command described above.

SUMMED ENERGY DISTRIBUTIONS-III

SREDSQ (N), ΔE , ΔX , ΔY , ΔZ and

SREDSQ (N)CENT , ΔE , ΔZ - The "SREDSQ" and "SREDSQ CENT" commands produce ensquared distributions using the current summed spot diagram data stored in the default summed spot diagram file, SPOTS.DAT. "CENT" specifies that the distribution center or reference point will be the spot centroid location. In the absence of "CENT", the vertex of the current image surface is used as the distribution center. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units) in modes "FOCAL" and "AFOCAL" and angular offsets (in radians) in modes "AFOCAL" and "UAFOCAL". "ΔZ" is a defocus term which is only applicable in the "FOCAL" and "UFOCAL" modes. If the qualifier words "N" or "NCENT" are used, no output is generated.

SREDSQ ACC , E , ΔX , ΔY , ΔZ and

SREDSQ CACC , E , ΔZ - The "SREDSQ ACC" and "SREDSQ CACC" commands produce no display. "SREDSQ ACC" returns to the X-register (accumulator), the length of the side of the square which encloses "E" percent energy. All the above comments concerning "ΔX" , "ΔY", and "ΔZ" apply in the same way as for the "SREDSQ" and "SREDSQ CENT" commands. "SREDSQ ACC" centers the distribution at the image surface vertex; "SREDSQ CACC" centers it at the spot centroid location. After tabular data is generated with the "SREDSQ" command, it may be graphically displayed using the "PLTRED" command described above.

SUMMED ENERGY DISTRIBUTIONS-IV
- This command is only of use from inside macros. Unlike the "SREDSQ" command, it can analyze "summed and saved" spot diagrams which are stored in files which have been given user specified names. The "REDSUMSQ" command uses "summed and saved" spot diagram data which was created by the "SPDSAVE" and "SPDADD" commands. The file read is "filename.DAT. If the file name is not explicitly entered, the file "SPOTS.DAT" will be used.

REDSUMSQ (filename) , E - The "REDSUMSQ" command produces no display but returns to the X-register (accumulator), the ensquaring side length which encloses "E" percent energy in the current "summed and saved" spot diagram. No "ΔX" , "ΔY", or "ΔZ" apply in this command. "REDSUMSQ" centers the distribution at the spot centroid.

INVERSE DISTRIBUTIONS
- In all of the above energy distribution commands, the qualifier words "ACC" and "CACC" were used to return to the X-register, the size of the circle or square which encircled or ensquared the percent energy specified in numeric word #1. If, instead, the qualifier words "ACCX" and "CACCX" are used, then, commands return to the X-register either the percent energy encircled by the circle whose radius is specified in numeric word #1 or the percent energy ensquared by the square whose side length was specified in numeric word #1.

GEOMETRICAL LINE SPREAD FUNCTIONS

LSF , N , ΔX , ΔY , ΔZ , θ and

LSF CENT , N , ΔZ , θ and

LSF ACC , pos , ΔX , ΔY , ΔZ, θ and

LSF CACC , pos , ΔZ , θ - These four "LSF" commands act in a similar manner to the four preceding "ESED" commands, except that they produce geometrical line spread functions based upon the current geometrical spot diagram. They calculate image intensity versus position across a line spread function. Peak intensity is always normalized to 1.0. The line spread function orientation is specified by "θ" (in degrees). "ΔX" , "ΔY" and "ΔZ" have the same meaning as in the above "RED" and "ESED" commands. "N" specifies the number of positions across the line spread function for which intensity values will be displayed. The default value for "N" is 21. "pos" specifies the position in the line spread function for which an intensity value will be calculated. The maximum allowable value for "N" is 100. The preceding figure illustrates line spread function orientation as a function of θ. Positions in the line spread function are specified in current lens system units in the "FOCAL" and "UFOCAL" modes and in radians in modes "AFOCAL" and "UAFOCAL". "ΔX" and "ΔY" are interpreted as linear offsets (in lens units) in modes "FOCAL" and "AFOCAL" and angular offsets (in radians) in modes "AFOCAL" and "UAFOCAL". "ΔZ" is a defocus term which is only applicable in the "FOCAL" and "UFOCAL" modes. For geometrically "perfect" systems, the spread function is always a delta function with height always equal to 1.0.

RAY TRACING SECTION

OLSF , N and
OLSF CENT , N and
OLSF ACC , pos and
OLSF CACC , pos - These four "OLSF" commands (meaning Old LSF) produce displays based upon a pre-existing geometrical line spread function calculated from spot diagram data via the preceding four "LSF" commands. They interpolate and display image intensity versus position across the existing line spread function. "N" specifies the number of positions across the line spread function for which intensity values will be displayed. The default value for "N" is 21. "pos" specifies the position in the line spread function for which an intensity value will be displayed. If no line spread function exists, a message to that effect is issued and no values are displayed. The default value for "N" is always 21. The maximum allowable value for "N" is 100. All offset dimensions for geometrical line spread functions are represented in the coordinate system of the image surface. The "RSPH" command, described later in this section, is used to specify the center of the geometrical line spread function. By default, the center of a geometrical line spread function is at the intersection of the chief ray with the image surface. After Line Spread Functions are generated, they may be graphically displayed using the "PLTLSF" command.

AUTOMATED LSF PLOTS

PLTLSF , (x-range) , dflag - The "PLTLSF" command causes a plot of the current geometrical Line Spread Function (LSF) data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTLSF" applies to the most recently generated LSF data, whether that data is generated using the "LSF" command or the "OLSF" command. The optional input value "x-range" sets the semi-extent of the X-axis scale. By default, the X or function extent scale will be sized so as to include the entire spread function. If no LSF data exists, a message to that effect is issued and no plot is generated. LSF data may be generated using the "LSF" command or the "OLSF" command which are described in the CMD section of this manual.

GEOMETRICAL OPTICAL TRANSFER FUNCTION - The commands described below generate various tabular outputs of the Geometrical Optical Transfer Function (GOTF). This transfer function is based only upon the residual geometrical aberrations of the current lens system and does not consider any of the effects of diffraction. It is best used for optical systems whose peak-to-valley optical path differences exceed one or two wavelengths at the reference wavelength. All "GOTF" commands use the existing spot diagram. If no spot diagram exists, one must first be calculated using the "SPD" command.

GOTF , Fmax , ΔF , θ , ΔZ - This version of the "GOTF" command generates an output of the GOTF from spatial frequency 0.0 to spatial frequency "Fmax" in frequency steps of "ΔF". The default for "Fmax" is the diffraction limit "cutoff" frequency, discussed in the FOE section of this manual. The smallest allowable value of "ΔF" is a value which produces 101 data points. "θ" = 0.0 degrees represents a vertical bar target (sinusoidal intensity variation in the X-direction). "θ" = 90.0 degrees represents a horizontal bar target (sinusoidal intensity variation in the Y-direction). "θ" is measured in a positive sense from the positive X-axis toward the positive Y-axis in the local coordinate system of the image surface. "ΔZ" represents a focus shift (in lens units) to be applied before the calculation is performed and is applicable only for modes "FOCAL" and "UFOCAL". "θ" = 0.0 degrees represents vertical bar targets (sinusoidal intensity variation in the X-direction). "θ" = 90.0 degrees represents horizontal bar targets (sinusoidal intensity variation in the Y-direction). In the absence of an explicit entry for "θ", GOTF values will be calculated for both "θ" = 0.0 and "θ" = 90.0 degrees. The default value for "ΔF" is "F_{max}"/ 10.0. The default value for "ΔZ" is 0.0. After GOTF data has been generated with this command, the data may be plotted using the "PLTGOTF" command.

GOTF IN OBJECT SPACE - All GOTF calculations are performed in the frequency domain of "image space". In the AFOCAL or UAFOCAL mode, the frequency units are "lp/mrad". In FOCAL or UFOCAL modes the frequency units are "lp/mm". Many times it proves convernient to express the MTF in the frequency domain of "object space" The following two commands provide the user with a way of telling the program that the tabular MTF listings and the graphical MTF plots of MTF versus frequency are to be displayed in the frequency domain of "object space".

SPACE (O or I) - The "SPACE" command instructs the program as to the spatial domain in which the tabular and graphical GOTF is to be represented. The default is "I" for image space. This command does not change the way the GOTF values are computed but it does change the spatial frequency units used in the tabular and graphical displays. ". Issuing this command with the "?" returns the current setting

NEAR or FAR - The "NEAR" and "FAR" commands are used to specify the units for optical transfer function display when space is set to "O". "NEAR" sets units to "lp/mm" whereas "FAR" specifies "lp/mrad". Issuing this command with the "?" returns the current setting. The program default setting is "FAR"

RAY TRACING SECTION

THRU-FOCUS/FREQ GOTF

GOTF TFOCUS , F , Zmin , Zmax , ΔZ , θ - The "GOTF TFOCUS" command generates an output of the through-focus GOTF at spatial frequency "F" in steps of "ΔZ" about the current image position. "θ" = 0.0 degrees represents a vertical bar target (sinusoidal intensity variation in the X-direction). "θ" = 90.0 degrees represents a horizontal bar target (sinusoidal intensity variation in the Y-direction). "θ" is measured in a positive sense from the positive X-axis toward the positive Y-axis in the local coordinate system of the image surface. "ΔZ" is the focus shift step size (in lens units). "GOTF TFOCUS" is applicable only for modes "FOCAL" and "UFOCAL". The default value for "θ" is 0.0 degrees representing vertical bar targets (sinusoidal intensity variation in the X-direction). The default value for "ΔZ" is ("Zmax" - "Zmin") / 10.0.

GOTF TFREQ , ΔZ , Fmin , Fmax , ΔF , θ - The "GOTF TFREQ" command generates an output of the through-frequency GOTF from frequency "Fmin" to frequency "Fmax" in frequency steps "ΔF" and at focus offset "ΔZ" about the current image position. "θ" = 0.0 degrees represents a vertical bar target (sinusoidal intensity variation in the X-direction). "θ" = 90.0 degrees represents a horizontal bar target (sinusoidal intensity variation in the Y-direction). "θ" is measured in a positive sense from the positive X-axis toward the positive Y-axis in the local coordinate system of the image surface. "ΔZ" is only used for modes "FOCAL" and "UFOCAL". The default value for "θ" is 0.0 degrees representing vertical bar targets (sinusoidal intensity variation in the X-direction). The default value for "ΔF" is ("Fmax" - "Fmin") / 10.0. The default value for "ΔZ" is 0.0.

GOTF ACC , F , θ , ΔZ - The "GOTF ACC" command causes the GOTF modulus, calculated at frequency "F", orientation θ and focus offset "ΔZ", to be placed into the accumulator or X-register. The GOTF phase is calculated and placed into the Y-register. The original content of the X-register is placed in the LASTX-register. The command produces no output. "ΔZ" is only used for modes "FOCAL" and "UFOCAL". Among other uses, this command makes the modulus and phase of the GOTF available as an optimization operand. The default value for "θ" is 0.0 degrees representing vertical bar targets (sinusoidal intensity variation in the X-direction). The default value for "ΔZ" is 0.0. Spatial frequency is always in units of line pairs per millimeter (lp/mm) for modes "FOCAL" and "UFOCAL" and in units of line pairs per milli-radian (lp/mr) for modes "AFOCAL" and "UAFOCAL". All offsets and image orientations for geometrical optical transfer functions are represented in the coordinate system of the image surface.

MULTIPLE FOV GOTF - If multiple field of view definitions are included in the lens database (using the "FLDS" command) and if the command which immediately precedes the "GOTF" command is not an "FOB" command and if "GOTF" is issued without qualifier or numeric input, then GOTF values will be computed for each of the defined multiple field of view positions. These values will be stored so that they may be plotted with the next "PLTGOTF" commands.

GOTF PLOTS

PLTGOTF (LEICA) , dflag

CASE: No qualifier word

In this case the "PLTGOTF" command causes a plot of the modulus of the existing Geometrical Optical Transfer Fuction data versus spatial frequency to be generated from 0 If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTGOTF" applies to the most recently generated GOTF. If no GOTF data exists, a message to that effect is issued and no plot is generated. There is no "max freq" input for PLTGOTF as the maximum frequency in under the control of the "GOTF" command itself. If GOTF data exists for both vertical and horizontal target orientations, they both will be included on one plot. If multiple field of view "GOTF" data exists, it will be plotted on a multiple field of view type of GOTF display. Each curve will be labeled as to field of view position and target orientation.

CASE: Qualifier word = "LEICA" (There must exist GOTF data for at least 5 multiple field of view positions)

In this case the "PLTGOTF" command causes a plot of the modulus of the existing Geometrical Optical Transfer Fuction data versus field of view to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTGOTF" applies to the most recently generated GOTF. If no GOTF data exists, a message to that effect is issued and no plot is generated. This command plots both target bar orientations of the first 10, non-zero frequency MTFs generated using the previous "GOTF" command. GOTF data is generated using the "GOTF" command described in the CMD section of this manual.

GEOLEICA (ON or YES or OFF or NO) , freq# - The GEOLEICA command is used to shut off any of the GOTF vs FOV plots in a "PLTGOTF LEICA" type of plot. The "freq#" can be 1 through 10. Once frequency numbers are turned "off" they stay "off" until they are "tuned on" of until the program ends. Entered with a "?", the status for all 10 frequencies will be displayed.

SURFACE SAG COMMANDS - The commands described below generate a printout of surface sag and surface normal direction cosine data. Sag data consists of Z-coordinates of points on a surface for specified X and Y-coordinates as well as the surface normal L, M and N direction cosines. N is positive if it points in the local coordinate system +Z direction.

RAY TRACING SECTION

SAG X , i , Xmin , Xmax , Δx , δy - The "SAG X" command generates surface sag and surface normal data for a line extending in the X direction of surface number "i". Sags are computed in intervals of Δx. The Y-coordinate is defined by "Y" = δ_y. "X" ranges from Xmin to Xmax

SAG Y , i , Ymin , Ymax , Δy, δx - The "SAG Y" command generates surface sag and surface normal data for a line extending in the Y direction of surface number "i". Sags are computed in intervals of Δy. The X-coordinate is defined by "X" = δ_x. "Y" ranges from Ymin to Ymax.

SAG (PT or PTACC) , i , X , Y - The "SAG PT" command generates sag and surface normal data for the point "X" and "Y" on surface "i". The resultant sag value is stored in the accumulator ("X"-register). The X and Y input values are placed in the "IX" and "IY" registers. The L, M and N direction cosines of the surface normal are placed in the "Y", "Z" and "T" registers. If "PT" is issued, the values will be displayed. If "PTACC" is issued, no values are displayed.

SAG FILE , i , N , code „ prflag - The "SAG FILE" command generates sag data over an "N" by "N" square grid on surface "i" and then saves that data to the ASCII file SAG.DAT. The data saved consists of the "x" and "y" coordinates of each grid point and the associated surface sag value at that grid point. The grid is processed from left to right and bottom to top starting at the most negative "x" and "y" point on the grid. The default value for "N" is 25. The grid is spread over the greatest extent of the clear aperture on surface "i". If no explicit clear aperture is assigned, then the grid is spread over a temporarily assigned clear aperture equal to the sum of the absolute values of PY and PCY or PX and PCX paraxial ray values at that surface (which ever is the larger sum). "SAG FILE" does not output the surface L, M and N surface normal direction cosines. The "code" value is interpreted via the following table. The SAG.DAT file may be plotted using the "PLOT SAGFILE" command. If "prflag" is omitted, statistics are displayed, else they are suppressed.

code	action
0 (default)	SAG due to all surface parameters.
1	SAG leaving out special surface definitions.
2	SAG leaving out all radius, toric radius, conics and aspheric definitions but using any existing special surface definitions.

In all "SAG" commands, X and Y coordinates are expressed in lens units. The "SAG" commands properly recognize all contributions to surface shape, including all special surface types.

SAGFILE PLOTTING

PLOT SAGFILE , drflag - The "PLOT SAGFILE" command causes a 3-D plot of the current SAG.DAT file, if one exists, to be displayed.The SAG.DAT file is generated by the "SAG FILE" command as described in the CMD section of this manual The horizontal axes represent the surface clear aperture. If "drflag" is left blank, the plot will be displayed to the screen. Otherwise it will not be displayed.

SAGFLROT ("YES" or "ON" or "NO" or "OFF") - The "SAGFLROT" command is used to specify whether or not the current SAG.DAT file is to be plotted with a 90 degree rotation or not. This helps see "hidden" features. Issued with the interrogator "?", "SAGFLROT" causes the current SAG.DAT file rotation status to be displayed. If the status is "YES" or "ON", then each time a SAG.DAT file is generated, it will be plotted with a 90 degree rotation

BEST FIT SPHERE - Best fit sphere calculations are useful when it is desired to determine the closest sphere to some non-spherical surface such that the sphere can first generated. This sphere will such that a minimum amount of material will need to be removed from it to form the desired non-spherical shape. The "best fit sphere" calculation is not supported by dedicated commands but instead a procedure using existing program commands is used to compute this value. This procedure is outlined in the following example. In this example, a rotationally symmetric concave, aspheric mirror will be the surface for which the best fit sphere is determined. Since this non-spherical surface is rotationally symmetric, only rays in the YZ-plane are needed. If the aspheric was not rotationally symmetric, more rays in the YZ and XZ-planes would be needed. Since the aspheric is a concave mirror, the GTE command is used in setting up the optimization. The use of GTE or LTE will need to be determined by the user depending on whether the best fit sphere will need to have a radius of curvature greater than or less than the non-spherical surface.

RAY TRACING SECTION

EXAMPLE:

It is desired to determine the best fit sphere to a concave, aspheric mirror. The mirror will be 10 cm in diameter. It will have a base radius of curvature of 35 cm, a conic constant of -0.085 and a 6th order aspheric coefficient of +0.123348x10⁻⁹.

STEP 1 Set up a new lens file by issuing the following commands:

LENS
UNITS CM
SAY , 5
TH 1D20
AIR
AIR
AIR
RD , -35
CC , -0.85
AE , 0.123348E-9
AIR
AIR
AIR
EOS
MODE AFOCAL

STEP 2. Make sure that field #1 and rays #1 to #11 are defined to represent sampling the aperture at 0.1 fractional aperture heights from an on-axis object position by issuing the following commands:

F1 , 0 0 0
R1 , 0
R2 , .1
R3 , .2
R4 , .3
R5 , .4
R6 , .5
R7 , .6
R8 , .7
R9 , .8
R10 , .9
R11 , 1.0

STEP 3. Set up the optimization definitions using as operands, the optical path length along each ray from surface 2 to 3. Set the variable to be the curvature of surface #2.

MERIT
GTE
OPL 0 1 3 1 1
OPL 0 1 3 1 2
OPL 0 1 3 1 3
OPL 0 1 3 1 4
OPL 0 1 3 1 5
OPL 0 1 3 1 6
OPL 0 1 3 1 7
OPL 0 1 3 1 8
OPL 0 1 3 1 9
OPL 0 1 3 1 10
OPL 0 1 3 1 11
COR
CV 0 .0000001 2
EOS

The CV operand on surface 2 with the very small weight keeps the sphere from taking on too much power. Make the weight small enough that none of the other operands go negative.

VARI
CV 2
EOS
STEP 4. Optimize surface 2 curvature using the following commands:
IT
PFIND 20
IT 5
ROBB
PFIND 20
IT 5
ROBB
STEP 5. Get the radius of curvature of surface 2 using the following command:
SHO RD 2
(the value will be [to three decimal places] -35.119)

Using the OPRD command, the OPLs differences between the best fit sphere and the non-spherical surface may be listed. The maximum of these values will be the maximum departure from the best fit sphere in lens units. If a more accurate computation is requires, the number of operands and rays may be increased and the optimization re-run.

BEST OPTICAL SURFACE - Best optical surface calculations are useful when it is desired to determine the closest sphere, conic or aspheric surface to some set of SAG values. The "best optical surface" calculation is not supported by dedicated commands but instead a procedure using existing program commands is used to compute these values. This procedure is outlined in the following example. In this example, the sag data at 10 radial points from the axis to the edge of a lens are known. Since this non-spherical surface is rotationally symmetric, only rays in the YZ-plane are needed. If the aspheric was not rotationally symmetric, more rays in the YZ and XZ-planes would be needed. Since the aspheric is a concave mirror, the GTE command is used in setting up the optimization. The use of GTE or LTE will need to be determined by the user depending on whether the best fit sphere will need to have a radius of curvature greater than or less than the non-spherical surface.

EXAMPLE:

It is desired to determine the best fit sphere to a concave, aspheric mirror. The mirror will be 10 cm in diameter. It will have a base radius of curvature of 35 cm, a conic constant of -0.085 and a 6th order aspheric coefficient of $+0.123348 \times 10^{-9}$.

STEP 1 Set up a new lens file by issuing the following commands:

LENS
UNITS CM
SAY , 5
TH 1D20
AIR
AIR
AIR
RD , -35
CC , -0.85
AE , 0.123348E-9
AIR
AIR
AIR
EOS
MODE AFOCAL

STEP 2. Make sure that field #1 and rays #1 to #11 are defined to represent sampling the aperture at 0.1 fractional aperture heights from an on-axis object position by issuing the following commands:

F1 , 0 0 0
R1 , 0
R2 , .1
R3 , .2
R4 , .3
R5 , .4
R6 , .5
R7 , .6
R8 , .7
R9 , .8
R10 , .9
R11 , 1.0

STEP 3. Set up the optimization definitions using as operands, the optical path length along each ray from surface 2 to 3. Set the variable to be the curvature of surface #2.

MERIT
GTE
OPL 0 1 3 1 1
OPL 0 1 3 1 2
OPL 0 1 3 1 3
OPL 0 1 3 1 4
OPL 0 1 3 1 5
OPL 0 1 3 1 6
OPL 0 1 3 1 7
OPL 0 1 3 1 8
OPL 0 1 3 1 9
OPL 0 1 3 1 10
OPL 0 1 3 1 11
COR
CV 0 .0000001 2
EOS

The CV operand on surface 2 with the very small weight keeps the sphere from taking on too much power. Make the weight small enough that none of the other operands go negative.

VARI
CV 2
EOS
STEP 4. Optimize surface 2 curvature using the following commands:
IT
PFIND 20
IT 5
ROBB
PFIND 20
IT 5
ROBB
STEP 5. Get the radius of curvature of surface 2 using the following command:
SHO RD 2
(the value will be [to three decimal places] -35.119)
Using the OPRD command, the OPLs differences between the best fit sphere and the non-spherical surface may be listed. The maximum of these values will be the maximum departure from the best fit sphere in lens units. If a more accurate computation is requires, the number of operands and rays may be increased and the optimization re-run.

LIMIT RAY CALCULATIONS

The "LIMRAYS" command generates a tabular printout of limit ray data for the current lens at the current control wavelength and current active configuration.

LIMRAYS (PARAX or REAL or VREAL) , (n) - For optical systems for which real rays cannot yet be traced, the qualifier word "PARAX" is provided. Using the "PARAX" qualifier word causes the limiting ray heights at each surface to be calculated as the sum of the absolute values of the marginal and chief paraxial ray heights at each surface. All clear apertures, surface tilts and surface decentrations are ignored. This version of the "LIMRAYS" command is useful during very early stages of design. Issuing the "LIMRAYS" command with no qualifier word or with the qualifier word "REAL" causes limit ray heights to be calculated using a set of unvignetted real rays. This set of rays consists of eight marginal rays traced around the periphery of the current reference surface from each of nine field of view positions traced from around the periphery of the current object surface. If there are no clear apertures assigned to the object and reference surfaces, then circular or elliptical clear apertures are assumed and they are sized by the current values of the SCY, SCX, SAY and SAX values respectively. If the clear apertures assigned to these surfaces are rectangular or racetrack in shape, then four of the marginal rays are positioned at the top, bottom, left and right sides of the clear apertures while the other four rays are positioned at the extremes of the "corners" of these clear apertures. If any of these 72 rays cannot be traced due to ray failures, excluding clear aperture of obscuration blocking, then a warning message is issued as part of the output. All clear aperture decentrations and tilts are considered during these calculations. Issuing the "LIMRAYS" command with the "VREAL" qualifier word causes limit ray heights to be calculated using a set of eight vignetted real marginal rays traced from the same nine field of view positions as described in the preceding paragraph. The vignetting factors for these rays are calculated automatically at each of the nine field of view positions. The "finesse" of the vignetting calculations is set with the "n" value. By default, "n" = 25 meaning that 50 rays are traced across both the X and Y-directions at the reference surface in order to determine the vignetting factors. "n" may be set as low as 10 or as high as 100. All clear aperture decentrations and tilts are also considered during these calculations. Tabular output when using the "PARAX" qualifier word consists of a table listing surface #, and maximum X and Y -coordinates of the limiting rays. Tabular output when using the "REAL" or "VREAL" qualifier words or when no qualifier is used consists of two tables. The first table lists surface #, and the minimum and maximum X and Y -coordinates of the limiting rays in the local coordinate system of each surface. The second table lists surface #, maximum radial dimension and suggested center position of the limit ray pattern in the local coordinate system of each surface. Vignetting factors are **ONLY** computed in the local XZ and YZ-planes of the reference surface. The "LIMRAYS" command is useful in setting the minimum part sizes for most optical systems being designed. In systems where there are many complex folds, it would be wise to verify the limit ray calculations by plotting beam footprints. Multi-configuration systems should always have their part sizes determined using the beam footprint plotting option.

RAY TRACING SECTION

BLKRAYS, (n) - The "BLKRAYS" command causes FOUR fans of rays to be traced through the current system in the current alternate configuration and at the control wavelength. An X-FAN, a Y-FAN, a P-FAN and an N-FAN. The tabular output displays the ray heights in the reference surface and whether the rays clear the system or are blocked by clear apertures, obscurations or other ray failure mechanisms. The surface number at which the ray fails is also shown. The fans are traced at the field of view position defined by the last "FOB" command. "n" designates the finesse of the fan. The default for n is 25. The lowest value allowed is 10, the highest is 100.

AUTOMATIC CLEAR APERTURES - The "SETCLAP" command works exactly the same as the "LIMRAYS" command except that instead of generating tabular output, it uses limit ray data to assign clear aperture data to surfaces. If a clear aperture is already assigned to a surface, the dimensions of the clear aperture and the clear aperture offsets are adjusted. If no clear aperture is assigned to a surface, a circular aperture will be assigned if the surface is not a "dummy" surface. This exclusion of "dummy" surfaces does not occur; however, if both starting and ending surfaces, "i" and "j", are explicitly input by the user. "SETCLAP" does not modify alternate configuration data. It only operates upon the current configuration. In order to set clear apertures for multi-configuration systems, run "SETCLAP" for each configuration, note the assigned clear aperture values and then issue the appropriate CONFIGS or UPDATE CONFIGS commands.

SETCLAP (PARAX or REAL or VREAL) , i , j , (n) - "i" and "j" specify the starting and ending surface numbers to which "SETCLAP" will apply. Defaults for "i" and "j" are surfaces 0 and the image surface. For optical systems for which real rays cannot yet be traced, the qualifier word "PARAX" is provided. Using the "PARAX" qualifier word causes the clear aperture values at each surface to be calculated as the sum of the absolute values of the marginal and chief paraxial ray heights at each surface. All clear apertures, surface tilts and surface decentrations are ignored when "PARAX" is used. This version of the "SETCLAP" command is useful during very early stages of design. Issuing the "SETCLAP" command with no qualifier word or with the qualifier word "REAL" clear aperture values to be calculated using a set of unvignetted real rays. This set of rays consists of eight marginal rays traced around the periphery of the current reference surface from each of nine field of view positions traced from around the periphery of the current object surface. If there are no clear apertures assigned to the object and reference surfaces, then circular or elliptical clear apertures are assumed and they are sized by the current values of the SCY, SCX, SAY and SAX values respectively. If the clear apertures assigned to these surfaces are rectangular or racetrack in shape, then four of the marginal rays are positioned at the top, bottom, left and right sides of the clear apertures while the other four rays are positioned at the extremes of the "corners" of these clear apertures. If any of these 72 rays cannot be traced due to ray failures, excluding clear aperture of obscuration blocking, then a warning message is issued and no clear apertures are assigned. All existing clear aperture decentrations and tilts are considered during these calculations. Issuing the "SETCLAP" command with the "VREAL" qualifier word causes clear aperture values to be calculated using a set of eight vignetted real marginal rays traced from the same nine field of view positions as described in the preceding paragraph. The vignetting factors for these rays are calculated automatically at each of the nine field of view positions. The "finesse" of the vignetting calculations is set with the "n" value. By default, "n" = 25 meaning that 50 rays are traced across both the X and Y-directions at the reference surface in order to determine the vignetting factors. "n" may be set as low as 10 or as high as 100. All existing clear aperture decentrations and tilts are also considered during these calculations. Vignetting factors are **ONLY** computed in the local XZ and YZ-planes of the reference surface. If the program determines that clear aperture decentrations should be assigned, they will be assigned if they are greater than or equal to 1.0×10^{-6} lens units. The "SETCLAP" command is useful in setting clear aperture values for most optical systems being designed. In systems where there are many complex folds, it would be wise to verify the clear aperture values by plotting beam footprints with commands. Multi-configuration systems should always have their clear aperture values determined using the beam footprint plotting option.

DISTORTION - Distortion is defined to be "FtanΘ distortion. For modes "FOCAL" and "UFOCAL", distortion is therefore defined by the following equation:

$$\%\mathrm{Dist} = \frac{\mathrm{HT}_{real\_chief\_ray} - \mathrm{HT}_{gen\_parax\_chief\_ray}}{\mathrm{HT}_{gen\_parax\_chief\_ray}} \times 100\%$$

The "HT"s are ray heights at the final surface. For modes "AFOCAL" and "UAFOCAL", distortion is defined by the following equation:

$$\%\mathrm{Dist} = \frac{\mathrm{Tan}\left(\mathrm{U}_{real\_chief\_ray}\right) - \mathrm{Tan}\left(\mathrm{u}_{gen\_parax\_chief\_ray}\right)}{\mathrm{Tan}\left(\mathrm{u}_{gen\_parax\_chief\_ray}\right)} \times 100\%$$

"U" and "u" are ray slope angles in radian measure. All ray heights and ray slopes are evaluated in the space of the final surface of the current lens system. Distortion calculations are based upon real chief rays and upon the "GENERALIZED PARAXIAL RAY TRACE". Since the "GENERALIZED PARAXIAL RAY TRACE" is based upon real differential rays, distortion calculations are valid for optical systems containing tilted and decentered surfaces.

RAY TRACING SECTION

DIST θ, factor , n - The "DIST" command generates tabular percent distortion data for the current lens. Distortion values are generated at "n" field of view positions along a line defined in object space. The starting point of this line is defined by the ray "RAY 0 0" traced from the central field point defined by "FOB 0 0". The default values for "θ" and "factor" are 0.0 and 1.0, respectively. "n" may range from 1 to 50. Its default value is 10. The ending point of this line is defined by the ray "RAY 0 0" traced from the field point "FOB Y_f , X_f", where "Y_f" and "X_f" are given by the following equations:

$$Y_f = factor \times cos(\theta)$$
$$X_f = factor \times sin(\theta)$$

In the default case, with "θ" = 0.0 and "factor" = 1.0, Y_f = 1.0 and X_f = 0.0. All calculations are performed at the current control wavelength. If the distortion is not calculable, a message to that effect is displayed and no data is displayed. After distortion calculations are performed, the data may be displayed in graphical form using the "PLTDIST" command. In systems with tilts and decenters in which the central, gut chief ray does not strike the final surface at zero height, a TILT AUTO may be required on the final surface in order to compute meaningful distortion values.

DISTORTION PLOTS

PLTDIST , (x-range) , dflag - The "PLTDIST" command causes a plot of the existing distortion data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. This is another automated plot routine. "PLTDIST" applies to the most recently generated distortion data. The optional input value "x-range", entered in aberration units, sets the semi-extent of the X or aberration axis scale. By default, the X or aberration scale semi-extent will be sized so as to include all current aberration data. If no distortion data exists, a message to that effect is issued and no plot is generated. Distortion data is generated using the "DIST" command described in the CMD section of this manual.

FISHEYE-DISTORTION - Fisheye-distortion is defined to be "FΘ distortion. For modes "FOCAL" and "UFOCAL", distortion is therefore defined by the following equation:

$$\%Dist = \frac{\left(\left(HT_{real\_chief\_ray} \times \left(\frac{U_{real\_chief\_ray}}{Tan\left(U_{real\_chief\_ray}\right)}\right)\right) - \left(HT_{gen\_parax\_chief\_ray} \times \left(\frac{u_{gen\_parax\_chief\_ray}}{Tan\left(u_{gen\_parax\_chief\_ray}\right)}\right)\right)\right)}{\left(HT_{gen\_parax\_chief\_ray} \times \left(\frac{u_{gen\_parax\_chief\_ray}}{Tan\left(u_{gen\_parax\_chief\_ray}\right)}\right)\right)} \times 100\%$$

The "HT"s are ray heights at the final surface. This distortion is a representation of the perpendicular distance from the generalized paraxial chief ray's intersection with the final surface to an extension of the real chief ray. "U" and "u" are ray slope angles in radian measure. For modes "AFOCAL" and "UAFOCAL", distortion is defined by the following equation:

$$\%Dist = \frac{\left(U_{real\_chief\_ray}\right) - \left(u_{gen\_parax\_chief\_ray}\right)}{\left(u_{gen\_parax\_chief\_ray}\right)} \times 100\%$$

All ray heights and ray slopes at computed in the space of the final surface of the current lens system. Distortion calculations are based upon real chief rays and upon the "GENERALIZED PARAXIAL RAY TRACE". Since the "GENERALIZED PARAXIAL RAY TRACE" is based upon real differential rays, distortion calculations are valid for optical systems containing tilted and decentered surfaces.

FISHDIST θ, factor , n - The "DIST" command generates tabular percent distortion data for the current lens. Distortion values are generated at "n" field of view positions along a line defined in object space. The starting point of this line is defined by the ray "RAY 0 0" traced from the central field point defined by "FOB 0 0". The default values for "θ" and "factor" are 0.0 and 1.0, respectively. "n" may range from 1 to 50. Its default value is 10. The ending point of this line is defined by the ray "RAY 0 0" traced from the field point "FOB Y_f , X_f", where "Y_f" and "X_f" are given by the following equations:

$$Y_f = factor \times cos(\theta)$$
$$X_f = factor \times sin(\theta)$$

In the default case, with "θ" = 0.0 and "factor" = 1.0, Y_f = 1.0 and X_f = 0.0. All calculations are performed at the current control wavelength. If the distortion is not calculable, a message to that effect is displayed and no data is displayed. After fisheye distortion calculations are performed, the data may be displayed in graphical form using the "PLTFDIST" command.

NOTE: In systems with tilts and decenters in which the central, gut chief ray does not strike the final surface at zero height, a TILT AUTO may be required on the final surface in order to compute meaningful distortion values.

FISHEYE DISTORTION PLOTS

PLTFDIST , (x-range) , dflag - The "PLTFDIST" command causes a plot of the existing distortion data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. This is another automated plot routine. "PLTDIST" applies to the most recently generated distortion data. The optional input value "x-range", entered in aberration units, sets the semi-extent of the X or aberration axis scale. By default, the X or aberration scale semi-extent will be sized so as to include all current aberration data. If no distortion data exists, a message to that effect is issued and no plot is generated. Distortion data is generated using the "DIST" command described in the CMD section of this manual.

FIELD CURVATURE AND ASTIGMATISM - The field curvature and astigmatism calculations are based upon real chief rays and upon the "GENERALIZED PARAXIAL RAY TRACE". Since the "GENERALIZED PARAXIAL RAY TRACE" is based upon real differential rays, the field curvature and astigmatism calculations are valid for optical systems containing tilted and decentered surfaces.

FLDCV θ, factor , n and **AST θ, factor , n** The "FLDCV" and "ASTIG" commands, respectively, generate tabular field curvature and astigmatism data for the current lens. Data values are generated at "n" field of view positions along a line defined in object space. The starting point of this line is defined by the ray "RAY 0 0" traced from the central field point "FOB 0 0". The default values for "θ" and "factor" are 0.0 and 1.0 respectively. "n" may range from 1 to 50. Its default value is 10. The ending point of this line is defined by the ray "RAY 0 0" traced from the field point defined by "FOB Y_f , X_f", where "Y_f" and "X_f" are given by the following equations:

$$Y_f = factor \times \cos(\theta)$$
$$X_f = factor \times \sin(\theta)$$

In the default case, with "θ" = 0.0 and "factor" = 1.0, Y_f = 1.0 and X_f = 0.0. All calculations are performed at the current control wavelength. If field curvature or astigmatism is not calculable, a message to that effect is displayed and no data is displayed. After a field curvature or astigmatism calculations are performed, the data may be displayed in graphical form using the "PLTFLDCV" and "PLTAST" commands.

FIELD CURVATURE PLOTS

PLTFLDCV , (x-range) , dflag - The "PLTFLDCV" command causes a plot of the existing field curvature data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed.

The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTFLDCV" applies to the most recently generated field curvature data. The optional input value "x-range" sets the semi-extent of the X or aberration axis scale. By default, the X or aberration scale semi-extent will be sized so as to include all current aberration data. If no field curvature data exists, a message to that effect is issued and no plot is generated. Field curvature data is generated using the "FLDCV" command described in the CMD section of this manual.

ASTIGMATISM PLOTS

PLTAST , (x-range) , dflag - The "PLTAST" command causes a plot of the existing astigmatism data to generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTAST" applies to the most recently generated astigmatism data. The optional input value "x-range" sets the semi-extent of the X or aberration axis scale. By default, the X or aberration scale semi-extent will be sized so as to include all current aberration data. If no astigmatism data exists, a message to that effect is issued and no plot is generated. Astigmatism data is generated using the "AST" command described in the CMD section of this manual.

RAY TRACING SECTION

BEAM FOOTPRINTS

FOOT GRID , n - The "FOOT GRID" command is used to change the grid size for footprint ray tracing. "n" may be set to a value greater than 4, indicating a 2n+1 x 2n+1 ray grid. The larger the grid size, the longer the ray grid ray trace will take and the larger the "FOOT1.DAT" file will become. The default for "n" is 4 yielding a 17 x 17 grid.

FOOT (APE) , i - The "FOOT" command generates ray beam footprint data at surface "i". The rays are traced from the last field point established with the last "FOB" command. The program traces a rectangular grid of rays from this object point through the current lens. The rays are aimed at coordinates in the NEWREF surface (current reference surface). The rectangular grid always fully fills the NEWREF reference surface with rays. The X, Y and Z coordinates of each ray at surface "i" and a fail/no fail code are remembered in the file "FOOT1.DAT". This saved "footprint" data is used by the next "PLOT FOOT" command issued. If the optional qualifier word "APE" is NOT used, then the fail/no fail code is set only by clear apertures and obscurations assigned to the NEWREF reference surface and by non-aperture/obscuration related ray failures. If the optional qualifier word "APE" is used, then the fail/no fail code setting considers clear aperture and obscuration assignments on all surfaces as well as non-aperture/obscuration ray failures. If no clear aperture is assigned to the NEWREF reference surface, then a temporary circular clear aperture will be assigned. Its semi-diameter will be equal to the larger of the XZ and YZ-paraxial marginal ray heights at the reference surface.

FOOTAREA (ACC) - The "FOOTAREA" command is used to calculate the area, in current lens units, of the last current beam footprint generated at the surface designated by the "i" input of the "FOOT" command. This calculation becomes more accurate as the number of rays in the footprint ray grid increases. The value is stored in the accumulator. The screen display is suppressed if the optional qualifier word "ACC" is included.

FOOTSANG (ACC) , x , y , z - The "FOOTSANG" command is used to calculate the solid angle, in steradians, subtended by the last beam footprint generated at the surface designated by the "i" input of the "FOOT" command. The calculation is performed from a point "x", "y" and "z" with respect to the vertex of the surface at which the beam footprint was computed. The value is stored in the accumulator. The screen display is suppressed if the optional qualifier word "ACC" is included.

AREA EQUIVALENT F-NUMBER - Using the "FOOT" and the "FOOTAREA" commands, the area of a beam from any object point may be calculated at the entrance pupil of an optical system. This is done by placing surface #1 at that entrance pupil using the "ASTOP EN" command. From this, an effective aperture diameter for an equivalent area circular aperture may be computed. If the real ray effective focal length is also computed and retrieved using the appropriate "GET" option, then an effective area F/# may be easily computed. This is an excellent metric for evaluating the variation in collection efficiency as a function of field position in optical systems with large amounts of pupil distortion.

The "PLOT FOOT" command is used to plot the current beam foot print.

BEAM FOOTPRINT PLOTS

PLOT FOOT - The "PLOT FOOT" command causes a plot of the current beam footprint, generated by the last "FOOT" command, to be plotted. In general, the "PLOT FOOT" command is used as shown in the following example. The example used the COOK TRIPLET delivered with the program.

LIB GET 1
FOOT GRID 10 (sets a 21x21 grid of rays)
FOB (specifies the rays will come from the on axis object point)
FOOT APE 2 (generates a 21x21 ray grid footprint at surface 2)
PLOT NEW (starts a fresh plot)
ORIENT 2 (sets the look vector so that the plot will be facing and normal to surface 2)
PLOT SCALE 2 2 (sets the scale factor to 2 - meaning the plot is twice life size)
PLOT CLAP 2 2 (plots the clear aperture of surface 2)
PLOT FOOT (plots the foot print)
FOB .5 (sets another object point)
FOOT APE 2 (traced another foot print from the FOB .5 position for surface 2)
PLOT FOOT (plots the new foot print)
DRAW (draws the plot on the screen)

The foot print appears as shown below with the on axis foot print filling surface 2 and the off axis foot print partiall filling surface 2:
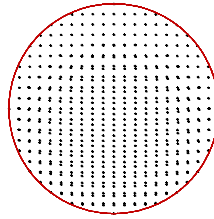
Example Beam Foot Print Plot

IMAGE ORIENTATION

IMAGEDIR (ALL or OB or OBJ) or

IMAGEDIR , i - The "IMAGEDIR" command displays the orientation of two vectors. These two vectors, named the "X-VECTOR" and the "Y-VECTOR" are originally oriented parallel to the local x and y-axes on the object surface. Whenever a chief ray is traced using the "FOB" command, and when chief ray differential ray tracing is "on", the results of the chief differential ray trace are used to determine the orientations of the "X-VECTOR" and the "Y-VECTOR" at each surface of the current lens database, in the loacal coordinate system of each surface. Since these vectors are determined for each chief ray traced, the resultant vectors may reflect coordinate system distortion in the lens database and may not always be exactly 90 degree from eachother.

RAY TRACE CONTROL PARAMETERS - Ray trace control parameter commands are used to set or to display parameters which effect the operation of ray tracing. With almost no exceptions, these control parameter values will not need to be altered by the use. The commands should be used with extreme care. Futhermore, if any of the ray tracing operating condition qualifier words is issued as a command word rather than a qualifier word, then if they are issued without numeric input, then they are treated as if they had been preceeded by the "PMP" command. If they are entered with numeric input, then they are treated as if they had been preceded by the "PM" command.

PMP (qualifier) - The "PMP" command displays the current value of the parameter identified by "qualifier".

RAY TRACING SECTION

PM (qualifier) , i - The "PM" command is used to set a control parameter, identified by "qualifier", to the numeric value specified by "i". The table below lists the various control parameters:

QUALIFIER	DESCRIPTION
SURTOL	This is the tolerance used for the iterative search for the ray intersection with an aspheric or other surface which cannot be analytically intersected. **Default value = 1.0D-8 lens units**
AIMTOL	This is the tolerance used for iterative ray aiming toward specific coordinates in the reference surface. **Default value = 1.0D-8 lens units**
CAIMTOL	This is the tolerance used for iterative ray aiming toward specific coordinates in the image plane when RXIM and RYIM are set. Make large enough to avoid ray aiming failures. **Default value = 1.0D-3 lens units**
NRAITR	This is the maximum number of iterations used in ray aiming and ray-surface intersecting. **Default value = 100**
DIFTOL	This is the fractional increment used in the calculation of the ray intercept derivatives like DY/DX or DYA/DY, etc. If, in some strange systems, differential ray failures occur, adjust this value up or down until they no longer occur. **Default value = $1.0D^{-3}$ x Relative Aperture Ht. on the Reference Surface.**
DELSUR	This is the starting derivative increment used in the calculation of the surface normals for non-flat, non-spherical or non-conic surfaces. **Default value = 0.0025**
SAGDEL	This is the starting surface position increment used in the calculation of the surface normals in SAG calculations. **Default value = 0.001**
MAXREG	This sets the maximum number of general purpose numeric and alpha numeric storage registers. Maximum allowed value is 100,000. **Default (also minimum) value = 4000**
MRAYS	This sets the maximum number of multiple surface intersections in an NSS surface group or the maximum number of steps when ray tracing in a gradient index material. **Default (also minimum) value = 200**
SERINC	This is the starting search increment used in chief ray aiming if the initial guess, based upon the paraxial ray trace, fails. It should never exceed 1/20 of the value assigned to SERLIM. **Default value = 0.01 lens units**
SERLIM	This is the limit of the search range used in chief ray aiming if the initial guess, based upon the paraxial ray trace, fails. It always be greater than 20 times the SERINC value. **Default value = 10.0 lens units**

SHORTCUT: If any of the above operating condition qualifier words is issued as a command word rather than a qualifier word, then if they are issued without numeric input, then they are treated as if they had been preceeded by the "PMP" command. If they are entered with appropriate numeric input, then they are treated as if they had been preceded by the "PM" command.

SAVING RAY DATA
SAVERAY - The "SAVERAY" command is used to save, for later use, all of the ray data associated with the current chief and regular ray. This saves all ray data including differential ray data if it exists.
RESTORING RAY DATA
RESTRAY - If ray data has been previously saved, it may be restored using the "RESTRAY" command. "RESTRAY" completely overwrites all internal memonry areas occupied by the existing "current" ray data.
CLEARING SAVED RAY DATA
CLEARRAY - If ray data has been previously saved, the "CLEARRAY" erases the internal data and deallocates any allocated memory which was allocated with the last "SAVERAY" command.
REFERENCE RAY SAVE - The current reference ray may be saved and reused in complex aperture function optical path difference calculations using the following commands.

SAVEREF - The "SAVEREF" command causes the the last reference ray and all associated values such as differential rays and differential ray pupil data to be saved for later use in complex aperture function calculations.
USEOLREF (YES or NO or ON or OFF) The "USEOLREF" tells all complex aperture function calculations ("CAPFN" in the FOE section of this manual) whether or not to use saved reference ray data (ON or YES) if it exists rather than using the most recent reference ray data. If saved reference ray data does not exits, current reference ray data will be used. The default is "NO" or "OFF".

HOW RAYS ARE AIMED -

CHIEF RAY AIMING - When the program traces an aimed chief ray, the program uses information from the paraxial ray trace to pick a first guess chief ray aiming point on the surface following the object surface. In most cases this guess is good enough to get a ray through the system and the iterative aiming to the center of the reference surface takes over. If the first guess is not good enough, an automatic search is undertaken. If this search fails, the user can still reset the aiming offsets with the "AIMRAY OFFSET", command described later in this section and then try to trace the chief ray again. In all cases tested, rays which really go through an optical system can also be traced by the program.

LARGE FIELDS OF VIEW When it is desired to trace rays through very wide field of view optical systems, in cases where the object distance magnitude is less than 1.0×10^{10} lens units, it is often helpful to use a small reference object height and then specify the larger desired object point with input values to the "FOB" command which are larger than 1.0. This can help mitigate the fact that the paraxial ray trace treats all angles as if they were tangents of the angles. This is exactly why the "scy fang" and "scx fang" values can never be set to +/- 90.0 degrees or beyond. In cases where the reference object heights are specified by "SCY FANG" and "SCX FANG", the program internally compensates for this behavior of the paraxial trace and no special action is needed. For optical systems which have fields of view greater than or equal to 180 degrees, the surface following the object surface MUST NOT BE FLAT. If that surface is PLANO, no field of view half angles greater than or equal to 90.0 degrees can be traced by this program. After a little thought, this fact should seem obvious. It may be useful to have surface #1 as a curved dummy surface. Sometimes, the ray trace demands it. Some experimentation may be useful with different SERINC and SERLIM values. May times, setting SCY FANG and SCX FANG to 1 degree and then calling out large FOB values is necessary in order to successfully trace rays through angles greater than 80 degrees off axis.

RAY TRACING SECTION

DIFFRACTION CALCULATIONS - All diffraction based calculations are issued as CMD level commands. All general statements concerning CMD level commands, made in the CMD section of this manual, apply equally to the commands described in this section.

COMPLEX APERTURE FUNCTION - The commands described below are used to create a COMPLEX APERTURE FUNCTION (CAPFN) for the current system. This is related to the PUPIL FUNCTION. The modulus of the PUPIL FUNCTION is equal to the square root of the COMPLEX APERTURE FUNCTION. The PUPIL FUNCTION is the basis of the diffraction MTF and diffraction Point Spread Function (PSF) calculations which follow. The CAPFN is **NOT** based upon the results of the most recent spot diagram generated by an "SPD" command but generates its own uniformly spaced, rectangular grid spot diagram. This rectangular grid is aimed at relative aperture coordinates in the system reference surface. Unlike the geometrical calculations, the CAPFN calculations take into account aperture apodization effects caused by entrance and exit pupil aberrations, anamorphic pupil stretching and the solid angle subtended by the entrance and exit pupils as seen from the object and image points. This apodization factor causes the resultant CAPFN to be adjusted so as to represent a grid of rays distributed uniformly, in direction cosine space, over the exit pupil.

CAPFN , n or **CAPFN PERFECT , n** or **CAPFN SILENT , n** - The "CAPFN" command causes a uniformly spaced, "n" x "n" rectangular grid of rays to be traced over the reference surface of the current system. "n" may be any even integer greater than or equal to 16. The default value for "n" is 16. A COMPLEX APERTURE FUNCTION is computed and held in memory for use in future diffraction based calculations. The qualifier "PERFECT" creates a perfect COMPLEX APERTURE FUNCTION with zero OPD. This "perfect" CAPFN considers all system obscurations and clear apertures. The "APOD" command settings, described earlier in the spot diagram section, are also used in weighting or apodizing the rays traced during "CAPFN" ray trace. If the program detects OPD differences across adjacent grid points of greater than λ/4, or if the entire wave front has more than one wave of OPD error, a message will be issued warning the user of that fact. "CAPFN SILENT" is exactly like "CAPFN" except that no warning messages or other output is generated. When "n" is explicitly input, it is also used to reset the value of the "capfnnrd" value. This new "capfnnrd" value will remain set to this value until explicitly reset by the user or until the program terminates execution.

CAPFNNRD , capfnnrd - The "CAPFNNRD" command is used to reset the default CAPFN grid dimension from the program default of 16 to an even integer greater value than or equal to 16. This saves time when issuing a large number of CAPFN commands which use the same ray grid size.

CAPFNOUT (file name) - The "CAPFNOUT" command causes the current COMPLEX APERTURE FUNCTION to be output to the ASCII file named (file name) .dat. The default file is CAPFNOUT.DAT if no file name is supplied. It is stored in the working program directory. The filename may be from 1 to 8 characters. The CAPFN is output a row at a time starting in the lower left (-x, -y) corner of the pupil grid. The first line of output is a header line and contains the number of rows/columns (N) in the CAPFN and the spacing between rows/columns (lens units for FOCAL systems or radians for AFOCAL systems). The next (NxN) lines consist of four values. They are the modulus (intensity), phase (2π. times the OPD in waves at the reference wavelength), the ray failure code and the surface at which the ray stopped. The format is D23.15,1X,D23.15,1X,I3,1X,I3.

CAPFNIN (file name) - The "CAPFNIN" command causes the COMPLEX APERTURE FUNCTION stored in the ASCII file named (file name) . DAT to be read into an internal program array. The default file is CAPFNOUT.DAT if no file name is supplied. After the file is read, the peak-to-valley and rms opd values for the CAPFN are computed and may be retrieved using the GET or SHOW PTOVOPD and RMSOPD commands.

CAPFNADD (file name) - The "CAPFNADD" command causes the COMPLEX APERTURE FUNCTION stored in the ASCII file named (file name) . DAT to be read and added into the internal program CAPFN array. The default file is CAPFNOUT.DAT if no file name is supplied. After the file is added, the peak-to-valley and rms opd values for the resultant CAPFN are computed and may be retrieved using the GET or SHOW PTOVOPD and RMSOPD commands. This command is useful in constructing composite CAPFNS generated from different lens files or different alternate configurations of the same lens file.

RAY TRACING SECTION

CAPFNCLR - The "CAPFNCLR" command causes the internal memory used by the "CAPFNIN" and "CAPFNADD" commands to be released.

CAPGRID λ# - The "CAPGRID" command causes the COMPLEX APERTURE FUNCTION for wavelength λ# to be output both as a grid apodization file, GRIDAPD.DAT, and a grid phase file GRIDOPD.DAT. The units of the phase file are current lens units. The grid spacing at the currrent reference surface, in lens units, will be placed into the accumulator and displayed on the current output device.

WAVEFRONT AND APERTURE MAPS - The commands described below are used to display, in a textual sense, both the wavefront and the aperture apodization functions relative to fractional reference surface position as they are represented in the current CAPFN.

WAMAP , i or **AMAP , i** - The "WAMAP" command displays a coded representation of the current wavefront map. The X-direction at the system reference surface is displayed horizontally and the Y-direction is displayed vertically. Following the "map" is a decoding system which relates the alphanumeric symbols used in the map to specific wavefront values. These wavefront values are in waves of the current wavelength used in the CAPFN generation. "i" specifies the wavelength number in the CAPFN to be mapped. The default for "i" is the control wavelength number. If no CAPFN data exists at wavelength number "i", a message to that effect will be displayed and no other action will be taken. The "AMAP" command displays a coded representation of the current aperture apodization map. The X-direction at the system reference surface is displayed horizontally and the Y-direction is displayed vertically. Following the "map" is a decoding system which relates the alphanumeric symbols used in the map to specific aperture transmission values. These aperture transmission values are relative to the average transmission through the aperture. "i" specifies the wavelength number in the CAPFN to be mapped. The default for "i" is the control wavelength number. If no CAPFN data exists at wavelength number "i", a message to that effect will be displayed and no other action will be taken.

WAVE FRONT MAP FITTING TO ZERNIKIE

FITZERN , λ# - The "FITZERN" command causes the current wave front represented in the current CAPFN to be fitted to the standard 37-term "Fringe" Zernike polynomial. The "Fringe" Zernike polynomial is discussed in some detail in the SPFIT and SPSRF manual sections. The fitting is performed using CAPFN generated OPD data generated at the wavelength number specified in numeric word #1. If this numeric input is left blank, then the current control wavelength is assumed. Since this Zernike polynomial is orthonormal only for unit circular apertures, the fitting will work best if a circular clear aperture is assigned to the reference surface. All ray obscurations are ignored during this fit. All rays not blocked by clear apertures are assumed to have unit intensity. The fit is performed in unit normalized reference surface coordinates and then scaled to the actual reference surface coordinates. The current reference surface aperture height at the control wavelength is used to normalize the reference surface coordinates. The coefficient values may be used in macros via the "GET ZERN37" command discussed in the CMD section of this manual. Complex Aperture Functions generated in systems with highly non-circular reference surface apertures, particularly those with high X-to-Y aspect ratios, should not be fit using Zernike polynomials. If this is done, even though the fit may seem "good" when checked with the "LISTOPD" command, the coefficients may not properly represent the true aberrations present in the system. Always use caution in these cases and check your results using X and Y OPD fans.

LISTOPD - The "LISTOPD" command causes a report of the last Fringe Zernike polynomial OPD map fit to be displayed. The actual reference surface coordinates, the raw OPDs, the fit OPDs and the fitting error are displayed for all rays not blocked by clear apertures or obscurations.

LISTZERN - The "LISTZERN" command causes a report of the coefficient values of last Fringe Zernike polynomial OPD map fit to be displayed.

LISTREPT - The "LISTREPT" produces a 37-tern Fringe Zernike report based upon the last wavefront map fit. The report displays RMS wavefront values, based upon the coefficient values. The calculation is based on the equations in Appendix 2 of "Optical Shop Testing" by Daniel Malacara.

RAY TRACING SECTION

CAPFN PLOTTING

PLOT CAPFNOPD , λ# , drflag , zmin , zmax - The "PLOT CAPFNOPD" command causes a 3-D plot of the wavefront part of the current Complex APerture FuNction (CAPFN), if one exists, to be displayed. Numeric word #1 specifies the wavelength number for which the wavefront data will be displayed. The default value is the control wavelength number. The horizontal axes are the relative exit pupil coordinates. If "drflag" is left blank, the plot will be displayed to the screen. Otherwise it will not be displayed. If "zmin" and "zmax" are not entered, the z-axis (opd) will be auto-scaled to a reasonable value. If auto-scaling is not desired, then both "zmin" and "zmax" must be explicitly entered. Units for "zmin" and "zmax" are waves are the current wavelength.

PLOT CAPFNAPD, λ# , drflag - The "PLOT CAPFNAPD" command causes a 3-D plot of the apodization part of the current Complex APerture FuNction (CAPFN), if one exists, to be displayed. Numeric word #1 specifies the wavelength number for which the wavefront data will be displayed. The default value is the control wavelength number. The horizontal axes are the relative exit pupil coordinates. If "drflag" is left blank, the plot will be displayed to the screen. Otherwise it will not be displayed.

CAPFNROT ("YES" or "ON" or "NO" or "OFF") - The "CAPFNROT" command is used to specify whether or not the current CAPFN is to be plotted with a 90 degree rotation or not. This helps see "hidden" features. Issued with the interrogator "?", "CAPFNROT" causes the current CAPFN rotation status to be displayed. If the status is "YES" or "ON", then each time a CAPFN is generated, it will be plotted with a 90 degree rotation.

PLOTCON CAPFNOPD , λ# , drflag , zstep - The "PLOTCON CAPFNOPD" command causes a 2-D contour plot of the wave front part of the current Complex APerture FuNction (CAPFN), if one exists, to be displayed. Numeric word #1 specifies the wavelength number for which the wave front data will be displayed. The default value is the control wavelength number. The horizontal axes are the relative exit pupil coordinates. If "drflag" is left blank, the plot will be displayed to the screen. Otherwise it will not be displayed. If "zstep" is not entered, then the steps between contours will be automatically set so that there are 10 contours. The units of "zstep" are fractions of the wavelength for which the CAPFN is being plotted. The maximum number of contours is 20. If "zstep" is set such that more than 20 contours would be drawn, then "zstep" is automatically re-adjusted so that 20 contours are drawn.

PLOTCON CAPFNAPD, λ# , drflag - The "PLOTCON CAPFNAPD" command causes a 2-D contour plot of the apodization part of the current Complex APerture FuNction (CAPFN), if one exists, to be displayed. Numeric word #1 specifies the wavelength number for which the wave front data will be displayed. The default value is the control wavelength number. The horizontal axes are the relative exit pupil coordinates. If "drflag" is left blank, the plot will be displayed to the screen. Otherwise it will not be displayed. 10 contours will be drawn from 0.0 to 100.0 % (maximum relative intensity).

OPD FIELD MAPS

RMSMAP , λ# , nrd , nflds , drflag - The "RMSMAP" command causes a contour plot of the RMS OPD to be generated and plotted over the field of view defined by the current SCY/SCX or SCY FANG/SCX FANG values stored in the lens database. The wavelength number is set by "λ#, numeric word #1. Its default is the control wavelength. The density of the ray grid traced over the system aperture is set by "nrd", numeric word #2. Its default is 16. "nrd" must be an even integer between 16 and 512. The number of field of view points across the full x and y-field of view is set by "nflds", numeric word #3. Its default is 3. It "drflag" is not explicitly entered, the results will be displayed to the screen, else automatic display will be suppressed.

PTVMAP , λ# , nrd , nflds , drflag - The "PTVMAP" works exactly as "RMSMAP" except "peak to valley" OPD will be plotted.

STRLMAP , λ# , nflds , drflag - The "STRLMAP" works exactly as "RMSMAP" except psf based Strehl Ratio will be plotted.

RAY TRACING SECTION

DIFFRACTION OPTICAL TRANSFER FUNCTION - The DOTF command described below generates the Diffraction Optical Transfer Function (DOTF). This transfer function is based upon residual optical path differences in the current lens system and considers the effects of diffraction due to apertures and obscurations. "DOTF" uses the existing CAPFN if one exists. If no CAPFN exists, then a "CAPFN" command is automatically issued using a default "capfnnrd" value of 16. The user may always change the default "capfnnrd" value with the "CAPFNNRD" command listed earlier. DOTF is always a response to a set of sinusoidally varying target bars.

DOTF (Y or X or YACC or XACC) , (f) , n - The "DOTF" command either generates a range of DOTF data from spatial frequency 0.0 to the "cutoff" frequency or it generates DOTF data at a single spatial frequency value "f". The qualifier word may be "Y", "YACC", "X" or "XACC". The "cutoff" frequency used in the DOTF calculation is based either on a true aberrated f/number or an aberrated entrance/exit pupil calculation, depending upon the current lens MODE and the SPACE in which the calculation is performed. The cutoff frequency calculation, used in DOTF, does not consider vignetting due to apertures or ray failures. This vignetting is included in the DOTF calculation by its inclusion in the complex aperture function (CAPFN). If the (optional) single frequency "f" is explicitly input, then the Modulation Transfer Function (MTF) and the Phase Transfer Function (PTF) values corresponding to that frequency will be generated and placed in the "X" and "Y" registers. These two values will be displayed if the qualifier words "Y" or "X" are used. If the qualifier "YACC" or "XACC" is used in the single frequency context, then all display will be suppressed. When a range of DOTF values are generated, the qualifier words "YACC" and "XACC" act exactly as do the qualifiers words "Y" and "X". Qualifier word "Y" or "YACC" causes DOTF data to be generated in response to horizontal target bars. This is known as YZ-plane response The qualifier word "X" or "XACC" causes DOTF data to be generated in response to vertical target bars. This is known as XZ-plane response. Horizontal target bars are target bars which are parallel to the local X-axis of the current reference surface. Vertical target bars are target bars which are parallel to the local Y-axis of the current reference surface. If no qualifier word is entered, DOTF data will be calculated and displayed for both vertical and horizontal target bar orientations. "n" specifies the number of data points to display during tabular output. The minimum for "n" is 3, the maximum is 100 and the default is 10. After DOTF data has been generated with this command, the data may be plotted using the "PLTDOTF" command.

The definitions of "horizontal" and "vertical" are referenced to the local coordinate system of the current reference surface. Only when the local X and Y-axes of the object and image surfaces are parallel to the local X and Y-axes of the reference surface will the target orientation definitions apply at the object and image surfaces. All DOTF calculations are polychromatic calculations weighted by the current spectral weight values as set with the "SPTWT" and "SPTWT2" commands. Monochromatic calculations are performed by setting all but one wavelength's spectral weight to zero. The "CUTOFF" frequency is defined to be:

In object space with the object at infinity (NEAR set and the object thickness less than 1.0D+5 mm) the "cutoff" frequency is just:

1000 times Entrance Pupil Diameter (EPD) divided by the shortest wavelength. The units are line pairs per milliradian (lp/mrad) In object space with a near object the "cutoff" frequency is just:

Entrance Pupil Diameter (EPD) (in mm) divided by the product of the shortest wavelength (in mm) and the distance from the current object surface to the entrance pupil (in mm). The units are line pairs per millimeter (lp/mm).

In image space with mode "AFOCAL" or "UAFOCAL" the "cutoff" frequency is just:

1000 X Exit Pupil Diameter (EPD) divided by the shortest wavelength. The units are line pairs per milliradian (lp/mrad).

In image space with mode "FOCAL" or "UFOCAL" the "cutoff" frequency is just:

Exit Pupil Diameter (EPD) (in mm) divided by the product of the shortest wavelength (in mm) and the distance from the exit pupil to the image surface (in mm). The units are line pairs per millimeter (lp/mm).

CUTOFF (O, OACC, I or IACC) - The "CUTOFF" command generates and displays the current value of the "cutoff" frequency. This "cutoff" frequency calculation is based either upon a real ray f/number calculation or a real ray entrance/exit pupil calculation depending upon the current lens MODE and the space in which the "cutoff" frequency is requested. The qualifier "O" or "I" causes the "cutoff" spatial frequency to be calculated either in "object" space or "image" space. The default qualifier is "I". The value of the "cutoff" frequency is always placed into the "X"-register. The qualifiers "OACC" and "IACC" work just as do "O" and "I" except that they suppress all display.

DOTF IN OBJECT SPACE - All DOTF calculations are performed in the frequency domain of "image space". In the AFOCAL or UAFOCAL mode, the frequency units are "lp/mrad". In FOCAL or UFOCAL modes the frequency units are "lp/mm". Many times it proves convenient to express the MTF in the frequency domain of "object space" The following two commands provide the user with a way of telling the program that the tabular MTF listings and the graphical MTF plots of MTF versus frequency are to be displayed in the frequency domain of "object space".

SPACE (O or I) - The "SPACE" command instructs the program as to the spatial domain in which the tabular and graphical DOTF is to be represented. The default is "I" for image space. This command does not change the way the DOTF values are computed but it does change the spatial frequency units used in the tabular and graphical displays. ". Issuing this command with the "?" returns the current setting

NEAR or **FAR** - The "NEAR" and "FAR" commands are used to specify the units for optical transfer function display when space is set to "O". "NEAR" sets units to "lp/mm" whereas "FAR" specifies "lp/mrad". Issuing this command with the "?" returns the current setting. The program default setting is "FAR"

REFERENCE SPHERE ADJUSTMENTS - The commands described below are used to modify the location of the center and the radius of curvature of the reference sphere for CAPFN OPD calculations. They do **NOT** move the center of the reference sphere or modify the reference sphere radius of curvature for individual ray OPDs or ray fan OPD calculations. These commands only apply for modes FOCAL and UFOCAL. They have no impact when modes AFOCAL and UAFOCAL are set. **This is the default condition when the program starts.**

RSPH CHIEF or **RSPH NOTILT** or **RSPH BEST** - The "RSPH CHIEF" command causes the center of the reference sphere to be located where the current chief ray crosses the current image surface. "RSPH NOTILT" attempts to remove wavefront tilt by fitting the wavefront to a sloped plane in a least squares sense. It uses this sloped plane to remove wavefront tilt and then estimates the resultant reference sphere center of curvature position such that the center of curvature still lies in the original image plane. "RSPH BEST" attempts to remove wavefront tilt and focus by fitting the wavefront to a tilted sphere in a least squares sense. It uses this tilted sphere to remove wavefront tilt and focus and then estimates the resultant reference sphere center of curvature position. The reference sphere center may no longer be located on the original image surface. If the "RSPH" command is issued followed by the "?", then the current mode for locating the center of the reference sphere will be displayed. These commands impact the behavior of RMS OPD calculations during CAPFN ray tracing. They, in turn, impact the calculation of the diffraction based optical transfer function and PFSs. In the case of polychromatic calculations, the reference sphere center position picked, is the best position considering all wavelength's opds. The "RSPH" command is also used during geometrical spot diagram ray tracing to specify the center of the geometrical line spread function before any additional offsets are applied.

NOTILT or **BEST** - The "NOTILT" command acts to remove wavefront tilt from the current complex aperture function (FOCAL and UFOCAL MODES only). This is done by fitting the wavefront to a sloped plane in a least squares sense. It uses this sloped plane to remove wavefront tilt and then estimates the resultant reference sphere center of curvature position such that the center of curvature still lies in the original image plane. The "BEST" command acts to remove wavefront focus and tilt from the current complex aperture function (FOCAL and UFOCAL MODES only). This is done by fitting the wavefront to a sloped plane in a least squares sense. It uses this sloped plane to remove wavefront focus and tilt and then estimates the resultant reference sphere center of curvature position such that the center of curvature still lies in the original image plane. In both cases the new resultant complex aperture function replaces the CAPFN which existed before the command was issued. The associated reference sphere motion may be retrieved using the "GET RSPHX", "GET RSPHY" and "GET RSPHZ" commands. New RMS and Peak to Valley wavefront errors are also automatically computed and are available via the "GET PTOVOPD" and "GET RMSOPD" commands.

MULTIPLE FOV DOTF - If multiple field of view definitions are included in the lens database (using the "FLDS" command) and if the command which immediately precedes the "DOTF" command is not an "FOB" command and if "DOTF" is issued without qualifier or numeric input, then DOTF values will be computed for the diffraction limit and for each of the defined multiple field of view positions. These values will be stored so that they may be plotted with the next "PLTDOTF" command. For multiple field of view DOTF calculations, if the reference sphere center location had been previously set to "BEST", it will be temporarily be reset to "NOTILT" for the duration of the calculations.

RAY TRACING SECTION

THRU-FOCUS DOTF - Many other optical design programs provide a thru-focus diffraction MTF calculation based upon the axial motion of the final surface of the lens database. This is usually performed via some motion of the final reference sphere center. Even though this method is fast, it is totally inadequate for most real optical designs for the following reasons:

The method ignores all AFOCAL systems

Many times in REAL optical systems "focus" is achieved through the motion of some element other than the image surface.

To support a useful thru-focus MTF capability the following commands are provided:

TFMOTION (X , Y or Z) , i , Δt , tmin , tmax - The "TFMOTION" command defines the motion of surface "i" which will be used to change system "focus". The qualifier word indicates whether the motion will be in the local X, Y or Z-direction with respect to the local surface coordinate system at surface "i". "Δt" is the increment of motion and "tmin" and "tmax" are the limits of the motion. The default direction is "Z". The default surface "i" is the final surface, which for AFOCAL and UAFOCAL modes won't really work and so should be changed by the user to a more effective surface in afocal systems. The default for "Δt" is 0.001 lens unit. The defaults for "tmin" and "tmax" are -5 and +5 times the current "Δt".

TFDOTF , freq , n - The "TFDOTF" command generates a range of DOTF data at spatial frequency "freq" over the thru-focus range specified by the last "TFMOTION" command. Both XZ (vertical target bars) and YZ (horizontal target bars)-plane modulus and phase values are displayed. "n" is the grid size for the complex aperture function. The default value is 16. The definitions of "horizontal" and "vertical" are referenced to the local coordinate system of the current reference surface. Only when the local X and Y-axes of the object and image surfaces are parallel to the local X and Y-axes of the reference surface will the target orientation definitions apply at the object and image surfaces. All DOTF calculations are polychromatic calculations weighted by the current spectral weight values as set with the "SPTWT" and "SPTWT2" commands. Monochromatic calculations are performed by setting all but one wavelength's spectral weight to zero.

DOTF PLOTS

PLTDOTF (LEICA) , (max-freq.) , dflag

CASE: No qualifier word

In this case the "PLTDOTF" command causes a plot of the modulus of the existing Diffraction Optical Transfer Fuction data versus spatial frequency to be generated. If "(max-freq) is entered (this input is not used in LEICA type plots), the plot will only go out to this frequency. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTDOTF" applies to the most recently generated DOTF. If no DOTF data exists, a message to that effect is issued and no plot is generated. If DOTF data exists for both vertical and horizontal target orientations, they both will be included on one plot. If multiple field of view "DOTF" data exists, it will be plotted on a multiple field of view type of DOTF display. Each curve will be labeled as to field of view position and target orientation.

CASE: Qualifier word = "LEICA" (There must exist DOTF data for at least 5 multiple field of view positions)

In this case the "PLTDOTF" command causes a plot of the modulus of the existing Diffraction Optical Transfer Fuction data versus field of view to be generated. "max-freq" input is ignored in this case. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTDOTF" applies to the most recently generated DOTF. If no DOTF data exists, a message to that effect is issued and no plot is generated. This command plots both target bar orientations of the first 10, non-zero frequency MTFs generated using the previous "DOTF" command. GOTF and DOTF data is generated using the "GOTF" and "DOTF" commands described in the CMD section of this manual.

DIFLEICA (ON or YES or OFF or NO) , freq# - The DIFLEICA command is used to shut off any of the DOTF vs FOV plots in a "PLTDOTF LEICA" type of plot. The "freq#" can be 1 through 10. Once frequency numbers are turned "off" they stay "off" until they are "tuned on" of until the program ends. Entered with a "?", the status for all 10 frequencies will be displayed.

DIFFRACTION PSF - Diffraction PSF's are calculable for both focal and afocal systems. Focal systems represent the PSF in lens units. Afocal systems represent the PSF in radian measure in the far field. The commands described below are used to generate a true diffraction Point Spread Function (PSF). They use the same routines which generate the CAPFN and which are described in the first part of this manual section.

RAY TRACING SECTION

PSF FROM THE CURRENT CAPFN - If a CAPFN already exists, it will be used to generate the next PSF. If a CAPFN does not exist, one will be generated. The ray grid size for that PSF will be set equal to the current "capfnnrd" value. "tgr" will be set to be a power of 2 and will initially be greater than or equal to four times the "capfnnrd". The "pgr" will be set to "tgr"-1. The user may reset the "tgr" and "pgr" values after the CAPFN is generated and before the PSF is generated. All "nrd", "pgr" and "tgr" values which are reset, will remain reset until explicitly reset again by the user or until the program terminates execution.

PARAMETER SETUP - The commands described below are used to set up the program parameters which will be used when generating the PSF. The PSF is polychromatic and includes information from any non-zero wavelength for which the spectral weight is non-zero.

PSF or **PSF PERFECT** or **PSF PERFNOOB , dflag , λ# , I** - The "PSF" command is used to generate a diffraction based Point Spread Function via a Fast Fourier Transform of the Complex Aperture Function. "PERFECT" causes all OPD errors to be set to ZERO. "PERFNOOB" causes all OPD to be set to ZERO and causes all obscurations to be ignored. If "dflag" is zero and PSF plotting is on, the plot will be drawn to the screen. If "dflag" is non-zero and PSF plotting is on, the plot will be generated but not drawn to the screen. If "λ#" is explicitly input, the PSF will be only computed using a pupil function at that wavelength #, else a polychromatic PSF will be generated. If "I" is a starting point object intensity. The default is 1.0 and it may be set to any value between 0.0 and 1.0.

NRD , nrd - The "NRD" command is used to specify the number of rays which will span the exit pupil of the current system at the shortest wavelength. The default value is 16. Any even integer greater than or equal to 16 and less than TGR may be used. Issued with the interrogator "?", "NRD" causes the current "nrd" value to be displayed.

PGR , pgr - The "PGR" command is used to specify the FFT transform plotting grid extent during PSF and Streaked PSF plotting. It also specifies the extent of the integration grid for the line spread function output tables in the PSF.DAT and SPSF.DAT files and the region considered during Pixel Linearity Analysis when the qualifier words "LSF" and "SLSF" are used. It may be set to any odd integer less than TGR. The default value is 127 which is the default "tgr" value minus 1. If the "tgr" value is decreased below that of the current "pgr" value, then the "pgr" value will be automatically reset to "tgr"-1. Issued with the interrogator "?", "PGR" causes the current "pgr" value to be displayed.

TGR , tgr - The "TGR" command is used to specify the FFT transform grid size. It may be any even integer power of 2 greater than or equal to 64. The default value is 128 which is four times the default value of "nrd" Issued with the interrogator "?", "TGR" causes the current "tgr" value to be displayed. TGR should always be at least two times the NRD.

GRI , gri - The "GRI" command is used to specify the FFT transform grid spacing. By default, the "gri" value is determined from the current "tgr" and "nrd" values and by the shortest wavelength and the f-number at the shortest wavelength. If a "gri" value is explicitly input by the user, then the program adjusts the "nrd" value and applies special ray scaling so as to yield the requested "gri" If the "NRD" command is issued after the "GRI" command is issued, then the existing "gri" specification will be cancelled and the "gri" will again be determined from the "tgr" and "nrd" values. In modes FOCAL and UFOCAL, "gri" is entered in lens units. In modes AFOCAL and UAFOCAL, gri is entered in "radians".

EXTENT , extent - The "EXTENT" command is used to specify the FFT transform displayed extent by using the existing PGR value to calculate a new internal "gri" value such that "gri"x"pgr" = "extent". This is just an alternate way for the user to specify the "gri" value.

PSFLIN - The "PSFLIN" command is used to switch the PSF presentation from the PSFLOG mode to the original default "linear" presentation. Issued with the interrogator "?", the current PSF presentation mode is displayed.

PSFLOG , d - The "PSFLOG" command is used to specify the PSF is to be replaced everywhere by its LOG_{10} spread over "d" decades. The default for "d" is "2". Issued with the interrogator "?", the current PSF presentation mode is displayed.

PSFPLOT ("YES" or "ON" or "NO" or "OFF" or "HCONLY") - The "PSFPLOT" command is used to specify whether or not the current PSF is to be plotted to the screen. Issued with the interrogator "?", "PLOTPSF" causes the current PSF plot status to be displayed. If the status is "YES" or "ON", then each time a PSF is generated, it will be plotted to the screen and will be available for re-draw using the "DRAW" command or for hard copy display using the "GRAOUT" command. If the qualified word "HCONLY" is used, "PSFPLOT YES" is assumed but no automatic "DRAW" command is issued and the PSF plot is not automatically displayed on the screen.

PSFROT ("YES" or "ON" or "NO" or "OFF") - The "PSFROT" command is used to specify whether or not the current PSF is to be plotted with a 90 degree rotation or not. This helps see "hidden" features. Issued with the interrogator "?", "PSFROT" causes the current PSF rotation status to be displayed. If the status is "YES" or "ON", then each time a PSF is generated, it will be plotted with a 90 degree rotation.

RAY TRACING SECTION

PSF FILE OUTPUT - The following commands control the output of the current PSF to the ASCII file PSF.DAT.

PSFTAG , psftag - The "PSFTAG" command is used to specify the character value of "psftag". "psftag" will be written as the first line of the ASCII PSF data file. The default value is "   PSF.DAT". The tag may be up to 12 characters long. Issued with the interrogator "?", "PSFTAG" causes the current "psftag" to be displayed

PSFLI , psfli - The "PSFLI" command is used to specify the character value of "psfli". "psfli" will be written as the second line of the ASCII PSF data file. The default value is "THIS IS AN ASCII REPRESENTATION OF A POINT SPREAD FUNCTION". The "psfli" may be up to 78 characters long. Issued with the interrogator "?", "PSFLI" causes the current "psfli" to be displayed

PSFWRITE , ("YES" or "ON" or "NO" or "OFF") - The "PSFWRITE" command is used to specify whether or not the current PSF is to be output to the ASCII file PSF.DAT. Issued with the interrogator "?", "PSFWRITE" causes the current PSF write status to be displayed. If the status is "YES" or "ON", then each time a PSF is generated, it will be output to the ASCII file PSF.DAT. If more than one PSF needs to be saved, use the "SYSTEM" command to issue "RENAME" or "COPY" commands from the operating system. The PSF.DAT file has the formats described below. The magnitude of the PSF is written out a row at a time starting at the -x,-y corner. The first "tgr-1" elements of the PSF will be the "bottom" row. The last row written out will be the top row starting at -x,+y and ending at +x,+y. The coordinates are in the coordinate system of the image surface. The magnitude of the PSF is scaled to a peak value of 32767. A PSF.DAT file must exist before a Pixel Linearity analysis can be performed.

PSF.DAT FORMAT

1. The first line of the file is the file "psftag" set by the "PSFTAG" command described above. This "psftag" is written in A12 format. The default is "PSF___.DAT".

2. The second line of the file contains the "psfli" set by the "PSFLI" command described above. The "psfli" is written in A78 format. The default is "THIS IS AN ASCII REPRESENTATION OF A POINT SPREAD FUNCTION".

3. The third line contains the value of "tgr-1" followed by the value of "pgr", written in I10,1x,I10 format.

4. The fourth line contains the current units being used. "CM", "MM", "IN" or "M" for centimeters, millimeters, inches or meters.

5. The fifth line contains the PSF extent and grid spacing in lens units. These are written in E15.8 , 1x , E15.8 format

6. The sixth line contains the X and Y-centroid locations of the PSF. These are written in E15.8, 1x, E15.8 format

7. The seventh line contains the X and Y-field of view coordinated followed by the units (DEGREES for infinite object distances or lens units ("CM", "MM", "IN" or "M" for finite object distances). Format is E15.8,1x,E15.8,1x,A9.

8. The next "tgr-1" x "tgr-1" lines contain the X and Y index counters of a PSF entry followed by the PSF intensity scaled to a peak value of 32767. Each line is written in 2I4 , I8 format.

9 .The next "tgr-1" lines contain the X index counter of the X-direction line spread function followed by the X-direction line spread function intensity values scaled to a peak value of 1.0000. Each line is written in I4 , G23.15 format. This line spread function is a result of a summation of all the columns in the PSF.

10. The next "tgr-1" lines contain the Y index counter of the Y-direction line spread function followed by the Y-direction line spread function intensity values scaled to a peak value of 1.0000. Each line is written in I4 , G23.15 format. This line spread function is a result of a summation of all the rows in the PSF.

11. The last line of the file contains the letters "EOF" standing for "End Of File".

PSFBIN , ("YES" or "ON" or "NO" or "OFF") - The "PSFBIN" command is used to specify whether or not the current PSF is to be output to the binary file PSFBIN.DAT. Issued with the interrogator "?", "PSFBIN" causes the current PSFBIN write status to be displayed. If the status is "YES" or "ON", then each time a PSF is generated, it will be output to the binary file PSFBIN.DAT. If more than one PSF needs to be saved, use the "SYSTEM" command to issue "RENAME" or "COPY" commands from the operating system. The PSFBIN.DAT file has the formats described below. The magnitude of the PSF is written out a row at a time starting at the -x,-y corner. The first "tgr-1" elements of the PSF will be the "bottom" row. The last row written out will be the top row starting at -x, +y and ending at +x, +y. The coordinates are in the coordinate system of the image surface.

PSFBIN.DAT FORMAT

1. The first record of the file comprises the total number of record in the file, as in INTEGER*4

2. The second record of the file comprises: tgr-1 (INTEGER*4), gri-spacing in the PSF (REAL*8), scalefactor (REAL*8), unit_flag (INTEGER*4), mode_flag (INTEGER*4). The scalefactor is the value which when multiplied into the PSF values, scales the peak PSF value to 32767. The unit_flag is 1 = inch, 2 = cm, 3 = mm and 4 = meters, the current lens units. The mode_flag is 1 = focal, 2 = afocal.

3. The third record comprises wavelengths #1 to #10, in micron units. Ten (REAL*8) items.

4. The fourth record comprises the wavelength spectral weights for wavelengths #1 to #10. Ten (REAL*8) items.

5. The next "tgr-1"x"tgr-1" records comprise the x (INTEGER*4) and y (INTEGER*4) - PSF index values followed by the associated raw PSF value (REAL*8)

There will always be ("tgr-1) x ("tgr-1") + 4 records in a PSFBIN.DAT file.

RAY TRACING SECTION

HOW PSF WORKS - PSF (PERFECT or PERFNOOB)The "PSF" command causes a diffraction PSF calculation to be performed for the field of view specified by the current "FOB" command. The optional qualifier "PERFECT" creates a perfect COMPLEX APERTURE FUNCTION with zero OPD. This "perfect" CAPFN considers all system obscurations and clear apertures. The optional qualifier "PERFNOOB" works exactly as "PERFECT" except that all system obscurations are ignored. The "APOD" command settings, described earlier in the spot diagram section, are also used in weighting or apodizing the rays traced during "CAPFN" ray trace which forms the basis of the PSF calculations The program performs the following operations whenever a PSF is requested via the "PSF" command:

A Complex Aperture Function (CAPFN) is created using a square ray grid of size "nrd" x "nrd" for the shortest wavelength for which there is a non-zero spectral weighting factor. This CAPFN is stored on disk just as would be done if a "CAPFN" command had been issued. The ray grid spacing is scaled for all other wavelengths in the pupil so as to produce equal grid spacing in the transform grid.

A grid spacing and a transform extent in the focal plane are computed, based upon the shortest wavelength and the image space F/number. This is the PSF grid spacing used in the FFT (Fast Fourier Transform).

The CAPFN is "zero padded" so as to be at the center of a "tgr" x "trg" sized pupil function.

A "tgr" x "tgr" Fast Fourier Transform is performed upon the pupil function for each wavelength, is multiplied by the current wavelength spectral weighting factor and is finally added to the final transform storage. By nature of the math, this grid is now of dimension "tgr"-1. The raw PSF peak value corresponding to each of the 10 wavelengths and before being multiplied by the spectral weighting factor, is stored in a general purpose storage registers 101 to 110. For example, The raw PSF peak for wavelength #1, is stored in register #101 and may be retrieved with the "RCL 101" command.

The central "tgr-1" x "tgr-1" values are saved in a temporary PSF storage area.

The PSF is then plotted to the screen (if "PSFPLOT" was set to "ON") and written to the ASCII file PSF.DAT (if "PSFWRITE was set to "ON")

PSF STREAKING - There may be times when it is desired to create a "streaked" diffraction PSF from original PSF which was stored in the PSF.DAT file. The following commands provide this capability.

STREAK PLOT ("YES" or "ON" or "NO" or "OFF") - The "STREAK PLOT" command is used to specify whether or not the streaked PSF is to be plotted to the screen. Issued with the interrogator "?", "STREAK PLOT" causes the current streaked PSF plot status to be displayed. If the status is "YES" or "ON", then each time a streaked PSF is generated, it will be plotted to the screen and will be available for re-draw using the "DRAW" command or for hard copy display using the "GRAOUT" command. The program default is "ON". "pgr"x"pgr" elements of the streaked PSF are displayed even though the entire streaked PSF is written to the SPSF.DAT file.

STREAK WRITE , ("YES" or "ON" or "NO" or "OFF") - The "STREAK WRITE" command is used to specify whether or not the streaked PSF is to be output to the ASCII file SPSF.DAT. Issued with the interrogator "?", "STREAK WRITE" causes the current streaked PSF write status to be displayed. If the status is "YES" or "ON", then each time a streaked PSF is generated, it will be output to the ASCII file SPSF.DAT. If more than one streaked PSF file needs to be saved, use the "SYSTEM" command to issue "RENAME" or "COPY" commands from the operating system. The SPSF.DAT file has exact same file format as used for the PSF.DAT file previously described except that no optional PSFLI or PSFTAG may be set by the user. The magnitude of the streaked PSF is written out a row at a time starting at the -x,-y corner. The first "m+tgr-1" elements of the PSF will be the "bottom" row. The last row written out will be the top row starting at -x,+y and ending at +x,+y. The coordinates are in the coordinate system of the reference surface. The magnitude of the streaked PSF is scaled to a peak value of 32767. "m" is the number of PSF grid spaces that the PSF is "streaked".

STREAK (X or Y or XY) , m - The "STREAK" command causes the current PSF stored in the PSF.DAT file to be streaked (shift-added) either in the X or Y or XY-direction by "m" "gri" units. A new streaked PSF is created in memory. The new streaked PSF has dimension "tgr-1+m"x"tgr-1+m". If "STREAK WRITE" has been set to "ON", the streaked psf will be written to the file SPSF.DAT. If "STREAK PLOT" has been set to "ON", the streaked psf will be plotted on the screen and may be re-drawn using the "DRAW" command or printed using the "GRAOUT" command.

RAY TRACING SECTION

PIXEL LINEARITY (CENTRIOD) ANALYSIS - Pixel linearity analysis is only available for systems in modes FOCAL and UFOCAL. Star Trackers (and other similar optical systems) which use CCD detectors, sometimes must locate a PSF centroid to within a small fraction of a CCD pixel. For these systems the designer may introduce specific levels of rotationally symmetric aberration such that the PSF image is spread out over several detector pixels while at the same time maintaining PSF symmetry. The Pixel Linearity Analysis commands described below provide a method for computing this PSF centroid location based upon an "n"x"n" grid of pixels and comparing this centroid position to the true centroid position. The difference between the true centroid position and the centroid position computed from the nxn array of pixels is called Linearity or Centroid Error. This error varies with the position of the PSF within a pixel in the nxn grid of pixels. The program computes this linearity error for a number of sub-pixel positions within a pixel for the nxn grid of pixels, displays these errors and then computes and displays an RMS centroid error. The current algorithm used is a first moment or arithmetic mean algorithm. A PSF must have been written to either the PSF.DAT or SPSF.DAT file before a Pixel Linearity Analysis can be performed. The dimensions of a sub-pixel are taken to be the PSF grid spacing value set during the PSF calculation by the values "nrd", "tgr" and the shortest wavelength and the system f/number. There are two commands which control pixel linearity Analysis. There are :

PIXEL , m , n - The "PIXEL" command is used to set up or specify "m" the number of sub-pixels per pixel and "n" the number of pixels in the CCD window. "n" specifies the "n"x"n" grid of pixels mentioned above. If the "PIXEL" command is not issued, then the default values for "m" and "n" will be 3 and 3 respectively. "m" must always be an odd integer. "n" may be even or odd.

CENTROID (LSF or SLFS or PSF or SPSF) - The "CENTROID" command causes a Pixel Linearity Analysis to be performed and the results sent to the screen or other current output device. If no optional qualifier word is issued (the same as using qualifier word "LSF"), the analysis is performed using the LSF data stored in the PSF.DAT file. If the qualifier "SLSF" is issued, the analysis is performed using the "streaked" LSF data stored in the SPSF.DAT file. If the qualifier word "PSF" is issued, the PSF data in file PSF.DAT is used and if the qualifier word "SPFS" is used, the streaked PSF data in the file SPSF.DAT is used. Existing Point Spread Functions stored in the files PSF.DAT or SPSF.DAT may be interpolated from their odd grids to even grids with the "PSFINT" and "PSFINTS" commands. The grid extents of these interpolated PSF's will be set to "pgr"+1. If this leads to PSF extrapolation rather than interpolation, then the extrapolated values will be set to zero.

PSFINT and **PSFINTS** - "PSFINT" causes interpolation of the file PSF.DAT to an even grid. PSFINTS causes interpolation of the file SPSF.DAT (a streaked PSF) to an even grid. The new interpolatied PSF is output to the file IPSF.DAT.

STREHL RATIO - There are two ways in which the STREHL ratio of the current lens database may be computed. The exact method and the approximate method. The exact method is described first. In this method, the STREHL ratio of an optical system is exactly defined to be the ratio of the peak value of the diffraction point spread function of the aberrated optical system to the peak value of the diffracting point spread function of the same system in the absence of aberrations.

STREHL (ACC or ACCNOOB or NOOB) - After a field of view position is defined using an "FOB" command, the "STREHL" command calculates, displays, and places into the X-register, the true value of the current optical system STREHL ratio. The PSFs which are used in this calculation are based upon PSF parameter values which would have been used if the "PSF" command had been issued. If "STREHL" is issued with the qualifier words "ACC" or "ACCNOOB", the STREHL ratio value will not be displayed. Issued with the qualifier words "NOOB" or "ACCNOOB" causes the strehl ratio calculation to ignore all system obscurations. The second method is an approximate method based upon the RMS wavefront error computed when a CAPFN (Complex Aperture Function) is produced. After appropriate "FOB" and "CAPFN" commands have been issued, the approximate STREHL ratio (see, Born and Wolf, Principles of Optics, Programing Press) may be calculated using the "APSTREHL" command. This approximation is generally valid for systems for which the RMS wavefront error does not exceed 0.1 wave. For monochromatic systems, there is an approximate relationship between the RMS wavefront error and STREHL ratio.

This approximate relationship is:

$$STREHL\_Ratio = e^{-(2\pi\sigma)^2}$$

where σ is the RMS wavefront error in waves.
For polychromatic systems, polychromatic RMS wavefront error is given by:

$$\sigma = \frac{\sum \dfrac{W_\lambda \sigma_\lambda^2}{\lambda^2}}{\sum \dfrac{W_\lambda}{\lambda^2}}$$

The summations are performed over all non-zero weighted wavelengths in the current lens database and:
are the wavelengths
W_λ are the wavelength spectral weights
σ_λ are the monochromatic RMS wavefront values at each individual wavelength.
is measured in waves at the weighted integrated wavelength which is given by:

$$\overline{\lambda}^2 = \frac{\sum \dfrac{W_\lambda}{\lambda^2}}{\sum \dfrac{W_\lambda}{\lambda^4}}$$

APSTREHL (ACC) - The "APSTREHL" command computes, displays and stores in the X-register, the approximate STREHL ratio based upon the RMS wave front error computed by the last issuance of the "CAPFN" command. If "APSTREHL" is issued with the qualifier word "ACC", the approximate STREHL ratio value will not be displayed.
DIFFRACTION ENERGY DISTRIBUTIONS
ENCIRCLED ENERGY
DRED (N) , ΔE , ΔX , ΔY - The "DRED" command produces a radial energy distribution (energy versus radial distance from the center of the PSF) using the current diffraction PSF data. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units for focal systems and radians for a focal systems) from the center of the PSF If the qualifier word "N" is used, no output is generated. After tabular data is generated with the "DRED" command, it may be graphically displayed using the "PLTRED" command.
DRED ACC , E , ΔX , ΔY - The "DRED ACC" command produces no display. "DRED ACC" returns to the X-register (accumulator), the radius of the circle which encloses "E" percent energy. All the above comments concerning "ΔX" and "ΔY" apply in the same way as for the "DRED" command.
ENSQUARED ENERGY
DREDSQ (N) , ΔE , ΔX , ΔY - The "DREDSQ" command produces an ensquared energy distribution (ensquaring square side length, centered at the PSF center, versus energy) using the current PSF data. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units for focal systems and radians for afocal systems) from the center of the PSF. If the qualifier word "N is used, no output is generated.
DREDSQ ACC , E , ΔX , ΔY - The "DREDSQ ACC" command produces no display. "DREDSQ ACC" returns to the X-register (accumulator), the side length of the square which encloses "E" percent energy. All the above comments concerning "ΔX" and "ΔY" apply in the same way as for the "DREDSQ" command. After tabular data is generated with the "DREDSQ" command, it may be graphically displayed using the "PLTRED" command.

RAY TRACING SECTION

INVERSE DISTRIBUTIONS ENSQUARED ENERGY - In all of the above energy distribution commands, the qualifier words "ACC" and "CACC" were used to return to the X-register, the size of the circle or square which encircled or ensquared the percent energy specified in numeric word #1. If, instead, the qualifier words "ACCX" and "CACCX" are used, then, commands return to the X-register either the percent energy encircled by the circle whose radius is specified in numeric word #1 or the percent energy ensquared by the square whose side length was specified in numeric word #1.

PSF CENTER - In all of the above energy distribution commands, the PSF is considered to be centered at the chief ray position on the image surface unless the "RSPH" command has been used to remove wave front tilt or wave front tilt and defocus from the wave front.

ILLUMINATION - Illumination analysis is generally performed at the CMD level of the program using a specialized set of CMD level commands.

ILLUMINATION RAY TRACING - It is extremely important to remember the following general information concerning the nature of non-global coordinate, trigonometric, illumination ray tracing as it is implemented here:

Ray coordinates at any surface are represented in the local coordinate system of that surface.

Illumination spot diagram data is represented in the coordinate system of the final surface of the system.

The commands which follow are used to:

(1)	DEFINE AN OBJECT POINT
(2)	TRACE AN INDIVIDUAL RAY
(3)	SET SPOT DIAGRAM PARAMETERS
(4)	TRACE ILLUMINATION SPOT DIAGRAMS
(5)	DISPLAY SPOT DIAGRAM RESULTS

Illumination rays are defined using relative fractional object surface coordinates and either relative fractional coordinates at surface #1 or angular ray coordinates in degrees measured relative to the chief ray. Relative fractional object coordinates are entered as fractions of the reference object height at the object surface using the "IFOB" command. Relative surface #1 coordinates and angular ray coordinates are entered either in lens units or degrees. Angular ray coordinates are measured in elevation and azimuth with respect to the current illumination chief ray defined by the last IFOB command.

NO RAY AIMING - Unlike the ray aiming used and described in the CMD section of this manual, illumination rays are not iteratively aimed. They are fired in predetermined directions. They either pass through the optical system or they do not, due to a number of different ray failure modes including ray blockages by clear apertures and obscurations.

ILLUMINATION OBJECT POINT (IFOB COMMAND)

IFOB , Y, X , Z , n - The "IFOB" command must be issued before any illumination rays or illumination spot diagrams can be traced. This command defines the object point from which subsequent illumination rays will be traced. It stays in effect until another "IFOB" command is issued or until it is canceled by some other program option such as "UPDATE LENS". "Y", "X" AND "Z" are the fractional y, x and z-coordinates of the object point measured in the coordinate system of the object surface. If "Z" is zero, the object point lies in the plane of the object surface. If "Z" is +1.0, then the object point is a positive z-distance from the object surface equal to the axial thickness of the current object surface. If "Z" is -1.0, then the object point is a negative z-distance from the object surface equal to the axial thickness of the current object surface. Issued with the interrogator "?", the "IFOB" command returns the last "IFOB" input data if a chief illumination ray exists. The fifth numeric word entry, "m" is used to specify the relative intensity of the reference ray. The default value is 1.0. It may be set to any non-zero value less than or equal to 1.0. Unlike the "FOB" command, no automatic ray is traced when the "IFOB" command executes. The choice of "qualifier word" selects the specific output to be displayed as shown in the following table:

NFOB , l , m , n - The "NFOB" command may be issued before illumination rays or illumination spot diagrams are traced. It is used to specify the "l", "m" and "n"-direction cosines of the chief ray since no ray aiming is performed during illumination ray tracing. By default, "l" and "m" are zero and "n"=1.0.

ILLUMINATION RAYS - Single illumination rays may be traced in an arbitrary order following an "IFOB" command. Single illumination ray trace commands generate no display except for the "IRAY CAOB" and "IRAYA CAOB" commands. Results of single ray traces may be displayed using the usual single ray data display commands which are described in the CMD section. There are four single illumination ray commands. They are: "IRAYA", "IRAYA CAOB", "IRAY" and "IRAY" CAOB" The "IRAYA" and "IRAYA CAOB" commands are most useful when the object is "buried" inside surface #1 such as when a lamp filament is at one focus of an elliptical reflector and the image or other following optics are placed near or beyond the second focus. These two commands allow illumination rays to be trace into hyper-hemispherical directions. The "IRAY" and "IRAY CAOB" commands, on the other hand, are very much like the "RAY" and "RAY CAOB" commands described in the CMD section. They have most use when the object surface is distantly removed from surface #1 and surface #1 subtends substantially less than 180 degrees as seen from the object surface.

IRAYA , el , az , n , I - The "IRAYA" command is used to specify illumination ray tracing in a particular direction with respect to the chief ray direction. "el" and "az" are the angular elevation and azimuth angles (in degrees) measured from the illumination chief ray direction as defined by the last "IFOB" command. "n" is the wavelength number. If no entry is made for "n", the ray is traced at the control wavelength number. "I" is the relative ray intensity which can be set to any non-zero value less than or equal to 1.0. The "az" angle is measured positive from 0 through 360 degrees (counter-clockwise) in a plane perpendicular to the direction of the chief ray. This definition is shown in the following figure. The positive Z-axis is coming out of the figure.
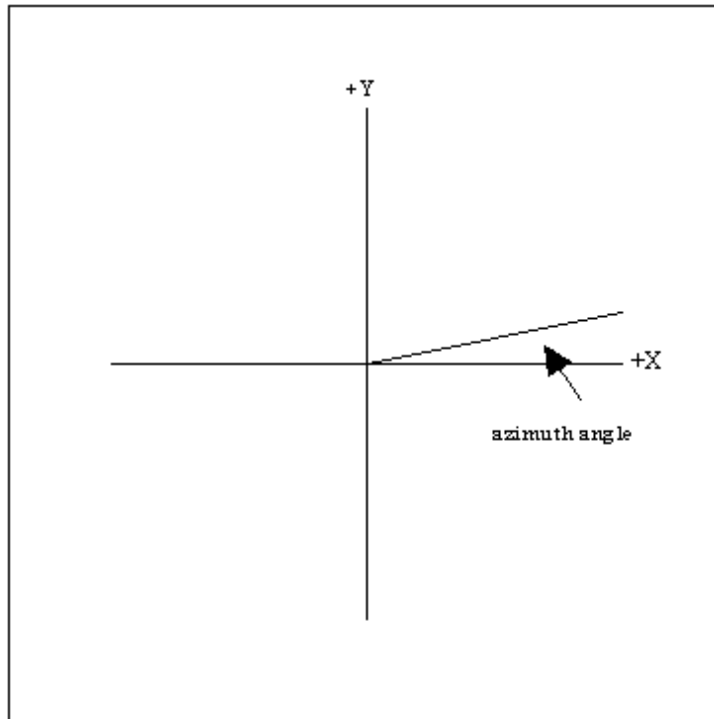
(AZ) IRAYA Angle Definition

The "el" angle is measured from 0 through 180 degrees from the direction of the current chief ray toward the IRAY direction.
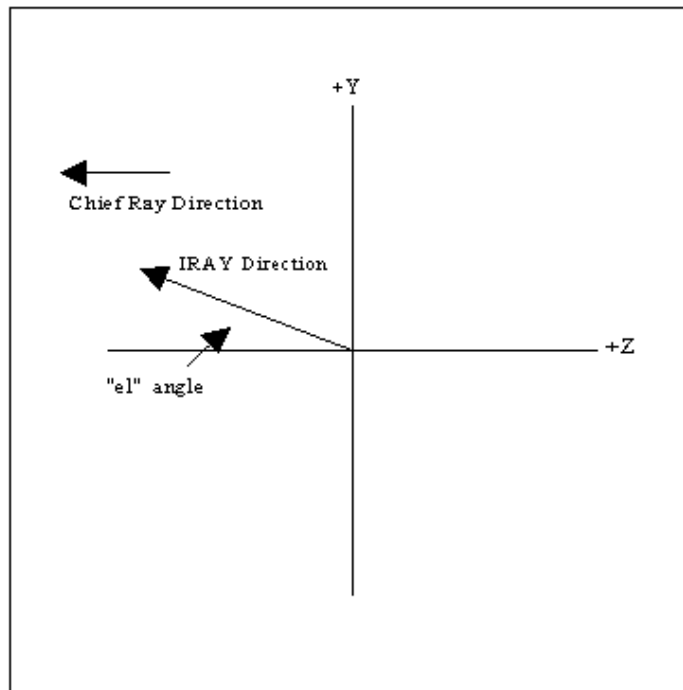
(EL) IRAYA Angle Definition

IRAYA CAOB , el , az , n , I - The "IRAYA CAOB" command works just like the standard "IRAYA" command, except that it causes checking for ray blockages due to clear apertures and obstructions. If a ray falls outside a clear aperture or within an obscuration, a ray failure message will be generated, saved internally and displayed. Clear apertures are not checked on the current object surface or the current image surface by "IRAYA CAOB".

RAY TRACING SECTION

IRAY , Y, X, n , I - The IRAY" command is very similar to the "RAY" command described in the CMD section. "Y" and "X" are the relative fractional surface #1 coordinates with respect to the vertex of surface #1. "n" is the wavelength number. If no entry is made for "n", the ray is traced at the control wavelength number. All decenters and tilts and decentered clear apertures are ignored by the "IRAY" command. "I" is the starting intensity of the ray. It is assumed to be 1.0 by default. It may be set to any value from 0.0 to 1.0.

IRAY CAOB , Y, X, n , I - The "IRAY CAOB" command works just like the standard "IRAY" command, except that it causes checking for ray blockages due to clear apertures and obstructions. If a ray falls outside a clear aperture or within an obscuration, a ray failure message will be generated, saved internally and displayed. Clear apertures are not checked on the current object surface or the current image surface by "IRAY CAOB".

SINGLE RAY DATA DISPLAY - Individual illumination ray data is displayed in exactly the same manner as all other single ray data is displayed, using the single ray data display commands described in the CMD section of this manual. Since differential rays are not traced, OPD data may be meaningless and should be ignored.

DIFFERENTIAL RAYS - No differential rays are traced when illumination rays are traced. No values based upon real differential rays will be evaluated correctly based upon single illumination rays.

GLOBAL COORDINATES - Global ray tracing is possible with illumination rays. See the global ray tracing description in the CMD section of this manual.

RAY DIAGNOSTICS - The "FOBDUMP" and RAYDUMP" commands described in the CMD section are available for diagnosing unexpected ray trace results for illumination rays. See the description in the CMD section of this manual.

ILLUMINATION SPOT DIAGRAMS - Illumination spot diagram ray tracing provides a means to trace a random distribution of illumination rays through the current lens system. Each ray in the distribution is aimed in a random direction with respect to the current chief illumination ray. Illumination spot diagram ray tracing is used to analyze illumination distribution properties of the current lens in its current active configuration. An "IFOB" command must be in effect before spot diagrams can be traced. Illumination spot diagram rays all have equal starting energy in the current version of the program. For the current version of the program, all reflections are assumed to be 100% efficient. There are no energy losses at refracting surfaces. These limitations will be removed in a future version of the program. Future versions will provide more control over the illumination nature of the object surface(s). Should the random number generator seed need be reset, use either the "NEWSEED" or "SEED" commands in the CMD section of the manual.

ISPD , n - The "ISPD" command causes a random distribution spot diagram to be traced from the field position defined by the last "IFOB" command. The maximum number of rays to be traced may be issued as numeric word #1. The random grid of rays is spread over a square which covers surface #1 so as to "fill" surface #1. If no clear aperture is defined on surface #1, a temporary clear aperture will be assigned just as is done with the "SPD" commands of the CMD section. The default value for numeric word #1 is 1000. "ISPD" is most useful when the object surface is far removed from surface #1 and surface #1 subtends less than 180 degrees when seen from the object surface. This command uses "IRAY CAOB" ray tracing.

ISPDA , n , ang - The "ISPDA" command causes a random distribution spot diagram to be traced from the field position defined by the last "IFOB" command. The maximum number of rays to be traced may be issued as numeric word #1. The maximum cone half-angle may be issued as numeric word #2. The default value for numeric word #1 is 1000. The cone half-angle must be explicitly input by the user. "ISPDA" is most useful when the object surface is near or "inside" surface #1 and when surface #1 subtends more than 180 degrees as seen from the object surface. This command uses "IRAYA CAOB" ray tracing.

DISPLAYING RESULTS - Illumination spot diagrams are stored in the same internal file locations as regular spots diagram results. The illumination spot diagrams may therefore be "saved" and "saved and summed" using the "SPDSAVE" and "SPDADD" commands described in the CMD section. The illumination spot diagrams and the "saved and summed" illumination spot diagrams may be graphically displayed using the " PLTSPD" command. The spot diagrams may be written to files just as can be done for non-illumination stop diagrams. This is the limit of the illumination ray tracing option in the current version of the program. These capabilities will be expanded in a later version of the program.

RAY TRACING SECTION

IMAGING - The following commands perform visualization of optical system imaging performance

COLOR (MONO or RGB) - The "COLOR" command specifies that the imagery will either be 8 bit monochrome (MONO) or 24 bit color (RGB). The wavelength used when MONO is set is the control wavelength. The wavelengths used in RGB mode are the control wavelength for Green, the first wavelength number in the secondary wavelength pair for Blue and the second wavelength in the secondary wavelength pair for Red. 8 bit data is written as 24 bit data with the R, G abd B values identical. The default color mode is MONO.

IOBJECT , X , Y , Δx , Δy - The "OBJECT" command defines a pixelated reference "Object Field of View". "X" and "Y" are the full extent dimensions of the "Object Field of View", assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength and intersecting the object surface. "Δx" and "Δy" are the "x" and "y" dimension of each pixel. All pixels are "rectangular". All values must be explicitly input. There is no dead space between pixels. If "x" and "y" are not integer divisors of "X" and "Y", "X" and "Y" will be adjusted so that they are. All "Object Plane" dimensions" are in lens units. The extents are measured from center of pixel positions.

IOBJECTN , X , Y , Nx , Ny - The "OBJECTN" command defines a pixelated reference "Object Field of View". "X" and "Y" are the full extent dimensions of the "Object Field of View", assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength. "Nx" and "Ny" are the number of pixels in the x and y-directions. All pixels are "rectangular". All values must be explicitly input. There is no dead space between pixels. All "Object Plane" dimensions" are in lens units. The extents are measured from center of pixel positions.

IOBJECTD Δx , Δy, Nx , Ny - The "IOBJECTD" command defines a pixilated reference "Object Field of View". "Δx" and "Δy" are the "x" and "y" lengths of a single pixel". The "Object Plane" is assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength. "Nx" and "Ny" are the number of pixels in the x and y-directions. All pixels are "rectangular" All values must be explicitly input. There is no dead space beteween pixels. All "Object Plane" dimensions" are in lens units.

OBJVAL (M, R, G or B) , i , j , value - The "OBJVAL" command sets the intensity value of the "i"th row and "j"th column object space to "value" where "value" ranges from 0 (zero intensity) to 255 (maximum intensity). M specifies MONO, R specifies Red, G specifies Green and B specifies Blue.

IIMAGE , X , Y , Δx , Δy - The "IMAGE" command defines a pixelated "Image Plane", "X" and "Y" are the full extent dimensions of the "Image Plane", assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength. "Δx" and "Δy" are the "x" and "y" lengths of each image plane pixel. All pixels are "rectangular". All values must be explicitly input. If "x" and "y" are not integer divisors of "X" and "Y", "X" and "Y" will be adjusted so that they are. All "Image Plane" dimensions" are in lens units. The extents are measured from center of pixel positions.

IIMAGEN , X , Y , Nx , Ny - The "IMAGEN" command defines a pixelated "Image Plane", "X" and "Y" are the full extent dimensions of the "Image Plane", assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength. "Nx" and "Ny" are the number of pixels in the x and y-directions. All pixels are "rectangular" All values must be explicitly imput. There is no dead space beteween pixels. All "Image Plane" dimensions" are in lens units. The extents are measured from center of pixel positions.

IIMAGED Δx , Δy, Nx , Ny - The "IMAGED" command defines a pixelated "Δx" and "Δy" are the "x" and "y" lengths of a single pixel". The "Image Plane" is assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength. "Nx" and "Ny" are the number of pixels in the x and y-directions. All pixels are "rectangular" All values must be explicitly imput. There is no dead space beteween pixels. All "Image Plane" dimensions" are in lens units.

IMTRACE1 - The "IMTRACE1" command causes one chief ray to be traced, at each wavelength set by the COLOR command, from each object plane pixel, through the current system, and terminating at the image plane. The image is then automatically built using the resulting "Image Plane" array. Since only chief rays are traced, only lateral chromatic aberration and distortion can be represented with this image tracing command.

IMTRACE2 - The "IMTRACE2" command is exactly like "IMTRACE1 , 1" except that an on-axis Point Spread Functions is generated (one for MONO and three for RGB mode) and are then used in the image plane, image reconstruction. The assumption is that the PSF is uniform over the field of view.

IMTRACE3 - The "IMTRACE3" command is exactly like "IMTRACE2 , 1" except that after each chief ray is traced, a diffraction based Point Spread Function is generated from the object point (one for MONO and three for RGB mode) and are then used in the image plane, image reconstruction. This is slow and should only be used when the PSF varies significantly across the field of view.

PSFTOIMG , n - The "PSFTOIMG" command causes the last Point Spread Function generated with a "PSF" command to be added to one of four storage levels in the Image Array designated by "n". "n" may be 1, 2, 3 or 4.

INTTOIMG , n - The "INTTOIMG" command causes the data saved in the INTEN.DAT file generated by an "INTEN" command to be added to one of four storage levels in the Image Array designated by "n". "n" may be 1, 2, 3 or 4.

RAY TRACING SECTION

IMSLICE (X or Y or DIAG) , offset , color # , k - The "IMSLICE" command a slice through the current Image Array to be plotted. The slice may be in the "X" or "Y" or "DIAG" direction. The offset is measurd from the bottom (X) or the left (Y) edge of the array. The offset defaults place the slice through the center of the Image Array. "DIAG" takes no user supplied offset. The offset is in pixels. Color # is the1, 2 or 3 for R, G or B. The default color # is 2. If "k" is not explicitly input, the resulting plot will be linear. I "k" is explicitly input, the plot will be log10 intensity.

LMINUSR , threshold , color # - The "LMINUSR" command plots the results of a left minus right analysis. The LEFT values are the 1 and 2 positions in the Image Array, the RIGHT values are the 3 and 4 positions. The "theshold" value (default 0.001) allows the user to elliminate small stored values. The color # is as in the IMSLICE command.

OTOBMP (filename with no extension) - The "OTOBMP" command causes the current object field of view array to be written as a bitmapped .BMP file. If the color mode is MONO, a monochromatic, 24 bit file will be created with identical R, G and B values. If the color mode is RGB, an RGB 24 bit, bitmapped file will be created. The file name will be "filename" with a BMP file extension.

ITOBMP (filename with no extension) - The "ITOBMP" command causes the current image plane array to be written as a bitmapped .BMP file. If the color mode is MONO, a monochromatic, 24 bit file will be created with identical R, G and B values. If the color mode is RGB, an RGB 24 bit, bitmapped file will be created. The file name will be "filename" with a BMP file extension.

OFROMBMP (filename with no extention) , X-extent - The "OFROMBMP" command causes the file named "filename".BMP to be read into the current object field of view array where it can be used as a source object field for image simulations. The full X-extent of the object field of view array, in current lens units in the object surface plane, is specified by "X". There is no default for "X". The dimensions of the .BMP file are used to automatically specify the Δx, Δy and full Y-extent of the object field of view array. The full extents are assumed to be measured from center of pixel positions.

IFROMBMP (filename with no extension) , X-extent - The "IFROMBMP" command causes the file named "filename".BMP to be read into the current image array. The full X-extent of the image array, in current lens units in the image surface plane, is specified by "X". There is no default for "X". The dimensions of the .BMP file are used to automatically specify the Δx, Δy and full Y-extent of the image array. The full extents are assumed to be measured from center of pixel positions.

PLTOBJ - The "PLTOBJ" command causes the object array to be plotted.

PLTIMG , trim pixels - The "PLTIMG" command causes the image array to be plotted. A non-zero value for "trim pixels" causes that many pixels to be trimmed from each edge of the image. This is used to trim off the dark edge caused by the fact that the object plane was not false padded.

BMPREADR (name of .BMP reader) - The "BMPREADER" command is used to set the name of the program bit map reader application. The current application is BMP.EXE and is provided with this program.

IMAGING DEMO - The included file "IMDEMO.DAT" contains a working demonstration of PSF imaging using the 24 bit .BMP file "PORT.BMP". "PORT.BMP" is a 320x240 RGB bitmapped image of the L. A. Airport area. Loading the demo by typing "**IN FILE IMDEMO.DAT**" causes a simple perfect (no aberrations, just diffraction effects) lens file to be loaded and stored in lens library file number 999. It then loads three macros named IMTEST1, IMTEST2 and IMTEST3 into the macro library. IMTEST1 performs perfect IMTRACE1 chief ray imaging. IMTEST2 assumes that the PSF is essentially uniform over the object field of view (as it really is) and performs IMTRACE2 imagery. IMTEST3 performs a new PSF for every 10th pixel row and column and performs IMTEST3 imagery. This is the slowest type of image reconstruction and is appropriate when aberrations are present which vary significantly over the field of view. The demo is run by typing "**IMTEST1 or IMTEST2 or IMTEST3**". The object image is first displayed to the screen. After you close this object file view, PSFs are created at each wavelength and then are convolved with the bit mapped file. This takes seconds to min on a P4 running at 2 GHz. The PSF is significantly larger than a pixel and so the resultant image is degraded, as expected. The TGR is set to 512. NRD is set to 64 and pgr is set to 91. PGR was set to 91 empirically to minimize aliasing during image reconstruction. The resultant image is then displayed to the screen. Setting the SAY value to greater than 1.0, speeds up the optical system and thus reduced the PSF size and the image degradation.

RAY TRACING SECTION

THE MULTI RAY TRACE - Multiple rays may be traced following an "FOB" command. Furthermore they may be traced from multiple FOV positions. The multiple ray trace commands generate no display. The "MFOBS" command is used to set up multiple FOV positions. The MRAYS command is used to set up multiple ray definitions. These commands populate a ray history file. They have no other purpose.

MFOBS , Y, X , n , m - If the number of FOBs to be traced ("m") is 1, then "Y" and "X" are the FOB values from which the chief ray will be traced. If the number of FOBs to be traced ("m") is greater than 1, then "Y" and "X" are the absolute values of fractional reference object heights. "n" is the wavelength number. If no entry is made for "n", the rays are traced at the control wavelength number. "m" is the dimension of an "m" x "m" array of rays extending from FOBs -X to +X and from -Y to +Y.

MRAYS (CAOB) , Y, X, n , I , m - If the number of RAYs to be traced ("m") is 1, then "Y" and "X" are the fractional reference aperture heights through which the ray will be aimed. If the number of rays to be traced ("m") is greater than 1, then "Y" and "X" are the absolute values of fractional reference surface coordinates. "n" is the wavelength number. If no entry is made for "n", the rays are traced at the control wavelength number. "I" is the starting ray intensity which may be set to any non-zero value less than or equal to 1.0. The default value for "I" is 1.0. If the reference surface has no clear aperture assigned, the actual reference ray coordinates will be calculated based upon the reference aperture height set by the paraxial ray trace. If a clear aperture has been assigned to the reference surface, the actual reference ray coordinates will be calculated based upon the fractional reference aperture height relative to the center of the clear aperture. "m" is the dimension of an "m" x "m" array of rays extending from -X to +X and from -Y to +Y. If the qualifier word "CAOB" is used, clear aperture checking is performed. Rays which fail are not added to the ray history.

MTRACE - The "MTRACE" command is used to execute a multi-ray trace.

MTRACEI , n , D , i - The "MTRACEI" command is used to execute a multi-ray trace and perform an intensity calculation at the current spot diagram surface specified by "i". By default, "i" is the final surface of the system (see the SPD command) for each FOB specified in the "MFOBS" command. "n" is the dimensionality of the 2-D intensity array centered at the spot diagram surface. "D" is the side length of the intensity map in lens units at the spot diagram surface. The intensity map is always square. Ray intensities are summed into this array. The angle of incidence (or the average when more than one ray impacts an intensity grid square, is also stored, along with its X and Y-components.

A report is also sent to the default output device. The report comprises:

FOB#, total summed intensity at surface i from that FOB, p-v intensity variation across surface, number of rays striking surface and average intensity at surface "i"

The final line reports for all FOBs:

Total summed intensity at surface "i", p-v intensity variation across surface, number of rays striking surface and average intensity at surface "i"

During the execution of the "MTRACEI" command, all ray aiming and differential ray tracing is temporarily turned "off".

THE SCREEN SURFACE

SCREEN (YES or ON or NO or OFF) , i , d , h , s , ang - A screen surface comprises a surface property which diminished the intensity of the radiation passing through that surface. It acts in a manner similar to an opaque plate with many small circular holes drilled in it on a uniform rectangular grid. "i" specifies which surface the screen will be attached to. "d" is the hole diameter. "h" is the screen's plate thickness. "s" is the x and y-hole spacing on an assumed rectangular grid. The default qualifier word is "ON". "SCREEN" issued with a "?" will return the "SCREEN" setting for the current lens prescription. The screen surface is not zoomable.

Rays are not blocked by the screen surface but the ray intensity of a group of rays representing a beam of light will be reduced by the following factor:

$$\text{Intensity} - \text{Reduction} = \frac{\pi\left(\dfrac{d}{2} - h\sin(\text{AOI})\right)\left(\dfrac{d}{2}\cos(\text{AOI}) - h\sin(\text{AOI})\right)}{s^2\cos(\text{AOI})}$$

AOI is the angle of incidence of each ray striking the screen. If AOI is 90 degrees, the Intensity-Reduction factor is 0.0. If the reduction factor goes negative. it is automatically set to 0.0. Near field diffraction is ignored. This is a slightly approximate representation of the true Intensity-Reduction factor but it avoids the necessity of performing a slow elliptical integral! "ang" is the angle of incidence beyond which nothing gets through the screen and relates to other screen geometry.

RAY TRACING SECTION

RAY HISTORIES

RHIST (YES or **ON** or **NO** or **OFF** or **WRITE** or **SWRITE)** - The "RHIST" command is used to turn ray history saving "on" ("YES" or "ON") or "off" ("NO" or "OFF") The default is "off". All ray data and differential ray data for all individual rays traced using the "MRAYS" command is saved for all surfaces. The qualifier word "WRITE" causes all this saved ray data to be written to a file named RAYHIST.DAT". One header line with the total number of rays in I10 format followed by the total number of surfaces in I4 format followed by the total number of field of view positions in I10 format. The header line is then followed (number of rays)x(number of the final surface+1) number of lines, each holding the following 93 data items:

Surface #

Sequential Ray #

1. Local X-coordinate
2. Local Y-coordinate
3. Local Z-coordinate
4. Local L-Direction Cosine after interaction
5. Local M-Direction Cosine after interaction
6. Local N-Direction Cosine after interaction
7. Optical Path Length from surface I-1 to surface I
8. Physical length from surface I-1 to surface I
9. Cosine of angle of incidence
10. Cosine of Angle of reflection, refraction or diffraction
11. Marginal XZ-slope angle (radians)
12. Marginal YZ-slope angle (radians)
13. Surface normal L-dircos
14. Surface normal M-dircos
15. Surface normal N-dircos
16. Local X-coordinate before interaction
17. Local Y-coordinate before interaction
18. Local Z-coordinate before interaction
19. Local L-Direction Cosine before interaction
20. Local M-Direction Cosine before interaction
21. Local N-Direction Cosine before interaction
22. Optical Path Length fron NEWOBJ surface to surface I
23. 1 for non-RV ray, -1 for RV ray (direction of ray)
24. 1 for POSRAY, -1 for not POSRAY (object distance negative)
25. Ray energy term
26. Local XL-Direction Cosine after interaction
27. Local XM-Direction Cosine after interaction
28. Local XN-Direction Cosine after interaction
29. Local YL-Direction Cosine after interaction
30. Local YM-Direction Cosine after interaction
31. Local YN-Direction Cosine after interaction
32. (NOT USED ALL ZERO)
33. (NOT USED ALL ZERO)
34. Polarization Parallel Modulus
35. Polarization Perpendicular Modulus
36. Polarization Parallel Phase
37. Polarization Perpendicular Phase
38. Polarization angle in degrees between Y-ray vector and the parallel plane
39. - 50. (NOT USED ALL ZERO)
51. XZ-plane X-coordinate chief differential trace
52. XZ-plane Y-coordinate chief differential trace
53. XZ-plane Z-coordinate chief differential trace
54. XZ-plane L-dircos chief differential trace (after interaction)
55. XZ-plane M-dircos chief differential trace (after interaction)
56. XZ-plane N-dircos chief differential trace (after interaction)
57. YZ-plane X-coordinate chief differential trace
58. YZ-plane Y-coordinate chief differential trace
59. YZ-plane Z-coordinate chief differential trace
60. YZ-plane L-dircos chief differential trace (after interaction)
61. YZ-plane M-dircos chief differential trace (after interaction)
62. YZ-plane N-dircos chief differential trace (after interaction)
63. XZ-plane L-dircos chief differential trace (before interaction)

64. XZ-plane M-dircos chief differential trace (before interaction)
65. XZ-plane N-dircos chief differential trace (before interaction)
66. YZ-plane L-dircos chief differential trace (before interaction)
67. YZ-plane M-dircos chief differential trace (before interaction)
68. YZ-plane N-dircos chief differential trace (before interaction)
69. XZ-plane X-coordinate marginal differential trace
70. XZ-plane Y-coordinate marginal differential trace
71. XZ-plane Z-coordinate marginal differential trace
72. XZ-plane L-dircos marginal differential trace (after interaction)
73. XZ-plane M-dircos marginal differential trace (after interaction)
74. XZ-plane N-dircos marginal differential trace (after interaction)
75. YZ-plane X-coordinate marginal differential trace
76. YZ-plane Y-coordinate marginal differential trace
77. YZ-plane Z-coordinate marginal differential trace
78. YZ-plane L-dircos marginal differential trace (after interaction)
79. YZ-plane M-dircos marginal differential trace (after interaction)
80. YZ-plane N-dircos marginal differential trace (after interaction)
81. YZ-plane L-dircos marginal differential trace (before interaction)
82. YZ-plane M-dircos marginal differential trace (before interaction)
83. YZ-plane N-dircos marginal differential trace (before interaction)
84. XZ-plane L-dircos marginal differential trace (before interaction)
85. XZ-plane M-dircos marginal differential trace (before interaction)
86. XZ-plane N-dircos marginal differential trace (before interaction)
87. X-coordinate of cheif ray at object surface
88. Y-coordinate of cheif ray at object surface
89. XZ-slope angle, in radians, of the chief ray at the object surface
90. YZ-slope angle, in radians, of the chief ray at the object surface
91. Sequential number of the chief ray (from 1 to the maximum number of chief rays)
92. RAYCOD(1) (Ray failure code, 0 = no fail)
93. RAYCOD(2) (Surface where ray stopped)
The qualifier word "SWRITE" causes a subset this saved ray data to be written to a file named RAYHIST.DAT. One header line with the total number of rays in I10 format followed by the total number of surfaces in I4 format followed by the total number of field of view positions in I10 format. The header line is then followed (number of rays)x(number of the final surface+1) number of lines, each holding the following 14 data items:
Surface #
Sequential Ray #
1. Local X-coordinate
2. Local Y-coordinate
3. Local Z-coordinate
4. Angle of Incidence
5. Ray Energy Term
6. X-component of the Angle of Incidence
7. Y-component of the Angle of Incidence
8. X-coordinate of cheif ray at object surface
9. Y-coordinate of cheif ray at object surface
10. XZ-slope angle, in radians, of the chief ray at the object surface
11. YZ-slope angle, in radians, of the chief ray at the object surface
12. Sequential number of the chief ray (from 1 to the maximum number of chief rays)
13. RAYCOD(1) (Ray failure code, 0 = no fail)
14. RAYCOD(2) (Surface where ray stopped)
INTENSITY - The following command provides a way to generate a surface intensity file INTEN.DAT from the RAYHIST.DAT file
INTEN , i , n , D - The "INTEN" command is used to generate a program internal intensity map for surface "i" from the current RAYHIST.DAT file when it is written as a "short" ray history file using the "SWRITE" qualifier of the "RHIST" command and a SCENE.DAT scene file if one exists. The scene file is an ascii file which is used to assign a ray intensity multiplicative factor to each ray intensity value, based upon the FOB position of the starting multi-ray ray trace on the object surface. The format of the scene file is:
# of FOB positions (must match the number of FOB positions stored in the short RAYHIST.DAT file)
multiplicative factor for FOB #1
multiplicative factor for FOB #2

RAY TRACING SECTION

multiplicative factor for the last FOB

FOB #1 is the FOB with the most negative X and Y-FOB values. **Be carefull to remember whether "FANG" was set in the "SCY" and "SCX" reference object specification commands.**

FOB #2 is the FOB with the most negative Y-FOB value but with a lesser X-FOB value than FOB #1

The next to last FOB has the most positive Y-FOB value but a less positive X-FOB value than the last FOB value

The last FOB has the most positive X-FOB and Y-FOB values. The SCENE.DAT file is read as free format. If no SCENE.DAT file exists, a uniform scene with all multiplicative factors = 1.0 is assumed. "n" is the dimension of the 2-D intensity array. "D" is the side length of the intensity map in lens units. The intensity map is always square. The map is assumed to be centered at the local coordinate origin of the specified surface. Ray intensities, multipled by the cosine of the angle of incidence are then summed into this array. If a SCENE.DAT file exists, then the appropriate scene multiplicative factor, based upon the FOB of the current ray, will be multiplied into the intensity. The angle of incidence (or the average when more than one ray impacts an intensity grid square, is also stored, along with its X and Y-components. After the short RAYHIST.DAT file is processed, the following data is written to the ASCII file INTEN.DAT. The lower left hand corner (X=-D/2,Y=-D/2) of the array is designated by the indecies 1,1, the upper right corner (X=D/2), Y=(D/2) of the array is designated by the indecies n,n. The INTEN.DAT file comprises a header line followed by nxn entries of the form x-index , y-index , summed intensity, angle of incidence (or average of angles of incidence), X-component angle of incidence (or average of X-components of the angles of incidence), Y-component angle of incidence (or average of Y-components of the angles of incidence).

INTEN.DAT file sample follows:

i , n , D

1 , 1 , summed intensities, raw summed AOIs, raw summed X-AOIs, averaged intensity, averaged AOI, averaged X-AOI, averaged Y-AOI

1 , 2 , summed intensities, raw summed AOIs, raw summed X-AOIs averaged intensity, averaged AOI, averaged X-AOI, averaged Y-AOI

.

.

n , n , summed intensities, raw summed AOIs, raw summed X-AOIs, averaged intensity, averaged AOI, averaged X-AOI, averaged Y-AOI

The "INTEN" command also writes a file named RHFOOT.DAT to enable "footprint" type plots to be generated for the INTEN surface "i".

A report is also sent to the default output device. the report comprises:

FOB#, total summed intensity at surface i from that FOB, p-v intensity variation across surface, rms intensity variation across surface, number of rays stricking surface

The final line reports for all FOBs:

total summed intensity at surface i , p-v intensity variation across surface, rms intensity variation across surface, number of rays stricking surface

PLOT RHFOOT   - The "PLOT RHFOOT" command causes a ray footprint plot to be generated from the current RHFOOT.DAT command. It assumes the surface is being viewed along its surface normal, so if the clear aperture is to be drawn, the "ORIENT , i , 1" command should be issued.

MACRO LANGUAGE SECTION

MACROS-INTRODUCTION - The macro processor is a powerful and useful built-in programming language feature which provides a means of programming any of the many program commands into macros and/or macro functions. Each macro can be given its own user-specified name. After creation, a macro or macro function is executed exactly as any program command by entering its name on the command line and pressing enter. Up to 999 macros may be defined and stored in an easy-to-use macro library. Of these 999 possible macros, 10 may be defined as macro functions. Each macro or macro function may consist of up to 1024 lines, including comments and the end-of-macro instruction "EOM". Each macro or macro function line may contain any program command, any pre-existing macro name or pre-existing macro function name as well as a host of macro processor specific commands . Macros may call other macros in nests up to 20 macros deep without loss of stored data.

THE MACRO DIRECTORY - All user-created macros are stored (by default) in the directory LIBMAC which resides just below the directory containing the PRG.EXE file. The macro directory file (not to be confused with an operating system disk directory) is the file named MAC.DAT. The macro body records comprising each macro and macro function are contained in up to 999 files with names which range from MAC001.DAT to MAC999.DAT. Whenever a macro name is input as a program command from the CMD level, the appropriate macro is loaded into memory from the macro directory file and then its component commands are executed. Macros are stored in a pre-parsed, semi-compiled format which enhances speed of execution.

MACRO DIRECTORY INITIALIZATION - Don't use these two next commands if you already have macros unless you want to destroy them! The MACRO library directory file MAC.DAT can be created new by entering the CMD level command:

IMF - This command followed by the "PROCEED" command will erase all existing macros, so use them only when establishing a new macro library. To avoid accidental destruction of the existing MACRO library, the "IMF" command performs no file initialization unless it is followed immediately by the "PROCEED" command.

PROCEED - If the CMD level command "PROCEED" is not immediately entered following the "IMF" command, then the "IMF" command is ignored and canceled. THIS INITIALIZATION PROCEDURE SHOULD BE USED WITH EXTREME CAUTION AS LARGE AMOUNTS OF DATA MAY BE LOST IF IT IS USED CARELESSLY. The "IMF" command is intended for a user who has no macro directory file or for a user who intentionally desires to clean the slate and begin anew with an empty macro directory file. It is also used by the program when establishing alternate macro directory files in other disk directories. The following pair of commands will erase all existing macros and flush the macro directory. Use them with caution.

IMF
PROCEED

ALTERNATE MACRO DIRECTORIES - The user may create and use alternate macro directories using the CMD level commands "MACDIR" or "CHGMAC". These commands are also described here and in the CMD section of the manual.

MACDIR or CHGMAC , (qualifier word)   - By default when the program begins execution, the macro library is located in the directory LIBMAC which sits just below the directory into which the main program was installed and from which the main program runs. The "MACDIR" command is used to change the current macro library directory to the directory named by the first six characters of the "qualifier word". If this directory exists, then only the internal program pointer, pointing to the macro library directory, is changed. If the directory does not yet exist, it is created. After creation of a new macro library directory, a new macro library must be initialized in this new directory via the "IMF" and "PROCEED" commands. The "MACDIR" command makes it possible to have access to as many macro libraries as desired, only limited by available disk space. If "MACDIR" is issued followed by a "?", the name of the current macro library directory will be displayed. The new directory name designated by the "qualifier word" must contain exactly six non-blank characters.

PERMANENT MACROS - Permanent macros are provided with the program and stored in the PERMAC directory. In order to list, edit, create or delete a permanent macro, change to the PERMAC directory, perform the macro operation and then, return to the default macro library directory. The example below, shows how to load the manufacturers lens librarys after the program is first installed. To run a permanent macro, simply issue the macro name. The program automatically searches the permanent macro library if the macro name issued is not in the current macro directory.

LODLENS

MACRO FUNCTIONS - Macro functions are very much like ordinary macros in that they are created, filed and executed just like macros. For a macro to be a macro function, it must be named either "FUN01", "FUN02", "FUN03", "FUN04", "FUN05", "FUN06", "FUN07", "FUN08", "FUN09","FUN10". A macro with one of these 10 reserved names is not only stored on disk as a regular macro but also kept in live computer memory while the program runs. When one of these macro functions is to be executed, it will be executed "from memory". The process of looking the macro up in the file "MAC.DAT" and then loading the macro from disk to memory is avoided. Macro functions execute many times faster than ordinary macros. This is why they are used in some types of optimization, tolerancing and special surface shape definition. For the rest of this section, macros and macro functions will be referred to simply as macros. When the program first begins to execute, a search of the macro directory file is performed. If there are macros with the reserved macro function names in the macro directory file, they are loaded into memory. If these functions are modified or deleted during program execution using the macro directory file manipulation commands, the macro function memory areas and the macro directory file are modified appropriately.

MACRO LANGUAGE SECTION

NEW PROGRAM COMMANDS - After creation and filing, a macro may be used just as a program command is used. The specific form may vary, but the general form is identical to the command input forms described in the INTRO SECTION. The exception is that no explicit provision is made for recognition of the interrogator symbol " ? ".

MACRO INVOCATION LINE - The program command line into which is typed a macro name in order to execute that macro will henceforth be known as the macro invocation line. **ON THE MACRO INVOCATION LINE ONLY, IF A STRING IS TO BE INPUT, IT MUST BE PECEEDED BY A COLON (:) SO IF THE STRING RTG IS TO BE INPUT AS A STRING, IT MUST BE INPUT AS :RTG. THIS IS THE ONLY PLACE IN THE PROGRAM WHERE A STRING MUST BE PRECEEDED BY A COLON.**

ELEMENTS OF A MACRO - A macro consists of the following elements:

MACRO HEADER - The "MACRO" command followed by a unique user defined name up to 8 characters long is known as the macro header.

BODY OF THE MACRO - The body of a macro may contain any combination of the regular program commands as well as special macro processing commands which will be described later in this section. Essentially any program command which may be issued from the keyboard may be included in the body of a macro. All commands within the macro body are processed sequentially unless special branching commands occur which change that sequential order.

MACRO PROCESSING COMMANDS - Commands which are valid only inside a macro and which act to modify the execution of a macro may be included in a macro. These commands may modify the order of macro execution, may allow external or internal data transfer and may turn on or off the macro execution tracing and single step execution features.

END OF MACRO - The last line in every macro must be "EOM" which stands for "End Of Macro".

MACRO EXAMPLES - For the impatient, here ere two sample macros, one simple, one not so simple. More examples or fragments of samples will be found later in this section.

First, a simple macro. It is just a series of program commands which will execute sequentially. It is used to display both the final surface, paraxial marginal ray height in the YZ-plane and also the EFL, BFL and FFL of the current lens. These commands may be typed into the command line one at a time if desired. A simpler macro editing and macro creation tool will be discussed in a page or two.

MACRO GETPY	(initializes the macro)
SHO PY	(move the marginal paraxial ray height value, PY, at the final surface of the current lens to the X-register and displays it)
FIRD	(display the EFL, BFL and FFL for the current lens)
EOM	(End Of Macro line)

The next macro is a modification of part of the first macro. It allows the user to input the surface number for which the marginal and chief ray heights are to be displayed. If no surface number is issued as the first numeric word of the macro invocation line, then final surface values will be displayed.

MACRO GETPYPCY	(initialize the macro)
NSUB DV –10,,,,,	(set the default value of the first numeric word to –10)
NSUB 0 1	(move the first numeric word of the macro invocation line into the X-register a.k.a "the accumulator")
BNEG A1	(if the X-register is negative, branch to the branch point A1)
BRU A2	(branch unconditionally to branch point A2)
BP A1	(branch point A1)
GET ISN	(get the image surface number and put it into the X-register)
BP A2	(branch point A2)
NSUB 1 0	(move the value in the X-register into the first numeric word of the next command)
SHO PY	(show the PY value at the surface number designated by the first numeric word)
NSUB 1 0	(move the value in the X-register into the first numeric word of the next command)
SHO PCY	(show the PCY value at the surface number designated by the first numeric word)
EOM	(End Of Macro line)

MACRO LANGUAGE SECTION

MACRO CREATION - As mentioned before, a macro can be created by simple typing it in, one line at a time at the program command prompt. If you do this, it is important to understand what the "MACRO" and "EOM" commands do. Here are the definitions but don't worry about them too much because the next method of macro creation takes care of these two commands automatically.

MACRO (macro name) - The "macro name" should not duplicate the name of a CMD level or macro processor command since all program input commands are always checked against a program command vocabulary list prior to checking against the macro name directory. A macro with the same name as a program command, therefore, can never be executed. The "MACRO" command causes the program to be shifted to the MACRO creation level from the CMD level.

ENDING MACRO CREATION - As mentioned before, termination of macro creation is performed with the command:

EOM - The "EOM" command terminates macro creation. If there are macro lines present in memory, the macro is filed in the macro directory file. If no macro lines are present in memory, no macro is filed. The program then returns to the CMD level.

MACRO NAME RULES - Each macro must have a unique name. Macros with identical names are not allowed. A previous macro of the same name is automatically deleted before the new same-named macro is created.

MACRO DELETION - A macro may be explicitly deleted from the macro directory file with the command:

MDEL (macro name) - If the named macro is not found in the macro directory file, a message to that effect is issued and the command is ignored. "MDEL" may be issued as a command from within a macro and; therefore, a macro may be written which executes and then deletes itself! I personally think that is pretty cool!

MACRO EDITING METHODS - Macro editing/creation may be performed in two distinctly different ways. The first way is implemented using the "LMEDIT" command and its associated built-in line oriented editor. This method will be discussed at the end of this macro section. It was the original macro editor before full screen editing was available. (Remember DOS?). It is not of much use now but it has been left in the program for use by users who learned this early edit method and who like the pain it produces in their head. The second and best method is a full screen edit mode. The user simply uses the "MEDIT" command described below.

MEDIT (macro name) - The "MEDIT" command can be used either to initiate editing of an existing macro or to create a new macro in the full screen macro-edit (medit) mode. If a macro with the name (macro name) exists, it is automatically sent to the macro full screen editor. If the macro does not exist, and empty macro with the specified name is opened with the program full screen editor. When the full screen editor is closed, the edited macro is read back into the macro directory before the next command is executed in the main program. It may then be listed or executed. After entering the full screen mode, any commands may be placed between the macro header line (the one that starts with the word MACRO) and the "EOM" command. In the full screen mode, a HELP menu is available which opens this MACRO manual section as a PDF file.
NOTE: This command may also be issued via the main program GUI interface menu system.

MREFRESH - The "MREFRESH" command can be issued from the CMD level during full screen macro editing. It moves the latest version of the existing macro, from the full screen editor's buffer into the current macro file directory. The macro may then be listed or executed.
NOTE: This command may also be issued via the main program GUI interface menu system.

MACRO DIRECTORY STATUS - The status and contents of the macro directory file may be interrogated by entering one or more of the following commands from the program CMD level:
NOTE: These commands may also be issued via the main program GUI interface menu system.

LIST ALL MACROS

MFL - The "MFL" command causes all macros to be displayed in their entirety.

LIST ALL MACRO NAMES

MFLN - The "MFLN" command causes a condensed listing of the names, creation times and dates and the first 40 characters of each macro's first comment line.

LIST A SPECIFIC MACRO

MFL (macro name) - This version of the "MFL" command causes all lines comprising the named macro to be listed. If no name is included, all the macros are listed. That mode is useful when outputting all macros to a disk file for backup.

LIST MACRO COMMENTS

MFLC (macro name) - The "MFLC" command causes all leading comment lines of the named macro to be listed.

MSTAT - The "MSTAT" command generates a message indicating the number of macros currently on file and the remaining number of empty spaces in the macro directory file. The "MFLN" and "MSTAT" commands are combined into one menu item.

MACRO PROCESSING COMMANDS - Besides being allowed to put almost every program command into a macro, there are special macro processing commands available. These commands can, among other things, control the sequence in which a macro executes.

INDEXING COMMANDS - In order to facilitate the construction of loops and to assist in the transfer of sequenced items of data, six index storage registers are provided. These registers are named "I", "J","K", "L", "M" and"N". Their specific use is discussed in the section on conditional branching commands. Associated with these registers are the test values "ITEST", "JTEST", "KTEST", "LTEST", "MTEST" and "NTEST". The values in these test registers are used in connection with the specific branching commands which test the contents of the index registers "I", "J","K", "L", "M" and "N". The index registers and the test registers are initialized to zero at the start of program execution. Only one register name at a time can be used with the "SET" command.

SET (I, J, K, L, M, N, ITEST, JTEST, KTEST, LTEST, MTEST or NTEST) , i - This version of the "SET" command causes the register named by the qualifier word ("I", "J","K", "L", "M", "N", "ITEST", "JTEST", "KTEST", "LTEST", "MTEST" or "NTEST") to be set to the value of "i". The numeric value can be positive or negative and is stored as a double precision. There is a short cut to setting these registers. Enter the register name with an equal sign appended, a space or comma (necessary) and the numerical value to which the register is to be set.

Example: **SET ITEST, 25.4 (or) ITEST= 25.4 sets the ITEST register to 25.4**

MOVE (I, J, K, L, M, N, ITEST, JTEST, KTEST, LTEST, MTEST or NTEST) - The "MOVE" command "moves" the numeric value stored in the register indicated by the qualifier word ("I", "J","K", "L", "M", "N", "ITEST", "JTEST", "KTEST", "LTEST", "MTEST" or "NTEST") into the accumulator register. ("MOVE" generally moves a value to the accumulator which is also called the X-register). "MOVE" may be used with all named registers as well as these "test" registers.

Example: **MOVE ITEST moves the value in the ITEST into the X-register**

STORE (I, J, K, L, M, N, ITEST, JTEST, KTEST, LTEST, MTEST or NTEST) - The "STORE" command causes the number in the accumulator to be stored in the register indicated by the qualifier word ("I", "J","K", "L", "M", "N", "ITEST", "JTEST", "KTEST", "LTEST", "MTEST" or "NTEST"). "STORE" may be used with all named registers.

Example: **STORE ITEST sets the ITEST to whatever value is currently in the X-register.**

INCR (I, J, K, L, M or N) , i - The "INCR" command causes the value in the indicated index register "I", "J","K", "L", "M" or "N") to be incremented by "i", a numeric value which may be positive or negative. If a numeric value is not specified, the default numeric value of 1.0 is used. "INCR" can be used with all named registers.

Example: **INCR I, .5 increments the value in the I register by 0.5**

BRANCHING COMMANDS - Branching commands are used to select alternative sequences of command processing within a macro. Branching commands may appear anywhere within a macro. These branching commands are not quire the "IF-THEN-ELSE-ENDIF" of FORTRAN but their low level nature makes them extremely flexible.

BP (branch point name) - The "BP" command defines a branch point having the name "branch point name". The branch point name is entered as a qualifier word. A branch point serves only as a marker and may appear anywhere within a macro. Branch commands refer to a branch point by name indicating that if the branch is taken, the next command processed is the command immediately following the named branch point. (This is similar to a LABEL in a programmable calculator program.) Branch point names must begin with one of the 26 characters of the alphabet and may not exceed eight alphanumeric characters in length.

BRQ (branch point name) , (test name) - The "BRQ" command specifies that if the current qualifier word of the macro (the qualifier word used in the macro invocation line or the qualifier as defined by the "QSUB DV" command) matches the indicated name test name, then the next command to be processed is the command immediately following the branch point named "branch point name". If no match exists, the "BRQ" command results in no action and macro processing continues sequentially.

MACRO LANGUAGE SECTION

ABOUT LINE COUNTS "lc" - In the branching commands which follow, a numeric line count, or "lc", may be used. If a non-zero "lc" has been entered, it is used instead of the branch point name to determine the location of the next command to be processed when branching takes place. If no entry is made for "lc", then the branch point named "branch point name" is used and the macro is searched for "BP branch point name". The line count "lc" may be positive or negative. It specifies the position of the next command to be processed relative to the position of the branch command when branching takes place. A value of "lc" = -9 indicates a branch to a command which is nine commands back from the branch command. The use of "lc" reduces the need for branch points but makes a macro harder to read. Avoid the use of "lc" unless there is no choice. "lc" is intended for use with macros written using HEXAGON, the old Hughes Aircraft Co. program.

BRERR (branch point name) , lc - The "BRERR" command, which stands for Branch on Read ERRor, causes branching to "BP branch point name" if the read error flag has been set. The read error flag is set by an unsuccessful execution of the "ATON" CMD level command. The "ATON" command is used to attempt to convert the first 23 characters read by the CMD level "PREAD" command into a numeric value. After the branching occurs, the read error flag is cleared.

BPOS (branch point name) , lc or **IF(X>0) (branch point name) , lc** - The "BPOS" or "IF(X>0)"command causes branching to "BP branch point name" if the value in the accumulator ("X"-register) is positive.

BNEG (branch point name) , lc or **IF(X<0) (branch point name) , lc** - The "BNEG" or "IF(X<0)"command causes branching to "BP branch point name" if the value in the accumulator is negative.

BZE (branch point name) , lc or **IF(X=0) (branch point name) , lc** - The "BZE" or "IF(X=0)" command causes branching to "BP branch point name" if the value in the accumulator is zero.

IF(X=Y) (branch point name) , lc - The "IF(X=Y)" command causes branching to "BP branch point name" if the value in the X-register is equal to the value in the Y-register.

IF(X>Y) (branch point name) , lc - The "IF(X>Y)"command causes branching to "BP branch point name" if the value in the X-register is greater than the value in the Y-register.

IF(X<Y) (branch point name) , lc - The "IF(X<Y)"command causes branching to "BP branch point name" if the value in the X-register is less than the value in the Y-register.

BRI (branch point name) , lc - The "BRI" command causes branching to "BP branch point name" if index register "I" equals "ITEST".

BRJ (branch point name) , lc - The "BRJ" command causes branching to "BP branch point name" if index register "J" equals "JTEST".

BRK (branch point name) , lc - The "BRK" command causes branching to "BP branch point name" if index register "K" equals "KTEST".

BRL (branch point name) , lc - The "BRL" command causes branching to "BP branch point name" if index register "L" equals "LTEST".

BRM (branch point name) , lc - The "BRM" command causes branching to "BP branch point name" if index register "M" equals "MTEST".

BRN (branch point name) , lc - The "BRN" command causes branching to "BP branch point name" if index register "N" equals "NTEST".

BRDQ (branch point name) , lc - The "BRDQ" command causes branching to "BP branch point name" if the qualifier in the macro invocation line was not explicitly entered or provided with a "QSUB" command.

BRDF1 (branch point name) , lc - The "BRDF1" command causes branching to "BP branch point name" if the numeric word #1 in the macro invocation line was not explicitly entered or provided with an "NSUB DV" command.

BRDF2 (branch point name) , lc - The "BRDF2" command causes branching to "BP branch point name" if the numeric word #2 in the macro invocation line was not explicitly entered or provided with an "NSUB DV" command.

BRDF3 (branch point name) , lc - The "BRDF3" command causes branching to "BP branch point name" if the numeric word #3 in the macro invocation line was not explicitly entered or provided with an "NSUB DV" command.

BRDF4 (branch point name) , lc - The "BRDF4" command causes branching to "BP branch point name" if the numeric word #4 in the macro invocation line was not explicitly entered or provided with an "NSUB DV" command.

BRDF5 (branch point name) , lc - The "BRDF5" command causes branching to "BP branch point name" if the numeric word #5 in the macro invocation line was not explicitly entered or provided with an "NSUB DV" command.

BRU (branch point name) , lc - The "BRU" command causes branching unconditionally to "BP branch point name".

BRANCH (branch point name) , i , j , lc - The "BRANCH" command causes branching to "BP branch point name" if "i"th numeric word in the macro invocation line has the value "j". If no branch point name is given and "lc" is non-zero, then a jump of "lc" lines is performed.

FLAGS IN BRANCHING - Up to 20 user flags may be set, tested and cleared. Setting and clearing of these flags is covered in the CMD section of this manual. Two commands can be used to test the value of up to five of these flags at any one time. If f_i is positive, then flag f_i satisfies the test if flag f_i is set on. If f_i is negative, then flag f_i satisfies the test if flag f_i is set off.

BRT (branch point name), f1 , f2 , f3 , f4 , f5 - The "BRT" command causes branching to "BP branch point name" only if all specified flags test on.

BRF (branch point name), f1 , f2 , f3 , f4 , f5 - The "BRF" command causes branching to "BP branch point name" if not all specified flags test on.

FLAG EXAMPLES - If flags 2, 4 and 5 are set "off" and 1 and 3 are "on", then **"BRT ABC , 1 , 3**" will cause branching to branch point ABC and **"BRF DEF , 2 , 4 , 5"** will cause branching to branch point DEF.

TERMINATION OF EXECUTION

RETURN - The "RETURN" command terminates a macro's execution and passes control back to the calling macro if there was one. Macro execution also terminates if the bottom of the macro "EOM" is reached and the preceding command is not a branch command.

EXTERNAL DATA TRANSFER - The following commands are external data transfer commands. External data transfer commands are used to transfer data from the macro invocation line directly into a normal program command line contained within that macro. External data transfer commands are also used to transfer data to and from the accumulator or X-register. The following external data transfer commands modify the next normal program command encountered after the data transfer command is encountered. Up to ten data transfer commands may precede a normal program command to be modified.

CSUB - The "CSUB" command replaces the command word of the command to be modified with either the qualifier word issued in the macro invocation line or the qualifier word supplied with a "QSUB DV" command.

QSUB - The "QSUB" command replaces the qualifier word of the command to be modified with either the qualifier word issued in the macro invocation line or the qualifier word supplied with a "QSUB DV" command.

QRSUB - The "QRSUB" command replaces the qualifier word of the command to be modified with the first eight characters of the last string read by a prompted read via the "PREAD" command described in the CMD section of this manual.

SSUB - The "SSUB" command replaces the alphanumeric string of the command to be modified with the alphanumeric string issued in the macro invocation line or the alphanumeric string supplied with an "SSUB DV" command.

CRSUB - The "CRSUB" command replaces the command word of the command to be modified with the first eight characters of the last string read by a prompted read via the "PREAD" command described in the CMD section of this manual.

DEFAULT INPUT DATA

QSUB DV (default qualifier word value)) - The "QSUB DV" command is used to set a non-blank default value for the qualifier word of the macro invocation line. This default value is used only when the macro invocation line contains no qualifier word.

SSUB DV (default alphanumeric string word value)) - The "SSUB DV" command is used to set a non-blank default value for the alphanumeric string word of the macro invocation line. This default value is used only when the macro invocation line contains no alphanumeric string input word.

ACCSUB (register name) , i - The "ACCSUB" command will substitute the named register for the accumulator during the subsequent "i" valid program commands. The accumulator will remain unchanged, and operations which normally operate upon the accumulator will operate upon the named register. All arithmetic processing commands and "STORE", "CSUB", "QSUB", "PUTR" and "WRITE" are valid for "ACCSUB". If a command invalid for accumulator substitution is encountered, it is processed without the substitution. If "i" is not specified, the default value is taken to be 1.0 .

MACRO LANGUAGE SECTION

NUMERIC DATA TRANSFER - The following external data transfer commands modify numeric entries. In all cases the first numeric word is the location where the value goes "to" and the second numeric word is the location where the value comes "from". Remember, "TO" and "FROM",

NSUB , j , k , A , B, C - The "NSUB" command causes the numeric value of numeric word "j" of the command to be modified to be replaced by:

$$(A \times vk + B) ** C$$

where "vk" is the numeric value of numeric word "k" of the macro invocation line. Both j and k are restricted to values 0, 1, 2, 3, 4 or 5. 0 refers to the accumulator or X-register. Default values are:

$$A = 1.0$$
$$B = 0.0$$
$$C = 1.0$$

NSUB RA , j , k , l, B, C - The "NSUB RA" command is equivalent to the "NSUB, j , k , A , B , C" command, except that the numeric value of numeric word "l" (lower case L, not 1) of the macro invocation line is used as the multiplicative constant, "A".

NSUB RB , j, k , A , m, C - The "NSUB RB" command is equivalent to the "NSUB, j , k , A , B , C" command, except that the numeric value of numeric word "m" of the macro invocation line is used as the additive constant, "B".

NSUB RC, j , k , A , B , n - The "NSUB RC" command is equivalent to the "NSUB , j , k , A , B, C" command, except that the numeric value of numeric word "n" of the macro invocation line is used as the power constant, "C".

NSUB RAB, j , k , l , m , C
NSUB RAC , j , k , l , B , n
NSUB RBC , j , k , A , m , n
NSUB RABC , j , k , l , m , n - These commands are combinations of the "RA", "RB" and "RC" NSUB commands.

DEFAULT NUMERIC VALUES

NSUB DV, NW1, NW2, NW3, NW4, NW5 - The "NSUB DV" command is used to set default values for the five numeric words of the macro invocation command. They are used to replace values of the numeric words left default or blank on the macro invocation line.
NOTES:
1. In all numeric data transfer commands, the second numeric value in any "NSUB" command (except "NSUB DV") is the address in the macro invocation line from which the value to be transferred is to be found.
2. In all numeric data transfer commands, the first numeric value in any "NSUB" command (except "NSUB DV") is the address in the next non-NSUB command to which the value to be transferred will be transferred.
3. In any "NSUB" command, a zero for numeric word j or k always means the accumulator. j = 0 causes transfer into the accumulator register; k = 0 causes transfer from the accumulator register. This is the ONLY case where an "NSUB" command does not modify another command.

OTHER DATA TRANSFERS

MOVE NW , i - The "MOVE NW" command is a special case of the "MOVE" command described in the arithmetic processor command section of the CMD section of this manual. The numeric value of the "i" th numeric word of the macro invocation line is moved into the accumulator. If "i" is zero, the value stored in the index register "I" is used in place of "i". If the integer value of the "I" register is equal to 0.0 or is greater than 5.0, then the integer value of the first numeric word is moved into the accumulator.

MACRO LANGUAGE SECTION

PUTR (register name) , i - The "PUTR" command causes the numeric value of numeric word "i" of the macro invocation line to be replaced by the value of the number in the named register. If "i" is zero, value of the index register "I" is used in place of "i". If the value of the "I" register is equal to 0 or if it is greater than 5, then the value stored in the named register is moved into the first numeric word of the macro invocation line.

NESTING MOVE WITH NSUB - The "MOVE" command may be nested with "NSUB" commands when NSUBing from the accumulator.
Example:

>   SET A 3
>   SET B 4
>   SET C 5
>   MOVE C
>   NSUB 1 0
>   MOVE A
>   NSUB 2 0
>   MOVE B
>   NSUB 3 0
>   FOB

is identical to issuing the command

>   FOB 5 , 3 , 4

The first three commands store 3, 4 and 5 into the registers A, B and C. **"MOVE C"** moves 5 to the accumulator. **"NSUB 1 0"** moves the accumulator value into the first numeric word of **"FOB"** . **"MOVE A"** moves 3 to the accumulator. **"NSUB 2 0"** moves the accumulator value into the second numeric word of **"FOB"** . **"MOVE B"** moves 4 to the accumulator. **"NSUB 3 0"** moves the accumulator value into the first numeric word of **"FOB"** .

MACRO NESTING - When a macro is invoked from within another macro, the macro is said to be "nested". If the nested macro invokes another macro, that macro is said to be nested at a level of two. Macro nesting is permitted up to a level of twenty. Two commands are provided to preserve the contents of the named registers (not the general purpose registers, however). These named registers are discussed in the CMD section of this manual.
NOTE: Macro functions, when they are used in the definitions of optimization operands, and macro functions FUN09 and FUN10, when used for special surfaces #5 and #11 definitions, do not support nesting. In these limited circumstances, they may not invoke macros or other macro functions.

SAVE - The "SAVE" command causes the current contents of the accumulator (register X) and registers A through H, Y, Z, T, IX, IY, IZ , I, J, ITEST, JTEST, LASTX and LASTIX to be saved.

RELOAD - The "RELOAD" command causes contents of the registers to be restored to the values which were saved by the last "SAVE" command issued at this nesting level. "SAVE" and "RELOAD" are operational at each of the 20 macro nesting levels.

TRACING MACRO EXECUTION - To trace the execution of a macro or macros (useful in debugging), the following two commands are provided:

TRACE ON - The "TRACE ON" command commences tracing the execution of all non-macro processing commands at the current nesting level. If a macro invokes another macro, that macro will only be traced if it contains a "TRACE ON" command as well.

TRACE OFF - This command terminates tracing at the current nesting level.

SINGLE STEP MACRO EXECUTION - To single step through the execution of a macro or macros (useful in debugging), the following two commands are provided:

SSTEP ON - The "SSTEP ON" command commences single step execution of all commands at the current nesting level. If a macro invokes another macro, that macro will only be single stepped if it contains a "SSTEP ON" command as well. During single stepping, pressing of any key on the keyboard causes the next macro command to be processed. There is an option to stop macro execution.

SSTEP OFF - This command terminates single step execution at the current nesting level.

PAUSING MACRO EXECUTION - To pause the execution of a macro at a specific line, the following command is provided:

PAUSE - The "PAUSE" command causes macro execution to be temporarily suspended at the location of the "PAUSE" command. Macro execution is resumed by pressing any key on the keyboard.

MACRO LANGUAGE SECTION

AUTOMATIC MACRO TERMINATION - By default, when a program command is run from within a macro and when that command's execution results in an error message, the macro from which that command was issued and any macros asssociated with that macro which exist in a macro nest will be automatically terminated. This protects the user from runaway macros. If this automatic macro termination is not desired, the following command is provided in order that the user can turn "on" or "off" this automatic macro termination feature.

MACFAIL (ON or OFF or YES or NO) - The "MACFAIL" command, issued from the CMD program level, is used to either enable or disable automatic macro termination in the presence of a program error condition. Issued with no input or with the "?", the current state of automatic macro termination will be displayed. "ON" or "YES" is the program default condition

RENAMING / COPYING MACROS - The following commands are used to rename and copy macros.

MRENAME (current macro name) (new macro name) - The command "MRENAME" requires explicit qualifier word and alphanumeric string input. The new macro named "new macro name" is created and the current macro named "current macro name" is extracted into it. Then the old macro is deleted.
NOTE: This command may also be issued via the main program GUI interface menu system.

MCOPY (current macro name) (new macro name) - The command "MCOPY" requires explicit qualifier word and alphanumeric string input. The new macro named "new macro name" is created and the current macro named "current macro name" is extracted into it. The old macro is left on file.
NOTE: This command may also be issued via the main program GUI interface menu system.

MACRO DIRECTORY FILE REPAIR - In the event that one or more of the MACXXX.DAT macro body data files becomes damaged or is inadvertently deleted, some of the macro commands will issue a message that the macro directory file is damaged. To repair this damage, do the following:
1) From the CMD level, issue an MFLN command and write down the names of the macros listed. This is a list of the macro names in the directory.
2) From the CMD level, issue an MFLC command. Write down the names of all macros which are listed with the MFLC command.
3) Any Macro name which appears in the list from the MFLN command, but not in the list from the MFLC command, should be deleted using the MDEL command. The body of these Macros is already gone; you are simply correcting the macro directory file.
NOTE: If the problem persists, contact Engineering Calculations! We want to make sure you are not seeing a BUG!

MANIPULATING MACRO LIBRARIES - The following commands are used to save and restore the contents of the current macro directory file.
WARNING: These two next two commands should not be used for saving and restoring the macro library when updating the program. The behavior of these commands in this situation is not reliable and alternate macro libraries will be lost!!!!!

MACSAVE - The command "MACSAVE" causes the contents of the current macro directory to be saved in the ASCII file MACSAV.DAT. This process erases the current contents of the EDITTEXT.DAT file and the previous contents of the MACSAV.DAT file.
NOTE: This command may also be issued via the main program GUI interface menu system.

MACREST - The command "MACREST" causes the contents of the current MACSAV.DAT file to be loaded into the current macro directory. This process erases the current contents of the EDITTEXT.DAT file and the previous contents of the current macro directory.
NOTE: This command may also be issued via the main program GUI interface menu system.

MACRO EDITING WITH LMEDIT - As was mentioned earlier, there in an older, line oriented editor which was the original macro editor and which works exactly like the horrible line editor in the HEXAGON program (the program I reverse engineered to make this program). For those who like history and pain, it has been left in the program. It is for old HEXAGON users who didn't have a full screen editor and LIKED IT THAT WAY! The "LMEDIT" command can be used either to initiate editing of an existing macro or to create a new macro in the macro-edit mode:

LMEDIT (macro name) - If the named macro already exists in the macro directory file, the named macro is transferred in its entirety from the macro directory file into a memory area where it is available for editing. At this point, the program is shifted to the MEDIT sub-level. If the named macro is new, the message "CREATING A NEW MACRO WITH LMEDIT" is printed, and the body of the new macro may be entered as in the macro creation mode. If a new macro is being created using "LMEDIT", the new macro is written in memory and is not entered into the macro directory file until the "FL" command (to be described) is issued. The key to understanding the use of this LMEDIT mode is the line pointer concept. The lines containing the commands which make up a macro are numbered sequentially in the memory area. The line pointer indicates the macro line number currently under edit consideration. As new macro lines are entered, the pointer is incremented so that it "points to" the most recently entered line. When the "LMEDIT macro name" command is issued, the line pointer is set to zero. As soon as another macro line is entered, the pointer is set to "1", etc. Any entry which is not one of the special editing commands (described in the next section) is entered as a line in the macro body following the position currently indicated by the pointer. Then the pointer is incremented by "1". The "LMEDIT" command may not be issued from within a macro (i.e., a macro cannot LMEDIT another macro or itself).

MACRO EDIT (LMEDIT) COMMANDS

BT - The "BT" command positions the macro line pointer to the last line (bottom) of the macro. Any input which follows this command is added at the end of the macro and becomes the new last line.

DE , i - The "DE" command deletes "i" lines from the macro beginning with the current line. If no entry is made for "i", just the current line is deleted (i.e. no entry is equivalent to i = 1). After deletion, the line pointer is positioned at the line following the last line deleted.

EX (macro name) , i , j - The "EX" command extracts lines "i" through line "j" of the named macro and inserts these lines after the current line of the macro being edited. The line pointer is left at the last line extracted. If the named macro is not found in the macro directory file, a message to that effect is printed and the line pointer is not moved. If no entry is made for "i" or "j", the entire named macro is extracted. If no entry is made for "j" but "i" is given, lines "i" through the end of the named macro are extracted.

GO , i - The "GO" command sets the macro line pointer at line "i" and displays that line. Any input entered after issuing "GO, i" is inserted after line "i". If no entry is made for "i", the line pointer is positioned at the top of the macro (equivalent to "GO, 0").

LO C (command word search target) - The "LO C" command causes the macro to be searched (starting from the line immediately following the current line) for a line containing the specific command word. The search terminates when the end of the macro is reached. If the command word is found, the line containing that word becomes the new current line. If the specified command word is not found, a message to that effect is displayed and the line pointer is positioned at the bottom of the macro.

LO Q (qualifier word search target) - The "LO Q" command functions in the same manner as the "LO C" command, except that the search is made for a qualifier word matching the specified word.
LO CQ (command and qualifier word search target) - The "LO CQ" command causes the macro to be searched for a line containing both the specified command word and specified qualifier word. The target command and qualifier words are entered as one string using one colon. They are separated by one or more blanks.

LO COQ (command or qualifier word search target) - The "LO COQ" command causes the macro to be searched for a line containing the specified word, either as a command or as a qualifier word.

NEXT - The "NEXT" command repeats the last search, thus avoiding considerable retyping of locate commands.

PR , i - The "PR" command causes "i" lines of the macro to be displayed beginning with the current line. If no entry for "i" is made, just the current line is printed. If "PR, i" is entered immediately following "PR", then "i" lines starting with the next line are displayed. The line pointer is always left at the last line displayed.

QUIT or **QU** - The "QUIT" or "QU" command terminates the macro editing session and returns the program to the CMD level without writing the current macro to the macro directory file. The current macro which was being entered is lost.

RE (new text of line being replaced) - The "RE" command causes the current macro line to be replaced by the specified text. The macro line pointer remains unchanged.

TP - The "TP" command positions the macro line pointer to the top of the macro. Any input entered following this command will precede all existing lines in the macro.

FL - The "FL" command writes the current edited macro into the macro directory file and returns the program to the CMD level. If the macro has no lines, a warning message to that effect is printed and no macro is stored.

ADVANCED STUFF (FOR EXPERTS ONLY)

BUILDING A NEW COMMAND - **The following commands are almost never needed except if you are writing a macro which is intended to create a new macro or which is intended to have advanced "intelligence". Unless you feel fearless, just ignore what follows.** The following commands were designed to be used both from the CMD level and from within macros. They are described here because their real value comes from their use inside macros. The philosophy behind these commands is as follows:

CWORD (the command word of the command under construction) - The command "CWORD" takes qualifier word input. If we were building the command "RTG ALL", the input following "CWORD" would be "RTG".

QWORD (the qualifier word of the command under construction) - The command "QWORD" takes qualifier word input. If we were building the command "RTG ALL", the input following "QWORD" would be "ALL".

STWORD (the alphanumeric string of the command under construction) - The command "STWORD" takes alphanumeric input. If we were building the command "M, Hello world !", the input following "STWORD" would be "Hello world !".

N1WORD , i The command "N1WORD" takes numeric word #1 input. If we were building the command "RTG , 2", the input following "N1WORD " would be "2".

N2WORD , i and
N3WORD , i and
N4WORD , i and
N5WORD , i - The commands "N2WORD", "N3WORD", "N4WORD" and "N5WORD" are similar to "N1WORD" and are used for setting up numeric words 2, 3, 4 and 5.

NEWCMD CLEAR - The "NEWCMD CLEAR" command clears the internal program storage areas set aside for the command under construction. This command should be used prior to the building of a new command.

NEWCMD - The "NEWCMD" command causes the newly-built program command to executed. In summary, if the command "RTG ALL" was to be constructed and executed from within a macro, the macro lines which could perform the task would be:

CWORD RTG
QWORD ALL
NEWCMD

SPECTRAL ANALYSIS SECTION

SPECT-GENERAL INFORMATION - The Spectral Analysis, or SPECT, level is the level at which wavelength dependent data files may be manipulated. At this level, optical system transmission and other wavelength dependent analyses can be performed. SPECT level commands may be issued from the keyboard or as part of a macro.

SPECT FILE INITIALIZATION - The SPECT disk file system is initially created by entering the CMD level command:

ITF - To avoid accidental destruction of the existing SPECT disk file system, the "ITF" command performs no file initialization unless it is followed immediately by the command:

PROCEED - If the CMD level command "PROCEED" is not immediately entered following the "ITF" command, then the "ITF" command is ignored and canceled. THIS INITIALIZATION PROCEDURE SHOULD BE USED WITH CAUTION AS LARGE AMOUNTS OF DATA MAY BE LOST IF IT IS USED CARELESSLY. The "ITF" command is intended for a user who has no SPECT disk file system or for a user who intentionally desires to clean the slate and begin anew with an empty SPECT disk file system.

SPECT LEVEL

SPECT - The "SPECT" command causes the program to move into the SPECT level. All SPECT level commands and a limited sub-set of CMD level commands may be issued at this level.

EOS or **END** - The "EOS" or "END" command causes the program to leave the SPECT level and return to the CMD level.

SPECT DISK DATABASE - Just as there is a Lens Library at the CMD level which is used to store and recall lens system data, there is also a disk based data structure at the SPECT level which is used to store and recall tables of wavelength dependent data. This wavelength dependent data may represent optical transmittance or reflectance values or other wavelength dependent data which needs to be stored, recalled and manipulated.

SPECT MEMORY ORGANIZATION - There are two areas of computer memory available within the SPECT level. These areas are named the WORK memory areas and the CUMULATIVE memory area.

WORK MEMORY AREA - The WORK memory area is a memory area into which a SPECT disk data file may be read. This memory area is large enough to store up to 1001 pairs of wavelength dependent data.

CUMULATIVE MEMORY AREA - The CUMULATIVE memory area is a memory area into which linearly interpolated wavelength dependent data is multiplied. This memory area is large enough to store up to 1001 pairs of wavelength dependent data.

MEMORY AREA COMMANDS

START - The "START" command causes all the wavelength dependent data in the CUMULATIVE memory area to be set to 1.0. A "START" command is automatically executed each time the SPECT level is entered and whenever a "WAVLN" command is issued.

WAVLN , λlower , λupper , ntot - The "WAVLN" command defines the spectral region to be used in the CUMULATIVE memory area. The "λlower" wavelength must be greater than zero, the "λupper" must be greater than the "λlower" and the number of entries, and "ntot" must be an integer in the range 1 to 1001. There are no defaults for the "λlower" and "λupper" input values. The default value for "ntot" is 1001. Whenever a "WAVLN" command is issued, an automatic "START" command is also issued.

INT - The "INT" command causes Simpson's rule to be used to integrate the CUMULATIVE AREA over the spectral region specified by the preceding "WAVLN" command. The value of the integral is printed along with the lower and upper bounds of the current spectral region. The value of the integral is also placed into the macro accumulator.

WORK - The "WORK" command displays the current contents of the WORK memory area to the current output device.

CUME - The "CUME" command displays the current contents of the CUMULATIVE memory area to the current output device.

NAME - The "NAME" command displays the name of the current SPECT disk file loaded in the WORK memory area..

SPECT DATABASE COMMANDS

DIRECT or **DIR** or **DIRECT , i** or **DIR , i** - The "DIRECT" or "DIR" command issued alone displays a directory listing of the entire SPECT disk database. If "DIRECT" or "DIR" is issued with the numeric entry "i", then the directory listing of just the "i"th file is displayed. The SPECT disk database can store up to 999 database files.

SPECTRAL ANALYSIS SECTION

DELETE (name) or **DELETE , i** - The "DELETE" command deletes the specified SPECT disk file. If "DELETE" is issued with the file name, the file with name = "name" will be deleted. If "DELETE" is issued with the numeric value "i", the "i"th SPECT disk file will be deleted.

FILE (name) - The "FILE" command causes the current wavelength dependent data in the WORK area to be stored on disk as a SPECT disk file with name = "name". Storage occurs only if there is data to store and if the file named "name" does not already exist.

LIST (name) or **LIST , i** or **LIST** - The "LIST *name*" command causes the SPECT disk file with name = "name" to be read into the WORK memory area and its contents displayed. "LIST , i" causes the "i"th SPECT disk file to be loaded into the WORK memory area and displayed. The "LIST" command simply displays the current WORK memory area.

PUNCH (name) or **PUNCH , i** or **PUNCH** - The "PUNCH" commands are identical to the "LIST" commands, except that the contents of the SPECT disk file are sent to the "CARDTEXT.DAT" file instead of to the display.

SPRINT (name) , a , b , c , d , e - The "SPRINT" command causes the SPECT disk file with name = "name" to be read into the WORK memory area. If the "*name*" is left blank, the CUMULATIVE memory area is moved into the WORK area. The data moved to the WORK area is modified by the transformations:

$$\lambda_{new} = \left(a \times \lambda_{old}\right) + b$$

and

$$f(\lambda)_{new} = \left[\left(c \times f(\lambda_{old})\right) + d\right]^{e}$$

If "a", "c" or "e" are blank, they are automatically set to 1.0. If "b" or "d" are left blank, they are set to zero. After the above transformations, the data in the WORK memory area is linearly interpolated to obtain n_{tot} equally spaced values between λ_{lower} and λ_{upper}. These n_{tot} functional values are displayed at the current output device. The CUMULATIVE memory area is not changed by this command. λ_{lower}, λ_{upper} and n_{tot} are specified by the last "WAVLN" command.

RENAME (old name) , (new name) - The "RENAME" command is used to rename a SPECT disk file named "old name" to "new name". "Old name" is entered as a qualifier word and "new name" is entered as a string.

DUP (old name) , (new name) - The "DUP" command is used to copy the SPECT disk file named "old name" to a new SPECT disk file named "new-name". "Old name" is entered as a qualifier word and "new name" is entered as a string.

GETFILE (name) , a , b , c , d , e - The "GETFILE" command causes the SPECT disk file with name = "name" to be read into the WORK memory area where it is modified by the transformations:

$$\lambda_{new} = \left(a \times \lambda_{old}\right) + b$$

and

$$f(\lambda)_{new} = \left[\left(c \times f(\lambda_{old})\right) + d\right]^{e}$$

If "a", "c" or "e" are blank, they are automatically set to 1.0. If "b" or "d" are left blank, they are set to zero. After the above transformations, the data in the WORK memory area is linearly interpolated to obtain n_{tot} equally spaced values between λ_{lower} and λ_{upper}. These n_{tot} functional values are then multiplied by the values currently in the CUMULATIVE memory area and the results are stored in the CUMULATIVE memory area. λ_{lower}, λ_{upper} and n_{tot} are specified by the last "WAVLN" command.

PUT (name) - The "PUT" command creates a SPECT disk file of name = "name". It will have n_{tot} points. The data in the current CUMULATIVE memory area is stored in this file. n_{tot} is specified by the last "WAVLN" command.

INTER (name) , λ - The "INTER" command is used to linearly interpolate a SPECT disk file with name = "name" to a value corresponding to the independent variable "λ". The interpolated value is displayed at the output device and placed into the accumulator.

BLACKBDY *(qualifier word) , T* - The "BLACKBDY" command without a "qualifier word" or with the qualifier "SRE" generates blackbody "spectral radiant emmittance" values at temperature "T". These values are calculated for each wavelength entry in the CUMULATIVE memory area and then multiplied into the CUMULATIVE memory area's stored functional values. "T" must be in degrees Kelvin. If "T" is not entered, 300.0 degrees Kelvin is assumed for the default. If the "qualifier word" "SRPE" is used, "spectral radiant photon emmittance" values are calculated and stored instead of "spectral radiant emmittance" values. The units of "spectral radiant emmittance" are: Watts-cm^{-2}-micron^{-1}. The units of "spectral radiant photon emmittance" are: Photons-sec^{-1}-cm^{-2}-micron^{-1}.

SPECT DATA INPUT

TABLE (filename) - The "TABLE" command is used to initiate the entry of data into an empty SPECT database disk file. "filename" is the name of that file. "TABLE" is followed by not more than 1001 input commands of the form:

DATA ,λ , f(λ) - where "λ " is the wavelength in microns and "f(λ)" is the functional value related to that wavelength. The entries must be in ascending order by wavelength.

ENDTABLE - The "ENDTABLE" command terminates file input and writes the data to the disk.

INSERT (name) ,λ , f(λ) - The "INSERT" command is used to insert an entry into the SPECT disk file with name = "name". The entry is positioned in the file by ascending value of "λ". This command may not be used to create a file or insert records into an "empty" file.

DROP name , i - This command causes the "i"th entry of the named SPECT disk file to be deleted or dropped from that file.

PHOTOPIC - This command causes the spect disk file named "PHOTOPIC" to be automatically created. It has 81 entries and represents the Photopic response function of the human eye from 0.380 micron to 0.780 micron. (Based on data taken from the American Institue of Physics Handbook.)

SCOTOPIC - This command causes the spect disk file named "SCOTOPIC" to be automatically created. It has 81 entries and represents the Scotopic response function of the human eye from 0.380 micron to 0.780 micron. (Based on data taken from the American Institue of Physics Handbook.)

SPECT FILE GRAPHICS - The following two The commands are used to graphically display the contents of a SPECT disk file. The plots are automatically displayed on the screen. They may then be re-displayed on the screen using the "DRAW" command or printed using the "GRAOUT" command. The two commands are identical in that they generate plots of the contents of SPECT disk files. They are different only in the fact that the "PLOTT" command labels the vertical axis as TRANSMISSION and the "PLOTR" command labels the vertical axis as REFLECTION. The horizontal scale will always be labeled "WAVELENGTH (MICRONS)".

PLOTT (file name) , λlower , λupper, F(λlower) , F(λupper) and
PLOTT , i , λlower , λupper, F(λlower) , F(λupper) and
PLOTR (file name) , λlower , λupper, F(λlower) , F(λupper) and
PLOTR , i , λlower , λupper, F(λlower) , F(λupper)   - If the "file name" version of each command is used, the contents of the SPECT disk file with name = "file name" will be plotted. If the version with SPECT disk file number "i" is used, the "i"th SPECT disk file will be plotted. If not entered explicitly, the plot will be scaled in X and Y so as to include all data in the designated file. This automatic scaling can be overridden by explicitly entering the X-plot limits, λ_{lower} and λ_{upper}, and the Y-plot limits, $F(\lambda_{lower})$ and $F(\lambda_{upper})$.

SPECTRAL WEIGHTING FACTORS - Many times it is necessary to determine a set of wavelengths with associated spectral weighting factors which will be used during the design or analysis of an optical system. These values depend upon the spectral characteristics of the source illumination filtered by any filters and upon the spectral response of the detector. If SPECT data files are created and stored, using the SPECT commands described earlier in this section, which describe the filtered illumination and the detector response, then the "WFACTOR" command may be used to determine an appropriate set of wavelengths and associated spectral weights.

WFACTOR , n - The "WFACTOR" command is entered with the number of wavelengths, "n", for which spectral weighting factors are desired. "WFACTOR" operates upon the current CUMULATIVE memory area. It first divides the CUMULATIVE area into "n" equal wavelength extent sub-sections. Each sub-section covers 1/"n" th of the spectral band included in the full CUMULATIVE area. The area of each of these equal wavelength sub-sections, normalized by the area under the complete CUMULATIVE area becomes the spectral weighting factor for that sub-section. Next, each sub-section is divided into two equal area pieces. The wavelength which lies at the boundary of these two equal area pieces of each sub-section becomes the wavelength for that sub-section. That wavelength is the wavelength which is to be related to that sub-sections spectral weighting factor.

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WEIGHTING FACTOR EXAMPLE - Source illunination for the system under consideration is to be a black body at 5600 degrees Kelvin. The detector response is to be the Photopic response of the human eye. The number of wavelengths, "n", will be 6.

Step 1
Enter the SPECT program level
COMMAND(S):

SPECT

Step 2
Set up the Cumulative area with 1001 points from wavelength 0.38 to 0.78 microns.
COMMAND(S):

START
WAVLN 0.38 0.78

Step 3
Create a SPECT database file named PHOTOPIC which contains the Photopic response on the human eye from 0.38 to 0.78 microns. Then multiply this file into the Cumulative area.
COMMANDS:

PHOTOPIC
GETFILE PHOTOPIC

Step 4
Multiply into the Cumulative area the black body radiant emmittance at T = 5600 degrees Kelvin.
COMMANDS:

BLACKBDY 5600

Step 5
Issue the command "WFACTOR " with a numerical argument "6"
COMMANDS:

WFACTOR 6

Results are:

WAVELENGTH - (MICRONS)	SPECTRAL WEIGHT
0.4382	0.00416
0.4986	0.12037
0.5486	0.57045
0.6006	0.28706
0.6574	0.01777
0.7226	0.01777

Step 6
Exit the SPECT level
COMMAND:

EOS or **END**

Now use the WV and WV2 update lens commands to input the new wavelengths and the SPTWT and SPTWT2 commands to enter the new spectral weights.

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GRAPHICS SECTION

GRAPH-GENERAL INFORMATION - All program graphical display options are described in this manual section. Most of the commands which generate graphical displays are issued only from the CMD level. A very few can be issued from the SPECT level. Except for the generation of the internal file, no other graphics output is supported in the "THE PROGRAM AS A SUBROUTINE" mode.

MODE OF OPERATION - The program performs all of its graphical output to an internal file. This file may be displayed on the display screen or printed to the current printer, if one is connected, by issuing specific drawing or printing commands.

DEVICE INDEPENDENT COORDINATES - The program uses a device independent graphical coordinate system for its communication with display and printing devices. The lower left-hand corner of each device has coordinates (X=0, Y=0), the upper left-hand corner of each device has coordinates (X=0, Y=7000), the upper right-hand corner of each device has coordinates (x=10000, Y=7000) and the lower right-hand corner of each device has coordinates (x=10000, y=0). Device independent coordinates are ALWAYS represented by integer values.

CMD LEVEL GRAPHICS COMMANDS

COLORSET (qualifier word) , color# - The "COLORSET" command issued with a "qualifier word" other than "RESET" is used to change the color of the graphic item designated by the "qualifier word" to the color value designated by "color#". The following table lists the allowed "qualifier words" with their meanings:

QUALIFIER	GRAPHIC ITEM	Default Color
RAYS	Ray color of rays in optical system plots	15 - (Black)
CLAP	Clear aperture color in optical system plots	3 - (Red)
COBS	Obscurations in optical system plots	9 - (Dark Yellow)
EDGE	Edge color in optical system plots	1 - (Yellow)
PROF	Surface profile color in optical system plots	1 - (Yellow)
AXIS	Axes drawn in optical system plots and ray positions drawn in beam footprint plots	15 - (Black)
GBAC	Graphics background color, all plots	0 - (White)
WAV1	1st wavelength used in a fan/spot plots and Primary Chromatic Difference fan plots	15 - (Black)
WAV2	2nd wavelength used in a fan/spot plots and Secondary Chromatic Difference fan plots	12 - (Dark Cyan)
WAV3	3rd wavelength used in a fan/spot plots	2 - (Light Magenta)
WAV4	4th wavelength used in a fan/spot plots	3 - (Light Red)
WAV5	5th wavelength used in a fan/spot plots	4 -(Light Cyan)
WAV6	6th wavelength used in a fan/spot plots	5 - (Light Green)
WAV7	7th wavelength used in a fan/spot plots	6 -(Light Blue)
WAV8	8th wavelength used in a fan/spot plots	7 - (Light Grey)
WAV9	9th wavelength used in a fan/spot plots	8 - (Dark Grey)
WAV10	10 wavelength used in a fan/spot plots	9 - (Dark Yellow)
FRAM	Graphic frame color in plots where a frame is used	15 - (Black)
LABL	Label color for all plot labels, notes and symbols	15 - (Black)
SPEC	Color of SPECT disk database plots	15 - (Black)
PEN	Color of pen in PLOT PEN commands	15 - (Black)

By default, the "LENS" command sets up the first five lens wavelengths to be 0.58756 μ, 0.48613 μ, 0.65627 μ, 0.43584 μ and 0.70652 μ. The first five wavelength colors are set in their default mode to simulate the appearance of these colors. There is no restriction on the order of wavelengths in the lens nor is there a restriction on the assignment of colors to various wavelengths.

GRAPHICS SECTION

COLORSET RESET - The "COLORSET RESET" command, issuable at any time from the CMD level, resets all graphics displays to their default colors. The following table lists the allowed "color#'s" with their associated colors:

color#	COLOR
-1	CURRENT BACKGROUND COLOR
0	WHITE
1	YELLOW
2	LIGHT MAGENTA
3	LIGHT RED
4	LIGHT CYAN
5	LIGHT GREEN
6	LIGHT BLUE
7	DARK GREY
8	LIGHT GREY
9	DARK YELLOW
10	DARK MAGENTA
11	DARK RED
12	DARK CYAN
13	DARK GREEN
14	DARK BLUE
15	BLACK

PLOT NEW - The "PLOT NEW" command initializeS the program for new graphical output. WARNING: ANY EXISTING PLOT DATA IN THE INTERNAL FILE WILL BE OVERWRITTEN AFTER THE "PLOT NEW" COMMAND IS ISSUED. Plot scaling, used in optical system graphics, is reset to "automatic" by these commands. The "PLOT NEW" command utilizes the entire screen and should be used for most graphics.

PLOT NAME , plot name - up to 60 characters in length - The "PLOT NAME" command is used to name the current plot with a name description of up to 60 characters long. The name will be used for identification purposes in the plot library.

PLOT ORIGIN , x , y - The "PLOT ORIGIN" command is used to reset the device independent coordinates of the current plot origin to the integer values "x" and "y". This new origin is remembered as the new plot origin. The program default values for the plot origin are x=0 and y=0. If "PLOT ORIGIN" is entered with blank input, the default values x=0 and y=0 will be used.

PLOT SYMBOL , i , H , IX , IY - The "PLOT SYMBOL" command is used to plot a point plot symbol at the pen position IX, IY in device independent coordinates. The symbol is designated by the integer numeric input "i" as designated in the following table:

SYMBOL NUMBER	SYMBOL
1	+ (plus sign)
2	x (small x)
3	(small square)
4	¦ (small triangle)
5	¦ (small inverted triangle)
6	quartered square
7	crossed triangle
8	crossed inverted triangle
9	square with x
10	triangle plus inverted triangle

The default symbol is number 1, a plus sign (+). The character height is specified with the integer numeric input value "H". "H" = integer print size value which can take on any integer value from 1 to 9 (smallest to largest). The height of a character in device independent units is always equal to the "H" value times 44 device independent units. The program default value for "H" is 1. This command generates graphical output.

PLOT LSTYLE , i - The "PLOT LSTYLE" command is used to set the line style used by the "PLOT PEN" command to the style specified by the integer numeric input "i" as designated in the following table:

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LINE STYLE NUMBER	LINE STYLE NAME	LINE STYLE
0	SOLID	_____
1	DOTS	....
2	SHORT DASH	-- -- -- -- -- -- -- -- -- -- -- -- --
3	DASH-DOT	--- - --- - --- - --- - --- - --
4	DASH-DOT-DOT	--- - - --- - - --- - - --- - - --- -
5	DASH-DOT-DOT-DOT	--- - - - --- - - - --- - - - --- - -
6	DASH-DASH-DOT-DOT	--- --- - - --- --- - - --- --- - -
7	DASH-DASH-DASH-DOT	--- --- --- - --- --- --- - --- ---
8	LONG DASH	----- ----- ----- ----- ----- -
9	LONG DASH-SHORT DASH	----- -- ----- -- ----- -- ----- --

The default line style is number 0, a solid line. This command does not generate graphical output by itself.

PLOT LWIDTH , (mult factor) - The "PLOT LWIDTH" command is used to adjust plotted line widths when plots are processed by the "GRAOUT" command. This command is ignored for screen graphics. The "mult factor" can be any positive number. Since different devices and have different default line widths assigned to them, it is best to use this command to adjust line widths after an initial "GRAOUT" has been performed without the use of this command. This command must preceed any line plotting for it to have an effect.

PLOT CHNOTE , H , THETA - The "PLOT CHNOTE" is used prior to the "PLOT NOTE" and "PLOT ACC" commands. It sets the character height with the integer numeric input value "H" and the printing angle to the integer value (in degrees) "THETA". The values set with this command remain in effect until the next "PLOT CHNOTE" or a "PLOT NEW" command is issued. "H" = integer print size value which can take on any integer value from 1 to 9 (smallest to largest). The height of a character in device independent units is always equal to the "H" value times 44 device independent units. "THETA" = integer text angle in degrees. Its default value is 0 degrees (range 0 to 360). Angles are measured counterclockwise from the positive X-axis (horizontal line pointing to the right) to the line of text. The program default value for "H" is 1. This command does not generate graphical output by itself.

PNOTE , character string of note - up to 79 characters in length - The "PNOTE" command established the content of the next note which will be plotted with "PLOT NOTE"

PLOT NOTE , IX , IY - The "PLOT NOTE" command annotates the plot with the last note established with the last "PNOTE" command (stripped of all leading and trailing blanks) beginning at the pen position IX, IY. This command generates graphical output by itself.

PLOT ACC , IX , IY , N , M - The "PLOT ACC" moves the pen to the location "IX" and "IY". The value in the macro accumulator (X-register) is then plotted beginning at this new pen position. N is an integer value from 1 to 10. It designates the number of positions to the right of the decimal place that are to be plotted. Decimal values are plotted in the "G" format form. If possible, the number is plotted in standard decimal form; otherwise, it is represented in exponential form. For decimal values, the formats used range from a G8.1 (N=1) to a G17.10 (N=10). If M is not blank (any numeric value may be used to set this to non-blank), the accumulator value is represented as an integer from -99999999 to 999999999. Integers outside this range are plotted as ********** (10 asterisks). All leading and trailing spaces are stripped from these values before they are plotted. The program default value for character height value used is 1 and that value can be changed using the "PLOT CHNOTE" command. This command generates graphical output by itself.

PLOT PEN , IX , IY , i - The "PLOT PEN" command is the basic command used to draw lines in device independent coordinates. The "pen" is moved from its current position to the device independent coordinates "IX" (horizontal). and "IY" (vertical). The pen status is determined by the integer value of "i" as specified in the table below. Line styles are changed using the "PLOT LSTYLE" command already described. "IX" and "IY" must be integer values. This command generates graphical output by itself.

PEN STATUS VALUE ("i")	PEN STATUS WHILE MOVING
1	NO CHANGE IN STATUS
2	LOWER PEN BEFORE MOVE
3	LIFT PEN BEFORE MOVE

PLOT FRAME , xl , yl , xu , yu - The "PLOT FRAME" command is the command used to draw a rectangular frame in the current frame color. "xl", "yl", "xu" and "yu" are the x and y coordinates of the lower left and upper-right hand corners of the frame. These frame corner coordinates are represented in device independent integer coordinates. The default input values are 1, 1, 9999 and 6999.

FRAME (YES or ON or OFF or NO) - The "FRAME" command is user to specify whether or not a frame is to be drawn around selected plots. The program default is "OFF or NO"

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GRID (ON or YES) or GRID (OFF or NO) - The "GRID (ON or YES)" and "GRID (OFF or NO)" commands either activate or deactivate the plotting of dotted grid lines in functional data plots such as GOTF, DOTF, RED, LSF etc..The default is "OFF". If turned "ON", this switch stays "ON" until turned "OFF" or until the program terminates.

AUTOMATED OPTICAL SYSTEM GRAPHICS - The optical system graphics commands described earlier in this section allow the designer considerable freedom in the generation of graphical representations of the current optical system database (lens database). They may be issued interactively from the keyboard or included as part of a macro. For those times when only a "quick look" at the optical system is needed, the "VIE" command has been added. Just as in the "FAN" command, this command does not require the designer to explicitly issue either a "PLOT NEW" command or a "DRAW" command.

VIE (qualifier word) , sf , i , j , dflag or **VIECO (qualifier word) , sf , i , j , dflag** - The CMD level commands "VIE" and "VIECO" causes a one-page drawing of the current lens system to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The two commands are identical except that "VIE" performs NO clear aperture/obscuration violation checking and plots rays which would be blocked by clear apertures and obscurations. "VIECO" will not plot rays which are blocked by clear apertures and obscurations. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. The following table lists all of the valid qualifier words and the associated plot orientations:

QUALIFIED WORD	ORIENTATION
(none) or **YZ**	YZ-view (X-axis into the screen)
XZ	XZ-view (Y-axis into of the screen)
XY	XY-view (Z-axis into the screen)
ORTHO	preset ortho-graphic view with the "look view" set to: elevation = 26.2 degrees azimuth = 232.2 degrees

The numeric inputs are:
NUMERIC WORD #1
"sf" is the scale factor. If "sf" is set to 0.5, for example, then the lens system will be drawn at one-half full size. If "sf" is omitted, the program will adjust the scale to fill the screen. The "sf" scale factor must be explicitly entered if the view is "XY".
NUMERIC WORD #2
"i" is the beginning surface number. If "i" is omitted, the plot will begin at the first non-infinite thickness surface.
NUMERIC WORD #3
"j" is the final surface number. If "j" is omitted, the plot will stop at the last surface of the lens database.
The relative extent of the marginal rays and fields of view can be controlled by adjusting the X and Y-object heights and X and Y-relative aperture heights in the lens database.

SHIFTING A VIE PLOT

VIEOFF , x-offset , y-offset , rotation - The CMD level command "VIEOFF" is used to offset and rotate a display which is to be generated by the next "VIE" command. It is intended for cases when the "VIE" automatic offsets are not by themselves acceptable. The "x-offset" and "y-offset" for the display are specified in device independent coordinates. The counterclockwise "rotation" about the display center is specified in degrees. The offsets are applied before the rotation. All offsets and the rotation are applied after the automatic offsets generated by "VIE". Remember that the bottom left-hand corner of the screen has device independent coordinates x=0, y=0 and the top right-hand corner has device independent coordinates x=10000, y=7000.

VIGNETTING IN A VIE PLOT

VIEVIG (YES or ON or NO or OFF) - The CMD level command "VIEVIG" is used to specify whether or not automatic vignetting factors should be calculated and applied to the rays being traced when "VIE" is issued. The default is to calculate vignetting factors (ON or YES) for each field point and to apply these in tracing the rays to be plotted. The vignetting factor calculation considers all ray blockage mechanisms except obscurations. The "ON" or "YES" and "OFF" or "NO" status is sticky and stays set until the program stops or until reset by the user. "VIEVIG (OFF or NO)" causes rays at full 1.0 fractional reference surface heights to be traced (if they can be) and plotted, even if those rays pass outside clear apertures set in the system.

OVERLAYING A VIE PLOT

VIEOVER - The CMD level command "VIEOVER" is used to overlay the next VIE over the previous VIE. Each time a VIE is to be overlaid upon a previous VIE, the "VIEOVER" command must be issued.

OPTICAL SYSTEM GRAPHICS - The next group of commands are used for graphically representing various aspects of the optical system stored in the program lens database. For the commands which take a starting surface number, the program default will be to start at the current object surface or the first lens surface beyond the current object surface whose absolute magnitude axial thickness is less than 1.0D+10. The default ending surface will always be the current image surface. No entry for the starting and ending surfaces will result in a plot of the entire lens system. Entry of the same value for the starting and ending surfaces will result in an attempted plot of just that one surface. Dummy surfaces without explicit clear apertures will not be plotted. Dummy surfaces are surfaces which have the identical refractive index of each side. These dummy surfaces will be drawn if they have explicit clear apertures assigned. The default in this case will be to draw them with dashed lines, however, the "PLOT NODASH" command will cause solid lines to be used instead. The object and image surfaces are never considered to be dummy surfaces. If no explicit clear aperture is assigned to a surface, the implicit aperture drawn by the profile and clear aperture plotting commands will be a circular clear aperture whose semi-diameter is equal to the sum of the paraxial marginal and paraxial chief ray heights at that surface. This implicit clear aperture will be centered at the location on the surface where the "FOB 0 0 0 1" chief ray intersects that surface.

NOTE: Scaling commands only apply to sequential lens database plotting. For NSS database plotting, use the "PLOT NSSSCALE" command described in the NSS manual section.

PLOT SCALE , x , y - The "PLOT SCALE" command sets the plot scale factors to values other than those automatically computed by the program. "y" is the number of thousands of device independent coordinate units which represent one lens unit in the Y (vertical) direction of the plot. A "y" scale factor of 10 would scale one unit of the object being plotted so that it plotted in 10,000 units of the device independent coordinate system. For most devices, 1000 units in the device independent coordinate system will be represented as 1.0 inch. "x" is the corresponding scale factor value in the X (horizontal) direction. The plot size values are also reset by the "PLOT SCALE" command. These size factors are just the reciprocal values of the scale factors. The default condition for scaling is automatic scaling. In automatic scaling, the program attempts to pick a set of scale factors which will fill the output device based upon the first plotting command requiring auto-scaling. After the scale factors are picked by the program or set by the user, they remain set until they are reset again using either the "PLOT SCALE", the "PLOT SIZE" or the "PLOT NEW" command. When making composite plots with auto-scaling, the data with the largest range should be plotted first.

PLOT NOSCALE - The "PLOT NOSCALE" command stops display of the scale factors on the current plot. If "PLOT SCALE" or "PLOT YESCALE" have been issued, scale factors will be displayed in the bottom left-hand corner of the plot.

PLOT YESCALE - The "PLOT YESCALE" command causes display of the scale factors in the lower left-hand corner of the current plot. This command is used to override the "PLOT NOSCALE" and "PLOT NOSIZE" commands without resetting the scale factors.

PLOT SIZE , x , y - The "PLOT SIZE" command sets the plot size factors to values other than those automatically computed by the program. "y" is the number of lens units per 1000 units of device independent coordinates. "x" is the corresponding size factor value in the X (horizontal) direction. The plot scale values are also reset by the "PLOT SIZE" command. These size factors are just the reciprocal values of the scale factors. The default condition for sizing is automatic. In automatic sizing, the program attempts to pick a set of size factors which will fill the output device based upon the first plotting command requiring auto-sizing. After the size factors are picked by the program or set by the user, they remain set until they are reset again using either the "PLOT SCALE", the "PLOT SIZE" or the "PLOT NEW" command. When making composite plots with auto-sizing, the data with the largest range should be plotted first.

PLOT NOSIZE - The "PLOT NOSIZE" command stops display of the size factors. If "PLOT SIZE" or "PLOT YESIZE" have been issued, size factors rather than scale factors will be displayed in the bottom left-hand corner of the plot. "PLOT NOSIZE" stops the plotting of size factors.

PLOT YESIZE - The "PLOT YESIZE" command causes display of the size factors in the lower left-hand corner of the current plot. This command is used to override "PLOT NOSIZE" and "PLOT NOSCALE" commands without resetting the size or scale factors.

PLOT AXIS - The "PLOT AXIS" command instructs the program that a coordinate axis is to be plotted on the current plot in the lower right-hand corner of the current plot. The axis will represent the current "PLOT LOOK"/"PLOT VIEW" setting.

PLOT LOOK , Vx , Vy , Vz - The "PLOT LOOK" command changes the "LOOK" vector for the current optical system plot. The "LOOK" vector is represented by the direction cosines Vx, Vy and Vz of a vector which point toward the "observer's position" from the system under observation. The vector is represented in the coordinate system of the surface which is currently acting as the global coordinate reference surface of the system for plotting. (See the discussion in the CMD LEVEL manual section on global raytracing and global coordinate). The plotted view is always "isometric". No attempt at other projections is made. The global reference surface for plotting is automatically selected by the program. The default for "PLOT LOOK" is "PLOT LOOK , -1 , 0 , 0". This results in a graphical representation of the system with the global reference axis +Y pointing up, the global reference axis +Z pointing to the right, the global reference axis +X pointing into the graphics page and the global reference X-axis pointing toward the observer. The "LOOK" vector remains the same until it is changed using another "PLOT LOOK", "PLOT VIEW" or a "PLOT NEW" command. The "PLOT VIEW" values are always automatically adjusted by a "PLOT LOOK" command.

The direction cosine input values do not have to be true normalized to 1.0 direction cosines. The program takes the first three input values, calculates the sum of their squares and divides each value by this normalization factor. The resultant normalized values are then stored as the "look vector" values. If the "PLOT LOOK" command is entered followed by a space and a "?", the current "look vector" values will be displayed on the screen. The plot may also be shifted in x and y and rotated about its center using the "PLOT XSFIFY". "PLOT YSHIFT" and "PLOT GAMMA" commands described later in this section.

PLOT YESLOOK - The "PLOT YESLOOK" displays the current "look" vector information in the lower portion of optical system plots.

PLOT NOLOOK - The "PLOT NOLOOK" cancels the effect of a "PLOT YESLOOK" command in optical system plots.

The "LOOK" vector concept is illustrated in the following figure:
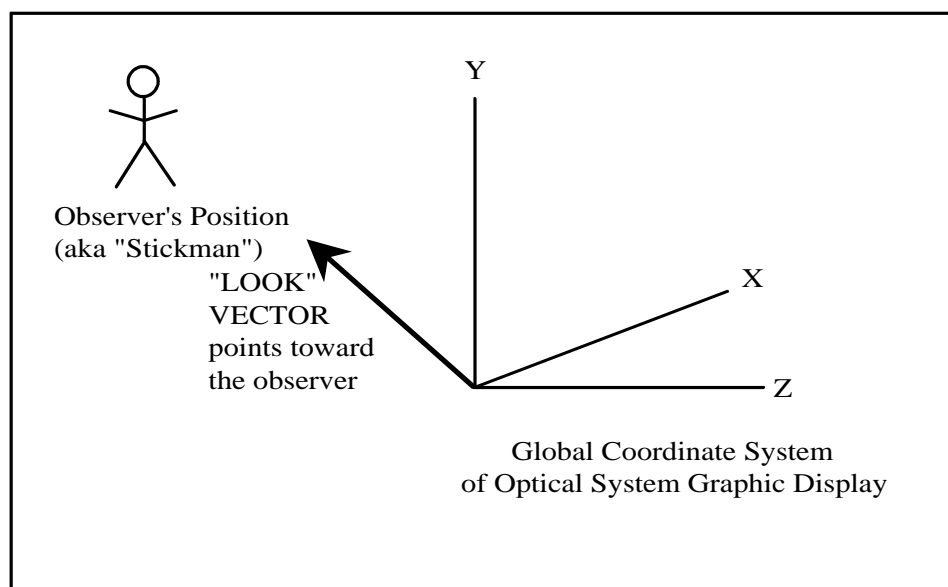
The "LOOK" Vector

PLOT VIEW , ELANG , AZANG - The "PLOT VIEW" command changes the "look angle" for the current optical system plot. The "look view" is represented by elevation viewing angle "ELANG" and azimuth viewing angle "AZANG". Both angles are in units of degrees. The default "plot view" elevation and azimuth angles are: "ELANG" = 0.0 degrees and "AZANG" = 270.0 degrees, which correspond to the default "plot look" vector (-1, 0, 0). "ELANG" is measured from 0.0 degrees to +/- 90.0 degrees. Positive/negative "ELANG"s represent an observer positioned above/below the XZ-plane of the current global reference coordinate system. "AZANG" is measured from 0.0 to 360.0 degrees in a right-handed sense from the +Z axis toward the +X axis about the +Y axis of the current global reference coordinate system. The "look angle" remains the same until it is changed using another "PLOT VIEW", "PLOT LOOK" or a "PLOT NEW" command. The "PLOT LOOK" values are always automatically adjusted by a "PLOT VIEW" command. The plot may also be shifted in x and y and rotated about its center using the "PLOT XSFIFY". "PLOT YSHIFT" and "PLOT GAMMA" commands described later in this section.

PLOT YESVIEW - The "PLOT YESVIEW" displays the current view angle information in the lower portion of optical system plots.

PLOT NOVIEW - The "PLOT NOVIEW" cancels the effect of a "PLOT YESVIEW" command in optical system plots. The viewing angles "ELANG" and "AZANG" are illustrated in the following figure:

GRAPHICS SECTION
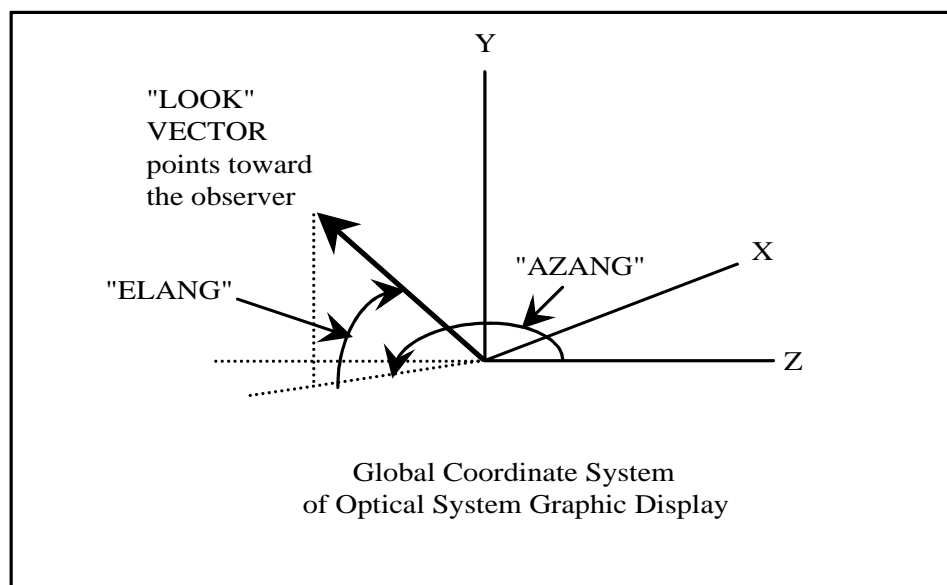
Viewing Angles "ELANG" and "AZANG"

ORIENT , i , shiftflag - The "ORIENT" command causes the "LOOK VECTOR" to be reset so that its X, Y and Z-components are equal to the L, M and N-direction cosines of the local Z-axis of surface "i". The "LOOK VECTOR" passes through the vertex of surface "i. "ORIENT" is used whenever the "LOOK VECTOR" needs to be set so as to look "normal" to a surface. The view angles are also reset. If "shiftflag" is set to any explicit value, the "ORIENT" command also does an automatic "PLOT XSHIFT" and "PLOT YSHIFT" so as to place the origin of the current global coordinate system at the center of the plot. This can then be subsequently modified by the user with "PLOT XSHIFT" and PLOT YSHIFT" commands. If "shiftflag" is not explicitly set to a value, the local origin of the surface is centered on the plot.

NORIENT , i , shiftflag - The "NORIENT" command causes the "LOOK VECTOR" to be reset so that its X, Y and Z-components are equal in magnitude but opposite in sign to the L, M and N-direction cosines of the local Z-axis of surface "i". The "LOOK VECTOR" passes through the vertex of surface. "NORIENT" is used instead of the "ORIENT" command when the "ORIENT" command causes the observer to view from the "wrong" side of surface "i". The view angles are also reset. If "shiftflag" is set to any explicit value, the "NORIENT" command also does an automatic "PLOT XSHIFT" and "PLOT YSHIFT" so as to place the origin of the current global coordinate system at the center of the plot. This can then be subsequently modified by the user with "PLOT XSHIFT" and PLOT YSHIFT" commands. If "shiftflag" is not explicitly set to a value, the local origin of the surface is centered on the plot.

PLOT LI - The "PLOT LI" command sets an internal program flag which causes the current "Lens Identifier" to be plotted on the current plot in the lower center when the next command, which generates optical system graphical output, is issued. If the "LI" is blank, no action is taken.

PLOT NOLI - The "PLOT NOLI" command cancels the effect of the "PLOT LI" command.

PLOT LBL , i - The "PLOT LBL" command sets an internal program flag which causes the lens database surface label at surface "i" to be plotted on the current plot in the upper left corner when the next command, which generates optical system graphical output, is issued. If the "LBL" for surface "i" is blank, no action is taken.

PLOT PROFY , i , j , , , clapflag and **PLOT PROFX , i , j , , , clapflag** - The "PLOT PROFY" and "PLOT PROFX" commands are used to plot the YZ and XZ-plane lens surface profile. These profiles are the projections of the surface's local coordinate system Y and X-axes upon the lens surface. The profile is bounded by the explicit or implicit clear aperture on that surface. A blank space will be left if there is an assigned obscuration. Mirror surfaces which have a non-zero mirror thickness assigned, will have an additional profile drawn which represents the back and sides of this mirror. If "clapflag" is 0 (the default), profiles are drawn even if no clear aperture is assigned. If "clapflag" is set non-zero, profiles are only drawn when clear apertures are assigned.

PLOT PROF , i , j , theta , , clapflag - The"PLOT PROF" command is a general form of the commands "PLOT PROFX" and "PLOT PROFY". It is used to plot surface profiles in any azimuthal orientation. The third numeric word "theta" specifies the azimuthal orientation angle. "Theta" is measured positive, counter-clockwize from the local surface positive x-axis to the local surface positive y-axis. "Theta" can be assigned any angle between 0.0 and 360.0 degrees. The default value for "theta" is 0.0. This is equivalent to a "PLOT PROFX" command. A "PLOT PROFY" command may be simulated with "theta" set to 90.0 degrees. The profile is bounded by the explicit or implicit clear aperture on that surface. A blank space will be left if there is an assigned obscuration. Mirror surfaces which have a non-zero mirror thickness assigned, will have an additional profile drawn which represents the back and sides of this mirror. This command generates no graphics for POLYGON clear aperture/obscuration surfaces. If "clapflag" is 0 (the default), profiles are drawn even if no clear aperture is assigned. If "clapflag" is set non-zero, profiles are only drawn when clear apertures are assigned.

PLOT EDGEY , i , j , , , clapflag and **PLOT EDGEX , i , j , , , clapflag** - The "PLOT EDGEY" and "PLOT EDGEX" commands are used to plot edges connecting non-air spaces. The edges connect the ends of surface profiles. These commands generate no graphics for POLYGON clear aperture/obscuration surfaces. If "clapflag" is 0 (the default), edges are drawn even if no clear aperture is assigned. If "clapflag" is set non-zero, edges are only drawn when clear apertures are assigned.

PLOT CLAP , i , j , k , , clapflag - The "PLOT CLAP" command is used to plot surface clear apertures projected onto the surface. The optional third numeric word "k" is used to specify fractional clear aperture plotting. The default value for "k" is 1.0. "k" may be set to any value greater than 0.0 and less than or equal to 1.0. Mirror surfaces which have a non-zero mirror thickness assigned, will have an additional clear aperture drawn which represents the back of this mirror. If "clapflag" is 0 (the default), clear apertures are drawn even if no clear aperture is assigned. If "clapflag" is set non-zero, edges are only drawn when clear apertures are assigned.

PLOT COBS , i , j - The "PLOT COBS" commands are used to plot surface obscurations projected onto the surface profile. The area inside the obscuration will be filled with a program selected cross-hatched pattern.

PLOT NODASH - The "PLOT NODASH" command is used to plot clear apertures and surface profiles of dummy surfaces with explicitly assigned clear apertures as solid rather than dashed lines.

PLOT DASH - The "PLOT DASH" command cancels the effect of the "PLOT NODASH" command.

PLOT RAY , i , j - The "PLOT RAY" command causes the most recent ray traced to be plotted from lens surface "i" to lens surface "j" . The internal operation of the "PLOT RAY" command is such that if the ray to be plotted is a failed ray, the ray will be plotted through the optical system up to the surface for which ray data becomes unreliable. This allows for "diagnostic" ray trace plots to be made. Rays may fail for any of the valid failure reason recognized by the program including ray failures due to blockages by clear apertures and obscurations when the "RAY CAOB" command is used to trace the ray.

PLOT RAYS , i , j , n , λ# , orintation_flag - The "PLOT RAYS" command causes a group of rays to be traced and plotted. from lens surface "i" to lens surface "j". "n" is the number of rays in the group, with a default value of 11. "λ#" is the wavelength number used for the trace, the default being the control wavelength. A chief ray, traced with a previous "FOB" command must already exist. If VIEVIG is OFF, the group is traced so as to fill the reference surface and rays are not blocked by clear apertures but are blocked by obscurations. If "VIEVIG" is ON, the extent of the group will be modified by automatic, on-the-fly, vignetting calculations and rays will be blocked by obscurations. If "orientation_flag" is set to 0, the default, the group will be a "fan" traced in the YZ plane. If "orientation_flag" is set to 1, the grpup will be a fan traced in the XZ-plane. If "orientation_flag" is set to 2, an aperture filling cone will be traced.

PLOT RAYSCO , i , j , n , λ# , orintation_flag - The "PLOT RAYSCO" is exactly like "PLOT RAYS" except that it drops failed rays reguardless of the VIEVIG setting.

PLOT PMRAYY , i , j - The "PLOT PMRAYY" command causes the upper and lower YZ-plane marginal generalized paraxial rays to be traced, referenced to the axial chief ray. Rays are drawn in "red". "i" and "j" are starting and ending surface numbers. The defaults are the object and image surfaces.

PLOT PMRAYX , i , j - The "PLOT PMRAYX" command causes the upper and lower XZ-plane marginal generalized paraxial rays to be traced, referenced to the axial chief ray. Rays are drawn in "red". "i" and "j" are starting and ending surface numbers. The defaults are the object and image surfaces.

PLOT PCRAYY , i , j - The "PLOT PCRAYY" command causes the upper and lower YZ-plane chief generalized paraxial rays to be traced, referenced to the axial chief ray. Rays are drawn in "red". "i" and "j" are starting and ending surface numbers. The defaults are the object and image surfaces.

PLOT PCRAYX , i , j - The "PLOT PCRAYX" command causes the upper and lower XZ-plane chief generalized paraxial rays to be traced, referenced to the axial chief ray. Rays are drawn in "red". "i" and "j" are starting and ending surface numbers. The defaults are the object and image surfaces.

VIRTRAY (ON or YES) or (OFF or NO)
The "VIRTRAY" command may be issued at any time from the CMD level. It sets a "sticky" switch which tells the program whether or not to draw "virtual" rays. "Virtual" rays are rays which go to and from dummy surfaces but which do not represent actual light paths in the optical system.. The program must always trace these "virtual" rays in order to correctly track optical path length (OPL). The program default is to not plot "virtual" rays. Most of the time, the user will not need to see these "virtual" rays. If the user wishes to draw the "virtual" rays, the command "VIRTRAY YES" should be issued. If the user then wishes to stop drawing "virtual" rays, the command "VIRTRAY NO" should be issued. "VIRTRAY" followed by the interrogator "?", will cause the current "VIRTRAY" setting to be displayed. The "PLOT NEW" command need not be issued before the "VIRTRAY" command can be issued.

PLOT VERTLINE , i , j - The "PLOT VERTLINE" command causes the line connecting the surface vertex locations from surface "i" to lens surface "j" to be plotted.

PLOT (RIGHT or CENTER or LEFT) - The "PLOT (RIGHT or CENTER or LEFT)" command attempts to RIGHT, CENTER or LEFT justify optical system plotting which follows these commands.

PLOT XSHIFT , x or PLOT YSHIFT , y - The "PLOT XSHIFT" and "PLOT YSHIFT" commands shift all optical system plotting which follows these commands, "x" or "y" device independent units, from their default positions. Positive and negative integer values are expected here.

PLOT GAMMA , γ - The "PLOT GAMMA" command rotates all optical system plotting which follows this command by γ integer degrees, counterclockwise about the center of the display. This center is located at x=5000 and y=3500 device independent units.

FIGURE , (alpha numeric string) - The "FIGURE" command allows the user to input a figure name for a following plot. Up to 80 characters may be entered.

PLOT FIGURE , x , y - The "PLOT FIGURE" command allows the user to place the current figure name on a graphic starting at coordinates "x" and "y" in the device independent coordinate system. If "x" or " y" are not input, their default values will be taken to be x=100 and y = 900.

PLOT LINE - The "PLOT LINE" command allows the user to draw a 3D line from coordinates X1, Y1, Z1 to coordinates X2, Y2 and Z2. The coordinates of these two points are always considered to be represented in the global coordinate system of the current optical system graphic in which the origin is either located at the vertex of surface 0 (for finit conjugate object points) or the vertex of surface 1 (for infinite conjugate object points). The coordinates of these two points are assigned using the following six commands. By default, both points are located at 0,0,0 when the program starts or when a new plot is initiated.

X1 or Y1 or Z1 or X2 or Y2 or Z2 - The "X1", "Y1", "Z1", "X2", "Y2" and"Z2" commands allows the user to specify the starting and ending coordinates of the next 3D line to be drawn. By default, the values are 0,0,0 when the program starts and when a new plot is initiated.

DISPLAYING GRAPHICS - The plotting commands discussed up to this point either set internal program flags or send graphics output to the disk internal file. At any time after issuing a "PLOT NEW" command and before issuing a "PLOT END" command, the current contents of the internal file may be displayed on the current screen display by issuing the "DRAW" command. After viewing this graphics display, pressing the <RETURN> key will clear these screen graphics and return the screen to the text mode for continued program input.

DRAW - The "DRAW" command is used to display graphics to the current screen device. Screen graphics is performed using an auxilliary piece of software named WDRAW.EXE.

GRAOUT - The "GRAOUT" command is used to generate monochrome (black and white) a hard copy of the current internal file to the default Windows printer controlled by the Windows Print Manager. Hardcopy graphics is performed using an auxilliary piece of software named WPLOT.EXE. "GRAOUT" is only included with the paid user support distribution of the program. It is a totally separate program.

GRAPHICS SECTION

GRAOUT COLOR - The "GRAOUT COLOR" command is used to generate color (color printers) or shaded grey scale (monchrome printers) hard copy of the current internal file to the default Windows printer controlled by the Windows Print Manager. If the default Windows printer is a PostScript printer, then EPS file capture is possible using custom settings in the Windows Print Manager set up windows.

GRAOUT WMF (optional file name up to 8 characters) - The "GRAOUT WMF" command is used to generate a monochrome (black and white) 16 bit Window's Metafile of the current internal file. The default file name is WMF.WMF. The file will always have the extension of WMF.

GRAOUT EMF (optional file name up to 8 characters) - The "GRAOUT EMF" command is used to generate a monochrome (black and white) 32 bit Extended Window's Metafile of the current internal file. The default file name is EMF.EMF. The file will always have the extension of WMF.

GRAOUT AMF (optional file name up to 8 characters) - The "GRAOUT AMF" command is used to generate a monochrome (black and white) 32 bit, Extended, Aldus Placeable Window's Metafile of the current internal file. The default file name is AMF.AMF. The file will always have the extension of WMF.

GRAOUT COLWMF (optional file name up to 8 characters) - The "GRAOUT COLWMF" command is used to generate a 16 bit Window's Metafile of the current internal file. The default file name is COLWMF.WMF. The file will always have the extension of WMF.

GRAOUT COLEMF (optional file name up to 8 characters) - The "GRAOUT COLEMF" command is used to generate a 32 bit Extended Window's Metafile of the current internal file. The default file name is COLEMF.EMF. The file will always have the extension of WMF.

GRAOUT COLAMF (optional file name up to 8 characters) - The "GRAOUT COLAMF" command is used to generate a 32 bit, Extended, Aldus Placeable Window's Metafile of the current internal file. The default file name is COLAMF.AMF. The file will always have the extension of WMF.

GRAOUT PCX (optional file name up to 8 characters) - The "GRAOUT PCX" command is used to generate a monochrome PCX file of the current internal file. The default file name is PCX.PCX. The file will always have the extension of PCX

GRAOUT COLPCX (optional file name up to 8 characters) - The "GRAOUT COLPCX" command is used to generate a color PCX file of the current internal file. The default file name is COLPCX.PCX. The file will always have the extension of PCX

GRAOUT BMP (optional file name up to 8 characters) - The "GRAOUT BMP" command is used to generate a monochrome BMP file of the current internal file. The default file name is BMP.BMP. The file will always have the extension of BMP.

GRAOUT COLBMP (optional file name up to 8 characters) - The "GRAOUT COLBMP" command is used to generate a color BMP file of the current internal file. The default file name is COLBMP.BMP. The file will always have the extension of BMP.

GRAOUT CBMP (optional file name up to 8 characters) - The "GRAOUT CBMP" co mmand is used to generate a monochrome compressed BMP file of the current internal file. The default file name is CBMP.BMP. The file will always have the extension of BMP.

GRAOUT COLCBMP (optional file name up to 8 characters) - The "GRAOUT COLCBMP" command is used to generate a compressed color BMP file of the current internal file. The default file name is COLCBMP.BMP. The file will always have the extension of BMP.

GRAOUT EPS (optional file name up to 8 characters) - The "GRAOUT EPS" command is used to generate a monochrome EPS (Encapsulated Post Script) file of the current internal file. The default file name is EPS.EPS. The file will always have the extension of EPS.

GRAOUT COLEPS (optional file name up to 8 characters) - The "GRAOUT COLEPS" command is used to generate a color EPS file of the current internal file. The default file name is COLEPS.EPS. The file will always have the extension of EPS.

GRAPHICS SCREEN DISPLAY

YESDRAW - The "YESDRAW" command is used to turn "on" screen graphics in the screen graphics mode. "On" is the default setting.

NODRAW - The "NODRAW" command is used to turn "off" screen graphics in the screen graphics mode. "On" is the default setting.

GRAPHICS SECTION

AUTO WMF GRAPHICS

YESWMF -The "YESWMF" c ommand is used to turn "on" automatic generation of a color Windows Metafile named RRR.WMF each time the "DRAW" command is issued by the program or by the user. "Off" is the default setting.

NOWMF - The "NOWMF" command is used to turn "off" automatic generation of a color Windows Metafile named RRR.WMF each time the "DRAW" command is issued by the program or by the user. "Off" is the default setting.

PLOT TERMINATION

PLOT END - The "PLOT END" command stops all graphic input to the current internal file, sets the internal program graphics flag to "off" and, if no graphic input was ever written to the internal file, then internal file is deleted. If graphic input was written to the internal file , then the internal file is saved.

THE PLOT LIBRARY - Just as there is a lens library, a macro library and a glass library, the program has a plot library. This library is used to save and recall plot files (copies of the internal file) for future use. After a "PLOT NEW" command is issued, the following commands may be used to graphically display or manipulate the contents of the program plot library:

IPF - The "IPF" command is the first of a two-part procedure used to initialize the plot library. To avoid accidental destruction of the existing plot library, the "IPF" command performs no plot library initialization unless it is followed immediately by the command:

PROCEED - If the command "PROCEED" is not immediately entered following the "IPF" command, then the "IPF" command is ignored and canceled. THIS INITIALIZATION PROCEDURE SHOULD BE USED WITH CAUTION AS LARGE AMOUNTS OF DATA MAY BE LOST IF IT IS USED CARELESSLY. The "IPF" command is intended for a user who has no plot library or for a user who intentionally desires to clean the slate and begin anew with an empty plot library.

PSTAT - The "PSTAT" command displays the number of plot file library entries used and the number of empty spaces remaining. The plot library can hold up to 999 plot files.

PLIB P - The "PLIB P" command displays a listing of the plot library file names with their time and date stamps. The names are specified using the "PLOT NAME" command described earlier in this section.

PLIB GET , i - The "PLIB GET" command causes the plot library entry designated by the integer library number "i" to be the target file for subsequent "DRAW" or "GRAOUT" commands. "i" can range from 1 to 999.

PLIB PUT , i or **PLIB PUT** - The "PLIB PUT" command stores the current contents of the internal file into either the plot library position designated by the integer value "i" or into the next open spot in the library if "i" is not specified. "i" can range from 1 to 999 .

PLIB DEL , i , j - The "PLIB DEL" command deletes the plotting library entries starting at the "i"th entry and ending with, and including, the "j"th entry. If "j" is omitted, only the "i"th entry is deleted.

LINE STYLES FOR FAN PLOTS - All transverse and longitudinal ray aberration and OPD fan plots use specific line styles based upon the wavelength number. They are:

WAVELENGTH #	LINE STYLE #
1	0
2	1
3	2
4	3
5	4
6	5
7	6
8	7
9	8
10	9

GRAPHICS SECTION

USER-DEFINED PLOTTING - The user may always issue a "PLOT NEW" command followed by "PLOT PEN" and other low level plotting command in order to generate a "user-defined" graphic. Using the re-entrant nature of the program graphics, the user can check on the progress of these plots by issuing "DRAW" commands periodically during this type of "user-defined" plotting. Normally, unction plotting; i.e. f(x) as a function of x would be slow and and so the following commands have been added which make plotting f(x) versus x relatively simple. It will be assumed that the user has issued a "PLOT NEW" command before using the following commands:

PLOT UXAXRNG , xstart , xstop - The "PLOT UXAXRNG" defines the x-locations of the start and stop of the x-axis of a user defined plot. The defaults are 2.0 and 8.0 inches respectively.

PLOT UYAXRNG , ystart , ystop - The "PLOT UYAXRNG" defines the y-locations of the start and stop of the y-axis of a user defined plot. The defaults are 1.4 and 5.6 inches respectively.

PLOT UXAXIS , xlower , xupper , dx , iflag , lflag - The "PLOT UXAXIS" defines the lower and upper limits for the units and extent of the x-axis of the plot. The x-axis will be spread from x=2.0 inches to x=8.0 inches on the plot assuming an 8-1/2 by 11 sheet of paper in the landscape mode, unless changed by the "PLOT UXAXRNG command. The x-axis will be divided into "d" intervals. The default for "dx" is 5. If "iflag" is non-zero, only the end point ticks will value lables, otherwise all ticks will be labled. If "lflag" is non-zero then no axis lables will be plotted.

PLOT UYAXIS , ylower , yupper , dy , iflag , lflag - The "PLOT UYAXIS" defines the lower and upper limits for the units and extent of the y-axis of the plot. The y-axis will be spread from y=1.4 inches to x=5.6 inches on the plot assuming an 8-1/2 by 11 sheet of paper in the landscape mode., unless changed by the "PLOT UYAXRNG command. The y-axis will be divided into "dy" intervals. The default for "dy" is 10. If "iflag" is non-zero, only the end point ticks will value lables, otherwise all ticks will be labled. If "lflag" is non-zero then no axis lables will be plotted.

PLOT UXAXISLB (x-axis label up to 40 characters) - The "PLOT UXAXISLB" defines the x-axis label. The label can be up to 40 characters.

PLOT UYAXISLB (y-axis label up to 40 characters) - The "PLOT UYAXISLB" defines the y-axis label. The label can be up to 40 characters.

PLOT UYLINE , xvalue - The "PLOT UYLINE" draws a line in the y-direction, the full extent of the length of the y-axis but located at x= "xvalue".

PLOT UXLINE , yvalue - The "PLOT UXLINE" draws a line in the x-direction, the full extent of the length of the x-axis but located at y= "yvalue".

PLOT UPLOT x-reglow , x-reghigh , y-reglow , y-reghigh , linestyle# - The "PLOT UPLOT" causes the functional values stored in general purpose storage registers numbered "y-reglow" to "y-reghigh" to be plotted versus the independent variable values stored in general purpose storage registers "x-reglow" to "x-reghigh". Straight line segments are used to connect all of the data points. Lines are drawn using the current color for plotted rays and in the line style designated "linestyle#". The default line style is a solid line, type 0. There are 10 available line styles designated as 0 to 9. Between issuances of "PLOT UPLOT" the values stored in the registers holding the functional values may be changed and as many user-defined functional plots as are desired can be plotted. The user may of course use "PLOT PEN" , "PLOT NOTE", and other user-defined plotting commands to augment these functional plots.

USER-PLOTTING EXAMPLE - The following macro named PLOTTEST generates a simple plot using 3 independent variable values 0, 2.5 and 5 and three associated dependent variable values 0, 1 and 10. The commands described above, used with the "SET X" command and the "STO" command are all that is required to generate a simple plot. The line style is set using the "PLOT LSTYLE" command. Line type 2 is a short dash type of line. To input this macro, simple type the following commands as they appear, each command followed by a press of the Enter key.

MACRO PLOTTEST
SET X 0
STO 1
SET X 2.5
STO 2
SET X 5
STO 3
SET X 0
STO 4
SET X 1
STO 5
SET X 10
STO 6
PLOT NEW
PLOT LSTYLE 2

GRAPHICS SECTION

PLOT UXAXIS 0 5
PLOT UYAXIS 0 10
PLOT UXAXISLB X-AXIS
PLOT UYAXISLB Y-AXIS
PLOT UPLOT 1 3 4 6
DRAW
EOM

OPTMIZATION SECTION

OPTIM-GENERAL INFORMATION - Optimization is the process of automatically changing values associated with lens database parameters, alternate configuration database parameters and/or special surfaces database parameters (known as variables) so that the values of a set of automatically defined or pre-defined or user-defined optical system metrics (known as operands) related to these databases change from their present values toward future targeted values. The set of variables is established at a program level beneath the CMD level known as the VARIABLE level. The program can have up to MAXREG/MAXOPT variables (the default is 4000 but it may be set to any value using the MAXREG and MAXOPT commands described else where) active in an optimization. The list of operands is established in a program level beneath the CMD level known as the MERIT level. The program can have up to MAXOPT operands active in a merit function . After the variables set (known hereafter as the "variables" and the operands set (known hereafter as the MERIT FUNCTION) have been established, optimization is carried out interactively by the user at the CMD level through a series of CMD level optimization commands. Several of the optimization techniques described in this section, are also described in the text, "NUMERICAL RECIPES in FORTRAN", second edition, Cambridge Press, 1992, authors: Press, Teukolsky, Vettering and Flannery. For the rest of this section, this text will simply be refered to as "NUMERICAL RECIPES".

OPTIMIZATION SPEED

The default mode of ray tracing for Roadrunner (LT) is full ray aiming to relative positions in the REFERENCE surface. This can be up to 10 times slower that when rays are fired at a lens, without ray aiming. If AIMRAY is set to NO, prior to optimization, the process of derivative calculation and operand evaluation can be greatly accelerated. The price for this acceleration is that rays are aimed at the paraxial rather than at the real entrance pupil and this may not be ideal for systems with decentered or tilted elements. If you wish to try this faster method of optimization, it is best to set SAY to "FLOAT" as this makes certain that the entrance pupil diameter will fill the clear aperture assigned to the stop surface.

VARIABLES

CREATING VARIABLES

VARIABLE or **VARI** - The "VARIABLE" or "VARI" command causes the program to leave the CMD level and enter the VARIABLE input level. The variables memory area is wiped clean and is ready for new variables input. Between "VARIABLE" or "VARI" and "EOS" or "END", any VARIABLE input level command may be entered.

EOS or **END** - The "EOS" or "END" or "END" command, issued from the VARIABLE level, causes the program to return to the CMD level. The variables set is left in memory and is ready for optimization.

MODIFYING VARIABLES

UPDATE VARIABLE or **U VB** - The "UPDATE VARIABLE" command, or its abbreviated form "U VB", causes the program to leave the CMD level and enter the UPDATE VARIABLE level. The variables memory area is opened and is ready for modification. Between "UPDATE VARIABLE" or "U VB" and "EOS" or "END", any UPDATE VARIABLE level command may be entered.

DEL (variable name) , i , j - The "DEL" command, issued from the UPDATE VARIABLE level, causes the program to delete the variable with name = "variable name" at surface "i" and alternate configuration "j". If "j" is not explicitly entered, it is assumed to be 1, the main configuration.

EOS or **END** - The "EOS" or "END" command, issued from the UPDATE VARIABLE level, causes the program to return to the CMD level. The variables set is left in memory and is ready for optimization.

CURVATURE OR RADIUS - The choice of whether to use curvature or radius of curvature as a variable in optimization must be addressed now. Curvature is the reciprocal of radius of curvature. Ray tracing equations are best cast in terms of curvature rather than radius of curvature. A zero curvature value represents a flat or "plano" surface. A zero radius of curvature represents a perfect point. Flat surfaces occur in real optical systems, point surfaces generally don't. Rays can't gereally be traced through point surfaces. Consider a surface with a radius of curvature of -10.0 lens units. As the surface becomes flatter, the radius of curvature becomes larger and larger until the radius becomes infinite when the surface becomes flat. This can not be represented well using our number system. If the surface is characterized by curvature instead of radius of curvature, the curvature value starts off at -0.1, decreases to 0.0 and then can become positive without ever going through a singularity at 0.0. This is why radius of curvature is a BAD variable and it makes optimization a nightmare as a curvature changes sign. Whenever the user uses RD or RDTOR as variables, the program attempts as best it can to convert the variable to CV or CVTOR respectively. DINCR values are NOT converted. The input DINCR value, if one is explicitly input, is always considered to be in units of curvature. The limit values input, if they are explicitly input, are converted to curvature equivalents as well as they can be but there are cases where the limits will be set back to the defaults of + and - 1.0D+20. This occurs when the limits have different signs and bracket 0.0 radius of curvature. Here is an example: Radius = -10.0. Limit values for radius of curvature are input as -20.0 and +30 lens units. The corresponding curvature values are -0.1 for the starting curvature value and -0.05 and +0.033333 for the bounding limit values. These limit values do not bracket the starting value!. In cases such as this, the program replaces the input limit vales with + and - 1.0D+20 inverse lens units or curvature.

OPTMIZATION SECTION

VARIABLES COMMANDS - The name of a variable is the name of the command used to insert that variable into the variable set. The commands have the following form:

(Variable Name) , i , wt , dincr , limit value 1 , limit value 2 or **(Variable Name) ALL , wt , dincr , limit value 1 , limit value 2** - "i" is the surface number in the lens database to which the variable is associated. "wt" is the relative weight or importance of the variable in the optimization process. The weight may range from 0.0 (not important) to 1.0 (most important). The default for "wt" is always 1.0. The "dincr" is the change to the variable value used in the derivative calculation. "dincr" values, if not explicitly input by the user, are set to "default" values. The default "dincr" values vary for each variable. They are listed in the next table. The "limit value 1" and "limit value 2" are boundary condition values. The order of input, i.e. high or low, is not important. Their defaults are -1.0D+20 and +1.0D+20, respectively for most variables. The default limits for angle variables are +/- 360.0 degrees. The default limits for refractive index values are 1.0 and 2.0. The default limits for "VNUM" are 0 and 200. The default limits for "DPART" are +/- 200. The default limits for deformable surface actuator variables are +1.0 and -1.0. The following table lists the lens and special surface database items which may be included in the variables set: If the second form of the command is issued, the one with qualifier word "ALL", then variables will be entered into the variable set for all eligible surfaces. The exceptions are: Curvatures or radii of a dummy surface or the object or the image surface will not be entered. Thicknesses of the object surface, the image surface and of entrance and exit pupil surfaces will not be entered. "INDEX", "VNUM" and "DPART" will only be entered for "MODEL" glasses and refractive index variables "N1" through "N10" will only be entered for "MYGLASS" glasses. For NSS variables, "i" is the NSS surface number.

VARIABLE NAME	DESCRIPTION	DEFAULT "dincr" VALUE
RD	Radius of curvature. This is automatically converted to CV.	
CV	Surface curvature	1.0D-5
TH	Axial distance to next surface	1.0D-5
CC	Surface conic constant	1.0D-7
AD	4th order aspheric coefficient	1.0D-11 / 1.0D-7 *
AE	6th order aspheric coefficient	1.0D-15 / 1.0D-7 *
AF	8th order aspheric coefficient	1.0D-19 / 1.0D-7 *
AG	10th order aspheric coefficient	1.0D-23 / 1.0D-7 *
AH	12th order aspheric coefficient	1.0D-27 / 1.0D-7 *
AI	14th order aspheric coefficient	1.0D-31 / 1.0D-7 *
AJ	16th order aspheric coefficient	1.0D-35 / 1.0D-7 *
AK	18th order aspheric coefficient	1.0D-37 / 1.0D-7 *
AL	20th order aspheric coefficient	1.0D-41 / 1.0D-7 *
RDTOR	Toric radius of curvature. This is automatically converted to CVTOR.	
CVTOR	Toric curvature	1.0D-5
CCTOR	Toric conic constant	1.0D-7
ADTOR	4th order anamorphic aspheric term	1.0D-11 / 1.0D-7 *
AETOR	6th order anamorphic aspheric term	1.0D-15 / 1.0D-7 *
AFTOR	8th order anamorphic aspheric term	1.0D-19 / 1.0D-7 *
AGTOR	10th order anamorphic aspheric term	1.0D-23 / 1.0D-7 *
ALPHA	Alpha surface tilt angle	1.0D-7 (degree)
BETA	Beta surface tilt angle	1.0D-7 (degree)
GAMMA	Gamma surface tilt angle	1.0D-7 (degree)
XD	Surface X-decentration	1.0D-7
YD	Surface Y-decentration	1.0D-7
ZD	Surface Z-decentration	1.0D-7
GALPHA	Global alpha surface tilt angle	1.0D-7 (degree)
GBETA	Global beta surface tilt angle	1.0D-7 (degree)
GGAMMA	Global gamma surface tilt angle	1.0D-7 (degree)
GXD	Surface global X-decentration	1.0D-7
GYD	Surface global Y-decentration	1.0D-7
GZD	Surface global Z-decentration	1.0D-7
PIVX	Surface alternate x-pivot location	1.0D-7
PIVY	Surface alternate y-pivot location	1.0D-7
PIVZ	Surface alternate z-pivot location	1.0D-7
N1 through N10	Refractive index at wavelength 1 to 10 for a "MYGLASS" material	1.0D-6
INDEX	Nd value of a "MODEL" glass	1.0D-6
VNUM	Vd value of a "MODEL" glass	1.0D-6

OPTMIZATION SECTION

VARIABLE NAME	DESCRIPTION	DEFAULT "dincr" VALUE
DPART	Partial Dispersion shift of a "MODEL" glass	1.0D-6
C1 through C96	96 special surface coefficients	1.0D-11
AC	2nd order surface aspheric term	1.0D-7 / 1.0D-7 *
CLPX	X - clear aperture height	1.0D-5
CLPY	Y - clear aperture height	1.0D-5
GRS	diffraction grating spacing	1.0D-5
ATxxxxx	Normalized actuator position for actuator number xxxx on a deformable surface. Range lies between 1.0 and –1.0. NOTE: ACTxxxx variables are only available at CFG 1. The xxxx values specify specific actuators which are to be variables. The counting scheme is illustrated in the LENS section of this manual in the DEFORMABLE surface description.	1.0D-11
MACVAR	Storage variable register. In the case of this variable, the first numeric word is the general purpose storage register number rather than a surface number.	1.0D-11
NSSXPOS	X-position of the NSS database surface	1.0D-7
NSSYPOS	Y-position of the NSS database surface	1.0D-7
NSSZPOZ	Z-position of the NSS database surface	1.0D-7
NSSALPH	Alpha rotation of the NSS database surface	1.0D-7 (degree)
NSSBETA	Beta rotation of the NSS database surface	1.0D-7 (degree)
NSSGAM	Gamma rotation of the NSS database surface	1.0D-7 (degree)
V1	Numeric word #1 of the SPROFILE definition	1.0D-7
V2	Numeric word #2 of the SPROFILE definition	1.0D-7
V3	Numeric word #3 of the SPROFILE definition	1.0D-7
V4	Numeric word #4 of the SPROFILE definition	1.0D-7
V5	Numeric word #5 of the SPROFILE definition	1.0D-7
P001 to P200	Value of NSS surface parameter 1 to 200	1.0D-7

The "dincr" values used for aspheric surface coefficients have three default values. The first default value is based upon an internal program algoithm which considers the control wavelength value and the paraxial marginal and paraxial chief ray heights at the current surface. In the case that both of these paraxial ray height values are zero, then the second or third default values, shown in the table above, will be used. The second default value will be used if the maximum value of the sum of the absolute values of the marginal and chief paraxial ray heights at the current lens is greater than or equal to 1.0 lens units. The third default value will be used if the the sum of the absolute values of the marginal and chief paraxial ray heights at the current is less than 1.0 lens units. If these defaults cause problems in a particular system, then set these aspheric "dincrs" by hand during variable specification. In alternate configuration optimization, the specific indices to be varied by the "N1" through "N10" variables must be explicitly input into the alternate configuration using the "N1" through "N10" UPDATE LENS commands from within the alternate configuration command structure. All lens solves and PIKUPs take precedence over variable definitions. If there is a conflict, the variable definition will be disallowed or deleted.

CONTROL OF VARIABLE LIMITS

Variable limits are held as hard limits beyond which the variable will not go. Variable limits are generally set in the syntax of the variable input or variable change syntax. There are a few instances wherein limits for all variables of one specific type may wish to be set. The default limits for the variables "TH", "CV" and "CVTOR" may be controlled using the following CMD level commands:

MXT , mxt - The "MXT" command resets the maximum allowable value for all TH variables to the value "mxt". By default, the value is 1.0D+20.

MNT , mnt - The "MNT" command resets the minimum allowable value for all TH variables to the value "mnt". By default, the value is -1.0D+20. For refractive systems in which no thicknesses should become zero, "mnt" should be set to some small non-zero value like 0.001.

MPR , mpr - The "MPR" command resets the maximum allowable value for all CV and CVTOR variables so that the resulting radius never takes on a value between "mnt" and "mxt". By default "mxt" = 1.0D-20.

MNR , mnr - The "MNR" command resets the minimum allowable value for all CV and CVTOR variables so that the resulting radius never takes on a value between "mnt" and "mxt". By default "mnt" = -1.0D-20.

CONFIGURATIONS FOR VARIABLES

CFG , i - The "CFG" command is a "sticky" command. It causes any variable added to the variables set to be active only for alternate configuration "i". Alternate configuration "i" will remain the understood configuration for variables input until changed by another "CFG" command or until an "EOS" or "END" command is issued. If the "CFG" is not entered, the main configuration, 1, is assumed.

DEFAULT DINCR VALUES

DINCR (variable name) , dincr - During variable input or update, a specific "dincr" value may be input for a each variable. If this is not done, then the default values listed in the previous table will be used as the "dincr" values. The "DINCR" command is a CMD level command which has been added to allow the user to change the default "dincr" values which will be used if specific "dincr" values are not input during variable input or update. For example; to change the default "dincr" value for all thickness variables to 0.01, the command "DINCR TH , 0.01" would be entered. If the user wishes to always have a different set of default "dincr" values each time the program is run, then the user can put a set of customized "DINCR" commands in the DEFAULTS.DAT file. If a variable has two default "dincr" values associated with it, the second default "dincr" value is changed by using the "DINCR" command with the variable name to which a "2" has been appended. To change the first default "dincr" value associated with ADTOR to .001, the command "DINCR ADTOR   .001" would be used. To change the second default "dincr" value associated with ADTOR to .00003, the command "DINCR ADTOR2 .00003" would be issued.

INTERROGATION OF VARIABLES - The next four commands are valid at the VARIABLE, the UPDATE VARIABLE and also at the CMD levels.

VB , i - The "VB" command displays the variable name, the associated lens database surface number, the associated alternate configuration number, the current variable value and the last change made to the variable. If "i" is explicitly input, only the variable data for variable number "i" will be displayed. If "i" is omitted, data for all current variables will be displayed.

VBA , i - The "VBA" command displays auxiliary variable data. Auxiliary variable data consists of the variable name, the associated lens database surface number, the associated alternate configuration number, the low limit value, the high limit value, the weighting factor and the current "dincr" multiplied by the current "DINMUL" value. If "i" is explicitly input, only the auxiliary variable data for variable number "i" will be displayed. If "i" is omitted, auxiliary data for all current variables will be displayed.

VB CFG , i - The "VB" command, issued with the qualifier word "CFG" and an explicit alternate configuration number "i", displays the variable names, the associated lens database surface number, the associated alternate configuration number, the current variable value and the last change made to the variable for all variables which are active in the specified alternate configuration. "i" must be explicitly input.

VBA CFG , i - The "VBA" command, issued with the qualifier word "CFG" and an explicit alternate configuration number "i", displays the variable names, the associated lens database surface number, the associated alternate configuration number, the low limit value, the high limit value, the weighting factor and the current "dincr" multiplied by the current "DINMUL" value for all variables which are active in the specified alternate configuration. "i" must be explicitly input.

OPERANDS AND THE MERIT FUNCTION - There are three techniques that may be employed in order to set up a merit function. The first technique is to let the program build one for you using the DEFAULT OPERAND BUILDER. The second method is to build a merit function using predefined operands from the list of available predefined operands found later in this section. The third method is for the user to design user-defined operands using macro functions. This last method is rarley needed and should be only attempted by experienced users. If the DEFAULT OPERAND BUILDER method is to be used with the addition of single ray based predefined operands, it should be remembered that the FIELDS and RAYS which are automatically set up by the DEFAULT OPERAND BUILDER will be the set of FIELDS and RAYS available for use with the single ray based predefined operands. If a single ray based predefined operand needs to be added to a merit function originally set up using the DEFAULT OPERAND BUILDER, then the user needs either to use the FIELDS and RAYS which were created by the DEFAULT OPERAND BUILDER or the user must "tack on" new FIELD and RAY definitions at the end of the current FIELDS and RAYS definitions.

DEFAULT OPERAND BUILDER - Building the best merit function for a specific optimization job is not a simple thing to do. People who can build good merit functions from scratch usually get the best designs. For those less adventurous, we provide a set of commands which will build a reasonably good set of operands which should get you started in optimization. These operands will only build the part of the merit function which corrects image quality. You will need to add other operands should you wish to control things like EFL, OAL etc. The commands described here replace any previously defined FIELD and RAY position definitions. FIELDS and RAYS will be discussed shortly. All command settings for the default operand builder remain in effect until a "MERIT" command is issued or until the program terminates. OK, here goes, I'll try to keep it simple. The following commands are CMD level commands issued only at the CMD level. The operands included in this "default" merit function are by no means the only operands which could be used. They may not be the best ones to use. Other operands from the extensive operand list may be added at any time to this "default" list.

OPTMIZATION SECTION

MONO/POLY CHROMATIC - The default mode of the default operand builder is MONOCHROMATIC. Operands are only created for the "control" wavelength. This is the most efficient way to use the default operand builder because chromatic effects are always best controlled by just a few rays traced at other than the control wavelength and large numbers of rays defining large numbers of operands at multiple wavelengths just don't ever work well in removing chromatic effects (chromatic effects are first order in nature and should be corrected via glass choice and power balance before higher order aberrations are corrected). This is not just true of this program but is true of all design codes. If it is desired to build polychromatic operands, use the "POLY" command but remember is very easy to create huge numbers of unresponsive operands if the default builder is used carelessly.

MONO and **POLY**   - Sets the default merit function builder to monochromatic or polychromatic mode. Default is "MONO"

NUMBER OF FIELD POSITIONS

DFP , n - The CMD command "DFP" is used to set the number of field of view positions to be used to construct the default merit function. The default value of "n", if "DFP" is not issued, is "3". All field positions are specified in terms of fractional object heights as is done when using the "FOB" command during regular ray tracing. A maximum of 25 field of view positions are allowed.

FP , i , fx , fy , fwt , λ#   - The CMD command "FP" is used to specify the fractional object or FOB values for field of view position "i". The "fwt" entry allows assigning different weights to operands belonging to different fields of view. If not explicitly entered, all field weights, "fwt", are set to 1.0. "λ#" is the wavelength at which the rays for that field point will be traced. Its default value will be the control wavelength. Before these field of view positions are set up, the FIELDS and RAYS discussed earlier are reset to their default values via automatic executions of the "FIELDS RESET" and "RAYS RESET" commands. It is almost never necessary to trace the chief rays generated by the "FP" commands at any wavelength other than the control wavelength. If no "FP" commands are issued, then the default values for the first three field of view positions will be:

i	fy	fx	fwt	λ#
1	0.0	0.0	1.0	control wavelength
2	0.7	0.0	1.0	control wavelength
3	1.0	0.0	1.0	control wavelength

OPTMIZATION SECTION

RAY GRID SHAPE

DFGRID (RECT or **HEX)** - The CMD command "DFGRID" is used to specify whether the ray grid distribution over the aperture is to be a rectangular grid, similar to the type of ray grid used in CODE-V or a hexapolar grid similar to the one used in ZEMAX. The default shape is "HEX".

RAY GRID SIZE

DFHEX , nring, nsec - This command is used to specify the number of pie sections in every ring, "nsec" (default = 8) and the number of radial rings, "nring" (default is 2, at fractional aperture radii of 1.0 and 0.5) which are to be used when the ray grid shape is set to "HEX". The radii of the rings will be set automatically so as to best sample the aperture. Maximum value for "nsec" is 32. Maximum value for "nring" is 20.

DFDEL , dfdel - This command is only used when the ray grid shape is set to "RECT". The CMD command "DFDEL" is used to set the fractional ray spacing in the reference surface for the grid of rays used by the operands. Valid input values range from 0.1054 to 1.414213. The ray pattern is rectangular and is always an even pattern (no ray at the reference surface center). For rectangular apertures, a square pattern of rays is used which covers the rectangle. For non-rectangular apertures, a circularly clipped rectangular pattern of rays is used which covers the non-rectangular aperture. The following table lists the number of rays in a "circularly clipped" pupil for various values of "dfdel". The default value is 0.385. This is the same ray pattern used in CODE-V.

"dfdel"	# rays (non-rect. aperture)
1.41423 – 0.632456	4
0.632455 – 0.471405	12
0.471404 – 0.392233	16
0.392232 – 0.342998	24
0.342997 – 0.282843	32
0.282842 – 0.262613	44
0.262612 – 0.232496	52
0.232495 – 0.220864	60
0.220863 – 0.210819	68
0.210818 - 0.202031	76
0.202030 – 0.194258	80
0.194257 – 0.181072	88
0.181072 – 0.175412	96
0.175411 – 0.165522	112
0.165521 – 0.157135	120
0.157134 – 0.153393	124
0.153392 – 0.149907	140
0.149906 – 0.143592	148
0.143591 – 0.140720	156
0.140719 – 0.135458	164
0.135457 – 0.133039	172
0.133038 – 0.130745	180
0.130744 – 0.128565	188
0.128564 – 0.126492	192
0.126491 – 0.120825	208
0.120824 – 0.117445	216
0.117444 – 0.115857	232
0.115856 – 0.114333	240
0.114332 – 0.112867	248
0.112866 – 0.108786	256
0.108786 – 0.107521	268
0.107520 – 0.105400	276

STARTING RECOMMENDATIONS

For rotationally symmetric systems with spherical surfaces start with dfdel = 0.385. For systems with conics use dfdel = 0.28. For systems with aspherics and anamorphics start at dfdef = 0.22 and go down as needed.

OPTMIZATION SECTION

OPERAND TYPES - There are two operand types. The first type is based only on transverse ray aberrations (positional for MODE FOCAL and UFOCAL and angular for MODE AFOCAL and UAFOCAL). The second type adds to these transverse aberrations, the derivatives of these aberrations with respect to position in the aperture and also adds Optical Path Differencs (OPD).

DFTYPE , merit type designator , wt1 , wt2 , wt3 - The CMD command "DFTYPE" is used to set the type of operands used in the default merit function according to the following table:

merit type designator	Operands used
1	DR *
2	DR, DRDR and OPD*

* The default type is type 1. If the lens mode is AFOCAL OR UAFOCAL, then DR is replaced by DRA and DRDR by DRADR. The "wt1" is used to assign a relative weight to the DR operands. "wt2" is used to assign a weight to the DRDR operands. "wt3" is used to assign a weight to the OPD operands. By default, "wt1", "wt2" and "wt3" are set to 1.0. The "VIG" command now works with all these operands.

CREATING/UPDATING OPERANDS

MAKEAUTO , cfg# - The "MAKEAUTO" command causes the program to create (if no operands exist) or update (if operands already exist) the merit function using a number of automatically generated UPDATE MERIT commands. All operands are created or modified using the current field and ray position definitions, APOD setting, and wavelength number λ#. Operands will be created for all wavelengths which have non-zero spectral weights. If "cfg#" is not specified, operands will be designated as alternate configuration #1 operands. Field and Ray position definitions are rebuilt each time the "MAKEAUTO" command is issued, based upon the field position definitions, the ray grid spacing definitions and the wavelength definitions stored with the field positions and specified in the "MAKEAUTO" command. Non-chief rays are always traced at the wavelength specified by the "MAKEAUTO" command. All "default" operands are understood to be evaluated at the final surface of the current lens database. It is not usually efficient to create full lists of operands for every wavelength unless it is known that the shape of the aberrations is a strong function of wavelength. It is better to create one set of operands at the control wavelength and then correct chromatic effects using operands like PACM, PACZ , PLCM, PLCZ, SACM, SACZ, SLCM and/or SLCZ.

CONFUSED – TRY THIS - Take all the defaults by simply entering the command "MAKEAUTO". This will yield a respectably good merit function for rotationally symmetric systems using spherical surfaces.

This is the end of the discussion of default merit functions.

CMD LEVEL OPTIMIZATION COMMANDS

The actual process of optimization is handled interactively by the user at the CMD level. A form of batch processing optimization can be simulated using macros. After the variables and the merit function have been defined, the following commands are used to initiate optimization:

ITER , n or **IT , n** - The "ITER" or "IT" command initiates "n" [blank = 1] cycles of a Levenberg-Marquart Damped Least Squares (DLS) optimization cycle. First, the current "dincr" value for each variable multiplied by the current "DINMUL" is used to calculate partial derivatives of each operand in the merit function. These first partial derivatives form the so-called "derivative matrix". Using the current PFAC or damping factor, the linearized least squares problem is then solved using Singular Value Decomposition (SVD). The result is a "solution vector". This is a vector whose components are the changes to the current variables which should cause the figure of merit to decrease. This "solution vector" is applied to the LENS, CONFIGS and/or SPSRF databases as appropriate, the operands are then re-evaluated and the new figure of merit and the change in figure of merit are displayed. The new figure of merit is also automatically placed in the accumulator or X-register.

OPTMIZATION SECTION

SV - The "SV" command initiates an abbreviated Levenberg-Marquart Damped Least Squares (DLS) optimization cycle using the current damping factor. If a derivative matrix already exists, it is used instead of calculating a new matrix. If no derivative matrix exists, then this command operates exactly as if it had been an "ITER" command.

RSV - The "RSV" command acts by issuing a "RESTORE" command followed by a "SV" command and is useful when doing a PFAC search by hand. If no derivative matrix exists, then this command operates exactly as if it had been an "ITER" command.

PFIND , max cycl. , change factor - The "PFIND" command causes a series of "PM PFAC (new damping factor)"and "RESOLVE" commands to be issued until an "optimum" damping factor has been found. The default "max cycl." is 10. The default "change factor" for constant multiplicative damping is 0.6. The default "change factor" for constant additive damping is 0.01. A "RESOLVE" is then performed and the current figure of merit is compared to the previous figure of merit. A decision is made as to whether a new "pfac" value will continue to reduce the figure of merit. When more than two unsuccessful attempts to reduce the figure of merit occur or when ten ("max cycl.") cycles have been performed, the process is stopped and the best damping factor and corresponding figure of merit are displayed. If "PFIND" parameters are reset, they remain as set until reset again or until program termination.

ITER FULL , n or **IT F , n** - "ITER FULL" or "IT F" causes "n" (blank = 1) cycles of ITER FULL to be executed. Each cycle consists of an "ITER" command followed by a "PFIND" command followed by a second "ITER" command to be issued. "RESTORE" will not undo this command.

ITER DIR , n or **IT D , n** - "ITER DIR" or "IT D" causes "n" (blank = 1) cycles of a "direct" rather than a "damped least squares" solution to be attempted. This only works when there is known to be an exact solution and can cause unexpected results if only an approximate solution exists.

ITER POWL , n or **IT P , n** - "ITER POWL" causes "n" (blank=1) cycles of Powell's optimization method to be performed. Each cycle of "ITER POWL" or "IT P" causes one full cycle of "Powell's Method" to be performed. If a damped least squares matrix exists, that matrix is made used. Powell's method is powerful and unrelated to the "damped least squares" method. It is provided as another tool which may have some merit in freeing some "stuck" systems. The damping factor has no effect during "ITER POWL.

ITER ADJUST , (n , m) or **IT A , (n , m)** or **IT ADJ (n , m)** - "ITER ADJUST" adjusts the lengths of each column in the change matrix used in damped least squares optimization by adjusting the variable "dincr" values so that the sums of the absolute values of each column of the change matrix (column totals) are each equal to the average of the sum of all the column totals. If "n" is present (any value), no new matrix is created if one already exists, else a new matrix is created. If "m" is present (any value), then the program operating condition "LINTOL" is used per the description for "LINTOL" to automatically re-set the DINMUL value, else the DINMUL value is left unchanged by "ITER ADJUST".

RESTORE , i - The "RESTORE" command causes the lens to be restored to its state before the last "ITER" or "ITER,1" command. The default value for "i" is 0 indicating a complete restore. "i" may range from 0 to 1. A non-zero "i" indicates the restore will be made as a fractional distance from the previous state to the current state. A value of "i" = 1 means that no restore will be applied. Restoration is made through fractional movement along the last solution vector. If it runs excessively long, you may cancel the run with a CTRL C or CTRL BREAK.

RESTORE MIN - The "RESTORE MIN" initiates a search along the current solution vertor for a minimum solution. The derivative matrix is not used.

OPTMIZATION SECTION

ROBB, β , δ , rmax - In the December 15, 1979 issue of APPLIED OPTICS, Vol. 18, No. 24, Paul N. Robb published a paper entitled "Accelerating convergence in automatic lens design". The article states that if a solution vector exists, that a greater improvement in the system figure of merit may sometimes be had by applying a scale factor to the solution vector and then applying that scaled solution vector to the lens. The paper only discussed this acceleration technique as it applied to a solution vector which came from a "damped least squares" solution method. This may be where the acceleration technique has its greatest potential benefit. In this program, the "ROBB" acceleration technique may be applied to any solution vector obtained from any of the solution methods listed above. The "ROBB" command causes a sequence of solution vector scaling by the scalar constant (β times δ). If the resultant figure of merit is less than it was using the un-scaled solution vector, then the scale factor is again multiplied by δ and the process is repeated. If the figure of merit fails to be reduced, the process stops and the last scaled solution vector which produced an improvement in the figure of merit is applied to the lens. By default β = 1.0 and δ = 1.1. Any values for β and δ may be issued with the "ROBB" command. Damping. If "rmax" number of cycles are performed, the process stops. The default value for "rmax" is 50.

ITER MDUMP or **IT MDP** - The "ITER MDUMP" command causes the current change or difference matrix to be displayed in a compact form. Four variables at a time are listed across the display and 20 operands at a time are listed down the display. If no matrix exists, a message to that effect is issued.

ITER MDUMPA or **IT MDPA** - The "ITER MDUMPA" command causes the current change or difference matrix to be displayed in a non-compact way with more attendant captioning. If no matrix exists, a message to that effect is issued. In order to avoid conflicts with the user-defined optimization described in the OPTUSER manual section (the optimization which specifically uses the macro named "MACROOPT"), the "IT", "ITER", "RESOLVE", "RSV", "RESTORE", "PFIND" and "ROBB" commands should NOT be used from within a macro while the macro "MACROOPT" is being used to define operands. This restriction does NOT apply when using macro functions to perform operand definitions.

VERBOSE ITER

OVERBOSE ("ON" or "YES" or "OFF" or "NO") - Whenever the user enters an "ITER" or a "RESOLV" command, the program outputs the resultant figure of merit at the conclusion of that optimization cycle. Sometimes the use wishes to automatically see the current values of all variables and operands after each iteration, even when multiple cycles of "ITER" are requested using the optional numeric word input for "ITER". Setting the "OVERBOSE" flag to "ON" or "YES" with the "OVERBOSE" command, causes this additional data to be output at the end of each cycle. The program default setting is "OVERBOSE OFF/NO". The setting is remembered as part of each specific lens database.

BOUNDARY CONDITIONS - The upper and lower limit values, which can be input in the variables definitions, are used only to trigger warning messages to be displayed if these boundary conditions are violated. It is up to the user to freeze and unfreeze variables if they move to unreasonable values.

NEW-TRY THIS - Programs which take control or optimization are nice right up to the point that they stop working. Then they are useless. This program does not take that control. It leaves it with you, the designer. I personally start with "ITER". Then I try to see if "PFIND" can find a better damping factor. Then another ITER. If the figure of merit increases, use "PFAC" to increase the damping factor. Also try "ROBB" and "ITER POWELL". No method works the same for any two designs. You will need to try different approaches, possible even changing the "dinmul" value with the "DINMUL" command. RESTORE will help go back a step if things blow up. Save good lenses before trying things during optimization as it is terrible to know you had and lost a good design after you optimized into a terrible design.

OPTMIZATION SECTION

OPERAND ACTION - The default operands described above, were all in the COR mode. The following commands designate how each operand is to be treated during the optimization process. In the absence of these commands, all operands will be assumed to be in the COR, or correction, mode. Each of these next five commands are "sticky" in that, after they are issued, they remain in effect until canceled by another of these five commands or by an "EOS" or "END" command. During the "UPDATE MERIT" mode when data values of an existing operand are being modified, the current correction mode of that operand will remain unchanged unless one of the following correction mode commands has already been explicitly issued. If one of the correction mode commands was explicitly issued, and then an existing operand data value is changed, the correction mode of the changed operand will be set to the new current correction mode.

COR - Any operand added to the merit function after the issuance of a "COR" command will be considered an active part of the merit function. The optimization process will attempt to "correct" the operand's value so that it becomes as similar to the specified target as is possible.

BYP - Any operand added to the merit function after the issuance of a "BYP" command will be considered an inactive part of the merit function. The optimization process will not attempt to "correct" the operand's value. The operand's value will be kept up to date and displayed when the "OPRD" command is issued.

HLD - Any operand added to the merit function after the issuance of an "HLD" command will be considered an active part of the merit function. The first time the operand value is calculated, that value will be assigned as the target value and the "HLD" will be converted to a "COR".

BLO or **GTE** - Any operand added to the merit function after the issuance of a "BLO" command will be considered an active part of the merit function when its value drops algebraically below that of the target value. This is equivalent to specifying that the value of the operand must remain Greater Than or Equal to the target value using the "GTE" command. The optimization process will attempt to maintain the operand's value so that it remains greater than or equal to the specified target. When the operand value (say for the ith operand) drops below the target value, its contribution to the merit function will be set to:

$$\mathrm{fmt}_i = \left(\mathrm{wt}_i \times \left[\mathrm{opval}_i - \mathrm{tarval}_i\right]\right)^2$$

The current value for the ith operand is opval_i and its target value is tarval_i.

BHI or **LTE** - Any operand added to the merit function after the issuance of a "BHI" command will be considered an active part of the merit function when its value exceeds the value of the target in an algebraic sense. This is equivalent to specifying that the value of the operand must remain Less Than or Equal to the target value using the "LTE" command. The optimization process will attempt to maintain the operand's value so that it remains less than or equal to the specified target. The current value for the ith operand is opval_i and its target value is tarval_i. When the operand value (say for the ith operand) exceeds the target value, its contribution to the merit function will be set to:

$$\mathrm{fmt}_i = \left(\mathrm{wt}_i \times \left[\mathrm{opval}_i - \mathrm{tarval}_i\right]\right)^2$$

INTERROGATING THE MERIT FUNCTION - The next eight commands are valid at the MERIT, the UPDATE MERIT and the CMD levels:

(OP or MR) , i - The "OP" or "MR" commands display the operand number, operand name, target value, weight and the values of the optional numeric words #3, #4 and #5 if they apply to the operand. If "i" is explicitly input, only the operand data for operand number "i" will be displayed. If "i" is omitted, data for all current operands will be displayed.

(OPA or MRA) , i - The "OPA" or "MRA" commands display auxiliary operand data. Auxiliary operand data consists of the operand number, operand name, target value, weight, associated macro function name if the operand is not a predefined operand, the value of numeric word #3 if applicable to the operand, the correction mode and the operand configuration number. If "i" is explicitly input, only the auxiliary operand data for operand number "i" will be displayed. If "i" is omitted, data for all current operands will be displayed.

(OP or MR) CFG , i - The "OP" or "MR" commands, issued with the qualifier word "CFG" and an explicit alternate configuration number "i", display the operand number, operand name, target value, weight and the values of the optional numeric words #3, #4 and #5 if they apply to the operand for all operands which are active in the specified alternate configuration. "i" must be explicitly input.

(OPA or MRA) CFG , i - The "OPA" or "MRA" commands, issued with the qualifier word "CFG" and an explicit alternate configuration number "i", display the operand number, operand name, target value, weight, associated macro function name if the operand is not a predefined operand, the value of numeric word #3 if applicable to the operand, the correction mode and the operand configuration number for all operands which are active in the specified configuration. displayed. "i" must be explicitly input.

OPTMIZATION SECTION

OPRD , i - The "OPRD" command displays current operand data in the merit function. The display consists of the operand name, current value, target value, weight, the contribution to the merit function and correction mode. If "i" is omitted, data for all current operands will be displayed. If "i" is explicitly input, only data for operand number "i" will be displayed. The program keeps track as to whether or not the operand values are up-to-date. If they are not, they will be brought up-to-date" prior to the listing. If they are up-to-date, the current values will be displayed.

OPRD CFG , i - The "OPRD" command, issued with the qualifier word "CFG" and an explicit alternate configuration number "i", displays current operand data in the merit function which is active in the specified alternate configuration. The display consists of the operand name, current value, target value, weight, the contribution to the merit function and correction mode. "i" must be explicitly input. The program keeps track as to whether or not the operand values are up-to-date. If they are not, they will be brought up-to-date" prior to the listing. If they are up-to-date, the current values will be displayed.

FMT , i - The "FMT" command displays the "figure of merit" for the current merit function value. The "figure of merit" is the sum of the squares of the differences between the current operand values and their target values multiplied by the operand weights. This definition implies that the square of the weights play the important role in the calculation of the "figure of merit". If "i" is omitted, the full figure of merit will be displayed. If "i" is explicitly input, only the figure of merit contribution due to operand number "i" will be displayed. The program keeps internal track as to whether or not the figure of merit is "up to date". If it is not, it will be re-evaluated prior to the listing. If it is up to date, the current value will be displayed. The "figure of merit" is just the sum of the individual operand contributions to the "figure of merit". "n" is the total number of operands.

$$fmt = \sum_{i=1}^{n} \left(wt_i \times \left[opval_i - tarval_i \right] \right)^2$$

FMT CFG , i - The "FMT" command, issued with the qualifier word "CFG" and an explicit alternate configuration number "i", displays the "figure of merit" for operands active in alternate configuration number "i". "i" must be explicitly input. The program keeps internal track as to whether or not the figure of merit is "up to date". If it is not, it will be re-evaluated prior to the listing. If it is up to date, the current value will be displayed.

OPTMIZATION SECTION

OPTIMIZATION CONTROL PARAMETERS

PMP (qualifier word) - The "PMP" command displays the current value of the parameter identified by "qualifier word". This command is also described in the CMD section.

PM (qualifier word) , i - The "PM" command is used to set a control parameter, identified by ″qualifier word", to the numeric value specified by "i". This command is also described in the CMD section. The table below lists the various control parameters:

QUALIFIER	DESCRIPTION
DINMUL	This is the multiplicative factor used with variable increment or "dincr" scaling. **Default value = 1.0. Minimum value - 1.0D-16**
PFAC	This is the damping factor used for damped least squares optimization. **Default value = 1.0**
MAXOPT	This sets the maximum number of variables and operands. Maximum allowed value is 100,000. **Default (also minimum) value = 4000**
ONTOL	This sets the tolerance to deternine if an operand is dependent upon a variable change. It is in units of the operand derivative. If the operand's derivative change is less than ONTOL, the derivative will be set identically to zero before the solution vector is calculated. Default **value = 1.0D-10**
SINGTOL	This sets the tolerance to deternine if an element in the singular value decomposition is to be zeroed out to remove a singularity before the solution vector is computed. **Default value = 1.0D-12.**
LINTOL	This sets the fractional tolerance to deternine if a change value in the damped least squares change matrix is sufficiently small compared to its associated operand value to be considered "linear" in change matrix space. If it is not and the second numeric word of the ITER ADJUST command is present, the DINMUL will automatically be changed so that the linearity condition is regained. **Default value = 0.1. Valid values are > 0.0 and < or = to 1.0.**

If any of the above operating condition qualifier words is issued as a command word rather than a qualifier word, and if they are issued without numeric input, they are then treated as if they had been preceded by the "PMP" command. If they are entered with appropriate numeric input, they are then treated as if they had been preceded by the "PM" command.

SAVING AND RELOADING OPTIMIZATION DATA - It would be convenient to be able to store and recall variable and merit function definitions to and from disk. Of course, macros could be written which contain the variables and merit function defining commands but, in the case that variables and a merit function were defined outside of a macro, the following CMD level commands will allow variables and merit function storage and recall:

OPTMIZATION SECTION

AUTO SAVE and **AUTO SAVE2** - The "AUTO SAVE" and "AUTO SAVE2" commands cause all current variables and merit function definitions to be stored on disk either in the "AUTO.DAT" file or the "AUTO2.DAT" file. This allows for two different sets of optimization definitions to be stored to disk.

AUTO RELOAD and **AUTO RELOAD2** - The "AUTO RELOAD" and "AUTO RELOAD2" commands cause all current variables and merit function definitions stored on disk in the "AUTO.DAT" or the "AUTO2.DAT" files to be reloaded into memory ready to be used for optimization.

After a lens database has been updated, and especially when surfaces have been added or removed, the surface numbers referred to in variables and merit function definitions and in the operand defining macro functions may be incorrect. After adding or deleting, or in other ways modifying, the lens database, reloaded or macro based variables and all merit function definitions should be reviewed before optimization proceeds.

DUMPING OPTIMIZATION DATA TO A MACRO

MACDMP (macro name) , (kode) - The "MACDMP" command causes all current variables and merit function definitions to be stored in the macro named by the qualifier word. If the numeric value of "kode" is omitted, both variables and merit definitions will be saved. If a 1 is entered for "kode", then only the variables definitions will be saved. If a 2 is entered for "kode", then only the merit definitions will be saved. The variable and merit definitions will be saved in a form which will allow them to be re-established by simply typing the macro's name at the CMD level. This is an excellent way to save the final optimization definitions when a design has been completed. Macros may only be up to 1024 lines long.

When large numbers of variables and merit definitions need to be dumped to macros, it may be wise to dump the variables in one macro and the merit definitions in another. After a lens database has been updated, and especially when surfaces have been added or removed, the surface numbers referred to in variables and merit function definitions may be incorrect. After adding or deleting, or in other ways modifying, the lens database, macro based variables and merit function definitions should be reviewed before optimization proceeds.

THE DO IT YOURSELF MERIT FUNCTION

CREATING THE MERIT FUNCTION

MERIT - The "MERIT command causes the program to leave the CMD level and enter the MERIT input level. The merit function is wiped clean and is ready for new merit function input. Between "MERIT" and "EOS" or "END", any MERIT input level command may be entered. It is in the MERIT and the UPDATE MERIT levels where operands are defined and input.

EOS or **END** - The "EOS" or "END" command, issued from the MERIT level, causes the program to return to the CMD level. The merit function is left in memory and is ready for optimization.

MODIFYING MERIT FUNCTIONS

UPDATE MERIT or **U M** - The "UPDATE MERIT" command, or its abbreviated form "U M", causes the program to leave the CMD level and enter the UPDATE MERIT level. The merit memory area is opened and is ready for modification. Between "UPDATE MERIT" or "U M" and "EOS" or "END", any UPDATE MERIT level command may be entered. It is in the MERIT and the UPDATE MERIT levels where operands are defined and input.

DEL , i - The "DEL" command, issued from the UPDATE MERIT level, causes the program to delete the "i"th operand from the current merit function.

EOS or **END** - The "EOS" or "END" command, issued from the UPDATE MERIT level, causes the program to return to the CMD level. The merit function is left in memory and is ready for optimization.

OPERANDS AND OPERAND ENTRY

PREDEFINED AND USER DEFINED - There are two other kind of operands besides the default operands used in the automatic merit function builder. They are predefined and user-defined. There are, furthermore, two kinds of predefined operands; "ray-based" and "non-ray-based". "Ray-based" operands are based upon the results of the tracing of one or more real trigonometric rays. "Non-ray-based" operands are everything else. First, predefined, "ray-based" operands are described; then, predefined, "non-ray-based" operands are described; and finally, user-defined operands are described.

PREDEFINED, RAY-BASED OPERANDS - Before "ray-based" operands can be entered, the rays upon which they are based must be defined. Ray-based operands can either depend upon the definition of individual fields and rays or they can depend upon the definition of grids of rays as established in and for spot diagram, optimization ray tracing.

OPTMIZATION SECTION

FIELDS, RAYS AND GRIDS OF RAYS - here is a provision in the program at the CMD level to define and remember up to 200 field-of-view positions and up to 5000 individual ray positions for use with the "ray-based", predefined operands. There is also provision in the program at the CMD level to define the grid pattern of rays to be used during spot diagram optimization ray tracing. When the program is run for the first time, a number of field and ray positions and a default spot diagram, optimization ray grid pattern will be set up. If the user modifies the field and ray position definitions, they will remain so modified from program session to program session until changed again by the user. The spot diagram grid pattern will be reset to its default each time the program begins, though this may be modified via entries to the DEFAULTS.DAT file. The commands which are used to define and modify the spot diagram grid patterns are discussed later. The commands used to define and modify the field and individual ray positions are discussed now.

FIELD POSITION DEFINITIONS - The default field positions, set up when the program first runs, are defined in the table which follows. Any of the 200 field positions may be modified, at the CMD level, by issuing one of the 200 field modifying commands "F1" through "F200" using the following syntax:

F(n) , Y , X , Z , n - If any of these field position definitions are changed, they will remain as changed from program session to program session. The "F(n)" command has the similar syntax as the "FOB" command but takes no qualifier word. The "F(n)" command, entered as F1 or F2 or F50, etc., is used to custom define the 200 field positions used in "ray-based", pre-defined operand specification. "Y", "X" are the fractional y and x-coordinates of the object point measured in the plane of the current object surface. Z is the z-position, in lens units, of the object point measured from and in the local coordinate system of the current object surface plane. "n" is the reference ray wavelength. If "n" is explicitly input, it can be 1 through 10, the reference ray is then traced at wavelength number "n". If "n" is not explicitly entered, it will be assumed to be the "control wavelength (cw)". The first 41 field position definitions have initial default values which are given in the next table. If these are modified by the user, they remain modified from program session to program session.

OPTMIZATION SECTION

F #	Y-FOB	X-FOB	Z-POS	n	(note)
1	0.0	0.0	0.0	cw	on-axis
2	1.0	0 0	0.0	cw	YZ-plane
3	-1.0	0 0	0.0	cw	YZ-plane
4	0.0	1 0	0.0	cw	XZ-plane
5	0.0	-1.0	0.0	cw	XZ-plane
6	0.866	0.0	0.0	cw	YZ-plane
7	-0.866	0.0	0.0	cw	YZ-plane
8	0.0	0 866	0.0	cw	XZ-plane
9	0.0	-0.866	0.0	cw	XZ-plane
10	0.707	0.0	0.0	cw	YZ-plane
11	-0.707	0.0	0.0	cw	YZ-plane
12	0.0	0 707	0.0	cw	XZ-plane
13	0.0	-0.707	0.0	cw	XZ-plane
14	0.5	0.0	0.0	cw	YZ-plane
15	-0.5	0.0	0.0	cw	YZ-plane
16	0.0	0 5	0.0	cw	XZ-plane
17	0.0	-0.5	0.0	cw	XZ-plane
18	1.0	1.0	0.0	cw	quad #1
19	1.0	-1.0	0.0	cw	quad #2
20	-1.0	1.0	0.0	cw	quad #4
21	-1.0	-1.0	0.0	cw	quad #3
22	0.866	0.866	0.0	cw	quad #1
23	0.866	-0.866	0.0	cw	quad #2
24	-0.866	0.866	0.0	cw	quad #4
25	-0.866	-0.866	0.0	cw	quad #3
26	0.707	0.707	0.0	cw	quad #1
27	0.707	-0.707	0.0	cw	quad #2
28	-0.707	0.707	0.0	cw	quad #4
29	-0.707	-0.707	0.0	cw	quad #3
30	0.5	0.5	0.0	cw	quad #1
31	0.5	-0.5	0.0	cw	quad #2
32	-0.5	0.5	0.0	cw	quad #4
33	-0.5	-0.5	0.0	cw	quad #3
34	0.612	0.612	0.0	cw	quad #1
35	0.612	-0.612	0.0	cw	quad #2
36	-0.612	0.612	0.0	cw	quad #4
37	-0.612	-0.612	0.0	cw	quad #3
38	0.354	0.354	0.0	cw	quad #1
39	0.354	-0.354	0.0	cw	quad #2
40	-0.354	0.354	0.0	cw	quad #4
41	-0.354	-0.354	0.0	cw	quad #3

The notation "quad" means that a field point is in a 45-degree orientation in one of the four quadrants of the XY-plane in the coordinate system of the current object surface. Field positions #42 to #200 are not automatically defined the first time the program runs. From program session to program session, the field settings are remembered in the disk file FIELDS.DAT in the main program directory.

FIELDS i , j - The "FIELDS" command is a CMD level command used to querry the current definition of fields number "i" through "j". To querry the definition of only one field, enter the field number as both "i" and "j".

FIELDS RESET - The "FIELDS RESET" command is a CMD level command used reset the field definitions to their original default values. It erases all user modifications to the field definitions.

OPTMIZATION SECTION

RAY POSITION DEFINITIONS - The default ray positions, set up when the program first runs, are given in the table which follows. Any of the 5000 ray positions may be modified, at the CMD level, by issuing one of the 5000 ray modifying commands "R1" through "R5000" using the following syntax:

R(n) , Y , X , n - If any of the position definitions are changed, they will remain as changed from program session to program session. The "R(n)" command has the same syntax as the "RAY" command but takes no qualifier word. The "R(n)" command, entered as R1 or R2 or R50, etc., is used to custom define the 5000 ray positions used in "ray-based", pre-defined operand specification. "Y", "X" are the fractional y and x-coordinates in the plane of the current reference surface. "n" is the ray wavelength. If "n" is explicitly input, it can be 1 through 10; the ray is then traced at wavelength number "n". If "n" is not explicitly entered, it will be assumed to be the "control wavelength". The first 123 ray position definitions have initial default values which are given in the next table. If these are modified by the user, they remain modified from program session to program session.

DEFAULT RAY POSITION DEFINITIONS				
R #	**Y**	**X**	**n**	**(note)**
1	0.0	0.0	cw	on-axis
2	1.0	0 0	cw	YZ-plane
3	-1.0	0 0	cw	YZ-plane
4	0.0	1.0	cw	XZ-plane
5	0.0	-1.0	cw	XZ-plane
6	0.866	0.0	cw	YZ-plane
7	-0.866	0.0	cw	YZ-plane
8	0.0	0 866	cw	XZ-plane
9	0.0	-0.866	cw	XZ-plane
10	0.707	0.0	cw	YZ-plane
11	-0.707	0.0	cw	YZ-plane
12	0.0	0 707	cw	XZ-plane
13	0.0	-0.707	cw	XZ-plane
14	0.5	0.0	cw	YZ-plane
15	-0.5	0.0	cw	YZ-plane
16	0.0	0 5	cw	XZ-plane
17	0.0	-0.5	cw	XZ-plane
18	1.0	1.0	cw	quad #1
19	1.0	-1.0	cw	quad #2
20	-1.0	1.0	cw	quad #4
21	-1.0	-1.0	cw	quad #3
22	0.866	0.866	cw	quad #1
23	0.866	-0.866	cw	quad #2
24	-0.866	0.866	cw	quad #4
25	-0.866	-0.866	cw	quad #3
26	0.707	0.707	cw	quad #1
27	0.707	-0.707	cw	quad #2
28	-0.707	0.707	cw	quad #4
29	-0.707	-0.707	cw	quad #3
30	0.5	0.5	cw	quad #1
31	0.5	-0.5	cw	quad #2
32	-0.5	0.5	cw	quad #4
33	-0.5	-0.5	cw	quad #3
34	0.612	0.612	cw	quad #1
35	0.612	-0.612	cw	quad #2
36	-0.612	0.612	cw	quad #4
37	-0.612	-0.612	cw	quad #3
38	0.354	0.354	cw	quad #1
39	0.354	-0.354	cw	quad #2
40	-0.354	0.354	cw	quad #4
41	-0.354	-0.354	cw	quad #3

The notation "quad" means that a ray is in a 45-degree orientation in one of the four quadrants of the XY-plane in the coordinate system of the current reference surface.

The second 41 ray positions (#42 through #82) are identical to the first 41, except that they are defined for first wavelength of the currently defined "primary chromatic pair (pcw)". The third set of 41 ray positions (#83 through #122) are also identical to the first 41, except that they are defined at the second wavelength of the currently defined "primary chromatic pair (pcw)". Ray positions #123 to #5000 are not automatically defined the first time the program runs. From program session to program session, the ray position definitions are remembered in the disk file RAYS.DAT in the main program directory.

RAYS i , j - The "RAYS" command is a CMD level command used to querry the current definition of rays number "i" through "j". To querry the definition of only one ray, enter the ray number as "i" and "j".

RAYS RESET - The "RAYS RESET" command is a CMD level command used reset the ray definitions to their original default values. It erases all user modifications to the ray definitions.

VIG (ON or YES or OFF or NO) - The "VIG" command is a CMD level command used to indicate if vignetting is to be automatically considered during the computation of some selected operands (see operand list). "ON" or "YES" turns the option on. "OFF" or "NO" turns the option off. When "OFF", marginal or fractional marginal rays are traced to fractional coordinates in the reference surface relative to the reference aperture height. When "ON", marginal or fractional rays are traced to a fractional coordinate in the reference surface relative to the height of the "highest" non-failing ray in the reference surface. Only operands which explicitly say they use the vignetting option are affected by this setting. "VIG" is set to "ON" by default when the program starts.

DIFERENTIAL RAY TRACING - The tracing of differential rays can considerably slow down the ray tracing speed during optimization. If none of the operands in use are based upon the differential ray trace, then the differential ray trace can be turner "off" using the "OPDIF" command. If you are not sure, then DON"T turn of the differential ray trace. The default is to leave it "on". "ON" or "YES" turns differential ray tracing "on", "OFF" or "NO" turns differential ray tracing "off".

OPDIF (ON or YES or OFF or NO) - Turns differential ray tracing ON or OFF in optimization.

SPOT DIAGRAMS USED IN OPTIMIZATION - Spot diagram and complex aperture function calculations during optimization are computed by tracing rays at all wavelengths for which spectral weights are non-zero. Specifying a wavelength in a field of view specification for a spot diagram or complex aperture function calculation only changes the wavelength for the chief or reference ray for the spot diagram or complex aperture function.

SPOT RAY GRID DEFINITIONS - The following commands control the nature of spot diagrams when they are used for optimization. These commands are all issued from the CMD level. The values which they set remain set until changed again by the user or until program termination. Control of spot diagrams for all other purposes is covered in the CMD and TOLERANCE sections of this manual.

OPSPOT (RECT, RING, RAND) - The CMD level "OPSPOT" command, issued with one of the three qualifier words ("RECT", "RING" or "RAND"), is used to set the type of grid or ray distribution to be used in spot diagram ray tracing during optimization. "RING" is the default type. "RING" causes circular or elliptical rings of rays to be traced. A temporary circular clear aperture will be assigned to the reference surface if no clear aperture is assigned to that surface. The default spot diagram will contain 33 rays. One ray at the center and eight rays each in four rings. The eight rays will be uniformly distributed in each ring. The default fractional reference surface diameters of the four default rings will be 0.5, 0.7, 0.866 and 1.0. The maximum number of rays which may be traced for and spot diagram or complex aperture function, per wavelength, is 100 excluding the central or chief ray. "RECT" causes a rectangular ray grid to be defined over the reference surface. "RECT" also causes circular clear aperture to be assigned to the reference surface if one has not yet been assigned. If the reference surface clear aperture is not square or circular, rays will have different spacings in the X and Y-direction orientations in the reference surface. If the qualifier "RAND" is used, a pseudo-random ray distribution over the reference surface will be traced. If no clear aperture is assigned to the reference surface, a circular clear aperture will be assigned. If a rectangular or racetrack clear aperture is used, the rays will be randomly distributed over a rectangular aperture. If a circular or elliptical clear aperture is used, the rays will be randomly distributed over the circular or elliptical aperture. Issued without a qualifier or with the interrogator "?", the current grid style will be displayed.

OPRINGS , n - The CMD level "OPRINGS" command is used to specify the number of rings to be used whenever the "OPSPOT RING" command is in effect. The maximum number of rings is set at 50. In general, these rings will be first defined as circular. Rays will be distributed uniformly around each circular ring and then, if needed, the circular ring will be scaled to the appropriate ellipse. Elliptical rings are used when an elliptical clear aperture has been assigned to the reference surface or when the SAY and SAX values are not equal. The program default for "n" is 4. These four default rings will have fractional aperture heights (relative fractional radius) of 0.4, 0.7, 0.866 and 1.0. Each default ring will have eight equally spaced rays on that ring. Angular offsets will be zero in this default configuration. Issued with no numeric input or with the special interrogator "?", "RINGS" displays the current number of rings that will be used.

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OPRING , i , r , m , θ - The CMD level "OPRING" command is used to specify the relative fractional radius "r" of ring "i", the number of rays "m" to be used in ring "i" and the angular offset "θ" of the first ray in ring "i". The program default value for "r", if "OPRING" is explicitly issued, is the reciprocal of the total number of rings times the number of the current ring. The maximum value for "r" is always 1.0. The maximum value for "m" is 100 per ring. The program default is 8 rays per ring. "θ" is the first ray angular offset value measured clockwise from the local Y-axis of the reference surface coordinate system toward the local X-axis of the reference surface coordinate system. The default value for " θ" is 0.0. With this default value in effect, the first ray in the ring will always lie on the local Y-axis of the reference surface coordinate system. Issued with no numeric input or with the special interrogator "?", "OPRING" displays the current data for each ring. Issued with numeric word #1 input only, "OPRING" displays the current data for ring "I".

OPRECT , n - The CMD level "OPRECT" command is used to specify the dimensions of the "n" X "n" rectangular grid of rays to be traced when "OPSPOT RECT" is in effect. The default value for "n" is 10. The maximum is 300. Issued with no numeric input or with the special interrogator "?", "OPRECT" displays the current number value of "n".

OPRANNUM , n - The CMD level "OPRANNUM" command is used to specify the total number of rays to be traced per wavelength when "OPSPOT RAND" is in effect. The default value for "n" is 50. There is no maximum. Issued with no numeric input or with the special interrogator "?", "OPRANNUM" displays the current numeric value of "n".

OPSPDRST - The CMD level "OPSPDRST" command is used to reset all spot diagram parameters used during spot diagram ray tracing, to their program default values. Whenever the characteristics of a spot pattern is modified by the user, all characteristics must be reset by the user. If, for example, the user sets the number of rings to 20, then the characteristics of every ring will need to be reset by the user using the "RING" command.

CAPFNS IN OPTIMIZATION - Complex aperture functions (CAPFNs) as used in optimization are similar to the complex aperture functions described in the CMD and OPTIMIZATION sections of this manual. The following two CMD level commands apply to CAPFNs when then are used in optimization:

GAUSS or **NOGAUSS** - The CMD level "GAUSS" and "NOGAUSS" commands apply only to predefined spot disgram and CAPFN operands.They specify as to whether or not Gaussian apodization will be ON or OFF during the spot diagram, optimization ray tracing. For setting the grid size for complex aperture function and MTF calculations:

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OPNRD , opnrd - The CMD level "OPNRD" command sets the number of rays across the exit pupil in CAPFN calculations when used in optimization. "opnrd" can be set to any even integer value greater than or equal to 16. The default value is 16. Once set, the "opnrd" value remains set until changed by the user or until the program terminates. The "APOD" settings, set with the "APOD" command and used in spot diagram optimization, also apply to aperture ray weighting in CAPFN calculations. The maximum number of rays which may be traced for any spot diagram or complex aperture function, per wavelength, is 100 excluding the central or chief ray.

CONFIGURATIONS FOR PREDEFINED OPERANDS

CFG , i - The MERIT and UPDATE MERIT level "CFG" command applys only to predefined operands and is always ignored for user-defined operands. It is a "sticky" command. It causes any predefined operand added to the operand list to be evaluated only for alternate configuration "i". Alternate configuration "i" will remain the understood configuration for predefined operand input until changed by another "CFG" command or until an "EOS" or "END" command is issued. If the "CFG" is not entered, the main configuration, 1, is assumed. This command has no effect upon user-defined operands.

OPERAND DESCRIPTORS - To help keep track of operands, the "OP_DESC" command is provided. It takes operand designators "OP1", "OP2", "OP3", "OP4" or "OP(# of operands)" as the qualifier word and takes up to a 69 character string description for each operand. These optional descriptions are displayed by the "OPRD", "MR", "OP", "MRA" and "OPA" commands.

OP_DESC (operand designator) (operand descrition 1 to 69 characters) - Sets the operand description.

PREDEFINED OPERANDS
All predefined operands are entered at the MERIT and UPDATE MERIT levels with the following command:

(predefined operand name) , t , wt , i , j , k - "t" is the operand "target" value set by the user. Its default is 0.0. "wt" is the relative weight assigned to the target. Its default value is 1.0. The names of all predefined operands and the meanings of the "i", "j" and "k" values, numeric words (nw) #3, #4 and #5, are listed in the following table:

PREDEFINED LENS DATABASE OPERANDS				
OPERAND NAME	**"i"** (nw#3)	**"j"** (nw#4)	**"k"** (nw#5)	**DESCRIPTION**
RD	surf #	(not used)	(not used)	Radius of curvature at surface "i"
CV	surf #	(not used)	(not used)	Curvature at surface "i"
TH	surf #	(not used)	(not used)	Thickness at surface "i"
CC	surf #	(not used)	(not used)	Conic constant at surface "i"
AC	surf #	(not used)	(not used)	2nd order aspheric at surface "i"
AD	surf #	(not used)	(not used)	4th order aspheric at surface "i"
AE	surf #	(not used)	(not used)	6th order aspheric at surface "i"
AF	surf #	(not used)	(not used)	8th order aspheric at surface "i"
AG	surf #	(not used)	(not used)	10th order aspheric at surface "i"
AH	surf #	(not used)	(not used)	12th order aspheric at surface "i"
AI	surf #	(not used)	(not used)	14th order aspheric at surface "i"
AJ	surf #	(not used)	(not used)	16th order aspheric at surface "i"
AK	surf #	(not used)	(not used)	18th order aspheric at surface "i"
AL	surf #	(not used)	(not used)	20th order aspheric at surface "i"
RDTOR	surf #	(not used)	(not used)	Toric radius of curvature at surface "i"
CVTOR	surf #	(not used)	(not used)	Toric curvature at surface "i"
CCTOR	surf #	(not used)	(not used)	Toric conic constant at surface "i"
ADTOR	surf #	(not used)	(not used)	Toric 4th order aspheric at surface "i"
AETOR	surf #	(not used)	(not used)	Toric 6th order aspheric at surface "i"
AFTOR	surf #	(not used)	(not used)	Toric 8th order aspheric at surface "i"
AGTOR	surf #	(not used)	(not used)	Toric 10th order aspheric at surface "i"
ALPHA	surf #	(not used)	(not used)	ALPHA surface tilt angle (degrees) at surface "i"
BETA	surf #	(not used)	(not used)	BETA surface tilt angle (degrees) at surface "i"
GAMMA	surf #	(not used)	(not used)	GAMMA surface tilt angle (degrees) at surface "i"
VNUM	surf #	(not used)	(not used)	V-number specifier for the "MODEL" glass at surface "i"

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PREDEFINED LENS DATABASE OPERANDS				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
DPART	surf#	(not used)	(not used)	Partial Dispersion shift for the "MODEL" glass at surface "i".
ABBE	surf#	(not used)	(not used)	V-number for the glass at surface "i" It is equal to: $$VNUM = \frac{(N_{cw} - 1)}{(N_{pcw1} - N_{pcw2})}$$ Where: pcw1 and pcw2 are the primary wavelength pair defined in the lens database.
PARTL	surf #	(not used)	(not used)	Partial Dispersion for the glass at surface "i". It is equal to: $$PARTL = \frac{(N_{cw} - N_{pcw2})}{(N_{pcw1} - N_{pcw2})}$$ Where: pcw1 and pcw2 are the primary wavelength pair defined in the lens database.
INDEX	surf #	(not used)	(not used)	Refractive index Nd or the "MODEL" glass at surface "i".
N1 to N10	surf #	(not used)	(not used)	Refractive index value at wavelengths #1 to #10 at surface "i".
XD	surf #	(not used)	(not used)	X-decenter at surface "i"
YD	surf #	(not used)	(not used)	Y-decenter at surface "i"
ZD	surf #	(not used)	(not used)	Z-decenter at surface "i"
XVERT	surf #	Global ref surf #	(not used)	Global X-coordinate of the vertex of surface "i", referenced to a global origin at surface "j".
YVERT	surf #	Global ref surf #	(not used)	Global Y-coordinate of the vertex of surface "i", referenced to a global origin at surface "j".
ZVERT	surf #	Global ref surf #	(not used)	Global Z-coordinate of the vertex of surface "i", referenced to a global origin at surface "j".
LXVERT	surf #	Global ref surf #	(not used)	Global X-direction cosine of the local X-axis of surface "i", referenced to a global origin at surface "j".
MXVERT	surf #	Global ref surf #	(not used)	Global Y-direction cosine of the local X-axis of surface "i", referenced to a global origin at surface "j".
NXVERT	surf #	Global ref surf #	(not used)	Global Z-direction cosine of the local X-axis of surface "i", referenced to a global origin at surface "j".
LYVERT	surf #	Global ref surf #	(not used)	Global X-direction cosine of the local Y-axis of surface "i", referenced to a global origin at surface "j".
MYVERT	surf #	Global ref surf #	(not used)	Global Y-direction cosine of the local Y-axis of surface "i", referenced to a global origin at surface "j".
NYVERT	surf #	Global ref surf #	(not used)	Global Z-direction cosine of the local Y-axis of surface "i", referenced to a global origin at surface "j".
LZVERT	surf #	Global ref surf #	(not used)	Global X-direction cosine of the local Z-axis of surface "i", referenced to a global origin at surface "j".

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OPTMIZATION SECTION

OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
spanning		PREDEFINED LENS DATABASE OPERANDS		
MZVERT	surf #	Global ref surf #	(not used)	Global Y-direction cosine of the local Z-axis of surface "i", referenced to a global origin at surface "j".
NZVERT	surf #	Global ref surf #	(not used)	Global Z-direction cosine of the local Z-axis of surface "i", referenced to a global origin at surface "j".
LENGTH or OAL	surf # (def=0)	surf # (def=last)	(not used)	Algebraic sum of axial thicknesses from surface "i" to surface "j"
MLENGTH or OPTLEN	surf # (def=0)	surf # (def=last)	(not used)	Physical length from surface "i" to surface "j" along a path connecting surface vertices and ignoring tilts and decentrations. This is the sum of the axial thicknesses multiplied by the refractive index in each space.
ET or ETY	surf #	(not used)	(not used)	Edge thickness from surface "i" to surface "i"+1. Surface tilts and decentrations are ignored. If clear apertures are assigned, they are assumed circular with the YZ-plane value being used. The larger of the values on surface "i" and "i"+1 is used. If no clear apertures are assigned, then the larger of the sums of PY+PCY on surfaces "i" and "i"+1 are used in the calculation. Clear aperture decentrations and tilts are ignored.
ETX	surf #	(not used)	(not used)	Edge thickness from surface "i" to surface "i"+1. Surface tilts and decentrations are ignored. If clear apertures are assigned, they are assumed circular with the XZ-plane value being used. The larger of the values on surface "i" and "i"+1 is used. If no clear apertures are assigned, then the larger of the sums of PX+PCX on surfaces "i" and "i"+1 are used in the calculation. Clear aperture decentrations and tilts are ignored.
C1 through C96	surf #	(not used)	(not used)	Any one of the 96 coefficients of a special surface attached to surface "i"
SHAPEFAC	surf #	(not used)	(not used)	This returns the shape factor for the lens element which begins at surface "i" and terminates at surface "i+1". The shape factor is defined by : $$SHAPEFAC = \frac{r_{i+1} + r_i}{r_{i+1} - r_i}$$ where: r is the radius of curvature

OPTMIZATION SECTION

PREDEFINED LENS DATABASE OPERANDS				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
PIVX	surf #	(not used)	(not used)	X-alternate pivot point at surface "i"
PIVY	surf #	(not used)	(not used)	Y-alternate pivot point at surface "i"
PIVZ	surf #	(not used)	(not used)	Z-alternate pivot point at surface "I"
CLPX	surf #	(not used)	(not used)	X-dimension of the clear aperture height at surface "I". Zero is returned if no clear aperture is assigned.
CLPY	surf #	(not used)	(not used)	Y-dimension of the clear aperture height at surface "I". Zero is returned if no clear aperture is assigned.
GRS	surf#	(not used)	(not used)	diffraction grating spacing
WEIGHT	surf # (def=0)	surf # (def=last)	(not used)	MASS in Kgs of elements from surface "i" to surface "j". This calculation assumes spherical surfaces and ignores all decenters and tilts. It uses the specific gravity assigned to surfaces with the lens database command "SPGR".
COST	surf # (def=0)	surf # (def=last)	(not used)	Cost in cost units based upon a WEIGHT calculation multiplied by the individual surface price/Kg values stored in the lens database.
ACT	surf #	actuator #	(not used)	The actuator value between –1.0 and 1.0 for actuator "j" on surface "i" if surface "i" is defined as a deformable surface.
ACTMAX	surf #	(not used)	(not used)	Returns the maximun actuator value on surface "i" if surface "i" is defined as a deformable surface.
ACTMIN	surf #	(not used)	(not used)	Returns the minumum actuator value on surface "i" if surface "i" is defined as a deformable surface.
ACTMEAN	surf #	(not used)	(not used)	Returns the average of all active actuator values on surface "i" if surface "i" is defined as a deformable surface.
ACTSDEV	surf #	(not used)	(not used)	Returns the standard deviation from the mean of all active actuator values on surface "i" if surface "i" is defined as a deformable surface.
ACTPTOV	surf #	(not used)	(not used)	Returns the peak to valley value for all active actuator values on surface "i" if surface "i" is defined as a deformable surface.

OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
PREDEFINED REAL SINGLE RAY BASED OPERANDS				
X	surf # (def=img)	Field Pos. #	Ray Pos.#	X-local coordinate at surface "i" at field position number "j" and ray position number "k" of last ray traced
Y	surf # (def=img)	Field Pos. #	Ray Pos.#	Y-local coordinate at surface "i" at field position number "j" and ray position number "k" of last ray traced
Z	surf # (def=img)	Field Pos. #	Ray Pos.#	Z-local coordinate at surface "i" at field position number "j" and ray position number "k" of last ray traced
DCL or K	surf # (def=img)	Field Pos. #	Ray Pos.#	L-direction cosine at surface "i" at field position number "j" and ray position number "k" of last ray traced
DCM or L	surf # (def=img)	Field Pos. #	Ray Pos.#	Z-direction cosine at surface "i" at field position number "j" and ray position number "k" of last ray traced
DCN or M	surf # (def=img)	Field Pos. #	Ray Pos.#	Z-direction cosine at surface "i" at field position number "j" and ray position number "k" of last ray traced
DX	surf # (def=img)	Field Pos. #	Ray Pos.#	DX at surface "i" of last ray traced X-Ray Coordinate minus X-Chief ray Coordinate. The "VIG" setting affects this operand.
DY	surf # (def=img)	Field Pos. #	Ray Pos.#	DY at surface "i" of last ray traced Y-Ray Coordinate minus Y-Chief ray Coordinate. The "VIG" setting affects this operand.
DXA	surf # (def=img)	Field Pos. #	Ray Pos.#	DXA at surface "i" of last ray traced XANG-Ray slope minus XANG-Chief ray slope (radians). The "VIG" setting affects this operand.
DYA	surf # (def=img)	Field Pos. #	Ray Pos.#	DYA at surface "i" of last ray traced YANG-Ray slope minus YANG-Chief ray slope (radians). The "VIG" setting affects this operand.
DR	surf # (def=img)	Field Pos. #	Ray Pos.#	DR at surface "i" of last ray traced Radial-Ray Coordinate minus Radial-Chief ray Coordinate. The "VIG" setting affects this operand.
DRA	surf # (def=img)	Field Pos. #	Ray Pos.#	DRA at surface "i" of last ray traced Radial-Ray slope minus Radial-Chief ray slope (radians). The "VIG" setting affects this operand.
XANG	surf # (def=img)	Field Pos. #	Ray Pos.#	XZ-plane slope angle at surface "i" of the last ray traced (radians)
YANG	surf # (def=img)	Field Pos. #	Ray Pos.#	YZ-plane slope angle at surface "i" of the last ray traced (radians)
OPL	surf #	Field Pos. #	Ray Pos.#	Optical path length along the specified ray from surface "i-1" to surface "i" (in lens units)

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	PREDEFINED REAL SINGLE RAY BASED OPERANDS			
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
OPD	Field Pos #	Ray Pos. #	(not used)	Optical path difference between the specified ray and the reference ray (in lens units). The "VIG" setting affects this operand.
OPDW	Field Pos #	Ray Pos. #	(not used)	Optical path difference between the specified ray and the reference ray (in waves at the wavelength used to trace the reference ray). The "VIG" setting affects this operand.
LOLD	surf # (def=img)	Field Pos. #	Ray Pos.#	X-direction cosine at surface "i" of the specified ray (before refraction, reflection or diffraction)
MOLD	surf # (def=img)	Field Pos. #	Ray Pos.#	Y-direction cosine at surface "i" of the specified ray (before refraction, reflection or diffraction)
NOLD	surf # (def=img)	Field Pos. #	Ray Pos.#	Z-direction cosine at surface "i" of the specified ray (before refraction, reflection or diffraction)
LEN	surf #	Field Pos. #	Ray Pos.#	Physical length along the specified ray from surface "i-1" to surface "i"
AII	surf # (def=img)	Field Pos. #	Ray Pos.#	Cosine of the angle of incidence of specified ray at surface "i"
AIP	surf # (def=img)	Field Pos. #	Ray Pos.#	Cosine of the angle of refraction, reflection or diffraction of specified ray at surface "i"
LN	surf #	Field Pos. #	Ray Pos.#	Local surface coordinate system X-direction cosine of the surface normal at surface "i" where the specified ray intersects surface "i"
MN	surf #	Field Pos. #	Ray Pos.#	Local surface coordinate system Y-direction cosine of the surface normal at surface "i" where the specified ray intersects surface "i"
NN	surf #	Field Pos. #	Ray Pos.#	Local surface coordinate system Z-direction cosine of the surface normal at surface "i" where the specified ray intersects surface "i"
PXPX	surf # (def=img)	Field Pos. #	(not used)	Derivative, at surface "i", of the X-coordinate of the specified chief ray traced with respect to a change in that chief ray's X-coordinate at the current object surface.

OPTMIZATION SECTION

PREDEFINED REAL SINGLE RAY BASED OPERANDS				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
PXPY	surf # (def=img)	Field Pos. #	(not used)	Derivative, at surface "i", of the X-coordinate of the specified chief ray traced with respect to a change in that chief ray's Y-coordinate at the current object surface.
PYPX	surf # (def=img)	Field Pos. #	(not used)	Derivative, at surface "i", of the Y-coordinate of the specified chief ray traced with respect to a change in that chief ray's X-coordinate at the current object surface.
PYPY	surf # (def=img)	Field Pos. #	(not used)	Derivative, at surface "i", of the Y-coordinate of the specified chief ray traced with respect to a change in that chief ray's Y-coordinate at the current object surface.
PXAPX	surf # (def=img)	Field Pos. #	(not used)	Derivative, at surface "i", of the XZ-plane radian measure slope angle of the specified chief ray traced with respect to a change in that chief ray's X-coordinate at the current object surface.
PXAPY	surf # (def=img)	Field Pos. #	(not used)	Derivative, at surface "i", of the XZ-plane radian measure slope angle of the specified chief ray traced with respect to a change in that chief ray's Y-coordinate at the current object surface.
PYAPX	surf # (def=img)	Field Pos. #	(not used)	Derivative, at surface "i", of the YZ-plane radian measure slope angle of the specified chief ray traced with respect to a change in that chief ray's X-coordinate at the current object surface.
PYAPY	surf # (def=img)	Field Pos. #	(not used)	Derivative, at surface "i", of the YZ-plane radian measure slope angle of the specified chief ray traced with respect to a change in that chief ray's Y-coordinate at the current object surface.
DXDX	surf # (def=img)	Field Pos. #	Ray Pos.#	Derivative, at surface "i", of the X-coordinate of the specified ray traced with respect to a change in that ray's X-coordinate at the current reference surface. The "VIG" setting affects this operand.

PREDEFINED REAL SINGLE RAY BASED OPERANDS				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
DXDY	surf # (def=img)	Field Pos. #	Ray Pos.#	Derivative, at surface "i", of the X-coordinate of the specified ray traced with respect to a change in that ray's Y-coordinate at the current reference surface. The "VIG" setting affects this operand.
DYDX	surf # (def=img)	Field Pos. #	Ray Pos.#	Derivative, at surface "i", of the Y-coordinate of the specified ray traced with respect to a change in that ray's X-coordinate at the current reference surface. The "VIG" setting affects this operand.
DYDY	surf # (def=img)	Field Pos. #	Ray Pos.#	Derivative, at surface "i", of the Y-coordinate of the specified ray traced with respect to a change in that ray's Y-coordinate at the current reference surface. The "VIG" setting affects this operand.
DXADX	surf # (def=img)	Field Pos. #	Ray Pos.#	Derivative, at surface "i", of the XZ-plane radian measure slope angle of the specified ray traced with respect to a change in that chief ray's X-coordinate at the current reference surface. The "VIG" setting affects this operand.
DXADY	surf # (def=img)	Field Pos. #	Ray Pos.#	Derivative, at surface "i", of the XZ-plane radian measure slope angle of the specified ray traced with respect to a change in that chief ray's Y-coordinate at the current reference surface. The "VIG" setting affects this operand.
DYADX	surf # (def=img)	Field Pos. #	Ray Pos.#	Derivative, at surface "i", of the YZ-plane radian measure slope angle of the specified ray traced with respect to a change in that chief ray's X-coordinate at the current reference surface. The "VIG" setting affects this operand.
DYADY	surf # (def=img)	Field Pos. #	Ray Pos.#	Derivative, at surface "i", of the YZ-plane slope angle of the specified ray traced with respect to a change in that ray's Y-coordinate at the current reference surface. The "VIG" setting affects this operand.
DRDR	surf # (def=img)	Field Pos. #	Ray Pos.#	Derivative, at surface "i", of the radial-coordinate of the specified ray traced with respect to a change in that ray's radial-coordinate at the current reference surface. The "VIG" setting affects this operand.
DRADR	surf # (def=img)	Field Pos. #	Ray Pos.#	Derivative, at surface "i", of the radial-coordinate (angular) of the specified ray traced with respect to a change in that ray's radial-coordinate at the current reference surface. The "VIG" setting affects this operand.
XREF	surf # (def=img)	Field Pos. #	(not used)	X-coordinate of the specified reference ray at surface "i"
YREF	surf # (def=img)	Field Pos. #	(not used)	Y-coordinate of the specified reference ray at surface "i"
ZREF	surf # (def=img)	Field Pos. #	(not used)	Z-coordinate of the specified reference ray at surface "i"
LREF	surf # (def=img)	Field Pos. #	(not used)	X-direction cosine of the specified reference ray at surface "i" after refraction, reflection or diffraction

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	PREDEFINED REAL SINGLE RAY BASED OPERANDS			
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
MREF	surf # (def=img)	Field Pos. #	(not used)	Y-direction cosine of the specified reference ray at surface "i" after refraction, reflection or diffraction
NREF	surf # (def=img)	Field Pos. #	(not used)	Z-direction cosine of the specified reference ray at surface "i" after refraction, reflection or diffraction
LREFOL	surf # (def=img)	Field Pos. #	(not used)	X-direction cosine of the specified reference ray at surface "i" before refraction, reflection or diffraction
MREFOL	surf # (def=img)	Field Pos. #	(not used)	Y-direction cosine of the specified reference ray at surface "i" before refraction, reflection or diffraction
NREFOL	surf # (def=img)	Field Pos. #	(not used)	Z-direction cosine of the specified reference ray at surface "i" before refraction, reflection or diffraction
LENREF	surf #	Field Pos. #	(not used)	Physical length along the specified reference ray from surface "i-1" to surface "i"
OPLREF	surf #	Field Pos. #	(not used)	Optical path length along the specified reference ray from surface "i-1" to surface "i"
IREF	surf # (def=img)	Field Pos. #	(not used)	Cosine of the angle of incidence of the specified reference ray at surface "i"
IPREF	surf # (def=img)	Field Pos. #	(not used)	Cosine of the angle of refraction, reflection or diffraction of the specified reference ray at surface "i"
XAREF	surf # (def=img)	Field Pos. #	Ray Pos.#	XZ-plane slope angle of the specified reference ray at surface "i", measured in radians
YAREF	surf # (def=img)	Field Pos. #	(not used)	YZ-plane slope angle of the specified reference ray at surface "i", measured in radians
LNREF	surf #	Field Pos. #	(not used)	X-direction cosine of the surface normal at surface "i" where the specified reference ray intersects surface "i"
MNREF	surf #	Field Pos. #	(not used)	Y-direction cosine of the surface normal at surface "i" where the specified reference ray intersects surface "i"
NNREF	surf #	Field Pos. #	(not used)	Z-direction cosine of the surface normal at surface "i" where the specified reference ray intersects surface "i"
GLX	surf #	Field Pos. #	Ray Pos.#	Global X-coordinate of the specified ray at surface "i"

OPTMIZATION SECTION

PREDEFINED REAL SINGLE RAY BASED OPERANDS				
OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
GLY	surf #	Field Pos. #	Ray Pos.#	Global Y-coordinate of the specified ray at surface "i"
GLZ	surf #	Field Pos. #	Ray Pos.#	Global Z-coordinate of the specified ray at surface "i"
GLL	surf #	Field Pos. #	Ray Pos.#	Global X-direction cosine of the specified ray traced at surface "i" after refraction, reflection or diffraction
GLM	surf #	Field Pos. #	Ray Pos.#	Global Y-direction cosine of the specified ray traced at surface "i" after refraction, reflection or diffraction
GLN	surf #	Field Pos. #	Ray Pos.#	Global Z-direction cosine of the specified ray traced at surface "i" after refraction, reflection or diffraction
GLLOLD	surf #	Field Pos. #	Ray Pos.#	Global X-direction cosine of the specified ray traced at surface "i" before refraction, reflection or diffraction
GLMOLD	surf #	Field Pos. #	Ray Pos.#	Global Y-direction cosine of the specified ray traced at surface "i" before refraction, reflection or diffraction
GLNOLD	surf #	Field Pos. #	Ray Pos.#	Global Z-direction cosine of the specified ray traced at surface "i" before refraction, reflection or diffraction
SYMX (symmetrical aberration determined from two rays in the XZ-plane of the current reference surface)	fractional ray height	Field Pos. #	Wavelength.#	For two rays traced in the XZ-plane of the current reference surface at fractional ray heights + and - "i", at field position "j" and at wavelength number "k", SYMX is the difference between the DX values of the two rays divided by 2.0 (modes FOCAL and UFOCAL) and is the difference between the DXA values of the two rays divided by 2.0 (modes AFOCAL ans UAFOCAL). The "VIG" setting affects this operand.
SYMY (symmetrical aberration determined from two rays in the YZ-plane of the current reference surface)	fractional ray height	Field Pos. #	Wavelength.#	The same as SYMX but using DY or DYA values of rays traced in the YZ-plane of the current reference surface at field position "j" and at wavelength number "k". The "VIG" setting affects this operand.

OPTMIZATION SECTION

PREDEFINED REAL SINGLE RAY BASED OPERANDS				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
ASYMX (asymmetrical aberration determined from two rays in the XZ-plane of the current reference surface)	fractional ray height	Field Pos. #	Wavelength.#	For two rays traced in the XZ-plane of the current reference surface at fractional ray heights + and - "i", at field position "j" and at wavelength number "k", ASYMX is the sum of the DX values of the two rays divided by 2.0 (modes FOCAL and UFOCAL) and is the sum of the DXA values of the two rays divided by 2.0 (modes AFOCAL ans UAFOCAL). The "VIG" setting affects this operand.
ASYMY (symmetrical aberration determined from two rays in the YZ-plane of the current reference surface)	fractional ray height	Field Pos. #	Wavelength.#	The same as ASYMX but using DY or DYA values of rays traced in the YZ-plane of the current reference surface at field position "j" and at wavelength number "k". The "VIG" setting affects this operand.
PACM	(not used)	(not used)	(not used)	Primary Axail Color Marginal. Sums of the absolute values of real ray DX and DY (mode FOCAL or UFOCAL) or DXA and DYA (mode AFOCAL or UAFOCAL) value differences, at the current image surface, for four on-axis marginal rays, traced at the current primary wavelength pair.
PACZ	(not used)	(not used)	(not used)	Primary Axail Color Zonal. Sums of the absolute values of real ray DX and DY (mode FOCAL or UFOCAL) or DXA and DYA (mode AFOCAL or UAFOCAL) value differences, at the current image surface, for four on-axis 0.7 zonal rays, traced at the current primary wavelength pair.

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	PREDEFINED REAL SINGLE RAY BASED OPERANDS			
OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
SACM	(not used)	(not used)	(not used)	Secondary Axail Color Marginal. Sums of the absolute values of real ray DX and DY (mode FOCAL or UFOCAL) or DXA and DYA (mode AFOCAL or UAFOCAL) value differences, at the current image surface, for four on-axis marginal rays, traced at the current secondary wavelength pair.
SACZ	(not used)	(not used)	(not used)	Secondary Axail Color Zonal. Sums of the absolute values of real ray DX and DY (mode FOCAL or UFOCAL) or DYA and DYA (mode AFOCAL or UAFOCAL) value differences, at the current image surface, for four on-axis 0.7 zonal rays, traced at the current secondary wavelength pair.
PLCM	(not used)	(not used)	(not used)	Primary Lateral Color Marginal. Sums of the absolute values of real ray DX and DY (mode FOCAL or UFOCAL) or DXA and DYA (mode AFOCAL or UAFOCAL) value differences, at the current image surface, for four full FOV , zero relative height rays, traced at the current primary wavelength pair.

OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
PREDEFINED REAL SINGLE RAY BASED OPERANDS				
PLCZ	(not used)	(not used)	(not used)	Primary Lateral Color Zonal. Sums of the absolute values of real ray DX and DY (mode FOCAL or UFOCAL) or DXA and DYA (mode AFOCAL or UAFOCAL) value differences, at the current image surface, for four 0.7 zonal FOV, zero relative height rays, traced at the current primary wavelength pair.
SLCM	(not used)	(not used)	(not used)	Secondary Lateral Color Marginal. Sums of the absolute values of real ray DX and DY (mode FOCAL or UFOCAL) or DXA and DYA (mode AFOCAL or UAFOCAL) value differences, at the current image surface, for four full FOV , zero relative height rays, traced at the current secondary wavelength pair.
SLCZ	(not used)	(not used)	(not used)	Secondary Lateral Color Zonal. Sums of the absolute values of real ray DX and DY (mode FOCAL or UFOCAL) or DXA and DYA (mode AFOCAL or UAFOCAL) value differences, at the current image surface, for four 0.7 zonal FOV, zero relative height rays, traced at the current secondary wavelength pair.
DMINUSD	(not used)	(not used)	(not used)	Conrady $\Sigma(D-d)\Delta n$ achromatization operand, where D are the optical path lengths along the +0.7, YZ-plane marginal ray traced from an on-axis image point at the control wavelength, d are axial separations and Δn are the refractive index variations for the primary chromatic pair of wavelegths. The summation is over all surfaces.

PREDEFINED SPOT DIAGRAM AND COMPLEX APERTURE FUNCTION (CAPFN) BASED OPERANDS				
OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
CENTX	Field Pos. #	Wavelength #	(not used)	X- centroid location in the current image surface of the spot diagram centroid. If numeric word "j" is not explicitly entered, all wavelengths and spectral weights are used.
CENTY	Field Pos. #	Wavelength #	(not used)	Y- centroid location in the current image surface of the spot diagram centroid. If numeric word "j" is not explicitly entered, all wavelengths and spectral weights are used.
RMS	Field Pos. #	Wavelength #	(not used)	RMS spot diameter for the spot diagram, at the specified field position, centered about the spot centroid location. If numeric word "j" is not explicitly entered, all wavelengths and spectral weights are used.
RMSX	Field Pos. #	Wavelength #	(not used)	X-dimension of the RMS spot size for the spot diagram, at the specified field position,. centered about the spot centroid location. If numeric word "j" is not explicitly entered, all wavelengths and spectral weights are used.
RMSY	Field Pos. #	Wavelength #	(not used)	Y-dimension of the RMS spot size for the spot diagram centered about the spot centroid location. If numeric word "j" is not explicitly entered, all wavelengths and spectral weights are used.
RSS	Field Pos. #	Wavelength #	(not used)	RSS spot diameter for the spot diagram, at the specified field position, centered about the chief ray location. If numeric word "j" is not explicitly entered, all wavelengths and spectral weights are used.
RSSX	Field Pos. #	Wavelength #	(not used)	X-dimension of the RSS spot size for the spot diagram ,at the specified field position, centered about the chief ray location. If numeric word "j" is not explicitly entered, all wavelengths and spectral weights are used.

OPTMIZATION SECTION

PREDEFINED SPOT DIAGRAM AND COMPLEX APERTURE FUNCTION (CAPFN) BASED OPERANDS				
OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
RSSY	Field Pos. #	Wavelength #	(not used)	Y-dimension of the RSS spot size for the spot ,at the specified field position, diagram centered about the cheif ray location. If numeric word "j" is not explicitly entered, all wavelengths and spectral weights are used.
RMSYX	Field Pos. #	Wavelength #	(not used)	Ratio of the Y-dimension of the RMS spot size to the X-dimension spot size for the spot ,at the specified field position, diagram centered about the cheif ray location. If numeric word "j" is not explicitly entered, all wavelengths and spectral weights are used.
RMSOPD	Field Pos. #	Wavelength #	(not used)	RMSOPD, in waves at the control wavelength, of the CAPFN at the specified field position. If numeric word "j" is not explicitly entered, all wavelengths and spectral weights are used.
ZERN37	Field Pos. #	Zern Coef #	Wavelength #	If a CAPFN for the specified field position does not exist, it is created using the default CAPFN ray grid. The wavefront, at wavelength "k",is fitted to a 37-term Fringe-Zernike Polynomial. The coefficient number "j" becomes the operand.
GREYS	Field Pos. #	OPD weight	Wavelength #	See the section above which describes Grey's optimization method. This operand uses the spot diagram ray pattern currently in effect. Ray are traced from the specified Field Pos # and Wavelength #. The "VIG" setting affects this operand.

PREDEFINED SPOT DIAGRAM AND COMPLEX APERTURE FUNCTION (CAPFN) BASED OPERANDS (cont'd)				
OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
MGOTF or GOTFM	Field Pos. #	spatial frequency	Orientation 0=vert bars 90=horiz bars	Value of the modulus of the geometrical polychromatic optical transfer function at field position "i" and spatial frequency "j".
PGOTF or GOTFP	Field Pos. #	spatial frequency	Orientation 0=vert bars 90=horiz bars	Value of the phase of the geometrical polychromatic optical transfer function at field position "i" and spatial frequency "j".
MDOTF or DOTFM	Field Pos. #	spatial frequency	Orientation 0=vert bars 90=horiz bars	Value of the modulus of the diffraction polychromatic optical transfer function at field position "i" and spatial frequency "j".
PDOTF or DOTFP	Field Pos. #	spatial frequency	Orientation 0=vert bars 90=horiz bars	Value of the phase of the diffraction polychromatic optical transfer function at field position "i" and spatial frequency "j".
RED	Field Pos #	% energy	(not used)	Diameter of the circle, in the appropriate units depending upon lens mode, which encircles "j" percent of the energy in a spot for field position "i". This is based upon the geometrical spot diagram and ignores diffraction. It is centered at the chief ray of field position "i".
REDCEN	Field Pos #	% energy	(not used)	Diameter of the circle, in the appropriate units depending upon lens mode, which encircles "j" percent of the energy in a spot for field position "i". This is based upon the geometrical spot diagram and ignores diffraction. It is centered at the location of the spot centroid.

OPTMIZATION SECTION

OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
PREDEFINED PARAXIAL RAY BASED OPERANDS				
PWRY	surf # (def=0)	surf # (def=last)	(not used)	YZ-plane paraxial, optical power of optical system from surface "i" to surface "j". Defaults for "i" and "j" are 0 and the final surface number.
PWRX	surf # (def=0)	surf # (def=last)	(not used)	Same as above except in the XZ-plane.
FLCLTH or **FLCLTHY**	surf # (def=0)	surf # (def=last)		YZ-plane, paraxial, effective focal length at the control wavelength of optical system from surface "i" to surface "j". Defaults for "i" and "j" are 0 and the final surface number.
FLCLTHX	surf # (def=0)	surf # (def=last)	(not used)	Same as FLCLTH except in the XZ-plane.
PY	surf # (def=last)	wavelength # (def=cw)	(not used)	YZ-plane, marginal paraxial ray height at surface "i" and at wavelength "j"
PX	surf # (def=last)	wavelength # (def=cw)	(not used)	Same as above except in the XZ-plane.
PCY	surf # (def=last)	wavelength # (def=cw)	(not used)	YZ-plane, chief paraxial ray height at surface "i" and at wavelength "j"
PCX	surf # (def=last)	wavelength # (def=cw)	(not used)	Same as above except in the XZ-plane.
PUY	surf # (def=last)	wavelength # (def=cw)	(not used)	YZ-plane, marginal paraxial ray tangent at surface "i" and at wavelength "j" after refraction or reflection
PUX	surf # (def=last)	wavelength # (def=cw)	(not used)	Same as above except in the XZ-plane.
PUCY	surf # (def=last)	wavelength # (def=cw)	(not used)	YZ-plane, chief paraxial ray tangent at surface "i" and at wavelength "j" after refraction or reflection
PUCX	surf # (def=last)	wavelength # (def=cw)	(not used)	Same as above except in the XZ-plane.
PIY	surf # (def=last)	wavelength # (def=cw)	(not used)	YZ-plane, marginal paraxial ray incident angle tangent at surface "i" and at wavelength "j"
PIX	surf # (def=last)	wavelength # (def=cw)	(not used)	Same as above except in the XZ-plane.
PICY	surf # (def=last)	wavelength # (def=cw)	(not used)	YZ-plane, chief paraxial ray incident angle tangent at surface "i" and at wavelength "j" before refraction or reflection
PICX	surf # (def=last)	wavelength # (def=cw)	(not used)	Same as above except in the XZ-plane.
PIYP	surf # (def=last)	wavelength # (def=cw)	(not used)	YZ-plane, marginal paraxial ray angle of refraction or reflection (tangent) at surface "i" and at wavelength "j"

OPTMIZATION SECTION

	PREDEFINED PARAXIAL RAY BASED OPERANDS			
OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
PIXP	surf # (def=last)	wavelength # (def=cw)	(not used)	Same as above except in the XZ-plane.
PICYP	surf # (def=last)	wavelength # (def=cw)	(not used)	YZ-plane, chief paraxial ray angle of refraction or reflection (tangent) at surface "i" and at wavelength "j"
PICXP	surf # (def=last)	wavelength # (def=cw)	(not used)	Same as above except in the XZ-plane.
IMDISX	surf #	(not used)	(not used)	XZ-plane. This is the position at which the paraxial marginal ray, in the space following surface "i", has zero height. It is represented in the coordinate system of surface "i".
IMDISY	surf #	(not used)	(not used)	Same as above except in the XZ-plane.

OPTMIZATION SECTION

PREDEFINED PARAXIAL CHROMATIC OPERANDS				
NOTE: Entering the number of the last surface (the default) for "i" in the next eight aberrations results in the system aberration total for that aberration being used as the operand value.				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
PACY	surf # (def=last)	(not used)	(not used)	YZ-plane, primary axial chromatic aberration at surface "i". If "i" is the final surface, system totals are calculated. This is the same data as displayed in the "FCHY" and "FCHX" commands.
PACX	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PLCY	surf # (def=last)	(not used)	(not used)	YZ-plane, primary lateral chromatic aberration at surface "i". If "i" is the final surface, system totals are calculated. This is the same data as displayed in the "FCHY" and "FCHX" commands.
PLCX	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SACY	surf # (def=last)	(not used)	(not used)	YZ-plane, secondary axial chromatic aberration at surface "i". If "i" is the final surface, system totals are calculated. This is the same data as displayed in the "FCHY" and "FCHX" commands.
SACX	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SLCY	surf # (def=last)	(not used)	(not used)	YZ-plane secondary lateral chromatic aberration at surface "i". If "i" is the final surface, system totals are calculated. This is the same data as displayed in the "FCHY" and "FCHX" commands.
SLCX	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.

PREDEFINED SPECIAL REAL RAY/PARAXIAL RAY BASED OPERANDS				
OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
MAGX	Field Pos. #	(not used)	(not used)	XZ-plane magnification. Uses the ratio of the X-slope of differential chief ray at the current object surface to the X-slope of differential chief ray at the current image surface.
MAGY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.
MAGXOR	Field Pos. #	(not used)	(not used)	XZ-plane reference magnification. Uses the ratio of X-slope of differential chief ray at object surface to the X-slope of differential chief ray at reference surface.
MAGYOR	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.
FFLX	Field Pos. #	(not used)	(not used)	XZ-plane front focal length. Based upon differential ray data.
FFLY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.
BFLX	Field Pos. #	(not used)	(not used)	XZ-plane back focal length. Based upon differential ray data.
BFLY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.
FFNX	Field Pos. #	(not used)	(not used)	XZ-plane front F-number. Uses the reciprocal of -2 times the scaled up slope of differential marginal ray at the current object surface.
FFNY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.
BFNX	Field Pos. #	(not used)	(not used)	XZ-plane back F-number. Uses the reciprocal of -2 times the scaled up slope of differential marginal ray at the current image surface.
BFNY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.
EFLX	Field Pos. #	(not used)	(not used)	XZ-plane effective focal length. Based upon differential ray data.
EFLY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.
ENDIAX	Field Pos. #	(not used)	(not used)	XZ-plane entrance pupil diameter. Based upon differential ray data.
ENDIAY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.

OPTMIZATION SECTION

PREDEFINED SPECIAL REAL RAY/PARAXIAL RAY BASED OPERANDS				
OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
EXDIAX	Field Pos. #	(not used)	(not used)	XZ-plane exit pupil diameter. Based upon differential ray data.
EXDIAY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.
ENPOSX	Field Pos. #	(not used)	(not used)	X-coordinate of the center of the entrance pupil. Differential ray data is used in the calculation and the value is represented in the coordinate system of the NEWOBJ+1 surface.
ENPOSY	Field Pos. #	(not used)	(not used)	Same as above except the Y-coordinate.
ENPOSZ	Field Pos. #	(not used)	(not used)	Same as above except the Z-coordinate.
EXPOSX	Field Pos. #	(not used)	(not used)	X-coordinate of the center of the exit pupil. Differential ray data is used in the calculation and the value is represented in the coordinate system of the NEWIMG surface.
EXPOSY	Field Pos. #	(not used)	(not used)	Same as above except the Y-coordinate.
EXPOSZ	Field Pos. #	(not used)	(not used)	Same as above except the Z-coordinate.
FNUMX	Field Pos. #	(not used)	(not used)	Image space F-number. Uses extreme upper and lower real marginal rays in the XZ-plane of the reference surface for the current FOB. Takes vignetting into account automatically. If no chief ray exist, a paxaial value is used instead.
FNUMY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.
OBFNUMX	Field Pos. #	(not used)	(not used)	Object space F-number. Uses extreme upper and lower real marginal rays in the XZ-plane of the reference surface for the current FOB. Takes vignetting into account automatically. If no chief ray exist, a paxaial value is used instead.
OBFNUMY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.
ENPDIAX	Field Pos. #	(not used)	(not used)	Entrance pupil diameter. Uses extreme upper and lower real marginal rays in the XZ-plane of the reference surface for the current FOB. Takes vignetting into account automatically. If no chief ray exist, a paxaial value is used instead.
ENPDIAY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.

OPTMIZATION SECTION

PREDEFINED SPECIAL REAL RAY/PARAXIAL RAY BASED OPERANDS				
OPERAND NAME	**"i"** (nw#3)	**"j"** (nw#4)	**"k"** (nw#5)	**DESCRIPTION**
EXPDIAX	Field Pos. #	(not used)	(not used)	Exit pupil diameter. Uses extreme upper and lower real marginal rays in the XZ-plane of the reference surface for the current FOB. Takes vignetting into account automatically. If no chief ray exist, a paxaial value is used instead.
EXPDIAY	Field Pos. #	(not used)	(not used)	Same as above except in the YZ-plane.
PUPDIAX	surf #	(not used)	(not used)	XZ-plane. This is 2.0 times the height of the paraxial marginal ray at the position relative to surface "i" at which the paraxial chief ray has zero height.
PUPDIAY	surf #	(not used)	(not used)	Same as above except in the YZ-plane.
PUPDISX	surf #	(not used)	(not used)	XZ-plane. This is the position at which the paraxial chief ray, in the space folloing surface "i", has zero height. It is represented in the coordinate system of surface "i".
PUPDISY	surf #	(not used)	(not used)	Same as above except in the YZ-plane.
CHFIMX	surf #	(not used)	(not used)	XZ-plane. This is the height of the paraxial chief ray at the position relative to surface "i" at which the paraxial marginal ray has zero height.
CHFIMY	surf #	(not used)	(not used)	Same as above except in the YZ-plane.
GPX	surf #	Field Pos. #	(not used)	XZ-plane generalized paraxial marginal ray height based upon differential rays about the chief ray.
GPY	surf #	Field Pos. #	(not used)	Same as above except in the YZ-plane.
GPUX	surf #	Field Pos. #	(not used)	XZ-plane generalized paraxial marginal ray slope based upon differential rays about the chief ray.
GPUY	surf #	Field Pos. #	(not used)	Same as above except in the YZ-plane.
GPCX	surf #	Field Pos. #	(not used)	XZ-plane generalized paraxial chief ray height based upon differential rays about the chief ray.
GPCY	surf #	Field Pos. #	(not used)	Same as above except in the YZ-plane.
GPUCX	surf #	Field Pos. #	(not used)	XZ-plane generalized paraxial chief ray slope based upon differential rays about the chief ray.
GPUCY	surf #	Field Pos. #	(not used)	Same as above except in the YZ-plane.

OPTMIZATION SECTION

PREDEFINED SPECIAL REAL RAY/PARAXIAL RAY BASED OPERANDS				
OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
DIST	Field Pos. #	(not used)	(not used)	Uses real chief and real chief differential ray traces to calculate percent distortion at the specified field point. Calculation is performed at the wavelength specified by the field point definition and for the current lens configuration. Value is valid for tilted and decentered systems. All surface types including special surfaces are recognized. See the "DIST" command in the CMD section.
FISHDIST	Field Pos. #	(not used)	(not used)	Similar to DIST but uses ray slope angles rather than slope angle tangents. See the "FISHDIST" command in the CMD section.
XFOC	Field Pos. #	(not used)	(not used)	XFOC returns the distance from the current image surface to the focus position of close XZ-plane marginal differential rays traced about the specified field point. Calculation is performed at the wavelength specified by the field point definition and for the current lens configuration. This distance is measured along the local Z-axis of the current image surface in the coordinate system of the current image surface **This is the X-field curvature. In modes FOCAL and UFOCAL, the units are lens units. In modes AFOCAL and UAFOCAL, the units are diopters. If, in the AFOCAL or UAFOCAL mode, the field curvature is too large to represent, it will be set to 1.0D20.**

PREDEFINED SPECIAL REAL RAY/PARAXIAL RAY BASED OPERANDS				
OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
YFOC	Field Pos. #	(not used)	(not used)	**Same as above except in the YZ-plane. This is the Y-field curvature. In modes FOCAL and UFOCAL, the units are lens units. In modes AFOCAL and UAFOCAL, the units are diopters. If, in the AFOCAL or UAFOCAL mode, the field curvature is too large to represent, it will be set to 1.0D20.**
AST	Field Pos. #	(not used)	(not used)	AST returns the the astigmatism along the specified field point. It is just the YFOC value minus the XFOC value. Calculation is performed at the wavelength specified by the field point definition and for the current lens configuration. **In modes FOCAL and UFOCAL, the units are lens units. In modes AFOCAL and UAFOCAL, the units are diopters. If, in the AFOCAL or UAFOCAL mode, the astigmatism is too large to represent, it will be set to 1.0D20.**

OPTMIZATION SECTION

<table>
<tr><td colspan="5" align="center">**PREDEFINED 3RD, 5TH AND 7TH ORDER ABERRATION OPERANDS**</td></tr>
<tr><td colspan="5">NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.</td></tr>
<tr><td>**OPERAND NAME**</td><td>**"i"**
 (nw#3)</td><td>**"j"**
 (nw#4)</td><td>**"k"**
 (nw#5)</td><td>**DESCRIPTION**</td></tr>
<tr><td>**SA3**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 3rd order SPHERICAL ABERRATION at surface "i" and at the control wavelength</td></tr>
<tr><td>**XSA3**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>**CMA3**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 3rd order COMA at surface "i" and at the control wavelength</td></tr>
<tr><td>**XCMA3**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>**AST3**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 3rd order ASTIGMATISM at surface "i" and at the control wavelength</td></tr>
<tr><td>**XAST3**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>**DIS3**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 3rd order DISTORTION at surface "i" and at the control wavelength</td></tr>
<tr><td>**XDIS3**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>**PTZ3**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 3rd order PETZVAL CURVATURE at surface "i" and at the control wavelength</td></tr>
<tr><td>**XPTZ3**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>**SA5**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 5th order SPHERICAL ABERRATION at surface "i" and at the control wavelength</td></tr>
<tr><td>**XSA5**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>**CMA5**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 5th order COMA at surface "i" and at the control wavelength</td></tr>
<tr><td>**XCMA5**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>**AST5**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 5th order ASTIGMATISM at surface "i" and at the control wavelength</td></tr>
<tr><td>**XAST5**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>**DIS5**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 5th order DISTORTION at surface "i" and at the control wavelength</td></tr>
<tr><td>**XDIS5**</td><td>surf # (def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
</table>

OPTMIZATION SECTION

OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
PREDEFINED 3RD, 5TH AND 7TH ORDER ABERRATION OPERANDS				
NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.				
PTZ5	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order PETZVAL CURVATURE at surface "i" and at the control wavelength
XPTZ5	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
TOBSA	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order TANGENTIAL OBLIQUE SPHERICAL ABERRATION at surface "i" and at the control wavelength
XTOBSA	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SOBSA	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order SAGITTAL OBLIQUE SPHERICAL ABERRATION at surface "i" and at the control wavelength
XSOBSA	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
ELCMA	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order ELLIPTICAL COMA at surface "i" and at the control wavelength
XELCMA	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
TAS	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order TANGENTIAL ASTIGMATISM at surface "i" and at the control wavelength
XTAS	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SAS	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order SAGITTAL ASTIGMATISM at surface "i" and at the control wavelength
XSAS	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SA7	surf # (def=last)	(not used)	(not used)	YZ-plane, 7th order SPHERICAL ABERRATION at surface "i" and at the control wavelength
XSA7	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SA3P	surf # (def=last)	(not used)	(not used)	YZ-plane, 3rd order SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XSA3P	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.

OPTMIZATION SECTION

<table>
<tr><th colspan="5" align="center">PREDEFINED 3RD, 5TH AND 7TH ORDER ABERRATION OPERANDS</th></tr>
<tr><td colspan="5">NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.</td></tr>
<tr>
<th>OPERAND NAME</th>
<th>"i"
(nw#3)</th>
<th>"j"
(nw#4)</th>
<th>"k"
(nw#5)</th>
<th>DESCRIPTION</th>
</tr>
<tr>
<td>CMA3P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>YZ-plane, 3rd order COMA, PRIMARY CHROMATIC DIFFERENCES
 at surface "i" and at the control
 wavelength</td>
</tr>
<tr>
<td>XCMA3P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>Same as above except in the XZ-plane.</td>
</tr>
<tr>
<td>AST3P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>YZ-plane, 3rd order ASTIGMATISM, PRIMARY CHROMATIC DIFFERENCES
at surface "i" and at the control
wavelength</td>
</tr>
<tr>
<td>XAST3P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>Same as above except in the XZ-plane.</td>
</tr>
<tr>
<td>DIS3P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>YZ-plane, 3rd order DISTORTION, PRIMARY CHROMATIC DIFFERENCES
at surface "i" and at the control
wavelength</td>
</tr>
<tr>
<td>XDIS3P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>Same as above except in the XZ-plane.</td>
</tr>
<tr>
<td>PTZ3P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>YZ-plane, 3rd order PETZVAL CURVATURE, PRIMARY CHROMATIC DIFFERENCES
at surface "i" and at the control
wavelength</td>
</tr>
<tr>
<td>XPTZ3P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>Same as above except in the XZ-plane.</td>
</tr>
<tr>
<td>SA5P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>YZ-plane, 5th order SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES
at surface "i" and at the control
wavelength</td>
</tr>
<tr>
<td>XSA5P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>Same as above except in the XZ-plane.</td>
</tr>
<tr>
<td>CMA5P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>YZ-plane, 5th order COMA, PRIMARY CHROMATIC DIFFERENCES
 at surface "i" and at the control
 wavelength</td>
</tr>
<tr>
<td>XCMA5P</td>
<td>surf #
(def=last)</td>
<td>(not used)</td>
<td>(not used)</td>
<td>Same as above except in the XZ-plane.</td>
</tr>
</table>

OPTMIZATION SECTION

NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.

OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
AST5P	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order ASTIGMATISM, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XAST5P	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
DIS5P	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order DISTORTION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XDIS5P	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PTZ5P	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order PETZVAL CURVATURE, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XPTZ5P	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
TOBSAP	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order TANGENTIAL OBLIQUE SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XTOBSAP	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SOBSAP	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order SAGITTAL OBLIQUE SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XSOBSAP	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
ELCMAP	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order ELLIPTICAL COMA, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XELCMAP	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.

OPTMIZATION SECTION

<table>
<tr><td colspan="5" align="center">**PREDEFINED 3RD, 5TH AND 7TH ORDER ABERRATION OPERANDS**</td></tr>
<tr><td colspan="5">NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.</td></tr>
<tr><td>**OPERAND NAME**</td><td>**"i"
(nw#3)**</td><td>**"j"
(nw#4)**</td><td>**"k"
(nw#5)**</td><td>**DESCRIPTION**</td></tr>
<tr><td>TASP</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 5th order TANGENTIAL ASTIGMATISM, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength</td></tr>
<tr><td>XTASP</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>SASP</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 5th order SAGITTAL ASTIGMATISM, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength</td></tr>
<tr><td>XSASP</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>SA7P</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 7th order SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength</td></tr>
<tr><td>XSA7P</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>SA3S</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 3rd order SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength</td></tr>
<tr><td>XSA3S</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>CMA3S</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 3rd order COMA, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength</td></tr>
<tr><td>XCMA3S</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
<tr><td>AST3S</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>YZ-plane, 3rd order ASTIGMATISM, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength</td></tr>
<tr><td>XAST3S</td><td>surf #
(def=last)</td><td>(not used)</td><td>(not used)</td><td>Same as above except in the XZ-plane.</td></tr>
</table>

OPTMIZATION SECTION

OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
PREDEFINED 3RD, 5TH AND 7TH ORDER ABERRATION OPERANDS				
NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.				
DIS3S	surf # (def=last)	(not used)	(not used)	YZ-plane, 3rd order DISTORTION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XDIS3S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PTZ3S	surf # (def=last)	(not used)	(not used)	YZ-plane, 3rd order PETZVAL CURVATURE, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XPTZ3S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SA5S	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XSA5S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
CMA5S	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order COMA, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XCMA5S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
AST5S	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order ASTIGMATISM, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XAST5S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
DIS5S	surf #	(not used)	(not used)	YZ-plane, 5th order DISTORTION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XDIS5S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.

OPTMIZATION SECTION

PREDEFINED 3RD, 5TH AND 7TH ORDER ABERRATION OPERANDS				
NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
PTZ5S	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order PETZVAL CURVATURE, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XPTZ5S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
TOBSAS	surf #	(not used)	(not used)	YZ-plane, 5th order TANGENTIAL OBLIQUE SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XTOBSAS	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SOBSAS	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order SAGITTAL OBLIQUE SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XSOBSAS	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
ELCMAS	surf #	(not used)	(not used)	YZ-plane, 5th order ELLIPTICAL COMA, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XELCMAS	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
TASS	surf # (def=last)	(not used)	(not used)	YZ-plane, 5th order TANGENTIAL ASTIGMATISM, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XTASS	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SASS	surf #	(not used)	(not used)	YZ-plane, 5th order SAGITTAL ASTIGMATISM, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XSASS	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.

OPTMIZATION SECTION

PREDEFINED 3RD, 5TH AND 7TH ORDER ABERRATION OPERANDS				
NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.				
OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
SA7S	surf # (def=last)	(not used)	(not used)	YZ-plane, 7th order SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i" and at the control wavelength
XSA7S	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
SA5I	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order SPHERICAL ABERRATION at surface "i" and at the control wavelength
XSA5I	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
CMA5I	surf # (def=last)	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order COMA at surface "i" and at the control wavelength
XCMA5I	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
AST5I	surf # (def=last)	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order ASTIGMATISM at surface "i" and at the control wavelength
XAST5I	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
DIS5I	surf #	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order DISTORTION at surface "i" and at the control wavelength
XDIS5I	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PTZ5I	surf # (def=last)	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order PETZVAL CURVATURE at surface "i" and at the control wavelength
XPTZ5I	surf #	(not used)	(not used)	Same as above except in the XZ-plane.
TOBSAI	surf # (def=last)	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order TANGENTIAL OBLIQUE SPHERICAL ABERRATION at surface "i" and at the control wavelength
XTOBSAI	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.

OPTMIZATION SECTION

PREDEFINED 3RD, 5TH AND 7TH ORDER ABERRATION OPERANDS				
NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
SOBSAI	surf # (def=last)	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order SAGITTAL OBLIQUE SPHERICAL ABERRATION at surface "i" and at the control wavelength
XSOBSAI	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
ELCMAI	surf # (def=last)	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order ELLIPTICAL COMA at surface "i" and at the control wavelength
XELCMAI	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
TASI	surf # (def=last)	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order TANGENTIAL ASTIGMATISM at surface "i" and at the control wavelength
XTASI	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SASI	surf # (def=last)	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 5th order SAGITTAL ASTIGMATISM at surface "i" and at the control wavelength
XSASI	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
SA7I	surf # (def=last)	(not used)	(not used)	Intrinsic surface contribution; YZ-plane, 7th order SPHERICAL ABERRATION at surface "i" and at the control wavelength
XSA7I	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PSA3	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order SPHERICAL ABERRATION at surface "i" and at the control wavelength
XPSA3	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PCMA3	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order COMA at surface "i" and at the control wavelength
PXCMA3	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.

OPTMIZATION SECTION

PREDEFINED 3RD, 5TH AND 7TH ORDER ABERRATION OPERANDS				
NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.				
OPERAND NAME	**"i"** (nw#3)	**"j"** (nw#4)	**"k"** (nw#5)	**DESCRIPTION**
PAST3	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order ASTIGMATISM at surface "i" and at the control wavelength
XPAST3	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PDIS3	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order DISTORTION at surface "i" and at the control wavelength
XPDIS3	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PPTZ3	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order PETZVAL CURVATURE at surface "i" and at the control wavelength
XPPTZ3	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PSA3P	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order SPHERICAL ABERRATION, PRIMARY CHROMATIC DIFFERENCES at surface "i"
XPSA3P	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PCMA3P	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order COMA, PRIMARY CHROMATIC DIFFERENCES at surface "i"
XPCMA3P	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PAST3P	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order ASTIGMATISM, PRIMARY CHROMATIC DIFFERENCES at surface "i"
XPAST3P	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.

OPTMIZATION SECTION

OPERAND NAME	"i" (nw#3)	"j" (nw#4)	"k" (nw#5)	DESCRIPTION
PREDEFINED 3RD, 5TH AND 7TH ORDER ABERRATION OPERANDS				
NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.				
PDIS3P	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order DISTORTION, PRIMARY CHROMATIC DIFFERENCES at surface "i"
XPDIS3P	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PPTZ3P	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order PETZVAL CURVATURE, PRIMARY CHROMATIC DIFFERENCES at surface "i"
XPPTZ3P	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PSA3S	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order SPHERICAL ABERRATION, SECONDARY CHROMATIC DIFFERENCES at surface "i"
PXSA3S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PCMA3S	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order COMA, SECONDARY CHROMATIC DIFFERENCES at surface "i"
XPCMA3S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PAST3S	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order ASTIGMATISM, SECONDARY CHROMATIC DIFFERENCES at surface "i"
XPAST3S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PDIS3S	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order DISTORTION, SECONDARY CHROMATIC DIFFERENCES at surface "i"
XPDIS3S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.

OPTMIZATION SECTION

PREDEFINED 3RD, 5TH AND 7TH ORDER ABERRATION OPERANDS				
NOTE: Entering the number of the last surface (the default) for "i" in the 3rd, 5th and 7th order aberrations results in the system aberration total for that aberration being used as the operand value.				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
PPTZ3S	surf # (def=last)	(not used)	(not used)	Exit pupil; YZ-plane, 3rd order PETZVAL CURVATURE, SECONDARY CHROMATIC DIFFERENCES at surface "i"
XPPTZ3S	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.
PTZCV	surf # (def=last)	(not used)	(not used)	This is the YZ-plane, third order Petzval curvature. Its value is independent of lens mode.
XPTZCV	surf # (def=last)	(not used)	(not used)	Same as above except in the XZ-plane.

OPTMIZATION SECTION

PREDEFINED GAUSSIAN BEAM OPERANDS				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
GBRADX	surf #	Field Pos. #	(not used)	The XZ-plane $1/e^2$ semi-diameter of the gaussian beam at surface "i" and at field position "j". Wavelength defined in the field position definition.
GBRADY	surf #	Field Pos. #	(not used)	This is the same as GBRADX except that it works in the YZ-plane.
GBDISX	surf #	Field Pos. #	(not used)	The distance from surface "i" to the next XZ-plane beam waist in the image space of surface "i". Wavelength defined in the field position definition.
GBDISY	surf #	Field Pos. #	(not used)	This is the same as GBDISX except that it works in the YZ-plane.
GBRCVX	surf #	Field Pos. #	(not used)	The XZ-plane wavefront radius of curvature at surface "i" in the image space of surface "i". Wavelength defined in the field position definition.
GBRCVY	surf #	Field Pos. #	(not used)	This is the same as GBRCVX except that it works in the YZ-plane.
GBWAISTX	surf #	Field Pos. #	(not used)	The XZ-plane $1/e^2$ semi-diameter of the beam waist in the image space of surface "I". Wavelength defined in the field position definition.
GBWAISTY	surf #	Field Pos. #	(not used)	This is the same as GBWAISTX except that it works in the YZ-plane.

PREDEFINED REAL RAY SPECTROMETER OPERANDS (See description following the GET list in the CMD section)				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**
CTSX or CTSY	wavelength #	pixel size (optional)	(not used)	Cross-track Spectral Co-registration Error at wavelength number "i".
SCEX or SCEY	pixel size (optional)	(not used)	(not used)	Spatial Co-registration Error for all defined wavelengths.

PREDEFINED REAL RAY COMPOSITE OPERANDS (Not available in GET or Tolerancing)				
OPERAND NAME	**"i"** **(nw#3)**	**"j"** **(nw#4)**	**"k"** **(nw#5)**	**DESCRIPTION**

OPTMIZATION SECTION				
CLEARX	fob#1**.**ray#1 example: 001.0012	fob#2**.**ray#2 example: 034.0005	surf#1**.**surf#2 example: 005.007	"i" and "j" are decimal entries with three digits to the left of the decimal point and four digits to the right. "k" is a decimal entry with three digits to the left of the decimal point and three digits to the right. For "i" and "j", the input represents the FOB and RAY numbers representing two rays as defined in the current Fields and Rays definitions. For "k", the input represents two surface numbers. The value returned as the "clearance-X" operand is: The signed, globally referenced, perpendicular-distance from the "first" ray (Vector A) as defined by "i" leaving the "first" surface defined in "k" to a point (point B) defined by the intersection of the "second" ray as defined in "j" with the "second" surface defined in "k". The calculation is performed on an XZ-plane projection. The returned operand value is positive if the point B lies above or to the right of the line (vector A), otherwise it is negative. All calculations are referenced to the global coordinate system of surface (surf#2). The first ray defined by fob#1, ray#1 leaving surf#1 defines vector A. The second ray defined by fob#2, ray#2 intersecting surf#2 defines point B. The returned value is the XZ-plane component of the perpendicular distance from point B to vector A. All calculations are performed in the global coordinate system referenced to the vertex of surf#2.
CLEARY	fob#1**.**ray#1 example: 001.0012	fob#2**.**ray#2 example: 034.0005	surf#1**.**surf#2 example: 005.007	"i" and "j" are decimal entries with three digits to the left of the decimal point and four digits to the right. "k" is a decimal entry with three digits to the left of the decimal point and three digits to the right. For "i" and "j", the input represents the FOB and RAY numbers representing two rays as defined in the current Fields and Rays definitions. For "k", the input represents two surface numbers. The value returned as the "clearance-Y" operand is: The signed, globally referenced, perpendicular-distance from the "first" ray (VectorA) as defined by "i" leaving the "first" surface defined in "k" to a point (point B) defined by the intersection of the "second" ray as defined in "j" with the "second" surface defined in "k". The calculation is performed on a YZ-plane projection. The returned operand value is positive if the point B lies above or to the right of the line (vector A), otherwise it is negative. All calculations are referenced to the global coordinate system of surface (surf#2). The first ray defined by fob#1, ray#1 leaving surf#1 defines vector A. The second ray defined by fob#2, ray#2 intersecting surf#2 defines point B. The returned value is the YZ-plane component of the perpendicular distance from point B to vector A. All calculations are performed in the global coordinate system referenced to the vertex of surf#2.

OPTMIZATION SECTION

OPERAND CALCULATION SPEED - All ray based predefined operands use a field position or a field position and a ray position designator in order to specify the field or field and ray upon which a specific operand is to be based. If operands are grouped together in the MERIT FUNCTION by field and ray position designation, then the program will always know if the existing ray or spot diagram used for the previous operand may be used for the current operand. If the user does this grouping when constructing a MERIT FUNCTION, the user will minimize the amount of time consumed in ray tracing during optimization.

USER-DEFINED OPERAND ENTRY - In the cases where the predefined operands discussed above are not appropriate for a particular design problem, user-defined operands are available. User-defined operands are specified as members of the merit function through the following command:

(macro function name) (operand name) , t , wt , n , w1 , w2 - "macro function name" is the command word of this command. "macro function name" can be "FUNC01" through "FUNC10". (See the discussion of macro functions and macros in the MACRO section). For user-defined operand entry, the macro function name is always explicitly required. "operand name" is the qualifier word. This is the user-supplied name or label for the operand. It can be any valid eight-character name as long as it is not the same as one of the predefined operand names described above. "t" is the "target value" of the operand. The default value for "t" is 0.0. "wt" is the relative weight for the operand in the merit function. "wt" must be non-negative. The default value for "wt" is 1.0. "n" is the number of a general purpose storage register (valid range 1 to MAXOPT) where the value of the operand is to be found after it is evaluated in the macro function designated by the command word. (See the discussion of the general purpose storage registers in the CMD section). "n" must always be explicitly input. In order to explicitly input "n" = 11 while inputting default "t" and "wt" values for operand named "OP1", using macro function number 1, the entry would be:

<p align="center">**FUNC01 OP1,,,11**</p>

"w1" and "w2" are optional numeric words #1 and #2 which may be used to transfer additional numeric input into the macro function designated by the command word. (See the discussion of the "NSUB" command in the MACRO section.). The user adds an operand definition to the merit function using the above command. The user then writes a macro function with the name designated by the command word. In that macro function, the value or values of operands are defined and placed in the appropriate general purpose storage registers. The designated macro functions are executed and operand values are evaluated and stored in the designated general purpose storage registers, automatically, during the optimization process. Anything that can be calculated in a macro function can be used as an operand. Since macro functions are always memory resident and are pre-complied, they execute very fast. This architecture is extremely flexible and powerful. It is flexible enough to even define operands which have no relationship to the sequential database but are depended upon parameters in the NSS database and computed from the results on the NSS ray trace.

VARIABLES EXAMPLES - It is assumed that the designer has decided which design parameters of an optical prescription are to be varied during optimization. For the sake of this sample variables definition, the designer will vary the radius of curvature of surfaces 1, 3, 5, 7 and 12, the thickness of surface 2 and 6 and the conic constant of surface 3. From the CMD level, the designer would type:

<p align="center">
VARIABLE
RD 1
RD 3
RD 5
RD 7
RD 12
TH 2
TH 6
CC 3
EOS or END
</p>

Alternatively, the designer could write a macro (lets name it MYVAR) which, when run, sets up the variables subfile. From the CMD level the designer would type:

<p align="center">
MACRO MYVAR
VARIABLE
RD 1
RD 3
RD 5
RD 7
RD 12
TH 2
TH 6
CC 3
EOS or END
EOM
</p>

Then, by typing the name of the macro, "MYVAR", the variables subfile would be created. Remember: A macro may also be created using the macro edit or MEDIT process described in the MACRO section of this manual or it may be created using a DOS level editor. Using a macro to store and initiate optimization files is the best way to ensure that the subfiles are not inadvertantly lost. After creation, the variable definition can be querried using the "VB" and VBA" CMD level commands described in this manual section. The variable definition will continue to exist until the next "VARIABLE" command is issued or until the program terminates. The automatic save and reload commands described above in this section may also be used to store and recall optimization definitions. They are easy to use. Just type "AUTO SAVE" or "AUTO SAVE2" to save and "AUTO RELOAD" or "AUTO RELOAD2" to reload.

MERIT FUNCTION EXAMPLES - These are not "default" merit funtions. "DEFAULT" merit functions are inherently bad things which make for poor designers and less than average designs. This program has no "default" merit function. We feel strongly on this point. Every user-defined operand definition has two parts. Part 1 is a macro funtion named "FUN01" through "FUN10" which loads various designer selected lens database related parameter values into selected general purpose storage registers. Part II is the MERIT definition which gives user-defined names to the aforementioned lens database related parameter values, gives instruction as to the specific general purpose storage registers where the values may be found, specifies operand desired target values and specifies operand weighting factors. It sounds like a lot, and it is. Specific setups can be as simple or as complex as the design problem warrants. The first sample is an optimization subfile made up of one paraxial raytrace based parameter which will represent "FOCUS". The macro function "FUN01" will be used. The designer would type:

MDEL FUN01
MACRO FUN01
GET PY,,,,,1
EOM

The macro function will automatically load general purpose storage register #1 with the YZ-plane paraxial marginal ray height at the image surface also called PY. The designer will not need to "run" the macro function. It will be run automatically during an optimization cycle. The designer then types from the CMD level:

MERIT
FOCUS 0 1 1
EOS or END

The "PY" value at the image surface has been named "FOCUS". It has a target value specified to be "0" with relative weight "1". It will be found by the automatic optimization routines in general storage register #1. If macro function "FUN02" or any other macro function other than "FUN01" had been used, the above three commands would need to be:

MERIT
FUNC02 FOCUS 0 1 1
EOS or END

For predefined operands, no macro function is needed. To target the "Y" coordinate of ray number 2 at field position 1 and at surface 5 to a value of 0 with a weight of 1, the MERIT entry would be:

MERIT
Y 0 1 5 1 2
EOS or END

To target the "Y" coordinate (a predefined operand) of ray number 2 at field position 1 at the "default" image surface to a value of 0 with a weight of 1, the MERIT entry would be:

MERIT
Y 0 1 ,, 1 2
EOS or END

Further examples may be found in the TUTORIAL MANUAL.

OPTMIZATION SECTION

USER OPTIM INFORMATION - User-defined optimization is similar to the lens database type of optimization. The only difference is that user-defined optimization supports one extra variable type and one extra operand type. User-defined optimization should be thought of as a super-set of the lens database optimization technique.

USER-VARIABLE COMMAND - Variable input syntax is exactly the same as described in the OPTIM section except that there is an additional variable named "MACVAR"."n" is the number of one of the 100000 (valid range 1 to 100000) general purpose storage registers available in the program. The default "dincr" value is 1.0D-10. Default limit values are -1.0D+20 AND +1.0D+20. The syntax of the command is:

MACVAR , n , wt , dincr , limit value 1 , limit value 2

OPERANDS AND OPERAND ENTRY - Operand entry is the same as described before except that there is one additional operand available named "MACOPT". The default operand target value "t" is 0.0. "wt" is the relative weight for the operand in the merit function. "wt" must be non-negative. The default value for "wt" is 1.0. "n" is the number of a general purpose storage register (valid range 1 to 1000) where the value of the operand is to be found after it is evaluated by an automatic execution of a macro named "MACROOPT". If this specific macro does not exist, zero will be returned for the operand values and optimization won't work correctly. Macro "MACROOPT" may be as simple or as complex as desired and may call any number of other macros. "n" must always be explicitly input. The syntax of the command is: **MACOPT , t , wt , n**

In order to explicitly input "n" = 11 while inputting default "t" and "wt" values, the entry would be:

MACOPT,,,11

LENS DATABASE INTERACTION - Normally, the program re-initializes variable and operand definitions whenever certain condition arise. This re-initialization occures whenever a lens is retrieved from the lens library and whenever certain internal lens database manipulations occur. Issuing the command "OPTMINIT" with qualifier "NO" or "OFF" causes this reinitialization process to be skipped until the program terminates or until "OPTMINIT" is issued with the "YES" or "ON" qualifier. If lenses are input from stored files as in "INPUT ED" types of input, the internal setting associated with the "OPTMINIT" command will have NO EFFECT. The syntax of the command is: **OPTMINIT (YES or ON or NO or OFF)**

Error! Not a valid filename.

CAD-GENERAL INFORMATION - The CAD (Computer Aided Design) section describes a number of different program features which can be used in support of opto-mechanical design and optical component fabrication. All commands in this section are issued from the program CMD level. The program performs all its CAD output to the specific files. These files may be imported to compatible CAD programs from outside this program.

3D-DXF COMMANDS - The 3D-DXF commands allow the user to create 3D-DXF polyline representations of the current lens configuration as well as rays traced through that lens. The resultant DXF files may be imported to compatible CAD programs from outside this program.

DXF NEW - The "DXF NEW" command initializes the program for new 3D DXF output. WARNING: ANY EXISTING 3D DXF DATA IN THE FILE **DXF3D.DXF** WILL BE DELETED WHEN THE "DXF NEW" COMMAND IS ISSUED.

DXF LAYER (8-character layer name) - The "DXF LAYER" command is used to specify the name of the current DXF layer name. The default layer is named: LAYER001. Issued with a "?", the current layer name is displayed. Layer names must be exactly 8 characters in length.

DXF GLBSURF , global surface number - The "DXF GLBSURF" command is used to specify the surface number, which will be used as the global origin for all DXF coordinates. Issued with a "?", the current DXF global surface number will be displayed. The default global surface number is usually 1 unless the thickness assigned to surface 1 is infinite.

DXF PROFY , i , j and **DXF PROFX , i , j** - The "DXF PROFY" and "DXF PROFX" commands are used to output the YZ and XZ-plane lens surface profiles to the current 3D DXF file. These profiles are the projections of the surface's local coordinate system Y and X-axes upon the lens surface. Each profile is bounded by the explicit or implicit clear aperture on that surface. A blank space will be left if there is an assigned obscuration.

DXF PROF , i , j , theta - The "DXF PROF" command is a general form of the commands "DXF PROFX" and "DXF PROFY". It is used to output surface profiles in any azimuthal orientation to the current #d DXF file. The third numeric word "theta" specifies the azimuthal orientation angle. "Theta" is measured positive, counter-clockwise from the local surface positive x-axis to the local surface positive y-axis. "Theta" can be assigned any angle between 0.0 and 360.0 degrees. The default value for "theta" is 0.0. This is equivalent to a "DXF PROFX" command. A "DXF PROFY" command may be simulated with "theta" set to 90.0 degrees. The profile is bounded by the explicit or implicit clear aperture on that surface. A blank space will be left if there is an assigned obscuration.

DXF EDGEY , i , j and **DXF EDGEX , i , j** - The "DXF EDGEY" and "DXF EDGEX" commands are used to output edges connecting non-air spaces. The edges connect the ends of surface profiles.

DXF CLAP , i , j , k - The "DXF CLAP" command is used to output surface clear apertures projected onto the surface to the current 3D DXF file. The optional third numeric word "k" is used to specify fractional clear aperture display The default value for "k" is 1.0. "k" may be set to any value greater than 0.0 and less than or equal to 1.0.

DXF RAY , i , j - The "DXF RAY" command causes the most recent ray traced to be added to the current 3D DXF file. Ray data will be added from lens surface "i" to lens surface "j" .The internal operation of the "DXF RAY" command is such that if the ray to be output is a failed ray, the ray will be represented through the optical system up to the surface for which ray data becomes unreliable. Rays may fail for any of the valid failure reason recognized by the program including ray failures due to blockages by clear apertures and obscurations when the "RAY CAOB" command is used to trace the ray. Prior to issuing a "DXF RAY" command, the "FOB" and "RAY" or "RAY CAOB" commands must be issued to generate the ray data.

DXF LINE - The "DXF LINE" command allows the user to add a 3D line from coordinates X1, Y1, Z1 to coordinates X2, Y2 and Z2. The coordinates of these two points are always considered to be represented in the global coordinate system of the current optical system graphic in which the origin is either located at the vertex of surface 0 (for finit conjugate object points) or the vertex of surface 1 (for infinite conjugate object points). The coordinates of these two points are assigned using the following six commands. By default, both points are located at 0,0,0 when the program starts or when a new plot is initiated.

X1 or Y1 or Z1 or X2 or Y2 or Z2 - The "X1", "Y1", "Z1", "X2", "Y2" and"Z2" commands allows the user to specify the starting and ending coordinates of the next 3D line to be drawn. By default, the values are 0,0,0 when the program starts and when a DXF file is initiated.

CAD SECTION

DXF END - The "DXF END" command stops all DXF output to the DXF3D.DXF file.

OPTICAL COMPONENT DRAWINGS - In support of the fabrication of single lenses, the following commands may be used in order to generate single lens engineering drawings. Except for the beginning surface number, all inputs to this set of commands have sensible default values.

PARTDRAW , n - The "PARTDRAW" command initializes and initiates lens part drawing. The starting surface number "n" must be explicitly entered. The lens drawn will start at surface "n" and end at surface "n+1" in the current lens database. The "PARTDRAW" command may be followed by the entry of optional values as shown in the table below. A "PARTGO" command must be used to indicate that no more options are to be entered and that the lens part drawing should be generated and placed in the NEUTRAL.DAT file. After the "PARTGO" command is issued, the part drawing may be displayed to the screen with a "DRAW" command or sent to a graphics file or hardcopy device with a "GRAOUT" command. "DRAW" and "GRAOUT" are described fully in the GRAPHICS section of this manual. All tolerance defaults shown in "inches" will be automatically converted to mm, cm or meters as needed depending upon the current system units. All part diameters and diameters-to-flat are taken from the lens database.

COMMAND	DEFAULT	DESCRIPTION
DIATOL , v	+/- 0.002 inch.	Outer diameter tolerance.
RADTOL , v1 , v2	+/- 0.1% of radius or +/- 4 fringes if flat.	Radius tolerance for each surface.
RADTLF , v1 , v2	+/- 0.1% of radius or +/- 4 fringes.	Radius tolerance in fringes for each surface.
FRNG , v1 , v2	1 fringe	Fringes of irregularity.
THITOL , v	+/- 0.002 inch.	Thickness tolerance.
CLERAP , v	OD value minus 0.08 inch.	Clear aperture of surfaces.
SURFQUAL , v	(blank)	Surface quality, up to 20 alpha/numeric characters.
FRNGDIA , v1 , v2	CLERAP	Diameter at which delta R per fringe is calculated for each surface.
CENTER , v	+/- 0.002 inch.	Surface to surface centration error.
BRKEDG , v	0.01 inch.	Break edges.
SURFCOAT , v	(blank)	Coating drawing number, up to 20 alpha/numeric characters.
SAGTOL , v1 , v2	+/- 0.002 inch.	Sag tolerance for each surface.
PRPNTL , v1 , v2	+/- 1.00 arc-sec	Tolerance of flat perpendicularity to optical axis for each surface in arc-sec. (This is the NORM. box)
TITLE , v	(blank)	Drawing title, up to 32 alpha/numeric characters.
DWGNO , (dwgno)	(blank)	Drawing number, up to 12 alpha/numeric characters.
SURFMATL , v	Material specified in lens database.	Surface material, up to 13 alpha/numeric characters.
GLSCD , v1 , v2	Stored in lens database glass catalog.	Glass code, each 3 digits.
WAVEL , v	For visible systems, 0.5461 microns. For non-visible systems, the control wavelength CW.	Wavelength for fringe and EFL, BFL, FFL calculations.

Any combination of above listed commands may be issued in any order. Incorrect values may be overwritten by issuing the command again with correct input. If only one value is entered for "SAGTOL" or "PRPNTL", it will apply to both surfaces. A single value for OD becomes the outer diameter of the lens. "RADTOL" and RADTLF" override each other.

PARTQUIT - The "PARTQUIT" command terminates all part drawing.

PARTGO - The "PARTGO" command causes a lens part drawing to be generated and stored in the neutral plot file NEUTRAL.DAT. It may be displayed on the screen or stored in alternate graphics file formats or printed using the "DRAW" and "GRAOUT" commands described in the GRAPHICS section of this manual.

DRAWING NOTES - The drawing notes used for various lens drawings are stored in ASCII format in the NOTES subdirectory beneath the main program directory. 11 drawing notes currently exist. The first line of each file contains an integer designating the number of lines in the note. This is always one less than the number of lines in the file. The user may change these but really, they should not be touched without making backup copies. Bad notes with incorrect counts can cause the program to crash. Notes 12 through 25 are blank and may be used by the user to add custom notation to the part drawing. The current notes are:

File NOTE1A.DAT (used for polycrystalline ZNS)

8

1. MATERIAL: POLYCRYSTALLINE OPTICAL GRADE ZINC SULFIDE (ZNS),
   CHEMICAL VAPOR DEPOSITED (CVD), STRESS FREE, FINE ANNEALED.
   THE AVERAGE TRANSMITTANCE THROUGH A POLISHED, UNCOATED 0.20
   IN. THICK (MIN.), NOMINAL SIZE SAMPLE CUT FROM THE SAME LOT
   OF MATERIAL AS THE LENS BLANK SHALL NOT BE LESS THAN:
   - A. 2.0 - 5.0 MICROMETERS 70%
   - B. 7.5 - 10.0 MICROMETERS 71%
   - C.   11.25   MICROMETERS 60%

File NOTE1B.DAT (used for polycrystalline Germanium)

8

1. MATERIAL: POLYCRYSTALLINE OPTICAL GRADE (5-30 OHM-CM) N-TYPE
   GERMANIUM, STRESS FREE, FINE ANNEALED. THE TRANSMITTANCE
   THROUGH A POLISHED, UNCOATED 0.20 IN. THICK (MIN.) NOMINAL
   SIZE SAMPLE CUT FROM THE SAME LOT OF MATERIAL AS THE LENS
   BLANK SHALL NOT BE LESS THAN:
   - A. 2.5 - 10.0 MICROMETERS 46%
   - B. 10.0 - 11.0 MICROMETERS 45%
   - C. 11.0 - 11.5 MICROMETERS 43%

File NOTE1C.DAT (used for polycrystalline ZNSE)

6

1. MATERIAL: POLYCRYSTALLINE OPTICAL GRADE ZINC SELENIDE (ZNSE),
   CHEMICAL VAPOR DEPOSITED (CVD), STRESS FREE, FINE ANNEALED.
   THE AVERAGE TRANSMITTANCE THROUGH A POLISHED, UNCOATED 0.20
   IN. THICK (MIN.), NOMINAL SIZE SAMPLE CUT FROM THE SAME LOT
   OF MATERIAL AS THE LENS BLANK SHALL NOT BE LESS THAN 70%
   AVERAGED OVER 2.0 TO 12.0 MICROMETERS

File NOTE1D.TXT (used for material not listed here and not in the standard manufacturer supplied glass catalogs)

1

1. MATERIAL: (SEE ATTACHED SHEET)

File NOTE1E.DAT (used for AMTIR-1)

12

1. MATERIAL: OPTICAL GRADE AMTIR-1 OR EQUIVALENT THAT MEETS
   THE FOLLOWING SPECIFICATIONS:
   - A. STRIA FREE.
   - B. BUBBLE AND INCLUSION FREE WHEN OBSERVED THROUGH A 10X
     INFRARED MICROSCOPE.
   - C. TRANSMITTANCE THROUGH A POLISHED, UNCOATED 0.20 IN.
     THICK (MIN.) NOMINAL SIZE SAMPLE CUR FROM THE SAME MELT
     RUN AS THE LENS BLANK SHALL NOT BE LESS THAN:
      2.0 - 10.5 MICROMETERS 67%
        11.0   MICROMETERS 65%
        11.5   MICROMETERS 63%
        12.0   MICROMETERS 62%

File NOTE1F.DAT (used for visible glasses in all of the standard glass catalogs)

2

1. MATERIAL: GLASS OPTICAL TYPECLASS 1, GRADE B,
   FINE ANNEALED, PER MIL-G-174

File NOTE2.DAT

1

2. ELEMENT IN ACCORDANCE WITH MIL-0-13830

File NOTE3.DAT

2

3. SURFACE MARKED "P" POLISHED. ALL OTHERS GROUND WITH 220
   GRIT SIZE OR EQUIVALENT

File NOTE4.DAT

2

4. CLEAR APERTURE : ENTRANCE:
EXIT:

File NOTE5.DAT

1

5. SURFACE QUALITY (PER MIL-C-48497):

File NOTE6.DAT (visible band materials)

10

6. RADIUS OF CURVATURE OF FINISHED PART SHALL BE WITHIN THE
   TOLERANCE RANGE SPECIFIED.
   WHEN USING A TEST GLASS (@ 0.5461 MICROMETER NOMINAL):
     A. TO MEASURE IRREGULARITY, SURFACE OF FINISHED PART SHALL
        FIT TEST GLASS WITHIN 4 TIMES THE IRREGULARITY CALL OUT.
     B. TO CALCULATE SURFACE RADIUS, INCLUDE FRINGE COUNT
        DEPARTURE FROM MEASURED TEST GLASS RADIUS AND
        UNCERTAINTY OF THE TEST GLASS RADIUS MEASUREMENT.
          FOR   R. R/FRINGE=   AT   DIA.
                   R. R/FRINGE=   AT   DIA.

FILE NOTE6A.DAT (used for both surfaces flat)

4

6. FLATNESS OF FINISHED PART SHALL BE WITHIN THE
4 TIMES THE IRREGULARTITY CALLOUT OVER THE ENTRANCE
   AND EXIT DIAMETERS WHEN USING A TEST GLASS AT
   AT A NOMINAL WAVELENGTH (MICRONS) =

File NOTE6B.DAT (surface 1 flat, surface 2 not flat)

16

6. RADIUS OF CURVATURE OF FINISHED PART SHALL BE WITHIN THE
   TOLERANCE RANGE SPECIFIED.
   WHEN USING A TEST GLASS (NOMINAL WAVELENGTH (MICRONS) =
     A. TO MEASURE IRREGULARITY, SURFACE OF FINISHED PART SHALL
        FIT TEST GLASS WITHIN 4 TIMES THE IRREGULARITY CALL OUT.
     B. TO CALCULATE SURFACE RADIUS, INCLUDE FRINGE COUNT
        DEPARTURE FROM MEASURED TEST GLASS RADIUS AND
        UNCERTAINTY OF THE TEST GLASS RADIUS MEASUREMENT.

FOR: SURFACE 1, FLAT TO WITHIN 4 TIMES THE
       IRREGULARITY CALLOUT
       AT: DIA.=

       FOR: SURFACE 2
    DELTA-R/FRINGE=
       AT: DIA.=

File NOTE6C.DAT (surface 1 not flat, surface 2 flat)
16
6. RADIUS OF CURVATURE OF FINISHED PART SHALL BE WITHIN THE
    TOLERANCE RANGE SPECIFIED.
    WHEN USING A TEST GLASS (NOMINAL WAVELENGTH (MICRONS) =
      A. TO MEASURE IRREGULARITY, SURFACE OF FINISHED PART SHALL
          FIT TEST GLASS WITHIN 4 TIMES THE IRREGULARITY CALL OUT.
      B. TO CALCULATE SURFACE RADIUS, INCLUDE FRINGE COUNT
          DEPARTURE FROM MEASURED TEST GLASS RADIUS AND
          UNCERTAINTY OF THE TEST GLASS RADIUS MEASUREMENT.

          FOR: SURFACE 1
    DELTA-R/FRINGE=
        AT: DIA.=

FOR: SURFACE 2, FLAT TO WITHIN 4 TIMES THE
        IRREGULARITY CALLOUT
        AT: DIA.=

File NOTE6D.DAT (neither surface flat)
16
6. RADIUS OF CURVATURE OF FINISHED PART SHALL BE WITHIN THE
    TOLERANCE RANGE SPECIFIED.
    WHEN USING A TEST GLASS (NOMINAL WAVELENGTH (MICRONS) =
      A. TO MEASURE IRREGULARITY, SURFACE OF FINISHED PART SHALL
          FIT TEST GLASS WITHIN 4 TIMES THE IRREGULARITY CALL OUT.
      B. TO CALCULATE SURFACE RADIUS, INCLUDE FRINGE COUNT
          DEPARTURE FROM MEASURED TEST GLASS RADIUS AND
          UNCERTAINTY OF THE TEST GLASS RADIUS MEASUREMENT.

          FOR: SURFACE 1
    DELTA-R/FRINGE=
        AT: DIA.=

          FOR: SURFACE 2
    DELTA-R/FRINGE=
        AT: DIA.=

File NOTE7.DAT
1
7. DATUM -A- IS THE LINE CONNECTING THE TWO CENTERS OF CURVATURE

File NOTE8.DAT
2
8. CENTERING ERROR TO BE LESS THAN :
    REFERENCED TO DIA. =

File NOTE9.DAT
1
9. BREAK EDGES, FACE WIDTH MAX.=

File NOTE10.DAT
1
10. COAT CLEAR APERTURES PER:

File NOTE11.DAT
4
11. REF. ONLY @ NOMINAL WAVELENGTH (MICRONS):
      EFL =
      BFL =
      FFL =

CAD SECTION

SAMPLE PART DRAWING - The following sample drawing was created by retrieving the COOKE TRIPLET distributed with the program and then issuing the following string of commands: **PARTDRAW 2;PARTGO;DRAW**

The drawing was output to a monochrome Bit Map file (BMP) and imported into this manual using the command: **GRAOUT BMP**.
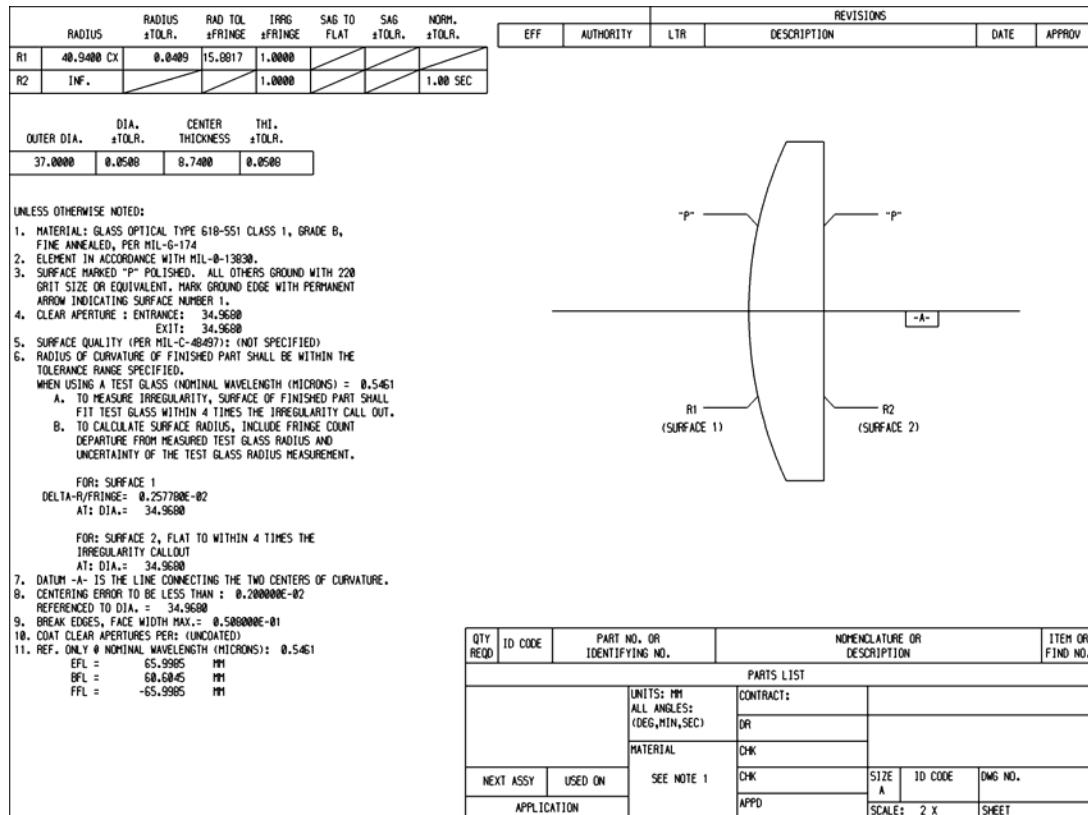
Sample Lens Part Drawing

TEST PLATE FITTING - The test plate fitting of an optical design is one of the more important phases of preparing a design for fabrication. The "TPLATE" command allows the user read/copy access to all currently installed testplate lists.

TPLATE (testplate list name) - The "TPLATE" command causes the built-in full screen edit program to open the designated testplate list. After the list is opened, any testplate radius may be copied into the Windows Clipboard and later pasted into the program command line as input to a "TESTRD" or "TESTCYL" command. Issued with the "?", the currently available testplate list names are displayed. Issued with the "LIST" qualifier, the command causes the names of the current testplate lists to be displayed along with their associated qualifier words.

TESTRD , surf# , testplate radius value - The "TESTRD" command causes surface designated by "surf#" to have its radius of curvature set to the "testplate radius value **in millimeters**". If the current lens database units are not millimeters, then the input testplate radius value will be converted from millimeters to the current lens database units and then assigned to the lens surface. Before the assignment is made, any curvature solve or pikup which would control the radius is removed. If the surface curvature is a current variable, that variable is removed from the variables list.

TESTCYL , surf# , testplate cylinder radius value - The "TESTCYL" command causes surface designated by "surf#" to have its toric radius of curvature set to the "testplate cylinder radius value **in millimeters**". If the current lens database units are not millimeters, then the input testplate cylinder radius value will be converted from millimeters to the current lens database units and then assigned to the lens surface. Before the assignment is made, any curvature solve or pikup which would control the toric radius is removed. If the surface toric curvature is a current variable, that variable is removed from the variables list.

All testplate values in the testplate databases are expressed in millimeters. Make sure to convert these units into the units being used in the lens database being testplated.

NON-SEQUENTIAL SYSTEM SECTION

NSS-GENERAL INFORMATION - This manual section describes the establishment and manipulation of the Non-Sequential Surface (NSS) optical system database through which non-sequential rays may be traced. There are no limits to size of the optical system which can be modeled in the NSS database. NSS databases are set up and manipulated using CMD level commands. There is no NSS program sub-level as was used with the sequential lens databases. Alternate configuration data (CFG) and the special surface data (SPSRF) are not explicitly used in the NSS database. Modeling an optical system with the NSS database and tracing NSS rays is totally independent of the standard lens database and sequential ray tracing.
NSSDEL - The NSSDEL command deletes the existing NSS database and frees all allocated memory used by the current NSS database.
NSSNEW - The NSSNEW command deletes the existing NSS database, frees all allocated memory used by the last NSS database and then allocates memory for a new NSS database. The initial size of the NSS database is 200 surfaces is increased automatically as needed.

NSS COORDINATE SYSTEM - The coordinate system for the NSS database is a global coordinate system with origin located at global coordinates X=0.0, Y=0.0, Z=0.0. The coordinate system is pure right handed.

NSS DATABSE - The NSS database consists of database items which relate to the entire database and database items which relate to specific NSS database SURFACES.

NON- SURFACE DATABASE ITEMS - The NSS database items which are not directly related to NSS database SURFACES are controlled by the following CMD level commands:
NSSUNITS (IN or CM or MM or M) - The linear units in an NSS database can be set to INCHES, CENTIMETERS, MILLIMETERS or METERS. The default NSSUNITS are INCHES. Issuing "NSSUNITS" with the interrogative "?" causes the current NSS linear units to be displayed.
NSSWV , λ#(1 to 10) , wavelength in microns - The "NSSWV" command is used to specify the values of any of the 10 wavelengths. Wavelength is ALWAYS expressed in MICRON units, 1.0 micron = 1.0×10^{-6} meter. By default, wavelength #1 = 1.0 micron. All other wavelengths are initially set to 0.0. Issuing "NSSWV" with the interrogative "?" causes the current NSS wavelengths and spectral weighting factors to be displayed.
NSSWT , λ#(1 to 10) , wavelength weight - The "NSSWT" command is used to specify the values of any of the 10 wavelength weights. By default, wavelength weight #1 = 1.0. All other wavelength weights are initially set to 0.0. Issuing "NSSWT" with the interrogative "?" causes the current NSS wavelengths and spectral weighting factors to be displayed.
UNIVERSE , terminal ray distance - The "UNIVERSE" command is used to specify a "terminal ray distance" to trace rays which "miss" all NSS SURFACES during ray tracing. By default the terminal ray distance is = 10000 NSS units.

SURFACES - An NSS SURFACE is an optical surface, such as a mirror surface, a lens surface or any other surface which can refract, reflect, diffract, scatter or absorb radiation.

SURFACE DEPENDENT COMMANDS - The following commands are used to specify NSS database items which are associated with specific NSS SURFACES

THE NSS SURFACE
SURFACE , surf_id - The "SURFACE" command is used to set the NSS SURFACE, designated by the integer "surf_id", to be the "current" NSS SURFACE within the "current" NSS SURFACE modifying commands will always be applied to the "current" NSS SURFACE. If the SURFACE specified by "surf_id" does not exist, it will be created. Issuing the "SURFACE" command with the interrogative "?" causes the current NSS SURFACE "surf_id" value to be displayed.

NON-SEQUENTIAL SYSTEM SECTION

NSS SURFACE DATA COMMANDS
SNAME , (1 to 80 character identifier for the "current" SURFACE") - The "SNAME" command is used to attach or change the name label associated with the "current" SURFACE. The default name is "(surf_id)", the surface ID number only..
SPROFILE (qualifier word) , v1 , v2 , v3 , v4 , v5 - The "SPROFILE" command uses the optional qualifier word and numeric words 1,2 , 3, 4 and 5 to specify the shape of the "current" NSS SURFACE. The following table lists allowed qualifier words with the meaning of the values "v1", "v2", "v3", "v4" and "v5". The default surface is a plano surface. If the qualifier word USER is used, the ray intersection and surface interaction for that surface type will need to be coded by the user in the NSS_USER.FOR subroutine. The * designates that the surface uses additional profile coefficients input using the "PARAM" command. In order for a surface to be considered an "active" surface which can be "seen" during NSS analysis or display operations, the NSS surface profile MUST BE ENTERED EXPLICITLY USING THE "PROFILE" command. All toric profiles are in the local XZ-plane.

Qualifier	NW#1	NW#2	NW#3	NW#4	NW#5
PLANO	2nd order	4th order	6th order	8th order	10th order
SPHERIC	Radius of Curvature	Conic Constant	4th order aspheric	6th order aspheric	8th order aspheric
ANAMORPH	Radius of Curvature	Conic Constant	4th order aspheric	6th order aspheric	8th order aspheric
MEM	# elements in X	# elements in Y	MEM Data File #	MEM pixel X-pitch	MEM pixel Y-pitch
USER	Value passed	Value passed	Value passed	Value passed	Value passed
TUBE	R (radius)	L (length)	not used	not used	not used

The "MEM" surface type is a "Multiple Element Mirror". It comprises an array of flat, rectangular mirror elements. The # of elements in each direction, the MEM data file # and the length of a single element in X and Y are specified by the 5 numeric words of the commend. MEN data files have the naming convention MEMxxx.DAT where xxx can be any numeric value (001, 002 etc). Addressing of elements starts at local -x, -y with address 1,1 and proceeds to the local +x, +y corner addressed as # elements in X, # elements in Y. Each line of the MEMxxx.DAT file has the following entry:
x-address, y-addrress, element state-x, element state-y, x-tilt error, y-tilt error.
where:
element state-x is:
0 = no x-tilt
1= +x-tilt
-1= -x-tilt
where:
element state-y is:
0 = no y-tilt
1= +y-tilt
-1= -y-tilt

x and y-tilt angles and errors are signed using the right-hand rule. Tilt errors are in degrees.

The power on a MEM pixel, acts to change the surface slope only. This is done since surface deflections are extremely small and ray trace speed would be adversely effected by implementing an aspheric surface intersection routine here.

The "TUBE" type of surface is a surface comprising a cylindrical tube with radius "R" and length "L". Before being positioned and oriented, it is considered to start at 0,0,0 and at 0,0,L. The inside of the tube is always media 1, the outside is always media 2.

SPARAM , parameter # , parameter value - The "SPARAM" command sets the values of additional NSS SURFACE profile parameters as described in the following table:

Parameter Number	PLANO	SPHERIC	ANAMORPH	MEM
1	(not used)	10th order aspheric	10th order aspheric	Angle (deg) for x-tilt (positive right-hand rule)
2	(not used)	12th order aspheric	4th order anamorphic	Angle (deg) for y-tilt (positive right-hand rule)
3	(not used)	14th order aspheric	6th order anamorphic	R^2 order power
4	(not used)	16th order aspheric	8th order anamorphic	R^4 order power
5	(not used)	18th order aspheric	10th order anamorphic	R^6 order power
6	(not used)	20th order aspheric	Toric Curvature (1/R)	R^8 order power

7	(not used)	(not used)	Toric Conic Constant	R^{10} order power
8	(not used)	(not used)	(not used)	Sub-pixel FULL length - X
9	(not used)	(not used)	(not used)	Sub-pixel FULL length - Y
10	(not used)	(not used)	(not used)	0 or 1, 0 = all of mem reflects, 1 = only sub-pixel reflects.
11 to 200				

Parameter Number	USER	TUBE		
1	Value passed to subroutine	(not used)		
2	Value passed to subroutine	(not used)		
3	Value passed to subroutine	(not used)		
4	Value passed to subroutine	(not used)		
5	Value passed to subroutine	(not used)		
6	Value passed to subroutine	(not used)		
7	Value passed to subroutine	(not used)		
8 to 200	Value passed to subroutine	(not used)		

SCLEAR - The "SCLEAR" command is used to specify that the current surface is no longer to be considered an active NSS surface. Its internal occupancy flag is cleared. The NSS surface pointer still points to the surface however.

SCLAP - The "SCLAP" command is used to specify the clear aperture assigned to an NSS surface. Issued without a qualifier word, the clear aperture will be circular. Optional qualifier words are "RECT" and "ELIP" for rectangular and elliptical clear apertures. Numeric inputs are defined in the following table. Clear apertures must be assigned to surfaces before ray tracing can proceed. Surfaces without clear apertures assigned would have infinite extents and could not be properly treated during ray tracing. NSS ray tracing must be able to consider every surface as a real bounded surface. The exception to this is the TUBE surface which is self-bounding. No explicit clear aperture is used on TUBE surfaces and if one is entered, it will be ignored.

Qualifier Word	Numeric word #1	Numeric Word #2	Numeric Word #3	Numeric Word #4	Numeric Word #5
(none)	Radius	Radius to flat	x-decenter	y-decenter	(not used)
ELIP	x-semi major axis	y-semi major axis	x-decenter	y-decenter	gamma rotation
RECT	x-half width	y-half width	x-decenter	y-decenter	gamma rotation

Before NSS rays are traced, the program uses the assigned clear aperture to automatically calculate bounding planes for each surface. This is possible for NSS surface profile types 1 to 9. For type 10, the user-defined profile, bounds must be explicitly input.

SBOUNDX - The "SBOUNDX" command is used to specify the –X and +X bounding values for the current surface when a user-defined surface profile has been selected with the "SPROFILE" command. Explicit bounds are ignored for TUBE surfaces.

SBOUNDY - The "SBOUNDY" command is used to specify the –Y and +Y bounding values for the current surface when a user-defined surface profile has been selected with the "SPROFILE" command. Explicit bounds are ignored for TUBE surfaces.

SBOUNDZ - The "SBOUNDZ" command is used to specify the –Z and +Z bounding values for the current surface when a user-defined surface profile has been selected with the "SPROFILE" command. Explicit bounds are ignored for TUBE surfaces.

SHOLE - The "SHOLE" command is used to specify a hole in an NSS surface. Issued without a qualifier word, the hole will be circular. Optional qualifier words are "RECT" and "ELIP" for rectangular and elliptical holes. Numeric inputs are defined in the following table. No explicit holes are used on TUBE surfaces and if entered, they will be ignored.

Qualifier Word	Numeric word #1	Numeric Word #2	Numeric Word #3	Numeric Word #4	Numeric Word #5
(none)	Radius	Radius to flat	x-decenter	y-decenter	(not used)
ELIP	x-semi major axis	y-semi major axis	x-decenter	y-decenter	gamma rotation
RECT	x-half width	y-half width	x-decenter	y-decenter	gamma rotation

NSS SURFACE LOCATION

SPOS , x , y , z , i - The "SPOS" command is used to specify the "x", "y" and "z" location of the vertex of the current NSS SURFACE. If the NSS SURFACE number "i" is not explicitly specified, the "x", "y" and "z" coordinates will be considered to be with respect to the global coordinate system origin. If "i" is explicitly input, "x", "y" and "z" and the "alpha", "beta" and "gamma" of the "SROT" command will be considered to be relative to the global coordinate location of NSS SURFACE "i". The default values are 0.0, 0.0, 0.0 and -1. "i" may not reference a surface which itself uses a relative positional reference. Positional references MAY NOT be nested.

NSS SURFACE ORIENTATION

SROT , alpha , beta , gamma - The "SROT" command is used to specify the orientation of the current NSS SURFACE. If the NSS SURFACE number "i" is not explicitly specified, the "alpha", "beta" and "gamma" Euler angles will be considered to be with respect to the global coordinate system origin. If "i" is explicitly input in the "SPOS" command, "alpha", "beta" and "gamma" will be considered to be relative to the global coordinate orientation of NSS SURFACE "i". The default values are 0.0, 0.0 and 0.0. The rotation angles "alpha", "beta" and "gamma" are specified in "degrees". These are Euler angles applied in the order "alpha", then "beta" and finally "gamma". The sign convention is via the right-hand rule.

DIFFRACTION GRATING

SGRT , m , d , l , m , n - The "GRT" command specifies the current surface is to be defined as a linearly ruled diffraction grating of order "m" with line spacing "d" in current system units. The generating planes which are used to generate this grating have a surface normal in the local coordinate system of the surface specified by the direction cosines "l", "m" and "n". This grating is the same type of grating which was described in the LENS section of this manual and used in the sequential lens database.

SGRTD - The "GRTD" command removes any diffraction grating definition on the current surface.

OPTICAL MATERIALS- Prior to the action of any "SPOS" or "SROT" commands, each NSS SURFACE is assumed to be located at the global origin 0.0,0.0,0.0. It is assumed to have two sides with the interfacing surface normal pointing in the +Z direction. The -Z side of a surface is always referred to as the MEDIA1 side/space of an NSS surface. The +Z side of an NSS surface is always referred to as the MEDIA2 side/space. This can also be thought of in terms of local surface normals at the local "vertex" of the surface as in the sequential lens database. In this case, the local surface +Z axis direction always points "into" MEDIA2 and away from MEDIA 1.

MEDIA1 (qualifier) (string) - The "MEDIA1" command specifies the refractive index of the optical material in the MEDIA1 space of an NSS SURFACE. The qualifier word refers to a valid program glass catalog name and the string refers to a valid program glass catalog glass name or number.

MEDIA2 (qualifier) (string) - The "MEDIA2" command specifies the refractive index of the optical material in the MEDIA2 space of an NSS SURFACE. The qualifier word refers to a valid program glass catalog name and the string refers to a valid program glass catalog glass name or number.

NSSN , media space indicator, wavelength number , new real refractive index, new imaginary refractive index - The "NSSN" command specifies the optical material in the space designated by numeric word #1 (value = 1 or 2) and at the wavelength specified by numeric word #2 (value = 1 to 10) should have its real refractive index replaced by the value in numeric word #3 and its imaginary refractive index replaced by the value in numeric word #4. This allows for full refractive index customization by the user.

NSSCOAT1 , n and **NSSCOAT2 , n** The "NSSCOAT1" and "NSSCOAT2" commands specify the NSS optical coating on the current surface will be set to the NSS coating type designated by the coating file number "n" (see the following discussion). NSS coating type numbers and the program coating database are described later in this section of this manual. The nature of the coating defined by the "NSSCOAT1" and NSSCOAT2" commands controls how a ray will interact with a surface when the ray is approaching the surface from the MEDIA1 or the MEDIA2 side of the surface. Multiple layers are always understood to be oriented such that the first layer is farthest from the interface between MEDIA1 and MEDIA2. If no coating is specified, an uncoated optical surface is assumed.

NSS SURFACE INTERACTION CODE

NSSINTER (R or T or A) , (space#) - The "NSSINTER" command is the command which the user uses in order to specify that refraction or reflection will occur at a surface in either space 1 or 2. The "NSSINTER" command sets the NSS ray interaction code on the current surface and in the space# 1 or 2. If space# 1 is specified, the interaction mode is used when a ray approaches the surface from MEDIA1 going toward MEDIA2. If space# 2 is specified, the interaction code is used when a ray approaches the surface from MEDIA2 going toward MEDIA1. If the interaction code is set to "T", the ray will transmit through the surface unless a TIR condition exists. If the interaction code is set to "R", then the ray will reflect from the surface. If the condition is set to "T" and a metallic coating exists on the surface, the ray will naturally be absorbed by the surface. If the condition is set to "A", the ray will be 100% absorbed. Coatings determine the reduction is relative ray energy only.

NSSDET The "NSSDET" command specifies the current surface to be the detector surface. There can be only one detector surface. Spot diagram irradiance plots are always generated at the DETECTOR surface. By default, if one is not explicitly set, and rays do not terminate in any other way, then rays will terminate after traveling the final distance specified by the last "UNIVERSE" command.

NSS SURFACE LINKS

NSSLINK (SPROFILE or SMEDIA or SCOATING or SINTRAC) , i - The "NSSLINK" command causes the NSS SURFACE profile data (including all NSS SURFACE parameters) or the NSS SURFACE media definitions or the NSS SURFACE coating definitions or the NSS SURFACE interaction codes (including diffraction grating definitions) of the current NSS SURFACE to be linked to the corresponding NSS SURFACE parameters of NSS SURFACE "i". By default, an NSS SURFACE is considered to be linked to itself. Issued with a "?", the current surfaces reference surface is displayed.

NON-SEQUENTIAL SYSTEM SECTION

NSS FILE COMMANDS - The following commands are used to save and reload NSS databases to disk.

NSSSAVE (file name) - The "NSSSAVE" command save the current NSS database to the file designated by the qualifier word "file name" into the directory "NSSDIR". The file extension is ".NSS"

NSSREST (file name) - The "NSSREST" command reloads the NSS database from the file with the name specified in the qualifier word "filename". This file, if it exists, will be retrieved from the "NSSDIR" directory.

NSS RAY TRACING - The following commands are used to prepare for ray tracing through the NSS database. Rays are traced until, their relative intensity drops below the ray trace threshold level set by the "NSSMINE" command or they interact with NSS surfaces more than the interaction threshold limit set with the "NSSNHIT" command.

NSSMINE , minimum relative ray energy - The "NSSMINE" command sets the minimum relative ray energy below which the ray is considered to have no energy. This is a relative fractional value with respect to the starting ray energy. The default value is 0.0.

NSSMHIT , maximum number of ray/surface interactions - The "NSSMHIT" command sets the maximum number of ray/surface interactions before the ray is considered to have no energy. The default value is 1000.

NSSSPLIT , YES or NO - The "NSSSPLIT" command sets the ray splitting command "ON" or "OFF". If "R" on a surface is non-zero and less than 1.0 and ray splitting is "ON" then ray splitting during ray tracing will occur, otherwise it won't. Ray splitting is not yet operational. (Ray splitting not yet operational)

NSSOBJ (REAL or VIRTUAL), X , Y , Z - The "NSSOBJ" command sets the location of the center of the source. The defaults are X = 0.0, Y = 0.0 and Z = -1.0D20. The default qualifier is "REAL" and it represents rays traced from each object grid point through each reference ray grid and then on into the NSS system. If "VIRTUAL" is issued, rays are traced from each reference grid point, into the NSS system in directions which would have taken the rays through the object point. No ray is actually traced to the object grid points, however.

OBJMEDIA (qualifier word) (string) - The "OBJMEDIA" command specifies the optical material in the OBJECT or starting space of an NSS database. The qualifier word refers to a valid program glass catalog name and the string refers to a valid program glass catalog glass name or number. The refractive index of this MEDIA may not be set so as to be absorptive and individual refractive index values may not be modified from program catalog values. By default, the MEDIA type is AIR.

NSSGRIDS , n , spacing - The "NSSGRIDS" command sets dimension of the source grid for NSS ray tracing. By default, "n" = 1. This grid is centered on the center of the source. "spacing" is the grid spacing in x and y in system units (local coordinate system of the source grid). The source grid lies in a plane perpendicular to the vector connecting the center of the source grid with the center of the reference grid. The default qualifier word is "CIRC" which means that a source grid is clipped, prior to tracing, as if a circular aperture had been assigned to the source grid. If the qualifier word "RECT" is issued, the rectangular pattern is traced with no clipping.

NSS REFERENCE RAY GRID - All NSS rays are aimed from locations in the NSS source grid to positions in the NSS reference grid. The NSS reference grid is the grid at which ray grids are defined using the "NSSGRIDR" command.

NSSREF, X , Y , Z - The "NSSREF" command sets the location of the center of the nss REFERENCE GRID. The defaults are X = 0.0, Y = 0.0 and Z = 0.0.

NSSGRIDR (CIRC or RECT) , n , spacing - The "NSSGRIDR" command sets dimension of the reference grid for NSS ray tracing. By default, "n" = 1. This grid is centered on the center of the reference grid. "spacing" is the grid spacing in x and y in system units (local coordinate system of the reference grid). The reference grid lies in a plane perpendicular to the vector connecting the center of the source grid with the center of the reference grid. The grid pattern is always arranged in a rectangular pattern. The default qualifier word is "CIRC" which means that a rectangular grid is clipped, prior to tracing, as if a circular aperture had been assigned to the reference grid. If the qualifier word "RECT" is issued, the rectangular pattern is traced with no clipping.

NSSAPODR , dbloss - The "NSSAPODR" command sets ray intensity level drop (in db) to "dbloss" at the edge (not the corners) of the reference ray grid due to a gaussian distribution intensity apodization. By default, "dbloss" is zero meaning a uniform intensity distribution If the x and y-fractional ray positions in the reference grid are given by "fx" and "fy" then "APX" and "APR" are given by the following equations:

$$APX = -\ln\left(10.0^{-\left(\frac{abs(dbloss)}{10.0}\right)}\right)$$

$$APR = \left(fx^2 + fy^2\right)$$

and the original ray intensity is reduced by:

$$I = I * e^{-(APX \times APR)}$$

cast in the more familiar optical $1/e^n$ intensity reduction terms, the absolute value of the "dbloss" term is given by:

$$dbloss = 10 * Log_{10}\left(e^{-n}\right)$$

NSS RAY AIMING - During NSS ray tracing, rays are traced from each source grid point in the NSS source through every

ray grid point in the NSS reference grid and then into the NSS optical system defined in the NSS database. Rays intersect surfaces with the same accuracies as set in sequential ray tracing using the SURTOL parameter.

NON-SEQUENTIAL SYSTEM SECTION

NSS RAY TRACE - The following command is used to trace rays in the NSS database. Rays will reflect if the TIR condition is found to be true and MEDIA2 is not set to "REFL" or if the TIR condition is not found to be true and MEDIA2 is set to REFL. In all other cases, except during ray splitting, a ray transmits rather than reflects at a surface. Ray splitting is not yet operational.

NSSPOL (ON or YES or OFF or NO)   - The "NSSPOL" command turns polarization calculations "ON" or "OFF" during NSS ray tracing. "NSSPOL" is not yet operational.

NSSTRACE (SPOT or SPOTADD)   - The "NSSTRACE" command initiates ray tracing in the current NSS database. Results for the ray trace are placed in the RAY HISTORY files NSSRHIST.DAT, NSSHIST.DAT and NSSHT.DAT. If optional qualifier words "SPOT" or "SPOTADD" are issued, then spot diagram files are generated with the next issuance of the "NSSSPOT" command.

NSS SPOT DIAGRAMS.
The qualifier words "SPOT" and "SPOTADD" prepare the program for the generation of a traditional spot diagram or a cumulative spot diagram which will be generated by the next "NSSSPOT" command. Each record in the file comprises:

local X-coord. , local Y-coord. , local Z-coord. , local L-dircos. , local M-dircos. , local N-dircos, Relative Ray Intensity , Physical Length from object, and Optical Path Length from the object.

All at the surface specified in the "NSSSPOT" command. If the distance from the object to the reference grid is greater than 1.0D+10 units, it is left out of the length results.

Data is in a free format, ASCII file named NSSLSPOT.DAT. Direction cosines and intensities are before surface interaction.

If "i" is specified beyond the current maximum active NSS surface, no trace is performed and an error message is issued.

NSSSPOT , i , j - The "NSSSPOT" command creates a spot diagram file names NSSSPOT.DAT for all rays intersecting surface "i". If "j" is issued, the only rays which have made "j" surface intersections will be includes, else all hits on surface "i" are included. Mean and RMS values of this spot may be "gotten" and displayed with the "GET" and "SHO" commands described in the CMD section of the manual with get qualifier words "NSSMEANX", "NSSMEANY", "NSSMEANR", "NSSRMSX", "NSSRMSY" AND "NSSRMSR".

NSS IRRADIANCE PLOTS.
IRRAD , j - The "IRRAD" command creates an irradiance plot from the current spot diagram file. The spot diagram surface must be pixelated using the following pixelization commands or no irradiance plot will be produced.

PIXNXNY , nx , ny , dx , dy , w - The "PIXNXNY" command sets the number of pixels in th x and y local directions on the current spot diagram surface "nx" and "ny" and the dimensions of the pixels in current system units "dx" and "dy". Each ray is assumed (before any apodization or coating losses) to carry "w" watts from the object surface.. By default, "w" is 1.0.

PIXCEN , x , y - The "PIXCEN" command sets the center location of the current pixelated irradiance grid. The default is at the center of the spot diagram surface at x = 0, y = 0.

NSS DATABASE DISLAY - The following command is used to display the NSS DATABASE.

NSSLIST (NOSURF) , i , j - The "NSSLIST" command displays the current NSS database in an "Engineer Friendly Format" to the current display device. If the optional qualifier word "NOSURF" is used, only non-surface specific data is displayed. If "i" is input, only surface "i" data is displayed. If "i" and "j" are input, surface "i" through surface "j" data will be displayed

NSSVERT - The "NSSVERT" command displays the current NSS surface vertex locations and orientation in the global coordinate system to the current display device.

NSS DATABASE OUTPUT - The following command is used to output the NSS DATABASE in a program readable format.

NSSLENO - The "NSSLENO" command outputs the current NSS database in a program readable format.

NSS DATABASE GRAPHICS - The following commands are used to generate a graphical representation of the current NSS database and the rays that have been traced through it. A "PLOT NEW" command should be given at the beginning of all NSS plotting.

PLOT NSSSCALE , sf - The "PLOT SCALE" command sets the NSS plot scale factors. "sf" is the number of thousands of device independent coordinate units which represent one lens unit int the plot. A "sf" scale factor of 10 would scale one unit of the object being plotted so that it plotted in 10,000 units of the device independent coordinate system. For most devices, 1000 units in the device independent coordinate system will be represented as 1.0 inch.

NSSORINT , i , rflag - The "NSSORINT" command causes the "LOOK VECTOR" to be reset so that its X, Y and Z-components are equal to the L, M and N-direction cosines of the local Z-axis of NSS SURFACE "i. The "LOOK VECTOR" passes through the local vertex of that surface. NSSORINT" is used whenever the "LOOK VECTOR" needs to be set so as to look "normal" to an NSS SURFACE looking from the MEDIA 1 sude. The view angles are also reset. If "rflag" is set to any explicit value, the look vector is set so as to look from the MEDIA 2 side of the surface instead of from the MEDIA 1 side.

PLOT NSSSURFS - The "PLOT NSSSURFS" command plots all NSS surfaces in the NSS DATABASE using whatever look vectors and scale factors have been set using the regular plotting commands.

PLOT NSSRAYS - The "PLOT NSSRAYS" command plots all NSS rays traced in with the last "NSSTRACE" command. using whatever look vectors and scale factors have been set using the regular plotting commands described in the GRAPHICS section of this manual.

PLOT NSSSPOT , bar - The "PLOT NSSSPOT" command plots all NSS rays traced in with the last "NSSTRACE" command. using whatever look vectors and scale factors have been set using the regular plotting commands described in the GRAPHICS section of this manual. The parameter "bar" is the semi-width of the bars drawn at each ray location, in device independent coordinates (about 0.001 inch). By default, "bar" is set to 1.

NSS SURFACE COATINGS

SURFACE COATING DATABASE - The SURFACE COATING database consists of user-generated ASCII files COAT0001.DAT through COAT1000.DAT. These files hold the complete description of all the types of single and multi-layer coatings available for use in the program. Up to 1000 individual coating files may be defined and redefined by the user.

NATURE OF THE COATING DESCRIPTIONS - Unlike most other optical design and analysis codes, the program contains a flexible syntax for describing optical surface coatings in many different ways. Each coating definition consists of a series data lines in an ASCII file which describe the type of coating and its characteristics. All coatings are prepared ahead of time by the user using any text editor. The syntax of every coating definition file begins with the header line which contains a single integer that specifies the coating type. The program currently has 4 coating types availabe. Any of these 4 coating types may be used in any of the 1000 different coating database files.

COATING TYPES - Valid coating types are defined below. Coatings are used for energy throughput calculations when surface coating dependent ray trace options are in are in effect. When performing polarization type calculations, only type 1 (no effect on polarization) or type 4 coatings will be used.

COATING TYPE 1 – No coating and no coating losses. Transmissions and reflections are 100% efficient. This is the program default and requires no coating definition file. If this type of coating is to be explicitly set in a coating definition file, only one entry, the coating type number 1 is needed as shown below:

1

COATING TYPE 2 - Coating type 2 is an uncoated surface with Fresnel losses. Uncoated transmissive surfaces exhibit simple Fresnel reflection losses. Reflections will experience no energy loss. A coating file used to define a type 2 coating has only one entry as shown below:

2

COATING TYPE 3 - Coating type 3 is a simple "e"% efficient coating where the default value for "e" is 100%. If a "TIR" condition is found, perfect 100% reflection will always occur. If reflection occurs at a surface with a type 3 coating (other than case of TIR), the reflectivity will be assumed to be "e"%. The file entry for this specific coating, if the efficienct were to be 85% is:

3
85

COATING TYPE 4 - Coating type 4 is the program general coating type. The first line in the coating file must be a **4**. The next N lines in the file comprise the user-supplied data for each of the N-layers of the coating. Each line starting at line 2 consists of a user supplied material name (up to 13 characters) followed by 10 real and then 10 imaginary refractive index values and then the layer thickness in microns. In multiple layer coatings, the first layer is the layer farthest from the substrait. As in regular program input, nested commas represent default values which are 1.0 for the real part and 0.0 for the imaginary part of the complex refractive index. As an example, a type 4 coating defined in the ASCII coating file COAT0025.DAT and consisting of a single layer of MGF2 with a complex refractive index at wavelength #1 of (1.38,0.0) and having a thickness of 0.34 microns would be defined using the following two lines in file COAT0025.DAT.

4
MGF2,1.38, , , , , , , , , ,0.0, , , , , , , , , ,0.34

NSS DATABASE DXF OUTPUT - The following commands are used to generate a DXF representation of the current NSS database and the rays that have been traced through it.

DXF NSSSURFS - The "DXF NSSSURFS" command adds all NSS surfaces in the NSS DATABASE to the current DXF output file. (See the CAD section for details on DXF output). (Not yet operational)

DXF NSSRAYS - The "DXF NSSRAYS" command adds all NSS rays in the NSSRHIST.DAT file to the current DXF output file. (See the CAD section for details on DXF output). (Not yet operational)

NON-SEQUENTIAL SYSTEM SECTION

NSS DATABASE RESOLUTION

NSSEOS - The "NSSEOS" command causes an explicit resolution of all NSS DATABASE items including linkages. If NSSMFUNC is set to a specific macro function and that function exists, that macro function is executed. Normally this database resolution is performed automatically but this command is provided to maximize program flexibility.

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