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SLIDERS: The Next Generation of Automated Optical Design Tools has arrived

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ABSTRACT

Optical design tools are presented to provide automatic generation of reflective optical systems for educational use. The tools are graphical in nature and use an interactive slider interface with freely available optical design software. Operation of the sliders provides input to adjust first-order and other system parameters (e.g. focal length), while appropriate system construction parameters are automatically updated to correct aberrations. Graphical output is also presented in real-time (e.g. a lens drawing) to provide the opportunity for a truly visual approach to optical design. Available systems include two- and three- mirror telescopes, relays, and afocal systems, either rotationally symmetric or having just a plane of symmetry. Demonstrations are presented.

Keywords: Geometrical optics, optics education, macros, teaching, optical design, lens design, reflective optics, mirrors.

1. INTRODUCTION

This paper concludes a series of related papers on the use of analytical design methods to provide automatic generation of reflective optical systems [1,2]. The purpose here is to present to the reader a user manual that provides instruction on installing and using the SLIDERS design tools, and background information on the types of systems currently available. In this paper, the word SLIDERS in all capital letters refers collectively to the package of design tools, whereas sliders in lower case refer to the individual slider windows available in the operating system.

The name SLIDERS comes from the graphical user interface on which these tools are based; an example of two sliders is illustrated in Figure 1. To operate them, one simply clicks on the arrowhead buttons to the left and right the slider, or alternatively to click and drag the square to the desired value for the particular variable. When the value of the slider is changed, a callback routine is invoked which adjusts this parameter in the lens data spreadsheet, and/or any other operations that have been coded into the macro, such as drawing or evaluating the lens. The resolution and range of the slider can be adjusted by using the up and down buttons to the right of each slider.

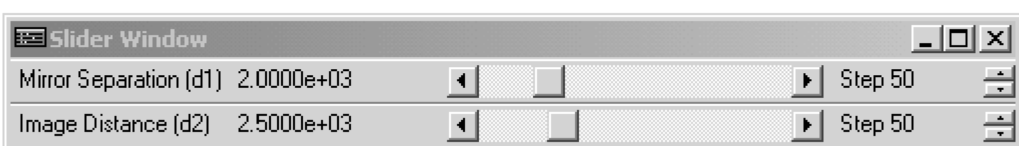

Figure 1. Example of slider windows used to control variables d1 and d2.

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SLIDERS is written specifically for the EDU version of OSLO [3]. This software is meant for educational purposes and is generously made free to the user from Lambda Research Corporation by download from http://www.lambdares.com. SLIDERS is written in the macro language of OSLO called "ccl", which is very similar to the c language.

2. INSTALLING SLIDERS OPTICAL DESIGN TOOLS

Disclaimer: Like OSLO EDU itself, these macro routines are intended for education use by all who want to learn more about optical design, either in conjunction with formal classes at an educational institution, or by self study. The author will not be liable for any damages, either direct or consequential, including damages for loss of business profits, business interruption, loss of information, or other loss, arising out of the use of, or the inability to use either OSLO EDU or the SLIDERS design tools, even if the author has been advised of, or is otherwise aware of the possibility of such damages, including inaccuracies within the software itself.

Step 1. Download and install OSLO EDU from http://www.lambdares.com.

Step 2. Contact the author (joe.howard@nasa.gov) to receive the ccl files and documentation for installing and using SLIDERS. These ccl files are free for educational use and should eventually be available from the Lambda Research Corporation website after they post their user exchange forum.

Step 3. Place all received ccl files into the "private\ccl" directory in the root folder where you installed OSLO EDU. One of these is named "a_menu.ccl", and its sole purpose is to add a menu for SLIDERS for OSLO EDU so the user can directly start one of the SLIDERS design tools from the menu bar. If you are an experienced OSLO user and have already created your own personalized a_menu.ccl, then cut and paste the "menu SLIDERS" portions of the provided ccl into your own a_menu.ccl to add the SLIDERS menu items.

Step 4. Start OSLO EDU, and type the word "ccl" (no quotes) on the command line. This compiles the ccl files into OSLO EDU, making the routines available for use. You should get a message in the text window that reads "*CCL Compilation Messages: No errors detected", and the SLIDERS menu should appear as shown in Figure 2. You are now ready to use SLIDERS.

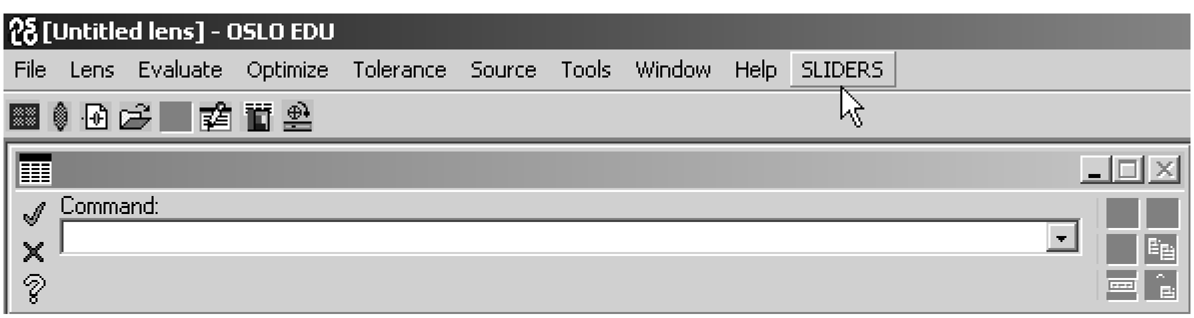

Figure 2. OSLO EDU menu after successful installation of SLIDERS.

3. USING SLIDERS

If you are new to optical design or OSLO, then you should spend some time getting familiar with the software and what it can do. SLIDERS nicely compliments this learning process, and educators and individuals are encouraged to contribute routines for future versions. After proper installation, starting SLIDERS is performed by simply selecting it in the menu bar, and choosing the system of interest. As an introduction, the first item in the menu will be used as a tutorial on SLIDERS.

Select the first item “2 mirror telescopes” on the SLIDERS menu and a slider window appears similar to Figure 3. Also appearing is an updated lens drawing of the current optical system, which is an F/20 Cassegrain telescope. Note that additional information appears in the text window regarding the last slider labeled “Telescope Class” — the class numbers are defined. In many routines throughout SLIDERS messages are displayed below the command line after each slider movement, which updates the user on system performance such as root-mean-square (RMS) spot diagram radius. Sliders can be used for continuous variables such as the d1 and d2 parameters, or distinct integers as mentioned in the last slider. Occasionally the integer type slider will be a yes/no switch to engage some option such as “Show spot diagrams?”

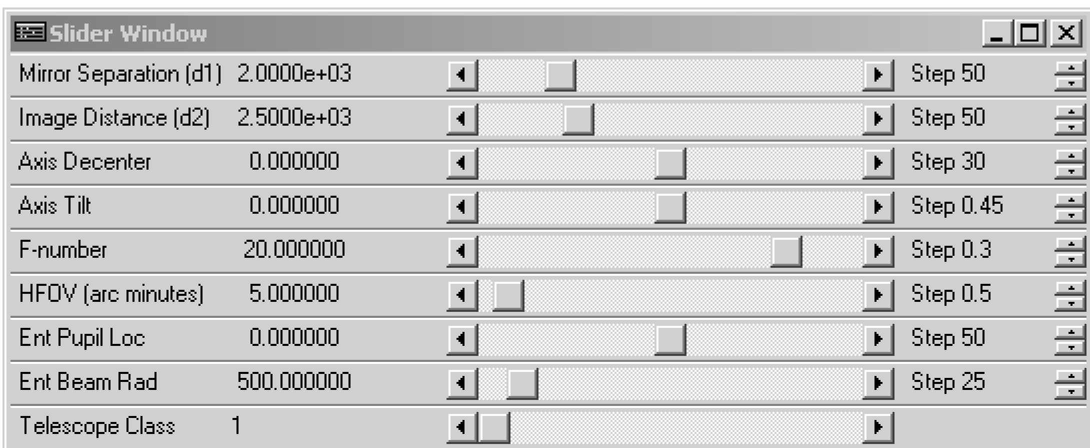

Figure 3. Slider window for "2 mirror telescopes".

The most important concept to understand about using SLIDERS is that the individual sliders not only control the parameter which they are labeled, but also other parameters in the optical system which are functions of the variable parameters. For example, the default Cassegrain telescope in the “2 mirror telescopes” routine only has the separation between the mirrors and the image distance as explicit parameters that can be controlled by the user. This is because the curvatures and conic constants on each mirror are actually solved for within the ccl macro using well-known equations that are functions of d1, d2, and the system f-number [4]. In this case, the individual degrees of freedom of the system (i.e. variables) are d1, d2 and the F-number, while the constrained parameters are the two curvatures and conic constants. Since these evaluations are performed each time the sliders are moved, the fundamental system is maintained within a “constrained configuration space” defined by the analytical equations placed in the macro. The original six degrees of freedom are reduced to just two (three if the f-number is a variable) by applying equations to ensure first and higher order image properties are satisfied. This is discussed in detail in Reference [2].

Five classes of constrained configuration spaces are available in the “2 mirror telescopes” SLIDERS routine. The first is the classical Cassegrain or Gregorian, where all spherical aberration is corrected, providing a geometrically perfect image at the axial image point. The second class is the Ritchey-Chretien design where third order spherical and coma aberrations are corrected (e.g. NASA’s Hubble Space Telescope), which generally provides better imagery over a finite field of view. The next two classes are of the Dall-Kirkham variety, where either the secondary or the primary mirror is spherical, respectively, and only third order spherical aberration is corrected. Finally, only spherical mirrors are used in the fifth class, where the macro simply sets the curvatures of each mirror to ensure the focus is at the image surface, and the desired f-number is maintained.

Rotational symmetry is assumed in the 2 mirror telescopes routine, but note that two of the sliders can be used to decenter or tilt the axis, if an unobstructed system is desired. Finally, system parameters such as the half field of view (HFOV), the entrance pupil location, and entrance beam radius can be set with their respective individual slider. When the desired system has been “dialed in”, SLIDERS is exited by simply closing the slider window. Note that most analyses such as spot diagrams and transverse ray plots, etc., can be performed with the slider window open, including saving the system, if need be.

4. SYSTEMS IN SLIDERS

This section describes some of the initial routines developed for SLIDERS. New ones are occasionally added and it is hoped that users will contribute some in the future, so please keep the latest version of SLIDERS by contacting the OSLO website at http://www.lambdares.com. The first routine under the SLIDERS menu is for “2 mirror telescopes” and is discussed in the previous section. What follows is a brief summary of each of the remaining submenus under SLIDERS, including references that the routines are based upon.

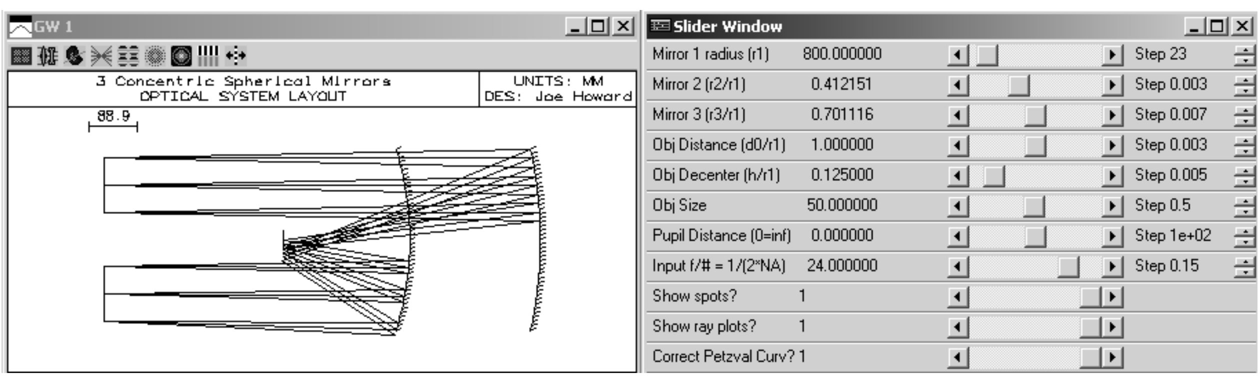

Figure 4. Concentric spherical mirror system.

Optical Design by Pictures. Three tutorial routines are discussed in Reference [1], and are included in SLIDERS to compliment the paper. The paper can be downloaded from the Lambda Research

Corporation website at http://www.lambdares.com/techsupport/techpapers.phtml, or a copy can be obtained by contacting the author (joe.howard@nasa.gov). The concentric spherical mirror system, Example 3 from the paper, is illustrated in Figure 4.

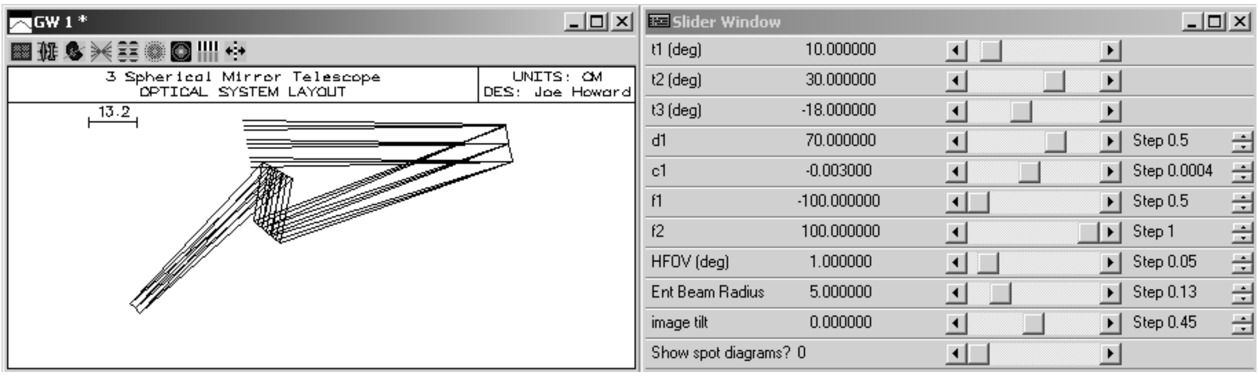

Figure 5. Three spherical mirror telescopes.

Spherical Mirrors. Some of the first routines to be demonstrated with SLIDERS were based on papers about one and two spherical mirror systems [5,6]. Studies of three and four spherical mirror systems followed [7,8], and these works were then added. Each of these spherical mirror systems assumes only plane symmetry, and all are based on the Hamiltonian methods as developed by Stone and Forbes [9,10]. References [5-8] all discuss systems at finite conjugates, and those with the object at infinity. Two and three mirror afocal systems are considered in [11], and multi-reflection systems are discussed in [12].

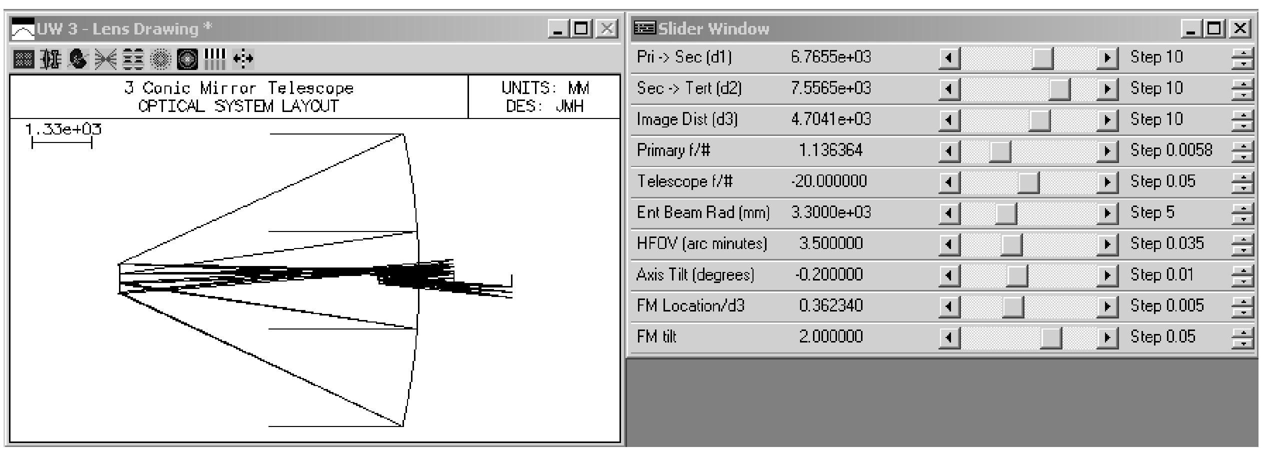

Figure 6. Three conic mirror telescope.

Conic Mirrors. Korsch presents multiple classes of rotationally symmetric conic mirror systems in his book, *Reflective Optics* [13]. This is perhaps the most complete work on analytical design tools for reflective systems ever published. Portions of his work are incorporated into SLIDERS, including the classic three-mirror-anastigmat (TMA) systems where the third order aberrations of spherical, coma, and astigmatism are all corrected. Figure 6 illustrates such a system, and happens to be similar to the current design for NASA's James Webb Space Telescope (JWST). A four-mirror system is also available, where third order distortion is corrected as well. Note that the available degrees of freedom do not follow those of Korsch, who liked to work in mirror magnifications. These values are converted to mirror separations where possible in order to control the configuration space in terms of package constraints, which is a common concern for space optics systems. Soon to be available here are recent works by Rakich and Rumsey [14], and Lynden-Bell [15].

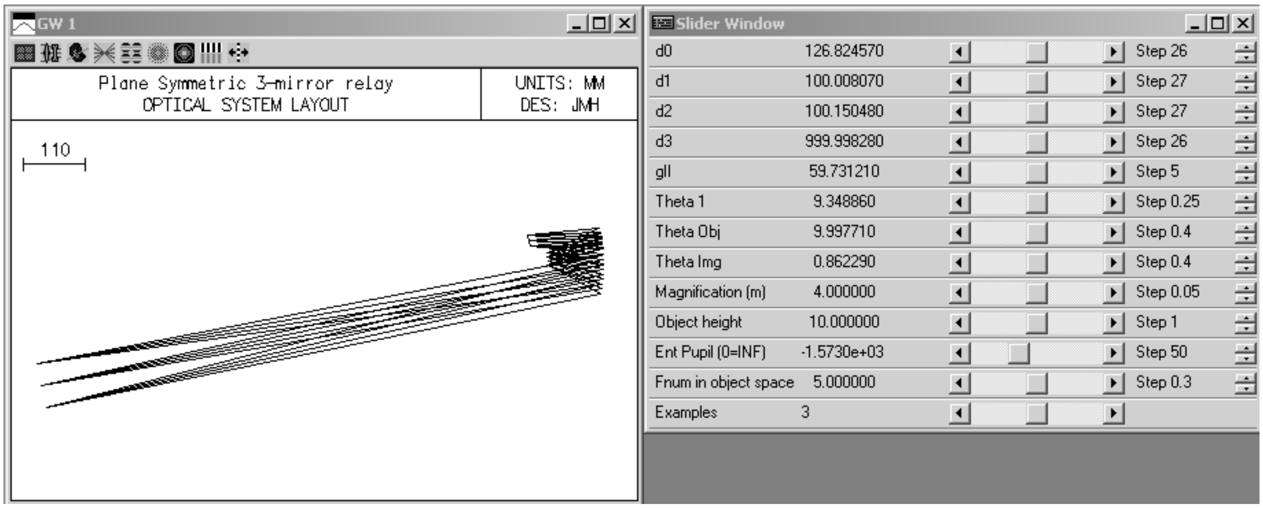

Figure 7. Plane symmetric three mirror conic relay.

Plane Symmetric Systems. Advanced Hamiltonian methods are used to develop these routines for systems with plane symmetry. These systems generally produce anamorphic imaging, where the magnifications are different in and out of the plane of symmetry. While this is a desirable condition for some optical systems, the routines currently included in SLIDERS set the magnifications equal to provide nonanamorphic imaging. Currently two and three mirror conic systems are included in SLIDERS, which are based on the works by Stone and Forbes [16], and Howard and Stone [17], respectively. Figure 7 illustrates an example of a projection system taken from [17].

Classroom Demonstrations. The final submenu in SLIDERS contains some demonstration routines useful for the classroom. Some are included with OSLO EDU and are added in this submenu for ease of access, and others are contributed by the author. Educators and students are encouraged to contribute their own routines to SLIDERS for general distribution.

5. CONCLUDING REMARKS

The motivation for generating SLIDERS has been purely academic. As such, only a moderate effort has been put forth to contain bugs in the code. Any effort to point out errors to the author is greatly appreciated and encouraged. Suggestions for new routines are also welcome.

Much of the work presented here can be implemented in refractive systems. The foundations exist but more can be developed — the results of such work would be a nice graduate level thesis topic.

ACKNOWLEDGEMENTS

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