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The Advanced Environmental Control System (AECS) Computer Program for Steady State Analysis and Preliminary System Sizing

FOREWORD

Changes in this revision are format/editorial only.

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1. SCOPE:

Many different computer programs have been developed to determine performance capabilities of aircraft environmental control systems, and to calculate size and weight tradeoffs during preliminary design. Many of these computer programs are limited in scope to a particular arrangement of components for a specific application. General techniques, providing flexibility to handle varied types of ECS configurations and different requirements (i.e., during conceptual or preliminary design, development, testing, production, and operation) are designated "company proprietary" and are not available for industry-wide use.

This document describes capabilities, limitations, and potentials of a particular computer program which provides a general ECS analysis capability, and is available for use in industry. This program, names AECS[1], was developed under the sponsorship of the U.S. Air Force Flight Dynamics Laboratory (References 1 and 2).

The basic operating modes and organizations of the program are described. Methods of problem definition, data inputs and outputs, control options, and computer system are discussed. The program's key capabilities and limitations, and recommendations for future improvements in AECS to facilitate its use as an industry-wide acceptable method for analysis, are also discussed.

1.1 Purpose:

The purpose of this AIR is to provide aircraft ECS engineers and their managers with information about a generalized computer program method for calculating steady state thermodynamic performance of an aircraft environmental control system. Many current computer programs are "company proprietary" or tend to be specifically oriented to a particular ECS configuration or system. This AIR describes a computer program general enough to allow analysis of essentially all types of environmental control systems. It is available to companies in the environmental control system industry. The general nature of the computer solution is useful for sizing activities and trade study during a preliminary design phase, as well as for detailed system performance analysis. The intent of this AIR is improved communication between aircraft user, aircraft manufacturer, and ECS equipment suppliers by use of an industry-wide computer program. This AIR describes the Advanced Environmental Control System Computer Program, and suggests further improvements to expand its capabilities.

1. Initially IECS

2. REFERENCES:

1. R. R. Dieckmann, et al, Development of Integrated Environmental Control System Designs for Aircraft, 4 Volumes, AFFDL-TR-72-9, May 1972.

2. A. E. Whitney, Advanced Environmental Control System Computer Program User's Manual, AFFDL-TR-76-77, August 1976.

3. D. R. Schaefer and E. F. Swain, IECS Computer Program User's Guide Supplement, ASD-ENFE-TM-76-3, March 1976.

4. K. J. Nielson, Methods in Numerical Analysis, Macmillan, 1956.

5. F. A. Costello, Advanced Environmental Control System (AECS) Simulation Program: Improved and New Components for Refrigeration Systems and an Additional Solution Procedure, AFWAL-TR-81-3139, February 1982.

6. J. L. Dyer, Improvements in the Vapor Cycle Capability of the Advanced Environmental Control System Computer Program, SAE 840943, July 1984.

7. Environmental Control System Transient Analysis Computer Program (EASY), SAE AIR1823.

3. GENERAL FEATURES OF AECS:

The generalized AECS steady state computer program has the following features:

1) The program can analyze current types of environmental control systems including air cycles (both simple and bootstrap), vapor cycles, hybrid systems, open or closed loop systems, liquid or gas cycles, fuel and expendables as heatsinks, and pressurization systems. It can analyze these systems alone or in combination.

2) The particular system configuration for analysis is entered into the program as input data, without programming language or change in the program. No computer programming capability is required to use the program.

3) The program is capable of evaluating ECS functions such as cockpit heating, cooling, and pressurization; avionics cooling; and air for anti-ice and rain removal, transparency defog, and auxiliary pressurization.

4) The program includes some generalized heat transfer capability to compute aircraft, compartment, and system heat loads.

5) The program, in addition to providing detailed thermodynamic cycle data for the performance of a given system for particular flight conditions, provides the capability to conduct sizing studies, on a component and on a system basis. The sizing studies include the impact of weight, cost, and reliability, and consider the effect on overall aircraft penalty.

3. (Continued):

f. The program can be used to obtain simplified approximations for conceptual studies, or detailed system characteristics for specific aircraft performance.

7) The program is usable on a major computer system. It is relatively simple to use by personnel familiar with aircraft ECS analyses. Means for rapid troubleshooting of errors and non-convergence are provided.

8) The program utilizes standard input-output formats and units.

9) The program is flexible for relatively simple additions and changes.

4. AECS COMPUTER PROGRAM:

The AECS Computer Program calculates steady state performance and preliminary sizing information for almost any aircraft ECS. Program organization, solutions techniques, use, and output content are summarized herein.

4.1 History of Program:

Development of the AECS Computer Program was sponsored by the U.S. Air Force. The initial version was completed in May 1972 (Reference 1), at which time it was designated as IECS. A user's supplement was issued in March 1976 (Reference 3). Improvements were completed in August 1976 (Reference 2), at which time it became designated as the AECS Computer Program. A subsequent update was issued in 1982 (Reference 5).

4.2 AECS Capabilities:

The AECS Computer Program calculates steady state thermodynamic performance[2], estimated component and system sizes, weights, cost, and reliability, and relative aircraft penalties for most aircraft ECS. Performance can be calculated for any ECS operating condition. Options include analysis of air and vapor cycles with several heat sink fluids and power sources.

Use of the AECS Computer Program requires input of simple coded data. No knowledge of computer programming techniques or computer language, such as Fortran, is needed. The coded input data define both complexity of the system to be analyzed and complexity of the analysis.

The AECS Computer Program can be used during ECS trade studies or to determine the performance of fully defined ECS. Simple, rough analysis techniques can be used to obtain comparative weights, cost, reliability, and aircraft penalties during a design definition phase. Detailed analysis techniques, included as options in AECS, also can be used to determine the steady state thermodynamic performance of all or any part of a prototype or production ECS.

2. For transient ECS analysis, other programs are recommended, e.g., see Reference 7.

4.3 Program Organization:

The AECS Computer Program is organized to provide two different types of analyses for aircraft ECS. The first is to determine the thermodynamic performance of an ECS or flow system, or of any part of a system. The second is to determine sizing information about the components of an aircraft ECS, or of an entire aircraft ECS.

The computer program structure is organized with two levels of overlays as shown in Figure 1. The first overlay level contains four segments: one for performance analysis, one for sizing analyses, and two supporting segments. Sizing analyses are made with performance information. This information is obtained directly from a performance analysis, or from the dummy performance segment which processes performance input data. The fourth segment accesses and loads or stores tabular data for an analysis. The performance and sizing overlay segments contain a second overlay level made up of three additional subsegments.

Each of the second overlay subsegments provides one of three functions. The first scans input data, prepares error messages about the input data if any are found, and combines previous and new data if a previous analysis is to be modified or changed. The second subsegment reads, checks, and stores data for use in the third subsegment. The third subsegment performs the designated analyses and stores the results for data output.

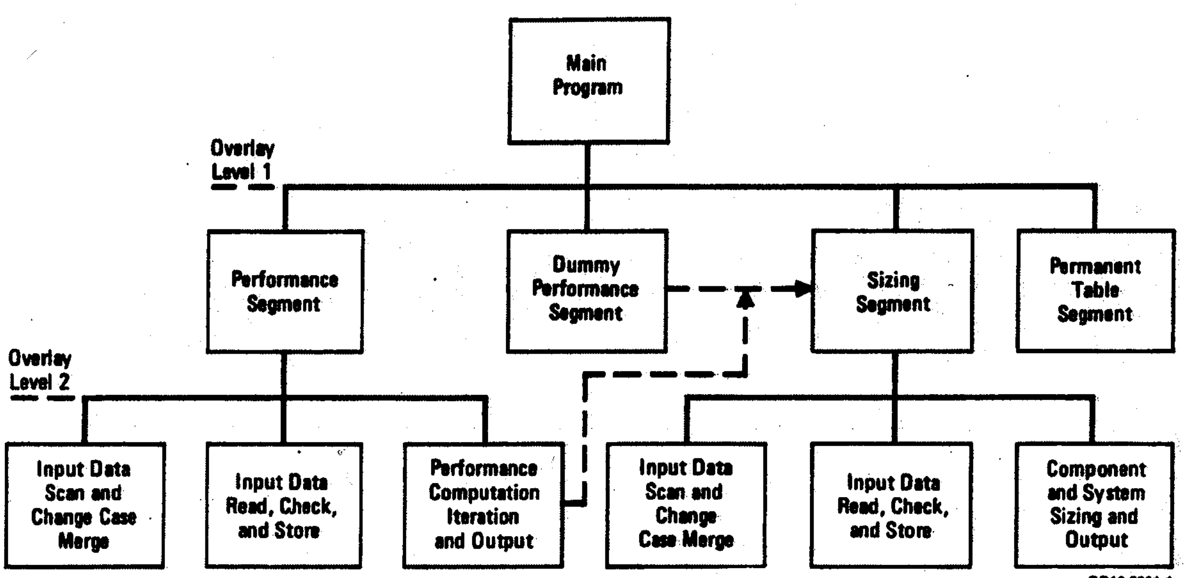


FIGURE 1 - Computer Program Structure

4.4 General Methods of Solution:

Two general solution methods are used in the analysis subsegments. One is simple explicit solution methods, which are used for equations which provide sizing information about many types of components. The second is generalized Newton-Raphson iteration method for solving sets of nonlinear equations. This method is used for the performance analysis and for some sizing analyses. The Newton-Raphson matrix solution method is discussed in the following paragraphs.

The objective of the iterative solution method is to determine numerical values of a set of key variables which initially are unknown. If these values were known, the solution of the nonlinear equations would be explicit. Examples of key variables are flow rates, the pressure ratio of a turbine or compressor, or control valve position. If assumed values are used, explicit solutions produce errors relative to boundary conditions for the nonlinear equations. When the errors are reduced to acceptably small values, a valid solution is obtained.

The generalized Newton-Raphson iteration method is used to modify assumed or estimated values of the key variables until the errors are acceptably small. Each application of the Newton-Raphson method (e.g., see Reference 4) provides better estimates for the key variables. The method is successively applied until the errors are reduced below the acceptable minimum values.

The iterative solution method, as used for a performance analyses, is summarized in Figure 2. System description information (components arrangement and performance, initial estimates for the key variables, and values of the boundary conditions) is used in the initial system analysis. System performance is sequentially calculated with the initial estimates by following the component arrangement defined by the input. This produces results which do not meet the boundary conditions (i.e., no system balance) and unacceptable errors. The initial values are perturbed (increased by 0.1%) and a second sequential analysis is made with the perturbed values. These two sets of values are used in the Newton-Raphson iteration method to define new values of the key variables. The system analysis loop is successively repeated until acceptably small errors are obtained. These results are output as the solution to the nonlinear equations which represent the system performance.

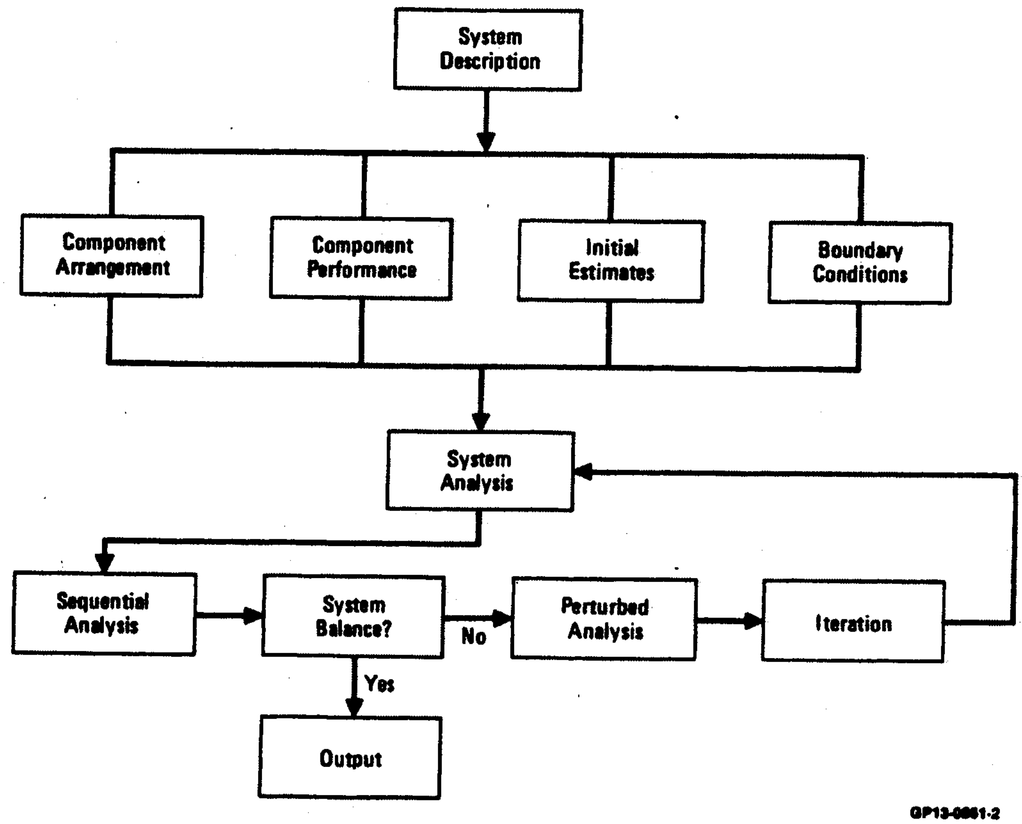


FIGURE 2 - Performance Solution Method

4.5 Modes of Operation:

The AECS Computer Program has two basic modes of operation. One is to determine the steady state thermodynamics performance of a flow system and the other is to provide equipment sizing information. The performance mode is generally used to determine parameters such as flow rates, temperatures, and pressures. Other information, such as heat exchanger effectiveness, flow areas, or efficiencies of turbines or compressors, is obtainable by simple input changes (which do not require Fortran statements). Sizing information which can be obtained includes component dimensions, weight, relative cost and reliability; total system weight, relative cost and reliability; and aircraft penalties due to an ECS.

4.5.1 Performance Mode: The performance mode of operation is used to calculate thermodynamic performance for all or any part of a flow system or ECS. Identification of the unknown parameters, whose values are to be determined by the program, is a user option. Analytical representation of the system and of its individual components may be simple, detailed, or a combination of simple and detailed definitions. Options are available to vary the amount of output detail desired. Analysis changes are readily accommodated to define removal or additions of components, different component characteristics, various mission or flight conditions, or different unknown variables and boundary conditions.

4.5.2 Sizing Mode: The sizing mode of operation is used to determine several types of sizing data about individual aircraft ECS components or about a complete ECS. Sizing data are based on performance information calculated by a performance analysis or on performance information provided by the user. Basic sizing results are provided for each component. Options are available to obtain system sizing information, system penalties imposed on an aircraft, and dataplots defining the predicted performance of some components. Analysis changes also can be accomplished via simple changes in input information.

4.6 Model Definition:

Preparation of the system math model information for a performance or sizing analysis normally involves three steps. The first step is to describe the problem to be solved. The second step is to relate the component name identifiers of the program to the problem. The third step is to prepare data describing the problem in the AECS formats.

4.6.1 Problem Description: Problem description for a performance analysis might consist of a schematic flow diagram of the ECS to be analyzed, tables or figures defining component performance, definition of the flight or ground conditions at which the system performance is to be analyzed, and appropriate data which define characteristics of engine bleed air or available power.

Problem description for a sizing analysis consists of component performance data (which can be obtained from a performance analysis), identification of general sizing data for some components (e.g., heat exchanger fin designation), and selected aircraft aerodynamic and engine performance parameters if ECS penalties on an aircraft are to be determined.

4.6.2 Use of Component Identifier Subroutines: The AECS Computer Program contains subroutines for computing the performance and for sizing numerous components of aircraft ECS. These subroutines are identified as abbreviations for component names or analysis techniques.

The AECS Computer Program user selects component name identifiers that provide the component and system analysis methods or model desired. A system flow schematic normally is prepared using the AECS component names. This flow schematic is used to define numerical identifications for locations between components where thermodynamic properties are to be determined.

4.6.3 Data Preparation: Data describing the mathematical analysis information to be used in the AECS Computer Program are prepared in four formats. These four formats represent the total math model for a performance or sizing analysis, but specific data in each are different. The four data formats contain: 1) general information such as system boundaries (e.g., altitude, Mach, humidity); 2) values of constants to be used in the analysis; 3) the component name identifiers to be used and integer number codes which describe how the subroutines are to be used; and 4) tables defining specific functional data in decimal form.

4.7 Problem Input:

Problem input data for a performance or sizing analysis are prepared in similar formats. These are the four formats which describe the math model preceded by identification and title information, and followed by analysis completion data. Problem input data order is depicted in Figure 3.

- Analysis Type - Analysis types are Performance, Sizing, or Changes to an immediately preceding performance or sizing analysis problem
- Title - The title is defined by the user
- General Problem Data - General problem data include ambient conditions, aircraft parameters, and optional output identifiers
- Table of Parameter Values - This table contains numerical values of parameters to be used in the analysis
- Component Name Identifiers - The component identifiers define analysis techniques or models for component performance or sizing, and general analysis techniques
- Tables of Functional Variables - The tables of functional variables define numerical data which represent functional relations between dependent and independent variables (e.g., fluid thermo-physical properties)
- Analysis Completion - The analysis completion input identifies if one or several problems are to be analyzed.

Additional specific comments about input for performance or sizing problems are presented in the following subsections. Primary differences in the type of input information occur in the component identifiers and tabular data.

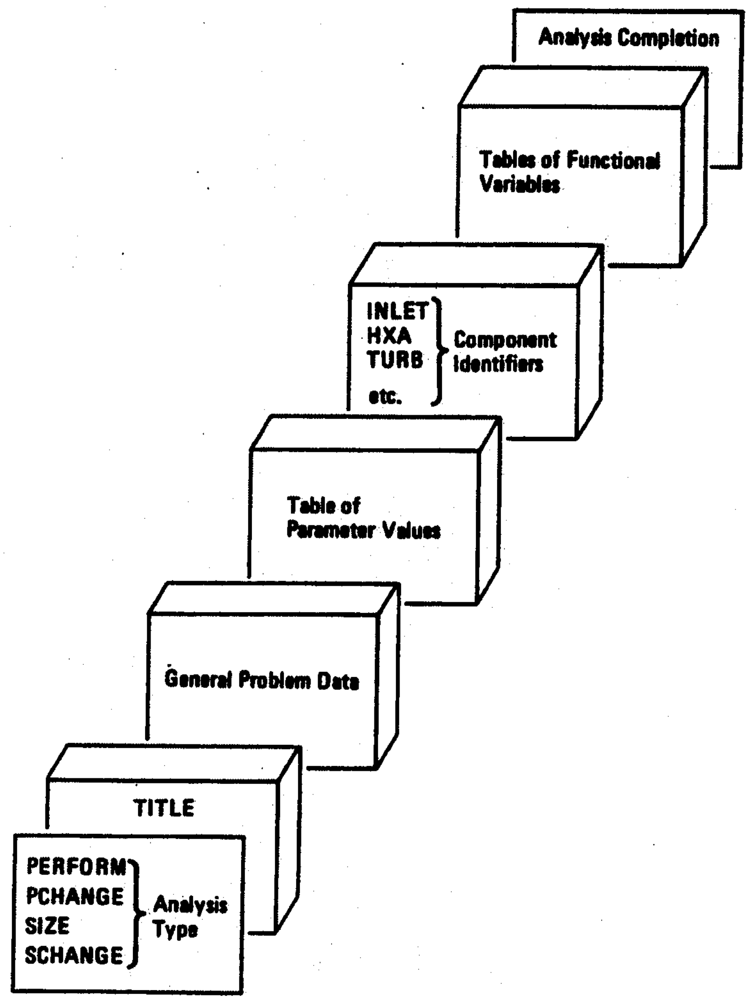


FIGURE 3 - Problem Input Data

4.7.1 Performance Input: Component name identifiers listed in a flow sequential manner (defining an explicit arrangement), and tabular data, which define the performance of individual components, are required for a performance analysis.

The sequential input of performance component names is started at an upstream location, and it is continued for each successive component or analysis model until an outlet or downstream location is defined. This input generally consists of: the component name identifier, a sequential identification number defined by the user, the input and output flow leg and station location numbers as defined on the user's schematic flow diagram, selected calculation options (such as a pressure drop analysis method), and integer numbers identifying numerical constants (parameter values) or tables to be used in the analysis.

Tabular input data include an identification code, an integer defining one of the 15 available table formats, a title, and the numerical tabular data. Types of data which are input in tabular formats include pressure drop versus air flow rate, heat exchanger effectiveness, and compressor and turbine adiabatic efficiency. Tables may be defined as data arrays. or functions of one, two, or three user selected independent variables.

4.7.2 Sizing Input: Component name identifiers for a sizing analysis normally can be listed in any order and the tabular data define generalized geometric and performance data for the components.

Input information for sizing component generally consists of: the component name identifier, an optional identification number, the flow leg and station location numbers which define input and output state properties for which the component is to be sized, calculation options (e.g., type of valve, power source for a fan or compressor, etc.), and integer numbers identifying parameter values and tables to be used in the analysis. The component name identifiers may be input in a designated order if a dependency between components is desired.

Tabular input data are prepared in the same format for sizing analysis as for performance analysis. Types of data input in tabular formats for component sizing include material thermophysical properties, general pressure loss factors for plumbing, and heat exchanger "f", "j", and geometric data.

4.8 Control Options:

The AECS Computer Program contains capabilities for many options which can be used to control an analysis and to mathematically simulate ECS controls. The user can obtain a performance or sizing analysis, or changes to either. He can define the fluid flowing in the components, the format of functional tables used, and how these tables are interpolated or extrapolated.

The performance analysis allows many options for defining system component arrangement and the number of components used. Detail for defining the performance of a component also is optional. For example, performance of a compressor can be analyzed with a constant or variable efficiency and pressure ratio with the pressure ratio obtained as a function of corrected flow rate, adiabatic head, or any other user defined independent variable; and thermal performance for heat exchangers can be based on constant or variable temperature effectiveness or heat transfer effectiveness.

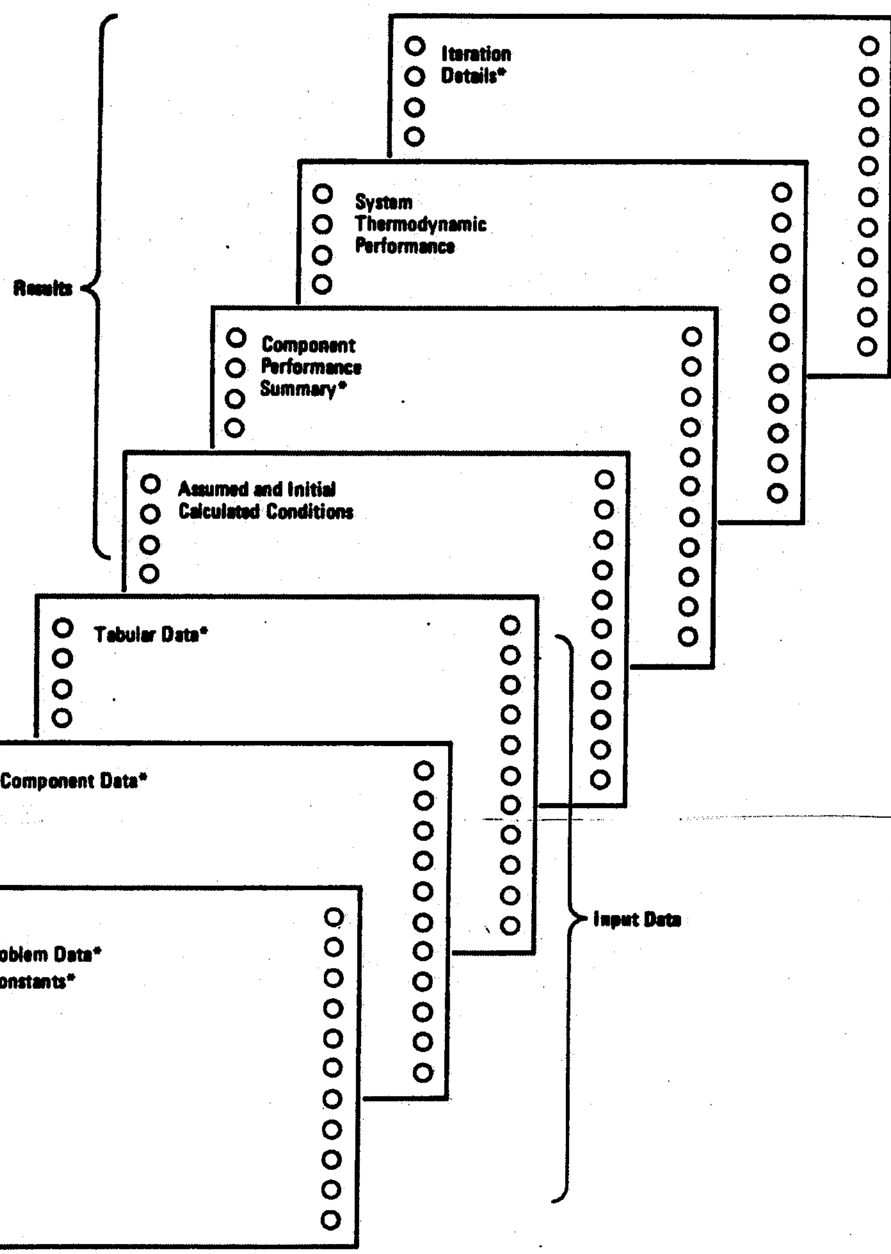
The simulation of ECS controls is provided by specification of where a variable is to be controlled and by control logic subroutines. For example, component identifier SENSOR is used to specify where temperature, pressure, flow rate of a fluid, humidity ratio in a gas stream or enthalpy of a refrigerant is to be controlled. Component identifiers CCS and MISC provide control options by defining analysis steps to be skipped, added, or changed. For example, if CCS is used to simulate the open or closed position of a shutoff valve, input which defines when to eliminate analysis of flow through the valve and its associated connecting lines is required.

A program user controls the performance conditions for which components are to be sized and general features of some components. Components can be sized individually or in relation to other components. User control options include materials for which components are to be sized, heat exchanger core arrangements and fin designations, the use of a radial or centrifugal air cycle machine, the power source to drive a compressor, type of valve (e.g., butterfly, poppet, etc.), and controller type (e.g., a simple cabin pressure controller or more complex electronic controller).

4.9 Program Output:

Program output for a performance or sizing analysis normally is provided as tabulated numerical values of calculation results. For either type of analysis, input data and intermediate results also may be output.

4.9.1 Performance Output: Output data from a performance analysis always includes the assumed and initially calculated thermodynamic conditions based on user input (i.e., results which produce errors at the boundary conditions) and the balanced system thermodynamic performance conditions (i.e., small acceptable errors at the boundary conditions). The user also may obtain detailed performance results for each component and details about each iterative analysis loop. A summary of performance output, which includes optional output data, is presented in Figure 4.



*Optional

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FIGURE 4 - Performance Output

4.9.1 (Continued):

System thermodynamic performance results and the assumed and initially calculated system conditions are provided in similar formats. Figure 5 is a typical output of system performance results, with each type of result identified by the user's numerical location code. Flow rates, pressures, temperatures, and humidity ratio or refrigerant enthalpy throughout the system are provided. (Flow rates are lb/min, pressures are psia, temperatures are °R, humidity is lb water/lb dry air, and enthalpy is Btu/lb). Information about initially unknown values (state variables) and boundary conditions of the problem (error variables) also are provided.

The optional component performance summary data provide thermodynamic conditions at the inlets and outlets of each component. Performance data unique to each component (e.g., effectiveness, pressure ratio, etc.) are included.

```
FLOW RATE(S)
(    1)    78.10  (    3)    78.10  (    5)     0.0   (    7)    78.10  (    9)     0.0  (   11)    78.10
(   13)   148.15  (   15)    39.59  (   17)   108.56  (   19)   148.15  (   21)     0.0  (   23)    78.10
PRESSURE(S)
(    2)    79.86  (    4)    78.07  (    6)    78.07  (    8)    76.84  (   10)    12.81 (   12)    12.76
(   14)    78.07  (   16)     0.00  (   18)    12.76  (   20)    12.76  (   22)    12.76 (   24)    12.00
(   26)    17.90  (   28)     6.18  (   30)     5.98  (   32)     4.53  (   34)     4.53 (   36)     4.53
(   38)     4.53  (   40)     4.53  (   42)     1.05  (   44)    12.00  (   46)     8.15
TEMPERATURE(S)
(    2) 1527.00  (    4) 1009.40  (    6) 1009.40  (    8)   591.97  (   10)  412.19 (   12)  412.19
(   14) 1009.40  (   16) 1009.40  (   18)  412.19  (   20)   412.19  (   22)  412.19 (   24)  412.19
(   26)  880.00  (   28)  880.00  (   30)  880.00  (   32)  1173.26  (   34) 1173.26 (   36) 1480.06
(   38) 1173.26  (   40) 1260.00  (   42) 1260.00  (   44)   412.10  (   46) 1489.06
HUMIDITY(S)/ENTHALFY(S)
(    2)     0.0  (    4)     0.0  (    6)     0.0  (    8)     0.0  (   10)     0.0  (   12)     0.0
(   14)     0.0  (   16)     0.0  (   18)     0.0  (   20)     0.0  (   22)     0.0  (   24)     0.0
(   26)     0.0  (   28)     0.0  (   30)     0.0  (   32)     0.0  (   34)     0.0  (   36)     0.0
(   38)     0.0  (   40)     0.0  (   42)     0.0  (   44)     1.000 (   46)     0.0
STATE VARIABLE TYPE(S)
    1)      2  (    2)    1(    3)   5    (     4)  6
STATE VARIABLE(S)
    1)    7.98622E   01  (  2)    1.48150E   02  (  3)  2.67218E-01   (   4)  1.58564E-04
ERROR VARIABLE TYPE(S)
(    1)      3  (    2)    2(    3)   5    (     4)  2
ERROR VARIABLE(S)
(    1)     -7.32422E-04  ( 2)-5.23567E-04   (     3)-2.74658E-03    (   4)  6.20842E-04
SOLUTION CONVERGED IN 9 TRY(S)
0   ERROR(S) DETECTED
```

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FIGURE 5 - System Performance Output

4.9.2 Sizing Output: Output data from a sizing analysis always includes information about each component, and, at user's option, system sizing and system penalty information. Typical information obtained from a sizing analysis is summarized in Figure 6.

```
COMPONENT COMP
   WEIGHT  13.39  COST UNITS  101.13  RELIABILITY INDEX 0.06793  DEVELOPMENT RISK 1.15
   W   39.59  PI  4.53  PO   8.15  TI  1173.26  TO 1489.06  HI  0.0  HO 0.0  FT  2  FN  1
   D    6.78  VOL  1409  N   60000. EFF 0.6394  HP -76.21  U  1775.  NS 166.79DS 1.01
   TIP SPEED EXCEEDS LIMITING VALUE
   DRIVE   1
COMPONENT HX
   WEIGHT  47.03  COST UNITS  97.82  RELIABILITY INDEX 0.00256  DEVELOPMENT RISK 1.00
   W   78.10  PI  79.886 PO 78.07  TI  1527.00  TO 1000.40 HI  0.0  HO 0.0  FT  2  FN 1
   W  148.15  PI   5.98  PO  4.53  TI   880.00  TO 1173.26 HI  0.0  HO 0.0  FT  2  FN 1
   LH   7.01  LC   5.77  LN 18.01  VOL  728.  WTC  31.7  EFF  0.8000NTU  2.898

*********
*SYSTEM*
*********
   WEIGHT   245.   COST UNITS   1223.   RELIABILITY INDEX   2.2638  DEVELOPMENT RISK 1.00
   WEIGHT STANDARD ERROR   8.9
   SHAFT POWER   0.0 HYDRAULIC POWER   44.9  ELECTRICAL POWER  0.0
   EQUIVALENT SHAFT POWER  50.
   BLEED AIR EXTRACTION   32.   FUEL CONSUMPTION   0.   DRAG   2.

***********
*PENALTIES*
***********
   RELATIVE GROSS TAKEOFF WEIGHT PENALTY    2.31 PERCENT
   RELATIVE PAYLOAD PENALTY                10.10 PERCENT
   RELATIVE RANGE PENALTY                   4.15 PERCENT
   RELATIVE EQUIVALENT DRAG PENALTY         3.52 PERCENT
   0 ERROR(S) DETECTED
```

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FIGURE 6 - Typical Sizing Output

4.9.2 (Continued):

Component sizing output data include its weight, relative cost and reliability, performance conditions for which it was sized, dimensions, and other information unique to each component.

Output data from analysis of system size and aircraft penalties represent a summation of the component data plus appropriate system installation factors. Output of the system sizing data is in a format similar to that for component sizing. In addition, the system weight standard error and the system power (i.e., direct shaft, hydraulic, and electrical) are output. ECS penalties are calculated relative to aircraft with no ECS.

4.10 Computer System:

The AECS Computer Program is written in the Fortran IV language for the CDC 6600 computer. It requires approximately 120K (octal) core size. Typical computer time is 1 second to 1 minute per analysis case, which depends on problem complexity. The AECS Computer Program is available from the United States Air Force[3], subject to their approval.

5. USAGE:

The AECS Computer Program may be applied to several types of ECS problems. For these applications, the user must be aware of the capabilities and limitations of the program. A list of suggested improvements needed by the AECS Computer Program also is presented.

5.1 Types of Application:

The AECS Computer Program can be applied to several types of environmental control system and subsystem analyses. Typical applications are listed below.

a) Simple, rough, or preliminary ECS performance at a few selected operating conditions.

b) Detailed ECS performance at numerous operating conditions.

c) Performance of an ECS component, and of small or major portions of an ECS (e.g., ram air circuits, conditioned air distribution circuits, a closed liquid circuit).

d) ECS performance based on using measured parameters to obtain other desired performance information.

e) Size and weight estimation of aircraft ECS components.

f) Comparisons of the size and weight of ECS components to meet different performance requirements or to meet different sizing criteria.

3. The AECS computer program is available from the United States Air Force (ASD/ENFEE, Wright-Patterson AFB, Ohio 45433). A blank computer tape should accompany all requests for the program. Requests from a foreign country must be sent through that country's embassy in Washington, D.C.

5.2 Program Capabilities and Limitations:

The AECS Computer Program offers capabilities for analyzing numerous types of ECS problems, provided the user does not exceed program limitations.

5.2.1 Capabilities: The AECS Computer Program provides desirable features of a generalized ECS steady state program. Additional information about unique program capabilities is listed below.

a) Input information consists of simple codes that cause the computer program to "connect" analysis techniques or models automatically (e.g., component name identifiers and integer number codes mathematically define the system performance analysis techniques).

b) Flexibility in the selection and identification of unknown variables is available.

c) Analyses may be based on simple rough data, very detailed data, or any mix of rough through detailed data.

d) Numerous formats for tabular data are available.

e) A user has flexibility in controlling program operation.

f) Variable solution convergence accuracies are available.

g) Only simple changes of input data are needed to obtain small changes in analyses.

h) Simple input changes are available to obtain numerous miscellaneous results not normally obtainable from the computer program.

5.2.2 Limitations: The AECS Computer Program has the limitations indicated below.

a) The input of system and subsystem definitions and characteristics must follow simple rules (i.e., trivial and overdefined systems, or incomplete input data, will not provide a converged solution).

b) The number of unknown (state) variables and boundary conditions (error variables) must be equal.

c) Results are dependent on values of boundary conditions used as input.

d) Failure to obtain a converged solution may be dependent on boundary conditions and initial guesses of unknown variables used as input.

5.2.2 (Continued):

e) The format for changes to a previously defined analysis input is simple, but all data to be changed must be input in the changed analysis (e.g., input of more than a different altitude and speed may be required if an analysis is to be made at these changed conditions).

f) Sizing results are estimated based on semi-empirical correlations of data.

5.3 Improvements Needed:

Further improvements are needed if the AECS Computer Program is to provide a broad capability for evaluating aircraft ECS. Needed improvements are:

a) Clarifications and improvements to users manuals (References 1 and 2);

b) Simple or standard output format;

c) Output of flow schematic diagram with results;

d) Techniques to improve the iterative solution method (Reference 5);

e) Techniques to simplify program use for obtaining multiple sets of results for a fixed ECS;

f) Further flexibility in defining ECS controls, such as zeroing out calculations for components when a limit is reached in a state variable;

g) Modifications or additions to component subroutines;

- sizing for additional heat exchanger configurations,
- greater detail in heat load definition and determination,
- typical ram air inlet and ram air outlet performance analysis,
- addition of numerous calculation techniques for pressure loss factors in ducting,
- expanded capabilities for analysis of vapor cycle ECS (Reference 6),
- ability to accept specialized user subroutines;

h) Modifications to allow more arbitrary arrangement of input data, which would be rearranged by the computer program;

i) More extensive data base for sizing analyses;

j) Additional data plotting options;

k) Addition of options for metric calculations;

l) Modification to allow for analysis of large models.

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3 F.S. Mach P	19	35	51	67
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8 F.S. S.T. TOTAL P	24 Pprim / Psec EJECT TURB	40 MOD Flow Boil P	56 ca / cmax table	TD 72 valve LC HX Heater Pan BOIL SZ TURBZ Vol Line RIM Rout
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FOREWORD

This Users Manual was developed by the McDonnell Douglas Corporation under Air Force Contract F33615-70-C-1235 "Development of Integrated Environmental Control System Designs for Aircraft". This development program was conducted under the sponsorship of the Air Force Flight Dynamics Laboratory, Project 6146, with Mr. Eugene A. Zara, FEE, as Project Engineer. This report is in four volumes:

I. ECS Design

II. ECS Computer Program

III. IECS Computer Program Users Manual

IV. Laboratory Demonstration Test

This ECS Computer Program Users Manual was prepared by the McDonnell Aircraft Company (MCAIR) of the McDonnell Douglas Corporation. The program manager was R. R. Dieckmann. The ECS Computer Program Group Leader was A. E. Whitney, assisted by C. E. Whitman and K. C. Li.

This technical report has been reviewed and is approved.

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ABSTRACT

This report volume presents a users manual for the Integrated Environmental Control Systems (IECS) Computer Program. The computer program was developed for the Air Force Flight Dynamics Laboratory. The computer program is capable of analyzing the steady state performance, determining typical sizing data, and evaluating relative aircraft penalties for virtually any air cycle or vapor cycle aircraft ECS. The program was written in the Fortran IV language for the CDC 6600 computer. This users manual provides instructions for setting up input data, describes the solution methods, and gives sample outputs. Sample problems are provided for a rough level performance and sizing analysis, and a detailed level performance analysis, including a listing of the input data and the output obtained.

Volume I of this report presents analytical design information which has been incorporated into the computer program. Volume II is a general description of the computer program. It includes sample problems for the rough performance and sizing of three Air Force aircraft, and the detailed performance and sizing of one Air Force aircraft. Volume IV of this report presents the laboratory demonstration ECS setup and results, and the computer program setup and results of detailed performance and sizing analyses to represent this ECS.

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LIST OF ILLUSTRATIONS

NOMENCLATURE

Symbol	Definition
A	Area, in^2
AC	Alternating Current
C_p	Specific Heat at Constant Pressure, Btu/lb-°R
CU	Cost Units
c	Speed of Sound, ft/sec
D	Aircraft Flight Drag plus ECS Momentum Drag, lb; Diameter, in.
DC	Direct Current
D_{ECS}	ECS Drag plus Thrust Reduction for ECS Fuel, lb
D_{eq}	Equivalent Drag, lb
DR	Development Risk Factor
D_r	Aircraft Flight Drag without ECS, lb
EV	Error Variable
FC	ECS Fuel Consumption, lb/hr
g	Gravitational Constant (32.17), lb-ft/lb-sec^2
H	Humidity (air), lb water/lb dry air; Enthalpy (refrigerant), Btu/lb
HP	Shaft power, hp
HS	Humidity at Saturation, lb water/lb dry air
J	Mechanical Equivalent of Heat (778), ft-lb/Btu
K	Valve or Line Loss Coefficient, psia/$(lb/min)^2$
k	Thermal Conductivity, Btu/hr-ft-°R
L	Length, in
LDR_r	Aircraft Lift to Drag Ratio without ECS
N	Rotational Speed, rpm
P	Pressure, lb/in^2
PD	Influence Partial Derivatives
PF	Perturbation Factor
P_o	Standard Pressure (14.7), lb/in^2
Q	Heat Flux, Btu/min
R	Aircraft Range without ECS
RI	Reliability Index
S	Entropy (refrigerant), Btu/lb-°R
SV	State Variable

NOMENCLATURE

Symbol	Definition
SFC_{ECS}	Engine(s) Specific Fuel Consumption including ECS, lb fuel/lb thrust-hr
SFC_r	Engine(s) Specific Fuel Consumption without ECS, lb fuel/lb thrust-hr
T	Temperature, °R
$\overline{T}$	Dry Air Rated Temperature, °R
TIME	Flight Time, min
THR	Engine(s) Thrust, lb
T_o	Standard Temperature (519), °R
V	Volume, in^3; Velocity, ft/sec; Specific Volume (refrigerant), ft^3/lb
W	Flow Rate, lb/min
WF	Weighing Factor
Wt_{ECS}	Installed ECS Wet Weight including Power Drive, lb
Wt_{emp}	Aircraft Empty Weight without ECS, lb
Wt_{ex}	Aircraft Expendable Coolant Weight, lb
Wt_{fuel}	Aircraft Fuel Weight, lb
Wt_{gr}	Aircraft Gross Takeoff Weight without ECS, lb
Wt_{pl}	Aircraft Payload Weight without ECS, lb
X	Ratio of Aircraft Expendable Weight to Aircraft Gross Takeoff Weight
X_r	Ratio of Aircraft Fuel Weight to the Aircraft Gross Takeoff Weight without the ECS
γ	Isentropic Exponent
ΔR	Aircraft Range Decrease Due to ECS
ΔWt_{gr}	Aircraft Gross Weight Increase Due to ECS, lb
ΔWt_{pl}	Aircraft Payload Decrease Due to ECS, lb
μ	Viscosity, lb/ft-sec
ρ	Density, lb/ft^3
σ	Density Ratio (ρ/ρ_o)

COMPUTER PROGRAM
CARD NAME AND PRINTOUT SYMBOLS

Component names for performance analyses are defined in Appendix A, for sizing analyses in Appendix B, and computer program subroutine names are defined in Appendix C. Numbers and letters in parentheses in the following list refer to sections of this Users Manual in which the following computer symbols are described more fully.

Word	Definition
A	Card Addition Change (4.10), or Area (A)
AD	Diffuser Exit Area (B)
AI	Inlet Area (B)
ALT	Altitude (4 or 5), or Altitude Card Name (4.10)
AN	Effective Nozzle Area (B)
AØ	Outlet Area (B)
ATM	Atmosphere (5)
B1 or B2	Multiplier (A)
BT	Boiling Temperature (B)
C	Constant (A), or Correction Factor (B)
CASEA, CASEB, CASEC, CASED	Case Specification Card Name (4.3)
CASEN	Case Name (4.3)
CBN	Common Block Name (G)
CC	Change Code (A or B)
CD	Discharge Coefficient (B)
CDA	Effective Leakage Area (B)
CF	Compression Factor (B)
CFM	Volumetric Flow Rate (A)
CMPNNT	Component Name (4.10)
CN	Card Name (4), or Component Name (A & B)
CØMMØN	Common Card Name (G)
CU	Drive Cost Units (B)
CUM	Cost Unit Multiplier (B)
CV	Control Value (A), or Condenser Core Volume (B)
CWT	Condenser Weight (B)
D	Card Deletion Change (4.10), or diameter (A&B)
DENS	Liquid Density (B)

Word	Definition
DR	Diameter Ratio (A)
DRAG	Drag (4.3 & B)
DRM	Development Risk Multiplier (B)
DS	Specific Diameter (B)
DSH	Degrees of Superheat (A)
DT	Throat Diameter (A)
DUMP	Iteration Dump Card Name (F)
EFF	Efficiency, or Effectiveness for Heat Exchange Components (A&B)
EF1 or EF2	Effectiveness, Side 1 or Side 2 (A)
EHPT	Total Equivalent Horsepower (B)
ELL	Electrical Line Length (4.3)
ENDCASE	Case End Card Name (4.7)
ENDJØB	Job End Card Name (4.12)
[illegible] or E.V.	Error Variable (3.1)
[illegible]N	Error Variable Number (5)
EV T	Error Variable Type (3&5)
EWT	Evaporator Weight (B), or Expendable Weight (B)
FC	Fuel Flow Rate (B)
FN	Fluid Property Table Relative Number (5.2 & D)
FT	Fluid Type (4.5 or D)
GENARG	General Argument Card Name (4.11)
GPM	Volumetric Flow Rate (A)
GWHP	Generator Weight Per Horsepower (4.3)
H	Humidity or Refrigerant Enthalpy (A&B)
HFG	Heat of Varporization (A&B)
HI	Inlet Humidity, or Inlet Refrigerant Enthalpy (A&B)
HLL	Hydraulic Line Length (4.3)
HØ	Outlet Humidity, or Outlet Refrigerant Enthalpy (A&B)
HP	Horsepower (A&B)
[illegible]	Humidity at Saturation (7.2)
[illegible]HP	Hydraulic Pump Weight Per Horsepower (4.3)
IAP	Ambient Property Table Relative Number (4.3)
IAPUT	APU Type (B)

Word	Definition
IBT	Boiler Type (B)
ICCP	Component Performance Print Control (4.3)
ICD	Discharge or Orifice Coefficient Table Relative Number (A)
ICT	Compressor Pressure Ratio and Efficiency Table Relative Number (A), or Control Type (A&B), or Compressor Type (B)
IC1 to IC17	Integer Data Field (4.5)
ID	Identification (A&B)
IDPC	Input Data Print Control (4.3)
IDT	Drive Type (B), or Dust Separator Type (B)
IE	Efficiency or Effectiveness Table Relative Number (A)
IEF	Water Removal Efficiency Table Relative Number (A), or Effectiveness Table Relative Number (B)
IF	Friction Factor Table Relative Number (A&B), or Fin Variable Table Relative Number (B)
IFCP	Engine SFC for Shaft Power Table Relative Number (4.3)
IFCW	Engine SFC for Bleed Air Table Relative Number (4.3)
IFGC	Fin Geometry Table Relative Number, Cold Side (B)
IFGR	Fin Geometry Table Relative Number, Refrigerant Side (B)
IFH	Fin Variable Table Relative Number, Hot Side (B)
IFLT	Heat Exchanger Flow Type (B)
IFN	Fluid Property Table Relative Number (A)
IFS	Fin Variable Table Relative Number, Source or Sink Side (B)
IFT	Fluid Type, or Fan Pressure Rise and Efficiency Table Relative Number (A)
IF1 or IF2	Fin Variable Table Relative Number, Side 1 or Side 2 (B)
IHEL	Heater Element Height (B)
IKT	Pressure Loss Factor Table Relative Number (A&B)

Word	Definition
ILEG	Leg Number (4.11)
ILT	Line Type (B)
IM	Material Property Table Relative Number (B)
IMC	Fin Material Property Table Relative Number, Cold Side (B)
IMH	Fin Material Property Table Relative Number, Hot Side (B)
IMR	Fin Material Property Table Relative Number, Refrigerant Side (B)
IMS	Fin Material Property Table Relative Number, Source or Sink Side (B)
IMSP	Separation Plate Material Property Table Relative Number (B)
IMT	Material Property Table Relative Number (B)
IMW	Tank Wall Material Table Relative Number (B)
IM1 or IM2	Fin Material Property Table Relative Number, Side 1 or Side 2 (B)
[illegible]D	Parameter Index (4.4), or index (G)
INLT	Inlet Type (B)
INM	Insulation Method (B)
INT	Insulation Type (B)
INTERP	Interpolation Code (5) (see NEI1, 4.6)
IØP	Option (A)
IØPR	Operation (A&B)
IØPT	Option (A&B)
IPA	Ambient Pressure Table Relative Number (4.3)
IPD	Pressure Drop Table Relative Number (A)
IPD1 or IPD2	Pressure Drop Table Relative Number, Side 1 or Side 2 (A)
IPR	Pressure Ratio Table Relative Number (A)
IPT	Pump Pressure Rise and Efficiency Table Relative Number (A), Pump Type (B)
IQ	Heat Load Table Relative Number (A)
ISIG	Pressure Drop Option (A)
[illegible]M	Number of MISC Cards to Skip (A&B)
ISP	Number of MISC Cards to Skip (A&B)
ISPP	System Penalty Print Option (4.3)

Word	Definition
ISRS	Speed Option (A)
ISSP	System Summation Print Option (4.3)
IST	Scale Type Code (4.6)
ISTA	Station Number (4.11)
ISZ	Number of MISC Cards to Skip (A)
ITA	Ambient Temperature Table Relative Number (4.3)
ITE	Table or Equation Option (A)
ITS	Source or Sink Temperature Table Relative Number (A), or Turbine Size Table Relative Number (B)
ITSP	Separation Plate Thickness Table Relative Number (B)
ITT	Turbine Flow Factor and Efficiency Table Relative Number (A), or Turbine Type (B)
ITYP	Value Type (B)
IUA	Overall Heat Transfer Coefficient Table Relative Number (A)
IVAL	Value Type (B)
IVM	Velocity or Mach Number Option (4.3)
IVT	Valve Type (B)
IVXN	Result Variable Relative Number (A or B)
IV1N or IV2N	Variable 1 or 2 Relative Number (A or B)
IV1T or IV2T	Variable 1 or 2 Types (A or B)
IWP	Water Property Table Relative Number (4.3)
IWR	Flow Ratio Table Relative Number (A)
K	Pressure Loss Coefficient (A)
KM	Minimum Pressure Loss Coefficient (A)
KP	Requirements Weighing Factor (B)
KT	Pressure Loss Factor (A or B), or Technical Weighing Factor (B)
L	Line or Flow Length (A or B)
L1 or L2	Heat Exchanger Core Flow Length, Side 1 or 2(B)
LC	Heat Exchanger Cold Side Flow Length (B)
LDR	Lift to Drag Ratio (4.3)
LEG	Flow Leg Card Name (4.11)
LH	Heat Exchanger Hot Side Flow Length (B)

Word	Definition
LN	Heat Exchanger No Flow Length (B)
LR	Refrigerant Side Flow Length (B)
LS	Heat Sink or Source Side Flow Length (B)
M	Mach Number (A or B), or (see TIME M)
MAP	Performance Map Option (B)
ME	Mechanical Efficiency (A)
N	Rotational Speed (A or B), or Dump Option (F)
NAR1 or NAR2	Argument Relative Number (4.6)
NAT1 or NAT2	Argument Type Code (4.6)
NC	Card Number (4.5)
NCS	Control Sensor Number (A)
ND	$N_S - D_S - \eta_{ad}$ Table Relative Number (B)
NDIM	Number of Dimensions (4.6)
NEI1 or NEI2	Extrapolation/Interpolation Code (4.6)
[illegible]	General Argument Number (4.11)
[illegible]	Leg Number (A or B)
NL1 or NL2	Inlet Leg Number, Side 1 or Side 2 (A)
NLEG	Number of Flow Legs (4.3), or Number of Legs Card Name (4.11)
NLF	Fan Leg Number (B)
NLI	Inlet Leg Number (A&B)
NLI1 or NLI2	Inlet Leg Number, Side 1 or Side 2 (A&B)
NLØ	Outlet Leg Number (A&B)
NLØ1 or NLØ2	Outlet Leg Number, Side 1 or Side 2 (A&B)
NLP	Ejector Primary Leg Number (A)
NLR	Refrigerant Leg Number (A&B)
NLS	Leg Number, Sink or Source Side (A&B), or Ejector Secondary (A)
NLT	Turbine Leg Number (B)
NØGØ	Stop Case Execution Card Name (4.9)
NP	Number of Parameters (4.4)
[illegible]1 or NP2	Number of Passes, Side 1 or Side 2 (B)
[illegible]H	Number of Passes, Hot Side (B)
[illegible]R	Relative Number of Permanent Table (4.6)
NPS	Number of Passes, Sink or Source Side (B)

Word	Definition
NPT	Type of Permanent Table (4.6)
NPT1 or NPT2	Number of Points of Independent Variables (4.6)
NPTS	Number of Points in Table (5)
NREL	Relative Number of Required Table (4.6)
NS	Station Number (A or B), or Specific Speed (B)
NSI	Inlet Station Number (A & B)
NSI1 or NSI2	Inlet Station Number, Side 1 or Side 2 (A&B)
NSIF	Fan Inlet Station Number (B)
NSIR	Refrigerant Inlet Station Number (A&B)
NSIS	Inlet Station Number, Source or Sink Side (A&B)
NSIT	Turbine Inlet Station Number (B)
NSØ	Outlet Station Number (A&B)
NSØ1 or NSØ2	Outlet Station Number, Side 1 or Side 2 (A&B)
NSØF	Fan Outlet Station Number (B)
NSØR	Refrigerant Outlet Station Number (A&B)
NSØS	Outlet Station Number, Source or Sink Side (A&B)
NSØT	Turbine Outlet Station Number (B)
NSP	Ejector Primary Station Number (A)
NSR	Relative Number of Same Table (4.6), or Number of Sensors (B)
NSS	Ejector Secondary Station Number (A)
NST	Type of Same Table (4.6), or Shaft Number (A&B)
NSTA	Number of Flow Stations (4.3), or Number of Stations Card Name (4.11)
NTU	Number of Transfer Units (B)
NTYP	Type of Required Table (4.6)
NV1 or NV2	Variable 1 or 2 Relative Number (A&B)
NVX	Result Relative Number (A&B)
ØBAE	Bleed Air for Other Systems (4.3)
ØEHP	Equivalent Horsepower for Other Systems (B)
ØSHP	Shaft Power for Other Systems (4.3)
P	Pressure (A or B), (or see TIME P)

Word	Definition
PAM	Ambient Pressure Card Name (4.10)
PAMB	Ambient Pressure (4.3)
PARAM	Parameter Table Card Name (4.4)
PASS	Iteration Pass Number (5.1)
PC	Compartment Pressure (B)
PCHANGE	Performance Change Case Card Name (4.10)
PD	Discharge Pressure or Pressure Drop (A), or Partial Derivative (F)
PDUMMY	Dummy Performance Case Card Name (4.11)
PERFØRM	Performance Case Card Name (4.1)
PF	Perturbation Factor (3)
PHX	Primary Heat Exchanger (User Input)
PI	Inlet Pressure (A&B)
PØ	Outlet Pressure (A&B)
PØW	Power Balance (A)
[illegible]	Primary to Secondary Pressure Ratio (A)
[illegible]	Pressure Ratio (A)
PREG	Regulator Pressure (A)
PRØP	Property (5)
PTAB	Permanent Table Card Name (4.6)
PTTL	Permanent Table Tape Loader Card Name (E)
PTV	Parameter Table Card Name (4.10)
PV	Parameter Value (4.10)
PWR	Shaft Power (A)
Q	Boiling Heat Rate or Heat Transferred (A)
QCHANGE	Quick Change Card Name (4.10)
QT	Heat Load (A)
R	Card Replacement Change (4.10)
RE	Reynolds Number (B)
RELN	Relative Number (5)
RI	Reliability Index (B)
SCHANGE	Sizing Change Case Card Name (4.10)
[illegible]	Shaft Horsepower (B)
SIZE	Sizing Case Card Name (4.1)
SPR	Secondary Pressure Ratio (A)

Word	Definition
SR	Split Ratio (A)
STA	Flow Station Card Name (4.11)
STAB	Same Table Card Name (4.6)
SV or S.V.	State Variable (3.1)
SV N	State Variable Number (5)
SV T	State Variable Type (7.1)
T	Temperature (A or B)
TA	Ambient Temperature (B)
TAM	Ambient Temperature Card Name (4.10)
TAMB	Ambient Temperature (4.3)
TABID	Table Identification Card Name (4.6)
TABT	Table Title Card Name (4.6)
TABV	Table Value Card Name (4.6)
TB	Boiling Temperature (A)
TC	Compartment Temperature (B)
TD	Line Temperature (B)
THK	Wall or Insulation Thickness (B)
THR	Engine Thrust (4.3)
THRC	Thrust Recovery (B)
TI	Inlet Temperature (A&B)
TI2	Inlet Temperature, Side 2 (A)
TIME D	Computer Time at Start of Dummy Performance (2)
TIME E	Computer Time at End of Performance Solution (2)
TIME M, P, Z	Computer Time at End of M, P, or Z Phase (2)
TITLE	Title Card Name (4.2)
TØ	Outlet Temperature (A&B)
TS	Insulation Surface Temperature (B)
TT	Table Title (4.6)
TV	Table Values (4.6)
TW	Wall Temperature (B)
TYPE	Control Type (7)
U	Tip Velocity (B)
V	Velocity (A or B)

[illegible]	Definition
V1 or V2	Variable 1 or Variable 2 Value (A&B)
VAL	Parameter Value (4.4), or General Argument Value (4.11)
VAL1, VAL2	Parameter Value (4.4)
VALUE	Parameter Value Card Name (4.4), or Initial Value (B)
VALUES	Parameter Values Card Name (4.4)
VL	Liquid Volume (B)
VLC	Liquid Volume in Cold Side Core (B)
VLH	Liquid Volume in Hot Side Core (B)
VØL	Volume (B)
VØM	Velocity or Mach Number (4.3)
VM	Velocity or Mach Number (4.10)
VX	Result Variable Value (A&B)
W	Flow Rate (A&B)
W2	Side 2 Flow Rate (A)
[illegible]	Boiling Rate (A)
[illegible]	Primary to Secondary Flow Ratio (A)
WT	Drive Weight (B)
WTBT	Total Bare Weight of APU (B)
WTC	Heat Exchanger Core Weight (B)
WTCD	Weight of Compressor with Drive (B)
WTE	Aircraft Empty Weight without ECS (4.3), or Extra Liquid Weight in Boiler (B)
WTF	Aircraft Engine Fuel Weight (4.3)
WTG	Aircraft Gross Takeoff Weight without ECS (4.3)
WTL	Weight of Filter or Refrigerant Lines (B)
WTM	Weight Multiplier (B)
WTP	Weight of Pump and Motor (B)
WTR	Weight of Reservoir or Receiver (B)
WTRC	Weight of Refrigerant Charge (B)
WTS	Selector Weight (B)
[illegible]	Multiple Card Deletion Code (4.10)
[illegible]	Inlet Elevation Minus Outlet Elevation (B)
******	Comment Card Name (4.8)

SECTION 1

INTRODUCTION

This report provides a Users Manual for the Integrated Environmental Control Systems (IECS) Computer Program. This computer program was developed to analyze aircraft environmental control systems. The program provides two functions: 1) performance analysis, and 2) sizing analysis.

The performance analysis section of the program computes the steady state performance of a system (i.e., the flow rate, pressure, temperature, and humidity or enthalpy at all locations within a system). The system is described by selecting available performance components and connecting them together to form a system. Virtually any system may be described by the user. The component performance data required may be specified by the user at data levels ranging from rough to refined (i.e., constant values to component maps).

The sizing analysis section of the program uses the performance analysis results to compute the size of a system. The size of the components consists of the characteristic dimensions, weight, weight standard error, installation weight, cost units, reliability index, development risk, and power consumed (shaft, electric, hydraulic, and fuel). The component sizes may be summed by the program to obtain the system size, and the system size may be used to compute the system penalties to the aircraft (i.e., drag, takeoff gross weight, range, and payload).

The computer program was written in Fortran IV for the CDC 6600 computer in an overlay structure. It requires approximately a 100K (octal) core size and a running time of approximately 5 seconds per case. The components are in modular form allowing future changes to be easily added. Although the program was developed to analyze aircraft environmental control systems, the program has many general components which may be used to analyze other systems (e.g., flow distribution systems, hydraulic systems, and fuel systems).

Additional data on environmental control systems (ECS) and on the ECS Computer Program usage is found in Volumes I, II, and IV.

SECTION 2

PROGRAM STRUCTURE

The computer program is divided into two main sections: 1) the performance analysis section, and 2) the sizing analysis section. The performance analysis section computes the steady state performance of the ECS (i.e., flow rates in each flow branch of the system; pressures and temperatures; humidities in airflow lines; and enthalpies in refrigerant lines) at points within the system. The performance section can be used independently of the remainder of the program. The sizing analysis section computes the size of the ECS (e.g., characteristic dimensions, weight, cost units, reliability index, and development risk). The sizing section can also be used to compute relative aircraft penalties of drag, takeoff gross weight, payload, and range. The sizing section is dependent on system performance, and any sizing analysis must be preceded by a performance analysis. The program also is structured to accept simple through detailed descriptions of an ECS and the components used in the ECS.

The performance or sizing analysis may consist of a full set of data, [illegible]led a base case; or it may consist of a partial set of data, consisting of changes to a base case, called a change case. A performance change case must always be preceded by a performance base case. A sizing change case must always be preceded by a sizing base case. Any sizing case must always be preceded by a performance base or performance change case.

The computer program has been structured into an overlay form to reduce the amount of main computer core storage required to run the program. The analysis section is contained in the "Performance Segment", and the sizing analysis section is contained in the "Sizing Segment". Also shown in Figure 1 at the first overlay level are the "Dummy Performance Segment" and the "Permanent Table Segment". The Dummy Performance Segment is a short section which allows the user to directly input performance data of a system for a sizing analysis without running a performance analysis. The Permanent Table Segment is provided to load permanent table data on a reserved magnetic tape. These data, once loaded on a tape, may be used by either a performance or sizing case. The permanent table tape loading is explained in Appendix E. The subroutines [illegible]tained in each overlay segment are given in Appendix C.

The performance and the sizing segments are both overlayed at the second level into three similar subsegments. The first subsegment, designated the M

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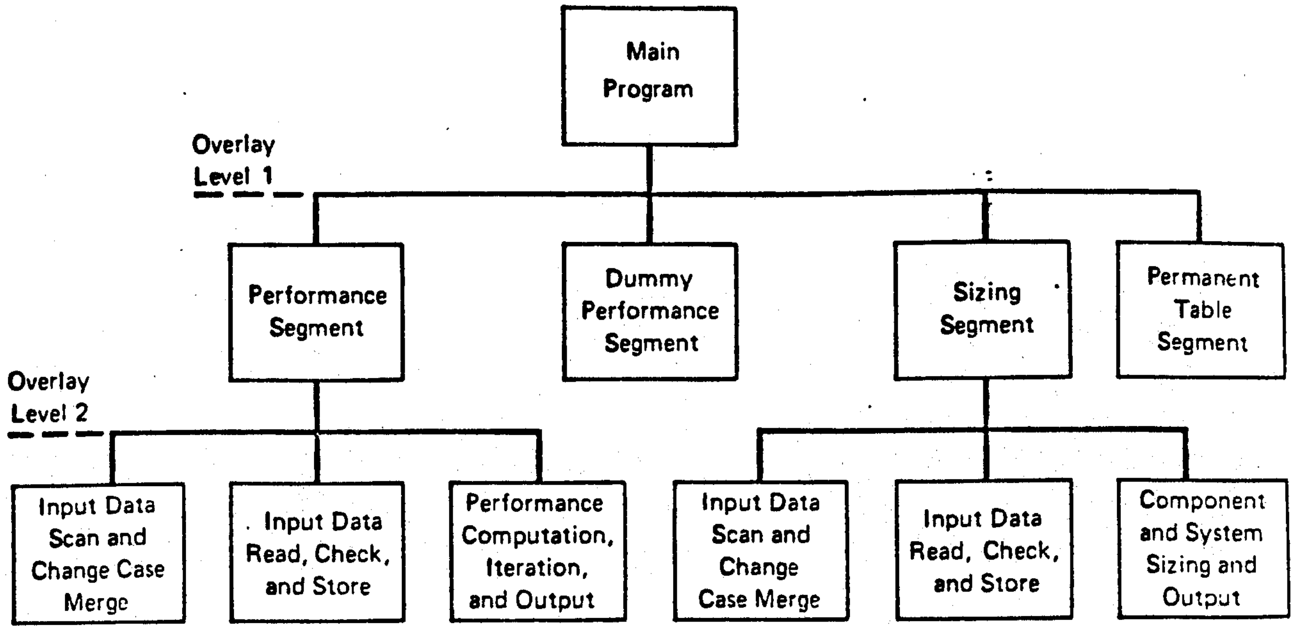

Figure 1 Computer Program Structure

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...se, preprocesses the input data cards for a case. Error messages are written if any data cards are determined to be missing, unrecognizable, or in the wrong order. Error messages written by the program are in the form:

ERROR n message

where n is a sequential count of the errors, and message states the error. For missing data cards a card containing blank data fields is provided by the program. For unrecognizable data cards, or for data cards in the wrong order, the subject cards are rejected from further processing. If the case being processed is a change case, the change cards will be merged with the base cards. These change cards allow for the removal or addition of components to the base case ECS, and designation of new conditions to be analyzed.

The second subsegment, designated the Z phase, reads the input data values, performs extensive error checks, and stores the data in the computer core storage for use by the third phase. Error messages are written if any data values are determined to be missing or incorrect.

The third subsegment, designated the P phase, performs the system ...alysis (i.e., either performance or sizing). If any errors were detected in the M or Z phases, the P phase will be bypassed. For a performance analysis the components are analyzed simultaneously to determine the system performance. For a sizing analysis the components are analyzed sequentially. The component sizing results can then be summed to give the system results, and the penalties can be determined.

Several computer clocking points are provided in the program. The computer time at the start of the M phase will be printed with the message TIME M, the computer time at the start of the Z phase will be printed with the message TIME Z, and the computer time at the start of the P phase will be printed with the message TIME P. For a performance case the computer time at the end of the solution will be printed with the message TIME E. For a dummy performance case the computer time at the start will be printed with the message TIME D. All computer times are in seconds.

SECTION 3
SOLUTION METHOD

The analysis of a flow system usually requires the simultaneous solution of a set of nonlinear equations. For a performance analysis and for the sizing of some components, the computer program uses the generalized Newton-Raphson iteration method. In a flow system there is a set of key variables, whose values, once known, allow the equations to be solved explicitly. These key variables are called "state variables". Examples of state variables are: inlet flow rate, flow split, compressor/turbine shaft speed, etc. If an initial guess is provided for each state variable, the equations can be solved. However, unless the state variables are given their correct values, certain conditions in the flow system will not be met. These conditions are called "error variables". Examples of error variables are: outlet pressure does not match the ambient pressure, the temperature at a control point is not the correct temperature, the compressor power does not balance the turbine power, etc. The correct solution is obtained when the set of state variables yields a set of error variables whose values are sufficiently small. For a unique solution the number of state variables must match the number of error variables.

3.1 Generalized Newton-Raphson Method

The generalized Newton-Raphson iteration method provides for iterating an initial set of state variables to yield a set of error variables which are sufficiently small. The Newton-Raphson method states that given an initial set of state variables SV_j ($j = 1,n$, where n is the number of state and error variables), and a corresponding computed set of error variables EV_i ($i = 1,n$), a better estimate of the state variables, that will produce a set of zero error variables, can be obtained from the equation (in matrix form):

$$[SV]_{new} = [SV]_{old} - [PD]^{-1} [EV]_{old} \tag{1}$$

where SV represents a column matrix of state variables, EV represents a column matrix of error variables, and PD represents a square matrix of influence partial derivatives $PD_{ij} = \partial EV_i / \partial SV_j$.

The partial derivatives are evaluated numerically by the approximation:

$$\frac{\partial EV_i}{\partial SV_j} \approx \frac{\Delta EV_i}{\Delta SV_j} = \frac{(EV_{perturbed} - EV)_i}{(SV_{perturbed} - SV)_j} \qquad (2)$$

where $SV_{perturbed}$ represents a changed value of the state variable by the amount

$$SV_{perturbed} = PF \times SV \qquad (3)$$

and $EV_{perturbed}$ represents the changed value of the error variable due to the changed state variable. The perturbation factor, PF, is stored in the program and has a value of 1.001.

The change in the state variable given by the iteration equation may greatly overpredict the correct value due to the nonlinearity of the flow system equations and due to the user's initial guess of the state variables. To improve convergence the iteration equation is modified to

$$[SV]_{new} = [SV]_{old} - WF\ [PD]^{-1}\ [EV]_{old} \qquad (4)$$

where WF represents a weighing factor whose value is less than or equal to one. The weighing factor has a built in value of 1.0. This modified equation, when repeatedly applied, will generally converge to a solution, if the problem specified by the user has a solution. The program has a built in limit of 25 iterations.

The values that have been built into the program for the perturbation factor, the weighing factor, the number of iterations allowed, etc., are based on program usage during the development of the program, and should be adequate for most problems. Provisions are made for user data cards to change some of the values built into the program (e.g., see Appendix G).

3.2 State and Error Variables

All state variables are assigned built in values for upper and lower limits, between which the state variable may vary to balance the system. The ten types of state variables for a performance case and their lower and upper limits are:

State Variable Type	Lower Limit	Upper Limit
1. Flow Rate	10^{-3}	10^{6}
2. Pressure	10^{-6}	10^{6}
3. Temperature	10^{-3}	10^{6}
4. Humidity or Enthalpy	10^{-12}	0.999
5. Split Ratio	10^{-3}	0.999
6. Control Valve Loss Coefficient	10^{-12}	10^{12}
7. Rotational Speed	10^{-3}	10^{6}
8. Pressure Ratio (compressor, turbine, etc.)	1.0	10^{6}
9. Pressure Ratio (orifice)	10^{-6}	0.999
10. Miscellaneous	10^{-12}	10^{12}

Ten error variable types are allowed in the program for a performance case. These are:

Error Variable Type

1. Flow Rate
2. Pressure
3. Temperature
4. Humidity or Enthalpy
5. Shaft Power Balance
6. not used
7. not used
8. not used
9. not used
10. Miscellaneous

All error variables are required to converge to a value of 0.01. This is an absolute number (i.e., flow rates are required to balance to 0.01 lb/min, pressures are required to balance to 0.01 psi, temperatures are required to balance to 0.01°R, etc.). This limit is adequate except for error variable types 4 and 10. These error variables should be scaled by the user (see performance component MISC, Appendix A).

3.3 Error Messages

Two error messages may be printed by the iterative solution process. The first message states that a singular matrix has been encountered during an iteration. This message indicates that an improper problem has been specified by the user, or that numerical significance has been lost by the computer. Numerical significance may be lost if state variables reach their lower or upper limits. If the singularity is due to zero rows or columns, additional error messages will be printed stating which rows and columns are zero. The second error message is nonconvergence. An iteration dump option (see Appendix F) has been provided to aid in the determination of the cause of nonconvergence. The dump may be selected by the user, or the dump will automatically be given for the last iteration of nonconvergent problems (dump option 2 level).

SECTION 4
PROGRAM INPUT

The input data for a performance or sizing analysis is input on cards in a common manner. A case is a set of cards arranged in groups as shown in Figure 2. Every data card contains a name in the first card columns. A case is started with a case control card, and ended by a case end card. Any number of cases may be run in a job. The last case in a job is followed by a job end card.

If an invalid case control card or a missing case control card is detected by the main program, an error message is written, and the input data is searched to find the next valid case control card. If any card in the groups between the case control card and the case end card contains an invalid card name, or is out of the order indicated in Figure 2, the card will be rejected during the M phase preprocessing and an error message written on the output. The valid card names and their input order are explained in the following sections.

Before the input data cards can be punched and input to the program, the user must define the problem which he wishes the program to solve. Care must be taken in defining the problem. If the problem specified does not have a solution, the program will not yield a solution.

The description of the problem usually starts with a schematic of the system. Using this schematic the user selects which flow lines, components, and controls are to be in his computer model of the system. A model may consist of the entire system, a portion of the system, or a single component. Each flow line is assigned a leg number. In each flow leg the user inserts the desired components, and defines component inlet and outlet station numbers. The physical components are simulated by the available mathematical components in the computer program. Controls are inserted in the model where desired. A portion of a typical computer model for a primary heat exchanger is shown in Figure 3. From this computer model of the system, and from the component data and flight conditions, the user may punch the required data cards. Input data forms are given in Appendix H. Except as noted the input is in a standard set of units.

All data, working space, and results of the program are stored in a single labeled common block. Storage areas in this block are dynamically

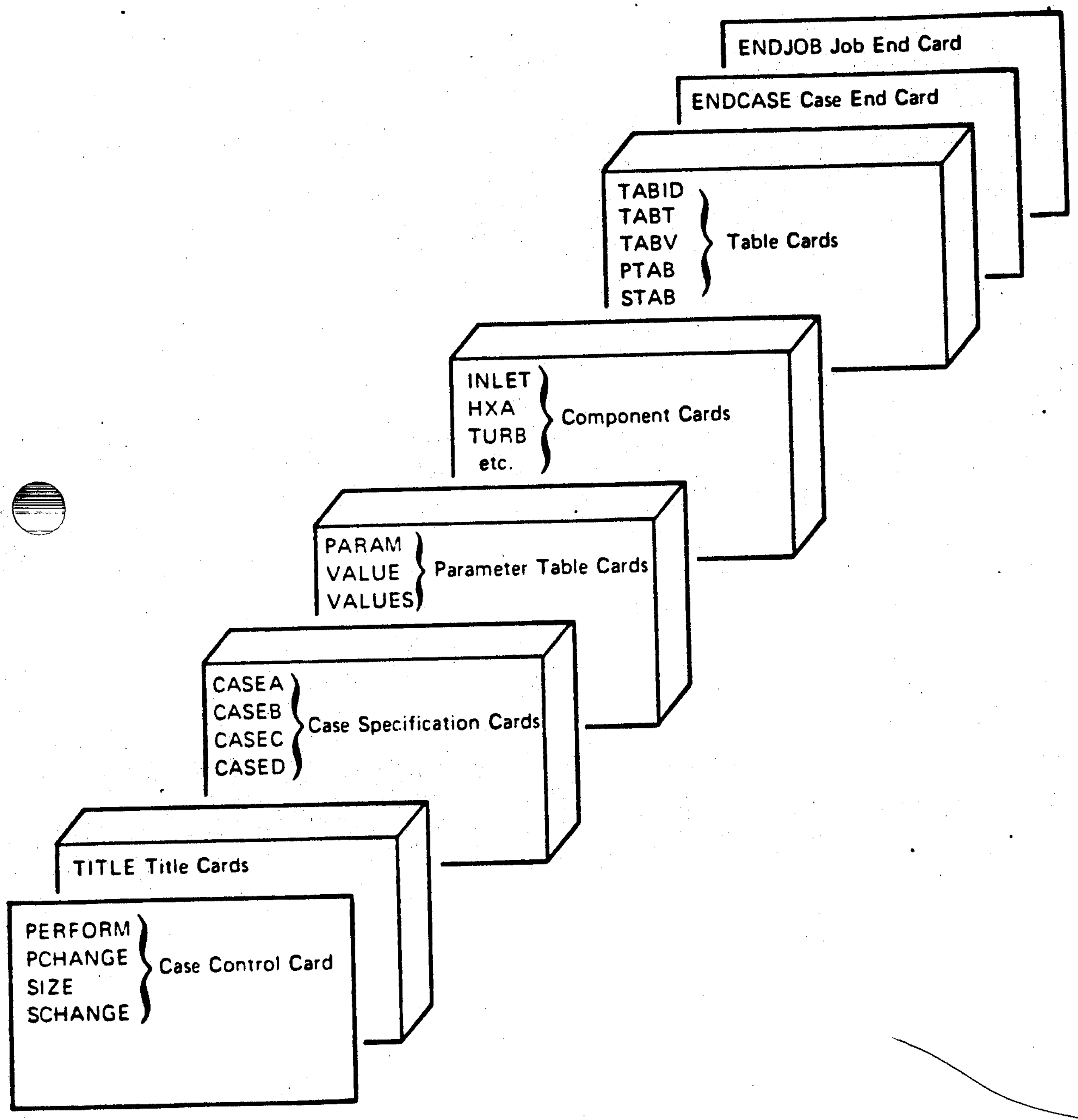

Figure 2 Program Input Data

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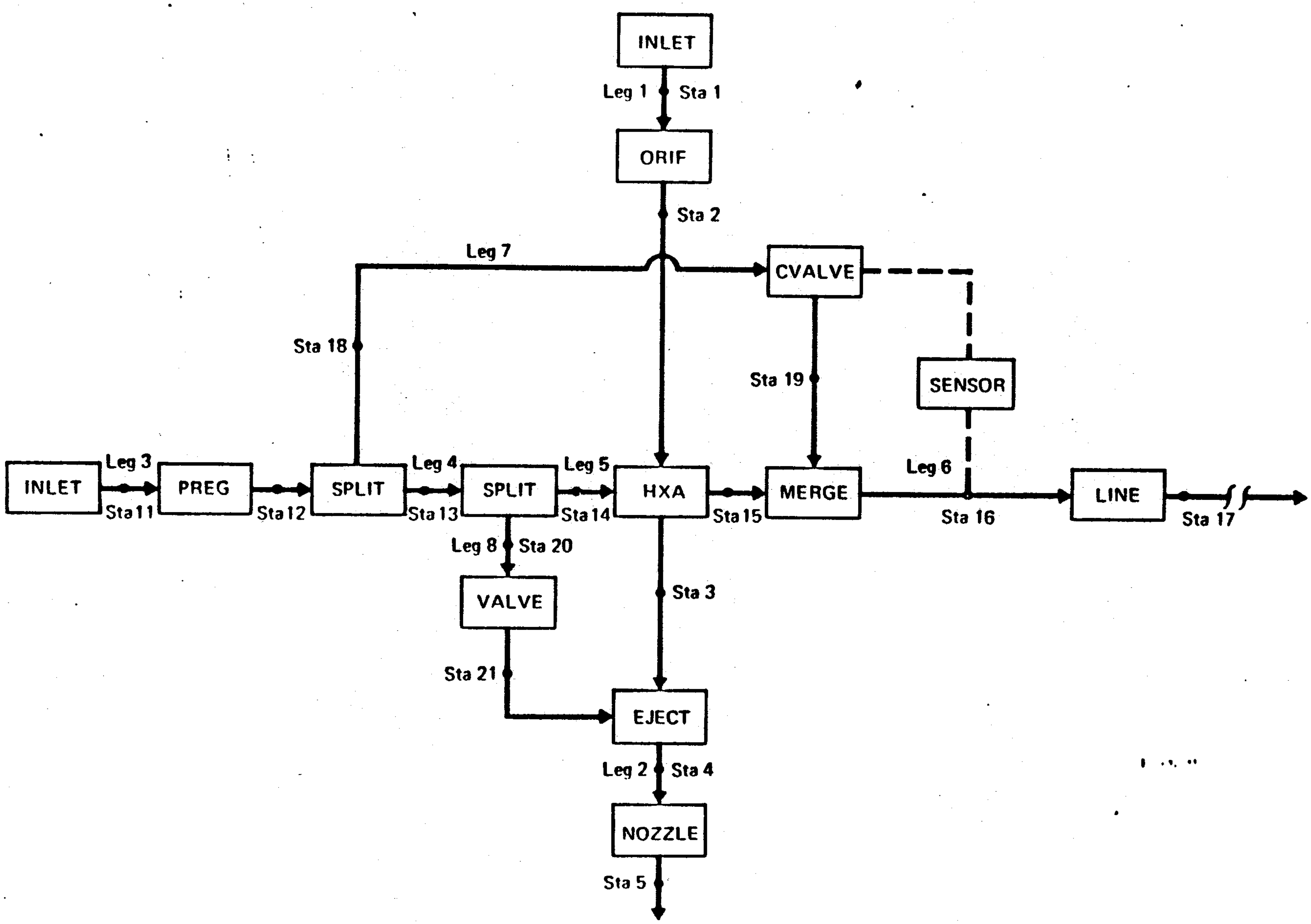

Figure 3 Computer Program Model Construction

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signed by the program. The block is subdivided into three subpools. Subpool zero contains information that must be shared between a performance and a sizing case. Subpool one contains information required only for the case being run. Subpool two is used for generating maps in the sizing section of the program. During the execution of the program any subpool whose size is exceeded will cause the job to be terminated with an error message specifying the subpool that has overflowed. Subpool sizes may be increased by reassigning subpool pointers or increasing the common block size.

4.1 Case Control Cards

A case control card must precede the data input for each case to identify the type of case to be run. A performance base case must be preceded by a PERFØRM card. The PERFØRM data card format is:

Card Column	Value
1-7	PERFØRM card name

A sizing base case must be preceded by a SIZE card. The SIZE data card [illegible]at is:

Card Column	Value
1-4	SIZE card name

A sizing case, either base or change, must be preceded by a performance case, either base, change, or dummy, and will use the results of the last performance case. If a sizing case is not preceded by a performance case, an error message will be written on the output and the case rejected. However, the M and Z phases for the rejected case will be processed, possibly detecting additional errors. If the last performance case input before a sizing case contained errors, the P phase of the sizing case will be bypassed. Additional information about case control cards is found in Sections 4.10 and 4.11.

4.2 Title Cards

Title cards can be input to the program for the purpose of identifying the case being run. There is no restriction on the number of title cards input. The title cards are printed, double spaced, on the second page of output for the case. If no title cards are input, the standard title GENERAL ECS PROGRAM [illegible] provided.

The first title card is printed at the top of each page of output. The [illegible]ge header will also contain the program name (IECS), a sequential case counter, a user problem name, the calendar date, and the case output page number.

The title data card format is:

Card Column	Value
1-5	TITLE card name
7-80	user title

4.3 Case Specification Cards

The case specification data cards consist of four data cards and must be input in the order CASEA, CASEB, CASEC, and CASED. The contents of these cards differ between a performance case and a sizing case, and are explained separately in the following sections.

4.3.1 Performance Case Specification Cards - The CASEA card specifies a case name, an input data print control, the number of legs and stations in the user's model, and the component performance print control. The CASEA data card format is:

Card Column	Name	Value
1-5	CN	CASEA card name
9-16	CASEN	alphameric case name.
17-20	IDPC	input data print control four digit code (ijkℓ) i = 0, case data printed i = 1, case data not printed j = 0, parameter data printed j = 1, parameter data not printed k = 0, component data printed k = 1, component data not printed ℓ = 0, table data printed ℓ = 1, table data not printed
24	NLEG	number of legs
28	NSTA	number of stations
32	ICPP	component performance print control = 0, print = 1, no print

The CASEB card specifies atmospheric pressure and temperature table relative numbers (if used), velocity/Mach number option, freestream fluid property table relative number, and the water property table relative number. The CASEB data card card format is:

Card Column	Name	Value
1-5	CN	CASEB card name
12	IPA	freestream or ambient pressure table relative number (type 14) if 0, use PAMB from CASEC card
16	ITA	freestream or ambient temperature table relative number (type 15) if 0, use TAMB from CASEC card
20	IVM	velocity/Mach number option = -1, input freestream velocity on CASED card = 0, input not required = +1, input freestream Mach number on CASED card
24	IAP	freestream or ambient property table relative number (type 10)
28	IWP	water property table relative number (type 10), wet air only

The CASEC card specifies altitude, ambient pressure, and ambient temperature. The CASEC data card format is:

Card Column	Name	Value
1-5	CN	CASEC card name
11-20	ALT	altitude, ft
21-30	PAMB	freestream or ambient pressure, psia (not used if IPA ≠ 0 on CASEB card)
31-40	TAMB	freestream or ambient temperature, °R (not used if ITA ≠ 0 on CASEB card)

The CASED card specifies velocity or Mach number. The CASED data card format is:

Card Column	Name	Value
1-5	CN	CASED card value
11-20	VØM	velocity, ft/sec, or Mach number (see IVM on CASEB card)

The card column indicated for the integer values on the CASEA and CASEB data cards specify the right hand column of a four column field. Input values must be right justified to this card column. If the input value for the number of legs is less than 1, the value will be changed to 1. If the input value for the number of stations is less than 2, the value will be changed to 2. The data fields on the CASEC and CASED cards represent real numbers and should be punched with a decimal point.

4.3.2 Sizing Case Specification Cards - The CASEA card specifies a case name, an input data print control, a system summation print control, a system penalty print control, and relative table numbers for engine specific fuel consumption. The CASEA data card format is:

Card Column	Name	Value
1-5	CN	CASEA card name
9-16	CASEN	alpha-numeric case name
20	IDPC	input data print control four digit code (ijkℓ) i = 0, case data printed i = 1, case data not printed j = 0, parameter data printed j = 1, parameter data not printed k = 0, component data printed k = 1, component data not printed ℓ = 0, table data printed ℓ = 1, table data not printed
24	ISSP	system summation print option = 0, print = 1, no print
28	ISPP	system penalty print option = 0, print = 1, no print
32	IFCW	engine specific fuel consumption for bleed air table relative number (type 41), not required if ISPP = 1
36	IFCP	engine specific fuel consumption for shaft power table relative number (type 42), not required if ISPP = 1

The card column indicated for the integer values on the CASEA data card specifies the right hand column of a four column field. Input values must be right justified to this card column.

The CASEB data card specifies values of flight time, engine thrust, aircraft parasitic drag without ECS, and aircraft lift to drag ratio.

These inputs are not required if ISPP = 1. The CASEB data card format is:

Card Column	Name	Value
1-5	CN	CASEB card name
11-20	TIME	flight time, min
21-30	THR	engine thrust, lb
31-40	DRAG	aircraft flight drag, lb
41-50	LDR	lift to drag ratio

The CASEC data card specifies values of aircraft empty weight without ECS, aircraft propulsive fuel weight, and aircraft gross takeoff weight without ECS. These inputs are not required if ISPP = 1. The CASEC data card format is:

Card Column	Name	Value
1-5	CN	CASEC card name
11-20	WTE	aircraft empty weight without ECS, lb
21-30	WTF	aircraft propulsive fuel weight, lb
31-40	WTG	aircraft gross takeoff weight without ECS, lb

The CASED data card specifies values of electrical line length for ECS electrical systems, hydraulic line length for ECS hydraulic power systems, electric generator weight per ECS horsepower required, hydraulic pump weight per ECS horsepower required, shaft horsepower extraction used in systems other than the ECS, and bleed air extraction used in systems other than the ECS. These inputs are not required if ISPP = 1. The CASED data card format is:

Card Column	Name	Value
1-5	CN	CASED card name
11-20	ELL	electrical line length, in
21-30	HLL	hydraulic line length, in
31-40	GWHP	generator weight per horsepower, lb/hp
41-50	HWHP	hydraulic pump weight per horsepower, lb/hp
51-60	ØSHP	shaft power extraction for other aircraft systems, hp
61-70	ØBAE	bleed air extraction for other aircraft systems, lb/min

The data card values on the CASEB, CASEC, and CASED cards are real numbers and should be punched with a decimal point.

The table of engine specific fuel consumption for bleed air use should be input as a function of engine thrust (general argument 62) and bleed air flow rate (general argument 63). The table of engine specific fuel consumption for shaft power use should be input as a function of engine thrust (general argument 62) and shaft horsepower (general argument 64). The specific fuel consumption is specified in lb fuel/lb thrust-hr.

4.4 Parameter Table Cards

The parameters required for a case are stored in a parameter table. The table provides single valued parameters representing component characteristic lengths, inlet and outlet conditions, desired control sensor values, etc. The table is also used to provide initial guesses for the state variables. Each parameter is referenced by an index, which represents its relative position within the table. Data card fields that refer to the parameter table are indicated in Appendices A and B by brackets around the data symbol. Parameter references that are left blank or punched with a zero will return a parameter value of zero. The size and contents of the table are specified by the user.

The parameter table is input by a group of cards. The first card in the group must be the PARAM card. This card specifies the number of values allowed for the parameter table. The PARAM data card format is:

Card Column	Name	Value
1-5	CN	PARAM card name
10	NP	number of parameters

The remaining cards in the group may be VALUE or VALUES cards in any combination. The VALUE card specifies the index number and value of one parameter. The VALUE data card format is:

Card Column	Name	Value
1-5	CN	VALUE card name
10	IND	parameter index
11-20	VAL	parameter value

The VALUES card specifies the values of five consecutive parameters in the table. The VALUES data card format is:

Card Column	Name	Value
1-6	CN	VALUES card name
10	IND	parameter index for the first value on the card
11-20	VAL1	parameter value IND

Card Column	Name	Value
21-30	VAL2	parameter value IND+1
31-40	VAL3	parameter value IND+2
41-50	VAL4	parameter value IND+3
51-60	VAL5	parameter value IND+4

Values after the first value on a VALUES card which exceed the specified table size are ignored.

Parameter values may be input in any order. If a parameter is input more than once, the last value specified will be assigned to the parameter. If the parameter index specified on a card is out of range of the specified table, the value or values on the data card will be ignored and an error message written on the output. Parameters that have not been defined will contain a large number (1×10^{75}). All parameter table locations which are referred to by component data cards must be initialized. The card columns indicated for the number of parameters and the parameter index specify the right hand column of a four column integer field, and values [in t]hese fields must be right justified. The data card columns for the [pa]rameter values represent real data fields, and values in these fields should be punched with a decimal point.

4.5 Component Cards

The component cards specify the components that are in the model of the system that the user is analyzing, and for a performance case they also specify the order in which they are connected. The data on these cards specify values directly (e.g., leg numbers, station numbers, options, etc.), or indirectly (e.g., parameter values, tables, etc.). The component data card format, for both performance and sizing components, is:

Card Column	Name	Value
1-6	CN	component card name
8	CC	change code
12	NC	card number
13-80	IC1-IC17	17 four column integer data fields

The available components for a performance case are described in Appendix A. The available components for a sizing case are described in Appendix B. The [com]ponent name must be punched left justified, while the card number and the [se]venteen integer data fields must be punched right justified. Data card fields that refer to the parameter table are indicated in Appendices A and B by brackets around the data symbol. Parameter references that are left blank or punched with a zero will return a parameter value of zero. The change case code and card number are described later in this section.

Extensive error checks are made on the component data cards. The leg and station numbers on a component data card may cause the following error messages:

1) the number of legs or stations defined is less than the number specified,
2) the number of legs or stations defined is more than the number specified,
3) a leg or station number referenced is invalid (i.e., ≤ 0),
4) a leg or station number referenced is undefined,
5) a leg or station number defined has been previously defined.

An error message will be written for an invalid fluid type (i.e., not a liquid, gas or refrigerant). An error message will also be written if a component uses the wrong fluid type (e.g., a refrigerant cannot be specified as flowing through a water separator).

The shaft number on a component data card may cause the following error messages:

1) a shaft number referenced is invalid (i.e., outside the range 1 to 10),
2) a shaft number referenced is undefined,
3) a shaft number defined has been previously defined,
4) a shaft number referenced has been ended.

An error message will be written if a reference to the parameter table is outside the range of the parameter table. An error message will be written if the value returned from the parameter table is undefined (i.e., 1×10^{75}).

Error messages will be written if too many tables are requested, or if a table is requested with an invalid identification. An error message will be written if the number of state variables does not match the number of error variables. A warning message will be written if the component card numbers are not in ascending order, which would prevent a change case from being run.

4.5.1 Performance Component Cards - The component data cards for a performance case are input in a serial order that provides the program with the computational order to determine the system performance. The general rule for component card input is that the upstream conditions of a component be input before the component card is input. For example, in Figure 3, before the heat exchanger component card, HXA, can be input, all components in both the bleed and primary ram lines must be input from the inlet to the heat exchanger. The subroutines called by the HXA component card will then compute the downstream conditions of the component, making these conditions available as the upstream conditions of the next component. Exceptions to this rule are the component cards: INLET, which is used to define any inlet flow line to the system; LØØPS, which is used to start a loop; MISC, which contains several miscellaneous operations; and HXB, which represents a heat exchanger for which both upstreams cannot be defined before the component card (e.g., a regenerative heat exchanger).

The component cards may generate state and error variables. Some component cards will automatically generate state and error variables, while others depend on user options. If the number of state variables generated by the component cards does not match the numbers of error variables generated, an error message will be written. Initial guesses for the state variable values must be greater than zero.

The components INLET, LØØPS, and optionally MISC are also used to define the fluids in the system. The fluids are defined by a relative number and type. Three fluid types are allowed in the program: fluid type 1 - liquid; fluid type 2 - gas; and fluid type 3 - refrigerant. Fluid properties are input in a table according to the fluid type. Appendix D explains the required tables.

All components which allow air flows (fluid type 2) allow for wet air. The component writeups in Appendix A show the temperature correction from a dry air rated temperature to a wet bulb temperature in a functional form. This function is explained in Appendix I.

4.5.2 Sizing Component Cards - Components are sized in the order that the component cards are input. Most components are sized independently. Some components have either an explicit or implicit dependence. An example of explicit dependence is the sizing of a line and valve to the same diameter. This may be handled by input of the LINE component card first to size the line diameter, use the MISC component card next to transfer the line diameter from the line to the valve, and use of a VALVE component card last to size the valve. An example of implicit dependence is the sizing of a compressor and turbine on the same shaft when the shaft speed has not been specified. The program is structured so that the first component input on a shaft, whose speed has not been specified, will determine the shaft speed. All the following components on the same shaft will automatically use the same speed.

Sizing for some components require iteration within the subroutines to determine the size. The state variables and error variables will automatically be set up for these components. State variable initial guesses, upper and lower limits, and the convergence error limit are built into each of these subroutines.

Some of the component cards allow the user to specify the characteristic dimensions of the components. If the user specifies these dimensions, the performance of the sized component may not match the performance passed from a performance case.

Some of the component cards allow generation of performance maps. The component is sized for the specified design point performance, and performance maps generated for a range of flows around the design point. These maps may then be input in a performance case to analyze off design performance of the sized system.

The component cards allow for user specified multipliers which are applied to the component weight, cost units, and development risk factor. If the card column for a multiplier is zero, or if it references a zero parameter table value, the multiplier is ignored. If the multiplier is nonzero, the product of the nonzero multiplier and the value computed by the subroutine is obtained. Provision has also been allowed for the user to specify the reliability index. If the card column for the reliability index is zero, or if it references a zero parameter table value, the built in reliability index for the component is used. If it is nonzero, the value specified by the user is used.

Component card(s) INIT is used to input known component size information. For example, if information about some components in a system are known and some components are to be sized, INIT cards are used to input the known information to obtain total system sizing. An INIT card is needed to input the ECS bleed air extraction rate for system sizing and system penalties.

4.6 Table Cards

The tables required for a case are each identified by a table relative number and a table type. The relative number is generally assigned by the user, while the table type is generally assigned by the computer program according to the usage of the table.

The form of a table is determined by its use. It may be in array form or in functional form. The array form consists of an array of values. The number, meaning, and order of the values are determined by the table usage. This table form generally provides several dependent variable values. The functional form consists of one dependent variable as a function of zero, one, or two independent variables (one, two, or three dimensional tables). The number of dimensions and independent variables selected for a table is entirely up to the user. Before the table can be used, all independent variable values must be computed. Some are computed automatically by the computer program, others must be computed by the user. Unless otherwise specified, all required tables are of the functional form.

The tables required for a case can be input by four methods: automatic table, same table, permanent table, and temporary table. Any table can be input by any method.

The automatic table method loads the required table directly from the permanent table tape. The permanent table tape is explained in Appendix E. The automatic table method is obtained by the user specifying a negative relative number for the required table. No additional data card is necessary. The table loaded from the tape will have the same positive identification as the required table.

The same table method specifies that the required table is to be the same as another required table. Input of this second table by any method will satisfy the input requirement of the first table. The same table method is obtained by input of a STAB data card. The STAB data card format is:

Card Column	Name	Value
1-4	CN	STAB card name
12	NREL	relative number of required table
16	NTYP	type of required table
20	NSR	relative number of the same table
24	NST	type of the same table

The permanent table method specifies that the required table is to be loaded from the permanent table tape. The user specifies which permanent table is to be loaded to satisfy the input of the required table. The permanent table method is obtained by input of atPTAB data card. The PTAB data card format is:

Card Column	Name	Value
1-4	CN	PTAB card name
12	NREL	relative number of required table
16	NTYP	type of required table
20	NPR	relative number of the permanent table
24	NPT	type of the permanent table

The temporary table method inputs the required table directly by cards. The table is input by a set of consecutive cards. The first card must be the table identification card (TABID). This card specifies the table identification, the table form, and other required information describing the table. The TABID data card format is:

Card Column	Name	Value
1-5	CN	TABID card name
12	NREL	relative number of required table
16	NTYP	type of required table
20	NDIM	number of dimensions
24	IST	scale type code
28	NAT1	type of first independent variable
32	NAR1	relative number of first independent variable
36	NEI1	extrapolation/interpolation code of first independent variable
40	NPT1	number of points of first independent variable
44	NAT2	type of second independent variable
48	NAR2	relative number of second independent variable
52	NEI2	extrapolation/interpolation code of second independent variable
56	NPT2	number of points of second independent variable

The second card is the table title card (TABT). The user may input any alphameric characters. The TABT data card format is:

Card Column	Name	Value
1-4	CN	TABT card name
7-80	TT	table title

The TABT card is optional. The remaining cards are the table value cards (TABV). These cards contain the array or functional values of the table. The TABV data card format is:

Card Column	Name	Value
1-4	CN	TABV card name
11-20		
21-30	TV	table values
31-40		
41-50		

The TABID card of an array table must specify NDIM as -1. The number of values in the array is specified in NPT1. The array values are input on TABV cards, four values per card. The number, values, and order must agree with the table usage.

The TABID card of a functional table may specify NDIM as 1, 2, 3 or 33. The remaining data fields and the TABV cards are dependent on the value specified. For a one dimensional table, NDIM = 1, the remaining TABID card fields are ignored. The table value is placed in the first field of TABV card.

For multidimensional tables, NDIM > 1, the user specifies the scale types, linear or log, in IST. The scale type codes are:

Scale Type Code (IST)		Dependent Variable Scale	First Independent Variable Scale	Second Independent Variable Scale
0	1D	linear	linear	linear
1		log	linear	linear
2	2D	linear	log	linear
3		log	log	linear
4	3D	linear	linear	log
5		log	linear	log
6		linear	log	log
7		log	log	log

Log values are base ten. Log scales are input as linear values with log conversion provided by the computer program.

The independent variables of a multidimensional table are specified by the argument type codes, NAT1 and NAT2, and the argument relative numbers NAR1 and NAR2. The argument type codes are:

Argument Type Code (NAT1 and NAT2)	Value
0	general argument
1	leg flow rate
2	station pressure
3	station temperature
4	station humidity/enthalpy

If the argument type is a general argument, the argument relative number specifies which general argument. The general arguments set up by the program are:

General Argument Number	Value	
1	solution iteration number	
2	altitude	performance case
3	Mach number (free stream)	performance case
4	velocity (free stream)	performance case
5	pressure (free stream)	performance case
6	temperature (free stream)	performance case
7	total pressure (free stream)	performance case
8	total temperature (free stream)	performance case
62	engine thrust	sizing penalty analysis
63	bleed air flow rate	sizing penalty analysis
64	shaft horsepower	sizing penalty analysis

Other general arguments are setup by the components as described in Appendices A and B. Other general arguments may be set up by the user through the component MISC. If the argument type is a leg flow rate, the argument relative number specifies the leg number. If the argument type is a station pressure, temperature or humidity/enthalpy, the argument relative number specifies the station number.

The extrapolation/interpolation codes, NEI1 and NEI2, are four digit code words, eeii, specified by the user to control extrapolation and interpolation. The digits ee control extrapolation. If ee has the value 00, the table is allowed to be extrapolated past either end of the independent variable. If ee has the value 01, the table is not allowed to be extrapolated past either end of the independent variable and the value used will be the last value at the extrapolated end. The digits ii specify the interpolation order. Interpolation orders of 00 through 07 can be specified.

The number of points for the independent variables is specified by NPT1 and NPT2. The number of points must always be at least one greater than the interpolation order. If the variable contains discontinuities, this rule must be met on each side of the discontinuity.

The table values for a two dimensional table, y = f(x), are input on TABV cards by (x,y) pairs, each card containing two pairs (x_1, y_1, x_2, y_2). The independent variable values, x, must be in ascending order. If log scales are specified, values must be greater than zero.

Three dimensional tables, y = f(x,z), can be specified by two formats. The first format, NDIM = 3, uses a regular grid. For each value of the second independent variable, z, the same values of the first independent variable, x, must be input. The second format, NDIM = 33, uses an irregular grid. For each value of the second independent variable, z, the user may input different values of the first independent variable, x, the only restriction being that each value of the second independent variable specify the same number of values of the first independent variable.

The table values for a regular grid three dimensional table are input on TABV data cards in the following manner:

1) starting on the first card, all values of the first independent variable in ascending order, four values per card;
2) starting on a new card, all values of the second independent variable in ascending order, four values per card;
3) starting on a new card, all values of the dependent variable in the order of all values for the first independent variable for the first value of the second independent variable, all values for the first independent variable for the second value of the second independent variable, etc., four values per card.

The table values for an irregular grid three dimensional table are input on TABV data cards in the following manner:

1) starting on the first card, all values of the first independent variable in ascending order for the first value of the second independent variable, four values per card;
2) starting on a new card, all values of the first independent variable in ascending order for the second value of the second independent variable, four values per card;
3) repeat step (2) for all remaining values of the second independent variable;

4) starting on a new card, all values of the second independent variable in ascending order, four values per card;

5) starting on a new card, all values of the dependent variable in the order of all values for the first set of the first independent variable for the first value of the second independent variable, all values for the second set of the first independent variable for the second value of the second independent variable, etc., four values per card.

Examples of input for the five tables described are shown in Figures 4 through 8.

During the loading of a table extensive checks are performed to determine its validity. Any errors that are detected are written on the output. These messages consist of:

1) a table that has been input is not required (no additional error checking is performed on this table);
2) a table that has been input has been previously input (no additional error checking is performed on this table);
3) a table has specified an incorrect number of dimensions (no additional error checking is performed on this table);
4) a permanent table requested is missing from the tape;
5) a same table requested is missing;
6) a table has an incorrect scale type;
7) a table has an incorrect argument type;
8) a table has an incorrect argument relative number;
9) a table has an incorrect extrapolation code;
10) a table has an incorrect interpolation code;
11) a table has an incorrect number of points;
12) a table has values that are not in ascending order;
13) a table has too many TABV data cards;
14) a table has too few TABV data cards.

If any errors are detected,an error message is written specifying that the table has been rejected. Additional error messages inform the user that a table is missing or that a fluid property or material property table has an incorrect form and/or number of values.

The card columns for the data fields of the TABID, PTAB, and STAB cards specify the right hand card column of a four column integer field. The data

GENERAL ECS PROGRAM — TEMPORARY TABLE INPUT 1

1		NREL 12	NTYP 16	NDIM 20	IST 24	NAT1 28	NAR1 32	NE11 36	NPT1 40	NAT2 44	NAR2 48	NE12 52	NPT2 56	60	64	68	72	76	80
TABID		2	2	-1					6										

1	7
TABT	SAMPLE ARRAY TABLE

1		11	20 21	30 31	40 41 50
TABV		value 1	value 2	value 3	value 4
		value 5	value 6		

Figure 4 Sample Table Input for NDIM = -1

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	GENERAL ECS PROGRAM	TEMPORARY TABLE INPUT

1		NREL 12	NTYP 16	NDIM 20	IST 24	NAT1 28	NAR1 32	NE11 36	NPT1 40	NAT2 44	NAR2 48	NE12 52	NPT2 56	60	64	68	72	76	80
TABID		?	?	1															

1	7
TABT	SAMPLE ^{b}FUNCTIONAL^b TABLE^b 1D^b Y = CONSTANT

1		11	20 21	30 31	40 41 50
TABV		constant			

Figure 5 Sample Table Input for NDIM = 1

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GENERAL ECS PROGRAM

TEMPORARY TABLE INPUT

1		NREL 12	NTYP 16	NDIM 20	IST 24	NAT1 28	NAR1 32	NE11 36	NPT1 40	NAT2 44	NAR2 48	NE12 52	NPT2 56	60	64	68	72	76	80
TABID		?	?	2	?	?	?	?											

1	7
TABT	SAMPLE bFUNCTIONALb TABLEb 2Db Y = F(X)

1	11 – 20	21 – 30	31 – 40	41 – 50
			X_2	Y (X_2)
TABV	X_1	Y (X_1)	X_4	Y (X_4)
	X_3	Y (X_3)		
	X_5	Y (X_5)		

Figure 6 Sample Table Input for NDIM = 2

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		GENERAL ECS PROGRAM	TEMPORARY TABLE INPUT 1

1		NREL 12	NTYP 16	NDIM 20	IST 24	NAT1 28	NAR1 32	NEI1 36	NPT1 40	NAT2 44	NAR2 48	NEI2 52	NPT2 56	60	64	68	72	76	80
TABID		?	?	3	?	?	?	?	5		?	?	3						

1	7
TABT	SAMPLE ᵇFUNCTIONAL TABLEᵇ 3Dᵇ Y = F(X, Z)

1		11	20 21	30 31	40 41 50
TABV		X_1	X_2	X_3	X_4
		X_5			
		Z_1	Z_2	Z_3	
		$Y(X_1, Z_1)$	$Y(X_2, Z_1)$	$Y(X_3, Z_1)$	$Y(X_4, Z_1)$
		$Y(X_5, Z_1)$	$Y(X_1, Z_2)$	$Y(X_2, Z_2)$	$Y(X_3, Z_2)$
		$Y(X_4, Z_2)$	$Y(X_5, Z_2)$	$Y(X_1, Z_3)$	$Y(X_2, Z_3)$
		$Y(X_3, Z_3)$	$Y(X_4, Z_3)$	$Y(X_5, Z_3)$	

Figure 7 Sample Table Input for NDIM = 3

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	GENERAL ECS PROGRAM	TEMPORARY TABLE INPUT 1

1		NREL 12	NTYP 16	NDIM 20	IST 24	NAT1 28	NAR1 32	NE11 36	NPT1 40	NAT2 44	NAR2 48	NE12 52	NPT2 56	60	64	68	72	76	80
TABID		?	?	33	?	?	?	?	3	?	?	?	2						

1	7
TABT	SAMPLE ^FUNCTIONAL TABLE^ 33D^ Y = F (X, Z)

1		11 — 20	21 — 30	31 — 40	41 — 50
TABV		X_1 for Z_1	X_2 for Z_1	X_3 for Z_1	
		X_1 for Z_2	X_2 for Z_2	X_3 for Z_2	
		Z_1	Z_2		
		$Y (X_1, Z_1)$	$Y (X_2, Z_1)$	$Y (X_3, Z_1)$	$Y (X_1, Z_2)$
		$Y (X_2, Z_2)$	$Y (X_3, Z_2)$		

Figure 8 Sample Table Input for NDIM = 33

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values must be right justified in these fields. The card columns for the data fields of the TABV card specify a real data field. These values should be punched with a decimal point.

The weighing factor table used in the Newton-Raphson iteration has been assigned a relative number 1, and a type 0. This table, although requested by the program, is optional. If the user inputs a table, it will be used. If a table is not input, a weighing factor of 1.0 will be used.

4.7 Case End Card

A case end card is required as the last card in each case. The case end data card format is:

Card Column	Name	Value
1-7	CN	ENDCASE card name

4.8 Comment Cards

Comment cards may be placed anywhere in the data cards for the user's convenience in identifying data. These cards will not appear in the output of the input data. The user can have the data cards listed to obtain the comment card printout. The comment card data format is:

Card Column	Name	Value
1-6	CN	****** card name
7-80	CMNT	comment

4.9 NØGØ Card

A NØGØ card may be used to stop the program from executing a case. This card should immediately follow the ENDCASE card. When the NØGØ card is used, the input data card names are checked (M phase) as described in the preceding sections, but the data card values are not checked (Z phase), and the case solution is not obtained (P phase). This card will usually be used in conjunction with change cases which are described in Section 4.10. The NØGØ card data format is:

Card Column	Name	Value
1-4	CN	NØGØ card name

4.10 Change Case Cards

The program provides for multiple cases to be run in a single job submittal. The performance analysis of an ECS is typically done for several operating conditions within the flight envelope. For this type of use, the basic model would be similar for all cases with only limited changes required for each case. The program change case feature allows the to specify changes to a base case, either performance or sizing, to form a new case. Changes may be additions, deletions, and replacements of cards. A PCHANGE case control card is used to input a change to a performance base case. The PCHANGE data card format is:

Card Column	Value
1-7	PCHANGE card name

A PERFØRM case must be input before a PCHANGE case can be input. A SCHANGE case control card is used to input a change to a sizing base case. The SCHANGE data card format is:

Card Column	Value
1-7	SCHANGE card name

A SIZE case must be input before a SCHANGE case can be input. A change case is ended by a case end card. Card changes to a base case have the same format as the cards in a base case, and must be input in the same group order as a base case. Note that changes are made by whole cards (i.e., a value on a base card cannot be changed without repunching the other values from the base card to the change card). All change cards will be printed on the first page of output for the change case.

If any title cards are input in the change case, all of the title cards in the base case will be replaced. If no title cards are input in the change case, all of the title cards of the base case will be included in the change case.

The case specification cards may be replaced in a change case on a one for one basis. Any case specification card input in the change case data will replace the corresponding case specification card of the base case. Any change case specification cards must be in the order: CASEA, CASEB, CASEC, CASED.

Parameter table changes are combined in a different manner. If a PARAM card is input in the change data, it will replace the PARAM card of the base case. VALUE and VALUES cards in the change data are added to the end of the base parameter table cards. Since these cards will be read last, they will override any values in the base case. Note that table values from both the base case and the change data are stored in the table, requiring the parameter table size specified on the PARAM card be large enough to hold all values.

The component data cards in the change data are merged with the base component data cards using the change code and card number fields of the component data cards. Card numbers of the base cards must be in ascending order, except for cards with card number zero. Cards with number zero may not be referred to in a change case. Change cards must be input in the order in which they are to be merged with the base cards. The change codes are R, A, D, and X.

The R change code specifies a card replacement. The input change card replaces the base card of the same card number. The card number cannot be zero.

The A change code specifies a card addition. The input change card is added after the base card of the same number. If the change card specifies card number zero, the change card is added after the previous change card operation has been performed. If the first change card input is an A card and specifies card number zero, it will be the first card in the merged set.

The D change code specifies a card deletion. The base card having the same card number is deleted. The card number cannot be zero. The component name on the change card is immaterial, except that it be a valid component name. The component name may also be specified as CMPNNT.

The X change code specifies multiple card deletion. The change card number specifies a card number in the base cards which is to be deleted and all cards following it. The component name on the change card is immaterial, except as noted under the D change code. If the change card specifies card number zero, the remaining cards in the base are deleted after the previous change card operation has been performed. If the first change card input is a X card and specifies card number zero, all base cards will be deleted.

If any component card changes specify an invalid operation or card number, an error message will be printed specifying an invalid change, and the card will be rejected.

Table cards (TABID, TABT, TABV, PTAB, and STAB) are changed by merging the change table cards before the base table cards. When the table cards are read, the changed table will be read first and stored. When the base tables are read, the corresponding tables input by the changes are bypassed.

If a temporary table is to be changed, the entire table must be changed (i.e., the TABID card, the TABT card (optional), and all TABV cards). The cards for a table must be in the correct order for a temporary table.

Any number of change cases may be run in a job. A PCHANGE case always changes the last PERFØRM case, and a SCHANGE case always changes the last SIZE case. Error messages will be written and further processing of the case deleted, if a PCHANGE case has not been preceded by a PERFØRM case or a SCHANGE case has not been preceded by a SIZE case. Any type of sizing case must have been preceded by a performance case, PERFØRM, PCHANGE, QCHANGE, or PDUMMY (see Section 4.11). A sizing case will always use the results of the last performance case.

There is an additional type of change case available for performance cases called quick change. This option changes the last case (performance) run and restricts the changes to a limited number of values. The QCHANGE case will not run if there are errors in the previous case. This type of change cannot be used immediately after a NØGØ case. The quick change feature does not use the M and Z phase processing, but directly changes data in the P phase. The change values are preceded by the QCHANGE case control card. The changes are ended by a case end card. The QCHANGE card data format is:

Card Column	Value
1-7	QCHANGE card name

The changes allowed and their data card formats are:

	Card Column	Name	Value
Card Type 1	1-3	CN	ALT card name
	11-20	A	altitude value, ft.
Card Type 2	1-3	CN	VØM card name
	11-20	VM	velocity, ft/sec, or Mach number value (must agree with IVM on last performance CASEB card input)
Card Type 3	1-3	CN	PAM card name.
	11-20	P	ambient pressure value, psia
Card Type 4	1-3	CN	TAM card name
	11-20	T	ambient temperature value, ^{o}R
Card Type 5	1-3	CN	PTV card name
	7-10	IND	parameter index
	11-20	PV	parameter value

All cards are optional, and may be input in any order. If more than one card changes the same value, the last value read will be used.

4.11 Dummy Performance Case Cards

The sizing section of the program is dependent on performance results. These performance values may be provided from the last performance analysis run by the program, either a PERFØRM, PCHANGE, or QCHANGE case. If the user does not desire to do a performance analysis, but wishes to directly input performance results, a dummy performance case may be input. A dummy performance case is specified by a PDUMMY case control card. The PDUMMY data card format is:

Card Column	Value
1-6	PDUMMY card name

The dummy performance data is ended by a case end card.

Five data card types are allowed in a dummy performance case. Before any leg defining cards are input the NLEG card must be input specifying the number of legs in the system. The NLEG data card format is:

Card Column	Name	Value
1-4	CN	NLEG card name
7-10	NLEG	number of legs (right justified)

Before any station defining cards are input the NSTA card must be input specifying the number of stations in the system. The NSTA data card format is:

Card Column	Name	Value
1-4	CN	NSTA card name
7-10	NSTA	number of stations (right justified)

The LEG cards define the fluid in a leg and the flow rate. The LEG data card format is:

Card Column	Name	Value
1-3	CN	LEG card name
7-10	ILEG	leg number (right justified)
11-15	IFT	fluid type (right justified)
16-20	IRN	fluid property table relative number (right justified)
21-30	W	flow rate

The STA cards define the fluid station pressure, temperature, and humidity or enthalpy. The STA data card format is:

Card Column	Name	Value
1-3	CN	STA card name
7-10	ISTA	station number (right justified)
11-20	P	pressure
21-30	T	temperature
31-40	H	humidity or enthalpy

The GENARG cards define the general arguments required for sizing, e.g. freestream pressure. The GENARG data card format is:

Card Column	Name	Value
1-6	CN	GENARG card name
7-10	NGA	general argument number (right justified)
11-20	VAL	general argument value

Except as noted under the NLEG and NSTA data cards, the data cards may be input in any order. A LEG card may be input with leg number zero to specify the free stream fluid. The flow rate on this card is ignored.

4.12 Job End Card

The last data card in a job submittal is the ENDJØB card. This card ...rms the program that the last case has been read. The ENDJØB data card ...rmat is:

Card Column	Name	Value
1-6	CN	ENDJØB card name

SECTION 5

PROGRAM OUTPUT

The output for a performance or sizing analysis may be split into three types: 1) output of the input data; 2) output of results; and 3) output of error and warning messages. Most of the output of the input data is optional as specified by the user in the IDPC data field on the CASEA data card. Output of the results contains sections which are always output, and sections which are at the user's option. Error messages are output specifying incorrect data or conditions. Warning messages are output specifying data or conditions that may be wrong, leaving final decision to the user. Additional output is available from the iteration dump option as explained in Appendix F.

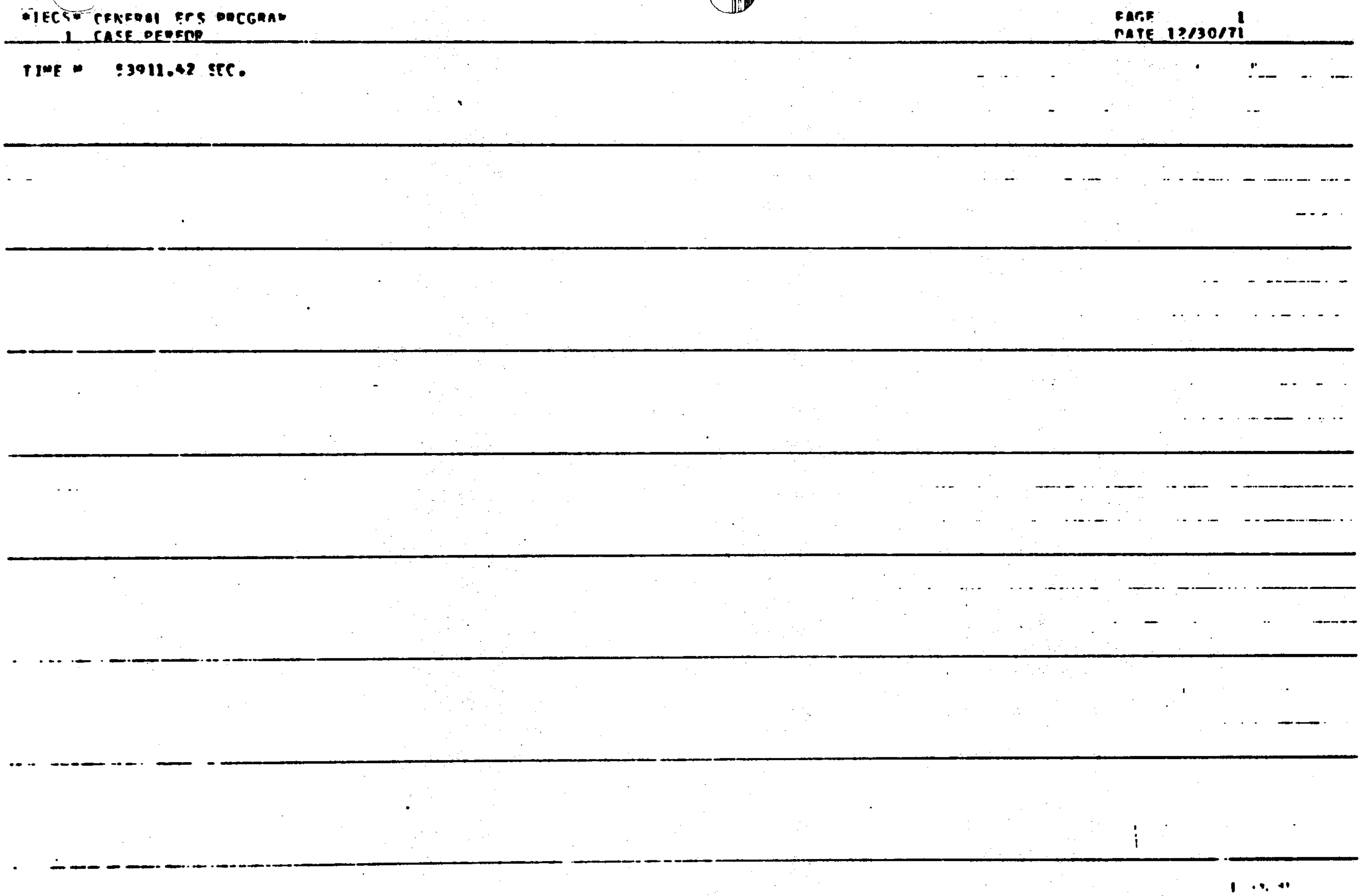
A sample of the output of the input data is given in Figure 9. The output shown is for a PERFØRM case. Page 1 of the output gives the computer time at the start of the M phase. Error messages would have appeared on this page if any data cards were missing, out of order, or contained invalid card names.

Page 2 of the output gives the computer time at the start of the Z phase. Also output on this page are the TITLE cards. Note that the first TITLE card has replaced the page header title.

Page 3 of the output gives the case specification data from the CASEA, CASEB, CASEC, and CASED data cards. The first line of output gives the case name, the number of legs, and the number of stations in the user's model. This line is always output for a performance case. Note that the case name has also been placed in the page header. The remaining lines of output on this page are optional. For a sizing case the first line of output will give the case name, the system summation option, and the system penalty option. The remaining data printout is optional.

Page 4 of the output gives the parameter table. The output of the values is optional. Note that parameter value number 30 is undefined.

Page 5 of the output gives the component cards, indicating the card columns. The output of the cards is optional. For a performance case the right hand side of the page will always give the state and error variable assignment. The printout of the assigned state and error variables, and any error messages for a data card, follow the printout of the component card. The state and error variable numbers shown are assigned sequentially and the type for each is printed.



IECS GENERAL ECS PROGRAM PAGE 1
1 CASE PERFOR DATE 12/30/71
TIME = 53911.42 SEC.

Figure 9 Sample Output of the Input Data

```
*IFCS* MINIGM LEVEL PERFORMANCE                                      PAGE       2
    1  CASE PERIOR                                                   DATE  12/30/71
TIME Z   53917.CS

      MACH 2.5
      ALT 60K
```

Figure 9   Sample Output of the Imput Data (Sheet 2)

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```
ATTCS? ROUGH LEVEL PERFORMANCE                                          PAGE        3
    1  CASE        1                                                    DATE 12/30/71

          CASE          1              12 LEG(S)          23 STATION(S)

ATM P       1.05

ATM T TABLE       -1

ATM FREQ TABLE       -1

ALTITUDE      60000.

MACH NUMBER   2.50

WATER FREQ TABLE       -2
```

Figure 9   Sample Output of the Input Data (Sheet 3)

```
PIPES* ROUGH LEVEL PERFORMANCE
    1  CASE      1                                                                                      PAGE        4
                                                                                                        DATE 12/30/71
 PARAMETER TABLE          20 VALUE(S)

(   1) 7.81000E 01 (   2) 1.80000E 02 (   3) 1.52700E 03 (   4) 0.0          (   5) 2.00000E 02 (   6) 1.79000E 01
(   7) 8.80000E 02 (   8) 4.00000E-01 (   9) 1.80000E 00 (  10) 9.80000E-01 (  11) 1.05000E 00 (  12) 1.00000E 00
(  13) 5.70000E 02 (  14) 1.03000E 03 (  15) 6.00000E 00 (  16) 0.0          (  17) 0.0          (  18) 1.50000E 01
(  19) 1.20000E 01 (  20) 4.77000E 00 (  21) 1.00000E-07 (  22) 9.99999E-07 (  23) 0.0          (  24) 0.0
(  25) 0.0         (  26) 3.20000E 01 (  27) 5.55999E-07 (  28) 3.00000E-04 (  29) 1.26000E 03 (  30) 1.00000E 75
```

Figure 9   Sample Output of the Input Data (Sheet 4)

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STEPS WHIGH LEVEL PERFORMANCE
1 CASE 1

PAGE 5
DATE 12/30/71

COMPONENT(S)

1 6 8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	
INLET2	10	1	2	100	1	12	3	4	2	-1	0	0	0	0	0	0	0	0	SV N 1 T 2
INLET1	20	13	26	1000	5	6	7	4	2	-1	0	0	0	0	0	0	0	0	SV N 2 T 1
ORIF	30	13	26	28	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
ORIF	40	13	28	30	0	2	0	0	0	0	0	0	0	0	0	0	0	0	
HEX	50	1	2	4	12	20	32	3	3	4	1	0	0	0	0	0	0	0	
SPLIT1	60	13	22	19	34	13	38	1	8	0	0	0	0	0	0	0	0	0	SV N 3 T 5
SHAFT	70	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
COMP	80	15	34	46	1	0	5	3	10	0	0	0	0	0	0	0	0	0	
ORIF	85	18	46	36	0	10	0	0	0	0	0	0	0	0	0	0	0	0	
MERGE	90	15	20	17	38	15	40	0	0	0	0	0	0	0	0	0	0	0	
SENSOR	91	3	40	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	EV N 1 T 3
CVALVE	95	19	40	42	0	21	28	0	0	0	0	0	0	0	0	0	0	0	SV N 4 T 6
SENSOR	96	2	42	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	EV N 2 T 2
SPLIT	110	1	4	3	6	9	14	0	12	0	0	0	0	0	0	0	0	0	
BOILER	120	3	6	8	1	5	13	2	14	0	0	0	0	0	0	0	0	0	
TURB	130	3	6	10	1	6	15	1	10	0	0	0	0	0	0	0	0	0	
SPOWER	140	1	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	EV N 3 T 5
LINE	150	2	10	12	0	0	6	0	0	0	0	0	0	0	0	0	0	0	
VALVE	160	5	14	16	0	0	7	0	0	0	0	0	0	0	0	0	0	0	
MERGE	170	2	12	5	16	1	18	0	0	0	0	0	0	0	0	0	0	0	
SPLIT	180	7	18	9	20	11	22	0	17	0	0	0	0	0	0	0	0	0	
WSEP	200	11	22	23	24	21	44	1	8	2	0	0	0	0	0	0	0	0	
SENSOR	210	2	24	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	EV N 4 T 2

STATE/ERROR VARIABLE(S) 4

Figure 9 Sample Output of the Imput Data (Sheet 5)

15 20
17 28 1540

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```
*IECS* ROUGH LEVEL PERFORMANCE                                                    PAGE        6
     1  CASE         1                                                            DATE  12/30/71
TABLES              10 REQUIRED
PERMANENT TABLE      1     10
PERMANENT TABLE      1     1*
PERMANENT TABLE      2     10
TABLE        1     0
        TITLE/WEIGHING FACTOR
        NDIM     2       IST      0
        ARGUMENT 1       TYPE     0     RELN     1       EXTRAP     0      INTERP     0      NPTS     6
                  1.00000E 00    5.00000E-02    7.00000E 00    1.00000E-01
                  3.00000E 00    2.00000E-01    4.00000E 00    5.00000E-01
                  6.00000E 00    7.00000E-01    8.00000E 00    9.50000E-01
TABLE        6     1
        TITLE/LINE - 3.10-12  -  PRESSURE DROP
        NDIM     2       IST      0
        ARGUMENT 1       TYPE     2     RELN     10      EXTRAP     0      INTERP     1      NPTS     2
                  1.00000E 00    9.00000E-03    1.00000E 02    4.00000E-01
TABLE        7     1
        TITLE/PRESSURE DROP - VALVE - 5.14-16
        NDIM     2       IST      0
        ARGUMENT 1       TYPE     2     RELN     14      EXTRAP     0      INTERP     1      NPTS     2
                  1.00000E 00    1.00000E 00    1.00000E 02    1.00000E 02
TABLE        8     1
        TITLE/SOP - WSEP
        NDIM     1
        VALUE =  8.25000E-01
TABLE        3     1
        TITLE/SCP - FX ELEC
        NDIM     2       IST      0
        ARGUMENT 1       TYPE     2     RELN     2       EXTRAP     0      INTERP     1      NPTS     2
                  1.00000E 01    5.00000E-01    1.00000E 02    5.00000E 00
TABLE        4     1
        TITLE/SOP - FX RAM
```

Figure 9   Sample Output of the Input Data (Sheet 6)

```
*TFCS* RANGE LEVEL PERFORMANCE                                                         PAGE        7
     1  CASE          1                                                                DATE 12/30/71

     NDIM      2      1ST      C
     ARGUMENT  1      TYPE     2      RELN    3C     EXTRAP     0     INTERP     1     NPTS     2
                1.0000CE 01    5.0CCCCE-C1    1.CCCCOE 02    5.00000E 00

 TABLE        5        1
     TITLE/SDP - BOILER

     NDIM      2      1ST      C
     ARGUMENT  1      TYPE     2      RELN    C      EXTRAP     0     INTERP     1     NPTS     2
                1.C0CCCE 01    5.4CCCCE-C1    1.CCCCOE 02    5.400COE 00

 TABLE        1        4
     TITLE/ORIF1 - PR

     NDIM      1
     VALUE =   3.450CCE-C1

 TABLE        2        4
     TITLE/ORIF2 - PR

     NDIM      1
     VALUE =   9.690CCE-C1

 TABLE LISTED BELOW IS NOT REQUIRED
     *TABID        4    4    C    C    C    C    C    C    C    0    0    0    0    0    0    0    0    0*
     *TAPT   NOZZLE PR                                                                                 *
     *TABV         .22                                                                                 *

 TABLE        1        5
     TITLE/HX EFFECTIVENESS

     NDIM      1
     VALUE =   8.000CCE-C1

 TABLE        2        5
     TITLE/BOILER EFFICIENCY

     NDIM      1
     VALUE =   9.5000CE-01

 TABLE        3        6
     TITLE/CCMP EFFICIENCY

     NDIM      1
```

Figure 9   Sample Output of the Input Data (Sheet 7)

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```
*TECS* RINIGH LEVEL PERFORMANCE
   1  CASE        1                                                          PAGE        8
                                                                             DATE 12/30/71
     VALUE =  6.40000E-01

TABLE       1     7
     TITLE/TURBINE EFFICIENCY

     NDIM       1
     VALUE =  7.80000E-01

TABLE LISTED BELOW IS NOT REQUIRED
     *TABID        1  17   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0*
     *TABT  NOZZLE ADIABATIC EFFICIENCY
     *TABV        1.

TABLE       2     17
     TITLE/WSEP - EFFICIENCY

     NDIM       1
     VALUE =  8.60000E-01

TABLE       10     4
     TITLE/ORIF PP - COPP LINE

     NDIM       1
     VALUE =  5.55500E-01

TABLE LISTED BELOW IS NOT REQUIRED
     *TABID        1   9   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0*
     *TABT  NOZZLE CC
     *TABV        .8
```

Figure 9   Sample Output of the Input Data (Sheet 8)

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Pages 6, 7 and 8 of the output give the table data. This output is optional. Shown in the output are requests for three permanent tables. Three tables have been input to this case that are not required.

5.1 Performance Case Output

The results of a performance case are output in three parts: 1) the initial conditions and results; 2) the component performance; and 3) the system performance. The initial conditions and results are always output if the case has state and error variables. The component performance output is optional as specified by the ICPP data field on the CASEA data card. The system performance is always output.

The initial conditions and results (PASS 1) are output on the first page of results following the P phase computer time printout. The output gives the state and error variable types, the initial values of the state variables, the resulting values of the error variables, the flow rate in every leg, and the pressure, temperature and humidity/enthalpy of every station. This output shows how good were the user's initial guess for the state variables.

A sample of the component performance output is given in Figure 10. [illegible]s sample is a section of the output from the case shown in Figure 9. Note that every component does not have printout. The printout generally gives the component name, leg and station numbers, fluid type and relative number, flow rate, and pressure, temperature and humidity/enthalpy for component inlets and outlets. Depending on the component, additional performance parameters may be given (e.g. the heat exchanger shown, HXA, gives the temperature effectivenesses of side 1 and side 2). Note the warning message specifying that this heat exchanger extrapolated the table with relative number 4 and type 1. This is a pressure drop table and was input as a two dimensional table. The argument gives the value of flow rate, and the value returned from the table lookup is given. Whether this extrapolation and result is valid is left to the user.

The system performance is given in Figure 11. This sample is also for the input shown in Figure 9. The output gives the solution ending time, TIME E, and the system performance: the flow rate in every leg; and the pressure, temperature, and humidity/enthalpy of every station. Also given are the state [illegible] error variable types, the final set of state variable values, and the final [illegible] of error variable values. This solution converged in 9 iterations, and no errors were detected either in the input data or the solution.

```
*IFCS* RHIGH LEVEL PERFORMANCE
  1  CASE       1                                                                      PAGE        10
                                                                                       DATE  12/30/71
 CCMPONENT MKA    EXTRAPOLATED TABLE      4     1 VALUE =  2.49203E-01 ARGUMENT(S)  5.98406E 00
 COMPONENT MKA 1
     NL        1   NSI      2   NSO      4   FI       2   FN      -1
     W     78.10   PI   75.86   PO   78.07   TI 1527.00   TO 1009.47   HI  0.0    HO  0.0
     NL       13   NSI     20   NSO     22   FI       2   FN      -1
     W    148.15   PI    5.56   PO    4.53   TI  880.00   TO 1173.26   HI  0.0    HO  0.0
     EF1 0.8000   EF2 0.4533
 COMPONENT COMP
     NL       15   NSI     24   NSO     46   FI       2   FN      -1
     W     39.59   PI    4.53   PO    8.15   TI 1173.26   TO 1489.06   HI  0.0    HO  0.0
     SHAFT     1   PR  1.8000   EFF 0.6400   HP  -77.76
 COMPONENT ORIF
     NL       15   NSI     46   NSO     26   FI       2   FN      -1
     W     39.59   PI    8.15   PO    4.53   TI 1489.06   TO 1489.06   HI  0.0    HO  0.0
     PR  0.5555
 COMPONENT CVALVE
     NL       19   NSI     40   NSO     42   FI       2   FN      -1
     W    148.15   PI    4.53   PO    1.05   TI 1260.00   TO 1260.00   HI  0.0    HO  0.0
     K   1.585642E-04
 COMPONENT BOILER
     NL        3   NSI      6   NSO      8   FI       2   FN      -1
     W     78.10   PI   78.07   PO   78.04   TI 1009.40   TO  591.97   HI  0.0    HO  0.0
     TB  570.00   EFF 0.5500   Q -8121.16   WS   -7.89
 COMPONENT TURB
```

Figure 10 Sample Output of Component Performance

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```
*TECS* HIGH LEVEL PERFORMANCE                                            PAGE      12
    1 CASE        1                                                      DATE 12/30/71

TIME E  53917.57

FLOW RATE(S)

(  1)   78.10 (  3)   78.10 (  5)    C.C  (  7)   78.10 (  9)    0.0  ( 11)   78.10
( 13)  148.15 ( 15)   25.59 ( 17)  1CE.56 ( 19)  148.15 ( 21)    C.3  ( 23)   78.10

PRESSURE(S)

(  2)   79.86 (  4)   78.C7 (  6)   78.C7 (  8)   76.84 ( 10)   12.81 ( 12)   12.76
( 15)   78.07 ( 16)    C.CC ( 18)   12.76 ( 20)   12.76 ( 22)   12.76 ( 24)   12.00
( 26)   17.90 ( 28)    6.18 ( 30)    5.58 ( 32)    4.51 ( 34)    4.51 ( 36)    4.53
( 38)    4.53 ( 40)    4.52 ( 42)    1.C5 ( 44)   12.00 ( 46)    8.15

TEMPERATURE(S)

(  2) 1527.00 (  4) 1CCS.4C (  6) 1CCS.4C (  8)  591.97 ( 10)  412.19 ( 12)  412.19
( 14) 1009.40 ( 16) 1CCS.40 ( 18)  412.19 ( 20)  412.19 ( 22)  412.19 ( 24)  412.19
( 26)  880.00 ( 28)  8CC.CO ( 30)  8CC.CC ( 32) 1173.26 ( 34) 1173.26 ( 36) 1489.06
( 38) 1173.26 ( 40) 12CC.CO ( 42) 12CC.CC ( 44)  412.19 ( 46) 1489.06

HUMIDITY(S)/ENTHALPY(S)

(  2) 0.0     (  4) C.0     (  6) C.C     (  8) 0.0     ( 13) 0.0     ( 12) 0.0
( 14) 0.0     ( 16) C.0     ( 18) C.C     ( 20) 0.0     ( 22) 0.0     ( 24) 0.0
( 26) 0.0     ( 28) C.C     ( 30) 0.C     ( 32) 0.0     ( 34) 0.0     ( 36) 0.0
( 38) 0.0     ( 40) C.C     ( 42) C.C     ( 44) 1.0000  ( 46) 0.0

STATE VARIABLE TYPE(S)
(  1)   2 (  2)   1 (  3)   5 (  4)   6

STATE VARIABLE(S)
(  1) 7.98622E 01 (  2) 1.4E15CE C2 (  3) 2.67218E-01 (  4) 1.58564E-04

ERROR VARIABLE TYPE(S)
(  1)   3 (  2)   2 (  3)   5 (  4)   2

ERROR VARIABLE(S)
(  1)-7.32422E-04 (  2)-5.23567E-04 (  3)-2.74658E-03 (  4) 5.20842E-04

SOLUTION CONVERGED IN     5 TRY(S)

     0 ERROR(S) DETECTED

CASE END
```

Figure 11 Sample Output of System Performance

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5.2 Sizing Case Output

The results of a sizing case are output in three parts: 1) the component size; 2) the system size; and 3) the system penalties. Additionally, some component cards allow the option to print and/or punch component performance maps. The component size output is always given. The system size output is optional as specified by the ISSP data field on the CASEA data card. The system penalties output is optional as specified by the ISPP data field on the CASEA data card.

A sample of the output of the component size is given in Figure 12. The printout generally gives the component name, weight, cost units, reliability index, development risk factor, and the performance conditions used to size the component (i.e., flow rate, pressure, temperature, humidity/enthalpy, and fluid type and relative number). Depending on the component, additional sizing parameters may be given (e.g., the heat exchanger shown, HX, gives the core dimensions, the core volume, the core weight, the heat transfer effectiveness, and number of transfer units).

A sample of the output of the system size and penalties is given in Figure 13. Following the solution end time, TIME E, the system sizing output consists of system weight (wet), cost units, reliability index, development risk factor, weight standard error, shaft power required, hydraulic power required, electric power required, equivalent shaft power extraction from the engine, ECS bleed air extraction from the engine (from component INIT), ECS fuel consumption, and momentum drag.

The system penalty output consists of relative gross takeoff weight penalty, relative payload penalty, relative range penalty, and relative equivalent drag penalty. These are calculated by the following equations:

Relative Gross Takeoff Weight Penalty:

$$\frac{\Delta Wt_{gr}}{Wt_{gr}} = \left(\frac{1}{1 - X_r}\right) \left(\frac{Wt_{ECS}}{Wt_{gr}}\right) + \left(\frac{D_{ECS}}{D_r}\right) \left[\ln \left(\frac{1}{1 - X_r}\right)\right] \tag{5}$$

where:

Wt_{gr} = aircraft gross takeoff weight without ECS

$X_r = \frac{Wt_{fuel}}{Wt_{gr}}$

Wt_{ECS} = installed ECS wet weight + power drive installation weight

```
 ...       DETAILED SIZING CASE
   2 CASE                                                                                   PAGE      12
                                                                                            DATE 11/23/71

COMPONENT COMP

      WEIGHT     7.41      COST UNITS    42.57 ,   RELIABILITY INDEX 0.06759     DEVELOPMENT RISK  1.CC
      W     63.70    FI    36.35   FC    7C.25   TI  636.62   TO  785.30   FI  0.0186   HO  0.0186   FT        2   FN        1
      ?      4.42   VCL    256.    A   57552.    EFF 0.7769   HP   -72.4F   U    1117.   NS   52.09   DS    1.55
      DRIVE    C
COMPONENT TURB   EXTRAPOLATED TABLE       1    17 VALUE =  1.47584E 00 ARGUMENT(S)  8.444CCE 01 8.C3288E-01
COMPONENT TURB

      WEIGHT     6.5C      COST UNITS    14.78       RELIABILITY INDEX C.C           DEVELOPMENT RISK  1.CC
      W     83.06    FI    65.5E   PC    18.CC   TI  869.77   TO  5C5.87   FI  0.0186   HO  C.0186   FT        2   FN        1
      J      4.CC   VCL    413.    A   57552.    EFF C.9033   HP    72.8C   L    1262.   NS   84.44   DS    1.5C
COMPONENT APL

      WEIGHT   212.61      COST UNITS   421.13       RELIABILITY INDEX C.24571     DEVELOPMENT RISK  1.15
      W     50.42    FI    14.7C   PO    45.66   TI  563.00   TO  890.00   FI  0.0186   HO  C.0186   FT        2   FN        1
      VCL  22323.   WTHT 2C5.7    SPHTIES.16    FC     163.
COMPONENT HX

      WEIGHT    25.2C      COST UNITS    52.55       RELIABILITY INDEX C.C1573     DEVELOPMENT RISK  1.CC
      W     63.CP    FI    4C.53   PC    38.7C   TI  671.00   TO  632.62   FI  C.0186   HO  C.0186   FT        2   FN        1
      W    234.54    FI    17.61   FC    17.1P   TI  554.54   TO  6PC.62   FI  C.C186   HO  C.0186   FT        2   FA        1
      LP    12.1C    LC     7.45   LN    15.5C   VCL   1411.   NTC    16.4   EFF 0.8622   NTU  3.C65
```

Figure 12 Sample Output of Component Sizing

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```
*IFCS* MAJOR COMPONENT SIZING                                                                          PAGE      12
    2  CASE  ECSSIZE                                                                                   DATE 12/22/71
 TIME E   49230.39

 ********
 *SYSTEM*
 ********

      WEIGHT     245.     COST UNITS   1223.     RELIABILITY INDEX  2.2638     DEVELOPMENT RISK  1.00

      WEIGHT STANDARD ERROR      5.9

      SHAFT POWER      0.0     HYDRAULIC POWER    44.9     ELECTRICAL POWER     9.0

      EQUIVALENT SHAFT POWER      50.

      BLEED AIR EXTRACTION       3.     FUEL CONSUMPTION       0.      DRAG       2.


 ***********
 *PENALTIES*
 ***********

      RELATIVE GROSS TAKEOFF WEIGHT PENALTY       1.86 PERCENT

      RELATIVE PAYLOAD PENALTY                    0.15 PERCENT

      RELATIVE RANGE PENALTY                      2.30 PERCENT

      RELATIVE EQUIVALENT DRAG PENALTY            1.58 PERCENT

      0 ERROR(S) EFFECTED

 CASE END
```

Figure 13 Sample Output of System Sizing and Penalties

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D_{ECS} = ECS momentum drag + $\dfrac{(SFC_{ECS} - SFC_r)\ (THR)}{SFC_r}$

SFC_{ECS} = engine(s) specific fuel consumption (lb fuel/hr-lb thrust) due to bleed air and/or shaft power extraction for ECS (the ECS bleed air extraction rate is obtained from component INIT)

SFC_r = engine(s) specific fuel consumption (lb fuel/hr-lb thrust) without ECS

D_r = aircraft flight drag without ECS

THR = engine thrust

Relative Payload Penalty:

$$\frac{\Delta Wt_{pl}}{Wt_{pl}} = \frac{(1 - X_r)\ [\ln (\frac{1}{1 - X_r})]\ (\frac{D_{ECS}}{D_r}) + (\frac{Wt_{ECS}}{Wt_{gr}})}{(1 - X_r) - (\frac{Wt_{emp}}{Wt_{gr}})} \quad (6)$$

where:

Wt_{emp} = aircraft empty weight without ECS

Relative Range Penalty:

$$\frac{\Delta R}{R} = 1 - \left[\frac{(SFC_r)\ (D_r)}{(SFC_{ECS} + FC/THR)\ D + 60\ Wt_{ex}/TIME}\right] \left[\frac{\ln (\frac{1}{1 - X})}{\ln (\frac{1}{1 - X_r})}\right] \quad (7)$$

where:

Wt_{ex} = expendable coolant weight

$X = \dfrac{Wt_{fuel} + Wt_{ex}}{Wt_{gr} + Wt_{ECS}}$

FC = ECS fuel consumption (lb/hr)

D = D_r + ECS momentum drag

TIME = flight time

Relative Equivalent Drag Penalty:

$$\frac{D_{eq}}{D_r} = \frac{D_{ECS} + Wt_{ECS}/LDR_r}{D_r} \quad (8)$$

where:

LDR_r = aircraft lift to drag ratio

SECTION 6
PROGRAM USAGE

Section 4 specified the basic input required by the program to analyze a system. The form of the input and the available component cards have been explained. Additional information is required to use the program to obtain the solution of a system. The components and solution of a performance analysis are almost at the complete control of the user, whereas the components of a sizing analysis have a specific use and the solution is almost completely controlled by the program.

The performance component cards have generally been named to match a physical component. Although the component cards may be used to represent these components, they may also be used to represent other physical components. The performance components cards represent mathematical components, which may be used to represent any physical component for which the equations apply. Some examples follow.

The card CVALVE generally represents a control valve, although it may be used to size an orifice. The pressure loss coefficient determined by CVALVE may be interpreted as an effective orifice pressure loss, and an orifice size can be computed by the user to give this pressure loss.

The card SPLIT generally represents a dividing of one flow line into two flow lines. It may be used as a flow diverter valve. It may also be used to represent leakage from a component.

The card ØRIF may be used to simulate a ram air inlet. The card NØZZLE may be used to simulate a ram air exit. It may also be used with a SPLIT card to represent leakage.

The card SENSØR represents a physical sensor. It may be used to define a condition in the system where no such physical sensor exists. Although a sensor in a physical system is connected to a control valve through a controller, a SENSØR card in the user's model need have no relationship to a CVALVE.

The card INIT is used to input known size information about one or more components. The information from the INIT card(s) is appropriately combined with information from components which are sized. The INIT card is needed to input the ECS bleed air extraction rate for system sizing and system penalty analyses.

Other variations of component card usage may be developed by the user. The most powerful subroutine in the program is called by the MISC performance component card. This allows for data, state variable, and error variable manipulation. Although the user may commonly use it to store parameter values or to set up general arguments for use by tables, the full usage must be developed as techniques by the user.

The weighing factor in the Newton-Raphson iteration method is optional. If the user does not input a table for the weighing factor, the program will use a unity factor. However, use of a weighing factor is recommended. The weighing factor should start at a small value at the first iteration (e.g., 0.05) and rise to a unity value as the iterations proceed. Analysis of an air cycle on a rough data level should allow a rapidly rising weighing factor. Analysis of a vapor cycle will require a slowly rising weighing factor. Two weighing factor tables are available on the permanent table tape. The sizing of a component may also require a weighing factor.

If a weighing factor has been used, and a performance analysis is non-convergent, the solution may converge if different initial guesses for the state variables are provided. The nonconvergent problem will output the values of the state variables and the error variables. Using these error variables, a better estimate of the state variables can be determined.

The two common causes of nonconvergence are data errors and specification of a condition that the system could not physically obtain. If the problem cannot be determined by inspecting the data or results, another technique is to reduce the number of degrees of freedom (i.e., the number of state variables). Since the performance of most components is dependent on flow rate, the fixing of all inlet flow rates and their associated split ratios may be useful in determining the cause of nonconvergence.

It is recommended that a user start analyzing a complex system at a rough level (i.e., leaving out minor flow lines, neglecting small pressure drops, using constant values in place of refined maps, etc.) and build up to a refined analysis. This will help to discover data error or impossible conditions, and to acquaint the user with the operation of the particular system he is analyzing.

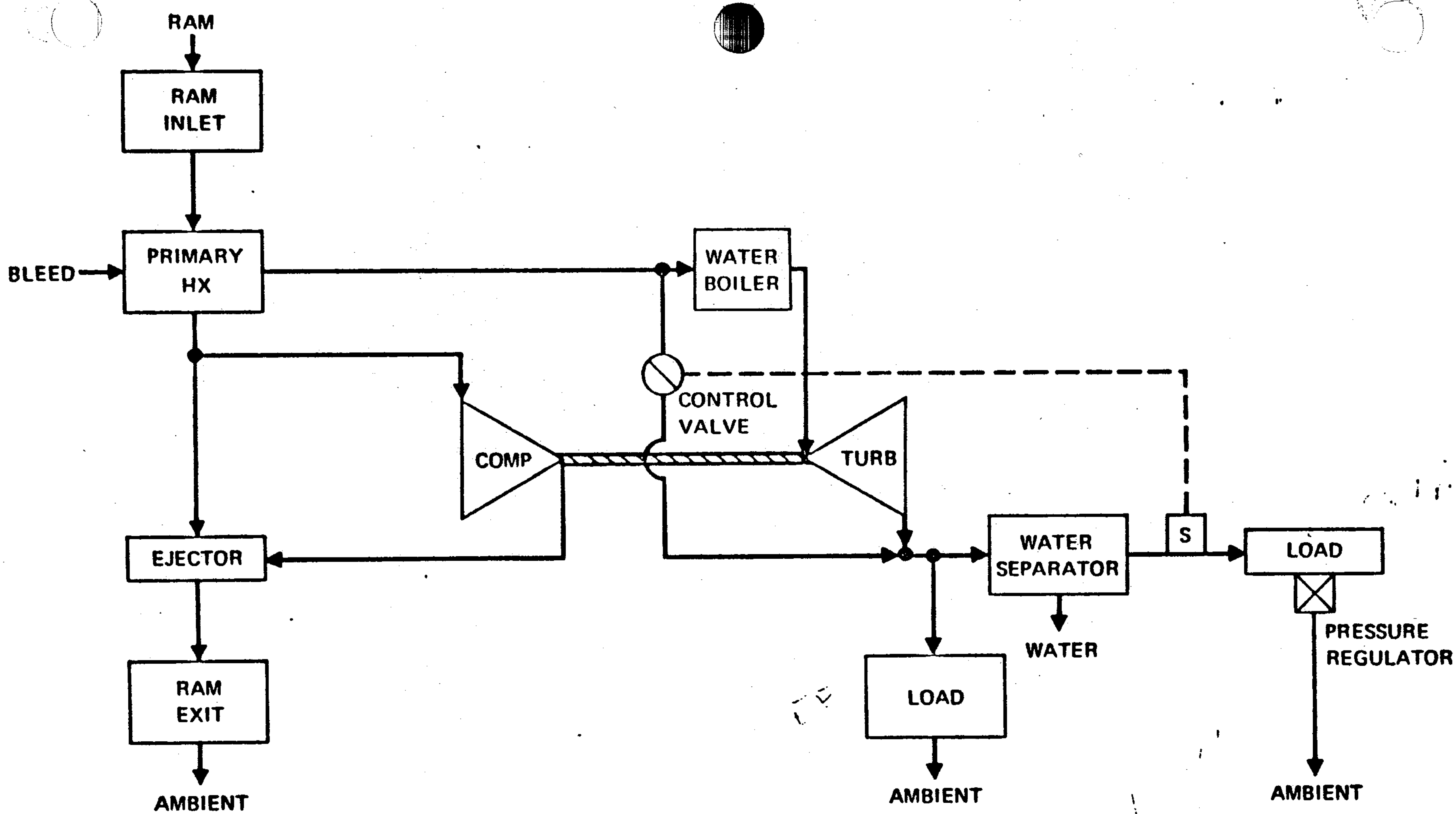
SECTION 7
SAMPLE PROBLEMS

Two sample problems are presented in this section to illustrate the proper setup of a model for performance and sizing analyses. The first sample problem consists of a rough performance case followed by a component sizing case. The second sample problem shows a detailed performance case. The sample problems do not show examples of the use of all component cards which are available or every possible combination.

7.1 Rough Performance Analysis and Sizing of Components

The first sample problem shows the setup for a simple air cycle ECS. A schematic for the ECS (in a typical format and in a computer program format, with the flow legs and stations labeled) is shown in Figure 14. A rough performance case contains a simplified data input. Only major components have been analyzed (i.e., most line pressure losses have been omitted since line lengths and diameters would be unknown). Figure 15 shows a complete listing of the input data for both the rough performance and sizing cases. (Notes on the right of this figure indicate card types.) A simplified input for tables is used. Constant values are used for tables which are design values. A detailed analysis would use two or three dimensional tables.

Bleed air flow was started in leg 1 with an INLET (card 10) which has a known flow rate, an unknown pressure, a known temperature, and no humidity. Ram air flow is started in leg 13 with an INLET (card 20) and has an unknown flow rate and known total pressure, total temperature and humidity consistent with the flight condition analyzed. Two ØRIF components (cards 30 and 40) were used to simulate pressure recovery for a ram air inlet and diffuser. At this point both inlet flows are defined for the primary heat exchanger HXA (card 50). At the exit of the primary heat exchanger on the ram air side the flow is divided in an unknown ratio with component SPLIT (card 60). Component SHAFT (card 70) is used to set up shaft number 1 for reference by following components (i.e., compressor and turbine). The compressor, CØMP (card 80), used a fixed pressure ratio. The component ØRIF (card 85) was used to compute an ejector pressure ratio and the flows were merged, component MERGE (card 90), with no pressure error. A temperature sensor, component SENSØR (card 91), was used to require a desired temperature in the merged ram circuit. A control valve, component CVALVE (card 95), was used to simulate the pressure loss through a ram exit.



TYPICAL FORMAT

Figure 14 Sample Problem 1 - Schematic of Rough Performance Model

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A pressure sensor, component SENSØR (card 96), was used to require a local pressure at the exit. The bleed flow leaving the heat exchanger is divided with a known split ratio by component SPLIT (card 110) for a hot air temperature control line and the turbine air flow. The case shown here was run full cold, therefore, there was no flow in the bypass line. The bleed air flow continues through a water boiler, component BØILER (card 120), where heat is removed. The bleed air is then expanded through the turbine, component TURB (card 130), which also has a fixed pressure ratio. A power balance for the turbine-compressor unit is required by component SPOWER (card 140). A pressure loss is computed downstream of the turbine with a line pressure loss, component LINE (card 150). A pressure loss across the hot air bypass valve is computed by component VALVE (card 160). This card is not required for this case since the flow in this leg is held to zero. The hot air bypass flow is merged with the turbine flow with no pressure error, component MERGE (card 170). Component SPLIT (card 180) provided for cooling air flow to be taken off upstream of the water separator, component WSEP (card 200), however, a known split ratio was used which directed all flow through the water separator for this case. A pressure sensor, component SENSOR (card 210), was used to require a desired pressure at the exit of the water separator.

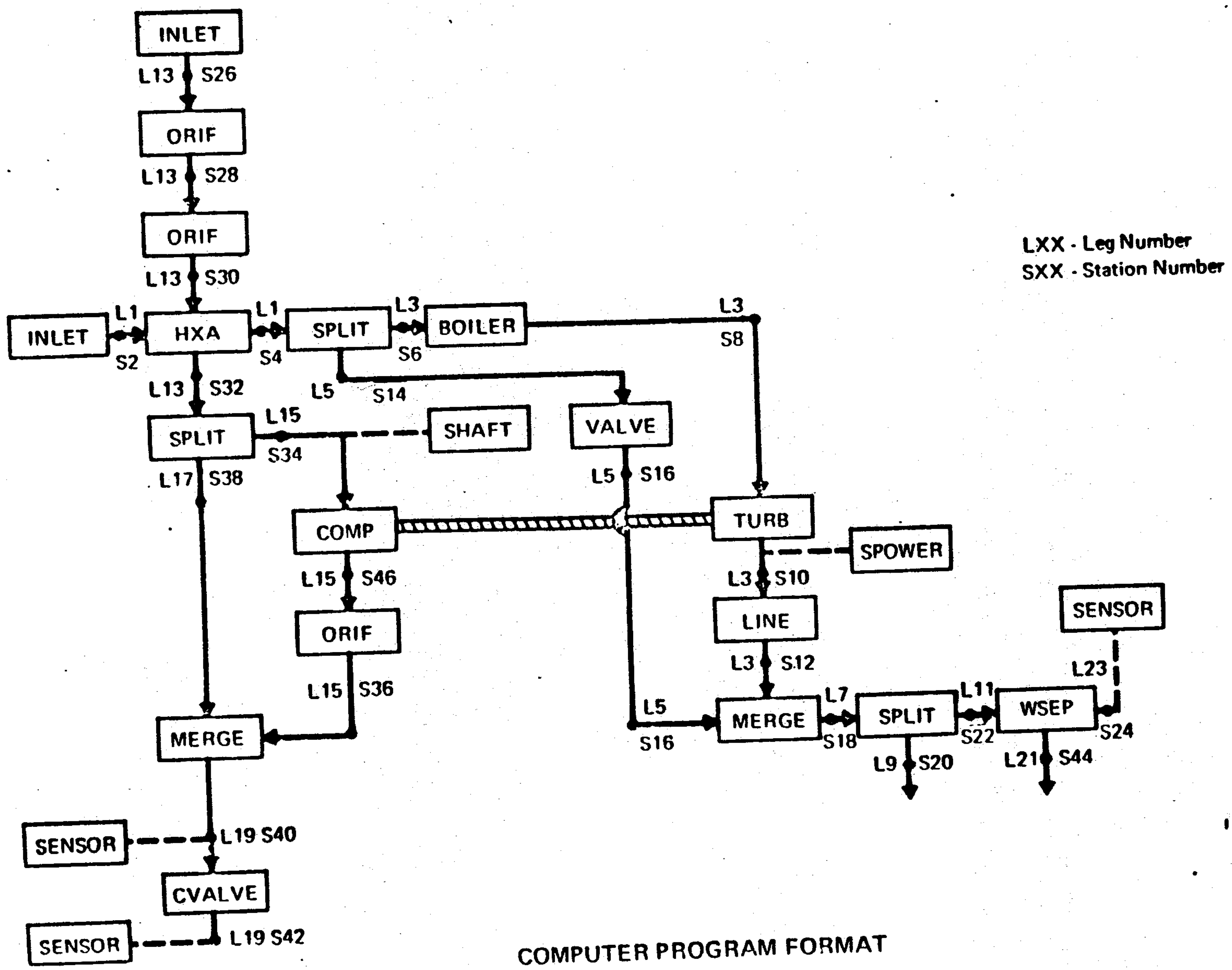
The sizing case sizes the following components only: turbine, compressor, heat exchanger, boiler, water separator, and a control. All tables required for this case are requested from the permanent table tape (see Appendix E).

The results for the performance and sizing cases are shown in Figure 16.

7.2 Detailed Performance Analysis

The second sample problem shows the setup for a detailed performance analysis for a bootstrap air cycle ECS. A schematic for the model, with the flow legs and stations labeled, is shown in Figure 17. The schematic shows the complete system including all lines. Figure 18 shows a complete listing of the input data for this case. The data is in detailed form (i.e., line lengths and diameters are used, and performance maps are used for the major components).

Bleed air flow was started in leg 1 with an INLET (card 1) which has an unknown flow rate, a known pressure, a known temperature, and a known humidity. The bleed flow next flows through a pressure regulator, component



COMPUTER PROGRAM FORMAT

Figure 14 Sample Problem 1 - Schematic of Rough Performance Model (Continued)

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```
1        10         20         30         40         50         60         70         80
*         *          *          *          *          *          *          *          *
********************************************************************************
PERFORM
TITLE
TITLE MACH 2.5
TITLE ALT 60K
CASEA           10000   12   23    0
CASEB      0   -1    1   -1   -2
CASEC     60000.      1.05       390.
CASED     2.5
PARAM    30
VALUES   0178.1       180.       1527.      0.         200.
VALUES   0617.9       880.       .4         1.2        .98
VALUES   111.05       1.0        570.       1030.      6.
VALUES   160.         .2         15.        12.0       4.773
VALUES   21      1.E-7       1.E-6
VALUE     9 1.8
VALUE    17 0.0
VALUE    26 32.0
VALUE    29 1260.
VALUE    27 .000001
VALUE    28 .0003
INLET       10    1    20100    1    2    3    4    2   -1
INLET       20   13   261000    5    6    7    4    2   -1
ORIF        30   13   26   28    0    1
ORIF        40   13   28   30    0    2
[illegible] 50    1    2    4   13   30   32    3    3    4    1
[illegible]T 60  13   32   15   34   17   38    1    8
[illegible]FT 70  1    0    0
[illegible]MP 80 15   34   46    1    0    9    3   10
ORIF        85   15   46   36    0   10
MERGE       90   15   36   17   38   19   40    0
SENSOR      91    3   40   29
CVALVE      95   19   40   42    0   27   28
SENSOR      96    2   42   11
SPLIT      110    1    4    3    6    5   14    0   12
BOILER     120    3    6    8    1    5   13    2   14
TURB       130    3    8   10    1    0   15    1   10
SPOWER     140    1   16
LINE       150    3   10   12    0    0    6
VALVE      160    5   14   16    0    0    7
MERGE      170    3   12    5   16    7   18    0
SPLIT      180    7   18    9   20   11   22    0   17
WSEP       200   11   22   23   24   21   44    1    8    2
SENSOR     210    2   24   19
TABID        1    0    2    0    0    1 000    6
TABT   WEIGHING FACTOR
TABV      1.0         .05         2.0         .10
TABV      3.0         .20         4.0         .50
TABV      6.0         .70         8.0         .95
TABID        6    1    2    0    2   10    1    2
TABT   LINE - 3,10-12  -  PRESSURE DROP
TABV      1.          .004        100.        .4
TABID        7    1    2    0    2   14    1    2
TABT   PRESSURE DROP - VALVE - 5,14-16
TABV      1.          1.          100.        100.
TABID        8    1    1
[illegible]   SDP - WSEP
          .825
********************************************************************************
```

Case Control Card

Title Cards

Case Specification Cards

Parameter Table Cards

Component Cards

Table Cards

Figure 15 Sample Problem 1 - Input Data Card Listing

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```
1        10        20        30        40        50        60        70        80
*        *         *         *         *         *         *         *         *
*********************************************************************************
TABID      3   1   2   0   2   2   1   2
TABT  SDP - HX BLEED                                              Table Cards (cont.)
TABV      10.       .5        100.      5.
TABID      4   1   2   0   2  30   1   2
TABT  SDP - HX RAM
TABV      10.       .5        100.      5.
TABID      5   1   2   0   2   6   1   2
TABT  SDP - BOILER
TABV      10.       .54       100.      5.4
TABID      1   4   1
TABT  ORIF1 - PR
TABV      .345
TABID      2   4   1
TABT  ORIF2 - PR
TABV      .969
TABID      4   4
TABT  NOZZLE PR
TABV      .22
TABID      1   5   1
TABT  HX EFFECTIVENESS
TABV      .8
TABID      2   5   1
TABT  BOILER EFFICIENCY
TABV      .95
TABID      3   6   1
TABT  COMP EFFICIENCY
TABV      .64
TABID      1   7   1
TABT  TURBINE EFFICIENCY
TABV      .76
TABID      1  17   1
TABT  NOZZLE ADIABATIC EFFICIENCY
TABV      1.
TABID      2  17   1
TABT  WSEP - EFFICIENCY
TABV      .806
TABID     10   4   1
TABT  ORIF PR - COMP LINE
TABV      .5555
TABID      1   9   1
TABT  NOZZLE CD
TABV      .8
ENDCASE                                                           Case End Card
SIZE                                                              Case Control Card
TITLE F-111A ROUGH SIZING                                         Title Card
CASEA                  1   1                                      Case Specification
CASEB                                                                  Cards
CASEC
CASED
PARAM    10                                                       Parameter Table
VALUES  01570.0   61.6        1030.0    31.7      1.0                  Cards
VALUES  061.1     0.6
TURB           3   8  10   1                      -1   1          Component Cards
COMP          15  34  46   1                      -1   1       1
HX                                 -2  -2  -2      1
HX1            1   2   4       1  -2  -8
HX2           13  30  32       1  -2  -1
*********************************************************************************
```

Figure 15 Sample Problem 1 - Input Data Card Listing (Sheet 2)

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```
1       10        20        30        40        50        60        70        80
*        *         *         *         *         *         *         *         *
********************************************************************************
BOIL1          3   6   8                   1   2   3   4       1 Component Cards
BOIL2                      1  -2  -2  -8  -3  -2  -2  -1          (cont.)
WSEP          11  22  24
CNTRL                          1   5   6   7   6  15
PTAB       1   0   1   0                                      Table Card
ENDCASE                                                       Case End Card
ENDJOB                                                        Job End Card
********************************************************************************
```

Figure 15 Sample Problem 1 - Input Data Card Listing (Sheet 3)

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```
*TECS* NINIUM LEVEL PERFORMANCE                                                          PAGE      14
      1 CASE       1                                                                    DATE 12/10/71
TIPE P    53917.95
SVT
(  1)    2 (   2)    1 (   3)    5 (   4)     6
EVT
(  1)    3 (   2)    2 (   3)    5 (   4)     2
PASS     1
S.V.
(  1) 1.80000E 02 (   2) 2.00000E 02 (   3) 4.00000E-01 (   4) 1.00000E-04
E.V.
(  1)-4.07937E 01 (   2)-8.46846E 00 (   3)-6.56990E 01 (   4) 1.70507E 01
M
(  1) 7.81000E 01 (  13) 2.00000E 02 (  15) 8.00000E 01 (  17) 1.20000E 02 (  19) 2.00000E 02 (   3) 7.81000E 01
(  5) 0.0         (   7) 7.81000E 01 (   5) 0.0         (  11) 7.81000E 01 (  23) 7.81000E 01 (  21) 0.0
P
(  2) 1.80000E 02 (  26) 1.75000E 01 (  28) 6.17550E 00 (  30) 5.98406E 00 (   4) 1.78204E 02 (  32) 4.58399E 00
( 34) 4.58399E 00 (  38) 4.58395E 00 (  46) 8.25118E 00 (  36) 4.58353E 00 (  40) 4.58353E 00 (  42)-7.41646E 00
(  6) 1.78204E 02 (  14) 1.78204E 02 (   8) 1.76597E 02 (  10) 2.94966E 01 (  12) 2.93786E 01 (  16) 3.05176E-05
( 18) 2.93786E 01 (  20) 2.53786E 01 (  22) 2.53786E 01 (  24) 2.90507E 01 (  44) 2.90507E 01
T
(  2) 1.82700E 03 (  26) 8.00000E 02 (  28) 8.00000E 02 (  30) 8.80000E 02 (   4) 1.00940E 03 (  32) 1.09724E 03
( 34) 1.09724E 03 (  38) 1.05324E 03 (  46) 1.35529E 03 (  36) 1.39529E 03 (  40) 1.21921E 03 (  42) 1.21921E 03
(  6) 1.00940E 03 (  14) 1.00540E 03 (   8) 5.51570E 02 (  10) 4.12188E 02 (  12) 4.12188E 02 (  16) 1.00940E 03
( 18) 4.12188E 02 (  20) 4.12188E 02 (  22) 4.12188E 02 (  24) 4.12188E 02 (  44) 4.12188E 02
H
(  2) 0.0         (  26) 0.0         (  28) 0.0         (  30) 0.0         (   4) 0.0         (  32) 0.0
( 34) 0.0         (  38) 0.0         (  46) 0.0         (  36) 0.0         (  40) 0.0         (  42) 0.0
(  6) 0.0         (  14) 0.0         (   8) 0.0         (  10) 0.0         (  12) 0.0         (  16) 0.0
( 18) 0.0         (  20) 0.0         (  22) 0.0         (  24) 0.0         (  44) 1.00000E 00
COMPONENT ORIF
      M      13  NSI     26  NSO     28  FI       2  FN      -1
      W   148.15   FI   12.50   PO    6.18   TI  880.00   TO  880.00   HI  0.0    HO  0.0
      PR  0.3450
COMPONENT ORIF
      M      13  NSI     28  NSO     30  FI       2  FN      -1
      W   148.15   FI    6.18   PO    5.52   TI  880.00   TO  880.00   HI  0.0    HO  0.0
      PR  0.9690
```

Figure 16 Sample Problem 1 - Computed Results

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```
*IECS* WINGM LEVEL PERFORMANCE                                                                PAGE      19
   1  CASE     1                                                                              DATE 12/30/71

CCMPONENT MEA    EXTRAPOLATED TABLE     4    I VALUE =  2.99203E-01  ARGUMENT(S)  5.98406E 00
CCMPONENT MEA
      NL       1   NSI      2   NSO      4   FT       2   FN      -1
      W    78.10   PI   79.86   PO   78.C7   TI 1527.00   TO 1009.40   HI  0.0    HO  0.0
      NL      13   NSI     2C   NSO     32   FT       2   FN      -1
      W   148.15   PI    5.56   PO    4.53   TI  880.00   TO 1173.26   HI  0.0    HO  0.0
      EF1 0.8000   EF2 C.4533
CCMPONENT COMP
      NL      15   NSI     34   NSO     4E   FT       2   FN      -1
      W    39.59   PI    4.53   PO    E.15   TI 1173.26   TO 1489.06   HI  0.0    HO  0.0
      SHAFT    1   FN  1.0CCC   EFF C.64CC   HP  -77.76
CCMPONENT ORIF
      NL      15   NSI     4E   NSO     3E   FT       2   FN      -1
      W    39.59   PI    8.15   PO    4.53   TI 1489.06   TO 1489.06   HI  0.0    HO  0.0
      PR  0.5555
CCMPONENT CVALVE
      NL      19   NSI     4C   NSC     42   FT       2   FN      -1
      W   148.15   PI    4.53   PO    1.C5   TI 1260.00   TO 1260.00   HI  0.0    HO  0.0
      K   1.585643E-C4
CCMPONENT BOILER
      NL       3   NSI      E   NSO      E   FT       2   FN      -1
      W    78.10   PI   78.07   PO   7E.64   TI 1CO9.40   TO  591.97   HI  0.0    HO  0.0
      TB  970.00   EFF C.55CC   Q -8121.1E   WR   -7.89
CCMPONENT TURB
```

Figure 16 Sample Problem 1 - Computed Results (Sheet 2)

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```
*IECS* ROUGH LEVEL PERFORMANCE                                                          PAGE      16
    1 CASE       1                                                                      DATE 12/30/71

    NL       3   NSI      E   NSO     1C   FT      2   FN     -1
    W    78.10   PI   7C.84   PU   12.81   TI 591.97   TO 412.19   HI 0.0      HO 0.0
    SHAFT    1   PR  6.CLCC   EFF 0.76CC   HP  77.76
CCPPONENT LINE
    NL       3   NSI     1C   NSO     12   FT      2   FN     -1
    W    78.10   FI   12.P1   PO   12.7C   TI 412.19   TO 412.19   HI 0.0      HO 0.0
    QT     0.0
CCPPCNENT VALVE
    NI       9   NSI     14   NSO     16   FT      2   FN     -1
    W      0.0   PI   18.07   PO    C.CC   TI 1CC9.40  TO 1009.40  HI 0.0      HO 0.0
CCPPCNENT WSEP
    NL      11   NS      22   FT       2   FN     -1
    W    78.10   F    12.7C   T   412.15   H     C.0
    NL      23   NS      24   FT       2   FN     -1
    W    78.10   F    12.CC   T   412.15   H     C.0
    NL      21   NS      44   FT       1   FN     -2
    W      0.0   F    12.CC   T   412.15   H  1.0000
    EFF 0.8060
```

Figure 16 Sample Problem 1 - Computed Results (Sheet 3)

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```
*IECS* ROUGH LEVEL PERFORMANCE                                                                    PAGE      17
     1  CASE      1                                                                               DATE 12/30/71

TIME E   53917.75

FLOW RATE(S)

(   1)   78.10 (   3)   78.10 (   5)     0.0 (   7)   78.10 (   9)     0.0 (  11)   78.10
(  13)  148.15 (  15)   35.55 (  17)  108.56 (  19)  148.15 (  21)     0.0 (  23)   78.10

PRESSURE(S)

(   2)   79.86 (   4)   78.07 (   6)   78.07 (   8)   76.84 (  10)   12.81 (  12)   12.76
(  14)   78.07 (  16)    0.00 (  18)   12.76 (  20)   12.76 (  22)   12.76 (  24)   12.00
(  26)   17.90 (  28)    6.18 (  30)    5.58 (  32)    4.53 (  34)    4.53 (  36)    4.53
(  38)    4.53 (  40)    4.53 (  42)    1.05 (  44)   12.00 (  46)    8.15

TEMPERATURE(S)

(   2) 1527.00 (   4) 1009.40 (   6) 1009.40 (   8)  591.97 (  10)  412.19 (  12)  412.19
(  14) 1039.40 (  16) 1009.40 (  18)  412.19 (  20)  412.19 (  22)  412.19 (  24)  412.19
(  26)  840.00 (  28)  860.00 (  30)  860.00 (  32) 1173.26 (  34) 1173.26 (  36) 1489.06
(  38) 1173.26 (  40) 1260.00 (  42) 1260.00 (  44)  412.19 (  46) 1489.06

HUMIDITY(S)/ENTHALPY(S)

(   2) 0.0     (   4) 0.0     (   6) 0.0     (   8) 0.0     (  10) 0.0     (  12) 0.0
(  14) 0.0     (  16) 0.0     (  18) 0.0     (  20) 0.0     (  22) 0.0     (  24) 0.0
(  26) 0.0     (  28) 0.0     (  30) 0.0     (  32) 0.0     (  34) 0.0     (  36) 0.0
(  38) 0.0     (  40) 0.0     (  42) 0.0     (  44) 1.0000  (  46) 0.0

STATE VARIABLE TYPE(S)
(   1)     2 (   2)     1 (   3)     5 (   4)     6

STATE VARIABLE(S)
(   1) 7.70622E 01 (   2) 1.48150E 02 (   3) 2.47210E-01 (   4) 1.58564E-04

ERROR VARIABLE TYPE(S)
(   1)     3 (   2)     2 (   3)     5 (   4)     7

ERROR VARIABLE(S)
(   1)-7.32422E-04 (   2)-5.23567E-04 (   3)-2.74658E-03 (   4) 6.20842E-04

SOLUTION CONVERGED IN      5 TRY(S)

     0 ERROR(S) DETECTED

CASE END
```

Figure 16   Sample Problem 1 - Computed Results (Sheet 4)

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```
NIECE0        ROUGH SIZING                                                                       PAGE         7
    2  CASE                                                                                      DATE 12/30/71

TIME D    19900.21

COMPONENT TURB
      WEIGHT    11.60      COST UNITS    64.29      RELIABILITY INDEX 0.0          DEVELOPMENT RISK  1.00
      W    79.10   PI    76.84   PO    12.91   TI  591.97   TO  412.19   HI  0.0      HO  0.0      FT      2   FN     1
      D     5.41   VOL   540.   N   60000.   EFF 0.7631   HP    70.34   U    1415.   NS    77.62   DS    1.66
COMPONENT COMP
      WEIGHT    18.30      COST UNITS   101.13      RELIABILITY INDEX 0.05793      DEVELOPMENT RISK  1.15
      W    39.59   PI     4.53   PO     8.15   TI 1173.26   TO 1489.06   HI  0.0      HO  0.0      FT      2   FN     1
      D     6.78   VOL  1439.   N   60000.   EFF 0.4394   HP   -76.21   U    1775.   NS   166.79   DS    1.01
      TIP SPEED EXCEEDS LIMITING VALUE
      DRIVE    1
COMPONENT HX
      WEIGHT    47.03      COST UNITS    97.82      RELIABILITY INDEX 0.00256      DEVELOPMENT RISK  1.00
      W    78.15   PI    79.86   PO    78.07   TI 1527.00   TO 1209.40   HI  0.0      HO  0.0      FT      2   FN     1
      W   148.15   PI     4.98   PO     4.53   TI  980.05   TO 1173.26   HI  0.0      HO  0.0      FT      2   FN     1
      LW    7.01   LC     5.77   LN    18.01   VOL    728.   WTC    31.7   EFF 0.8000   NTU  2.898
COMPONENT HOIL    EXTRAPOLATED TABLE     -8   -32 VALUE =  2.98067E-02 ARGUMENT(S)  4.29282E 03
COMPONENT HOIL    EXTRAPOLATED TABLE     -8   -33 VALUE =  7.96469E-03 ARGUMENT(S)  4.29282E 03
```

Figure 16 Sample Problem 1 - Computed Results (Sheet 5)

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```
OTECSA      ROUGH SIZING
  2  CASE                                                                                   PAGE        8
                                                                                            DATE 12730771
COMPONENT BOIL
     WEIGHT   32.63    COST UNITS  118.45    RELIABILITY INDEX 0.02165    DEVELOPMENT RISK  1.15
     W   78.10   PI   78.07   PO   76.84   TI 1309.43   TO  591.97   HI  0.0     HO  0.0     FT     2  FN     1
     LH    3.99  LC    8.46  LW    8.46  VCL   279.   WTC   10.3   FWT  245.2  EFF 0.9500  NTU  2.996
COMPONENT WSEP
     WEIGHT    7.31    COST UNITS   34.33    RELIABILITY INDEX 0.00285    DEVELOPMENT RISK  1.00
     W   78.10   PI   12.76   PO   12.30   TI  412.19   TO  412.19   HI  0.0     HO  0.0     FT     2  FN     1
     VOL  1454.
COMPONENT CNTRL
     WEIGHT    7.48    COST UNITS  187.39    RELIABILITY INDEX 0.27314    DEVELOPMENT RISK  1.00
     TYPE     1   VOL    217.
```

Figure 16   Sample Problem 1 - Computed Results (Sheet 6)

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PPEG (card 30), and then through a flow control valve, component VALVE (card 50), which is used to limit the flow to a maximum value. The base case assumes that the flow is below the maximum and that the flow control valve is wide open, therefore a fixed value is used with a minimum loss coefficient. The flow is then divided, component SPLIT (card 60), into leg 17 and leg 3. Leg 17 is a hot air line for temperature control at station 52. Leg 3 is the remainder of the bleed air which flows through the primary heat exchanger. Ram air flow is started in leg 101 with an INLET (card 100) which has a known flow, a known pressure, a known temperature, and a known humidity. Ram air flow is looked up in a table (table 1,99) and put in the parameter table location 15 for the INLET subroutine to use. This manipulation of the data is done with MISC (card 90). Pressure for the inlet is computed by using total free stream pressure (general argument 7) and correcting for inlet pressure recovery by multiplying by a inlet recovery pressure ratio and placing the result in parameter location 16. This is also done with MISC (card 80). The ram air flow is symmetrically divided, component SPLIT (card 110), since the system shown is one of two identical systems. The ram flow is divided for the primary heat exchanger and secondary heat exchanger legs with a SPLIT (card 150). AT this point both inlet flows are defined for the primary heat exchanger HXA (card 170).

The bleed flow is divided, component SPLIT (card 190) into the compressor airflow, leg 5, and the hot air bypass airflow, leg 7. The air then flows through the compressor, component CØMP (card 220), the secondary heat exchanger, component HXA (card 250), and through the turbine, component TURB (card 320). Hot air is combined with the turbine air, component MERGE (card 360) for temperature control. Component VALVE (card 364) was used to compute the pressure loss across an ice screen. The turbine air flows through the water separator, component WSEP (card 370) and on to a flow merge, component MERGE (card 410), with a hot air temperature control line, leg 17. The two ram air flows for the primary and secondary heat exchangers are combined, component MERGE (card 460). Leg 7 and leg 17 both have control valves, components CVALVE (cards 340 and 300).

The base model includes all lines which are part of the system. The ...se run, however, requires the flow control valve to limit bleed flow ...d did not require hot air for temperature control (leg 7 and leg 17).

The base case is left unchanged and input with a NØGØ card immediately after the ENDCASE card. This prevents the base case from being run. A PCHANGE case is input with changes to the base case for the conditions desired. The valve, component VALVE (card 50), in the base case is replaced with a control valve, component CVALVE (card 50). The limiting flow ($64\sqrt{\sigma}$) is computed using component MISC (5 cards), which is put in parameter location 70 for use with the flow sensor, component SENSØR. Leg 7 and leg 17 are completely removed in the change case by replacing the SPLIT and MERGE component cards with CNNCT cards and deleting all components in both legs. Several parameter table values were changed for this case to input bleed pressure, bleed temperature, ambient humidity, etc. One table was also input in the change case to specify ram air flow.

The results for the detailed performance case are shown in Figure 19.

```
1        10         20          30          40          50          60          70          80
*        *          *           *           *           *           *           *           *
********************************************************************************************
COMMON  CE  187   20000.      SHAFT SPEED LOWER LIMIT
PERFORM
TITLE      DETAILED ANALYSIS
TITLE ALTITUDE - 35K
TITLE MACH NO - 0.75
CASEA                  14  37
CASEB       0   0   1  -1  -2
CASEC      35000.     3.467      375.
CASED      0.75
PARAM    80
VALUES   0150.        21.95      714.50     0.         0.
VALUES   065.0        3.0        30.467     8.5        3.0
VALUES   110.         .5         60.        3.0        100.
VALUES   164.984      417.19     0.         3.0        3.0
VALUES   215          .5         3.0        3.0        40000.
VALUES   261.0        3.0        3.0        3.0        3.0
VALUES   313.0        1.0        10.        3.0           1.0E-5
VALUES   36     1.0E-310.        3.                1.0E-5    1.0E-3
VALUES   4140.        3.0        0.         .99        545.
VALUES   4685.0       45.66      890.       .01857     30.
VALUES   513.5        69.0       4.0        400.       11.79
VALUES   560.         44.35      1.0        .74        2.68
VALUES   611.0        2.0        1.0        2.4        3.6
VALUES   6625.        4.0        2.0        35.3       0.
VALUES   71     1.0E-5     1.0E-364.0       1.2        1.0
INLET       1   1   21000   1   2   3   4   2  -1
LINE       20   1   2   4   0   1  -1   5   1   6   7   0
PREG       30   1   4   6   1   0   1       8
LINE       40   1   6   8   0   1  -1  59   1   9  10   0
VALVE      50   1   8  10   0   2  11
SPLIT      60   1  10   3  12  17  56   1  12
LINE       70   3  12  14   0   1  -1  60   1  13  14   0
MISC       80  -1  16   0   7   3  -1  44   1
MISC       90  -1  15  -2   1   0
INLET     100 101 1020000  15  16  17  18   2  -1
SPLIT     110 101 102 105 106   0   0  -1
SPLIT     150 105 106 107 110 109 108   1  22
HXA       170   3  14  16 107 110 114   3   4   5   2
LINE      180   3  16  18   0   1  -1  61   1  19  20   0
SPLIT     190   3  18   5  20   7  22   1  22
LINE      200   5  20  24   0   1  -1  62   1  23  24   0
SHAFT     210   1  01  25
COMP      220   5  24  26   1   2       1  26
LINE      230   5  26  28   0   1  -1   5   1  27  28   0
HXA       250   5  28  30 104 108 112   3   2   3   1
LINE      310   5  30  32   0   1  -1   5   1  29  30   0
TURB      320   5  32  34   1   2  31   1  32
LINE      330   7  22  36   0   1  -1   5   1  33  34   0
CVALVE    340   7  36  38   1  35  36
LINE      350   7  38  40   0   1  -1  63   1  37  38
MERGE     360   7  40   5  34   9  44   1
VALVE     364   9  44  76   1   0   9
LINE      366   9  76  78   0   1  -1  65   1  66  67
WSEP      370   9  78  13  48  11  46   1   6   1
CNNCT     380  13  48  13  50
CVALVE    390  17  56  58   1  39  40
LINE      400  17  58  60   0   1  -1  74   1  41  42   0
********************************************************************************************
```

Figure 18 Sample Problem 2 - Input Data Card Listing

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```
1        10        20        30        40        50        60        70        80
*         *         *         *         *         *         *         *         *
********************************************************************************
MERGE    410  17  60  13  50  15  52   1
SPOWER   420   1  43
SENSOR   440   2  52  55
SENSOR   450   3  44  54
MERGE    460 107 114 109 112 111 116   1
TABID      1   0   2   0   0   1 000   6
TABT   WEIGHING FACTOR
TABV       1.0        .05       2.0        .10
TABV       3.0        .20       4.0        .50
TABV       6.0        .70       8.0        .95
TABID      1   1   2   3   0  41   1   4
TABT   OPEN FLOW CONTROL VALVE - 27 PSIG
TABV       10.0       0.015     80.0       0.94
TABV       150.0      3.5       200.0      7.0
TABID      2   1   2   3   0  41   1   8
TABT   SHX BLEED SDP
TABV       15.        .221      25.        .516
TABV       35.        1.08      45.        1.83
TABV       55.        2.73      70.        4.4
TABV       90.        7.024     105.       9.82
TABID      3   1   2   3   0  42   1   6
TABT   SHX RAM SDP
TABV       40.        .0242     80.        .0625
TABV       120.       .114      180.       .219
TABV       210.       .289      230.       .348
TABID      4   1   2   3   0  41   1   5
TABT   PHX BLEED SDP
TABV       20.        .246      35.        .688
TABV       50.        1.30      70.        2.53
TABV       90.        4.05
TABID      5   1   2   3   0  42   1   6
TABT   PHX RAM SDP
TABV       22.        .0153     60.        .0513
TABV       90.        .0895     120.       .142
TABV       160.       .226      200.       .323
TABID      6   1  33   0   0  41   1   4   0  30   1   2
TABT   WSEP SDP
TABV       30.        55.       80.        90.
TABV       30.        65.       80.        90.
TABV       0.         1.0
TABV       .1965      .496      .928       1.184
TABV       .624       1.331     1.911      2.274
TABID      7   1   2   3   0  41   1   3
TABT   OPEN CROSSFEED VALVE SDP
TABV       30.        .0025     60.        .01
TABV       300.       .32
TABID      8   1   1
TABT   CHECK VALVE SDP
TABV       0.0
TABID      9   1   2   3   0  41   1   4
TABT   SDP - ICE SCREEN
TABV       30.        .11       60.        .467
TABV       75.        .69       90.        .96
TABID      1   2   2   3   0  21   1   5
TABT   90 DEGREE KT VS RE
TABV            1.0E41.5            1.5E5.30
TABV            3.5E5.20            1.0E6.165
TABV            3.0E6.16
********************************************************************************
```

Figure 18 Sample Problem 2 - Input Data Card Listing (Sheet 2)

K508

K504

```
1        10        20        30        40        50        60        70        80
*         *         *         *         *         *         *         *         *
********************************************************************************
TABID       1    4  33    0    0  220001   20    0  250001    5
TABT   COMP - PR
TABV        10.4      12.3      14.5      15.5
TABV        16.6      17.8      19.4      20.8
TABV        25.0      26.6      28.1      28.9
TABV        29.7      30.6      31.6      32.4
TABV        34.0      35.2      35.9      36.6
TABV        12.5      14.6      16.9      18.2
TABV        19.4      20.7      22.6      24.1
TABV        29.6      31.1      32.9      33.7
TABV        34.5      35.2      36.5      37.6
TABV        38.9      39.9      40.7      41.4
TABV        15.3      17.8      20.3      22.1
TABV        23.4      24.8      26.0      27.7
TABV        34.2      35.7      37.1      38.2
TABV        39.0      39.9      41.2      42.3
TABV        43.7      44.8      45.5      46.1
TABV        18.7      21.6      24.4      26.5
TABV        28.1      29.7      31.6      35.0
TABV        38.5      40.7      42.3      43.3
TABV        44.1      45.3      46.2      46.9
TABV        47.4      48.3      48.9      49.4
TABV        29.7      31.9      34.1      36.1
TABV        38.5      40.0      43.9      46.2
TABV        47.6      48.5      49.8      50.8
TABV        51.3      52.0      52.3      52.7
TABV        53.0      53.2      53.4      53.6
TABV        40000.    45000.    50000.    55000.
TABV        60000.
TABV        1.51      1.52      1.521     1.52
TABV        1.51      1.50      1.49      1.48
TABV        1.43      1.40      1.38      1.36
TABV        1.34      1.32      1.29      1.26
TABV        1.20      1.15      1.10      1.06
TABV        1.67      1.671     1.672     1.671
TABV        1.67      1.66      1.65      1.64
TABV        1.55      1.52      1.48      1.45
TABV        1.43      1.41      1.37      1.32
TABV        1.26      1.20      1.14      1.08
TABV        1.86      1.87      1.881     1.88
TABV        1.87      1.86      1.85      1.83
TABV        1.71      1.67      1.63      1.60
TABV        1.57      1.54      1.48      1.42
TABV        1.34      1.26      1.19      1.10
TABV        2.08      2.10      2.101     2.09
TABV        2.08      2.06      2.04      1.98
TABV        1.90      1.83      1.78      1.73
TABV        1.68      1.60      1.53      1.47
TABV        1.42      1.33      1.24      1.14
TABV        2.36      2.33      2.30      2.26
TABV        2.22      2.18      2.07      1.99
TABV        1.91      1.85      1.76      1.67
TABV        1.60      1.52      1.47      1.41
TABV        1.35      1.30      1.24      1.18
********************************************************************************
```

Flow

RPM

press ratio

Figure 18 Sample Problem 2 - Input Data Card Listing (Sheet 3)

K508

K504

```
1         10         20         30         40         50         60         70         80
*          *          *          *          *          *          *          *          *
********************************************************************************
TABID       1    5    3    0    0   41    1    6    0   42    1    9
TABT   SHX EFFECTIVENESS
TABV        20.          40.          60.          80.
TABV        110.         140.
TABV        40.          50.          60.          80.
TABV        100.         120.         150.         200.
TABV        300.
TABV        .863         .713         .580         .475
TABV        .355         .265         .886         .766
TABV        .648         .544         .413         .313
TABV        .900         .810         .700         .600
TABV        .462         .352         .917         .855
TABV        .774         .680         .535         .414
TABV        .932         .880         .818         .747
TABV        .630         .504         .946         .905
TABV        .856         .797         .698         .590
TABV        .960         .935         .900         .854
TABV        .775         .690         .965         .957
TABV        .941         .912         .846         .768
TABV        .966         .960         .950         .937
TABV        .895         .828
TABID       2    5    3    0    0   410001    6    0   420001   14
TABT   EFFECTIVENESS - PHX
TABV        10.          30.          50.          70.
TABV        90.          110.
TABV        25.          30.          40.          50.
TABV        60.          70.          80.          90.
TABV        100.         120.         140.         160.
TABV        180.         200.
TABV        .88          .63          .43          .33
TABV        .26          .22          .90          .68
TABV        .49          .38          .31          .26
TABV        .93          .75          .59          .47
TABV        .38          .32          .94          .81
TABV        .66          .55          .45          .36
TABV        .95          .84          .71          .60
TABV        .50          .41          .96          .87
TABV        .75          .65          .55          .46
TABV        .96          .88          .78          .68
TABV        .59          .50          .96          .90
TABV        .81          .71          .62          .54
TABV        .97          .91          .83          .74
TABV        .65          .57          .97          .93
TABV        .85          .77          .70          .63
TABV        .97          .94          .87          .80
TABV        .73          .67          .97          .94
TABV        .89          .83          .76          .70
TABV        .98          .95          .90          .84
TABV        .79          .73          .98          .95
TABV        .92          .86          .81          .76
TABID       1    6   33    0    0   220001   20    0   250001    5
TABT   COMPRESSOR EFFICIENCY
TABV        10.4         12.3         14.5         15.5
TABV        16.6         17.8         19.4         20.8
TABV        25.0         26.6         28.1         28.9
TABV        29.7         30.6         31.6         32.4
********************************************************************************
```

Flow [illegible]

Figure 18 Sample Problem 2 - Input Data Card Listing (Sheet 4)

```
1       10        20        30        40        50        60        70        80
*        *         *         *         *         *         *         *         *
********************************************************************************
TABV     34.0      35.2      35.9      36.6
TABV     12.5      14.6      16.9      18.2
TABV     19.4      20.7      22.6      24.1
TABV     29.6      31.1      32.9      33.7
TABV     34.5      35.2      36.5      37.6
TABV     38.9      39.9      40.7      41.4
TABV     15.3      17.8      20.3      22.1
TABV     23.4      24.8      26.0      27.7
TABV     34.2      35.7      37.1      38.2
TABV     39.0      39.9      41.2      42.3
TABV     43.7      44.8      45.5      46.1
TABV     18.7      21.6      24.4      26.5
TABV     28.1      29.7      31.6      35.0
TABV     38.5      40.7      42.3      43.3
TABV     44.1      45.3      46.2      46.9
TABV     47.4      48.3      48.9      49.4
TABV     29.7      31.9      34.1      36.1
TABV     38.5      40.0      43.9      46.2
TABV     47.6      48.5      49.8      50.8
TABV     51.3      52.0      52.3      52.7
TABV     53.0      53.2      53.4      53.6
TABV     40000.    45000.    50000.    55000.
TABV     60000.
TABV     .60       .65       .70       .72
TABV     .74       .76       .78       .79
TABV     .79       .78       .76       .74
TABV     .72       .70       .65       .60
TABV     .50       .40       .30       .20
TABV     .60       .65       .70       .72
TABV     .74       .76       .78       .79
TABV     .79       .78       .76       .74
TABV     .72       .70       .65       .60
TABV     .50       .40       .30       .20
TABV     .60       .65       .70       .72
TABV     .74       .76       .77       .78
TABV     .78       .77       .76       .74
TABV     .72       .70       .65       .60
TABV     .50       .40       .30       .20
TABV     .60       .65       .70       .72
TABV     .74       .76       .77       .78
TABV     .77       .76       .74       .72
TABV     .70       .65       .60       .55
TABV     .50       .40       .30       .20
TABV     .70       .72       .74       .76
TABV     .77       .77       .76       .74
TABV     .72       .70       .65       .60
TABV     .55       .50       .45       .40
TABV     .35       .30       .25       .20
TABID     1    7    3    0    0   23    1   12    0   24    1    4
TABT  TURBINE EFFICIENCY S/O OPEN
TABV     500.      1000.     1500.     2000.
TABV     2500.     3000.     3400.     3600.
TABV     3800.     4000.     4200.     4400.
TABV     2.0       3.0       3.5       4.0
TABV     .163      .310      .444      .566
TABV     .662      .733      .766      .776
TABV     .781      .780      .770      .745
********************************************************************************
```

Figure 18 Sample Problem 2 - Input Data Card Listing (Sheet 5)

```
1        10        20        30        40        50        60        70        80
*         *         *         *         *         *         *         *         *
*********************************************************************************
TABV      .165      .315      .450      .575
TABV      .676      .752      .789      .802
TABV      .809      .810      .802      .787
TABV      .166      .316      .453      .578
TABV      .681      .760      .797      .807
TABV      .810      .810      .804      .792
TABV      .220      .413      .567      .682
TABV      .750      .783      .795      .800
TABV      .800      .800      .795      .789
TABID       1   8   3   0   0  24   1   9   0  25   1   4
TABT   FLOW FACTOR -TURBINE S/O OPEN
TABV      1.0       1.25      1.5       2.0
TABV      2.5       3.0       3.5       4.0
TABV      20.0
TABV      36450.    41000.    45560.    50120.
TABV      0.0       22.00     25.5      29.25
TABV      30.57     31.17     31.4      31.43
TABV      31.45     0.        20.44     24.2
TABV      28.37     30.13     30.88     31.1
TABV      31.13     31.16     0.        17.3
TABV      22.0      27.23     29.5      30.35
TABV      30.6      30.72     30.74     0.0
TABV      13.7      19.5      25.63     28.62
TABV      29.81     30.16     30.28     30.3
TABID       1  17   2   0   0  41   1   6
TABT   WSEP EFF - 130 GR
TABV      30.       .735      55.       .80
TABV      65.       .810      75.       .815
TABV      80.       .81       90.       .79
TABID       1  99  33   0   0   3   1   8   0   2   1   8
TABT   RAM AIR FLOW
TABV      .150      .180      .235      .283
TABV      .328      .390      .435      .465
TABV      .195      .245      .295      .350
TABV      .405      .455      .500      .535
TABV      .245      .290      .355      .425
TABV      .495      .555      .605      .640
TABV      .303      .355      .430      .515
TABV      .600      .680      .740      .780
TABV      .370      .435      .525      .625
TABV      .735      .835      .905      .945
TABV      .455      .535      .650      .760
TABV      .850      .900      .950      1.0
TABV      .555      .655      .700      .795
TABV      .850      .915      .950      1.0
TABV      .690      .700      .750      .800
TABV      .850      .900      .950      1.0
TABV      0.        5000.     10000.    15000.
TABV      20000.    25000.    30000.    35000.
TABV      300.      400.      500.      600.
TABV      700.      800.      900.      1000.
TABV      300.      400.      500.      600.
TABV      700.      800.      900.      1000.
TABV      300.      400.      500.      600.
TABV      700.      800.      900.      1000.
TABV      300.      400.      500.      600.
TABV      700.      800.      900.      1000.
*********************************************************************************
```

Figure 18 Sample Problem 2 - Input Data Card Listing (Sheet 6)

```
1        10        20        30        40        50        60        70        80
*         *         *         *         *         *         *         *         *
*********************************************************************************
TABV      300.      400.      500.      600.
TABV      700.      800.      900.      1000.
TABV      300.      400.      500.      600.
TABV      660.      700.      735.      800.
TABV      300.      400.      435.      500.
TABV      545.      600.      630.      675.
TABV      300.      310.      350.      390.
TABV      425.      460.      500.      535.
ENDCASE
NOGO
PCHANGE
TITLE          DETAILED ANALYSIS
TITLE MACH NO - 0. 38
TITLE ALTITUDE - SEA LEVEL
TITLE NO LEGS 12
TITLE NO STATIONS 30
TITLE DELETED LEG 7 AND STATIONS 22,36,38,40
TITLE  DELETED LEG 17 AND STATIONS 56,58,60
CASEA          NO 1    0  12  30    0
CASEC      0.0         14.69      563.
CASED      0.53
VALUE    2  55.97
VALUE    3  871.
VALUE    4   0.01857
VALUE    8 41.7
VALUE   55  15.40
CVALVE R  50   1   8  10   1  71  72
MISC   A  50  -1  70  -1  69   3   2   8   0
MISC   A      -1  70  -1  70   4   3   8   0
MISC   A      -1  70  -1  70  -2           0
MISC   A      -1  70  -1  70   3  -1  73   0
SENSOR A       1   1  70
CNNCT  R  60   1  10   3  12
MISC   A  90  -1  17   0   8   0
CNNCT  A 180   3  18   5  20
SPLIT  D 190
CNNCT  A 320   5  34   9  44
LINE   D 330
CVALVE D 340
LINE   D 350
MERGE  D 360
CVALVE D 390  17  56  58
LINE   D 400  17  58  60
CNNCT  R 410  13  48  15  52
SENSOR D 450   3  44  54
TABID      1  99   1
TABT  RAM AIR FLOW
TABV     978.55
ENDCASE
ENDJOB
*********************************************************************************
```

Figure 18 Sample Problem 2 - Input Data Card Listing (Sheet 7)

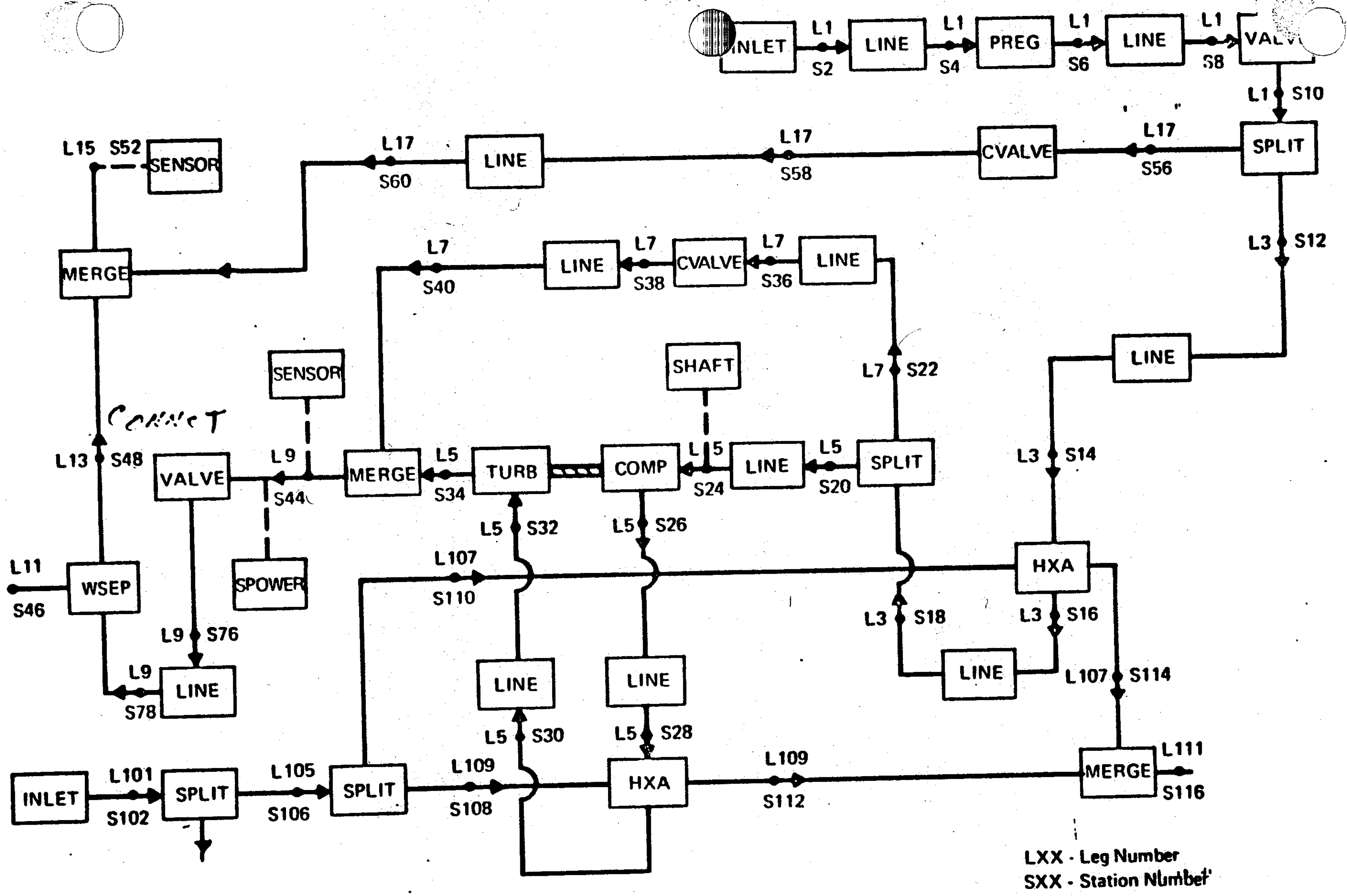

Figure 17 Sample Problem 2 - Schematic of Detailed Performance Model

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```
BIFCS6      DETAILED ANALYSIS
   2  CASE      NO 1                                                                  PAGE      19
                                                                                      DATE 12/28/71
TIME P    51992.36

SVT
(   1)    1 (   2)    6 (   3)    5 (   4)    7 (   5)    8

EVT
(   1)    1 (   2)    1 (   3)    5 (   4)    2 (   5)    2

PASS     1

S.V.
(    1) 5.00000E 01 (    2) 1.00000E-03 (    3) 5.00000E-01 (    4) 4.00000E 04 (    5) 3.00000E 00

E.V.
(    1)-3.31470E 01 (    2)-1.76593E 01 (    3) 1.44317E 01 (    4) 1.09774E 00 (    5)-6.38275E-02

W
(    1) 5.00000E 01 (    3) 5.00000E 01 (  101) 9.78550E 02 (  105) 4.89275E 02 (  107) 2.44637E 02 (  109) 2.44637E 02
(    5) 5.00000E 01 (    9) 5.00000E 01 (   13) 4.96273E 01 (   11) 3.72642E-01 (   15) 4.96273E 01 (  111) 4.89275E 02

P
(    2) 5.59700E 01 (    4) 5.59655E 01 (    6) 4.17000E 01 (    8) 4.18672E 01 (   10) 4.01883E 01 (   12) 4.01883E 01
(   14) 3.99312E 01 (  102) 1.76066E 01 (  106) 1.76066E 01 (  110) 1.76066E 01 (  108) 1.76066E 01 (   16) 3.92510E 01
(  114) 1.71602E 01 (   18) 3.92110E 01 (   20) 3.92110E 01 (   24) 3.91336E 01 (   26) 5.39488E 01 (   28) 5.39467E 01
(   30) 5.31913E 01 (  112) 1.72240E 01 (   32) 5.31894E 01 (   34) 1.77298E 01 (   44) 1.77298E 01 (   76) 1.74654E 01
(   78) 1.73664E 01 (   48) 1.64977E 01 (   46) 1.64977E 01 (   50) 1.64977E 01 (   52) 1.64977E 01 (  116) 1.71921E 01

T
(    2) 8.71000E 02 (    4) 8.71000E 02 (    6) 8.71000E 02 (    8) 8.71000E 02 (   10) 8.71000E 02 (   12) 8.71000E 02
(   14) 8.70999E 02 (  102) 5.94536E 02 (  106) 5.94536E 02 (  110) 5.94536E 02 (  108) 5.94536E 02 (   16) 6.04313E 02
(  114) 6.50203E 02 (   18) 6.04312E 02 (   20) 6.04312E 02 (   24) 6.04312E 02 (   26) 6.76083E 02 (   28) 6.76083E 02
(   30) 5.98477E 02 (  112) 6.10476E 02 (   32) 5.58476E 02 (   34) 5.18445E 02 (   44) 5.18445E 02 (   76) 5.18204E 02
(   78) 5.18113E 02 (   48) 5.17296E 02 (   46) 5.18113E 02 (   50) 5.17296E 02 (   52) 5.17296E 02 (  116) 6.30387E 02

H
(    2) 1.85700E-02 (    4) 1.85700E-02 (    6) 1.85700E-02 (    8) 1.85700E-02 (   10) 1.85700E-02 (   12) 1.85700E-02
(   14) 1.85700E-02 (  102) 0.0         (  106) 0.0         (  110) 0.0         (  108) 0.0         (   16) 1.85700E-02
(  114) 0.0         (   18) 1.85700E-02 (   20) 1.85700E-02 (   24) 1.85700E-02 (   26) 1.85700E-02 (   28) 1.85700E-02
(   30) 1.85700E-02 (  112) 0.0         (   32) 1.85700E-02 (   34) 1.85700E-02 (   44) 1.85700E-02 (   76) 1.85700E-02
(   78) 1.85700E-02 (   48) 1.09788E-02 (   46) 1.00000E 00 (   50) 1.09788E-02 (   52) 1.09788E-02 (  116) 0.0

COMPONENT LINE

     NL      1   NSI     2   NSO     4   FT      2   FN     -1

     W   83.08   PI   55.97   PO   55.96   TI  871.00   TO  971.00   HI  0.0186   HO  0.0186
```

Figure 19 Sample Problem 2 - Computed Results

K504 K508

```
 DIFFSO       DETAILED ANALYSIS                                                              PAGE      16
    2  CASE       NO 1                                                                       DATE 12/28/71

       DT     0.0     V    162.67    W    0.1130
 COMPONENT PREG
       NL        1   NSI        4   NSO        6   FT        2   FN       -1
       W     83.08   PI     55.96   PO     41.70   TI   871.00   TO   871.00   WI  0.0186   WO  0.0186
 COMPONENT LINE
       NL        1   NSI        6   NSO        8   FT        2   FN       -1
       W     83.08   PI     41.70   PO     41.58   TI   871.00   TO   871.00   WI  0.0186   WO  0.0186
       DT     0.0     V    218.93    W    0.1520
 COMPONENT CVALVE
       NL        1   NSI        8   NSO       10   FT        2   FN       -1
       W     83.08   PI     41.58   PO     41.07   TI   871.00   TO   871.00   WI  0.0186   WO  0.0186
       K   1.243923E-04
 COMPONENT MISC
       VX   1.467713E 03   IVXT    -1   IVXN    70   IOPR     3   IOPT     0
       V1   3.529999E 01   IV1T    -1   IV1N    69
       V2   4.157828E 01   IV2T     2   IV2N     8
 COMPONENT MISC
       VX   1.685090E 00   IVXT    -1   IVXN    70   IOPR     4   IOPT     0
       V1   1.467713E 03   IV1T    -1   IV1N    70
       V2   8.709995E 02   IV2T     3   IV2N     8
 COMPONENT MISC
       VX   1.298110E 00   IVXT    -1   IVXN    70   IOPR    -2   IOPT     0
       V1   1.685090E 00   IV1T    -1   IV1N    70
 COMPONENT MISC
       VX   8.307904E 01   IVXT    -1   IVXN    70   IOPR     3   IOPT     0
       V1   1.298110E 00   IV1T    -1   IV1N    7C
```

Figure 19 Sample Problem 2 - Computed Results (Sheet 2)

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```
SISFSO      DETAILED ANALYSIS                                                                          PAGE       17
   2  CASE      NO 1                                                                                   DATE 12/28/71

      V2   6.400000E 01   IV2T    -1   IV2N    73

 COMPONENT LINE

      NL        3   NSI      12   NSO      14   FT        2   FN       -1

      W     83.08   PI    41.07   PO    40.53   TI   871.00   TO   871.00   HI  0.0186   HO  0.0186

      DT      0.0   V    224.58   M    0.1560

 COMPONENT MISC

      VX   9.785498E 02   IVXT    -1   IVXN    15   IOPR      0   IOPT      0
      VI   9.785498E 02   IVIT    -2   IVIN     5

 COMPONENT MISC

      VX   5.945364E 02   IVXT    -1   IVXN    17   IOPR      0   IOPT      0
      VI   5.945364E 02   IVIT     0   IVIN     8

 COMPONENT HXA     EXTRAPOLATED TABLE      2      5 VALUE =  8.62249E-01  ARGUMENT(S)  8.30778E 01 2.34944E 02

 COMPONENT HXA     EXTRAPOLATED TABLE      5      1 VALUE =  4.17951E-01  ARGUMENT(S)  2.34944E 02

 COMPONENT HXA

      NL        3   NSI      14   NSO      16   FT        2   FN       -1

      W     83.08   PI    40.53   PO    38.70   TI   871.00   TO   632.62   HI  0.0186   HO  0.0186

      NL      107   NSI     110   NSO     114   FT        2   FN       -1

      W    234.94   PI    17.61   PO    17.18   TI   594.54   TO   680.62   HI  0.0     HO  0.0

      EF1 0.8622    EF2 0.3114

 COMPONENT LINE

      NL        3   NSI      16   NSO      18   FT        2   FN       -1

      W     83.08   PI    38.70   PO    38.60   TI   632.62   TO   632.62   HI  0.0186   HO  0.0186
```

Figure 19 Sample Problem 2 - Computed Results (Sheet 3)

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```
GIFCSO       DETAILED ANALYSIS                                                                      PAGE       18
   2  CASE      NO 1                                                                                DATE 12/28/71

     DT     0.0    V    171.30   M    0.1391
COMPONENT LINE
     NL       5   NSI     20   NSO     24   FT      2   FN     -1
     W    83.08   PI   38.60   PO   38.39   TI  632.62   TO  632.62   HI  0.0186   HO  0.0186
     DT     0.0    V    172.20   M    0.1398
COMPONENT SHAFT
     SHAFT    1   N   57952.
COMPONENT COMP
     NL       5   NSI     24   NSO     26   FT      2   FN     -1
     W    83.08   PI   38.39   PO   70.29   TI  632.62   TO  785.30   HI  0.0186   HO  0.0186
     SHAFT    1   PR  1.9309   EFF 0.7768   HP  -72.48
COMPONENT LINE
     NL       5   NSI     26   NSO     28   FT      2   FN     -1
     W    83.08   PI   70.29   PO   70.29   TI  785.30   TO  785.30   HI  0.0186   HO  0.0186
     DT     0.0    V    116.76   M    0.0853
COMPONENT HXA    EXTRAPOLATED TABLE      3     1 VALUE =  4.27328E-01 ARGUMENT(S)  2.54331E 02
COMPONENT HXA
```

Figure 19 Sample Problem 2 - Computed Results (Sheet 4)

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```
4IFFS0      DETAILED ANALYSIS                                                                        PAGE      19
    2  CASE      NO 1                                                                                DATE 12/28/71

      NL        5   NSI     28   NSO     30   FT        2   FN       -1
      W     83.08   PI   70.79   PO   68.59   TI   785.30   TO   609.77   HI   0.0186   HO   0.0186
      NL      109   NSI    108   NSO    112   FT        2   FN       -1
      W    254.33   PI   17.61   PO   17.18   TI   594.54   TO   652.64   HI   0.0      HO   0.0
      EF1 0.9201    EF2 0.3046
COMPCNENT LINE
      NL        5   NSI     30   NSO     32   FT        2   FN       -1
      W     83.08   PI   68.59   PO   68.58   TI   609.77   TO   609.77   HI   0.0186   HO   0.0186
      DT      0.0   V    92.92   M   0.0768
COMPONENT TURB   EXTRAPOLATED TABLE      1     R VALUE =  2.99116E 01 ARGUMENT(S)  3.81008E 00 5.34649E 04
COMPONENT TURB
      NL        5   NSI     32   NSO     34   FT        2   FN       -1
      W     83.08   PI   68.58   PO   18.00   TI   609.77   TO   509.87   HI   0.0186   HO   0.0186
      ***CONDENSATION - MS 0.00618
      SHAFT    1   PR  3.8101   FFF 0.7992   HP    72.48
COMPCNENT VALVE
      NL        9   NSI     44   NSO     76   FT        2   FN       -1
      W     83.08   PI   18.00   PO   17.33   TI   509.87   TO   509.35   HI   0.0186   HO   0.0186
      ***CONDENSATION - MS 0.00631
COMPCNENT LINE
```

Figure 19 Sample Problem 2 - Computed Results (Sheet 5)

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```
SIECSS      DETAILED ANALYSIS                                         PAGE      20
   2  CASE     NO 1                                                   DATE 12/28/71

     NL       9   NSI     76   NSO     78   FT      2   FN     -1
     W    83.08   PI   17.33   PO   17.11   TI 509.35   TO 504.17   HI 0.0186   HO 0.0186
     ***CONDENSATION - MS 0.00635
     QT    0.0    V   174.98   H   0.1582
 COMPONENT WSEP
     NL       9   NS      78   FT       2   FN     -1
     W    83.08   P    17.11   T   509.17   H  0.0186
     NL      13   NS      48   FT       2   FN     -1
     W    82.30   P    15.40   T   507.73   H  0.0090
     ***CONDENSATION - MS 0.00670
     NL      11   NS      46   FT       1   FN     -2
     W     0.78   P    15.40   T   509.17   H  1.0000
     EFF 0.8038
```

Figure 19   Sample Problem 2 - Computed Results (Sheet 6)

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```
SIECSO      DETAILED ANALYSIS                                                                     PAGE    21
   2  CASE      NO 1                                                                               DATE 12/28/71

TIME E   51593.55

FLOW RATE(S)

(   1)   83.08 (   3)   83.08 (   5)   83.08 (   9)   83.08 (  11)    0.78 (  13)   82.30
(  15)   82.30 ( 101)  978.55 ( 105)  489.27 ( 107)  234.94 ( 109)  254.33 ( 111)  489.27

PRESSURE(S)

(   2)   55.97 (   4)   55.96 (   6)   41.70 (   8)   41.58 (  10)   41.07 (  12)   41.07
(  14)   40.53 (  16)   38.70 (  18)   38.60 (  20)   38.60 (  24)   38.39 (  26)   70.29
(  28)   70.29 (  30)   68.59 (  32)   68.58 (  34)   18.00 (  44)   18.00 (  46)   15.40
(  48)   15.40 (  50)   15.40 (  52)   15.40 (  76)   17.33 (  78)   17.11 ( 102)   17.61
( 106)   17.61 ( 108)   17.61 ( 110)   17.61 ( 112)   17.19 ( 114)   17.18 ( 116)   17.18

TEMPERATURE(S)

(   2)  871.00 (   4)  871.00 (   6)  871.00 (   8)  871.00 (  10)  871.00 (  12)  871.00
(  14)  871.03 (  16)  632.62 (  18)  632.62 (  20)  632.62 (  24)  632.62 (  26)  785.30
(  28)  785.30 (  30)  609.77 (  32)  609.77 (  34)  509.87 (  44)  509.87 (  46)  509.17
(  48)  507.73 (  50)  507.73 (  52)  507.73 (  76)  509.35 (  78)  509.17 ( 102)  594.54
( 106)  594.54 ( 108)  594.54 ( 110)  594.54 ( 112)  652.64 ( 114)  680.82 ( 116)  666.10

HUMIDITY(S)/ENTHALPY(S)

(   2)  0.0186 (   4)  0.0186 (   6)  0.0186 (   8)  0.0186 (  10)  0.0186 (  12)  0.0186
(  14)  0.0186 (  16)  0.0186 (  18)  0.0186 (  20)  0.0186 (  24)  0.0186 (  26)  0.0186
(  28)  0.0186 (  30)  0.0186 (  32)  0.0186 (  34)  0.0186 (  44)  0.0186 (  46)  1.0000
(  48)  0.0090 (  50)  0.0090 (  52)  0.0090 (  76)  0.0186 (  78)  0.0186 ( 102)  0.0
( 106)  0.0    ( 108)  0.0    ( 110)  0.0    ( 112)  0.0    ( 114)  0.0    ( 116)  0.0

STATE VARIABLE TYPE(S)
(   1)    1 (   2)    6 (   3)    5 (   4)    7 (   5)    8

STATE VARIABLE(S)
(   1) 8.30778E 01 (   2) 1.24392E-04 (   3) 4.80187E-01 (   4) 5.79519E 04 (   5) 3.81008E 00

ERROR VARIABLE TYPE(S)
(   1)    1 (   2)    1 (   3)    5 (   4)    2 (   5)    2

ERROR VARIABLE(S)
(   1)-1.28174E-03 (   2) 1.77002E-03 (   3) 3.41797E-03 (   4) 4.07219E-04 (   5) 0.0

SOLUTION CONVERGED IN      9 TRY(S)

        0 ERROR(S) DETECTED

CASE END
```

Figure 19   Sample Problem 2 - Computed Results (Sheet 7)

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APPENDIX A

PERFORMANCE COMPONENTS

Component Name	Component	Section
APU	Auxiliary Power Unit	A1
BØILER	Boiler	A2
CNNCT	Leg and Station Connector	A3
CØMP	Compressor	A4
COND	Condenser	A5
CVALVE	Control Valve	A6
DRAIN	Water Drain	A7
DSEP	Dust Separator	A8
EJECT	Ejector	A9
EVAP	Evaporator	A10
FAN	Fan	A11
HXA	Heat Exchanger	A12
HXB	Heat Exchanger	A13
INJECT	Water Injector	A14
INLET	Inlet to ECS	A15
LINE	Line	A16
LØØP	Fluid Loop	A17
MERGE	Flow Merge	A18
MISC	Miscellaneous Operations	A19
NØZZLE	Nozzle	A20
ØRIF	Orifice	A21
ØUTLET	Outlet from ECS	A22
PREG	Pressure Regulator	A23
PUMP	Pump	A24
QLØAD	Compartment Heat Load	A25
SENSØR	Flow, Pressure, Temperature, Humidity/ Enthalpy Sensor	A26
SHAFT	Shaft Initialization	A27
SPLIT	Flow Split	A28
SPØWER	Shaft Power Balance	A29
TURB	Turbine	A30
VALVE	Valve	A31

VCØMP	Vapor Cycle Compressor	A32
VLINE	Vapor Line	A33
WSEP	Water Separator	A34

Notes: 1. Data card fields which refer to the parameter table are indicated by brackets, [ ].

2. A card column specified by a single value represents the right-hand column of a four column integer data field. Data values punched in these fields must be right justified.

A1

Performance Component APU

Auxiliary Power Unit

Purpose: This component will compute the performance of an APU used to supply bleed air and/or shaft power.

Options: APU performance is computed with the following options:

NL = 0 no bleed air supplied

NL ≠ 0 bleed air supplied

NST = 0 no shaft power is supplied

NST ≠ 0 shaft power is supplied

Equations:

$$P_{out} = P_{in} \cdot PR$$

$$\overline{T}_{out} = T_{in} \cdot PR^{\left(\frac{\gamma-1}{\eta_p \gamma}\right)}$$

$$H_{out} = H_{in}$$

$$T_{out} = f\,(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

Restrictions:

1. This component can only be used for fluid type 2.
2. The APU shaft number must be previously defined (see component SHAFT).

Notes:

1. Fluid properties

   γ - evaluated at T_{in}
2. Bleed air and shaft power options may be used simultaneously.
3. The component performance printout consists of the following items:

   NL - leg number

   NSI - inlet station number

   NSØ - outlet station number

   FT - fluid type

   FN - fluid number

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W - flow rate
PI - inlet pressure
PØ - outlet pressure
TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity
HØ - outlet humidity

if NL ≠ 0

PR - pressure ratio
EFF - polytropic efficiency

if NST ≠ 0

SHAFT - shaft number
HP - horsepower

Performance Component APU

Data Card Format

Card Column	Symbol	Value
1-3	CN	APU component name
8	CC	change code
12	NC	card number
16	NL	leg number = 0 no bleed air ≠ 0 bleed air
20	NSI	inlet station number (if NL ≠ 0)
24	NSØ	outlet station number (if NL ≠ 0)
28	NST	shaft number = 0 no shaft power ≠ 0 shaft power
32	[PR]	pressure ratio (P_{out}/P_{in})(if NL ≠ 0)
36	[EFF]	polytropic efficiency (if NL ≠ 0)
40	[PWR]	shaft power supplied (if NST ≠ 0)

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A2

Performance Component BØILER

Boiler

Purpose: This component will compute the heat transfer performance and flow side pressure drop for a boiler.

Options: The flow side pressure drop may be computed with the following options:

ISIG = 0 ΔP is read from a table

ISIG = 1 $\sigma\Delta P$ is read from a table

Equations:

$$P_{out} = P_{in} - \Delta P$$

<u>if $T_{in} > T_{boil}$</u>

$$T_{out} = T_{in} - \varepsilon \left(T_{in} - T_{boil}\right)$$

<u>if $T_{in} \leq T_{boil}$</u>

$$\overline{T}_{out} = T_{in}$$

$$H_{out} = H_{in}$$

$$T_{out} = f\left(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out}\right)$$

$$Q = W \cdot C_p \left(\overline{T}_{out} - T_{in}\right)$$

$$W_{boil} = Q/H_{fg}$$

Required Tables:

ΔP or $\sigma\Delta P$ - Table ID(IPD,1) - Pressure drop

ε - Table ID(IE,5) - Temperature effectiveness

Restrictions:

1. This component may only be used for fluid types 1 and 2.

Notes:

1. The following general arguments are set up in this component.
   - argument 26 - boiling temperature
   - argument 41 - flow in leg
   - argument 43 - inlet pressure
2. Fluid properties

   σ - evaluated at P_{in}, T_{avg}

   C_p - evaluated at T_{avg}

   where $T_{avg} = (T_{in} + T_{out})/2$
3. The component performance printout consists of the following items:

NL	- leg number
NSI	- inlet station number
NSØ	- outlet station number
FT	- fluid type
FN	- fluid number
W	- flow rate
PI	- inlet pressure
PØ	- outlet pressure
TI	- inlet temperature
TØ	- outlet temperature
HI	- inlet humidity
HØ	- outlet humidity
TB	- boiling temperature
EFF	- temperature effectiveness
Q	- boiling heat rate

if HFG $\neq$ 0.

WB	- boiling rate

Performance Component BØILER

Data Card Format

Card Column	Symbol	Value
1-6	CN	BØILER component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	ISIG	option = 0 use ΔP = 1 use $\sigma\Delta P$
32	IPD	pressure drop table relative number (type 1)
36	[TB]	boiling temperature
40	IE	temperature effectiveness table relative number (type 5)
44	[HFG]	heat of vaporization (optional)

See Vol. IV

A3

Performance Component CNNCT

Leg and Station Connector

Purpose: This component may be used to connect legs and/or stations in a model to add or delete components in a change case.

Options: None

Equations:

$$W_{out} = W_{in}$$

$$P_{out} = P_{in}$$

$$T_{out} = T_{in}$$

$$H_{out} = H_{in}$$

Notes:

1. There is no performance printout for this component.
2. Inlet and outlet leg numbers may be equal or different. Inlet and outlet station numbers may be equal or different.

Performance Component CNNCT

Data Card Format

Card Column	Symbol	Value
1-5	CN	CNNCT component name
8	CC	Change code
12	NC	card number
16	NLI	inlet leg number
20	NSI	inlet station number
24	NLØ	outlet leg number
28	NSØ	outlet station number

Performance Component CØMP

Compressor

Purpose: This component will compute compressor performance.

Options: Compressor performance is computed with the following options:

IØP = 0 - Fixed pressure ratio with efficiency read from a table. No state variable or error variable is set up.

IØP = 1 - Variable pressure ratio with efficiency read from a table. A type 8 state variable is set up for the pressure ratio.

IØP = 2 - Pressure ratio and efficiency maps are used. No state or error variables are set up.

Equations:

State variable = PR (type 8) (optional)

$$P_{out} = P_{in} \cdot PR$$

$$\overline{T}_{out} = T_{in} + T_{in} \left(PR^{\frac{\gamma-1}{\gamma}} - 1\right)/\eta_c$$

$$H_{out} = H_{in}$$

$$T_{out} = f\,(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

$$HP = 0.02356\, WC_p\, (T_{in} - \overline{T}_{out})/\eta_m$$

Required Tables:

η_c - Table ID (ICT,6) - Compressor efficiency

for IOP = 2 only

PR - Table ID (ICT,4) - Compressor pressure ratio (P_{out}/P_{in})

Restrictions:

1. This component can only be used for fluid type 2.
2. The CØMP shaft number must be previously defined (see component SHAFT).

Notes:

1. The following general arguments are set up in this component:

   - argument 22, corrected flow $\frac{W\sqrt{T_{in}/519}}{P_{in}/14.7}$
   - argument 25, corrected speed $N/\sqrt{T_{in}/519}$
   - argument 41, flow in leg

2. Fluid properties:

   γ - evaluated at T_{in}

   C_p - evaluated at $T_{avg} = (T_{in} + \overline{T}_{out})/2$

3. A shaft power balance may be obtained by inserting a SPØWER card (see SPØWER component).

4. Compressor efficiency will be limited to values less than or equal to 1.0. The user should check the component output to determine whether the value has been limited.

5. The component performance printout consists of the following items:

   NL - leg number
   NSI - inlet station number
   NSØ - outlet station number
   FT - fluid type
   FN - fluid number
   W - flow rate
   PI - inlet pressure
   PØ - outlet pressure
   TI - inlet temperature
   TØ - outlet temperature
   HI - inlet humidity
   HØ - outlet humidity
   SHAFT - shaft number
   PR - compressor pressure ratio
   EFF - compressor efficiency
   HP - compressor horsepower

Performance Component CØMP

Data Card Format

Card Column	Symbol	Value
1-4	CN	CØMP component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	NST	shaft number
32	IØP	option = 0 - fixed pressure ratio = 1 - variable pressure ratio (no map) = 2 - variable pressure ratio (map)
36	[PR]	pressure ratio P_{out}/P_{in} if IØP = 0 fixed pressure ratio value = 1 pressure ratio initial guess = 2 not used
40	ICT	efficiency table relative number (type 6) also if IØP = 2 pressure ratio table relative number (type 4)
44	[ME]	mechanical efficiency

See Vol IV

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A5

Performance Component C$\emptyset$ND

Condenser

Purpose: This component will compute the heat exchange and pressure drop for a refrigerant condenser.

Options: Pressure drop is computed on the sink side of the condenser for the following options:

ISIG = 0 use ΔP

ISIG = 1 use $\sigma \Delta P$

Equations:

for refrigerant

$$H_{in} = f\,(P_{in}, T_{in})$$

$$P_{out} = P_{in}$$

$$T_{cond} = f\,(P_{in})$$

$$V_g = f\,(P_{in}, T_{cond})$$

$$H_g = f\,(P_{in}, T_{cond}, V_g)$$

$$H_{fg} = f\,(T_{cond})$$

$$H_{out} = H_g - H_{fg}$$

$$Q = W\,(H_{in} - H_{out})$$

$$T_{out} = T_{cond}$$

for sink

$$P_{out} = P_{in} - \Delta P$$

$$\overline{T}_{out} = T_{in} + \varepsilon\,(T_{cond} - T_{in})$$

$$H_{out} = H_{in}$$

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$$T_{out} = f(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

$$\overline{T}'_{out} = T_{in} + Q/W\,C_p$$

$$\text{Error Variable} = T_{out} - \overline{T}'_{out} \quad \text{(type 3)}$$

Requried Tables:

ΔP or $\sigma\Delta P$ - Table ID(IPD,1) - Sink side pressure drop

ϵ - Table ID (IE,5) - Sink side temperature effectiveness

Restrictions:

1. The refrigerant side fluid must be type 3. The sink side fluid must be type 1 or 2.

Notes:

1. The following general arguments are set up in this component.
   - argument 41 - sink side flow rate
   - argument 42 - refrigerant side flow rate
   - argument 43 - sink side inlet pressure
2. Fluid properties:
   C_p - evaluated at T_{in}
   σ - evaluated at P_{in}, T_{in}
3. The component performance printout consists of the following items:

NL	- leg number	for refrigerant and sink side
NSI	- inlet station number	
NSØ	- outlet station number	
FT	- fluid type	
FN	- fluid number	
W	- flow rate	
PI	- inlet pressure	
PØ	- outlet pressure	
TI	- inlet temperature	
TØ	- outlet temperature	
HI	- inlet enthalpy/humidity	
HØ	- outlet enthalpy/humidity	

EFF - sink side temperature effectiveness

Q - heat transfer

Performance Component CØND

Data Card Format

Card Column	Symbol	Value	
1-4	CN	CØND component name	
8	CC	change code	
12	NC	card number	
16	NLR	leg number	refrigerant side
20	NSIR	inlet station number	refrigerant side
24	NSØR	outlet station number	refrigerant side
28	NLS	leg number	sink side
32	NSIS	inlet station number	sink side
36	NSØS	outlet station number	sink side
40	ISIG	option = 0 use ΔP = 1 use $\sigma \Delta P$	sink side only
44	IPD	sink side pressure drop table relative number (type 1)	
48	IE	sink side temperature effectiveness table relative number (type 5)	

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A6

Performance Component CVALVE

Control Valve

Purpose: This component will compute the pressure loss across a modulating valve with a variable loss coefficient.

Options: Pressure loss is computed with the following options.

ISIG = 0 - ΔP is calculated

ISIG = 1 - $\sigma\Delta P$ is calculated

Equations:

State Variable = K (type 6)

$$\left.\begin{matrix}\Delta P \\ \sigma\Delta P\end{matrix}\right\} = KW^2$$

$$P_{out} = P_{in} - \Delta P$$

$$\overline{T}_{out} = T_{in}$$

$$H_{out} = H_{in}$$

$$T_{out} = f\,(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

Notes:

1. The component performance printout consists of the following items:

NL - leg number
NSI - inlet station number
NSØ - outlet station number
FT - fluid type
FN - fluid number
W - flow rate
PI - inlet pressure
PØ - outlet pressure
TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity/enthalpy
HØ - outlet humidity/enthalpy
K - loss coefficient

Performance Component CVALVE

Data Card Format

Card Column	Symbol	Value
1-6	CN	CVALVE component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	ISIG	option = 0 use ΔP = 1 use $\sigma \Delta P$
32	[KM]	minimum value of K
36	[K]	K initial guess

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A7

Performance Component DRAIN

Water Drain

Purpose: This component will compute the water removed from a saturated fluid stream. No pressure drop is computed for the drain component.

Equations:

$$P_{out} = P_{in}$$

$$T_{out} = T_{in}$$

<u>if $H_{in} > H_{sat}$</u>

$$\Delta H = \eta \, (H_{in} - H_{sat})$$

$$H_{out} = H_{in} - \Delta H$$

$$\Delta W = \Delta H \bullet W_{in}/(1 + H_{in})$$

$$W_{out} = W_{in} - \Delta W$$

$$W_{drain} = \Delta W$$

<u>if $H_{in} \leq H_{sat}$</u>

$$H_{out} = H_{in}$$

$$W_{out} = W_{in}$$

$$W_{drain} = 0.0$$

Required Tables:

η - Table ID(IEF,17) - Drain efficiency

Restrictions:

1. This component may only be used for fluid type 2.

Notes:

1. The component performance printout consists of the following items:

NL	- leg number	for inlet, outlet and drain leg
NS	- station number	for inlet, outlet and drain leg
FT	- fluid type	for inlet, outlet and drain leg
FN	- fluid number	for inlet, outlet and drain leg
W	- flow rate	for inlet, outlet and drain leg
P	- pressure	for inlet, outlet and drain leg
T	- temperature	for inlet, outlet and drain leg
H	- humidity	for inlet, outlet and drain leg
EFF	- drain efficiency	

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Performance Component DRAIN

Data Card Format

Card Column	Symbol	Value
1-5	CN	DRAIN component name
8-	CC	change code
12	NC	card number
16	NLI	inlet leg number
20	NSI	inlet station number
24	NLØ1	outlet leg number
28	NSØ1	outlet station number
32	NLØ2	drain leg number
36	NSØ2	drain station number
40	IEF	water removal efficiency table relative number (type 17)

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Performance Component DSEP

Dust Separator

Purpose: This component will compute pressure loss across a dust separator.

Options: Pressure drops are computed by the following options:

ITE = 0 ΔP or $\sigma\Delta P$ is read from a table

ITE = 1 ΔP is calculated from equation 1

ITE = 2 ΔP is calculated from equation 2

Equations:

$$P_{out} = P_{in} - \Delta P$$

where

$$\left.\begin{matrix}\Delta P \\ \sigma\Delta P\end{matrix}\right\} = \text{table lookup}$$

or

$$\Delta P = 1.008 \times 10^{-3} K_t W^2/\rho D^4 \qquad (1)$$

or

$$\left.\begin{matrix}\Delta P \\ \sigma\Delta P\end{matrix}\right\} = KW^2 \qquad (2)$$

$$\bar{T}_{out} = T_{in}$$

$$H_{out} = H_{in}$$

$$T_{out} = f(P_{in}, T_{in}, H_{in}, P_{out}, \bar{T}_{out}, H_{out})$$

Required Tables:

for ITE = 0 only

ΔP or $\sigma\Delta P$ - Table ID(IPD,1) - Pressure drop

Restrictions:

1. This component can use only fluid type 2.

Notes:

1. The following general argument is set up in this component:
   - argument 41, flow in leg
2. Fluid properties:
   ρ - evaluated at P_{in}, T_{in}
   σ - evaluated at P_{in}, T_{in}

3. The component performance printout consists of the following items:

NL - leg number
NSI - inlet station number
NSØ - outlet station number
FT - fluid type
FN - fluid number
W - flow rate
PI - inlet pressure
PØ - outlet pressure
TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity
HØ - outlet humdity

Performance Component DSEP

Data Card Format

Card Column	Symbol	Value
1-4	CN	DSEP component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	ISIG	option (for ITE = 0, 2) = 0 use ΔP = 1 use $\sigma\Delta P$
32	ITE	table or equation option = 0 use table = 1 use equation 1 = 2 use equation 2
if ITE = 0		
[36	IPD	pressure drop table relative number (type 1)
if ITE = 1		
[36	[KT]	K_t
40	[D]	diameter
if ITE = 2		
[36	[K]	K

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Performance Component EJECT

Ejector

Purpose: This component will compute ejector performance.

Options: Ejector performance is computed with the following options:

$I\emptyset P = 0$ primary to secondary flow is specified

$I\emptyset P = 1$ primary flow is computed

Equations:

$$PR = P_{sec}/P_{pri}$$

$$PR_{crit} = \left(\frac{2}{\gamma+1}\right)^{\left(\frac{\gamma}{\gamma-1}\right)}$$ = P_c/P_1 [illegible] = 0.528 (ISENTROPIC)

if $PR < PR_{crit}$ then $PR = PR_{crit}$

for $I\emptyset P = 0$

$$W_{calc} = W_{sec} \cdot WR$$ – For Sonic Flow

for $I\emptyset P = 1$

$$W_{calc} = 40.124\, C_D A \sqrt{\frac{\gamma}{\gamma-1}\,\rho\, P_{pri}\left(PR^{2/\gamma} - PR^{\gamma+1/\gamma}\right)}$$ – For Subsonic Flow (ISENTROPIC)

$$W_{out} = W_{pri} + W_{sec}$$

$$W_W = \left(\frac{H_{pri}}{1 + H_{pri}}\right) W_{pri} + \left(\frac{H_{sec}}{1 + H_{sec}}\right) W_{sec}$$

$$H_{out} = W_W/(W_{out} - W_W)$$

$$P_{out} = P_{sec} \cdot PR_{sec}$$

$$T_{PI} = T_{pri} \cdot PR^{(\gamma-1)/\gamma}$$

$$\overline{T}_{out} = (W_{sec}\ T_{sec} + W_{pri}\ T_{PI})/W_{out}$$

$$T_{out} = f\ (P_{pri},\ T_{pri},\ H_{pri},\ P_{sec},\ T_{sec},\ H_{sec},\ P_{out},\ \overline{T}_{out},\ H_{out})$$

$$\text{Error Variable} = W_{calc} - W_{pri} \quad \text{(type 1)}$$

Required Tables:

PR_{sec} - Table ID(IPR,4) - Secondary pressure ratio (P_{out}/P_{sec})

if IØP = 0

WR - Table ID(IWR,19) - Primary to secondary flow ratio

if IØP = 1

C_D - Table ID(ICD,9) - Primary nozzle discharge coefficient

Restrictions:

1. This component can only be used for fluid type 2.

Notes:

1. The following general arguments are set up in this component:
   - argument 24, primary to secondary pressure ratio
   - argument 41, primary flow
   - argument 42, secondary flow

   for IØP = 1 only

   - argument 27, secondary to primary corrected flow ratio

$$\left(\frac{W\sqrt{T}}{P}\right)_{sec} \Big/ \left(\frac{W\sqrt{T}}{P}\right)_{pri}$$

2. Fluid properties:

   γ - evaluated at T_{pri}

   ρ - evaluated at P_{pri}, T_{pri}

3. The component performance printout consists of the following items:

   NL - leg number

   NS - station number

   FT - fluid type

   FN - fluid number

   W - flow rate

   P - pressure

   For primary, secondary and outlet leg

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T - temperature
H - humidity
for primary, secondary and outlet leg

PPR - primary to secondary pressure ratio
SPR - secondary pressure ratio
WR - secondary to primary flow ratio

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Performance Component EJECT

Data Card Format

Card Column	Symbol	Value
1-5	CN	EJECT component name
8	CC	change code
12	NC	card number
16	NLP	primary leg number
20	NSP	primary station number
24	NLS	secondary leg number
28	NSS	secondary station number
32	NLØ	outlet leg number
36	NSØ	outlet station number
40	IPR	secondary pressure ratio (P_{out}/P_{sec}) table relative number (type 4)
44	IØP	option = 0 flow ratio specified = 1 flow ratio calculated
if IØP = 0		
48	IWR	primary to secondary flow ratio table relative number (type 19)
if IØP = 1		
48	ICD	discharge coefficient table relative number (type 9)
52	[D]	primary nozzle throat diameter
56	[A]	primary nozzle throat area, if [A] = 0, use $A = \pi D^2/4$

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Performance Component EVAP

Evaporator

Purpose: This component will compute the heat exchange and pressure drop for a refrigerant evaporator.

Options: Pressure drop is computed on the source side of the evaporator for the following options:

ISIG = 0 use ΔP

ISIG = 1 use $\sigma\Delta P$

Equations:

<u>for refrigerant</u>

$$H_{in} = f(P_{in}, T_{in})$$

$$P_{out} = P_{in}$$

$$T_{evap} = T_{in}$$

$$T_{out} = T_{evap} + \Delta T_{superheat}$$

$$V_g = f(P_{out}, T_{out})$$

$$H_{out} = f(P_{out}, T_{out}, V_g)$$

$$Q = W(H_{out} - H_{in})$$

<u>for source</u>

$$P_{out} = P_{in} - \Delta P$$

$$\overline{T}_{out} = T_{in} - \varepsilon (T_{in} - T_{evap})$$

$$H_{out} = H_{in}$$

$$T_{out} = f(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

$$\overline{T}'_{out} = T_{in} - Q/W.C_p$$

$$\text{Error Variable} = \overline{T}_{out} - \overline{T}'_{out} \text{ (type 3)}$$

Required Tables:

ΔP or $\sigma\Delta P$ - Table ID(IPD,1) - Source side pressure drop

ε - Table ID(IE,5) - Source side temperature effectiveness

Restrictions:

1. The refrigerant side fluid must be type 3. The source side fluid must be type 1 or 2.

Notes:

1. The following general arguments are set up in this component:
   - argument 41, source side flow rate
   - argument 42, refrigerant side flow rate
   - argument 43, source side inlet pressure
2. Fluid properties:

   C_p - evaluated at T_{in}

   σ - evaluated at P_{in}, T_{in}
3. The component performance printout consists of the following items:

NL	- leg number	for refrigerant and source sides
NSI	- inlet station number	for refrigerant and source sides
NSØ	- outlet station number	for refrigerant and source sides
FT	- fluid type	for refrigerant and source sides
FN	- fluid number	for refrigerant and source sides
W	- flow rate	for refrigerant and source sides
PI	- inlet pressure	for refrigerant and source sides
PØ	- outlet pressure	for refrigerant and source sides
TI	- inlet temperature	for refrigerant and source sides
TØ	- outlet temperature	for refrigerant and source sides
HI	- inlet enthalpy/humidity	for refrigerant and source sides
HØ	- outlet enthalpy/humidity	for refrigerant and source sides
EFF	- source side temperature effectiveness	
Q	- heat transfer	

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Performance Component EVAP

Data Card Format

Card Column	Symbol	Value	
1-4	CN	EVAP component name	
8	CC	change code	
12	NC	card number	
16	NLR	leg number	refrigerant side
20	NSIR	inlet station number	refrigerant side
24	NSØR	outlet station number	refrigerant side
28	NLS	leg number	source side
32	NSIS	inlet station number	source side
36	NSØS	outlet station number	source side
40	ISIG	option = 0 use ΔP = 1 use $\sigma\Delta P$	source side only
44	IPD	source side pressure drop table relative number (type 1)	
48	IE	source side temperature effectiveness table relative number (type 5)	
52	[DSH]	refrigerant outlet degrees of superheat	

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Performance Component FAN

Fan

Purpose: This component will compute fan performance.

Equations:

$$P_{out} = P_{in} + \Delta P$$

$$\overline{T}_{out} = T_{in} + [T_{in} \, (PR^{\gamma-1/\gamma} - 1)/\eta_f]$$

$$H_{out} = H_{in}$$

$$T_{out} = f\,(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

$$HP = 0.02356 \, W \, C_p \, (T_{in} - \overline{T}_{out})/\eta_m$$

Required Tables:

ΔP - Table ID(IFT,16) - Fan pressure rise

η_f - Table ID(IFT,17) - Fan efficiency

Restrictions:

1. This component may only be used for fluid type 2.
2. The FAN shaft number must be previously defined (see component SHAFT).

Notes:

1. The following general arguments are set up in this subroutine:
   - argument 28 - inlet volumetric flow (cfm)
   - argument 41 - flow in leg
2. Fluid properties:

   ρ - evaluated at P_{in}, T_{in}

   γ - evaluated at T_{in}

   C_p - evaluated at T_{in}
3. A shaft power balance may be obtained by inserting a SPØWER card (see component SPØWER).
4. The component performance printout consists of the following items:

   NL - leg number

   NSI - inlet station number

NSØ - outlet station number
FT - fluid type
FN - fluid number
W - flow rate
PI - inlet pressure
PØ - outlet pressure
TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity
HØ - outlet humdiity
SHAFT - shaft number
CFM - inlet volumetric flow
EFF - static efficiency
HP - fan horsepower

Performance Component FAN

Data Card Format

Card Column	Symbol	Value
1-3	CN	FAN component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	NST	shaft number
32	IFT	pressure rise table relative number (type 16)
		static efficiency table relative number (type 17)
36	[ME]	mechanical efficiency /03

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Performance Component HXA

Heat Exchanger

Purpose: This component will compute heat transfer and pressure drops. for both sides of a heat exchanger when both inlet flows have been defined.

Options: Pressure drops are computed for sides 1 and 2 with the following options:

ISIG = 0 use ΔP side 1 and 2

ISIG = 1 use $\sigma\Delta P$ side 1; ΔP side 2

ISIG - 2 use ΔP side 1; $\sigma\Delta P$ side 2

ISIG = 3 use $\sigma\Delta P$ side 1 and 2

Equations:

$$P_{out} = P_{in} - \Delta P \qquad \text{sides 1 and 2}$$

$$\overline{T}_{out_1} = T_{in_1} - \varepsilon_1 (T_{in_1} - T_{in_2})$$

$$\varepsilon_2 = (W_1 C_{p_1} / W_2 C_{p_2}) \varepsilon_1$$

$$\overline{T}_{out_2} = T_{in_2} + \varepsilon_2 (T_{in_1} - T_{in_2})$$

$$H_{out_1} = H_{in_1}$$

$$H_{out_2} = H_{out_2}$$

$$T_{out_1} = f (P_{in_1}, T_{in_1}, H_{in_1}, P_{out_1}, \overline{T}_{out_1}, H_{out_1})$$

$$T_{out_2} = f (P_{in_2}, T_{in_2}, H_{in_2}, P_{out_2}, \overline{T}_{out_2}, H_{out_2})$$

Required Tables:

ΔP or $\sigma\Delta P$ - Table ID (IPD1, 1) - Pressure drop side 1

ΔP or $\sigma\Delta$ - Table ID (IPD2, 1) - Pressure drop side 2

ε_1 - Table ID (IE,5) - Temperature effectiveness side 1

Restrictions:

1. This component can only use fluid types 1 and 2.

Notes:

1. The following general arguments are set up in this component:
   - argument 41, flow in side 1
   - argument 42, flow in side 2
   - argument 43, inlet pressure side 1
   - argument 44, inlet pressure side 2
2. Fluid properties

   C_p - evaluated a T_{in}

   σ - evaluated at $T_{avg} = (T_{in} + \overline{T}_{out})/2$
3. The temperature effectiveness of both side 1 and side 2 will be limited: $0 \leq \varepsilon_1 \leq 1$; $0 \leq \varepsilon_2 \leq 1$. The user should check the component output to determine whether values have been limited.
4. The component performance printout consists of the following items:

NL	- leg number	side 1 and 2
NSI	- inlet station number	
NSØ	- outlet station number	
FT	- fluid type	
FN	- fluid number	
W	- flow rate	
PI	- inlet pressure	
PØ	- outlet pressure	
TI	- inlet temperature	
TØ	- outlet temperature	
HI	- inlet humidity	
HØ	- outlet humidity	

EF1 - side 1 effectiveness

EF2 - side 2 effectiveness

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Performance Component HXA

Data Card Format

Card Column	Symbol	Value
1-3	CN	HXA component name
8	CC	change code
12	NC	card number
16	NL1	leg number
20	NSI1	inlet station number (side 1)
24	NSØ1	outlet station number (side 1)
28	NL2	leg number
32	NSI2	inlet station number (side 2)
36	NSØ2	outlet station number (side 2)
40	ISIG	option = 0 use ΔP both sides = 1 use σΔP side 1 = 2 use σΔP side 2 = 3 use σΔP both sides
44	IPD1	side 1 pressure drop table relative number (type 1)
48	IPD2	side 2 pressure drop table relative number (type 1)
52	IE	side 1 temperature effectiveness table relative number (type 5)

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Performance Component HXB
Heat Exchanger

Purpose: This component will compute heat transfer and pressure losses for a heat exchanger where only one inlet flow has defined values and the other inlet flow has not yet been defined. This component may be used to compute the performance for a regenerative type heat exchanger. Two state variables are set up (types 1 and 3) the first time the heat exchanger appears in the component data cards (HXB1). Two error variables are computed (types 1 and 3) the second time the heat exchanger appears in the component data cards (HXB2).

Options: Pressure drops are computed for sides 1 and 2 with the following options:

ISIG = 0 use ΔP

ISIG = 1 use $\sigma\Delta P$

Equations:

State Variable 1 = W_2 assumed (type 1) (optional)

State Variable 2 = T_2 assumed (type 3)

$P_{out} = P_{in} - \Delta P$ sides 1 and 2

$$\overline{T}_{out_1} = T_{in_1} - \varepsilon_1 (T_{in_1} - T_{in_2})$$

$$\varepsilon_2 = (W_1 C_{p_1} / W_2 C_{p_2}) \varepsilon_1$$

$$\overline{T}_{out_2} = T_{in_2} + \varepsilon_2 (T_{in_1} - T_{in_2})$$

$$H_{out_1} = H_{in_1}$$

$$H_{out_2} = H_{in_2}$$

$$T_{out_1} = f(P_{in_1}, T_{in_1}, H_{in_1}, P_{out_1}, \overline{T}_{out_1}, H_{out_1})$$

$$T_{out_2} = f(P_{in_2}, T_{in_2}, H_{in_2}, P_{out_2}, \overline{T}_{out_2}, H_{out_2})$$

Error Variable 1 = W_2 assumed - W_2 computed (type 1) (optional)

Error Variable 2 = T_2 assumed - T_2 computed (type 3)

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Required Tables:

ΔP or $\sigma\Delta P$ - Table ID(IPD1,1) - Pressure drop side 1

ΔP or $\sigma\Delta P$ - Table ID(IPD2,1) - Pressure drop side 2

ε_1 - Table ID(IE,5) - Temperature effectiveness side 1

Restrictions:

1. This component can only use fluid types 1 and 2.
2. HXB1 side 1 is leg with known values, and HXB2 side 1 is leg with unknown values (i.e., side 1 and side 2 are reversed on HXB2).

Notes:

1. If no initial guess is input for side 2 flow rate and temperature, the initial guess is assigned the same values as the flow rate and temperature for side 1. This normally results in larger error variables being computed than if the user inputs a guess.
2. The following general arguments are set up in this component:
   - arugment 41, flow in HXB1, side 1
   - argument 42, flow in HXB1, side 2
   - argument 43, inlet pressure HXB1, side 1
   - argument 44, inlet pressure HXB1, side 2
3. Fluid properties

   C_p - evaluated at T_{in}

   σ - evaluated at P_{in}, $T_{avg} = (T_{in} + \overline{T}_{out})/2$
4. No state variable for flow rate is set up if the leg numbers for side 1 and side 2 are the same.
5. The component performance printout consists of the following items:

NL	- leg number	side 1 and 2
NSI	- inlet station number	
NSØ	- outlet station number	
FT	- fluid type	
FN	- fluid number	
W	- flow rate	

PI	- inlet pressure	side 1 and 2
PØ	- outlet pressure	
TI	- inlet temperature	
TØ	- outlet temperature	
HI	- inlet humidity	
HØ	- outlet humidity	
EFF	- effectiveness	

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Performance Component HXB

Data Card Format

Card Column	Symbol	Value	
1-4	CN	HXB1 or HXB2 component name	
8	CC	change code	
12	NC	card number	
16	NL1	leg number	side 1
20	NSI1	inlet station number	side 1
24	NSØ1	outlet station number	side 1
28	NL2	leg number	side 2
32	NSI2	inlet station number	side 2
36	NSØ2	outlet station number	side 2
40	ISIG	option = 0 use ΔP = 1 use $\sigma\Delta P$	
44	IPD1	side 1 pressure drop table relative number (type 1)	

for HXB1 data card only

Card Column	Symbol	Value
48	IE	side 1 temperature effectiveness table relative number (type 5)
52	[W2]	side 2 flow rate initial guess (optional)
56	[TI2]	side 2 inlet temperature initial guess (optional)

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Performance Component INJECT

Water Injector

Purpose: This component will compute the mass and energy balance for the addition of water to a gas flow.

Equations:

$$W_{out} = W_{in} + W_{water}$$

$$P_{out} = P_{in}$$

$$T_{out} = T_{in}$$

$$H_{out} = W_{out} \, (1 + H_{in})/W_{in} - 1$$

$$T_{out} = f \, (P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

Restrictions:

1. The inlet leg must use fluid type 2 and the water leg must be fluid type 1.

Notes:

1. A message will be printed if the pressure in the water leg is less than the pressure in the inlet leg. The mass and energy balance will be computed regardless of the message.
2. The component performance printout consists of the following items:

   NL - leg number
   NS - station number
   FT - fluid type
   FN - fluid number
   W - flow rate
   P - pressure
   T - temperature
   H - humidity

   for inlet, water and outlet legs

Performance Component INJECT

Data Card Format

Card Column	Symbol	Value
1-6	CN	INJECT component name
8	CC	change code
12	NC	card number
16	NLI1	inlet leg number
20	NSI1	inlet station number
24	NLI2	water leg number
28	NSI2	water station number
32	NLØ	outlet leg number
36	NSØ	outlet station number

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Performance Component INLET

Inlet to ECS

Purpose: This component specifies an inlet to the ECS. Values of flow, pressure, temperature and humidity for the flow leg are defined. The user may specify either constant values or assumed values which are allowed to vary to balance the system.

Options: The values may be input as constant values or assumed values as specified by the code work ijkℓ. The digit i specifies the flow rate option, the digit j the pressure option, the digit k the temperature option, and the digit ℓ the humidity option. If the digit is 0, the respective value is a known value and if the digit is 1 the value is assumed. The following state variables may be set up:

State variable type 1 - flow
State variable type 2 - pressure
State variable type 3 - temperature
State variable type 4 - humidity

Required Tables:

- - Table ID(IFN,10) - Fluid properties

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Performance Component INLET

Data Card Format

Card Column	Symbol	Value
1-5	CN	INLET component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NS	station number
24	IØP	option = ijkℓ
		i = 0 flow rate known
		21 i = 1 flow rate unknown
		j = 0 pressure known
		22 j = 1 pressure unknown
		k = 0 temperature known
		23 k = 1 temperature unknown
		ℓ = 0 humidity known
		24 ℓ = 1 humidity known
28	[W]	inlet flow rate (initial guess if i = 1) Location
32	[P]	inlet pressure (initial guess if j = 1)
36	[T]	inlet temperature (initial guess if k = 1)
40	[H]	inlet humidity (initial guess if ℓ = 1)
44	IFT	inlet fluid type
48	IFN	inlet fluid property table relative number (type 10)

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Performance Component LINE

Line

Purpose: This component will compute pressure drop and heat exchange for a circular or non-circular flow passage.

Options: Pressure drops are computed by the following options:

ITE = 0 - ΔP or $\sigma\Delta P$ is read from a table

ITE = 1 - ΔP is calculated from equation 1

ITE = 2 - ΔP or $\sigma\Delta P$ is calculated from equation 2

Heat exchange to the fluid is optional for all pressure drop calculations.

Equations:

$$P_{out} = P_{in} - \Delta P$$

where

$$\left.\begin{matrix}\Delta P \\ \sigma\Delta P\end{matrix}\right\} = \text{table lookup}$$

or

\# of bends

$$\Delta P = 6.216 \times 10^{-4} \left(4\, f\, \overset{\ell}{\cancel{L}}/D + \underline{C}\, K_t\right) W^2/\rho A^2 \qquad (1)$$

or

$$\left.\begin{matrix}\Delta P \\ \sigma\Delta P\end{matrix}\right\} = KW^2 \qquad (2)$$

$$T_f = (T_{in} + \overline{T}_{out})/2$$

$$Q_t = UA\,(T_s - T_f) \cdot B1 + Q\,B2$$

$$\overline{T}_{out} = T_{in} + Q_t/W\,C_p$$

$$H_{out} = H_{in}$$

$$T_{out} = f\,(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

Required Tables:

for ITE = 0 only

ΔP or $\sigma\Delta P$ - Table ID (IPD,1) - Pressure drop for ITE = 1 only

f - Table ID (IF,3) - Friction factor

K_t - Table ID (IKT,2) - Pressure loss coefficient

optional

UA - Table ID (IUA,11) - Overall heat transfer coefficient

T_S - Table ID (ITS,12) - Source/Sink temperature

Q - Table ID (IQ,13) - Heat Load

Restrictions:

1. This component can use only fluid types 1 and 2.

Notes:

1. The following general argument is setup in this component:
   - argument 21, Reynolds number
   - argument 41, flow in leg
2. Fluid properties:

   C_T - evaluated T_{in}

   μ - evaluated at T_{avg}

   ρ - evaluated P_{in}, T_{avg}

   σ - evaluated P_{in}, T_{avg}

   where $T_{avg} = (T_{in} + \overline{T}_{out})/2$
3. The component performance printout consists of the following items:

   NL - leg number

   NSI - inlet station number

   NSØ - outlet station number

   FT - fluid type

   FN - fluid number

   W - flow rate

   PI - inlet pressure

   PØ - outlet pressure

   TI - inlet temperature

   TØ - outlet temperature

   HI - inlet humdiity

   HØ - outlet humidity

   QT - heat load

(if $[A] \neq 0$)

V - fluid velocity (fluid types 1 and 2)

M - fluid Mach number (fluid type 2)

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Performance Component LINE

Data Card Format

Card Column	Symbol	Value
1-4	CN	LINE component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	ISIG	option (for ITE = 0 or 2) = 0 use ΔP = 1 use $\sigma\Delta P$
32	ITE	table or equation option = 0 use table for pressure drop = 1 use equation 1 = 2 use equation 2
if ITE = 0		
36	IPD	pressure drop table relative number (type 1)
if ITE = 1		
36	IF	friction factor table relative number (type 3)
40	[C]	constant # Bends
44	IKT	K_t table relative number (type 2)
48	[L]	length
52	[D]	hydraulic diameter
56	[A]	cross-sectional area; if [A] = 0, use $A = \pi D^2/4$
if ITE = 2		
44	[K]	loss coefficient
52	[D]	hydraulic diameter (optional)
56	[A]	cross sectional area; if [A] = 0, use $A = \pi D^2/4$ (optional)

60	IUA	overall heat transfer coefficient table relative number (type 11)	
64	ITS	source/sink temperature table relative number (type 12)	
68	[B1]	multiplier	optional
72	IQ	heat load table relative number (type 13)	
76	[B2]	multiplier	

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Performance Component LØØP

Fluid Loop

Purpose: This component specifies the start and end of a fluid loop. The loop is fictitiously cut, forming a loop start and loop end. The loop is started by a LØØPS card and ended by a LØØPE card. Values of flow rate, pressure, temperature, and humidity are defined for the starting flow leg. The user may specify either known values or assumed values which are allowed to vary to balance the system.

Options: Loop start

The loop starting values may be input as known values or assumed values as specified by the code word ijkℓ on the LØØPS data card. The digit i specifies the flow rate option, the digit j the pressure option, the digit k the temperature option, and the digit ℓ the humidity option. If the digit is 0 the respective value is known and if the digit is 1 the value is assumed. The following state variables may be set up:

State variable type 1 - flow

State variable type 2 - pressure

State variable type 3 - temperature

State variable type 4 - humidity

Loop end

The loop end values which are to be matched are specified by the code word ijkℓ on the LØØPE data card. The digit i specifies the flow rate option, the digit j the pressure option, the digit k the temperature option, and the digit ℓ the humidity option. If the digit is 0 no matching of start and end values will occur and if the digit is 1 the values will be matched. The following error variables may be set up.

Error variable type 1 - flow

Error variable type 2 - pressure

Error variable type 3 - temperature

Error variable type 4 - humidity/enthalpy

Equations:

Error Variable = loop start value - loop end value

(A17.1)(LØØP)

Required Tables:

-- Table ID (IFN,10) - Fluid properties

Restrictions:

1. Conditions at the loop end which will automatically be satisfied must not be specified as error variables on the LØØPE data card. For example, a loop containing only one flow leg will automatically balance the flow rate at the loop end.
2. A refrigerant loop cannot select enthalpy as a state variable. The loop starting pressure and temperature must define a superheated or saturated vapor.

10,395-10

Performance Component LØØP

Data Card Format

LOOP 20,20 90,395

Card Column	Symbol	Value
1-5	CN	LØØPS component name
8	CC	change code
12	NC	card number
16	NLI	inlet leg number
20	NSI	inlet station number
24	NLØ	outlet leg number
28	NSØ	outlet station number
32	IFT	fluid type
36	IFN	fluid property table relative number (type 10)
40	IØP	option = ijkℓ i = 0 flow rate known i = 1 flow rate unknown j = 0 pressure known j = 1 pressure unknown k = 0 temperature known k = 1 temperature unknown ℓ = 0 humidity known ℓ = 1 humidity unknown
44	[W]	loop starting values and/or initial guesses
48	[P]	
52	[T]	
56	[H]	

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Performance Component LØØP

Data Card Format

Card Column	Symbol	Value
1-5	CN	LØØPE component name
8	CC	change code
12	NC	card number
16	NLI	inlet leg number
20	NSI	inlet station number
24	NLØ	outlet leg number
28	NSØ	outlet station number
32	IØP	option = ijkℓ
		i = 0 no flow error
		i = 1 flow error
		j = 0 no pressure error
		j = 1 pressure error
		k = 0 no temperature error
		k = 1 temperature error
		ℓ = 0 no humidity/enthalpy error
		ℓ = 1 humidity/enthalpy error

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Performance Component MERGE

Flow Merge

Purpose: This component will merge two flow lines into one line.

Options: The flow merge is computed with the following options:

Option - 1 - Symmetric merge, no error variable is computed

Option 0 - Merge, no pressure balance required, no error variable computed

Option 1 - Merge, pressure balance required, type 2 error variable computed

Equations:

for IØP = -1 only

$$W_{out} = 2 \cdot W_{in_1}$$

$$P_{out} = P_{in_1}$$

$$T_{out} = T_{in_1}$$

$$H_{out} = H_{in_1}$$

for IØP = 0 or 1

$$W_{out} = W_{in_1} + W_{in_2}$$

for IØP = 0

$$P_{out} = P_{in_1}$$

for IØP = 1

$$P_{out} = (P_{in_1} \cdot W_{in_1} + P_{in_2} \cdot W_{in_2})/W_{out}$$

$$\overline{T}_{out} = (W_{in_1} \cdot C_{p_1} \cdot T_{in_1} + W_{in_2} \cdot C_{p_2} \cdot T_{in_2})/(W_{out}\ C_{p_{out}})$$

$$C1 = H_{in_1}/(1.0 + H_{in_1})$$

$$C2 = H_{in_2}/(1.0 + H_{in_2})$$

$$H_{out} = (C1 \cdot W_{in_1} + C2 \cdot W_{in_2})/(W_{out} - C1 \cdot W_{in_1} + C2 \cdot W_{in_2})$$

$$T_{out} = f\,(P_{in_1}, T_{in_1}, H_{in_1}, P_{in_2}, T_{in_2}, H_{in_2}, P_{out}, \overline{T}_{out}, H_{out})$$

Error Variable = $P_{in_1} - P_{in_2}$ (type 2) (optional)

Notes:

1. Fluid properties:

   C_{p_1} - evaluated at T_{in_1}

   C_{p_2} - evaluated at T_{in_2}

   $C_{p_{out}}$ - evaluated at $T = (W_{in_1} \cdot T_{in_1} + W_{in_2} \cdot T_{in_2})/W_{out}$

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Performance Component MERGE

Data Card Format

Card Column	Symbol	Value
1-5	CN	MERGE component name
8	CC	change code
12	NC	card number
16	NLI1	inlet 1 leg number
20	NSI1	inlet 1 station number
24	NLI2	inlet 2 leg number (not required if IOP = -1)
28	NSI2	inlet 2 station number (not required if IØP = -1)
32	NLØ	outlet leg number
36	NSØ	outlet station number
40	IØP	option = -1 symmetric merge = 0 merge (no pressure balance) = 1 merge (pressure balance)

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Performance Component MISC

Miscellaneous Operations

Purpose: This component may be used to compute any value desired using basic mathematical expressions. The result of the operation may be a function of one or two variables. The result may be a general argument, a flow rate, a pressure, a temperature, a humidity/enthalpy, a parameter table value, a state variable or an error variable. Variables one and two may be any of the above listed types with the addition of a table lookup value.

Options: The operations which are a function of one variable are: equality, absolute value, square root, base ten logarithm, natural logarithm, ten to a power, and e to a power. The operations which are a function of two variables are: addition, subtraction, multiplication, division, the minimum of two variables, the maximum of two variables, variable one to the variable two power, average value, and a code which indicates that variable one is either less than, equal to, or greater than variable two. The last option also allows for skipping data cards. The user may specify if the operation will be done for only the first iteration; for all iterations. The user may set up state and error variables or change state and error variables. The latter options are done for all perturbations and iterations.

Equations:

if IØPR $\leq$ 0

VX = f (V1)

if IØPR > 0

VX = f (V1, V2)

Notes:

1. The component performance printout consists of the following items:

VX - result variable value

IVXT - result variable type

IVXN - result variable relative number

IØPR - operation code

IØPT - option code

V1	- variable value	variable one
IV1T	- variable type	
IV1N	- variable relative number	
V2	- variable value	variable two (printed if IØPR >0)
IV2T	- variable type	
IV2N	- variable relative number	

The printout will not be given for results which are performed only on the first iteration, or for results which generate state variables.

Performance Component MISC

Data Card Format

Card Column	Symbol	Value
1-4	CN	MISC component name
8	CC	change code
12	NC	card number
16	IVXT	result type = 0 - general argument = 1 - flow rate = 2 - pressure = 3 - temperature = 4 - humidity = -1 - parameter value = -2 - not allowed = -3 - state variable = -4 - error variable
20	NVX	result relative number if IVXT = 0 - general argument number = 1 - leg number = 2 - = 3 - station number = 4 - = -1 - parameter index = -2 - not allowed = -3 - zero if IØPT = 1, state variable number if IØPT = -1 = -4 - zero if IØPT = 1, error variable number if IØPT = -1
24	IV1T	variable one type = 0 - general argument = 1 - flow rate = 2 - pressure = 3 - temperature = 4 - humidity = -1 - parameter value = -2 - table (type 99) = -3 - state variable = -4 - error variable
28	NV1	variable one relative number if IV1T = 0 - general argument relative number = 1 - leg number = 2 - = 3 - station number = 4 -

= -1 - parameter index
= -2 - table relative number (type 99)
= -3 - state variable number
= -4 - error variable number

32	IØPR	operation

if IØPR > 0 VX = f(V1, V2)

= 1 - V1 + V2
= 2 - V1 - V2
= 3 - V1 x V2
= 4 - V1 ÷ V2
= 5 - minimum value (V1, V2)
= 6 - maximum value (V1, V2)
= 7 - $V1^{V2}$
= 8 - (V1 + V2)/2
= 9 - $\left\{\begin{array}{l} 0 \text{ if } V1 = V2 \\ 1 \text{ if } V1 > V2 \\ -1 \text{ if } V1 < V2 \end{array}\right\}$ and skip (see ISP, ISZ, and ISM)

if IØPR = 0

VX = V1

if IØPR < 0 VX = f(V1)

= -1 - $|V1|$
= -2 - $\sqrt{V1}$
= -3 - log V1
= -4 - ln V1
= -5 - 10^{V1}
= -6 - e^{V1}

36	IV2T	variable two type V2 (same as IV1T)
40	NV2	variable two relative number (same as NV1)
44	IØPT	option

if IVXT -1, 0, 1, 2, 3, 4

1 perform operation only on first iteration
0 perform operation on all iterations and perturbations
-1 perform operation on all iterations

if IVXT = -3, -4

1 generate result and initialize/generate state variable or compute error variable
-1 change state variable/compute error variable

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if IØPR = 9

48	ISP	number of MISC cards to skip forward if V1 > V2
52	ISZ	number of MISC cards to skip forward if V1 = V2
56	ISM	number of MISC cards to skip forward if V1 < V2

if IVXT = 1 and leg is undefined

60	IFT	fluid type
64	IFN	fluid property table relative number (type 10)

See Vol. IV

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Performance Component NOZZLE

Nozzle

Purpose: This component will compute nozzle performance for choked and unchoked nozzles and ram air exits.

Options: Nozzle performance is calculated using the following options:

IØP = 0 pressure ratio across the nozzle is specified in a table. A type 2 error variable is computed.

IØP = 1 pressure ratio across the nozzle is calculated. A type 1 error variable is computed.

Equations:

$$PR = P_{discharge}/P_{in}$$

$$PR_{critical} = [2/(\gamma+1)]^{\gamma/(\gamma-1)}$$

if $PR < PR_{critical}$, then $PR = PR_{critical}$

<u>if IØP = 0</u>

$$P_{out} = P_{in} \cdot PR$$

$$\text{Error Variable} = P_{out} - P_{discharge}$$

<u>if IØP = 1</u>

$$P_{out} = P_{discharge}$$

$$W_{calc} = \frac{40.124 \cdot C_D \cdot A \sqrt{[\gamma/(\gamma-1)]\ \rho \cdot P_{in}\ [PR^{2/\gamma} - PR^{(\gamma+1)/\gamma}]}}{\sqrt{1 - DR^4\ PR^{2/\gamma}}}$$

$$\text{Error Variable} = W_{in} - W_{calc} \ \text{(type 1)}$$

$$\bar{T}_{out} = T_{in}\ [1 - \eta_n\ (1 - PR^{(\gamma-1)/\gamma})]$$

$$H_{out} = H_{in}$$

$$T_{out} = f\,(P_{in},\ T_{in},\ H_{in},\ P_{out},\ \overline{T}_{out},\ H_{out})$$

Required Tables:

if IØP = 0

PR - Table ID(IPR,4) - Nozzle pressure ratio ($P_{discharge}/P_{in}$)

if IØP = 1

C_D - Table ID(ICD,9) - Nozzle discharge coefficient

η_n - Table ID(IE,17) - Nozzle efficiency

Restrictions:

1. This component can only be used for fluid type 2.

Notes:

1. The following general arguments are set in this component:
   - argument 27, flow ratio (W/W_∞) where $W_\infty = \rho_\infty\ A\ V_\infty$
   - argument 41, flow in leg
2. Fluid properties:

   γ - evaluated at T_{in}

   ρ - evaluated at P_{in}, T_{in}
3. The component performance printout consists of the following items:

   NL - leg number

   NSI - inlet station number

   NSØ - outlet station number

   FT - fluid type

   FN - fluid number

   W - flow rate

   PI - inlet pressure

   PØ - outlet pressure

   TI - inlet temperature

   TØ - outlet temperature

   HI - inlet humidity

   HØ - outlet humidity

   PR - nozzle pressure ratio

   EFF - nozzle adiabatic efficiency

Performance Component NØZZLE

Data Card Format

Card Column	Symbol	Value
1-6	CN	NØZZLE component name
- 8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	[PD]	discharge pressure
32	IØP	option = 0 pressure ratio specified = 1 pressure ratio calculated

if IØP = 0

Card Column	Symbol	Value
36	IPR	nozzle pressure ratio table relative number (type 4)
40	IE	adiabatic efficiency table relative number (type 17)

if IØP = 1

Card Column	Symbol	Value
36	ICD	discharge coefficient table relative number (type 9)
40	IE	adiabatic efficiency table relative number (type 17)
44	[DR]	diameter ratio D_{throat}/D_{line}
48	[D]	throat diameter
52	[A]	throat area; if [A] = 0, use $A = \pi D^2/4$

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Performance Component ØRIF

Orifice

Purpose: This component will compute the pressure loss across an orifice.

Options: Orifice pressure loss is computed with the following options:

ITE = 0 - Liquid pressure loss (ΔP) is read from a table.
- Gas pressure ratio (P_{out}/P_{in}) is read from a table.

ITE = 1 - Liquid pressure loss is computed from equation 1.
- Gas pressure ratio is computed from equation 1.
A state variable type 9 for pressure ratio is set up and an error variable type 1 for flow rate is computed.

Equations:

for fluid type 1 - Liquid

$$P_{out} = P_{in} - \Delta P$$

where

$$\Delta P = \text{table lookup}$$

or

$$\Delta P = \left[W\sqrt{1 - DR^4} / \cancel{(\rho} \cdot (31.513 \cdot C_D \cdot D_t^2)\right]^2 \frac{1}{\rho}$$

for fluid type 2 - Gas

State Variable = PR (type 9) (optional)

$$PR = P_{out}/P_{in} = \text{table lookup}$$

$$P_{out} = P_{in} \cdot \boxed{PR}$$

$$PR_{critical} = [2/(\gamma+1)]^{\gamma/(\gamma-1)}$$

$$W_{calc} = \frac{31.513 \cdot C_D \cdot D_t^2 \sqrt{(\gamma - \cancel{1})/(\gamma-1)\, \rho \cdot P_{in}\, [PR^{2/\gamma} - PR^{(\gamma+1)/\gamma}]}}{\sqrt{1 - DR^4\, PR^{2/\gamma}}}$$

$$\text{Error Variable} = W_{calc} - W_{in}$$

$$\overline{T}_{out} = T_{in}$$

$$H_{out} = H_{in}$$

$$T_{out} = f(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

Required Tables:

for ITE = 0, fluid type 1

ΔP - Table ID (IPD,1) - Pressure loss

for ITE = 0, fluid type 2

PR - Table ID(IPD,4) - Pressure ratio

for ITE = 1, fluid types 1 & 2

C_D - Table ID (ICD,9) - Orifice coefficient

Restrictions:

1. This component may only be used for fluid types 1 and 2.

Notes:

1. The following general arguments are set up in this component.
   - argument 20, diameter ratio D_t/D_{line}
   - argument 21, Reynolds number $0.2565\ W\ D_{line}/\mu$
   - argument 33, flow function $W\sqrt{T_{in}}/(0.78539 \cdot P_{in} \cdot D_t^{2})$
   - argument 41, flow in leg
2. Fluid properties

   ρ - evaluated at T_{in}, P_{in}

   γ - evaluated at T_{in}

   μ - evaluated at T_{in}
3. The component performance printout consists of the following items:

   NL - leg number

   NSL - inlet station number

   NSØ - outlet station number

   FT - fluid type

   FN - fluid number

   W - flow rate

   PI - inlet pressure

   PØ - outlet pressure

   TI - inlet temperature

   TØ - outlet temperature

   HI - inlet humidity

   HØ - outlet humidity

   for fluid type 1

   PD - Pressure drop

for fluid type 2

PR - Pressure ratio

1—6

9.67571
8.70814

Performance Component ØRIF

Data Card Format

Card Column	Symbol	Value
1-4	CN	ØRIF component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	ITE	table or equation option = 0 use table = 1 use equation
if ITE = 0		
32	IPD	pressure drop table relative number - fluid type 1 (type 1) or pressure ratio table relative number - fluid type 2 (type 4)
if ITE = 1		
32	ICD 700	orifice coefficient table relative number (type 9)
36	[DT] 231	throat diameter 6.00
40	[DR] 232	diameter ratio D_{throat}/D_{line} 1.00

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Performance Component ØUTLET

Outlet from ECS

Purpose: This component specifies an outlet from the ECS. The user may specify values of flow rate, pressure, temperature, and humidity which are to be matched.

Options: The values which are to be matched are specified by the code word ijkℓ. The digit i specifies the flow rate option, j the pressure option, k the temperature option, and ℓ the humidity/enthalpy option. If the digit is 0 no matching of the values will occur, and if the digit is 1 the program will balance the model to match the value specified. The following error variables may be set up:

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Error variable type 1 - flow

Error variable type 2 - pressure

Error variable type 3 - temperature

Error variable type 4 - humidity/enthalpy

Equations:

Error Variable = computed value - outlet value

Notes:

1. This component is optional and is not required to terminate a leg if no values are to be matched.

Performance Component ØUTLET
Data Card Format

Card Column	Symbol	Value
1-6	CN	ØUTLET component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NS	station number
24	IØP	option = ijkℓ
		i = 0 no flow rate error
		i = 1 flow rate error
		j = 0 no pressure error
		j = 1 pressure error
		k = 0 no temperature error
		k = 1 temperature error
		ℓ = 0 no humidity/enthalpy error
		ℓ = 1 humidity/enthalpy error
28	[W]	outlet flow rate (if i = 1)
32	[P]	outlet pressure (if j = 1)
36	[T]	outlet temperature (if k = 1)
40	[H]	outlet humidity/enthalpy (if ℓ = 1)

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Performance Component PREG
Pressure Regulator

Purpose: This component will compute the performance of a pressure regulator. A minimum pressure loss is computed across the regulator. If the outlet pressure exceeds the regulator set value, the outlet pressure is reduced to the set value.

Options: Pressure losses are calculated with the following options:

ITE = 0 ΔP or $\sigma\Delta P$ is read from a table

ITE = 1 ΔP is calculated from equation 1

ITE = 2 ΔP or $\sigma\Delta P$ is calculated from equation 2

Equations:

$$P_{out} = P_{in} - \Delta P$$

where

$$\left.\begin{matrix}\Delta P \\ \sigma\Delta P\end{matrix}\right\} = \text{table lookup}$$

or

$$\Delta P = 1.008 \times 10^{-3} K_t W^2/D^4 \qquad (1)$$

or

$$\left.\begin{matrix}\Delta P \\ \sigma\Delta P\end{matrix}\right\} = KW^2 \qquad (2)$$

if $P_{out} > P_{reg}$, then $P_{out} = P_{reg}$

$$\overline{T}_{out} = T_{in}$$

$$H_{out} = H_{in}$$

$$T_{out} = f\,(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

Required Tables:

for ITE = 0 only

ΔP or $\sigma\Delta P$ - Table ID (IPD,1) - Pressure drop

Restrictions:

1. This component can only be used for fluid types 1 and 2.

Notes:

1. The following general argument is set up in this component:
   - argument 41, flow in leg
2. Fluid properties:
   σ - evaluated at P_{in}, T_{in}
   ρ - evaluated at P_{in}, T_{in}
3. The component performance printout consists of the following items:

   NL - leg number
   NSI - inlet station number
   NSØ - outlet station number
   FT - fluid type
   FN - fluid number
   W - flow rate
   PI - inlet pressure
   PØ - outlet pressure
   TI - inlet temperature
   TØ - outlet temperature
   HI - inlet humidity
   HØ - outlet humidity

Performance Component PREG

Data Card Format

Card Column	Symbol	Value
1-5	CN	PREG component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	ISIG	option (for ITE = 0, 2) = 0 use ΔP = 1 use σΔP
32	ITE	table or equation option = 0 use table = 1 use equation 1 = 2 use equation 2
if ITE = 0		
[36	IPD	pressure drop table relative number (type 1)
if ITE = 1		
[36	[KT]	K_t
[40	[D]	diameter
if ITE = 2		
[36	[K]	K
44	[PREG]	regulator pressure setting

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Performance Component PUMP

Pump

Purpose: This component will compute pump performance.

Equations:

$$P_{out} = P_{in} + \Delta P$$

$$FPWR = 4.3636 \times 10^{-3}\ \Delta P\ W/\rho \text{ (fluid power)}$$

$$SPWR = FPWR/\eta_p \text{ (shaft power)}$$

$$HP = SPWR/\eta_m$$

$$Q_t = 42.416\ (SPWR-FPWR)$$

$$T_{out} = T_{in} + Q_t/W \cdot C_p$$

Required Tables:

ΔP - Table ID(IPT,16) - Pump pressure rise

η_s - Table ID(IPT,17) - Pump static efficiency

Restrictions:

1. This component may only be used for fluid type 1.
2. The PUMP shaft number must be previously defined (see component SHAFT).

Notes:

1. The following general arguments are set up in this component:
   - argument 29 - inlet volumetric flow (gpm)
   - argument 31 - pressure rise (ΔP)
   - argument 41 - flow in leg
2. Fluid properties:
   ρ - evaluated at P_{in}, T_{in}
   C_p - evaluated at T_{in}
3. A shaft power balance may be obtained by inserting an SPØWER card (see subroutine SPØWER).

4. The component performance printout consists of the following items:

NL	- leg number	
NSI	- inlet station number	
NSØ	- outlet station number	
FT	- fluid type	
FN	- fluid number	
W	- flow rate	
PI	- inlet pressure	
PØ	- outlet pressure	
TI	- inlet temperature	
TØ	- outlet temperature	
HI	- inlet humidity	not applicable
HØ	- outlet humidity	not applicable
SHAFT	- shaft number	
GPM	- volumetric flow rate	
EFF	- static efficiency	
HP	- pump horsepower	

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Performance Component PUMP

Data Card Format

Card Column	Symbol	Value
1-4	CN	PUMP component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	NST	shaft number
32	IPT	pressure rise table relative number (type 16)
		static efficiency table relative number (type 17)
36	[ME]	mechanical efficiency

Performance Component QLOAD

Compartment Heat Load

Purpose: This component may be used to simulate an equipment compartment or cabin. It allows for both heat transfer and pressure drop.

Options: Pressure drops are computed with the following options:

ISIG = 0 use ΔP

ISIG = 1 use $\sigma\Delta P$

Equations:

$$P_{out} = P_{in} - \Delta P$$

$$Q_t = UA\ (T_s - T_f)\cdot B1 + Q\cdot B2$$

$$T_f = (T_{in} + T_{out})/2$$

$$\overline{T}_{out} = T_{in} + Q_t/W_{in}\cdot C_p$$

$$H_{out} = H_{in}$$

$$T_{out} = F\ (P_{in},\ T_{in},\ H_{in},\ P_{out},\ \overline{T}_{out},\ H_{out})$$

Required Tables:

ΔP or $\sigma\Delta P$ - Table ID(IPD,1) - Pressure drop

optional:

UA - Table ID(IUA,11) - Overall heat transfer coefficient

T_s - Table ID(ITS,12) - Source/Sink temperature

Q - Table ID(IQ,13) - Heat load

Restrictions:

1. This component can use only fluid types 1 and 2.

Notes:

1. The following general argument is set up in this component:
   - argument 41, flow in leg
2. Fluid properties:
   C_p - evaluated at T_{in}
   σ - evaluated at T_{avg}
   where $T_{avg} = (T_{in} + T_{out})/2$

3. The component performance printout consists of the following items:

NL - leg number
NSI - inlet station number
NSØ - outlet station number
FT - fluid type
FN - fluid number
W - flow rate
PI - inlet pressure
PØ - outlet pressure
TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity
HØ - outlet humidity
QT - heat load

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Performance Component QLØAD

Data Card Format

Card Column	Symbol	Value	
1-5	CN	QLØAD component name	
8	CC	change code	
12	NC	card number	
16	NL	leg number	
20	NSI	inlet station number	
24	NSØ	outlet station number	
28	ISIG	option = 0 use ΔP = 1 use $\sigma\Delta P$	
32	IPD	pressure drop table relative number (type 1)	
36	IUA	overall heat transfer coefficient table relative number (type 11)	optional
40	ITS	source/sink temperature table relative number (type 12)	optional
44	[B1]	multiplier	optional
48	IQ	heat load table relative number (type 13)	optional
52	[B2]	multiplier	optional

See VOL. II

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Performance Component SENSØR

Flow rate, Pressure, Temperature, Humidity/Enthalpy Sensor

Purpose: This component represents a flow rate, pressure, temperature, or humidity/enthalpy sensor and will require the system to balance to the desired value.

Options: Error variables are computed with the following options:

ICT = 1 - flow rate sensor error computed (type 1)

ICT = 2 - pressure sensor error computed (type 2)

ICT = 3 - temperature sensor error computed (type 3)

ICT = 4 - humidity/enthalpy sensor error computed (type 4)

Equations:

Error Variable = computed value - control value

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Performance Component SENSØR

Data Card Format

Card Column	Symbol	Value
1-6	CN	SENSØR component name
8	CC	change code
12	NC	card number
16	ICT	control type = 1 flow rate = 2 pressure = 3 temperature = 4 humidity/enthalpy
20	NCS	number of control sensor if ICT = 1 leg number = 2, = 3, = 4 station number
24	[CV]	control value

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Performance Component SHAFT

Shaft Initialization

Purpose: This component will initialize a shaft number for reference by other subroutines, i.e., CØMP, TURB, VCØMP, FAN, PUMP, APU.

Options: This subroutine has the following options:

ISRS = 0 fixed speed or no speed

ISRS = 1 variable speed. A type 7 state variable is setup.

Equations:

State Variable = N (type 7) (optional)

Restrictions:

1. A SHAFT data card defining a shaft must appear before that shaft number is referenced by any other component data cards.
2. Shaft numbers must be limited to values of 1 through 10.

Notes:

1. The component performance printout consists of the following items:

   SHAFT - shaft number

   N - shaft speed

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Performance Component SHAFT

Data Card Format

Card Column	Symbol	Value
1-5	CN	SHAFT component name
8	CC	change code
12	NC	card number
16	NST	shaft number
20	ISRS	speed option = 0 fixed speed or no speed = 1 variable speed
24	[N]	speed value if ISRS = 0 fixed speed or no speed = 1 speed initial guess

See VOL. IV

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Performance Component SPLIT

Flow Split

Purpose: This component will split a flow line into two outlet flow lines.

Options: The flow split is computed with the following options:

Option -1 - Symmetric split. No state variable is set up.

Option 0 - Fixed split ratio. No state variable is set up.

Option 1 - Variable split ratio. A state variable type 6 is set up for the split ratio.

Equations:

State Variable = SR = W_{out1}/W_{in} (type 6) (optional)

for IØP = -1

$$W_{out1} = W_{in}/2$$

for IØP = 0, 1

$$W_{out1} = SR\ W_{in}$$

$$W_{out2} = W_{in} - W_{out1}$$

$$P_{out1} = P_{out2} = P_{in}$$

$$T_{out1} = T_{out2} = T_{in}$$

$$H_{out1} = H_{out2} = H_{in}$$

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Performance Component SPLIT

Data Card Format

Card Column	Symbol	Value
1-5	CN	SPLIT component name
8	CC	change code
12	NC	card number
16	NLI	inlet leg number
20	NSI	inlet station number
24	NLØ1	outlet 1 leg number
28	NSØ1	outlet 1 station number
32	NLØ2	outlet 2 leg number (not required if IØP = -1)
36	NSØ2	outlet 2 station number (not required if IØP = -1)
40	IØP	option = -1 symmetric split = 0 specified split ratio = 1 unknown split ratio
44	[SR]	split ratio (not required if IØP = -1, initial guess if IØP = 1)

W, = S.R. Win

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Performance Component SPØWER

Shaft Power Balance

Purpoeg: This component is used to compute a power balance for a shaft and to specify the power balance desired.

Equations:

Error Variable = Σ(HP) - power balance desired (type 5)

Restrictions:

1. The SPØWER data card for a shaft must follow the last component card which references the shaft number on the SPØWER card.
2. Shaft numbers may only have values of 1 through 10 and must agree with the shaft number referenced on a SHAFT card.

Notes:

1. A power balance on a shaft is optional and may be omitted if the error variable is not required regardless of the shaft speed being specified as state variable.
2. Power required from a shaft (e.g. compressor power) is summed as a negative value and power supplied to a shaft (e.g., turbine) is summed as a positive value.

Performance Component SPØWER

Data Card Format

Card Column	Symbol	Value
1-6	CN	SPØWER component name
8	CC	change code
12	NC	card number
16	NST	shaft number
20	[PØW]	power balance desired

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Performance Component TURB

Turbine

Purpose: This component will compute turbine performance.

Options: Turbine performance is computed with the following options:

Option 0 - Fixed pressure ratio with efficiency read from table. No state variable or error variable is set up.

Option 1 - Variable pressure ratio with efficiency read from table. A type 8 state variable is set up for the pressure ratio.

Option 2 - Efficiency and flow factor maps are used. A type 8 state variable for the pressure ratio and a type 1 error variable for the nozzle flow balance are set up.

Equations:

State Variable = PR (type 8) (optional)

$$P_{out} = P_{in}/PR$$

$$\Delta T_i = T_{in}\,[1 - (1/PR)^{(\gamma-1)/\gamma}]$$

$$\overline{T}_{out} = T_{in} - \eta_t\,\Delta T_i$$

$$H_{out} = H_{in}$$

$$T_{out} = f\,(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

$$HP = 0.02356\,.W.\,C_p\,(T_{in} - \overline{T}_{out})\,\eta_m$$

if IØP = 2

$$W_{calc} = F_f\,P_{in}/\sqrt{T_{in}}$$

Error Variable = W - W_{calc}

Required Tables:

η_t - Table ID(ITT,7) - Turbine efficiency

for IØP = 2 only

F_f - Table ID(ITT,8) - Turbine flow factor

Restrictions:

1. This component can only be used for fluid type 2.

Notes:

1. The following general arguments are set up in this component :
   - argument 24, pressure ratio P_{in}/P_{out}
   - argument 23, velocity factor $N/\sqrt{\Delta T_i}$
   - argument 25, corrected speed $N/\sqrt{T_{in}/519}$
   - argument 41, flow in leg
2. Fluid properties:

   γ - evaluated at T_{in}

   C_p - evaluated at $T_{avg} = (T_{in} + T_{out})/2$
3. A shaft power balance may be obtained by inserting a SPØWER card (see component SPOWER).
4. The component performance printout consists of the following items:

   NL - leg number
   NSI - inlet station number
   NSØ - outlet station number
   FT - fluid type
   FN - fluid number
   W - flow rate
   PI - inlet pressure
   PØ - outlet pressure
   TI - inlet temperature
   TØ - outlet temperature
   HI - inlet humidity
   HØ - outlet humidity
   SHAFT - shaft number
   PR - pressure ratio
   EFF - turbine efficiency
   HP - turbine power

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Performance Component TURB

Data Card Format

Card Column	Symbol	Value
1-4	CN	TURB component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	NST	shaft number
32	IØP	option = 0 - fixed pressure ratio = 1 - variable pressure ratio (no map) = 2 - variable pressure ratio (map)
36	[PR]	pressure ratio P_{in}/P_{out} if IØP = 0 fixed pressure ratio = 1, = 2 } pressure ratio assumed value
40	ITT	efficiency table relative number (type 7) also if IØP = 2 flow factor table relative number (type 8)
44	[ME]	mechanical efficiency

See VOL IV

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Performance Component VALVE

Valve

Purpose: This component will compute the pressure drop in a fixed valve.

Options: Pressure drops are computed by the following options.

ITE = 0 ΔP or $\sigma\Delta P$ is read from a table

ITE = 1 ΔP is calculated from equation 1

ITE = 2 ΔP or $\sigma\Delta P$ is calculated from equation 2

Equations:

$$P_{out} = P_{in} - \Delta P$$

where

$$\left.\begin{matrix}\Delta P \\ \sigma\Delta P\end{matrix}\right\} = \text{table lookup}$$

or

$$\Delta P = 1.008 \times 10^{-3} K_t W^2/\rho D^4 \qquad (1)$$

or

$$\left.\begin{matrix}\Delta P \\ \sigma\Delta P\end{matrix}\right\} = KW^2 \qquad (2)$$

$$\overline{T}_{out} = T_{in}$$

$$H_{out} = H_{in}$$

$$T_{out} = f\,(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

Required Tables:

for ITE = 0 only

ΔP or $\sigma\Delta P$ - Table ID (IPD,1) - Pressure drop

Restrictions:

1. This component can use only fluid types 1 and 2.

Notes:

1. The following general argument is set up in this component:
   - argument 41, flow in leg
2. Fluid properties:
   - σ - evaluated at P_{in}, T_{in}
   - ρ - evaluated at P_{in}, T_{in}

3. The component performance printout consists of the following items:

NL - leg number
NSI - inlet station number
NSØ - outlet station number
FT - fluid type
FN - fluid number
W - flow rate
PI - inlet pressure
PØ - outlet pressure
TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity
HØ - outlet humidity

Performance Component VALVE

Data Card Format

Card Column	Symbol	Value
1-5	CN	VALVE component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	ISIG	option (for ITE = 0, 2) = 0 use ΔP = 1 use σΔP
32	ITE	table or equation option = 0 use table = 1 use equation 1 = 2 use equation 2
if ITE = 0		
[36	IPD	pressure drop table relative number (type 1)
if ITE = 1		
[36	[KT]	K_t
40	[D]	diameter
if ITE = 2		
[36	[K]	K

Performance Component VCØMP

Vapor Cycle Compressor

Purpose: This component will compute vapor cycle compressor performance.

Options: Vapor cycle compressor performance is computed with the following options:

IØP = 0 - Fixed pressure ratio with efficiency read from a table. No state variable or error variable is set up.

IØP = 1 - Variable pressure ratio with efficiency read from a table. A type 8 state variable is set up for the pressure ratio.

IØP = 2 - Pressure ratio and efficiency maps are used. No state variable or error variable is set up.

Equations:

State Variable = PR (type 8) (optional)

$$P_{out} = P_{in} \cdot PR$$

$$V_{in} = f(P_{in}, T_{in})$$

$$H_{in} = f(P_{in}, T_{in}, V_{in})$$

$$S_{in} = f(T_{in}, V_{in})$$

$$S'_{out} = S_{in}$$

$$T'_{out}, V'_{out} = f(P_{out}, S'_{out})$$

$$H'_{out} = f(P_{out}, T'_{out}, V'_{out})$$

$$H_{out} = H_{in} + (H'_{out} - H_{in})/\eta_c$$

$$T_{out} = f(P_{out}, H_{out})$$

$$HP = 0.02356 \cdot W (H_{in} - H_{out})$$

Required Tables:

η_c - Table ID(ICT,6) - Compressor efficiency

for IØP = 2 only

PR - Table ID(ICT,4) - Compressor pressure ratio

Restrictions:

1. This component can only be used for fluid type 3.
2. The VCØMP shaft number must be previously defined (see component SHAFT).
3. The inlet state of the compressor must be a saturated or superheated vapor.

Notes:

1. The following general arguments are set up in this component:
   - argument 28, inlet volumetric flow (cfm)
   - argument 41, flow in leg
2. A shaft power balance may be obtained by inserting a SPØWER data card (see SPØWER component).
3. The component performance printout consists of the following items:

   NL - leg number
   NSI - inlet station number
   NSØ - outlet station number
   FT - fluid type
   FN - fluid number
   W - flow rate
   PI - inlet pressure
   PØ - outlet pressure
   TI - inlet temperature
   TØ - outlet temperature
   HI - inlet enthalpy
   HØ - outlet enthalpy
   SHAFT - shaft number
   PR - compressor pressure ratio
   EFF - compressor efficiency
   HP - compressor horsepower

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Performance Component VCØMP
Data Card Format

Card Column	Symbol	Value
1-5	CN	VCØMP component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	NST	shaft number
32	IØP	option = 0 fixed pressure ratio = 1 variable pressure ratio (no map) = 2 variable pressure ratio (map)
36	[PR]	pressure ratio if IØP = 0 fixed pressure ratio = 1 pressure ratio initial guess = 2 not used
40	ICT	efficiency table relative number (type 6) also if IØP = 2 pressure ratio table relative number (type 4)
44	[ME]	mechanical efficiency

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Performance Component VLINE

Vapor Line

Purpose: This component will compute a pressure loss in a refrigerant line.

Equations:

$$P_{out} = P_{in} - \Delta P$$

$$H_{out} = H_{in}$$

$$T_{out}, V_{out} = f\ (H_{out}, P_{out})$$

Required Tables:

ΔP - Table ID (IPD,1) - Pressure drop

Restrictions:

1. This component can only be used for fluid type 3
2. The state of the refrigerant must be a saturated or superheated vapor.

Notes:

1. The following general argument is set up in this component
   - argument 41 - flow in leg

Performance Component VLINE

Data Card Format

Card Column	Symbol	Value
1-5	CN	VLINE component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	-	
32	IPD	pressure drop table relative number (type 1)

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Performance Component WSEP

Water Separator

Purpose: This component will compute water separator moisture removal and pressure drop.

Options: The water separator pressure drop may be computed with the following options:

ISIG = 0 ΔP is read from a table

ISIG = 1 $\sigma\Delta P$ is read from a table

Equations:

$$P_{out} = P_{in} - \Delta P$$

$$\overline{T}_{out} = T_{in}$$

$$H_{sat} = f\ (P_{out}, \overline{T}_{out})$$

<u>if $H_{in} \leq H_{sat}$</u>

$$H_{out} = H_{in}$$

$$W_{out} = W_{in}$$

$$W_{drain} = 0.0$$

<u>if $H_{in} > H_{sat}$</u>

$$\Delta H = \eta\ (H_{in} - H_{sat})$$

$$H_{out} = H_{in} - H_{out}$$

$$\Delta W = \Delta H \cdot W/(1 + H_{in})$$

$$W_{out} = W_{in} - \Delta W$$

$$W_{drain} = \Delta W$$

$$T_{out} = f\ (P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$$

Required Tables:

ΔP or $\sigma\Delta P$ - Table ID(IPD,1) - Pressure drop

η - Table ID(IEF,17) - Water separator efficiency

Restrictions:

1. This component may only be used for fluid type 2.

Notes:

1. The following general arguments are set up in this component :
   - argument 30, wet/dry entrained moisture code
     $= 0.0$ if $H_{in} < H_{sat}$
     $= 1.0$ if $H_{in} \geq H_{sat}$
   - argument 41, flow in leg
2. Fluid properties:
   σ - evaluated at P_{in}, T_{in}
3. The component performance printout consists of the following items:

NL	- leg number	for inlet, outlet, and drain leg
NS	- station number	
FT	- fluid type	
FN	- fluid number	
W	- flow rate	
P	- pressure	
T	- temperature	
H	- humidity	
EFF	- water separator efficiency	

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Performance Component WSEP

Data Card Format

Card Column	Symbol	Value
1-4	CN	WSEP component name
8	CC	change code
12	NC	card number
16	NLI	inlet leg number
20	NSI	inlet station number
24	NLØ1	outlet leg number
28	NSØ2	outlet station number
32	NLØ2	water drain leg number
36	NSØ2	water drain station number
40	ISIG	option = 0 use ΔP = 1 use σΔP
44	IPD	pressure drop table relative number (type 1)
48	IEF	water collection efficiency table relative number (type 17)

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APPENDIX B

SIZING COMPONENTS

Component Name	Component	Section
APU	Auxiliary Power Unit	B1
BØIL	Boiler	B2
CNTRL	System Control	B3
CØMP	Compressor	B4
CØND	Condenser	B5
DSEP	Dust Separator	B6
EJECT	Ejector	B7
EVAP	Evaporator	B8
FAN	Fan	B9
HEATER	Resistance Heater	B10
HX	Heat Exchanger	B11
INIT	Initialization	B12
INSLTN	Insulation	B13
LINE	Line	B14
MISC	Miscellaneous Operations	B15
PUMP	Pump	B16
RIN	Ram Air Inlet	B17
RØUT	Ram Air Outlet	B18
TURB	Turbine	B19
VALVE	Valve	B20
VCØMP	Vapor Cycle Compressor	B21
WSEP	Water Separator	B22

Notes: 1. Data card fields which refer to the parameter table are indicated by brackets, [ ].

2. A card column specified by a single value represents the righthand column of a four column integer data field. Data values punched in these fields must be right justified.

— See ACFS

Sizing Component APU

Auxiliary Power Unit

Purpose: This component will compute weight, cost units, reliability index, development risk factor, fuel flow rate, and volume for APU. The available APU types are:

IAPUT	Type
1	bleed air extraction with or without shaft power extraction
2	shaft power extraction only

Equations:

1. Weight:

For IAPUT = 1:

$$Wt = \frac{0.398\,(EHP)_{ECS}}{(4.215 \times 10^{-4})(EHP)_T + 0.159}$$

For IAPUT = 2:

$$Wt = \frac{0.398\,(EHP)_{ECS}}{(6.29 \times 10^{-4})(EHP)_T + 0.253}$$

where

$$(EHP)_{ECS} = (HP)_{shaft} + W\,C_p\,T_{out}\left[1 - \left(\frac{P_{out}}{P_{in}}\right)^{\frac{1-\gamma}{\gamma}}\right]/42.42$$

$$(EHP)_T = (EHP)_{ECS} + (HP)_{other\ system}$$

2. Cost Units:

$$CU = 7.3(EHP)_{ECS}$$

3. Reliability Index:

$$RI = 0.24971$$

4. Development Risk Factor:

$$DR = 1.15$$

5. Weight Standard Error:

For IAPUT = 1:

$$Wt_d = 0.1809\ Wt$$

For IAPUT = 2:

$$Wt_d = 0.3241\ Wt$$

6. Installation Weight Factor:

$$Wt_i = 1.5126\ Wt$$

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7. Fuel Flow Rate:

For IAPUT = 1:

$$W_{fu} = [1.5 - 1.158 \times 10^{-3}(EHP)_T](EHP)_{ECS}$$

For IAPUT = 2:

$$W_{fu} = [1.55 - 2.43 \times 10^{-3}(EHP)_T](EHP)_{ECS}$$

8. Volume:

For IAPUT = 1:

$$V = \frac{(EHP)_{ECS}}{(1.343 \times 10^{-5})(EHP)_T + 2.95 \times 10^{-3}}$$

For IAPUT = 2:

$$V = \frac{(EHP)_{ECS}}{(9.919 \times 10^{-6})(EHP)_T + 6.83 \times 10^{-3}}$$

Restrictions:

1. This component can only be used for fluid type 2.

Notes:

1. The component printout consists of weight, cost units, reliability index, development risk factor, and the following items:

W	- flow rate	for APU with bleed air extraction by ECS
PI	- inlet pressure	
PØ	- outlet pressure	
TI	- inlet temperature	
TØ	- outlet temperature	
HI	- inlet humidity	
HØ	- outlet humidity	
FT	- fluid type	
FN	- fluid properties table relative number	
SHAFT	- shaft number	for APU with shaft power extraction by ECS
SHP	- shaft horsepower	
VØL	- volume	
WTBT	- total bare weight	

EHPT - total equivalent horsepower

FC - fuel flow rate (lb/hr)

2. The value of volume is stored in general argument 71.

Sizing Component APU

Data Card Format

Card Column	Symbol	Value
1-3	CN	APU component name
8	CC	change code
12	NC	card number
16	NL	leg number
		= 0 without bleed air extraction by ECS
		> 0 with bleed air extraction by ECS
20	NSI	inlet station number (not required if NL = 0)
24	NSØ	outlet station number (not required if NL = 0)
28	NST	shaft number
		= 0 without shaft power extraction by ECS
		> 0 with shaft power extraction by ECS
32	[WTM]	weight multiplier (optional)
36	[CUM]	cost unit multiplier (optional)
40	[RI]	reliability index (optional)
44	[DRM]	development risk factor multiplier (optional)
48	IAPUT	APU type
		= 1 bleed air extraction with or without shaft power extraction
		= 2 shaft power extraction only
52	[ØEHP]	equivalent horsepower required by other systems

Sizing Component BØIL
Boiler

Purpose: This component will compute core dimensions, weight, cost units, reliability index, development risk factor, core volume, and the required expendable coolant weight for boilers. The available types of boilers are:

IBT	Type
1	integral boiler
2	boiler with separate storage tank

Equations:

1. Weight:

   (a) Core Weight:

   The same equations for heat exchanger core weight are applicable to the boiler core. (See HX component)

   (b) Boiler Weight (dry):

   For IBT = 1:

$$Wt = Wt_{core} + 3.4722 \times 10^{-4} \rho_{metal} (V + V_{liquid})^{2/3}$$

   For IBT = 2:

$$Wt = Wt_{core} + 3.0382 \times 10^{-4} \rho_{metal} V_{liquid}^{2/3}$$

2. Cost Units:

   CU = 29.7 + 2.72 Wt

3. Reliability Index:

   RI = 0.02165

4. Development Risk Factor:

   If the average pressure is less than or equal to 314.7 psi:

   DR = 1.15

   If the average pressure is greater than 314.7 psi:

$$DR = 1.15 \left[1.0 + \left(\frac{P_{ave} - 314.7}{283.0}\right)^2\right]$$

5. Weight Standard Error:

   $Wt_{\sigma} = 0.12\ Wt$

6. Installation Weight Factor:

$Wt_i = 0.205\ Wt$

7. Core Dimensions (if not specified):

Core dimensions L_H, L_C, and L_N are obtained iteratively by the generalized Newton Raphson method from the following three equations:

$$L_N = r_a L_C$$

$$\Delta P_H = \frac{Re_H^2\ \mu_H^2\ (1 + \psi_H^2)}{1029.568\ r_{hH}^2\ \rho_{1H}} \left[\frac{f_H\ L_H\ N_{PH}(\rho_{1H}/\rho_{2H} + 1)}{2r_{hH}(1 + \psi_H^2)} + \frac{\rho_{1H}}{\rho_{2H}} - 1\right]$$

$$\varepsilon = 1 - e^{-NTU}$$

where

r_a = aspect ratio (L_N/L_C)

= 1.0

$$NTU = \frac{\eta_{OH}\ j_H\ L_H\ N_{PH}}{r_{hH}\ Pr_H^{2/3}}$$

$$\psi_H = \frac{b_H\ \beta_H\ r_{hH}}{b_H + b_C + 2\ t_{SP}}$$

$$Re_H = \frac{0.8 r_{hH}\ W_H\ N_{PH}}{\mu_H\ L_C\ L_N\ \psi_H}$$

$$\eta_{OH} = 1 - (A_F/A)_H \left[1 - \frac{\tanh\ (m_H\ \ell_{eH})}{m_H\ \ell_{eH}}\right]$$

$$m_H = \left[\frac{1800\ C_{pH}\ \mu_H\ Re_H\ j_H\ (1 + t_{FH}/\xi_H)}{r_{hH}\ t_{FH}\ PR_H^{2/3}\ k_H}\right]^{1/2}$$

8. Core Volume:

$V = L_H\ L_C\ L_N$

9. Cold Side Liquid Volume:

$V_{liquid} = 1728\ W\ C_p\ (T_{in} - T_{out})/(H_{fg}\ \rho_{sat})$

10. Volume of hot side liquid inside the core:

$$V_{LH} = \psi_H V$$

Required Tables:

- Table ID (IFH,31 and IFGC,31) - fin geometry (hot side and cold side), refer to HX component for table description.

f - Table ID (IFH,32) - fin friction factor (hot side), refer to HX component for table description.

j - Table ID (IFH,33) - fin Colburn modulus (hot side), refer to HX component for table description.

t_{SP} - Table ID (ITSP,34) - separation plate thickness, refer to HX component for table description.

- Table ID (IMH,20) - hot side fin material properties.
- Table ID (IMC,20) - cold side fin material properties.
- Table ID (IMSP,20) - separation plate material properties.
- Table ID (IMW,20) - storage tank wall material properties.

Restrictions:

1. This component is used for sizing plate fin boilers.
2. This component can only be used for fluid types 1 and 2 on the hot side.
3. The core dimensions L_H, L_C, L_N must either be all specified by the user or be all unspecified.

Notes:

1. Two consecutive data cards are required, BØIL1 and BØIL2. The BØIL1 card must precede the BØIL2 card.
2. The same table relative number is used for the fin geometry table, the fin friction factor table, and the fin Colburn modulus table of the hot side.
3. Hot side fluid properties are evaluated at average temperature, $T_{ave} = (T_{in} + T_{out})/2$, and average pressure, $P_{ave} = (P_{in} + P_{out})/2$
4. The component printout consists of boiler weight, cost units, reliability index, development risk factor, and the following items:

$$\left.\begin{array}{ll} \text{W} & \text{- flow rate} \\ \text{PI} & \text{- inlet pressure} \\ \text{PØ} & \text{- outlet pressure} \end{array}\right\} \text{hot side}$$

TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity
HØ - outlet humidity
FT - fluid type
FN - fluid properties table relative number

} hot side

LH - hot side flow length
LC - cold side flow length
LN - no flow length
VØL - core volume
WTC - core weight
EWT - expendable coolant weight
EFF - effectiveness (not printed if core dimensions are specified)
NTU - number of heat transfer units (not printed if core dimensions are specified)
VL - volume of hot side liquid inside the core (not printed if hot side is a gas)

5. Four performance map options are available. They are

   Option 0 - no maps
   Option 1 - print maps
   Option 2 - punch maps
   Option 3 - print and punch maps

   The map produced will consist of effectiveness versus hot side flow rate, and $\sigma\Delta P$ (if a gas) or ΔP (if a liquid) of hot side versus hot side flow rate.

6. If core dimensions are not specified by the user and the iteration dump option is selected, the following information is printed:

   (a) State Variables (S.V.) - the two values printed are L_H and L_C, respectively.

   (b) Error Variables (E.V.) - the two values printed are the difference of the calculated and the given hot side pressure drops, and the difference of the calculated and the given effectivenesses, respectively.

(c) The four values printed after the error variables are Re_H, NTU, ε, and η_{OH}, respectively.

7. The convergence limits for pressure drop and effectiveness are 0.01 and 0.0001, respectively. The upper and the lower limits for the state variables are 100.0 and 0.1, respectively.

8. The dry air rated hot side outlet temperature is used for effectiveness calculation.

9. Values of L_H, L_C, L_N, V, and V_{LH} are stored in general arguments 71, 72, 73, 74, and 75, respectively.

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Sizing Component BØIL

Data Card Format

1. BOIL1 Data Card

Card Column	Symbol	Value
1-5	CN	BØIL1 component name
8	CC	change code
12	NC	card number
16	NL	leg number, hot side
20	NSI	inlet station number, hot side
24	NSØ	outlet station number, hot side
28	[WTM]	weight multiplier (optional)
32	[CUM]	cost unit multiplier (optional)
36	[RI]	reliability index (optional)
40	[DRM]	development risk factor multiplier (optional)
44	[BT]	boiling temperature of cold side liquid
48	[DENS]	cold side liquid density at boiling temperature
52	[HFG]	heat of vaporization of cold side liquid
56	[TIME]	boiler usage time
60	[WTE]	extra cold side liquid weight
64	IBT	boiler type = 1 integral boiler = 2 boiler with separate storage tank
68	MAP	performance map options = 0 no maps = 1 print maps = 2 punch maps = 3 print and punch maps

2. BØIL2 Data Card

Card Column	Symbol	Value
1-5	CN	BØIL2 component name
8	CC	change code
12	NC	card number
16	[LH]	core flow length, hot side = 0 computed > 0 user specified
20	[LC]	core flow length, cold side = 0 computed > 0 user specified
24	[LN]	no flow length = 0 computed > 0 user specified
28	NPH	number of passes, hot side
32	IMH	fin material properties table relative number, hot side (type 20)
36	IMC	fin material properties table relative number, cold side (type 20)
40	IFH	fin variable tables relative number, hot side (types 31, 32, 33)
44	IFGC	fin geometry table relative number, cold side (type 31)
48	IMSP	separation plate material properties table relative number (type 20)
52	ITSP	separation plate thickness table relative number (type 34)
56	IMW	storage tank wall material properties table relative number (type 20)

B3

Sizing Component CNTRL

System Control

Purpose: This component will compute weight, cost units, reliability index, development risk factor, and volume for system control. The available control types are:

ICT	Type
1	temperature control, electronic, fighter or light bomber
2	temperature control, electronic, cargo or heavy bomber
3	temperature control, pneumatic or electro-pneumatic
4	cabin pressure control, fighter or light bomber
5	cabin pressure control, cargo or heavy bomber

Equations:

1. Weight:

For ICT = 1 & 2:

$$Wt = [\frac{NIAØ}{3} + Wt_{selector} + 0.2\ (\text{number of sensors})]\ K_T\ K_P$$

For ICT = 3:

$$Wt = (0.5D + 1.75)\ K_T\ K_P$$

For ICT = 4:

$$Wt = 6.0$$

For ICT = 5:

$$Wt = 0.096W + 51.45$$

2. Cost Units:

For ICT = 1:

$$CU = [14.6 + 0.545\ (NIAØ)]\ Wt\ K_T\ K_P$$

For ICT = 2:

$$CU = [14.85 + 1.04\ (NIAØ)]\ Wt\ K_T\ K_P$$

For ICT = 3:

$$CU = (2.48D + 13.6)\ K_T\ K_P$$

For ICT = 4:

$$CU = 49.5$$

For ICT = 5:

$$CU = (6.45 + 0.0176W)\ Wt$$

3. Reliability Index:

For ICT = 1 & 2:

$$RI = 0.04628 + 0.03781 \text{ (number of sensors)}$$

For ICT = 3:

$$RI = 0.00582 + 0.03781 \text{ (number of sensors)}$$

For ICT = 4 & 5:

$$RI = 0.24448$$

4. Development Risk Factor:

$$DR = 1.0$$

5. Weight Standard Error:

For ICT = 1, 2, and 3:

$$Wt_d = 0.41 \text{ Wt}$$

For ICT = 4 & 5:

$$Wt_d = 0.24 \text{ Wt}$$

6. Installation Weight Factor:

$$Wt_i = 0.205 \text{ Wt}$$

7. Volume:

For ICT = 1 & 2:

$$V = [11.43 \text{ (NIAØ)} + 25.71] K_T K_P$$

For ICT = 3:

$$V = (40.0D + 20.0) K_T K_P$$

For ICT = 4:

$$V = 250.0$$

For ICT = 5:

$$V = 8.065W + 5671.0$$

8. Thrust Recovery (for ICT = 5):

$$\text{Thrust} = 6.587 \times 10^{-4} W_j \bar{c} \left[\frac{\left(\frac{P_{cabin}}{P_{ambient}}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\gamma - 1} \right]^{1/2}$$

where

$\bar{c}$ = the speed of sound at the nozzle exit

$$W_j = W - \frac{31.82(C_D A) P_{cabin}}{\sqrt{T_{cabin}}}$$

Restrictions:

1. This component can only be used for fluid type 2 if ICT = 5

Notes:

1. Temperature control sizing method applies to water separator anti-ice control, vapor cycle control, and other controls which modulate flow.
2. For ICT = 5, this component has an option to compute the thrust recovery.
3. The component printout consists of weight, cost units, reliability index, development risk factor, and the following items:

   VØL - volume

   ICT - control type

   THRC - thrust recovery (for ICT = 5 and if thrust recovery option is used only)

Sizing Component CNTRL

Data Card Format

Card Column	Symbol	Value
1-5	CN	CNTRL component name
8	CC	change code
12	NC	card number
16	[WTM]	weight multiplier (optional)
20	[CUM]	cost unit multiplier (optional)
24	[RI]	reliability index (optional)
28	[DRM]	development risk factor multiplier (optional)
32	ICT	control type
		= 1 temperature control, electronic, fighter or light bomber
		= 2 temperature control, electronic, cargo or heavy bomber
		= 3 temperature control, pneumatic or electro-pneumatic
		= 4 cabin pressure control, fighter or light bomber
		= 5 cabin pressure contrcl, cargo or heavy bomber
if ICT = 1 & 2		
36	[KT]	technical weighing factor
40	[KP]	requirements weighing factor
44	[WTS]	selector weight
48	NSR	number of sensors
52	NIAØ	number of inputs and outputs
if ICT = 3		
36	[KT]	technical weighing factor
40	[KP]	requirements weighing factor
44	[D]	control valve diameter
if ICT = 4		
no additional data required.		
if ICT = 5		
36	NL	cabin leg number

Card Column	Symbol	Value
40	NS	cabin outlet station number = 0 no thrust recovery > 0 thrust recovery computed
44	[CDA]	effective leakage area (not required if NS = 0)

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Sizing Component C∅MP
Compressor

Purpose: This component will compute weight, cost units, reliability index, development risk factor, volume, wheel diameter and/or shaft speed for an air cycle compressor (centrifugal or axial). It will also compute weight, cost units, volume, efficiency, and input horsepower for drives. The available types of drives are:

IDT	Type
0	drive not to be sized
1	turbine
2	electric motor, AC
3	electric motor, DC
4	hydraulic motor
5	shaft, engine, or APU

Equations:

1. Weight:

For compressor:

$$Wt_{comp} = 0.4D^2$$

For drive (IDT = 2):

$$Wt_{drive} = 2.0 + 2.3 \times 10^5\ HP^{5/6}/N_{drive}^{1.25}$$

For drive (IDT = 3):

$$Wt_{drive} = 1.5 + 3.83 \times 10^5\ HP^{5/6}/N_{drive}^{1.25}$$

For drive (IDT = 4 and N < 20,000 rpm):

$$Wt_{drive} = K(DPR)^{1/2}$$

where DRP = 139.094 HP/N

$K = 11.37$ if $DPRL \leq DPR \leq DPRU$

$K = 24.1158$ if $DPR > DPRU$

$K = 12.0615$ if $DPR < DPRL$

$$DPRL = e^{-(1.519 + 3.784 \times 10^{-4}N)}$$

$$DPRU = e^{(2.706 - 3.453 \times 10^{-4}N)}$$

For drive (IDT = 4 and N $\geq$ 20,000 rpm):

$$Wt_{drive} = 2.0113\ (HP)^{1/2}$$

For drive (IDT = 5):

$$Wt_{drive} = Wt_{comp}$$

2. Cost Units:

For compressor:

$$CU = 5.5\ Wt_{comp}$$

For drive (IDT = 2):

$$CU = 4.0 + 0.6\ Wt_{drive}$$

For drive (IDT = 3):

$$CU = 3.0 + Wt_{drive}$$

For drive (IDT = 4):

$$CU = 17.0 + 4.57\ Wt_{drive}$$

For drive (IDT = 5):

$$CU = 0.0$$

3. Reliability Index (for compressor and drive):

RI = 0.06793

4. Development Risk Factor (for compressor and drive):

If $T_{out} \leq 1460°R$, $U \leq 1500$ ft/sec, and $N \leq 60{,}000$ rpm:

$$DR = 1.0$$

If $T_{out} > 1460°R$, $U > 1500$ ft/sec, and $N > 60{,}000$ rpm:

$$DR = [1 + (\frac{T_{out} - 1460}{1000})^2][1 + (\frac{U - 1500}{707})^2]$$

$$[1 + (\frac{N - 60{,}000}{42{,}500})^2]$$

5. Weight Standard Error:

For compressor:

$$Wt_d = 0.164\ Wt_{comp}$$

For drive (IDT = 2):

$$Wt_d = 0.111\ Wt_{drive}$$

For drive (IDT = 3):

$$Wt_d = 0.259\ Wt_{drive}$$

For drive (IDT = 4 & 5):

$$Wt_d = 0.2\ Wt_{drive}$$

6. Installation Weight Factor (for compressor):

$$Wt_i = 0.205\ Wt_{comp}$$

7. Volume:

For compressor:

$$V_{comp} = 0.6666667\ D^4$$

For drive (IDT = 2 and 3):

$$V_{drive} = 10\ Wt_{dr}$$

For drive (IDT = 4):

$$V_{drive} = 20\ Wt_{drive}$$

8. Efficiency:

For compressor:

$$\eta_{ad} = T_{in}\ [(P_{out}/P_{in})^{\frac{\gamma-1}{\gamma}} - 1]/(\bar{T}_{out} - T_{in})$$

For drive (IDT = 2):

$$\eta = K_1\ (1 - 0.281/HP^{0.169})$$

where

$K_1 = 1.02$ ($11{,}000$ rpm $\leq N \leq 22{,}000$ rpm)

$K_1 = 1.0$ ($7{,}200$ rpm $\leq N < 11{,}000$ rpm)

$K_1 = 0.98$ ($N < 7{,}200$ rpm)

For drive (IDT = 3):

$$\eta = K_2\ (1 - 0.281/HP^{0.169})$$

where $K_2 = f(N)$, and is found by first order interpolation with the following data points:

K_2	N(rpm)
1.04	22,000
1.02	11,500
1.0	7,500
0.98	5,500

For drive (IDT = 4):

$$\eta = 0.82$$

9. Horsepower:

For compressor:

$$HP = 0.02356\ W\ C_p\ (\bar{T}_{out} - T_{in})$$

For drives:

$$HP_{in} = HP/\eta$$

10. Wheel Diameter (if not specified):

$$D = 12\, D_s\, Q^{1/2}/H^{1/4}$$

where

$D_s = f\,(N_s, \eta_{ad})$ $(N_s - D_s - \eta_{ad}$ table)

$Q = W/\rho_{in}$

$H = 778\, C_p\, T_{in}\, [(P_{out}/P_{in})^{\frac{\gamma-1}{\gamma}} - 1]$

$N_s = NQ^{1/2}/H^{3/4}$

11. Shaft Speed (if not specified):

$N = N_s\, H^{3/4}/Q^{1/2}$

where N_s is found iteratively from a $N_s - D_s - \eta_{ad}$ table by the generalized Newton-Raphson method.

12. Tip Speed:

$U = 0.004363\, D\, N$

Required Tables:

$(N_s - D_s - \eta_{ad})$ - Table ID (ND,36) - 3 or 33 dimensional, the first independent variable is N_s (argument type 0; argument relative number 59), the second independent variable is η_{ad} (argument type 0; argument relative number 60), and the dependent variable is D_s.

Restrictions:

1. This component can only be used for fluid type 2.

Notes:

1. If both shaft speed and wheel diameter are not specified, the built in limiting shaft speed is used for wheel diameter calculation. If this results in an excessive tip speed (a warning message "tip speed exceeds limiting value" is printed), the built in limiting tip speed is used to determine the wheel diameter and shaft speed iteratively by the generalized Newton-Raphson method.

2. The shaft speed of an AC electric motor drive is defined in the following manner:

motor speed (N_{drive})	compressor speed (N)
5,500	N < 7,200
7,500	7,200 ≤ N < 11,000
11,500	11,000 ≤ N < 22,000 .

3. If the compressor shaft speed exceeds 22,000 rpm for IDT = 2 & 3, an error message "shaft speed too high for motor drive" is printed. The drive sizing is then bypassed.
4. If the compressor speed exceeds 20,000 rpm for IDT = 4, the drive is sized based on a 20,000 rpm geared unit. A message "hydraulic motor geared" is then printed.
5. The drive is not sized for IDT = 0 & 1.
6. The component printout consists of compressor weight, cost units, reliability index, development risk factor, and the following items:

W - flow rate
PI - inlet pressure
PØ - outlet pressure
TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity
HØ - outlet humidity
FT - fluid type
FN - fluid properties table relative number
D - wheel diameter
VØL - volume
N - shaft speed
EFF - efficiency
HP - horsepower
U - tip speed
NS - specific speed
DS - specific diameter

If a drive is sized, additional printout consists of drive type and the following items:

EFF - drive efficiency

HP - drive input horsepower

WT - drive weight

CU - drive cost unit

VØL - drive volume (if IDT $\neq$ 5)

7. If iteration is employed and the iteration dump option is selected, the following information is printed for each iteration:
   (a) State Variable (S.V.) - specific speed
   (b) Error Variable (E.V.) - If the conditions described in Note 1 occur, the printed value is the difference of the calculated tip speed and the limiting tip speed. If the wheel diameter is specified, the printed value is the difference of the calculated and the known specific diameter.
8. The convergence limit is 0.001. The upper and the lower limits for the state variable are 10,000 and 1.0,respectively.
9. The values of the wheel diameter and the compressor volume are stored in the general arguments 71 and 72,respectively. If rotational speed is determined, it will be stored in general argument (80 + NST).
10. The built in limiting rotational speed and the limiting tip speed are 60,000 rpm and 1500 ft/sec, respectively. Users may override this by specifying a different value with a CØMMØN card.

Sizing Component CØMP

Data Card Format

Card Column	Symbol	Value
1-5	CN	CØMP component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	NST	shaft number
32	[WTM]	weight multiplier (optional)
36	[CUM]	cost unit multiplier (optional)
40	[RI]	reliability index (optional)
44	[DRM]	development risk factor multiplier (optional)
48	[D]	wheel diameter = 0 computed > 0 user specified
52	ND	N_s - D_s - η_{ad} table relative number (type 36)
56	ICT	compressor type = 1 high pressure ratio = 2 low pressure ratio
60	-	
64	IDT	drive type = 0 drive not to be sized = 1 turbine = 2 electric motor, AC = 3 electric motor, DC = 4 hydraulic motor = 5 shaft, engine or APU

B5

Sizing Component CØND

Condenser

Purpose: This component will compute core dimensions, weight, cost units, reliability index, development risk factor, and core volume for vapor cycle condensers.

Equations:

1. Weight:

   (a) Core Weight:

   The same equations for heat exchanger core weight are applicable to the condenser core weight calculation. (See HX subroutine. Note that variables with subscript H (hot side) refer to refrigerant side, and those with subscript C (cold side) refer to heat sink side.)

   (b) Condenser Weight:

$$Wt = 3.23126\ Wt_{core}/(V)^{0.118}$$

2. Cost Units:

   $CU = 29.7 + 2.72\ Wt$

3. Reliability Index:

   $RI = 0.00306$

4. Development Risk Factor:

   If the average pressure is less than or equal to 314.7 psi:

   $DR = 1.0$

   If the average pressure is greater than 314.7 psi:

   $DR = 1.0 + [(P_{ave} - 314.7)/283.0]^2$

5. Weight Standard Error:

   $Wt_d = 0.12\ Wt$

6. Installation Weight Factor:

   $Wt_i = 0.205\ Wt$

7. Core Dimensions (if not specified):

   Core dimensions L_R, L_S, and L_N are obtained iteratively by the generalized Newton Raphson method from the following three equations:

$$L_R = 6.0 + 0.08\, L_N + (0.96\, L_N + 0.0064\, L_N^2)^{1/2}$$

$$\Delta P_S = \frac{Re_S^2\, \mu_S^2\, (1 + \psi_S^2)}{1029.568\, r_{hS}^2\, \rho_{1S}} \left[\frac{f_S\, L_S\, N_{PS}(\rho_{1S}/\rho_{2S} + 1)}{2\, r_{hS}\, (1 + \psi_S^2)} + \frac{\rho_{1S}}{\rho_{2S}} - 1\right]$$

$$\varepsilon = 1 - e^{-NTU}$$

where

$$NTU = \frac{L_R\, L_S\, L_N}{(WC_p)_S \left[0.8 \left(\frac{r_h^2}{C_p\, \mu\, Re} \frac{P_r^{2/3}}{j\, \psi\, \eta_o}\right)_S + \left(\frac{r_h}{h\, \psi}\right)_R\right]}$$

$$h_R = 0.023148 \text{ Btu/min in.}^2 {}^\circ F$$

$$\psi_S = \frac{b_S\, \beta_S\, r_{hS}}{b_S + b_R + 2t_{SP}}$$

$$\psi_R = \frac{b_R\, \beta_R\, r_{hR}}{b_S + b_R + 2t_{SP}}$$

$$Re_S = \frac{0.8 r_{hS}\, W_S\, N_{PS}}{\mu_S\, L_R\, L_N\, \psi_S}$$

$$\eta_{oS} = 1 - (A_F/A)_S \left[1 - \frac{\tanh\, (m_S\, \ell_{eS})}{m_S\, \ell_{eS}}\right]$$

$$m_S = \left[\frac{1800\, C_{pS}\, \mu_S\, Re_S\, j_S\, (1 + t_{FS}/\xi_S)}{r_{hS}\, t_{FS}\, Pr_S^{2/3}\, h_S}\right]^{1/2}$$

8. Core Volume:

$$V = L_R\, L_S\, L_N$$

9. Volume of heat sink liquid inside the core:

$$V_{LS} = \psi_S\, V$$

Required Tables:

- Table ID (IFS, 31 and IFGR,31) - fin geometry (heat sink side and refrigerant side), refer to HX component for table description.

f - Table ID (IFS,32) - fin friction factor (heat sink side), refer to HX component for table description.

j - Table ID (IFS,33) - fin Colburn modulus (heat sink side), refer to HX component for table description.

t_{SP} - Table ID (ITSP,34) - separation plate thickness, refer to HX component for table description.

- Table ID (IMS,20) - heat sink side fin material properties.
- Table ID (IMR,20) - refrigerant side fin material properties.
- Table ID (IMSP,20) - separation plate material properties.

Restrictions:

1. This component is used for sizing plate fin cross flow vapor cycle condensers.
2. This component can only be used for fluid types 1 and 2 on the heat sink side.
3. The core dimensions (L_R, L_S, L_N) must either be all specified by the user or be all unspecified.

Notes:

1. Two consecutive data cards are required, CØND1 and CØND2. CØND1 card must precede CØND2 card.
2. The same table relative number is used for the fin geometry table, the fin friction factor table, and the fin Colburn modulus table of the heat sink side.
3. Heat sink side fluid properties are evaluated at average temperature, $T_{ave} = (T_{in} + T_{out})/2$, and average pressure, $P_{ave} = (P_{in} + P_{out})/2$.
4. The component printout consists of condenser weight, cost units, reliability index, development risk factor, and the following items:

W - flow rate PI - inlet pressure PØ - outlet pressure	heat sink side

TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity
HØ - outlet humidity
FT - fluid type
FN - fluid properties table relative number

(TI through FN: heat sink side)

LS - heat sink side flow length
LR - refrigerant side flow length
LN - no flow length
VØL - core volume
WTC - core weight
EFF - effectiveness (not printed if core dimensions are specified)
NTU - number of heat transfer units (not printed if core dimensions are specified)
VL - volume of heat sink liquid inside the core (not printed if heat sink is a gas)

5. Four performance map options are available. They are
Option 0 - no maps
Option 1 - print maps
Option 2 - punch maps
Option 3 - print and punch maps
The maps produced will consist of effectiveness versus heat sink flow rate, and $\sigma\Delta P$ (if a gas) or ΔP (if a liquid) of heat sink side versus heat sink flow rate.

6. If core dimensions are not specified by the user and the iteration dump option is selected, the following information is printed for each iteration:
   (a) State Variables (S.V.) - the values printed are L_S and L_N, respectively.
   (b) Error Variables (E.V.) - the two values printed are the difference of the calculated and the given heat sink side pressure drops, and the difference of the calculated and the given effectivenesses, respectively.

(c) The four values printed after the error variables are Re_S, NTU, ε, and η_{oS}, respectively.

7. The convergence limits for pressure drop and effectiveness are 0.01 and 0.0001, respectively. The upper and the lower limits for the state variables are 100.0 and 0.1, respectively.

8. The dry air rated heat sink outlet temperature is used for effectiveness calculation.

9. Values of L_S, L_R, L_N, V, V_{LS}, and Wt are stored in general arguments 71, 72, 73, 74, 75, and 76, respectively.

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Sizing Component CØND

Data Card Format

1. CØND1 Data Card

Card Column	Symbol	Value
1-5	CN	CØND1 component name
8	CC	change code
12	NC	card number
16	NLS	leg number, heat sink side
20	NSIS	inlet station number, heat sink side
24	NSØS	outlet station number, heat sink side
28	NSØR	outlet station number, refrigerant side
32	[WTM]	weight multiplier (optional)
36	[CUM]	cost unit multiplier (optional)
40	[RI]	reliability index (optional)
44	[DRM]	development risk factor multiplier (optional)
48	MAP	performance map options = 0 no maps = 1 print maps = 2 punch maps = 3 print and punch maps

CØND2 Data Card

Card Column	Symbol	Value
1-5	CN	CØND2 component name
8	CC	change code
12	NC	card number
16	[LS]	core flow length, heat sink side = 0 computed > 0 user specified
20	[LR]	core flow length, refrigerant side = 0 computed > 0 user specified
24	[LN]	no flow length = 0 computed > 0 user specified
28	NPS	number of passes, heat sink side
32	IMS	fin material properties table relative number, heat sink side (type 20)
36	IMR	fin material properties table relative number, refrigerant side (type 20)
40	IFS	fin variable table relative number, heat sink side (types 31, 32, 33) 1, -5
44	IFGR	fin geometry table relative number, refrigerant side (type 31)
48	IMSP	separation plate material properties table relative number (type 20)
52	ITSP	separation plate thickness table relative number (type 34)

40 1

41 5

Sizing Component DSEP

Dust Separator

Purpose: This component will compute weight, cost units, reliability index, development risk factor, and volume for dust separators. The available dust separator types are:

IDT	Type
1	static
2	self-cleaning, high pressure

Equations:

1. Weight:

   For IDT = 1:

   $$Wt = 0.195\ W^{0.79}$$

   For IDT =2:

   $$Wt = 0.5 + 0.0346\ W$$

2. Cost Units:

   For IDT = 1:

   $$CU = 5.4 + 0.71\ Wt$$

   For IDT = 2:

   $$CU = 9.11 + 1.07\ Wt$$

3. Reliability Index:

   $$RI = 0.04135$$

4. Development Risk Factor:

   $$DR = 1.0$$

5. Weight Standard Error:

   For IDT = 1:

   $$Wt_d = 0.04\ Wt$$

   For IDT = 2:

   $$Wt_d = 0.1225\ Wt$$

6. Installation Weight Factor:

   $$Wt_i = 0.205\ Wt$$

7. Volume:

   For IDT = 1:

   $$V = 7.3\ Wt^{1.28}$$

   For IDT = 2:

   $$V = 19.0\ Wt^{1.5}$$

Restrictions:

1. This component can only be used for fluid type 2.

Notes:

1. The component printout consist of weight, cost units, reliability index, development risk factor, and the following items:

   W - flow rate

   PI - inlet pressure

   PØ - outlet pressure

   TI - inlet temperature

   TØ - outlet temperature

   HI - inlet humidity

   HØ - outlet humidity

   FT - fluid type

   FN - fluid properties table relative number

   VØL - volume

2. The value of volume is stored in general argument 71.

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Sizing Component DSEP

Data Card Format

Card Column	Symbol	Value
1-4	CN	DSEP component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	[WTM]	weight multiplier (optional)
32	[CUM]	cost unit multiplier (optional)
36	[RI]	reliability index (optional)
40	[DRM]	development risk factor multiplier (optional)
44	IDT	dust separator type = 1 static = 2 self-cleaning, high pressure

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Sizing Component EJECT

Ejector

Purpose: This component will compute weight, cost units, reliability index, development risk factor, effective nozzle area, and volume for an ejector assembly, which includes a mixing tube, high pressure tubing, and nozzles.

Equations:

1. Weights:

   $Wt = 20.0\ (2.5\ B + 2)\ t\ \rho/1728$

2. Cost Units:

   $CU = 17.96 + 5.36\ Wt^{0.64} + 0.139\ Wt^{1.65}$

3. Reliability Index:

   $RI = 0.00177$

4. Development Risk Factor:

   $DR = 1.0$

5. Weight Standard Error:

   $Wt_d = 0.25\ Wt$

6. Installation Weight Factor:

   $Wt_i = 0.205\ Wt$

7. Volume:

   $V = 38.6\ B$

8. Effective Nozzle Area:

   If flow is choked:

   $$A = (W/28.3725)\left[\gamma\ P_{in}\ \rho_{in}\ \left(\frac{2}{1+\gamma}\right)^{\frac{\gamma+1}{\gamma-1}}\right]^{1/2}$$

   If flow is not choked:

   $$A = (W/40.1248)\left(\frac{\gamma}{\gamma-1}\ P_{in}\ \rho_{in}\right)^{1/2}\left[(P_{out}/P_{in})^{\frac{2}{\gamma}} - (P_{out}/P_{in})^{\frac{\gamma+1}{\gamma}}\right]^{1/2}$$

9. Number of Single - Nozzle Ejector Modules:

$\frac{A}{0.0371}$	0.0 ~ 3.0	3.0 ~ 5.0	5.0 ~ 7.0	7.0 ~ 9.0	etc
B	2	4	6	8	etc

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Required Tables:

- Table ID (IMT,20) - mixing tube material properties.

Restrictions:

1. This component can only be used for fluid type 2.

Notes:

1. The component printout consists of weight, cost units, reliability index, development risk factor, and the following items:

   W - primary flow rate

   PI - primary flow inlet pressure

   PØ - primary flow outlet pressure

   TI - primary flow inlet temperature

   TØ - primary flow outlet temperature

   HI - primary flow inlet humidity

   HØ - primary flow outlet humidity

   FT - primary flow fluid type

   FN - primary flow fluid properties table relative number

   AN - effective nozzle area

   VØL - volume

2. The value of volume is stored in general argument 71.

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Sizing Component EJECT

Data Card Format

Card Column	Symbol	Value
1-5	CN	EJECT component name
8	CC	change code
12	NC	card number
16	NL	leg number, primary flow
20	NSI	inlet station number, primary flow
24	NSØ	outlet station number, primary flow
28	[WTM]	weight multiplier (optional)
32	[CUM]	cost unit multiplier (optional)
36	[RI]	reliability index (optional)
40	[DRM]	development risk factor multiplier (optional)
44	[THK]	mixing tube wall thickness
48	IMT	material properties table relative number (type 20)

Sizing Component EVAP
Evaporator

Purpose: This component will compute core dimensions, weight, cost units, reliability index, development risk factor, and core volume for vapor cycle evaporators.

Equations:

1. Weight:

   (a) Core Weight:

   The same equations for heat exchanger core weight are applicable to the evaporator core weight calculation. (See HX component.) Note that variables with subscript C (cold side) refer to refrigerant side, and those with subscript H (hot side) refer to heat source side.

   (b) Evaporator Weight:

$$Wt = 3.23126\ Wt_{core}/(V)^{0.118}$$

2. Cost Units:

   $CU = 29.7 + 2.72\ Wt$

3. Reliability Index:

   $RI = 0.00216$

4. Development Risk Factor:

   If the average pressure is less than or equal to 314.7 psi:

   $DR = 1.2$

   If the average pressure is greater than 314.7 psi:

$$DR = 1.2\left[1.0 + \left(\frac{P_{ave} - 314.7}{283}\right)^2\right]$$

5. Weight Standard Error:

   $Wt_d = 0.12\ Wt$

6. Installation Weight Factor:

   $Wt_i = 0.205\ Wt$

7. Core Dimensions (if not specified):

   Core dimensions L_R, L_S and L_N are obtained iteratively by the generalized Newton Raphson method from the following three equations:

$$L_R = 3.0 + 0.18\ L_N + (1.08\ L_N + 0.0324\ L_N^{\ 2})^{1/2}$$

$$\Delta P_S = \frac{Re_S^{\ 2}\ \mu_S^{\ 2}\ (1 + \psi_S^{\ 2})}{1029.568\ r_{hS}^{\ 2}\ \rho_{1S}}\ \left[\frac{f_S\ L_S\ N_{PS}(\rho_{1S}/\rho_{2S} + 1)}{2\ r_{hS}\ (1 + \psi_S^{\ 2})} + \frac{\rho_{1S}}{\rho_{2S}} - 1\right]$$

$$\varepsilon = 1 - e^{-NTU}$$

where

$$NTU = \frac{L_R\ L_S\ L_N}{(WC_p)_S\ \left[0.8\ \left(\frac{r_h^{\ 2}\ Pr^{2/3}}{C_p\ \mu\ Re\ j\ \psi\ \eta_o}\right)_S + \left(\frac{r_h}{h\ \psi}\right)_R\right]}$$

$$h_R = 0.017361\ \text{Btu/min in}^2\ {}^\circ F$$

$$\psi_S = \frac{b_S\ \beta_S\ r_{hS}}{b_S + b_R + 2t_{SP}}$$

$$\psi_R = \frac{b_R\ \beta_R\ r_{hR}}{b_S + b_R + 2t_{SP}}$$

$$Re_S = \frac{0.8 r_{hS}\ W_S\ N_{PS}}{\mu_S\ L_R\ L_N\ \psi_S}$$

$$\eta_{oS} = 1 - (A_F/A)_S\ \left[1 - \frac{\tanh\ (m_S\ \ell_{eS})}{m_S\ \ell_{eS}}\right]$$

$$m_S = \left[\frac{1800\ C_{pS}\ \mu_S\ Re_S\ j_S\ (1 + t_{FS}/\xi_S)}{r_{hS}\ t_{FS}\ Pr_S^{\ 2/3}\ k_S}\right]^{1/2}$$

8. Core Volume:

$$V = L_R\ L_S\ L_N$$

9. Volume of heat source liquid inside the core:

$$V_{LS} = \psi_S\ V$$

Required Tables:

- Table ID (IFS,31 and IFGR,31) - fin geometry (heat source side and refrigerant side), refer to HX component for table description.

f - Table ID (IFS,32) - fin friction factor (heat source side), refer to HX component for table description.

j - Table ID (IFS,33) - fin Colburn modulus (heat source side), refer to HX component for table description.

t_{SP} - Table ID (ITSP,34) - separation plate thickness, refer to HX component for table description.

- Table ID (IMS,20) - heat source side fin material properties.
- Table ID (IMR,20) - refrigerant side fin material properties.
- Table ID (IMSP,20) - separation plate material properties.

Restrictions:

1. This component is used for sizing plate fin cross flow vapor cycle evaporators.
2. This component can only be used for fluid types 1 and 2 on the heat source side.
3. The core dimensions (L_R, L_S, L_N) must either be all specified by the user or be all unspecified.

Notes:

1. Two consecutive data cards are required, EVAP1 and EVAP2. The EVAP1 card must precede the EVAP2 card.
2. The same table relative number is used for the fin geometry table, the fin friction factor table, and the fin Colburn modulus table of the heat source side.
3. Heat source side fluid properties are evaluated at average temperature, $T_{ave} = (T_{in} + T_{out})/2$, and average pressure, $P_{ave} = (P_{in} + P_{out})/2$.
4. The component printout consists of evaporator weight, cost units, reliability index, development risk factor, and the following items:

W - flow rate
PI - inlet pressure
PØ - outlet pressure
TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity
HØ - outlet humidity
FT - fluid type
FN - fluid properties table relative number

(W through FN: heat source side)

LS - heat source side flow length
LR - refrigerant side flow length
LN - no flow length
VØL - core volume
WTC - core weight
EFF - effectiveness (not printed if core dimensions are specified)
NTU - number of heat transfer units (not printed if core dimensions are specified)
VL - volume of heat source liquid inside the core (not printed if heat source is a gas)

5. Four performance map options are available. They are
   Option 0 - no maps
   Option 1 - print maps
   Option 2 - punch maps
   Option 3 - print and punch maps

   The maps produced will consist of effectiveness versus heat source flow rate, and $\sigma\Delta P$ (if a gas) or ΔP (if a liquid) of heat source side versus heat source flow rate.

6. If core dimensions are not specified by the user and the iteration dump option is selected, the following information is printed for each iteration:
   (a) State Variables (S.V.) - the two values printed are L_S and L_N, respectively.

(b) Error Variables (E.V.) - the two values printed are the difference of the calculated and the given heat source side pressure drops, and the difference of the calculated and the given effectivenesses, respectively.

(c) The four values printed after the error variables are Re_S, NTU, ε, and η_{oS}, respectively.

7. The convergence limits for pressure drop and effectiveness are 0.01 and 0.0001, respectively. The upper and the lower limits for state variables are 100.0 and 0.1, respectively.

8. The dry air rated heat source outlet temperature is used for effectiveness calculation.

9. Values of L_S, L_R, L_N, V, V_{LS}, and Wt are stored in general arguments 71, 72, 73, 74, 75, and 76, respectively.

Sizing Component EVAP

Data Card Format

1. EVAP1 Data Card

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Card Column	Symbol	Value
1-5	CN	EVAP1 component name
8	CC	change code
12	NC	card number
16	NLS	leg number, heat source side
20	NSIS	inlet station number, heat source side
24	NSØS	outlet station number, heat source side
28	NSØR	outlet station number, refrigerant side
32	[WTM]	weight multiplier (optional)
36	[CUM]	cost unit multiplier (optional)
40	[RI]	reliability index (optional)
44	[DRM]	development risk factor multiplier (optional)
48	MAP	performance map options
		= 0 no maps = 1 print maps = 2 punch maps = 3 print and punch maps

2. EVAP2 Data Card

Card Column	Symbol	Value
1-5	CN	EVAP2 component name
8	CC	change code
12	NC	card number
16	[LS]	core flow length, heat source side = 0 computed > 0 user specified
20	[LR]	core flow length, refrigerant side = 0 computed > 0 user specified
24	[LN]	no flow length = 0 computed > 0 user specified
28	NPS	number of passes, heat source side
32	IMS	fin material properties table relative number, heat source side (type 20)
36	IMR	fin material properties table relative number, refrigerant side (type 20)
40	IFS	fin variable table relative number, heat source side (types 31, 32, 33)
44	IFGR	fin geometry table relative number, refrigerant side (type 31)
48	IMSP	separation plate material properties table relative number (type 20)
52	ITSP	separation plate thickness table relative number (type 34)

Sizing Component FAN

Fan

Purpose: This component will compute weight, cost units, reliability index, blade tip diameter, and volume for a fan (including a drive). The available types of drives are:

IDT	Type
2	electric motor, AC
3	electric motor, DC
4	hydraulic motor
6	tip turbine

Equations:

1. Weight:

   For IDT = 2 & 3:

   $Wt = 0.26\ D^2$

   For IDT = 4:

   $Wt = 0.178\ D^2$

   For IDT = 6:

   $Wt = 0.109\ D_E^2$

   where D_E = effective blade tip diameter

2. Cost Units:

   For IDT = 2:

   $CU = 14.29 + 0.46\ Wt$

   For IDT = 3:

   $CU = 4.87 + 0.76\ Wt$

   For IDT = 4:

   $CU = 58.587 + 1.725\ Wt$

   For IDT = 6:

   $CU = 5.5\ Wt$

3. Reliability Index:

   For IDT = 2 & 3:

   $RI = 0.00546$

   For IDT = 4:

   $RI = 0.01162$

   For IDT = 6:

   $RI = 0.00707$

4. Development Risk Factor:

$DR = 1.0$

5. Weight Standard Error:

For IDT = 2 & 3:

$Wt_d = 0.25\ Wt$

For IDT = 4:

$Wt_d = 0.109\ Wt$

For IDT = 6:

$Wt_d = 0.199\ Wt$

6. Installation Weight Factor:

$Wt_i = 0.205\ Wt$

7. Volume:

For IDT = 2, 3 & 4:

$V = 1.3\ D^3$

For IDT = 6:

$V = 0.8666667\ D_E{}^3$

8. Blade Tip Diameter (if not specified):

$$D = 16.8\ \left(\frac{W}{\rho N}\right)^{1/3} \quad (1)$$

9. Effective Blade Tip Diameter (for IDT = 6):

$$D_E = D + 2\ h \quad (2)$$

The effective blade tip diameter is found interatively by the generalized Newton Raphson method from Equation (1), Equation (2), turbine $N_s - D_s - \eta_{ad}$ table, and turbine $N_s - h/D - \eta_{ad}$ table.

10. Fan Horsepower:

$HP = 0.02356\ W\ C_p\ (T_{out} - T_{in})$

11. Fan Adiabatic Efficiency:

$$\eta_{ad} = \frac{T_{in}\ [(P_{out}/P_{in})^{\frac{\gamma-1}{\gamma}} - 1]}{T_{out} - T_{in}}$$

Required Tables (for IDT = 6 only):

$(N_s - D_s - \eta_{ad})$ - Table ID (ITS,37) - 3 or 33 dimensional, the first independent variable is N_s (argument type 0; argument relative number 59), the second independent variable is η_{ad} (argument type 0; argument relative number 60), and the dependent variable is D_s.

$(N_s - h/D - \eta_{ad})$ - Table ID (ITS,38) - 3 or 33 dimensional, the first independent variable is N_s (argument type 0; argument relative number 59), the second independent variable is η_{ad} (argument type 0, argument relative number 60), and the dependent variable is h/D.

Restrictions:

1. This component can only be used for fluid type 2.
2. Shaft speed must be specified for IDT = 2, 3, & 4. For IDT = 6, the effective blade tip diameter and shaft speed must be either both specified or both unspecified.

Notes:

1. The component printout consists of weight, cost units, reliability index, development risk factor, and the following items:

   W - flow rate
   PI - inlet pressure
   PØ - outlet pressure
   TI - inlet temperature
   TØ - outlet temperature
   HI - inlet humidity
   HØ - outlet humidity
   FT - fluid type
   FN - fluid properties table relative number
   D - blade tip diameter (if IDT = 2, 3, & 4) or effective blade tip diameter (if IDT = 6)
   VØL - volume
   N - shaft speed
   EFF - fan adiabatic efficiency
   HP - fan fluid horsepower

Additional printout consists of drive type and the following items:

EFF - drive efficiency

HP - drive input horsepower

W - turbine flow rate

PI - turbine inlet pressure

PØ - turbine outlet pressure

TI - turbine inlet temperature

TØ - turbine outlet temperature

HI - turbine inlet humidity

HØ - turbine outlet humidity

FT - fluid type

FN - fluid properties table relative number

(W through FN: for IDT = 6 only)

2. If iteration is employed and the iteration dump option is selected, the following information is printed for each iteration:
   (a) State Variable (S.V.) - specific speed.
   (b) Error Variable (E.V.) - the difference of the calculated turbine wheel diameter and the calculated effective fan blade tip diameter.
3. The convergence limit is 0.001. The upper and lower limits for the state variable are 1000.0 and 1.0 respectively.
4. The values of the blade tip diameter (or effective blade tip diameter) and the volume are stored in general argument 71 and 72, respectively.
5. For IDT = 6, the limiting rotational speed and the limiting tip speed are 60,000 rpm and 1,500 ft/sec, respectively. Users may override this by specifying a different value with a CØMMØN card.

Sizing Component FAN

Data Card Format

Card Column	Symbol	Value
1-3	CN	FAN component name
8	CC	change code
12	NC	card number
16	NLF	fan leg number
20	NSIF	fan inlet station number
24	NSØF	fan outlet station number
28	NST	shaft number
32	[WTM]	weight multiplier (optional)
36	[CUM]	cost unit multiplier (optional)
40	[RI]	reliability index
44	[DRM]	development risk factor multiplier (optional)
48	[D]	fan tip diameter (if IDT = 2, 3, & 4) or turbine tip diameter (if IDT = 6) = 0 computed > 0 user specified
52	IDT	drive type = 2 electric motor, AC = 3 electric motor, DC = 4 hydraulic motor = 6 tip turbine
56	NLT	turbine leg number (not required if IDT ≠ 6)
60	NSIT	turbine inlet station number (not required if IDT ≠ 6)
64	NSØT	turbine outlet station number (not required if IDT ≠ 6)
68	ITS	turbine sizing characteristic table relative number (types 37 & 38, not required if IDT ≠ 6)

Sizing Component HEATER

Resistance Heater

Purpose: This component will compute weight, cost units, reliability index, development risk factor, volume, and flow length for resistance heaters.

Equations:

1. Weight:

   $Wt = \rho V/1728$

   where

   $\rho = 20.0$ $(V \leq 794.3\ in^3)$

   $\rho = 374.11/V^{0.4384}$ $(V > 794.3\ in^3)$

2. Cost Units:

   $CU = 2.08\ Wt$

3. Reliability Index:

   $RI = 0.01109$

4. Development Risk Factor:

   $DR = 1.0$

5. Weight Standard Error:

   $Wt_d = 0.12\ Wt$

6. Installation Weight Factor:

   $Wt_i = 0.205\ Wt$

7. Volume:

   $V = 1.21444\ WC_p\ (\overline{T}_{out} - T_{in})$

8. Flow Length (if not specified and the performance map is required: The flow length L is obtained iteratively by the generalized Newton Raphson method from the following equation:

$$\Delta P = \frac{Re^2\ \mu^2\ (1 + \psi^2)}{1029.568\ r_h^2\ \rho_1} \left[\frac{Lf\ (\rho_1/\rho_2 + 1)}{2r_h\ (1 + \psi^2)} + \frac{\rho_1}{\rho_2} - 1\right]$$

where

$$Re = 0.8\ r_h\ W\ L/(\mu\ V\ \psi)$$

$$\psi = \frac{b\ \beta\ r_h}{b + b' + 0.012}$$

b' = heater element height

Required Tables (if the map option is not 0):

- Table ID (IF,31) - fin geometry, refer to HX component for table description.

f - Table ID (IF,32) - fin friction factor, refer to HX component for table description.

Restriction:

1. This component can only be used for fluid type 2.

Notes:

1. The same table relative number is used for the fin geometry table and the fin friction factor table.
2. Fluid properties are evaluated at average temperature, $T_{ave} = (T_{in} + T_{out})/2$, and average pressure, $P_{ave} = (P_{in} + P_{out})/2$.
3. The component printout consists of weight, cost units, reliability index, development risk factor, and the following items:

   W - flow rate

   PI - inlet pressure

   PØ - outlet pressure

   TI - inlet temperature

   TØ - outlet temperature

   HI - inlet humidity

   HØ - outlet humidity

   FT - fluid type

   FN - fluid properties table relative number

   VØL - volume

   L - flow length (if the map option is not 0)
4. If iteration is employed and the iteration dump option is selected, the following information is printed for each iteration:

   (a) State Variable (S.V.) - flow length

   (b) Error Variable (E.V.) - the difference of the calculated and the given pressure drops.

   (c) RE - Reynolds number
5. The convergence limit is 0.01. The upper and the lower limits of the state variables are 100.0 and 0.1 respectively.

6. Four performance map options are available. They are:

Option 0 - no map

Option 1 - print map

Option 2 - punch map

Option 3 - print and punch map.

The maps produced will give values of σΔP versus flow rate.

7. The values of the flow length and the volume are stored in general arguments 71 and 72, respectively.

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Sizing Component HEATER

Data Card Format

Card Column	Symbol	Value
1-6	CN	HEATER component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	[WTM]	weight multiplier (optional)
32	[CUM]	cost unit multiplier (optional)
36	[RI]	reliability index (optional)
40	[DRM]	development risk factor multiplier (optional)
44	[L]	flow length (not required if MAP = 0) = 0 computed > 0 user specified
48	[IHEL]	heater element height (not required if MAP = 0)
52	IF	fin variable tables relative number (types 31 and 32, not required if MAP = 0)
56	MAP	performance map options = 0 no map = 1 print map = 2 punch map = 3 print and punch map

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Sizing Component HX

Heat Exchanger

Purpose: This component will compute core dimensions, weight, cost units, reliability index, development risk factor, and core volume for heat exchangers.

Equations:

1. Weight:

(a) Core Weight:

If $\rho_{SP} < 460$:

$$Wt_{core} = \frac{\rho_{FH}V_H + \rho_{FC}V_C + \rho_{SP}t_{SP}L_CL_H\ (N_HN_{SH} + N_CN_{SC} + 1.0)}{1728}$$

If $\rho_{SP} \geq 460$:

$$Wt_{core} = \frac{\rho_{FH}V_H + \rho_{FC}V_C + \rho_{SP}t_{SP}L_CL_H\ (N_HN_{SH} + N_CN_{SC} + 1.0)}{1728}$$

$$+ 6.44 \times 10^{-4}\ L_CL_H\ (N_HN_{SH} + N_CN_{SC} + 1.0)$$

where

$$N_H = \frac{L_N - b_C - 2t_{SP}}{b_H + b_C + 2t_{SP}}$$

$$N_C = N_H + 1$$

$$V_H = N_H\ [b_H - (N_{SH} - 1)\ t_{SP}]\ L_C\ L_H$$

$$V_C = N_C\ [b_C - (N_{SC} - 1)\ t_{SP}]\ L_C\ L_H$$

$$\rho_F = \frac{t_F p \rho_{metal} [B + 1/p - (9 - 2\pi)t_F]}{B} \text{ - rectangular fin}$$

$$\rho_F = \frac{t_F p \rho_{metal}\ [B + (\pi - 2)/2p - t_F]}{B} \text{ - rounded fin}$$

$$\rho_F = \frac{t_F p \rho_{metal}\ [S + 3t_F\emptyset]}{B} \text{ - triangular fin}$$

$$B = \frac{b - (N_S - 1)\ t_{SP}}{N_S}$$

$$\phi = 2 \cos^{-1} \left(\frac{3t_F}{a + 3t_F}\right)$$

$$a = \frac{-1 + 6p^2 t_F B + (1 - 12 p^2 t_F + p^2 B^2)^{1/2}}{1/(3t_F) - 12p^2 t_F}$$

$$S = 1/(p \cos(\phi/2)) - 6t_F p (B + 2a)$$

(b) Heat Exchanger Weight:

$$Wt = 3.23126\, Wt_{core} / (V)^{0.118}$$

2. Cost Units:

$CU = 2.08\ Wt$

3. Reliability Index:

$RI = 0.00256$ (gas/gas HX)

$RI = 0.00328$ (gas/liquid HX)

$RI = 0.00106$ (liquid/liquid HX)

4. Development Risk Factor:

For gas/gas HX:

$$DR = 1.0 \qquad (T \leq 1760°R,\ P \leq 314.7\text{ psi})$$

$$DR = 1.0 + \left(\frac{T - 1760}{425}\right)^2 + \left(\frac{P - 314.7}{283}\right)^2 \qquad (T > 1760°R,\ P > 314.7\text{ psi})$$

For gas/liquid or liquid/liquid HX:

$$DR = 1.0 \qquad (P \leq 314.7\text{ psi})$$

$$DR = 1.0 + \left(\frac{P - 314.7}{283}\right)^2 \qquad (P > 314.7\text{ psi})$$

5. Weight Standard Error:

$Wt_d = 0.12\ Wt$

6. Installation Weight Factor:

$Wt_i = 0.205\ Wt$

7. Core Dimensions (if not specified):

Core dimensions L_H, L_C and L_N are obtained iteratively by the generalized Newton Raphson method from the following three equations:

$$\Delta P_H = \frac{Re_H^2\ \mu_H^2\ (1 + \psi_H^2)}{1029.568\ r_{hH}^2\ \rho_{1H}}\ [\frac{f_H\ L_H\ N_{PH}(\rho_{1H}/\rho_{2H} + 1)}{2r_{hH}\ (1 + \psi_H^2)} + \frac{\rho_{1H}}{\rho_{2H}} - 1]$$

$$\Delta P_C = \frac{Re_C^2\ \mu_C^2\ (1 + \psi_C^2)}{1029.568\ r_{hC}^2\ \rho_{1C}} \cdot [\frac{f_C\ L_C\ N_{PC}(\rho_{1C}/\rho_{2C} + 1)}{2r_{hC}\ (1 + \psi_C^2)} + \frac{\rho_{1C}}{\rho_{2C}} - 1]$$

$\varepsilon = f\ (NTU,\ CC)$ (HX effectiveness table)

where

$$NTU = 12r_{hH}\ W_H\ L_H\ N_{PH}/[(WC_p)_{min}\ \psi_H\ \mu_H\ Re_H$$

$$(\frac{r_{hH}^2\ Pr_H^{2/3}}{\eta_{OH}\ C_{pH}\ \mu_H\ \psi_H\ j_H\ Re_H} + \frac{r_{hC}^2\ Pr_C^{2/3}}{\eta_{OC}\ C_{pC}\ \mu_C\ \psi_C\ j_C\ Re_C})]$$

$CC = (WC_p)_{min}/(WC_p)_{max}$ (both fluids mixed or both fluids unmixed)

$CC = (WC_p)_{mixed}/(WC_p)_{unmixed}$ (one fluid mixed)

$$\psi_H = \frac{b_H\ \beta_H\ r_{hH}}{b_H + b_C + 2t_{SP}}$$

$$\psi_C = \frac{b_C\ \beta_C\ r_{hC}}{b_H + b_C + 2t_{SP}}$$

$$Re_H = \frac{0.8\ r_{hH}\ W_H\ N_{PH}}{\mu_H\ L_C\ L_N\ \psi_H}$$

$$Re_C = \frac{0.8\ r_{hC}\ W_C\ N_{PC}}{\mu_C\ L_H\ L_N\ \psi_C}$$

$$\eta_{OH} = 1 - (\frac{A_F}{A})_H \left[1 - \frac{\tanh (m_H \ell_{eH})}{m_H \ell_{eH}}\right]$$

$$\eta_{OC} = 1 - (\frac{A_F}{A})_C \left[1 - \frac{\tanh (m_C \ell_{eC})}{m_C \ell_{eC}}\right]$$

$$m_H = \left[\frac{1800 C_{pH} \mu_H Re_H j_H (1 + t_{FH}/\xi_H)}{r_{hH} t_{FH} Pr_H^{2/3} k_H}\right]^{1/2}$$

$$m_C = \left[\frac{1800 C_{pC} \mu_C Re_C j_C (1 + t_{FC}/\xi_C)}{r_{hC} t_{FC} Pr_C^{2/3} k_C}\right]^{1/2}$$

8. Core Volume:

$V = L_H L_C L_N$

9. Volume of liquid inside the core:

$V_{LH} = \psi_H V$

$V_{LC} = \psi_C V$

Required Tables:

- Table ID (IF1,31 and IF2,31) - fin geometry (side 1 and side 2), -1 dimensional, 9 table values are in the following order:

A_F/A - fin area/total area

p - fin pitch

b - stack height

r_h - hydraulic radius

t_F - fin thickness

β - total heat transfer area/volume of one side

ξ - effective length in flow direction

FS - fin shape code

= 1.0 rectangular fin

= 2.0 rounded fin

= 3.0 triangular fin

N_S - number of sandwiches

= 1.0 single

= 2.0 double

= 3.0 triple

etc.

f - Table ID (IF1,32 and IF2,32) - fin friction factor (side 1 and side 2), 2 dimensional, the independent variable is Reynolds number (argument type 0; argument relative number 21), and the dependent variable is friction factor.

j - Table ID (IF1,33 and IF2,33) - fin Colburn modulus (side 1 and side 2), 2 dimensional, the independent variable is Reynolds number (argument type 0; argument relative number 21), and the dependent variable is Colburn modulus.

ε - Table ID (IEF,5) - heat transfer effectiveness, 3 or 33 dimensional, the first independent variable is NTU(argument type 0; argument relative number 55), the second independent variable is $(WC_p)_{min}/(WC_p)_{max}$ or $(WC_p)_{mixed}/(WC_p)_{unmixed}$ (argument type 0; argument relative number 56), and the dependent variable is heat transfer effectiveness.

t_{SP} - Table ID (ITSP,34) - separation plate thickness.

- Table ID (IM1,20) - side 1 fin material properties.
- Table ID (IM2,20) - side 2 fin material properties.
- Table ID (IMSP,20) - separation plate material properties.

Restrictions:

1. This component is used for sizing a plate fin cross flow heat exchanger.
2. The component can only be used for fluid types 1 and 2.
3. The core dimensions (L_H, L_C, L_N) must either be all specified by the user or be all unspecified.

Notes:

1. Three consecutive data cards are required, HX, HX1 and HX2. The HX card must precede HX1 and HX2 cards.
2. For each side of the heat exchanger, the same table relative number is used for the fin geometry table, the fin friction factor table and the fin Colburn modulus table.
3. Fluid properties are evaluated at average temperature, $T_{ave} = (T_{in} + T_{out})/2$, and average pressure, $P_{ave} = (P_{in} + P_{out})/2$.
4. The component printout consists of heat exchanger weight, cost units, reliability index, development risk factor, and the following items:

   W - flow rate
   PI - inlet pressure
   PØ - outlet pressure
   TI - inlet temperature
   TØ - outlet temperature
   HI - inlet humidity
   HØ - outlet humidity
   FT - fluid type
   FN - fluid properties table relative number

   (W through FN: hot side and cold side)

   LH - hot side flow length
   LC - cold side flow length
   LN - no flow length
   VØL - core volume
   WTC - core weight
   EFF - heat transfer effectiveness (not printed if core dimensions are specified)
   NTU - number of heat transfer units (not printed if core dimensions are specified)
   VLH - volume of hot side liquid inside the core (not printed if hot side fluid is a gas)
   VLC - volume of cold side liquid inside the core (not printed if cold side fluid is a gas)

5. Four performance map options are available. They are:

   Option 0 - no maps

   Option 1 - print maps

   Option 2 - punch maps

   Option 3 - print and punch maps

   The maps produced will consist of the hot side temperature effectiveness, and $\sigma\Delta P$ (if a gas) or ΔP (if a liquid) for both sides versus their flow rate.

6. If core dimensions are not specified by the user and the iteration dump option is selected, the following information is printed for each iteration:

   (a) State Variables (S.V.) - the three values printed are L_H, L_C, and L_N, respectively.

   (b) Error Variables (E.V.) - the three values printed are the difference of the calculated and the given hot side pressure drops, the difference of the calculated and the given cold side pressure drops, and the difference of the calculated and the given heat transfer effectivenesses, respectively.

   (c) The six values printed after the error variables are Re_H, Re_C, NTU, ε, η_{OH}, and η_{OC}, respectively.

7. The convergence limits for pressure drops and heat transfer effectivenesses are 0.01 and 0.0001, respectively. The upper and lower limits for state variables are 100.0 and 0.1, respectively.

8. The dry air rated hot side outlet temperature is used for the performance effectiveness calculation.

9. Values of L_H, L_C, L_N, V, V_{LH}, and V_{LC} are stored in general arguments 71, 72, 73, 74, 75 and 76, respectively.

2. HX1 Data Card

Card Column	Symbol	Value
1-3	CN	HX1 component name
8	CC	change code
12	NC	card number
16	NL1	leg number, side 1
20	NSI1	inlet station number, side 1
24	NSØ1	outlet station number, side 1
28	[L1]	core flow length, side 1 = 0 computed > 0 user specified
32	NP1	number of passes, side 1
36	IM1	fin material properties table relative number, side 1 (type 20)
40	IF1	fin variable tables relative number, side 1 (types 31, 32, 33)

3. HX2 Data Card

Card Column	Symbol	Value
1-3	CN	HX2 component name
8	CC	change code
12	NC	card number
16	NL2	leg number, side 2
20	NSI2	inlet station number, side 2
24	NSØ2	outlet station number, side 2
28	[L2]	core flow length, side 2 = 0 computed > 0 user specified
32	NP2	number of passes, side 2
36	IM2	fin material properties table relative number, side 2 (type 20)
40	IF2	fin variable tables relative number, side 2 (types 31, 32, 33)

Sizing Component HX

Data Cards Format

1. HX Data Card

Card Column	Symbol	Value
1-2	CN	HX component name
8	CC	change code
12	NC	card number
16	[WTM]	weight multiplier (optional)
20	[CUM]	cost unit multiplier (optional)
24	[RI]	reliability index (optional)
28	[DRM]	development risk factor multiplier (optional)
32	[LN]	no flow length = 0 computed > 0 user specified
36	IMSP	separation plate material table relative number (type 20)
40	ITSP	separation plate thickness table relative number (type 34)
44	IEF	effectiveness table relative number (type 5)
48	MAP	performance map options = 0 no maps = 1 print maps = 2 punch maps = 3 print and punch maps
52	IFLT	flow type = 1 both sides unmixed = 2 both sides mixed = 3 side 1 mixed, side 2 unmixed = 4 side 1 unmixed, side 2 mixed

2. HX1 Data Card

Card Column	Symbol	Value
1-3	CN	HX1 component name
8	CC	change code
12	[illegible]	card number
16	[illegible]	leg number, side 1
20	NSI1	inlet station number, side 1
24	NSØ1	outlet station number, side 1
28	[L1]	core flow length, side 1 = 0 computed > 0 user specified
32	NP1	number of passes, side 1
36	IM1	fin material properties table relative number, side 1 (type 20)
40	IF1	fin variable tables relative number, side 1 (types 31, 32, 33)

3. HX2 Data Card

Card Column	Symbol	Value
1-3	CN	HX2 component name
8	CC	change code
12	NC	card number
16	NL2	leg number, side 2
20	NSI2	inlet station number, side 2
24	NSØ2	outlet station number, side 2
28	[L2]	core flow length, side 2 = 0 computed > 0 user specified
32	NP2	number of passes, side 2
36	IM2	fin material properties table relative number, side 2 (type 20)
40	IF2	fin variable tables relative number, side 2 (types 31, 32, 33)

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Sizing Component INIT

Initialization

Purpose: This component is used to initialize a known component value. The available types of values are:

ITYP	Value
1	weight
2	cost units
3	reliability index
4	development risk factor
5	weight standard error
6	electrical power
7	shaft power
8	hydraulic power
9	bleed air extraction
10	fuel flow rate (lb/hr)
11	drag
12	expendable coolant weight

Equations:

For ITYP = 1, 2, 3, and 6 through 12

$$(\quad)_{system} = (\quad)_{system} + \text{Value}$$

For ITYP = 4

$$DR_{system} = DR_{system} \times \text{Value}$$

For ITYP = 5

$$(Wt_d)^2_{system} = (Wt_d)^2_{system} + (\text{Value})^2$$

Notes:

1. This component may be used to define an additional system development risk factor.
2. This component must be used to define bleed air extraction if system penalty calculation is required.
3. The component printout consists of initialization type and value.

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Sizing Component INIT

Data Card Format

Card Column	Symbol	Value
1-4	CN	INIT component name
8	CC	change code
12	NC	card number
16	ITYP	type of initialized value
		= 1 weight
		= 2 cost unit
		= 3 reliability index
		= 4 development risk factor
		= 5 weight standard error
		= 6 electrical power
		= 7 shaft power
		= 8 hydraulic power
		= 9 bleed air extraction
		= 10 fuel flow rate
		= 11 drag
		= 12 expendable coolant weight
20	[VALUE]	initialized value

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Sizing Component INSLTN

Insulation

Purpose: This component will compute weight, cost units, reliability index, development risk factor, and insulation thickness for ducting and compartment insulation. The available insulation types and insulation methods are:

INT	Insulation Type
1	bleed air line
2	conditioned air distribution line
3	compartment

INM	Insulation Method
1	wrap around (for INT = 1 & 2)
	blanket (for INT = 3)
2	integral blanket (for INT = 1 & 2)
	blanket with air gap (for INT = 3)
3	removable blanket with radiation reflector (for INT = 1)
4	air gap radiation shield (for INT = 1)

Equations:

1. Weight:

For INT = 1 and INM = 1 & 3:

$$Wt = L\ [(1.9667 \times 10^{-3}\ \rho_i\ D\ + 7.0 \times 10^{-4}\ \rho_i + 7.7 \times 10^{-2})(t - 0.25) + 4.25 \times 10^{-4}\ \rho_i\ D + 0.01\ D\ + 2.0833 \times 10^{-4}\ \rho_i + 1.59167 \times 10^{-2})] \qquad (1)$$

For INT = 1 and INM = 2:

$$Wt = L[(5.5 \times 10^{-3}\ t + 5.8833 \times 10^{-3})\ D - 0.015\ t - 5.8333 \times 10^{-4}] \qquad (2)$$

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For INT = 1 and INM = 4:

$$Wt = L[(6.0667 \times 10^{-3} D + 8.6 \times 10^{-3})(t - 0.25) + 2.35 \times 10^{-3} D + 1.0667 \times 10^{-3})] \quad (3)$$

For INT = 2 and INM = 1:

$$Wt = L (D + t)(6.1078 \times 10^{-4} + 1.0917 \times 10^{-3} t) \quad (4)$$

For INT = 2 and INM = 2:

$$Wt = L [(D + t)(9.725 \times 10^{-3} + 1.275 \times 10^{-3} t) - 4.8625 \times 10^{-3} D] \quad (5)$$

For INT = 3:

$$Wt = A [3.646 \times 10^{-4} t / CF + 5.104 \times 10^{-4}] \quad (6)$$

2. Cost Units:

For INT = 1:

$$CU = L [0.009583t (D + t) + 0.04425]$$

For INT = 2:

$$CU = 0.002378 DL$$

For INT = 3:

$$CU = A (6.944 \times 10^{-4} + 7.9167 \times 10^{-4} t)$$

3. Reliability Index:

$$RI = 0.00001$$

4. Development Risk Factor:

$$DR = 1.0$$

5. Weight Standard Error:

For INT = 1 and INM = 1 & 3:

$$Wt_d = 0.055 Wt$$

For INT = 1 and INM = 2:

$$Wt_d = 0.149 \; Wt$$

For INT = 1 and INM = 4:

$$Wt_d = 0.167 \; Wt$$

For INT = 2:

$$Wt_d = 0.15 \; Wt$$

For INT = 3:

$$Wt_d = 0.15 \; Wt$$

6. Installation Weight Factor:

$$Wt_i = 0.205 \; Wt$$

7. Thickness (if not specified):

For INT = 1 and INM = 1 & 2:

$$t_{calc} = 0.045 \; (T_D - 460) \; / \; (T_S - 0.2 \; T_D - 416)$$

For INT = 1 and INM = 3:

$$t_{calc} = 0.064 \; (T_D - 460) \; / \; (T_S - 0.2 \; T_D - 416)$$

For INT = 1 and INM = 4:

$$t_{calc} = 0.06 \; (T_D - 460) \; / \; (T_S - 0.2 \; T_D - 416)$$

For INT = 1 and all INM

$$t = t_{calc} \quad \text{if } 0 < t_{calc} \leq 1$$

$$t = 1 \quad \text{if } t_{calc} \leq 0 \text{ or } t_{calc} > 1$$

For INT = 2:

$$t = \frac{D}{2} \left(e^{c} - 1\right)$$

where

$$c = 2\pi \; k_i \left(\frac{T_{in} + T_{out}}{2} - T_A\right) / \; (q/L)$$

$$\frac{q}{L} = 60 \; W \; C_p \; (T_{in} - T_{out})/L$$

For INT = 3:

$$t = 12 \; (LF) \; k_i \; (T_S - T_C) \; / \; (q_T/A)$$

where

LF = heat leak factor

= 2.625

$$q_T/A = q_c/A + q_r/A$$

$$= 1.5 \left(\frac{P_A}{14.7}\right)^{1/2} \cdot (T_C - T_A) + 0.9 \; (1.714 \times 10^{-9})(T_C^{\,4} - T_A^{\,4})$$

Required Tables:

- Table ID(INT,20) - insulation material properties.

Restrictions:

1. Equation (1) applies only to line diameters greater than 1.5 inches.
2. Equation (2) applies only to 3 pcf insulation with a 0.006 inch thick stainless steel outer cover and a 0.002 inch thick aluminum radiation reflector.
3. Equation (3) applies only to line diameters approximately one inch or greater.
4. Equation (4) applies only to 0.6 pcf insulation with 0.125 lb per square yard cover sheets.
5. Equation (5) applies only to 0.6 pcf insulation with 5 ounces per square yard cover sheets.

Notes:

1. The insulation weights for flange clamps and expansion bellows are included in the installation weight factor.
2. The component printout consists of weight, cost units, reliability index, development risk factor, and the following item:

   THK - insulation thickness or air gap size
3. The insulation material properties table input is always required although it is not always required in the computation. For INT = 1 and INM = 4, the user may input a dummy material properties table.
4. The insulation conductivity, k_i, is evaluated at an average temperature of insulation inner and outer surfaces. The insulation density, ρ_i, is constant. C_p is evaluated at the inlet temperature, T_{in}.

Sizing Component INSLTN

Data Card Format

Card Column	Symbol	Value
1-6	CN	INSLTN component name
8	CC	change code
12	NC	card number
16	[WTM]	weight multiplier (optional)
20	[CUM]	cost unit multiplier (optional)
24	[RI]	reliability index (optional)
28	[DRM]	development risk factor multiplier (optional)
32	INT	insulation type = 1 bleed air line = 2 distribution line = 3 compartment
36	INM	insulation method = 1 wrap around (for INT = 1 & 2) blanket (for INT = 3) = 2 integral blanket (for INT = 1 & 2) blanket with air gap (for INT= 3) = 3 removable blanket with radiation reflector (for INT = 1) = 4 air gap radiation shield (for INT = 1)
If INT = 1		
40	[THK]	insulation thickness or air gap size = 0 computed > 0 user specified
44	[D]	line outer diameter
48	[L]	line length
52	[TD]	line temperature (not required if [THK] > 0) = 0 use fluid inlet temperature > 0 user specified
56	NSI	inlet station number (not required if [THK] > 0 or [TD] > 0)
60	[TS]	insulation outer surface temperature (not required if [THK] > 0)
64	-	
68	IMT	insulation material properties table relative number (type 20)

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If INT = 2

40	[THK]	insulation thickness = 0 computed > 0 user specified
44	[D]	line outer diameter
48	[L]	line length
52	[TA]	abmient temperature (not required if [THK] > 0)
56	NL	leg number
60	NSI	inlet station number
64	NSØ	outlet station number
68	IMT	insulation material properties table relative number (type 20)

If INT = 3

40	[THK]	insulation thickness = 0 computed > 0 user specified
44	[A]	insulation area
48	[PC]	compartment pressure (not required if [THK] > 0)
52	[TC]	compartment temperature (not required if [THK] > 0)
56	[TW]	compartment wall temperature (not required if [THK] > 0)
60	[TS]	insulation outer surface temperature (not required if [THK] > 0)
64	[CF]	compression factor
68	IMT	insulation material properties table relative number (type 20)

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Sizing Component LINE

Line

Purpose: This component will compute weight, cost units, reliability index, development risk factor, and inside diameter for lines. The available types of lines are:

ILT	Type
1	high pressure bleed line, aluminum
2	high pressure bleed line, steel
3	low pressure distribution or ram air line
4	refrigeration package line
5	liquid coolant line, aluminum

Equations:

1. Weight:

For ILT = 1:

$$Wt = 0.34\ D\ t\ L$$

For ILT = 2:

$$Wt = (2.4\ D + 1.25)\ t\ L$$

For ILT = 3:

$$Wt = 0.0137\ D\ L \qquad (D \leq 3.5)$$

$$Wt = (0.0179\ D - 0.0147)\ L \qquad (D > 3.5)$$

For ILT = 4:

$$Wt = 0.7\ (2.4\ D + 1.25)\ t\ L$$

For ILT = 5:

$$Wt = 0.3071\ (D + t)\ t\ L$$

2. Cost Units:

For ILT = 1 & 5:

$$CU = (0.0097\ D + 0.0191)\ L$$

For ILT = 2 & 4:

$$CU = (0.103\ D + 0.026)\ L \qquad (D \leq 2.5)$$

$$CU = (0.231\ D - 0.295)\ L \qquad (D > 2.5)$$

For ILT = 3:

$$CU = (0.011\ D + 0.0295)\ L \qquad (D \leq 3.5)$$

$$CU = (0.0254\ D - 0.0233)\ L \qquad (D > 3.5)$$

3. Reliability Index:

For ILT = 1, 2 & 4:

$$RI = 0.01164$$

For ILT = 3:

$$RI = 0.00291$$

For ILT = 5:

$$RI = 0.00285$$

4. Development Risk Factor:

$$DR = 1.0$$

5. Weight Standard Error:

$$Wt_d = 0.15\ Wt + 0.158\ Wt_i$$

6. Installation Weight:

For ILT = 1, 2, & 3:

$$Wt_i = 3.45 \times 10^{-4}\ (D\ L)^{1.58}$$

For ILT = 4 & 5:

$$Wt_i = 0.0$$

7. Liquid Volume (for ILT = 5 only):

$$V = \frac{\pi}{4} D^2 L$$

8. Inside Diameter (if not specified):

$$\Delta P = 1.008 \times 10^{-3} \left(\frac{4\ f\ L}{D} + C\ K_t\right) \frac{W^2}{\rho\ D^4} - \frac{\rho\ Z}{1728}$$

where

Z = inlet elevation - outlet elevation

The above equation is solved for inside diameter iteratively by the generalized Newton Raphson method.

9. Wall Thickness (if not specified):

For ILT = 1:

$t = 0.035$ $(D \leq 3.5)$

$t = 0.042$ $(D > 3.5)$

For ILT = 2 & 4:

$$t = 0.00677\ D + 0.00322$$

For ILT = 5:

$t = 0.01$ $(D \leq 1.0)$

$t = 0.028$ $(D > 1.0)$

For ILT = 3:

Wall thickness is not required.

Required Tables (if inside diameter is not specified):

f - Table ID(IF,3) - friction factor

K_t - Table ID (IKT,2) - bend pressure loss factor

Restrictions:

1. This component can only be used for fluid types 1 (if ILT = 1) or 2 (if ILT ≠ 1)

Notes:

1. The component printout consists of weight, cost units, reliability index, development risk factor, and the following items:

   W - flow rate
   PI - inlet pressure
   PØ - outlet pressure
   TI - inlet temperature
   TØ - outlet temperature
   HI - inlet humidity
   HØ - outlet humidity
   FT - fluid type
   FN - fluid properties table relative number
   D - inside diameter
   THK - wall thickness (for ILT ≠ 3 only)
   V - velocity
   M - Mach number (for ILT ≠ 5 only)
   VL - liquid volume (for ILT = 5 only)

2. If a line inside diameter is not specified and the iteration dump option is selected, the following information is printed for each iteration:
   (a) State Variable (S.V.) - line inside diameter.
   (b) Error Variable (E.V.) - the difference of the calculated and the given pressure drops.
   (c) RE - Reynolds number.

3. The convergence limit is 0.01. The upper and lower limits for the state variable are 10.0 and 0.1, respectively.
4. The values of inside diameter, velocity, Mach number, and liquid volume are stored in general arguments 71, 72, 73, and 74, respectively.
5. Reynolds number is available in general argument 21, and diameter is available in general argument 57, for the f and K_t table lookup.
6. If diameter is not specified, the f or the K_t term can be optional, but not both.

Sizing Component LINE

Data Card Format

Card Column	Symbol	Value
1-4	CN	LINE component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	[WTM]	weight multiplier (optional)
32	[CUM]	cost unit multiplier (optional)
36	[RI]	reliability index (optional)
40	[DRM]	development risk factor multiplier (optional)
44	[D]	inside diameter = 0 computed > 0 user specified
48	[L]	line length
52	[THK]	wall thickness (not required if ILT = 3) = 0 computed > 0 user specified
56	[Z]	difference in elevation between line inlet and outlet
60	IF	friction factor table relative number (type 3, optional)
64	[C]	correction factor for loss of bends other than 90° (optional)
68	IKT	90° bend pressure loss factor table relative number (type 2, optional)
72	ILT	line type = 1 high pressure bleed line, aluminum = 2 high pressure bleed line, steel = 3 low pressure distribution or ram air line = 4 refrigeration package line = 5 liquid coolant line, aluminum

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Sizing Component MISC

Miscellaneous Operations

Purpose: This component will compute any value desired using basic mathematical expressions. The result of the operation may be a general argument or a parameter table value. Variables one and two may be a general argument, a flow rate, a pressure, a temperature, a humidity, a parameter table value or a table lookup value.

Options: The operations which are a function of one variable are: equality, absolute value, square root, base ten logarithm, natural logarithm, ten to a power, and e to a power. The operations which are a function of two variables are: addition, subtraction, multiplication, division, the minimum of two variables, the maximum of two variables, variable one to the variable two power, average value, and a code which indicates that variable one is either less than, equal to, or greater than variable two.

Equations:

if IØPR $\leq$ 0

VX = f (V1)

if IØPR > 0

VX = f (V1, V2)

Notes:

1. The component printout consists of the following items:

VX	- result variable value		
IVXT	- result variable type		
IVXN	- result variable relative number		
IØPR	- operation code		
V1	- variable value	}	variable one
IV1T	- variable type	}	
IV1N	- variable relative number	}	
V2	- variable value	}	variable two (printed if IØPR > 0)
IV2T	- variable type	}	
IV2N	- variable relative number	}	

Sizing Component MISC

Data Card Format

Card Column	Symbol	Value
1-4	CN	MISC component name
8	CC	change code
12	NC	card number
16	IVXT	result type = 0 - general argument = -1 - parameter value
20	NVX	result relative number If IVXT = 0 - general argument number = -1 - parameter index
24	IV1T	variable one type = 0 - general argument = 1 - flow rate = 2 - pressure = 3 - temperature = 4 - humidity = -1 - parameter value = -2 - table (type 99)
28	NV1	variable one relative number if IV1T = 0 - general argument relative number = 1 - leg number = 2 - } = 3 - } station number = 4 - } = -1 - parameter index = -2 - table relative number (type 99)
32	IØPR	operation if IØPR > 0 VX = f(V1, V2) = 1 - V1 + V2 = 2 - V1 - V2 = 3 - V1 x V2 = 4 - V1 ÷ V2 = 5 - minimum value (V1, V2) = 6 - maximum value (V1, V2) = 7 - $V1^{V2}$ = 8 - (V1 + V2)/2

		= 9 - 0 if V1 = V2 1 if V1 > V2 -1 if V1 < V2 if IØPR = 0 VX = V1 if IØPR < 0 VX = f(V1) = -1 - V1 = -2 - V1 = -3 - log V1 = -4 - ln V1 = -5 - 10^{V1} = -6 - e^{V1}
36	IV2T	variable two type (same as IV1T)
40	NV2	variable two relative number (same as NV1)

Sizing Component PUMP

Pump

Purpose: This component will compute weight, cost units, reliability index, development risk factor, and volume for a pump package. It will also compute the efficiency and the horsepower for a pump and its drive. The available pump types are:

IPT	Type
1	vane or gear
2	centrifugal

Equations:

1. Weight:

   For pump and motor:

   For IPT = 1:

   $Wt_p = 2.1$ $\quad$ $(DPR < 0.088\ in^3/rev)$

   $Wt_p = 10.63\ (DPR)^{2/3}$ $\quad$ $(DPR \geq 0.088\ in^3/rev)$

   For IPT = 2:

   $Wt_p = 2.1$ $\quad$ $(DPR < 0.028\ in^3/rev)$

   $Wt_p = 22.92\ (DPR)^{2/3}$ $\quad$ $(DPR \geq 0.028\ in^3/rev)$

   where

   $$DPR = 1728\ W/(\rho\ N)$$

   For reservoir:

   $$Wt_r = 0.131\ V_f^{2/3}$$

   where

   $$V_f = Wt_{liquid}\ (1/\rho_{high} - 1/\rho_{low})$$

   $$Wt_{liquid} = \rho_{in}\ V_{liquid}$$

   For filter:

   $$Wt_{filter} = 0.55 + 0.9575\ W/\rho$$

   For pump package:

   $$Wt = 1.125\ (Wt_p + Wt_r + Wt_{filter}) + Wt_{liquid}$$

2. Cost Units:

   $$CU = 81.2 + 1.05\ (Wt_p + Wt_r + Wt_{filter})$$

3. Reliability Index:

   $$RI = 0.04016$$

4. Development Risk Factor:

   $$DR = 1.0$$

5. Weight Standard Error:

$$Wt_d = (0.0361\ Wt_P{}^2 + 0.0551\ Wt_r{}^2 + 0.0441\ Wt^2_{filter})^{1/2}$$

6. Installation Weight Factor:

$$Wt_i = 0.205\ (Wt_P + Wt_r + Wt_{filter})$$

7. Volume:

$$V = 33.04\ (Wt_P + Wt_r + Wt_{filter})$$

8. Horsepower:

(a) Fluid horsepower:

$$HP_f = 4.3636 \times 10^{-3}\ (P_{out} - P_{in})\ W/\rho_{in}$$

(b) Shaft Horsepower:

$$HP_S = HP_f + WC_P\ (T_{out} - T_{in})/42.416$$

9. Efficiency:

$$\eta = HP_f/HP_S$$

Restrictions:

1. This component can only be used for fluid type 1.
2. This component is used for sizing an electric motor driven pump only.
3. Shaft speed must be specified by the user.

Notes:

1. Refer to sizing subroutine CØMP for drive type, and equations (DC motor) for drive efficiency and horsepower.
2. The volumetric change of the total amount of liquid in the liquid loop is computed at a high temperature of 710°R and a low temperature of 395°R.
3. The component printout consists of weight (including weight of liquid in the liquid loop subsystem), cost units, reliability index, and development risk factor of the pump package, and the following items:

W - flow rate

PI - inlet pressure

PØ - outlet pressure

TI - inlet temperature

TØ - outlet temperature

HI - inlet humidity

HØ - outlet humdiity

FT - fluid type

FN - fluid properties table relative number

WTP - weight of pump and motor

WTR - weight of reservoir

WTL - weight of filter

VØL - volume of the pump package

N - shaft speed

EFF - pump efficiency

HP - pump shaft horsepower

Additional printout consists of drive type and the following items:

EFF - drive efficiency

HP - drive input horsepower

4. The value of package volume is stored in general argument 71.

Sizing Component PUMP

Data Card Format

Card Column	Symbol	Value
1-4	CN	PUMP component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	NST	shaft number
32	[WTM]	weight multiplier (optional)
36	[CUM]	cost unit multiplier (optional)
40	[RI]	reliability index (optional)
44	[DRM]	development risk factor multiplier (optional)
48	[VL]	liquid volume in the whole liquid loop
52	IPT	pump type = 1 vane or gear = 2 centrifugal

Sizing Component RIN
Ram Air Inlet

Purpose: This component will compute weight, cost units, reliability index, development risk factor, inlet area, diffuser exit area, volume, and drag for inlets. The available inlet types are:

INLT	Type
1	flush inlet
2	scoop inlet
3	nose inlet
4	engine duct inlet

Equations:

1. Weight:

   $Wt = \rho\, t_e\, (8\, A_I + S)/1728$

   where t_e is the effective wall thickness of inlet and diffuser.

2. Cost Units:

   $CU = 13.0 + 0.139\, Wt^{1.65}$

3. Reliability Index:

   $RI = 0.0001$

4. Development Risk Factor:

   $DR = 1.0$

5. Weight Standard Error:

   $Wt_d = 0.25\, Wt$

6. Installation Weight Factor:

   $Wt_i = 0.205\, Wt$

7. Inlet Area:

   For INLT = 1:

$$A_I = \frac{3.6823\, W}{\rho_\infty\, V_\infty} \quad \text{(for flight condition, } V_\infty > 0\text{)}$$

$$A_I = \frac{W\sqrt{T_\infty}}{8.9376\, P_\infty} \quad \text{(for sea level static condition, } V_\infty = 0\text{)}$$

For INLT = 2:

$$A_I = \frac{3.4286\ W}{\rho_\infty\ V_\infty}$$ (for subsonic flight condition)

$$A_I = \frac{3\ W}{\rho_\infty\ V_\infty}$$ (for supersonic flight condition)

$$A_I = \frac{W\sqrt{T_\infty}}{8.9376\ P_\infty}$$ (for sea level static condition)

For INLT = 3:

$$A_I = \frac{3\ W}{\rho_\infty\ V_\infty}$$ (for flight condition)

$$A_I = \frac{W\sqrt{T_\infty}}{8.9376\ P_\infty}$$ (for sea level static condition)

For INLT = 4:

$$A_I = \frac{2.4\ W}{0.3\ \rho_I\ c_I}$$

where c_I is the speed of sound at the inlet.

8. Diffuser Exit Area:

$$A_D = \frac{2.4\ W}{0.15\ \rho_D\ c_D}$$

where c_D is the speed of sound at the diffuser exit.

9. Diffuser Surface Area:

$$S = \frac{A_D - A_I}{0.10453}$$

10. Volume:

$$V = 1.89\ A_I^{1.5} + \frac{(\sqrt{A_D} - \sqrt{A_I})(A_I + A_D + \sqrt{A_I\ A_D})}{0.5589}$$

11. Drag:

$$D = \frac{W\ V_\infty}{1932}$$

Required Tables:

- Table ID (IM,20) - material properties

Restrictions:

1. This component can only be used for fluid type 2.

Notes:

1. An inlet consists of an inlet section and a diffuser.
2. The outlet station refers to the station at the end of the mixing section.
3. The component printout consists of weight, cost units, reliability index, development risk factor, and the following items:

   W - flow rate
   PI - free stream pressure
   PØ - outlet pressure
   TI - free stream temperature
   TØ - outlet temperature
   HI - free stream humidity
   HØ - outlet humidity
   FT - fluid type
   FN - fluid properties table relative number
   AI - inlet area
   AD - diffuser exit area
   VØL - volume
   DRAG - inlet drag
4. If S < 0.0, the diffuser is not sized. A message is printed, and A_D is set to zero.
5. The free stream fluid, free stream pressure, temperature, Mach number, and velocity must be defined.
6. The values of volume and inlet area are stored in general argument 71 and 72, respectively.

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Sizing Component RIN

Data Card Format

Card Column	Symbol	Value
1-3	CN	RIN component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSØ	mixing section outlet station number
24	[WTM]	weight multiplier (optional)
28	[CUM]	cost unit multiplier (optional)
32	[RI]	reliability index (optional)
36	[DRM]	development risk factor multiplier (optional)
40	[AI]	inlet area = 0 computed > 0 user specified
44	[THK]	effective wall thickness
48	IM	material properties table relative number (type 20)
52	INLT	inlet type = 1 flush inlet = 2 scoop inlet = 3 nose inlet = 4 engine duct inlet

Sizing Component RØUT

Ram Air Outlet

Purpose: This component will compute weight, cost units, reliability index, development risk factor, outlet area, and volume for an outlet of a ram air duct.

Equations:

1. Weight:

   $$Wt = 4.5 \rho t_e (1.0 + 1.69 A_0^{1/2} + 1.2 A_0)$$

2. Cost Units:

   $$CU = 13.0 + 0.139 Wt^{1.65}$$

3. Reliability Index:

   $$RI = 0.00010$$

4. Development Risk Factor:

   $$DR = 1.0$$

5. Weight Standard Error:

   $$Wt_d = 0.25 Wt$$

6. Installation Weight Factor:

   $$Wt_i = 0.205 Wt$$

7. Volume

   $$V = 0.85 A_0^{1.5}$$

8. Outlet Area:

   $$A_0 = (W/40.1248C_D)(\frac{\gamma}{\gamma-1} P_0 \rho_0)^{1/2} [(PR)^{\frac{2}{\gamma}} - (PR)^{\frac{\gamma+1}{\gamma}}]^{1/2}$$

   $$PR = P_{ambient}/P_0$$

Required Table:

- Table ID (IM,20) - material properties

Restriction:

1. This component can only be used for fluid type 2.

Notes:

1. The component printout consists of weight, cost units, reliability index, development risk factor, and the following items:

W	- flow rate
PI	- inlet pressure
PØ	- outlet pressure
TI	- inlet temperature
TØ	- outlet temperature
HI	- inlet humidity
HØ	- outlet humidity
FT	- fluid type
FN	- fluid properties table relative number
AØ	- outlet area
VØL	- volume

2. The values of volume and outlet area are stored in general arguments 71 and 72 respectively.

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Sizing Component RØUT

Data Card Format

Card Column	Symbol	Value
1-4	CN	RØUT component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	[WTM]	weight multiplier (optional)
32	[CUM]	cost unit multiplier (optional)
36	[RI]	reliability index (optional)
40	[DRM]	development risk factor multiplier (optional)
44	[AØ]	outlet area = 0 computed > 0 user specified
48	[THK]	effective wall thickness
52	IM	material properties table relative number (table 20)
56	[CD]	discharge coefficient (not required if [AØ] > 0)

Sizing Component TURB

Turbine

Purpose: This component will compute weight, cost units, reliability index, development risk factor, volume, wheel diameter and/or shaft speed for an air cycle turbine (centrifugal or axial).

Equations:

1. Weight:

   $Wt = 0.4\ D^2$

2. Cost Units:

   $CU = 5.5\ Wt$

3. Reliability Index:

   $RI = 0.0$

4. Development Risk Factor:

   $DR = 1.0$

5. Weight Standard Error:

   $Wt_d = 0.164\ Wt$

6. Installation Weight Factor:

   $Wt_i = 0.205\ Wt$

7. Volume:

   $V = 0.6666667\ D^4$

8. Efficiency:

   $$\eta_{ad} = (T_{in} - \overline{T}_{out})/[T_{in}\ \{1.0 - (P_{out}/P_{in})^{\frac{\gamma-1}{\gamma}}\}]$$

9. Horsepower:

   $HP = 0.02356\ WC_p\ (T_{in} - \overline{T}_{out})$

10. Wheel Diameter (if not specified):

   $D = 12\ D_s\ Q^{1/2}/H^{1/4}$

   where

   $D_s = f\ (N_s, \eta_{ad})$ ($N_s - D_s - \eta_{ad}$ table)

   $Q = W/\rho_{in}$

$$H = 778\, C_p\, T_{in}\, [1.0 - (P_{out}/P_{in})^{\frac{\gamma-1}{\gamma}}]$$

$$N_s = N\, Q^{1/2}/H^{3/4}$$

11. Shaft speed (if not specified):

$$N = N_s\, H^{3/4}/Q^{1/2}$$

where N_s is found iteratively from $N_s - D_s - \eta_{ad}$ table by the generalized Newton Raphson method.

12. Tip speed:

$$U = 0.004363\, D\, N$$

Required Tables:

$(N_s - D_s - \eta_{ad})$ - Table ID (ND,37) - 3 or 33 dimensional, the first independent variable is N_s (argument type 0; argument relative number 59), the second independent variable is η_{ad} (argument type 0; argument relative number 60), and the dependent variable is D_s.

Restrictions:

1. This component can only be used for fluid type 2.

Notes:

1. If both shaft speed and wheel diameter are not specified, the built in limiting shaft speed is used for wheel diameter calculation. If this results in an excessive tip speed (a warning message "tip speed exceeds limiting value" is printed), the built in limiting tip speed is used to determine the wheel diameter and shaft speed iteratively by the generalized Newton Raphson method.
2. The component printout consists of weight, cost units, reliability index, development risk factor, and the following items:

W - flow rate

PI - inlet pressure

PØ - outlet pressure

TI - inlet temperature

TØ - outlet temprature

HI - inlet humidity

HØ - outlet humidity

FT - fluid type

FN - fluid properties table relative number

D - wheel diameter

VØL - volume

N - shaft speed

EFF - efficiency

HP - horsepower

U - tip speed

NS - specific speed

DS - specific diameter

3. The reliability index and the development risk factor are accounted for in the component driven by the turbine.
4. If iteration is employed and the iteration dump option is selected, the following information is printed for each iteration:
   (a) State Variable (S.V.) - specific speed
   (b) Error Variable (E.V.) - if the conditions described in Note 1 occur, the printed value is the difference of the calculated tip speed and the limiting tip speed. If the wheel diameter is specified, the printed value is the difference of the calculated and the known specific diameters.
5. The convergence limit is 0.001. The upper and the lower limits for the state variable are 10,000 and 1.0,respectively.
6. The values of the wheel diameter and the compressor volume are stored in the general arguments 71 and 72,respectively. If rotational speed is determined, it will be stored in general argument (80 + NST).
7. The built in limiting rotational speed and the limiting tip speed are 60,000 rpm and 2,000 ft/sec, respectively. Users may override this by specifying a different value with a CØMMØN card.

Sizing Component TURB
Data Card Format

Card Column	Symbol	Value
1-4	CN	TURB component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	NST	shaft number
32	[WTM]	weight multiplier (optional)
36	[CUM]	cost unit multiplier (optional)
40	[RI]	reliability index (optional)
44	[DRM]	development risk factor multiplier (optional)
48	[D]	wheel diameter = 0 computed > 0 user specified
52	ND	$N_s - D_s - \eta_{ad}$ table relative number (type 37)
56	ITT	turbine type = 1 centrifugal = 2 axial

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Sizing Component VALVE

Valve

Purpose: This component will compute weight, cost units, reliability index, development risk factor, and inside diameter for valves.

IVT	Type
1	pneumatic butterfly
2	electric butterfly
3	45° stem poppet
4	60° stem poppet
5	90° stem poppet
6	split flapper check

Equations:

1. Weight:

For IVT = 1 through 6 and fluid type 1:

$Wt = 1.1$

For IVT = 1 and fluid type 2:

$Wt = 2.68\ D - 1.0$ (steel)

$Wt = 0.7\ D + 0.35$ (aluminum, $D \leq 2.5$)

$Wt = 1.26\ D - 1.05$ (aluminum, $D > 2.5$)

For IVT = 2 and fluid type 2:

$Wt = 1.14\ D + 0.9$ (steel)

$Wt = 0.56\ D + 1.1$ (aluminum)

For IVT = 3, 4, 5 and fluid type 2:

$Wt = 2.04\ D + 0.225$ (steel)

$Wt = 0.833\ D - 0.05$ (aluminum)

For IVT = 6 and fluid type 2:

$Wt = 0.625\ D - 0.625$ (steel)

$Wt = 0.33\ D - 0.38$ (aluminum)

2. Cost Units:

For IVT = 1 through 6 and fluid type 1:

$CU = 5.4$

For IVT = 1, 2 and fluid type 2:

$CU = 1.13\ (D\ Wt)^{1.11}$ ($D\ Wt > 17.5$)

$CU = 27.0$ ($D\ Wt \leq 17.5$)

For IVT = 3, 4, 5 and fluid type 2:

$CU = 8.4 \ (D\ Wt)^{0.192}$ (D Wt > 0.1)

$CU = 5.4$ (D Wt $\leq$ 0.1)

For IVT = 6 and fluid type 2:

$CU = 3.7 \ (D\ Wt)^{0.193}$ (D Wt > 0.1)

$CU = 2.37$ (D Wt $\leq$ 0.1)

3. Reliability Index:

For IVT = 1 through 6 and fluid type 1:

RI = 0.00219

For IVT = 1 and fluid type 2:

RI = 0.0461

For IVT = 2 and fluid type 2:

RI = 0.07649

For IVT = 3, 4, 5 and fluid type 2:

RI = 0.05291

For IVT = 6 and fluid type 2:

RI = 0.0571

4. Development Risk Factor:

DR = 1.0 (T $\leq$ 1460°R, P $\leq$ 364.7 psi)

$$DR = 1.0 + \left(\frac{T-1460}{450}\right)^2 + \left(\frac{P-364.7}{585}\right)^2$$

(T > 1460°R, P > 364.7 psi)

5. Weight Standard Error:

For IVT = 1 through 6 and fluid type 1:

$Wt_d = 0.303\ Wt$ (steel)

$Wt_d = 0.348\ Wt$ (aluminum)

For IVT = 1 and fluid type 2:

$Wt_d = 0.35\ Wt$ (steel)

$Wt_d = 0.339\ Wt$ (aluminum)

For IVT = 2 and fluid type 2:

$Wt_d = 0.201\ Wt$ (steel)

$Wt_d = 0.174\ Wt$ (aluminum)

For IVT = 3, 4, 5 and fluid type 2:

$Wt_d = 0.303\ Wt$ (steel)

$Wt_d = 0.348\ Wt$ (aluminum)

For IVT = 6 and fluid type 2:

$Wt_d = 0.3\ Wt$ (steel)

$Wt_d = 0.359\ Wt$ (aluminum)

6. Installation Weight Factor:

$Wt_i = 0.0$

7. Diameter (if not specified):

$$D = [1.008 \times 10^{-3}\ K_t\ W^2/(\rho\ \Delta P)]^{0.25}$$

where K_t = 0.43 for IVT = 1 & 2
= 2.74 for IVT = 3
= 3.4 for IVT = 4
= 6.5 for IVT = 5
= 0.68 for IVT = 6

Restrictions:

1. This component can only be used for fluid types 1 and 2.

Notes:

1. The component printout consists of weight, cost units, reliability index, development risk factor and the following items:

W - flow rate
PI - inlet pressure
PØ - outlet pressure
TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity
HØ - outlet humidity
FT - fluid type
FN - fluid properties table relative number
D - inside diameter
KT - pressure loss coefficient
V - velocity
M - Mach number (for fluid type 2 only)

2. Steel valve equations are used if inlet temperature is greater than or equal to T_{LM}. Aluminum valve equations are used if it is less than T_{LM}. The built in T_{LM} is 960°R. Users may override this by specifying a different T_{LM} with a CØMMØN card.

3. The minimum weight for IVT = 1 is 0.5. For IVT = 3 through 5, the minimum weight is 0.3. For IVT = 6, it is 0.25.

4. The values of inside diameter, velocity, and Mach number are stored in the general arguments 71, 72, and 73, respectively.

Sizing Component VALVE

Data Card Format

Card Column	Symbol	Value
1-5	CN	VALVE component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	[WTM]	weight multiplier (optional)
32	[CUM]	cost unit multiplier (optional)
36	[RI]	reliability index (optional)
40	[DRM]	development risk factor multiplier (optional)
44	[D]	inside diameter = 0 computed > 0 user specified
48	IVT	valve type = 1 butterfly, pneumatic = 2 butterfly, electric = 3 poppet, 45° stem = 4 poppet, 60° stem = 5 poppet, 90° stem = 6 check, split flapper

Sizing Component $\underline{VCØMP}$

Vapor Cycle Compressor

Purpose: This component will compute weight, cost units, reliability index, and development risk factor for a vapor cycle compressor assembly, which includes the compressor, the drive, refrigerant charge, refrigerant lines, and the receiver. The available types of drives are:

IDT	Type
1	turbine
2	electric motor, AC
3	electric motor, DC
4	hydraulic motor

Equations:

1. Weight:

For compressor:

$Wt_{comp} = 0.5\ Wt_{drive}$

For refrigerant charge:

$Wt_{rc} = \rho\ V_{rc}/1728$

where

$V_{rc} = 0.3\ V_{evap} + 0.6\ V_{cond} + 5.184W\ V_{in}$

V_{in} = specific volume at compressor inlet

For receiver:

$Wt_r = 0.012\ V_{rc}$

For refrigerant lines:

$Wt_{line} = (Wt_{drive} + Wt_{comp} + Wt_{evap} + Wt_{cond} + Wt_r) \times (0.1 + 0.01\ L)$

2. Cost Units:

For IDT = 1:

$CU = 5.5\ Wt_{comp}$

For IDT = 2 & 3:

$CU = 34.7 + 17.3\ (Wt_{comp} + Wt_{drive})$

For IDT = 4

$CU = 17.0 + 4.88\ (Wt_{comp} + Wt_{drive})$

3. Reliability Index:

For IDT = 1:

$$RI = 0.02576$$

For IDT = 2 & 3:

$$RI = 0.00873$$

For IDT = 4:

$$RI = 0.02576$$

4. Development Risk Factor:

For IDT = 1:

$$DR = 1.15$$

For IDT = 2, 3, & 4:

$$DR = 1.0$$

5. Weight Standard Error:

For IDT = 1:

$$Wt_d = [(0.164\ Wt_{comp})^2 + (0.12\ Wt_r)^2 + (0.12\ Wt_{rc})^2 + (0.12\ Wt_{line})^2]^{1/2}$$

For IDT = 2:

$$Wt_d = [(0.1665\ Wt_{drive})^2 + (0.12\ Wt_r)^2 + (0.12\ Wt_{rc})^2 + (0.12\ Wt_{line})^2]^{1/2}$$

For IDT = 3:

$$Wt_d = [(0.388\ Wt_{drive})^2 + (0.12\ Wt_r)^2 + (0.12\ Wt_{rc})^2 + (0.12\ Wt_{line})^2]^{1/2}$$

For IDT = 4:

$$Wt_d = [(0.3\ Wt_{drive})^2 + (0.12\ Wt_r)^2 + (0.12\ Wt_{rc})^2 + (0.12\ Wt_{line})^2]^{1/2}$$

6. Installation Weight Factor:

$$Wt_i = 0.205\ (Wt_{drive} + Wt_{comp} + Wt_r)$$

7. Volume:

For IDT = 1

$$V = 0.2\ D^4_{turb}$$

For IDT = 2 & 3:

$$V = 10\ (Wt_{drive} + Wt_{comp})$$

For IDT = 4

$$V = 20\ (Wt_{drive} + Wt_{comp})$$

8. Compressor Horsepower:

$$HP = 0.02356\ W\ (H_{out} - H_{in})$$

9. Compressor Efficiency:

$$\eta = (H_s - H_{in})/(H_{out} - H_{in})$$

Restriction:

1. This component can only be used for fluid type 3.

Notes:

1. Refer to sizing subroutine CØMP section for equations pertinent to drives.
2. The component printout consists of weight, cost units, reliability index, development risk factor, and the following items:

W - flow rate
PI - inlet pressure
PØ - outlet pressure
TI - inlet temperature
TØ - outlet temperature
HI - inlet humidity
HØ - outlet humidity
FT - fluid type
FN - fluid properties table relative number
WTCD - weight of compressor with drive
WTR - weight of receiver
WTRC - weight of refrigerant charge
WTL - weight of refrigerant lines
VØL - volume of compressor with drive
N - shaft speed
EFF - compressor efficiency
HP - compressor fluid horsepower

Additional printout consists of drive type and the following items:

EFF - drive efficiency

HP - drive input horsepower

WT - drive weight

3. The refrigerant charge density is evaluated at 15°F below the compressor inlet temperature.
4. The value of volume is stored in general argument 71.

Sizing Component VCØMP

Data Card Format

Card Column	Symbol	Value
1-5	CN	VCØMP component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	NST	shaft number
32	[WTM]	weight multiplier (optional)
36	[CUM]	cost unit multiplier (optional)
40	[RI]	reliability index (optional)
44	[DRM]	development risk factor multiplier (optional)
48	[EV]	evaporator core volume
52	[CV]	condenser core volume
56	IDT	types of drives = 1 turbine = 2 electric motor, AC = 3 electric motor, DC = 4 hydraulic motor
60	[D]	turbine wheel diameter (not required if IDT $\neq$ 1)
64	-	
68	[L]	line length between evaporator and condenser
72	[CWT]	condenser weight
76	[EWT]	evaporator weight

Sizing Component WSEP

Water Separator

Purpose: This component will compute weight, cost units, reliability index, development risk factor, and volume for water separators.

Equations:

1. Weight:

   $Wt = 0.0936\ W$

2. Cost Units:

   $CU = 18.82 + 2.08\ Wt$

3. Reliability Index:

   $RI = 0.00285$

4. Development Risk Factor:

   $DR = 1.0$

5. Weight Standard Error:

   $Wt_d = 0.173\ Wt$

6. Installation Weight Factor:

   $Wt_i = 0.205\ Wt$

7. Volume:

   $V = 2.11\ W^{1.5}$

Restrictions:

1. This component can only be used for fluid type 2.

Notes:

1. The component printout consists of weight, cost units, reliability index, development risk factor, and the following items:

   W - flow rate
   PI - inlet pressure
   PØ - outlet pressure
   TI - inlet temperature
   TØ - outlet temperature
   HI - inlet humidity
   HØ - outlet humidity
   FT - fluid type
   FN - fluid properties table relative number
   VØL - volume

2. The value of volume is stored in general argument 71.

Sizing Component WSEP

Data Card Format

Card Column	Symbol	Value
1-4	CN	WSEP component name
8	CC	change code
12	NC	card number
16	NL	leg number
20	NSI	inlet station number
24	NSØ	outlet station number
28	[WTM]	weight multiplier (optional)
32	[CUM]	cost unit multiplier (optional)
36	[RI]	reliability index (optional)
40	[DRM]	development risk factor multiplier (optional)

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APPENDIX C

SUBROUTINE DEFINITION AND OVERLAY STRUCTURE

This appendix presents a description of the function of the subroutines in the program and the overlay structure which is used.

C1 Computer Program Subroutine Descriptions

The subroutine descriptions are listed in three sections: 1) the performance subroutines, 2) the sizing subroutines, and 3) the general subroutines.

C1.1 Performance Subroutine Description. All performance analyses use two major subroutines: one for data reading, checking, and storing (Z phase), which has a Z as the last letter in the subroutine name; and a second for computing the component performance (P phase), which has a P as the last letter in the subroutine name. All performance subroutines have the letter P as the second last letter in the subroutine name. Some subroutines are combined as multiple entry points.

APUPP APUPZ	APU performance component
BOILPP BOILPZ	BOILER performance component
CNNTPP CNNTPZ	CNNCT performance component
COMPPP COMPPZ	COMP performance component
CONDPP CONDPZ	COND performance component
CVLVPP CVLVPZ	CVALVE performance component
DRNPP DRNPZ	DRAIN performance component
EJCTPP EJCTPZ	EJECT performance component
EVAPPP EVAPPZ	EVAP performance component
FANPP FANPZ	FAN performance component

HXAPP HXAPZ	HXA performance component
HXB1PP HXB2PP HXB1PZ HXB2PZ	HXB performance component
INJTPP INJTPZ	INJECT performance component
INLTPP INLTPZ	INLET performance component
LINEPP LINEPZ	LINE performance component
LPEPP LPEPZ LPSPP LPSPZ	LOOP performance component
MRGPP MRGPZ	MERGE performance component
MISCPP MISCPZ	MISC performance component
NZZLPP NZZLPZ	NOZZLE performance component
ORIFPP ORIFPZ	ORIF performance component
OTLTPP OTLTPZ	OUTLET performance component
PREGPP PREGPZ	PREG performance component
PUMPPP PUMPPZ	PUMP performance component
QLDPP QLDPZ	QLOAD performance component
SENPP SENPZ	SENSOR performance component
SHFTPP SHFTPZ	SHAFT performance component

SPLTPP SPLTPZ	SPLIT performance component
SPOWPP SPOWPZ	SPOWER performance component
TURBPP TURBPZ	TURB performance component
VLVPP VLVPZ	VALVE and DSEP performance component
VCMPPP VCMPPZ	VCOMP performance component
VLNEPP VLNEPZ	VLINE performance component
WSEPPP WSEPPZ	WSEP performance component
USERPP USERPZ	USERP performance component (This is a dummy subroutine, which has been linked into the program, allowing for insertion of user coding to compute performance.)

C1.2 Sizing Subroutine Description. The sizing analyses also use two major subroutine types as explained above: one for data reading, checking, and storing (Z phase); and a second for the computation of component size (P phase). All sizing subroutines have the letter S as the second last letter in the subroutine name.

APUSP APUSZ	APU sizing component
BOILSP BOL1SZ BOL2SZ	BOIL sizing component
CNTRSP CNTRSZ	CNTRL sizing component
COMPSP COMPSZ	COMP sizing component
CONDSP CON1SZ CON2SZ	COND sizing component
DSEPSP DSEPSZ	DSEP sizing component

EJCTSP EJCTSZ	EJECT sizing component
EVAPSP EVA1SZ EVA2SZ	EVAP sizing component
FANSP FANSZ	FAN sizing component
EHTRSP EHTRSZ	HEATER sizing component
HXSP HXSZ HX1SZ HX2SZ	HX sizing component
INITSP INITSZ	INIT sizing component
INSLSP INSLSZ	INSLTN sizing component
LINESP LINESZ	LINE sizing component
MISCSP MISCSZ	MISC sizing component
PUMPSP PUMPSZ	PUMP sizing component
RINSP RINSZ	RIN sizing component
ROUTSP ROUTSZ	ROUT sizing component
TURBSP TURBSZ	TURB sizing component
VLVSP VLVSZ	VALVE sizing component
VCMPSP VCMPSZ	VCOMP sizing component
WSEPSP WSEPSZ	WSEP sizing component

USERSP }
USERSZ } USERS sizing component (This is a dummy subroutine, which has been linked into the program, allowing for insertion of user coding to compute sizing.)

C1.3 General Subroutine Descriptions. This section lists all of the subroutines not covered in the preceeding sections.

Program	Function
COND	Computes thermal conductivity for liquids and gas
DEN	Computes density for liquids and gases
FDC	Frees dynamic core data block or subpool
FLAGRA	Computes table interpolation polynomial
FLDZF	Defines freestream fluid for performance case
FLUIDP	Locates fluid property table and computes standard density
FLUIDS	Defines fluid for sizing case
FLUIDZ	Defines fluid (except freestream) for performance case
FRR	Returns fluid block location
FRS	Sets fluid block location
FTL	Checks fluid type limitation
FTR	Returns fluid type
GAM	Computes isentropic exponent for gases
GDCC	Gets dynamic core data block (conditionally)
GDCU	Gets dynamic core data block (unconditionally)
HSOP	Outputs condensation message for performance printout
IACDB	Assigns component data block
IAEV	Assigns error variable
IASV	Assigns state variable
ILEGN	Assigns internal leg number
INPUTA	Controls preprocessing of input data
IPAREN	Outputs integer numbers with indexes in parentheses
IPARM	Returns parameter table location
IPRNTH	Outputs integer numbers with indexes in parentheses
IRCDB	Returns location of component data block
ISTAN	Assigns internal station number
ITIDN	Assigns internal table identification
ITLUP	Array table location lookup
LDC	Returns location currently available in dynamic core subpool

LEGRS	Sets leg definition
LEGRT	Tests for leg definition
LINES	Counts number of lines printed per page and prints page header
MAIN	Main control program
MCHK	Checks matrix for zero rows or columns
MDISSR	Searches table values for table lookup subroutine
MDSCT	Multi-dimensional table lookup control
MPDUM	Control program for dummy performance case
MPERF	Phase control (M, Z, and P phase) for performance case
MPRNT	Outputs matrix coefficients and constant vector
MRGE	Merges base case and change case input data
MSIZE	Phase control (M, Z, and P phases) for sizing cases
MSOL	Matrix solution
MXSTO	Stores matrix coefficients and constant vector
OUTPTA	Outputs system performance
OUTPTB	Outputs system sizing and penalties
PARAMR	Reads parameter table
PAREN	Outputs real numbers in E format with indexes in parentheses
PARNF2	Outputs real numbers in F format with indexes in parentheses
PARNF5	Outputs real numbers in F format with indexes in parentheses
PARNTH	Outputs real numbers in E format with indexes in parentheses
PCASER	Reads performance case data cards
PCOMPP	Calls for performance component subroutine P phase
PCOMPR	Calls for performance component subroutine Z phase
PIOP	Outputs component performance
PMM	Performance M phase control
POLYI	Computes polynomial for property evaluation
PPM	Performance P phase control
PTABR	Reads permanent table data
PTTL	Permanent table tape loading
PZM	Performance Z phase control

READA	Reads input data cards
READB	Reads base case input data cards from temporary file for merging with change data cards
READC	Reads change case input data cards from temporary file for merging with base data cards
RDB	Reads base case component data cards from temporary file for merging with change data cards
RDC	Reads change case component data cards for merging with base data cards
SCASER	Reads sizing case data cards
SCI	Outputs sizing performance specifications
SCO	Outputs component size
SCOMPP	Calls for sizing component subroutine P phase
SCOMPR	Calls for sizing component subroutine Z phase
SHP	Computes specific heat at constant pressure for liquids and gases
SIG	Computes standard density ratio for liquids and gases
SMM	Sizing M phase control
SOLN1	Controls the performance iteration solution
SOS	Computes the speed of sound for gases
SPM	Sizing P phase control
SRE	Sets shaft end
SRS	Defines shaft number
SRT	Tests for shaft definition and shaft end
SSA	Sums component size into system size
SSR	Checks shaft number in sizing
STABR	Resolves same table specifications
STARS	Sets station definition
START	Tests for station definition
SZM	Sizing Z phase control
TABC	Checks tables
TABR	Reads table data cards
TDB	Computes dry bulb outlet temperature
TDBI	Computes dry air rated outlet temperature
TDB1	Computes saturation humidity

TDB2	
TDB3	Computes dry bulb outlet temperature for fluid merge
TDB4	
TLUP	Table lookup control
VDL	Computes refrigerant liquid density
VH	Computes refrigerant enthalpy for superheated vapor
VHFG	Computes refrigerant heat of vaporization
VIS	Computes viscosity for liquids and gases
VPS	Computes refrigerant saturated vapor pressure
VS	Computes refrigerant entropy for superheated vapor
VSOS	Computes refrigerant speed of sound in superheated vapor
VSV	Computes refrigerant specific volume for superheated vapor
VTAV1	Computes refrigerant superheated vapor temperature and specific volume for a known pressure and entropy
VTAV2	Computes refrigerant superheated vapor temperature and specific volume for a known pressure and enthalpy
VTS	Computes refrigerant saturated vapor temperature
WRTEA	Writes input data cards on temporary file for processing during Z phase
WRTEB	Writes merged data on temporary file for processing during Z phase
WRTEC	Writes merged data on temporary file for processing during Z phase
/CC/	Common block containing values needed for performance and sizing
/CP/	Common block for performance components
/CS/	Common block for sizing components
/DC/	Common block for dynamic core

C2 Computer Program Overlay Structure

The program is overlayed to reduce the core size requirements. The subroutines are arranged in the following overlay segments:

OVERLAY (0, 0)			
MAIN	/CC/	/CP/	/CS/
/DC/	LINES	PARNTH	PAREN
PARNF2	PARNF5	IPRNTH	IPAREN
GDCC	GDCU	FDC	LDC
system routines			
OVERLAY (1, 0)			
MPERF			
OVERLAY (1, 1)			
PMM	INPUTA	READA	READB
READC	WRTEA	WRTEB	WRTEC
RDB	RDC	MRGE	
OVERLAY (1, 2)			
PZM	PCASER	PARAMR	PCOMPR
TABR	PTABR	STABR	TABC
IACDB	ILEGN	ISTAN	LEGRS
LEGRT	STARS	START	SRS
SRT	SRE	FLUIDZ	FLDZF
FRS	FRR	FTR	FTL
IPARM	ITIDN	IASV	IAEV
USERPZ	INLTPZ	OTLTPZ	SPLTPZ
MRGEPZ	HXAPZ	VLVPZ	PREGPZ
CVLVPZ	SENPZ	LINEPZ	COMPPZ
TURBPZ	SHFTPZ	SPOWPZ	QLDPZ
NZZLPZ	ORIFPZ	HXB1PZ	HXB2PZ
MISCPZ	PUMPPZ	FANPZ	APUPZ
EJCTPZ	BOILPZ	WSEPPZ	DRNPZ
INJTPZ	LPSPZ	LPEPZ	CNNTPZ
VLNEPZ	VCMPPZ	CONDPZ	EVAPPZ
OVERLAY (1, 3)			
PPM	SOLN1	PCOMPP	OUTPTA
IRCD	TLUP	ITLUP	MDSCT
MDISSR	FLAGRA	FLUIDP	SIG
DEN	SH	VIS	COND
GAM	SOS	POLYI	TDB
TDB1	TDB2	TDB3	TDB4
VPS	VTS	VSV	VH
VS	VDL	VHFG	VTAV1
VTAV2	VSOS	MXSTO	MPRNT

MCHK	MSOL	PIOP	HSOP
USERPP	INLTPP	OTLTPP	SPLTPP
MRGEPP	HXAPP	VLVPP	PREGPP
CVLVPP	SENPP	LINEPP	COMPPP
TURBPP	SHFTPP	SPOWPP	QLDPP
NZZLPP	ORIFPP	HXB1PP	HXB2PP
MISCPP	PUMPPP	FANPP	APUPP
EJCTPP	BOILPP	WSEPPP	DRNPP
INJTPP	LPSPP	LPEPP	CNNTPP
VLNEPP	VCMPPP	CONDPP	EVAPPP

<u>OVERLAY (2, 0)</u>

MSIZE

<u>OVERLAY (2, 1)</u>

SMM	INPUTA	READA	READB
READC	RDB	RDC	WRTEA
WRTEB	WRTEC	MRGE	

<u>OVERLAY (2, 2)</u>

SZM	SCASER	PARAMR	SCOMPR
TABR	PTABR	STABR	TABC
CDB	ILEGN	ISTAN	FLUIDS
SSR	FTL	IPARM	ITIDN
USERSZ	VLVSZ	DSEPSZ	WSEPSZ
EJCTSZ	APUSZ	RINSZ	ROUTSZ
HXSZ	HX1SZ	HX2SZ	LINESZ
CON1SZ	CON2SZ	EVA1SZ	EVA2SZ
BOIL1SZ	BOIL2SZ	EHTRSZ	COMPSZ
PUMPSZ	FANSZ	VCMPSZ	CNTRSZ
INSLSZ	INITSZ	MISCSZ	

<u>OVERLAY (2, 3)</u>

SPM	SCOMPP	OUTPTB	IRCDB
TLUP	ITLUP	MDSCT	MDISSR
FLAGRA	FLUIDP	SIG	DEN
SH	VIS	COND	GAM
SOS	POLYI	TDBI	VPS
VTS	VSV	VH	VS
VDL	VHFG	VTAV1	VTAV2
S	MXSTO	MPRNT	MCHK
MSOL	SSA	SCO	SCI

USERSP	VLVSP	DSEPSP	WSEPSP
EJCTSP	APUSP	RINSP	ROUTSP
HSXP	LINESP	CONDSP	EVAPSP
BOILSP	EHTRSP	COMPSP	TURBSP
PUMPSP	FANSP	VCMPSP	CNTRSP
INSLSP	INITSP	MISCSP	

<u>OVERLAY (3, 0)</u>

MPDUM	ILEGN	ISTAN

<u>OVERLAY (4, 0)</u>

PTTL

APPENDIX D

SOLID AND FLUID PROPERTIES

Solid and fluid properties are computed by equations in the computer program. The equation coefficients are entered through an array table (-1 dimensional table). Solid properties are assigned as type 20 tables, and fluid properties are assigned as type 10 tables. Tables required for a case may be entered either as temporary or permanent tables. Properties available on the permanent table tape are given in Appendix E.

Three fluid property types are provided:

Fluid type 1 specifies a liquid,

Fluid type 2 specifies a gas,

Fluid type 3 specifies a refrigerant.

D.1 Solid Properties

The solid properties ρ, C_p, and k are required. The equations are:

$$\rho = a_o$$

$$C_p = \sum_{i=0}^{2} b_i T^i$$

$$k = \sum_{i=0}^{2} c_i T^i$$

The array table must specify 7 values with the coefficients entered in the order:

a_o	b_o	b_1	b_2
c_o	c_1	c_2	-

D.2 Liquid Properties

The liquid properties ρ, C_p, μ, and k are required. The equations are:

$$\rho = \sum_{i=0}^{2} a_i T^i$$

$$C_p = \sum_{i=0}^{2} b_i T^i$$

$$\log \mu = \sum_{i=0}^{2} c_i T^i$$

$$k = \sum_{i=0}^{2} d_i T^i$$

The array table must specify 12 values with the coefficients entered in the order:

a_o	a_1	a_2	b_o
b_1	b_2	c_o	c_1
c_2	d_o	d_1	d_2

D.3 Gas Properties

The gas properties ρ, C_p, μ, k, γ, and c are required. The equations are:

$$\rho = 144\ P/RT$$

$$C_p = \sum_{i=0}^{5} a_i T^i$$

$V: \frac{m\nu RT}{P}$

$m = \frac{VP}{RT}$

$$\mu = \sum_{i=0}^{5} b_i T^i$$

$$k = \sum_{i=0}^{5} c_i T^i$$

$$\gamma = \sum_{i=0}^{5} d_i T^i$$

$$c = \sqrt{\gamma g R T}$$

The array table must specify 25 values with the coefficients entered in the order:

R/144	a_o	a_1	a_2
a_3	a_4	a_5	b_o
b_5	c_o	c_1	c_2
c_3	c_4	c_5	d_o
d_1	d_2	d_3	d_4
d_5	-	-	-

D.4 Refrigerant Properties

The refrigerant properties are defined by the equations:

$$\log P_{sat} = A - \frac{B}{T} - C \log T + DT + \frac{E(F-T)}{T} \log (F-T)$$

$$\rho_{liq} = \rho_c + \sum_{i=1}^{4} c_i \,(1-T/T_c)^{e_i}$$

$$P = \frac{RT}{(V-b)} + \sum_{i=2}^{5} \frac{A_i + B_i T + C_i e^{-kT/T_c}}{(V-b)^i}$$

$$H = \alpha T + \frac{\beta T^2}{2} + \frac{\gamma T^3}{3} + \frac{\delta T^4}{4} - \frac{\varepsilon}{T}$$

$$+ \frac{144}{J} \left[PV + \sum_{i=2}^{5} \frac{A_i}{(i-1)(V-b)^{(i-1)}}\right]$$

$$+ \frac{144}{J} e^{-kT/T_c} \left(1 + \frac{kT}{T_c}\right) \sum_{i=2}^{5} \frac{C_i}{(i-1)(V-b)^{(i-1)}}$$

$$+ X$$

$$S = \alpha \ln T + \beta T + \frac{\gamma T^2}{2} + \frac{\delta T^3}{3} - \frac{\varepsilon}{2T^2}$$

$$+ \frac{144}{J} \left[R \ln (V-b) - \sum_{i=2}^{5} \frac{B_i}{(i-1)(V-b)^{(i-1)}}\right]$$

$$+ \frac{144}{J} \frac{k}{T_c} e^{-kT/T_c} \sum_{i=2}^{5} \frac{C_i}{(i-1)(V-b)^{(i-1)}}$$

$$+ Y$$

$$c = V \sqrt{g \left[\frac{\left(\frac{\partial S}{\partial V}\right)_T^2 J}{\left(\frac{\partial S}{\partial T}\right)_V} - \left(\frac{\partial P}{\partial V}\right)_T\right]}$$

The array table must specify 38 values with the coefficients entered in the order:

R	T_c	ρ_c	c_1
e_1	c_2	e_2	c_3
e_3	c_4	e_4	A
B	C	D	E
F	b	A_2	B_2
C_2	A_3	B_3	C_3
A_4	B_4	C_4	A_5
B_5	C_5	k	α
β	γ	δ	ε
X	Y	-	-

APPENDIX E

PERMANENT TABLES

The ECS computer program is capable of storing tables on a magnetic tape and using them when requested. These tables are called permanent tables, and the magnetic tape is called the permanent table tape. A set of standard permanent tables is provided with the computer program. The user may add additional tables to the tape.

E.1 Permanent Table Tape Loading

The user must run a permanent table tape loading job on the ECS computer program to store the tables on the permanent table tape. The permanent table tape is referred to by the Fortran logical unit number 1. The tables to be stored on the permanent table tape (TABID, TABT, and TABV cards) are input in ascending order by the table type. Within each type the tables are input in ascending order by the table relative number. The combined table relative number and table type must not be duplicated. If more than one user is using the permanent table tape, coordination of the tape loading is required. The set of table cards must be preceded by the permanent table tape loader case control card (PTTL in card columns 1 through 4). A printout of the tables can be obtained during the tape loading by following the case control card by a print control card (PRINT in card columns 1 through 5). The last table is followed by an end job control card (ENDJØB in card columns 1 through 6). No other cases may be run during the tape loading job. During the table loading the tables are not checked for ascending order or checked for correct values. Any user table placed on the permanent table tape should first be used as a temporary table. Permanent tables are limited to 1000 values.

E.2 Standard Permanent Tables

The standard permanent tables provided with the ECS computer program are listed below. The identification (ID) gives the table relative number and type, respectively.

ID 1,0 Weighing Factor: rapidly rising weighing factor versus iteration number (general argument 1).

ID 2,0 Weighing Factor: slowly rising weighing factor versus iteration number (general argument 1).

ID	1,1	Pressure Drop: rough level heat exchanger pressure drop (air side 1) versus inlet pressure (general argument 43) ($\sigma\Delta P = 0.05\ P_{in}$)
ID	2,1	Pressure Drop: rough level heat exchanger pressure drop (air side 2) versus inlet pressure (general argument 44) ($\sigma\Delta P = 0.05\ P_{in}$)
ID	3,1	Pressure Drop: rough level heat exchanger pressure drop (liquid side) (constant, 2.0)
ID	4,1	Pressure Drop: Zero pressure drop (constant, 0.0)
ID	1,3	Friction Factor: smooth pipe friction factor versus Reynolds Number (general argument 21)
ID	2,3	Friction Factor: equivalent duct friction factor versus diameter (general argument 57) ($f = 0.002656D$)
ID	3,3	Friction Factor: equivalent duct friction factor (constant, 0.01404)
ID	1,5	Effectiveness: rough level heat exchanger effectiveness (constant, 0.8)
ID	2,5	Effectiveness: heat exchanger effectiveness (crossflow, single pass, both sides unmixed) versus NTU (general argument 55) and C_{min}/C_{max} (general argument 56)
ID	2,5	Effectiveness: heat exchanger effectiveness versus NTU (general argument 55) and C_{min}/C_{max} (general argument 56)
ID	1,6	Compressor Efficiency: rough level compressor efficiency (constant, 0.64)
ID	1,7	Turbine Efficiency: rough level turbine efficiency (constant, 0.76)
ID	1,10	Fluid Properties: air (gas)
ID	2,10	Fluid Properties: water (liquid)
ID	3,10	Fluid Properties: ethylene gylcol (62.5%)/water (liquid)
ID	4,10	Fluid Properties: JP-4 (liquid)
ID	5,10	Fluid Properties: Coolanol 25 (liquid)
ID	6,10	Fluid Properties: Coolanol 45 (liquid)
ID	7,10	Fluid Properties: FC-75 (liquid)
ID	8,10	Fluid Properties: FC-77 (liquid)
	11,10	Fluid Properties: R-11 (refrigerant)
ID	12,10	Fluid Properties: R-12 (refrigerant)
ID	13,10	Fluid Properties: R-114 (refrigerant)

1 - liquid
2 - gas
3 - refrig

ID 1,14 Atmospheric Pressure
ID 1,15 Atmospheric Temperature
standard day versus geometric altitude (general argument 2)

ID 2,14 Atmospheric Pressure
ID 2,15 Atmospheric Temperature
hot day versus geopotential altitude (general argument 2)

ID 3,14 Atmospheric Pressure
ID 3,15 Atmospheric Temperature
cold day versus geopotential altitude (general argument 2)

ID 4,14 Atmospheric Pressure
ID 4,15 Atmospheric Temperature
tropical day versus geopotential altitude (general argument 2)

ID 5,14 Atmospheric Pressure
ID 5,15 Atmospheric Temperature
polar day versus geopotential altitude (general argument 2)

ID 1,17 Efficiency: general efficiency (constant, 1.0)

ID 1,20 Solid Properties: aluminum alloy (2024-T4)

ID 2,20 Solid Properties: steel (1095)

ID 3,20 Solid Properties: nickel alloy (A286)

ID 4,20 Solid Properties: magnesium alloy (HK31A(H24))

ID 5,20 Solid Properties: Microlite AA (phenolic resin)

ID 6,20 Solid Properties: Microlite AA (silcone binder)

ID 7,20 Solid Properties: Thermoflex (RF 300)

8,20 Solid Properties:

ID 1,31 Fin Geometry
ID 1,32 Fin Friction Factor
ID 1,33 Fin Colburn Modulus
fin 15.76R(D)-0.153/0.149-1/7(0)-0.004 versus Reynolds number (general argument 21)

ID 2,31 Fin Geometry
ID 2,32 Fin Friction Factor
ID 2,33 Fin Colburn Modulus
fin 25.01R(S)-0.201/0.200-1/9(0)-0.004 versus Reynolds number (general argument 21)

ID 3,31 Fin Geometry
ID 3,32 Fin Friction Factor
ID 3,33 Fin Colburn Modulus
fin 12.18R(D)-0.178/0.174-0.178(0)-0.004 versus Reynolds number (general argument 21)

ID 4,31 Fin Geometry
ID 4,32 Fin Friction Factor
ID 4,33 Fin Colburn Modulus
fin 16.00R(D)-0.126/0.125-1/8(0)-0.006 versus Reynolds number (general argument 21)

ID 5,31 Fin Geometry
ID 5,32 Fin Friction Factor
ID 5,33 Fin Colburn Modulus
fin 20.06R(D)-0.100/0.098-1/8(0)-0.004 versus Reynolds number (general argument 21)

ID 6,31 Fin Geometry
ID 6,32 Fin Friction Factor
ID 6,33 Fin Colburn Modulus
fin 15.61R(S)-0.251/0.25-1/8(0)-0.004 versus Reynolds number (general argument 21)

ID	7,31	Fin Geometry	fin
ID	7,32	Fin Friction Factor	19.35R(S)-0.0755/0.075-1/10(0)-0.004
ID	7,33	Fin Colburn Modulus	versus Reynolds number (general argument 21)
ID	8,31	Fin Geometry	fin
ID	8,32	Fin Friction Factor	24.12R(S)-0.075/0.075-1/9(0)-0.004
ID	8,33	Fin Colburn Modulus	versus Reynolds number (general argument 21)
ID	9,31	Fin Geometry	fin
ID	9,32	Fin Friction Factor	11.94R(D)-0.11-1/2(0)-0.006
ID	9,33	Fin Colburn Modulus	versus Reynolds number (general argument 21)
ID	10,31	Fin Geometry	fin
ID	10,32	Fin Friction Factor	15.4R(D)-0.1-1/4(0)-0.006
ID	10,33	Fin Colburn Modulus	versus Reynolds number (general argument 21)
ID	11,31	Fin Geometry	fin
ID	11,32	Fin Friction Factor	27.03R(S)-0.251/0.251-1/10(0)
ID	11,33	Fin Colburn Modulus	versus Reynolds number (general argument 21)
ID	12,31	Fin Geometry	fin
ID	12,32	Fin Friction Factor	16.96T(D)-0.126/0.125-5.0(P)-0.006
ID	12,33	Fin Colburn Modulus	versus Reynolds number (general argument 21)

ID 1,34 Separator Plate Thickness: separator plate thickness for strip fin, aluminum (constant, 0.012)

ID 2,34 Separator Plate Thickness: separator plate thickness for strip fin, steel or nickel (constant, 0.006)

ID 1,36 Compressor N_S-D_S: radial compressor specific diameter versus specific speed (general argument 59) and efficiency (general argument 60)

ID 2,36 Compressor N_S-D_S: axial compressor specific diameter versus specific speed (general argument 59) and efficiency (general argument 60)

ID 1,37 Turbine N_S-D_S: radial turbine specific diameter versus specific speed (general argument 59) and efficiency (general argument 60)

ID 2,37 Turbine N_S-D_S: axial turbine specific diameter versus specific speed (general argument 59) and efficiency (general argument 60)

ID ✓ 2,38 Turbine N_S-D_S: axial turbine blade height to diameter ratio versus specific speed (general argument 59) and efficiency (general argument 60)

APPENDIX F

ITERATION DUMP

The performance solution of a system or the sizing of a component may involve an iterative process. If the user has provided the program with correct data and a reasonable initial guess of the state variables and if the problem specified has a solution,the program should have no trouble in yielding a solution to the problem. Otherwise the problem will be nonconvergent. The most common cause of nonconvergence is the user specification of a system which does not have an answer, i.e., the system cannot physically meet the user's specifications. The determination of the cause of nonconvergence may be a difficult process. To assist in the determination a program iteration dump option has been provided.

F.1 Dump Option

The iteration dump option may be set by the user by preceding the case control card by the iteration dump card. The iteration dump data card format is:

Card Column	Contents
1-4	DUMP
11-15	option (right justified)

The option value may be any number less than or equal to 3. The dump option is stored in the program and will remain at the set value until it is again changed.

Dump 0

The program initially sets the dump option at zero. This option value specifies no dump. This value must be specified by the user to turn off the dump in a case that has been preceded by a case in which the dump was selected.

Dump 1

This dump option gives a limited dump. The pass number for each iteration will be printed on the output, followed by the values of all state and error variables. For a performance case the flow rate in every leg, and pressure, temperature, and humidity/enthalpy for every station will be printed on the output. For a sizing case additional values may be output as described in their component writeups (see Appendix B). The output from this dump option should not be excessive.

Dump 2

The output for this dump option will include all of the output for dump option 1. Additionally the partial derivative matrix, PD, will be output for each iteration. The total output for this option will be substantially greater than for dump option 1.

Dump 3

The output for this dump option will include all of the output for dump option 2. Additionally the dump will be output not only for all iterations, but also for all perturbations. The output from this dump option will be excessive.

Dump -N

The output for this dump option is the same as dump option 2, except that the dump will only be given for the first N iterations.

F.2 Dump Interpretation

The iterative solution of a problem is a simultaneous solution. Any error or condition that cannot be obtained in one section of a system may influence other sections of the system. In some cases the dependence may be so great that the dump is impossible to interpret. In other cases the different sections of the dump may be interpreted to point right to the problem.

The state and error variable printout gives the step by step progress of the solution. The state variables control the solution, and the error variables specify how well the state variables match the solution. A common cause of nonconvergence is that state variables reach their upper or lower limits.

The printout of the flow rate in every leg and the pressure, temperature, and humidity/enthalpy at every station in the system is useful in checking the component performance. For example, an excessive pressure drop across a component may lead to a bad table value that specifies the pressure drop for that component.

The matrix printout gives the augmented matrix of the Newton-Raphson solution. The term in row i, column j represents the partial derivative of error variable i with respect to state variable j. If the term is zero, it means that changing the state variable j has no effect on the error variable i. If matrix row i is zero (a singular matrix), the error variable i is independent of the change of any state variable. If matrix column j is zero (a singular matrix), all error variables are independent of a change in the state variable j.

APPENDIX G

CØMMØN CARDS

The computer program has built in constants that are used in performance and sizing analyses. Many of these constants have been stored in the labeled common block CC, and represent both integer and real values. Some of the values represent data correlations. Other values control the solution. Provisions are available in the computer program for a user to temporarily change these constants during his job. Values changed by a user for one case in his job remain changed for following cases in his job unless he rechanges them.

Values in the CC labeled common block may be changed by preceding a case control card by CØMMØN cards. The CØMMØN data card format for changing an integer value is:

Card Column	Name	Value
1-6	CN	CØMMØN card name
9-10	CBN	CI common block name
11-15	IND	index (right justified)
16-20	IVAL	integer value (right justified)

The CØMMØN data card format for changing a real value is:

Card Column	Name	Value
1-6	CN	CØMMØN card name
9-10	CBN	CE common block name
11-15	IND	index (right justified)
16-25	VAL	real value (punched with decimal point)

Any number of CØMMØN cards may precede the case control cards.

Some of the values which may be changed by the user are:

Type	Index	Value (built in)
integer	36	number of general arguments allowed, should not be less than 100 (120)
integer	41	number of tables allowed (100)
integer	76	number of iterations allowed, system performance and component sizing (25)
real	77	perturbation factor (1.001)
real	83	system performance error limit (0.01)
real	120	valve material (aluminum/steel limit (960°R)

real	125	limiting rotational speed for sizing components (60000.0 rpm)
real	126	limiting tip speed for compressor sizing (1500.0 ft/sec)
real	127	limiting tip speed for turbine sizing (2000.0 ft/sec)

CØMMØN cards cannot immediately precede a quick change case (QCHANGE).

APPENDIX H

DATA INPUT FORMS

Form Description	Section
Case Control Cards 1	H1
Title Cards	H2
Performance Case Cards	H3
Sizing Case Cards	H4
Parameter Table Input 1	H5
Parameter Table Input 2	H6
Component Cards	H7
Temporary Table Input 1	H8
Temporary Table Input 2	H9
Permanent Table Input	H10
Same Table Input	H11
Case Control Cards 2	H12
QCHANGE Input	H13
Dummy Performance General Argument Input	H14
Dummy Performance Leg Input	H15
Dummy Performance Station Input	H16

DECK NO. IECS	GENERAL ECS PROGRAM	CASE CONTROL CARDS 1
1		
PERFORM		
PCHANGE		
PDUMMY		
QCHANGE		
SIZE		
SCHANGE		

DECK NO. IECS	GENERAL ECS PROGRAM	TITLE CARDS

1 7 80

TITLE

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DECK NO. IECS	GENERAL ECS PROGRAM	PERFORMANCE CASE CARDS

CASEN - case name, 8 alpha-numeric characters
IDPC - input data print control (ijkℓ)
  i = 0, case data printed
  i = 1, case data not printed
  j = 0, parameter data printed
  j = 1, parameter data not printed
  k = 0, component data printed
  k = 1, component data not printed
  ℓ = 0, table data printed
  ℓ = 1, table data not printed
NLEG - number of legs
NSTA - number of stations
ICPP - index for component performance print
  = 0, print
  = 1, no print
IPA - freestream pressure table relative number (type 14)
  if 0, use PAMB from CASEC card
ITA - freestream temperature table relative number (type 15)
  if 0, use TAMB from CASEC card

IVM - velocity or Mach number option
  = -1, input freestream velocity on CASED card
  = 0, input not required
  = +1, input freestream Mach number on CASED card
IAP - freestream fluid property table relative number (type 10)
IWP - water property table relative number (type 10), wet air only
ALT - altitude
PAMB - freestream pressure (if IPA = 0)
TAMB - freestream temperature (if ITA = 0)
VØM - freestream velocity (if IVM = -1)
  freestream Mach number (if IVM = +1)

1		CASEN 16	IDPC 20	NLEG 24	NSTA 28	ICPP 32	36	40	44	48	52	56	60	64	68	72	76	80
CASEA																		

1		IPA 12	ITA 16	IVM 20	IAP 24	IWP 28	32	36	40	44	48	52	56	60	64	68	72	76	80
CASEB																			

1		11 ALT 20	21 PAMB 30	31 TAMB 40	41 50	51 60	61 70	71 80
CASEC								

1		11 VØM 20	21 30	31 40	41 50	51 60	61 70	71 80
CASED								

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DECK NO. IECS	GENERAL ECS PROGRAM	SIZING CASE CARDS

CASEN - case name, 8 alpha-numeric characters
IDPC - input data print control (ijkℓ)
- i = 0, case data printed
- i = 1, case data not printed
- j = 0, parameter data printed
- j = 1, parameter data not printed
- k = 0, component data printed
- k = 1, component data not printed
- ℓ = 0, table data printed
- ℓ = 1, table data not printed

ISSP - system summation print
- = 0, print
- = 1, no print

ISPP - system penalty print
- = 0, print
- = 1, no print

for ISPP = 0 only

IFCW - specific fuel consumption for bleed air table relative number (type 41)
IFCP - specific fuel consumption for shaft power table relative number (type 42)
TIME - flight time
THR - thrust
DRAG - parasitic drag
LDR - lift drag ratio
WTE - aircraft empty weight less ECS
WTF - aircraft propulsive fuel weight
WTG - aircraft gross take-off weight less ECS
ELL - electrical line length
HLL - hydraulic line length
GWHP - generator weight per horsepower
HWHP - hydraulic pump weight per horsepower
ØSHP - shaft horsepower, not ECS
ØBAE - bleed air required, not ECS

1 CASEA	CASEN	IDCP	ISSP	ISPP	IFCW	IFCP											
	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80

CASEB	TIME	THR	DRAG	LDR			
	11 20	21 30	31 40	41 50	51 60	61 70	71 80

CASEC	WTE	WTF	WTG				
	11 20	21 30	31 40	41 50	51 60	61 70	71 80

CASED	ELL	HLL	GWHP	HWHP	ØSHP	ØBAE	
	11 20	21 30	31 40	41 50	51 60	61 70	71 80

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DECK NO. IECS		GENERAL ECS PROGRAM		PARAMETER TABLE INPUT 1	
1	No. 10				
PARAM					
1	Index 10	11 20	21 30	31 40	41 50	51 60
VALUES	01					
	06					
	11					
	16					
	21					
	26					
	31					
	36					
	41					
	46					
	51					
	56					
	61					
	66					
	71					
	76					
	81					
	86					
	91					
	96					
	101					
	106					

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DECK NO. IECS	GENERAL ECS PROGRAM	PARAMETER TABLE INPUT 2

1	IND 10	11 20
VALUE		

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DECK NO. IECS			GENERAL ECS PROGRAM						COMPONENT CARDS										
NAME 1	CC 8	NC 12	IC 1 16	IC 2 20	IC 3 24	IC 4 28	IC 5 32	IC 6 36	IC 7 40	IC 8 44	IC 9 48	IC 10 52	IC 11 56	IC 12 60	IC 13 64	IC 14 68	IC 15 72	IC 16 76	IC 17 80

DECK NO IECS	GENERAL ECS PROGRAM	TEMPORARY TABLE INPUT 1

1 TABID		NREL 12	NTYP 16	NDIM 20	IST 24	NAT1 28	NAR1 32	NEI1 36	NPT1 40	NAT2 44	NAR2 48	NEI2 52	NPT2 56	60	64	68	72	76	80

1 TABT	7

1 TABV	11	20 21	30 31	40 41	50

DECK NO. 1ECS	GENERAL ECS PROGRAM	TEMPORARY TABLE INPUT 2

1 TABID		NREL 12	NTYP 16	NDIM 20	IST 24	NAT1 28	NAR1 32	NEI1 36	NPT1 40	NAT2 44	NAR2 48	NEI2 52	NPT2 56	60	64	68	72	76	80

1 TABT	7

1 TABV		11	20 21	30 31	40 41 50
↓					

1 TABID		NREL 12	NTYP 16	N JIM 20	IST 24	NAT1 28	NAR1 32	NEI1 36	NPT1 40	NAT2 44	NAR2 48	NEI2 52	NPT2 56	60	64	68	72	76	80

1 TABT	7

1 TABV		11	20 21	30 31	40 41 50
↓					

1 TABID		NREL 12	NTYP 16	NDIM 20	IST 24	NAT1 28	NAR1 32	NEI1 36	NPT1 40	NAT2 44	NAR2 48	NEI2 52	NPT2 56	60	64	68	72	76	80

1 TABT	7

1 TABV		11	20 21	30 31	40 41 50
↓					

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DECK NO. IECS	GENERAL ECS PROGRAM	PERMANENT TABLE INPUT

1 PTAB		NREL 12	NTYP 16	NPR 20	NPT 24														

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DECK NO. IECS	GENERAL ECS PROGRAM	SAME TABLE INPUT

1		NREL 12	NTYP 16	NSR 20	NST 24
STAB					

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DECK NO. IECS	GENERAL ECS PROGRAM	CASE CONTROL CARDS 2

```
1
ENDCASE

NØGØ

ENDJØB
```


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DECK NO. IECS	GENERAL ECS PROGRAM	QCHANGE INPUT

1		11 20	
ALT			
VØM			
PAM			
TAM			

1	IND 10	11 VALUE 20	
PTV			

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DECK NO. IECS	GENERAL ECS PROGRAM	DUMMY PERFORMANCE GENERAL ARGUMENT INPUT

1	IGA 10	11 VALUE 20	
GENARG			

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DECK NO. IECS	GENERAL ECS PROGRAM	DUMMY PERFORMANCE LEG INPUT

1	NLEG 10			
NLEG				
1	ILEG 10	IFT 15	IRN 20	21 W 30
LEG				

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DECK NO. IECS		GENERAL ECS PROGRAM		DUMMY PERFORMANCE STATION INPUT	
1	NSTA 10				
NSTA					
1	ISTA 10	11 P 20	21 T 30	31 H 40	
STA					

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APPENDIX I

PSYCHROMETRIC CALCULATIONS

The program automatically computes dry bulb outlet temperatures for all components if the fluid specified for the component is a gas (type 2) and if the humidity is greater than zero. The psychrometric calculations are valid for any gas.

Dry outlet temperatures, $\overline{T}_{out}$, are computed in all component performance subroutines. In Appendix A, the dry bulb temperature calculation is denoted by the function: $T_{out} = f\,(P_{in}, T_{in}, H_{in}, P_{out}, \overline{T}_{out}, H_{out})$. The dry outlet condition is checked for saturation. If the outlet is unsaturated, no correction is made in the outlet temperature, i.e. $T_{out} = \overline{T}_{out}$. If the outlet is saturated, the outlet enthalpy is computed and the corrected outlet temperature determined using the following equations.

$$H_{in} = (1 - M_{in})\, C_{p_{in}} \cdot T_{in} + M_{V_{in}} \cdot H_{V_{in}} + M_{L_{in}} \cdot H_{L_{in}}$$

where M_{in} - inlet humidity, $lb_{water}/lb_{mixture}$

M_V - water vapor ratio, $lb_{vapor}/lb_{mixture}$

M_L - liquid water ratio, $lb_{liquid}/lb_{mixture}$

H_V - water vapor enthalpy, Btu/lb

H_L - liquid water enthalpy, Btu/lb

$$\Delta H_{dry\ gas} = C_{p_{in}} \cdot T_{in} - C_{p_{out}} \cdot \overline{T}_{out}$$

$$H_{out} = H_{in} - \Delta H_{dry\ gas}$$

$$H_{dry\ bulb} = H_{out}$$

$$H_{dry\ bulb} = (1 - M_{out})\, C_{p_{out}}\, T_{out} + M_{V_{out}}\, H_{V_{out}} + M_{L_{out}}\, H_{L_{out}}$$

A value assumed for the dry bulb outlet temperature, T_{out}, in the last equation is iterated upon until the correct dry bulb temperature has been computed. All of the variables in the last equation with the exception of $H_{dry\ bulb}$ and M_{out} are a function of the assumed temperature, T_{out}, and outlet pressure, P_{out}, and must be evaluated for each iteration as the

APPENDIX J

COMPUTER EXTERNAL DEVICES

Fortran Unit Number	Purpose
1	permanent table storage - binary file
5	system input - cards
6	system output - printed
7	system output - punched
8, 9, 10, 11, 12, 13	scratch storage (card images) - coded files

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13. ABSTRACT

This report volume presents a users manual for the Integrated Environmental Control Systems (IECS) Computer Program. The computer program was developed for the Air Force Flight Dynamics Laboratory. The computer program is capable of analyzing the steady state performance, determining typical sizing data, and evaluating relative aircraft penalties for virtually any air cycle or vapor cycle aircraft ECS. The program was written in the Fortran IV language for the CDC 6600 computer. This users manual provides instructions for setting up input data, describes the solution methods, and gives sample outputs. Sample problems are provided for a rough level performance and sizing analysis, and a detailed level performance analysis, including a listing of the input data and the output obtained.

Volume I of this report presents analytical design information which has been incorporated into the computer program. Volume II is a general description of the computer program. It includes sample problems for the rough performance and sizing of one Air Force aircraft. Volume IV of this report presents the laboratory demonstration ECS setup and results, and the computer program setup and results of detailed performance and sizing analyses to represent this ECS.

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Aircraft Equipment						
Air Conditioning Equipment						
Environmental Control Systems						
Cooling Systems						
Heat Exchangers						
Turbomachinery						
Centrifugal Compressors						
Water Separators						
Dust Filters						
Fans						
Liquid Cooling						
Coolant Pumps						
Evaporators						
Refrigerant Compressors						
Refrigerant Condensers						
Auxiliary Power Units						
Electric Motors						
Hydraulic Motors						
Ducts						
Butterfly Valves						
Poppet Valves						
Check Valves						
Inlets						
Outlets						
Ejectors						
Insulation						
Pneumatic Temperature Control						
Electronic Temperature Control						
Pressure Control						
Moisture						
Computer Program						
Flow Control						