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ENVIRONMENTAL CONTROL SYSTEM TRANSIENT ANALYSIS COMPUTER PROGRAM (EASY)

TABLE OF CONTENTS

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1. PURPOSE: A generalized computer program for calculating transient thermodynamic performance of aircraft environmental control systems (ECS), and transient and dynamic analysis methods for aircraft ECS are discussed in this report.

2. SCOPE: The Environmental Control Analysis SYstem (EASY) computer program is summarized in this report. Development of this computer program initially was sponsored by the U.S. Air Force Flight Dynamics Laboratory. (See References 1, 2, 3, and 4.) It provides techniques for determination of steady state and dynamic (transient) ECS performance, and of control system stability; and for synthesis of optimal ECS control systems. The program is available from the U.S. Air Force, or as a proprietary commercial version.

   General uses of a transient analysis computer program for ECS design and development, and general features of EASY relative to these uses, are presented. This report summarizes the nine analysis options of EASY, EASY program organization for analyzing ECS, data input to the program and resulting data output, and a discussion of EASY limitations.

   Appendices provide general definitions for dynamic analysis, and samples of input and output for EASY.

3. BACKGROUND ON COMPUTERIZED TRANSIENT ECS ANALYSIS: Computerized ECS analysis techniques can improve ECS design and development, and reduce overall ECS development costs.

   The evolution of an aircraft ECS -- from concept, to design and development, to production -- is a significant investment in manpower, resources, and time. An initial phase in the design and development of an ECS involves three tasks: 1) definition of system components to meet aircraft requirements; 2) development of components to meet system performance; and 3) development of controls for desired system operation (see Figure 1). Use of an ECS "breadboard" lab, for prototype component and system development, could aid these tasks. This lab contains various ECS components; an air supply at variable pressure, temperature, and flow; and load "banks" to simulate cabin, electronics cooling, defogging, and other types of ECS loads. With the use of this "breadboard" lab, a prototype ECS is "connected" for development testing. New concepts are tried, various control schemes are investigated, and design performance is demonstrated. This "breadboard" lab significantly reduces ECS development costs.

Generalized ECS "breadboard" labs are not available, but the process can be simulated by computer analysis. (See Figure 1.) Computer simulation of the ECS is a type of "breadboard" lab. ECS components, air supplies, and heat loads exist as mathematical models. The prototype ECS is defined with computer instructions. Pressures, temperatures, humidities, and flows at various locations in the system are computer input. Results are similar to those achieved in the hypothetical ECS "breadboard" lab. New concepts can be tried, various control schemes can be investigated, and transient and steady state performance can be demonstrated much faster and easier, with less risk, than using prototype hardware.

The EASY transient analysis computer program is one technique for simulating the dynamic performance of aircraft environmental control systems. Other techniques are analog computers, general purpose simulation languages (such as MIMIC, Reference 5), and special purpose ECS dynamic analysis programs. Analog computers and general purpose simulation languages require considerable effort, by the analyst, to model an ECS. Special purpose ECS dynamic analysis programs often are designated "company proprietary" and are not available for general use. EASY is a general analysis program which can be applied readily to many different ECS. Its availability is defined in Section 5.6. It has application to other types of systems also (see Section 6.2).

4. GENERAL FEATURES OF EASY: The EASY computer program is a potentially effective analytical capability that can be an integral part of the overall design and development of environmental control systems. Some key analytical capabilities of EASY, and salient aspects for its use, are summarized. Further comments about use of EASY are provided in Section 5.0.

4.1 Analysis Capabilities: The EASY computer program can be used to evaluate the operation of existing ECS, to define and evaluate controls for new ECS, and for control changes to existing ECS. The dynamic operation of existing ECS, due to programmed or unplanned changes (e.g., part failure, out-of-tolerance controller, etc.) at any normal steady operating condition, can be determined. EASY can be used to define the operating logic of ECS controller schemes, and to determine controller gains that assure system stability. Simulations for portions of a total ECS (i.e., which can be isolated easily), or details of a complete ECS can be modelled analytically.

Most types of aircraft ECS can be analyzed. This includes air cycles (simple and bootstrap), vapor cycles, open and closed loop systems, heat transport loops, liquid heat sinks, and pressurization systems. Analysis capability for vapor cycles is a later addition (References 7 and 8). Due to the time and cost involved in using EASY, it should be used very prudently. For example, it may not be cost effective to use this program for routine system comparisons or trade studies, or for complex multiple loop systems.

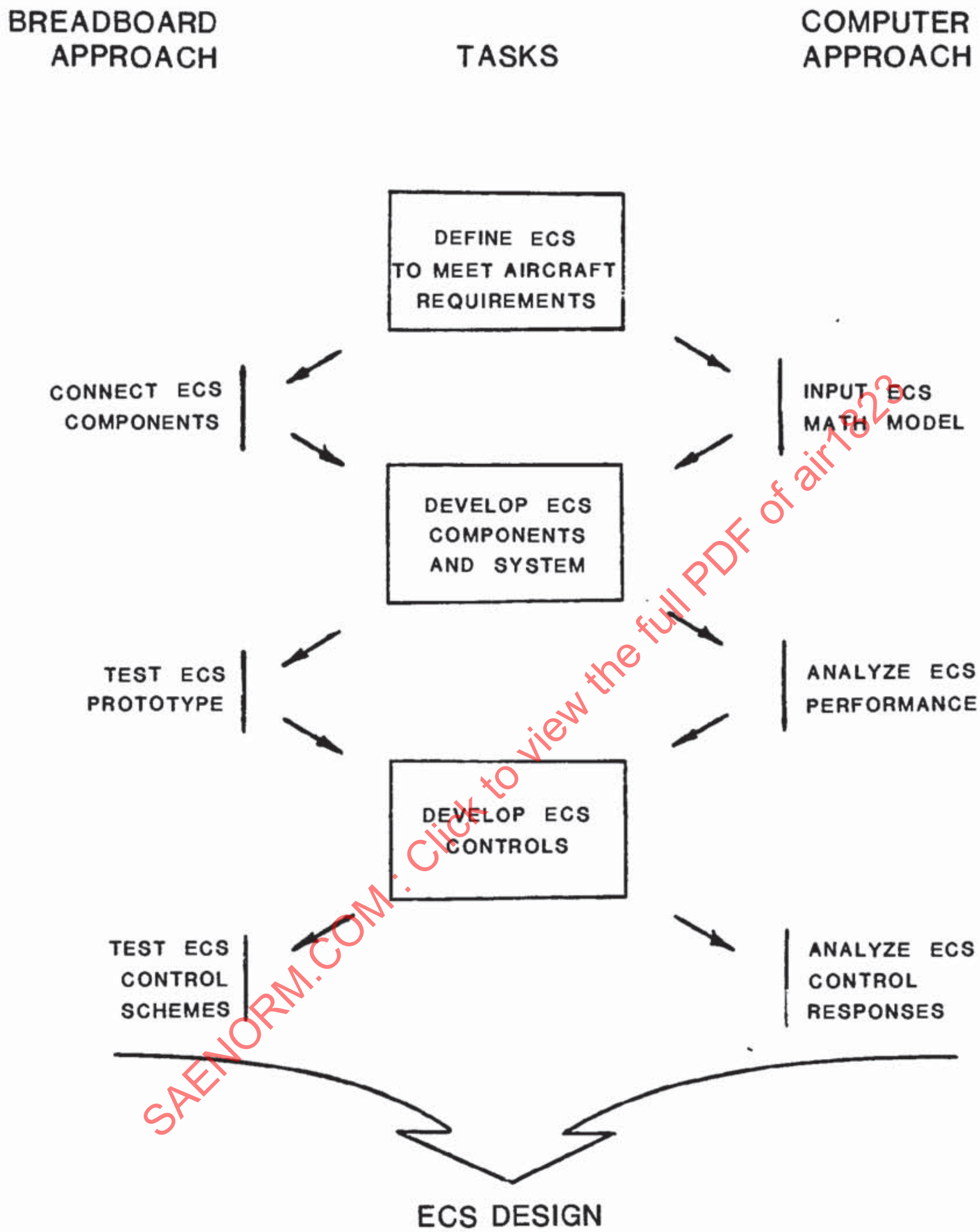


Figure 1 - ECS DEVELOPMENT APPROACHES

System configuration is defined with a set of "standard components" from the EASY ECS library and interconnections between the components. Special components can be defined by FORTRAN statements, if the standard components are not appropriate.

EASY allows simulation of dynamic responses and control systems described by nonlinear differential equations. Unique features of EASY are its flexible and efficient nonlinear simulation capability and a comprehensive set of control analysis techniques. EASY combines these in an integrated program - allowing both types of analysis to be performed using the same system model data.

Nine types of thermodynamic and control dynamic analyses can be conducted. Data needed for these analyses include numerical values defining ECS components characteristics and system boundary conditions (e.g., initial conditions). A single FORTRAN model, compatible with all analysis options, is defined by the program.

Other program capabilities are as follows: 1) program input is simple codes to connect discrete elements with built-in techniques (these techniques represent the performance and functions of aircraft ECS components); 2) definitions of ECS control functions can be simple and generalized, or detailed, or both; 3) six nonlinear dynamic analysis techniques are available; 4) message codes are provided as cautions about errors in input; 5) engineering problems that can be modelled by differential equations with variable or constant coefficients can be analyzed and 6) the transient response of a complete ECS, or of a part of an ECS, can be obtained.

4.2 Usage Aspects: EASY is a large, complex computer program. It can be operated on CDC/CYBER, IBM, or DEC VAX computers. Means for rapid troubleshooting of errors are provided.

A general background on control dynamics is suggested for users. One approach is a combined effort of a controls analyst and an ECS engineer. Difficulty in obtaining solutions may occur, and some skill (and art) may be required to obtain solutions. Initial use may need to be discussed with an experienced user.

The EASY computer program can be applied to several types of environmental control system analyses. Typical applications are: 1) detailed stability and transient response of an ECS component or subsystem; 2) transient response of a complete ECS, with less detail than in 1); 3) cabin cool-down and warm-up; 4) transient thermal responses of avionic equipment; and 5) cabin and avionics cooling performance adequacy during aircraft transient maneuvers.

Predicted results are only as good as the models defined with EASY. EASY mathematical models are approximations to real ECS. Simulation using EASY does not provide answers to all system questions, but it should provide key data regarding fundamental system performance.

5. EASY COMPUTER PROGRAM: The EASY computer program is designed to model mathematically the dynamic performance of most aircraft ECS. In general, ECS performance is mathematically described by a system of nonlinear differential equations of the first order in terms of state variables (a math model). This set of state equations can be arranged with the time derivative term on the left hand side (the derivative of the state variable), and the state variables and inputs on the right hand side. In EASY, the state equations are integrated by a suitable method, and a complete description of system performance as a function of time - the transient solution - is obtained.

The EASY program contains options to solve the system of equations by linearization techniques, and for a steady state condition. Steady state is a limit solution with time approaching an infinite value. A linear solution is obtained by linearization of the equations about some operating point. Steady state* is for system analysis in an initial design phase. Linear approximation analysis (linearization) is useful for more detailed system modeling, such as classical frequency response analyses. Full simulation, by solving the nonlinear equations, is the highest level of transient analysis for investigation of system transient responses.

Program solution techniques, program organization, use, and input and output are summarized herein.

5.1 History of Program: Development of the EASY ECS computer program was sponsored by the U.S. Air Force, and was completed in July 1977 (References 1 and 2). Experimental verification of the program was completed at the same time (Reference 3). Development of additional components for the analysis of vapor cycle systems are available (References 7 and 8).

5.2 EASY Program Capabilities: The nine ECS solution techniques of the EASY program, and a summary of results obtained from their use are provided in Table I.

5.3 Program Organization - The EASY computer program contains three subprograms. These are the Model Generation Program, the Analysis Program, and the File Maintenance Program. Relations between these sub-programs, data input and output, and data files are shown in Figure 2.

* Although EASY can be used for steady state analyses, other programs which are intended only for steady state analysis may be more efficient, e.g., see Reference 6.

TABLE I

RESULTS FROM EASY ECS ANALYSIS

ANALYSIS	RESULTS
1. Steady State	o ECS THERMODYNAMIC PERFORMANCE AT SINGLE OR MULTIPLE CONDITIONS
2. Nonlinear	o TIME RESPONSE OF ECS
3. Linear	o DEGREE OF ECS CONTROL STABILITY OR INSTABILITY
4. Stability Margin	o REGIONS OF STABLE ECS OPERATION
5. Transfer Function	o VARIATION OR RESPONSE OF ECS OUTPUT FOR SPECIFIED INPUT
6. Root Locus	o LOCUS OF ECS SOLUTION PARAMETERS, TO DETERMINE BETTER VALUES
7. Eigenvalue Sensitivity	o SENSITIVITY OF ECS STABILITY TO CHANGES OF SPECIFIED PARAMETERS; OR IDENTIFICATION OF CRITICAL ECS PARAMETERS
8. Function Scan	o GRAPHICAL PRESENTATION OF TABULAR ECS INPUT DATA
9. Optimal Controller	o "GOOD" CONTROL CONFIGURATION FOR AN ECS

5.3.1 Model Generation Program: The Model Generation Program prepares descriptive information and FORTRAN source codes for the ECS model, using input data which functionally describe the ECS. The FORTRAN codes are a series of calls to subroutines describing various ECS components.

The model description input are commands which describe how standard component subroutines are interconnected to define the ECS flow system schematic to be analyzed. Inputs from components to other connected components are specified by commands in a specified EASY format. Standard components subroutines include general performance analysis methods for ECS components, control elements, and miscellaneous functions. (See Table II for short summary of component types.) These are available in the EASY subroutine library. If an ECS cannot be modeled with existing standard components, new component subroutines can be defined and included in the model description by appropriate FORTRAN statements, or the new standard components subroutines may be added to the library of existing ones.

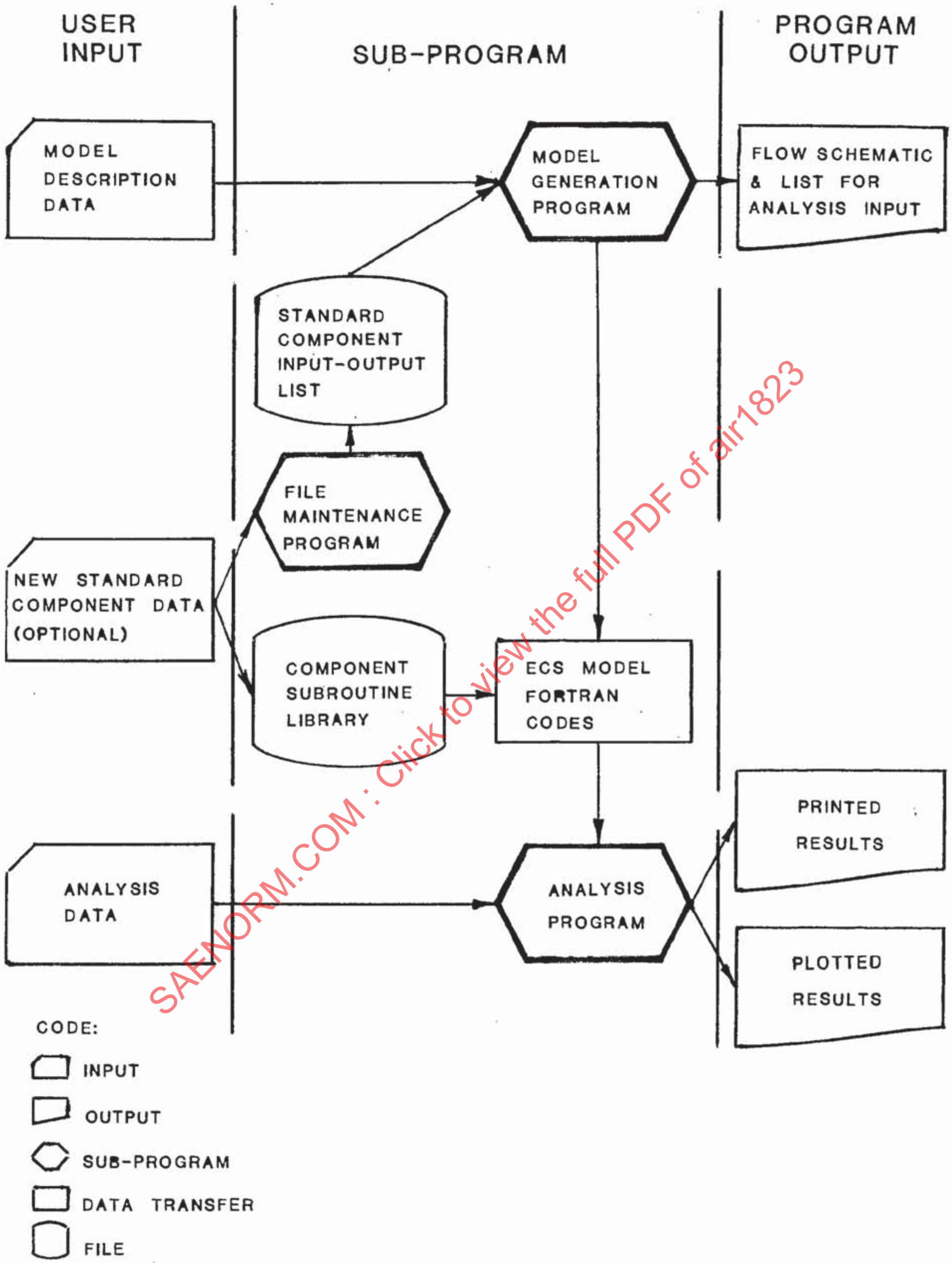


Figure 2 - EASY PROGRAM ORGANIZATION

TABLE II

TYPES OF EASY STANDARD COMPONENTS

- o AIR CYCLE REFRIGERATION COMPONENTS
- o VAPOR CYCLE REGRIGERATION COMPONENTS
- o DUCTING COMPONENTS
- o ECS CONTROL COMPONENTS
- o GENERALIZED CONTROLLERS
- o GENERALIZED TRANSFER FUNCTIONS
- o GENERAL ANALYTICAL AND MISCELLANEOUS FUNCTIONS

The EASY Model Generation program generates a schematic flow diagram of the ECS model. The flow schematic shows interconnections between standard components, and input and output data (e.g., temperatures, pressures, humidities) that are common at each interconnection. The schematic is produced on the lineprinter. It provides a rapid graphic check on the program's interpretation of the model description.

The Model Generation Program produces a list of input data that is required by each component to complete the model description. These data are used in the Analysis Program. Both scalar parameters and tabular data are included in this list. The Analysis Program assumes that any quantity not supplied by another component will be supplied as a fixed parameter by the input. Thus, items in the input data list may reveal a connection that was omitted from the ECS model description.

The Model Generation Program also generates a subroutine to load tabular data required by the model for the Analysis Program.

5.3.2 Analysis Program: The EASY Analysis Program has options for several different dynamic, linear, or nonlinear analysis techniques, and for synthesis of optimal linear controllers.

The Analysis Program provides options for application of the analysis technique considered to be best suited to a particular problem. Several different ECS models (i.e., linear model, steady state model) do not need to be generated.

The Analysis Program uses the FORTRAN codes describing the ECS model and numerical values for the items defined in the input data list by the Model Generation Program. Output can be in optional printed formats determined for the analysis technique used, and in many cases as plotted results.

5.3.3 File Maintenance Program: The File Maintenance Program is used to modify and to load new standard component input and output descriptions onto a permanent file. This program is used only when it is necessary to modify the input, output, or table list of an existing standard component, or when a new standard component is to be added to the system.

5.4 Problem Input: Two input files normally are required for EASY use. These are for the Model Generation Program and for the Analysis Program. The third input file, for the File Maintenance Program, is not needed for all analyses. Sample input for the Model Generation Program and the Analysis Program are provided in Appendix B.

5.4.1 Model Generation Program Input: Model Generation Program (MGP) input consists of command statements, descriptive ECS data, and additional FORTRAN statements as user options. This input information is summarized in Table III. Sample MGP input are presented in Appendix B.

TABLE III

MODEL GENERATION PROGRAM INPUT CONTENT

- COMMAND STATEMENTS (AS APPROPRIATE)
  - INPUT DATA IDENTIFICATION
  - INPUT DATA REQUESTS
- SYSTEM DATA
  - COMPONENTS: 2-LETTER CODES FOR ECS COMPONENTS
  - LOCATIONS: WHERE ECS COMPONENTS ARE LOCATED ON A OUTPUT SCHEMATIC
  - INTERCONNECTIONS: COMPONENT NAME AND POSITION WHERE CONNECTION COMES FROM
POSITION WHERE INLET CONNECTION IS MADE
- FORTRAN STATEMENTS (OPTIONAL)
  - ADDITIONAL ECS MODEL FEATURES
  - NON-STANDARD COMPONENT DATA

5.4.2 Analysis Program Input: Analysis Program input consists of command statements, and coded and numerical data lists. (See Table IV.) The types of input data required to define specific details for each ECS component are output by the Model Generation Program, as an aid in preparing Analysis Program input.

TABLE IV

ANALYSIS PROGRAM INPUT CONTENT

- COMMAND STATEMENTS (AS APPROPRIATE)
  - INPUT DATA IDENTIFICATION
  - ANALYSIS TYPE REQUESTS
  - OUTPUT FORMAT REQUESTS
- DATA
  - TABULAR
  - PARAMETER VALUES
  - INITIAL CONDITIONS FOR ECS MODEL
  - STATE VARIABLES

Command statements identify each data item being input; they specify analysis types being requested; and they define output formats desired for each analysis. There are command statements for each of the nine analysis types discussed in Section 5.2. Command statements also provide for:

- definition of parameter, rate, state, and variable names;
- Initialization of conditions, operating points, and initial time values;
- definition and control of lineprinter, punch, and plotter output;
- input of table data;
- specification of titles for plotted data;
- format for output of punched, printed, and plotted data.

A sample Analysis Program input list is provided in Appendix B.

5.5 Program Output: The EASY program produces lineprinter output from the Model Generation Program; and lineprinter plotted output from the Analysis Program. Only time histories and steady state scan graphics are available with lineprinter plots. The generation of plotted output requires use of specialized software (which is not part of the EASY program).

TABLE V

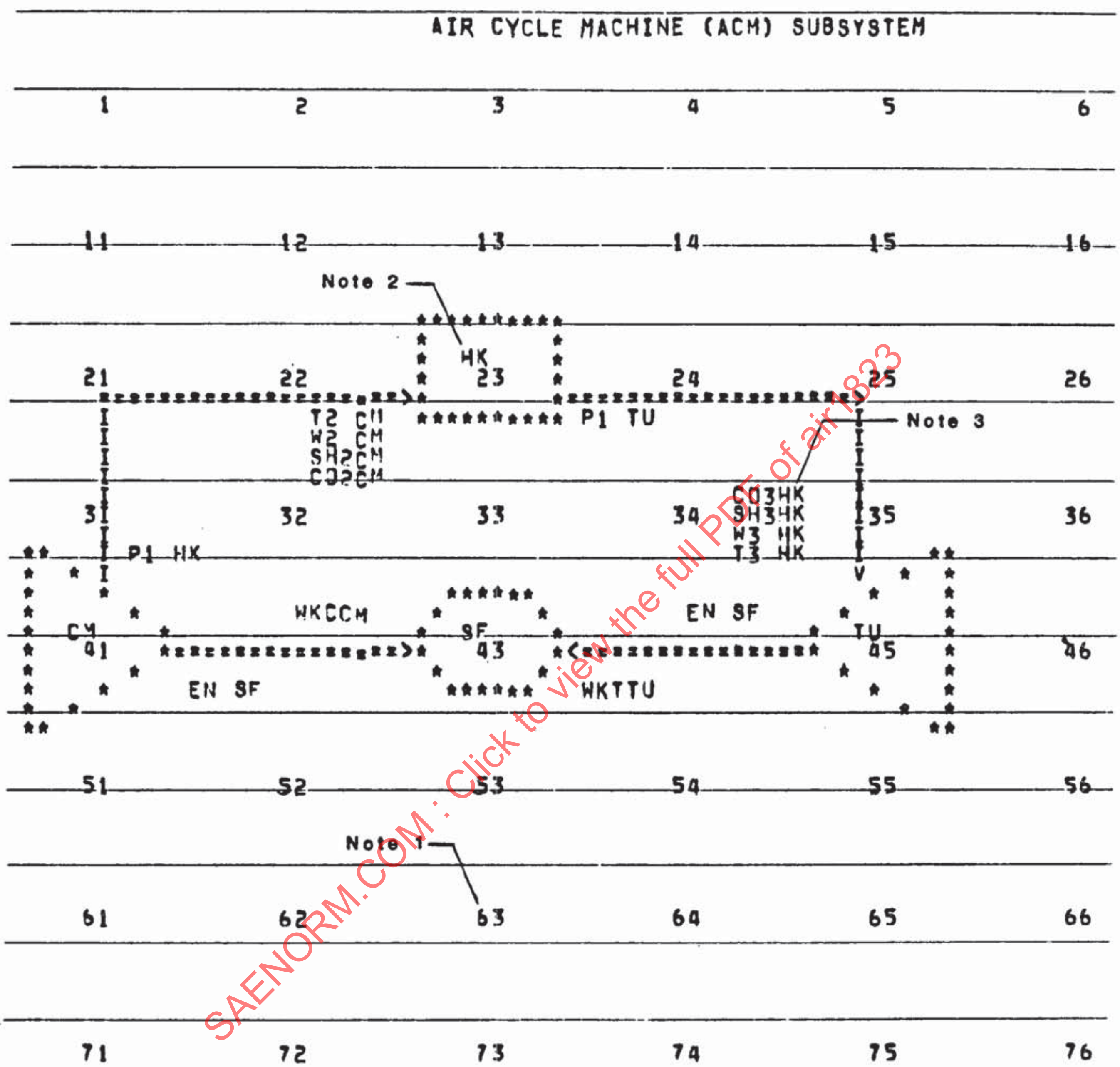
MODEL GENERATION PROGRAM OUTPUT

ALWAYS OUTPUT

- INPUT LISTING
- INPUT COMMAND LIST
- WARNING MESSAGES (WHEN APPLICABLE)

OPTIONAL OUTPUT	DESCRIPTION
o ECS FLOW SCHEMATIC	o SIMPLE LINE PRINTER SCHEMATIC OF SYSTEM BEING MODELED, TO ENABLE USER TO IDENTIFY ERRORS IN THE MODEL DESCRIPTION. SEE EXAMPLE, FIGURE 3.
o IDENTIFICATION OF DATA NEEDED FOR ANALYSIS PROGRAM	o INCLUDES DATA REQUIREMENTS SUCH AS TABLES, PARAMETERS, AND INITIAL CONDITIONS FOR STATE VARIABLES. SEE SAMPLE OUTPUT, APPENDIX B.
o LISTING OF SUBROUTINE CALLING STANDARD COMPONENTS	o LISTING OF SUBROUTINE EQMO WHICH DEFINES EQUATIONS USED IN THE ANALYSIS PROGRAM.
o LISTING OF SUBROUTINE SETTING DATA ACCESSED BY ANALYSIS PROGRAM	o LISTING OF SUBROUTINE DATAIN, WHICH SETS THE NUMBER OF STATES, VARIABLES, AND PARAMETERS THAT ARE ACCESSED BY THE ANALYSIS PROGRAM.

5.5.1 Model Generation Program Output: Some forms of data are always output by the Model Generation Program, and some are output per user option. These are summarized in Table V.



Notes

1. Numbers are positions used to locate components on schematic
2. Two letters inside geometric shapes indicate component types
3. Alphanumeric codes identify data transfer between components

Figure 3 - SAMPLE ECS FLOW SCHEMATIC AS MODEL GENERATION PROGRAM (MGP) OUTPUT

5.5.2 Analysis Program Output: Analysis Program output is unique for each of the nine types of analyses (see Section 5.2). Two general types of data or information also may be output by the Analysis Program. One is a graphical output of all tabular data. This provides a convenient visual check of input data. (See Appendix B for a sample of this output.) The second is output if the Analysis Program encounters difficulty in interpreting analysis instructions or in performing analysis, and warning messages are provided. A summary of Analysis Program output is provided in Table VI.

TABLE VI

ANALYSIS PROGRAM OUTPUT

ANALYSIS TYPE	ECS OUTPUT DATA	AVAILABLE OUTPUT FORMAT
STEADY STATE	o STATE CONDITIONS o RATES o PARAMETER VALUES o VARIABLE VALUES	o LINEPRINTER o PLOTS
NONLINEAR	o ECS PARAMETERS VERSUS TIME	o LINEPRINTER o PLOTS
LINEAR	o STATE VARIABLES AND DERIVATIVES o STABILITY MATRIX o EIGENVALUES	o LINEPRINTER
STABILITY MARGINS	o PARAMETER LIMITS o NATURAL FREQUENCIES	o LINEPRINTER
TRANSFER FUNCTIONS	o FREQUENCY RESPONSE FUNCTIONS	o LINEPRINTER o BODE PLOT o NICHOLS PLOT o NYQUIST PLOT
ROOT LOCUS	o ROOT LOCUS	o LINEPRINTER o PLOTS
EIGENVALUE SENSITIVITY	o EIGENVALUES AND SENSITIVITY MEASURES	o LINEPRINTER
FUNCTION SCAN	o GRAPHICAL FORMS OF FUNCTIONAL RELATIONS	o PLOTS
OPTIMAL CONTROLLER	o CONTROLLER GAIN ARRAYS o SENSOR ARRAYS o STABILITY MATRIX ARRAYS o CRITERIA ARRAYS	o LINEPRINTER o PUNCH CARDS

5.6 Computer System: The EASY Computer program is written in FORTRAN IV language. It can be operated on the CDC/CYBER family of computers (6600, 760, and 176), or on the IBM or DEC VAX computers. Core requirements are a function of model size and use of the optimal controller synthesis capability. Typical core requirements (Octal) are provided in Table VII.

TABLE VII

CORE REQUIREMENTS

MODEL SIZE (NO. OF STATES)	ANALYSIS ONLY	WITH OPTIMAL CONTROLLER SYNTHESIS
10	120K	140K
30	170K	230K
50	200K	300K

Execution times are very dependent on model size and on the type of analyses that are run.

The EASY computer program is avaialble 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, DC.

6. LIMITATIONS AND OTHER USAGE: Users of the EASY computer program must be aware of its limitations. Suggested improvements to the program, and other uses and variations of EASY also are presented.

6.1 Limitations: The EASY program has the following limitations.

1) Equations representing ECS performance must be in state variable form (i.e., they must consist of a set of explicit first order equations).

2) The practical upper limit of model size is approximately seventy-five state variables. It is desirable to limit model size to less than forty state variables to avoid excessive computer costs.

3) Convergence of a steady state analysis is not guaranteed. Normal rules for solutions to nonlinear equations apply. For example, avoid discontinuities and make reasonable estimates of initial conditions.

4) Specific limits on EASY input are 100 component identifiers per model; 50 tables per model; and 10 optimal controller inputs, outputs, or criteria.

5) Some closed loop systems with inherent implicit loops are difficult to analyze due to the EASY program structure.

6) The IBM version of EASY is not fully operational at present. Software changes to the original CDC/CYBER version were required for use on IBM and PDP VAX computers.

6.2 Usage on Other Types of Systems: The EASY program has been applied to other systems as indicated below:

o aircraft and missile simulation and control
o power plant modeling and control
o passenger vehicle dynamic performance assessment
o chemical process simulation and control
o electrical power distribution stability
o servo designs for tape drives, machine tools, pointing systems
o game animal population dynamics and control
o instrumentation compensation design
o aircraft arresting systems
o aircraft hydraulic systems.

6.3 EASY4, EASY5(CE), and EASY5: There are three current versions of the EASY computer program. EASY4 is the original EASY program. EASY5(CE) is an improved version of EASY which was used for analysis of ejection seat stability for a Crew Escape system (Reference 9). These two versions are available from USAF. The EASY5 version is a proprietary program available commercially (Reference 10).

There are two significantly new capabilities in EASY5, which are not in EASY4 or in EASY5(CE). One is enhanced capabilities for Optimal Control Design, and the second is the Macrocomponent capability. The latter allows reduction in the number of states for new components. Other differences between the three EASY versions are indicated in Table VIII.

7. REFERENCES:

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3. G. S. Duleba, et al, Experimental Verification of ECS Dynamics Computer Program, AFFDL-TR-77-104, October 1977.

4. A. J. P. Lloyd and V. K. Rajpaul, Dynamic Analysis Environmental Control Systems the "EASY" Way, ASME Paper 77-ENAs-6, July 1977.

5. H. E. Petersen and F. J. Sausom, MIMIC - A Digital Simulator Program, Air Force Document SESCA Internal Memo 65-12, May 1965.

6. The Advanced Environmental Control System (AECS) Computer Program for Steady State Analysis and Preliminary System Sizing, SAE AIR 1706A, October 1986.

7. J. Chi, Vapor Cycle (VCS) Transient and Steady State Analysis Computer Program, AFWAL-TR-81-3143, October 1981.

8. G. S. Duleba, EASY Vapor Cycle Dynamic Analysis, AFWAL-TR-84-3082, October, 1984.

9. C. L. West, B. R. Ummel, and R. F. Yurczyk, Analysis of Ejection Seat Stability Using EASY Program, 2 Volumes, AFWAL-TR-80-3014, September 1980.

10. Boeing Computer Services, P.O. Box 24346, Seattle, WA 98124.

TABLE VIII

DIFFERENCES BETWEEN EASY4, EASY5(CE), AND EASY5

Cabability	EASY4	EASY5(CE)	EASY5
1. FULLY INTEGRATED FORTRAN COMPONENTS	NO	YES	YES
2. OPTIMAL CONTROLLER IMPROVEMENTS a. FORTRAN CONNECTIONS b. FROZEN STATES c. REAL EIGENVALUE LIMIT	NO	NO	YES
3. DISCRETE ANALYSIS	NO	OLD ALGORITHMS	YES
4. VECTOR/MATRIX CAPABILITIES	NO	YES	YES
5. MACRO COMPONENTS	NO	NO	YES
6. VECTOR COMPONENTS	NO	YES	YES
7. LINEAR MODEL GENERATION	NO	NO	YES
8. LINEAR MODEL REDUCTION	NO	NO	YES
9. THREE DIMENSIONAL TABLES	NO	YES	YES
10. TRANSFER FUNCTION ZEROES	NO	OLD ALGORITHMS	YES
11. COMPLETE PRINTER PLOTS	NO	NO	YES
12. AUXILIARY INPUT FILES	NO	YES	YES
13. DEBUG FEATURE	NO	YES	YES
14. ALTERABLE TABLE STORAGE	NO	YES	YES
15. SECONDARY TINC, PRATE, OUTRATE AND PRINT CONTROL	NO	YES	YES
16. CALCULATE INITIAL CONDITION OPTION	NO	YES	YES
17. SUPPRESS TABLE PRINTBACK OPTION	NO	YES	YES
18. SINGLE PASS THROUGH MODEL	NO	YES	YES

APPENDIX A - DEFINITIONS

1) Analysis Program - The Analysis Program is that part of EASY which performs the ECS transient analysis.

2) Bode Plot - A Bode plot presents system frequency response data plotted in rectangular coordinate form. The magnitude ratio (output-to-input) and phase angle (time relationship of output-to-input) are plotted against frequency of a change in input.

3) Eigenvalues - Eigenvalues are the roots (or solution parameters) of a system's characteristic equation. The roots are complex numbers, with a real and an imaginary part.

4) Eigenvalue Sensitivity - Eigenvalue sensitivity is a quantitative measure of the change in system eigenvalues for a given change in the magnitude of a design parameter.

5) EASY - Environmental Control Analysis SYstem computer program. (References 1 and 4.)

6) File Maintenance Program - The File Maintenance Program is that part of the EASY program which is used to load component models or to modify the standard component models.

7) Frequency Response - Frequency response refers to the steady state response of a system to a sinusoidal input of fixed amplitude.

8) Function Scan - Function scan is a feature of the EASY program that provides a graphic output of algebraic functional relationships or of tabulated data input by a user.

9) Gain Margin - The gain margin is the factor by which the loop gain must be multiplied, for a system to reach the stability boundary.

10) Kalman Filter - The Kalman filter is an optimal estimator or filtering technique for estimating the state of a linear system.

11) Laplace Transform - The Laplace transform is a mathematical relationship that is used to transform a function from the time domain to a transformed domain.

12) Linear or Nonlinear Analysis - Nonlinear systems may be analyzed by using a linear approximation of the nonlinear equations about a specific point, or by using a number of digital computer techniques available for solving nonlinear differential equations.

13) Linear and Nonlinear Differential Equations -

$$C_0 \frac{d^n x}{dt^n} + C_1 \frac{d^{n-1} x}{dt^{n-1}} + \ldots + C_{n-1} \frac{dx}{dt} + C_n x = f(t),$$

is linear if there are no products or nonlinear functions of the dependent variable x or its derivatives. Examples of nonlinear differential equations are:

$$\frac{d^2x}{dt^2} + \frac{dx}{dt} + x^3 = 0;$$

$$\frac{dx^3}{dt} = 0;$$

$$\frac{d^2x}{dt^2} + x \frac{dx}{dt} + x^2 = 0$$

14) Linear Regulator - A linear regulator is a special case for minimization of the performance index to obtain optimal performance.

15) Model Generation Program - The Model Generation Program (MGP) of EASY assembles the ECS by organizing standard components or new components, and components interconnections, based on user inputs.

16) Nichols Plot - A Nichols plot is the logarithm of the output-to-input magnitude ratio plotted against the phase angle, as the frequency of a sinusoidal input is varied.

17) Nyquist Plot - The Nyquist plot provides magnitudes and phase relationships (in polar form) between system input and response for any excitation frequency.

18) Optimal Control - Optimal control is when the values of the control parameters (transfer function) are chosen such that a selected performance index is maximized (or minimized).

19) Phase Angle - Phase angle is a measure of how a system's output response lags or leads a sinusoidal input to the system.

20) Root Locus Analysis - The root locus analysis is a graphical procedure for determining all possible roots of the characteristic equation for a control system.

21) System Characteristic Equation - The characteristic equation is the denominator of the system transfer function.

22) Stability Matrix - A stability matrix is the eigenvalues of a system about an operating point.

23) Standard Components - Standard components, in the EASY computer program, are subroutines which define dynamic performance relations of ECS components and controls, dynamic performance relations of general basic controls, and miscellaneous analytical functions.

24) State Variables - State variables are variables which completely describe the behavior of a dynamic system.

25) Transfer Function - The transfer function for any component or system is defined as the ratio of the Laplace transform of the output to the Laplace transform of the input.

$$\text{Transfer Function Form} = \frac{a_1 s + b_1}{a_2 s^2 + b_2 s + c_2}$$

APPENDIX B

SAMPLE EASY INPUT AND OUTPUT

Several samples of input to and output from the EASY Model Generation Program and Analysis Program are provided.

The sample EASY input and output are for a simply defined bootstrap air cycle ECS. A flow schematic of this ECS is provided in Figure B-1. It represents air flow into a compressor, air flow from the compressor to a heat exchanger, and flow from the heat exchanger to a turbine. The compressor is shaft powered by the turbine. The EASY 2-letter codes for the four components also are noted in the figure.

B.1 Model Generation Program Input - A sample Model Generation Program input for the bootstrap ECS and an additional feature about the air cycle machine (turbine driven compressor unit) are presented in Figure B-2.

The first line of input, LIST STANDARD COMPONENTS, calls for a listing of all standard components.

Input lines 2 through 6 define the ECS model, where the four components are to be located on a lineprinter flow schematic output, and interconnections between components (identified as INPUTS). MODEL DESCRIPTION specifies the start of the ECS description input, followed by the title to be used on the lineprinter flow schematic.

The compressor symbol on the flow schematic output is to be located at position 041, the heat exchanger at position 023, and so on. The heat exchanger receives inputs from compressor output port location number 2, with a connection to the heat exchanger at inlet port number 1. The turbine receives inputs from heat exchanger port number 3, with a connection to turbine port number 1.

Lines 7 through 19 define an additional feature which cannot be modeled using standard components. Any unique limits on the analysis must be defined in the MGP input. These lines are FORTRAN statements to check whether the air cycle machine shaft speed (EN SF) exceeds a specified value (RPMLIM) corresponding to a machine failure. If this occurs in the Analysis Program, the analysis is terminated and a diagnostic message is output.

B.2 Model Generation Program Output - A sample of Model Generation Program output providing a list of required input data for the Analysis Program is provided in Figure B-3. This output gives coded alphanumeric data indicating type of tabular data needed for each component, the specific parameters for which values are required, and states for which initial conditions and error control values are needed. This output aids preparation of Analysis Program input.