

ENVIRONMENTAL CONTROL SYSTEM TRANSIENT ANALYSIS COMPUTER PROGRAM (EASY)

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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.

BREADBOARD  
APPROACH

TASKS

COMPUTER  
APPROACH

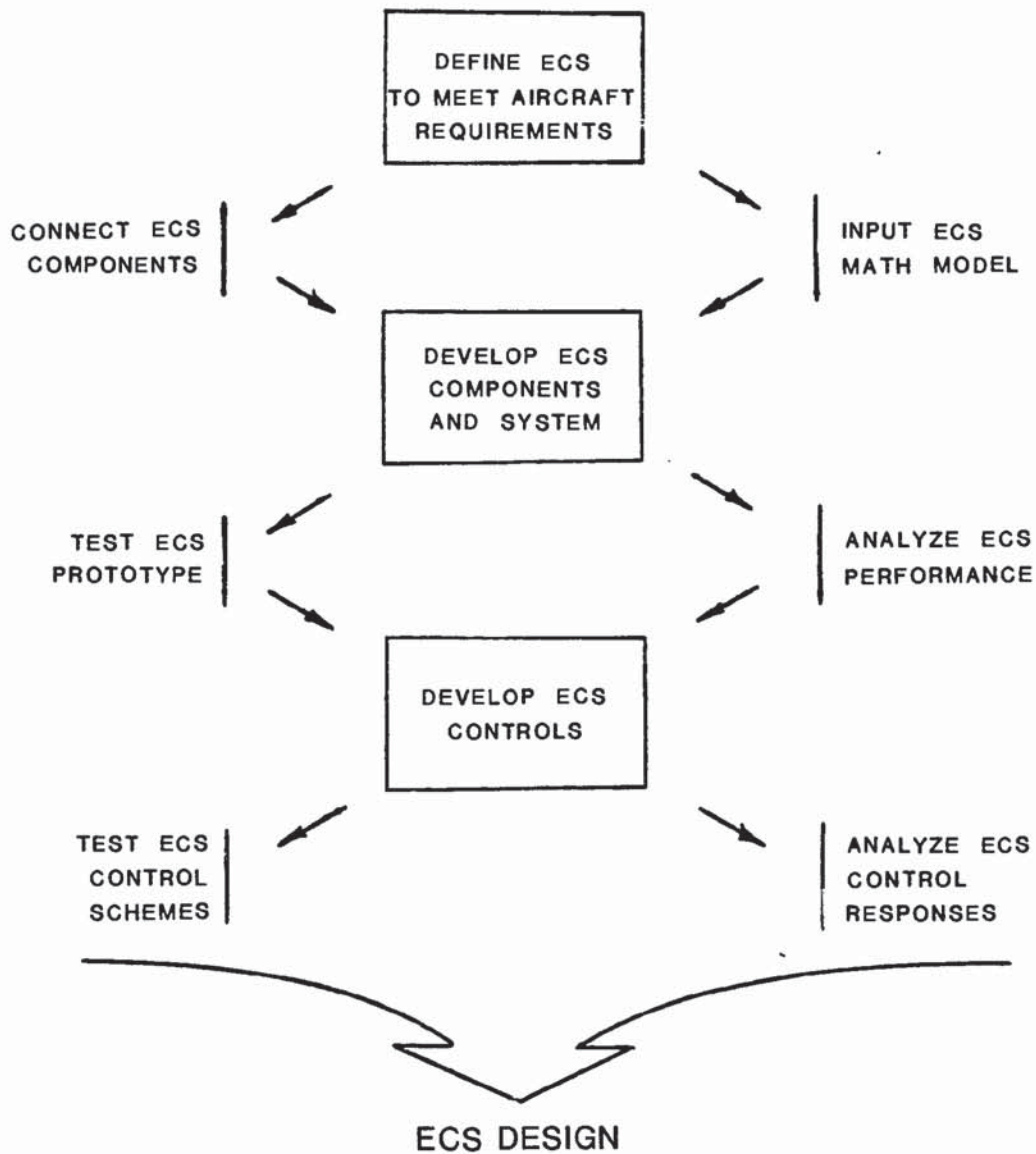


Figure 1 - ECS DEVELOPMENT APPROACHES

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 component 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.

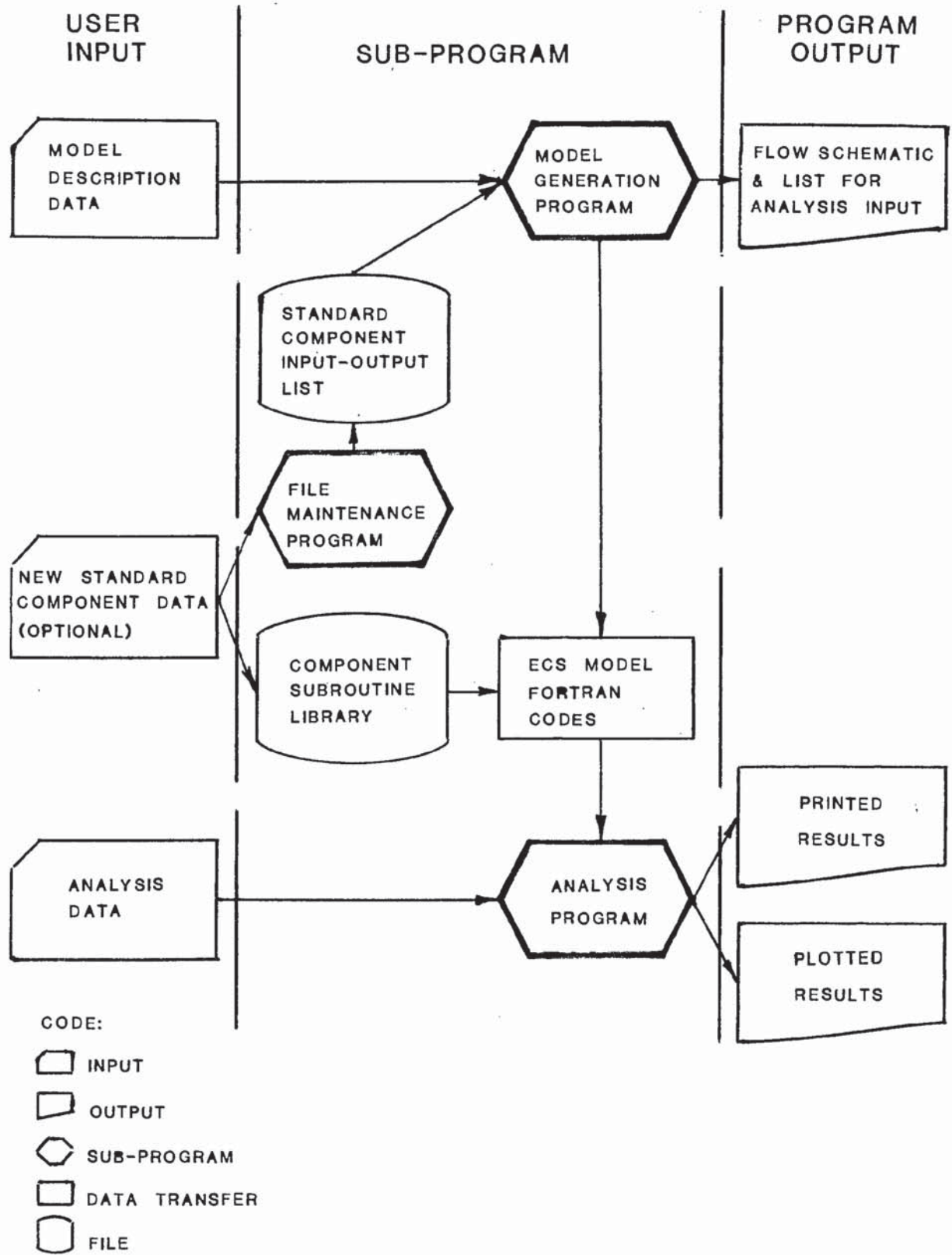


Figure 2 - EASY PROGRAM ORGANIZATION

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.