

AEROSPACE INFORMATION REPORT

SAE AIR1823

REV. B

Issued 1986-10
Reaffirmed 2003-10
Cancelled 2011-05

Superseding AIR1823A

Engineering Analysis System (EASY) Computer Program
for Dynamic Analysis of Aircraft ECS

RATIONALE

The computer program on which this document is based is quite old. The program in the form that the document is based on, is little used. There is an improved version, but it is proprietary and would be difficult to document. There are other programs being used for ECS transient analysis. It does not seem appropriate to just document one of many available programs. The document should be cancelled.

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1. SCOPE:

The Engineering Analysis SYstem (EASY) computer program is summarized in this report. It provides techniques for analysis of steady-state and dynamic (transient) environmental control system (ECS) performance, control system stability, and for synthesis of optimal ECS.

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.

1.1 Purpose:

A generalized computer program for determining transient thermodynamic performance of aircraft ECS, and methods for dynamic analysis of aircraft ECS are discussed in this report.

2. REFERENCES:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

2.1.1 AIR1706 The Advanced Environmental Control System (AECS) Computer Program for Steady-State Analysis and Preliminary System Sizing

2.1.2 SAE 881001 J.F. Defenbaugh, W.S. Heglund and A.L. Markunas, A Dynamic Model for Vapor Cycle Cooling Systems

2.2 Other References:

2.2.1 A. J. P. Lloyd, et al, Environmental Control System Transient Analysis, 4 Volumes, AFFDL-TR-77-102, October 1977.

2.2.2 G. S. Duleba, Application of the EASY Dynamic Analysis Program to Aircraft Environmental Control Systems - Reference Guide, AFFDL-TR-77-103, October 1977.

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

- 2.2.4 A. J. P. Lloyd and V. K. Rajpaul, Dynamic Analysis Environmental Control Systems the "EASY" Way, ASME Paper 77-ENAs-6, July 1977.
- 2.2.5 H. E. Petersen and F. J. Sausom, MIMIC - A Digital Simulator Program, Air Force Document SESA Internal Memo 65-12, May 1965.
- 2.2.6 J. Chi, Vapor Cycle (VCS) Transient and Steady-State Analysis Computer Program, AFWAL-TR-81-3143, October 1981.
- 2.2.7 G. S. Duleba, EASY Vapor Cycle Dynamic Analysis, AFWAL-TR-84-3082, October, 1984.
- 2.2.8 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.
- 2.2.9 EASY5x is a commercial product available from Boeing Computer Services (Telephone number 1-800-426-1443).

2.3 Definitions:

- 2.3.1 ANALYSIS PROGRAM: The Analysis Program is that part of EASY which performs the ECS transient analysis.
- 2.3.2 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.
- 2.3.3 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.
- 2.3.4 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.
- 2.3.5 EASY: Engineering Analysis SYstem computer program. (References 1 and 4.)
- 2.3.6 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.
- 2.3.7 FREQUENCY RESPONSE: Frequency response refers to the steady-state response of a system to a sinusoidal input of fixed amplitude.
- 2.3.8 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.
- 2.3.9 GAIN MARGIN: The gain margin is the factor by which the loop gain must be multiplied, for a system to reach the stability boundary.
- 2.3.10 KALMAN FILTER: The Kalman filter is an optimal estimator or filtering technique for estimating the state of a linear system.

- 2.3.11 **LAPLACE TRANSFORM:** The Laplace transform is a mathematical relationship that is used to transform a function from the time domain to a transformed domain.
- 2.3.12 **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.
- 2.3.13 **LINEAR AND NONLINEAR DIFFERENTIAL EQUATIONS:**

$$c_0 \frac{d^n x}{dt^n} + c_1 \frac{d^{n-1} x}{dt^{n-1}} + \dots + c_{n-1} \frac{dx}{dt} + c_n x = f(t) \quad (\text{Eq.1})$$

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

$$\frac{d^2 x}{dt^2} + \frac{dx}{dt} + x^3 = 0 \quad (\text{Eq.2})$$

$$\frac{dx^3}{dt} = 0 \quad (\text{Eq.3})$$

$$\frac{d^2 x}{dt^2} + x \frac{dx}{dt} + x^2 = 0 \quad (\text{Eq.4})$$

- 2.3.14 **LINEAR REGULATOR:** A linear regulator is a controller which can be implemented using only linear differential and algebraic equations.
- 2.3.15 **MODEL GENERATION PROGRAM:** The Model Generation Program of EASY assembles the ECS by organizing standard components or new components, and components interconnections, based on user inputs.
- 2.3.16 **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.
- 2.3.17 **NYQUIST PLOT:** The Nyquist plot provides magnitudes and phase relationships (in polar form) between system input and response for any excitation frequency.
- 2.3.18 **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).
- 2.3.19 **PHASE ANGLE:** Phase angle is a measure of how a system's output response lags or leads a sinusoidal input to the system.
- 2.3.20 **ROOT LOCUS ANALYSIS:** The root locus analysis is a graphical procedure for determining all possible roots of the characteristic equation for a control system.

- 2.3.21 **SYSTEM CHARACTERISTIC EQUATION:** The characteristic equation is the denominator of the system transfer function.
- 2.3.22 **STABILITY MATRIX:** A stability matrix is the eigenvalues of a system about an operating point.
- 2.3.23 **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.
- 2.3.24 **STATE VARIABLES:** State variables are variables which completely describe the behavior of a dynamic system.
- 2.3.25 **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.

$$\text{Transfer Function Form} = \frac{a_1s + b_1}{a_2s^2 + b_2s + c_2} \quad (\text{Eq.5})$$

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 the following three tasks:

- a. Definition of system components to meet aircraft requirements
- b. Development of components to meet system performance
- c. 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.

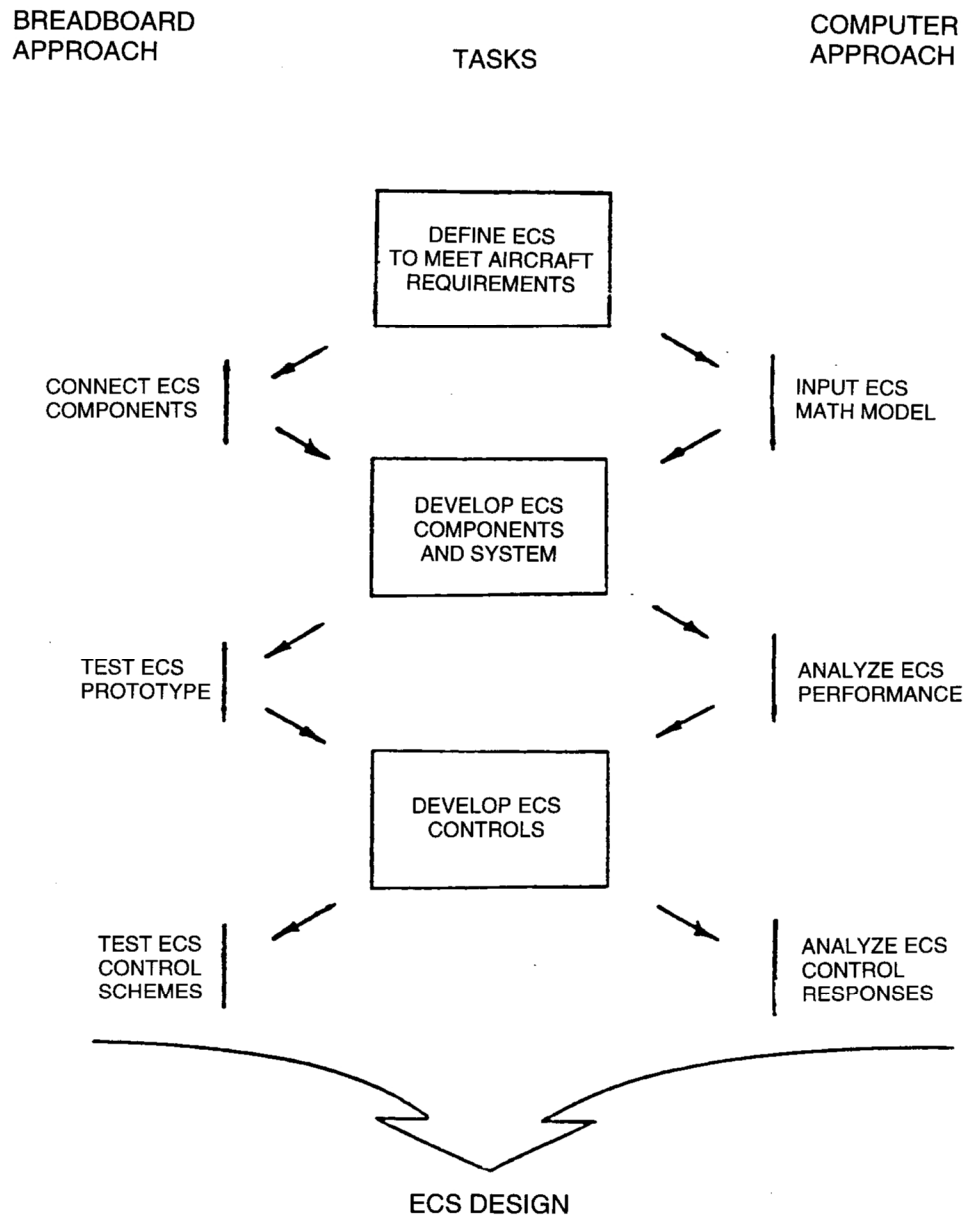


FIGURE 1 - ECS Development Approaches

3. (Continued):

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 (Reference 2.2.5), 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 5.6. It has application to other types of systems also (see 6.2).

Development of this computer program initially was sponsored by the U.S. Air Force Flight Dynamics Laboratory (see References 2.2.1, 2.2.2, 2.2.3, and 2.2.4). An early version of the EASY computer program is available from the U.S. Air Force and later proprietary versions are available commercially.

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 ECS. 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.

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 2.1.2, 2.2.6, and 2.2.7). 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.

4.1 (Continued):

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:

- a. Program inputs are simple codes to connect discrete elements with built-in techniques (these techniques represent the performance and functions of aircraft ECS components)
- b. Definitions of ECS control functions can be simple and generalized, or detailed, or both
- c. Six nonlinear dynamic analysis techniques are available
- d. Message codes are provided as cautions about errors in input
- e. Engineering problems that can be modelled by differential equations with variable or constant coefficients can be analyzed
- f. 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. It can also be operated on interactive engineering workstation computers. Means for rapid troubleshooting of errors are provided, but may be limited by the machine being used.

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: