SAE Aerospace
An SAE International Group

AEROSPACE INFORMATION REPORT

AIR1706 REV. B

Issued 1981-10
Revised 1997-10
Reaffirmed 2003-10

Superseding AIR1706A

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[1], 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.

1. 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.

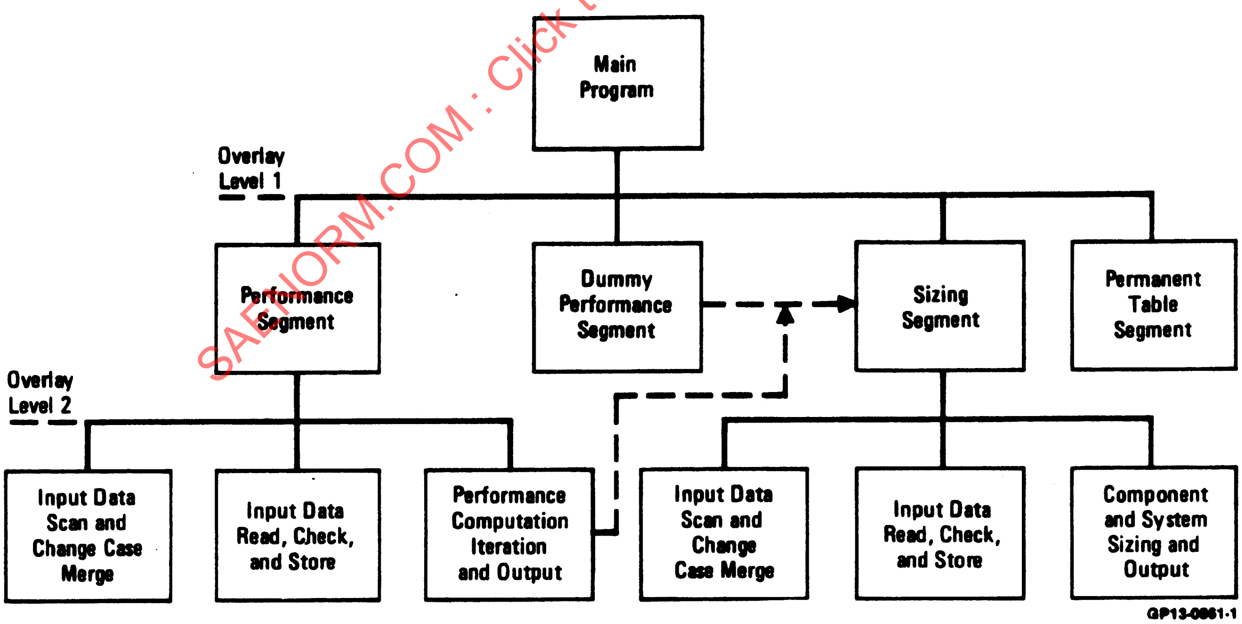

FIGURE 1 - Computer Program Structure

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.

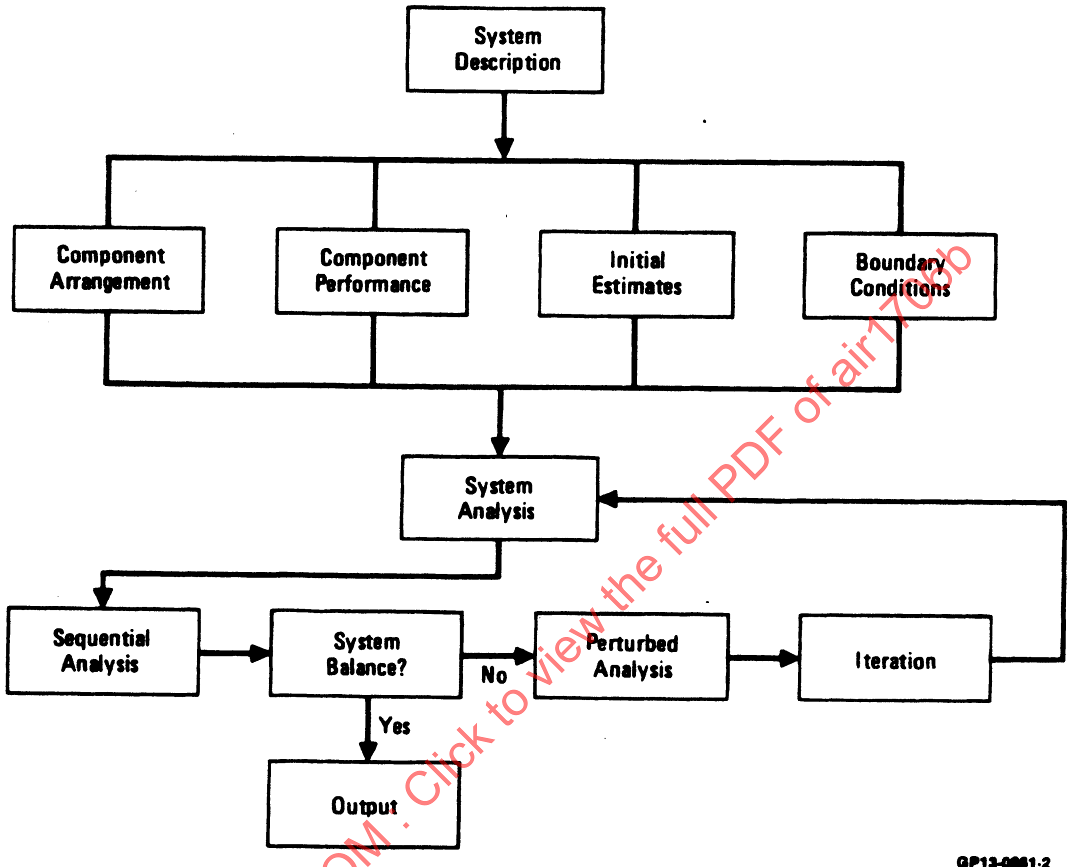

FIGURE 2 - Performance Solution Method

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.

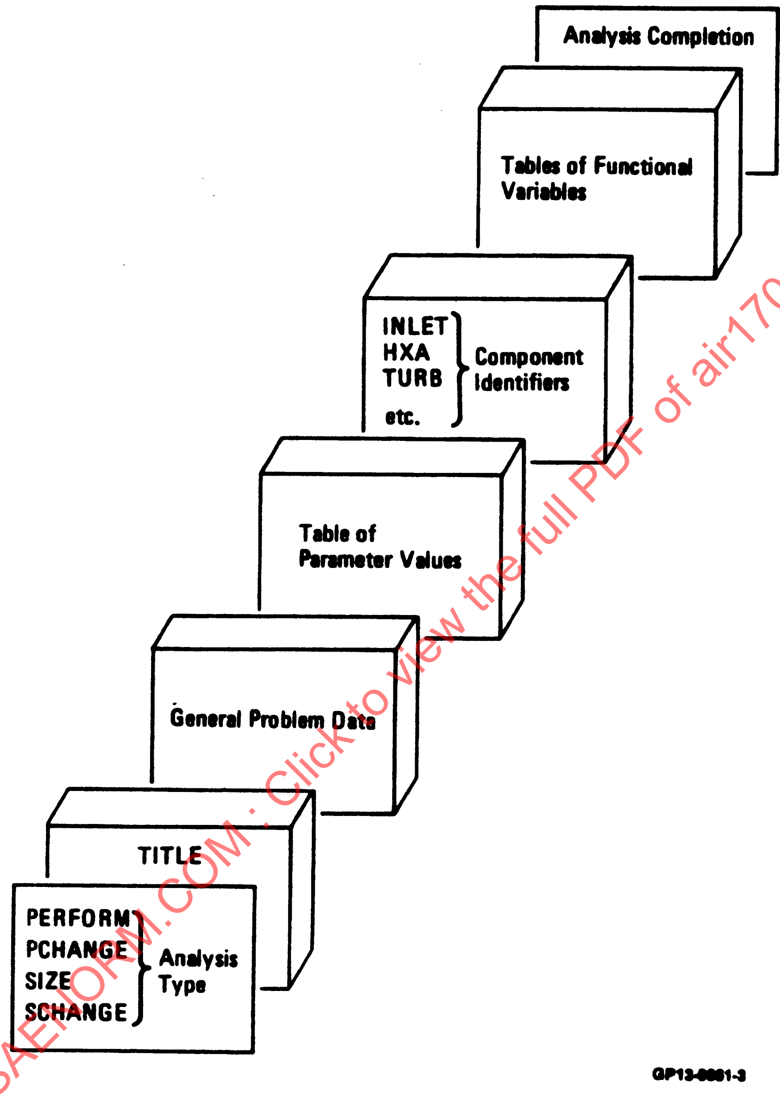

FIGURE 3 - Problem Input Data

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.

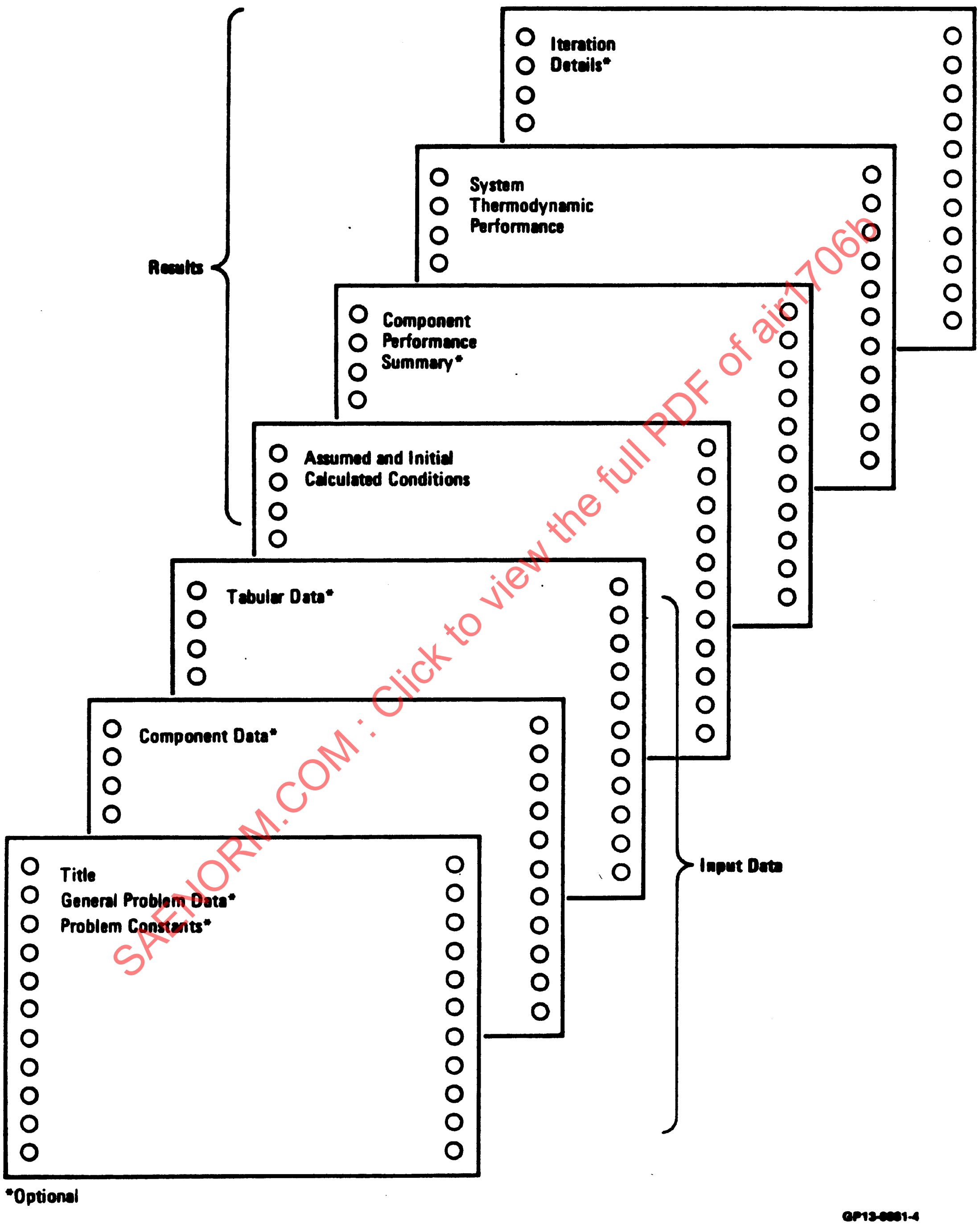

FIGURE 4 - Performance Output

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)/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)    1.000 (  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