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DEVELOPMENT OF INTEGRATED ENVIRONMENTAL CONTROL SYSTEM DESIGNS FOR AIRCRAFT

VOLUME IV-LABORATORY DEMONSTRATION TEST

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FOREWORD

This report presents results 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

The Laboratory Demonstration Test described in this volume was performed by the McDonnell Aircraft Company (MCAIR) of the McDonnell Douglas Corporation. The program manager was R. R. Dieckmann, and S. F. Glover was the Laboratory Demonstration Test Group Leader assisted by R. N. Johnson. R. C. Turner was the test engineer and was assisted by J. L. Williford.

Use of ECS components from AiResearch Division of the Garrett Corporation and from Vap-Air Division, Vapor Corporation is acknowledged.

This technical report has been reviewed and is approved.

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ABSTRACT

This report presents the results of a study of Environmental Control System (ECS) designs for aircraft. The study was performed for the Air Force Flight Dynamics Laboratory. A test ECS and associated laboratory test facility, the test conditions and testing procedures, and the factors evaluated with the test results are discussed. The Laboratory Demonstration Test ECS consisted of an F-4E cabin system, several additional off-the-shelf components to improve the system performance (i.e., which provide better temperature and flow control than is presently specified), appropriate laboratory equipment for system assembly and heat load simulation, and instrumentation for test monitoring. Testing of this ECS was performed at several conditions which simulate the flight envelope of a high performance fighter aircraft. Tests were performed with and without various system components to show their contributions to the improved system capacity, and system temperature and flow control.

The ECS Computer Program described in Volume II was used to predict detailed performance of the laboratory demonstration ECS, and thus to provide an evaluation of the test data. In the process the validity of the computer program is illustrated. The computer program also was used to determine component and system sizes (using the analytical design information of Volume I), and system penalties of this ECS to a typical fighter aircraft. Volume II includes sample problems for the rough performance and sizing analyses of three Air Force aircraft, and the detailed performance and sizing of one Air Force aircraft. Volume III (ICES Computer Program Users Manual) contains information on how to use the computer program and a complete description of sample problems for rough performance and sizing analyses, and detailed performance analysis.

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NOMENCLATURE AND SYMBOLS

Symbol	Definition
C	Controller
CES	Cooling Effects System
COMP	Compressor
CU	Cost Unit
CV	Control Valve
D	Diameter
EQUIP	Equipment
H	Humidity, lb water/lb dry air
HX	Heat Exchanger
$K_{1,2,etc}$	Constant or Parameter Defined in Text
K	Pressure Loss Factor (KW^m form)
KW	Kilowatts
L	Length, inches (unless ft is noted)
M	Flowmeter
N	Speed, rpm
P	Pressure, psia
R	Regulator
REGEN	Regenerative Heat Exchanger
S	Sensor
SL	Sea Level
T	Temperature, °R (unless °F is noted)
TURB	Turbine
UA	Overall Conductance, Btu/hr°F
V	Valve
W	Flow, lb/min
WSEP	Water Separator
	Subscripts
c	Heat Exchanger Cold Flow Side
e	Effective
H	Heat Exchanger Hot Flow Side
N	Heat Exchanger No Flow Side
Te	Technical

Note: Component names and some computer program nomenclature used in Sections 6 and 7 are defined in Volume II, Sections 3 and 4.

SECTION 1

INTRODUCTION

An advanced environmental control system configuration was assembled, instrumented, and tested at MCAIR. This volume describes the laboratory ECS test setup and presents the test results.

Previous studies (e.g., References 1 and 2) indicate that high temperature levels and temperature cycling of electronic components can be detrimental to equipment reliability. One contributor to the detrimental temperature fluctuations and temperature levels is the variations in the engine bleed air supply to the air cycle refrigeration package. The engine bleed air pressure varies considerably as a function of the flight or ground operating conditions resulting in a range of the air temperatures and air flow rates being provided to the equipment. This causes reduced equipment reliability and pilot discomfort.

One objective of this test was to show how the addition of certain components to a typical ECS can reduce temperature and flow rate cycling of the conditioned air at various flight conditions of a typical fighter aircraft. Other objectives were to show that the test ECS can provide design capacity, moisture control, and to provide performance data to be evaluated by the computer program. In the process of data evaluation, the validity of the computer program is illustrated. Sizing and evaluation of penalties of the test article ECS in an assumed flight configuration also are included in this report to illustrate use of other portions of the computer program.

SECTION 2

ENVIRONMENTAL CONTROL SYSTEM

The test ECS consisted basically of an F-4 open loop bootstrap air cycle system. The flow circuit was altered to include additional components which can improve system performance for the conditioned air supplied to individual cockpit and equipment thermal simulators. A cooling effects system was used to improve control of the air temperature and flow rate to the equipment simulator. The use of a regenerative heat exchanger and a simulated boost compressor increased system capacity. A water separator provided moisture control. The system configuration which includes the above components and appropriate instrumentation is described in the following sections.

2.1 Description of Test Article

The test ECS is a bread board layout of an F-4 cabin environmental control system with a regenerative loop, and parallel cabin and equipment heat load simulators. Figure 1 is a schematic of the test ECS. Figure 2 is a photograph of the system installed in the laboratory altitude chamber. Most of the components were flight qualified items. Exceptions were the thermal simulators, some of the valves, and the ducting connecting the components. Most of the non-flight qualified items were obtained from MCAIR laboratory supplies or were fabricated in the laboratory. The above items are listed in Table I by description and name or symbol as identified in the system schematic, Figure 1. The test ECS was enclosed in a MCAIR altitude chamber with the exception of controllers C1, C2, and C3. These were located outside for calibration and control. Some of the control valves that had remote controls outside the chamber also are indicated in Table I.

System performance at pressure altitudes up to 45,000 feet was evaluated. Two laboratory air supplies were utilized for this test. Engine bleed air conditions as well as boost compressor exit conditions were simulated by the facility high pressure air supply ($P \leq 300$ psia). Ram air temperatures and flow rates were provided by the facility low pressure air supply ($P \leq 35$ psia). During conditions of inadequate ram air flow (i.e., ground operation) the bleed air ejector was used to induce the air flow through the ram circuit. Ejector control was provided by valve V2. See Figure 1. Regulator R1 was required to control the bleed air supply pressure at sensor location S6 to a nominal 62 psig. The bleed air was cooled by the ram air sink in heat exchanger HX4 before being routed to the compressor. Discharge air from HX4

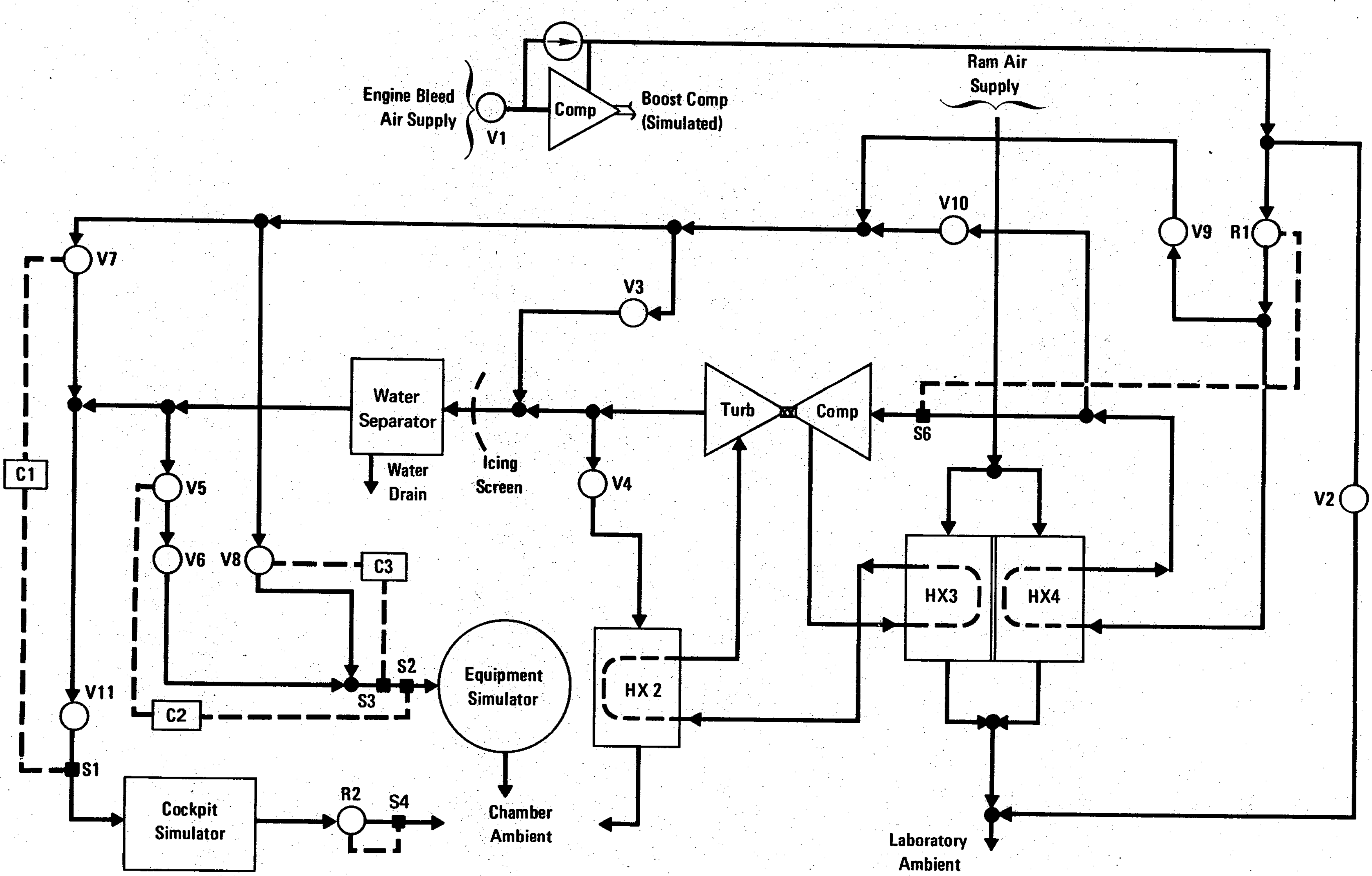


Figure 1 Laboratory Demonstration Test Article ECS

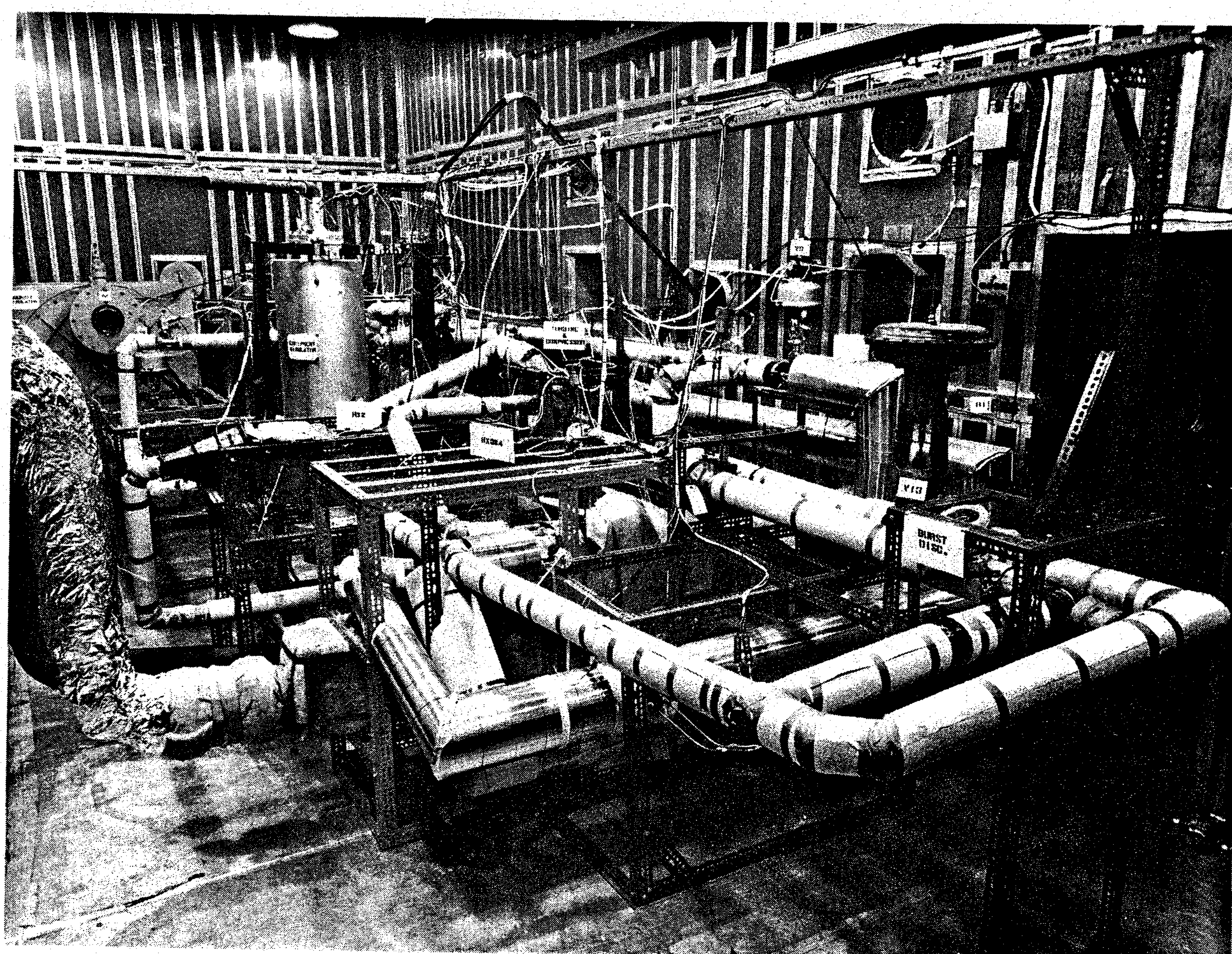


Figure 2 Laboratory Setup of Test Article ECS

TABLE I LABORATORY DEMONSTRATION TEST ITEMS

Item	Symbol	Description
Valve	V1	Facility High Pressure Air Supply Control
Valve	V2	Ejector Shut-off Valve - Remote Control
Valve	V3	Water Separator Anti-ice Valve
Valve	V4	Regenerator Flow Control - Remote Operating Valve
Valve	V5	Cooling Effects Control Valve - Remote Control (C2)
Valve	V6	Cooling Air Flow Control - Remote Operating Valve
Valve	V7	Cockpit Temperature Control Valve - Remote Control (C1)
Valve	V8	Equipment Temperature Control Valve - Remote Control (C3)
Valve	V9	Hot Air Source Temperature Control Valve - Remote Operated
Valve	V10	Cold Air Mix Control Valve - Remote Operated
Valve	V11	Cockpit Air Flow Control - Remote Operated
Regulator	R1	System Pressure Regulator and Shut-off Valve
Regulator	R2	Cockpit Simulator Pressure Control Valve
Sensor	S1	Cockpit Simulator Inlet Temperature Sensor
Sensor	S2	Cooling Effects System Sensor
Sensor	S3	Equipment Simulator Inlet Temperature Sensor
Sensor	S4	Ambient Pressure Tap
Sensor	S6	Pressure Tap for Regulator, R1
Controller	C1	Cockpit Temperature Controller
Controller	C2	Cooling Effects System Controller
Controller	C3	Cockpit Temperature Controller
Simulator	–	Cockpit Simulator, Approx. 35 ft^3, Cylindrical Tank with Heating and Cooling Capability
Simulator	–	Equipment Simulator In-line Heater
Ducting	–	All Interconnecting Ducting Required to Assemble the System
Water Separator	–	Water Separator with Dew Point Anti-ice Control
Anti-ice Screen	–	24 Mesh Screen
Cooling Turbine	Comp/ Turb	Bootstrap Cycle Turbine Driven Compressor
Heat Ex-changer	HX2	Regenerator - Ducting Arrangement, Turbine Discharge Routed Through the Two Pass Side, Hot Air Routed Through the Single Pass Side
Heat Ex-changer	HX3& HX4	Primary and Secondary Heat Exchanger Packaged in Parallel to the Ram Air Stream
Ejector	–	Part of the HX3 and HX4 Assembly
Ejector Discharge Housing	–	Ram Air Exit Housing

also was used for mixing with hot bleed air, and was controlled remotely by valves V9 and V10 to a maximum mixed temperature of 400°F. This air was used for temperature control at the thermal simulators. The maximum hot air temperature of 400°F was included as a safety design precaution. Recent Air Force contract specifications call for maintaining bleed air temperatures in the vicinity of fuel tanks below the auto-ignition temperature of the fuel. This requirement also is reflected in the Federal Aviation Agency FAR 25 (Reference 3).

Energy added to the bleed air by the compressor allows an effective exchange of heat with the ram sink heat exchanger HX3. A regenerative heat exchanger (HX2) was used to increase the cooling capacity of the ECS. A portion of the turbine exit flow was used as the heat sink. Manual control of the sink flow rate was provided by remote control valve V4. The energy extracted from the air as it flowed through the turbine supplied the power to the compressor. Since the same air flow, less bearing cooling losses, was routed through the turbine and compressor no work could be done by the turbine-compressor unit. Thus, the change in internal energy (temperature drop) from the compressor inlet to the turbine exit must equal the energy lost to the ram and regenerative heat sinks. For constant heat sink and regulated bleed air supply states, the exit state of the turbine determined the cooling capacity of the ECS.

The water separator provides moisture control of the air supplied to the cockpit and equipment simulators during high humidity conditions. The water separator had a pneumatic icing screen control with the icing screen upstream of the water separator. Hot air was supplied via modulation of valve V3.

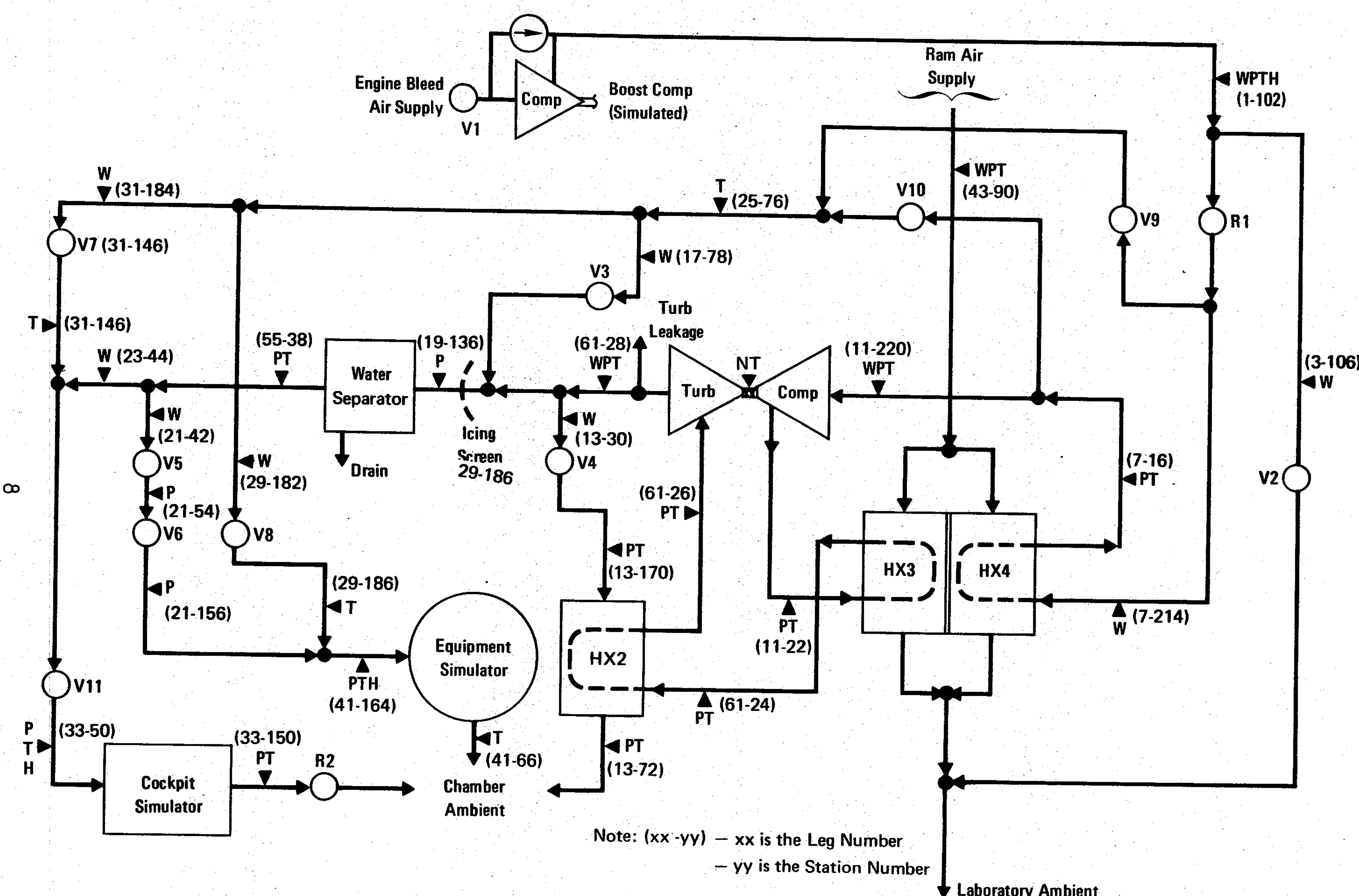
Maintaining an approximate heat sink potential to the equipment simulator was the function of the cooling effects system. Valve V5 regulated the flow based on the demands of sensor S2 and controller C2. Sensor S2 contained a heated resistance winding. As air flowed over the winding and changed its temperature, its resistance varied. The change in sensor resistance monitored by controller C2 caused a change in the setting of valve V5. The resulting change in flow drove the winding temperature back to its design value, a steady state condition. Thus the air flow cooled the specified equipment load while maintaining approximately the same discharge temperature from the load.

The air temperature at the equipment simulator inlet was monitored by sensor S3. Controller C3 modulated valve V8 to achieve the pre-set temperature level. Thus, the cooling effects system in conjunction with the temperature control system was to provide a constant flow. The equipment simulator contained a 90 KW in-line heater. Control valve V6 maintained a typical pressure drop through the equipment simulator circuit before the air was discharged to chamber ambient. Valve V6 was also used when the cooling effects system was inactivated to ensure adequate flow potential to the cockpit.

A portion of the total available conditioned air flow was routed to the cockpit simulator. Valve V11 was used to achieve the specified flow to the cockpit simulator. Temperature control of the cockpit cooling air was provided by mixing hot air with the cooling air. Valve V7 was automatically controlled to maintain the specified average cockpit temperature. A 35 cubic foot pressure vessel, supplied by the laboratory, contained the required heating and cooling units to simulate cockpit heat loads. Cockpit pressure was controlled by regulator R2. Pressure tap S4 provided ambient reference pressure to R2. A typical fighter aircraft cockpit pressure schedule was maintained.

2.2 Instrumentation Requirements

Measurement of the state properties of the air in various portions of the system permitted monitoring and calculation of component and system performance. The recorded parameters were temperatures, pressures, flow rates, humidity, and turbomachine speed and bearing temperature. All instrumentation was located five diameters from the last upstream obstruction to flow whenever possible. The various property measurements were continuously recorded at a rate of 10 or 100 readings per second. Equilibrium conditions for each steady state test were recorded at a rate of 1 reading per second. The type of measurements taken at the locations shown in Figure 3 are described in Table II.



Note: (xx-yy) — xx is the Leg Number
— yy is the Station Number

Figure 3 Test Article ECS Instrumentation

TABLE II
LABORATORY DEMONSTRATION TEST INSTRUMENTATION

Location	Description	PARAMETER: Speed rpm	Pressure psia	Tempera-ture °F	Flow lb/min	INSTRUMENTATION: Magnetic Collar	Static Ring	Trans-ducer	Thermo couple	Calibrated Duct	Orifice Meter	RANGE in Applicable Units	TOLERANCE in Applicable Units
1-102	System Inlet State		P 	 T 	 W			P 	 T 		 W	0→300 200→1000 0→80	±2 ±2 ±3
3-106	Ejector Primary				W						W	0→40	±3
7-214	HX4 Inlet				W						W	0→40	±4
7-16	HX4 Exit		P 	 T				P 	 T			0→100 100→550	±1 ±2
11-220	Compressor Inlet		P 	 T 	 W			P 	 T 		 W	0→100 100→550 0→40	±1 ±2 ±.6
11-22	Compressor Exit		P 	 T			P 		 T			0→150 200→1000	±1.3 ±2
13-30	Regenerator Flow				W					W		0→10	±.8
13-170	Regenerator Inlet		P 	 T				P 	 T			0→20 -160→120	±.5 ±2
13-72	Regenerator Exit		P 	 T				P 	 T			0→20 -50→400	±.5 ±2
17-78	Anti-Ice Control				W						W	0→15	±.3
19-136	Water Separator Inlet		P					P				0→25	±.5
21-42	Equipment Cold Air Flow				W					W		0→30	±.8
21-54	Cooling Effects Valve Exit			P				P				0→20	±.5
21-156	Valve, V6, Exit			P				P				0→20	±.5
23-44	Cockpit Cold Air Flow				W					W		0→30	±.8

TABLE II
LABORATORY DEMONSTRATION TEST INSTRUMENTATION (Cont.)

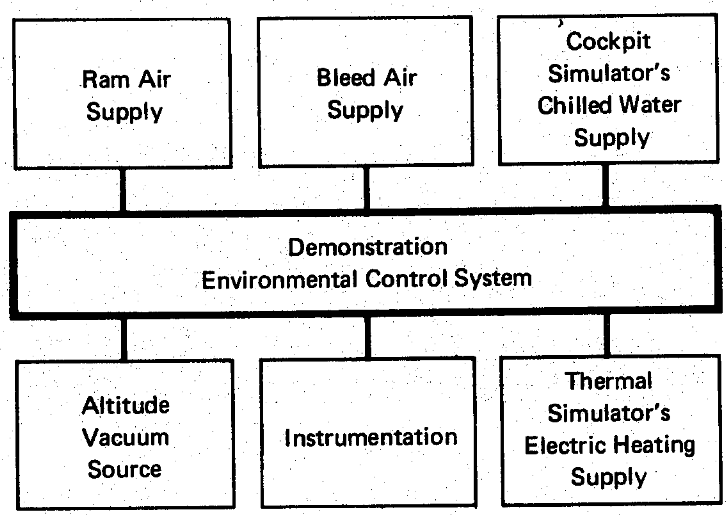
Location	Description	Parameter: Speed rpm	Parameter: Pressure psia	Parameter: Temperature °F	Parameter: Flow lb/min	Instrumentation: Magnetic Collar	Instrumentation: Static Ring	Instrumentation: Transducer	Instrumentation: Thermocouple	Instrumentation: Calibrated Duct	Instrumentation: Orifice Meter	Range in Applicable Units	Tolerance in Applicable Units
25-76	Hot Air Source			T					T			0→600	±2
29-182	Equipment Hot Air				W					W		0→10	±1
29-186				T					T			0→600	±2
31-146	Cockpit Hot Air			T					T			0→600	±2
31-184					W						W	0→10	±1.3
33-50	Cockpit Inlet		P					P				0→20	±.5
				T					T			-160→120	±2
33-150	Cockpit Exit - Regulator, R2, Inlet		P					P				0→20	±.5
				T					T			0→200	±2
41-164	Equipment Inlet		P					P				0→20	±.5
				T					T			0→120	±2
41-66	Equipment Exit			T					T			50→250	±2
43-90	Ram Air Inlet State		P					P				15→35	±.3
				T					T			0→400	±2
					W						W	0→450	±15
51-300	HX4 Ram Exit*		P					P				12→17	±.5
47-98	Ejector Exit*		P					P				12→20	±.36
				T					T			0→550	±2
55-38	Water Separator Exit		P					P				0→25	±.5
				T					T			-160→120	±2
61-24	HX2 Inlet		P					P				0→150	±2
				T					T			0→500	±2
61-26	HX2 Exit		P					P				0→150	±2
				T					T			0→500	±2
61-28	Turbine Exit	N				N						0→70,000	±120
			P					P				0→25	±.5
				T					T			-160→120	±2
					W					W		0→40	±2.5

*Not shown on Figure 3.

SECTION 3

SUPPORTING LABORATORY TEST FACILITY

The MCAIR laboratory facilities were used to provide a suitable environment for the ECS demonstration test. The basic facilities described in this section are located in Building 103 at MCAIR, St. Louis. The 14 foot Tenney altitude chamber was used in this test. The data sensing and recording devices and techniques are described. The MCAIR laboratory facilities interface with the demonstration ECS as indicated in the block diagram below.



3.1 Facility Inputs and Environments of Test Article

The facility schematic showing how simulated bleed and ram air were supplied to the test article enclosed in an altitude chamber is illustrated in Figure 4. A large multiple stage compressor provided as the common supply for ram and bleed air. The compressor discharge air was cooled in the after-cooler to ambient temperature and dried to a -20°F (or lower) dew point as it circulated through the desiccant type drier. From this point air was routed through the vortex cooler when lower ram air temperatures, down to at a minimum of -60°F, were desired. The common supply of hotter ram air and bleed air could be heated to any desired temperature from 100°F to 500°F via use of the air to air inter-cooler (heat sink is inter-stage air of compressor) and the gas fired air heater, operating individually or simultaneously. After passing through the first regulator (R) the air flow

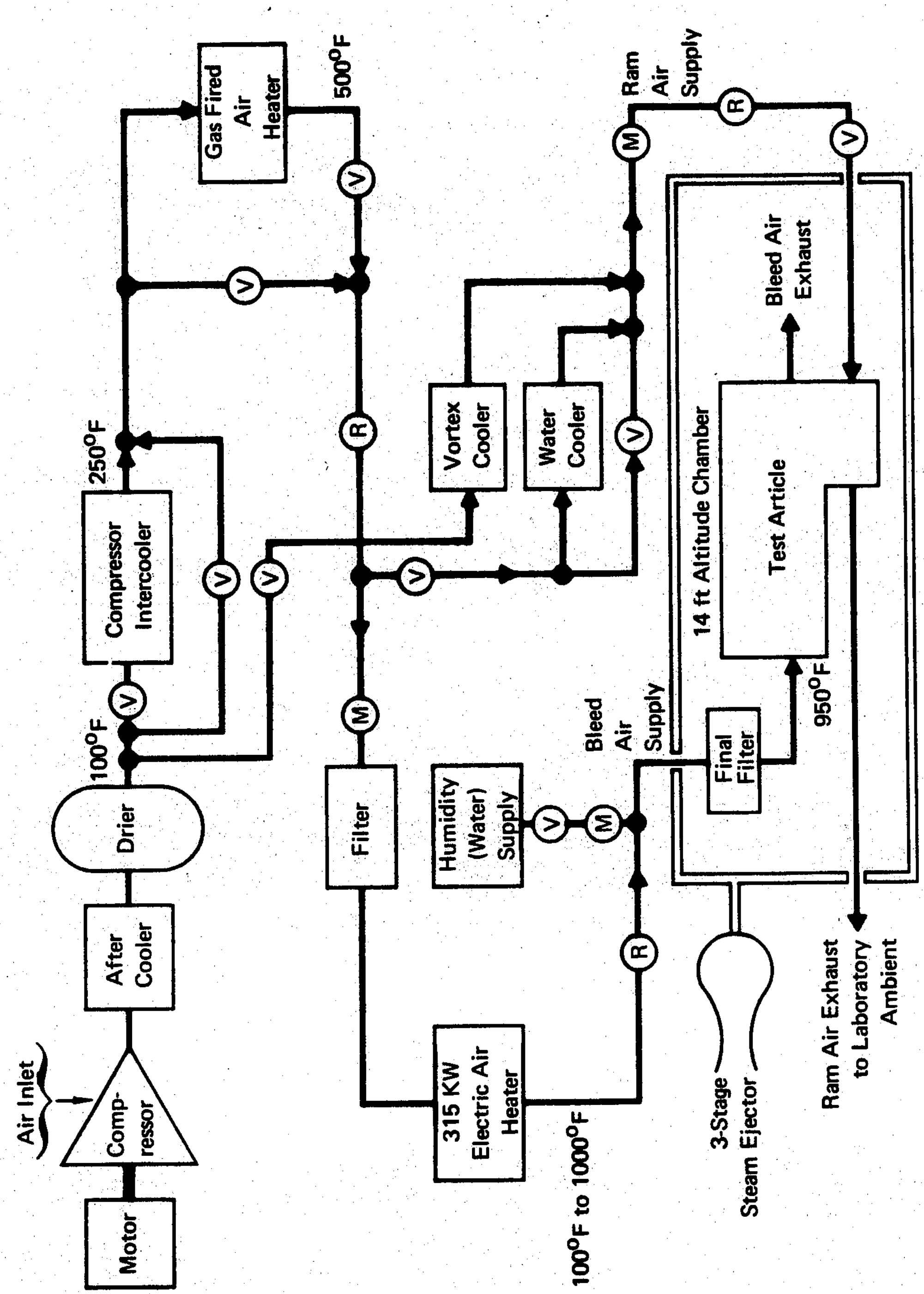


Figure 4 Facility Air Supply

was split. Hotter ram air was routed down to another split where part of it passed through the water cooler and was mixed with the bypassed portion to obtain the proper temperature. Ram air flow from either the vortex cooler or the hotter ram air supply was measured, and controlled by regulating the pressure before it passed through the chamber wall to the test article. The exit ram air from the test article was routed through the chamber wall and discharged to laboratory ambient.

The bleed air flow rate was measured. The air was filtered then heated to the desired temperature by the 315 KW electric air heater. The pressure was regulated to any pressure less than 300 psia, atomized water was added to provide the required humidity, and the conditioned air was filtered again after passing through the chamber wall before entering the test article. Maximum dry air temperature at the test article was maintained at approximately 950°F. As atomized water was added to maintain the desired humidity level, the maximum obtainable temperature was reduced due to the heat required to vaporize the water. The minimum temperature at which bleed air could be supplied was approximately 100°F.

A 3-stage steam ejector provided the pressure altitude within the chamber required for the ECS bleed air circuitry. Cooling air from the regenerator, equipment simulator, and cockpit simulator were discharged to the chamber as indicated in Figure 1. Uncontrolled leakages from the total ECS also escaped to the chamber. The cockpit thermal simulator was equipped with resistance type electric heaters and chilled water cooling coils. The cooling coils were supplied with chilled water at temperatures that were controlled down to 40°F, to simulate cold cockpit conditions (i.e., ECS heating). The thermal load of the equipment simulator was provided by an electric air heater.

3.2 Instrumentation

Instrumentation required in the ECS and the above test facilities included pressure gages, manometers, and pressure transducers for pressure and flow measurements. Temperatures were measured using thermocouples and the humidity entering the test setup was determined by measuring injected water and air flow rate. Condensate from the water separator drain was collected in a container. A strain gage mounted on the mechanism supporting the container measured the weight of the condensate. Humidity entering each simulator was indicated by wet and dry bulb temperature measurements. The et bulb temperature was measured by a thermocouple mounted in saturated wicking and located inside the duct.

Power supplied to the electric air heaters in the cockpit and equipment simulators was measured. The power was controlled by auto-transformers.

The test parameters tabulated in Table II and indicated schematically in Figure 2 were recorded with the MDC Central Data Acquisition System (CDAS). This system is a moderate speed, digital data system used for gathering and reducing instrumentation signals from tests conducted in the laboratory. The CDAS is composed of four major components: the Central Control Unit, the Test Site Control Unit, the Data Patchboard and Signal Conditioning Unit, and the real-time Data Displays. A block diagram of the system is shown in Figure 5.

The Signal Conditioning Unit is located in another building and was connected to the sensors on the test article through the instrumentation cable complex (Data Patchboard). The Signal Conditioning Unit contains a calibration power supply, a transducer excitation supplier, and multiplexers o time share the signals.

The Test Site Control Unit is located in the control room with the Signal Conditioning Unit and contains amplifiers, multiplexers, and a hard-line interface to the Central Control Unit.

The signals were received from the Central Control Unit and recorded on magnetic tape. The Central Control Unit controls the program mode, data scan rate, calibration controls, and provisions for pre-setting alarm limits on individual channels.

Two types of data display devices were used at the test control site for real-time information in engineering units: a 21 inch digital data cathode ray tube scope, and a digital printer.

The cathode ray tube scope can display any ten pre-selected parameters simultaneously along with an elapsed time display. Any of the ten channels can be changed for any other channel in the data system by means of a key-board control.

The digital printer provided printout, in engineering units, on a strip similar to adding machine paper. The printer is capable of printing all channels, up to twenty selected channels, or a single channel can be selected and monitored for any period of time. The printer operates on command or

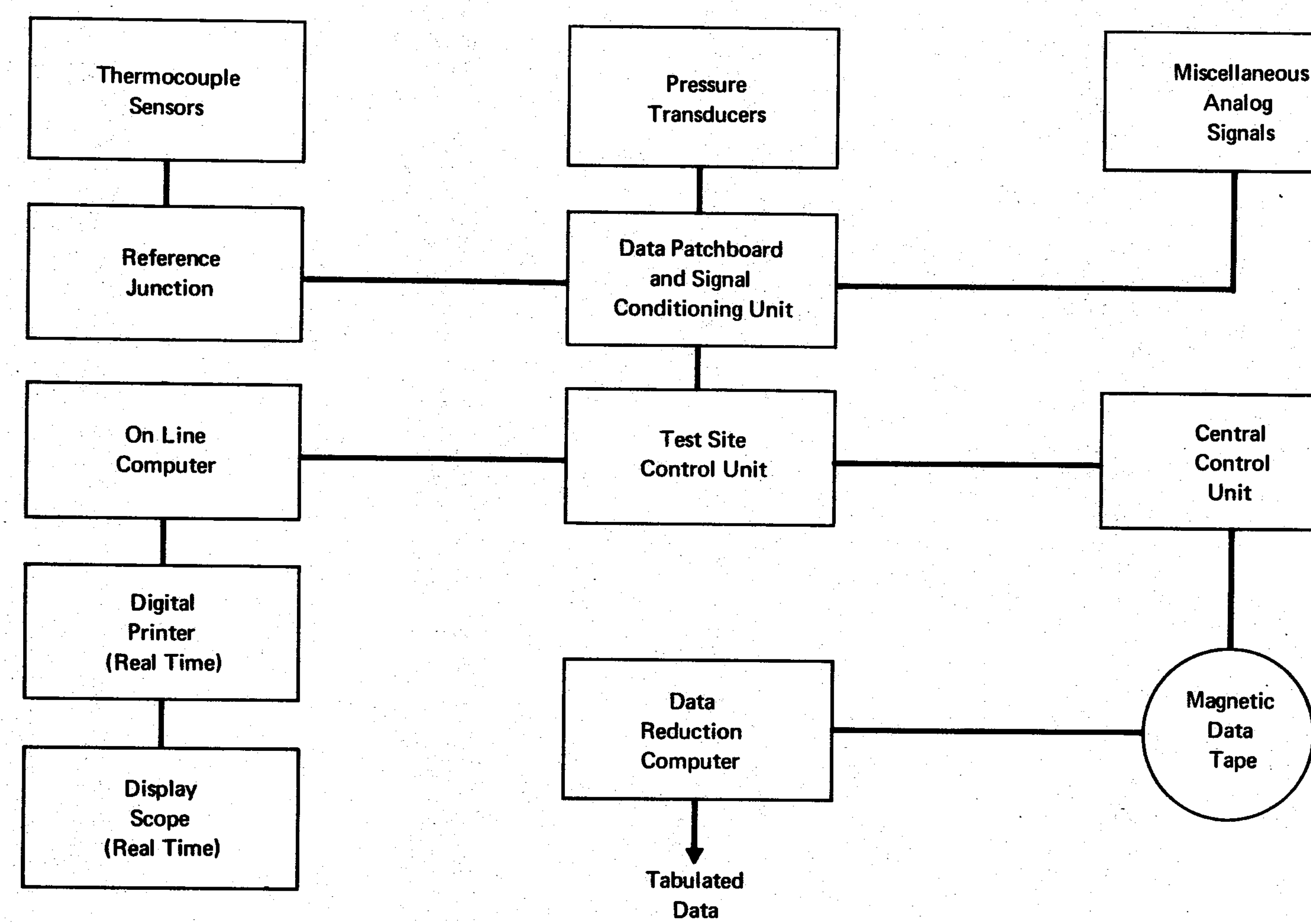


Figure 5 Central Data Acquisition System Block Diagram

can be programmed to print at any pre-selected time interval for any length of time.

Recorded data were processed into tabulated data. Equations for determining flow rates, heat loads, and turbine speed were solved in real-time by the data computer and displayed on the scope and the printer.

SECTION 4

TEST CONDITIONS AND COMPONENT CHARACTERISTICS

Various test conditions were selected to evaluate the Laboratory Demonstration ECS. From the assumed test conditions, various component characteristics were determined to properly define the test article and the supporting laboratory facility requirements. Required boundary conditions are included for each test run.

4.1 Selection and Identification of Test Conditions

The test conditions were selected to indicate the system operating conditions under which the three components (boost compressor, regenerator, and cooling effects system) could be utilized most effectively to improve cooling capacity, and flow and temperature control. Moisture control (by use of a water separator) also was demonstrated. The test conditions are shown on a typical speed-altitude operating envelope for a fighter aircraft to illustrate the practicality of their selection. (See Figure 6.)

The boost compressor and regenerator were employed to determine their effect on the cooling capacity of the system. The boost compressor was used when the engine bleed air supply pressure was low. These conditions occur at low engine speeds. The more common occurrences are indicated at the following points on the operating envelope in Figure 6; engine idle, sea level static (point 1); high altitude, low speed loiter (point 2); and engine idle descent from altitude (point 2 to point 1 through point 4). The regenerator is most effectively employed at high altitude, high speed conditions (point 3) where the ram air sink temperatures and the aerodynamic heat loads are maximum. Moisture control is demonstrated at low altitude: sea level static conditions (point 1), and at low and high speed flight conditions (points 4 and 5). System capacity, and flow and temperature control are of interest for all test conditions.

The cooling effects system was utilized to maintain a constant flow rate to the equipment simulator during the above test conditions. The five steady state test conditions and the mission profile test conditions are defined in more detail in Table III. The use of the boost compressor, the regenerator, and the cooling effects system are indicated in the last three columns of the table. The "On" mode means the component or system is active while "Off" means inactive. The cooling effects system valve was held full open in the "Off" mode.

TABLE III LABORATORY DEMONSTRATION TEST CONDITIONS

Operating Condition △1 (Ref: Fig. 6 & 7)	Test Run	Ambient Conditions			Boost Compressor	Regenerator	Cooling Effects System
		Altitude 1000 Ft	Temp. (Day) △2	Humidity Grains			
1 Ground Idle Static	1a	SL	(Hot Desert)	–	On	Off	On
	1b	SL	(Hot Desert)	–	On	Off	Off
	1c	SL	(Hot Desert)	–	Off	Off	On
	1d	SL	(Tropical)	154	On	Off	On
	1e	SL	(Tropical)	154	Off	Off	On
	1f △3	SL	(Tropical)	154	Off	Off	On
	1g △3	SL	(Tropical)	154	On	Off	On
	1h △3	SL	(Tropical)	154	On	Off	Off
2 High Altitude Loiter	2a	35	(Tropical)	–	On	Off	On
	2b	35	(Tropical)	–	On	Off	Off
	2c	35	(Tropical)	–	Off	Off	On
3 High Altitude High Velocity	3a	45	(ICAO Std)	–	Off	On	Off
	3b	45	(ICAO Std)	–	Off	Off	Off
	3a-1 △3	45	(ICAO Std)	–	Off	On	Off
4 Low Altitude Loiter	4a	7	(Hot)	182	On	Off	On
	4b	7	(Hot)	182	Off	Off	On
	4c	7	(Cold)	–	Off	Off	On
	4d	7	(Cold)	–	Off	Off	Off
5 Sea Level High Velocity	5a	SL	(Hot)	154	Off	Off	On
	5b	SL	(Hot)	154	Off	Off	Off
6 Idle Descent Transient	6a	Initial to Final Condition: 2a to 1d					
	6b	Initial to Final Condition: 2c to 1e					

△1 Steady state tests except as noted

△2 Reference 4 Except for Operating Condition 3.

△3 Discussed in Sections 5 and 6

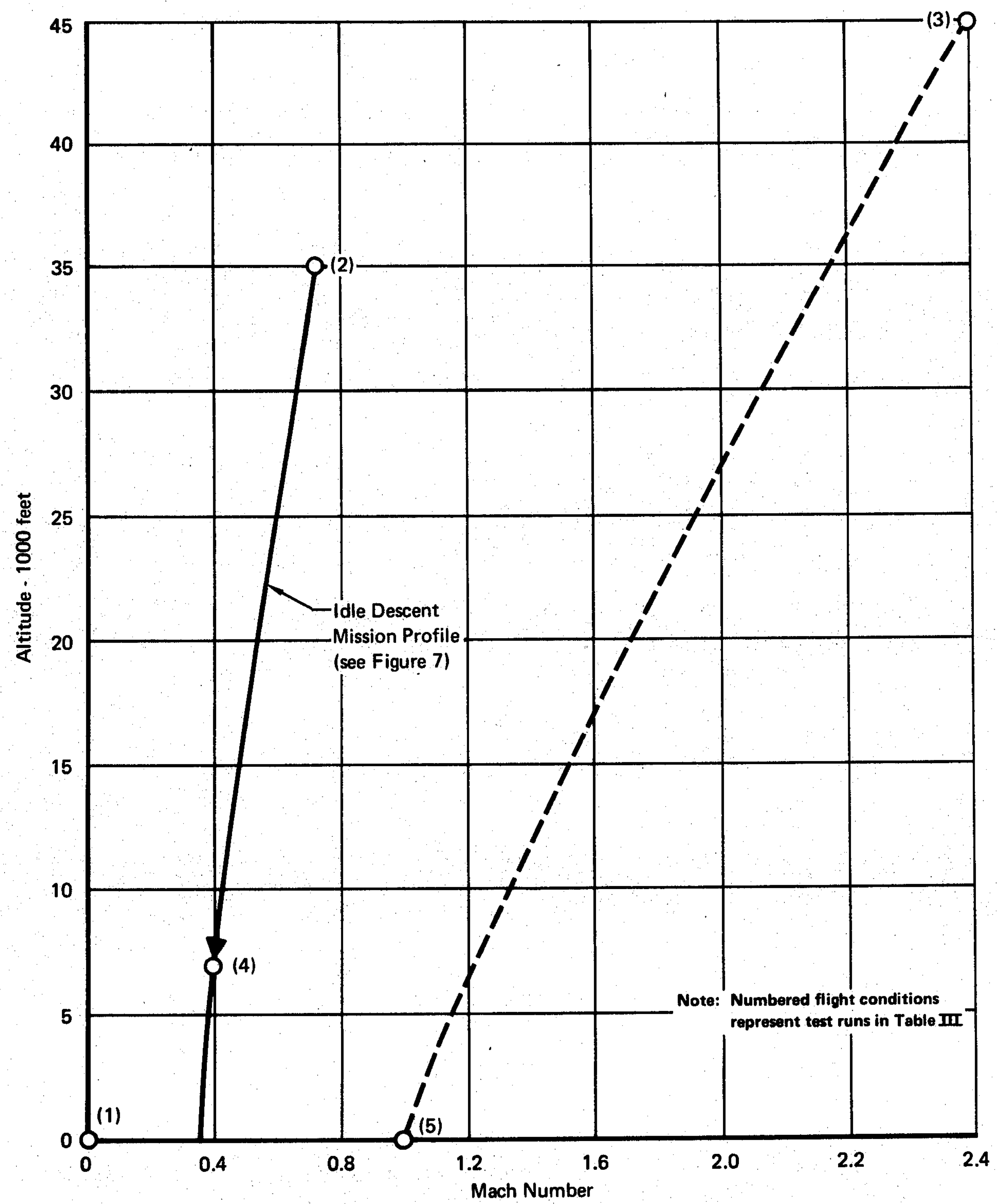


Figure 6 Typical Fighter Aircraft Operating Envelope

ring this OFF condition valve V6 was used to simulate a nominal pressure altitude schedule of 1 to 2 psi above the cabin schedule.

Mach number versus altitude for the mission profile test is shown in Figure 6. Altitude and Mach number versus time for this test condition are indicated in Figure 7.

4.2 Component Characteristics

Criteria and assumptions were necessary to determine the required control and performance characteristics of various components in the test article ECS. These characteristics were necessary for design, calibration, and operation of some test article and laboratory support equipment. The primary component characteristics were design equipment flow rate (controlled by the cooling effects system), simulator loads, control temperatures, control of valves in the distribution circuits, simulated boost compressor performance and control, and regenerator control.

4.2.1 Equipment Design Flow Rate and Simulated Loads - The criteria used to determine the equipment design flow rate, and the equipment and cockpit simulated loads are as follows. The equipment air flow rate is to be maintained at a constant value simultaneously with a constant inlet air temperature of 70°F. The maximum equipment outlet air temperature is to be 140°F. Cockpit inlet air temperature is to be maintained as a function of cockpit load and flow rate to provide the proper cockpit average temperature. Cockpit average temperatures utilized to provide adequate pilot comfort are to be based on requirements of Reference 4. The individual heat loads which make up the equipment and cockpit heat loads are assumed to be known. Details of these heat loads are discussed in the next section. At this point in the discussion it is sufficient to know that aerodynamic heating causes the largest variation in both the cockpit and equipment heat loads, and that the equipment to cockpit heat load ratio for the hottest environment is two.

Operating Conditions 3 and 5 (in Table III) were selected for determining the design flow rate to the equipment. The environments for these conditions are more severe and the heat loads higher than other conditions. Therefore, it was assumed that these two operating conditions are critical for an ECS which is to provide the required equipment flow rate while also cooling the cockpit. In the other operating conditions the boost compressor is to be used when the ECS capacity is low due to low pressure engine bleed air. The equip-

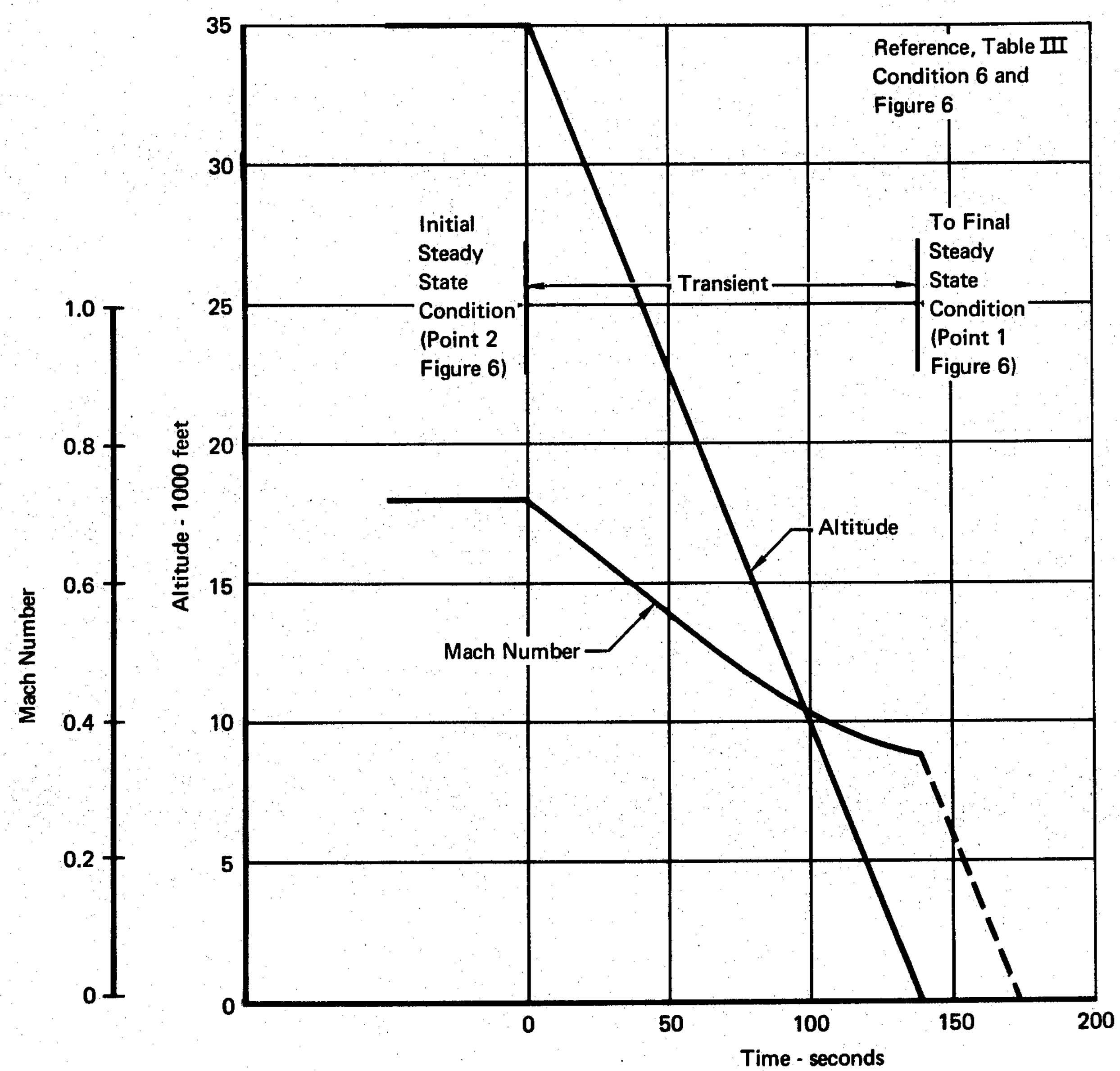


Figure 7 Idle Descent Mission Profile

ment design flow rate was selected as the lower equipment flow rate determined by computer program analyses of Operating Conditions 3 and 5. (The CES was in the "Off" mode so as not to restrict the flow, and in Condition 3 the regenerator was used to increase capacity.) The design flow rate was found to be 14 lb/min for Operating Condition 3a. The CES was calibrated to control to this flow rate at an inlet temperature of 70°F.

In summary the following parameters were obtained for Operating Condition 3: an equipment design flow rate of 14 lb/min at an inlet temperature of 70°F, a maximum equipment exit air temperature of 140°F (the maximum loads occur in Condition 3, therefore the maximum exit temperature of 140°F is applicable), and an equipment to cockpit heat load ratio of two. Based on these parameters, cockpit and equipment loads were determined for Operating Condition 3, and then for all other conditions using the Condition 3 loads as reference values.

4.2.1.1 Simulated Loads - The equipment thermal simulator heat load represents the design electrical equipment heat load plus an aerodynamic heat load. A typical aerodynamic heat load of 10 percent of the total load was used for Operating Condition 3, Table III. Assuming a constant overall heat transfer coefficient between the external air (i.e., adiabatic wall temperature) and the average equipment compartment air temperature of 105°F, the aerodynamic heat loads were calculated by the computer program for all operating conditions. In some of the low speed cases this heat flux was negative (i.e., heat loss from the simulated equipment compartment). The electrical portion of the equipment heat load was held constant for all test conditions.

The cockpit load represents the sum of metabolic, cockpit electrical equipment, solar, and aerodynamic heat loads. The relative values of these individual portions are typical of a one man cockpit. The reference values for each of the individual portions were obtained from the total cockpit heat load determined for Operating Condition 3. The aerodynamic reference load was used to calculate the overall heat transfer coefficient. Heat loads applicable to the other operating conditions were determined by using the same overall heat transfer coefficient and corresponding temperature differences (adiabatic wall temperature minus required cockpit average temperature). The required cockpit average temperatures are discussed in the next section. The solar reference load was also reduced to values applicable to the operating conditions as a function of altitude. Metabolic and electrical loads were held constant for all conditions. Both the cockpit and equipment simulator loads are listed in Table IV as determined by the computer program.

Heat load simulation was achieved via the thermal simulators' heating and cooling controls in conjunction with calculated heat loads. The simulated heat loads within the simulators were calculated via the CDAS computer as a function of temperature drop through each simulator and corresponding flow rates. These heat load values were read from the display scope (Figure 5) and the simulator heat controls were regulated until the proper loads were displayed. This procedure did not require that the massive simulators be insulated and that considerable time be consumed in obtaining equilibrium from one test condition to the next. That is, part of the heat load was simulated by the heat sink capacity of the simulators and equilibrium conditions were simulated by regulating the heaters and coolers inside the simulators.

4.2.1.2 Cockpit Average Temperature - The cockpit loads are representative of comfortable cockpit conditions. Comfortable conditions were maintained by regulating the cockpit inlet air temperature and air flow. This provided average cockpit temperatures which were equal to, or more comfortable than, those specified in Reference 4. The maximum specified average cockpit temperature for the ground idle static Hot Desert Day (Table III, Condition 1) is 100°F. To provide more comfort 90°F was maintained in the test. By the same reasoning, approximately 80°F was selected for the test runs of Operating Conditions 3 and 5. The 80°F average cockpit temperature, for the high velocity Operating Conditions 3 and 5, was to provide a more comfortable temperature than the maximum specified for a typical flight duration of 10 minutes. For all other operating conditions, the average cockpit temperature goal was 70°F or 80°F for cooling or heating conditions, respectively (see Table IV).

4.2.2 Characteristics of Distribution Valves - The primary objective of the cooling effects system (CES) and equipment temperature control system valves was to maintain the design flow rate of 14 lb/min at the design inlet temperature of 70°F. The secondary objective of the CES was to maintain a constant heat sink capacity when the temperature was not controlled to 70°F (i.e., flow controlled to a higher or lower value when the temperature was greater than or less than 70°F, respectively). A constant heat sink capacity

TABLE IV REQUIRED BOUNDARY CONDITIONS

Operating Condition	Test Run	Equipment Load btu/min	Cockpit Load btu/min	Cockpit Ave Temp. °F	Bleed Air Supply		Ram Air Supply	
					Pressure (1) psia	Temp. °F	Temp. °F	Flow lb/min
1 Ground	(1a)	214	48	90	77 (2)	669	125	–
Idle	(1b)	214	48	90	77 (2)	669	125	–
Static	(1c)	214	48	90	71	492	125	–
	(1d)	210	45	80	77 (2)	600	90	–
(Ejector	(1e)	210	45	80	71	434	90	–
Operating)	(1f)	210	45	80	40	450	90	–
	(1g)	210	45	80	80 (2)	450	90	–
	(1h)	210	45	80	80 (2)	450	90	–
2 High Altitude	(2a)	200	25	70	65 (2)	791	1	65
Loiter	(2b)	200	25	70	65 (2)	791	1	65
	(2c)	200	25	70	67	597	1	65
3 High Altitude	(3a)	235	118	80	135	873	381	194
High Velocity	(3b)	235	118	80	135	873	381	194
	(3a-1)	229	100	80	135	873	297	192
4 Low Altitude	(4a)	213	56	70	73	648	94	106
Loiter	(4b)	213	56	70	70	475	94	106
	(4c)	197	-18	80	70	316	-1	111
	(4d)	197	-18	80	70	316	-1	111
5 Sea Level	(5a)	222	71	80	283	850	215	415
High Velocity	(5b)	222	71	80	283	850	215	415

(1) Required pressure at location (11–220) or (1-102) in Figure 3 with or without Boost Compressor respectively

(2) Boost Compressor On.

design would maintain a constant exit temperature regardless of the inlet temperature. This could not be obtained since the CES was not specifically design for the test article ECS (i.e., internal adjustment of CES would be required).

With the CES "Off" (V5 full open) valve V6 was manually controlled to simulate a control valve which would provide an automatic pressure-altitude schedule (1 to 2 psia above the cockpit pressure-altitude schedule at the cold air split as determined by computer analyses). Valves V7 and V11 were controlled to provide the proper cockpit average temperature, the same function as is described above.

Regardless of the CES control mode, a pressure at least equal to the pressure-altitude schedule (with the proper cockpit average temperature and a minimum cockpit flow rate of 4 lb/min) was given priority over the equipment flow rate. With the CES "Off", the pressure was equal to the pressure-altitude schedule. With the CES "On", the pressure was permitted to exceed the schedule.

4.2.3 Boost Compressor Design and Regenerator Control - Design characteristics for the simulated boost compressor and its associated controls were determined to maintain a selected ECS bleed air supply pressure of slightly more than 62 psig, which is the nominal design point of pressure regulator R1. This pressure was to be maintained for the operating condition (1, 2, 4, or 6 in Table III) which required the maximum pressure ratio. The maximum pressure ratio was determined by calculation to be approximately 1.5. A typical compressor adiabatic efficiency of 64% (Volume I) was used with the above pressure ratio. The Bleed Air Supply Temperature listed in Table IV includes the heat of compression of the boost compressor when applicable. Since the pressure ratio of 1.5 was derived to always maintain a pressure above the regulated pressure of 62 psig, the Bleed Air Supply Pressures in Table IV are listed as 62 psi above ambient pressure (applicable to location (11-220) in Figure 3) when the boost compressor is "On". The boost compressor controls were assumed to activate the boost compressor at any engine bleed air supply pressure below 55 psig when the CES valve was full open. (The Bleed Air Supply Pressures when the boost compressor was "Off" are discussed in the next section.)

The turbine discharge flow to the regenerative heat exchanger was controlled by manually controlled valve V4 to a fixed turbine discharge flow split.

4.3 Boundary Conditions

The required steady state boundary conditions consist of bleed and ram air supplies, altitude-pressure environment, equipment and cockpit loads, cockpit average temperatures, and equipment inlet temperature. These boundary condition parameters are tabulated in Tables III and IV. The simulated loads and average cockpit temperatures are discussed in Sections 4.2.1.1 and 4.2.1.2 respectively. Equipment inlet temperature was 70°F.

The engine bleed air pressure and temperature supplied to the ECS was based on a typical turbojet engine with a pressure ratio of 12 and a compressor efficiency of 83 percent, which results in a temperature ratio of 2.23 at a sea level, maximum power condition. When the boost compressor is "Off", the values in the Bleed Air Supply Pressure and Temperature columns of Table IV are applicable to location (1-102) in Figure 3. When the boost compressor is "On", the applicable location for the pressure is location (11-220). The applicable location of the temperature remains at (1-102) in either case. The engine bleed air supply pressures and temperatures were calculated by the computer program as part of each performance case.

The ram air temperatures are total temperatures defined by the type of day and altitude in Table III and the Mach number in Figure 6. The flow rates were calculated using the ram air circuit hardware characteristic data. Both ram air temperatures and flow rates were calculated via the computer program.

The end points for the transient tests (6a and 6b) are defined by certain steady state tests as indicated in Table III. The transient nature of test conditions 6a and 6b is partially defined in Section 4.1 in conjunction with Figures 6 and 7. Other required boundary conditions are transient engine bleed air supply temperature and pressure, and ram air temperature and flow rate. These data are presented in Figures 8 and 9. The ram air properties in Figure 8 are applicable to test conditions 6a and 6b. The bleed air properties of Figure 9 are applicable to 6b only (without boost compressor). With the boost compressor, the required bleed air pressure was to be controlled so that the ECS pressure regulator would control the pressure continuously throughout the transient test. Bleed temperature with the boost compressor "On" was to be increased by 175°F (i.e., add 175° to bleed air

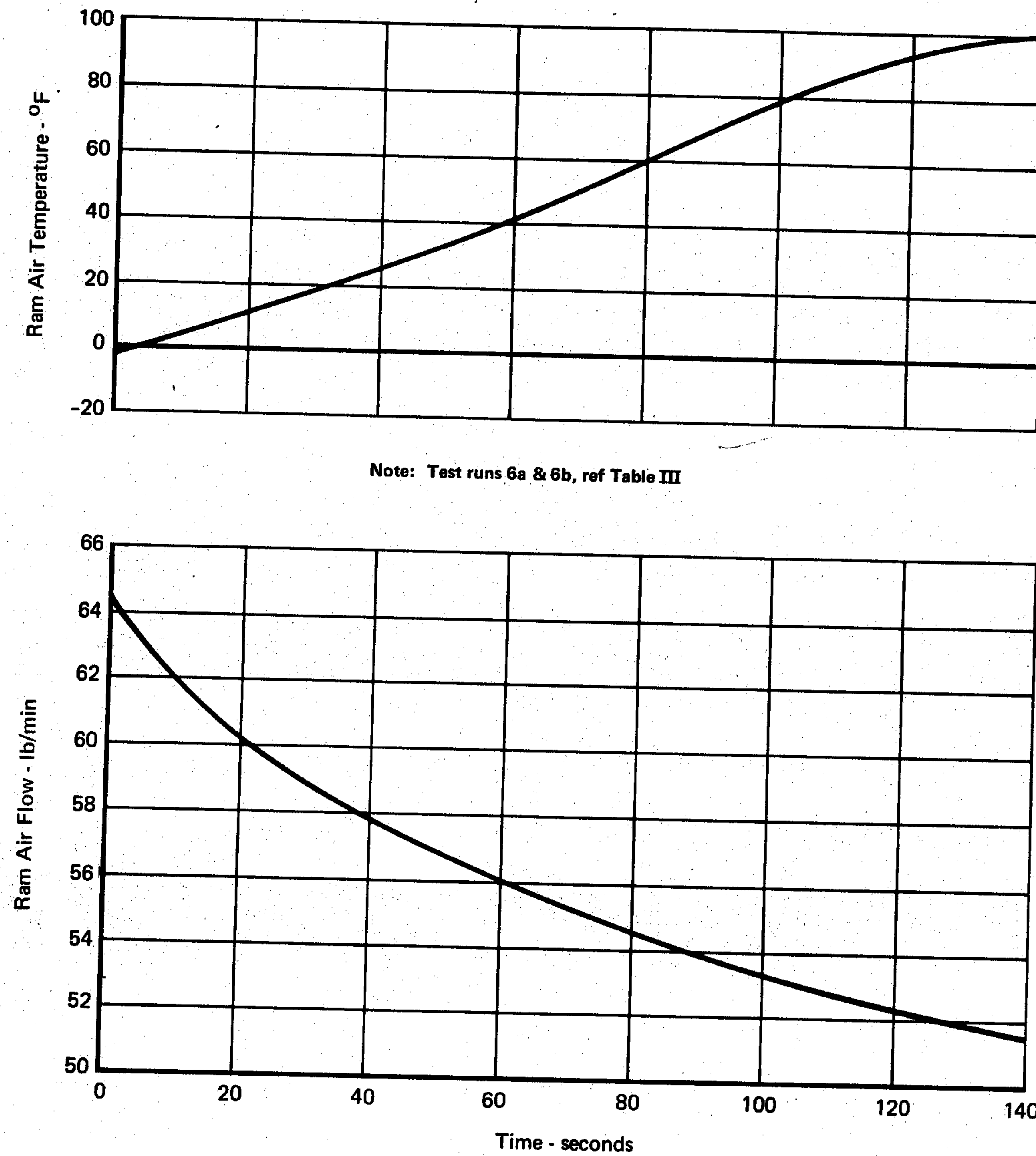


Figure 8 Required Ram Air Inlet Properties for Idle Descent Missions

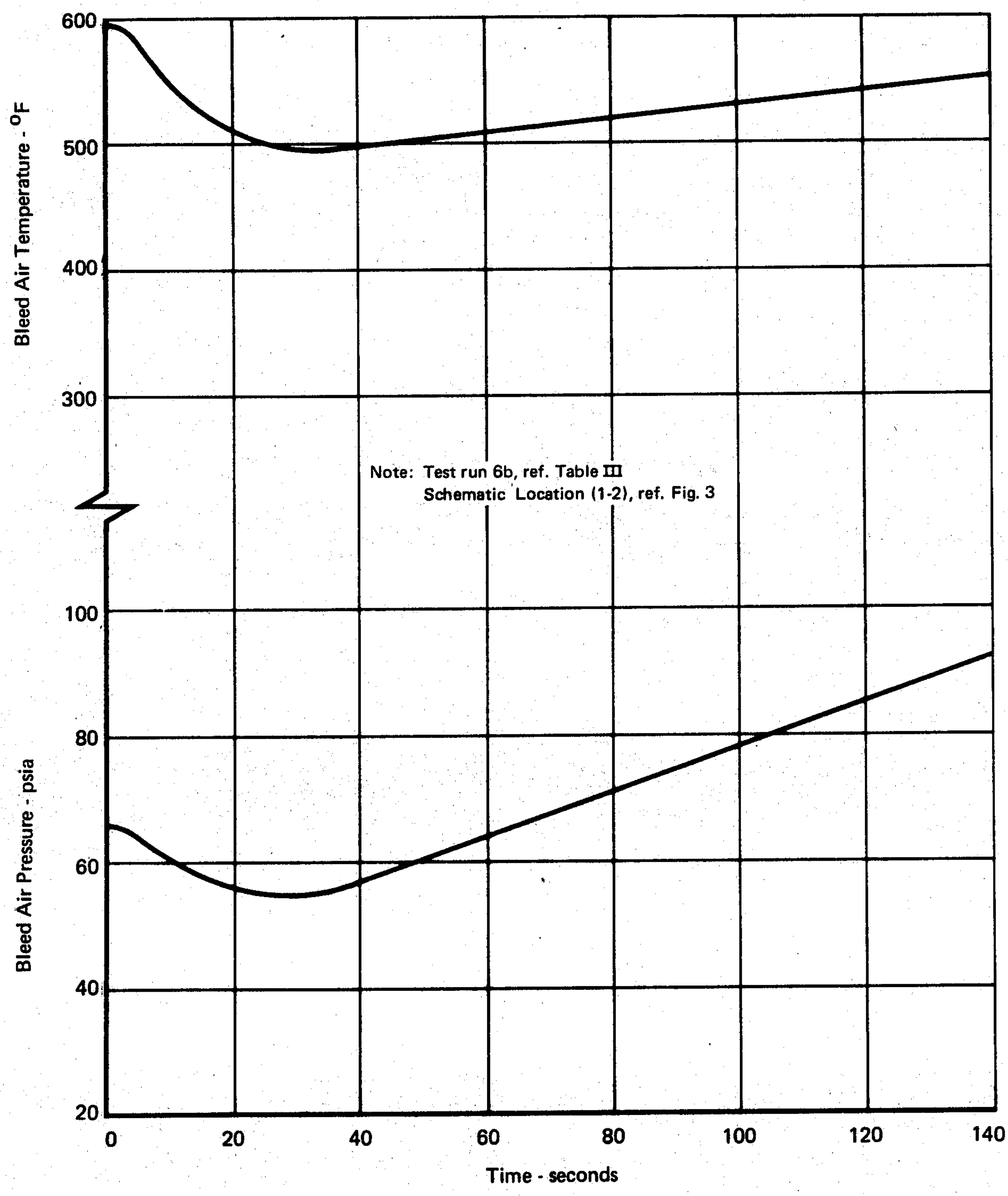


Figure 9 Required Bleed Air Inlet Properties for Idle Descent Mission

temperature curve of Figure 9) for the entire duration of the test. This is an adequate approximation of a pressure ratio of 1.5 and an efficiency of 64% for the boost compressor.

SECTION 5

TEST PROCEDURES

Two general test procedures are explained. One is for the steady state tests and the other is for the idle descent mission tests. Some specific details are included, where required, to clarify the test procedure.

5.1 General Procedure for Steady State Tests

A general test procedure is applicable to all of the steady state tests. This procedure includes the pertinent information typical of all of the detailed test procedures used for each steady state test identified in Tables III and IV without including the repetitious details. The procedural steps were:

(1) Pressure environment of the test article was established by evacuating the altitude chamber to the proper pressure.

(2) Ram air temperature and flow were established by routing the air through the appropriate circuitry depending on the required temperature (described in Section 2).

(3) The various control valves were set to the proper mode or position prior to turning the bleed air on. (See Figure 1.) This consisted of activating the automatic control valves: system pressure regulator R1; temperature control valves V7 and V8; the anti-ice valve V3; and the cooling effects system (CES) valve V5 as required. When the CES was not being used, valve V5 was full open. Initially, valves V7 and V8 were almost fully open to expedite heating of the hot air manifold to its operating temperature via remote manual control of valves V9 and V10. Other manually controlled valves were positioned: the regenerative heat exchanger valve V4 and ejector valve V2 were opened as required by the specific test being run, and valves V6 and V11 were opened to allow system flow when the bleed air was turned on.

(4) Bleed air temperature, pressure, and moisture content were established to the proper values as the air was supplied to the system. The proper moisture content in the bleed air supply was maintained by metering water into the bleed air as a function of the bleed air flow rate.

(5) Adjustments were made to obtain required air flow rates, temperatures, and pressures throughout the system. The hot trim air temperature was controlled to 400°F by regulating valves V9 and V10. Controller C3 was adjusted in the automatic mode to control the inlet equipment simulator temperature to 70°F. Controller C1 was adjusted in the automatic mode to control the cockpit simulator inlet temperature to a predetermined calculated value. Valves V6 and V11 were adjusted to obtain a predetermined calculated flow split and the required pressure-altitude schedule upstream of V6. When the CES was used, it was turned on and adjusted to control the design flow rate of 14 lb/min at an inlet temperature (sensor S2) of 70°F. When the regenerative heat exchanger was used valve, V4 was controlled to provide a fixed flow split of the turbine discharge air to the regenerative heat exchanger. Since the above adjustments had interrelated effects on the various flow rates, temperatures, and pressures, repeated adjustments were necessary. The final adjustment of the cockpit flow rate or inlet temperature was based on a test site calculation to satisfy the cockpit average temperature requirement as a function of inlet cockpit temperature, flow rate, and cockpit simulator heat load. Knowing the required load (Table IV) and one of the other two parameters, the third was calculated.

(6) After stabilization was achieved, data was recorded. Stabilization was determined by observing the rate of change of the two simulator inlet temperatures and flow rates, the cold air flow rates, and the temperatures upstream of the hot air mix points.

Further specific details are presented next to provide clarity to the steady state test program.

The high altitude, high velocity operating condition denoted as Test Run 3a could not be achieved without exceeding the bootstrap turbomachine bearing temperature limitation of 300°F. The required values of bleed air temperature and flow rate, and ram air flow rate to the system were achieved as listed in Table IV. However, as the ram air temperature was increased so did the turbomachine bearing temperature (to allowed maximums of approximately 310°F ram air temperature and 290°F bearing temperature). Thus the high bearing temperature prevented testing at the 3a condition even though the turbine outlet temperature never exceeded 20°F. Since the above test condition could not be achieved, the ram air properties were adjusted to simulate Mach 2.17 at 45,000 feet altitude. This condition (denoted as 3a-1 in Table III) was established with a corresponding bearing temperature of 290°F while utilizing the regenerative heat exchanger. Since the bearing temperature was still near its upper limit, a repeat of the test condition without the regenerator (3b-1) was not feasible. However, it was calculated and is discussed with the test results in Section 6.

The thermal simulators required up to half an hour more than the system components for stabilized conditions to be achieved during preliminary testing. The temperature changes across the simulators was not significant during this additional time period, hence the test system was considered stabilized when the system components reached steady state conditions.

The system pressure regulator R1 controlled the inlet pressure into the bootstrap compressor at about 5 to 6 psi below the nominal specification value. For this reason the effect of the boost compressor was less beneficial to system performance than anticipated. Two changes could have been made to show an application where the boost compressor would have been more effective. One was to replace the pressure regulator R1 with another type of regulator which would control to a higher system pressure. The second change was to reduce the engine bleed air supply pressure.

The first change was not made because no other pressure regulator was readily available. Therefore, the second change was made. More tests were performed using F-4, J-79 engine data. This engine application provides lower pressure bleed air to the ECS than the typical data initially utilized. Thus a large improvement in ECS performance was demonstrated through comparative use of a boost compressor in additional test runs (1f, 1g, and 1h in Tables III and IV).

5.2 General Procedure for Idle Descent Tests

Two idle descent mission profile tests (indicated in Table III) were run. The required ram air and bleed air supplies are defined in Section 4, and in Figures 8 and 9. Note that the required bleed air temperature varies 100°F during the 140 second descent mission. Because of the large heat sink capacity of the high pressure bleed air supply circuitry, it was not feasible to simulate rapid changes in bleed air temperature. Therefore, the bleed air temperature was held at a constant mean temperature, and the other bleed air and ram air properties were varied during the two simulated missions. The bleed air temperature for test run 6a (with boost compressor, BC) was 705°F and for test run 6b (without BC) it was 530°F. No moisture was added to the bleed air.

The bleed air supply pressure in Test Run 6a (with BC) was held high enough so that the system pressure regulator R1 could regulate the pressure at all times. In Test Run 6b (without BC) the bleed air supply pressure was controlled reasonably close to the required pressure profile in Figure 9. The required ram air supply temperature and flow rate profiles were approximated by a step change 50 seconds after the start of the simulated mission. The required ram air supply properties were the same for both test runs (per Figure 8).

The chamber pressure-altitude environment was changed in accordance with the required rate of descent.

All manual remote control valves were set for the initial condition and were not changed during the descent mission. The CES, the equipment and cockpit hot trim air valves, the system pressure regulator R1, and the cabin dump valve R2 functioned in the automatic mode.

SECTION 6

EVALUATION OF TEST RESULTS

The steady state and transient test results are presented. The adequacy of the test article ECS in satisfying the system performance requirements and the contribution of the additional components (i.e., boost compressor, regenerative heat exchanger, and cooling effects system) are discussed in Section 6.1. A description of the computer models which were set up to represent the test article ECS is presented in Section 6.2. Use of these models in the computer program (the computer program is described in Volume II) illustrates the validity of the computer models and the computer program. Calculated ECS performance using the computer program is compared with the steady state test results in Section 6.3. Boundary parameters used in the computer program results presented in Section 6.3 are from the test results presented in Section 6.1. The computer program results confirm the results of the tests (discussed in Section 6.1), and provide expanded evaluation information about the test program.

6.1 Steady State System Performance

The steady state test results are presented to show the adequacy of the test article ECS in satisfying the system requirements (i.e., flows, temperatures, capacity, moisture removal, and pressure-altitude schedules). This is done by presenting the system performance considering that all components (including the boost compressor, regenerator, and cooling effects system) comprise an integral system. The contribution of each of the above three components also is presented.

System performance at the equipment simulator and at the cockpit simulator for all the steady state test conditions of Table III is tabulated in Tables V and VI. The most effective configuration which most nearly satisfies all system requirements includes all three of the additional components: boost compressor, regenerative heat exchanger, and CES. The test runs which simulate a system which includes these three components as an integral system are denoted in Table V by boldface type. Various parameters are considered in comparing these test runs with all of the other runs which do not include all three of the additional components as a system configuration. The configuration which contains these components is referred to as the Integral System, and the other configurations which do not include all three of the additional components are referred to as the Other Systems.

TABLE V SYSTEM PERFORMANCE AT EQUIPMENT SIMULATOR

Operating Condition	Test Run No. [1]	Boost Compressor	CES	Equipment Simulator Parameters					
				Inlet Temp - ^{o}F (Test)	Flow Lb/Min (Test)	Capacity Btu/Min (Test)	Capacity Btu/Min (Req'd)	Under-Cooling %	Over-Cooling %
Ground Idle, Static	**1a**	**On**	**On**	**69.2**	**11.2**	**191**	**214**	**11**	**–**
	1b	On	Off	72.2	18.0	293	214	–	37
	1c	Off	On	68.8	10.9	183	214	14	–
	1d	**On**	**On**	**71.2**	**14.5**	**240**	**210**	**–**	**14**
	1e	Off	On	70.4	14.5	242	210	–	15
	1f	Off	On	67.4	6.9	120	210	43	–
	1g	**On**	**On**	**77.0**	**13.9**	**244**	**210**	**–**	**16**
	1h	On	Off	66.2	16.3	288	210	–	37
High Altitude, Loiter	**2a**	**On**	**On**	**73.2**	**14.1**	**226**	**200**	**–**	**13**
	2b	On	Off	73.1	20.8	334	200	–	67
	2c	Off	On	72.4	16.1	262	200	–	31
High Altitude, High Speed	**3a-1 [2]**	**Off**	**Off**	**73.4**	**14.0**	**225**	**229**	**2**	**–**
	3b-1 [3]	Off	Off	73.4	18.71	–	229	–	–
Low Altitude, Loiter	**4a**	**On**	**On**	**67.2**	**11.3**	**198**	**213**	**7**	**–**
	4b	Off	On	68.4	12.6	216	213	–	2
	4c	**Off**	**On**	**88.0**	**17.7**	**220**	**197**	**–**	**12**
	4d	Off	Off	69.2	29.8	506	197	–	156
Sea Level, High Speed	**5a**	**Off**	**On**	**84.6**	**15.9**	**211**	**222**	**5**	**–**
	5b	Off	Off	75.1	21.0	328	222	–	47

[1] Most effective system configuration consisting of all components is denoted by enlarged bold type

[2] With regenerator on

[3] With regenerator off (calculated data)

TABLE VI SYSTEM PERFORMANCE AT COCKPIT SIMULATOR

Operating Condition	Test Run No.	Boost Compressor	CES	Cockpit Simulator Parameters: Inlet Temp - °F (Test)	Inlet Temp - °F (Req'd)	Achieveable Ave. Temp (Test) 3	Ave. Temp °F (Req'd)
Ground Idle, Static	1a	On	On	76.3	80.6	Yes	90
	1b	On	Off	77.4	78.8	Yes	90
	1c	Off	On	75.3	80.5	Yes	90
	1d	On	On	74.0	72.6	Yes	80
	1e	Off	On	70.1	69.7	Yes	80
	1f	Off	On	75.4	62.0	Yes	80
	1g	On	On	78.2	73.7	Yes	80
	1h	On	Off	78.2	72.4	Yes	80
High Altitude, Loiter	2a	On	On	63.1	66.3	Yes	70
	2b	On	Off	65.6	65.5	Yes	70
	2c	Off	On	73.6	66.8	Yes	70
High Altitude, High Speed	3a-1 1	Off	Off	40.7	36.3	Yes	80
	3b-1 2	Off	Off	40.7	36.3	–	80
Low Altitude, Loiter	4a	On	On	62.1	62.9	Yes	70
	4b	Off	On	64.3	61.8	Yes	70
	4c	Off	On	88.1	81.6	No	80
	4d	Off	Off	77.9	82.7	Yes	80
Sea Level, High Speed	5a	Off	On	84.6	64.3	No	80
	5b	Off	Off	75.1	59.2	No	80

1 With regenerator on

2 With regenerator off (calculated data)

3 Yes indicates Ave. Temp (req'd) was achievable by better control of hot trim air, No indicates Ave. Temp (req'd) was not achievable because the hot trim air valve was closed.

in Reference 4, a USAF Specification. If the maximum values in Reference 4 for a typical 10 minute flight duration were used, the average required cockpit temperatures for 5a and 5b would be 96°F. The average cock-pit temperature was achieveable in 5b and it was 4°F above the requirement of 96°F in 5a.

Adequate moisture control was maintained in the applicable tests (i.e., the water laden tests 1d, 1e, 4a, 4b, 5a and 5b). Extra tests 1f, 1g and 1h also contained water but only the input quantity was measured. The temperatures measured at the simulator inlets indicate that no entrained moisture was present. The parameters measured in tests 1d, 1e, 4a, 4b, 5a and 5b were water and bleed air flow rates supplied to the ECS, weight measurements of condensate from the drain pipe of the water separator, and wet and dry bulb temperatures at the simulator inlets. The water removal efficiency was between 52 and 60% for test conditions 1d and 1e, and between 70 and 75% for test conditions 4a and 4b. Efficiency could not be calculated for conditions 5a and 5b because of test procedure errors concerning condensate measurements. The recorded wet bulb temperatures also were the same as the corresponding dry bulb temperatures and higher than the saturation temperature as determined from the inlet air and water flow rates. Probably the wicks of the wet bulb thermocouples were dry. An estimate of the water removal efficiency based primarily on test runs 4a and 4b efficiency is 70%. In these test runs the coalescer is known to have been less contaminated with dirt than in the later test runs, 1d and 1e.

6.1.1 <u>Boost Compressor Comparison</u> - The effects of the boost compressor in the test article ECS are shown in Table VII. Test conditions 1d and 1e, 2a and 2c, and 4a and 4b are discussed first. The properties of the bleed air supplied to the system containing the simulated boost compressor are discussed in Section 4. The increase in bleed air pressure at the compressor inlet was not very large as indicated in Table VII. This increase was smaller than anticipated since the pressure regulator (R1 in Figure 1) consistently controlled the pressure at the compressor inlet (R1 sense point) to values which were 5 to 7 psi below the nominal design point of the regulator. Therefore, even though a simulated boost compressor with a pressure ratio of 1.5 was used the pressure increase at the compressor inlet was small and the corresponding temperature rise (due to boost compressor heat of compression, see Table VII) was relatively large. This resulted in a small increase in system performance contributed by the boost compressor, as shown by the turbine discharge properties in the last two columns of the table.

TABLE VII BOOST COMPRESSOR COMPARISON

Operating Condition	Test Runs Compared	Boost Compressor	CES	Bootstrap Air Cycle			
				Compressor Inlet		Turbine Discharge	
				Temp °F	Pressure psia	Flow lb/min	Temp °F
Ground Idle, Static	1d and	On	On	279	71.1	24.9	57.5
	1e	Off	On	198	61.4	21.4	54.1
	1g and	On	On	243	67.5	23.4	52.2
	1f	Off	On	141	34.1	10.4	48.3
High Altitude, Loiter	2a and	On	On	327	59.3	20.6	-58.4
	2c	Off	On	136	55.5	20.7	-87.6
Low Altitude, Loiter	4a and	On	On	198	65.8	24.3	33.1
	4b	Off	On	148	59.4	21.2	33.0

The variation in flow rate to the equipment simulator is 11.2 to 15.9 lb/min for the Integral System, and 6.9 to 29.8 lb/min for the Other Systems. (See Table V.) (The results of test run 4c were not considered since the anti-ice valve was open because of an abnormally high back pressure. The turbine discharge temperature was -75°F.) The variations in equipment cooling capacities between the two systems also are shown in Table V. The column labeled "Capacity (Test)" is based on the test flow rate and a temperature difference of 70°F (inlet temperature 70°F and outlet temperature 140°F). The "Capacity (Req'd)" column is the calculated equipment loads as described in Section 4. A large difference between required and test capacity would result in a large variance in equipment temperatures and potentially could lower equipment reliability. Therefore, the variances in capacities were calculated based on the reference capacities (column labeled "Req'd") and denoted as percentage under-cooling or percentage over-cooling in the last two columns of Table V. (Capacity variance is the difference between test and required capacities.) The maximum variations are 11% under-cooling to 16% over-cooling for the Integral System and 43% under-cooling to 156% overcooling for the Other Systems.

Indications of achieved cockpit comfort are presented in Table VI in terms of average cockpit temperature requirements as discussed in Section 4. The required average temperature was not always obtained but the capacity to obtain this temperature was available most of the time as indicated by a YES in the "Achievable Ave Temp" column. The test inlet temperatures and the required inlet temperatures (i.e., to provide the required average cockpit temperatures) are included. The required inlet air temperatures were calculated as a function of the test flow rates, and the required cockpit loads and required average temperatures. The cockpit flow rate was never below the 4 lb/min minimum requirement. The maximum difference between the test and required inlet temperatures was 13°F for the conditions where the average cockpit temperatures are achievable.

The test conditions where the required average cockpit temperatures were unachievable are 4c, 5a, and 5b. The required average cockpit temperature in 4c was unachievable due to abnormal system operation which caused the anti-ice valve to go full open. The turbine discharge air in test conditions 5a and 5b was too hot to achieve the comfortable cockpit average temperatures as indicated in Section 4. It was explained in Section 4 that the average cockpit temperatures were selected at lower values than the maximums specified

Some aircraft engines provide bleed air pressures which are significantly lower than those used in test runs 1d and 1e. The bleed air properties of the F-4 engine (which has lower bleed air pressures) at idle static conditions, and an assumed boost compressor pressure ratio of two were used in additional tests (test runs 1g and 1f). The result, as shown in the last two columns of Table VII, was that the ECS capacity was increased by a factor of about 2.5. Also, referring back to Table V, note that the equipment was not undercooled while using this simulated boost compressor.

6.1.2 Regenerative Heat Exchanger Comparison - Test data could not be obtained for Operating Condition 3a (see Table III) using the regenerative heat exchanger at Mach 2.4 because the turbine bearing temperature rose to the upper design limit of 300°F before the required ram air temperature could be achieved. A simulated speed of Mach 2.17 was achieved in conjunction with a bearing temperature of 290°F, as a replacement for Operating Condition 3a. This test condition was run using the regenerative heat exchanger and is identified as 3a-1 as explained in Section 5.1. Since the bearing temperature was 290°F when the regenerative heat exchanger was used, it could not be turned off without exceeding the 300°F limit. Therefore performance for Operating Condition 3b-1 was calculated.

Performance test data for test condition 3a-1 and calculated data for test condition 3b-1 are included in Tables V and VI. Although the capacity without the regenerator remains high enough to satisfy the required loads and temperatures, the trend of a regenerative heat exchanger is shown. The calculations showed a turbine discharge temperature which was 47°F higher when the regenerator was not used (i.e., turbine discharge temperature was -29°F with the regenerator and +18°F without it). These temperatures are for an operating condition at a speed of Mach 2.17 at 45,000 feet altitude. Previous calculations without the use of the regenerator indicated a rise in turbine discharge temperature of approximately 45°F for an increase in speed from Mach 2.2 to 2.4. Adding a temperature differential based on this data to the 18°F turbine discharge temperature (i.e., data representative of Mach 2.17 without regenerator) results in a turbine discharge temperature close to 70°F for Mach 2.4. With this cooling air temperature it would be nearly impossible to provide comfortable cockpit cooling and adequate equipment cooling. Assuming the temperature reduction effects of the regenerator are the same at Mach 2.4 as at Mach 2.17, enough cooling capacity would be available at Mach 2.4 to supply needs of the cockpit and equipment simulators if the regenerator could be used.

6.1.3 Cooling Effects System Comparison - The performance contribution of the CES is shown in Table VIII. The three data columns labeled "Equipment Simulator" were included in Table V and previously explained. The background for determination of these data is not repeated here. When the CES was on, the design flow rate was 14 lb/min. In test runs 4c and 5a the flow rates were too high. They were expected to be high since the inlet temperatures were above the 70°F design point temperature. The low flow rate for test run 1a occurred since the test condition could not be stabilized completely. One possible reason is that Condition 1a was inherently an unstable condition for the various automatic controls (i.e., CES, two temperature controllers C1 and C3, pressure regulator R1, water separator anti-ice control V3, and cabin pressure regulator R2), since they were not designed to function together in the same system.

The effect of using a CES is shown by the percentage under-cooling and over-cooling. The cooling variations were 11% under-cooling to 16% over-cooling with the CES, and 28% to 156% over-cooling without the CES.

Another parameter that indicates the effectiveness of the CES is conversation of engine bleed air. (See the last column of Table VIII.) The total bleed air utilized in the system was determined for each test run. The greatest savings might have been expected during the Cold Day, Low Altitude, Loiter Condition (4c) when a large part of the air bypasses the turbine via the hot trim air lines. In this test the bleed air could be reduced via the CES by only 6%. The reduction was limited by the high pressure ratio turbine (i.e., the turbine almost always operates in the near-choked mode). If a lower pressure ratio turbine had been utilized the flow reduction would have been considerably larger since the total flow (to cabin and equipment simulators) was about 100% more than was needed. Most of this extra flow was routed to the cabin simulator while the CES was "On". This was necessary because back pressuring the turbine was not very effective in reducing the turbine flow. A larger reduction also could have been realized if the control valve had been used upstream of the turbomachinery. With the control valve upstream of the turbine, the turbine would have been forced to operate in the nonchoked mode. (No CES valve to provide this type of system design was readily available).

TABLE VIII COOLING EFFECTS SYSTEM COMPARISON

Operating Condition	Test Runs Compared	Boost Compressor	CES	Equipment Simulator			Engine Bleed Air Conserved Using CES
				Flow Lb/Min	Under-Cooling %	Over-Cooling %	
Ground Idle, Static	1a and	On	On	11.2	11	–	9%
	1b	On	Off	19.8	–	37	
	1g and	On	On	13.9	–	16	–
	1h	On	Off	16.3	–	37	
High Altitude, Loiter	2a and	On	On	14.1	–	13	15%
	2b	On	Off	20.8	–	28	
Low Altitude, Loiter	4c and	Off	On	17.7	–	12	6%
	4d	Off	Off	29.8	–	156	
Sea Level, High Speed	5a and	Off	On	15.9	5	–	11%
	5b	Off	Off	21.0	–	55	

6.2 Computer Model

A mathematical model of the laboratory test ECS was prepared for use with the computer program described in Volume II. Several levels of analytical detail were involved in describing the performance of the various components. Detailed data were used to describe the turbine-compressor unit and the heat exchangers. These data consisted of vendor supplied performance maps. Line pressure drops were computed by inputting known diameters, lengths, bend loss factors, orifice flow factors, etc., (e.g., from Reference 5). Assumed performance as described in Section 4 was used to simulate the boost compressor.

The primary objectives for developing the computer model were to use it to evaluate the test data and, in the process, to validate the computer program. Using the computer model as a "tool" to establish test boundary conditions and component characteristics were secondary objectives.

The above objectives were accomplished by using the computer program in two sets of analyses. The first set was run prior to the tests and the second set afterwards. Test boundary conditions and component characteristics were established in the first set of analyses. These included direct calculation of simulated equipment and cockpit heat loads, and properties of the ram air and engine bleed air supplies. The bleed air supply requirements to simulate the boost compressor also were calculated directly. The equipment design flow rate, the pressure-altitude schedule for the equipment circuit, and the boost compressor design pressure ratio were established as a result of reviewing several computer runs. The details of how the above information was obtained, and the results of the calculations are included in Section 4. In conjunction with the above information, nominal pressure-altitude schedules for the system pressure regulator R1 and the cabin dump valve-pressure regulator R2 (see Figure 1) were used. Thus, nominal system performance was obtained in the first set of analyses.

During the course of the above analyses it was found that the performance map data for the regenerative heat exchanger were incomplete. This was indicated by an unreasonably high heat exchanger effectiveness calculated by the computer as a linear extrapolation of the available performance data. This heat exchanger was designed for larger flow rates than were common in these tests. More data points were added to the available maps by cross-plotting these available maps. This allowed the linear interpolation (up to seventh order is available in the computer program) of the data by the computer program to obtain satisfactory heat exchanger performance.

The computer input was changed after the test. Test values of the boundary conditions and of some of the actual component characteristics were used instead of nominal values and calculations. Test values of the inlet ram and bleed air properties, the system pressure regulator settings, the turbine exit pressure, and the cold air flow split to the simulators were used. The test data indicated heat losses in some of the ECS lines (most significantly in the hot trim air lines). Generalized overall conductances (UA's) were determined for the hot trim air lines. Use of these UA's in the computer program did not provide good correlation with the hot trim air test temperature at the cold air mix points. The reason was that the UA's varied as a complex function of the air line temperature as well as flow rate. During the tests hot trim lines were initially heated to the specified design temperature of 400°F by allowing full flow through the simulators. Then the flow rates were automatically controlled to lower values to obtain the required inlet temperatures at the simulators. The hot trim air flow rates varied for the different operating conditions. (Measurement accuracies at low air flow rates was not very good, See Table II.) This resulted in different rates of cool down of the trim air lines. The quasi-equilibrium points at which the data were taken for each condition resulted in different trim air line temperatures. Therefore, the measured inlet hot air trim temperatures were input as boundary conditions in the computer program in lieu of the UA's.

Flow rate and temperature balances were calculated throughout the system. Pressure balance calculations in the distribution system lines (i.e., in legs 21, 29, and 33 of Figures 3 or 10), and pressure loss effects of the distribution system control valves (i.e., valves V5, V6, and V11 in Figures 1 or 3) were not included in the analysis (i.e., negligible valve pressure drops were included in the computer model input). The flow split to leg 53 and the turbine discharge pressure were controlled to the test values. (This flow split is in the line from the primary heat exchanger before it reaches the bootstrap compressor as indicated in Figure 10.) Capability of the system to cool the equipment and cockpit simulator loads (i.e., the total system load) was provided by defining the flow split ratio at the cold air junction downstream of the water separator as the test flow split ratio, and by allowing the trim

Basic Model: 28 Legs, 80 Stations (See Section 6.2.1)

P Change Options:

Boost Comp: +0 Legs, +0 Stations
Ejector: +1 Leg, +5 Stations
Regenerative HX: +1 Leg, +4 Stations

CES: +0 Legs, +0 Stations
Water Sep: +0 Legs, +0 Stations

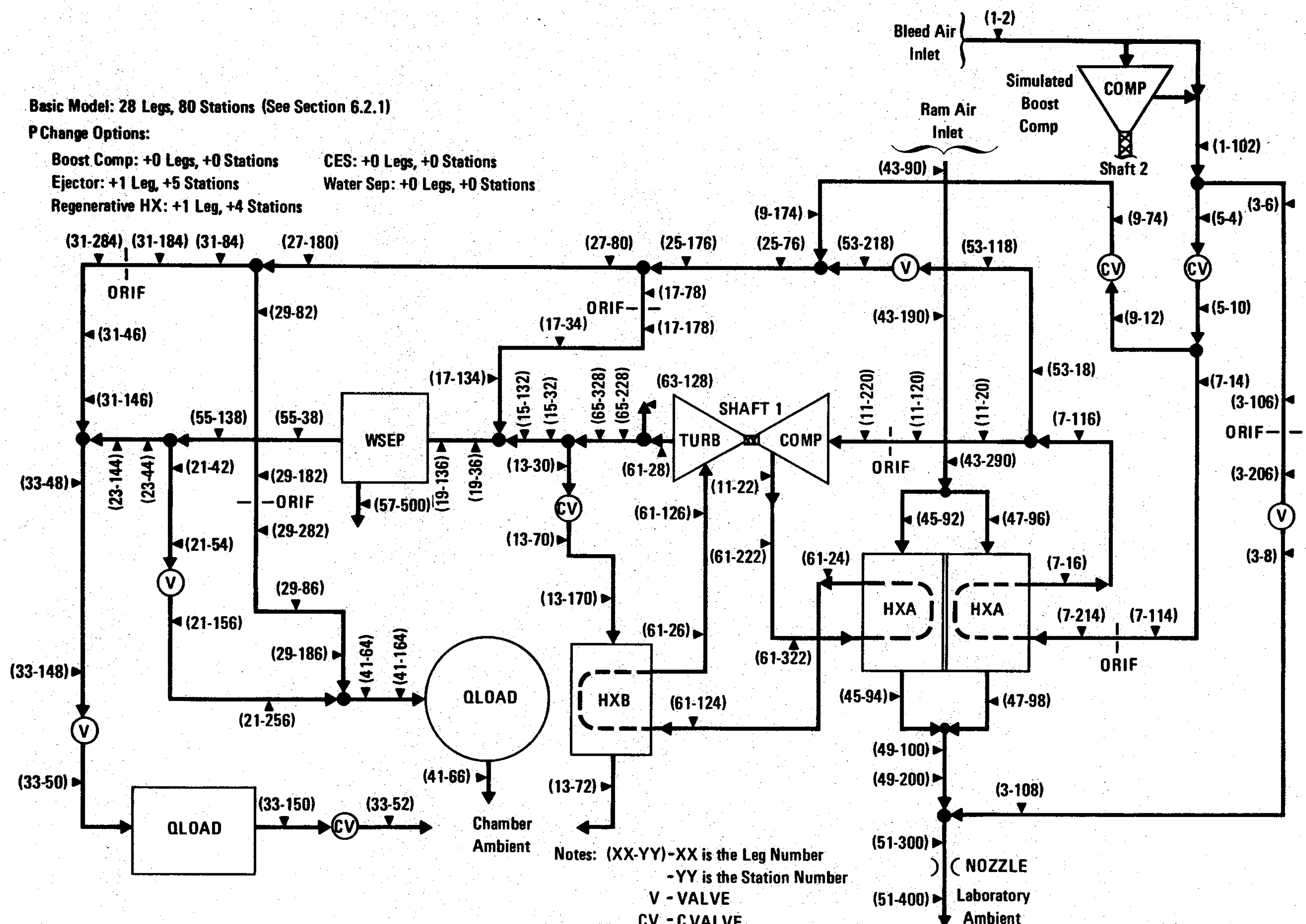


Figure 10 Test Article ECS Computer Model

air flow rates to vary until the mixed air temperatures at the simulator inlets were equal to the test temperature at these points.

All temperatures, flow rates, humidities, and pressures were balanced throughout the system (except for the pressures downstream of the turbine exit as previously discussed). Pressure drops were calculated between the turbine exit and the control valve locations, and from these points to the simulator exits. Since some control valve pressure drops (i.e., valves V5, V6, and V11) were not computed by the program, the calculated pressures at the simulators exists should have been higher than the ambient pressure. Comparisons of the measured ambient pressures and the calculated simulator exit pressures revealed this to be true. In other words, the calculations showed that adequate pressures were available to provide the required cockpit and equipment pressurization needs.

Description of the computer model set-up to calculate system performance using the test boundary conditions is presented in the following sections. The test boundary conditions for all runs are tabulated in Appendix A. More detail concerning evaluation of the test data and comparison of test and calculated data is presented in Section 6.3.

6.2.1 <u>Computer Model Description</u> - The computer model was constructed in two phases. First, a basic system model was prepared. The computer program input data contained all the parameter data, table data, and components common to each test configuration. In the next phase additions were made to the basic model via the PCHANGE option in the program. These additions were made to describe each test condition. Each PCHANGE involved the addition of the CES, the regenerative heat exchanger, the boost compressor, and the ejector as required by the test condition. Boundary conditions were also input via PCHANGE. Descriptions of the computer program components are presented in Volume II.

6.2.1.1 <u>Basic Computer Model</u> - Figure 10 shows the test article ECS computer model. The program output of the basic model component data cards describing this ECS schematic is shown in Figure 11. Detail performance data were input to describe the turbomachinery, heat exchangers, and water separator performance. Line pressure drop information was input as functions of friction factors, bend loss factors, lengths, and diameters. Test pressure drops (in the form $\sigma\Delta P$) were input for ram air inlet and exit lines. Valve pressure loss coefficients were input (so that ΔP was a function of KW^2). Control valve pressure losses were calculated as a function of KW^2 with component CVALVE, where K was calculated iteratively by the computer program. QLOAD was

LABORATORY CEMONATRATION TEST
CASE IECS

COMPONENT(S)

1 6 8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	
INLET	13	1	2	1000	1	2	3	4	2	-1	0	0	0	0	0	0	0	0	
																			SV N 1 T 1
CNNCT	15	1	2	1	102	C	0	0	0	0	0	0	0	0	0	0	0	0	
CNNCT	20	1	102	5	4	C	C	0	0	0	0	0	0	0	0	0	0	0	
CVALVE	30	5	4	10	C	12	13	0	0	0	0	0	0	0	0	0	0	0	
																			SV N 2 T 6
SPLIT	40	5	1C	9	12	7	14	1	14	0	0	0	0	0	0	0	0	0	
																			SV N 3 T 5
CVALVE	50	5	12	74	C	15	16	0	0	0	0	0	0	0	0	0	0	0	
																			SV N 4 T 6
LINE	60	9	74	174	C	1	-1	17	1	18	19	20	0	0	0	0	0	0	
LINE	70	7	14	114	C	1	-1	21	1	22	23	24	0	0	0	0	0	0	
MISC	74	C	101	-1	265	C	0	0	0	0	0	0	0	0	0	0	0	0	
ORIF	75	7	114	214	C	3	187	186	0	0	0	0	0	0	0	0	0	0	
INLET	80	43	9C	0	25	26	27	28	2	-1	0	0	0	0	0	0	0	0	
CNNCT	90	43	9C	43	190	C	C	0	0	0	0	0	0	0	0	0	0	0	
LINE	95	43	190	290	1	C	11	0	0	0	0	0	0	0	0	0	0	0	
SPLIT	100	43	29C	45	52	47	96	1	33	0	0	0	0	0	0	0	0	0	
																			SV N 5 T 5
HXA	110	7	214	16	47	56	98	3	1	2	1	0	0	0	0	0	0	0	
LINE	120	7	16	116	C	1	-1	34	1	35	36	37	0	0	0	0	0	0	
SPLIT	130	7	116	53	18	11	20	0	38	0	0	0	0	0	0	0	0	0	
LINE	140	53	18	118	C	1	-1	39	1	40	41	42	0	0	0	0	0	0	
VALVE	145	53	118	218	C	1	188	189	0	0	0	0	0	0	0	0	0	0	
MERGE	150	53	218	9	174	25	76	1	0	0	0	0	0	0	0	0	0	0	
																			EV N 1 T 2
LINE	170	25	76	176	C	1	-1	44	1	45	46	47	0	0	0	0	0	0	
LINE	190	11	20	120	C	1	-1	49	1	50	51	52	0	0	0	0	0	0	
MISC	194	C	101	-1	266	C	0	0	0	0	0	0	0	0	0	0	0	0	
ORIF	195	11	12C	220	0	3	191	190	0	0	0	0	0	0	0	0	0	0	
SHAFT	200	1	1	53	C	C	C	0	0	0	0	0	0	0	0	0	0	0	
																			SV N 6 T 7
COMP	210	11	22C	22	1	2	C	-1	54	0	0	0	0	0	0	0	0	0	
SENSOR	215	2	22C	48	C	C	C	0	0	0	0	0	0	0	0	0	0	0	
																			EV N 2 T 2
CNNCT	216	11	22	61	222	C	0	0	0	0	0	0	0	0	0	0	0	0	
LINE	220	61	222	322	0	1	-1	55	1	56	57	58	5	2	56	3	272	0	
HXA	230	61	322	24	45	92	94	3	1	2	1	0	0	0	0	0	0	0	
MERGE	240	45	94	47	58	45	10C	1	0	0	0	0	0	0	0	0	0	0	
																			EV N 3 T 2
LINE	245	45	10C	200	1	C	12	0	0	0	0	0	0	0	0	0	0	0	
CNNCT	250	49	20C	51	300	C	C	0	0	0	0	0	0	0	0	0	0	0	
CNNCT	260	51	30C	51	40C	C	0	0	0	0	0	0	0	0	0	0	0	0	
OUTLET	270	51	40C	0	C	C	C	0	0	0	0	0	0	0	0	0	0	0	
LINE	280	61	24	124	C	1	-1	69	1	70	71	72	0	0	0	0	0	0	
VALVE	290	61	124	26	1	C	6	0	0	0	0	0	0	0	0	0	0	0	

Figure 11 Component Data Cards Output (Sheet 1)

LABORATORY CEMONATRATION TEST
CASE IECS

LINE	300	61	26	126	C	1	-1	73	1	74	75	76	0	0	0	0	0	0
TURB	310	61	126	28	1	2	77	-1	78	0	0	0	0	0	0	0	0	0
EV N 4 T 1																		
SV N 7 T 8																		
SPGHER	320	1	75	C	C	C	0	0	0	0	0	0	0	0	0	0	0	0
EV N 5 T 5																		
SENSOR	0	2	28	276	C	C	C	0	0	0	0	0	0	0	0	0	0	0
EV N 6 T 2																		
SPLIT	325	61	26	63	128	65	228	1	257	0	0	0	0	0	0	0	0	0
SV N 8 T 5																		
SENSOR	326	1	63	246	C	C	C	0	0	0	0	0	0	0	0	0	0	0
EV N 7 T 1																		
LINE	330	65	228	328	C	1	-1	80	1	81	82	83	5	2	81	3	0	0
CNNCT	340	65	328	15	32	C	C	0	0	0	0	0	0	0	0	0	0	0
LINE	390	15	32	132	C	1	-1	95	1	96	97	98	0	0	0	0	0	0
SPLIT	400	25	176	17	78	27	80	1	99	0	0	0	0	0	0	0	0	0
SV N 9 T 5																		
MISC	404	C	101	-1	267	C	0	0	0	0	0	0	0	0	0	0	0	0
ORIF	405	17	78	178	C	3	193	192	0	0	0	0	0	0	0	0	0	0
CNNCT	410	17	178	17	34	C	0	0	0	0	0	0	0	0	0	0	0	0
LINE	415	17	34	134	C	1	-1	102	1	103	104	105	0	0	0	0	0	0
MISC	420	3	134	-1	262	C	0	0	0	0	0	0	0	0	0	0	0	0
MERGE	430	15	132	17	134	15	36	0	0	0	0	0	0	0	0	0	0	0
SENSOR	431	3	36	110	0	C	0	0	0	0	0	0	0	0	0	0	0	0
EV N 8 T 3																		
CNNCT	440	19	36	19	136	C	0	0	0	0	0	0	0	0	0	0	0	0
WSEP	450	19	136	55	38	57	500	1	7	2	0	0	0	0	0	0	0	0
LINE	470	55	38	138	0	1	-1	111	1	112	113	114	0	0	0	0	0	0
SPLIT	480	55	138	21	62	23	46	0	115	0	0	0	0	0	0	0	0	0
LINE	490	23	44	144	C	1	-1	116	1	117	118	119	0	0	0	0	0	0
LINE	500	27	80	180	C	1	-1	120	1	121	122	123	0	0	0	0	0	0
SPLIT	510	27	180	29	82	31	84	1	124	0	0	0	0	0	0	0	0	0
SV N 10 T 5																		
LINE	520	29	82	182	0	1	-1	125	1	126	127	128	0	0	0	0	0	0
MISC	524	C	101	-1	268	C	0	0	0	0	0	0	0	0	0	0	0	0
ORIF	525	29	182	282	0	3	195	194	0	0	0	0	0	0	0	0	0	0
CNNCT	530	29	282	29	86	C	C	0	0	0	0	0	0	0	0	0	0	0
LINE	535	29	86	186	C	1	-1	196	1	197	198	199	0	0	0	0	0	0
CNNCT	540	21	42	21	54	C	C	0	0	0	0	0	0	0	0	0	0	0
VALVE	550	21	54	156	1	2	133	0	0	0	0	0	0	0	0	0	0	0
LINE	560	21	156	256	0	1	-1	135	1	136	137	138	0	0	0	0	0	0
MISC	565	3	186	-1	261	C	0	0	0	0	0	0	0	0	0	0	0	0
MERGE	570	21	256	29	166	41	64	0	0	0	0	0	0	0	0	0	0	0
SENSOR	571	3	64	139	C	C	0	0	0	0	0	0	0	0	0	0	0	0
EV N 9 T 3																		
LINE	590	41	64	164	C	1	-1	141	1	142	143	144	0	0	0	0	0	0
OLOAD	600	41	164	66	1	5	2	1	145	2	145	0	0	0	0	0	0	0
LINE	630	31	84	184	C	1	-1	151	1	152	153	154	0	0	0	0	0	0
MISC	634	C	101	-1	265	C	0	0	0	0	0	0	0	0	0	0	0	0
ORIF	635	31	184	284	C	3	201	200	0	0	0	0	0	0	0	0	0	0
CNNCT	640	31	284	31	66	C	0	0	0	0	0	0	0	0	0	0	0	0

Figure 11 Component Data Cards Output (Sheet 2)

LABORATORY DEMONSTRATION TEST
CASE IECS

LINE	645	31	46	146	C	1	-1	202	1	203	204	205	0	0	0	0	0	0
MISC	649	3	146	-1	26C	C	0	0	0	0	0	0	0	0	0	0	0	0
MERGE	650	23	144	31	146	33	48	0	0	0	0	0	0	0	0	0	0	0
SENSOR	651	3	48	163	0	C	C	0	0	0	0	0	0	0	0	0	0	0

EV N 10 T 3

LINE	660	33	48	148	C	1	-1	157	1	158	159	160	0	0	0	0	0	0
VALVE	670	33	148	5C	C	2	131	0	0	0	0	0	0	0	0	0	0	0
QLOAD	700	33	5C	15C	1	6	1	1	145	1	145	0	0	0	0	0	0	0

STATE/ERROR VARIABLE(S) 10

Figure 11 Component Data Cards Output (Sheet 3)

used to describe the equipment and cockpit simulator heat loads consistent with the requirements established in Section 4.

Several component data cards that are used for special purposes are also shown in Figure 11. Examples for each type are discussed next. The use of several CNNCT cards is noted. Card 20 (the first column of numbers represent the component card number) allowed for the addition of several cards to describe the engine bleed air circuit to the ejector. Card 250 allows for the addition of MERGE to connect the ejector line to the ram air circuit. Card 340 provides space for addition of the several cards required to describe the regenerative heat exchanger circuit. CNNCT cards were also used to delete components not required for the analysis.

MISC cards were used to calculate terms not available in the standard component list. MISC was used after card 15 for cases 1a through 1e to calculate the flow split ratio to the ejector line. MISC was used to set the hot line merge temperature to the test values. MISC cards 420, 565, and 649 set the temperatures at Stations 134, 186, and 146, respectively. MISC was used to load the several orifice meter pressure ratios (see Appendix A) into general argument 101. This allowed ORIF to calculate the pressure drop consistent with the laboratory data.

Simulation of the side one (hot side) pressure drop of the regenerative heat exchanger was made by using VALVE (card 290) except for Condition 3. HXB replaced VALVE when the regenerator was being used.

6.2.1.2 Computer Model PCHANGE - Performance change cases were used for each test condition. The boundary conditions that were obtained from the test data and input for each condition are identified in Table IX. Appendix A presents the data used in each change case. In addition to specifying the test boundary condition, the model configuration was altered, if required, to represent the next test configuration. Four basic model changes were used, either singly or in combination as the following components were added to the system.

(1) Boost Compressor - This change did not alter the basic model. Parameter data required by INLET (card 13) described the pressure rise and temperature rise due to the compression process. These data are representative of a 64% efficient compressor operating at a pressure ratio of 1.5.

(2) Ejector - This change added one leg and five stations to the basic model.

TABLE IX - COMPUTER MODEL BOUNDARY CONDITION DESCRIPTION

Parameter Description	Program Paramater Table Location	Schematic Location	
		Leg	Station
Bleed Air Pressure, psia	2	1	102
Bleed Air Temperature, °R	3	1	102
Bleed Air Humidity, lb/lb	4	1	102
Ram Air Flow, lb/min	25	43	–
Ram Air Pressure, psia	26	43	90
Ram Air Temperature, °R	27	43	90
Ram Air Humidity, lb/lb	28	43	90
Flow Split Ratio to Leg 53	38	53	–
Compressor Inlet Pressure, psia	48	11	220
Flow Split Ratio to Leg 13	84	13	–
Water Separator Inlet Temperature, °R	110	19	36
Flow Split Ratio to Leg 21	115	21	–
Equipment Simulator Inlet Temperature, °R	139	41	64
Cockpit Simulator Inlet Temperature, °R	163	33	48
Turbomachinery Leakage Flow, lb/min	246	63	–
Ejector Flow, lb/min	259	3	–
Trim Air Merge Temperature, °R	260	31	146
Trim Air Merge Temperature, °R	261	29	186
Trim Air Merge Temperature, °R	262	17	134
Pressure Ratio at ORIF	264	3	106
Pressure Ratio at ORIF	265	7	114
Pressure Ratio at ORIF	266	11	120
Pressure Ratio at ORIF	267	17	78
Pressure Ratio at ORIF	268	29	182
Pressure Ratio at ORIF	269	31	184
Turbine Exit Pressure	276	61	28

The following cards describe changes to simulate the ejector:

MISC	A	15
SPLIT	R	20
LINE	A	
MISC	A	
ØRIF	A	
VALVE	A	
LINE	A	
MERGE	R	250

The engine bleed air flow to the ejector was set up with these cards. Ejector performance was not calculated (erroneous pressures for determining the pumping ratio were measured). The ram air flow used in the calculations was based on test data. (See Appendix A.)

(3) Regenerative Heat Exchanger - One leg and five stations were added to the basic model to describe the regenerative heat exchanger. The following cards were added to the basic model via PCHANGE:

HXB1	R	280
SPLIT	R	340
LINE	A	
HXB2	A	
OUTLET	A	

These cards set up the regenerative circuit. HXB1 replaced VALVE (card 280), which accounted for the hot side pressure drop when the regenerator was not used.

(4) Cooling Effects System (CES) - No model changes were made to evaluate the CES. The test values for flow rates were input in the form of a fixed split ratio at the cold air split downstream of the water separator. Calculated inlet temperatures at the equipment simulator were controlled to the test values.

6.3 Comparison of Test and Calculated Results

Computer analyses were made for the steady state test conditions. These analyses were used to evaluate the laboratory tests. The comparative evaluations of test and computer results show the validity and flexibility of the computer program.

Comparisons of test and computed data for pertinent performance parameters are shown in Table X. Temperature drops across the hot sides of the heat ex-

TABLE X COMPARISON OF TEST AND CALCULATED DATA (SHEET 1)

Comparison Parameter	Ground Idle Static Operating Condition														
	1a			1b			1c			1d			1e		
	Test	Calculated	% Deviation	Test	Calculated	% Deviation	Test	Calculated	% Deviation	Test	Calculated	% Deviation	Test	Calculated	% Deviation
Primary Heat Exchanger Hot Side ΔT, ^oR	341.7	364.6	-6.7	319.3	347.7	-8.8	248.1	258.2	-4.0	303.0	357.8	−18.0	224.5	236.8	-5.5
Primary Heat Exchanger Effectiveness	0.63	0.66	-4.8	0.60	0.64	-6.7	0.68	.70	-2.9	0.61	0.70	−14.7	0.67	0.70	-4.5
Compressor Pressure Ratio	1.40	1.40	0	1.54	1.52	1.2	1.39	1.39	0	1.56	1.52	2.5	1.53	1.51	1.3
Compressor Temperature Rise, ^oR	124.9	139.8	-12.0	168.6	182.3	-8.1	113.5	123.4	-8.8	166.5	166.4	0.0	147.1	148.8	-1.1
Secondary Heat Exchanger Hot Side ΔT, ^oR	235.0	235.0	0	261.0	258.8	0.8	174.0	175.4	-0.8	238.9	229.3	4.0	182.9	176.7	3.4
Secondary Heat Exchanger Effectiveness	0.74	0.72	2.7	0.69	0.68	1.4	0.77	0.75	2.3	0.68	0.72	−4.0	0.72	0.71	1.4
Turbine Pressure Ratio	3.92	3.88	1.0	5.89	5.77	2.0	3.45	3.41	1.2	5.90	5.75	2.5	4.96	4.84	2.4
Turbine Temperature Drop, ^oR	152.9	151.3	1.0	196.6	197.8	-0.6	131.2	132.7	-1.1	146.4	126.1	13.8	106.6	104.4	2.1
Turbine Flow Rate, lb/min	20.9	20.5	1.8	23.3	22.7	2.3	18.9	18.5	2.1	24.3	23.87	1.7	21.4	20.46	4.4
Turbine Exit Temperature, ^oR	510.0	521.4	-2.2	500.2	510.1	-2.0	499.2	506.9	1.5	517.5	516.0	0.3	514.1	520.8	-1.3
Cockpit Flow Rate, lb/min	10.7	10.8	-0.9	8.9	8.6	3.6	10.6	10.3	3.0	12.6	13.0	−3.1	9.0	8.8	2.1
Cockpit Inlet Temperature, ^oR	536.2	536.2	0	537.4	537.4	0	535.3	535.3	0	534.0	534.3	0	530.1	530.0	0
Equipment Flow Rate, lb/min	11.2	10.3	7.9	18.0	17.0	5.7	10.9	10.8	0.6	14.4	14.6	−1.3	14.4	13.3	7.7
Equipment Inlet Temperature, ^oR	529.2	529.0	0	532.2	532.0	0	528.8	528.8	0	531.1	531.1	0	530.4	530.4	0

TABLE X COMPARISON OF TEST AND CALCULATED DATA (SHEET 2)

Comparison Parameter	High Altitude Loiter Operating Condition								
	2a			2b			2c		
	Test	Calculated	% Deviation	Test	Calculated	% Deviation	Test	Calculated	% Deviation
Primary Heat Exchanger Hot Side ΔT, ^{o}R	449.0	517.5	–15.1	422.2	582.2	–37.8	436.9	455.2	–4.1
Primary Heat Exchanger Effectiveness	0.58	0.65	–12.0	0.54	0.60	–11.1	0.76	0.77	-1.3
Compressor Pressure Ratio	1.49	1.49	0.0	1.49	1.49	0.0	1.47	1.43	2.7
Compressor Temperature Rise, ^{o}R	149.6	164.5	–9.9	140.5	172.8	–22.9	117.2	120.0	–2.3
Secondary Heat Exchanger Hot Side ΔT, ^{o}R	365.6	346.0	5.3	375.7	380.7	–1.3	214.2	214.8	–0.2
Secondary Heat Exchanger Effectiveness	0.78	0.79	–1.2	0.77	0.78	–1.2	0.86	0.84	2.3
Turbine Pressure Ratio	7.61	7.69	–1.0	8.24	8.32	–0.9	4.89	4.75	2.8
Turbine Temperature Drop, ^{o}R	170.1	178.5	–4.9	177.6	188.3	–6.0	125.0	128.7	–2.9
Turbine Flow Rate, lb/min	20.6	21.1	–2.4	22.1	22.3	–0.9	20.7	19.5	5.7
Turbine Exit Temperature, ^{o}R	401.6	375.4	6.5	388.3	378.0	2.6	385.6	376.1	2.46
Cockpit Flow Rate, lb/min	13.8	16.0	–15.9	11.38	13.5	–18.6	15.87	15.3	3.5
Cockpit Inlet Temperature, ^{o}R	523.1	523.1	0	525.6	525.6	0	533.6	533.6	0
Equipment Flow Rate, lb/min	14.1	16.9	–19.8	20.8	22.3	–7.2	16.1	15.7	2.4
Equipment Inlet Temperature, ^{o}R	533.0	533.2	0	533.1	533.1	0	532.4	532.4	0

TABLE X COMPARISON OF TEST AND CALCULATED DATA (SHEET 3)

Comparison Parameter	High Altitude High Speed Operating Condition					
	3a			3b		
	Test	Calculated	% Deviation	Test	Calculated	% Deviation
Primary Heat Exchanger Hot Side ΔT, ^{o}R	510.8	531.5	–4.1	–	531.4	–
Primary Heat Exchanger Effectiveness	0.96	0.97	–1.0	–	0.97	–
Compressor Pressure Ratio	1.71	1.68	1.8	–	1.8	–
Compressor Temperature Rise, ^{o}R	205.5	233.7	–13.7	–	264.4	–
Secondary Heat Exchanger Hot Side ΔT, ^{o}R	212.0	245.1	15.6	–	275	–
Secondary Heat Exchanger Effectiveness	0.94	0.98	–4.3	–	0.98	–
Regenerative Heat Exchanger Hot Side ΔT, ^{o}R	61.23	99.03	–61.4	–	–	–
Regenerative Heat Exchanger Effectiveness	0.24	0.23	–4.16	–	–	–
Turbine Pressure Ratio	11.8	11.8	0	–	12.5	–
Turbine Temperature Drop, ^{o}R	231.9	254.7	–9.8	–	287.6	–
Turbine Flow Rate, lb/min	21.4	21.3	0.5	–	21.3	–
Turbine Exit Temperature, ^{o}R	478.9	431.4	9.7	–	478.3	–
Cockpit Flow Rate, lb/min	5.6	4.7	16.7	–	5.7	–
Cockpit Inlet Temperature, ^{o}R	500.7	500.7	0	–	500.7	–
Equipment Flow Rate, lb/min	14.0	15.7	–12.1	–	18.7	–
Equipment Inlet Temperature, ^{o}R	533.4	533.4	0	–	533.4	–

TABLE X COMPARISON OF TEST AND CALCULATED DATA (SHEET 4)

Comparison Parameter	Low Altitude Loiter Operating Condition											
	4a			4b			4c			4d		
	Test	Calculated	% Deviation	Test	Calculated	% Deviation	Test	Calculated	% Deviation	Test	Calculated	% Deviation
Primary Heat Exchanger Hot Side ΔT, ^oR	440.0	459.5	4.4	313.1	321.6	-2.7	282.1	276.0	2.1	277.8	277.6	0.0
Primary Heat Exchanger Effectiveness	0.81	0.83	-2.5	0.86	0.87	-1.2	0.90	0.87	3.3	0.88	0.87	1.1
Compressor Pressure Ratio	1.62	1.57	3.0	1.53	1.51	1.3	1.38	1.37	0.7	1.55	1.43	7.7
Compressor Temperature Rise, ^oR	158.7	166.4	-4.7	130.3	139.1	-6.7	81.1	87.6	-8.1	104.4	100.5	3.7
Secondary Heat Exchanger Hot Side ΔT, ^oR	212.0	207.7	2.0	149.0	149.2	-0.1	104.2	115.8	-11.1	129.3	124.6	3.6
Secondary Heat Exchanger Effectiveness	0.82	0.88	-7.3	0.82	0.91	-11.0	0.93	0.90	3.2	0.92	0.88	4.3
Turbine Pressure Ratio	6.53	6.34	2.9	4.73	4.66	1.5	3.23	3.16	2.2	4.17	3.87	7.2
Turbine Temperature Drop, ^oR	111.6	110.6	9.8	95.5	87.9	7.9	84.4	93.4	-10.6	107.9	107.1	0.7
Turbine Flow Rate, lb/min	24.2	23.3	3.7	21.2	20.3	4.2	21.0	21.6	3.3	23.9	22.3	6.7
Turbine Exit Temperature, ^oR	493.1	509.4	-3.3	493.0	506.8	2.8	384.5	379.3	1.3	364.7	368.1	-0.9
Cockpit Flow Rate, lb/min	16.4	18.0	-9.7	14.3	13.4	6.5	23.7	23.3	1.6	14.1	13.5	4.2
Cockpit Inlet Temperature, ^oR	522.6	522.6	0	524.3	524.3	0	548.0	548.0	0	537.9	537.9	0
Equipment Flow Rate, lb/min	11.3	12.7	-12.4	12.5	12.3	1.8	17.6	17.3	1.7	29.7	28.5	4.0
Equipment Inlet Temperature ^oR	527.2	527.2	0	528.3	528.3	0	548.0	548.0	0	529.1	529.1	0

TABLE X COMPARISON OF TEST AND CALCULATED DATA (SHEET 5)

Comparison Parameter	Sea Level High Speed Operating Conditions					
	5a			5b		
	Test	Calculated	% Deviation	Test	Calculated	% Deviation
Primary Heat Exchanger Hot Side ΔT, °R	584.1	615.2	–5.3	555.2	589.3	–6.1
Primary Heat Exchanger Effectiveness	0.97	0.99	–2.0	0.96	0.99	–3.1
Compressor Pressure Ratio	1.55	1.5	3.2	1.67	1.58	5.3
Compressor Temperature Rise, °R	161.6	152.8	5.4	185.5	182.9	1.4
Secondary Heat Exchanger Hot Side ΔT, °R	157.5	155.0	1.5	191.1	185.5	2.9
Secondary Heat Exchanger Effectiveness	0.94	0.99	–5.3	0.94	0.99	–5.3
Turbine Pressure Ratio	4.64	4.46	3.8	6.25	5.93	5.1
Turbine Temperature Drop, °R	136.4	144.5	–5.9	201.9	174.5	13.5
Turbine Flow Rate, lb/min	25.6	23.9	6.6	27.6	25.6	7.2
Turbine Exit Temperature, °R	543.5	530.0	2.4	535.8	522.0	2.5
Cockpit Flow Rate, lb/min	10.0	10.7	–7.0	7.1	8.06	–13.5
Cockpit Inlet Temperature, °R	538.4	538.4	0	531.3	531.3	0
Equipment Flow Rate, lb/min	15.8	15.2	3.7	21.4	24.28	–13.4
Equipment Inlet Temperature, °R	533.1	533.1	0	531.9	531.9	0

changers and corresponding effectiveness indicate the performance of the heat exchangers. Pressure ratios and temperature changes across the compressor and the turbine are indicative of the turbomachinery performance. Turbine exit air temperatures and flow rates show the potential capacity of the bootstrap air cycle independent of the water separator and distribution system. Inlet temperatures and flow rates to the cockpit and equipment simulators indicate the system capacity. For each test condition the test and the calculated values of the performance parameters are listed. The comparison of the test and calculated parameters is shown as the percentage deviation referenced to the test value. The deviations are denoted as negative when the test values are smaller than the calculations and positive when the test values are larger. All air properties and flow rates throughout the system, as calculated by the computer program, are included in Appendix B.

Generally the flow and pressure deviations were within the data measurement accuracies as denoted by the "Tolerance" column of Table II. The larger temperature deviations could not be attributed to temperature measurement inaccuracies. In some cases they were attributable to the test performance of the turbomachinery and primary heat exchanger not corresponding to the available performance maps. In some cases the ram air flow rates were calculated from measured data other than the measured flow rates. Inaccuracies in the data could have caused some of the temperature deviations. Deviations in each of the five steady state operating conditions are discussed in the following sections.

6.3.1 Sea Level Static Conditions - The comparative data in Sheet 1 of Table X represent sea level static operating conditions 1a through 1e. For this particular group of tests the ram air flow rate measurements were found to be unreliable due to the noise level in the instrumentation system. Therefore, the flow rates for these test conditions were calculated from ram and bleed air temperatures, bleed air flow rates, and the heat exchanger performance maps. Effectiveness values were calculated for the primary and secondary heat exchangers. Knowing these effectiveness values and bleed air flow rates, the ram air flow rates were obtained from the performance maps. Good correlation was obtained between test and calculated flow rates and temperatures at the turbine exit and at the simulator inlets. This indicates good correlations of air cycle system performances and system capacities.

The greatest deviations were for primary heat exchanger temperature drop and effectiveness in Operating Condition 1d. The reason for these deviations is believed to be that the available heat exchanger effectiveness map was not representative of the actual heat exchanger performance. The effectiveness map does not account for different performance at different temperatures with the same ram air and bleed air flow rates (i.e., each point on the effectiveness map is based on a particular average air temperature). It is believed that the test temperatures for condition 1d were significantly different from those that the map is based on. Other deviations are generally less than ten percent.

A characteristic of the operating conditions where significant quantities of moisture were present (i.e., 1d and 1e) was that condensation often occurred in the turbine expansion process. When this happened, a small measurement error in water input into the air stream could result in a significant deviation in turbine exit temperature. Therefore, any test measurement of water input that was high would result in a calculated temperature higher than the test value. The temperature change would be caused by heat being absorbed by the air as the extra water vapor condensed. This may have occurred in Condition 1e where the calculated turbine discharge temperature was higher than the test value. The opposite temperature trend would occur if the water input measurement was too low. The above characteristics are also applicable to other test runs where water was added (i.e., 4a, 4b, 5a, and 5b).

6.3.2 <u>High Altitude Loiter Conditions</u> - The deviations in primary heat exchanger temperature drop and effectiveness for Conditions 2a and 2b are believed to be high for the same reason as discussed in the previous section. The compressor temperature rises are also high for conditions 2a and 2b. Compressor temperature rise deviations indicate that the compressor operating point does not agree with the available performance data. The turbomachine appeared to operate at a lower than expected rotational speed. No significant variation in the turbine nozzle area, which would affect speed, was observed during the tests. However, turbomachine leakage flow for bearing cooling varied considerably. (Refer to Appendix A.) The leakage was calculated as 2.69 lb/min for operating condition 2a and as a negligible value for condition 2c. The result of a low leakage flow would be increased bearing friction losses between the turbine and compressor which would require a lower operating speed in order to maintain the bearings below maximum temperature limits.

The deviations for equipment and cockpit flow rates appear large. However, the absolute difference in the parameters are small. Most of the deviations are within measurement accuracy of the instrumentation.

6.3.3 <u>High Altitude High Velocity Conditions</u> - A single test run (3a) was made for the high altitude high velocity operating condition. The data in Sheet 3 of Table X indicate that a different turbomachine operating point was observed in the test than was computed from the available performance data. The test and computed heat exchanger effectivenesses, and turbomachinery pressure ratios and flow rates were about the same, but the test and computed turbomachinery temperature changes were considerably different. This resulted in a significant deviation in turbine exit temperature. The primary reason for this is believed to be the low bearing cooling air flow rate of 0.17 lb/min. This flow rate is more than an order of magnitude lower than that measured for most of the other test conditions.

The comparative regenerative heat exchanger effectiveness values are nearly the same. The hot side temperature drops are considerably different. (See Table X.) This occurrence was due to the difference in the turbomachinery performance. The lower turbine exit temperature resulted in a higher heat transfer from the hot side of the regenerative heat exchanger.

The effect of using the regenerative heat exchanger at the high altitude, high velocity operating condition is indicated by comparing calculations for test conditions 3a and 3b. Turbine exit temperature was reduced by 47°F by using the regenerative heat exchanger. Details concerning the effects of using the regenerative heat exchanger at Mach 2.17 and 2.4 are included in Section 6.1.2.

6.3.4 <u>Low Altitude Loiter Conditions</u> - Four tests were run for this condition. Comparison of conditions 4a and 4b (using wet bleed air), and conditions 4c and 4d (using dry bleed air), are contained in Table X. Reasonable correlation between the test and calculated system capacities were observed.

A noticeable difference between calculated and test turbine temperature drop was observed for conditions 4a and 4b. Approximately one half of the observed difference could have been due to the inaccuracy of the measured water injection rates, which affects the calculated turbine exit temperature.

Conditions 4c and 4d showed good correlation, with the deviation on turbine exit temperature under 2% and on flow rate within 6.7%. Secondary heat exchanger performance for condition 4c was noted as the most significant deviation between the test and calculated data. Considering the accumulated error for ram flow and the several other temperatures (see Table II), the deviation for the heat exchanger performance is not unreasonable.

6.3.5 Sea Level High Speed Conditions - Two tests were run at this condition using wet bleed air. Comparison of the test and calculated data, presented in Table X, show reasonable correlations. The greatest deviation is in the turbine temperature drop. This could be attributed partially to inaccuracy in measuring the rate of water injection into the bleed air described in the previous section.

The test data indicated that temperature drops occurred across the hot trim and cold air merges upstream of the simulators (i.e., temperature drops from locations (55-38) to (41-164) and from (55-38) to (33-50) shown in Figure 3). Since this could not occur with the measured trim flow rates and temperatures, the test data were corrected. The test values for trim air flow rate to each simulator were corrected to account for the temperatures observed at the inlets to the simulators. This resulted in adequate correlation of flow rates and temperatures at the simulators.

6.4 Idle Descent Mission Performance

The boundary conditions of the idle descent mission are discussed. These consist of approximations of the required ram and bleed air supply properties and of the required chamber pressure-altitude. Next the system performance for the simulated missions is discussed.

6.4.1 Boundary Conditions - The bleed air supply pressure was held at 100 psia during test condition 6a to simulate the effects of a boost compressor. Thus the ECS pressure regulator controlled the inlet pressure to the bootstrap compressor throughout the descent mission. A constant supply pressure (rather than a transient)was used to simulate the effects of the boost compressor since control of the pressure at the pressure regulator is a throttling process (i.e., essentially constant enthalpy). The pressure regulator controlled the pressure between 54 and 60 psig at the compressor inlet. (The nominal specification design pressure is 62 psig.)

Test Condition 6b was run without a simulated boost compressor. The goal was to control the bleed air supply pressure to the transient requirement of Figure 9. The maximum variance from this requirement was 3 psi,and the average variance was less than 1.5 psi.

The bleed air supply temperatures were successfully controlled to nearly constant values of 705°F for test run 6a and 530°F for test run 6b per the test procedure discussed in Section 5.4. The average difference between the required transient temperature profile of test run 6b and the approximation of it (i.e., the constant temperature) was 20°F. This is less than 2% of the absolute temperatures. Slightly better simulation of bleed air supply temperature was achieved for test run 6a.

The changes in ram air temperatures and flow rates were approximated by single step functions as shown in Figures 12 and 13, where the test data and test requirements are shown. The initial ram air temperatures were maintained for about the first 50 seconds then raised to values near the final required temperatures. The average temperature difference between test and required data was 15°F for test 6a, and 16°F for test 6b. Similar approaches were made to control the ram air flow rates. In tests 6a and 6b, the average test flow rate differed from the required rate by 7 and 14 lb/min, respectively.

Chamber ambient pressure was maintained very close to the required descent profile.

6.4.2 <u>System Performance</u> - The difference in total system capacity in the two test runs, with and without the boost compressor, was small. This was expected since the initial and final steady state tests, which were the end points of the transient tests, had already been run. Total capacity is indicated by the turbine discharge flow and temperature data shown in Figure 14. At high altitude (i.e., during the first half of the descent) use of the boost compressor appeared to provide slightly greater capacity whereas the capacity at lower altitudes was greater with the boost compressor off.

The variation in turbine discharge flow rate (Figure 14) was greater than the flow variation in the equipment circuit (Figure 15). The 37% flow variation at the turbine exit was reduced to 25% at the equipment simulator inlet. This is the result of the cooling effects system flow control in the equipment circuit. The turbine discharge temperature variations were fairly smooth (Figure 14) during the tests. However, the equipment inlet temperature variations were more erratic. Although the temperature variations at the equipment inlet are not too bad, they could have been better if the temperature controller and the CES flow controller had been designed to function in the same system. An integrated design of the test article ECS also would have improved the CES performance.

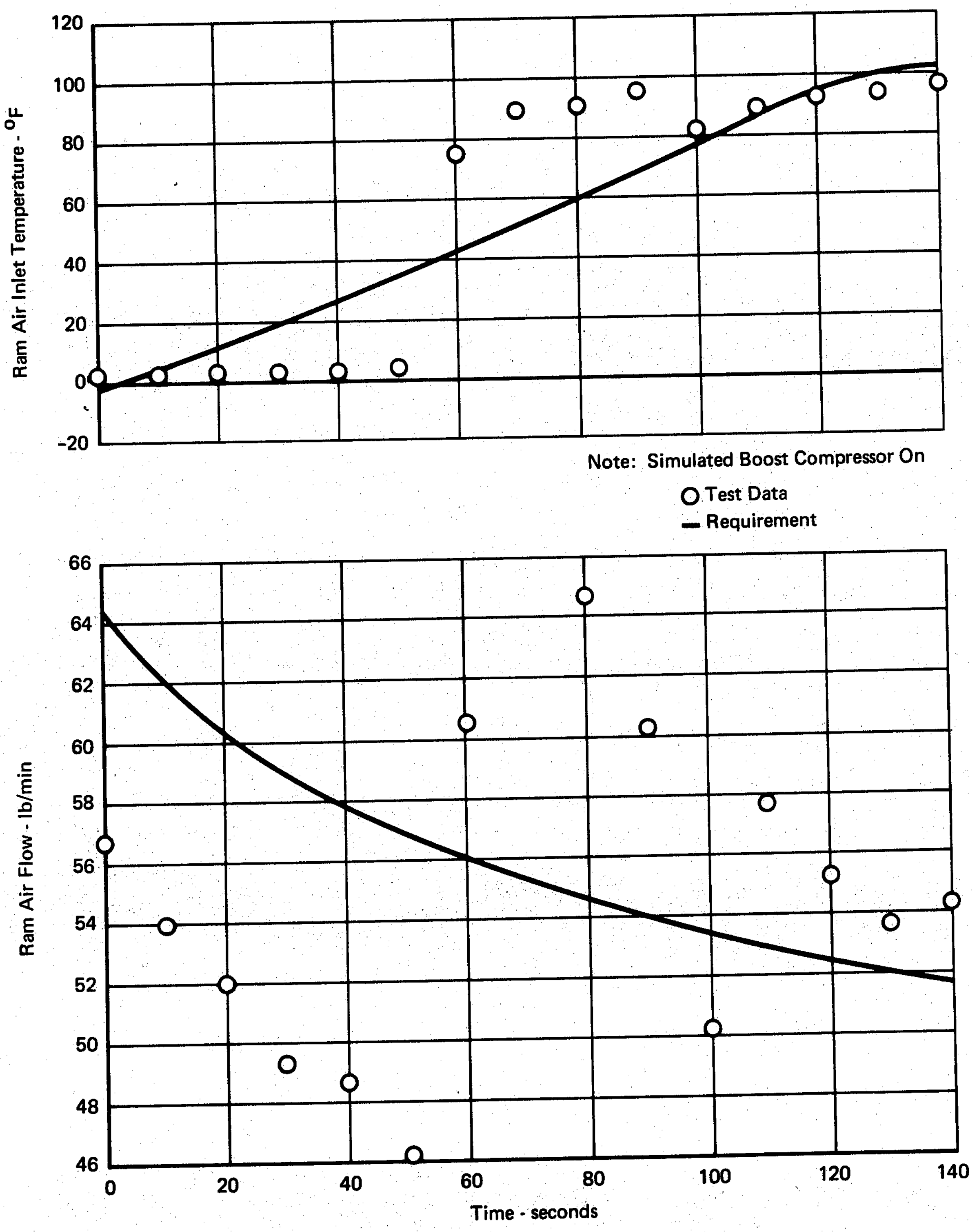


Figure 12 Achieved Ram Air Idle Descent Mission - Operating Condition 6a

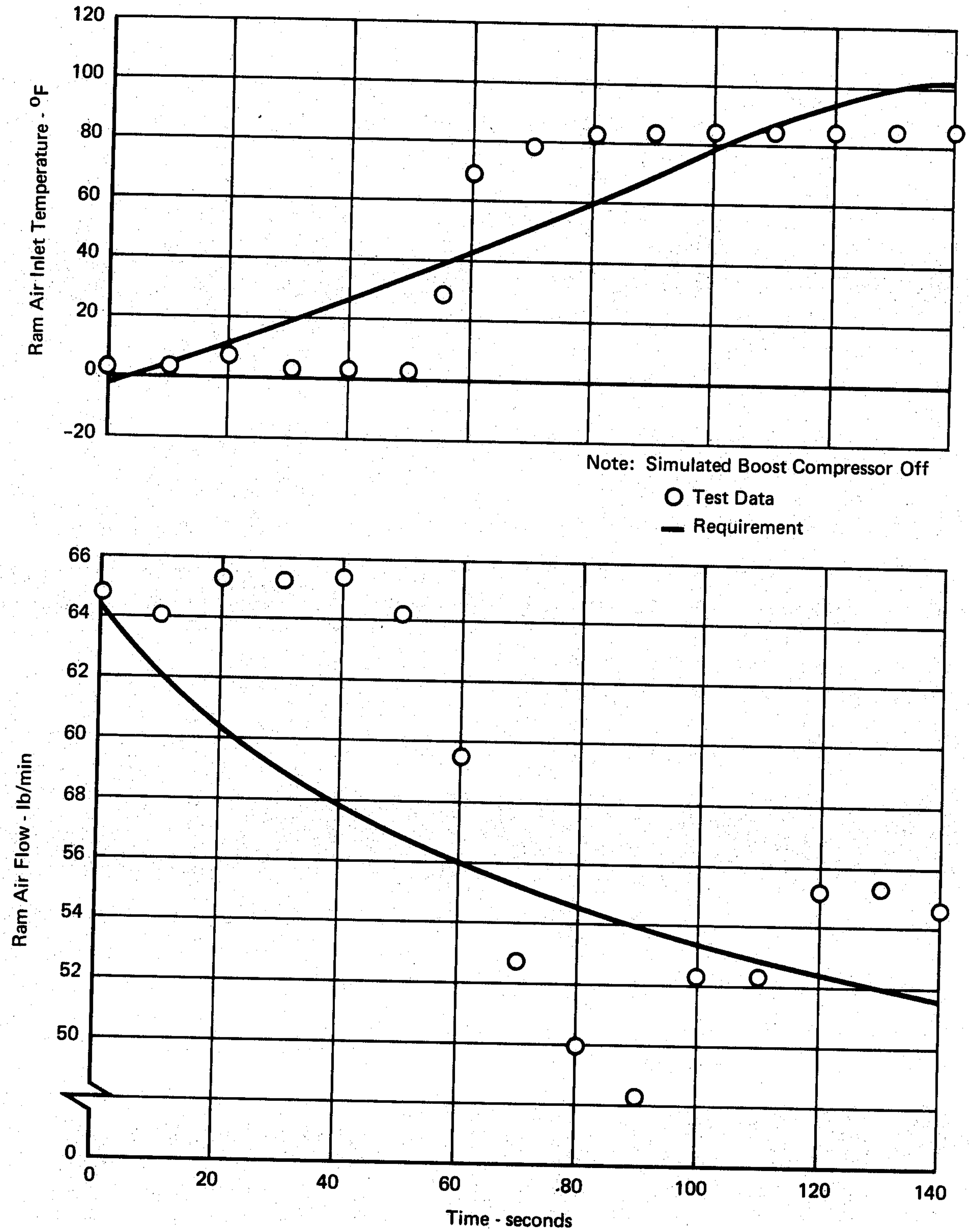


Figure 13 Achieved Ram Air Idle Descent Mission - Operating Condition 6b

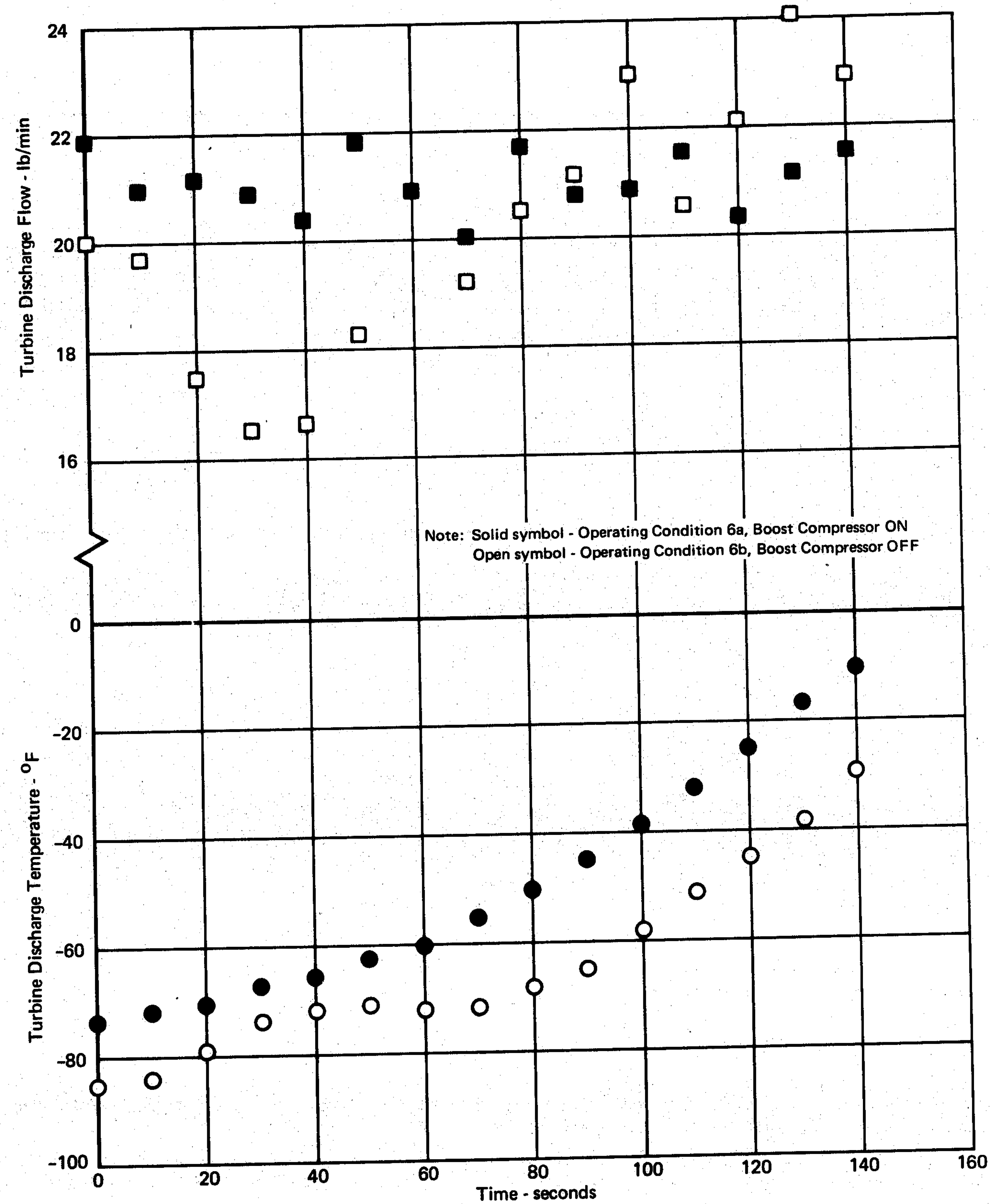


Figure 14 Turbine Discharge Idle Descent Mission Data

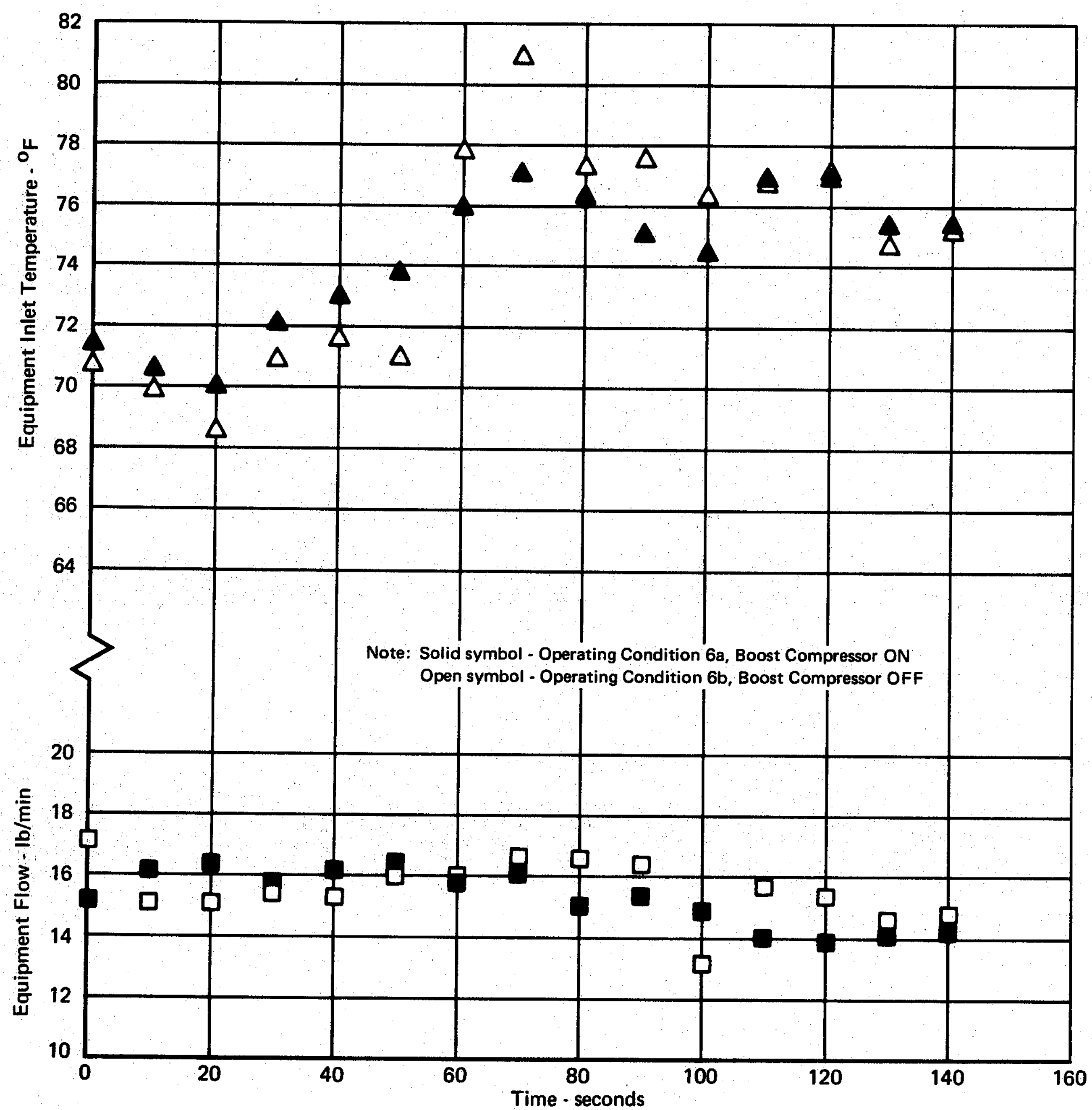


Figure 15 Equipment Inlet Simulator Idle Descent Mission Data

SECTION 7

SIZING ANALYSIS

A sizing analysis of the laboratory test ECS configuration was made using the computer program described in Volume II. The results of this analysis were system sizing and system penalty parameters. The system sizing results include the installed weight and weight standard error, cost units, reliability index, development risk, and power requirements. The system penalty parameters are relative range reduction, drag increase, gross takeoff weight increase, and payload weight reduction. The sizing analysis was made for the test ECS configuration as it would be installed in an aircraft. Correlations to the test article components are inappropriate since the components used in the test were not designed specifically for the system tested in the laboratory. The objective of this sizing analysis was to illustrate and to provide further evaluations of the computer program.

The laboratory ECS which was sized included a boost compressor, a regenerative heat exchanger, and a cooling effects system.

7.1 Component Sizing

The discussion of the component sizing is divided into four parts: lines, valves, controls, and major components. A summary of input data used for the sizing analysis of each group is presented. The performance input (i.e., flow, temperature, pressures, and humidities) was generally from the test condition (of the five basic conditions in Table III) which produced the highest flow through each component. Usually this was the sea level high velocity condition (i.e., 5a in Table III). Exceptions are indicated in the following sections. These exceptions include the boost compressor (condition 1), the regenerative heat exchanger (condition 3a), the secondary and primary heat exchangers (condition 4a), and some of the hot bleed air lines used for temperature control.

7.1.1 Line Sizing - Typical lengths of lines between system components were assumed. These lengths are different from those actually used in the ECS in the laboratory test because the laboratory ECS line lengths are not typical of a system installed in an aircraft. (See laboratory installation in Figure 2.) Pressure drops in these lines were based on a Mach number of 0.15 for fighter aircraft. An effective friction factor based on $K/L = 0.00014\ D_e^{-4}$ (to account for typical bends, duct roughness, etc.)

was used to obtain an effective line diameter. (See Section 3.10.1 of Volume I.) The assumed line lengths, and the line diameters and weights calculated by the computer program are presented in Table XI. In an actual system nominal diameters would be used.

7.1.2 Valve Sizing - Valve diameters were assumed equal to the diameter of the line in which they are located. A line diameter was not available for several of the valves, hence a reasonable diameter was assumed and specified on the computer program input sheet. The valve types, diameters, and weights are summarized in Table XII. In an actual system nominal diameters would be used.

7.1.3 Control Sizing - The following controls for this ECS were sized: boost compressor and system shutoff control with over-temperature switch, remote sensor for the pressure regulator, switch to open the ejector shutoff vavle, ECS controls to regulate the maximum trim air temperature and the flow to the regenerative heat exchanger at high speeds, pneumatic control for the anti-ice valve, equipment temperature and flow (CES) control, cockpit temperature and flow control, and cockpit pressure regulator. The sizing information input into the computer program, and weight which were output are summarized in Table XIII. An explanation for some of these controls follows. Flow to the regenerative head exchanger was assumed to be modulated when the turbine outlet temperature was above a preset temperature (e.g., 70°F). The equipment temperature and flow control was to provide 14 lb/min of air at 70°F to the equipment heat load. The cockpit temperature control included an automatic/manual selector used by the pilot, with the flow control in the automatic mode dependent on a sensor which indicates heat load (e.g., cabin average or outlet temperature, ram air temperature, etc.). The equipment and cabin temperature controls, and the boost compressor control had a technical weighting factor (K_T) of 1.2 because of these new approaches.

7.1.4 Major Component Sizing - The major component sizing discussion is subdivided into heat exchangers, turbomachines, water separator, and ram air circuit components.

7.1.4.1 Heat Exchangers - The primary and secondary heat exchangers were sized with the low altitude loiter performance data, and the regenerative heat exchanger was sized for the high altitude high velocity condition.

TABLE XI LINE SIZING SUMMARY

Description	Location			Length in.	Diameter in.	Weight lb.
	Leg	Inlet Station	Outlet Station			
Engine to Shutoff Valve	1	2	102	240	2.19	28.40
Regulator to Primary HX	7	14	114	43	1.31	2.31
Primary HX to Comp Bypass	7	16	116	15	1.24	0.74
Bypass to Comp Inlet	11	20	120	15	1.25	0.74
Hot Air to Trim Manifold	9	74	174	15	1.15	0.67
Cold Air to Trim Manifold	53	18	118	10	1.06	0.40
Trim to Anti-Ice Split	25	76	176	30	1.16	1.34
Ejector	3	6	106	30	1.25	1.50
Anti-Ice Valve to WSep	17	34	134	20	0.81	0.64
Trim to Cockpit/Equip. Split	27	80	180	50	1.70	3.95
Trim to Equip. Valve	29	82	182	15	0.76	0.47
Trim to Equip. Merge	29	86	186	30	1.59	2.13
Trim to Cockpit Valve	31	84	184	15	0.58	0.40
Trim to Cockpit Merge	31	46	146	30	1.21	1.43
Comp to Secondary HX	61	222	322	32	1.11	1.35
Secondary HX to Regen HX	61	24	124	30	1.10	1.25
Regen HX to Turbine	61	26	126	37	1.13	1.60
Turbine to WSep	65	228	328	30	2.50	1.03
Regen Valve to Regen HX	13	70	170	30	1.45	0.59
WSep to Split	55	38	138	56	2.54	1.95

TABLE XII VALVE SIZING SUMMARY

Description*	Location		Type**	Diameter in.	Weight lb
	Leg	Inlet Station			
Boost Compressor Regulator and System Shutoff	1	2	1	2.19	3.40
Pressure Regulator (R1)	5	4	1	2.00	4.36
Boost Compressor Check	1	2	6	2.19	0.74
Boost Compressor Motor Shutoff	101	600	5	0.50	1.10
Trim Air (V9)	9	12	2	1.15	2.19
Ejector Shutoff (V2)	3	206	2	1.25	2.32
Trim Air Check (V10)	53	118	6	1.06	.25
Anti-Ice (V3)	17	178	1	0.81	1.16
Regenerative HX Shutoff (V4)	13	30	2	1.45	1.91
Equipment Temperature (V8)	29	282	2	0.76	1.77
Cockpit Temperature (V7)	31	284	2	0.58	1.56
Equipment CES (V5)	21	42	2	2.00	2.22
Cockpit Flow (V11)	33	148	2	2.00	2.22

*(XX) is symbol in Figure 3.

**Type is computer program IVT.

1 - pneumatic butterfly
2 - electric butterfly
5 - poppet
6 - check

TABLE XIII CONTROL SIZING SUMMARY

Description	Type*	No. of Sensors	NIAO	Weight lb	Comment
Boost Compressor and System Shutoff	1	3	7	3.52	$K_{Te} = 1.2$
System Pressure Regulator	3	1	–	2.75	Valve D = 2.00 in.
Package (Trim Air Temperature and Regenerator Flow)	1	2	6	2.40	
Ejector Shutoff	1	1	0	0.20	
Anti-Ice	3	1	–	2.15	Valve D = 0.81 in.
Equipment Temperature and CES	1	4	8	4.16	$K_{Te} = 1.2$
Cockpit Temperature and Flow	1	5	10	5.92	$K_{Te} = 1.2$ Selector Weight = 0.6 lb
Cockpit Pressure Regulator	4	–	–	6.00	

*Type is computer program ICT:

1 - electronic temperature control
3 - pneumatic temperature control
5 - cockpit pressure control

Specification of the core fin geometry was based on maximum inlet pressure for each inlet flow leg, using Figure 42 of Volume I. The fin geometries selected for these heat exchangers were:

Primary and Secondary Heat Exchangers

Hot Side - - 24.12 R(S) - 0.075/0.075 - 1/9 (0) - 0.004

Cold Side - - 19.35 R(S) - 0.0755/0.075 - 1/10 (0) - 0.004

Regenerative Heat Exchanger

Hot Side - - 24.12 R(S) - 0.075/0.075 - 1/9 (0) - 0.004

Cold Side - - 15.76 R(D) - 0.153/0.149 - 1/7 (0) - 0.004

Complex headers were assumed for all three heat exchangers. A summary of the heat exchanger sizing results is:

Heat Exchanger	Dimensions - in. L_N	L_C	L_H	Weight lb.	CU
Primary	8.89	2.32	12.40	26.47	55.05
Secondary	9.05	2.45	11.76	27.32	56.83
Regenerative	1.37	3.40	5.63	1.86	3.87

7.1.4.2 Turbomachines - Two turbomachines were sized - the bootstrap air cycle turbine and compressor, and the boost compressor with a hydraulic motor drive. The air cycle turbine and compressor were assumed to be centrifugal flow designs sized at the sea level high velocity condition 5a. The boost compressor (also a centrifugal design) design speed was assumed to be 60,000 rpm at the sea level static condition 1d. A summary of the turbomachine sizing results is:

Component	Wheel Dia. in	Weight lb	CU
Turbine	4.07	6.61	36.37
Compressor	3.26	4.26	23.41
Boost Compressor	3.83	5.87	32.26
Hydraulic Motor and Gear Train		12.20	72.77

7.1.4.3 Water Separator - The water separator was sized with the sea level high velocity (condition 5a) performance output. The results were a weight of 2.36 lb, and 23.74 cost units.

7.1.4.4 Ram Air Circuit Components - The ram air circuit components included the ram inlet, ram outlet, and bleed air ejector. The ram air inlet and outlet were sized for the sea level high velocity condition using the weight correlations in Volume I. The bleed air ejector (and its mixing tube) was sized for the sea level static condition. The resulting ram air inlet weight was 5.91 lb, the outlet weight was 9.93 lb, and the weight of the ejector plus mixing tube was 8.72 lb.

7.2 System Sizing

System sizing parameters determined by the computer program include the system installed weight, cost units, reliability index, development risk, standard error of the system weight, power required by the ECS, the total bleed air extraction, and the ram air drag. The system installed weight is the sum of all component weights, determined at their respective "design point" performance conditions, plus the installation weight factors defined in Volume I. The weight standard error is the square root of the sum of the squares of the weight errors of the components. Component percentage standard errors are found in Volume I, as are the cost units, reliability index, and development risk. The computer program output of the system sizing parameters is shown in Figure 16.

7.3 System Penalties

Four system penalties relative to a typical fighter aircraft also are presented in Figure 16. These are gross takeoff weight increase, payload weight decrease, range reduction, and equivalent drag relative to a typical fighter aircraft without an ECS. The aircraft gross takeoff weight without ECS was assumed to be 22,000 lb, its empty weight without ECS was assumed to be 13,500 lb, and its basic fuel weight was assumed to be 4500 lb. A penalty to provide a small amount of electrical power for the controls was neglected. The penalty for use of hydraulic power to drive the boost compressor is 0.5 lb/HP plus 0.045 lb/HP per foot of hydraulic lines (assumed to be 10 ft). Power taken from the engine for other systems is assumed to be 60 HP (e.g., 30 HP hydraulic and 30 HP for electrical generator). The engine thrust required is assumed to be 2000 lb for a high altitude loiter condition lasting one hour, and the estimated lift to drag ratio is 20. The typical effects of bleed air and shaft power on engine specific fuel consumption which were used for the penalty analysis are shown in Figures 17 and 18. The output comment "COMPONENT OUTPTB EXTRAPOLATED TABLE" in Figure 16 means an extrapolation of power was made above the highest horsepower curve data (i.e., the 100 horsepower curve in Figure 18).

```
*TECS* MAJOR COMPONENT SIZING
    2  CASE   ECSSIZE

TIME F    77182.25

********
*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     0.0

       EQUIVALENT SHAFT POWER      50.

       BLEED AIR EXTRACTION      37.      FUEL CONSUMPTION       0.      DRAG       2.

COMPONENT OUTPTS EXTRAPOLATED TABLE       2    42 VALUE =  1.00495E 00 ARGUMENT(S)  2.00000E 03 1.09892E 02

***********
*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

CASE END
```

$60 + \frac{44.9}{.9} = 109.89$

Figure 16 System Sizing and Penalty Output

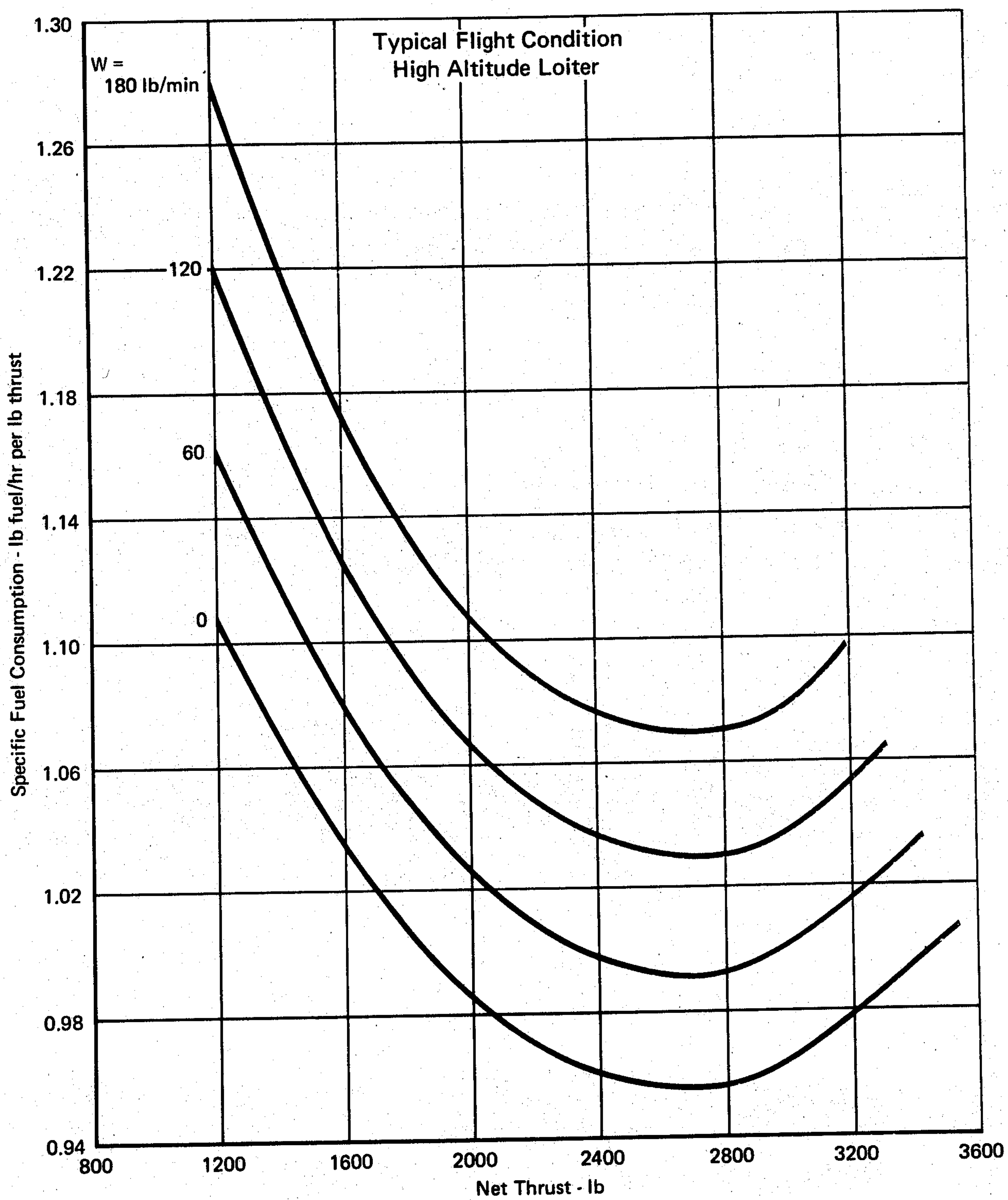


Figure 17 Effect of Compressor Discharge Bleed Air on Engine Performance

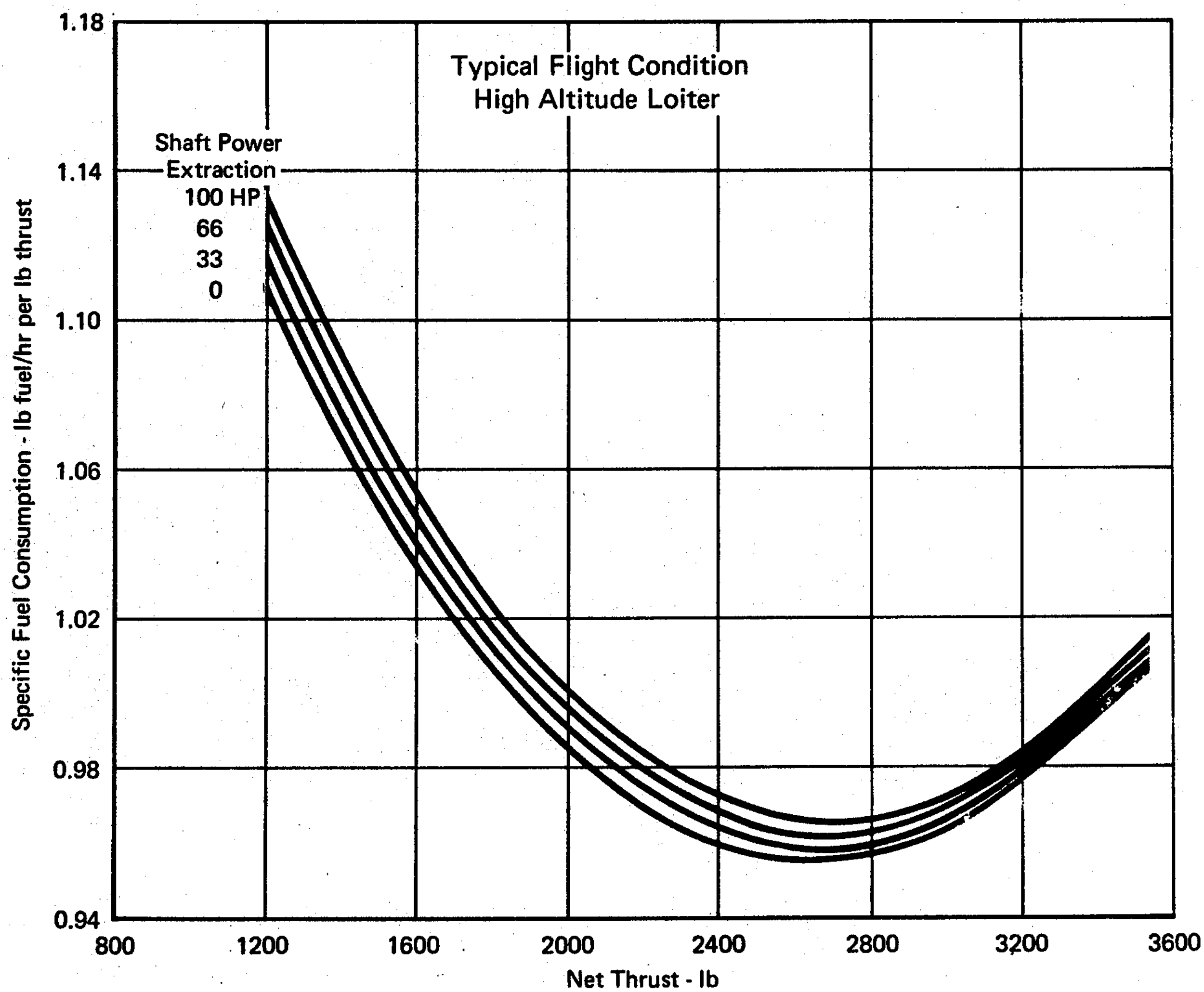


Figure 18 Effect of Shaft Power Extraction on Engine Performance

The system penalties shown in Figure 16 represent the following:

% increase in gross takeoff weight due to the ECS, assuming range and payload were constant.

% decrease in payload weight due to the ECS, assuming range and gross takeoff weight were constant.

% reduction in range due to the ECS, assuming gross takeoff weight and payload weight were constant.

% increase in drag due to the ECS.

SECTION 8

SUMMARY COMMENTS

Summary comments concerning conclusions observed from the test results, a key assumption basic to the test objectives, and some pertinent information obtained as a result of using the computer program to evaluate the test data and to size the system are presented.

1. The three additional components were all shown to be assets to the system performance. The regenerator and boost compressor increased capacity in certain areas of the operating envelope so that maintaining a constant inlet equipment temperature and constant flow rate (via the CES) appears feasible. The system configuration including the above three components met the design capacity requirements except at the sea level high speed operating condition, which was 5% low.
2. The boost compressor looks promising for use at low engine speeds (i.e., low bleed air pressures) during idle and loiter operating conditions. This is illustrated by test runs 1f, 1g, and 1h.
3. The cooling effects system valve would have provided lower bleed air usage penalties while maintaining adequate temperature control, if it had been located upstream of the turbomachinery (instead of downstream as in the test).
4. It was assumed that the reliability of cooled or heated avionic equipment is improved if the temperature cycling of the equipment is reduced. This is based on tests described in Reference 1 and 2, and it is the reason that a constant inlet equipment temperature was specified for the tests.
5. The test ECS was not assembled as an actual flight configuration ECS. One difference was the long lines that were used between the components. The long lines were advantageous for the measurement of accurate air properties. They were disadvantageous in that heat losses were higher. Another difference was that the addition of the extra components changed the performance characteristics of the system (i.e., the components were not designed to function specifically in the test system). Therefore, system performance was not optimum.

6. The computer program was shown to be a desirable tool in evaluating test article ECS performance data. This evaluation inherently illustrates the validity of the computer program.
7. The inability to show correlation between the test performance data and that determined by the computer program during initial evaluation of the test data illustrated the importance of using input data which accurately describe each component. Some incomplete heat exchanger map data and unknown duct heat losses were detrimental to obtaining good performance correlation between the test and computer program results.
8. The correlation of the test and calculated data is based on using vendor performance maps for analysis of major components (i.e., turbomachinery, heat exchangers, and water separator) and empirical data (i.e., from Reference 5) for calculating duct pressure losses.
9. The sizing analysis illustrates the use of the sizing portion of the computer program. The components and system sizing output parameters are not optimized.

APPENDIX A

COMPUTER MODEL BOUNDARY CONDITION DATA

The boundary data used in the computer program for each test condition analyzed are listed in the following table. These data are identified in conjunction with the computer program in Section 6.2.1.2.

COMPUTER MODEL BOUNDARY CONDITIONS

PARAMETER DESCRIPTION	PARAMETER LOCATION	TEST CONDITIONS														
		1a	1b	1c	1d	1e	2a	2b	2c	3a	4a	4b	4c	4d	5a	5b
BLEED PRESSURE, psia	2	99.8	97.5	69.9	105.0	69.4	110.0	107.0	65.22	134.0	77.9	68.2	70.2	70.0	204	206
BLEED TEMPERATURE, °R	3	1133.0	1132.0	950.0	1063.0	890.0	1253.0	1258.5	1055.0	1308.0	1111.4	927.0	777.0	777.0	1292.0	1288.7
BLEED HUMIDITY, lb/lb	4	0.	0.	0.	.0201	.022	0.	0.	0.	0.	.03	.024	0.	0.	.014	.016
RAM FLOW, lb/min	25	45.0	45.0	45.0	55.0	45.0	59.0	60.0	66.7	209.0	106.4	107.0	107.2	106.0	406.0	407.0
RAM PRESSURE, psia	26	14.6	14.89	14.6	14.8	14.8	14.9	14.9	14.9	18.3	15.7	15.6	11.4	15.7	25.9	26.2
RAM TEMPERATURE, °R	27	579.4	584.9	581.4	555.4	553.4	465.7	460.0	464.2	759.4	557.0	557.0	459.3	459.3	674.0	695.6
RAM HUMIDITY, lb/lb	28	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
FLOW SPLIT TO LEG 53	38	.0990	.0680	.0980	.0010	.0010	.2300	.2920	.1449	.0622	.1281	.1330	.0742	.0197	.0218	.0233
COMPRESSOR INLET P, psia	48	69.5	71.2	62.0	71.1	61.4	59.3	63.3	65.22	59.1	65.7	59.4	63.1	61.8	75.2	76.5
FLOW SPLIT TO LEG 13	84	-	-	-	-	-	-	-	-	.2407	-	-	-	-	-	-
WATER SEPARATOR INLET T, °R	110	525.0	515.0	510.0	520.0	522.5	443.5	420.0	433.9	489.7	515.0	515.0	522.0	422.9	533.0	529.0
FLOW SPLIT TO LEG 21	115	.4929	.6695	.5110	.5295	.6004	.5046	.6517	.5070	.7719	.4009	.4662	.4258	.6917	.6265	.7471
EQUIPMENT SIMULATOR INLET T, °R	139	529.0	532.0	528.8	531.1	530.4	533.2	533.1	532.4	533.4	527.1	528.3	548.0	529.1	535.6	531.9
COCKPIT SIMULATOR INLET T, °R	163	536.2	537.4	535.3	534.3	530.0	523.1	525.6	533.6	500.7	522.0	524.3	548.0	537.9	538.4	531.9
TURBOMACHINE LEAKAGE, lb/min	246	2.92	1.98	2.50	.07	.39	2.69	1.93	.03	.17	3.42	3.16	1.75	1.75	1.28	1.28
EJECTOR FLOW, lb/min	259	31.4	30.68	24.16	34.60	24.80	-	-	-	-	-	-	-	-	-	-
TRIM TEMPERATURE, STA 146, °R	260	731.7	763.4	733.9	753.3	741.8	839.3	817.4	801.1	572.0	787.9	702.1	632.4	730.2	576.0	673.0
TRIM TEMPERATURE, STA 186, °R	261	652.7	788.0	678.4	739.9	745.2	833.0	839.5	796.6	884.0	762.2	698.3	632.3	741.5	551.7	625.0
TRIM TEMPERATURE, STA 134, °R	262	548.1	546.4	527.1	629.9	631.6	605.6	520.8	757.8	898.6	550.5	555.3	764.8	576.0	775.7	587.0
ORIF LEG 3 PRESSURE RATIO	264	.9575	.9583	.9576	.9530	.9573	-	-	-	-	-	-	-	-	-	-
ORIF LEG 7 PRESSURE RATIO	265	.9829	.9818	.9849	.9836	.9855	.9456	.9453	.9766	.9749	.9536	.9853	.9863	.9839	.9790	.9766
ORIF LEG 11 PRESSURE RATIO	266	.9767	.9716	.9782	.9706	.9728	.9677	.9664	.9721	.9662	.9694	.9734	.9799	.9750	.9736	.9689
ORIF LEG 17 PRESSURE RATIO	267	.9930	.9930	.9936	.9998	.9997	.9790	.9869	.9840	.9990	.9928	.9728	.8444	.9393	.9990	.9990
ORIF LEG 29 PRESSURE RATIO	268	.9995	.9976	.9987	.9986	.9975	.9888	.9663	.9783	.9978	.9969	.9975	.9990	.8737	.9990	.9990
ORIF LEG 31 PRESSURE RATIO	269	.9995	.9996	.9990	.9996	.9999	.9942	.9937	.9863	.9980	.9973	.9981	.9990	.9747	.974	.9685
TURBINE EXIT PRESSURE, psia	276	23.7	17.6	23.8	17.7	18.0	10.8	10.6	15.8	7.8	15.3	18.1	26.0	21.6	23.9	19.2

APPENDIX B

CALCULATED PERFORMANCE DATA

Copies of the computer program output summary data sheets for each test condition analyzed are included. State and error variables are identified. Air flow rate data are included for each leg of the computer model, and pressure, temperature, and humidity data are included for each station location of the model (see Figure 10).

LABORATORY DEMONSTRATION TEST
CASE IECS-1A

FLOW RATE(S)

(1)	54.49	(3)	30.36	(5)	24.13	(7)	22.78	(9)	1.34	(11)	20.52
(15)	17.59	(17)	2.71	(19)	20.31	(21)	10.01	(23)	10.30	(25)	3.61
(27)	0.90	(29)	0.32	(31)	0.58	(33)	10.87	(41)	10.33	(43)	45.00
(45)	23.31	(47)	21.69	(49)	45.00	(51)	75.36	(53)	2.26	(55)	20.31
(57)	0.0	(61)	20.52	(63)	2.53	(65)	17.59				

PRESSURE(S)

(2)	99.80	(4)	55.60	(6)	55.60	(8)	94.13	(10)	78.69	(12)	78.69
(14)	78.69	(16)	71.65	(18)	71.35	(20)	71.35	(22)	97.38	(24)	93.63
(26)	92.13	(28)	23.70	(32)	23.69	(34)	70.84	(36)	23.69	(38)	23.25
(42)	23.24	(44)	23.24	(46)	71.31	(48)	23.23	(50)	23.20	(54)	23.24
(64)	23.20	(66)	23.03	(74)	71.35	(76)	71.35	(78)	71.34	(80)	71.34
(82)	71.34	(84)	71.34	(86)	71.31	(90)	14.60	(92)	14.58	(94)	14.55
(96)	14.58	(98)	14.55	(100)	14.55	(102)	99.80	(106)	99.26	(108)	87.55
(114)	78.02	(116)	71.35	(118)	71.35	(120)	71.16	(124)	93.39	(126)	91.88
(128)	23.70	(132)	23.69	(134)	70.70	(136)	23.69	(138)	23.24	(144)	23.23
(146)	71.30	(148)	23.20	(150)	23.11	(156)	23.24	(164)	23.18	(174)	71.35
(176)	71.34	(178)	70.84	(180)	71.34	(182)	71.34	(184)	71.34	(186)	71.31
(190)	14.60	(200)	14.57	(206)	55.04	(214)	76.69	(218)	71.35	(220)	69.50
(222)	97.38	(228)	23.70	(256)	23.20	(282)	71.31	(284)	71.31	(290)	14.58
(300)	14.52	(322)	56.36	(328)	23.69	(400)	14.52	(500)	23.25		

TEMPERATURE(S)

(2)	1133.00	(4)	1133.00	(6)	1133.00	(8)	1133.00	(10)	1133.00	(12)	1133.00
(14)	1133.00	(16)	768.40	(18)	768.39	(20)	768.39	(22)	908.24	(24)	672.74
(26)	672.73	(28)	521.43	(32)	521.43	(34)	908.84	(36)	525.00	(38)	525.00
(42)	525.00	(44)	525.00	(46)	909.83	(48)	536.20	(50)	536.20	(54)	525.00
(64)	529.00	(66)	619.61	(74)	1133.00	(76)	908.84	(78)	908.84	(80)	908.84
(82)	908.93	(84)	528.83	(86)	908.83	(90)	579.40	(92)	579.40	(94)	792.04
(96)	579.40	(98)	581.58	(100)	984.51	(102)	1133.00	(106)	1133.00	(108)	1133.00
(114)	1133.00	(116)	768.39	(118)	768.39	(120)	768.39	(124)	672.73	(126)	672.73
(128)	521.43	(132)	521.43	(134)	548.10	(136)	525.00	(138)	525.00	(144)	525.00
(146)	731.70	(148)	536.20	(150)	555.22	(156)	525.00	(164)	529.00	(174)	1133.00
(176)	913.84	(178)	908.84	(180)	908.83	(182)	908.83	(184)	908.83	(186)	652.70
(190)	579.40	(200)	884.51	(206)	1133.00	(214)	1133.00	(218)	768.39	(220)	768.39
(222)	908.24	(228)	521.43	(256)	525.00	(282)	908.83	(284)	908.83	(290)	579.40
(300)	987.02	(322)	908.24	(328)	521.43	(400)	987.02	(500)	525.00		

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	(32)	0.0	(34)	0.0	(36)	0.0	(38)	0.0
(42)	0.0	(44)	0.0	(46)	0.0	(48)	0.0	(50)	0.0	(54)	0.0
(64)	0.0	(66)	0.0	(74)	0.0	(76)	0.0	(78)	0.0	(80)	0.0

```
      LABORATORY DEMONSTRATION TEST
      CASE IFCS-1A

(  82)  0.0    (  84)  0.0    (  86)  0.0    (  90)  0.0    (  92)  0.0    (  94)  0.0
(  96)  0.0    (  98)  0.0    ( 100)  0.0    ( 102)  0.0    ( 106)  0.0    ( 108)  0.0
( 114)  0.0    ( 116)  0.0    ( 118)  0.0    ( 120)  0.0    ( 124)  0.0    ( 126)  0.0
( 128)  0.0    ( 132)  0.0    ( 134)  0.0    ( 136)  0.0    ( 138)  0.0    ( 144)  0.0
( 146)  0.0    ( 148)  0.0    ( 150)  0.0    ( 156)  0.0    ( 164)  0.0    ( 174)  0.0
( 176)  0.0    ( 178)  0.0    ( 180)  0.0    ( 182)  0.0    ( 184)  0.0    ( 186)  0.0
( 190)  0.0    ( 200)  0.0    ( 206)  0.0    ( 214)  0.0    ( 218)  0.0    ( 220)  0.0
( 222)  0.0    ( 226)  0.0    ( 256)  0.0    ( 282)  0.0    ( 284)  0.0    ( 290)  0.0
( 300)  0.0    ( 322)  0.0    ( 328)  0.0    ( 400)  0.0    ( 500)  1.0000

STATE VARIABLE TYPE(S)
(   1)    1 (   2)    6 (   3)    5 (   4)    6 (   5)    5 (   6)    7 (   7)    8 (   8)    5 (   9)    5 (  10)    5

STATE VARIABLE(S)
(   1) 5.44859E 01 (   2) 3.62545E-02 (   3) 5.57391E-02 (   4) 4.05937E 00 (   5) 5.18061E-01 (   6) 5.50457E 04
(   7) 3.87694E 00 (   8) 1.42590E-01 (   9) 7.51869E-01 (  10) 3.56504E-01

ERROR VARIABLE TYPE(S)
(   1)    2 (   2)    2 (   3)    2 (   4)    1 (   5)    5 (   6)    2 (   7)    1 (   8)    3 (   9)    3 (  10)    3

ERROR VARIABLE(S)
(   1) 3.05176E-05 (   2) 1.52588E-05 (   3) 0.0         (   4)-1.52588E-05 (   5) 1.06812E-04 (   6) 1.52588E-05
(   7) 0.0         (   8) 4.88281E-04 (   9) 4.88281E-04 (  10) 4.88281E-04

SOLUTION CONVERGED IN      5 TRY(S)

      0 ERROR(S) DETECTED

CASE END
```

LABORATORY DEMONSTRATION TEST
CASE IECS-1B

FLOW RATE(S)

(1)	56.91	(3)	25.22	(5)	27.69	(7)	24.34	(9)	3.35	(11)	22.69
(15)	20.71	(17)	3.21	(19)	23.92	(21)	16.02	(23)	7.91	(25)	5.01
(27)	1.79	(29)	1.03	(31)	0.76	(33)	8.67	(41)	17.05	(43)	45.00
(45)	23.10	(47)	21.90	(49)	45.00	(51)	74.22	(53)	1.66	(55)	23.92
(57)	0.0	(61)	22.69	(63)	1.58	(65)	20.71				

PRESSURE(S)

(2)	97.50	(4)	97.50	(6)	97.50	(8)	92.07	(10)	81.64	(12)	81.64
(14)	81.64	(16)	73.65	(18)	73.51	(20)	73.51	(22)	108.32	(24)	103.99
(26)	102.27	(28)	17.66	(32)	17.64	(34)	72.99	(36)	17.64	(38)	16.93
(42)	16.91	(44)	16.91	(46)	73.47	(48)	16.91	(50)	16.88	(54)	16.91
(64)	16.78	(66)	16.18	(74)	73.51	(76)	73.51	(78)	73.50	(80)	73.50
(82)	73.50	(84)	73.50	(86)	73.32	(90)	14.89	(92)	14.87	(94)	14.84
(96)	14.87	(98)	14.84	(100)	14.84	(102)	97.50	(106)	96.99	(108)	85.76
(114)	80.91	(116)	73.51	(118)	73.51	(120)	73.28	(124)	103.72	(126)	101.99
(128)	17.66	(132)	17.64	(134)	72.77	(136)	17.64	(138)	16.91	(144)	16.91
(146)	73.46	(148)	16.68	(150)	16.60	(156)	16.91	(164)	16.73	(174)	73.51
(176)	73.50	(178)	72.59	(180)	73.50	(182)	73.50	(184)	73.50	(186)	73.32
(190)	14.69	(200)	14.81	(206)	52.54	(214)	79.44	(219)	73.51	(220)	71.20
(222)	108.32	(226)	17.66	(256)	16.78	(282)	73.32	(284)	73.47	(290)	14.87
(300)	14.81	(322)	107.14	(328)	17.64	(400)	14.81	(500)	16.93		

TEMPERATURE(S)

(2)	1132.00	(4)	1132.00	(6)	1132.00	(8)	1132.00	(10)	1132.00	(12)	1132.00
(14)	1132.00	(16)	784.45	(18)	784.45	(20)	784.45	(22)	966.77	(24)	707.94
(26)	707.94	(28)	510.11	(32)	510.11	(34)	1020.98	(36)	515.00	(38)	515.00
(42)	515.00	(44)	515.00	(46)	1020.98	(48)	537.40	(50)	537.40	(54)	515.00
(64)	532.00	(66)	587.28	(74)	1132.00	(76)	1020.98	(78)	1020.98	(80)	1020.98
(82)	1020.98	(84)	1020.98	(86)	1020.98	(90)	584.90	(92)	584.90	(94)	847.14
(96)	584.90	(98)	950.69	(100)	917.76	(102)	1132.00	(106)	1132.00	(108)	1132.00
(114)	1132.00	(116)	784.45	(118)	784.45	(120)	784.45	(124)	707.94	(126)	707.94
(128)	510.11	(132)	510.11	(134)	546.40	(136)	515.00	(139)	515.00	(144)	515.00
(146)	763.37	(148)	537.40	(150)	560.65	(156)	515.00	(164)	532.00	(174)	1132.00
(176)	1020.98	(178)	1020.98	(180)	1020.98	(182)	1020.98	(184)	1020.98	(186)	788.09
(190)	584.90	(200)	917.76	(206)	1132.00	(214)	1132.00	(219)	784.45	(220)	784.45
(222)	966.77	(228)	510.11	(256)	515.00	(282)	1020.98	(284)	1020.98	(290)	584.90
(300)	1003.72	(322)	966.77	(328)	510.11	(400)	1003.72	(500)	515.00		

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	(32)	0.0	(34)	0.0	(36)	0.0	(38)	0.0
(42)	0.0	(44)	0.0	(46)	0.0	(48)	0.0	(50)	0.0	(54)	0.0
(64)	0.0	(66)	0.0	(74)	0.0	(76)	0.0	(78)	0.0	(80)	0.0

```
        LABORATORY DEMONSTRATION TEST
        CASE IECS-1E

 (  82)  0.0     (  84)  0.0     (  86)  0.0     (  50)  0.0     (  92)  0.0     (  94)  0.0
 (  96)  0.0     (  98)  0.0     ( 100)  0.0     ( 102)  0.0     ( 106)  0.0     ( 108)  0.0
 ( 114)  0.0     ( 116)  0.0     ( 118)  0.0     ( 120)  0.0     ( 124)  0.0     ( 126)  0.0
 ( 128)  0.0     ( 132)  0.0     ( 134)  0.0     ( 136)  0.0     ( 138)  0.0     ( 144)  0.0
 ( 146)  0.0     ( 148)  0.0     ( 150)  0.0     ( 156)  0.0     ( 164)  0.0     ( 174)  0.0
 ( 176)  0.0     ( 178)  0.0     ( 180)  0.0     ( 182)  0.0     ( 184)  0.0     ( 186)  0.0
 ( 190)  0.0     ( 200)  0.0     ( 206)  0.0     ( 214)  0.0     ( 218)  0.0     ( 220)  0.0
 ( 222)  0.0     ( 228)  0.0     ( 256)  0.0     ( 282)  0.0     ( 284)  0.0     ( 290)  0.0
 ( 300)  0.0     ( 322)  0.0     ( 328)  0.0     ( 400)  0.0     ( 500)  1.0000

 STATE VARIABLE TYPE(S)
 (   1)     1 (   2)     6 (   3)     5 (   4)     6 (   5)     5 (   6)     7 (   7)     8 (   8)     5 (   9)     5 (  10)     5

 STATE VARIABLE(S)
 (   1) 5.69117E 01 (   2) 2.06789E-02 (   3) 1.20983E-01 (   4) 7.24519E-01 (   5) 5.13307E-01 (   6) 6.21483E 04
 (   7) 5.77505E 00 (   8) 8.71049E-02 (   9) 6.41965E-01 (  10) 5.74905E-01

 ERROR VARIABLE TYPE(S)
 (   1)     2 (   2)     2 (   3)     2 (   4)     1 (   5)     5 (   6)     2 (   7)     1 (   8)     3 (   9)     3 (  10)     3

 ERROR VARIABLE(S)
 (   1) 1.52588E-05 (   2) 3.05176E-05 (   3) 0.0           (   4) 1.52588E-05 (   5) 2.28882E-04 (   6)-1.52588E-05
 (   7) 0.0         (   8)-2.44141E-04 (   9) 0.0           (  10) 2.44141E-04

 SOLUTION CONVERGED IN     5 TRY(S)

        0 ERROR(S) DETECTED

 CASE END
```

LABORATORY DEMONSTRATION TEST
CASE IECS-1C

FLOW RATE(S)

(1)	47.50	(3)	23.81	(5)	23.69	(7)	20.51	(9)	3.18	(11)	18.50
(15)	16.00	(17)	2.85	(19)	18.86	(21)	9.64	(23)	9.22	(25)	5.19
(27)	2.33	(29)	1.19	(31)	1.15	(33)	10.37	(41)	10.83	(43)	45.00
(45)	22.98	(47)	22.02	(49)	45.00	(51)	68.81	(53)	2.01	(55)	18.86
(57)	0.0	(61)	18.50	(63)	2.50	(65)	16.00				

PRESSURE(S)

(2)	69.90	(4)	69.90	(6)	69.90	(8)	65.86	(10)	69.38	(12)	69.38
(14)	69.38	(16)	63.79	(18)	63.54	(20)	63.54	(22)	86.11	(24)	87.88
(26)	81.57	(28)	23.83	(32)	23.82	(34)	63.12	(36)	23.82	(38)	23.43
(42)	23.42	(44)	23.42	(46)	63.46	(48)	23.42	(53)	23.39	(54)	23.42
(64)	23.39	(66)	23.21	(74)	63.54	(76)	63.54	(78)	63.53	(80)	63.53
(82)	63.53	(84)	63.53	(86)	63.45	(90)	14.60	(92)	14.58	(94)	14.55
(96)	14.58	(98)	14.55	(100)	14.55	(102)	69.90	(106)	69.50	(108)	60.79
(114)	68.86	(116)	63.54	(118)	63.54	(120)	63.38	(124)	82.68	(126)	81.35
(128)	23.83	(132)	23.82	(134)	62.96	(136)	23.82	(139)	23.42	(144)	23.42
(146)	63.44	(148)	23.40	(150)	23.31	(156)	23.42	(164)	23.37	(174)	63.54
(176)	63.53	(178)	63.12	(180)	63.53	(182)	63.53	(184)	63.53	(186)	63.44
(190)	14.60	(200)	14.52	(206)	66.55	(214)	67.82	(218)	63.54	(220)	62.00
(222)	86.11	(228)	23.93	(256)	23.39	(282)	63.45	(284)	63.46	(290)	14.58
(300)	14.52	(322)	85.26	(328)	23.82	(400)	14.52	(500)	23.43		

TEMPERATURE(S)

(2)	950.00	(4)	950.00	(6)	950.00	(8)	950.00	(10)	950.00	(12)	950.00
(14)	950.00	(16)	691.74	(18)	691.74	(20)	691.74	(22)	815.18	(24)	639.69
(26)	639.69	(28)	506.94	(32)	506.94	(34)	852.24	(36)	510.00	(38)	510.00
(42)	510.00	(44)	510.00	(46)	852.24	(48)	535.30	(50)	535.30	(54)	510.00
(64)	528.80	(66)	815.35	(74)	950.00	(76)	852.24	(78)	852.24	(80)	852.24
(82)	852.24	(84)	852.24	(86)	852.24	(90)	581.40	(92)	581.40	(94)	725.05
(96)	581.40	(98)	829.23	(100)	776.41	(102)	950.00	(106)	950.00	(108)	950.00
(114)	950.00	(116)	691.74	(118)	691.74	(120)	691.74	(124)	639.69	(126)	639.69
(128)	506.94	(132)	506.94	(134)	527.11	(136)	510.00	(138)	510.00	(144)	510.00
(146)	733.92	(148)	535.30	(150)	555.30	(156)	510.00	(164)	528.80	(174)	950.00
(176)	852.24	(178)	852.24	(180)	852.24	(182)	852.24	(184)	852.24	(186)	678.37
(190)	581.40	(200)	776.41	(206)	950.00	(214)	950.00	(218)	691.74	(220)	691.74
(222)	815.18	(228)	506.94	(256)	510.00	(282)	852.24	(284)	852.24	(290)	581.40
(300)	837.49	(322)	815.18	(328)	506.94	(400)	837.49	(500)	510.00		

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	(32)	0.0	(34)	0.0	(36)	0.0	(38)	0.0
(42)	0.0	(44)	0.0	(46)	0.0	(48)	0.0	(50)	0.0	(54)	0.0
(64)	0.0	(66)	0.0	(74)	0.0	(76)	0.0	(78)	0.0	(80)	0.0

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LABORATORY DEMONSTRATION TEST
CASE TCCS-1C

(  82) 0.0    (  84) 0.0    (  86) 0.0    (  90) 0.0    (  92) 0.0    (  94) 0.0
(  96) 0.0    (  98) 0.0    ( 100) 0.0    ( 102) 0.0    ( 106) 0.0    ( 108) 0.0
( 114) 0.0    ( 116) 0.0    ( 118) 0.0    ( 120) 0.0    ( 124) 0.0    ( 126) 0.0
( 128) 0.0    ( 132) 0.0    ( 134) 0.0    ( 136) 0.0    ( 138) 0.0    ( 144) 0.0
( 146) 0.0    ( 148) 0.0    ( 150) 0.0    ( 156) 0.0    ( 164) 0.0    ( 174) 0.0
( 176) 0.0    ( 178) 0.0    ( 180) 0.0    ( 182) 0.0    ( 184) 0.0    ( 186) 0.0
( 190) 0.0    ( 200) 0.0    ( 206) 0.0    ( 214) 0.0    ( 218) 0.0    ( 220) 0.0
( 222) 0.0    ( 228) 0.0    ( 256) 0.0    ( 282) 0.0    ( 284) 0.0    ( 290) 0.0
( 300) 0.0    ( 322) 0.0    ( 328) 0.0    ( 400) 0.0    ( 500) 1.0000

STATE VARIABLE TYPE(S)
(  1)   1 (  2)   6 (  3)   5 (  4)   6 (  5)   5 (  6)   7 (  7)   8 (  8)   5 (  9)   5 ( 10)   5

STATE VARIABLE(S)
(  1) 4.75042E 01 (  2) 9.27548E-04 (  3) 1.34186E-01 (  4) 5.77638E-01 (  5) 5.10685E-01 (  6) 5.14862E 04
(  7) 3.41378E 00 (  8) 1.35167E-01 (  9) 5.59117E-01 ( 10) 5.09419E-01

ERROR VARIABLE TYPE(S)
(  1)   2 (  2)   2 (  3)   2 (  4)   1 (  5)   5 (  6)   2 (  7)   1 (  8)   3 (  9)   3 ( 10)   3

ERROR VARIABLE(S)
(  1) 1.93195E-04 (  2) 7.62939E-05 (  3) 0.0         (  4) 4.57764E-05 (  5) 3.24249E-04 (  6)-4.57764E-05
(  7)-2.86102E-06 (  8)-7.32422E-04 (  9)-4.88281E-04 ( 10)-1.46484E-03

SOLUTION CONVERGED IN      9 TRY(S)

     0 ERROR(S) DETECTED

CASE END
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LABORATORY CEMCNSTRATION TEST
CASE IECS-1C

FLCW RATE(S)

(1)	63.67	(3)	35.71	(5)	27.56	(7)	23.89	(9)	4.07	(11)	23.87
(15)	23.80	(17)	1.39	(19)	25.19	(21)	13.23	(23)	11.75	(25)	4.09
(27)	2.70	(29)	1.37	(31)	1.33	(33)	13.08	(41)	14.60	(43)	55.00
(45)	28.26	(47)	26.74	(49)	55.CC	(51)	90.71	(53)	0.02	(55)	24.98
(57)	0.21	(61)	23.87	(63)	C.C7	(65)	23.80				

PRESSURE(S)

(2)	1C5.00	(4)	1C5.C0	(6)	1C5.CC	(8)	98.33	(10)	80.76	(12)	80.76
(14)	80.76	(16)	73.77	(18)	73.48	(20)	73.48	(22)	108.52	(24)	104.22
(26)	102.51	(28)	17.76	(32)	17.74	(34)	73.46	(36)	17.73	(38)	16.97
(42)	16.95	(44)	16.95	(46)	73.44	(48)	16.95	(50)	16.89	(54)	16.95
(64)	16.87	(66)	16.42	(74)	73.48	(76)	73.48	(78)	73.47	(80)	73.47
(82)	73.47	(84)	73.47	(86)	73.37	(9C)	14.80	(92)	14.77	(94)	14.73
(96)	14.77	(98)	14.73	(1CC)	14.73	(1C2)	105.00	(106)	104.36	(108)	90.71
(114)	80.10	(116)	73.48	(118)	73.48	(120)	73.25	(124)	103.95	(126)	102.23
(128)	17.76	(132)	17.73	(134)	73.41	(136)	17.73	(138)	16.95	(144)	16.95
(146)	73.41	(148)	16.89	(15C)	16.71	(156)	16.95	(164)	16.83	(174)	73.48
(176)	73.47	(178)	73.46	(18C)	73.47	(182)	73.47	(184)	73.47	(186)	73.36
(190)	14.80	(2C0)	14.69	(2C6)	99.45	(214)	78.78	(218)	73.48	(220)	71.10
(222)	108.52	(228)	17.76	(256)	16.87	(282)	73.37	(284)	73.44	(290)	14.77
(300)	14.69	(322)	1C7.36	(328)	17.74	(4C0)	14.69	(500)	16.97		

TEMPERATURE(S)

(2)	1063.00	(4)	1C63.00	(6)	1C63.C0	(8)	1063.00	(10)	1063.00	(12)	1063.00
(14)	1063.00	(16)	705.11	(18)	7C5.11	(20)	705.11	(22)	871.55	(24)	642.23
(26)	642.23	(28)	516.C6	(32)	516.C4	(34)	1060.86	(36)	520.00	(38)	519.27
(42)	519.25	(44)	519.25	(46)	1C6C.86	(48)	534.30	(50)	534.30	(54)	519.25
(64)	531.10	(66)	554.27	(74)	1C63.CC	(76)	1060.86	(78)	1060.86	(80)	1060.86
(82)	1060.86	(84)	1060.86	(86)	1C6C.86	(90)	554.40	(92)	554.40	(94)	752.65
(96)	554.40	(98)	888.19	(1CC)	819.22	(1C2)	1063.00	(106)	1063.00	(108)	1063.00
(114)	1063.00	(116)	705.11	(118)	7C5.11	(120)	705.11	(124)	642.23	(126)	642.23
(128)	516.06	(132)	516.C4	(134)	629.99	(136)	520.00	(138)	519.25	(144)	519.24
(146)	753.32	(148)	534.30	(15C)	547.13	(156)	519.25	(164)	531.10	(174)	1063.00
(176)	1060.86	(178)	1C6C.86	(18C)	1C6C.86	(182)	1060.86	(184)	1060.86	(186)	739.90
(190)	554.40	(200)	819.22	(2C6)	1063.C0	(214)	1063.00	(218)	705.11	(220)	705.11
(222)	871.55	(228)	516.C6	(256)	515.16	(282)	1060.86	(284)	1060.86	(290)	554.40
(300)	914.64	(322)	871.55	(328)	516.C4	(4C0)	914.64	(500)	520.00		

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0201	(4)	C.C2C1	(6)	C.C2C1	(8)	0.0201	(10)	0.0201	(12)	0.0201
(14)	0.0201	(16)	0.02C1	(18)	C.C2C1	(2C)	0.0201	(22)	0.0201	(24)	0.0201
(26)	0.0201	(28)	C.C2C1	(32)	C.02C1	(34)	0.0201	(36)	0.0201	(38)	0.0118
(42)	0.0118	(44)	0.0118	(46)	C.02C1	(48)	0.0126	(50)	0.0126	(54)	0.0118
(64)	0.0126	(66)	0.0126	(74)	C.C2C1	(76)	0.0201	(78)	0.0201	(80)	0.0201

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LABORATORY DEMONSTRATION TEST
CASE IECS-1C

( 82) 0.0201 ( 84) 0.0201 ( 86) 0.0201 ( 90) 0.0    ( 92) 0.0    ( 94) 0.0
( 96) 0.0    ( 98) 0.0    ( 100) 0.0   ( 102) 0.0201 ( 106) 0.0201 ( 108) 0.0201
( 114) 0.0201 ( 116) 0.0201 ( 118) 0.0201 ( 120) 0.0201 ( 124) 0.0201 ( 126) 0.0201
( 128) 0.0201 ( 132) 0.0201 ( 134) 0.0201 ( 136) 0.0201 ( 138) 0.0118 ( 144) 0.0118
( 146) 0.0201 ( 148) 0.0126 ( 150) 0.0126 ( 156) 0.0118 ( 164) 0.0126 ( 174) 0.0201
( 176) 0.0201 ( 178) 0.0201 ( 180) 0.0201 ( 182) 0.0201 ( 184) 0.0201 ( 186) 0.0201
( 190) 0.0    ( 200) 0.0    ( 206) 0.0201 ( 214) 0.0201 ( 218) 0.0201 ( 220) 0.0201
( 222) 0.0201 ( 228) 0.0201 ( 256) 0.0118 ( 282) 0.0201 ( 284) 0.0201 ( 290) 0.0
( 300) 0.0078 ( 322) 0.0201 ( 328) 0.0201 ( 400) 0.0078 ( 500) 1.0000

STATE VARIABLE TYPE(S)
(  1)   1 (  2)   6 (  3)   5 (  4)   6 (  5)   5 (  6)   7 (  7)   8 (  8)   5 (  9)   5 ( 10)   5

STATE VARIABLE(S)
(  1) 6.36718E 01 (  2) 3.10046E-02 (  3) 1.45420E-01 (  4) 4.40254E-01 (  5) 5.13741E-01 (  6) 5.91587E 04
(  7) 5.75601E 00 (  8) 3.01629E-03 (  9) 3.39222E-01 ( 10) 5.08250E-01

ERROR VARIABLE TYPE(S)
(  1)   2 (  2)   2 (  3)   2 (  4)   1 (  5)   5 (  6)   2 (  7)   1 (  8)   3 (  9)   3 ( 10)   3

ERROR VARIABLE(S)
(  1) 0.0         (  2) 3.05176E-05 (  3) 0.0         (  4)-3.05176E-05 (  5)-1.52588E-05 (  6) 1.52588E-05
(  7)-5.96046E-08 (  8) 7.32422E-04 (  9) 4.15039E-03 ( 10) 1.95313E-03

SOLUTION CONVERGED IN    8 TRY(S)

    0 ERROR(S) DETECTED

CASE END
```

LABORATORY DEMONSTRATION TEST
CASE IECS-1E

FLOW RATE(S)

(1)	46.57	(3)	23.77	(5)	22.60	(7)	20.47	(9)	2.33	(11)	20.45
(15)	20.06	(17)	0.54	(19)	20.60	(21)	12.26	(23)	8.16	(25)	2.35
(27)	1.81	(29)	1.11	(31)	0.70	(33)	8.86	(41)	13.37	(43)	45.00
(45)	22.80	(47)	22.20	(49)	45.00	(51)	68.77	(53)	0.02	(55)	20.42
(57)	0.18	(61)	20.45	(63)	0.39	(65)	20.06				

PRESSURE(S)

(2)	69.40	(4)	69.40	(6)	69.40	(8)	65.43	(10)	68.81	(12)	69.81
(14)	69.81	(16)	63.53	(18)	63.30	(20)	63.30	(22)	92.42	(24)	88.90
(26)	87.44	(28)	18.03	(32)	18.01	(34)	63.27	(36)	18.01	(38)	17.42
(42)	17.41	(44)	17.41	(46)	63.29	(48)	17.41	(50)	17.38	(54)	17.41
(64)	17.33	(66)	16.97	(74)	63.30	(76)	63.30	(78)	63.29	(80)	63.29
(82)	63.29	(84)	63.29	(86)	63.13	(90)	14.80	(92)	14.78	(94)	14.76
(96)	14.79	(98)	14.76	(100)	14.76	(102)	69.40	(105)	69.02	(108)	69.73
(114)	68.33	(116)	63.30	(118)	63.30	(120)	63.12	(124)	88.67	(126)	87.21
(128)	18.03	(132)	18.01	(134)	63.27	(136)	18.01	(138)	17.41	(144)	17.41
(146)	63.28	(148)	17.38	(150)	17.30	(156)	17.41	(164)	17.30	(174)	63.30
(176)	63.29	(178)	63.27	(180)	63.29	(182)	63.29	(184)	63.29	(186)	63.13
(190)	14.80	(200)	14.73	(206)	66.09	(214)	67.34	(213)	63.30	(220)	61.40
(222)	92.42	(228)	18.03	(256)	17.33	(282)	63.13	(284)	63.29	(290)	14.78
(300)	14.73	(322)	91.49	(328)	18.01	(400)	14.73	(500)	17.42		

TEMPERATURE(S)

(2)	890.00	(4)	890.00	(6)	890.00	(8)	890.00	(10)	890.00	(12)	890.00
(14)	890.00	(16)	653.21	(18)	653.21	(20)	653.21	(22)	801.94	(24)	625.20
(26)	625.20	(28)	520.79	(32)	520.78	(34)	887.97	(36)	522.50	(38)	521.95
(42)	521.94	(44)	521.94	(46)	887.97	(48)	530.00	(50)	529.97	(54)	521.94
(64)	530.40	(66)	557.62	(74)	850.00	(76)	887.97	(78)	887.97	(80)	887.97
(82)	887.97	(84)	887.97	(86)	887.97	(90)	553.40	(92)	553.40	(94)	714.60
(96)	553.40	(98)	777.30	(100)	745.67	(102)	890.00	(106)	890.00	(108)	890.00
(114)	890.00	(116)	653.21	(118)	653.21	(120)	653.21	(124)	625.20	(126)	625.20
(128)	520.79	(132)	520.78	(134)	631.57	(136)	522.50	(138)	521.94	(144)	521.93
(146)	741.78	(148)	529.97	(150)	547.16	(156)	521.93	(164)	530.37	(174)	890.00
(176)	887.97	(178)	887.97	(180)	887.97	(182)	867.97	(184)	887.97	(186)	745.19
(190)	553.40	(200)	745.66	(206)	850.00	(214)	890.00	(218)	653.21	(220)	653.21
(222)	801.94	(228)	520.79	(256)	521.86	(282)	887.97	(284)	887.97	(290)	553.40
(300)	795.79	(322)	801.94	(328)	520.78	(400)	795.79	(500)	522.50		

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0220	(4)	0.0220	(6)	0.0220	(8)	0.0220	(10)	0.0220	(12)	0.0220
(14)	0.0220	(16)	0.0220	(19)	0.0220	(20)	0.0220	(22)	0.0220	(24)	0.0220
(26)	0.0220	(28)	0.0220	(32)	0.0220	(34)	0.0220	(36)	0.0220	(38)	0.0130
(42)	0.0130	(44)	0.0130	(46)	0.0220	(48)	0.0137	(50)	0.0137	(54)	0.0130
(64)	0.0137	(66)	0.0137	(74)	0.0220	(76)	0.0220	(78)	0.0220	(80)	0.0220

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     LABORATORY DEMONSTRATION TEST
     CASE IECS-1E

( 82) 0.0220 ( 84) 0.0220 ( 86) 0.0220 ( 90) 0.0    ( 92) 0.0    ( 94) 0.0
( 96) 0.0    ( 98) 0.0    ( 100) 0.0   ( 102) 0.0220 ( 106) 0.0220 ( 108) 0.0220
( 114) 0.0220 ( 116) 0.0220 ( 118) 0.0220 ( 120) 0.0220 ( 124) 0.0220 ( 126) 0.0220
( 128) 0.0220 ( 132) 0.0220 ( 134) 0.0220 ( 136) 0.0220 ( 138) 0.0130 ( 144) 0.0130
( 146) 0.0220 ( 148) 0.0137 ( 150) 0.0137 ( 156) 0.0130 ( 164) 0.0137 ( 174) 0.0220
( 176) 0.0220 ( 178) 0.0220 ( 180) 0.0220 ( 182) 0.0220 ( 184) 0.0220 ( 186) 0.0220
( 190) 0.0    ( 200) 0.0    ( 206) 0.0220 ( 214) 0.0220 ( 218) 0.0220 ( 220) 0.0220
( 222) 0.0220 ( 228) 0.0220 ( 256) 0.0130 ( 282) 0.0220 ( 284) 0.0220 ( 290) 0.0
( 300) 0.0075 ( 322) 0.0220 ( 328) 0.0220 ( 400) 0.0075 ( 500) 1.0000

STATE VARIABLE TYPE(S)
(   1)    1 (   2)    6 (   3)    5 (   4)    6 (   5)    5 (   6)    7 (   7)    8 (   8)    5 (   9)    5 (  10)    5

STATE VARIABLE(S)
(   1) 4.65683E 01 (   2) 1.13359E-03 (   3) 1.02148E-01 (   4) 1.01600E 00 (   5) 5.06722E-01 (   6) 5.58529E 04
(   7) 4.83673E 00 (   8) 1.90189E-02 (   9) 2.29497E-01 (  10) 6.13938E-01

ERROR VARIABLE TYPE(S)
(   1)    2 (   2)    2 (   3)    2 (   4)    1 (   5)    5 (   6)    2 (   7)    1 (   8)    3 (   9)    3 (  10)    3

ERROR VARIABLE(S)
(   1) 0.0          (   2) 4.57764E-05 (   3) 0.0          (   4)-3.05176E-05 (   5) 1.22070E-04 (   6) 0.0
(   7)-4.76837E-07 (   8) 9.76563E-04 (   9) 2.15727E-03 (  10) 3.90625E-03

SOLUTION CONVERGED IN    10 TRY(S)

     0 ERROR(S) DETECTED

CASE END
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LABORATORY DEMONSTRATION TEST
CASE IECS-2A

FLOW RATE(S)

(1)	35.58	(5)	35.58	(7)	27.46	(9)	8.12	(11)	21.12	(15)	18.43
(17)	7.59	(19)	26.03	(21)	13.13	(23)	12.89	(25)	14.46	(27)	6.87
(29)	3.76	(31)	3.11	(33)	16.00	(41)	16.90	(43)	59.00	(45)	31.44
(47)	27.56	(49)	59.00	(51)	59.00	(53)	6.34	(55)	26.03	(57)	0.0
(61)	21.12	(63)	2.69	(65)	18.43						

PRESSURE(S)

(2)	110.00	(4)	110.00	(10)	75.47	(12)	75.47	(14)	75.47	(16)	61.97
(18)	61.50	(20)	61.50	(22)	88.83	(24)	84.76	(26)	83.32	(28)	10.80
(32)	10.78	(34)	60.12	(36)	10.78	(38)	9.68	(42)	9.64	(44)	9.64
(46)	61.05	(48)	9.63	(50)	9.49	(54)	9.64	(64)	9.51	(66)	8.46
(74)	61.51	(76)	61.48	(78)	61.41	(80)	61.41	(82)	61.41	(84)	61.41
(86)	60.71	(90)	14.90	(92)	14.87	(94)	14.83	(96)	14.87	(98)	14.83
(100)	14.83	(102)	110.00	(114)	74.37	(116)	61.50	(118)	61.48	(120)	61.28
(124)	84.54	(126)	83.09	(128)	10.80	(132)	10.78	(134)	58.86	(136)	10.78
(138)	9.64	(144)	9.63	(146)	60.87	(148)	9.49	(150)	9.03	(156)	9.64
(164)	9.42	(174)	61.48	(176)	61.41	(178)	60.12	(180)	61.41	(182)	61.40
(184)	61.40	(186)	60.69	(190)	14.90	(200)	14.78	(214)	70.32	(218)	61.48
(220)	59.30	(222)	88.83	(228)	10.80	(256)	9.51	(282)	60.71	(284)	61.05
(290)	14.87	(300)	14.78	(322)	87.67	(328)	10.78	(400)	14.78	(500)	9.68

TEMPERATURE(S)

(2)	1253.00	(4)	1253.00	(10)	1253.00	(12)	1253.00	(14)	1253.00	(16)	735.49
(18)	735.49	(20)	735.49	(22)	899.99	(24)	553.98	(26)	553.98	(28)	375.43
(32)	375.43	(34)	1035.70	(36)	443.50	(38)	443.50	(42)	443.50	(44)	443.50
(46)	1035.70	(48)	523.10	(50)	523.10	(54)	443.50	(64)	533.20	(66)	585.44
(74)	1253.00	(76)	1035.70	(78)	1035.70	(80)	1035.70	(82)	1035.70	(84)	1035.70
(86)	1035.70	(90)	465.70	(92)	465.70	(94)	704.93	(96)	465.70	(98)	1017.48
(100)	854.46	(102)	1253.00	(114)	1253.00	(116)	735.49	(118)	735.49	(120)	735.49
(124)	553.98	(126)	553.98	(128)	375.43	(132)	375.43	(134)	605.60	(136)	443.50
(138)	443.50	(144)	443.50	(146)	839.30	(148)	523.10	(150)	528.97	(156)	443.50
(164)	533.20	(174)	1253.00	(176)	1035.70	(178)	1035.70	(180)	1035.70	(182)	1035.70
(184)	1035.70	(186)	833.00	(190)	465.70	(200)	854.46	(214)	1253.00	(218)	735.49
(220)	735.49	(222)	899.99	(228)	375.43	(256)	443.50	(282)	1035.70	(284)	1035.70
(290)	465.70	(300)	854.46	(322)	899.99	(328)	375.43	(400)	854.46	(500)	443.50

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0	(4)	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
(32)	0.0	(34)	0.0	(36)	0.0	(38)	0.0	(42)	0.0	(44)	0.0
(46)	0.0	(48)	0.0	(50)	0.0	(54)	0.0	(64)	0.0	(66)	0.0
(74)	0.0	(76)	0.0	(78)	0.0	(80)	0.0	(82)	0.0	(84)	0.0
(86)	0.0	(90)	0.0	(92)	0.0	(94)	0.0	(96)	0.0	(98)	0.0
(100)	0.0	(102)	0.0	(114)	0.0	(116)	0.0	(118)	0.0	(120)	0.0

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LABCRATORY DEMONSTRATION TEST
CASE IECS-2A

( 124)  0.0   ( 126)  0.0   ( 128)  0.0   ( 132)  0.0   ( 134)  0.0   ( 136)  0.0
( 138)  0.0   ( 144)  0.0   ( 146)  0.0   ( 148)  0.0   ( 150)  0.0   ( 156)  0.0
( 164)  0.0   ( 174)  0.0   ( 176)  0.0   ( 178)  0.0   ( 180)  0.0   ( 182)  0.0
( 184)  0.0   ( 186)  0.0   ( 190)  0.0   ( 200)  0.0   ( 214)  0.0   ( 218)  0.0
( 220)  0.0   ( 222)  0.0   ( 228)  0.0   ( 256)  0.0   ( 282)  0.0   ( 284)  0.0
( 290)  0.0   ( 300)  0.0   ( 322)  0.0   ( 328)  0.0   ( 400)  0.0   ( 500)  1.0000

STATE VARIABLE TYPE(S)
(    1)    1 (    2)    6 (    3)    5 (    4)    6 (    5)    5 (    6)    7 (    7)    8 (    8)    5 (    9)    5 (   10)    5

STATE VARIABLE(S)
(    1) 3.55834E 01 (    2) 2.72679E-02 (    3) 2.28268E-01 (    4) 2.11706E-01 (    5) 5.32916E-01 (    6) 5.91937E 04
(    7) 7.69368E 00 (    8) 1.27255E-01 (    9) 5.25186E-01 (   10) 5.47762E-01

ERROR VARIABLE TYPE(S)
(    1)    2 (    2)    2 (    3)    2 (    4)    1 (    5)    5 (    6)    2 (    7)    1 (    8)    3 (    9)    3 (   10)    3

ERROR VARIABLE(S)
(    1) 0.0         (    2) 7.62939E-05 (    3) 0.0         (    4) 1.52588E-05 (    5) 1.52588E-04 (    6) 7.24792E-05
(    7)-9.53674E-07 (    8)-4.88281E-04 (    9)-2.44141E-04 (   10)-2.44141E-04

SCLUTICN CCNVERGED IN      8 TRY(S)

     0 ERRCR(S) DETECTED

CASE END
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LABORATORY DEMONSTRATION TEST
CASE IECS-2B

FLOW RATE(S)

(1)	40.82	(5)	40.82	(7)	31.54	(9)	9.28	(11)	22.33	(15)	20.40		
(17)	8.40	(19)	28.80	(21)	18.77	(23)	10.03	(25)	18.49	(27)	10.09		
(29)	6.61	(31)	3.48	(33)	13.51	(41)	25.38	(43)	60.00	(45)	31.90		
(47)	28.10	(49)	60.00	(51)	60.00	(53)	9.21	(55)	28.80	(57)	0.0		
(61)	22.33	(63)	1.93	(65)	20.40								

PRESSURE(S)

(2)	107.00	(4)	107.00	(10)	82.43	(12)	82.43	(14)	82.43	(16)	66.34		
(18)	65.75	(20)	65.75	(22)	94.87	(24)	90.43	(26)	88.90	(28)	10.65		
(32)	10.63	(34)	64.74	(36)	10.63	(38)	9.43	(42)	9.39	(44)	9.39		
(46)	65.17	(48)	9.38	(50)	9.28	(54)	9.39	(64)	9.15	(66)	6.70		
(74)	65.73	(76)	65.70	(78)	65.60	(80)	65.60	(82)	65.59	(84)	65.59		
(86)	63.37	(90)	14.90	(92)	14.87	(94)	14.83	(96)	14.87	(98)	14.83		
(100)	14.83	(102)	107.00	(114)	81.12	(116)	65.75	(118)	65.71	(120)	65.50		
(124)	90.20	(126)	88.66	(128)	10.65	(132)	10.63	(134)	63.34	(136)	10.63		
(138)	9.39	(144)	9.38	(146)	64.98	(148)	9.28	(150)	8.94	(156)	9.39		
(164)	8.94	(174)	65.70	(176)	65.60	(178)	64.74	(180)	65.59	(182)	65.58		
(184)	65.59	(186)	63.30	(190)	14.90	(200)	14.77	(214)	76.68	(218)	65.70		
(220)	63.30	(222)	94.87	(228)	10.65	(256)	9.15	(282)	63.37	(284)	65.17		
(290)	14.87	(300)	14.77	(322)	93.59	(328)	10.63	(400)	14.77	(500)	9.43		

TEMPERATURE(S)

(2)	1258.50	(4)	1258.50	(10)	1258.50	(12)	1258.50	(14)	1258.50	(16)	774.25		
(18)	774.25	(20)	774.25	(22)	947.09	(24)	566.34	(26)	566.34	(28)	378.02		
(32)	378.02	(34)	1025.87	(36)	420.00	(38)	420.00	(42)	420.00	(44)	420.00		
(46)	1025.86	(48)	525.60	(50)	525.60	(54)	420.00	(64)	533.10	(66)	568.02		
(74)	1258.50	(76)	1025.87	(78)	1025.87	(80)	1025.87	(82)	1025.86	(84)	1025.86		
(86)	1025.86	(90)	460.00	(92)	460.00	(94)	735.57	(96)	460.00	(98)	1042.03		
(100)	882.50	(102)	1258.50	(114)	1258.50	(116)	774.25	(118)	774.25	(120)	774.25		
(124)	566.34	(126)	566.34	(128)	378.02	(132)	378.02	(134)	520.80	(136)	420.00		
(138)	420.00	(144)	420.00	(146)	817.39	(148)	525.60	(150)	532.28	(156)	420.00		
(164)	533.10	(174)	1258.50	(176)	1025.87	(178)	1025.87	(180)	1025.86	(182)	1025.86		
(184)	1025.86	(186)	839.46	(190)	460.00	(200)	882.50	(214)	1258.50	(218)	774.25		
(220)	774.25	(222)	947.09	(228)	378.02	(256)	420.00	(282)	1025.86	(284)	1025.86		
(290)	460.00	(300)	882.50	(322)	947.09	(328)	378.02	(400)	882.50	(500)	420.00		

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0	(4)	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
(32)	0.0	(34)	0.0	(36)	0.0	(38)	0.0	(42)	0.0	(44)	0.0
(46)	0.0	(48)	0.0	(50)	0.0	(54)	0.0	(64)	0.0	(66)	0.0
(74)	0.0	(76)	0.0	(78)	0.0	(80)	0.0	(82)	0.0	(84)	0.0
(86)	0.0	(90)	0.0	(92)	0.0	(94)	0.0	(96)	0.0	(98)	0.0
(100)	0.0	(102)	0.0	(114)	0.0	(116)	0.0	(118)	0.0	(120)	0.0

```
LABORATORY DEMONSTRATION TEST
CASE IECS-2B

( 124)  0.0    ( 126)  0.0    ( 128)  0.0    ( 132)  0.0    ( 134)  0.0    ( 136)  0.0
( 138)  0.0    ( 144)  0.0    ( 146)  0.0    ( 148)  0.0    ( 150)  0.0    ( 156)  0.0
( 164)  0.0    ( 174)  0.0    ( 176)  0.0    ( 178)  0.0    ( 180)  0.0    ( 182)  0.0
( 184)  0.0    ( 186)  0.0    ( 190)  0.0    ( 200)  0.0    ( 214)  0.0    ( 218)  0.0
( 220)  0.0    ( 222)  0.0    ( 228)  0.0    ( 256)  0.0    ( 282)  0.0    ( 284)  0.0
( 290)  0.0    ( 300)  0.0    ( 322)  0.0    ( 328)  0.0    ( 400)  0.0    ( 500)  1.0000

STATE VARIABLE TYPE(S)
(   1)   1 (   2)   6 (   3)   5 (   4)   6 (   5)   5 (   6)   7 (   7)   8 (   8)   5 (   9)   5 (  10)   5

STATE VARIABLE(S)
(   1) 4.08203E 01 (   2) 1.47434E-02 (   3) 2.27460E-01 (   4) 1.93741E-01 (   5) 5.31746E-01 (   6) 6.08113E 04
(   7) 8.32460E 00 (   8) 8.65319E-02 (   9) 4.54476E-01 (  10) 6.55487E-01

ERROR VARIABLE TYPE(S)
(   1)   2 (   2)   2 (   3)   2 (   4)   1 (   5)   5 (   6)   2 (   7)   1 (   8)   3 (   9)   3 (  10)   3

ERROR VARIABLE(S)
(   1)-1.37329E-04 (   2) 1.52588E-05 (   3) 0.0         (   4)-7.62939E-05 (   5) 0.0         (   6) 7.53403E-05
(   7)-1.90735E-06 (   8)-2.44141E-04 (   9)-2.44141E-04 (  10) 0.0

SOLUTION CONVERGED IN      8 TRY(S)

      0 ERROR(S) DETECTED

CASE END
```

LABORATORY DEMONSTRATION TEST
CASE IECS-2C

FLOW RATE(S)

(1)	31.16	(5)	31.16	(7)	22.91	(9)	8.25	(11)	19.59	(15)	19.56
(17)	3.37	(19)	22.92	(21)	11.62	(23)	11.30	(25)	11.57	(27)	8.21
(29)	4.16	(31)	4.04	(33)	15.34	(41)	15.78	(43)	66.70	(45)	35.15
(47)	31.55	(49)	66.70	(51)	66.70	(53)	3.32	(55)	22.92	(57)	0.0
(61)	19.59	(63)	0.03	(65)	19.56						

PRESSURE(S)

(2)	65.22	(4)	65.22	(10)	65.21	(12)	65.21	(14)	65.21	(16)	57.54
(18)	57.26	(20)	57.26	(22)	79.88	(24)	76.61	(26)	75.36	(28)	15.80
(32)	15.79	(34)	56.29	(36)	15.78	(38)	15.15	(42)	15.14	(44)	15.14
(46)	56.45	(48)	15.13	(50)	15.04	(54)	15.14	(64)	15.07	(66)	14.49
(74)	57.28	(76)	57.25	(78)	57.21	(80)	57.21	(82)	57.20	(84)	57.20
(86)	55.96	(90)	14.90	(92)	14.86	(94)	14.82	(96)	14.86	(98)	14.82
(100)	14.82	(102)	65.22	(114)	64.45	(116)	57.26	(118)	57.25	(120)	57.09
(124)	76.42	(126)	75.16	(128)	15.80	(132)	15.78	(134)	56.03	(136)	15.78
(138)	15.14	(144)	15.13	(146)	56.18	(148)	15.05	(150)	14.77	(156)	15.13
(164)	15.02	(174)	57.25	(176)	57.21	(178)	56.29	(180)	57.20	(182)	57.20
(184)	57.20	(186)	55.93	(190)	14.90	(200)	14.77	(214)	62.94	(218)	57.25
(220)	55.50	(222)	79.88	(228)	15.80	(256)	15.07	(282)	55.96	(284)	56.45
(290)	14.86	(300)	14.77	(322)	79.00	(328)	15.79	(400)	14.77	(500)	15.15

TEMPERATURE(S)

(2)	1055.00	(4)	1055.00	(10)	1055.00	(12)	1055.00	(14)	1055.00	(16)	599.72
(18)	599.72	(20)	599.72	(22)	719.75	(24)	504.88	(26)	504.88	(28)	376.13
(32)	376.13	(34)	930.49	(36)	433.90	(38)	433.90	(42)	433.90	(44)	433.90
(46)	930.49	(48)	533.60	(50)	533.60	(54)	433.90	(64)	532.40	(66)	588.29
(74)	1055.00	(76)	930.49	(78)	930.49	(80)	930.49	(82)	930.49	(84)	930.49
(86)	930.49	(90)	464.20	(92)	464.20	(94)	585.50	(96)	464.20	(98)	809.98
(100)	693.33	(102)	1055.00	(114)	1055.00	(116)	599.72	(118)	599.72	(120)	599.72
(124)	504.88	(126)	504.88	(128)	376.13	(132)	376.13	(134)	757.80	(136)	433.90
(138)	433.90	(144)	433.90	(146)	801.14	(148)	533.60	(150)	538.87	(156)	433.90
(164)	532.40	(174)	1055.00	(176)	930.49	(178)	930.49	(180)	930.49	(182)	930.49
(184)	930.49	(186)	796.64	(190)	464.20	(200)	693.33	(214)	1055.00	(218)	599.72
(220)	599.72	(222)	719.75	(228)	376.13	(256)	433.90	(282)	930.49	(284)	930.49
(290)	464.20	(300)	693.33	(322)	719.75	(328)	376.13	(400)	693.33	(500)	433.90

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0	(4)	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
(32)	0.0	(34)	0.0	(36)	0.0	(38)	0.0	(42)	0.0	(44)	0.0
(46)	0.0	(48)	0.0	(50)	0.0	(54)	0.0	(64)	0.0	(66)	0.0
(74)	0.0	(76)	0.0	(78)	0.0	(80)	0.0	(82)	0.0	(84)	0.0
(86)	0.0	(90)	0.0	(92)	0.0	(94)	0.0	(96)	0.0	(98)	0.0
(100)	0.0	(102)	0.0	(114)	0.0	(116)	0.0	(118)	0.0	(120)	0.0

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        LABORATORY DEMONSTRATION TEST
        CASE IECS-2C

 ( 124)  0.0     ( 126)  0.0     ( 128)  0.0     ( 132)  0.0     ( 134)  0.0     ( 136)  0.0
 ( 138)  0.0     ( 144)  0.0     ( 146)  0.0     ( 148)  0.0     ( 150)  0.0     ( 156)  0.0
 ( 164)  0.0     ( 174)  0.0     ( 176)  0.0     ( 178)  0.0     ( 180)  0.0     ( 182)  0.0
 ( 184)  0.0     ( 186)  0.0     ( 190)  0.0     ( 200)  0.0     ( 214)  0.0     ( 218)  0.0
 ( 220)  0.0     ( 222)  0.0     ( 228)  0.0     ( 256)  0.0     ( 282)  0.0     ( 284)  0.0
 ( 290)  0.0     ( 300)  0.0     ( 322)  0.0     ( 328)  0.0     ( 400)  0.0     ( 500)  1.0000

 STATE VARIABLE TYPE(S)
 (   1)    1 (   2)    2 (   3)    5 (   4)    6 (   5)    5 (   6)    7 (   7)    8 (   8)    5 (   9)    5 (  10)    5

 STATE VARIABLE(S)
 (   1) 3.11584E 01 (   2) 6.52172E 01 (   3) 2.64856E-01 (   4) 1.16416E-01 (   5) 5.26969E-01 (   6) 5.04596E 04
 (   7) 4.75704E 00 (   8) 1.53164E-03 (   9) 2.90806E-01 (  10) 5.07228E-01

 ERROR VARIABLE TYPE(S)
 (   1)    2 (   2)    2 (   3)    2 (   4)    1 (   5)    5 (   6)    2 (   7)    1 (   8)    3 (   9)    3 (  10)    3

 ERROR VARIABLE(S)
 (   1) 1.52588E-05 (   2)-1.52588E-05 (   3) 9.53674E-07 (   4) 1.52588E-05 (   5)-3.24249E-05 (   6)-9.53674E-07
 (   7) 0.0         (   8) 0.0         (   9) 0.0         (  10) 0.0

 SOLUTICN CONVERGED IN      8 TRY(S)

      0 ERROR(S) DETECTED

 CASE END
```

LABORATORY DEMONSTRATION TEST
CASE IECS-3A

FLOW RATE(S)

(1)	25.74	(5)	25.74	(7)	22.68	(9)	3.06	(11)	21.27	(13)	5.08
(15)	16.02	(17)	2.17	(19)	18.19	(21)	14.04	(23)	4.15	(25)	4.47
(27)	2.31	(29)	1.67	(31)	0.63	(33)	4.78	(41)	15.71	(43)	209.00
(45)	105.83	(47)	103.17	(49)	209.00	(51)	209.00	(53)	1.41	(55)	18.19
(57)	0.0	(61)	21.27	(63)	0.17	(65)	21.10				

PRESSURE(S)

(2)	134.00	(4)	134.00	(10)	70.55	(12)	70.55	(14)	70.55	(16)	61.76		
(18)	61.41	(20)	61.41	(22)	59.46	(24)	95.06	(26)	93.34	(28)	7.88		
(30)	7.85	(32)	7.85	(34)	61.34	(36)	7.84	(38)	6.77	(42)	6.74		
(44)	6.74	(46)	61.27	(48)	6.74	(50)	6.72	(54)	6.74	(64)	6.50		
(66)	5.15	(70)	7.85	(72)	7.82	(74)	61.41	(76)	61.41	(78)	61.40		
(80)	61.40	(82)	61.40	(84)	61.40	(86)	61.26	(90)	18.30	(92)	17.83		
(94)	17.43	(96)	17.83	(98)	17.43	(100)	17.43	(102)	134.00	(114)	69.68		
(116)	61.41	(118)	61.41	(120)	61.17	(124)	94.78	(126)	93.08	(128)	7.88		
(132)	7.84	(134)	61.20	(136)	7.84	(138)	6.74	(144)	6.74	(146)	61.26		
(148)	6.72	(150)	6.65	(156)	6.73	(164)	6.39	(170)	7.83	(174)	61.41		
(176)	61.40	(178)	61.24	(180)	61.40	(182)	61.40	(184)	61.40	(186)	61.25		
(190)	18.30	(200)	16.88	(214)	67.53	(218)	61.41	(220)	59.10	(222)	99.46		
(228)	7.88	(256)	6.50	(282)	61.26	(284)	61.27	(290)	17.83	(300)	16.88		
(322)	98.27	(328)	7.85	(400)	16.88	(500)	6.77						

TEMPERATURE(S)

(2)	1308.00	(4)	1308.00	(10)	1308.00	(12)	1308.00	(14)	1308.00	(16)	776.50
(18)	776.50	(20)	776.50	(22)	1010.25	(24)	765.14	(26)	686.10	(28)	431.39
(30)	431.39	(32)	431.39	(34)	1148.98	(36)	489.70	(38)	489.70	(42)	489.70
(44)	489.70	(46)	1148.98	(48)	500.70	(50)	500.70	(54)	489.70	(64)	533.40
(66)	596.91	(70)	431.39	(72)	765.13	(74)	1308.00	(76)	1148.98	(78)	1148.98
(80)	1148.98	(82)	1148.98	(84)	1148.98	(86)	1148.98	(90)	759.40	(92)	759.40
(94)	809.86	(96)	759.40	(98)	883.20	(100)	846.26	(102)	1308.00	(114)	1308.00
(116)	776.50	(118)	776.50	(120)	776.50	(124)	765.13	(126)	686.10	(128)	431.39
(132)	431.39	(134)	698.66	(136)	489.70	(138)	489.70	(144)	489.70	(146)	572.00
(148)	500.70	(150)	587.39	(156)	489.70	(164)	533.40	(170)	431.39	(174)	1308.00
(176)	1148.98	(178)	1148.98	(180)	1148.98	(182)	1148.98	(184)	1148.98	(186)	884.00
(190)	759.40	(200)	846.26	(214)	1308.00	(218)	776.50	(220)	776.50	(222)	1010.25
(226)	431.39	(256)	489.70	(282)	1148.98	(284)	1148.98	(290)	759.40	(300)	846.26
(322)	1010.25	(328)	431.39	(400)	846.26	(500)	489.70				

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0	(4)	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	(42)	0.0
(44)	0.0	(46)	0.0	(48)	0.0	(50)	0.0	(54)	0.0	(64)	0.0
(66)	0.0	(70)	0.0	(72)	0.0	(74)	0.0	(76)	0.0	(78)	0.0

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LABORATORY DEMONSTRATION TEST
CASE TECS-3A

( 80) 0.0    ( 82) 0.0    ( 84) 0.0    ( 86) 0.0    ( 90) 0.0    ( 92) 0.0
( 94) 0.0    ( 96) 0.0    ( 98) 0.0    ( 100) 0.0   ( 102) 0.0   ( 114) 0.0
( 116) 0.0   ( 118) 0.0   ( 120) 0.0   ( 124) 0.0   ( 126) 0.0   ( 128) 0.0
( 132) 0.0   ( 134) 0.0   ( 136) 0.0   ( 138) 0.0   ( 144) 0.0   ( 146) 0.0
( 148) 0.0   ( 150) 0.0   ( 156) 0.0   ( 164) 0.0   ( 170) 0.0   ( 174) 0.0
( 176) 0.0   ( 178) 0.0   ( 180) 0.0   ( 182) 0.0   ( 184) 0.0   ( 186) 0.0
( 190) 0.0   ( 200) 0.0   ( 214) 0.0   ( 218) 0.0   ( 220) 0.0   ( 222) 0.0
( 228) 0.0   ( 256) 0.0   ( 282) 0.0   ( 284) 0.0   ( 290) 0.0   ( 300) 0.0
( 322) 0.0   ( 328) 0.0   ( 400) 0.0   ( 500) 1.0000

STATE VARIABLE TYPE(S)
(  1)   1 (  2)   6 (  3)   5 (  4)   6 (  5)   5 (  6)   7 (  7)   1 (  8)   3 (  9)   8 ( 10)   5
( 11)   5 ( 12)   5

STATE VARIABLE(S)
(  1) 2.57402E 01 (  2) 9.57708E-02 (  3) 1.15002E-01 (  4) 9.73567E-01 (  5) 5.06360E-01 (  6) 7.00164E 04
(  7) 5.07792E 00 (  8) 4.31387E 02 (  9) 1.18116E 01 ( 10) 7.99379E-03 ( 11) 4.84737E-01 ( 12) 7.24533E-01

ERROR VARIABLE TYPE(S)
(  1)   2 (  2)   2 (  3)   2 (  4)   1 (  5)   5 (  6)   2 (  7)   1 (  8)   1 (  9)   3 ( 10)   3
( 11)   3 ( 12)   3

ERROR VARIABLE(S)
(  1)-1.52588E-05 (  2) 6.10352E-05 (  3) 1.52588E-05 (  4)-3.05176E-05 (  5) 1.67847E-04 (  6) 6.67572E-06
(  7)-1.19209E-07 (  8) 9.53674E-07 (  9) 4.88281E-04 ( 10)-1.46484E-03 ( 11)-1.22070E-03 ( 12)-1.22070E-03

SOLUTION CONVERGED IN      8 TRY(S)

     0 ERROR(S) DETECTED

CASE END
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LABORATORY DEMONSTRATION TEST
CASE IECS-3B

FLOW RATE(S)

(1)	27.38	(5)	27.38	(7)	22.74	(9)	4.65	(11)	21.32	(15)	21.15
(17)	0.56	(19)	21.71	(21)	16.76	(23)	4.95	(25)	6.06	(27)	5.50
(29)	2.36	(31)	3.14	(33)	8.09	(41)	19.12	(43)	209.00	(45)	105.71
(47)	103.29	(49)	209.00	(51)	209.00	(53)	1.41	(55)	21.71	(57)	0.0
(61)	21.32	(63)	0.17	(65)	21.15						

PRESSURE(S)

(2)	134.00	(4)	134.00	(10)	70.58	(12)	70.58	(14)	70.58	(16)	61.76
(18)	61.41	(20)	61.41	(22)	104.84	(24)	100.56	(26)	98.85	(28)	7.88
(32)	7.84	(34)	61.33	(36)	7.83	(38)	6.49	(42)	6.45	(44)	6.45
(46)	61.76	(48)	6.44	(50)	6.39	(54)	6.45	(64)	6.11	(66)	3.97
(74)	61.42	(76)	61.41	(78)	61.39	(80)	61.39	(82)	61.39	(84)	61.39
(86)	61.25	(90)	18.30	(92)	17.83	(94)	17.43	(96)	17.83	(98)	17.43
(100)	17.43	(102)	134.00	(114)	69.71	(116)	61.41	(118)	61.41	(120)	61.17
(124)	100.79	(126)	98.57	(128)	7.88	(132)	7.83	(134)	61.32	(136)	7.83
(138)	6.45	(144)	6.44	(146)	61.05	(148)	6.39	(150)	6.21	(156)	6.44
(164)	5.92	(174)	61.41	(176)	61.39	(178)	61.33	(180)	61.39	(182)	61.39
(184)	61.38	(186)	61.24	(190)	18.30	(200)	16.88	(214)	67.96	(218)	61.41
(220)	59.10	(222)	104.84	(228)	7.88	(256)	6.11	(282)	61.25	(284)	61.26
(290)	17.83	(300)	16.88	(322)	103.67	(328)	7.84	(400)	16.38	(500)	6.49

TEMPERATURE(S)

(2)	1308.00	(4)	1308.00	(10)	1308.00	(12)	1308.00	(14)	1308.00	(16)	776.61
(18)	776.61	(20)	776.61	(22)	1041.02	(24)	765.93	(26)	765.93	(28)	478.30
(32)	478.30	(34)	1191.01	(36)	489.70	(38)	489.70	(42)	489.70	(44)	489.70
(46)	1191.01	(48)	500.70	(50)	500.70	(54)	489.70	(64)	533.40	(66)	585.71
(74)	1308.00	(76)	1191.01	(78)	1191.01	(80)	1191.01	(82)	1191.01	(84)	1191.01
(86)	1191.01	(90)	759.40	(92)	759.40	(94)	816.43	(96)	759.40	(98)	883.36
(100)	849.67	(102)	1308.00	(114)	1308.00	(116)	776.61	(118)	776.61	(120)	776.61
(124)	765.93	(126)	765.93	(128)	478.30	(132)	478.30	(134)	898.56	(136)	489.70
(138)	489.70	(144)	489.70	(146)	518.00	(148)	500.70	(150)	554.53	(156)	489.70
(164)	533.40	(174)	1308.00	(176)	1191.01	(178)	1191.01	(180)	1191.01	(182)	1191.01
(184)	1191.01	(186)	832.00	(190)	759.40	(200)	849.67	(214)	1308.00	(218)	776.61
(220)	776.61	(222)	1041.02	(228)	478.30	(256)	489.70	(282)	1191.01	(284)	1191.01
(290)	759.40	(300)	849.67	(322)	1041.02	(328)	478.30	(400)	849.67	(500)	489.70

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0	(4)	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
(32)	0.0	(34)	0.0	(36)	0.0	(38)	0.0	(42)	0.0	(44)	0.0
(46)	0.0	(48)	0.0	(50)	0.0	(54)	0.0	(64)	0.0	(66)	0.0
(74)	0.0	(76)	0.0	(78)	0.0	(80)	0.0	(82)	0.0	(84)	0.0
(86)	0.0	(90)	0.0	(92)	0.0	(94)	0.0	(96)	0.0	(98)	0.0
(100)	0.0	(102)	0.0	(114)	0.0	(116)	0.0	(118)	0.0	(120)	0.0

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        LABORATORY DEMONSTRATION TEST
        CASE TECS-38

( 124)  0.0    ( 126)  0.0    ( 128)  0.0    ( 132)  0.0    ( 134)  0.0    ( 136)  0.0
( 138)  0.0    ( 144)  0.0    ( 146)  0.0    ( 148)  0.0    ( 150)  0.0    ( 156)  0.0
( 164)  0.0    ( 174)  0.0    ( 176)  0.0    ( 178)  0.0    ( 180)  0.0    ( 182)  0.0
( 184)  0.0    ( 186)  0.0    ( 190)  0.0    ( 200)  0.0    ( 214)  0.0    ( 218)  0.0
( 220)  0.0    ( 222)  0.0    ( 228)  0.0    ( 256)  0.0    ( 282)  0.0    ( 284)  0.0
( 290)  0.0    ( 300)  0.0    ( 322)  0.0    ( 328)  0.0    ( 400)  0.0    ( 500)  1.0000

STATE VARIABLE TYPE(S)
(   1)    1 (   2)    6 (   3)    5 (   4)    6 (   5)    5 (   6)    7 (   7)    8 (   8)    5 (   9)    5 (  10)    5

STATE VARIABLE(S)
(   1) 2.73826E 01 (   2) 8.45762E-02 (   3) 1.69669E-01 (   4) 4.24612E-01 (   5) 5.05798E-01 (   6) 7.39366E 04
(   7) 1.25083E 01 (   8) 7.97282E-03 (   9) 9.27139E-02 (  10) 4.28788E-01

ERROR VARIABLE TYPE(S)
(   1)    2 (   2)    2 (   3)    2 (   4)    1 (   5)    5 (   6)    2 (   7)    1 (   8)    3 (   9)    3 (  10)    3

ERROR VARIABLE(S)
(   1)-3.05176E-05 (   2) 6.10352E-05 (   3)-1.52588E-05 (   4) 1.52588E-05 (   5)-5.95093E-04 (   6)-8.58307E-06
(   7)-2.38419E-07 (   8)-4.88281E-04 (   9) 4.88281E-04 (  10)-1.70898E-03

SOLUTION CONVERGED IN        8 TRY(S)

        0 ERROR(S) DETECTED

CASE END
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LABORATORY DEMONSTRATION TEST
CASE IECS-4A

FLOW RATE(S)

(1)	34.72	(5)	34.72	(7)	26.80	(9)	7.92	(11)	23.37	(15)	19.95
(17)	8.90	(19)	28.85	(21)	11.38	(23)	17.01	(25)	11.35	(27)	2.45
(29)	1.39	(31)	1.06	(33)	18.07	(41)	12.77	(43)	106.40	(45)	54.95
(47)	51.45	(49)	106.40	(51)	106.40	(53)	3.43	(55)	28.40	(57)	0.46
(61)	23.37	(63)	3.42	(65)	19.55						

PRESSURE(S)

(2)	79.50	(4)	75.50	(10)	79.49	(12)	79.49	(14)	79.49	(16)	68.34
(18)	67.99	(20)	67.99	(22)	103.09	(24)	99.05	(26)	97.41	(28)	15.32
(32)	15.30	(34)	67.45	(36)	15.30	(38)	14.28	(42)	14.25	(44)	14.25
(46)	67.76	(48)	14.23	(50)	14.11	(54)	14.25	(64)	14.17	(66)	13.76
(74)	68.00	(76)	67.58	(78)	67.94	(80)	67.94	(82)	67.94	(84)	67.94
(86)	67.73	(90)	15.70	(92)	15.60	(94)	15.49	(96)	15.60	(98)	15.49
(100)	15.49	(102)	79.50	(114)	78.61	(116)	67.99	(118)	67.98	(120)	67.77
(124)	98.79	(126)	97.14	(128)	15.32	(132)	15.30	(134)	66.05	(136)	15.30
(138)	14.25	(144)	14.23	(146)	67.74	(148)	14.11	(150)	13.71	(156)	14.24
(164)	14.13	(174)	67.58	(176)	67.54	(178)	67.45	(180)	67.94	(182)	67.94
(184)	67.94	(186)	67.73	(190)	15.70	(200)	15.35	(214)	74.96	(218)	67.98
(220)	65.70	(222)	103.09	(228)	15.32	(256)	14.17	(282)	67.73	(284)	67.76
(290)	15.60	(300)	15.35	(322)	102.00	(328)	15.30	(400)	15.35	(500)	14.28

TEMPERATURE(S)

(2)	1111.40	(4)	1111.40	(10)	1111.40	(12)	1111.40	(14)	1111.40	(16)	651.87
(18)	651.87	(20)	651.87	(22)	818.31	(24)	610.61	(26)	610.15	(28)	509.40
(32)	509.39	(34)	969.84	(36)	515.00	(38)	513.88	(42)	513.84	(44)	513.84
(46)	969.84	(48)	522.01	(50)	521.85	(54)	513.84	(64)	527.10	(66)	596.08
(74)	1111.40	(76)	969.84	(78)	969.84	(80)	969.84	(82)	969.84	(84)	969.84
(86)	969.84	(90)	557.00	(92)	557.00	(94)	656.46	(96)	557.00	(98)	808.21
(100)	730.63	(102)	1111.40	(114)	1111.40	(116)	651.87	(118)	651.87	(120)	651.87
(124)	610.54	(126)	610.07	(128)	509.40	(132)	509.38	(134)	550.50	(136)	515.00
(138)	513.84	(144)	513.83	(146)	787.50	(148)	521.85	(150)	525.08	(156)	513.84
(164)	527.05	(174)	1111.40	(176)	969.84	(178)	969.64	(180)	969.84	(182)	969.84
(184)	969.84	(186)	762.20	(190)	557.00	(200)	730.63	(214)	1111.40	(218)	651.87
(220)	651.87	(222)	818.31	(228)	509.40	(256)	513.75	(282)	969.84	(284)	969.84
(290)	557.00	(300)	730.63	(322)	818.31	(328)	509.39	(400)	730.63	(500)	515.00

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0300	(4)	0.0300	(10)	0.0300	(12)	0.0300	(14)	0.0300	(16)	0.0300
(18)	0.0300	(20)	0.0300	(22)	0.0300	(24)	0.0300	(26)	0.0300	(28)	0.0300
(32)	0.0300	(34)	0.0300	(36)	0.0300	(38)	0.0137	(42)	0.0137	(44)	0.0137
(46)	0.0300	(48)	0.0146	(50)	0.0146	(54)	0.0137	(64)	0.0154	(66)	0.0154
(74)	0.0300	(76)	0.0300	(78)	0.0300	(80)	0.0300	(82)	0.0300	(84)	0.0300
(86)	0.0300	(90)	0.0	(92)	0.0	(94)	0.0	(96)	0.0	(98)	0.0
(100)	0.0	(102)	0.0300	(114)	0.0300	(116)	0.0300	(118)	0.0300	(120)	0.0300

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LABORATORY CEMONATRATION TEST
CASE IECS-4A

( 124)  0.0300 ( 126)  C.03CC ( 128)  C.C3CC ( 132)  0.0300 ( 134)  0.0300 ( 136)  0.0300
( 138)  0.0137 ( 144)  0.0137 ( 146)  C.C3CC ( 148)  0.0146 ( 150)  0.0146 ( 156)  0.0137
( 164)  0.0154 ( 174)  C.03CU ( 176)  C.C3CC ( 178)  0.0300 ( 1F))  0.0300 ( 187)  0.0300
( 184)  0.0300 ( 186)  C.03CC ( 19C)  0.C    ( 2CC)  0.0    ( 214)  0.0300 ( 218)  0.0300
( 220)  0.0300 ( 222)  C.C3CC ( 228)  C.C3CC ( 256)  0.0137 ( 282)  0.0300 ( 284)  0.0300
( 290)  0.0    ( 3CC)  C.C    ( 322)  C.C3CO ( 328)  0.0300 ( 4C0)  0.0    ( 500)  1.0000

STATE VARIABLE TYPE(S)
(   1)   1 (   2)   2 (   3)   5 (   4)   6 (   5)   5 (   6)   7 (   7)   8 (   8)   5 (   9)   5 (  10)   5

STATE VARIABLE(S)
(   1) 3.47226E 01 (   2) 7.94594E 01 (   3) 2.2E104E-01 (   4) 1.83076E-01 (   5) 5.16409E-01 (   6) 5.99237E 04
(   7) 6.34074E 00 (   8) 1.46349E-01 (   9) 7.84240E-01 (  10) 5.67751E-01

ERRCR VARIABLE TYPE(S)
(   1)   2 (   2)   2 (   3)   2 (   4)   1 (   5)   5 (   6)   2 (   7)   1 (   8)   3 (   9)   3 (  10)   3

ERRCR VARIABLE(S)
(   1)-5.03540E-C4 (   2)-1.67847E-04 (   3) C.0         (   4) 4.57764E-05 (   5)-1.52588E-04 (   6)-6.38962E-05
(   7)-1.90735E-06 (   8)-1.95313E-03 (   9)-4.88281E-04 (  10) 5.12695E-03

SCLUTICN CONVERCEC IN    8 TRY(S)

    0 ERROR(S) CETECTEC

CASE END
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LABORATORY DEMONSTRATION TEST
CASE IECS-4F

FLOW RATE(S)

(1)	29.18	(5)	29.18	(7)	23.41	(9)	5.77	(11)	20.30	(15)	17.14
(17)	5.99	(19)	23.13	(21)	10.65	(23)	12.19	(25)	8.88	(27)	2.89
(29)	1.67	(31)	1.22	(33)	13.41	(41)	12.32	(43)	107.00	(45)	54.52
(47)	52.48	(49)	107.00	(51)	107.00	(53)	3.11	(55)	22.85	(57)	0.28
(61)	20.30	(63)	3.16	(65)	17.14						

PRESSURE(S)

(2)	68.20	(4)	68.20	(10)	67.15	(12)	67.15	(14)	67.15	(16)	61.47
(18)	61.19	(20)	61.19	(22)	89.53	(24)	86.23	(26)	84.82	(28)	19.16
(32)	18.15	(34)	59.50	(36)	18.15	(38)	17.48	(42)	17.47	(44)	17.47
(46)	61.05	(48)	17.46	(50)	17.40	(54)	17.47	(64)	17.41	(66)	17.10
(74)	61.20	(76)	61.19	(78)	61.16	(80)	61.16	(82)	61.16	(84)	61.16
(86)	61.01	(90)	15.60	(92)	15.49	(94)	15.39	(96)	15.49	(98)	15.39
(100)	15.39	(102)	68.20	(114)	66.49	(116)	61.19	(118)	61.19	(120)	61.02
(124)	86.01	(126)	84.59	(128)	18.16	(132)	18.15	(134)	58.87	(136)	19.15
(138)	17.47	(144)	17.46	(146)	61.02	(148)	17.40	(150)	17.22	(156)	17.47
(164)	17.38	(174)	61.19	(176)	61.16	(178)	59.50	(180)	61.16	(182)	61.16
(184)	61.16	(186)	61.01	(190)	15.60	(200)	15.26	(214)	66.42	(218)	61.19
(220)	59.40	(222)	89.53	(228)	18.16	(256)	17.41	(282)	61.01	(284)	61.05
(290)	15.49	(300)	15.26	(322)	88.66	(328)	18.15	(400)	15.26	(500)	17.48

TEMPERATURE(S)

(2)	927.00	(4)	927.00	(10)	927.00	(12)	927.00	(14)	927.00	(16)	605.35
(18)	605.35	(20)	605.35	(22)	744.37	(24)	595.25	(26)	594.84	(28)	506.84
(32)	506.83	(34)	815.67	(36)	515.00	(38)	514.44	(42)	514.43	(44)	514.43
(46)	815.67	(48)	524.20	(50)	524.24	(54)	514.43	(64)	528.30	(66)	509.80
(74)	927.00	(76)	815.67	(78)	815.67	(80)	815.67	(82)	815.67	(84)	815.67
(86)	815.67	(90)	557.00	(92)	557.00	(94)	621.16	(96)	557.00	(98)	704.61
(100)	662.31	(102)	927.00	(114)	927.00	(116)	605.35	(119)	605.35	(120)	605.35
(124)	595.17	(126)	594.77	(128)	506.84	(132)	506.83	(134)	555.30	(136)	515.00
(138)	514.43	(144)	514.42	(146)	702.09	(148)	524.24	(150)	531.49	(156)	514.42
(164)	528.27	(174)	927.00	(176)	815.67	(178)	815.67	(180)	815.67	(182)	815.67
(184)	815.67	(186)	658.29	(190)	557.00	(200)	562.31	(214)	927.00	(218)	605.35
(220)	605.35	(222)	744.37	(228)	506.84	(256)	514.37	(282)	915.67	(284)	815.67
(290)	557.00	(300)	662.31	(322)	744.37	(328)	506.83	(400)	662.31	(500)	515.00

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0240	(4)	0.0240	(10)	0.0240	(12)	0.0240	(14)	0.0240	(16)	0.0240
(18)	0.0240	(20)	0.0240	(22)	0.0240	(24)	0.0240	(26)	0.0240	(28)	0.0240
(32)	0.0240	(34)	0.0240	(36)	0.0240	(38)	0.0115	(42)	0.0115	(44)	0.0115
(46)	0.0240	(48)	0.0126	(50)	0.0126	(54)	0.0115	(64)	0.0131	(66)	0.0131
(74)	0.0240	(76)	0.0240	(78)	0.0240	(80)	0.0240	(82)	0.0240	(84)	0.0240
(86)	0.0240	(90)	0.0	(92)	0.0	(94)	0.0	(96)	0.0	(99)	0.0
(100)	0.0	(102)	0.0240	(114)	0.0240	(116)	0.0240	(119)	0.0240	(120)	0.0240

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      LABORATORY DEMONSTRATION TEST
      CASE TECS-4E

( 124)  0.0240 ( 126)  0.0240 ( 128)  0.0240 ( 132)  0.0240 ( 134)  0.0240 ( 136)  0.0240
( 138)  0.0115 ( 144)  0.0115 ( 146)  0.0240 ( 148)  0.0126 ( 150)  0.0126 ( 156)  0.0115
( 164)  0.0131 ( 174)  0.0240 ( 176)  0.0240 ( 178)  0.0240 ( 180)  0.0240 ( 182)  0.0240
( 184)  0.0240 ( 186)  0.0240 ( 190)  0.0    ( 200)  0.0    ( 214)  0.0240 ( 218)  0.0240
( 220)  0.0240 ( 222)  0.0240 ( 228)  0.0240 ( 256)  0.0115 ( 282)  0.0240 ( 284)  0.0240
( 290)  0.0    ( 300)  0.0    ( 322)  0.0240 ( 328)  0.0240 ( 400)  0.0    ( 500)  1.0000

STATE VARIABLE TYPE(S)
(  1)   1 (  2)   6 (  3)   6 (  4)   6 (  5)   5 (  6)   7 (  7)   8 (  8)   5 (  9)   5 ( 10)   5

STATE VARIABLE(S)
(  1) 2.91760E 01 (  2) 1.23052E-03 (  3) 1.97610E-01 (  4) 1.79156E-01 (  5) 5.09532E-01 (  6) 5.38233E 04
(  7) 4.55813E 00 (  8) 1.55541E-01 (  9) 6.74440E-01 ( 10) 5.78099E-01

ERROR VARIABLE TYPE(S)
(  1)   2 (  2)   2 (  3)   2 (  4)   1 (  5)   5 (  6)   2 (  7)   1 (  8)   3 (  9)   3 ( 10)   3

ERROR VARIABLE(S)
(  1)-4.57764E-05 (  2) 0.0          (  3)-9.53674E-07 (  4)-1.52588E-05 (  5) 4.57764E-05 (  6) 0.0
(  7)-2.86102E-06 (  8)-2.44141E-04 (  9) 0.0          ( 10) 2.68555E-03

SOLUTION CONVERGED IN      10 TRY(S)

     0 ERROR(S) DETECTED

CASE END
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LABORATORY DEMONSTRATION TEST
CASE IECS-4C

FLOW RATE(S)

(1)	42.46	(5)	42.46	(7)	23.43	(9)	19.03	(11)	21.69	(15)	19.94
(17)	11.26	(19)	31.20	(21)	13.28	(23)	17.91	(25)	20.77	(27)	9.52
(29)	4.05	(31)	5.47	(33)	23.38	(41)	17.33	(43)	107.20	(45)	54.78
(47)	52.42	(49)	107.20	(51)	107.20	(53)	1.74	(55)	31.20	(57)	0.0
(61)	21.69	(63)	1.75	(65)	19.94						

PRESSURE(S)

(2)	70.25	(4)	70.25	(10)	70.23	(12)	70.23	(14)	70.23	(16)	64.76
(18)	64.54	(20)	64.54	(22)	86.82	(24)	83.77	(26)	82.47	(28)	26.00
(32)	25.99	(34)	54.42	(36)	25.99	(38)	25.32	(42)	25.30	(44)	25.30
(46)	64.38	(48)	25.29	(50)	25.17	(54)	25.30	(64)	25.24	(66)	24.82
(74)	64.62	(76)	64.54	(78)	64.45	(80)	64.45	(82)	64.45	(84)	64.45
(86)	64.38	(90)	11.40	(92)	11.28	(94)	11.16	(96)	11.28	(98)	11.16
(100)	11.16	(102)	70.25	(114)	69.71	(116)	64.54	(118)	64.54	(120)	64.39
(124)	83.57	(126)	82.26	(128)	26.00	(132)	25.99	(134)	52.38	(136)	25.99
(138)	25.30	(144)	25.29	(146)	64.06	(148)	25.18	(150)	24.78	(156)	25.30
(164)	25.20	(174)	64.54	(176)	64.45	(178)	54.42	(180)	64.45	(182)	64.44
(184)	64.44	(186)	64.36	(190)	11.40	(200)	11.02	(214)	68.75	(218)	64.54
(220)	63.10	(222)	86.82	(228)	26.00	(256)	25.24	(282)	64.38	(284)	64.38
(290)	11.28	(300)	11.02	(322)	86.04	(328)	25.99	(400)	11.02	(500)	25.32

TEMPERATURE(S)

(2)	777.00	(4)	777.00	(10)	777.00	(12)	777.00	(14)	777.00	(16)	500.95
(18)	500.95	(20)	500.95	(22)	588.59	(24)	472.79	(26)	472.79	(28)	379.34
(32)	379.34	(34)	754.64	(36)	522.00	(38)	522.00	(42)	522.00	(44)	522.00
(46)	754.64	(48)	548.00	(50)	548.00	(54)	522.00	(64)	548.00	(66)	598.47
(74)	777.00	(76)	754.64	(78)	754.64	(8C)	754.64	(82)	754.64	(84)	754.64
(86)	754.64	(90)	459.30	(92)	459.30	(94)	505.36	(96)	459.30	(98)	584.87
(100)	544.40	(102)	777.00	(114)	777.00	(116)	500.95	(118)	500.95	(120)	500.95
(124)	472.79	(126)	472.79	(128)	379.34	(132)	379.34	(134)	764.88	(136)	522.00
(138)	522.00	(144)	522.00	(146)	632.18	(148)	548.00	(150)	550.22	(156)	522.00
(164)	548.00	(174)	777.00	(176)	754.64	(178)	754.64	(180)	754.64	(182)	754.64
(184)	754.64	(186)	632.30	(190)	459.30	(20C)	544.40	(214)	777.00	(218)	500.95
(220)	500.95	(222)	588.59	(228)	379.34	(256)	522.00	(282)	754.64	(284)	754.64
(290)	459.30	(300)	544.40	(322)	588.59	(328)	379.34	(400)	544.40	(500)	572.00

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0	(4)	0.0	(1C)	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
(32)	0.0	(34)	0.0	(36)	0.0	(38)	0.0	(42)	0.0	(44)	0.0
(46)	0.0	(48)	0.0	(5C)	0.0	(54)	0.0	(64)	0.0	(66)	0.0
(74)	0.0	(76)	0.0	(78)	0.0	(8C)	0.0	(82)	0.0	(84)	0.0
(86)	0.0	(90)	0.0	(92)	0.0	(94)	0.0	(96)	0.0	(98)	0.0
(100)	0.0	(107)	0.0	(114)	0.0	(116)	0.0	(118)	0.0	(120)	0.0

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LABORATORY DEMONSTRATION TEST
CASE IECS-4C

( 124)  0.0    ( 126)  0.0    ( 128)  0.0    ( 132)  0.0    ( 134)  0.0    ( 136)  0.0
( 138)  0.0    ( 144)  0.0    ( 146)  0.0    ( 148)  0.0    ( 150)  0.0    ( 156)  0.0
( 164)  0.0    ( 174)  0.0    ( 176)  0.0    ( 178)  0.0    ( 180)  0.0    ( 182)  0.0
( 184)  0.0    ( 186)  0.0    ( 190)  0.0    ( 200)  0.0    ( 214)  0.0    ( 218)  0.0
( 220)  0.0    ( 222)  0.0    ( 228)  0.0    ( 256)  0.0    ( 282)  0.0    ( 284)  0.0
( 290)  0.0    ( 300)  0.0    ( 322)  0.0    ( 328)  0.0    ( 400)  0.0    ( 500)  1.0000

STATE VARIABLE TYPE(S)
(   1)    1 (   2)    2 (   3)    5 (   4)    6 (   5)    5 (   6)    7 (   7)    8 (   8)    5 (   9)    5 (  10)    5

STATE VARIABLE(S)
(   1) 4.24620E 01 (   2) 7.02475E 01 (   3) 4.48260E-01 (   4) 1.54918E-02 (   5) 5.11032E-01 (   6) 4.30894E 04
(   7) 3.16392E 00 (   8) 8.06836E-02 (   9) 5.41899E-01 (  10) 4.25442E-01

ERROR VARIABLE TYPE(S)
(   1)    2 (   2)    2 (   3)    2 (   4)    1 (   5)    5 (   6)    2 (   7)    1 (   8)    3 (   9)    3 (  10)    3

ERROR VARIABLE(S)
(   1)-1.52588E-05 (   2)-1.52588E-05 (   3)-9.53674E-07 (   4) 0.0         (   5) 6.19888E-05 (   6)-1.52588E-05
(   7)-1.90735E-06 (   8) 1.46484E-03 (   9) 1.46484E-03 (  10) 1.70898E-03

SOLUTION CONVERGED IN      7 TRY(S)

     0 ERROR(S) DETECTED

CASE END
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LABORATORY DEMONSTRATION TEST
CASE IECS-4D

FLOW RATE(S)

(1)	43.89	(5)	43.89	(7)	22.80	(9)	21.09	(11)	22.35	(15)	20.60
(17)	7.26	(19)	27.86	(21)	19.27	(23)	8.59	(25)	21.54	(27)	14.28
(29)	9.31	(31)	4.97	(33)	13.56	(41)	28.58	(43)	106.00	(45)	54.06
(47)	51.94	(49)	106.00	(51)	106.00	(53)	0.45	(55)	27.86	(57)	0.0
(61)	22.35	(63)	1.75	(65)	20.60						

PRESSURE(S)

(2)	70.00	(4)	70.00	(10)	69.20	(12)	69.20	(14)	69.20	(16)	63.75
(18)	63.54	(20)	63.54	(22)	88.85	(24)	85.63	(26)	84.28	(28)	21.67
(32)	21.66	(34)	59.59	(36)	21.66	(38)	21.09	(42)	21.07	(44)	21.07
(46)	62.14	(48)	21.07	(50)	21.02	(54)	21.07	(64)	20.96	(66)	19.64
(74)	63.64	(76)	63.54	(78)	63.44	(80)	63.44	(82)	63.43	(84)	63.43
(86)	55.41	(90)	15.70	(92)	15.61	(94)	15.53	(96)	15.61	(98)	15.53
(100)	15.53	(102)	70.00	(114)	68.70	(116)	63.54	(118)	63.54	(120)	63.38
(124)	85.43	(126)	84.06	(128)	21.67	(132)	21.66	(134)	58.74	(136)	21.66
(138)	21.07	(144)	21.07	(146)	61.86	(148)	21.02	(150)	20.87	(156)	21.07
(164)	20.85	(174)	63.54	(176)	63.44	(178)	59.59	(180)	63.43	(182)	63.42
(184)	63.43	(186)	55.30	(190)	15.70	(200)	15.43	(214)	67.59	(218)	63.54
(220)	61.80	(222)	88.85	(228)	21.67	(256)	20.96	(282)	55.41	(284)	62.14
(290)	15.61	(300)	15.43	(322)	88.02	(328)	21.66	(400)	15.43	(500)	21.09

TEMPERATURE(S)

(2)	777.00	(4)	777.00	(10)	777.00	(12)	777.00	(14)	777.00	(16)	499.39
(18)	499.39	(20)	499.39	(22)	599.89	(24)	475.29	(26)	475.29	(28)	368.10
(32)	368.10	(34)	771.41	(36)	422.90	(38)	422.90	(42)	422.90	(44)	422.90
(46)	771.41	(48)	537.90	(50)	537.90	(54)	422.90	(64)	529.10	(66)	560.17
(74)	777.00	(76)	771.41	(78)	771.41	(80)	771.41	(82)	771.41	(84)	771.41
(86)	771.41	(90)	459.30	(92)	459.30	(94)	511.09	(96)	459.30	(98)	583.33
(100)	546.62	(102)	777.00	(114)	777.00	(116)	499.39	(118)	499.38	(120)	499.38
(124)	475.29	(126)	475.29	(128)	368.10	(132)	368.10	(134)	576.00	(136)	422.90
(138)	422.90	(144)	422.90	(146)	730.23	(148)	537.90	(150)	542.56	(156)	422.90
(164)	529.10	(174)	777.00	(176)	771.41	(178)	771.41	(180)	771.41	(182)	771.41
(184)	771.41	(186)	741.52	(190)	459.30	(200)	546.62	(214)	777.00	(218)	499.38
(220)	499.38	(222)	599.89	(228)	368.10	(256)	422.90	(282)	771.41	(284)	771.41
(290)	459.30	(300)	546.62	(322)	599.89	(328)	368.10	(400)	546.62	(500)	422.90

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0	(4)	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
(32)	0.0	(34)	0.0	(36)	0.0	(38)	0.0	(42)	0.0	(44)	0.0
(46)	0.0	(48)	0.0	(50)	0.0	(54)	0.0	(64)	0.0	(66)	0.0
(74)	0.0	(76)	0.0	(78)	0.0	(80)	0.0	(82)	0.0	(84)	0.0
(86)	0.0	(90)	0.0	(92)	0.0	(94)	0.0	(96)	0.0	(98)	0.0
(100)	0.0	(102)	0.0	(114)	0.0	(116)	0.0	(118)	0.0	(120)	0.0

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LABORATORY DEMONSTRATION TEST
         CASE IECS-4D

( 124)  0.0     ( 126)  0.0     ( 128)  0.0     ( 132)  0.0     ( 134)  0.0     ( 136)  0.0
( 138)  0.0     ( 144)  0.0     ( 146)  0.0     ( 148)  0.0     ( 150)  0.0     ( 156)  0.0
( 164)  0.0     ( 174)  0.0     ( 176)  0.0     ( 178)  0.0     ( 180)  0.0     ( 182)  0.0
( 184)  0.0     ( 186)  0.0     ( 190)  0.0     ( 200)  0.0     ( 214)  0.0     ( 218)  0.0
( 220)  0.0     ( 222)  0.0     ( 228)  0.0     ( 256)  0.0     ( 282)  0.0     ( 284)  0.0
( 290)  0.0     ( 300)  0.0     ( 322)  0.0     ( 328)  0.0     ( 400)  0.0     ( 500)  1.0000

STATE VARIABLE TYPE(S)
(   1)    1 (   2)    6 (   3)    5 (   4)    6 (   5)    5 (   6)    7 (   7)    8 (   8)    5 (   9)    5 (  10)    5

STATE VARIABLE(S)
(   1) 4.38909E 01 (   2) 4.14068E-04 (   3) 4.80544E-01 (   4) 1.25114E-02 (   5) 5.10001E-01 (   6) 4.58789E 04
(   7) 3.87918E 00 (   8) 7.82988E-02 (   9) 3.36844E-01 (  10) 6.52023E-01

ERROR VARIABLE TYPE(S)
(   1)    2 (   2)    2 (   3)    2 (   4)    1 (   5)    5 (   6)    2 (   7)    1 (   8)    3 (   9)    3 (  10)    3

ERROR VARIABLE(S)
(   1)-1.52588E-05 (   2)-4.57764E-05 (   3) 0.0         (   4)-4.57764E-05 (   5) 1.62125E-05 (   6) 3.05176E-05
(   7)-2.86102E-06 (   8) 2.44141E-04 (   9) 4.88281E-04 (  10)-2.44141E-04

SOLUTICN CCNVERGED IN      8 TRY(S)

     0 ERROR(S) DETECTED

CASE END
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LABCRATORY DEMONSTRATION TEST
CASE IECS-5A

FLOW RATE(S)

(1)	27.33	(5)	27.33	(7)	24.52	(9)	2.82	(11)	23.98	(15)	22.70
(17)	0.64	(19)	23.34	(21)	14.59	(23)	8.70	(25)	3.35	(27)	2.71
(29)	0.65	(31)	2.06	(33)	10.76	(41)	15.24	(43)	406.00	(45)	205.50
(47)	200.50	(49)	406.00	(51)	406.00	(53)	0.53	(55)	23.28	(57)	0.06
(61)	23.98	(63)	1.28	(65)	22.70						

PRESSURE(S)

(2)	204.00	(4)	204.00	(10)	85.88	(12)	85.88	(14)	85.88	(16)	77.72
(18)	77.44	(20)	77.44	(22)	112.80	(24)	108.71	(26)	106.97	(28)	23.90
(32)	23.88	(34)	77.36	(36)	23.88	(38)	23.35	(42)	23.34	(44)	23.34
(46)	75.42	(48)	23.34	(50)	23.31	(54)	23.34	(64)	23.26	(66)	22.91
(74)	77.45	(76)	77.44	(78)	77.44	(80)	77.44	(82)	77.44	(84)	77.44
(86)	77.36	(90)	25.90	(92)	24.79	(94)	23.96	(96)	24.79	(98)	23.96
(100)	23.96	(102)	204.00	(114)	85.07	(116)	77.44	(118)	77.44	(120)	77.24
(124)	108.44	(126)	106.69	(128)	23.90	(132)	23.88	(134)	77.35	(136)	23.88
(138)	23.34	(144)	23.34	(146)	23.34	(148)	23.31	(150)	23.22	(156)	23.34
(164)	23.23	(174)	77.44	(176)	77.44	(178)	77.36	(180)	77.44	(182)	77.44
(184)	77.44	(186)	23.34	(190)	25.90	(200)	22.67	(214)	83.28	(218)	77.44
(220)	75.20	(222)	112.80	(228)	23.90	(256)	23.26	(282)	77.36	(284)	75.42
(290)	24.79	(300)	22.67	(322)	111.74	(328)	23.88	(400)	22.67	(500)	23.35

TEMPERATURE(S)

(2)	1292.00	(4)	1292.00	(10)	1292.00	(12)	1292.00	(14)	1292.00	(16)	676.78
(18)	676.78	(20)	676.78	(22)	829.66	(24)	674.59	(26)	674.59	(28)	530.08
(32)	530.06	(34)	1201.71	(36)	533.00	(38)	532.60	(42)	532.59	(44)	532.59
(46)	1201.71	(48)	538.40	(50)	538.40	(54)	532.59	(64)	535.60	(66)	599.34
(74)	1292.00	(76)	1201.72	(78)	1201.71	(80)	1201.71	(82)	1201.71	(84)	1201.71
(86)	1201.71	(90)	674.00	(92)	674.00	(94)	692.32	(96)	674.00	(98)	754.08
(100)	722.95	(102)	1292.00	(114)	1292.00	(116)	676.78	(118)	676.78	(120)	676.78
(124)	674.59	(126)	674.58	(128)	530.08	(132)	530.06	(134)	775.78	(136)	533.00
(138)	532.59	(144)	532.59	(146)	576.00	(148)	538.40	(150)	564.26	(156)	532.59
(164)	535.60	(174)	1292.00	(176)	1201.71	(178)	1201.71	(180)	1201.71	(182)	1201.71
(184)	1201.71	(186)	672.00	(190)	674.00	(200)	722.95	(214)	1292.00	(218)	676.78
(220)	676.78	(222)	829.66	(228)	530.08	(256)	532.53	(282)	1201.71	(284)	1201.71
(290)	674.00	(300)	722.95	(322)	829.66	(328)	530.06	(400)	722.95	(500)	533.00

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0140	(4)	0.0140	(10)	0.014C	(12)	0.0140	(14)	0.0140	(16)	0.0140
(18)	0.0140	(20)	0.0140	(22)	0.0140	(24)	0.0140	(26)	0.014C	(28)	0.0140
(32)	0.0140	(34)	0.0140	(36)	0.0140	(38)	0.0115	(42)	0.0115	(44)	0.0115
(46)	0.0140	(48)	0.0120	(50)	0.0120	(54)	0.0115	(64)	0.0116	(66)	0.0116
(74)	0.0140	(76)	0.0140	(78)	0.0140	(80)	0.0140	(82)	0.0140	(84)	0.0140
(86)	0.0140	(90)	0.0	(92)	0.0	(94)	0.0	(96)	0.0	(98)	0.0
(100)	0.0	(102)	0.0140	(114)	0.0140	(116)	0.0140	(118)	0.0140	(120)	0.0140

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        LABORATORY DEMONSTRATION TEST
        CASE IECS-5A

( 124)  0.0140 ( 126)  0.0140 ( 128)  0.0140 ( 132)  0.0140 ( 134)  0.0140 ( 136)  0.0140
( 138)  0.0115 ( 144)  0.0115 ( 146)  0.0140 ( 148)  0.0120 ( 150)  0.0120 ( 156)  0.0115
( 164)  0.0116 ( 174)  0.0140 ( 176)  0.0140 ( 178)  0.0140 ( 180)  0.0140 ( 182)  0.0140
( 184)  0.0140 ( 186)  0.0140 ( 190)  0.0    ( 200)  0.0    ( 214)  0.0140 ( 218)  0.0140
( 220)  0.0140 ( 222)  0.0140 ( 228)  0.0140 ( 256)  0.0115 ( 282)  0.0140 ( 284)  0.0140
( 290)  0.0    ( 300)  0.0    ( 322)  0.0140 ( 328)  0.0140 ( 400)  0.0    ( 500)  1.0000

STATE VARIABLE TYPE(S)
(   1)    1 (   2)    6 (   3)    5 (   4)    6 (   5)    5 (   6)    7 (   7)    8 (   8)    5 (   9)    5 (  10)    5

STATE VARIABLE(S)
(   1) 2.73340E 01 (   2) 1.58094E-01 (   3) 1.03042E-01 (   4) 1.06313E 00 (   5) 5.06157E-01 (   6) 5.65075E 04
(   7) 4.46386E 00 (   8) 5.33712E-02 (   9) 1.90217E-01 (  10) 2.39714E-01

ERROR VARIABLE TYPE(S)
(   1)    2 (   2)    2 (   3)    2 (   4)    1 (   5)    5 (   6)    2 (   7)    1 (   8)    3 (   9)    3 (  10)    3

ERROR VARIABLE(S)
(   1)-3.05176E-05 (   2) 9.15527E-05 (   3) 1.52588E-05 (   4)-3.05176E-05 (   5) 4.57764E-05 (   6) 3.05176E-05
(   7) 0.0         (   8) 1.95313E-03 (   9) 7.32422E-04 (  10)-2.44141E-04

SOLUTION CONVERGED IN      11 TRY(S)

      0 ERROR(S) DETECTED

CASE END
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LABORATORY DEMONSTRATION TEST
CASE IECS-5B

FLOW RATE(S)

(1)	33.67	(5)	33.67	(7)	26.30	(9)	7.37	(11)	25.69	(15)	24.41
(17)	6.27	(19)	30.68	(21)	22.88	(23)	7.74	(25)	7.98	(27)	1.71
(29)	1.40	(31)	0.31	(33)	8.06	(41)	24.28	(43)	407.00	(45)	205.79
(47)	201.21	(49)	407.00	(51)	407.00	(53)	0.62	(55)	30.62	(57)	0.05
(61)	25.69	(63)	1.28	(65)	24.41						

PRESSURE(S)

(2)	206.00	(4)	206.00	(10)	88.74	(12)	88.74	(14)	88.74	(16)	79.51
(18)	79.19	(20)	79.19	(22)	121.24	(24)	116.63	(26)	114.73	(28)	19.27
(32)	19.25	(34)	79.09	(36)	19.24	(38)	18.35	(42)	18.32	(44)	18.32
(46)	76.67	(48)	18.32	(50)	18.29	(54)	18.32	(64)	18.09	(66)	16.97
(74)	79.21	(76)	79.19	(78)	79.17	(80)	79.17	(82)	79.17	(84)	79.17
(86)	79.09	(90)	26.20	(92)	25.06	(94)	24.21	(96)	25.06	(98)	24.21
(100)	24.21	(102)	206.00	(114)	87.84	(116)	79.19	(118)	79.19	(120)	78.96
(124)	116.34	(126)	114.41	(128)	19.27	(132)	19.24	(134)	78.26	(136)	19.24
(138)	18.32	(144)	18.32	(146)	18.32	(148)	18.29	(150)	18.23	(156)	18.31
(164)	17.99	(174)	79.19	(176)	79.17	(178)	79.09	(180)	79.17	(182)	79.17
(184)	79.17	(186)	18.32	(190)	26.20	(200)	22.88	(214)	85.79	(218)	79.19
(220)	76.50	(222)	121.24	(228)	19.27	(256)	18.09	(282)	79.09	(284)	76.67
(290)	25.06	(300)	22.88	(322)	120.03	(328)	19.25	(400)	22.88	(500)	18.35

TEMPERATURE(S)

(2)	1288.67	(4)	1288.67	(10)	1288.67	(12)	1288.67	(14)	1288.67	(16)	699.29
(18)	699.29	(20)	699.29	(22)	882.19	(24)	696.60	(26)	696.60	(28)	522.04
(32)	522.03	(34)	1247.02	(36)	529.00	(38)	528.11	(42)	528.08	(44)	528.08
(46)	1247.02	(48)	531.90	(50)	531.90	(54)	528.08	(64)	531.90	(66)	572.19
(74)	1288.67	(76)	1247.02	(78)	1247.02	(80)	1247.02	(82)	1247.02	(84)	1247.02
(86)	1247.02	(90)	695.60	(92)	695.60	(94)	719.14	(96)	695.60	(98)	777.46
(100)	748.09	(102)	1288.67	(114)	1288.67	(116)	699.29	(118)	699.29	(120)	699.29
(124)	696.60	(126)	696.60	(128)	522.04	(132)	522.02	(134)	587.00	(136)	529.00
(138)	528.08	(144)	528.08	(146)	673.00	(148)	531.90	(150)	566.72	(156)	528.08
(164)	531.90	(174)	1288.67	(176)	1247.02	(178)	1247.02	(180)	1247.02	(182)	1247.02
(184)	1247.02	(186)	625.00	(190)	695.60	(200)	748.09	(214)	1288.67	(218)	699.29
(220)	699.29	(222)	882.19	(228)	522.04	(256)	527.84	(282)	1247.02	(284)	1247.02
(290)	695.60	(300)	748.09	(322)	882.19	(328)	522.03	(400)	748.09	(500)	529.00

HUMIDITY(S)/ENTHALPY(S)

(2)	0.0140	(4)	0.0140	(10)	0.0140	(12)	0.0140	(14)	0.0140	(16)	0.0140
(18)	0.0140	(20)	0.0140	(22)	0.0140	(24)	0.0140	(26)	0.0140	(28)	0.0140
(32)	0.0140	(34)	0.0140	(36)	0.0140	(38)	0.0123	(42)	0.0123	(44)	0.0123
(46)	0.0140	(48)	0.0123	(50)	0.0123	(54)	0.0123	(64)	0.0124	(66)	0.0124
(74)	0.0140	(76)	0.0140	(78)	0.0140	(80)	0.0140	(82)	0.0140	(84)	0.0140
(86)	0.0140	(90)	0.0	(92)	0.0	(94)	0.0	(96)	0.0	(98)	0.0
(100)	0.0	(102)	0.0140	(114)	0.0140	(116)	0.0140	(118)	0.0140	(120)	0.0140

```
         LABORATORY DEMONSTRATION TEST
         CASE IECS-5B

( 124)  0.0140 ( 126)  0.0140 ( 128)  0.0140 ( 132)  0.0140 ( 134)  0.0140 ( 136)  0.0140
( 138)  0.0123 ( 144)  0.0123 ( 146)  0.0140 ( 148)  0.0123 ( 150)  0.0123 ( 156)  0.0123
( 164)  0.0124 ( 174)  0.0140 ( 176)  0.0140 ( 178)  0.0140 ( 180)  0.0140 ( 182)  0.0140
( 184)  0.0140 ( 186)  0.0140 ( 190)  0.0     ( 200)  0.0     ( 214)  0.0140 ( 218)  0.0140
( 220)  0.0140 ( 222)  0.0140 ( 228)  0.0140 ( 256)  0.0123 ( 282)  0.0140 ( 284)  0.0140
( 290)  0.0    ( 300)  0.0    ( 322)  0.0140 ( 328)  0.0140 ( 400)  0.0    ( 500)  1.0000

STATE VARIABLE TYPE(S)
(   1)    1 (   2)    6 (   3)    5 (   4)    6 (   5)    5 (   6)    7 (   7)    8 (   8)    5 (   9)    5 (  10)    5

STATE VARIABLE(S)
(  1) 3.36686E 01 (   2) 1.03445E-01 (   3) 2.18775E-01 (   4) 1.75599E-01 (   5) 5.05627E-01 (   6) 6.17030E 04
(  7) 5.93743E 00 (   8) 4.98297E-02 (   9) 7.85565E-01 (  10) 8.18112E-01

ERROR VARIABLE TYPE(S)
(   1)    2 (   2)    2 (   3)    2 (   4)    1 (   5)    5 (   6)    2 (   7)    1 (   8)    3 (   9)    3 (  10)    3

ERROR VARIABLE(S)
(  1)-1.52588E-05 (   2) 1.37329E-04 (   3) 0.0         (   4)-6.10352E-05 (   5) 6.10352E-05 (   6) 4.57764E-05
(  7) 0.0         (   8) 7.32422E-04 (   9) 1.95313E-03 (  10) 3.66211E-03

SOLUTION CONVERGED IN      10 TRY(S)

    0 ERROR(S) DETECTED

CASE END
```

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13. ABSTRACT
This report presents the results of a study of Environmental Control System (ECS) designs for aircraft. The study was performed for the Air Force Flight Dynamics Laboratory. A test ECS and associated laboratory test facility, the test conditions and testing procedures, and the factors evaluated with the test results are discussed. The Laboratory Demonstration Test ECS consisted of an F-4E cabin system, several additional off-the-shelf components to improve the system performance (i.e., which provide better temperature and flow control than is presently specified), appropriate laboratory equipment for system assembly and heat load simulation, and instrumentation for test monitoring. Testing of this ECS was performed at several conditions which simulate the flight envelope of a high performance fighter aircraft. Tests were performed with and without various system components to show their contributions to the improved system capacity, and system temperature and flow control.

The ECS Computer Program described in Volume II was used to predict detailed performance of the laboratory demonstration ECS, and thus to provide an evaluation of the test data. In the process the validity of the computer program is illustrated. The computer program also was used to determine component and system sizes (using the analytical design information of Volume I), and system penalties of this ECS to a typical fighter aircraft. Volume II includes sample problems for the rough performance and sizing analyses of three Air Force aircraft, and the detailed performance and sizing of one Air Force aircraft. Volume III (IECS Computer Program Users Manual) contains information on how to use the computer program and a complete description of sample problems for rough performance and sizing analyses, and detailed performance analysis.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aircraft Equipment						
Butterfly Valves						
Check Valves						
Compressor						
Duct						
Environmental Control System						
Heat Exchangers						
Insulation						
Electronic Temperature Control						
Heat Sinks						
Heat Transfer						
Heat Transfer Coefficients						
Reliability						
Pressure Control						
Pressure Regulators						
Moisture						
Computer Program						
Flow Control						
Remote Control						
Simulators						
Temperature Control						
Thermal Stability						
Turbomachinery						
Turbine						
Water Separator						
Valves						