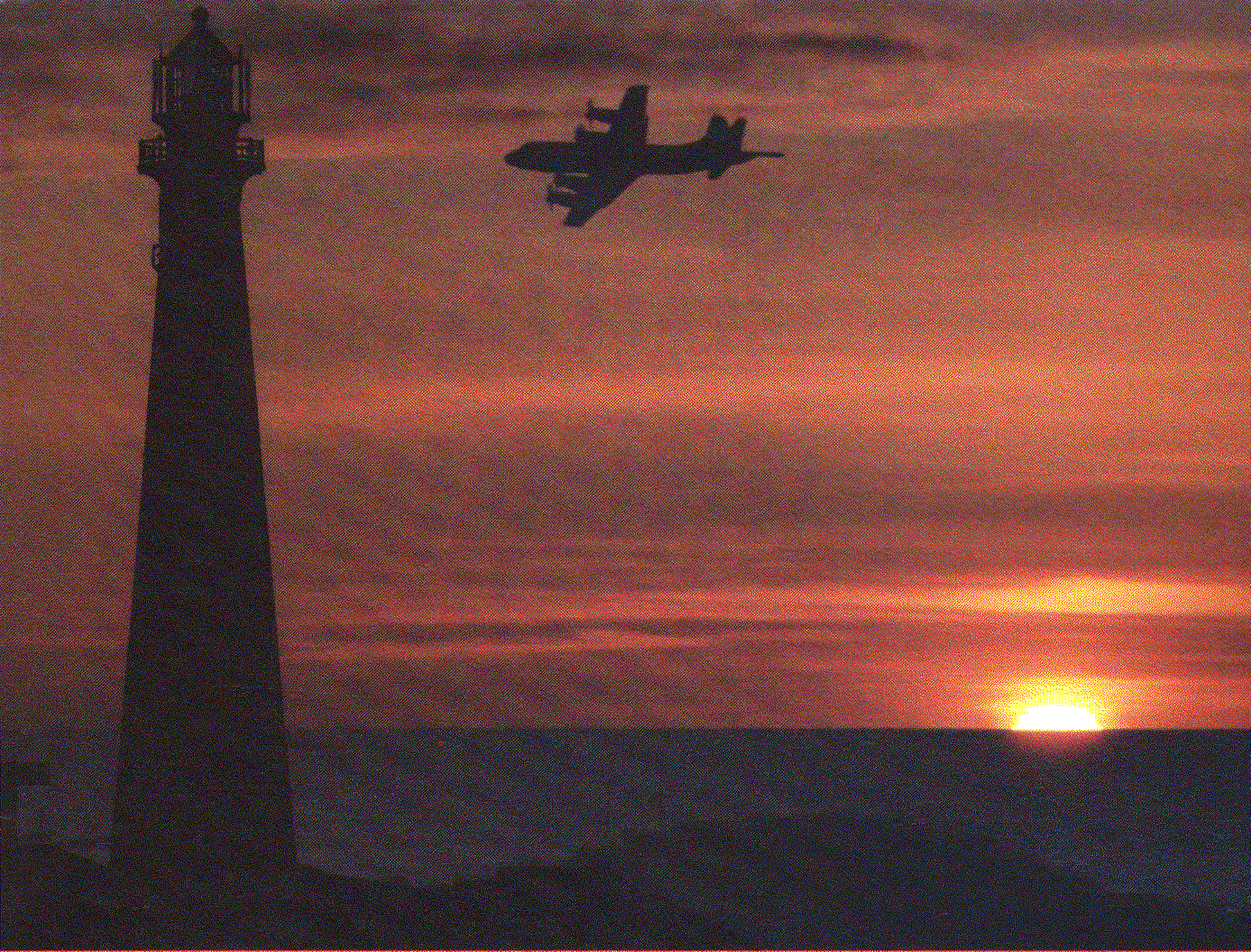

ORION • SERVICE digest

issue 41 AUGUST 1983

LOCKHEED • CALIFORNIA COMPANY

P-3 ENVIRONMENTAL CONTROL SYSTEM

ISSUE 41 AUGUST 1983
LOCKHEED-CALIFORNIA COMPANY

TABLE OF CONTENTS

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FRONT AND BACK COVERS

Royal Norwegian Air Forces No. 333 Squadron was commissioned during World War II on 8 February 1942 at Woodhaven, Scotland. Equipped with de Havilland Mosquito bombers and Consolidated Catalina flying boats, the squadron's primary missions were to fly anti-submarine patrols and to escort convoys in the North Atlantic. They also conducted reconnaissance of the Norwegian coastline and maintained traffic in secret passengers to their occupied country.

When Norway was liberated in 1945, No. 333 Squadron went home. During their three years of combat, they sank 4 U-boats and damaged 8 others. They shot down 18 German aircraft, probably shot down 3 enemy aircraft, and damaged 3 enemy aircraft. These victories were achieved at the cost of the lives of 33 squadron members.

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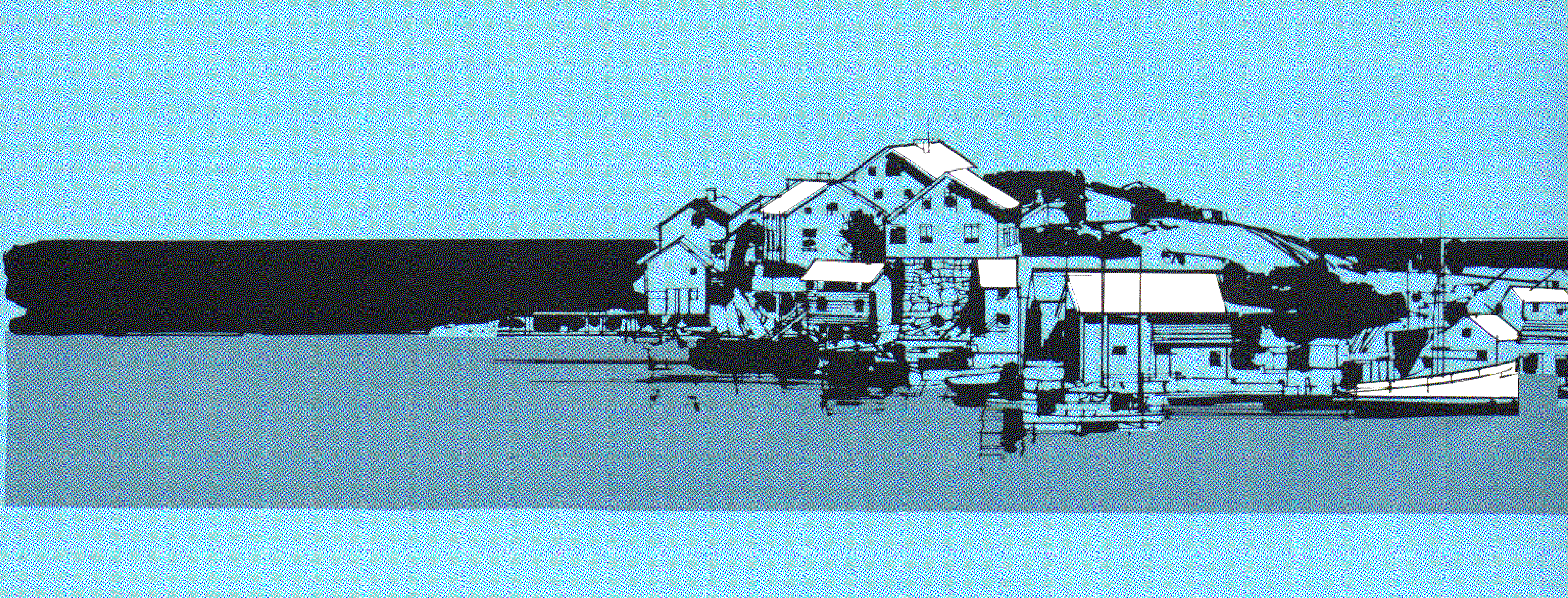

From their arrival in Norway until 1956, the squadron made its home base primarily at Sola Airfield near Stavanger. During the postwar years, the squadron also established a permanent detachment in north Norway. From this locale, the squadron proved that year-around air traffic could operate above the Arctic Circle.

In 1961, No. 333 Squadron replaced their Catalina aircraft with Grumman HU-16B Albatross amphibians. Following transition to their new aircraft and training on new ASW equipment, the squadron was again combat-ready. Two years later, the entire squadron moved north to their present home, Andoya Air Base, from which they have conducted operations over the North Atlantic and the North Sea.

During the next few years, developments within the field of ASW equipment and the need for a strengthened NATO flank made it evident that it would be desirable to equip the squadron with even more sophisticated ASW systems and faster aircraft. In 1969, No 333 Squadron took possession of their new Lockheed P-3B Orions in the United States, and by the fall of that year they had returned to Norway combat-ready and equipped with the finest ASW aircraft the world had seen.

Today, the squadron continues to perform its missions flying P-3B Orion aircraft. Its daily military missions are surveillance and ASW. In addition, No. 333 Squadron has made mail deliveries to Sptizbergen and other remote outposts in the Arctic, performed search and rescue missions and ambulance flights, and carried out such diverse tasks as mine destruction, searches of herring shoals, ice reconnaissance, mapping and aerial photography of Spitzbergen, tallying the number of seals off Greenland, and observing volcanic eruptions of Jan Mayan Island. Probably the best-known squadron in the Royal Norweigan Air Force, No. 333 Squadron is the only RNAF squadron that has been in continual service since it was commissioned.

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editor **WAYNE CRADDUCK**
art and production by **ALLEN LUDLOFF**

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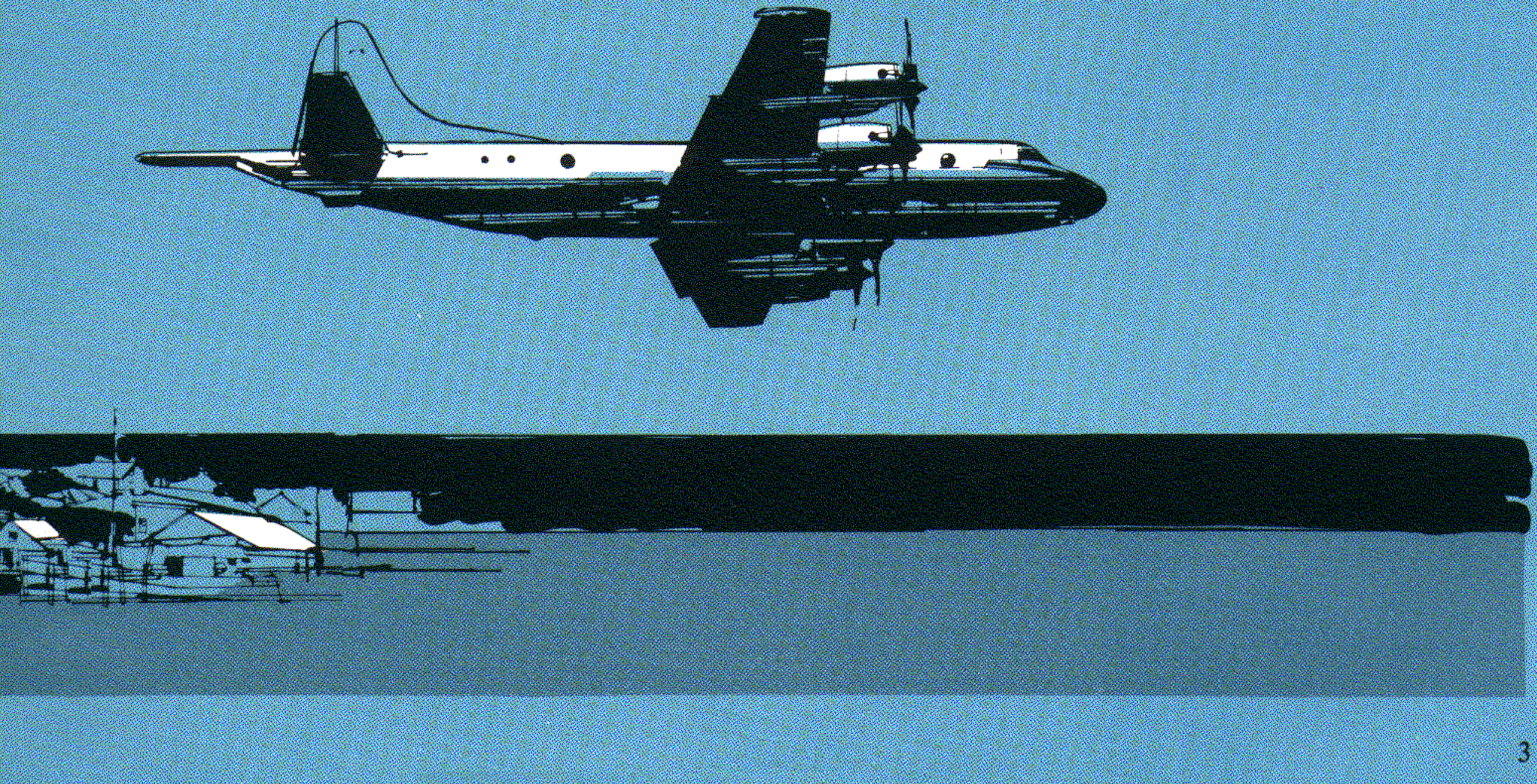

P-3 Environmental Control System

by Tom Blakely
Senior Representative
P-3 Field Service
Government Product Support

INTRODUCTION

Aircraft environmental control systems (ECS) are designed to provide air at the proper temperature, humidity and flow to maintain a comfortable environment for the flight crew and the avionics equipment. Since the P-3 aircraft encounters widely varying environmental conditions during normal operations, its environmental control systems require some fairly complex controls in order to maintain proper atmospheric conditions within the aircraft. Correct operation of these control systems is vital for the ECS to perform its function. This article describes the basic operation of the P-3 environmental control system and provides some general guidelines to aid in evaluation and isolation of system malfunctions.

This article addresses the P-3 environmental control system in five parts: (1) air delivery source operation (Engine Driven Compressors and APU/Air Multiplier), (2) basic operation of the air cycle system, (3) electronic temperature control system operation, (4) basic operation of the pressurization controls, and (5) features of the BR61-101 Temperature Control System Test Set and some guidelines for its use in fault isolation. This article does not supersede the material on P-3 air conditioning presented in Orion Service Digest Issue 16. Rather, it is intended as additional information to aid the operator and maintenance technician. The information presented does, however, reflect the current P-3 ECS configuration, taking into account modifications that have been implemented since the publication of OSD No. 16 in 1967. The reader may refer to OSD No. 16 if a more detailed explanation of certain aspects of system operation is desired.

AIR DELIVERY EQUIPMENT

In order for the ECS to maintain a comfortable cabin environment, air at the proper temperature and flow volume must be available. The air flow sources in the P-3 aircraft are the Engine Driven Compressors (EDCs) and the Auxiliary Power Unit/Air Multiplier combination. The EDCs are single-stage centrifugal air compressors with fully automatic controls. They supply air to the ECS during flight and are operable only when the No. 2 and No. 3 engines are running. The EDCs serve also as a secondary air source for the ECS during ground operation. The APU/Air Multiplier Package (AMP) is available as a source of air only while the aircraft is on the ground. This combination is the normal source of ECS air during preflight and maintenance evolutions.

EDC OPERATIONS The P-3 has two EDCs, one to supply air to each of the two air cycle cooling systems. The foldout ECS schematic at the back of this magazine shows the relationship of the EDCs to the air cycle system. During EDC operation there is no interconnect between the flight station and cabin systems until well downstream in the air distribution section. The No. 2 engine EDC supplies air to the right-hand (flight station) air cycle cooling system and the No. 3 EDC supplies air to the left-hand (cabin) air cycle system. The duct crossover is in the APU compartment and allows the ducts some flexibility for expansion. The compressor is mounted to a drive pad on the left side of the T-56 engine reduction gearbox assembly. With the engine running at 100 percent power (13,820 rpm), the compressor drive shaft runs at approximately 3690 rpm and the compressor impeller runs at 45,239 rpm.

All P-3 aircraft produced prior to the P-3C Update III model are equipped with EDCs adjusted for an 81 hp maximum power drive requirement. P-3C Update III aircraft are equipped with uprated EDCs that have a 101 hp maximum power extraction.[1] The EDC's maximum drive power requirement assumes that the engine is operating at 100 percent rpm and that the EDC is operating at its maximum airflow volume and maximum pressure ratio. The uprated EDC supplies air at a higher flow rate, which increases the ECS capacity. At sea level, the air flow rate from the 101 hp EDC is approximately 72 lb/min compared to 60 lb/min from the 81 hp EDC.

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[1] As this article was being prepared, plans were being developed to install (on an attrition basis) the uprated 101 hp EDC on selected pre-Update III P-3 aircraft in lieu of the 81 hp unit.

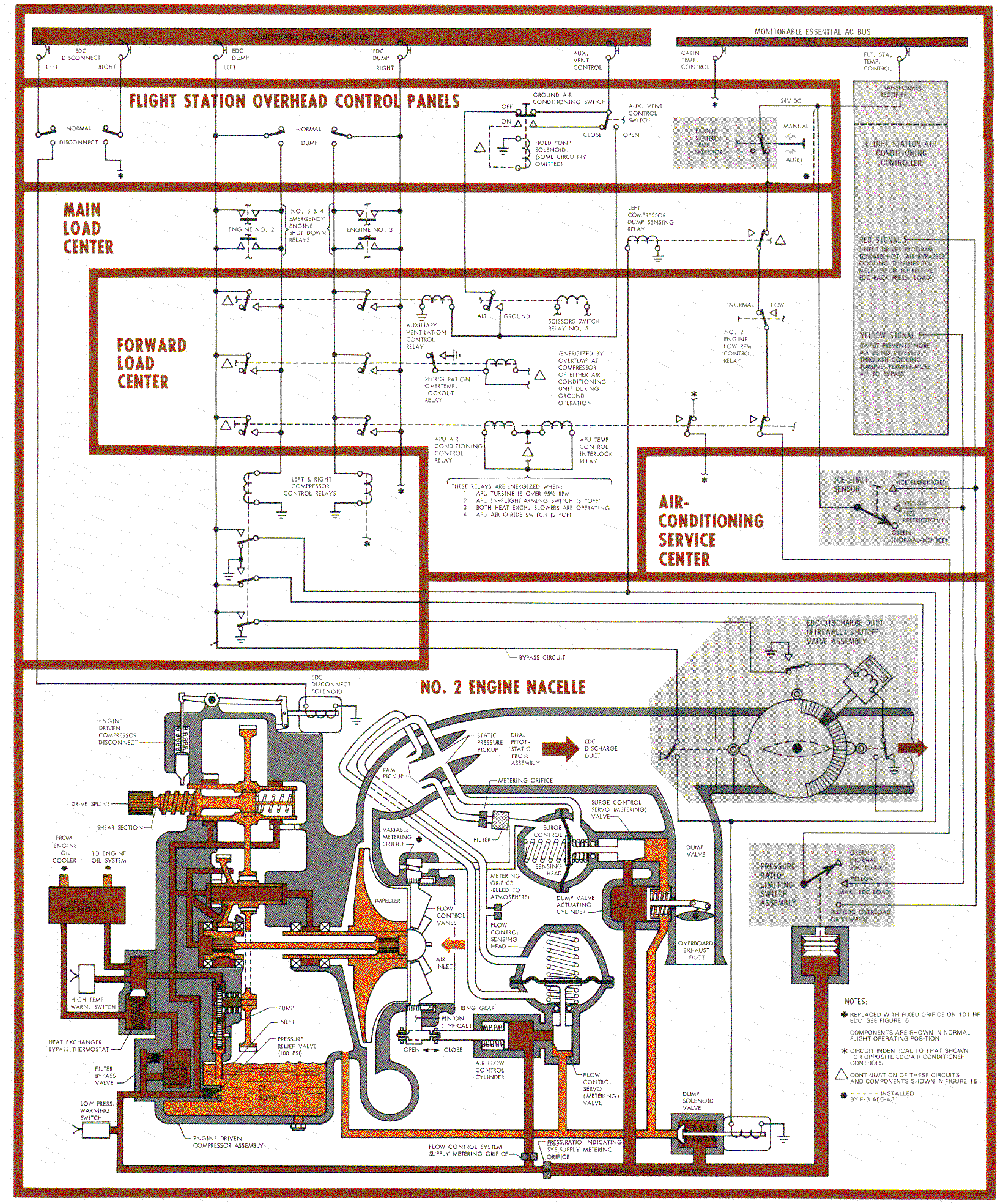


Figure 1. Left Engine Driven Compressor and Controls Schematic, Showing Interconnect with Related Air Conditioning System via the Pressure Ratio Limiting and Ice Limiting Protection Systems. See Figure 15 for additional interconnecting control circuits.

Figure 1 is a functional diagram of the left EDC and its control system. This figure shows that the EDC drive shaft has a shear section, machined just behind the drive spline, that is designed to shear at 4400 in/lb applied torque (approximately 257 hp). This design provides a safety factor of approximately 3.1 for the 81 hp EDC and approximately 2.5 for the 101 hp EDC. Under normal operating conditions, the EDC automatic control systems limit the load on the EDC so that its power demands do not exceed its design limits.

The EDC has its own self-contained lubrication system that operates with a nominal pressure of 100 psig. EDC oil is cooled in an oil-to-oil heat exchange with the engine oil system. (The oil supplies of the two systems do not mix.) The EDC oil system is used both to lubricate the EDC rotating components and for hydraulic actuation of the EDC flow and surge control systems.

The EDC operating controls are located on the Cabin Air Compressor control panel in the flight station, along with the other ECS controls and indicators (see Figure 2). Each EDC has a compressor inlet/discharge pressure indicator, a high oil temperature warning light, a manual compressor dump control switch, and a red guarded disconnect control switch.

The controls for the flight station and cabin air cycle systems are located on the Air Conditioning panel, directly above the EDC controls. The function of these controls will be discussed in detail later in this article. However, at this point in the article, the point that we want to make is that the EDC and air cycle system controls are organized on the control panels relative to the location of the air supply source (the EDC). Thus, since the left EDC supplies air to the flight station air cycle system, the controls are grouped on the left side of the respective control panels. Similarly, the controls for the right EDC and the cabin air cycle system are grouped on the right side of the control panels. The grouping of these instruments and controls is a useful point to remember when performing fault isolation procedures on the EDCs and the air cycle cooling systems.

The compressor inlet/discharge pressure indicators are electrical synchro-type indicators. The inlet pressure transducer is located in the engine nacelle and plumbed to a static pressure tap at the EDC inlet. The discharge pressure transducer is located on the FS 323 bulkhead in the APU compartment and measures the EDC discharge pressure downstream of the EDC firewall shutoff valve.

The EDC disconnect switch enables the flight crew to energize circuitry that initiates mechanical disconnect of the EDC drive shaft from the engine reduction gearbox. An EDC disconnect should only be performed with the engine running at 100 percent rpm. When the switch is actuated, the EDC disconnect solenoid on the EDC housing is energized, which releases a spring-loaded pawl and fulcrum assembly. This allows the disconnect tang to drop into a worm gear machined into the EDC drive shaft. When the shaft is rotating, the tang causes the shaft to retract from the engine gearbox and move into the EDC drive housing. A successful disconnect is indicated by observing the inlet/discharge needle spread become zero on the appropriate compressor pressure gauge, and illumination of the EDC low oil pressure warning light. EDC reconnect is a ground operation that is accomplished after engine shutdown. The reconnect can be performed without removing

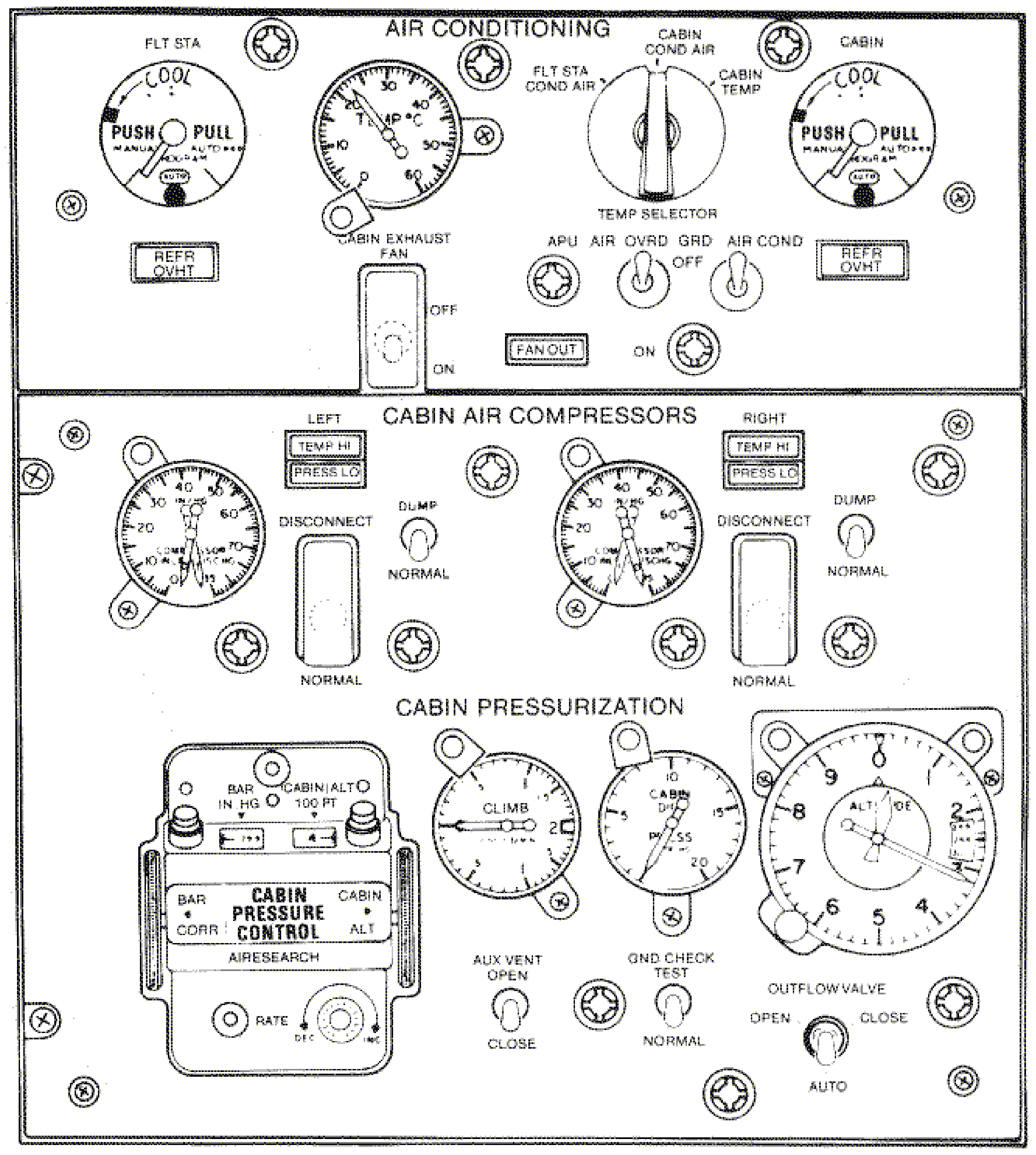


Figure 2. Air Conditioning and Pressurization System Control Panels

the EDC from the reduction gearbox. An EDC disconnect checker rod is installed in the EDC housing, just aft of the mounting flange. Maintenance personnel can use this device to determine visually if the EDC drive shaft is connected or disconnected.

Air Flow Control The constant-speed impeller of the single-stage centrifugal compressor is designed to operate efficiently in the relatively low-density air found at high altitudes. However, as the aircraft climbs and descends, the density of the air at the EDC inlet changes considerably. Since the compressor impeller is designed to run with a relatively low-density air intake, something must be done to control the mass flow (lb/min) of air through the EDC at lower altitudes. This is accomplished by adjusting the angle of attack at the EDC air inlet and the area of the compressor inlet with a set of eleven flow control vanes (see Figure 3). At low altitudes where the air density is high, the vanes are driven towards the closed position to reduce the air inlet area and the angle of attack at the inlet. If the vanes were not installed or if they fail to close during a descent, the compressor would attempt to process too much air. The horsepower required to drive the impeller would exceed the EDC's design limit (81 hp or 101 hp, times the safety factor), and the resulting overload would shear the driveshaft.

The EDC flow control system has a sensing head that uses pneumatic signals from the pitot-static assembly in the compressor discharge duct to position a flow control oil pressure metering valve (see Figures 4 and 5). Oil is supplied from the EDC lubrication system at the nominal pressure of 100 psig to the air flow control cylinder. The piston in the control cylinder is spring-loaded to drive the flow control vanes closed in the absence of oil pressure. The oil pressure in the flow control cylinder is determined by the position of the flow control metering valve. The orifice in the flow control system supply line isolates the hydraulic control pressure to prevent surge control system pressure from affecting flow control pressure. If the air mass flow in the compressor exceeds the proper volume, the ram (pitot) pressure signal to the flow control sensing head will increase relative to the sensed static pressure. This increase in differential pressure will cause the diaphragm in the sensing head and the flow control metering valve to move up. Hydraulic pressure in the flow control cylinder will be reduced as oil is bypassed through the metering valve and returned to the sump. This will result in the control cylinder spring moving the linkage and driving the inlet vanes towards the closed position, reducing the air flow.

Note that there is a bleed-to-atmosphere metering

Photos courtesy of the Garrett Corporation

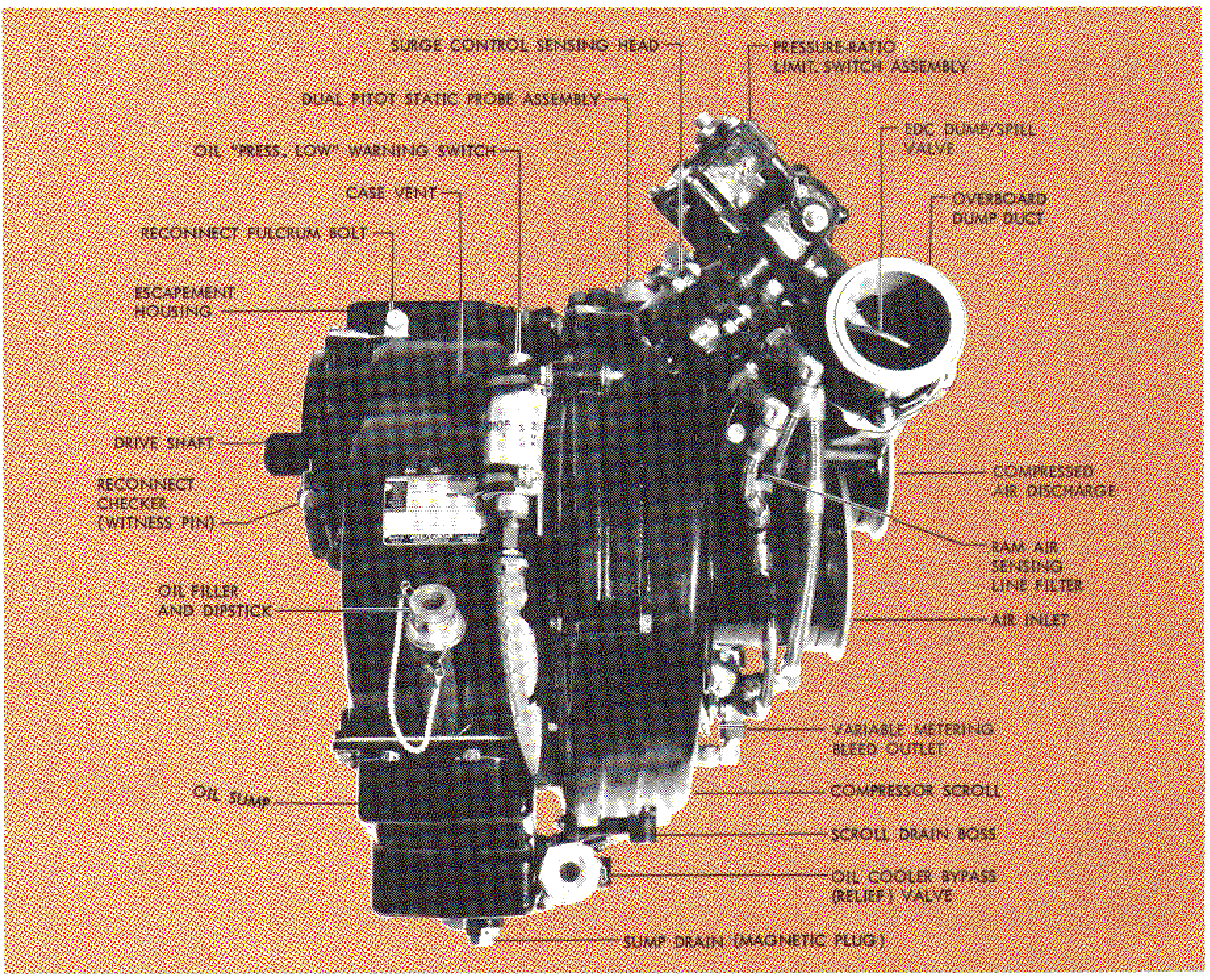
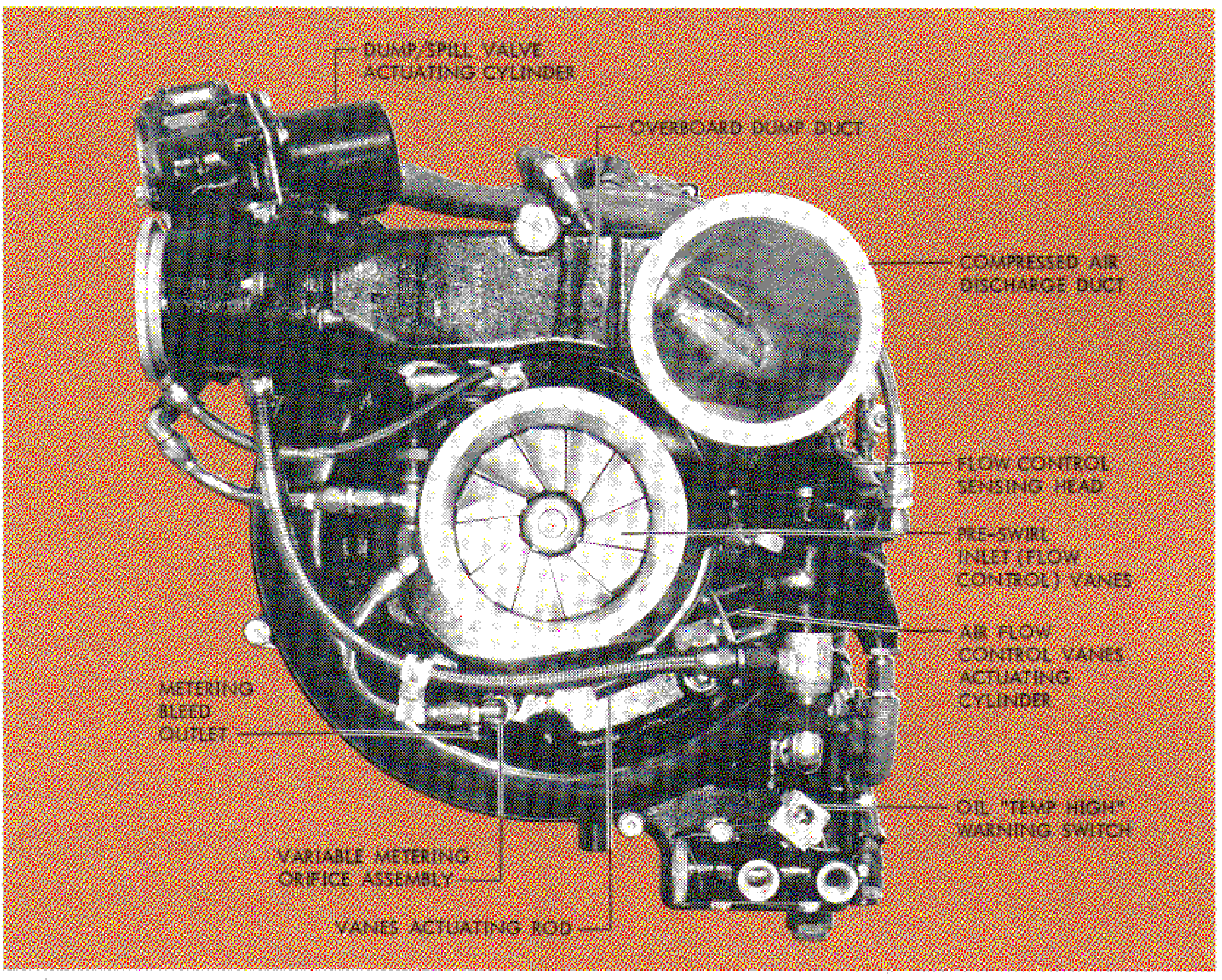


Figure 3.
Engine Driven Compressor (EDC)

Left-Side View

orifice mounted in the flow control static pressure line. The purpose of this controlled "leak" is to artificially increase the difference between the ram and static pressures in order to fine-tune the operation of the flow control with changes in altitude. For *hot-day* conditions, the flow control will fully open the vanes on the 101 hp EDC at approximately 8000 feet. Under the same hot-day conditions, the flow control vanes on the 81 hp EDC will fully open at a slightly higher altitude.

The function of this controlled leak often has been the source of some confusion to maintenance personnel. It may appear that during a descent the atmospheric pressure to which the orifice is bleeding is increasing and would, therefore, cause the pressure in the static sensing line to increase rather than decrease. The important point to remember here is that the static pressure being bled is *compressor discharge pressure*. Pressure in the static sensing line will always be higher than ambient atmospheric pressure, allowing air to bleed from the metering orifice regardless of altitude. This orifice, shown in Figure 3, is a No. 4 plumb-



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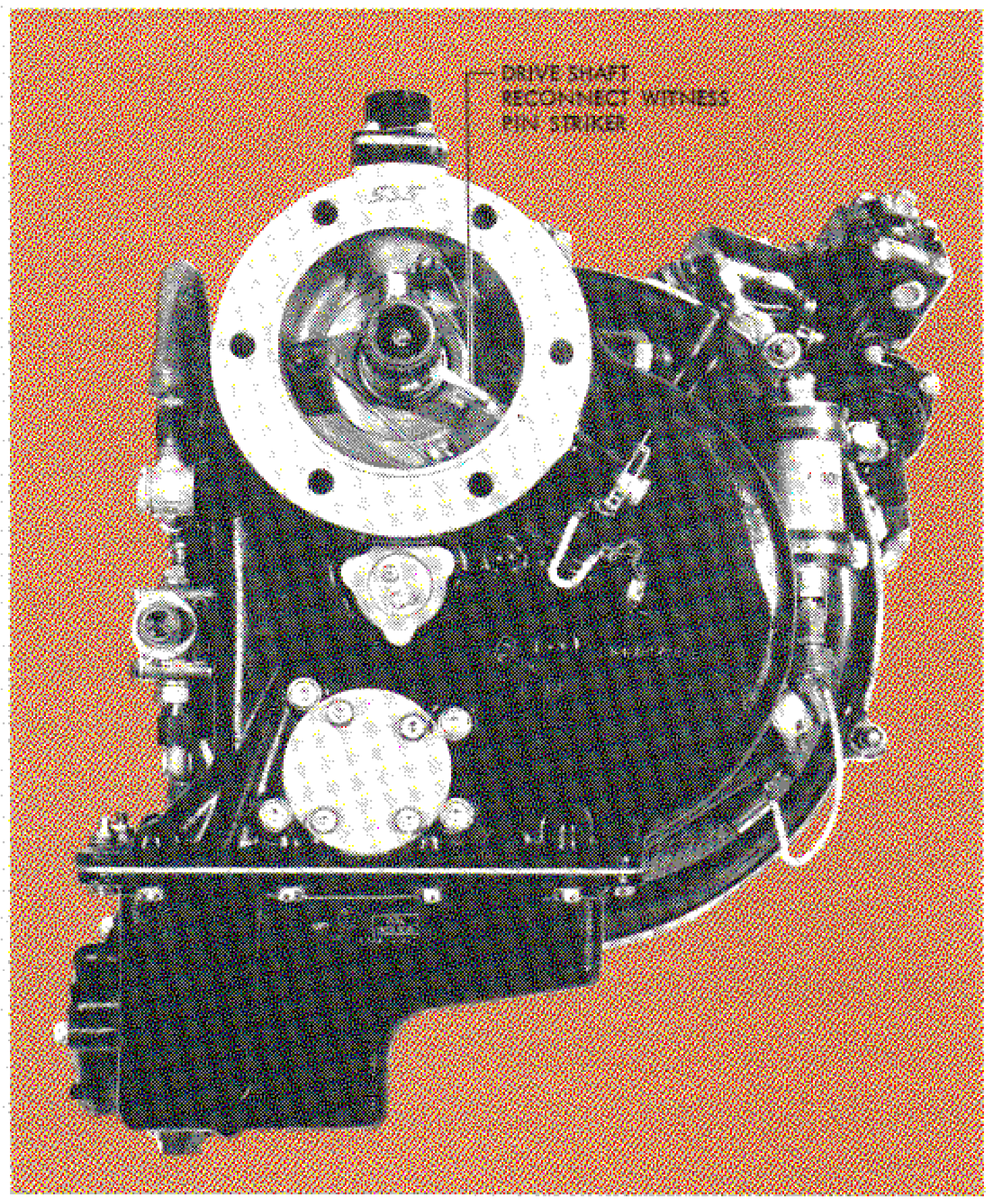
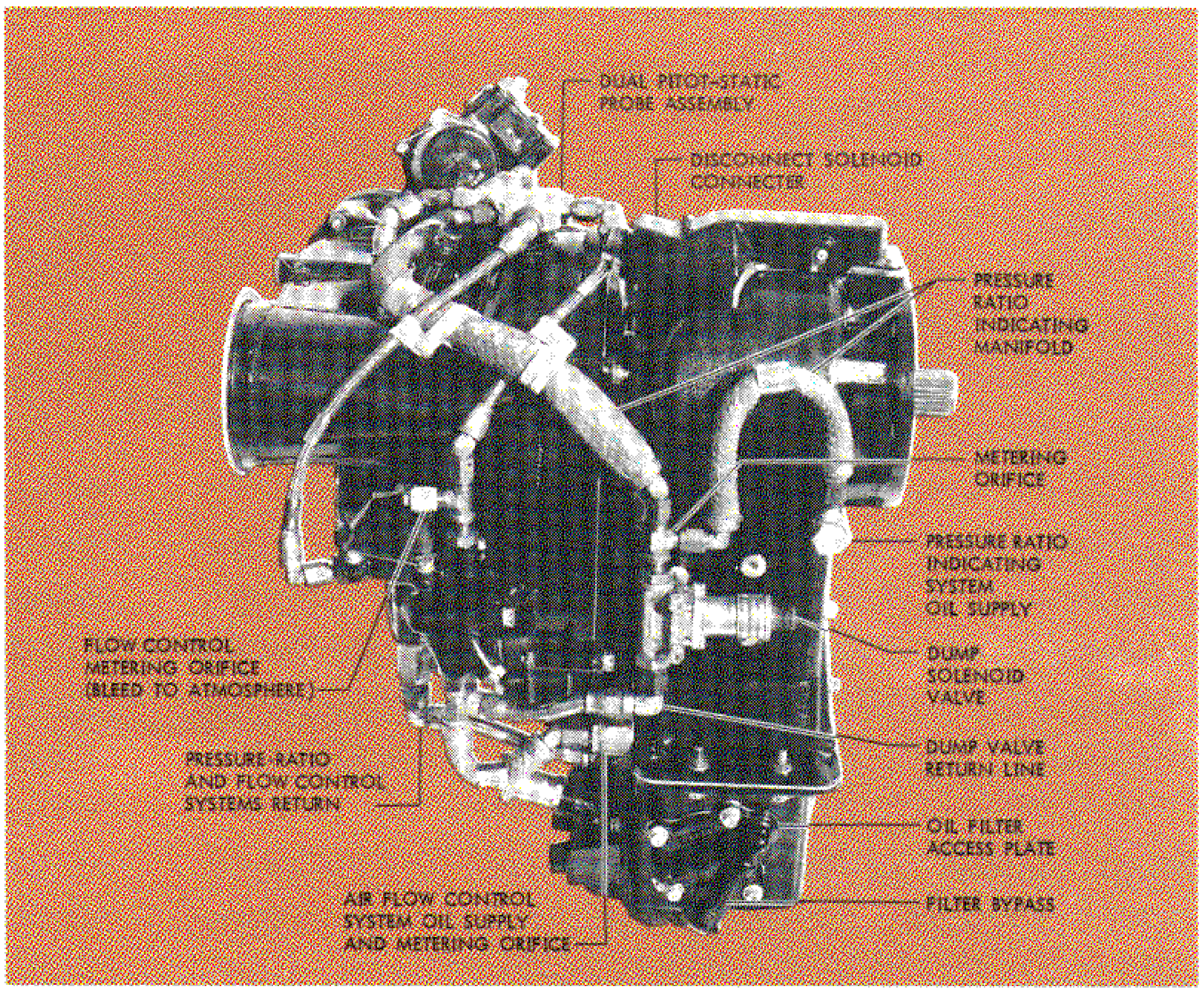
◀ *EDC View Looking Forward*



EDC View Looking Aft, Below Left

EDC Right-Side View ▼



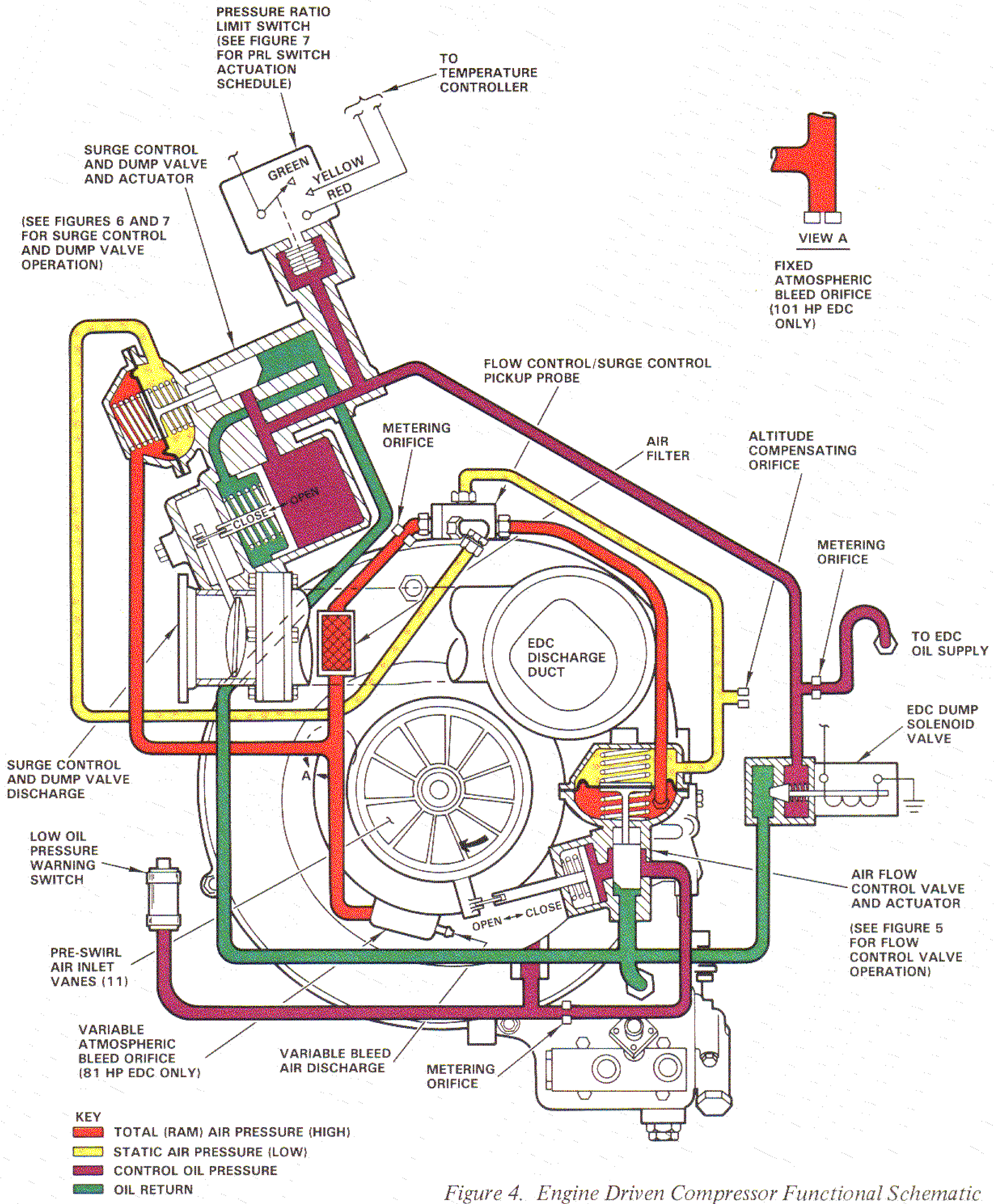


Figure 4. Engine Driven Compressor Functional Schematic

ing cap with a special metering hole drilled through it. If this special cap were inadvertently replaced with a solid cap, the result would be an overloaded EDC. This cap should be checked if trouble with the flow control system is suspected.

Surge Control As we have seen, the flow control system regulates the air volume that is being compressed in the EDC to avoid overloading the EDC drive. Centrifugal compressors are subject to another source of overload that occurs when excessive back pressure is applied at the compressor discharge by components downstream. In the case of the EDC, high back pressures will occur when the temperature control system sets the control valves to a "full cold" condition (the "A" and "C" valves to zero bypass, and the "B" valve full open). When the control valves are driven to

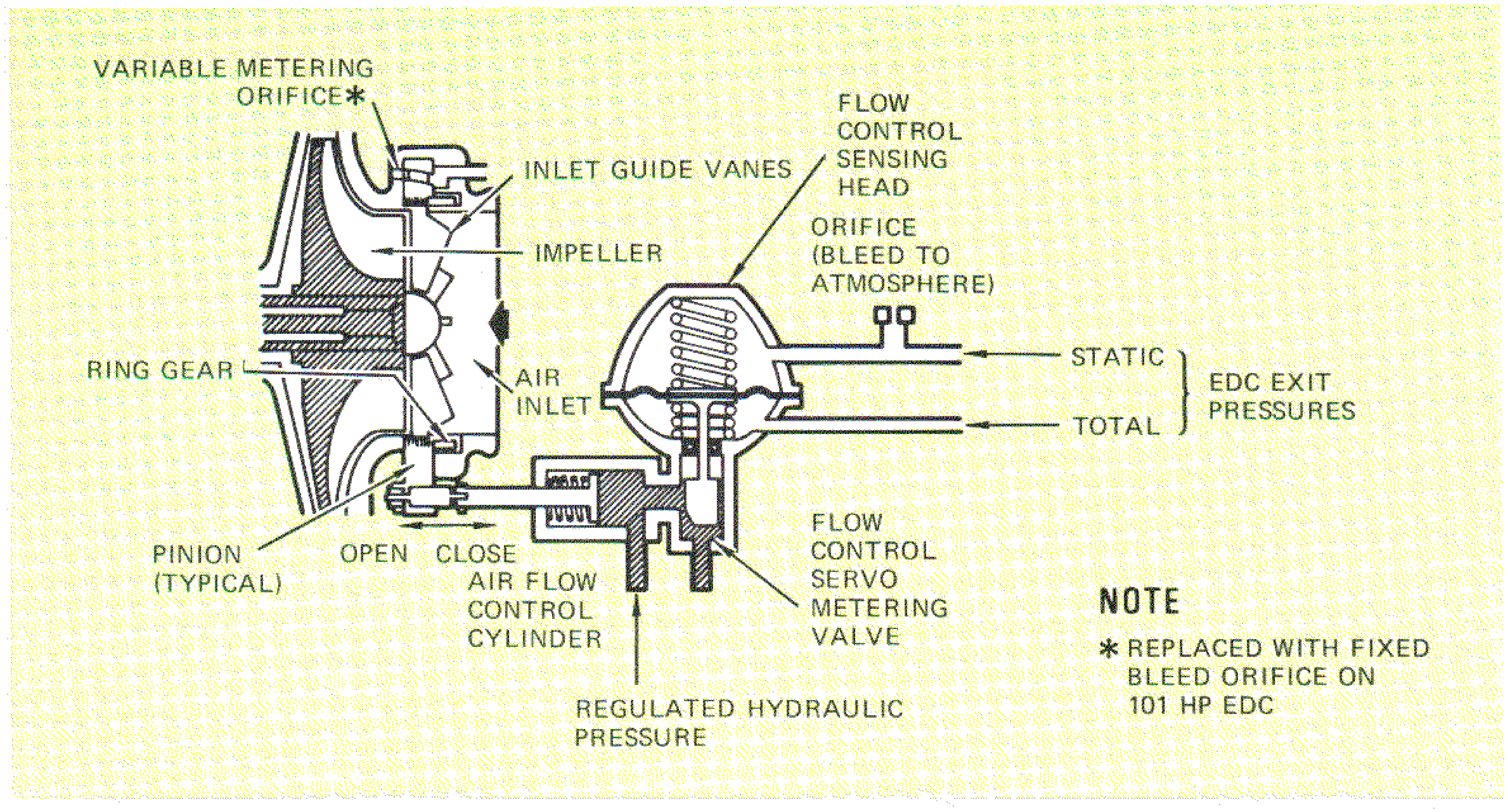


Figure 5.
Engine Driven Compressor Flow Control System Schematic

these positions, the entire discharge of the EDC is passed through the bootstrap refrigeration unit, which imposes a considerable back pressure. When this condition occurs, the static pressure in the EDC discharge duct rises until the pressure ratio (discharge pressure/ inlet pressure) across the compressor exceeds its designed capability. At this point the compressor can do no more work, and the high pressure air in the discharge duct "spills" backward through the EDC. When the air flow through the EDC reverses, the discharge static pressure decreases to a point below the designed maximum pressure ratio and the EDC recovers and resumes pumping air in the proper direction. This process is known as compressor surge and is a major cause of EDC failure. It is usually indicated by fluctuation of the compressor discharge pressure needle during EDC operation.

The EDC surge control system is a pneumatically sensed/hydraulically activated control system that opens the compressor dump valve to reduce the back pressure at the EDC discharge duct (see Figures 4 and 6). During normal operation (when the EDC is not approaching a surge), ram (total)

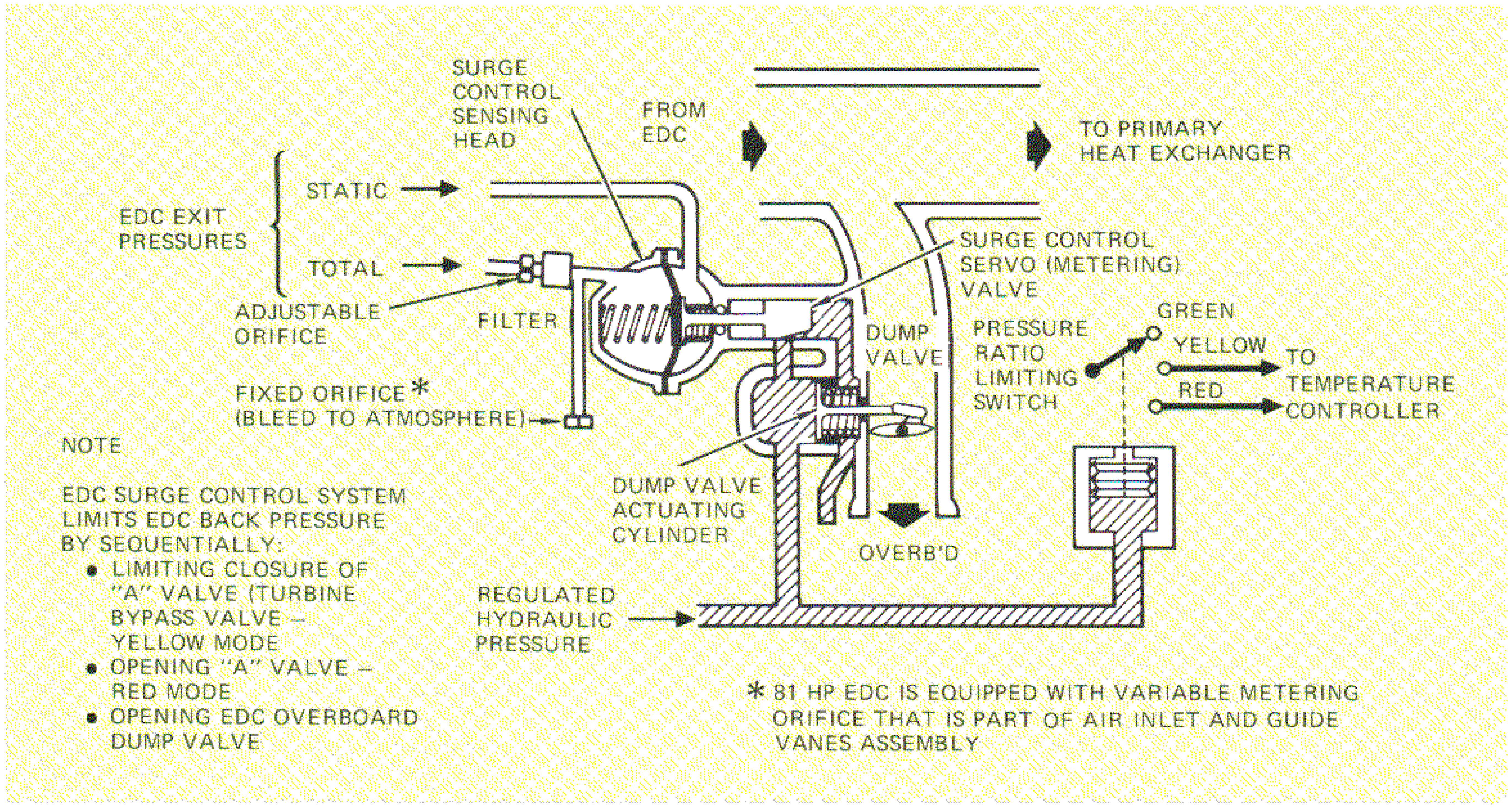


Figure 6.
Engine Driven Compressor Surge Control System Schematic

and static pressures to the surge control sensing head position the diaphragm and servo metering valve to block oil flow from the dump valve actuating cylinder. This maintains control oil pressure on the actuating cylinder piston. If the control oil pressure at the dump valve actuating cylinder is reduced, the spring-loaded piston will open the dump valve and allow a portion of the EDC discharge to exhaust overboard.

The EDC dump solenoid valve is also part of the EDC surge control system. It is a normally-closed/electrically-opened hydraulic valve that bypasses all of the surge control supply oil pressure back to the EDC sump when it is energized. This, in turn, reduces the pressure on the dump valve actuating piston to zero and allows the dump valve to open fully. This is called an electric or manual dump, to differentiate it from the automatic dump that occurs as a result of excessive EDC back pressure. The EDC dump solenoid valve (sometimes called the minimum ratio solenoid valve) is energized automatically by the air conditioning control system any time the EDC is not required or when the Dump Switch on the compressor control panel is set to DUMP.

When the control oil pressure is applied to the dump valve actuating piston, the spring pressure is overcome and the dump valve is held shut (see Figure 6). If the backpressure in the discharge duct rises, the air flow velocity will decrease and cause a rise in the static pressure at the surge control sensing head. This will move the surge control metering valve and begin to reduce the control oil pressure. As in the flow control system, a metering orifice is installed in the surge control oil supply line to prevent hydraulic control pressure interaction with the flow control metered pressure. Note that the surge control oil pressure also affects the position of the pressure ratio limiter (PRL) switch. Before an actual surge condition occurs, the surge control begins to move the surge control metering valve to reduce the control oil pressure.

As the control oil pressure drops below 72 psig, the PRL switch moves from what is called the "green" position into the "yellow" position (see Figure 7.[2] This signals the temperature controller that the EDC is operating at maximum load. Even

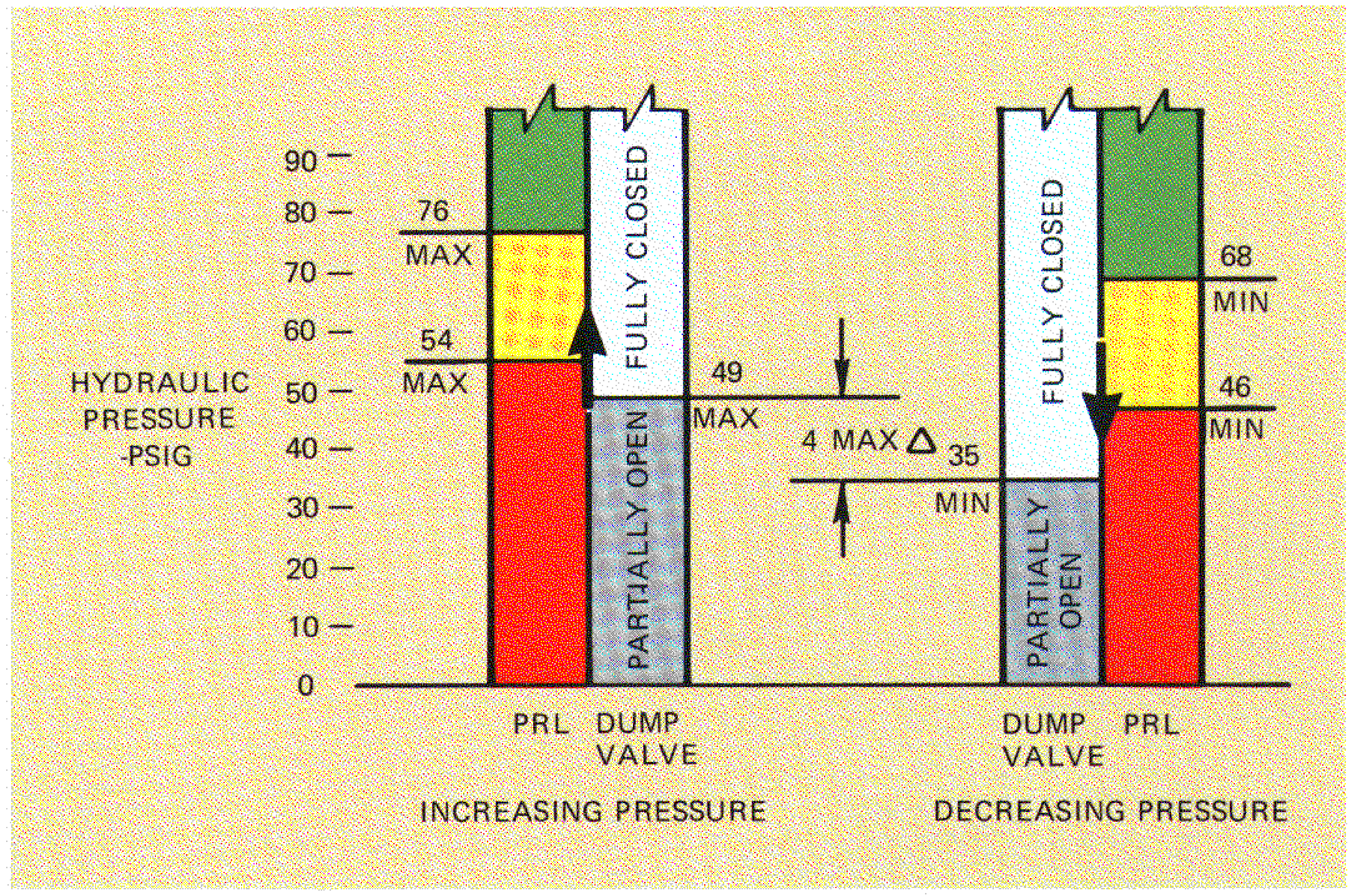


Figure 7.
Engine Driven Compressor Dump Valve and Pressure Ratio Limiter Activation Hydraulic Pressures

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[2] The green, yellow and red PRL switch positions designate the three modes of temperature control system operation. These operating mode color designations aid the maintenance technician to evaluate system operation in each mode during functional testing with a temperature control system test set. The flight crew/operator has no indicators to show the mode (green, yellow or red) in which the system is operating.

though the control oil pressure has dropped below 72 psig, there is still enough force on the dump valve actuating piston to overcome the dump valve spring and keep the valve shut. If back pressure continues to rise and causes the control oil pressure to decrease below 50 psig, the PRL switch will move into the "red" position, indicating an EDC overload. At this point, the control oil pressure is still holding the dump valve closed. An in-depth description of the "yellow" and "red" modes of temperature control system operation will be presented later in this article. Suffice it to say for now that when signaled, the temperature controller takes action to try and reduce the back pressure on the EDC. On P-3 aircraft through the P-3C Update II model, the pressure ratio limiter is available only in the automatic mode of temperature control system operation.[3] P-3C Update III aircraft have PRL protection in both the automatic and manual modes of temperature control system operation. If the engine driving the EDC is being operated at low rpm, the EDC control oil pressure will be insufficient to maintain the PRL switch in the green condition. This could cause the PRL system to send erroneous signals to the temperature controller, which would result in excessive loss of air conditioning system cooling capacity. For this reason, the electrical excitation to the PRL switch is shut off during low rpm engine operation.

If the temperature control system is being operated in the manual mode, or if the response of the temperature control system to the PRL signals does not reduce the back pressure at the EDC, the EDC surge control will drop the control oil pressure slightly below 50 psig. This will allow the dump valve to crack open and discharge a portion of the compressor air flow overboard. The dump valve position is modulated or varied at this point to maintain the maximum compressor discharge pressure without surge. Maintenance personnel can verify that the dump valve is open by observing the EDC dump door located on the No. 2 and No. 3 engine left-hand cowl doors. Approximately 3 psi air pressure is required to hold this spring-loaded door open.

Operation with an EDC at maximum load and dumping air overboard has several detrimental consequences. If the EDC is dumping air overboard, air flow that would normally be available for cooling the crew and avionics equipment is being *lost* overboard. As mentioned previously, effective environmental control requires an air supply at the proper temperature and flow rate. In addition, an EDC that is dumping air overboard is operating at its peak horsepower requirement. Extended EDC operation at maximum load will cause its components to wear and may result in decreased EDC service life.

Note that the EDC surge control ram and static pressure ports sense compressor discharge air flow. Compressor surge occurs if an excessive air pressure ratio (discharge pressure/inlet pressure) develops across the compressor. Since the EDC inlet air pressure varies with altitude, an additional control must be added to readjust the operating point of the surge control as the atmospheric inlet pressure changes. On the 81 hp EDC, this control is a variable orifice that is adjusted by the EDC flow control system. Recall that the flow control system varies the position of the inlet guide vanes as the air density changes during climbs and descents. The variable orifice is adjusted from the minimum bleed condition at low altitude to a maximum bleed condition at high altitude. This allows the surge control sensing head to begin the EDC dump process at the lower static pressures present at higher altitudes. The 101 hp EDC uses a fixed bleed orifice rather than a variable orifice for this purpose.

The EDC discharge is ducted from the engine nacelle to a valve called the EDC firewall shutoff valve. The purpose of this valve is to isolate the EDC from the air cycle system any time that the EDC is dumped. The firewall shutoff valve is operated by a 28 VDC motor that positions the valve butterfly to either full-open or full-closed within a period of approximately 20 seconds. Three switches control the position of the firewall shutoff valve and the power to the EDC dump solenoid valve. These switches are operated by a sequencing cam in the valve actuator. Switch operation is timed to maintain the EDC in a dumped condition any time that the firewall shut-

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[3] During the writing of this article, a RAMEC was proposed which would also provide PRL in the manual mode of temperature control system operation. The RAMEC resulted in the issue of P-3 AFC-431.

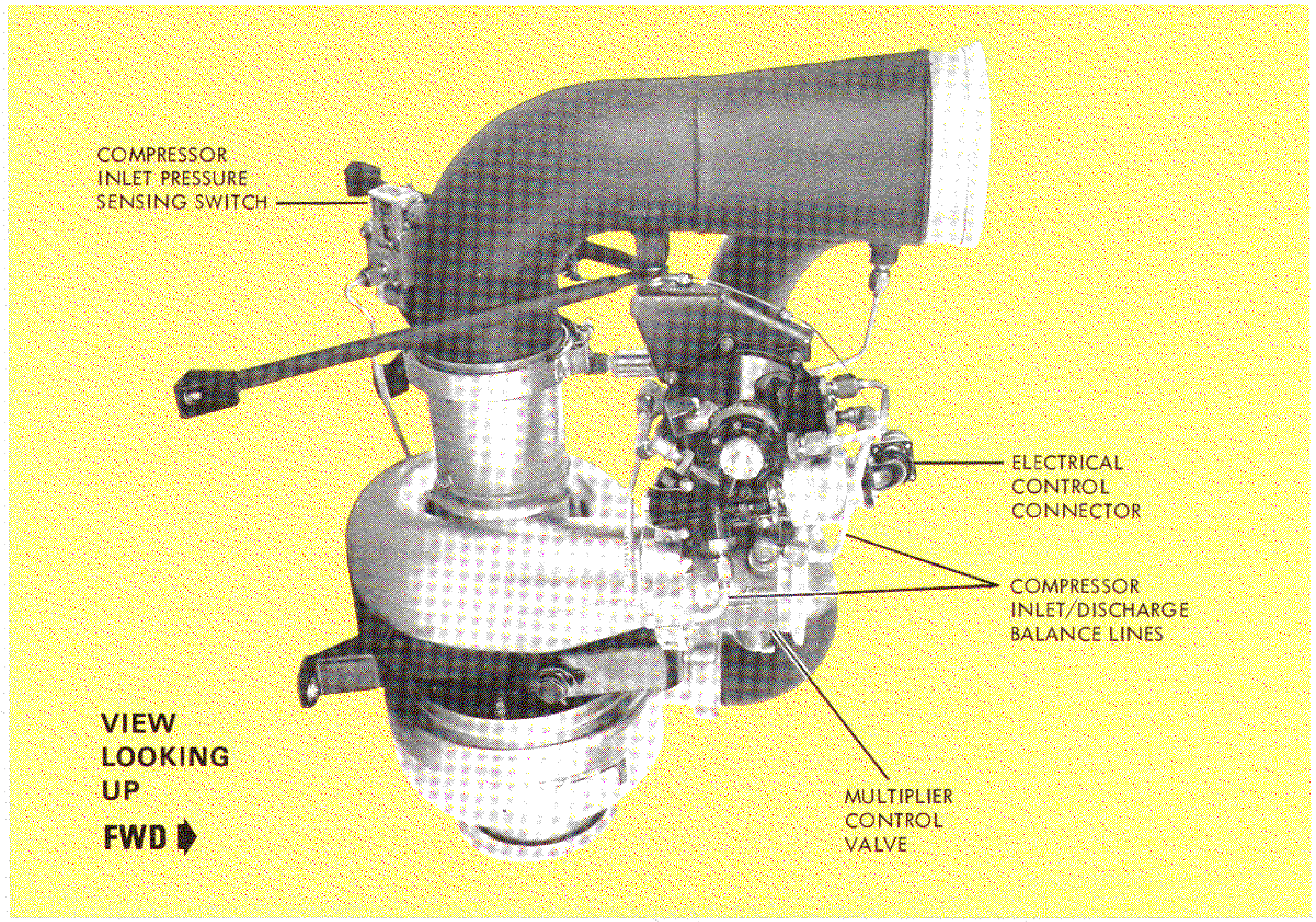


Figure 8. Air Multiplier Package (AMP)

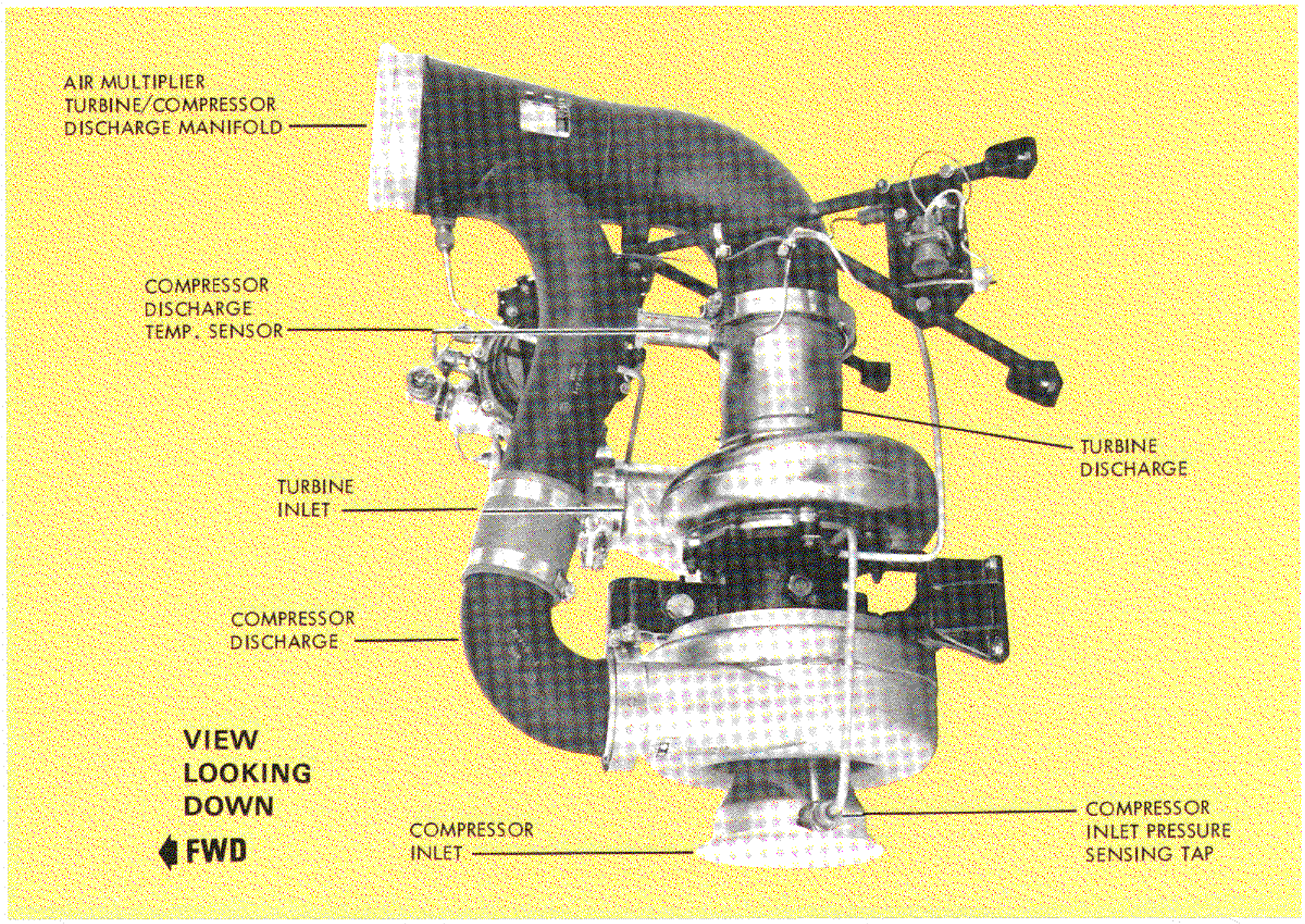
off valve is not fully open. The firewall shutoff valves are located in the inboard nacelle fillet area of the No. 2 and No. 3 engines.

The engine driven compressors are the only source of air for the P-3 environmental control system during flight. However, on the ground they are a secondary air source. The next section discusses the primary source of air during ground operation, the APU/Air Multiplier combination.

APU/AIR MULTIPLIER OPERATION The APU/Air Multiplier (APU/AMP) supplies air to the environmental control system during ground operation. It serves as a single source of air with a flow rate equal to that supplied by the two EDCs. With the engines operating at normal rpm, each 81 hp EDC supplies air to its respective air cycle cooling system at the rate of approximately 60 lb/min. Under the same operating conditions, the 101 hp EDC supplies air at a rate of approximately 72 lb/min. Orion aircraft through the P-3C Update II model are equipped with an APU/AMP that supplies air to a duct common to both cooling systems at a rate of approximately 125 lb/min. P-3C Update III aircraft are equipped with a high performance APU that, when matched with the AMP, will deliver air at approximately 130 lb/min. The air volume divides in the air cycle system interconnection duct, with half going to the flight station air cycle cooling system and half to the cabin cooling system.

The operation of the APU is described in detail in Orion Service Digest No. 18. For the purposes of this article though, several important points should be noted. The function of the APU is to supply the aircraft with 115 VAC 400 Hz electrical power, and with high-volume, relatively-low pressure bleed air for starting the engines and for ground air conditioning. The design of the APU control system dictates that the APU generator has priority for APU power, with any excess APU capacity made available as compressor bleed air.

The APU compressor discharge air bleed rate is controlled by the APU bleed load control valve. This valve is mounted to a flange on the APU turbine plenum, and couples the bleed air supply into a T-duct mounted on the APU compartment forward bulkhead (FS 288). The APU bleed load control valve is energized electrically when ground air conditioning is selected, but its position and corresponding bleed rate are controlled by



a pneumatic pressure sensing system. Whenever air is bled from a gas turbine engine, additional fuel must be added to the remaining compressor discharge upstream from the turbine to ensure that the engine has adequate power to maintain the proper shaft speed. The amount of additional fuel that may be added is limited by the maximum inlet temperature and corresponding exhaust gas temperature that the turbine is designed to withstand. The maximum APU exhaust gas temperature (EGT) is limited by controlling the amount of air being bled. The pneumatic load control thermostat, located in the APU exhaust duct, limits the EGT by opening at a preset temperature and reducing the control air pressure for the load control valve. This, in turn, positions the APU bleed load control valve butterfly to reduce the amount of compressor discharge air being bled.

The APU bleed air system is designed to supply air at the pressure and flow rate required to start the T-56 turboprop engines. As such, the air discharge pressure is too high and the flow rate is too low for the APU to be an effective stand-alone source of air for ground air conditioning. In order to provide air at a pressure and flow rate suitable for ground air conditioning, the APU bleed air discharge is passed through a device called the Air Multiplier Package (AMP) shown in Figure 8. The AMP consists of a turbocompressor, and a pressure regulator and shutoff valve assembly. The high pressure APU discharge is ducted to the pressure regulator and shutoff valve, which in turn controls the air flow rate into the turbine of the turbo-compressor. As air flows into the turbine, it expands and the air pressure is reduced. The turbine converts the energy of the pressure reduction process into shaft power, which is used to drive a centrifugal compressor. The compressor draws additional air in from the atmosphere, compresses it to a pressure approximately equal to the AMP turbine discharge, and delivers it to a duct where the compressor and turbine air discharges are combined. Thus, the AMP turbo-compressor reduces the APU discharge pressure during the air flow expansion process in the turbine, and the mass air flow rate is increased by the compressor drawing additional air from the atmosphere.

The AMP pressure regulator and shutoff valve senses the turbine inlet and discharge air pressures, then adjusts the air flow rate to the AMP turbine. Figure 9 shows this valve and its pressure control lines. When the valve solenoid is energized, the pressure sense lines provide AMP turbine upstream and downstream pressure to the valve regulator, which in turn uses the pressure drop across the turbine to control the butterfly valve actuator. This controlling action maintains a proper air flow rate to the air multiplier and prevents turbo-compressor overspeed.

A pressure sensing switch on the AMP compressor inlet and a thermal sensing switch in the compressor discharge duct protect the air multiplier if an inlet blockage or a turbocompressor overheat condition occurs. (These two switches do not contribute to the air regulation.) The switches are set to sense low compressor inlet pressure and excessive compressor temperature. When its preset value is exceeded, the affected switch actuates and signals the air conditioning electrical control system to de-energize the AMP pressure regulator and shut down the turbo-compressor within 1/2 second. When this occurs, the GRD AIR COND switch and the heat exchanger cooling fans remain on, but the air flow in the system is shut off. The pressure regulator valve can be reenergized by cycling the GRD AIR COND switch to reset the electrical controls. A similar shutdown condition will occur if one of the bootstrap refrigeration units overheats. However, if this occurs, the cause will be identified by illumination of the REFR OVHT light.

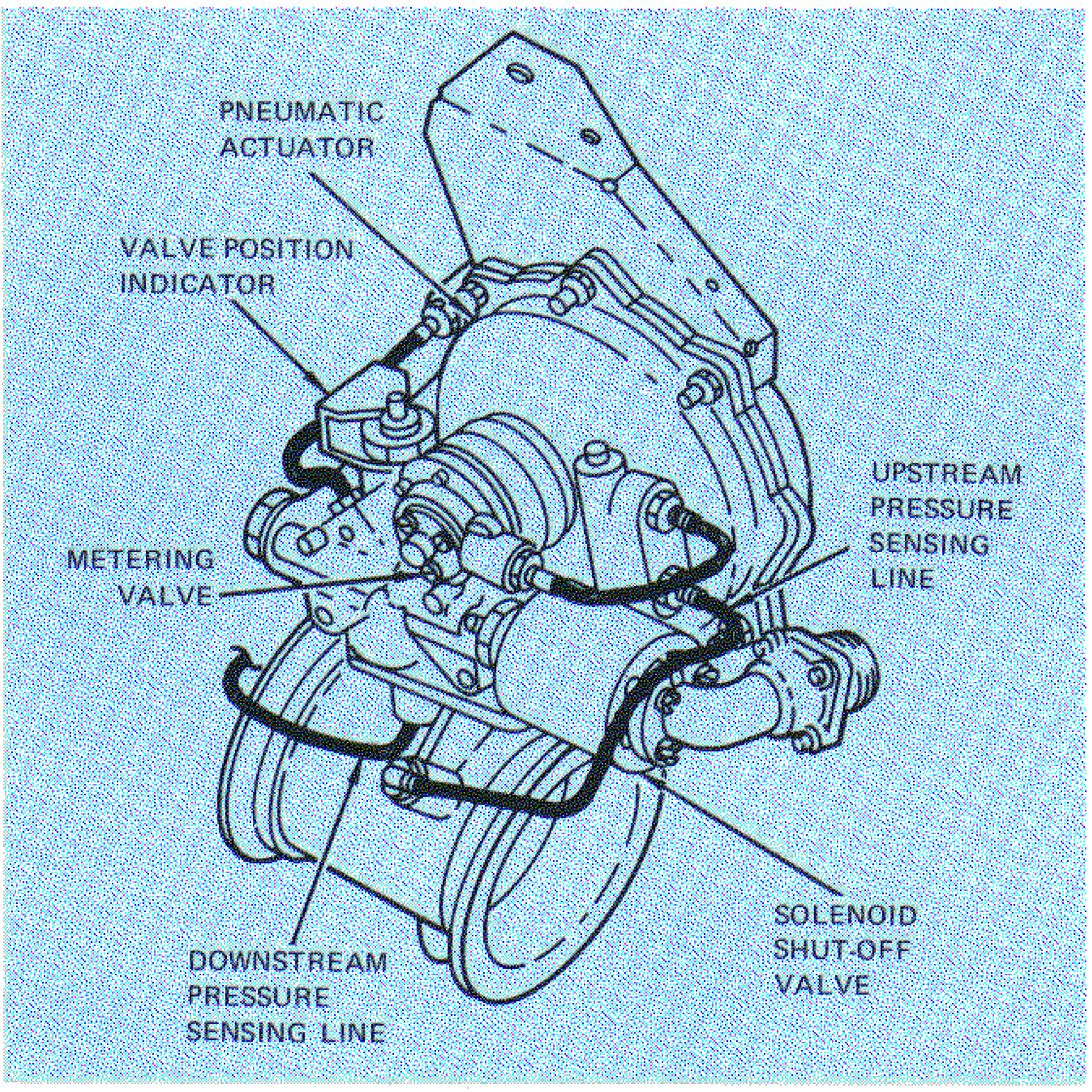


Figure 9. Air Multiplier Pressure Regulator and Shutoff Valve

NOMINAL PERFORMANCE

APU OPERATION GROUND
● MAX. COOLING 103°F
● HEATING – 40°F DAY

FLIGHT
● 1500 FT. 225 KNOTS
MAX. COOLING 97.5°F

	PRESSURE INCHES Hg ABSOLUTE	DEGREES °F	WEIGHT-FLOW (LB. PER MINUTE)
A	110 128 —	460 320 —	85.5 174 —
B	105 83 —	460 320 —	85.5 72.6 —
C	65.3 52.3 —	287 57 —	40.1 53 —
D	65 52 —	342 165 —	125 125 —
E	— — 59.6	— — 325	— — 60
F	61.1 — 58.8	342 — 325	62.5 — 60
G	57.5 — 55.5	142 — 134	62.5 — 60
H	98.5 — 93.8	266 — 252	62.5 — 60
J	96.2 — 91.5	131 — 126	62.5 — 60
K	30.44 36.44 28.87	35 165 36	62.5 62.5 60

The combined APU/AMP discharge air is fed to a duct that interconnects the two air cycle cooling systems. Later in this article, we will see how the temperature control system adjusts the position of two bypass valves and one shutoff valve in order to regulate the internal cabin temperature. However, at this point it should be noted that as the temperature control system moves the valves, the back pressure that is sensed by the air source (EDC or APU/AMP) varies.

An environmental control system that employs a single source of air to supply two air cycle cooling systems that operate at different back pressures will have air flow problems unless a control is added to balance the air flow. If the air flow is not properly balanced, the air cycle cooling system with the lower back pressure (as the result of more air bypass) will rob air from the unit with a higher back pressure. The P-3 ECS employs two flow-limiting venturis to balance the air flow when the APU/AMP is the air supply source.

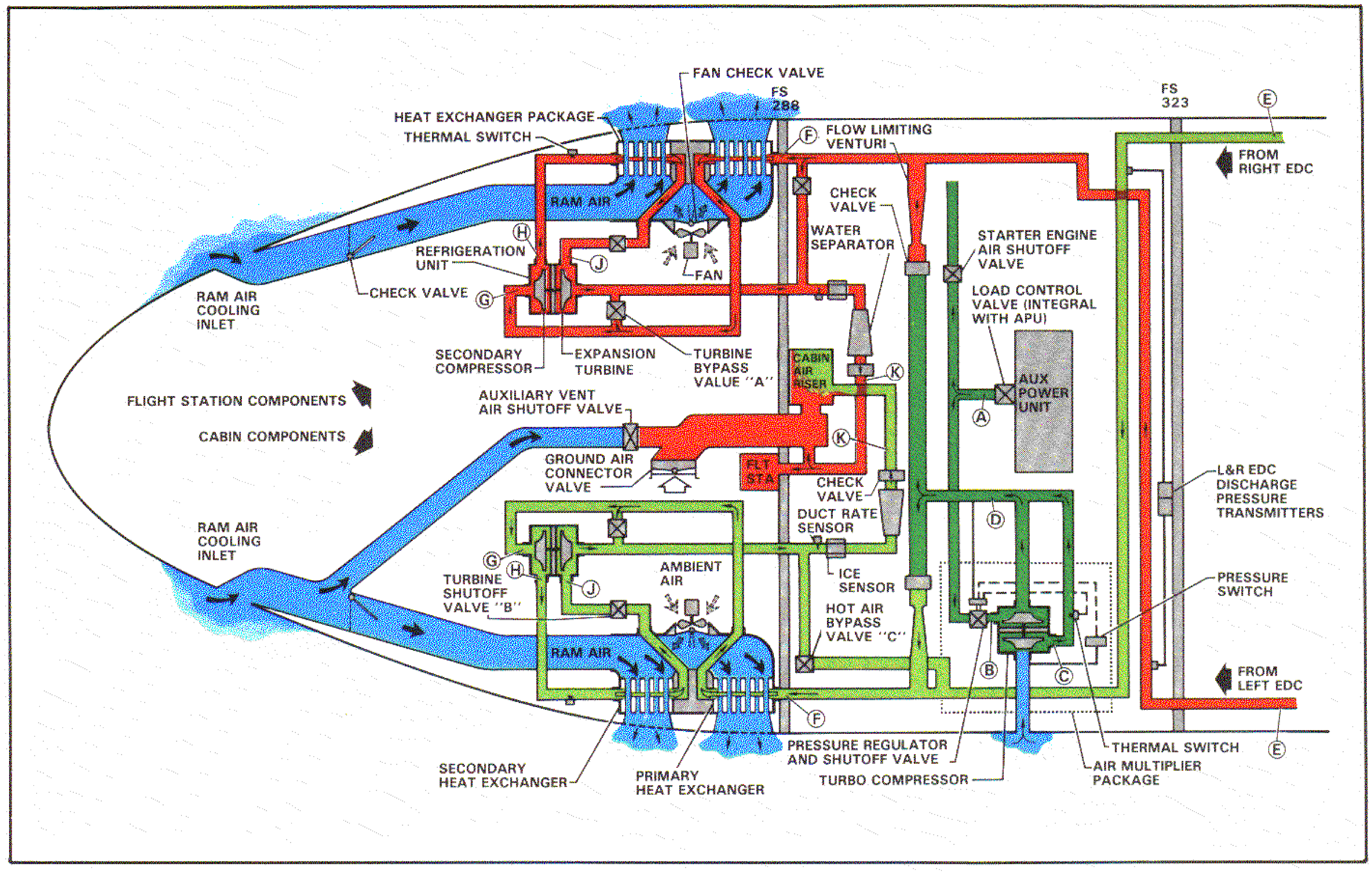


Figure 10. P-3 Air Conditioning System Schematic Diagram

The flow-limiting venturis (see Figure 10) maintain approximately balanced air flow from the APU/AMP to both ECS air cycle cooling systems, regardless of back pressure conditions. As the air enters the venturi throat, it is accelerated to the speed of sound. When this sonic condition exists, the air flow at the venturi throats is maximum. This will deliver air mass flow at approximately balanced flow rates to each of the two air cycle systems. Each venturi assembly also contains an upstream check valve (see Figure 10) that prevents EDC air from flowing through the AMP compressor during flight. This check valve is a bi-petal type flapper valve (see Figure 11) that is

Photo courtesy of the AiResearch Manufacturing Company

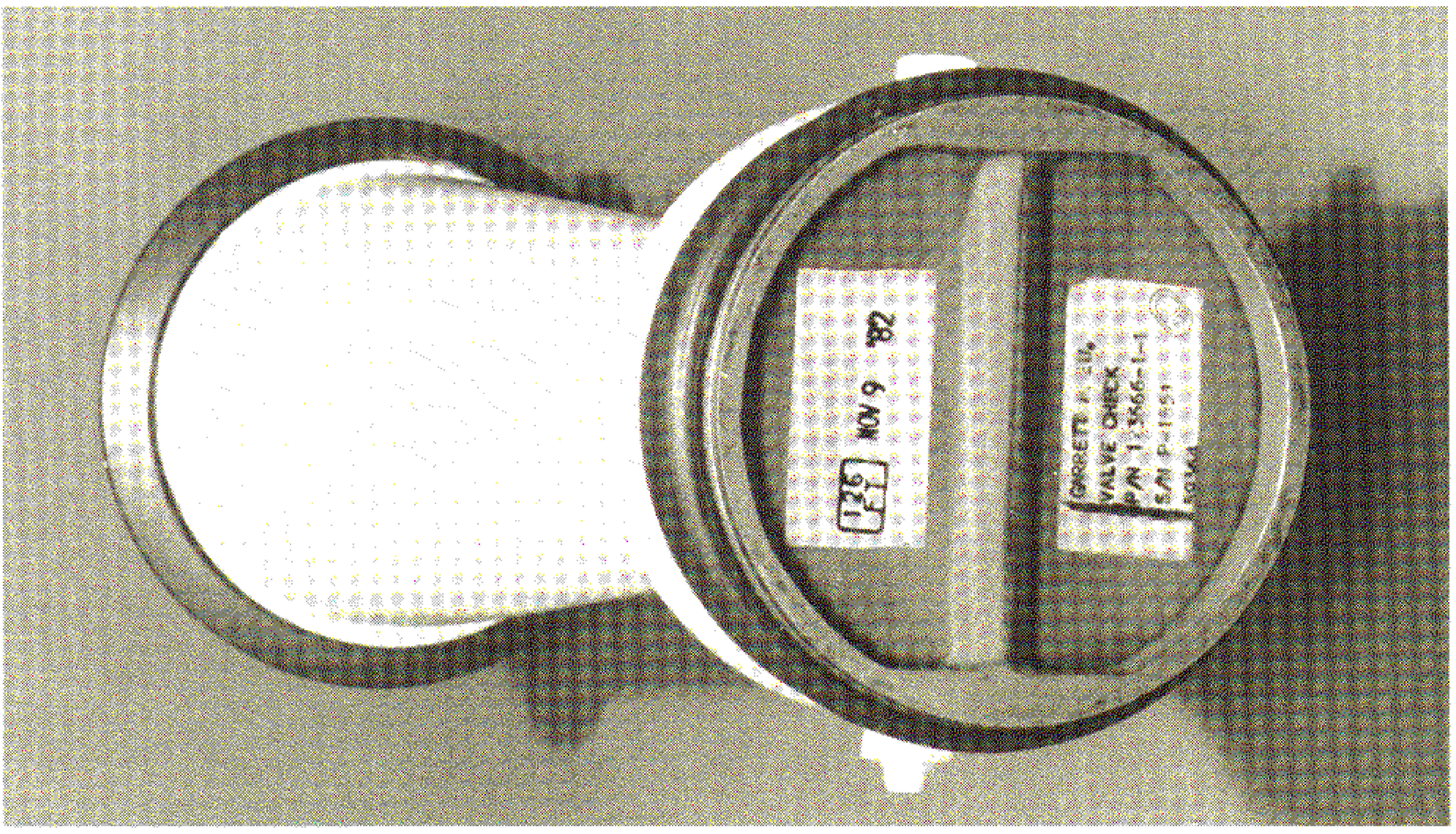


*Figure 11.
Auxiliary Power Unit/Air Multiplier Package Venturi Check Valve. Note that the valve is oriented so that the valve flapper hinge line is vertical.*

opened by the AMP airflow and closed by the EDC air flow. Since this check valve does not have a spring to keep it closed in the absence of airflow, be certain that it is installed with the hinge line vertical to assure proper check valve operation.

Referring to the foldout ECS schematic, the reader will see that during ground air conditioning operation of the APU/AMP, the EDC ducting is pressurized out to the EDC firewall shutoff valves. Normally, there will be no air flow to the EDCs when operating in this condition. However, the air pressure in the ducts (as sensed by the EDC discharge pressure transmitter) will be the same as the air cycle cooling system back pressure. We shall see later that this information can be useful during fault isolation of ECS malfunctions. It should also be noted that if the EDC firewall shutoff valve fails to close fully or if there is a leak in the ECS ducting, there would be a loss of airflow during ground air conditioning operation.

AIR CYCLE SYSTEM OPERATION

The air cycle cooling system controls temperature and humidity of the air used for flight station and cabin pressurization and ventilation. The P-3 aircraft has what is called an *open* cooling system. This means that a continuous supply of fresh air is pumped in from the atmosphere, conditioned, circulated through the cabin, and exhausted overboard. This is in contrast to a closed system, in which the air in the cabin is continuously recirculated and reconditioned. Figure 12 is a block diagram of the P-3 ECS.

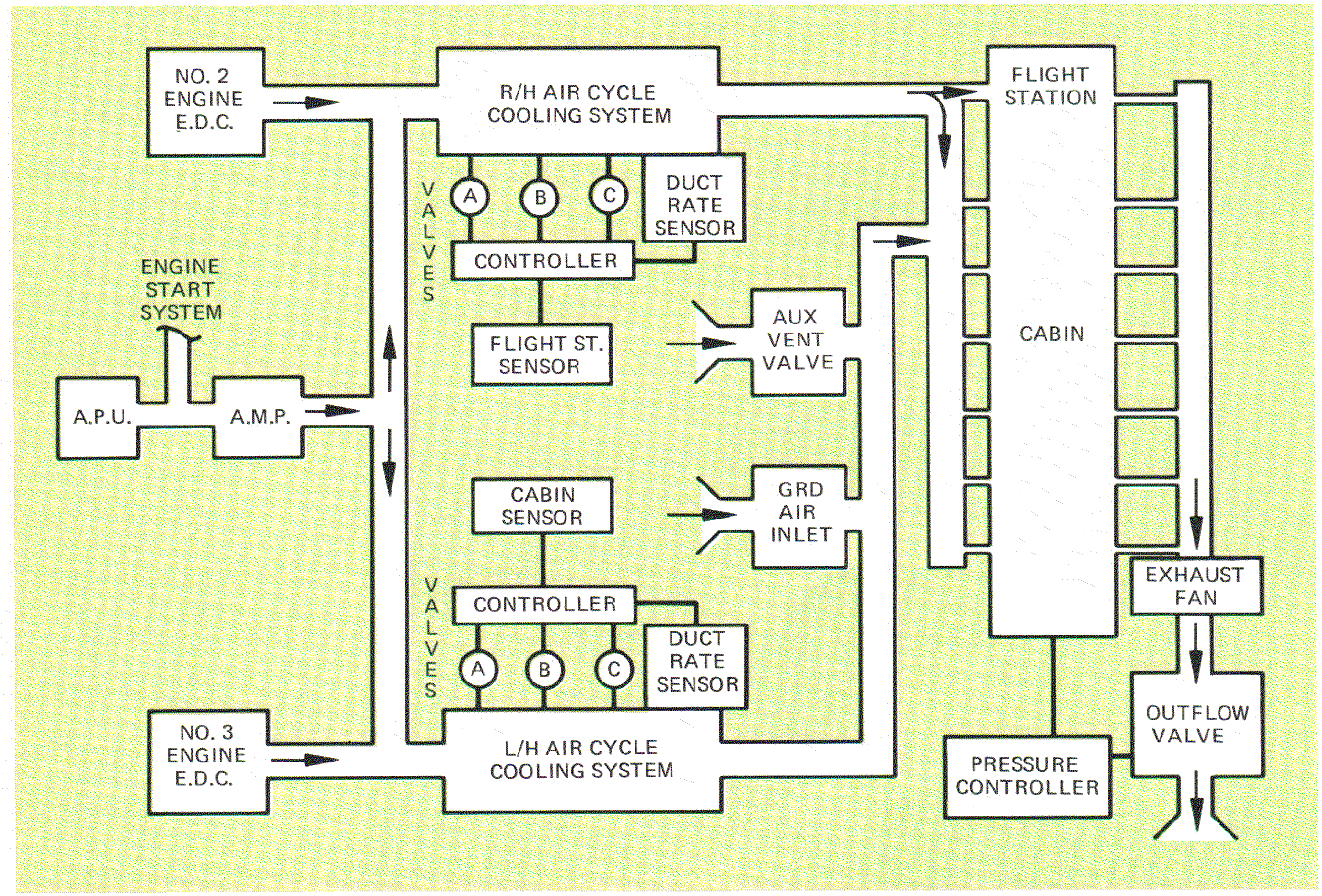


Figure 12. Environmental Control System Block Diagram


KKBL

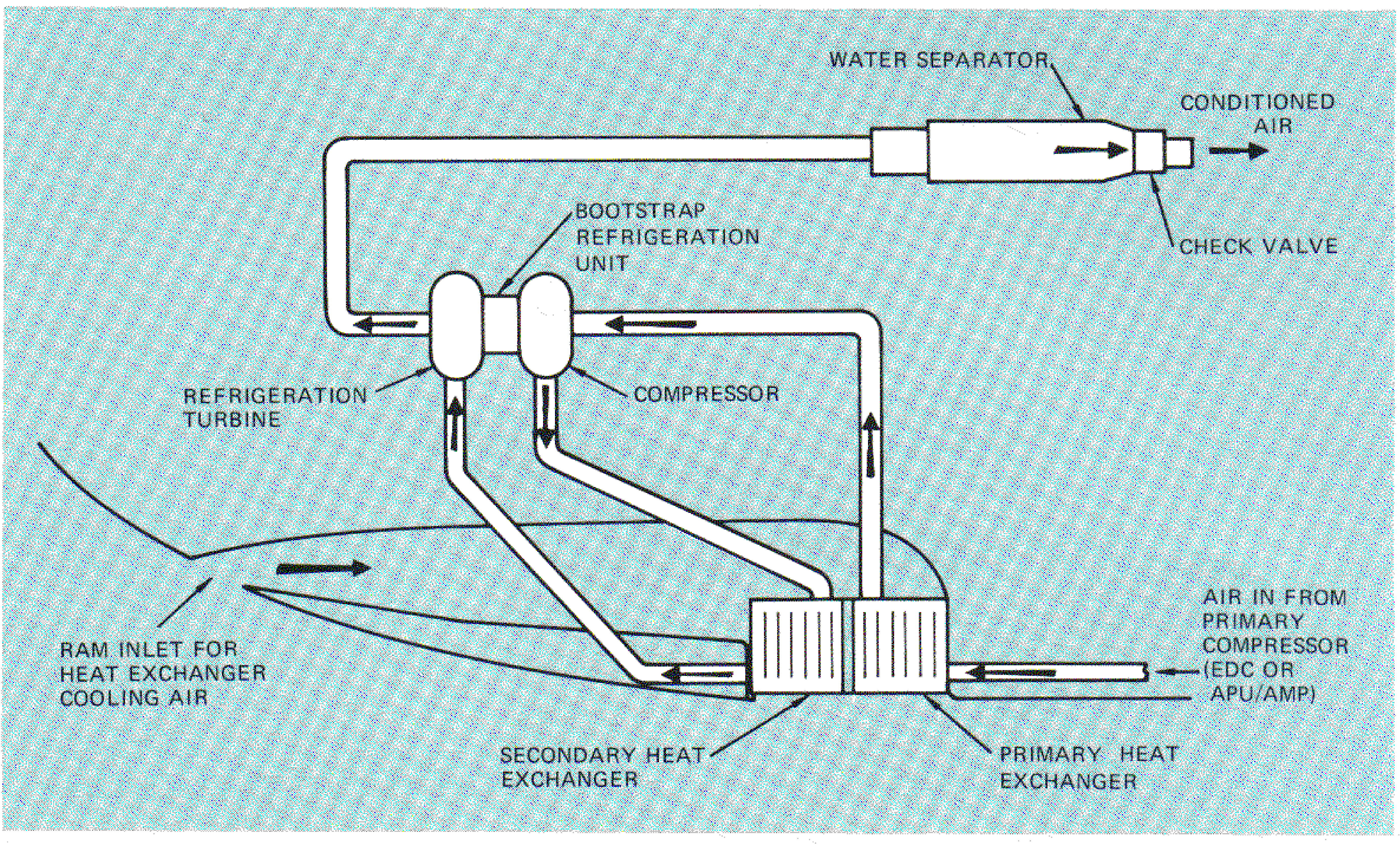


Figure 13. Air Cycle Cooling System Schematic

The P-3 aircraft has two independent air cycle cooling systems of identical capacity, one to supply air to the cabin area and the other to supply air to the flight station. The air cycle cooling equipment is produced by the AiResearch Mfg. Co. Since the flight station area is small compared to the main cabin area, part of the flight station cooling system air discharge is distributed to the cabin area (aft of the FS 288 bulkhead.) On P-3 aircraft through the P-3C Update II model, half of the flight station cooling system air is supplied to the cabin air distribution system. On P-3C Update III aircraft, 33 percent of the flight station cooling air system discharge is distributed to the flight station and 67 percent is distributed to the cabin. This change of air flow distribution has been achieved by installing an orifice in the flight station air supply duct of P-3C Update III aircraft. Figure 13 is a schematic of one of the air cycle cooling systems.

Operation of the air cycle cooling system requires that air be delivered to it at elevated pressure and temperature from some primary compressor. In the P-3 aircraft this air source is either the Engine Driven Compressor or the APU/Air Multiplier. The air enters the air cycle cooling system through the primary heat exchanger. As the air flows inside the tubes of the heat exchanger, high volume, low pressure air flows over the outside of the heat exchanger tubes and fins and cools the air inside. A relatively low pressure drop (approximately 3 to 4 inches Hg) occurs to the conditioned air inside of the tubes during the heat extraction process. In flight, the cooling air that flows through the heat exchangers is ducted from ram air inlets located on each side of the fuselage (see Figure 10 and the foldout ECS schematic).

During ground operation when the ram air source is not available, the heat exchanger cooling air is provided by electric motor-driven blower fans that draw air from the nose wheel well area. The fan assembly is shown in Figure 14. A check valve downstream from the fan closes when the fan is not running. This prevents ram air from leaking into the wheel well during flight and any accompanying loss in heat exchanger performance. For the same reason, spring-loaded flapper doors in the ram air intakes are closed during ground operation to prevent ground fan discharge from leaking out of the ram air inlets.

The discharge from the primary heat exchanger is warm high pressure air that is approximately 57°C (135°F) at sea level and approximately 2 atmospheres. This air discharge is ducted into the inlet of a component called the Bootstrap/Refrigeration unit. The compressor of the bootstrap unit then compresses the air received from

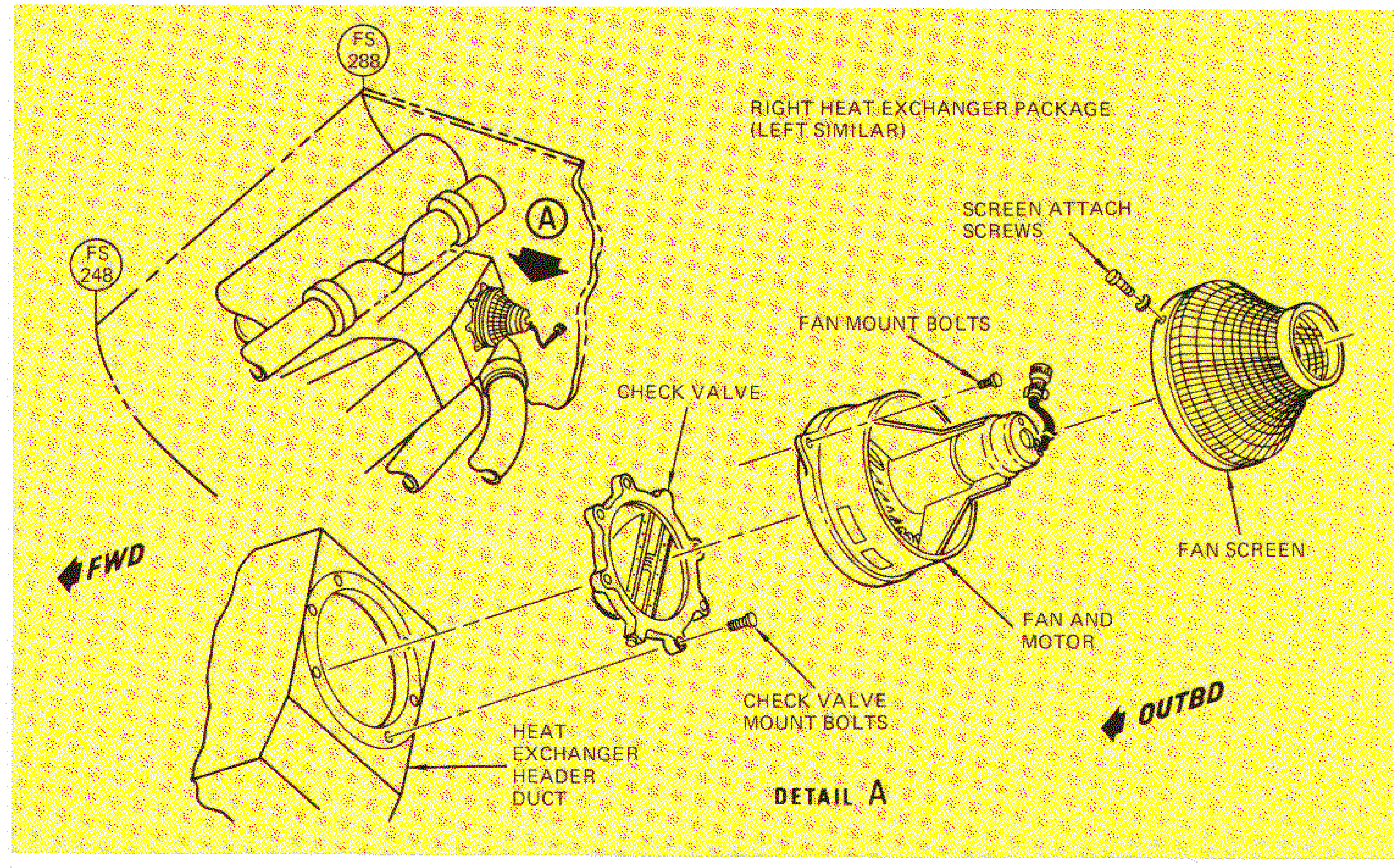


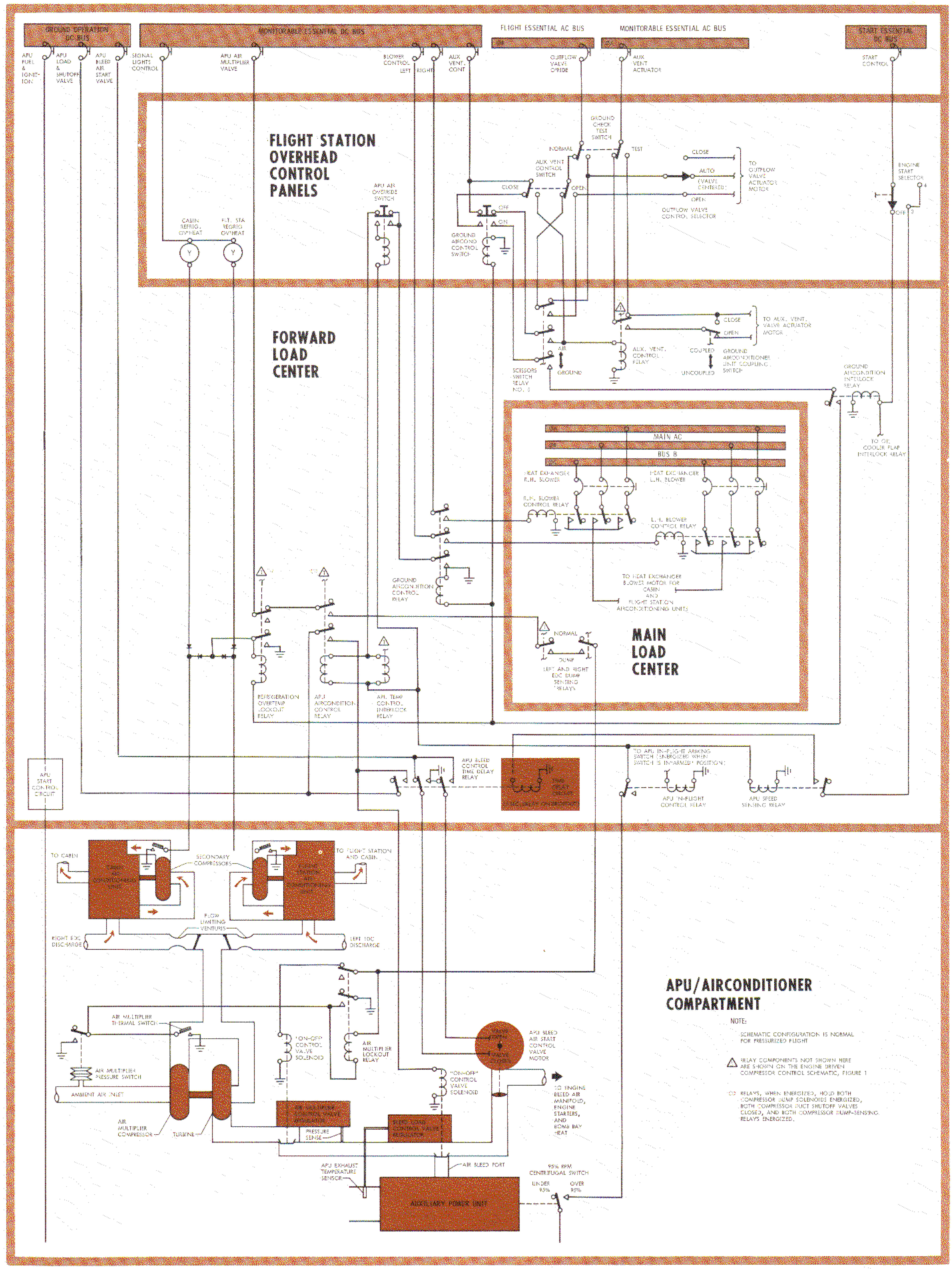
Figure 14. Air Cycle Cooling System Heat Exchanger Cooling Fan Installation

the primary compressor and heat exchanger to an even higher pressure. Once again, as in any compression process, the air temperature is also elevated. Therefore, the discharge from the bootstrap compressor is channeled through a secondary heat exchanger to remove some of the heat added by compression. As with the primary heat exchanger, a slight pressure drop develops across the secondary heat exchanger. The discharge from the secondary heat exchanger also is warm, high pressure air that is approximately 55°C (131°F) at sea level and approximately 3 atmospheres. This air discharge is routed to the turbine section of the bootstrap unit.

A turbine, whether it is part of an aircraft engine, an APU, a turbocharger, or a refrigeration unit, is designed to convert air flow to mechanical power. The turbine extracts the energy from the air, effecting a dramatic drop in air pressure and temperature. The extracted energy is converted by the turbine into shaft power and is used to supply the power required to drive the bootstrap compressor. For the turbine to cool the air to a low enough temperature, it must receive the air at high pressure and it must have a shaft power load. The bootstrap compressor provides the high pressure required for efficient turbine performance and, in so doing, also provides the required turbine load. The turbine discharge is cold, low pressure air. In addition, the temperature reduction of the air as it passes through the turbine causes condensation of airborne water vapor. This water exits the turbine as a fog of water droplets.

A thermal switch mounted in the bootstrap compressor discharge duct, upstream from the secondary heat exchanger inlet, senses the temperature of the compressor discharge air. If the heat exchanger cooling air flow becomes inadequate, the bootstrap unit will overheat and the compressor discharge temperature will rise. If this temperature reaches approximately 165°C (329°F), the thermal switch closes and supplies a ground to energize the Refrigeration Overtemp Lockout relay and illuminate the appropriate REFR OVHT indicator on the Air Conditioning control panel (see Figure 15). When this occurs on the ground, the air supply source (EDCs or Air Multiplier) is shut down. If the air cycle system is operating off the EDCs, both compressors will be dumped electrically by an overheat of either bootstrap unit. In flight, the appropriate REFR OVHT light will illuminate, but the EDCs will not dump. The thermal switch recovers (reopens) when the bootstrap compressor discharge temperature drops to approximately 143°C (289°F).

In order to control the humidity in the cabin, the refrigeration turbine air discharge is passed



NOTE:

SCHEMATIC CONFIGURATION IS NORMAL FOR PRESSURIZED FLIGHT

△ RELAY COMPONENTS NOT SHOWN HERE ARE SHOWN ON THE ENGINE DRIVEN COMPRESSOR CONTROL SCHEMATIC, FIGURE 1

CD RELAYS, WHEN ENERGIZED, HOLD BOTH COMPRESSOR DUMP SOLENOIDS ENERGIZED, BOTH COMPRESSOR DUCT SHUTOFF VALVES CLOSED, AND BOTH COMPRESSOR DUMP-SENSING RELAYS ENERGIZED.

Figure 15. P-3 Air Conditioning System Schematic, Showing Air Flow Control, Warning and Protective Circuits

through a water separator. The water separator assembly has a cloth liner (called a coalescer bag) which is stretched over a metal support that has numerous small vanes. As the moisture-laden air flows through the liner, the airborne water (which is extremely fine particles of fog) precipitates into droplets. The vanes in the coalescer bag support impart a swirling motion to the air/liquid water mix, causing the heavier water droplets to be thrown into the collector portion of the water separator. From there, the water is ultimately drained overboard or recovered to cool the heat exchangers. This process removes approximately 78 percent of the free moisture from the conditioned air.

The water condensation that occurs in the refrigeration turbine represents an undesirable loss of ECS cooling capacity. In P-3 aircraft prior to the P-3C Update III model, this water is drained from the water separators and discharged overboard. In the P-3C Update III aircraft, the water that is drained from the water separators is used to supply a water spray cooling system and recover some of the lost ECS cooling capacity. The water spray cooling system consists of a reservoir that collects the condensate from the water separator, and a set of pressurized nozzles through which the water is sprayed onto the secondary heat exchanger. This water spray causes the secondary heat exchanger to transfer heat more efficiently as the heat exchanger pre-cools the air supply to the refrigeration turbine air inlet. The water spray nozzles are pressurized with conditioned air bled from the air cycle system. A water spray system is under development for pre-Update III P-3 aircraft.

The cooled and dehumidified water separator discharge air is now ready for delivery to the flight station and cabin. After leaving the water separator, the air flows through a check valve and into the air distribution riser ducts. The check valve is a flapper-type valve that closes in the absence of air flow from the water separator. Should it be necessary to dump an EDC and shut down one of the two air cycle systems in flight, this valve will close to prevent loss of air flow and pressurization from the operating system through the system that was shut down. At this point in the air distribution system, the flight station cooling system discharge is split and a portion is added to the cabin system air flow.

In the flight station, the air flows primarily from an outlet mounted over the flight station entrance. After providing cooling for the flight station, most of the air is exhausted to the cabin area through the flight station entrance. In addition, a one-inch diameter duct is mounted above and behind the pilot's head. This duct is connected to the ECS exhaust system and provides the location where the ambient temperature of the flight station is measured. The sensor mounted in this duct provides signals that the temperature control system uses to regulate flight station temperature.

In the cabin, the air is distributed by a longitudinal overhead duct and flows downward into the aisle to cool the crew. The air then flows into the bottom of the avionic equipment racks, up past the electronics gear, and into the exhaust system tuskers mounted near the top of the electronic bays. The exhaust system will be discussed in the section dealing with pressurization.

Up to this point, we have discussed the air delivery source equipment and the air cycle cooling system. It should be noted that air is flowing through the air cycle cooling system at three different temperatures: (1) *hot air* from the primary compressor or air source before it enters the primary heat exchanger; (2) *warm or tepid* air at the primary heat exchanger discharge; and (3) *cold air* at the refrigeration turbine discharge. The next section describes the operation of the temperature control system, which meters the hot, warm and cold air so that it can be blended to maintain the desired cabin conditions.

TEMPERATURE CONTROL SYSTEM

The P-3 aircraft is equipped with two temperature control systems, one for the flight station and one for the main cabin area. Each temperature control system consists of a temperature controller, a selector/indicator unit, a master temperature sensor, a duct temperature rate-of-change sensor, and three air flow control butterfly valves. The temperature controller and selector/indicator units and the sensors are designed and manufactured by Hamilton Standard Div., United Technologies Corp. The control valves are manufactured by either the Borg-Warner Corp. (the "Weston"-type valve) or by the Barber-Colman Co.

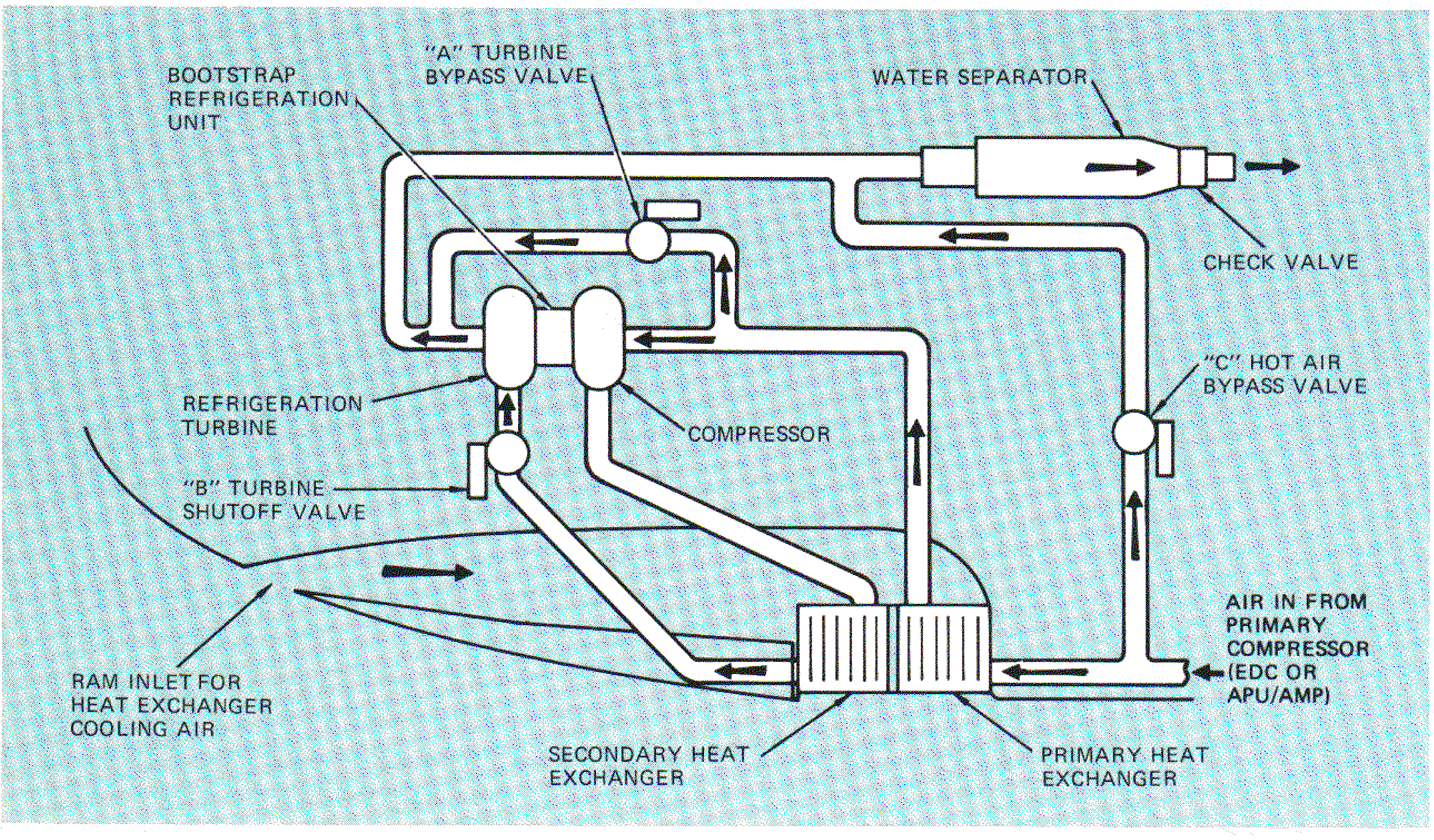


Figure 16. Air Cycle Cooling System, with Temperature Control System Air Flow Control Valves

Briefly, to operate the temperature control system, the flight crew sets the selector/indicator at the desired temperature. This information is transmitted to the temperature controller, along with signals from the sensors that provide the actual cabin or flight station temperature and the rate of temperature change at the water separator inlet. The temperature controller then positions the three air control valves in a programmed schedule to properly blend the hot, warm and cool air flowing in the air cycle cooling system in order to obtain the selected flight station or cabin temperature.

A comprehensive knowledge of the temperature control system is vital to the maintenance technician because this is the system into which the BR61-101 Test Set connects. We will examine how the temperature control system functions in greater detail, beginning with the function of the air flow control valves.

CONTROL VALVES As seen in Figure 16, the temperature control system employs the basic air cycle cooling system, two valve-controlled bypass ducts, and one shutoff valve. The hot air bypass C Valve controls the amount of *hot* primary compressor discharge air that will be bypassed around the air cycle cooling system. The turbine bypass A Valve controls the amount of *warm* air that will be bypassed around the bootstrap refrigeration unit. The turbine shutoff B Valve controls the volume of air flowing through the refrigeration turbine for cooling. The 3-1/2 inch diameter B and C Valves are identical and have the same part number. The A Valve has a diameter of 4-1/2 inches.

All three control valves operate on the same principle. Each valve is driven by a two-phase AC servo motor as shown in Figure 17. One phase is called the reference winding and is powered by 115 volt phase A power from the Temperature Control System power circuit breaker. The other phase is called the control winding, and is turned on and off by the servo amplifier in the temperature control unit. The normal drive voltage on the control winding is 30 to 50 VAC. The direction of valve rotation is determined by the phase angle relationship between the voltage in the control winding and the voltage in the reference winding. The voltage in the control winding will be either in phase or 180 degrees out-of-phase with the reference voltage. The motor then drives the valve butterfly and feedback potentiometer. The A Valve feedback potentiometer is energized by 27 VDC, which is developed by a regulated, fil-

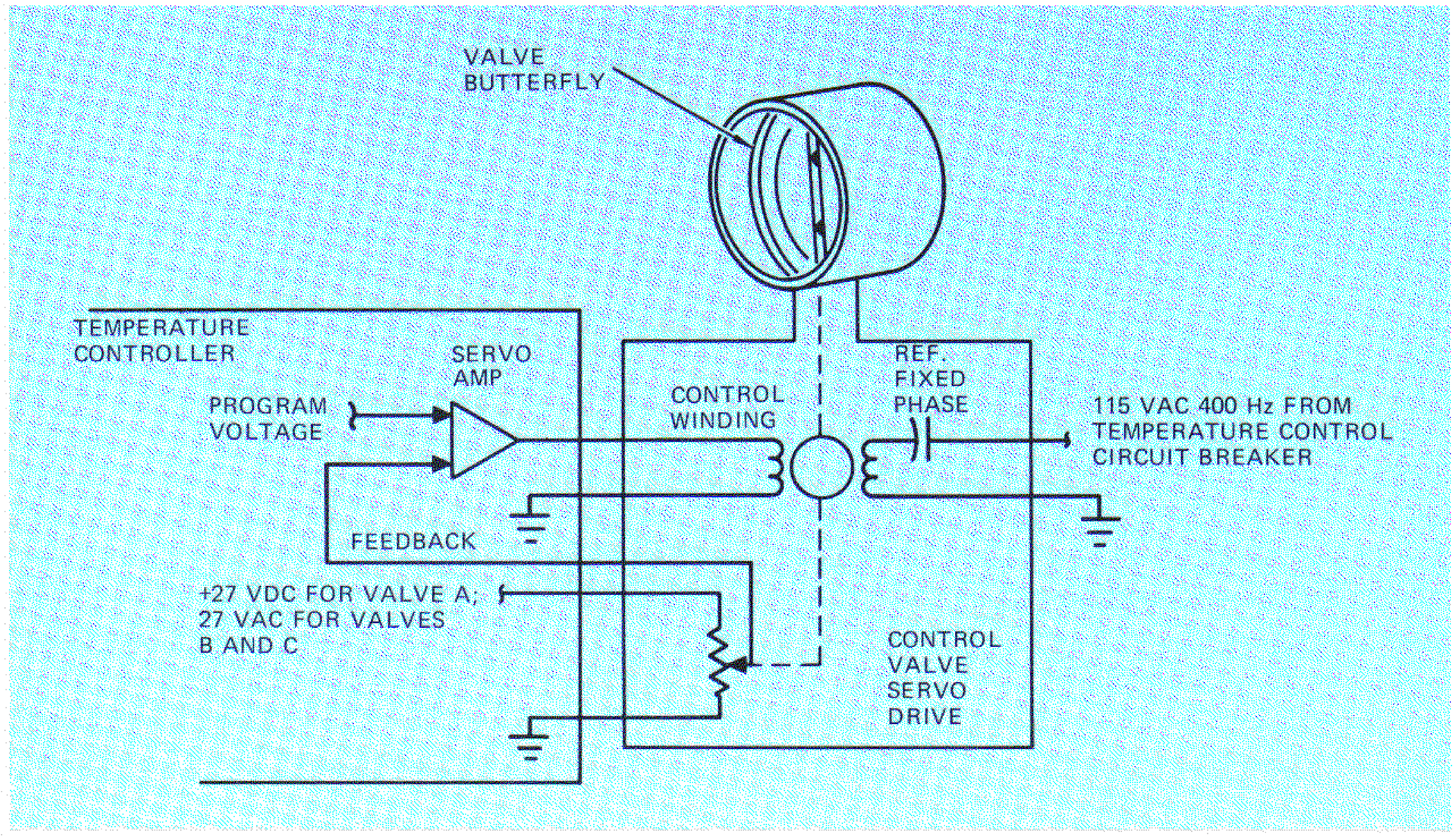


Figure 17. Temperature Controller and Air Flow Control Valve Servo Drive Circuit

tered power supply inside the controller. The B and C Valve feedback potentiometers are energized by 27 VAC, also developed inside of the controller.

Currently, two different types of A, B, and C valves are available for use on the P-3 aircraft. They are manufactured by the Borg-Warner Corp. (the "Weston"-type valve), or by the Barber-Colman Co., and examples of both makes are shown in Figure 18. The most notable external difference is the design of the valve actuator. The valves are identical to their counterparts in function and may be used interchangeably, although some rerouting of wiring harnesses is required. The proper routing for these wire harnesses is shown in the P-3 Maintenance Instruction Manual.

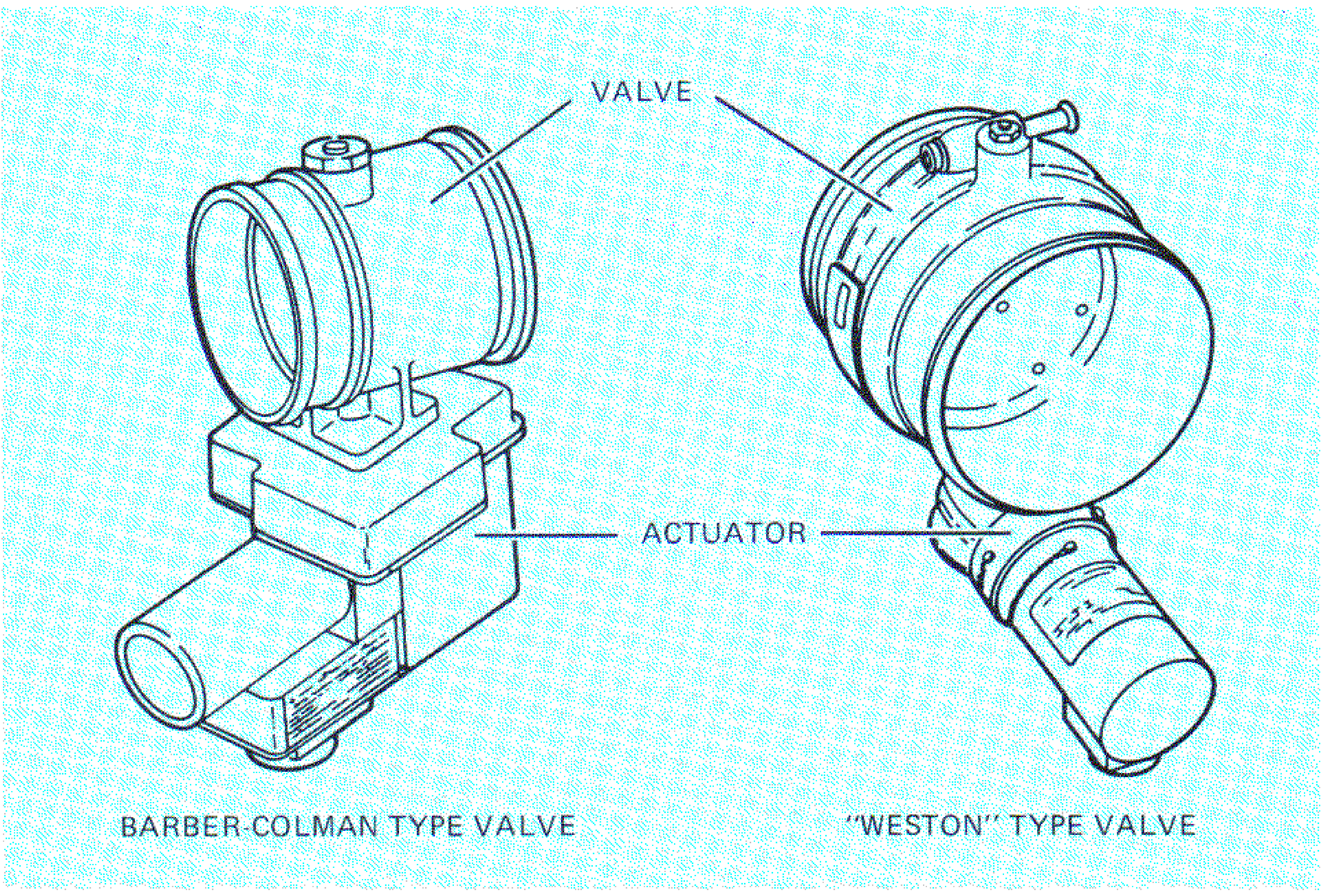


Figure 18. Temperature Control System Air Flow Control Valves

TEMPERATURE CONTROL SYSTEM OPERATION The P-3 temperature control system has two modes of operation, automatic and manual. The operational mode and the desired temperature are selected by the flight crew with the selector/indicator located on the Air Conditioning control panel. These signals are sent from the selector/indicator to the temperature controller located in the forward electrical load center.

In either operational mode, the air flow control valves are positioned by a command that is developed in the temperature controller. This command is called *program voltage*. The response of a control valve to a specific program voltage will be the same, whether the system is operating in the automatic or manual mode. The difference in the two operational modes is the process that the temperature controller uses to develop the program voltage. Signals from the ice limiting and pressure ratio limiting systems will cause the temperature controller to override the program voltage command to the A Valve, but cannot alter the program voltage.

In the following paragraphs we shall discuss how the temperature control system operates in the automatic mode, how the ice limiting and pressure ratio limiting systems affect temperature control system operation, and finally how the system operates in the manual mode.

Automatic Mode The automatic mode of operation regulates the cabin or flight station environment at a temperature setting between 18°C (full cold, AUTO) and 29°C (full hot, AUTO) depending on the setting of the selector bug. The face of the selector/indicator has reference marks on it at settings of 21°C (one dot), 23°C (two dots), and 27°C (three dots).

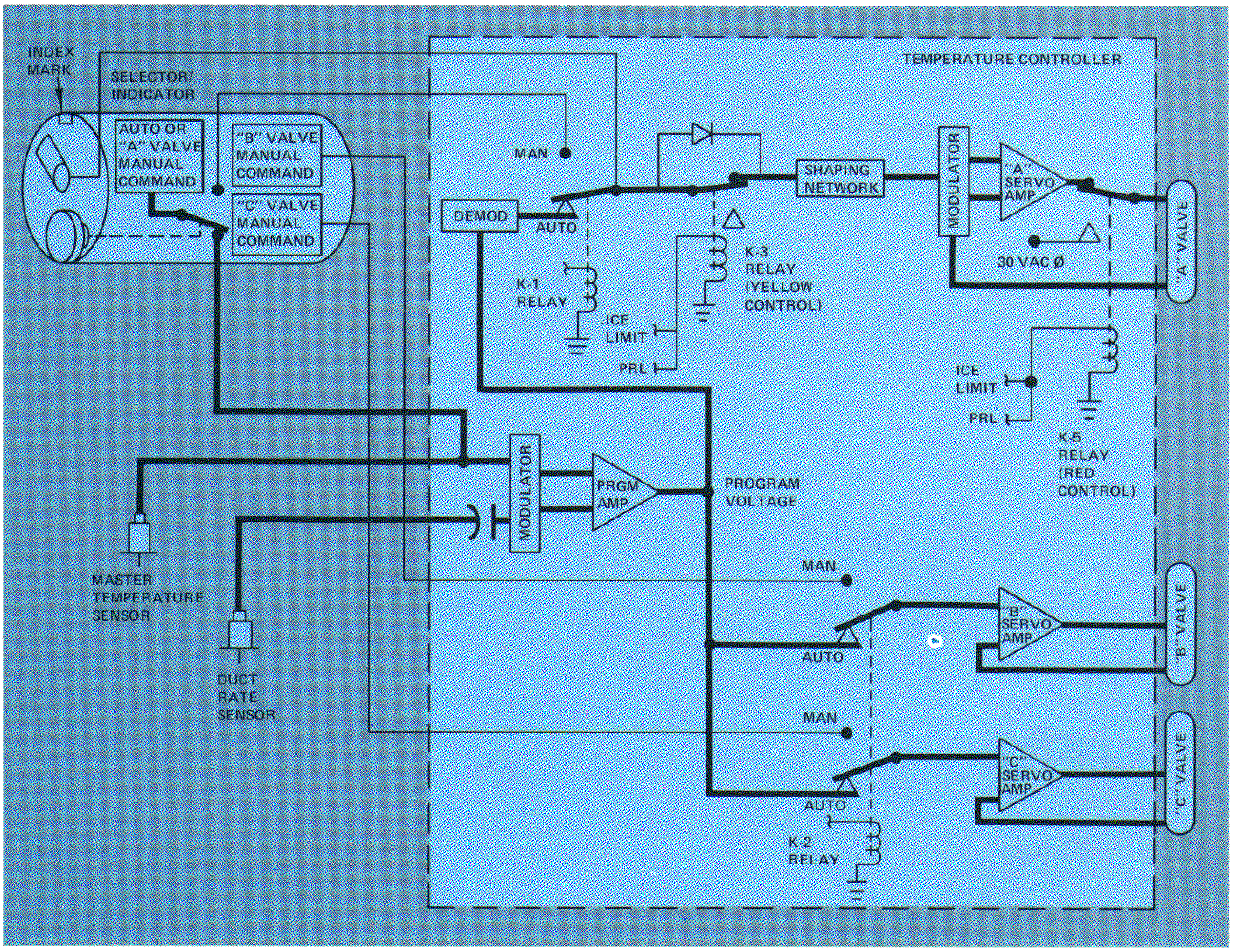


Figure 19. Temperature Control System Schematic – Automatic Mode

In the automatic mode, the temperature controller program amplifier receives three inputs and uses them to determine the proper control valve positions (see Figure 19). First, the flight crew uses the selector/indicator (programmer) to select a desired temperature. This, in effect, tells the controller what the flight crew wants. The setting of the system's AUTO command potentiometer is adjusted by pulling the selector/indicator control knob to the AUTO position, then rotating the knob. The selector index mark or "bug" indicates the system setting. The potentiometer receives excitation from the same 27 VDC power supply in the controller that provides excitation for the A Valve feedback potentiometer. The master temperature sensor provides the second input to the temperature controller program amplifier. This device is a thermistor that senses the current flight station or cabin ambient temperature. The flight station master temperature sensor on all P-3 aircraft is installed in the exhaust duct inlet located above and behind the pilot's head. The cabin master temperature sensor on P-3A/B aircraft is installed in an exhaust duct located at the navigator's station. On P-3C aircraft through the Update II model, the cabin master temperature sensor is installed in an exhaust duct that is connected to a screen on the B3 electronics rack door. On P-3C Update III aircraft, this sensor is installed on a perforated plate on the aft face of electronics rack D3.

The temperature controller program amplifier compares the temperature setting requested by the flight crew (selector/indicator) with the actual cabin or flight station temperature (master temperature sensor), and develops an output called the program voltage. This signal is a dc voltage that varies from approximately 0 to 10 VDC. Zero program voltage equates to a command for the three servo amplifiers to drive the air flow control valves to obtain maximum cooling. Ten volts of program voltage is a command for full heating. The selector/indicator needle, called the Program Position Indicator (PPI), is positioned by the command from the program amplifier (0 to 10 VDC). The PPI tells the flight crew *what the system is going to produce*, regardless of the position of the selector bug.

It would seem reasonable that the combination of the selector command potentiometer and the master temperature sensor inputs would be all that is required to properly maintain the desired temperature in the aircraft. For example, if the selector was set in a mid-range (2-dot) position, but the actual temperature inside of the aircraft was very hot, one would expect the temperature controller to drive the system towards a cool setting as indicated on the selector/indicator needle. However, as in many control systems, an instability would occur when the actual temperature was approaching the desired temperature unless some means of controlling the rate of temperature change was introduced. In this system the duct rate sensor provides a signal that enables the temperature controller to perform this function.

The duct rate sensor senses the rate of temperature change in the air supply duct (deg/min), then it sends a third signal that is proportional to this rate of change to the controller program amplifier. As shown in Figure 10, the duct rate sensor is mounted in the system supply duct at the control valve blending location. This is the point where the hot air bypass, the warm turbine bypass and the cold refrigeration unit air discharges are blended. As the three valves move in response to changes in program voltage or position, the temperature of the air will change at a proportional rate. The duct rate sensor is a bridge device with a thermistor in each leg. One thermistor is encased in metal while the other is exposed to the air flow. As the temperature of the air flowing across the sensor changes, the two thermistors respond at a different rate. This unbalances the bridge and creates the rate-of-change signal. The duct rate sensor tells the controller *what the temperature is going to do.*

Due to the difference in the sizes of the flight station and the cabin, the duct rate sensors for the two systems respond at different rates. As a result, the duct rate sensors are not interchangeable and have different mounting hole configurations.

Let's review briefly what we have to this point. The flight crew makes a temperature selection by adjusting the position of the bug on the selector/indicator. The program amplifier in the temperature controller compares this selected temperature to the actual temperature sensed by the master temperature sensor, then develops a system command called the program voltage that is displayed by the indicator needle in the selector/indicator. When the control system valves move,

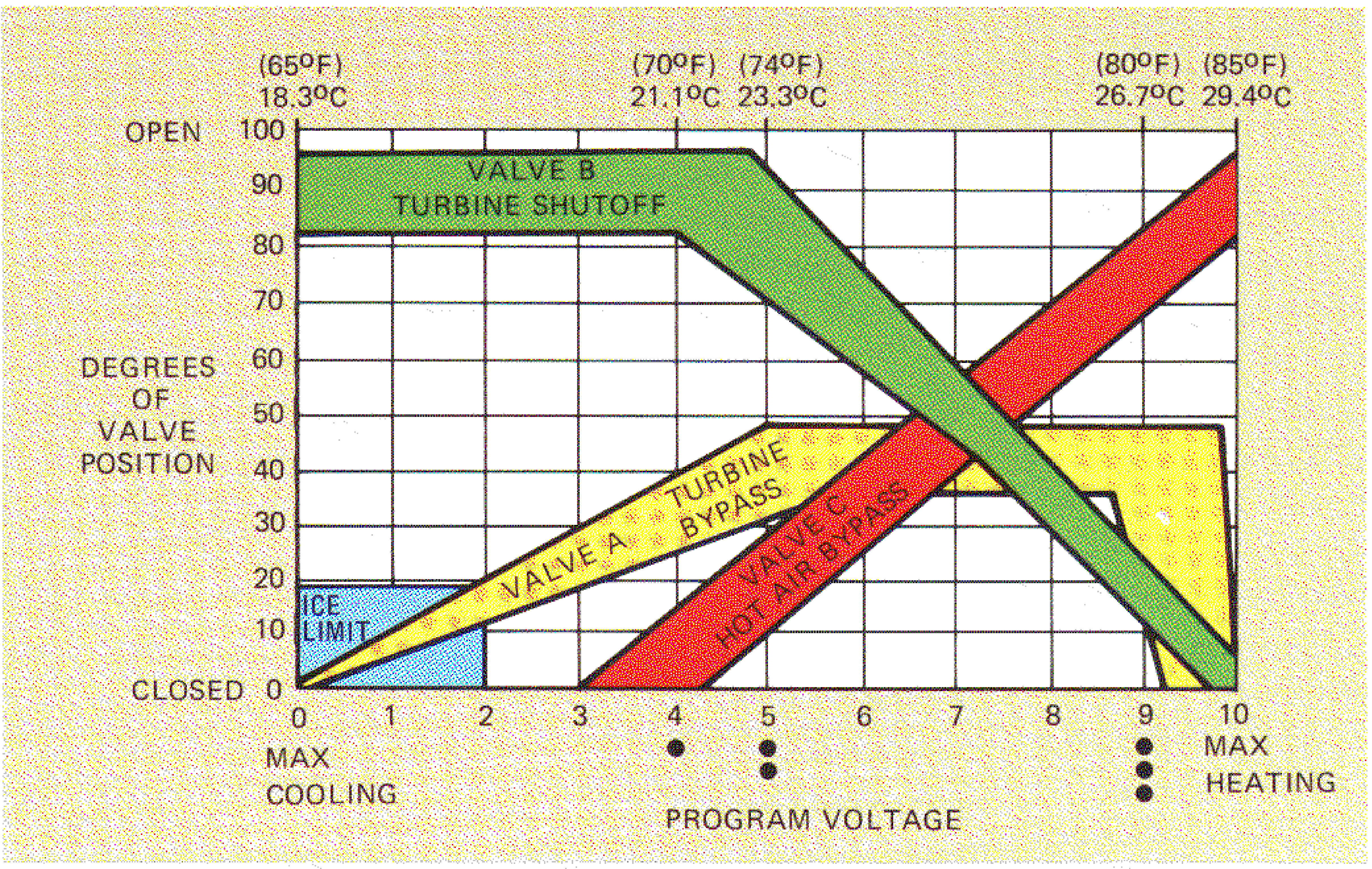


Figure 20. Air Flow Control Valve Position vs. Program Voltage

the duct rate sensor sends a signal to the program amplifier that is proportional to the rate of temperature change in the ducts. This in turn enables the system to anticipate temperature changes in the aircraft, and provides stability in temperature control system operation.

The program voltage developed by the program amplifier is now applied through some additional circuitry inside the temperature controller to the three valve drive servo amplifiers. Each valve's servo amplifier compares the program voltage to the signal from the valve feedback potentiometers. If the servo amplifier senses that the valve's feedback potentiometer is not in the position that corresponds to the program voltage input, it drives the valve to the proper position.

Figure 20 is a graph that depicts the schedule of valve positions for the 0 to 10 VDC program volt-

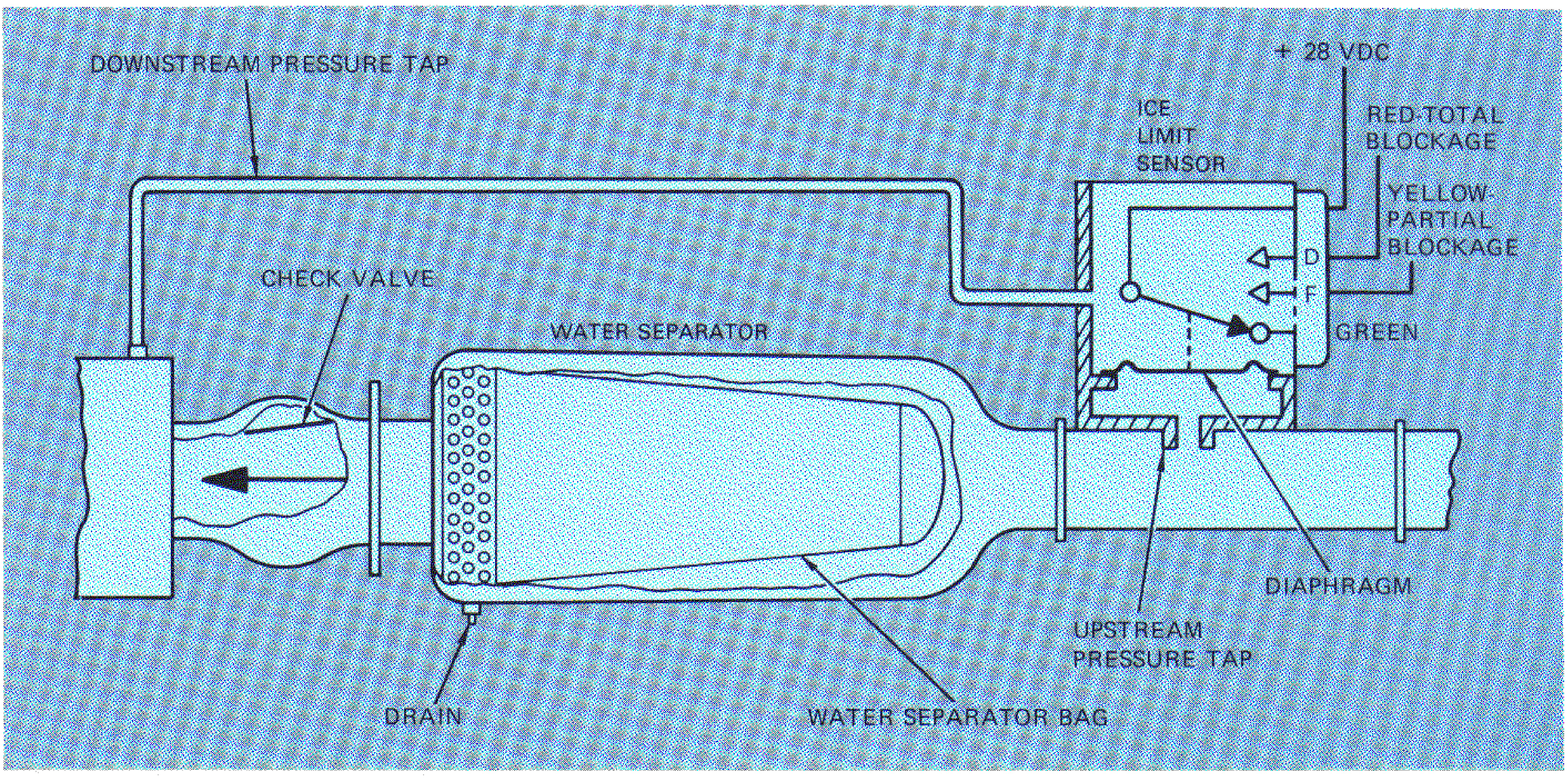


Figure 21. Water Separator and Ice Limit Sensor Schematic

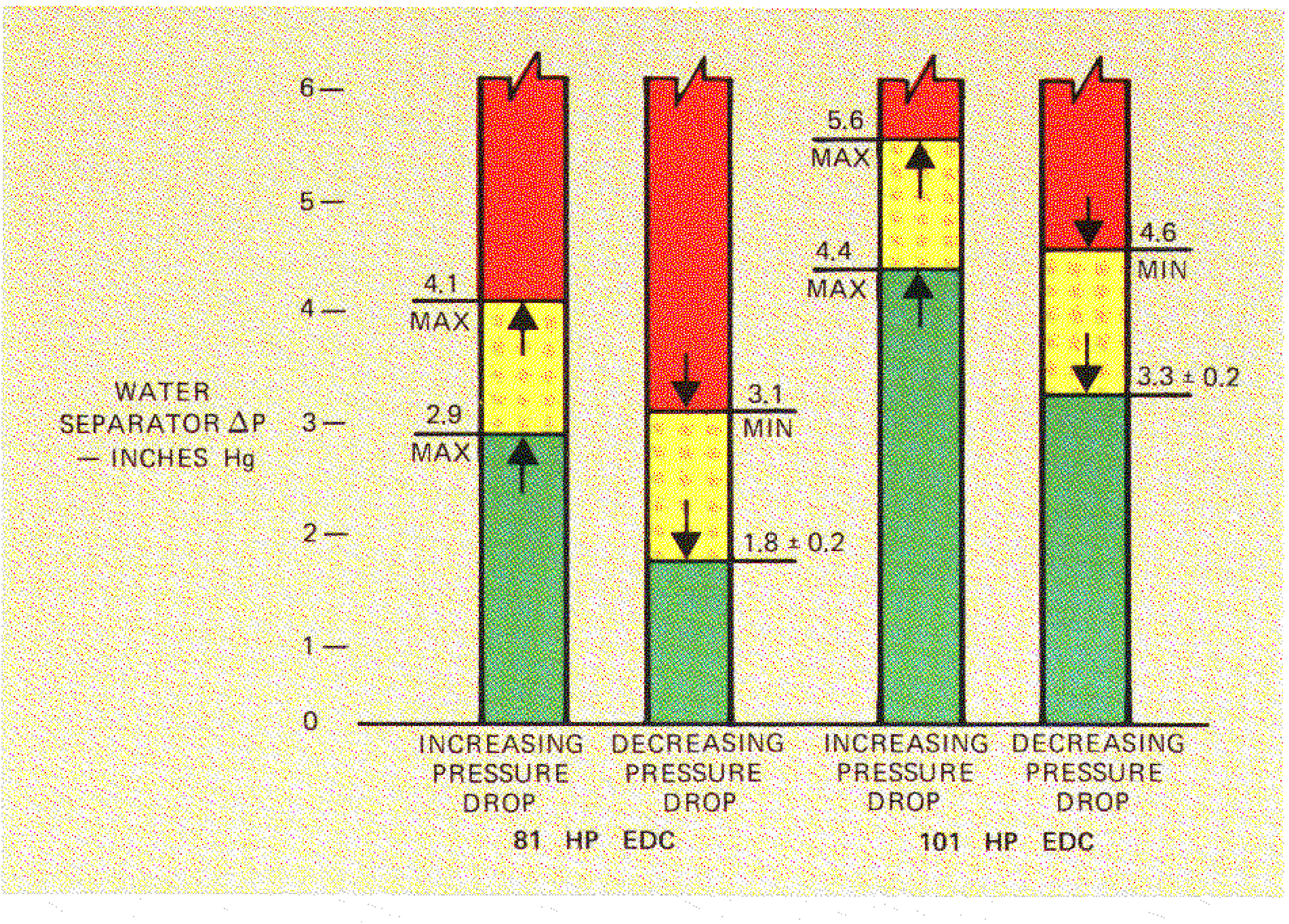


Figure 22.
Ice Limit Sensor Control Activation Pressures

age. Note that for a full cold command (0 VDC program voltage), the C Valve (hot air bypass) is shut, the A Valve (turbine bypass) is shut, and the B Valve (turbine shutoff) is open. Thus, when "full cold" is commanded, all of the air flow into the air cycle cooling system is being cooled in the refrigeration turbine. If the control system demands heating, the program voltage will start to increase. This will be indicated to the operator by clockwise movement of the selector/indicator needle. Warm or hot air will now be bypassed around various portions of the air cycle cooling system until the desired temperature is obtained. The B and C Valve operation schedules are similar in response but opposite in direction. On the other hand, the A Valve has a relatively complicated operation schedule. This is because the A Valve controls the bypass of air that is warm, but close to a comfortable temperature. The program voltage most commonly runs in the range of 0 to approximately 5 VDC. It should be emphasized that this is the region where the A Valve is doing all of the temperature regulation work.

Ice Limiting and Pressure Ratio Limiting As we have seen, the temperature control system control valves are regulated to provide a discharge temperature that will ultimately stabilize the flight station and cabin temperature. When the valve positions set the system up for full-cold air delivery, the following two conditions must be monitored to preclude damage to the ECS: (1) under certain atmospheric conditions, water separator bag icing can occur; (2) with the A and C bypass valves closed, maximum air cycle cooling system back pressure can be imposed on the engine driven compressor. Water separator bag icing will cause reduced air flow and high back pressure on the air cycle cooling system. High back pressure from the air cycle cooling system will cause the pressure ratio across the EDC to exceed its design limits and cause a compressor surge condition. The compressor surge may cause a loss of cooling air at the dump valve or damage the EDC. Fortunately, the temperature control system has automatic protection systems to alleviate icing and back pressure.

Figure 21 shows a device called the ice limit sensor that is mounted on the upstream side of the water separator assembly. This device is merely a piece of duct with a pressure switch mounted on it. One side of the pressure switch senses the air pressure upstream from the water separator bag, and the other side senses the air pressure downstream from the water separator bag. When the bag is covered with ice, the air flow is impeded and a greater-than-normal pressure drop develops across the bag.

When the pressure differential exceeds 2.9 inches Hg (see Figure 22), a switch actuates in the ice sensor and energizes the K-3 "yellow mode" control relay in the temperature controller. On aircraft equipped with 101 hp EDCs, the ECS ice sensors require a higher setting because the air flow rate is higher. The "yellow" condition on these aircraft is set at 4.4 inches Hg pressure drop across the water separator.

The temperature control system now automatically shifts from its normal "green mode" of operation to the "yellow mode." During the "yellow mode," changes are made to the circuitry in the temperature controller that slow or arrest the rate of closure of the A Valve. If the A Valve were commanded to *open* during this mode, the controller would allow valve movement. However, any A Valve movement in response to a command to close would occur very slowly, if at all. EDC pressure ratio limiter "yellow mode" control signals, as discussed in the section on EDC operation, will result in identical operation of the temperature controller.

Icing and back pressure conditions generally occur when the A Valve is within 15 to 20 degrees of being fully closed. This is the point at which less and less air is bypassed around the bootstrap refrigeration unit. Often, the restricted A Valve movement will be enough to clear a momentary icing or back pressure problem. However, if the condition worsens and the ice limiter senses an increase in pressure drop across the water separator bag to 4.1 inches Hg (5.6 inches Hg for aircraft equipped with 101 Hp EDCs), the high pressure switch actuates and energizes the K-5 "red mode" control relay in the temperature controller. The pressure ratio limiter also has a "red mode" switch to energize this control relay.

When energized, the K-5 "red mode" relay disconnects the A Valve control winding from its servo amplifier and reconnects it to a voltage supply that is of the proper phase to drive the valve open. Note that opening the A Valve will cause warm air to bypass the refrigeration unit and melt the ice on the water separator bag. On aircraft equipped with the 81 hp EDC, the ice limit sensor "red mode" switch will reopen as the pressure across the water separator bag drops below 3.1 inches Hg, and the "yellow mode" switch will reopen as the pressure across the bag decreases to 1.8 inches Hg. On aircraft equipped with the 101 hp EDC, the ice limit sensor "red mode" switch will reopen as the pressure across the water separator bag decreases to 4.6 inches Hg, and the "yellow mode" switch will reopen as the pressure across the bag decreases to 3.3 inches Hg.

As the A Valve bypasses air around the refrigeration unit, the back pressure from the air cycle cooling system is reduced. The "red mode" overrides the valve schedule, and if for any reason the system was to become "locked" in this mode, the A Valve would continue to drive to 90 degrees open. The A Valve is used for this function because its cycling can provide the desired effect without the dramatic fluctuations of cabin temperature that would occur if the C Valve were used.

Manual Mode The manual mode of operation for the temperature control system is a backup mode to be used in case the automatic mode fails. Figure 23 shows the temperature controller circuitry set up for manual mode operation. The auto/manual mode select relays K-1 and K-2 are deenergized when the selector/indicator mode select switch is set to manual. This disconnects the valve servo amplifier inputs from the program amplifier and connects them to three potentiometers in the selector/indicator. The potentiometer that was used for the automatic system command is now connected to the temperature control unit A Valve drive circuit, and the B and C Valve manual potentiometers are connected to their respective servo amplifiers. The PPI needle still indicates the program voltage to which the valve servo amplifiers will respond in positioning the valves; however, there is no temperature regulation. The valves follow the program voltage as shown on the program graph on Figure 20.

In the manual mode, the selector bug commands control valve position rather than setting a temperature. If the flight crew is uncomfortable, the valve positions must be changed by moving the selector bug. The PPI needle should follow the selector bug closely (within one needle width) as the bug is moved. The master temperature sensor, duct rate sensor and program amplifier inputs are not used in the manual mode. Pre-Update III P-3 aircraft on which P-3 AFC-352 has been incorporated have the ice limiting function available in the manual mode, but the pressure ratio limiting function is de-energized.[4] P-3C Update III aircraft have both ice limiting and pressure ratio limiting in the manual mode.

CABIN PRESSURIZATION AND VENTILATION

In flight, the engine driven compressors and the air cycle cooling unit provide cool, dehumidified air for the flight crew and the avionics equipment. However, as the aircraft climbs and the atmospheric pressure drops, the flight crew must have a means of controlling cabin pressure in order to maintain sufficient oxygen for flight crew requirements. In the P-3 aircraft, pressurization is obtained and controlled by restricting the amount of air that is exhausted overboard.

The foldout ECS schematic shows details of the cabin exhaust system as it is configured in production P-3C aircraft SERNO 161002 (LCC S/N 5684). Other P-3C aircraft are similar. The cabin exhaust system on P-3A/B aircraft uses the same basic principle, although the exhaust ducting is different. Once the conditioned air has absorbed the heat generated by the crew and avionics equipment, it is collected by the exhaust tuskers located in the overhead area of the electronic bays. The two major exhaust ducts, one for each side of the P-3C aircraft, join in the G2 racks (as shown in the foldout ECS schematic) and duct

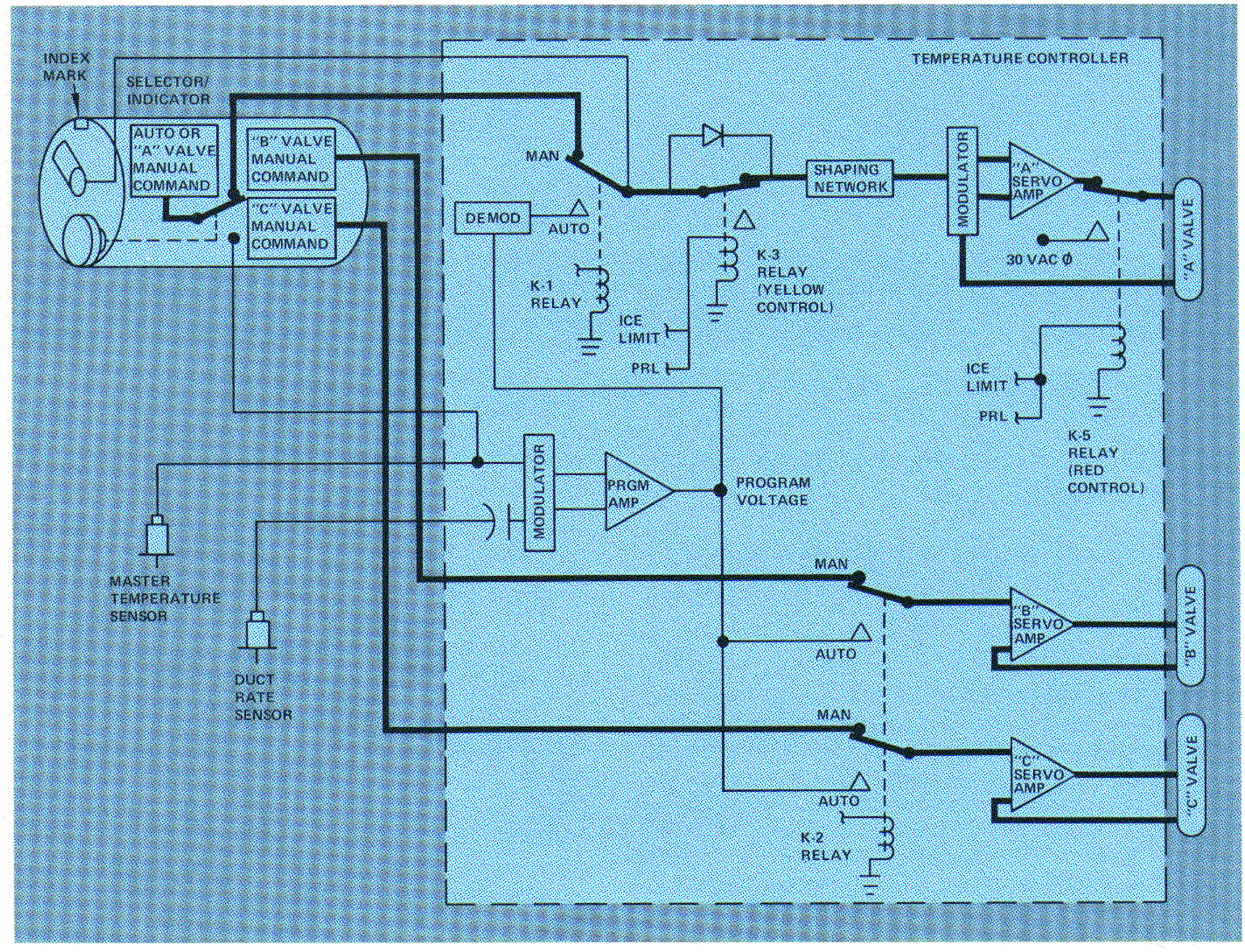


Figure 23. Temperature Control System Schematic – Manual Mode

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[4] During preparation of this article, a RAMEC was proposed which would also provide PRL in the manual mode of temperature control system operation. The RAMEC resulted in the issue of P-3 AFC-431.

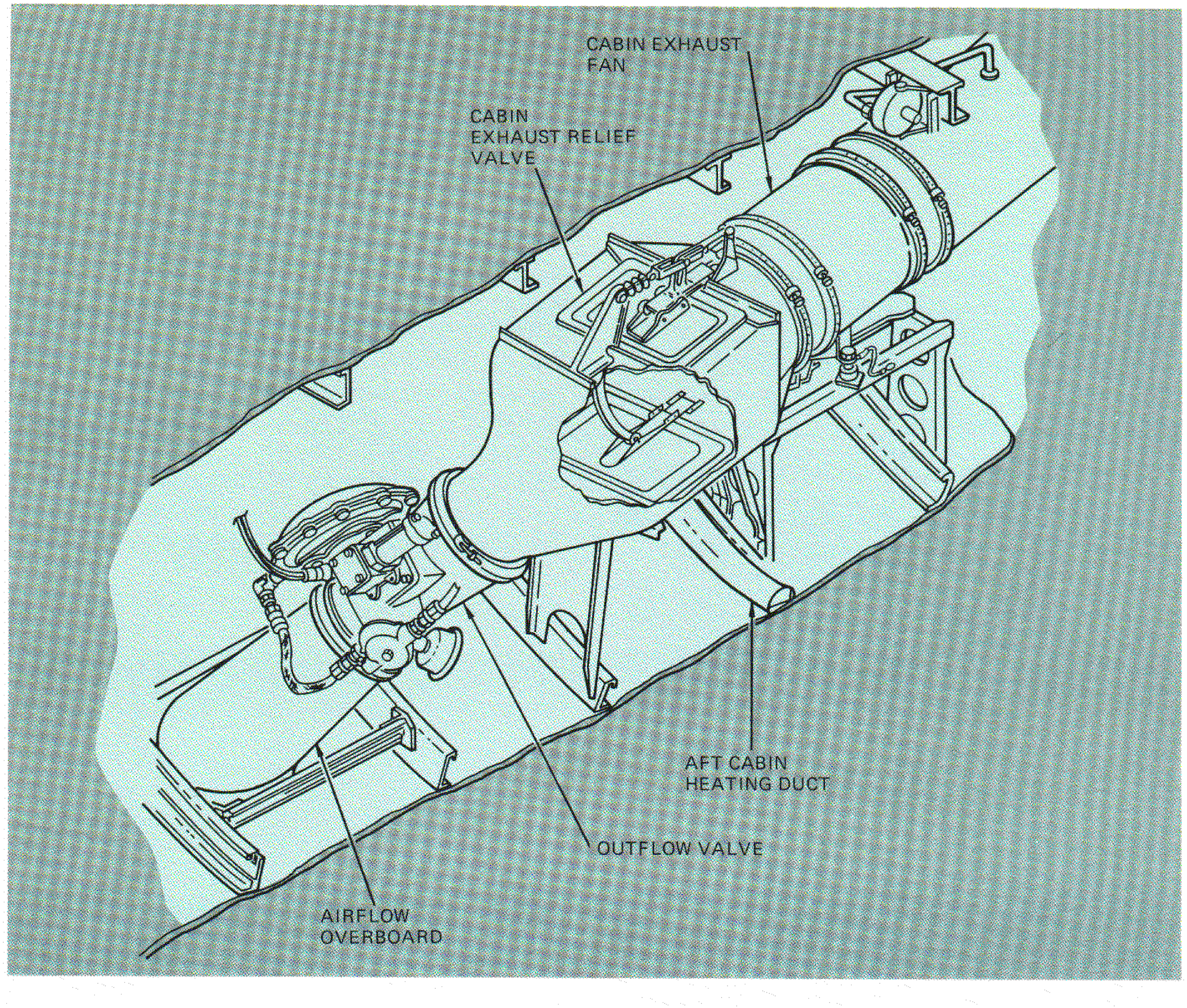

Figure 24. Cabin Pressurization System Outflow Valve Installation

the "used" air beneath the cabin floor to the exhaust fan (see Figure 24).[5]

The cabin exhaust fan provides the suction to establish air flow through the racks. This fan is driven by a 115 VAC 3-phase motor and is controlled with the red guarded cabin exhaust fan switch on the flight station Air Conditioning control panel. The FAN OUT warning light is located next to the exhaust fan control switch (see Figure 2). The warning light will illuminate whenever the exhaust fan differential pressure switch senses a loss of flow. This is an indication that the exhaust fan is shut down or has failed. P-3A/B aircraft are equipped with an exhaust fan that has a flow rate of 1500 cubic feet per minute (CFM). Pre-Update III P-3C aircraft are equipped with a 2500 CFM exhaust fan, and the P-3C Update III aircraft are equipped with a two-speed exhaust fan rated at 3500 CFM in low speed and 4500 CFM in high speed. Production P-3C Update III aircraft have the exhaust fan wired for low-speed operation

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[5] P-3 aircraft equipped with the LTN-72 Inertial Navigation System have an additional control that provides adequate cooling air for the inertial navigation units if the cabin exhaust fan fails. This control consists of a ported butterfly valve in the H1 electronics rack exhaust duct and a mechanical control lever that is located on the front of the rack. When the control lever is set to the NORMAL position, the butterfly valve is closed and its port acts as an air flow restricting orifice. When the control lever is set to the EMERGENCY position, the butterfly valve is opened, eliminating the restriction and increasing the air flow.

only, with the high-speed capability preserved to accommodate avionics growth.

After leaving the fan, the exhaust air passes through a relief valve assembly designed to protect the ducting from rupturing due to excessive internal pressure or collapsing due to an internal vacuum. During normal operation, the exhaust fan air flow exceeds the overboard air discharge allowed by the pressurization system outflow valve. This causes the relief valve flapper to open partially, allowing warm air to recirculate back to the cabin from under the cabin floor. P-3C aircraft SERNO 157327 (LCC S/N 5542) and subsequent have a recirculation duct that collects warm exhaust fan discharge and uses it to heat the galley area. P-3C Update III aircraft are equipped with additional air recirculation ducting, through which warm air is supplied to the aft observer stations and both galley seats. The remaining exhaust air then passes from the relief valve to the outflow valve.

PRESSURIZATION CONTROL The outflow valve is the final component that controls how much air is exhausted overboard (see Figure 25). This is a butterfly-type valve that can be controlled automatically by pneumatic signals from the cabin pressure controller or manually by the crew with an electric actuator. In addition, the electric actuator drives the outflow valve fully open to depressurize the cabin when the aircraft lands.

The Outflow Valve, Grd Check, and Aux Vent switches on the Cabin Pressurization control panel (see Figure 2) work in conjunction to control the outflow valve electric actuator. On the ground, the weight-on-wheels circuits hold the outflow valve open automatically and override any selection made with the Outflow Valve switch. To ground test the cabin pressurization control system, the weight-on-wheels circuits can be defeated by selecting TEST with the Grd Check switch. During flight or ground testing, the operator can slew the valve electrically to the closed position by positioning the Outflow Valve switch to CLOSED. By selecting the Outflow Valve switch to AUTO, the operator can center the valve butterfly and allow the pneumatic cabin pressure controller to take command of valve position. If the Aux Vent switch is set to OPEN, both the outflow valve and the auxiliary ventilation valve will be driven open electrically.

With the Outflow Valve switch set to AUTO, the position of the valve butterfly is controlled by the pneumatic actuator. The outflow valve pneumatic control system is actuated by a pressure signal

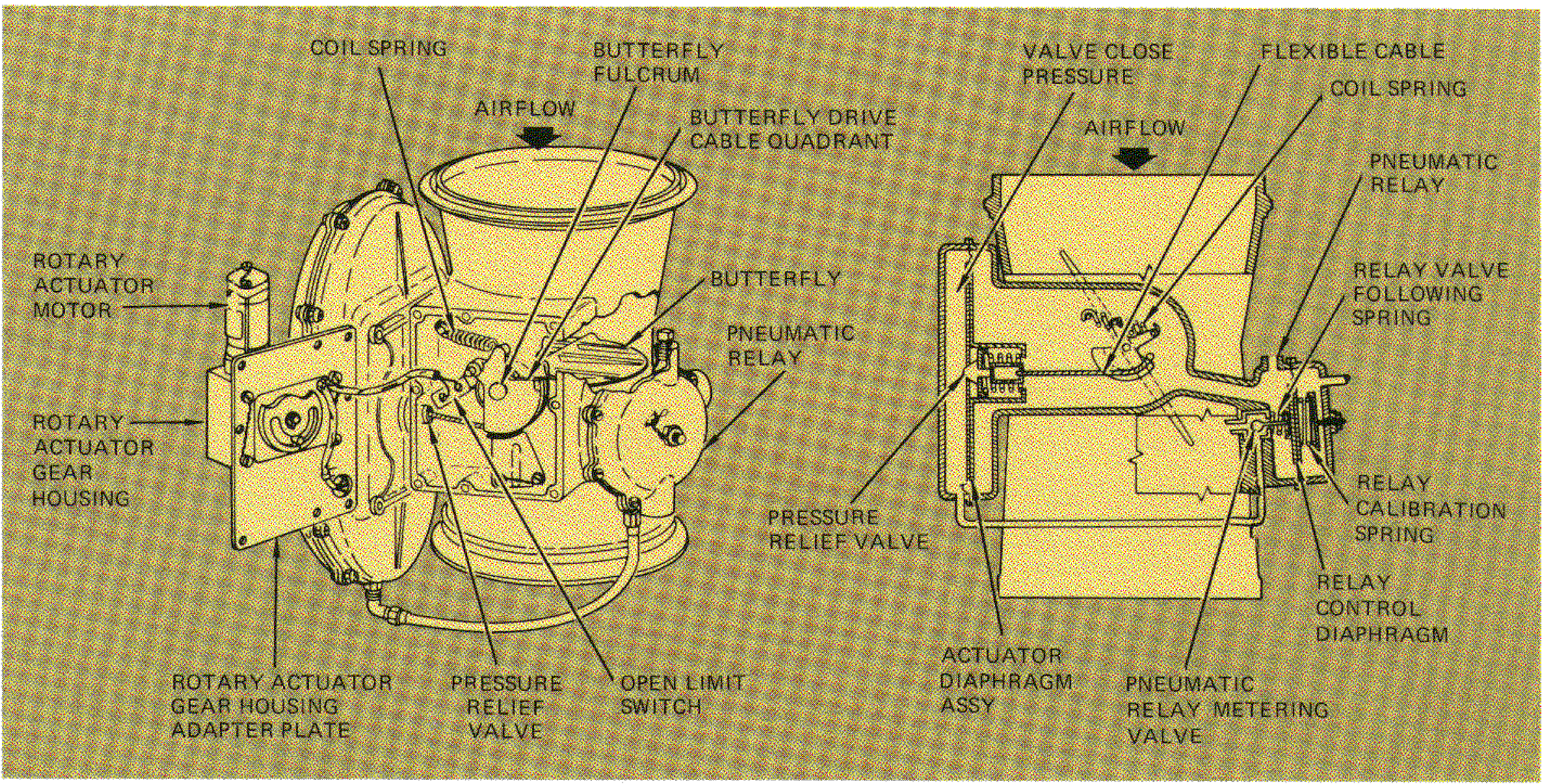


Figure 25. Cabin Pressurization System Outflow Valve Schematic

from the cabin pressure controller located on the flight station Cabin Pressurization control panel (see Figure 2). The cabin pressure controller is divided into an upper control chamber and a lower rate chamber, which are separated by a flexible diaphragm. The air pressure in the control chamber is applied to the outflow valve pneumatic relay. The outflow valve butterfly is spring-restrained to the closed position. The pneumatic relay adjusts the control pressure on the actuator to overcome the spring force and modulate the valve open. Note that the valve pneumatic relay is referenced to cabin pressure. Figure 26 is a schematic of the cabin pressure control system.

If the cabin pressure is higher than desired, the outflow valve control pressure will be low relative to the cabin pressure, and the pneumatic relay will open its metering valve and vent the close side of the actuator diaphragm. In turn, the higher cabin pressure will cause the outflow valve actuator diaphragm to move and pull the butterfly open, allowing more air to exhaust overboard and reduce the cabin pressure. When the cabin pressure becomes lower than desired, the outflow valve control pressure is high relative to the cabin pressure, closing the pneumatic relay metering valve. This in turn equalizes the pressure on both sides of the outflow valve actuator diaphragm and allows the spring to slew the valve butterfly towards the closed position.

Basic Cabin Pressurization Control System Operation (Pre-Update III P-3 Aircraft). The cabin pressure controller (Figure 27) operates in one of two modes, isobaric control or pressure differential control. During normal operation, the flight crew selects the desired cabin altitude and barometric correction setting, which in turn adjusts the spring tension on the diaphragm control (altitude adjustment assembly). Note that the control and rate chambers are interconnected by a small capillary tube. When the air pressure in the cabin changes, the control chamber pressure and rate chamber pressure follow this change. However, since the capillary tube and the pressurization rate control needle valve meter the air flow between the control and rate chambers, the rate chamber pressure does not equalize as rapidly as that in the control chamber. The flight crew can adjust this air flow metering action by rotating the rate change knob on the cabin pressure controller. This adjusts the position of the rate needle valve and allows the cabin pressurization rate to be varied from ap-

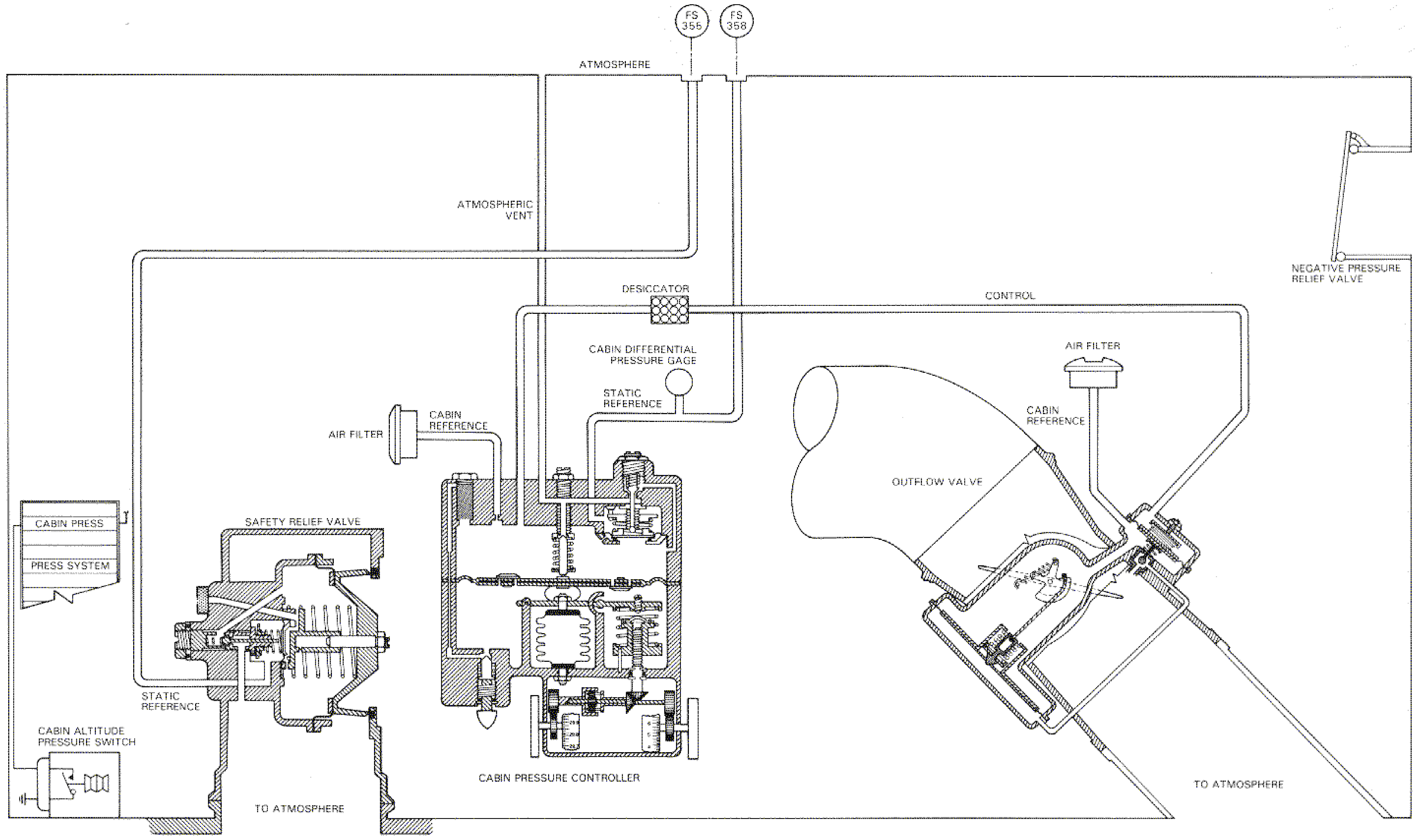


Figure 26. Cabin Pressure Control System Schematic

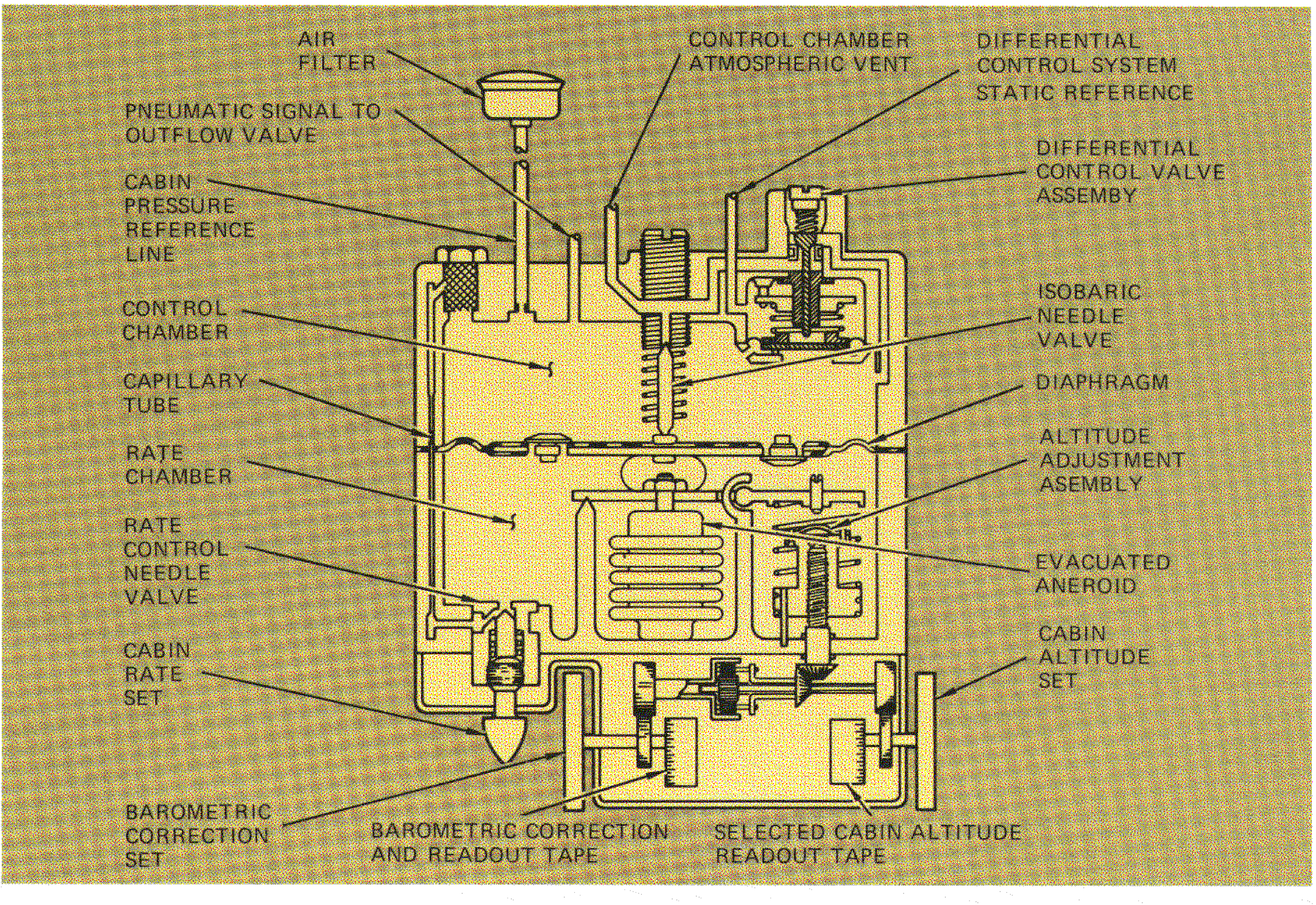


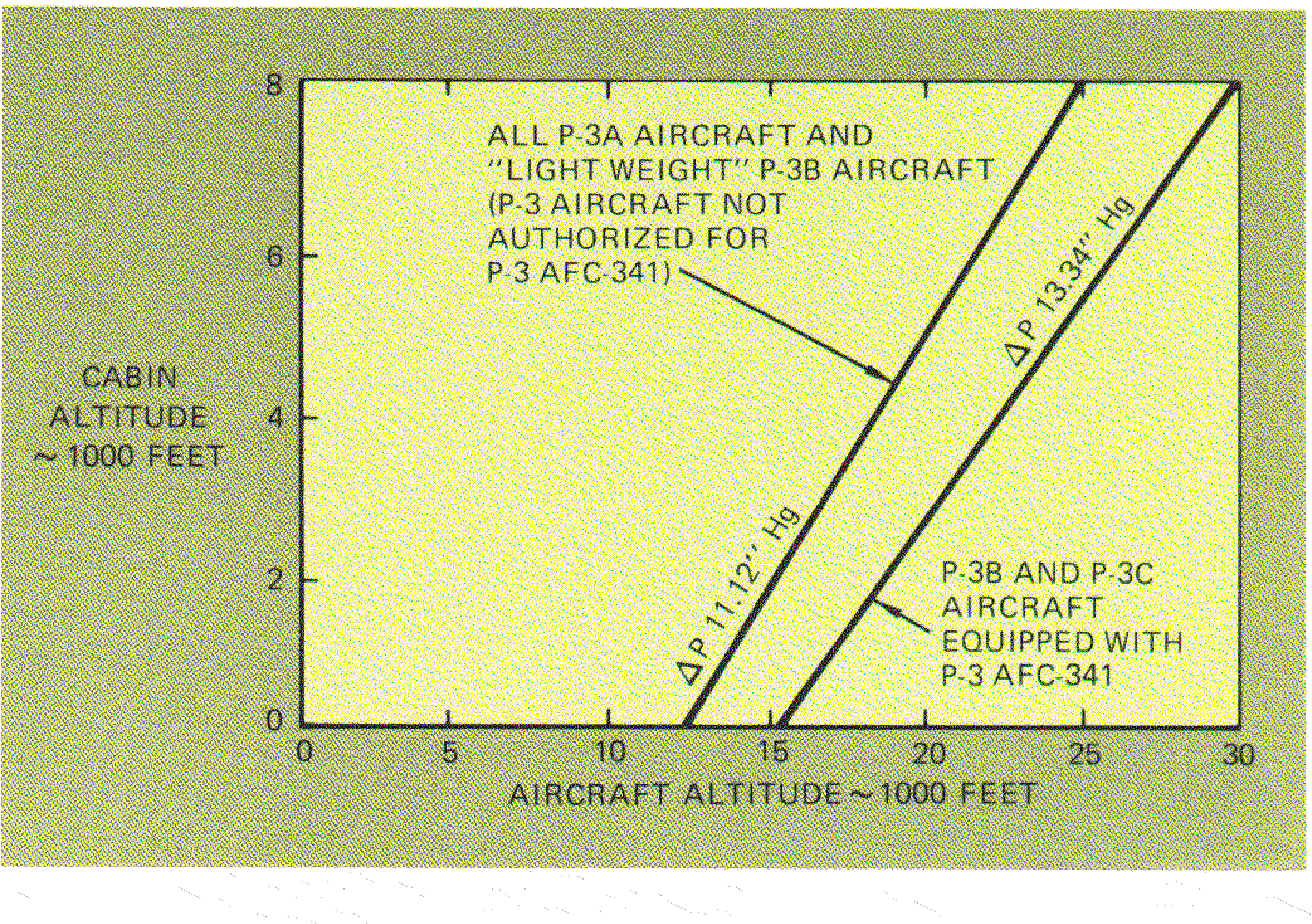
Figure 27. Cabin Pressure Controller

proximately 200 to 2000 feet per minute. The actual pressurization rate is indicated on the cabin pressure rate-of-climb indicator located on the Cabin Pressurization control panel.

When the cabin pressure is high, the diaphragm in the cabin pressure controller initially moves down and unseats the isobaric needle valve in the control chamber. This vents the control chamber through an atmospheric vent located on the outside of the fuselage above the copilot's head, resulting in a reduced control pressure signal. This in turn allows the outflow valve pneumatic relay to vent, and the high cabin reference pressure to be applied to the outflow valve pneumatic actuator, opening the valve butterfly (see Figure 26). As the pressures in the two chambers begin to equalize, the isobaric needle valve restricts the flow from the control chamber through the atmospheric vent, causing the pressure signal to the outflow valve to rise. The controller continues to modulate the pressure signal to the outflow valve as it fine tunes the cabin pressure. The actual cabin pressure altitude will be indicated on the Cabin Pressurization control panel cabin altimeter.

The process of controlling the pressurization to a specified cabin altitude is called isobaric control. In the event of improper settings relative to flight altitude, or a malfunction in the isobaric control system, the cabin controller contains a pressure differential control system that limits the maximum fuselage pressure differential (see Figure 27). The pressure differential control valve monitors the difference between cabin static pressure (as sensed by the control chamber) and atmospheric static pressure. This pressure also is indicated on the cabin differential pressure gauge in inches Hg. If the differential pressure exceeds 13.3 inches Hg (11.1 inches Hg for aircraft not incorporating P-3 AFC-341), the pressure differential control valve diaphragm unseats the pressure differential control needle valve and dumps the control chamber pressure through the atmospheric vent. This overrides the action of the isobaric needle valve and commands the outflow valve

Figure 28.
Cabin Pressurization Schedules for P-3A/B Aircraft that Do Not Incorporate P-3 AFC-341, and for P-3B/C Aircraft Equipped with P-3 AFC-341 by Retrofit or During Production



open in order to limit the cabin pressure to a safe differential.

Figure 28 is a graph that depicts the operating schedule for the *differential control function* of the cabin pressure controller. The graph shows the controller operation schedule at a maximum pressure differential of 13.3 inches Hg for production P-3C aircraft SERNO 160290 (LCC S/N 5653) and up, and for P-3 aircraft that have incorporated P-3 AFC-341. The graph also shows a controller operation schedule at a maximum pressure differential of 11.1 inches Hg for all P-3A aircraft and for the earlier "lightweight" P-3B aircraft. These early P-3A/B aircraft are structurally limited to a maximum normal cabin pressure differential of 11.1 inches Hg.

Figure 28 shows that at the maximum cabin pressure differential, the pressure controller will maintain the cabin altitude at sea level up to an aircraft altitude of 15,450 feet on aircraft that use the 13.3 inches Hg maximum pressure differential schedule. The pressure controller on aircraft limited to a maximum cabin pressure differential of 11.1 inches Hg (installation of P-3 AFC-341 not authorized) will maintain a cabin altitude of sea level up to an aircraft altitude of 12,300 feet. If the aircraft climbs above the maximum altitude at which the pressure controller will maintain sea level cabin altitude, and if the controller is set to a cabin altitude that would cause the cabin pressure to exceed the maximum pressure differential, the pressure differential protection system will limit the cabin altitude as shown in Figure 28 to maintain the maximum cabin pressure differential.

If both the isobaric control and pressure differential control systems fail, a safety relief valve located beneath the copilot's seat will operate independent of the cabin pressure controller/outflow valve system to maintain the maximum allowable cabin pressure. This valve is set to open at a differential pressure of 13.9 to 14.4 inches Hg (11.7 to 12.2 inches Hg for aircraft not incorporating P-3 AFC-341). The safety relief valve is referenced to atmospheric static pressure in the same fuselage area as the pressure differential control valve.

The flight crew is alerted to cabin pressurization system failures by two lights located on the flight station master caution light panel. The CABIN PRESS light is illuminated by a pressure switch in the forward load center if the cabin altitude exceeds 10,000 (± 300) feet. The light extinguishes as the cabin altitude decreases to 9000 (± 300) feet. The PRESS SYSTEM light illuminates if one of the following failures occurs: (1) EDC oil pressure is low, (2) EDC oil temperature is high, (3) cabin exhaust fan shutdown, or (4) air refrigeration unit overheat. The purpose of this light is to direct the operators attention to the air conditioning and pressurization system control panel to determine the system failure.

The cabin pressure control system is composed of many small, delicate components that require clean, dry air to operate properly. The cabin pressure reference inlets on the cabin pressure controller and the outflow valve are designed with replaceable filter elements to assure that control air is clean. A desiccator is mounted in the pneumatic line that transmits the pressure control signal from the controller to the outflow valve. Its function is to remove any moisture that could freeze in the line. The desiccator is located in the forward load center, and access can be gained to it through the spare bulb locker door.

The cabin pressurization system automatically limits the maximum cabin differential pressure to prevent overpressurization. A valve called the negative pressure relief valve, mounted in the aft pressure bulkhead, prevents the cabin pressure from becoming lower than ambient atmospheric pressure. The valve is a mechanical flapper type that is normally held in the closed position by the angle at which the valve is mounted. This valve is opened by the pressure differential when the atmospheric pressure is greater than the cabin pressure, and allows air flow into the cabin in order to equalize the pressure differential.

P-3C Update III Stepped Pressurization Schedule The cooling capacity of the ECS can be increased at lower aircraft flight altitudes by decreasing the maximum cabin pressure differential control limit. This will increase the pressure ratio across the bootstrap refrigeration turbines, which will reduce the output temperature and under certain conditions increase the flow rate of the conditioned air from the air cycle cooling system. The P-3C Update III aircraft employs a modified cabin pressurization system that limits the maximum cabin pressure differential to 11.1 inches Hg at flight altitudes below 16,800 feet, and to 13.3 inches Hg at flight altitudes above 20,470 feet.

This modified pressurization control system uses a non AFC-341 pressure controller (11.1 inches Hg maximum differential control setting), which is designated the primary controller. An auxiliary pressure controller has been added to provide the 2.2 inches Hg increase in differential pressure control that is required above 20,470 feet flight altitude. Figures 29 and 30 show the difference between the basic P-3 pressure differential control system and the stepped pressure differential control system. Note that in the stepped control system, the primary controller static reference and the control chamber atmospheric vent line are plumbed into the auxiliary controller. The auxiliary controller is then connected to the pressurization system atmospheric static reference port. When maximum cabin pressure differential is selected (as explained below), the primary controller will maintain a cabin altitude of sea level up to a flight altitude of 12,300 feet, and a cabin altitude of 3000 feet at a flight altitude of 16,800 feet.

At intermediate flight altitudes, crew comfort and performance are dependent upon maintaining an adequate cabin altitude. This necessitates a higher cabin differential pressure, which results in a

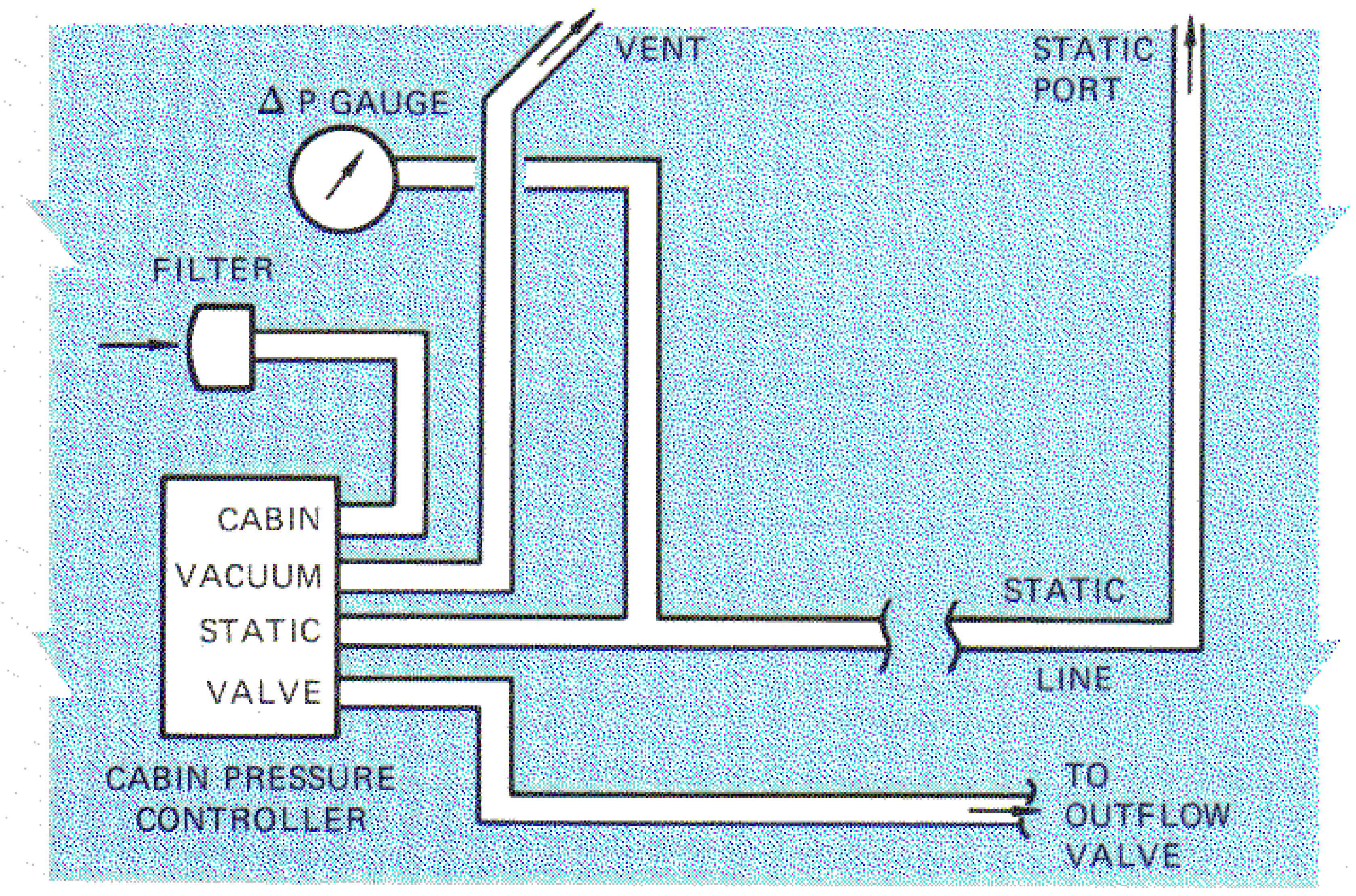


Figure 29. Cabin Pressure Control System Block Diagram for P-3 Aircraft through the P-3C Update II Model

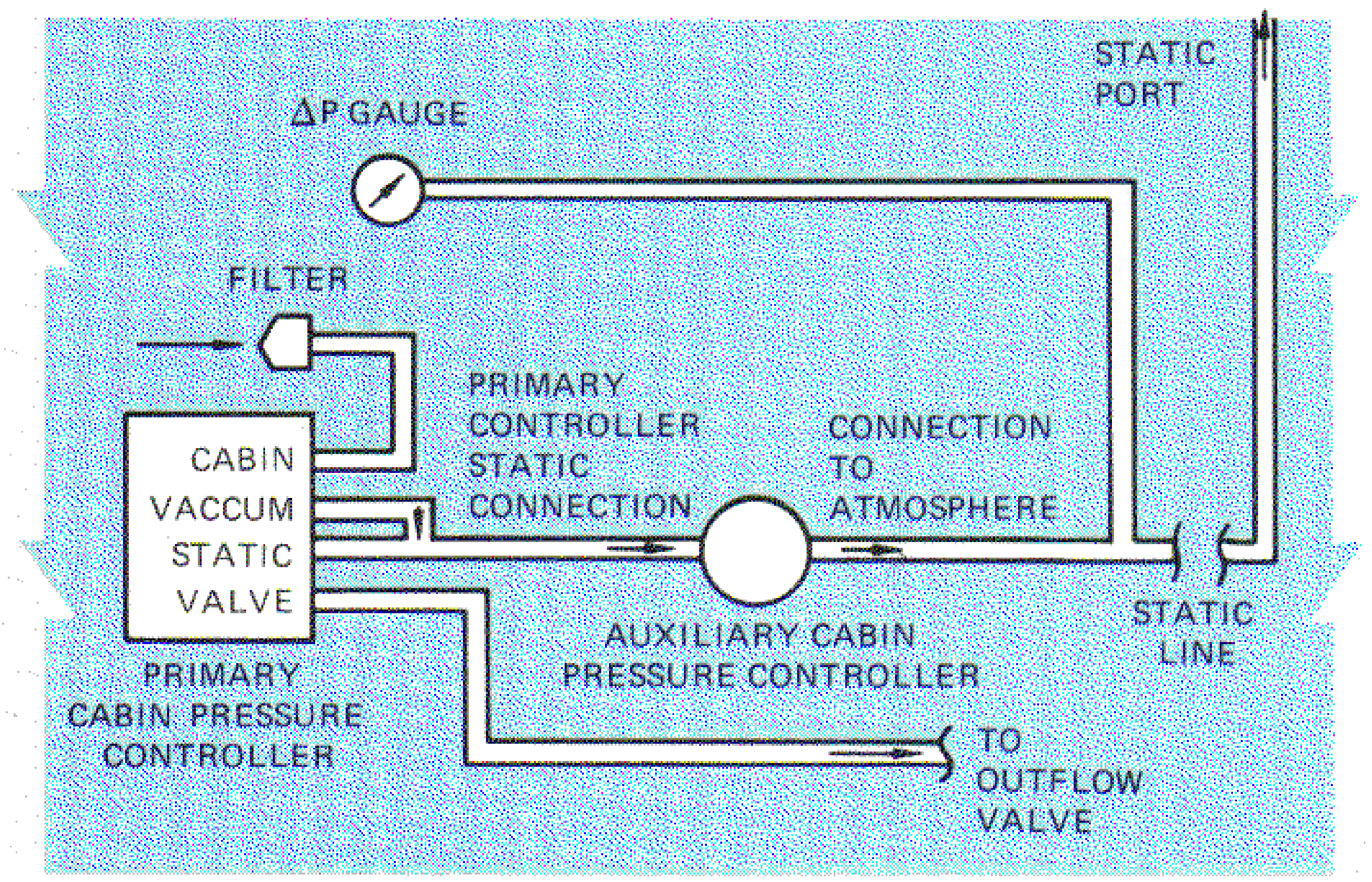


Figure 30. Cabin Pressure Control System Block Diagram for P-3C Update III Aircraft

tradeoff between cabin altitude and bootstrap refrigeration turbine performance. The cabin altitude requirement is fulfilled by gradually increasing the maximum cabin pressure differential limit from 11.1 inches Hg to 13.3 inches Hg as the aircraft climbs from 16,800 feet to 20,470 feet. This introduces a "step" in the cabin pressurization schedule between these two flight altitudes at which a cabin altitude of 3000 feet is maintained. Above 20,470 feet flight altitude, the maximum cabin pressure differential limit is 13.3 inches Hg. The graph in Figure 31 shows this stepped cabin pressurization schedule. The cabin pressurization control system will function in accordance with this full stepped pressurization schedule *only* if the cabin altitude selector is set for sea level (maximum differential pressure) before takeoff, and the selector remains at that setting for the entire flight. If the cabin altitude selection is higher than sea level, the system will automatically control to that altitude until the corresponding cabin differential limit of the stepped pressure schedule is reached.

As the aircraft ascends from 16,800 feet, the auxiliary controller develops an artificial atmospheric static reference pressure that causes the primary controller to continue to sense a differential pressure of 11.1 inches Hg. Note from Figure 31 that the primary controller continues to adjust the outflow valve to maintain a constant 3000 feet cabin altitude. However, the decrease in atmospheric pressure will cause an increase in the *actual* cabin differential pressure. At this point, a pressure drop that is equivalent to the difference between the static pressure at 16,800 feet and the actual atmospheric pressure at the current flight altitude is developing across the auxiliary controller. When the primary controller is operating at maximum pressure differential, air is flowing from the control chamber (see Figure 27), through the differential control valve, and through the atmospheric vent. For the P-3C Update III pressurization control system, the continuous air flow through the atmospheric vent is metered by the auxiliary controller (Figure 32) to create the required static reference pressure for the primary controller. Thus, during the climb from 16,800 feet to 20,470 feet, the increasing pressure drop across the auxiliary controller produces a constant 16,800 feet sensed pressure altitude at the primary controller static reference.

When the aircraft has ascended to 20,470 feet, the pressure differential across the auxiliary controller reaches 2.2 inches Hg, the limit that the auxiliary controller can sense. At this altitude, the *total* pressure differential sensed by the primary *and* auxiliary controllers is 13.3 inches Hg (11.1 plus 2.2 inches Hg). Above 20,470 feet flight altitude, the primary and auxiliary controllers act in series and limit the maximum cabin pressure differen-

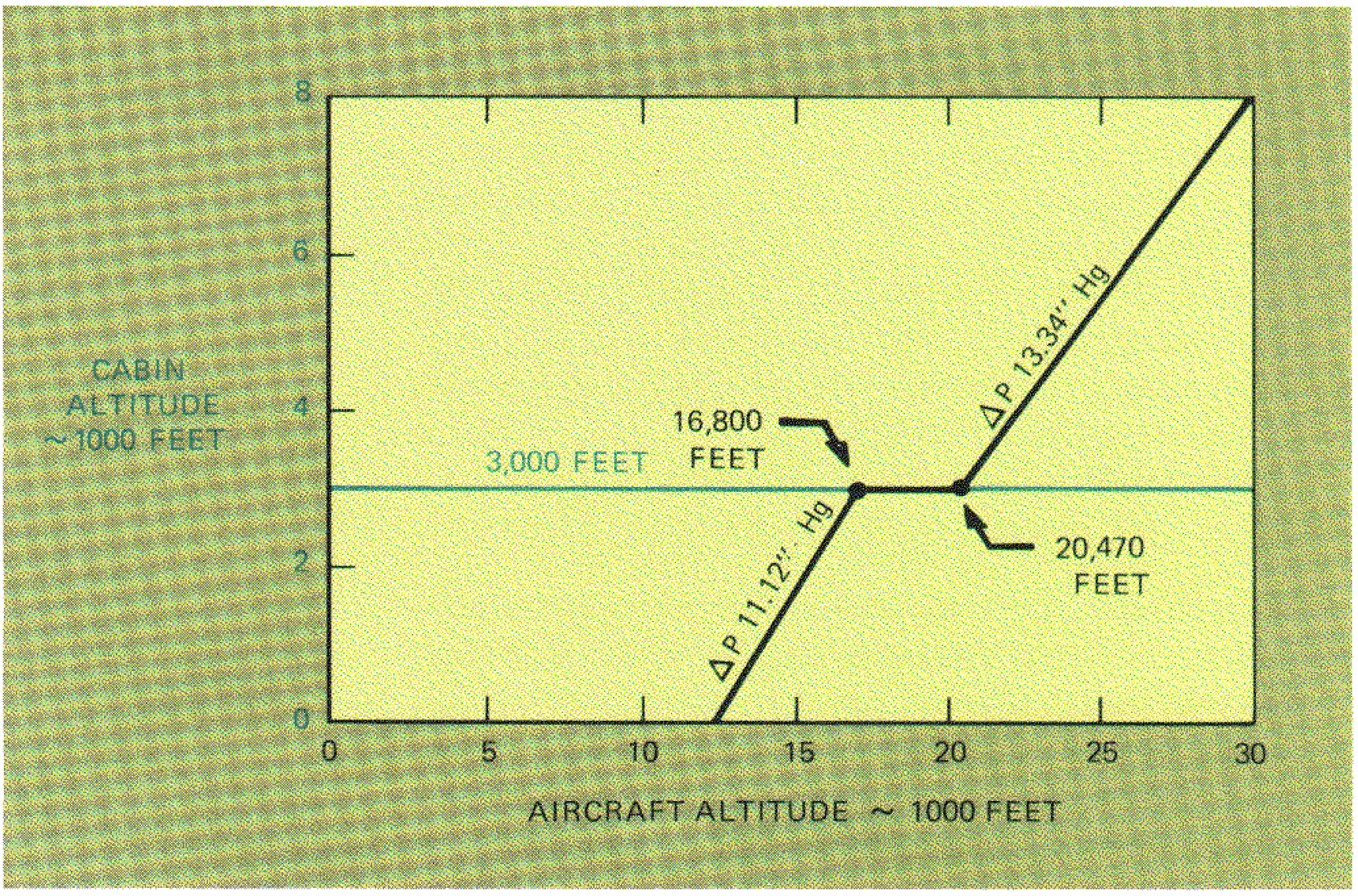


Figure 31. Stepped Pressurization Schedule for P-3C Update III Aircraft

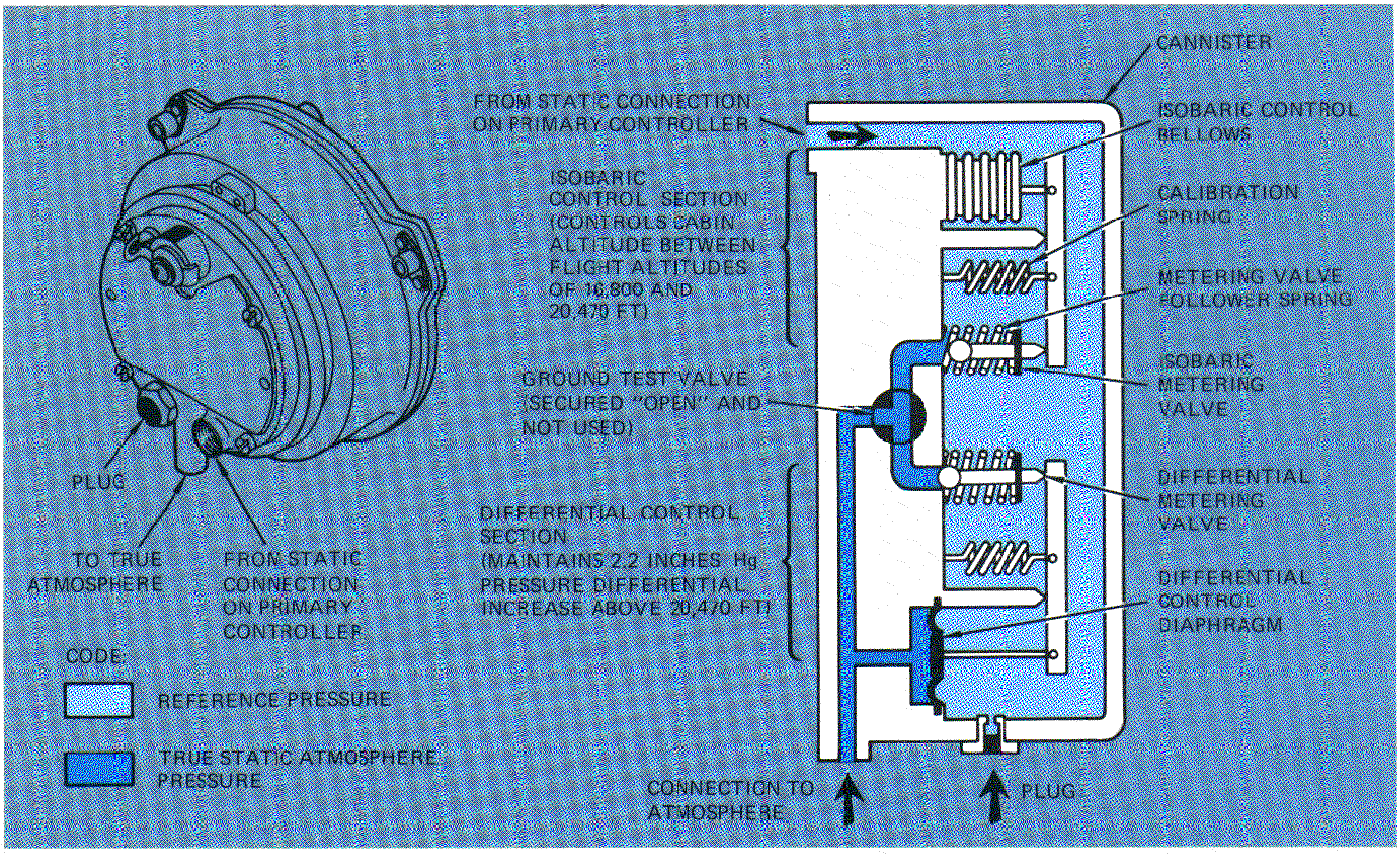


Figure 32. Auxiliary Cabin Pressure Controller – P-3C Update III Aircraft

tial to 13.3 inches Hg. The cabin pressure safety relief valve on P-3C Update III aircraft is set at 13.9 to 14.4 inches Hg, the same setting that is specified for the basic P-3C aircraft.

AUXILIARY VENTILATION If both EDCs fail during flight, the crew can provide air flow to the distribution ducting by opening the auxiliary ventilation valve. The foldout ECS schematic shows the relationship of the auxiliary ventilation valve to the flight station and cabin air distribution risers. The aircraft ventilation control system will automatically dump both EDCs or shut down the APU/AMP if the auxiliary ventilation valve is open. When the airflow in the air cycle cooling systems shuts down, the check valves on the water separator discharge close to prevent loss of auxiliary ventilation air flow. (Note that the auxiliary ventilation valve receives air from the left side ram air inlet.)

The auxiliary ventilation valve actuator has no intermediate positions; the valve is either fully open or fully closed. When the aircraft lands, the weight-on-wheels circuits override the switch position and drive the auxiliary ventilation valve open at the same time as the outflow valve is driven open. These valves are driven open at this time to aid in cabin depressurization. Initiating ground cart air conditioning will drive the auxiliary ventilation valve shut. This prevents loss of cooling air overboard through the aircraft's ram air ducting.

BR61-101 TEMPERATURE CONTROL SYSTEM TEST SET

Since the fleet introduction of the P-3 aircraft, the standard test set used to isolate faults of the temperature control system has been the B092-101 Test Set. This test set provides the technician with three basic troubleshooting functions:

1. The test set monitors temperature control system operation and provides indications of actual air flow control valve position in degrees, control system program voltage, interlock operation and system condition (green, yellow or red).

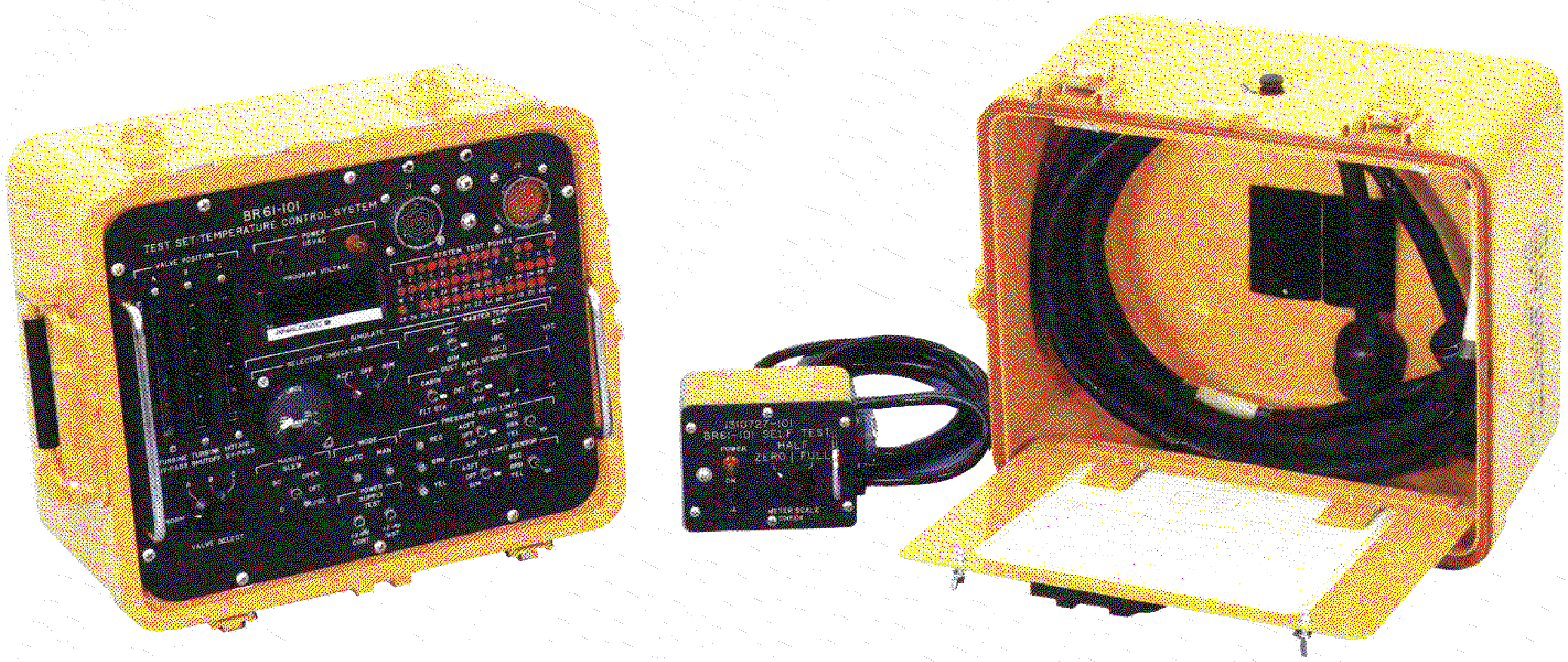


Figure 33. BR61-101 Temperature Control System Test Set

2. The test set allows the technician to substitute simulators for the three AUTO mode program inputs (selector, master temperature sensor, duct rate sensor) and the two ice limit/pressure ratio limit modes (yellow and red).

3. It permits the technician to override the temperature controller and drive the three air flow control valves independently.

Over the years, problems developed with the use and supportability of the B092-101 Test Set. These were primarily due to aircraft system and support equipment changes, initial test set design shortcomings, and parts obsolescence. To overcome these problems, the new BR61-101 Test Set has been designed as a replacement for the B092-101 Test Set. Figure 33 shows the BR61-101 Test Set, its self-test unit, and interface cable. The BR61-101 Test Set has a volume of 2.1 cu ft and weighs 34 lbs. With the case lid closed, its dimensions are 14 inches wide by 16 inches long and 16 inches high. The BR61-101 Test Set is equipped with a self-test unit to provide the operator with a go/no-go test of the three valve position meters and the program voltmeter. This unit is stored in the case lid and requires 115 VAC 400 Hz power to operate. The test set uses a single interface cable with a Y-branch at each end.

The BR61-101 Test Set is an intercept-type tester, which connects in series between the temperature controller and the control system (see Figure 34).

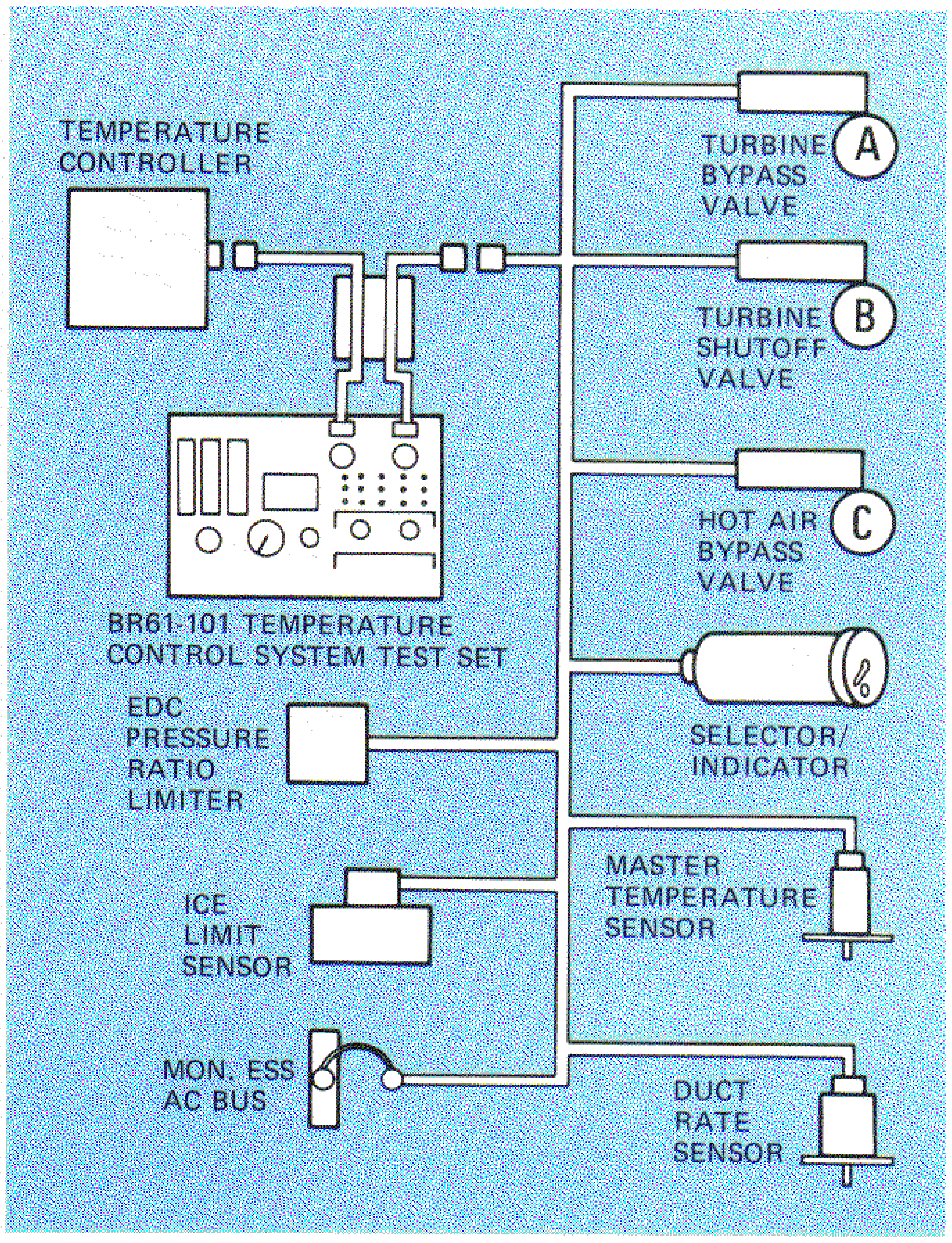


Figure 34. BR61-101 Test Set/Temperature Control System Interface

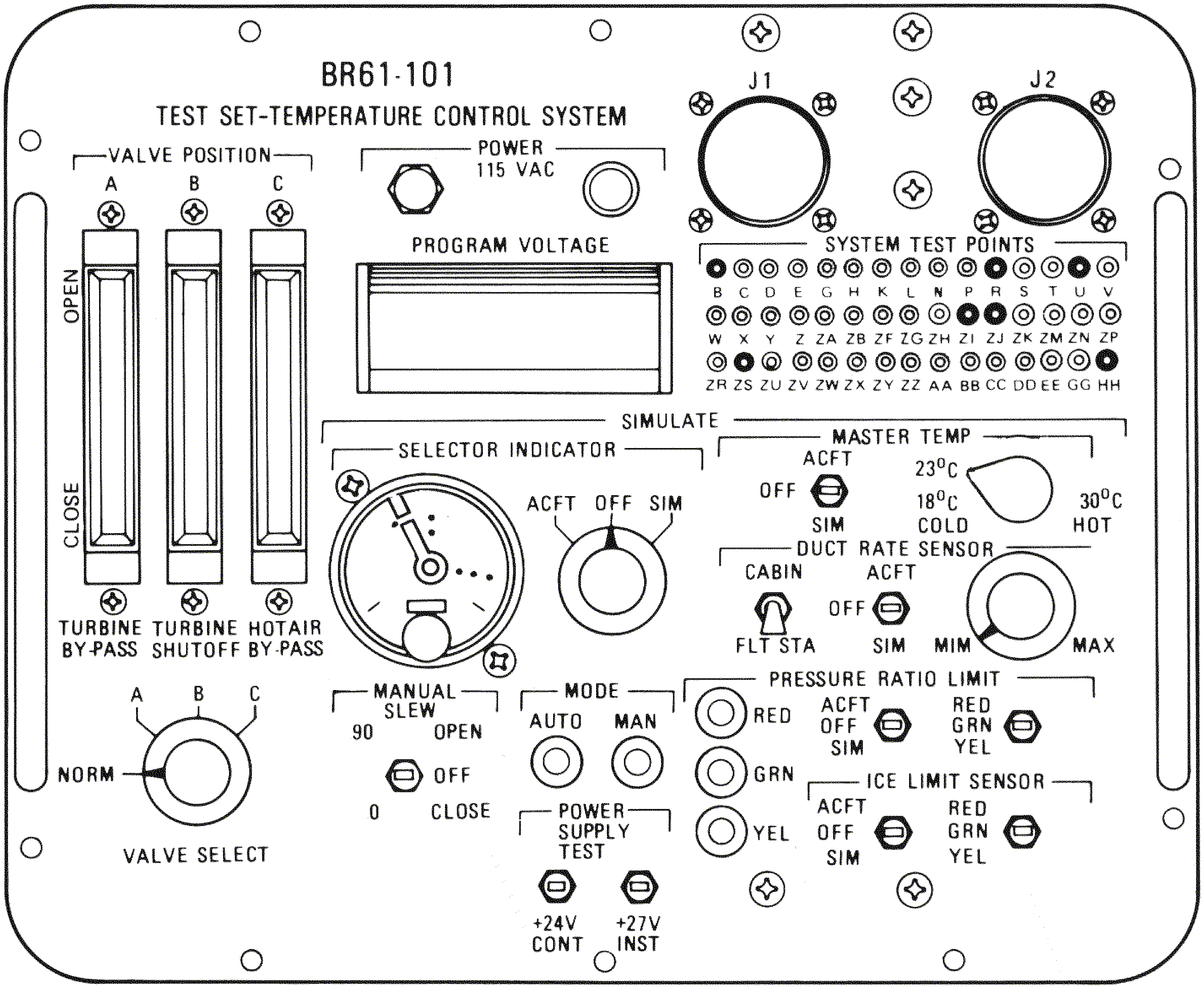


Figure 35. BR61-101 Test Set Control Panel

Every wire in the temperature control system, except the three control valve motor reference winding power wires, passes through the connector on the temperature controller. As a result, with the test set hooked up, every wire that connects to the temperature controller will pass through the BR61-101 Test Set.

The functional design requirements for the new test set are almost identical to the requirements for the older B092-101 Test Set. The BR61-101 Test Set can simulate temperature controller inputs; it can monitor valve position, temperature controller program voltage and power supplies; and it can drive the control valves independently. The new test set incorporates additional features as a result of operational experience with the older B092-101 Test Set. These features include a test point breakout that facilitates fault isolation of wiring problems; improved simulators; elimination of sneak circuits; and more automatic operation of the test set. With these features, the BR61-101 Test Set has fewer switches that require initial set-up for a test (12 switches for the BR61-101 Test Set compared to 19 switches for the B092-101 Test Set), it is easier to operate, and it has considerably more test capability than the B092-101 Test Set.

BR61-101 TEST SET PANEL LAYOUT The control panel of the BR61-101 Test Set is shown in Figure 35. The interface cable plugs into connectors J1 and J2 on the control panel. With the cable hooked up, the temperature control system wiring to the temperature controller is intercepted and routed into the test set through connector J2. Signals are sent from the test set to the temperature controller through connector J1. The 115 VAC 400 Hz power required to operate the test set comes from the Temperature Control System Power circuit breaker on the Monitorable Essential AC Bus, Phase A. That particular circuit breaker supplies all of the power required to operate the temperature control system. The test set has its own 5 amp power circuit breaker that is in series with the main circuit breaker. When the BR61-101 Test Set is connected to the aircraft temperature control system, pulling either circuit breaker will remove power from the temperature control system.

The left side of the test set control panel contains the air flow control valve position indicators and the manual controls to slew the valves. The position indicators are solid-state light-emitting diode (LED) readouts. Figure 36 shows the BR61-101 set in a self-test mode with the indicators illuminated. They consist of 100 light segments, each segment corresponding to 1 degree of control valve movement. The control valve position indicators are voltmeters that are connected across the valve feedback potentiometers as shown in Figure 37. The Valve Select switch is used to operate one of the control valves manually without disturbing the other two valves. When the Valve Select switch is moved out of the NORM position, all three control valves are disconnected from the temperature controller servo amplifier, and the selected valve is connected to the Manual Slew switch. The Manual Slew switch can then be used to open or close the selected control valve.

The Manual Slew switch controls the power to the valve servo motor control winding. The BR61-101 Test Set has an independent power supply for this function, which makes the manual slew test independent of the temperature controller.

The meter labeled Program Voltage takes the place of the voltmeter on the older B092-101 Test Set. Troubleshooting experience with the B092-101 Test Set indicated that the full-range voltmeter (0 to 1200 volts AC and DC) is not necessary. The primary use of the voltmeter is to measure program voltage, which ranges from 0 to 10 VDC. The only other requirement for a voltmeter during a normal system checkout is to measure the temperature controller +27 VDC instrumentation and +24 VDC control power supplies. Because of the established priority, the voltmeter is

Figure 36. BR61-101 Test Set in a Self-test Mode

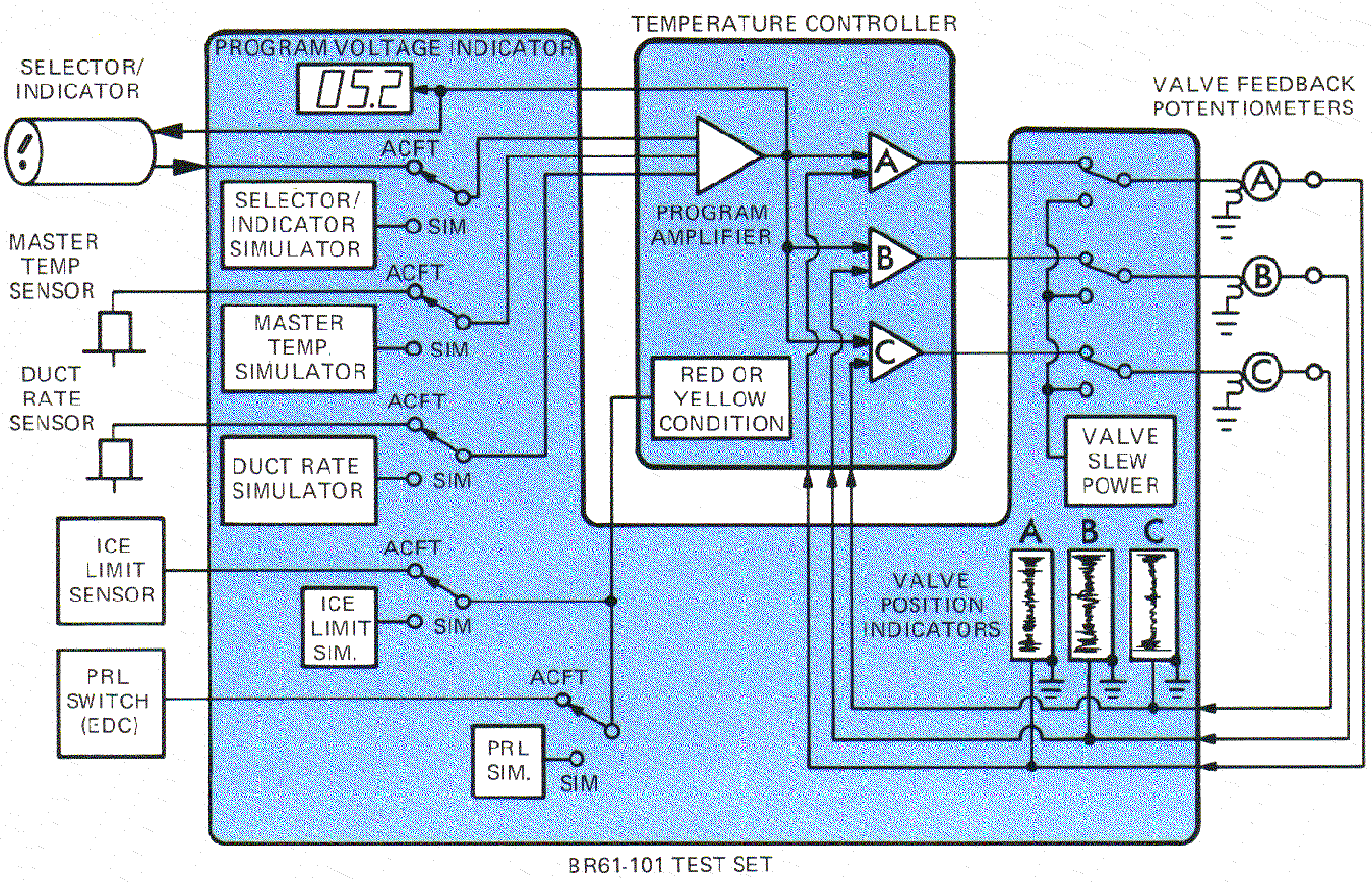


Figure 37. BR61-101 Test Set Functional Block Diagram

automatically connected to read program voltage when power is applied to the test set. The Power Supply Test switches at the bottom of the control panel are momentary contact switches that, when pressed, connect the meter input to the appropriate power supply. When the switches are released, the voltmeter is automatically reconnected to read program voltage. The voltmeter is a solid-state, digital device that is automatically scaled for the voltage being checked and provides a direct numerical readout down to tenths of a volt.

Dominating the center of the panel is a standard aircraft temperature control system selector/indicator. The switch adjacent to this instrument allows the technician to substitute it for one of the selector/indicators in the aircraft. With the selector switch in SIM, every function of the aircraft system selector/indicator is replaced by the BR61-101 Test Set selector/indicator. In addition to transferring the temperature command and program voltage indicator functions, the system mode is also controlled from the test set selector/indicator while SIM is selected. This precludes the need for the special switches required on the older B092-101 Test Set for setting up the test operational mode.

When the BR61-101 Test Set is employed, the entire temperature control system and test set will operate in the mode (AUTO or MAN) selected by either the aircraft or test set selector/indicator, depending on the position of the test set ACFT-OFF-SIM switch. This eliminates the possibility of the technician attempting to operate the aircraft temperature control system and the test set in different modes. Two lights labeled MODE are located directly below the selector/indicator switch. These lights indicate the actual system and test set mode of operation. Certain selector/indicator failures or aircraft wiring problems can cause the system not to switch from manual to auto mode, even though the AUTO flag is displayed on the selector/indicator. The mode lights enable the technician to determine if the system is actually switching operational modes.

In the section of this article that described opera-

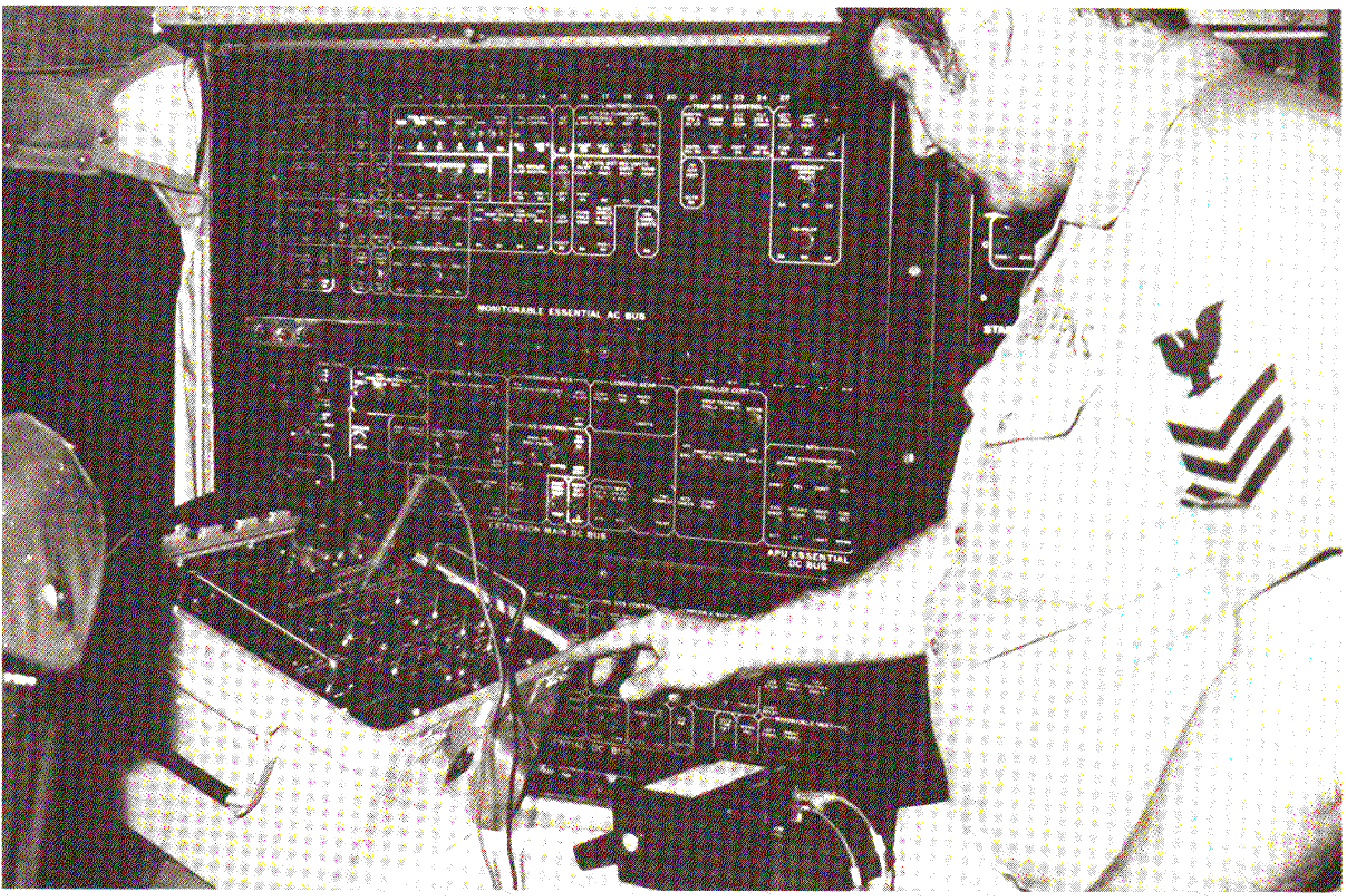


Photo by Dick Pond

tion of the temperature control system, we discussed the three sources of inputs that the temperature controller uses to develop program voltage or position in the automatic mode. Briefly, they are: (1) the selector/indicator, which allows the flight crew to signal the temperature controller for the desired temperature; (2) the master temperature sensor, which provides the temperature controller with a signal that indicates the actual temperature in the flight station or cabin; and (3) the duct rate sensor, which indicates to the temperature controller the rate-of-change of the air temperature in the system supply ducts. The BR61-101 Test Set enables the technician to selectively simulate these inputs one at a time, all three together, or in any combination as an aid for fault isolation (see Figure 37).

The simulators for the master temperature sensor and the duct rate sensor are located on the right side of the test set panel. When the ACFT-OFF-SIM switches are placed to the SIM position, they substitute the variable sensor simulators in place of the aircraft systems sensor. Note from Figure 37 that when a simulator is selected, both the aircraft sensor and the associated aircraft wiring are switched out of the circuit.

The master temperature sensor simulator is calibrated in degrees centigrade, corresponding to regulated temperatures for full cold, 2-dot and full hot in the AUTO mode.

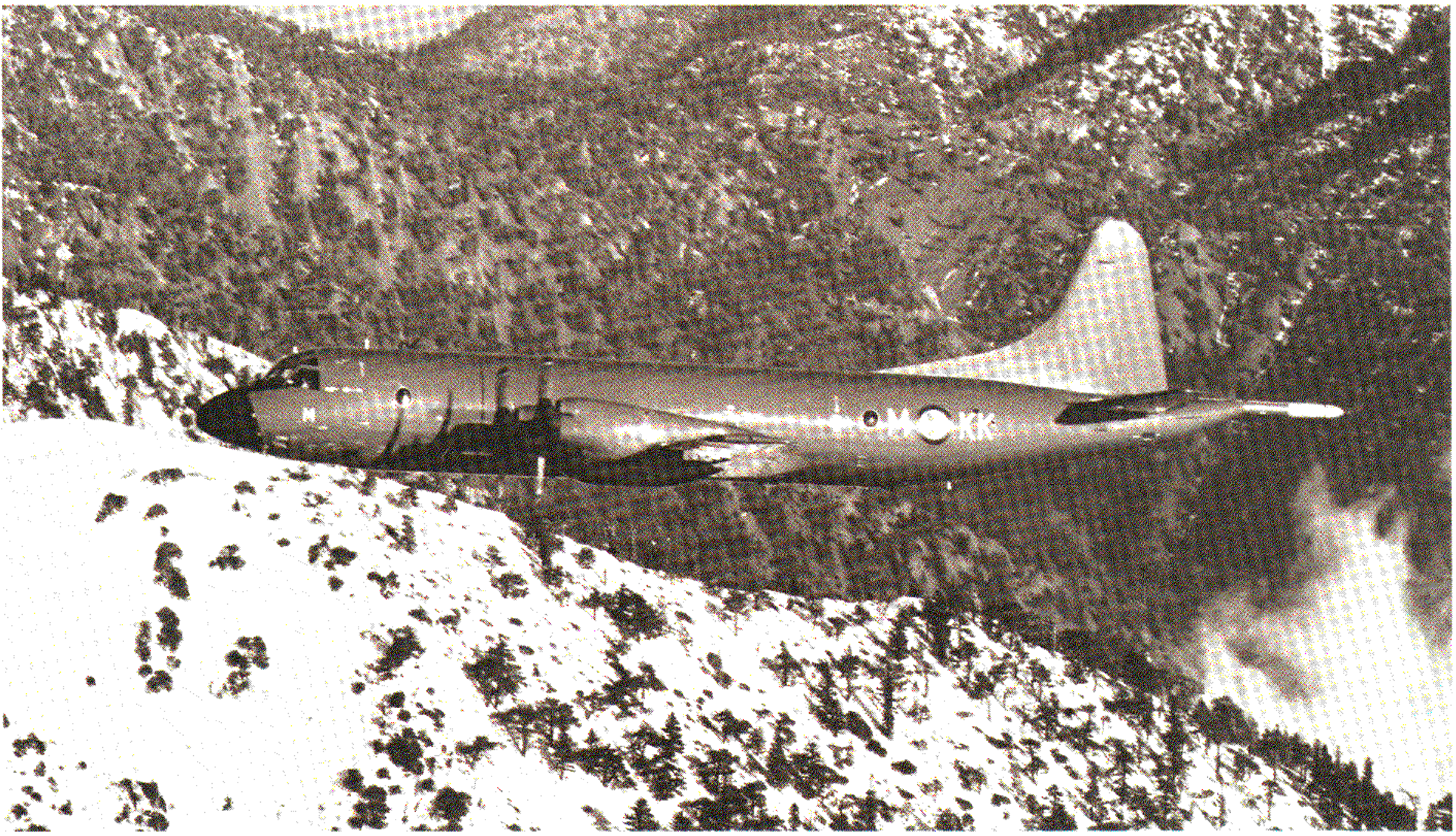
The duct rate sensor simulator is labeled MIN at the full CCW position and MAX at the full CW position. This labeling corresponds to a minimum or maximum rate of change (deg/min) as sensed by the duct rate sensor. The duct rate sensor simulator has a CABIN/FLT STA switch to select the proper duct rate simulation for the cabin or flight station. This is necessary because the flight station and cabin duct rate sensors are not interchangeable. This feature improves the quality of the duct rate sensor simulation by the BR61-101 Test Set.

The BR61-101 Test Set also allows the technician to monitor the EDC pressure ratio limiter and the water separator ice limiter protection systems. Three lights on the panel (green, yellow and red) illuminate to display the system condition. The green light is automatically turned on by the test set in the absence of a yellow or red operating condition. During normal temperature control system operation with the APU/AMP serving as the air supply source, any yellow or red operating condition will be due to icing on the water separator bag. Recall that the EDC PRL system is electrically de-energized when the EDC is dumped. If the temperature control system is operating with the EDCs serving as the air supply source, the yellow and red lights could be illuminated by signals from either the PRL or the ice limiter protection systems. The actual source of the yellow or red operating condition can be determined by selecting either the PRL or Ice Limit Sensor ACFT-OFF-SIM switch to the OFF position. If the protection system condition light goes out when the switch is activated to OFF, that sensor is sending the signal. With either the Pressure Ratio Limit or the Ice Limit Sensor control switch set to SIM, the corresponding aircraft sensor is disconnected and the test set condition simulator switch is connected to the temperature controller.

In the upper right corner of the control panel, directly below the J1 and J2 connector receptacles, there is a matrix of system test points. The test point identification letter corresponds to the pin in the temperature controller connector plug. The test points are all wired in parallel. They are designed to be used with a voltmeter while the system power is on, and with an ohmmeter while the system power is off. The black test points are connected to wires that are connected to aircraft grounds. Some of the red test points are also grounded when the temperature controller is connected to the test set.

As a result of the test point-to-pin relationship, all that the technician needs in order to use the test points is the standard temperature control system schematic. The test point matrix can facilitate troubleshooting by allowing the technician to test the temperature control system for proper drive voltages while the temperature controller is hooked up and power is on. In addition, the test points simplify the task of checking the system wiring and components for open circuits and shorts. With the system powered down and the temperature controller disconnected, most of the ground circuits for the major components (valves, selector/indicator, temperature sensors, etc.) are also disconnected. Using an ohmmeter, the continuity and isolation from ground for the various components and wiring can be checked from the test set.

BR61-101 TEST SET OPERATION During a functional checkout of the aircraft temperature control system, the BR61-101 Test Set can be used to monitor and observe the system operation. It also



permits the technician to simulate and override operation of various system components. The initial switch settings, as given in the appropriate Maintenance Instruction Manual, configure the test set to monitor system operation. With the initial set-up, the operator can read program voltage, valve position, system operation mode (AUTO or MAN) and system operating condition (green, yellow or red).

As mentioned previously, comparing the location of the program position indicator (PPI) needle to the graph in Figure 20 tells the technician where the control valves should be positioned. The program voltmeter on the BR61-101 Test Set establishes a numerical value for the PPI indication. This value can be used at any time, regardless of selector position, to determine proper control valve positions from the chart. The important point here is that the valve position *must* correspond to the program voltage. The only allowable exception is the A Valve, which may be out of position (open excessively) if the control system is in a yellow or red mode as indicated on the test set.

When testing the air flow control valves, the use of the BR61-101 Test Set's manual slew function will simplify fault isolation. The following criteria must be met to determine if the control valves are operating properly: (1) the valve actuator must be capable of driving the valve; (2) the feedback potentiometer operation must be smooth and continuous, as indicated on the test set position meters; (3) movement of the valve as indicated on the test set must result in changes in conditioned air temperature and compressor discharge pressure. The valve feedback potentiometer is a part of the actuator assembly and, as such, indicates the position to which the valve motor has been driven. If the valve butterfly or butterfly drive fails, the valve feedback potentiometer will signal proper actuator operation even though the valve is not capable of controlling air flow. For this reason, it is important that the technician monitor air cycle system operation with the aircraft instruments to determine if control valve actuation is producing the desired effects.

One of the complaints commonly voiced about the B092-101 Test Set is that it cannot be used to isolate a dirty water separator bag. The ice limit sensor detects the pressure drop that occurs across the water separator bag if ice forms on the bag and causes a blockage. Unfortunately, the ice limiter cannot differentiate between a blockage caused by ice or by dirt. If the pressure drop develops as a result of ice buildup, the temperature control unit's action of overriding the A Valve to bypass warm air around the refrigeration turbine will be effective in eliminating the blockage. However, if the pressure drop is caused by dirt on the water separator bag, the control system will also respond by overriding the A Valve as described above. This action will be totally ineffective in clearing the blockage and only result in an increase of conditioned air temperature.

The problem encountered in trying to design a test set that can positively isolate a dirty water separator bag can be traced directly to inability of the electronic temperature control system to differentiate between a blockage caused by dirt and one caused by ice. The electronic test set can only monitor the signals being received by the temperature controller. However, the astute technician can determine with reasonable accuracy if the blockage is dirt by observing the operation of the control system during a yellow or red condition. If the system is cycling between the yellow and red modes of operation, check the system's conditioned air output temperature. If it is much above 3°C, the bag is at least partially plugged with dirt. In order for ice to develop, the refrigeration turbine must be delivering air with condensed moisture to the water separator at approximately 0°C. If the conditioned air temperature is considerably higher, the ice blockage would melt (which would preclude ice as being the problem).

Most conditions that cause water separator blockage will affect both bags. This occurs when the system is operating on the APU/AMP (single air source) or when the aircraft is operated at low levels (both EDCs receiving the same air mass). However, if there were an internal EDC oil leak or a massive propeller leak on engine No. 2 or No. 3, only one water separator bag may be blocked. It should be noted that the ice limiter and PRL simulators on the test set send yellow and red condition signals to the temperature controller only. These simulators test only the temperature controller's *response to the condition* and do not provide an indication of improper operation of the ice limiter or pressure ratio limiter.

After the technician has verified that the control valves and the ice limiter/water separator are functioning properly, the temperature controller should be checked to determine if it is operating properly in both the manual and the automatic modes. Checkout of the manual mode requires nothing more than observing that the PPI needle is within one needle-width of the selector bug, and that the needle tracks smoothly as the bug is rotated. Observe both the PPI needle and the BR61-101 Test Set program voltmeter indications for stability. After the cabin temperature has come to within the range of approximately 15° to 25°C, the automatic mode can be tested. In the full cold condition, the temperature control system should maintain a cabin temperature of 18° to 20°C. During the automatic mode of operation, it is normal to see a large split between the selector bug and PPI needle. The important thing to note during these tests is that the temperature control system command (as indicated by the PPI needle position and the test set program voltage) is driving the system *to attain* the desired cabin temperature.

The experienced operator may expedite temperature control system checkout by observing system operation in the cabin or flight station for proper trends rather than for absolute temperature output. The following are examples of proper trends:

- Outside Air Temp - 0°C

  Cabin Temp - 10°C

  Selection - Full cold, automatic

  PPI Needle - Expect to see the control system drive the PPI needle above the two-dot position and remain there until the aircraft interior *warms* to the lower limit of automatic mode operation.

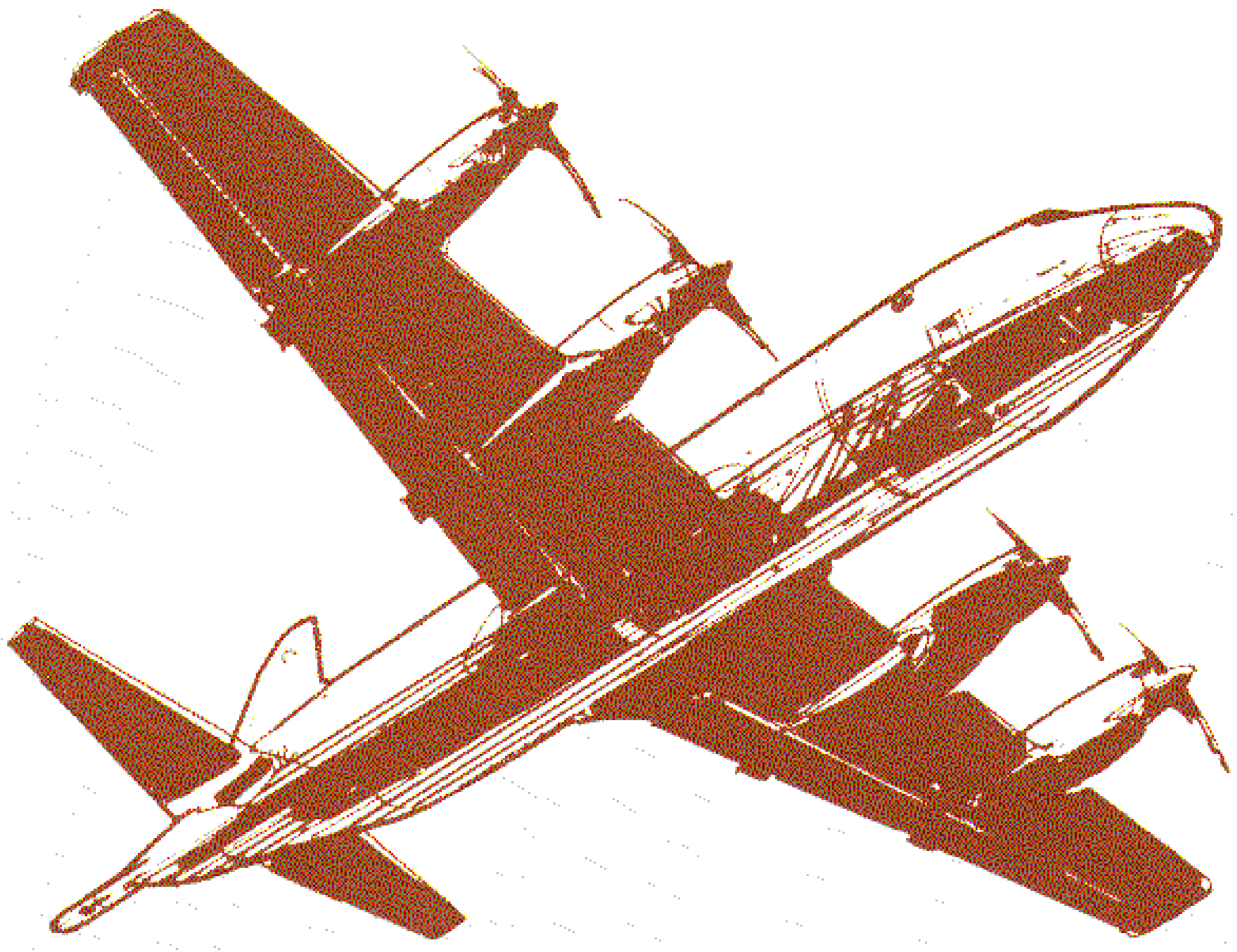
- Outside Temp - 32°C

  Cabin Temp - 30°C

  Selection - Two dot, automatic

  PPI Needle - Expect to see the control system drive the PPI needle to full cold and remain there until the aircraft interior *cools.*

In the automatic mode, as in manual, the temperature control system program voltage should be stable. As the internal cabin temperature approaches the selected temperature the PPI needle



will begin to slew towards the selector set bug. This should occur slowly and smoothly, and the actual temperature should not overshoot the selected temperature. If the system program voltage and conditioned air temperature are drifting when the temperature control system is operating in the automatic mode, it is an indication that one of the inputs to the temperature controller program amplifier (selector, master temperature sensor, or duct rate sensor) has failed. If the inputs are proven to be reliable, then the program amplifier is suspect.

The program amplifier is very sensitive to rapid, small variations of the three temperature control system inputs. Consequently, the technician should perform a careful analysis when using the simulators on the BR61-101 Test Set and allow adequate time for proper response by the program amplifier. In the automatic mode the program voltage is the output of the program amplifier, and is the result of the amplifier processing inputs from the selector, master temperature sensor and the duct rate sensor. In the manual mode the inputs from these components are bypassed, and the program voltage is developed in the selector/indicator manual command circuits. There should be no difference in the response of the air flow control valve drive system to a specific program voltage during operation in either the automatic or the manual mode. If the valve drive system positions the valves correctly in manual, a properly aligned temperature controller will produce the same valve positions in the automatic mode. The object of the automatic mode tests is to verify temperature regulation and stability, as commanded by the program amplifier and indicated by the PPI needle.

One additional point may aid the technician to isolate automatic mode temperature control problems. The cabin of the P-3 aircraft has considerable volume that must be cooled or heated to a desired temperature as quickly as possible. If one enters a room of equivalent size and turns on the ECS (window air conditioner, central heat/air systems, etc.), it will require some time for the ECS to stabilize the room temperature. The aircraft ECS is no different in this respect; the system also must be allowed time to stabilize the cabin temperature before the technician attempts fault isolation procedures. In addition, the aircraft is equipped with bypass ducts through which very warm or very cold air is delivered to speed up the temperature stabilization process. Thus, during periods of temperature stabilization (usually right after the system has been turned on), the delivery air temperature may seem excessively cold or hot. If the system is driving in the proper direction (to obtain the desired temperature) and the temperature of the delivery air coming from the risers corresponds to the program voltage, it is best to allow the system to operate as designed and wait for the cabin temperature to stabilize.

It should be noted that when the operator shifts the mode selector from manual to automatic, several changes take place rapidly that cause the program amplifier control signal to saturate and produce a full hot command (10 VDC program voltage) for a brief period. It is common for this condition to last for up to 90 seconds. This signal should not be confused with the program voltage command. Once again, the temperature control system (like all electronics systems) requires time to stabilize.

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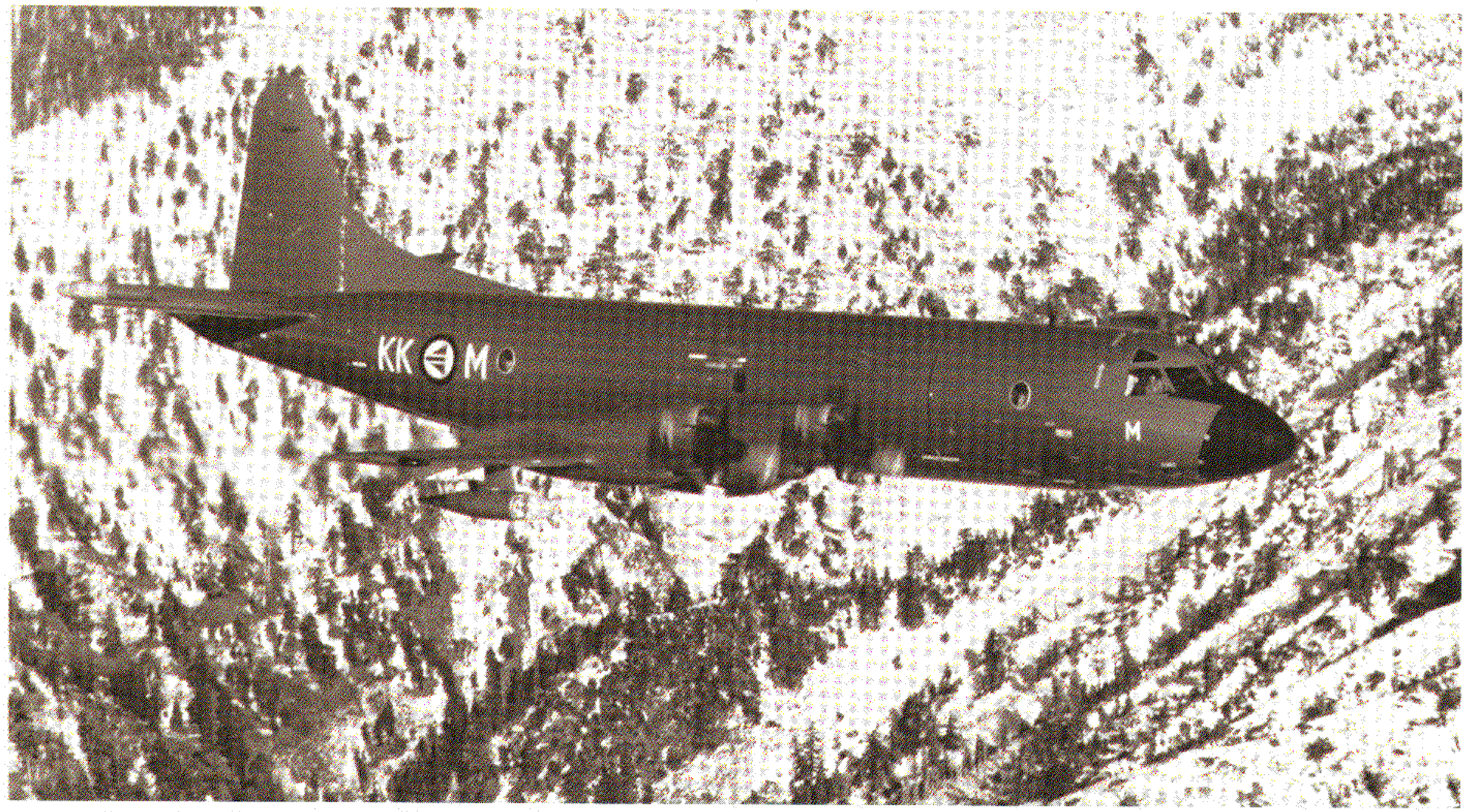

ECS FAULT ISOLATION

Environmental control system failures are generally the result of a malfunction in one of the following areas: (1) failure of the EDC or APU/AMP to deliver adequate air flow; (2) reduced operating efficiency of the air cycle cooling system (heat exchangers, refrigeration turbine/bootstrap unit, heat exchanger cooling flow rate); and (3) failure of the temperature control system to properly regulate the warm and hot air bypass around the air cycle cooling system. Temperature control system failures have been discussed earlier in this article.

Malfunctions of the air delivery or air cycle cooling equipment severely affect the ability of the ECS to maintain a cool environment. Fault isolation is often difficult, and requires the technician to make an analysis of the problem based on several observations. Since it is difficult or time-consuming to remove most of the affected equipment, it is of the utmost importance to establish with reasonable certainty whether or not a suspect component is defective.

It is important that the technician verify that the air flow control valves are operating properly before attempting to perform fault isolation procedures on the air sources or air cycle cooling systems. The technician can then use the air flow control valves to control the bypass of air around the various portions of the cooling equipment during subsequent fault isolation procedures. The air discharge pressures and conditioned air temperatures will vary as the A and C Valves are moved to bypass air around the bootstrap refrigeration unit or the entire air cycle cooling system. The greatest demands on the air source equipment occur when the A and C Valves are both closed and the entire air flow is circulating through the bootstrap unit.

When the air flow control valves are actuated to the full cold condition, the spread between the inlet and discharge pressure indications will vary, depending on ambient conditions (temperature, pressure, density). However, the pressure differential should be approximately 30 inches Hg. A low pressure spread with the control valves actuated to the full cold condition indicates that the air source is failing to deliver rated air flow or that there is a leak. An adequate or excessive pressure spread with low air flow indicates a blockage downstream of the pressure sensors or, in some cases, a leak in the air distribution system. In general, if a pressure spread of 30 inches Hg can be obtained, the air delivery equipment is functioning properly.

As the air flows through the air cycle cooling system, the primary heat exchanger cools the air supply, the bootstrap compressor elevates the air pressure, the secondary heat exchanger removes some of the heat added during compression, and the refrigeration turbine cools the air and condenses the water vapor. With the control valves in the full cold position, the difference between the flight station and cabin conditioned air temperatures should be less than 1°C. This temperature spread may vary slightly as the result of icing on the water separator bags, but if the system is operating properly and the bags are clean, the conditioned air temperature variations should be minimal. If the pressure spread seems adequate but the conditioned air temperature is high, the following conditions are suspect: (1) primary heat exchanger blockage, (2) heat exchanger cooling air is leaking, (3) secondary heat exchanger blockage, or (4) refrigeration turbine performance is low.

Primary heat exchanger blockage is evidenced by high conditioned air temperature and high back pressure. This problem can be isolated by opening and closing first the A Valve, then the C Valve. The air flow through the primary heat exchanger should produce a relatively low pressure drop. If the primary heat exchanger is blocked, opening the A Valve and bypassing the bootstrap unit will not allow the appropriate drop in discharge pressure. If the C Valve is opened and the pressure drops, the heat exchanger is suspect.

The conditioned air temperature will also be excessive if the bootstrap unit is operating inefficiently. If the secondary heat exchanger's cooling air (exhausted through the louvered heat exchanger access panels) is cool, the refrigeration turbine and/or the secondary heat exchanger should be checked for blockage or damage. The heat that is removed by the secondary heat exchanger is developed during the compression process in the bootstrap compressor. If the secondary heat exchanger is blocked or the refrigeration turbine is not rotating on-speed, the compression process will not generate the normal amount of heat, and the heat exchanger cooling air discharge will be relatively cool.

The moisture entrained in the air is condensed to water droplets in the refrigeration turbine and centrifugally separated from the air in the water separator. With the control valves in both temperature control systems set in the full cold position, an equal amount of water from each system should be condensed and drained overboard. If one system is making water and the other is not, the air cycle system that is not making water should be checked to determine the cause of the inefficient operation.[6]

For the heat exchangers to operate properly, there must be an adequate flow of cooling air. If cooling air flow is low, check for air leakage in the ground fan system. Also, check the ram air inlets for ground fan air outlfow. Excessive air flow from the ram air inlet may indicate a failed ram air check valve.

When troubleshooting any ECS malfunction, the most important point for the technician to remember is to allow time for system operation to stabilize. After this has occurred, verify that the temperature control valves are operating properly, determine if the air delivery is proper, and verify that the air cycle cooling equipment is operating efficiently. Base your decisions on all of the system operational indications that are available, including those from the flight station-mounted conditioned air temperature and compressor gauges, and the BR61-101 Test Set. Finally, *be certain* to observe the instructions and procedures presented in the official maintenance publications.

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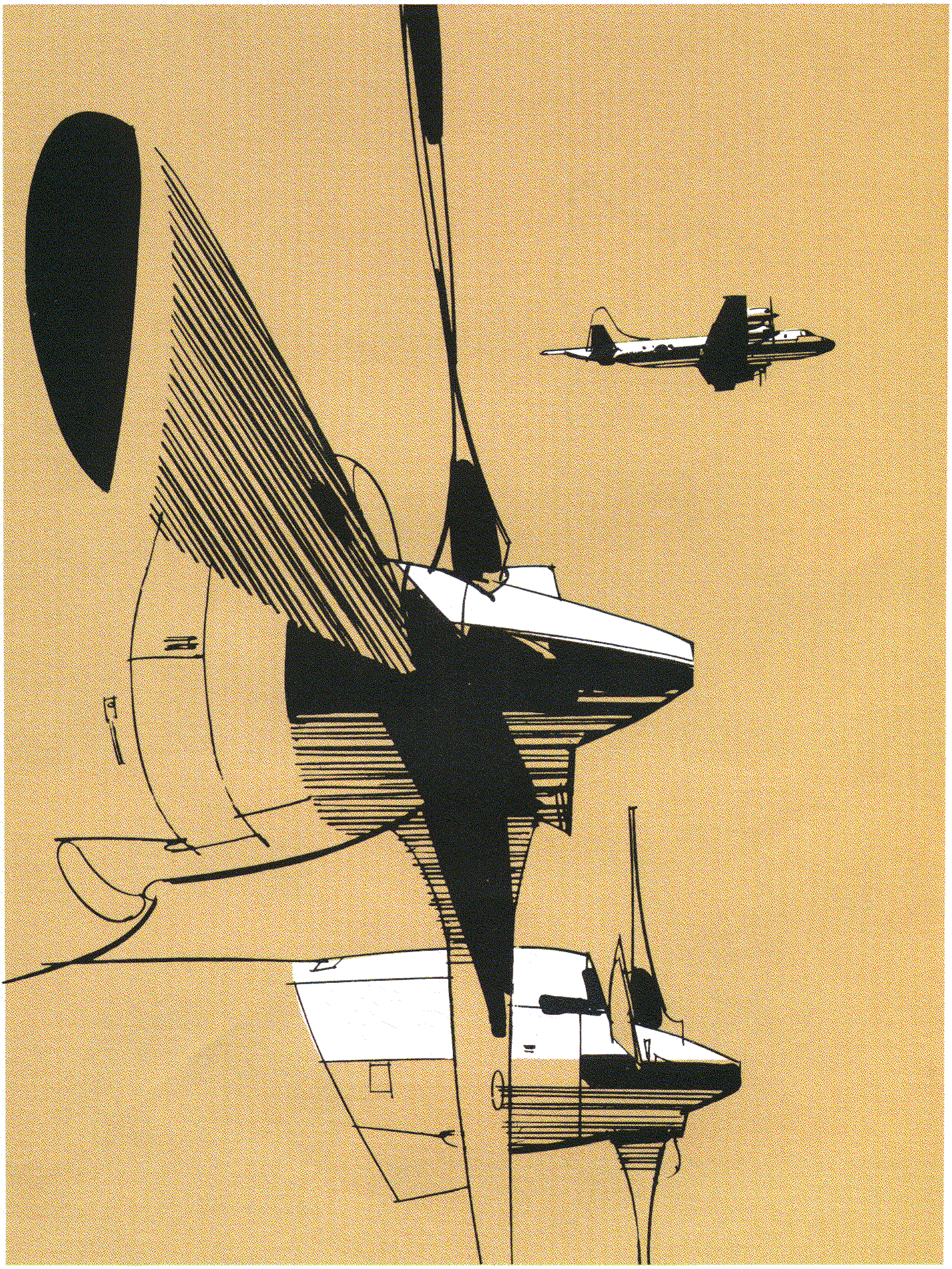
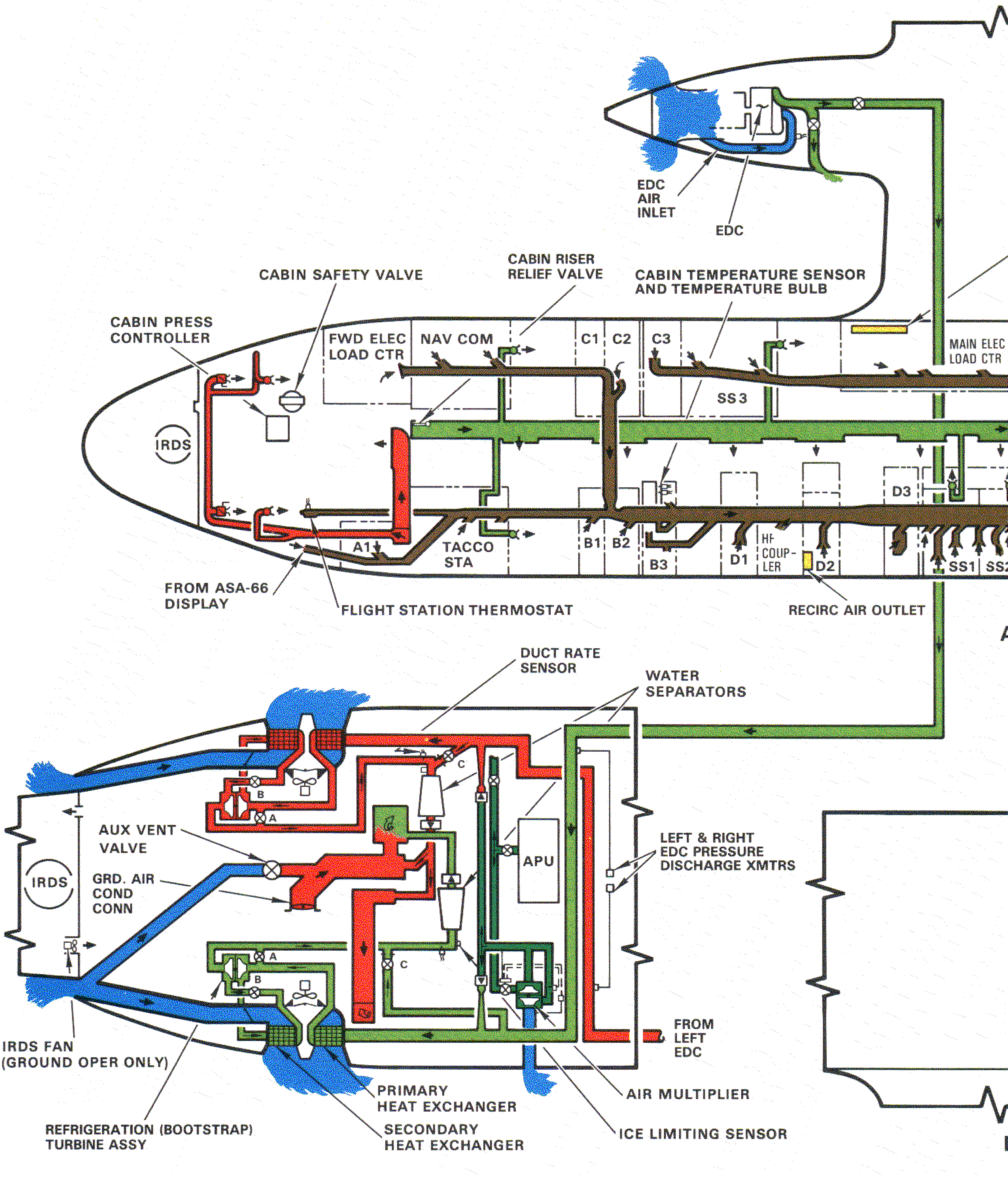
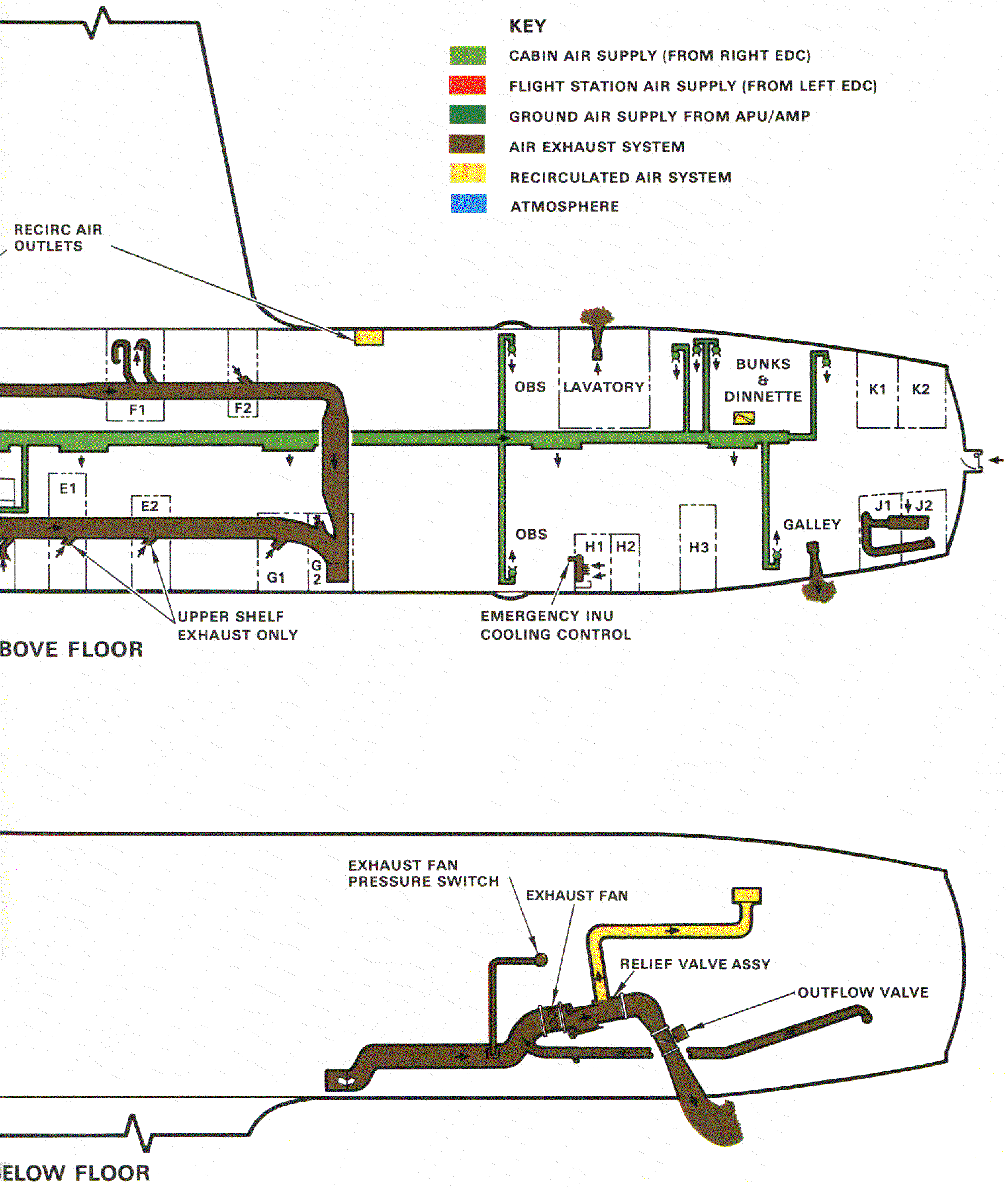
[6] On P-3C Update III aircraft, little (if any) water will drain overboard because these aircraft are equipped with the heat exchanger water spray system.





Schematic of the Environmental Control System, Air Distribution System and Air Exhaust System for P-3C Update II Aircraft


KEY
🟩 CABIN AIR SUPPLY (FROM RIGHT EDC)
🟥 FLIGHT STATION AIR SUPPLY (FROM LEFT EDC)
🟩 GROUND AIR SUPPLY FROM APU/AMP
🟫 AIR EXHAUST SYSTEM
🟨 RECIRCULATED AIR SYSTEM
🟦 ATMOSPHERE
RECIRC AIR
OUTLETS
F1
F2
E1
E2
G1
G
2
OBS
LAVATORY
BUNKS
&
DINNETTE
K1
K2
OBS
H1
H2
H3
GALLEY
J1
J2
UPPER SHELF
EXHAUST ONLY
EMERGENCY INU
COOLING CONTROL
BOVE FLOOR
EXHAUST FAN
PRESSURE SWITCH
EXHAUST FAN
RELIEF VALVE ASSY
OUTFLOW VALVE
ELOW FLOOR

ACKNOWLEDGEMENT

The author and editor wish to express their appreciation to the following individuals who provided support and assistance during the preparation of this article.

Doug Cone
Herb Franck
Carl Malkow
Madelyn Merle
Dick Pond
Herb Rosenberg
Tom Sedgwick
Charles Shields
Dave Weyers
of the Lockheed-California Company,

James Emmons, AiResearch Manufacturing Company;
and
Stanley Thomas, NAVAIR Engineering Support Office, NAS Alameda

Their constructive comments, recommendations and special assistance were invaluable.

Tom Blakely
Wayne Cradduck

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