ORION

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ORION

P-3 AIRCONDITIONING

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FRONT AND BACK COVERS: Commissioned in July of 1943 as Patrol Bombing Squadron 146, the Blue Sharks of Patrol Squadron Six have flown three varieties of Lockheed equipment to counter aggression in the Pacific with the aggressive reflexes inherent to their namesake.

After earning 2 battle stars in the latter months of the War in the Pacific with their PV-1's (see photo, facing page), VP-6 operated about a year from Barbers Point before assignment to Whidbey Island, Washington, where they were re-equipped with P-2V Neptunes. In 1950, having learned the arts of ASW and demonstrated their proficiency on deployment to Alaska, they were the first to take the P-2V into battle in Korea. Operating under Fleet Air Wing 6 they won the Navy Unit Commendation and the Korean Presidential Unit Citation in a variety of assignments: flying Yellow Sea patrols, covering the Inchon landings, reconnoitering, and aiding the Hamburg and Chosen Reservoir actions.

In the first years following the Korean conflict, VP-6 operated from Guam (making deployments to Sangley Point, P.I.), then from Barbers Point with deployments to Kodiak and to Iwakuni, Japan. For four years, beginning in 1960, the squadron alternated between training and 6-month's deployment to Iwakuni; then the cycle was interrupted dramatically at the time of the Tonkin Gulf crisis. On a scant 3-day notice, VP-6 departed Barbers Point to operate from Naha, Okinawa in support of the Seventh Fleet, winning an official commendation for the efficient professionalism they demonstrated in the following 6 months during which time their operational base changed 5 times in all, with detachments of Blue Sharks operating from 4 satellite facilities.

In late January 1965 the squadron returned to Barbers Point; a few months later they began transition training to the P-3 Orion, and before year's end VP-6 was again fully operational.

In June 1966 the squadron deployed to Adak, Alaska, and their high degree of professionalism with the latest generation of Lockheed equipment is proven by the fact that Squadron combat readiness has remained "in the Green" and maintenance availability has averaged 80% since that time.

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P-3
AIRCONDITIONING

INTRODUCTION

THIS ARTICLE describes the P-3 airconditioning system at a time of transition. The system originally designed for the P-3A has been redesigned for later aircraft to enable the airconditioning units to be utilized during ground operation using bleed air from an Auxiliary Power Unit gas turbine engine, thus obviating the necessity to operate aircraft engines for the purpose. Although the original system is still in use on many aircraft, all aircraft will eventually be fitted with the new design. For this reason, in these pages we have given only brief mention and no detailed description of those system components that are used only in the original design.

For the benefit of those who are operating aircraft of the original configuration, we should explain that many of the subsystems discussed here *are* directly applicable to their aircraft. The engine driven compressors are not changed in the modification except that the electrical circuitry of the compressor control relays is interconnected with the controls of the APU bleed air system.

Also, although the re-designed airconditioning units are greatly different in appearance, their theory of operation is unchanged and the controls are identical. However, the older system utilized an engine bleed air/jet pump system to cool the four airconditioning heat exchangers during ground operation, whereas the new installation is designed so that they can be operated from the APU with the engines shut down, and two electric fans are substituted for the engine bleed air jet pumps. Therefore, the complex jet pump control circuitry required to establish safeguards and sequential operation of valves and exhaust doors is no longer utilized and it not described in this article.

A plan-form diagram of the current basic airconditioning system is located at the centerfold of this magazine for convenient reference. Readers are urged to consult the master diagram frequently if they are not already thoroughly familiar with the general plan of the airconditioning system, for it has a direct or indirect effect on all the many subsystems described herein.

CABIN AIR COMPRESSORS

A single stage Engine Driven Compressor (EDC), mounted on the lower left side of the accessory drive of each inboard engine, draws air from the engine inlet air duct and compresses it as necessary for pressurization and airconditioning to create a comfortable cabin atmosphere. As can be seen in the schematic at Figure 5, the compressors have a fixed-gear-ratio drive. At normal engine speed (13,820 rpm) the compressor input drive shaft turns at 3,690 rpm and the impeller turns at 45,260 rpm. Each compressor weighs about 62 lb. dry and has an oil system which holds .95 US Gal. of MIL-L-23699, the same lubricant used by the engines and the Auxiliary Power Unit (APU).

Lubrication System pressure, as developed by an integral gear-type pump, is limited by a relief valve to 95 to 110 psi. This pressure is monitored by a pressure switch which illuminates a "PRESS LOW" light on the Cabin Air Compressors control panel in the flight station when pressure is below 50 psig. EDC oil is routed through an oil-to-oil heat exchanger via a pressure relief valve which will bypass the EDC oil around the heat exchanger if the resistance to flow *through* the exchanger is in excess of 20 psi. Engine oil, flowing from the engine oil cooler is used to cool the EDC oil, without, of course, admixture of the two system supplies. After the initial warmup, EDC oil is generally about 185°F (85°C). A thermal switch senses EDC oil temperature and illuminates

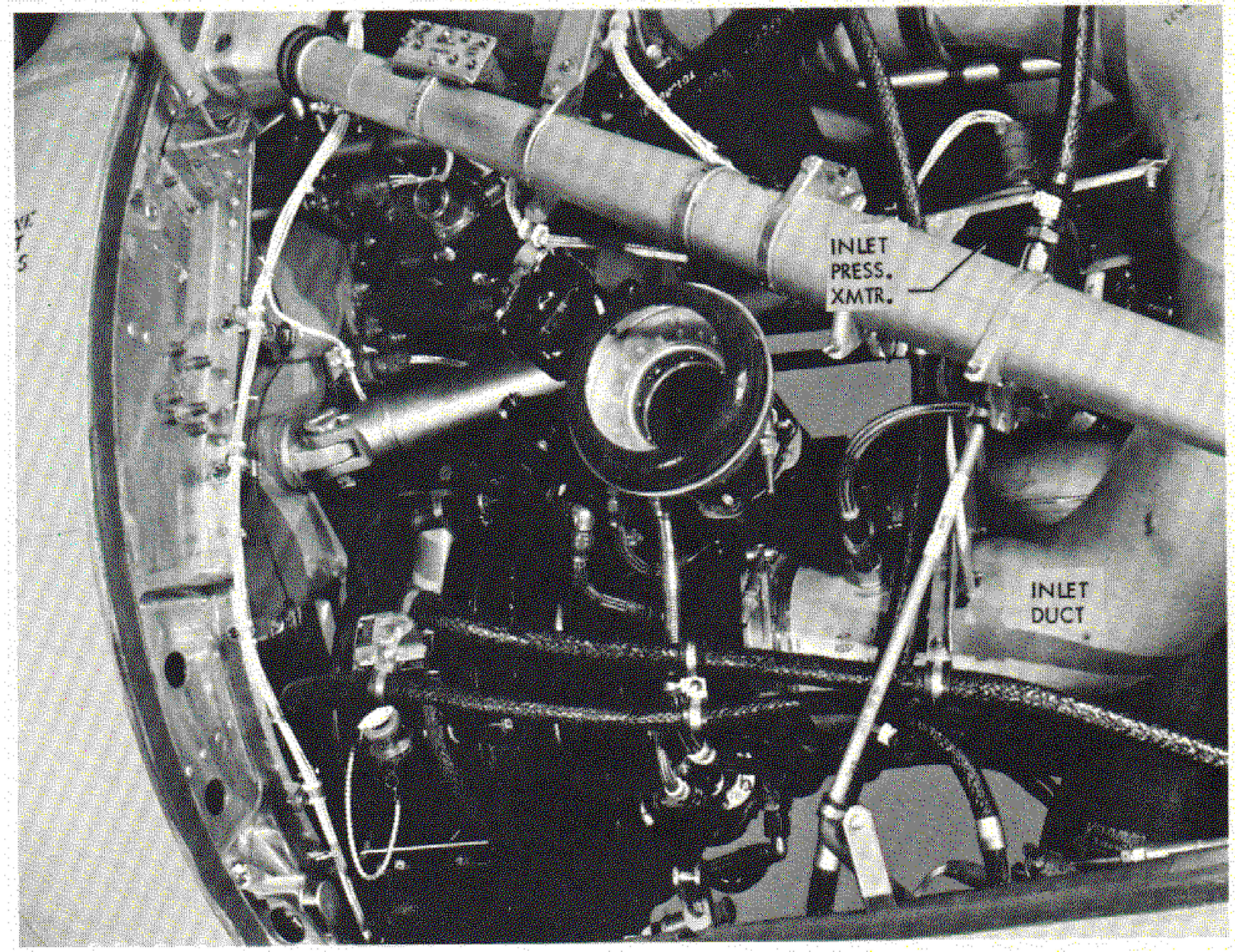
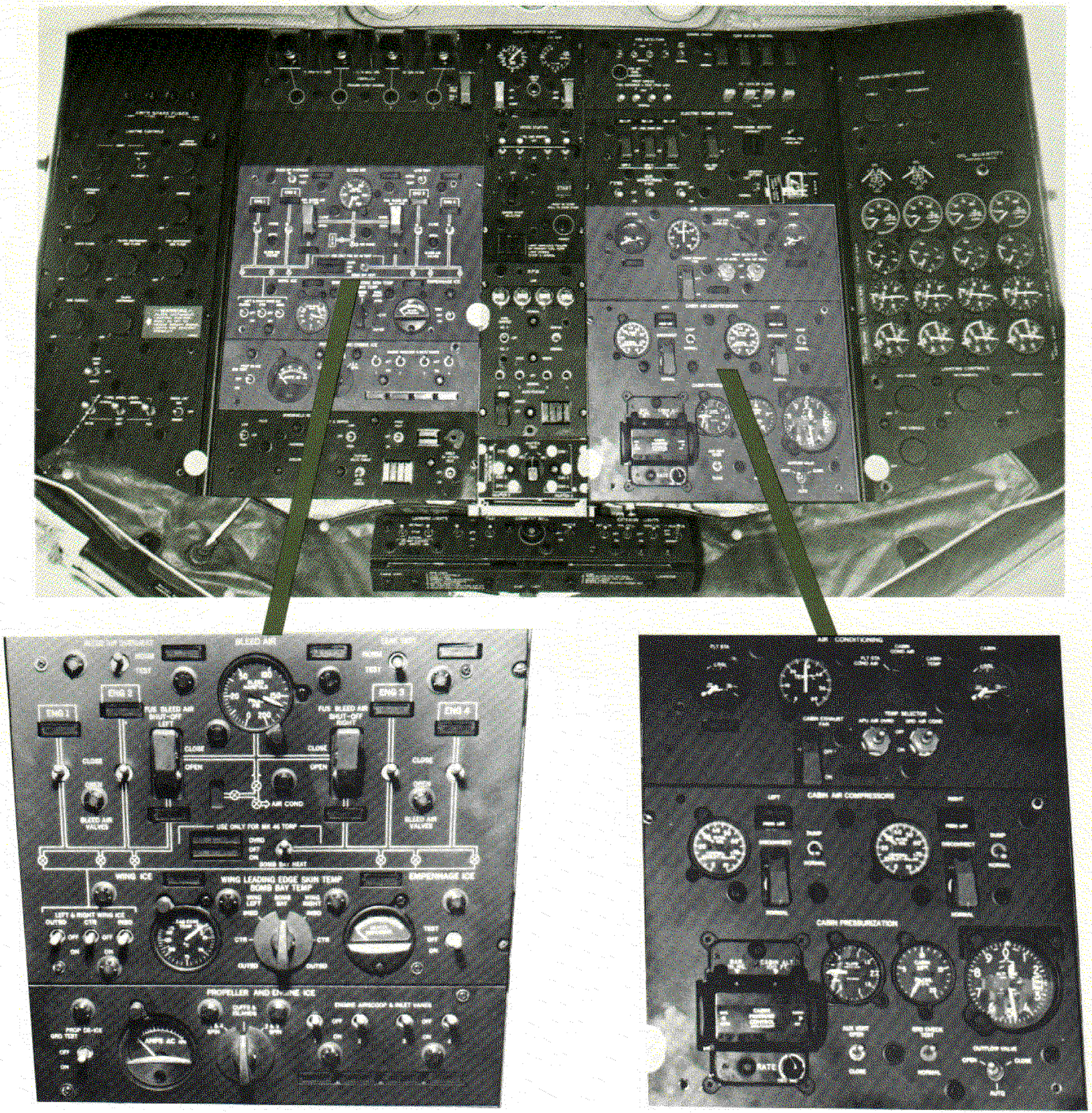


Figure 1
View of EDC
Installation—Left Side
of Either Inboard
Engine Nacelle



Flight Station Overhead Control Panels with Sub-panels Incorporating Principal Airconditioning Controls. Note the Bomb Bay Heat switch, HOT and COLD warning lights, and Temp. Indicator selector on panel at left.

a "TEMP HIGH" light adjacent to the "PRESS LOW" light if temperature exceeds 250°F (121°C). After cooling, the EDC oil is filtered and distributed to spray nozzles and drilled bushings for gear and shaft lubrication. Oil is also tapped off the EDC lubrication system through two .040-in. metering orifices for use as hydraulic power by the servomechanisms of the surge prevention and dump system and the EDC flow control system. These servo systems provide automatically the most efficient use of the EDC as described under "Compressor Output Regulation and Relief."

A shear section in the EDC drive shaft acts as a fuse to protect the engine accessory drive. The impeller wheel is driven by a long quill-shaft which acts as a torque bar to absorb transient loads.

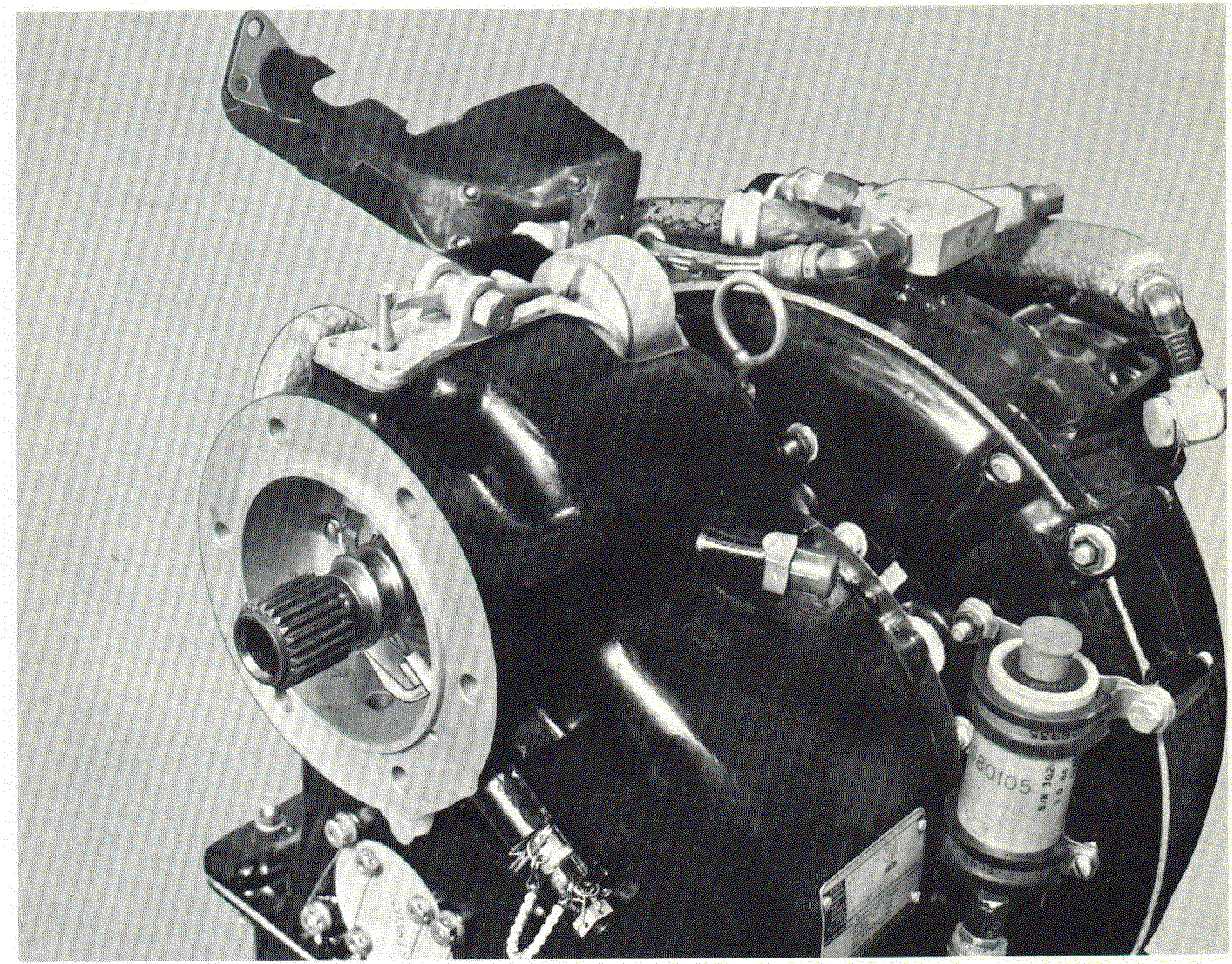


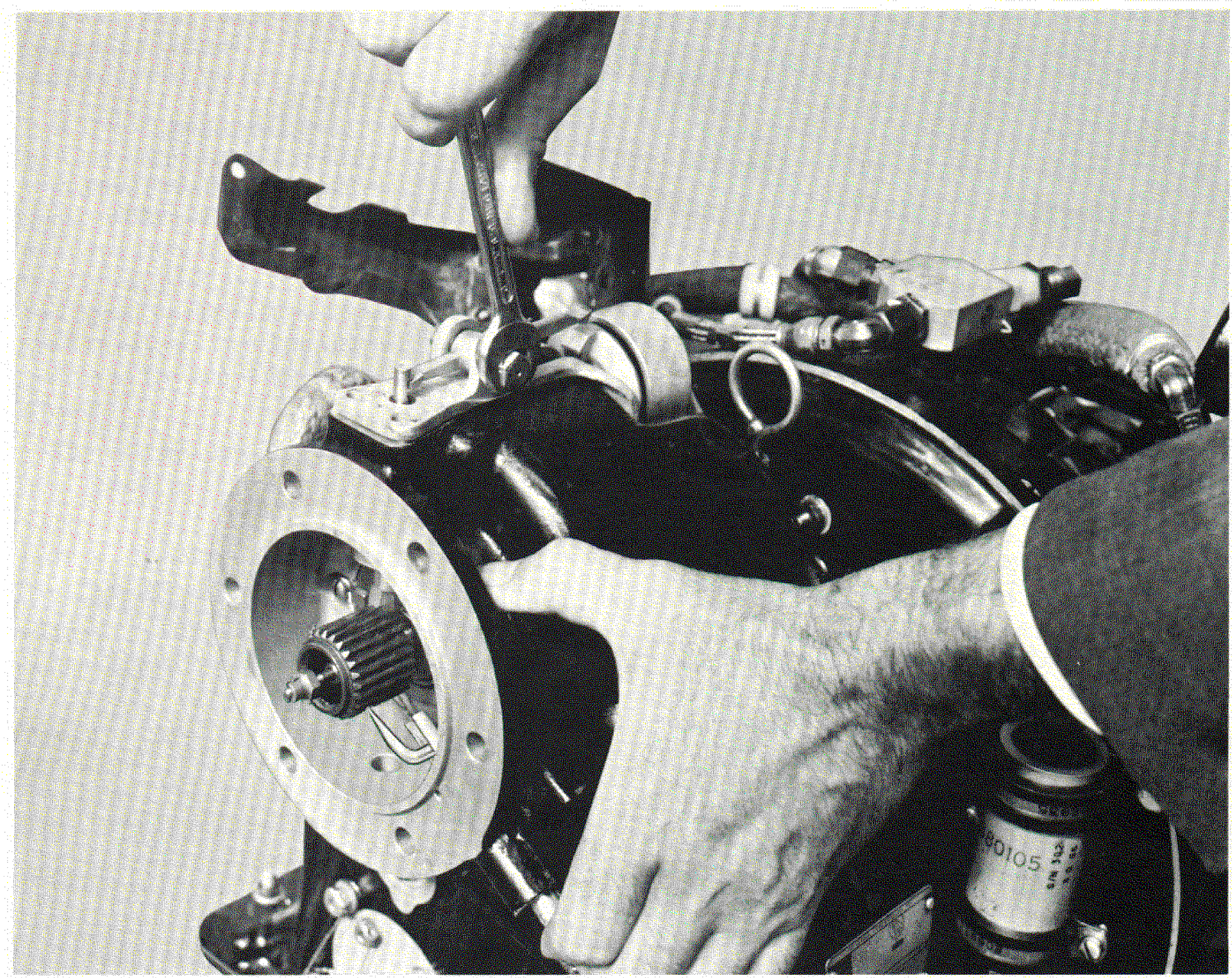
Figure 2

Drive End of Dismounted EDC with Top Housing Removed to Show Disconnect Escapement Linkage. Left view is normal operating configuration with escapement latched and drive shaft extended. Right view shows configuration after Disconnect has been triggered. Note witness pin striker bottoms on retracted drive spline and note small clockwise rotation required to re-engage fulcrum with solenoid latch.

Disconnect System Either EDC may be disengaged while the engines are operating by actuating the related Disconnect switch located on the Cabin Air Compressor Control Panel. When this guarded switch is turned to "DISCONNECT" a solenoid on the EDC releases a spring-loaded tang (see Figure 5). The tang engages a worm on the rotating EDC drive shaft which withdraws the drive spline from engagement with the engine accessory drive gear spline.

No attempt should be made to disconnect an EDC unless the engine is operating, for "NORMAL" engine rpm is needed to ensure full retraction of the drive shaft. The switch guard is drilled so that breakaway safety wire can be installed to prevent inadvertent operation of the switch, and if such a wire is found broken it furnishes a warning that the switch may have been actuated and *the EDC drive engagement must be checked before the engine is started.*

Switch actuation while the engine is shut down will almost certainly result in serious damage to the



engine and drive shaft splines if the engine is started without re-setting the disconnect mechanism. For this reason, mere suspicion that the Disconnect switch has been actuated makes it imperative to ascertain that the escapement is properly set and that the EDC drive has full engagement before the engine is started. A small guard housing atop the EDC conceals the escapement mechanism from visual inspection to determine whether or not it has been released, and there is a possibility of damaging a mechanism in attempting to re-set it when it has not actually been triggered. Therefore it is suggested that the Disconnect switch be deliberately actuated before proceeding with the EDC engagement check-out to be sure of the escapement position.

The check-out procedure is then carried out by:

1) "Cocking" a pawl against its spring load, using a ½-in. wrench to turn the pawl fulcrum bolt clockwise as shown in Figure 2, until it re-engages the solenoid-actuated latch. This withdraws the tang and permits the retracted drive shaft to re-engage the drive spline under the force from a spring. Note that the pawl fulcrum bolt need be turned only a few degrees to re-engage the solenoid latch. Many pawls have been broken by attempting to turn the bolt beyond the latch point, thus necessitating removal and replacement of the EDC.

2) Checking that the drive spline has full engagement with the accessory drive gear. A spring loaded "witness" pin is provided for this purpose. If the EDC shaft is satisfactorily engaged, it will be possible to depress the witness pin full travel. If the witness pin head cannot be bottomed on the compressor case, the engagement is not complete and it will be necessary to turn the propeller manually (in the direction of normal rotation) to align the spline.

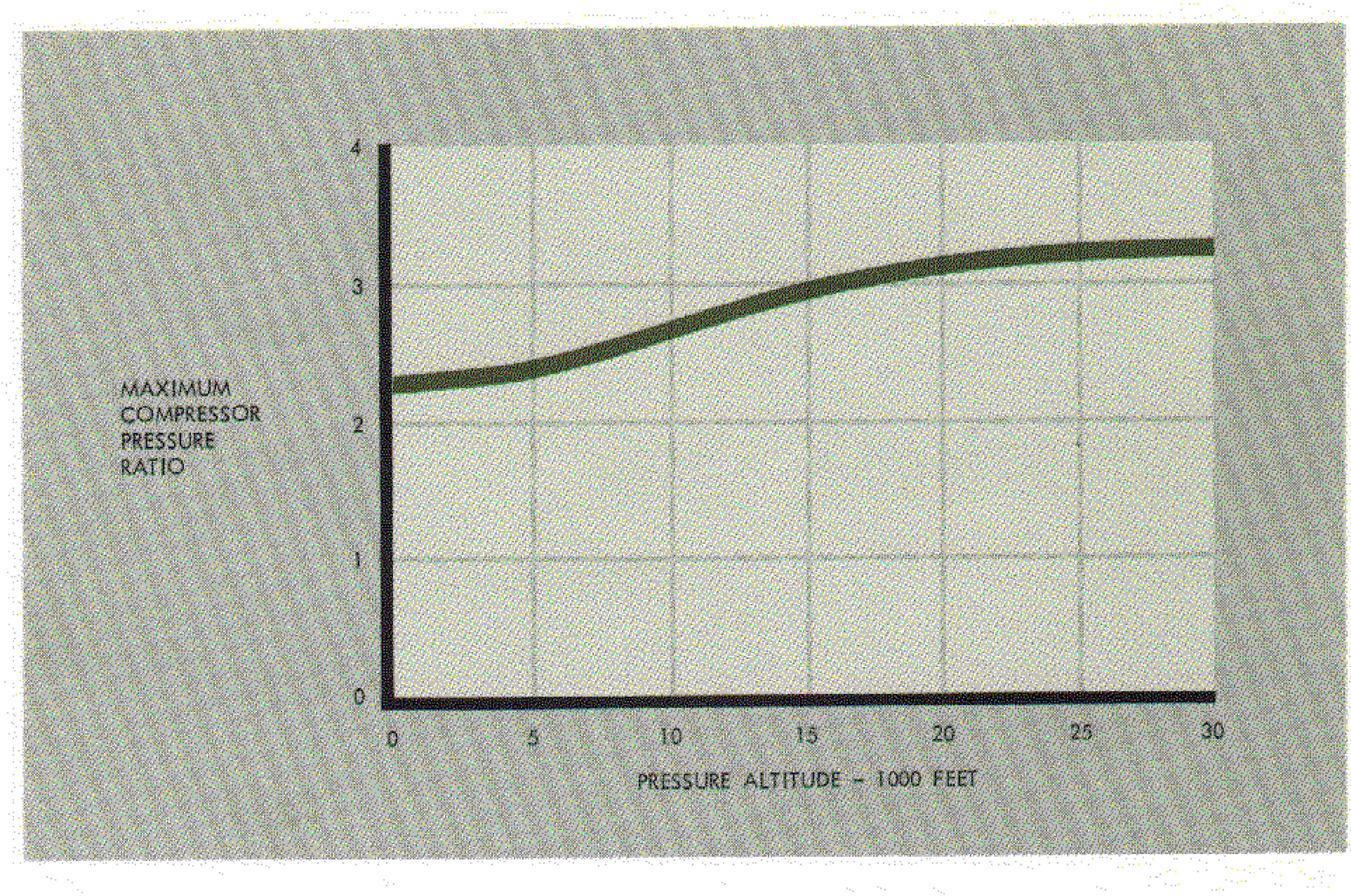


Figure 3
EDC Performance Curve
in Terms of Pressure-Ratio
(Discharge to Inlet) Throughout
P-3 Operating Altitude Range

COMPRESSOR OUTPUT REGULATION AND RELIEF The impeller blades are "sized" and shaped to do an efficient job of compressing the thin air at high altitude. A constant speed impeller of this design has much too great a capacity at low-altitude atmospheric density and usually it is necessary that the amount of air flow through the compressor be limited at altitudes below about 20,000 feet to prevent the impeller from overloading its drive and to provide just the required weight-flow of air to the airconditioners and cabin. The air supplied to the cabin is generally defined in terms of its weight-flow — a meaningful measurement of the raw product to be processed by the ventilating,* temperature, and pressure controlling components. A uniform supply of air is as important to these pneumatic components as a stable supply of electrical power is to electrical components. Although air is more than 300 percent as dense at sea level as it is at the P-3's service ceiling, the compressor control permits output to increase only about 37 percent — yielding at maximum altitude some 46 lb. of air per minute at 3.11 times the ambient atmospheric pressure; increasing at sea level to 63 lb. of air per minute at 2.15 atmospheres. These are nominal values. Maximum values are given in Figure 3 in terms of Pressure Ratios (discharge pressure divided by inlet pressure).

The weight-flow is controlled by varying the pitch of 11 tapered pre-swirl vanes which are mounted radially in the inlet duct immediately upstream of the impeller.

The air flow control cylinder is the actuating member of a servo system that senses the EDC output, then uses pressurized oil taken off the EDC lubrication system as "muscle" to position a ring gear which, through pinion gears fixed to the individual vane hubs, positions the vanes. The system is shown in Figure 5.

One element of a dual pitot static probe mounted in the EDC discharge duct provides ram and static pressure signals, which are impressed on opposite sides of a sensing head diaphragm. The position of this diaphragm determines the position of a servo valve. As can be seen in Figure 5, movement of the servo valve will impose more or less restriction on the flow of control oil to return, producing more or less control oil pressure in the vane actuating cylinder. The control is such that a too-high mass flow produces low control oil pressure and the spring load on the vane actuating piston closes the vanes.

At high altitude, full capacity of the EDC is needed, and the vanes are normally "streamlined" to permit full flow. As the airplane descends from high altitude, the impeller compresses more of the denser air until the pickups at the impeller discharge sense the passage of full rated flow and the vanes begin to close. This restricts inlet air, of course, and since the reduced inlet air flow swirls in the direction of impeller rotation it meets the constant speed impeller blades at a reduced angle of incidence. The effect is comparable to reducing a power plant's

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**Although the output of one compressor alone is sufficient to sustain cabin pressure at any operating altitude, it should be noted here that one of the primary functions of the airconditioning system on the P-3 is to ventilate the many heat-generating electronic equipments, and this capability is reduced by 50% if only one EDC is operative. For this reason, takeoff with one EDC inoperative is not recommended.*

propeller blade angle, in that the prop blast (or compressor output) is less intense and the power required to turn the propeller (or impeller) is reduced.

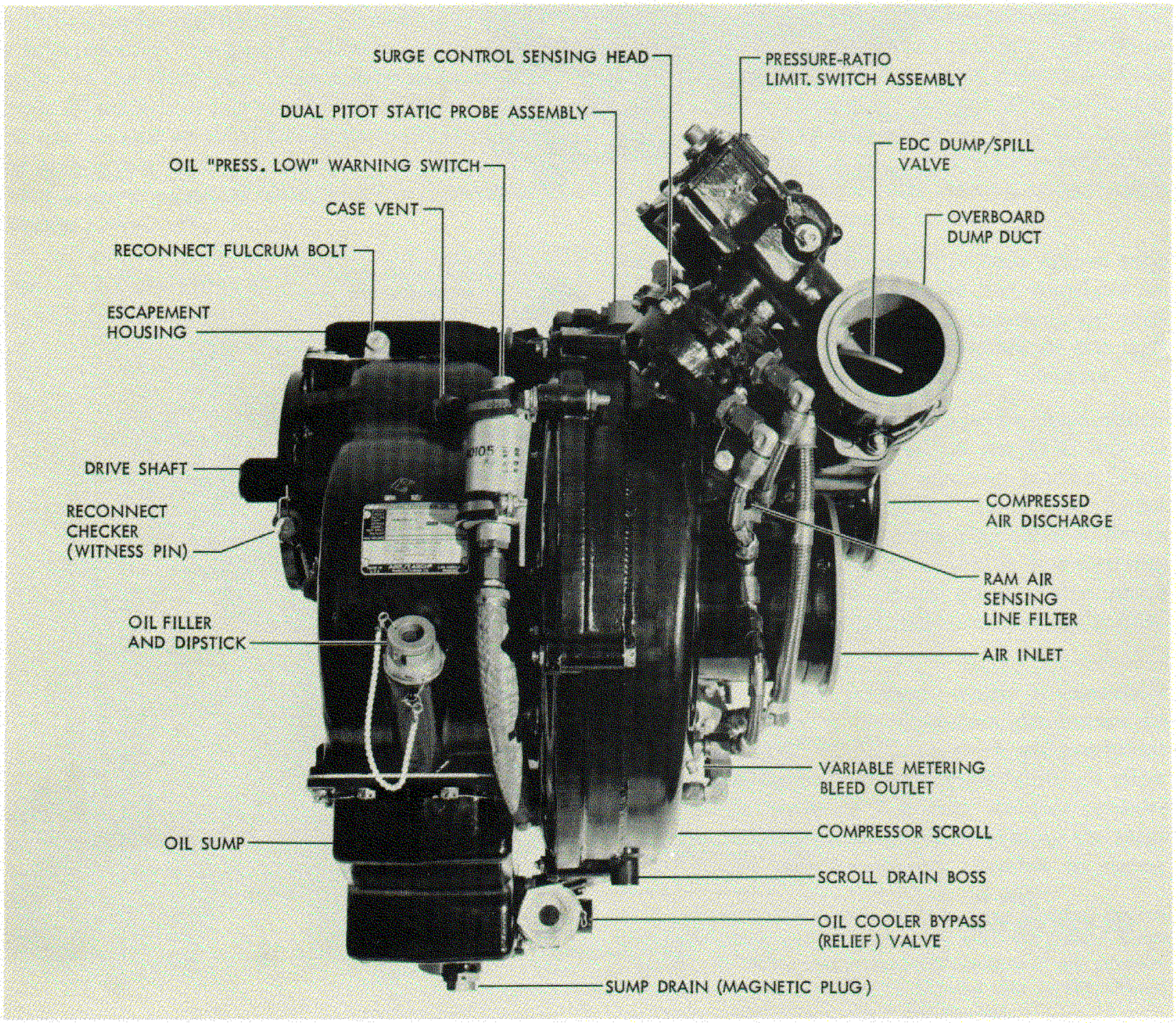
It will be noted (in Figure 5) that the static pressure sensing line to the Flow Control valve is fitted with a metering orifice which bleeds a portion of the signal off to atmosphere. As the airplane descends, more and more of the static signal bleeds off through this orifice. This augments the effectiveness of the ram signal at the control head and the swirl vanes close at an ever increasing rate in approximate proportion to the rate at which density increases during descent.

The altitude compensating orifice is provided by a hole drilled in an ordinary ¼-inch plumbing cap. We bring this to your attention for the reason that instances have been reported in which someone removed the cap and, not realizing it contained this important metering orifice, replaced it with an undrilled cap. If this orifice is blocked, the compressor will attempt to pass a flow in excess of 50% more than its rated mass flow at ordinary field altitude, *severely* overloading the drive.

The temperature *rise* across the compressor due to the heat of compression is about 247°F (119°C) at max altitude and decreases as the airplane descends to about 215°F (102°C) at sea level. This loss of 32°F is more than offset by the rise in OAT, and the compressor discharge temperature will usually increase about 100°F (55°C) during the descent from a high altitude flight.

Figure 4a EDC Left-side View. See next page for other views.

Photo courtesy of Ralph Wortmann,
The Garrett Corporation



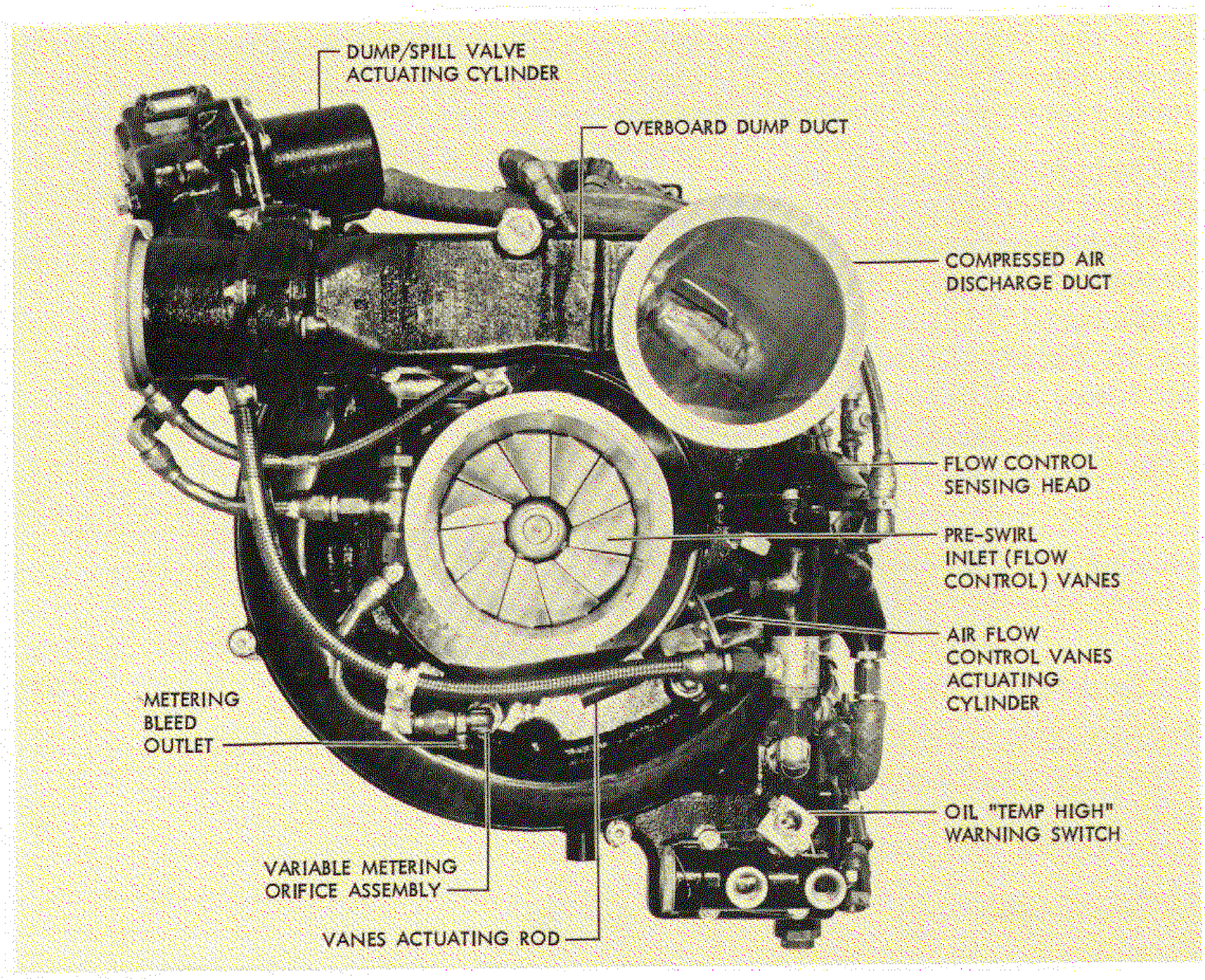


Figure 4b
EDC View
Looking Forward

Photos courtesy of Ralph Wortmann, The Garrett Corporation

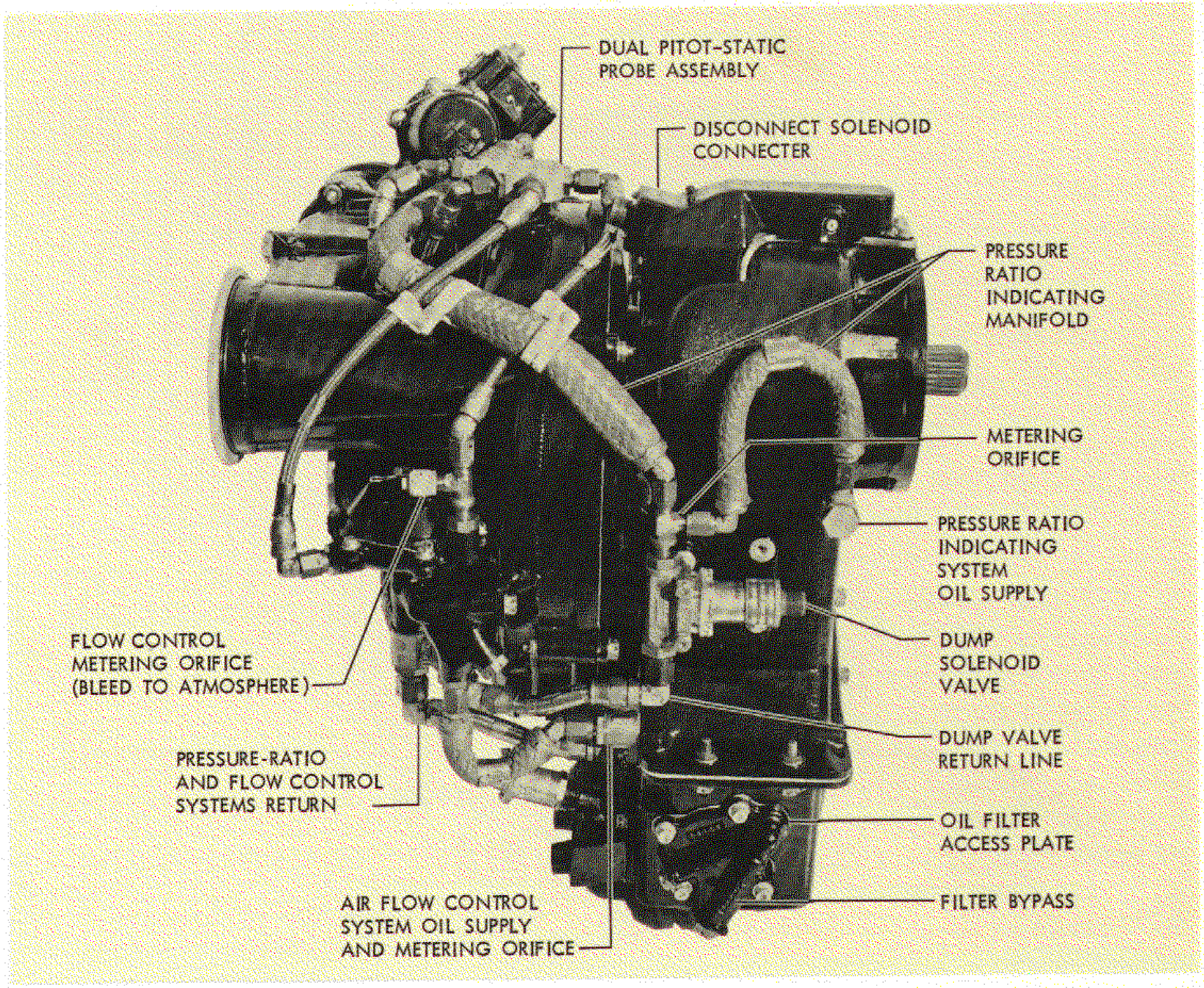
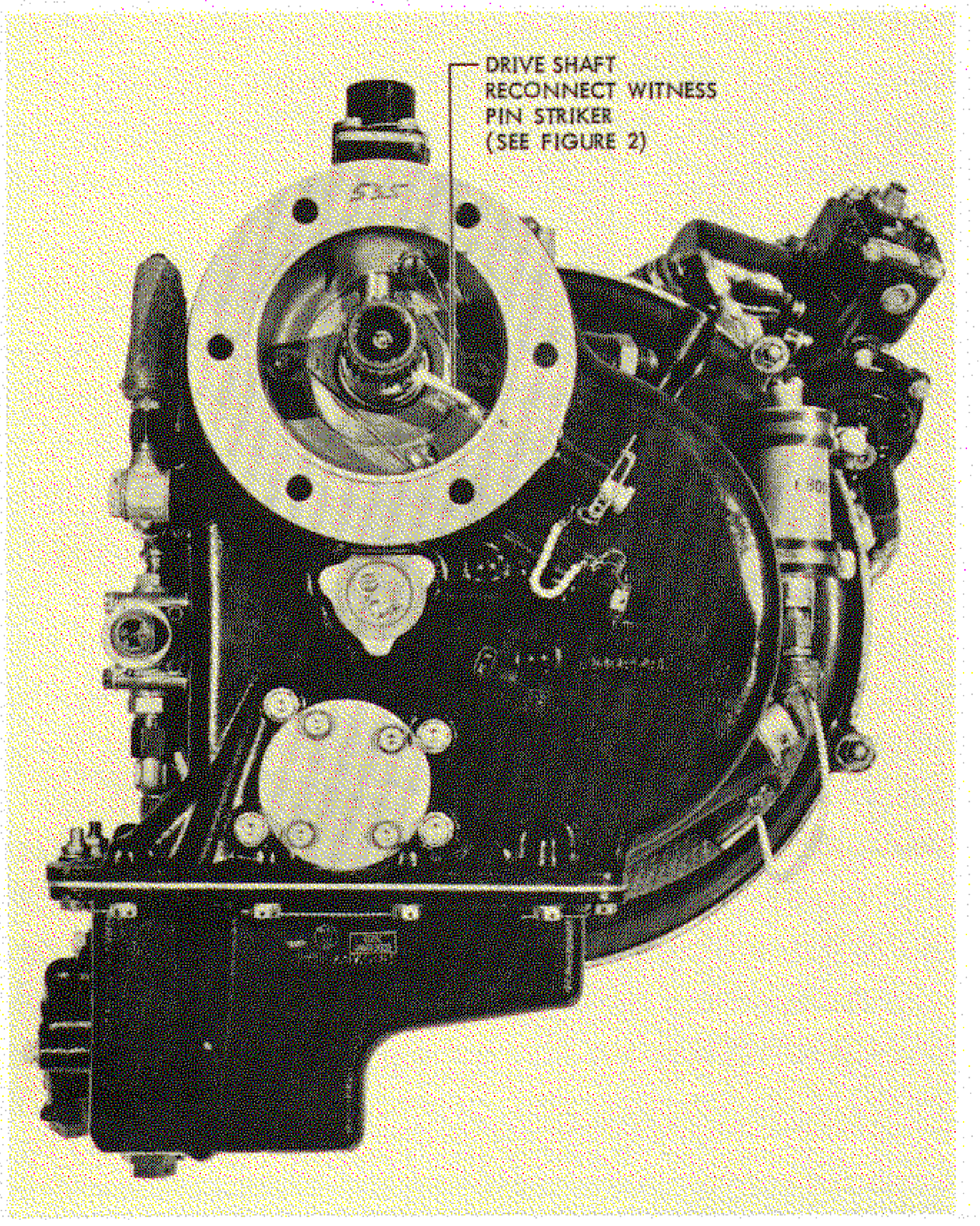


Figure 4c
EDC Right-side View

The heat of compression is utilized to warm the cabin at high altitude and in cold weather, but obviously at low altitude and on warm days a great deal of heat must be extracted before the air enters the cabin, and normally this is done automatically. When cabin temperature rises above that selected by the operator, the temperature control system repositions three valves to divert more of the compressor discharge air through the heat exchangers and the cooling turbine of the P-3's air-cycle cooling system (located forward of the bomb-bay). This creates considerable back-pressure in the EDC discharge duct, i.e., the pressure differential across the impeller will usually be largest at low altitude.

If back pressure in the discharge duct exceeds the EDC's ability to compress, air spills backwards through the impeller. This momentarily lowers the discharge duct pressure sufficiently for proper flow to resume until it again reverses and the cycle will, in theory, repeat indefinitely — a condition commonly referred to as "surging." Actually, the load oscillations in the drive gear train will be so severe that about 30 seconds or less of surge operation will shear the fuse section of the EDC drive shaft. Obviously, the compressor back pressure must be limited to a value below the critical range which will precipitate surging.

Figure 4d EDC View Looking Aft



The surge control system provides this protection by sensing a critical condition of air flow and pressure at the EDC discharge duct and:

1) Relieving or eliminating that part of the total EDC back pressure imposed by the air cycle cooling turbines.*
2) Operating a spill valve system, commonly referred to as the "dump valve," which modulates the compressor discharge pressure by spilling enough of the EDC output overboard to maintain a tolerable discharge duct pressure vs flow condition.

This valve has sufficient capacity to automatically spill all the EDC output in response to its pneumatic control if the duct to the cabin is totally blocked far downstream at the airconditioners. The valve also has an electrical control circuit and can be opened manually from the flight station, in which case it functions as a dump valve. The dump function will be described later. In this article we will use either term — spill valve or dump valve — in context with the function under discussion. We are at present concerned with the automatic "spill" function of this valve, which serves as the primary surge-preventing device, and the pressure-ratio limiting system which shares the valve's automatic control.

The surge control sensing system protects against surging by means of a servo system that translates increasing compressor load into diminishing oil pressure, thus operating pressure switches or the spill valve to hold the EDC load within tolerance.

As shown in Figure 5, a separate fixed-orifice-metered flow of oil is tapped off the EDC lubrication system into an oil-line segment, labeled "Pressure-Ratio Indicating Manifold" on Figure 5, for use by the surge control system. The outlet to return for this flow is controlled by a variable flow metering valve which has a pneumatic actuator that reacts to the balance of ram and static pressures in the EDC discharge duct.

Compressor inlet pressure, which is essentially equivalent to static ambient pressure, determines the discharge pressure vs flow value which will precipitate surging, and the surge control must "shift" to allow for the wide range of operating ambient pressure conditions. This is provided for by venting the surge control's ram pressure sensing chamber to atmos-

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**This system, known as the pressure-ratio limiting system, responds slowly and it operates so near the critical range that it will only serve as surge protection if the pressure buildup is gradual, such as a buildup due to the change in environment during climb and descent.*

phere through a variable orifice located in the hub of one swirl vane as shown schematically in Figure 5, pictorially in Figure 4.

The variable orifice is smallest when the swirl vanes are closed. When the swirl vanes are open, calling for increased flow, the variable orifice is largest and the ram pressure signal at the sensing head (which tends to hold the surge spill valve closed) is weakened. Since the swirl vanes operate as a function of altitude, the control system of the surge spill valve "shifts" gradually to a different controlling range at higher altitude, demanding a higher flow rate and/or relieving the compressor discharge at a lower absolute static pressure at high altitude.

When the impeller is operating within its capabilities, a high-rate flow will be sensed by the pitot probe, and a modest static pressure will be sensed by the static pickups. This will produce the normal configuration as depicted in Figure 5, in which full lubrication system pressure (100 psi, nominal) is developed in the dump valve actuator piston — a pressure that is more than sufficient to overcome the actuator spring force and hold the spill valve closed.

As the EDC load approaches maximum, flow through the discharge duct will slow, the ram pressure signal will decay* while the static pressure grows, the pneumatic actuator will re-position the metering valve, and oil pressure in the Pressure-Ratio Indicating Manifold will diminish.

If the oil manifold pressure drops to the 72-to-50-psi range, the EDC is operating at near-maximum capacity, and no further load should be imposed. Accordingly, one of the Pressure-Ratio Limiting (PRL) switch contacts shown in Figure 5** will be energized in this range, sending a signal to the airconditioning control circuits. This signal will prevent the control, if it is operating in the Automatic mode, from diverting a larger share of the EDC discharge through the cooling turbine, which would have the effect of producing more back-pressure in the EDC discharge duct. The PRL signal that accomplishes this is aptly termed "Yellow Signal." An ice detecting system, which senses an incipient ice blockage in the water separator down stream of the airconditioning components, is connected in parallel with the PRL system, and it too can produce the Yellow Signal, provided that the temperature control system is operated in the "AUTO" mode.

If for some reason, such as an increase in cabin pressure, discharge duct static pressure continues to build, pressure in the Pressure Ratio Indicating Manifold will decay further, and below 50 psi the second PRL switch contact will be energized, introducing an overriding signal (known as the "Red Signal") for warm air in the automatic temperature control system. This will shunt an increasing increment of the EDC output around the cooling turbine (the principal cause of excessive load on the EDC) or all of it if necessary, to relieve the EDC load, assuming again that the temperature control system is operating in Automatic mode. As shown in Figure 5 the ice detecting system can also produce the Red Signal.

If an operator selects "MANUAL" temp control and demands "full cold" both the PRL and the ice limiting systems are made inoperative, and if the EDC load continues to increase until oil pressure in the Pressure-Ratio Indicating Manifold drops below 45 psi, a surge condition is imminent. At this time spring force on the dump valve actuator will begin to open the valve, "spilling" enough of the EDC discharge overboard to forestall the surge condition.

Flow rate through the EDC is quite low when the engines are operating at "LOW RPM" speed. Consequently the ram pressure signal to the surge control head is insufficient to hold the spill valve closed. The decline in spill valve control oil pressure would normally work through the pressure ratio limiting circuit to drive the cooling turbine bypass valves toward the open (full hot) position, and the major part of the total air cycle cooling capacity would be lost if the pressure-ratio limiting systems were permitted their normal function during "LOW RPM" ground operation. For this reason the related pressure-ratio limiting circuit is automatically disarmed when "LOW RPM" is selected on Engines No. 2 & 3. In this circumstance some air will be lost, unavoidably, through the spill valve, but the air cycle cooling system is enabled to operate and provide a reduced flow of cool air to the distribution systems during "LOW RPM" operation.

**The rate of decay is largely determined by the variable metering orifice on the pre-swirl vane hub (see Figure 5). It should be noted that ANY minute obstruction here will have a profound effect on the surge control system, especially the Pressure Ratio Limiting system.*

***For schematic simplicity, we have portrayed both the PRL and the Ice Limiter switch assemblies as single-pole, 3-position units in Figure 5. Actually, two single-pole, 2-position switches are employed by these assemblies, but schematically their function is exactly as shown in Figure 5.*

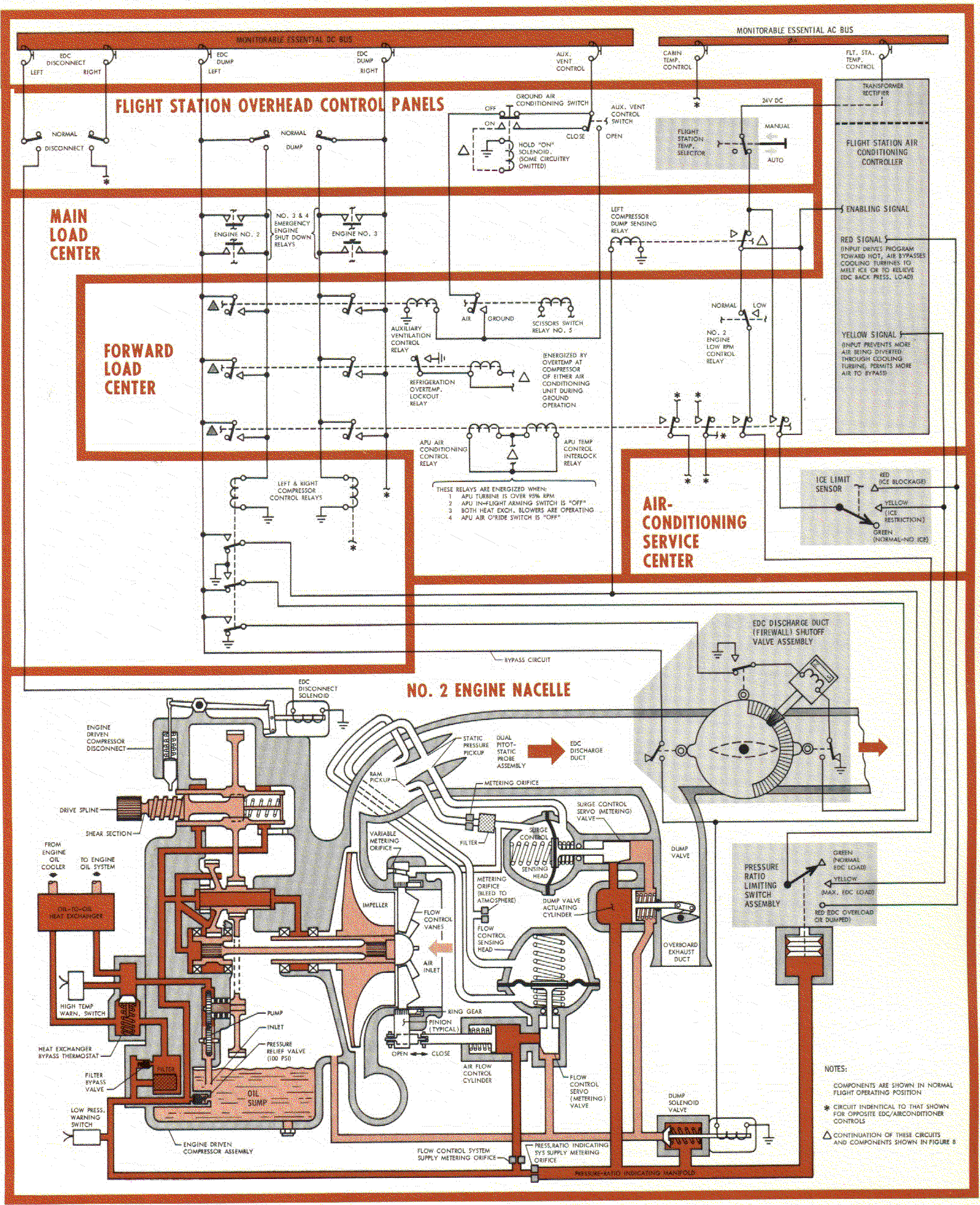


Figure 5 Mechanical/Hydraulic/Pneumatic/Electrical Schematic of Left EDC and Controls Showing Interconnect with Related Airconditioner via the Pressure-Ratio and Ice Limiting Protective Systems. See Figure 8 for additional interconnecting control circuits.

The interrelationship of hydraulic and mechanical forces in the EDC control is of interest here. In addition to illuminating the "PRESS LOW" light in the flight station, any situation resulting in a total loss of oil pressure in the lubrication system will: 1), simulate an excessive flow condition in the vane control actuator, closing the swirl vanes to minimum flow position and 2), simulate an excessive back-pressure load in the EDC discharge duct, dumping all EDC output overboard. This provides a "fail-to-the-safe" condition in the event of a malfunction rendering the lube system or the EDC control inoperative, and it also minimizes the cranking load required to drive the EDC during engine start.

The Pressure-Ratio Indicating Manifold also provides a convenient means by which the EDC output can be intentionally dumped overboard. By energizing the "Dump Valve Solenoid" shown in Figure 5, all pressure in the Pressure-Ratio Indicating Manifold is routed to return, the dump valve spring will open the valve, and all EDC output will be dumped overboard.

There is one flight station control for each EDC — the Left and Right Dump switches on the Cabin Air Compressor overhead control panel — whose only function is to operate the related compressor control relay. This is the basic dump system.

Energizing the compressor control relay produces certain side effects which should be well understood at this point in the discussion because there are a number of other automatic and manual controls described in the following pages which energize the compressor control relay as a supplementary effect to their primary purpose.

As shown in Figure 5, compressor control relay actuation directly energizes the dump solenoid, the dump sensing relay, and the "Close" coils of a reversible motor-actuated shutoff valve (sometimes called the "firewall" valve) in the EDC discharge duct — the supply duct for one of the P-3's twin airconditioning units. The motor actuation is, of course, slow in comparison to the dump valve response, which provides a definite sequence, ensuring that the compressor discharge will have an outlet overboard* before its outlet to the fuselage is blocked. Note, also, that as the shutoff valve moves from its full open position, it mechanically actuates a switch in a "bypass" circuit. This bypass provides the necessary reverse sequence, ensuring that the EDC discharge will be continually dumped overboard until the shutoff valve is again completely open, providing an outlet to the fuselage for the EDC discharge. We bring this to your attention because the electrical connector at the dump valve solenoid is sometimes overlooked during EDC installation, and in almost every instance the new Engine Driven Compressor surged (against the positive blockage provided by a closed discharge duct shutoff valve) so severely as to break the EDC drive shaft.**

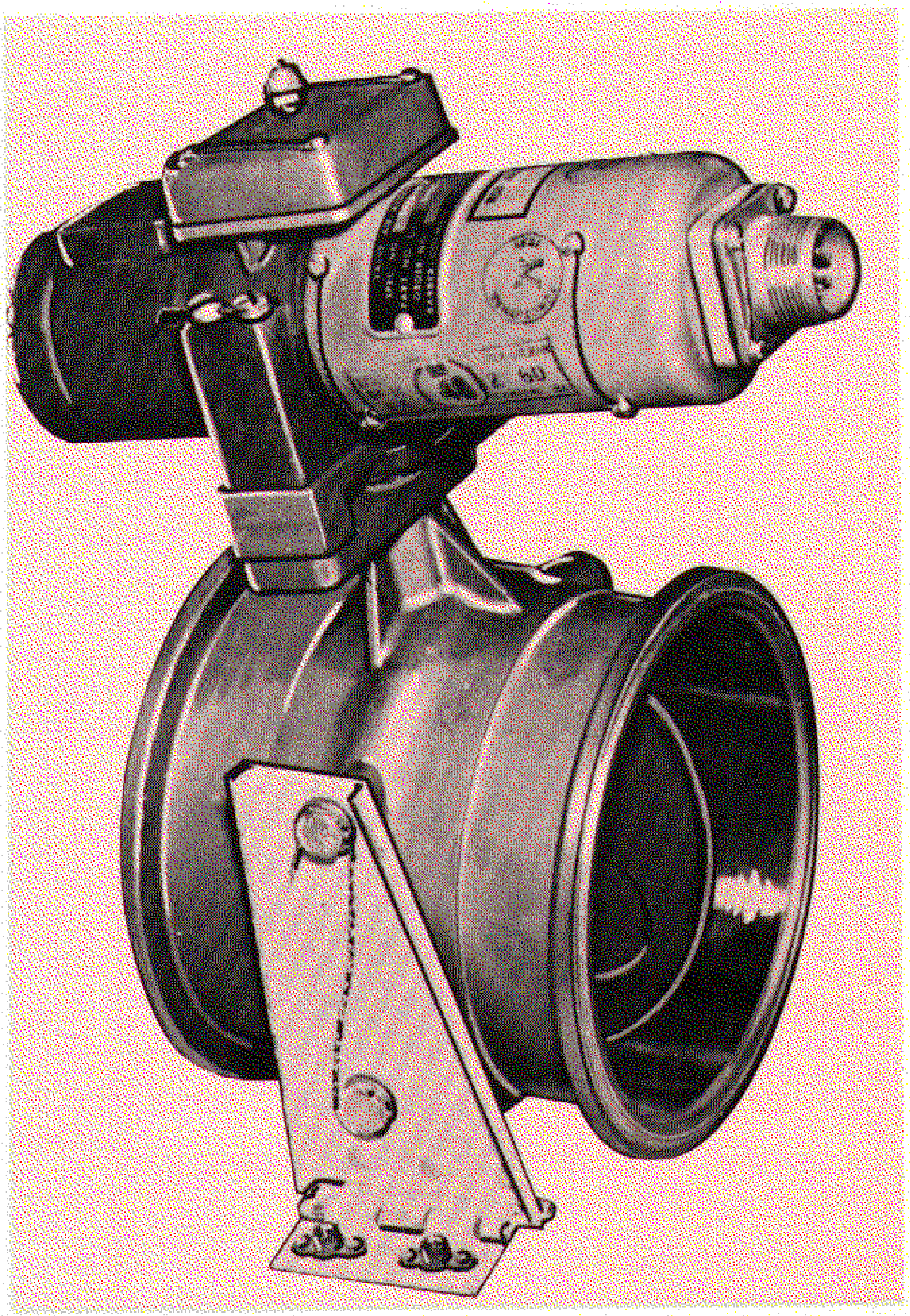
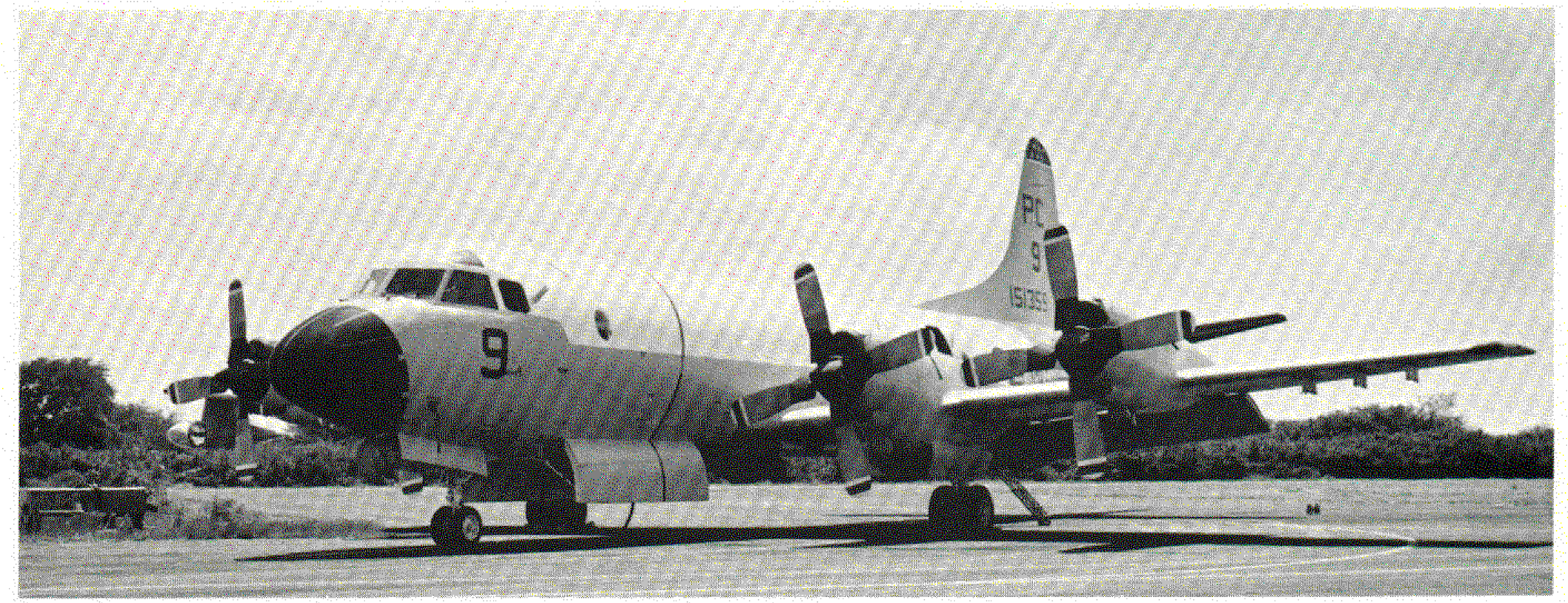


Figure 6 EDC Discharge Duct Shutoff (Firewall) Valve Assembly. Valve is installed adjacent to inboard nacelle in nacelle-to-fuselage wing leading edge.

**Actually, the dump valve cannot* completely *relieve the compressor, for the spring loaded dump exhaust door in the side of the nacelle requires about 3 psi to open. This arrangement prevents ram air from windmilling the impeller after the EDC has been disconnected during flight.*

***A standard operating procedure for dealing with in-flight fuselage fires has the effect of "tricking" the EDC controls — undumping the EDC's without opening the discharge duct shutoff valves. It should be noted that the risk to the EDC is less at flight altitude, and that the nature of the immediate emergency makes it imperative to accept the risk of damaging the EDC drives rather than to disconnect them, thereby losing the capability of pressurized operation for the balance of the flight.*



The dump sensing relay provides two functions. One of its contacts opens and renders the temperature controller for the related airconditioning unit (which now has no source of supply) inoperative, and, simultaneously, both the PRL and the Ice Limiter switches are de-energized. Thus, the airconditioning control valves will retain the operating configuration that existed at the time the EDC was dumped. Without this provision, a "RED" signal would be transmitted from the PRL switches when the dump solenoid valve removes all pressure from the Pressure-Ratio Indicating Manifold, and the airconditioning control valves would be driven to the "Full Hot" configuration.

The second set of dump sensing relay contacts closes a circuit that is connected in series with similar contacts of the other EDC dump sensing relay (see Figure 8). If the other dump sensing relay is closed also, indicating that neither engine driven air source is available to the airconditioning units, the circuit is completed. When complete, this circuit makes it possible for the operator to obtain air from the auxiliary power unit engine for both airconditioning units, when the aircraft is on the ground, and to regain use of the temperature controllers with ice-limiting protection, but without interference from the PRL system. Conversely, the series circuit through the EDC dump sensing relays prevents the airconditioning units from being fed from two sources simultaneously.

As indicated in Figure 5, the EDC's can be dumped separately through use of one other flight station control — this being one of the functions performed when an inboard engine is shut down with the Emergency Engine Shutdown system — and both compressors are dumped simultaneously if the operator selects "OPEN" at the Auxiliary Ventilation control switch. There are a variety of other means by which the compressor control relays can become energized, but these are all incidental to various ground operating airconditioning configurations, and will be mentioned in those discussions.

A dual-pointer inlet/discharge indicator for each compressor is located on the Cabin Air Compressor Control panel. These gauges are electrically operated, utilizing pressure transducers, and are calibrated to show inches of mercury absolute pressure. On a static airplane all pointers will show the existing field barometric pressure, and during operation the inlet needles will show the approximate ambient barometric pressure; slightly less during ground operation, slightly more during flight because of ram air at the inlet.

The discharge pressure transducers sense pressure downstream of the discharge duct shutoff valve. Consequently, the "spread" between the inlet and discharge pointers will represent the pressure rise across the compressor only when the compressor is supplying air to the cabin.

As shown in Figure 1, inlet pressure is sensed at a point just upstream of the EDC intake. Although the Engine Start procedures do not specifically require that the EDC inlet pressure be checked when an inboard engine is started, it is prudent to do so. A sharp drop in inlet pressure as the EDC comes up to speed is indicative of a blocked intake duct, and, as proven in a number of instances, a few seconds of operation will cause major damage to the EDC. It should be noted that dumping the EDC will *not* alleviate the situation — preferably the engine start will be discontinued.

The indicators provide a quick and convenient means for cross-checking EDC performance against the performance of the related airconditioner unit. Operating unpressurized on the ground at "NORMAL RPM" with the airconditioner programmers at "full hot" should produce the minimum pressure rise across the EDC (8 to 10 in Hg), and the intake/discharge spread indicated on the two gauges should be coincident within 1 in. Hg. Selecting full cold in the "AUTO" mode under the same conditions will test the EDC's performance in support of maximum airconditioner load. Both pressure indicators should show at least a 32-in. Hg pressure rise when the temperature indicators reach full cold position.

The inlet/discharge indicators also offer a means of monitoring EDC/airconditioner performance during flight, but the operator must be well acquainted with the many variable factors which, in combination, affect the discharge readings if he is to accurately analyze performance. For example, the spread between the pointers for the left and right EDC's will almost certainly *not* be equal during normal operation for the reason (discussed in the latter pages of this article) that their related airconditioner units will seldom create identical back-pressure loads while operating in "AUTO" mode.

If the air conditioners are operating under identical load conditions, as indicated by identical program indicator readings, the left and right EDC inlet/discharge readings should be *approximately* equal, but here too a considerable discrepancy may exist without a certain indication of malfunction. Note that there are additive tolerances involved: one for EDC output, another for the airconditioners in respect to the back pressure they may impose under specific operating conditions, and a further tolerance for gauge accuracy — a double allowance for the latter inasmuch as two gauges are involved.

If a malfunction is undoubtedly indicated in view of prevailing circumstances, it should be borne in mind that any one of six components may be at fault (either EDC, either airconditioner and/or controls, either indicator), and further investigation is usually required to ascertain the nature and location of the problem.*

Little if anything can be learned from the indicators after an EDC is dumped. The EDC will continue to produce pressure of about 3 psi to hold open the spring-loaded dump exit door in the side of the nacelle, cabin pressure will be present at the distribution ducting, and either or both may leak to the discharge duct pressure tap to produce an apparent pressure rise across the EDC.

APU AIR-BLEED SYSTEMS

The APU is a multi-purpose, constant-speed, gas turbine unit mounted immediately forward of the bomb bay, which inducts air through a door on the belly of the aircraft; exhausts it through the right side door depicted in Figure 10. The unit drives a generator for electric power supply and incorporates an oversize compressor section whose excess capacity (that not required by the combustion/turbine section to maintain 100% speed) can be tapped for engine starting or for the airconditioning/pressurization systems during ground operation. Figure 7 shows the unit prepared for installation.

LOAD CONTROL The compressor air bleed is regulated by a Load Control valve that provides an "on-off" capability and also meters the bleed flow as required to prevent overheat of the APU turbine (note the Exhaust Temp Sensor in Figure 7). If limit temperature is developed by the APU in attempting to maintain rated speed while under the combined load of generator and air bleed, the load control valve modulates the air bleed. In other words, the bleed load regulator ensures that the use of bleed air is subordinated to the electrical system requirement for 400 cps power.

At ordinary field altitude the APU compressor capacity is ample to sustain a generator load of 60 kva together with a bleed-air load of 100 lbs per minute, but the decrease in ambient air density at flight altitudes detracts from the compressor's excess capacity, and it is necessary to limit the APU work load to generator support during flight. (Then too, there is no requirement for bleed air either to start engines or operate the airconditioner units during flight.) Accordingly, as can be seen in Figure 8, the circuitry that controls the bleed load valve's "on-off" function is routed through a number of components that reflect pertinent operating criteria, thus ensuring that the APU is not taxed for air under unsuitable conditions. Figure 8 is largely self explanatory in respect to the criteria for operating the bleed load control valve, but we will enumerate them here for greater clarity:

**Lockheed Flight Test personnel find that the APU offers a valuable means of resolving such difficulties. By operating the airconditioners in "MANUAL" mode, unpressurized, from a common air source, the spread differential may repeat, in which case the EDC's are absolved, or it may be eliminated, indicating that one of the EDC's is at fault. A word of caution, however: in such a test it is necessary to be certain that there is* no *icing of the airconditioner water separators.*

1. Power must be available to the APU Start Control circuit breaker on the Ground Operation DC Bus. This is provided automatically when the NLG is not up and locked, or, alternatively, the bus can be energized by manually selecting "ARMED" position of the APU In-flight Arming switch during flight.
2. The APU "START" must be initiated (circuitry not shown on Figure 8), and APU speed must be above 95%, as indicated by closure of the 95% centrifugal switch.
3. The APU In-Flight Control Relay must be de-energized, that is, the In-flight Arming Switch must be "OFF." As noted above, it is necessary to select "ARMED" position to start the APU in flight, and when this is done the energized control relay automatically precludes subsequent utilization of bleed air.

4A. If APU bleed air is to be used for engine starting, an engine position must be selected at the Engine Start Selector Switch. This energizes the APU Bleed Control Time Delay Relay.* Closing of the TD Relay transfers power from the APU Load and Shut-off Valve circuit breaker to the Bleed Load Control Shut-off Solenoid and simultaneously applies APU Bleed Air Start Valve power to open this motor operated valve. This pressurizes the Engine Bleed Air Manifold, the manifold which supplies air for engine starting and other pneumatic services.

4B. If APU bleed air is to be utilized for Ground Airconditioning, Items 1, 2, and 3 apply as before, but not 4A. Instead, a different network, discussed under "The APU Bleed Air Multiplier" heading, is energized by selecting "OFF" at the Engine Start Selector and "ON" at the Ground Airconditioning switch.

Note that the requirement for different Engine Start Selector positions to obtain APU bleed air for engine starting and airconditioning makes it physically impossible to concurrently utilize air for both purposes.

A bomb bay heat modification (see colored circuitry and Note No. 2 on Figure 8) will permit the APU Bleed Air Start valve to open and pressurize the Engine Bleed Air Manifold at the same time APU

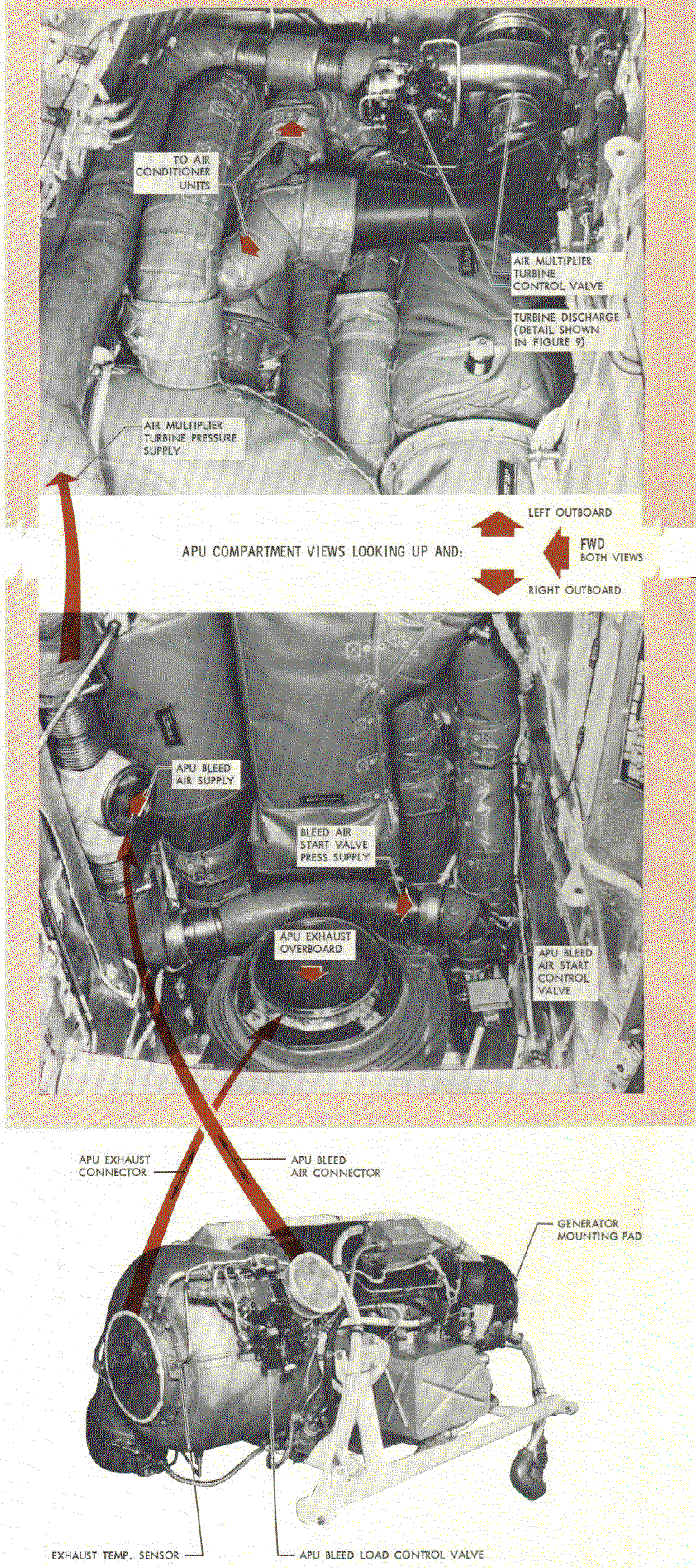


Figure 7 Auxiliary Power Unit and General Plan of Related Airflow and Ducting in APU Compartment. See pages 22-23 for orientation of access and airflow doors.

**This relay closes immediately when energized, delays dropping out when de-energized. The delay obviates rapid cycling of the Bleed Air Start valve motor as the Start Selector is moved from one engine position to another during engine start.*

air is being used for ground airconditioning. But it should be noted that the airconditioner air supply will be terminated immediately when any engine position is selected at the Engine Start Selector preparatory to engine start.

In summation, the various services provided by the APU are given an automatic priority — by diverse methods of control — in which:

1. The generator has top priority always. It can be utilized at any time below 20,000 ft. altitude, including ground operation in conjunction with the APU engine-starting or airconditioning service.

2. The engine start service is restricted to ground operation, but it has second priority, being limited only in respect to the quantity of compressed air which can be drawn from the APU without inducing an overtemp in the exhaust.

3. The airconditioner service has bottom priority. It is restricted to ground operation, it will be pre-empted by a demand for engine start, and, as with the start system, the quantity of air supplied is limited by the regulator function of the bleed load control valve.

GROUND AIRCONDITIONING The ground airconditioning network is necessarily an extensive one, for the system must discriminate between alternative air sources and, since the system may operate for extended periods without an operator in the flight station, additional safeguards must be introduced to make the system self-supervising during ground operation. The circuitry is too extensive to delve deeply here into all the detailed workings which can be gleaned by careful scrutiny of Figure 8, but we will highlight some of the major functions.

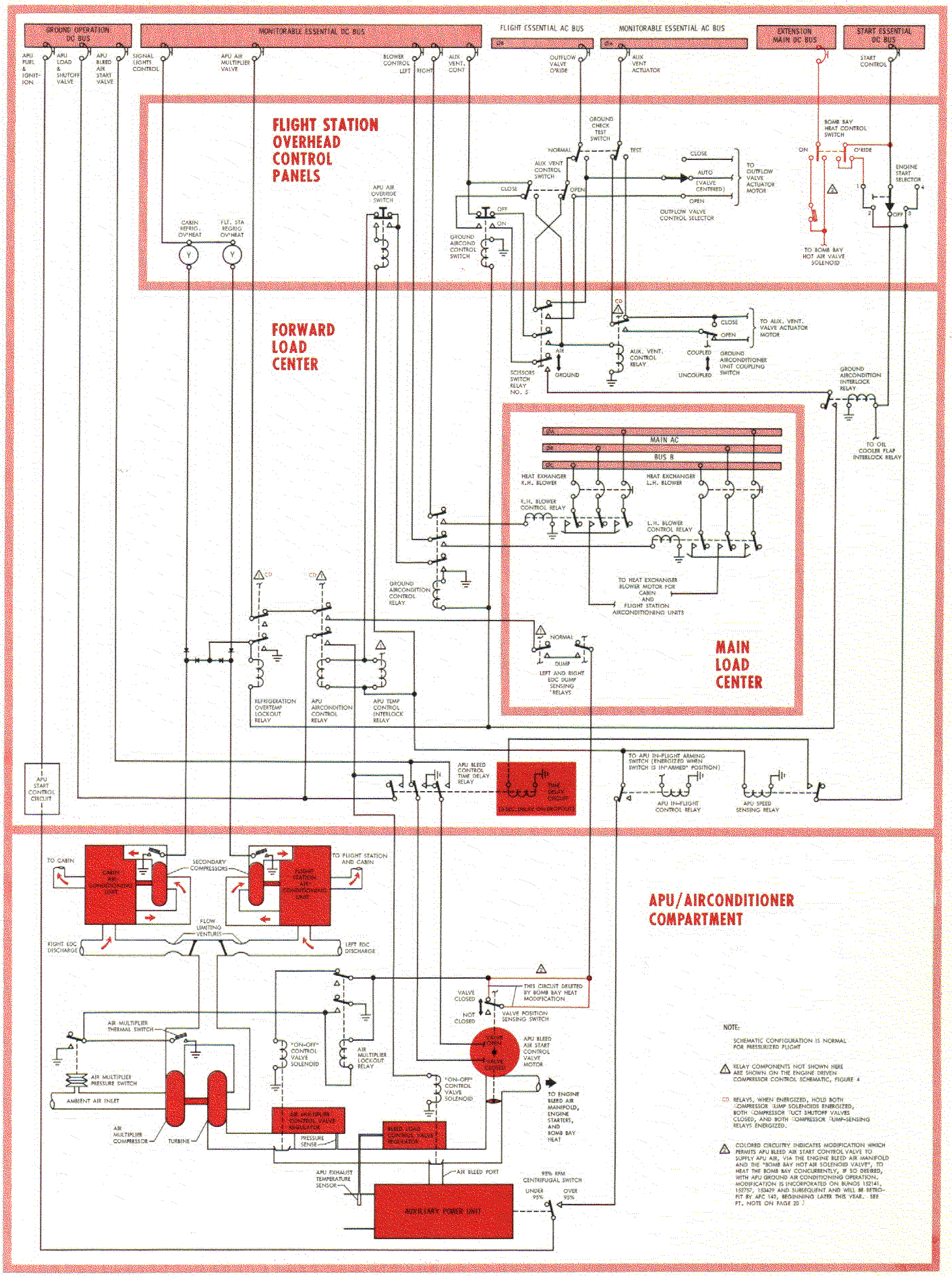
The APU Airconditioning Control relay occupies a key position in the interlocking circuitry. It is dependent for its operation on power from the speed sensing switch in the APU, and on continual operation of the heat exchanger blowers as indicated by closure of the Ground Airconditioning Control Relay. If the APU is above 95% rpm when Ground Airconditioning is selected "ON", both relays will be energized, energizing the blower motors and re-energizing both compressor control relays (dumping the EDC's), and opening the APU load control valve. If the APU is not operating, the APU Airconditioning Control Relay will *not* be energized when the Ground Airconditioning switch is selected "ON", in which case the Bleed Load Control valve will remain closed and the compressor control relays will not be energized.

Thus, an automatic priority is established by the Ground Airconditioning Switch and the APU Airconditioning Control Relay in which APU air will be utilized for airconditioning so long as the APU is operating on speed; the EDC's are made operable (i.e., they are "undumped") and their supply channels to the airconditioning systems are opened if the APU is inoperative or if its speed falls to less than 95% of rated speed.

Of course, if both EDC's are being driven by the inboard engines and the APU is inoperative when Ground Airconditioning is selected "ON," the EDC's will supply the airconditioning units in lieu of the APU. But if the APU is subsequently started, it will pre-empt the task automatically when it comes up to speed, coincidentally dumping both EDC's and closing their discharge duct shutoff valves.

If during APU operation the operator wishes to utilize EDC air for ground airconditioning in preference to APU air, he can do so by actuating the APU Air Override switch adjacent to the Ground Airconditioning Control switch. The override switch effectively simulates an inoperative or under-speed APU, but note that the switch has a "hold-on" solenoid that actually utilizes the signal from the 95% switch to hold the switch at override position. In the event the APU actually does drop underspeed momentarily, the reaction of the system may be puzzling at first glance, and we will digress briefly to explain that it is a normal system reaction — not indicative of trouble in the airconditioner systems.

At the time the APU goes below 95%, the override switch will revert to its normal ("OFF") position. This has no immediate effect, for the EDC's will continue to supply the airconditioning units, but when the APU comes back up to speed, the usual priority will prevail, that is, the EDC's will dump and the APU will feed the airconditioners.



NOTE:

SCHEMATIC CONFIGURATION IS NORMAL FOR PRESSURIZED FLIGHT

⚠1 RELAY COMPONENTS NOT SHOWN HERE ARE SHOWN ON THE ENGINE DRIVEN COMPRESSOR CONTROL SCHEMATIC, FIGURE 4

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

⚠2 COLORED CIRCUITRY INDICATES MODIFICATION WHICH PERMITS APU BLEED AIR START CONTROL VALVE TO SUPPLY APU AIR, VIA THE ENGINE BLEED AIR MANIFOLD AND THE "BOMB BAY HOT AIR SOLENOID VALVE", TO HEAT THE BOMB BAY CONCURRENTLY, IF SO DESIRED, WITH APU GROUND AIR CONDITIONING OPERATION. MODIFICATION IS INCORPORATED ON BUNOS 152141, 152757, 153429 AND SUBSEQUENT AND WILL BE RETROFIT BY AFC 142, BEGINNING LATER THIS YEAR. SEE FT. NOTE ON PAGE 20)

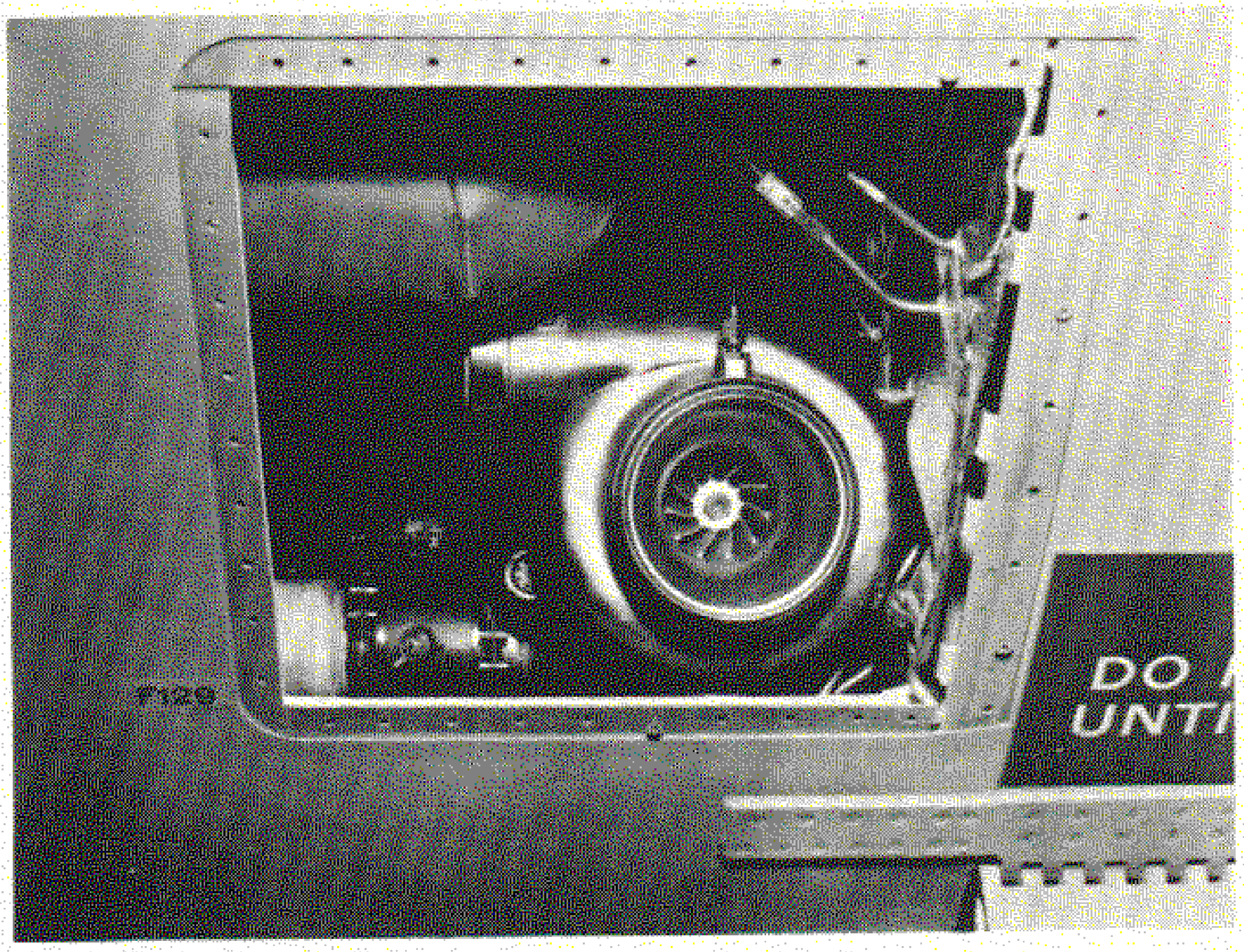
Figure 8 Master Schematic of P-3 Airconditioning Airflow Control, Warning, and Protective Circuits

THE APU BLEED AIR MULTIPLIER The pressure and weight-flow of bleed air from the APU compressor is well suited to the needs of the engine starters, but the pressure is much too high and the weight-flow is much too low for the P-3's twin airconditioning units. The air multiplier shown in Figure 9 is of unique design, specifically tailored to rectify these discrepancies. Bleed air directed through the turbine section of the multiplier experiences approximately a 50% pressure drop and a considerable drop in temperature. The turbine drives a compressor impeller which draws ambient air through an inlet forward and above the LH bomb bay door, compresses it to the same level as the turbine exhaust air, and the discharges from both units are ducted into a common manifold which feeds both airconditioning units.

The two airconditioning units are separately controlled, and it is possible that one of the units would present considerably more restriction to flow from the air multiplier manifold than the other. For example, if the Flight Station Temp controller were set for warmer air than the Cabin controller, the former would bleed off a disproportionate share of air from the manifold, starving the latter unit. To prevent this, the supply to each unit is channeled through an individual flow venturi. The throat of each venturi "throttles" the flow, accelerating it to sonic speed (the speed beyond which further acceleration is impossible) at approximately the same weight-flow as the EDC supplies at Normal RPM at sea level.

The pressure and weight-flow of air available for use by the air multiplier turbine is subject to wide variations according to atmospheric density and the generator load being supported by the APU. For this reason a sophisticated flow regulator is provided to meter air upstream of the multiplier turbine inlet. By modulating the supply to correct for upstream pressure variations, this regulator maintains a uniform flow to the multiplier turbine and also limits the flow as necessary to keep turbine speed within safe limits if too much air is available from the APU.

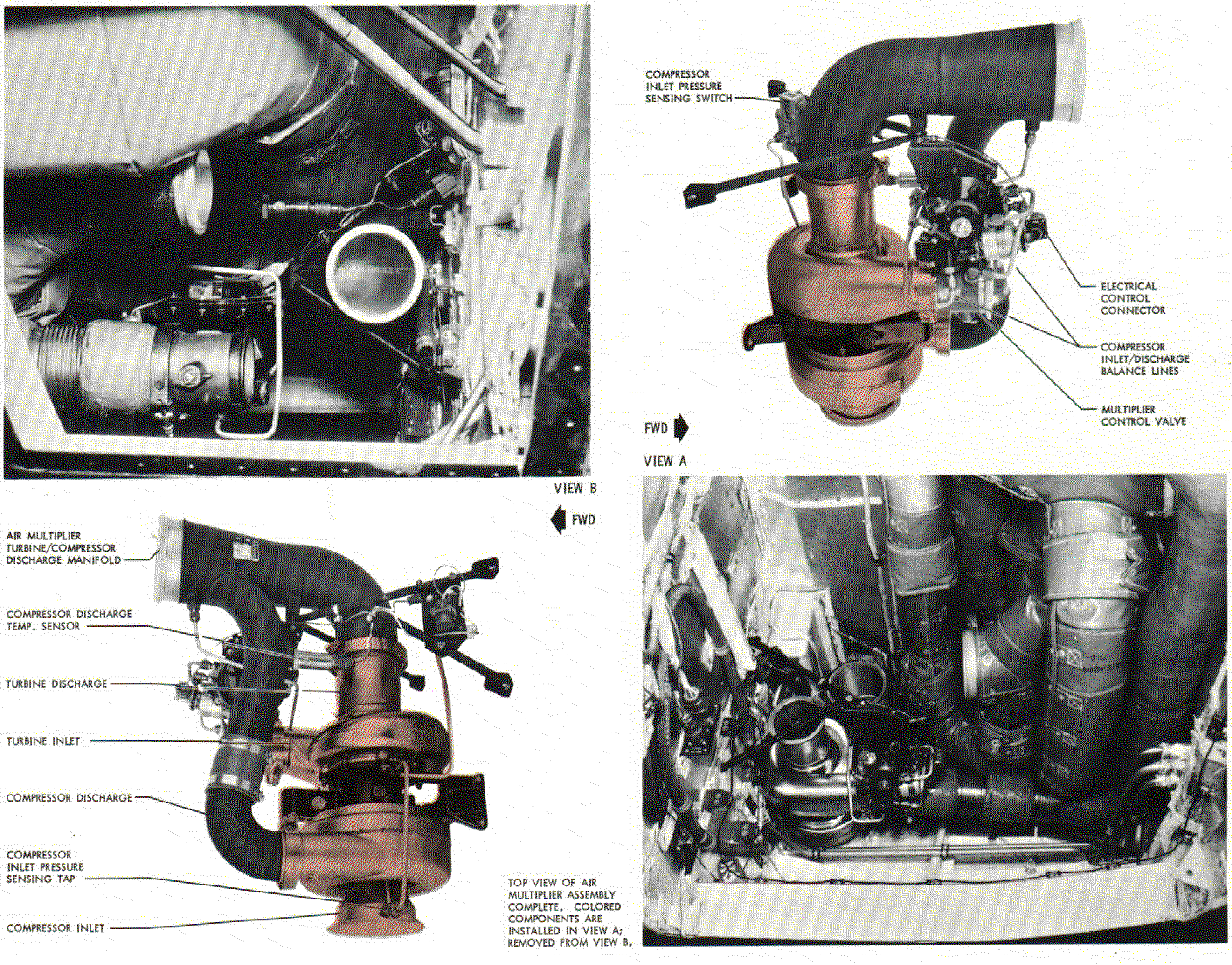
The regulator has a solenoid controlled ON-OFF arrangement similar to the load control regulator discussed previously. To energize this solenoid, all the requirements delineated in the "Load Control" discussion in Items 1, 2, 3, and 4B must be satisfied. Then, after the APU Airconditioning relay has been energized (by 4B: selecting "OFF" at the Engine Start Selector; "ON" at the Ground Aircondition switch) power is routed to the multiplier solenoid through a series of components which establish numerous prerequisites for use of the air multiplier.



As can be seen in Figure 8, the prerequisites are:

1. The Refrigeration Overtemp Lockout Relay must not be energized. Obviously, during Ground Airconditioning operation, this relay ensures that the air multiplier will shut down if either airconditioning unit is overheated. Thereafter it will remain shut down until a), the overheated unit cools and b), the operator manually resets the system by selecting the Ground Airconditioning Switch to "OFF" and then back to "ON". There are a number of possible causes of overheat, the most likely one being a malfunction of the related systems heat exchanger blower, or inadvertent de-energizing of the blowers by monitoring the bus (MAIN AC Bus B) that supplies power to the blower motors.
2. The Left and Right EDC Dump Sensing Relays must both be energized, indicating that air is available from neither of these sources. This will normally be the case for although the Aux. Vent. Control Relay de-energizes the dump circuits when Ground Airconditioning is selected "ON," the APU Airconditioning Control Relay immediately re-energizes them, and will hold both EDC dump solenoids continuously energized unless the APU Air Override Switch is selected "ON."
3. The Bleed Air Start Valve must be closed.*

**As shown on Figure 8, the circuit through the Air Start Valve position sensing switch is eliminated on aircraft incorporating the Bomb Bay Heat modification. On those aircraft it is possible to utilize the air multiplier while the APU Start Valve is open if engines are not actually being started.*



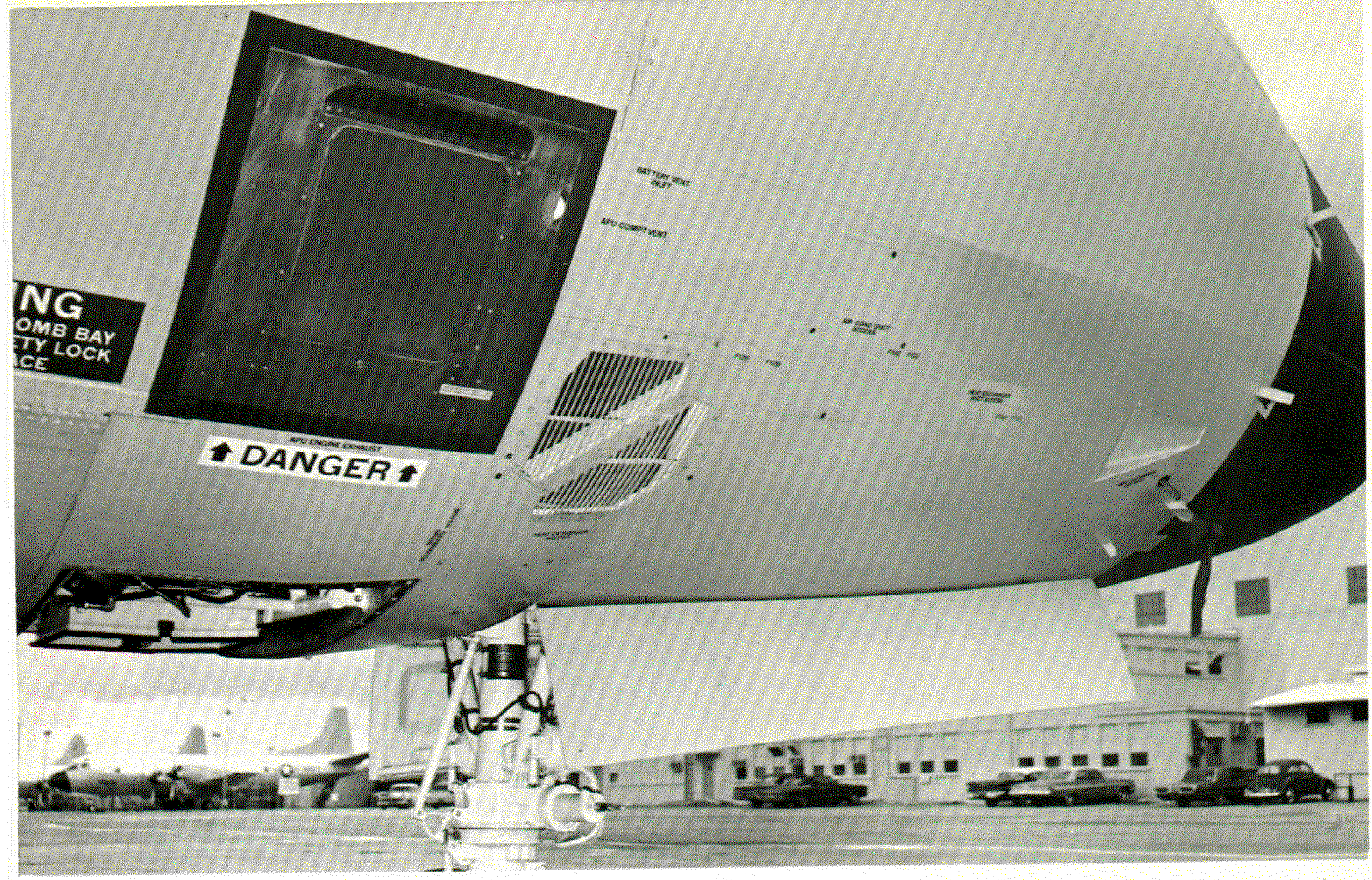
TOP VIEW OF AIR MULTIPLIER ASSEMBLY COMPLETE. COLORED COMPONENTS ARE INSTALLED IN VIEW A; REMOVED FROM VIEW B.

Figure 9 Details of Air Multiplier Assembly and Installation Views Looking Inboard (View B) and Outboard (View A)

Once the air multiplier is operating, two additional components, a pressure sensing switch and a thermal switch, monitor airflow conditions at the inlet and outlet (respectively) of the multiplier compressor. Both sensors protect against overspeed of the multiplier, for either switch can de-energize the air multiplier solenoid and set a lockout relay which prevents re-energization of the solenoid until the Ground Air-conditioning switch is selected "OFF" and back to "ON" — the identical procedure required to reset following overtemp of one of the secondary compressors.

The pressure switch closes when it senses excessive pressure drop in the multiplier compressor-inlet air duct. If the lock-out was due to pressure switch actuation the pressure differential will disappear immediately when the multiplier shuts down and the reset procedure will re-open the air multiplier regulator, but, of course, if an inlet blockage still exists or if an over-speed recurrs the system will lock-out again.

The temperature sensor is located in the discharge duct of the air multiplier compressor. Whereas the pressure switch guards against starvation at the compressor inlet, the temperature sensor guards against excessive compressor output, such as might occur if the pressure regulator failed to limit inlet air to the turbine, or if excessively hot air is ingested into the compressor inlet. A lockout due to an overheat will respond to the reset procedure outlined above, but the thermal switch must be allowed to cool for a period — otherwise it will persistently lock out the air multiplier. Of course, the cause of the overtemp should always be determined and obviated *before* re-activating the system.



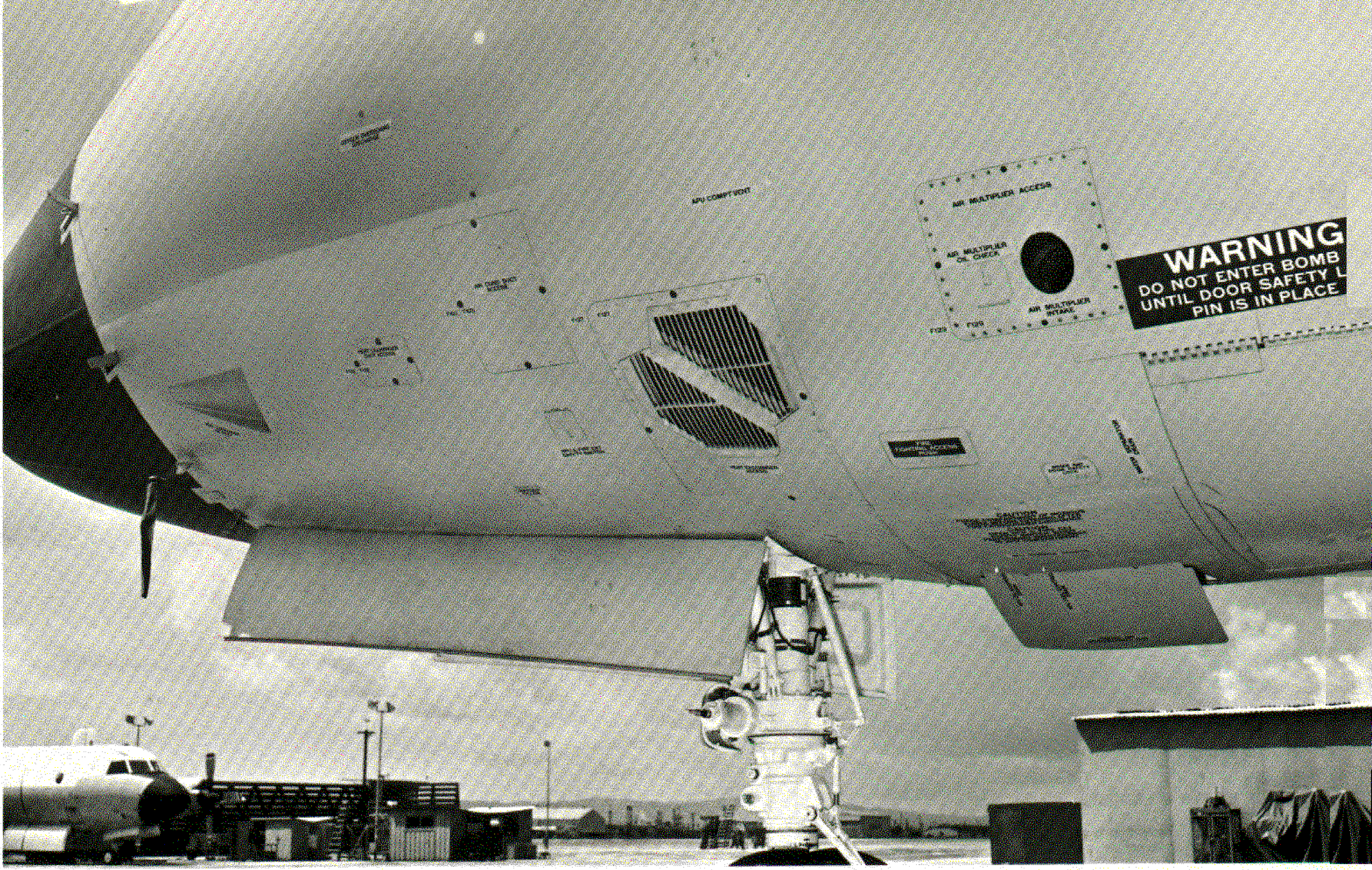
Auxiliary Ventilation There are situations in which it is unnecessary, inconvenient, or impossible to utilize the airconditioning units, but nonetheless desirable to ventilate the fuselage area and the electronic/electrical cabinets. The auxiliary ventilation system provides the necessary facility for such contingencies.

The required ventilating air is inducted through a branch off the ram air duct to the left hand (cabin) airconditioner heat exchangers (see Figure 11). This branch duct permits the ram air to bypass the airconditioning units and utilize both airconditioner internal distribution outlets. As shown in Figure 11, the Aux Vent duct is equipped with a motor actuated shutoff valve and, as shown in Figure 8, this motor is interconnected with the cabin air outflow valve actuator, thus ensuring that ram air entering the fuselage will always find the exit duct open.

The system *can* be utilized in flight (by selecting "OPEN" at the Aux Vent control switch); it will be actuated automatically at touchdown (by Scissors Switch Relay No. 5), and in both cases the L and R compressor Control Relays are energized coincidentally. The provision for automatic operation is, of course, a safety feature ensuring cabin depressurization at touchdown, for the personnel exits cannot be opened unless cabin differential pressure is at a very low value.

During ground operations, one or two of the three subsystems that usually operate in unison (Aux Vent valve, Outflow valve, and EDC Dump controls) will be detached automatically and operate independently under various circumstances. For example, if a ground airconditioning supply hose is coupled to the attachment on the Aux Vent duct shown in Figure 11, a switch on the receptacle access door frame closes the Aux Vent valve automatically, but the Outflow valve and the compressor control relays are not affected. The Aux Vent closure prevents the supplied air from "spilling" (back flowing through the ram air intake), but of course the Outflow should remain open for ventilation and there is no need to "undump" the compressors while a separate air source is available.

With a multiple-source environmental control system such as the Orion's, there is need of an intricate network of interlocking controls to permit the overall system to be operated simply through use of a few controls. It would be needlessly tedious to discuss more of the interlocking features in detail, but for the benefit of those who may need to learn, or to review, the system capabilities, Table 1 provides a brief summary of system response to control actuation in routine operation and in some special circumstances.



APU/Airconditioner Access and Related Ducting. Ram air entering scoops above NLG door leading edge exits through louvers above NLG Strut. APU Air Inlet door at bottom, just forward of bomb bay, shown open in left side view, removed in right side view. APU Engine Exhaust door on right side, shown closed, is hinged at bottom.

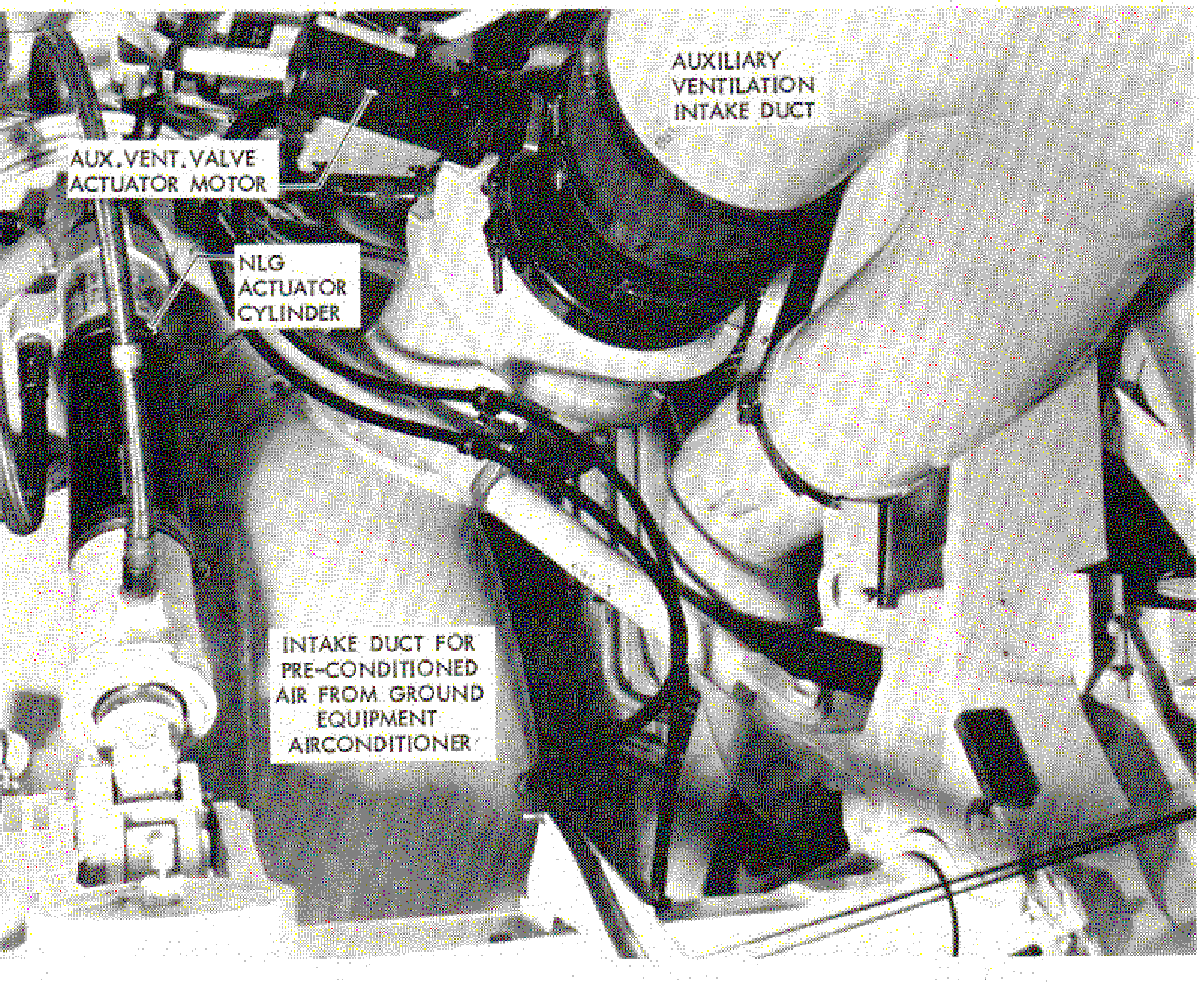
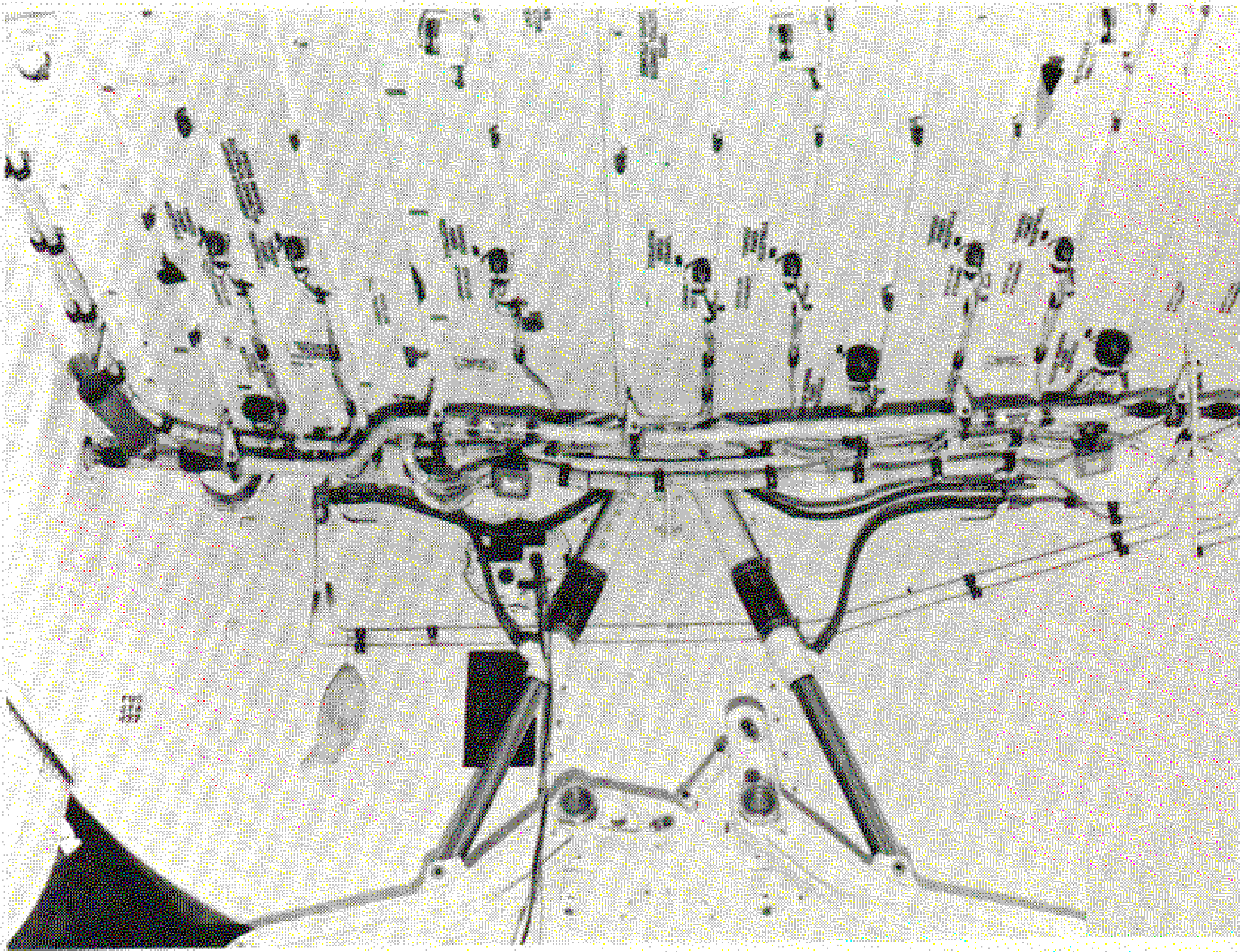


Figure 10 View Looking Aft From NLG Wheel Well



Bomb Bay Heat Installation, View Looking Aft.

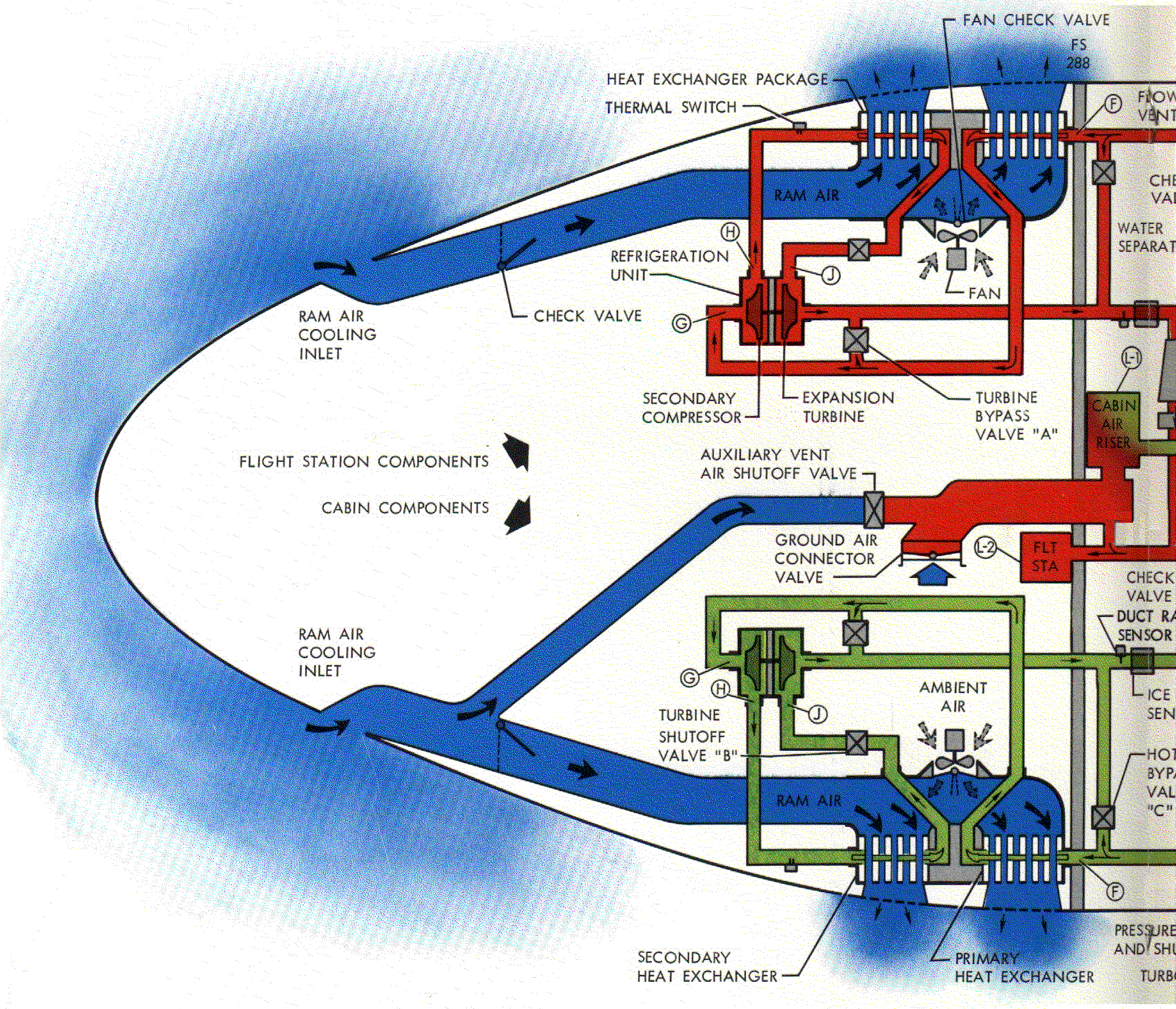
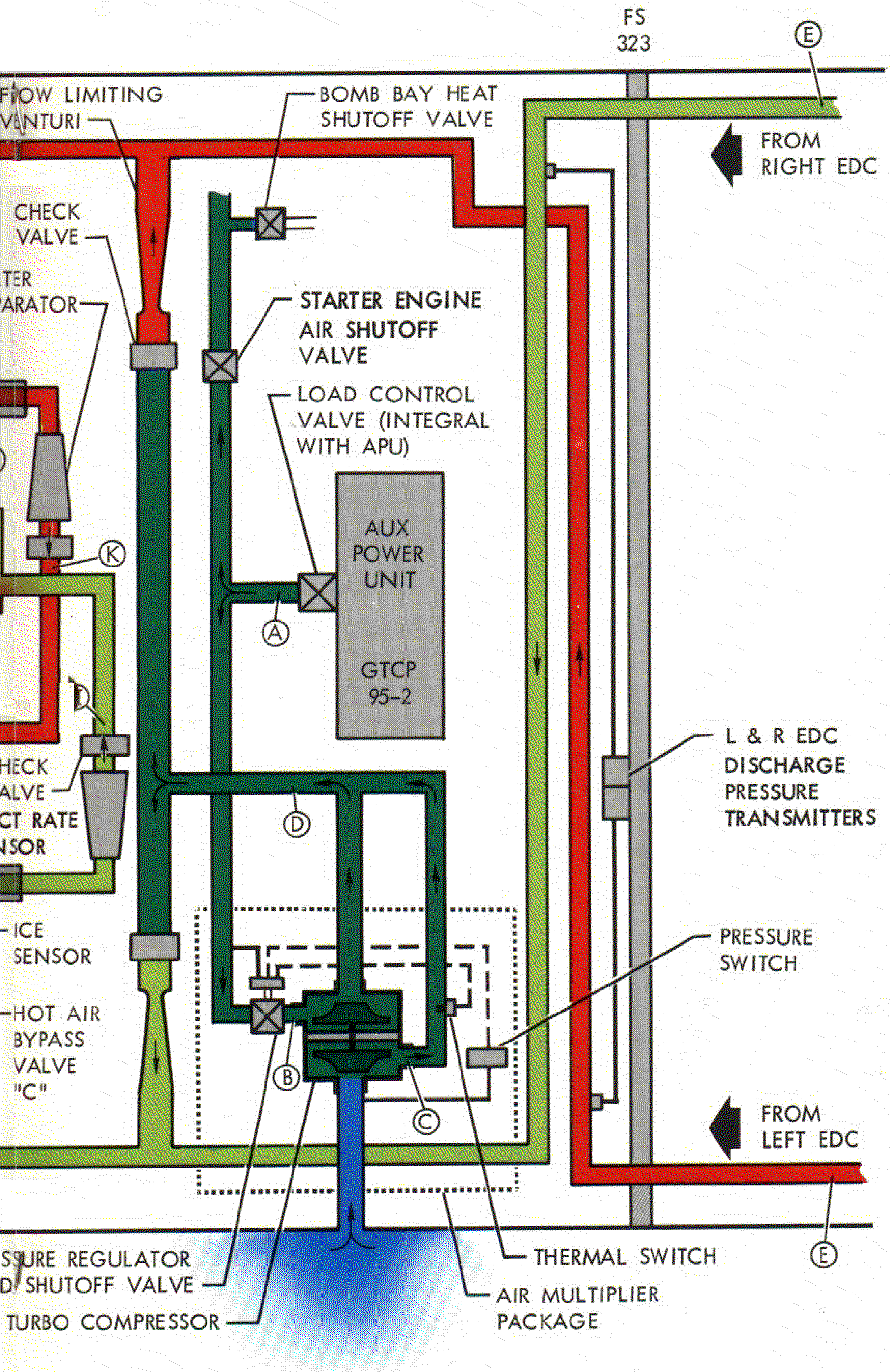


Figure 11 P-3 Airconditioning Schematic Diagram



NOMINAL PERFORMANCE

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

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

	PRESSURE IN 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 (DAR)** 165 36 (DAR)**	62.5 62.5 60
L-1			80+(APPROX.)
L-2			40+(APPROX.)

* POTENTIAL APU FLOW

** DRY AIR RATED

AIR REFRIGERATION

The temperature of the air supply from the engine-driven compressors or the air multiplier exceeds that of the outside air by over 200°F. This air requires at least *some* cooling before it enters the cabin-pressure area, except during operations in an extremely frigid environment. After a portion of the heated air has been routed through bootstrap-type air-cycle refrigeration components and cooled, it is blended with the remaining hot air to attain the desired air output temperature. Then the blended air is distributed to the flight station and cabin areas.

AIR-CYCLE? BOOTSTRAP? If the operation of the Orion airconditioning system is to be well understood, the terms *air-cycle* and *bootstrap* must be clearly defined. A simple air-cycle system cools air by transferring heat from the compressed air to ambient air, and by extracting work from the compressed air as it is being expanded. This extraction of work removes energy from the air, and results in a reduction of the air's temperature. Our simplified example in Figure 12 supplies cool air by utilizing a source of compressed air, a heat exchanger, a cooling (air expansion) turbine, and a fan that performs work by inducing ambient air to flow across the heat exchanger.

First, ambient air is compressed, then passed through the heat exchanger — a device that is physically and functionally similar to an automobile's water radiator or to an oil cooler. As the hot compressed air traverses the heat exchanger's passages, heat energy is transferred from the compressed air via the passage walls and cooling fins to the ambient (fresh) air that is ventilating the exchanger. This heat transfer lowers the energy level of the compressed air considerably, and is accompanied by a temperature drop to a point just slightly above that of the outside ambient air.

Since the air is still compressed, yet more energy (heat) can be extracted by putting the air to work driving an expansion turbine. In Figure 12, a load is applied to the turbine by coupling the suction fan to it, ensuring that the air will expend a substantial amount of energy driving the turbine. This causes a further drop of air temperature. The fan, in return, ventilates the heat exchanger with ambient air. Finally, slightly cool, compressed air exits the expansion turbine ready for distribution.

In contrast to the air-cycle system is the more familiar vapor-cycle system commonly employed by domestic refrigerators, auto airconditioners, and several modern commercial transport aircraft. The vapor-cycle system utilizes a closed refrigeration system in which an entrapped gas (such as freon) is pressurized and cooled so that it condenses into a liquid; the liquefied gas is throttled to expand and evaporate to cool a heat exchanger in the refrigerated area; and the gas is then recompressed and recycled. Thus, the vapor-cycle system's refrigerant is continuously changing from the gaseous phase to the liquid phase, then back to the gaseous phase, etc. Antithetically, the air-cycle system's refrigerant is air, and it always remains in the gaseous phase.

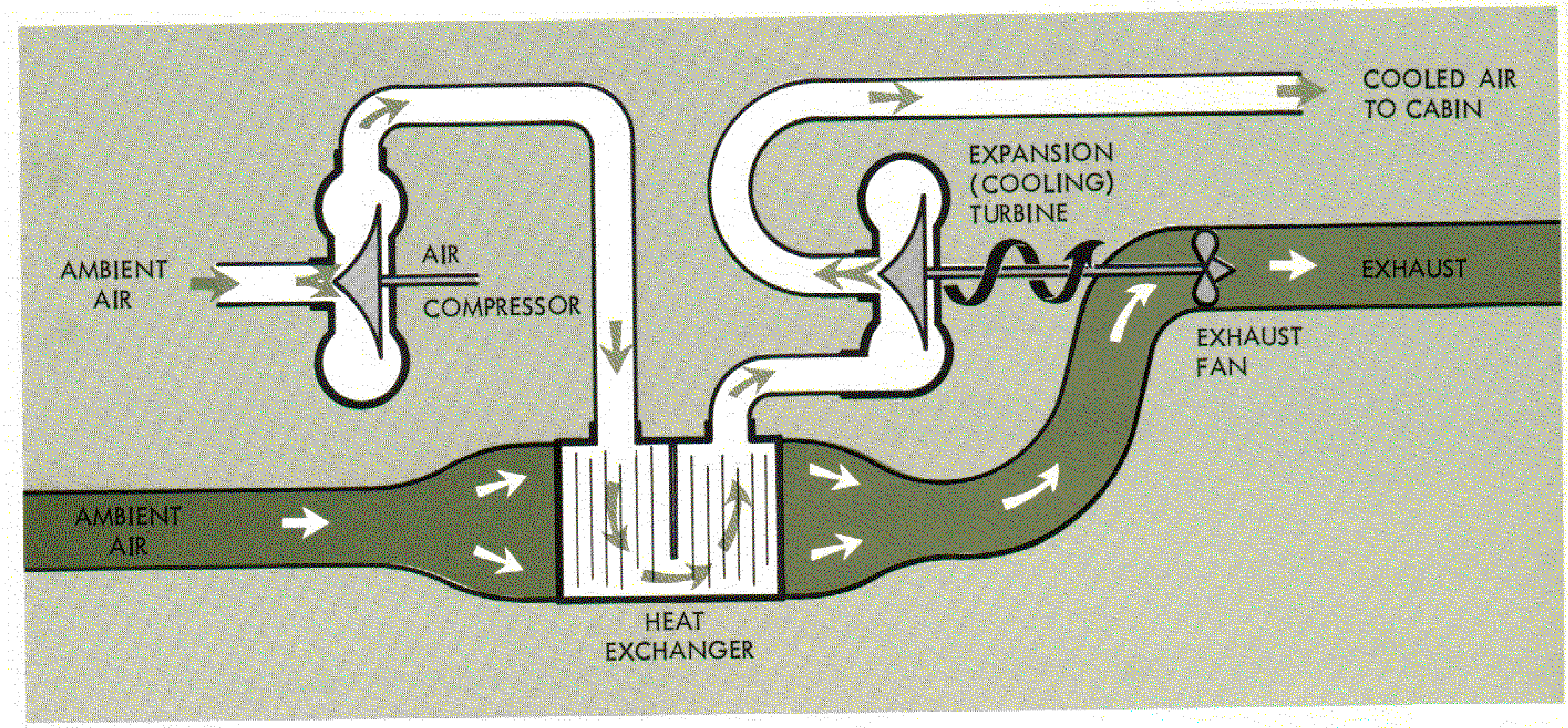


Figure 12 Simple Air-Cycle Refrigeration System

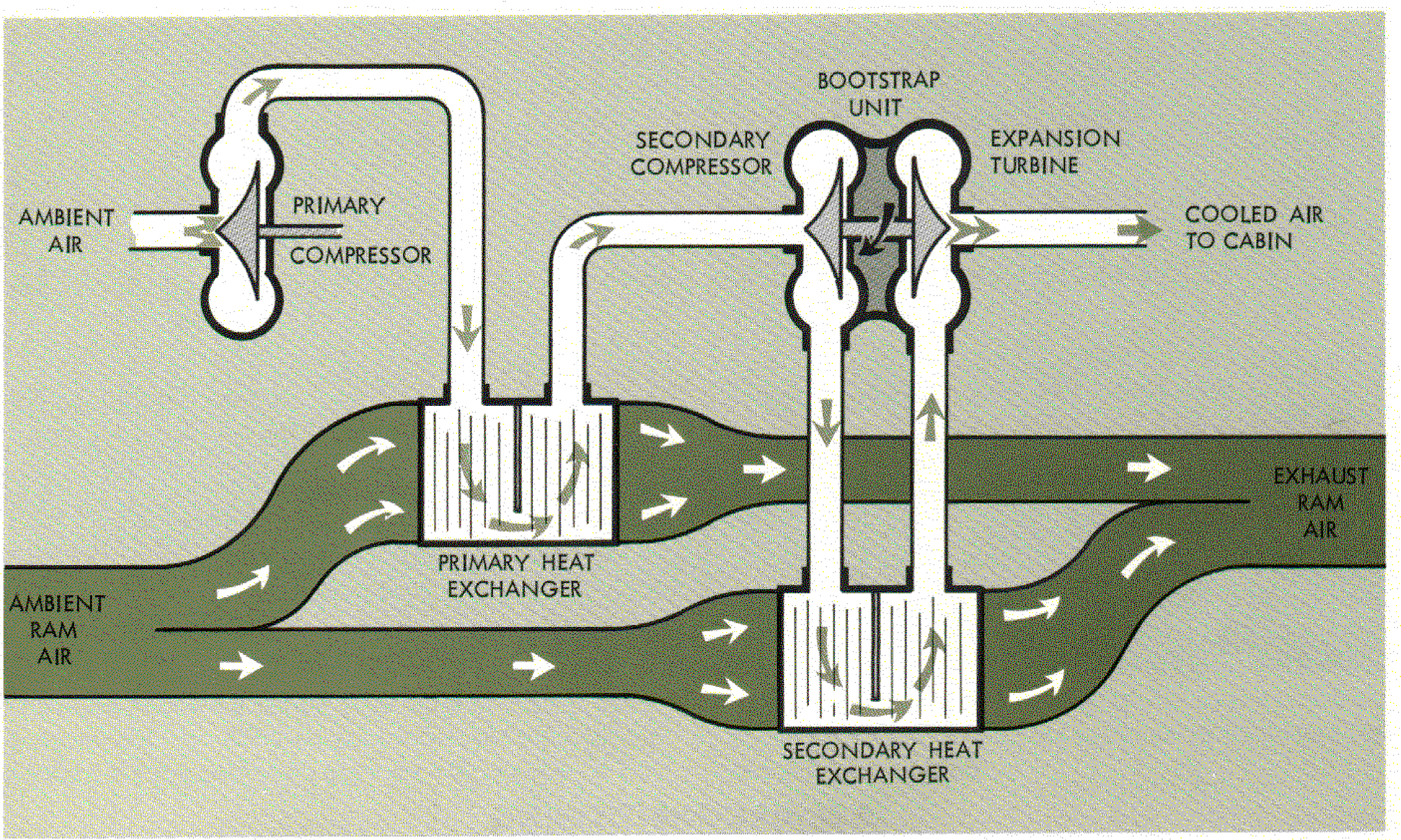


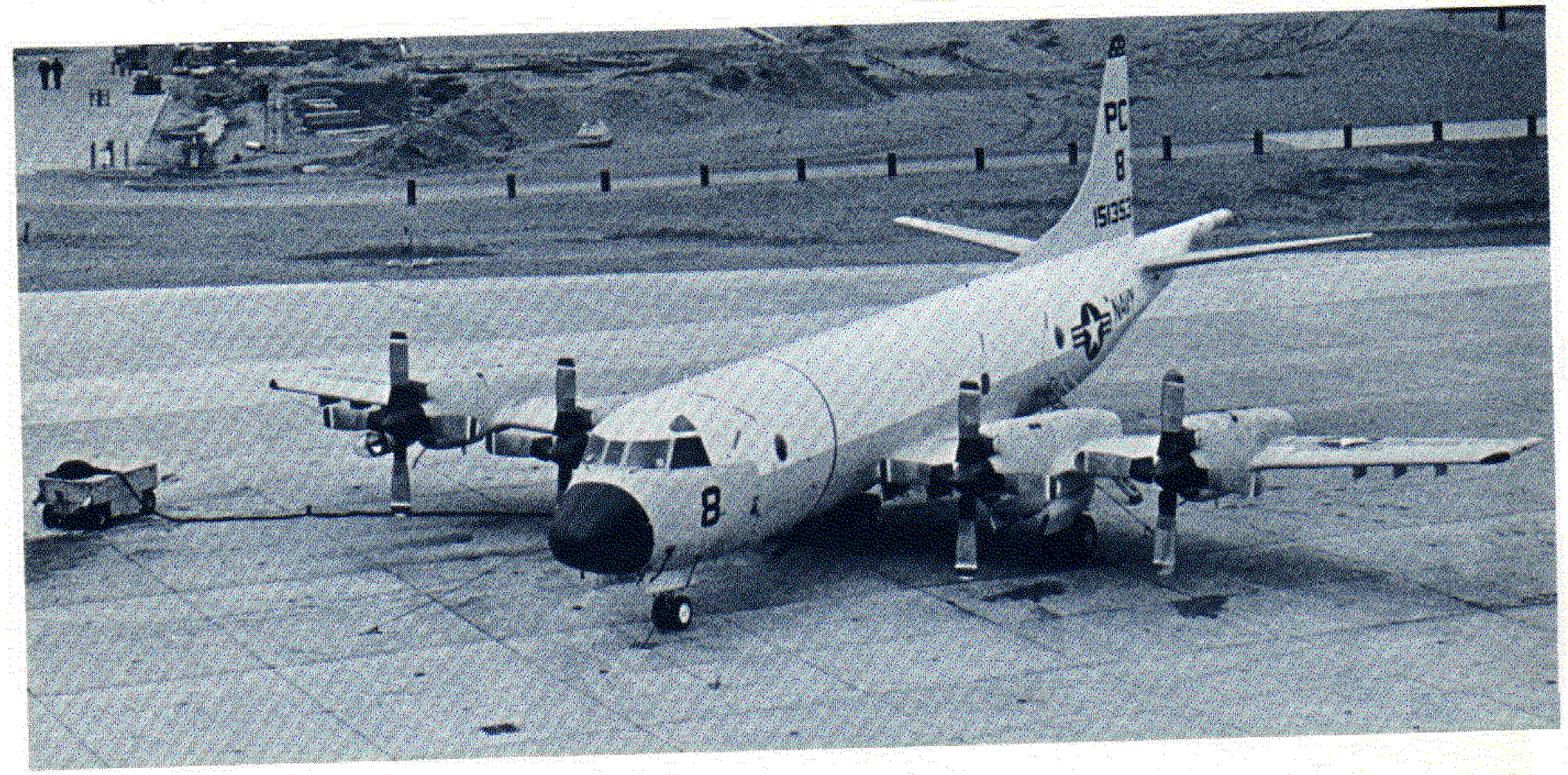
Figure 13 Bootstrap Air-Cycle Refrigeration System

But what of the term *bootstrap?* "Bootstrap" implies self-help, as in the expression "lifting yourself by your own bootstraps." The turbine/heat exchanger fan arrangement of Figure 12 has some qualities of a bootstrap unit, for work expended to remove heat from the compressed air is recovered and used to power the suction fan that ventilates the system's heat exchanger. However, the true bootstrap unit is a compressor/expansion turbine assembly similar to the one used in the system shown in Figure 13.

After ambient air has been compressed and passed through a primary heat exchanger, it is routed to the bootstrap unit compressor. The bootstrap unit compresses the air a second time, elevating the air pressure appreciably above that of the primary compressor air output and elevating the air temperature to a level that may approximate or exceed that of the primary compressor air output. Next, the highly compressed air is passed through a secondary heat exchanger (where it is cooled again by the heat transfer process), then it is routed back to the expansion turbine segment of the bootstrap unit. The air decompresses as it passes through and drives the expansion turbine, and the turbine (attached to the same shaft as the compressor) recovers sufficient energy from the expanding air to drive the bootstrap compressor. This not only supplies more highly compressed air to the expansion turbine, but it extracts more heat from the air. The air that exits from the expansion turbine is cool and ready for distribution. A system incorporating a compressor/expansion turbine unit is called a bootstrap system.

In Figures 12 and 13, it can be assumed that the conditioned air was "used", then exhausted from the conditioned area. An air-cycle system that provides a continuous supply of *fresh* conditioned air and exhausts the "used" air back to ambient atmosphere is called an *open* air-cycle system. However, if the air-cycle system *reclaims* the "used" air for re-conditioning and recirculation, it is called a *closed* air-cycle system.

In summation, "air-cycle" describes an airconditioning system that employs air as the refrigerant. A "bootstrap" air-cycle system differs from a simple air-cycle system because it has a secondary air compressor/expansion turbine unit and a secondary heat exchanger. The P-3 has two independent bootstrap open air-cycle systems, and, although they are somewhat more complex than the example shown in Figure 13, their *modus operandi* is the same.



P-3 AIRCONDITIONING

The heart of the Orion airconditioning system is the two bootstrap-type, open air-cycle refrigeration sub-systems: the flight station sub-system and the cabin sub-system (henceforth given the full-fledged status of systems). Each is an independent system in its own right, complete with an individual source of compressed fresh air and its own electronic temperature control equipment. Both air-cycle systems' refrigeration components are located in the airconditioning service center and in the nose wheel well.

The decision to install an auxiliary power unit (APU), an integrated air-cycle system, and an integrated starting system on all P-3 aircraft by retrofit or during production has resulted in extensive redesign of the original air-cycle systems and relocation of their components. Until all older P-3 aircraft have been APU-equipped through incorporation of Airframe Change No. 110, there will be two basic configurations of airconditioning systems. Their differences are discussed in the paragraphs that follow.

P-3 AIR-CYCLE SYSTEMS The earlier (APU-less) version of the Orion air-cycle system consists of the following components: a ram-air cooled primary heat exchanger, a bootstrap (compressor-turbine) refrigeration unit, a ram-air cooled secondary heat exchanger, an air mixing muffler, an ice limiting sensor, a water separator, and three airflow control valves. Each heat exchanger has an engine bleed air-powered jet pump to induce ambient air to ventilate and cool the heat exchanger during ground operation. Integral with each air-cycle system are the temperature control system components (actually, the airflow control valves and ice limiting sensor fall into this category), that modulate the airflow through or around the air-cycle system refrigeration components.

It was found that a bootstrap unit can overheat if the heat exchanger ventilation ducting becomes restricted. Beginning with P-3 aircraft BUNO 151377, a compressor-turbine overheat warning circuit was installed on each air-cycle system. As first modified, each system had two thermal switches installed in its ducting, one near the bootstrap compressor outlet (this switch closes at 330°F) and the other near the cooling turbine inlet (this switch closes at 220°F). These two switches were wired in parallel, their circuitry leading to the system's "REFR OVHT" light on the Air Conditioning panel and the "PRESS SYSTEM" master caution light on the Main Instrument Panel. If an overheat condition occurred, at least one of the switches would close, and both warning lights would illuminate. Incorporation of Airframe Change No. 38 retrofitted all earlier aircraft to this configuration. Design changes later incurred by the installation of the auxiliary power unit have deleted the thermal switch near the cooling turbine inlet.

At P-3 aircraft BUNO 152141, 152164 and subsequent, an APU-air multiplier package was installed in the airconditioning service center. This area was not exactly commodious during pre-APU days, consequently this welcome addition made it necessary to do a bit of re-designing. In the newer configuration, each system's primary and secondary heat exchangers were physically combined into a single package, and the two bleed-air jet pumps were discarded in favor of a single electrical fan, coincidently eliminating the need for a considerable amount of heat exchanger and jet-pump ventilating system ducting. Finally, each air-cycle system's design was revised to eliminate the need for an air mixing muff. Eventually, through incorporation of Airframe Change No. 110 during major overhauls, all P-3 aircraft will be modified to this later configuration shown schematically on the centerfold of this magazine.

Where the Hot Wind Blows The engine driven compressors and the APU-air multiplier package (if the aircraft is equipped with one) are the sources of hot compressed air for the aircraft's two air-cycle systems. During flight the No. 2 EDC supplies air to the flight station system, and the No. 3 EDC supplies air to the cabin system. The APU-air multiplier package is *not* an airconditioning air source during flight. During ground operations the APU-air multiplier package serves as the primary air source for both air-cycle systems, while the EDCs are the alternate air sources for their respective systems.

At first glance, it may appear that a considerable amount of work was expended to install each system's refrigeration components on the wrong side of the fuselage. The flight station system's air supply is ducted from the left-hand (No. 2) EDC to refrigeration components located on the right-hand side of the fuselage. Conversely, the right-hand (No. 3) EDC supplies air to the cabin system although this system's refrigeration components are on the left-hand side of the fuselage. This design was selected to afford structural flexibility to the ducting, allowing it to expand or contract as the air pressure and/or temperature changes.

Photo courtesy of
Ralph Wortmann,
The Garrett Corporation

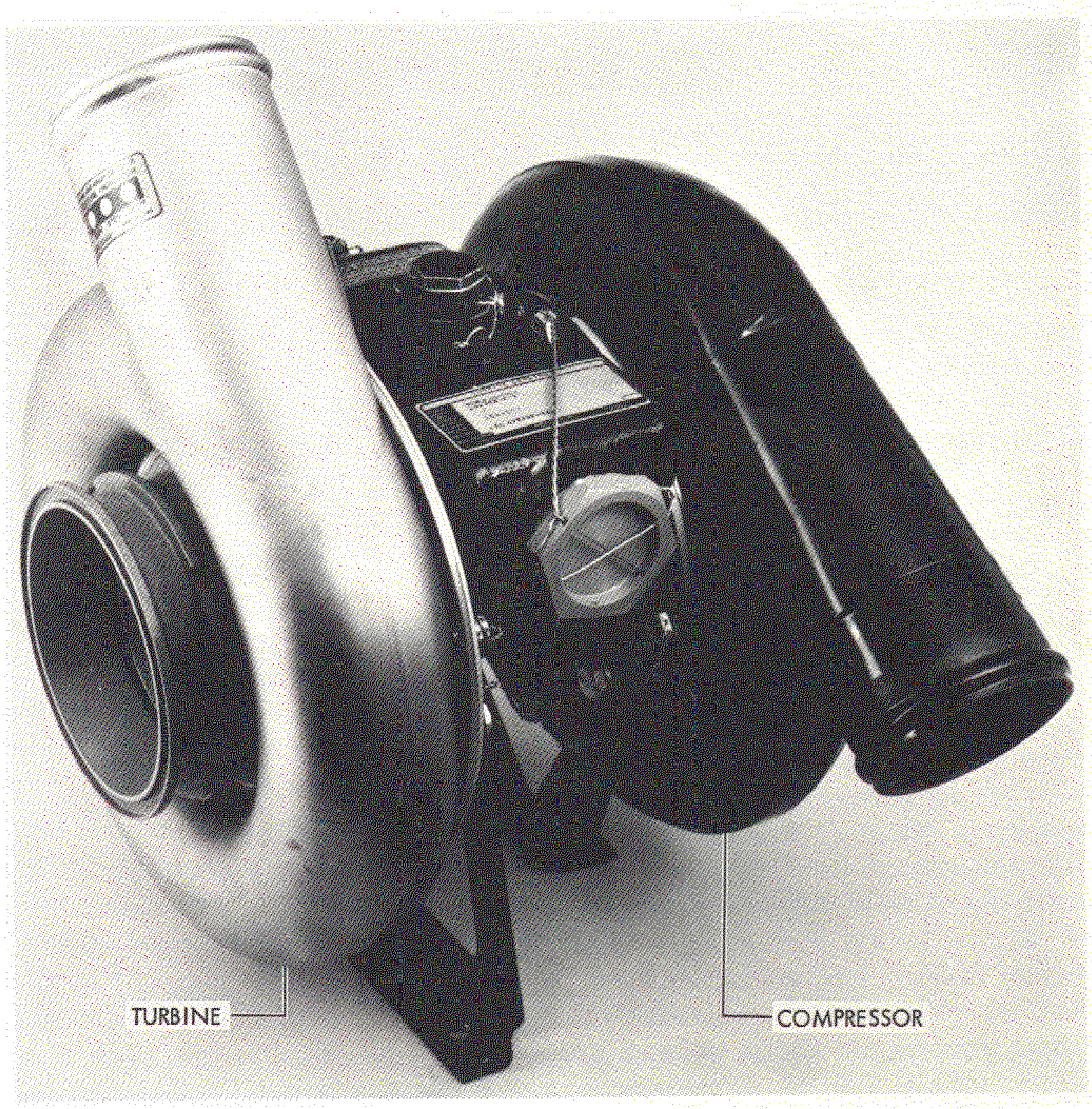


Figure 14
P-3 Bootstrap Unit

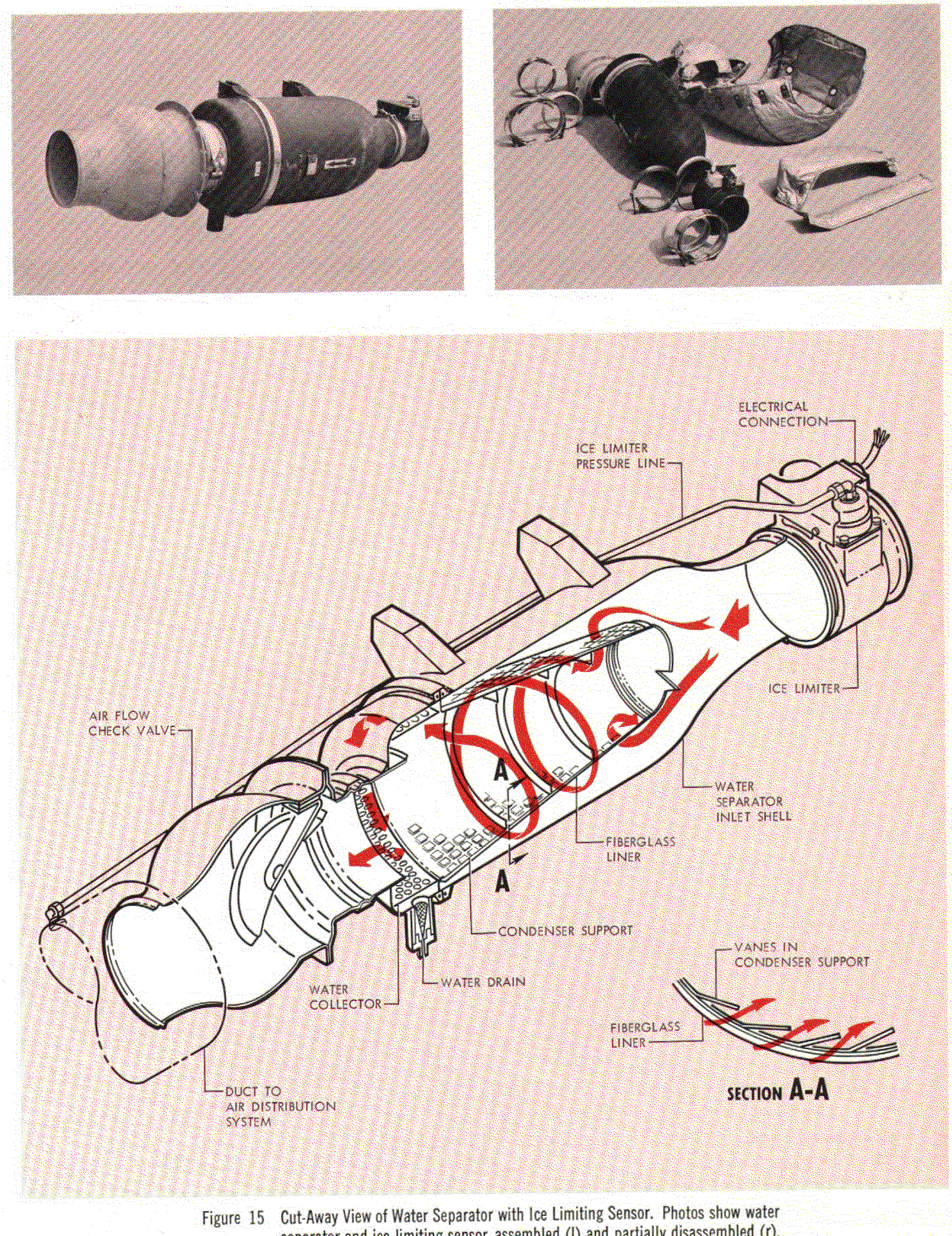


Figure 15 Cut-Away View of Water Separator with Ice Limiting Sensor. Photos show water separator and ice limiting sensor assembled (l) and partially disassembled (r).

Using the centerfold, let us trace the path of one of the air-cycle systems. The hot compressed air enters the airconditioning service center, located under the flight station/cabin floor aft of the nose wheel well and forward of the bomb bay. Portions of the air flow are routed around or through the air-cycle system refrigeration components. This is done by modulating three airflow control valves—the hot air bypass valve, the turbine bypass valve, and the turbine shut-off valve. These valves, directed by the temperature control system, meter the precise ratio of hot, tepid, and cold air to the mixing muff (in aircraft without the APU) or to the ducting downstream from the air refrigeration components (APU-equipped aircraft) where it is blended to the requested temperature. The function of the three control valves is treated in greater detail in the section titled "Temperature Control." After blending, the processed air is passed through a water separator (Figure 15) to remove excess moisture from the air before it is distributed within the aircraft.

Immediately upon entering the water separator, the processed air encounters a dense fiber glass liner that condenses the moisture particles into droplets. After the air has passed through the liner, hundreds of small vanes impart a swirling motion to the air and the airborne water droplets. This swirling motion centrifuges most of the water droplets from the air into the collector where the water accumulates and is drained overboard. The air, thus relieved of about 70% of its free moisture, is ducted into the flight station or cabin and distributed.

There are occasions when ice could form in the water separator. Because of this, an ice limiting sensor is installed in the ducting upstream from the water separator. Initial formation of ice in the water separator causes a pressure drop across the separator. The ice limiting sensor detects this pressure drop and signals the temperature control system to raise the air temperature, or at least not permit the air temperature to get any colder. The function of the ice limiting sensor and its effect on the temperature control system will be discussed in the next section.

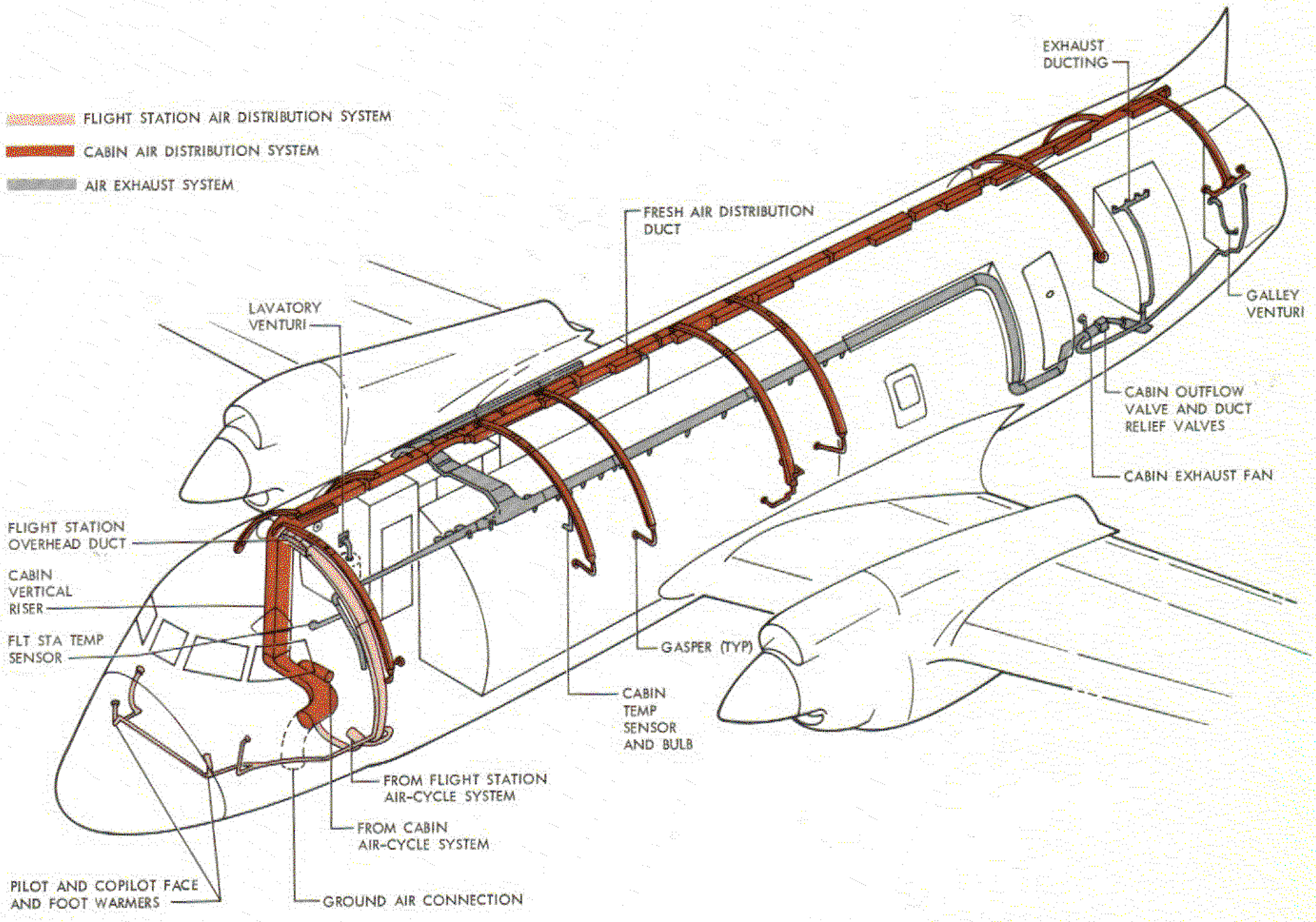


Figure 16 Air Distribution and Exhaust Systems

At this point, let us switch to Figure 16 and resume tracing the path of the processed air. The air, which is slightly pressurized, is ducted through the flight station and cabin distribution systems to the occupied areas of the airplane.* From these areas the air passes through exhaust ducts in the flight station, or through openings in the main cabin electronics racks, around the electronics equipment, and then into the exhaust ducts. The object is to keep the temperature in the electronics bays from exceeding 130°F. After the air is drawn into (or flows into) the exhaust ducting, it is exhausted overboard through the cabin outflow valve. During pressurized operation, some air is exhausted overboard through two venturis, one in the lavatory and (when it is in use) one in the galley. A negligible amount of air also leaks overboard through the fuselage structure. A suction fan is installed in the exhaust air duct to ensure that fresh processed air is continuously circulated through the aircraft. Even when the air-cycle systems are not functioning, when the aircraft is unpressurized, or when the auxiliary ventilation system is in use, operation of the exhaust fan ensures that there will be adequate air circulation through the fuselage.

Thus, air travels from an engine-driven compressor to the airconditioning service center where it is processed by air refrigeration components, then it is distributed within the fuselage and discharged back into the atmosphere. During its trip, the processed air maintains a comfortable temperature at the crew stations, acts as a heat sink for the electrical and electronic equipment, and carries excessive heat and unpleasant odors from the fuselage as it is vented overboard. In the following section we shall discuss how the temperature of the processed air is controlled, and examine the equipment that does this task.

**Although the flight station and the cabin air-cycle systems each process an equal amount of air, due to its smaller volume the flight station requires considerably less processed air than the cabin does. To compensate for this inequity, about half of the air processed by the flight station system is diverted to the cabin system's distribution riser.*

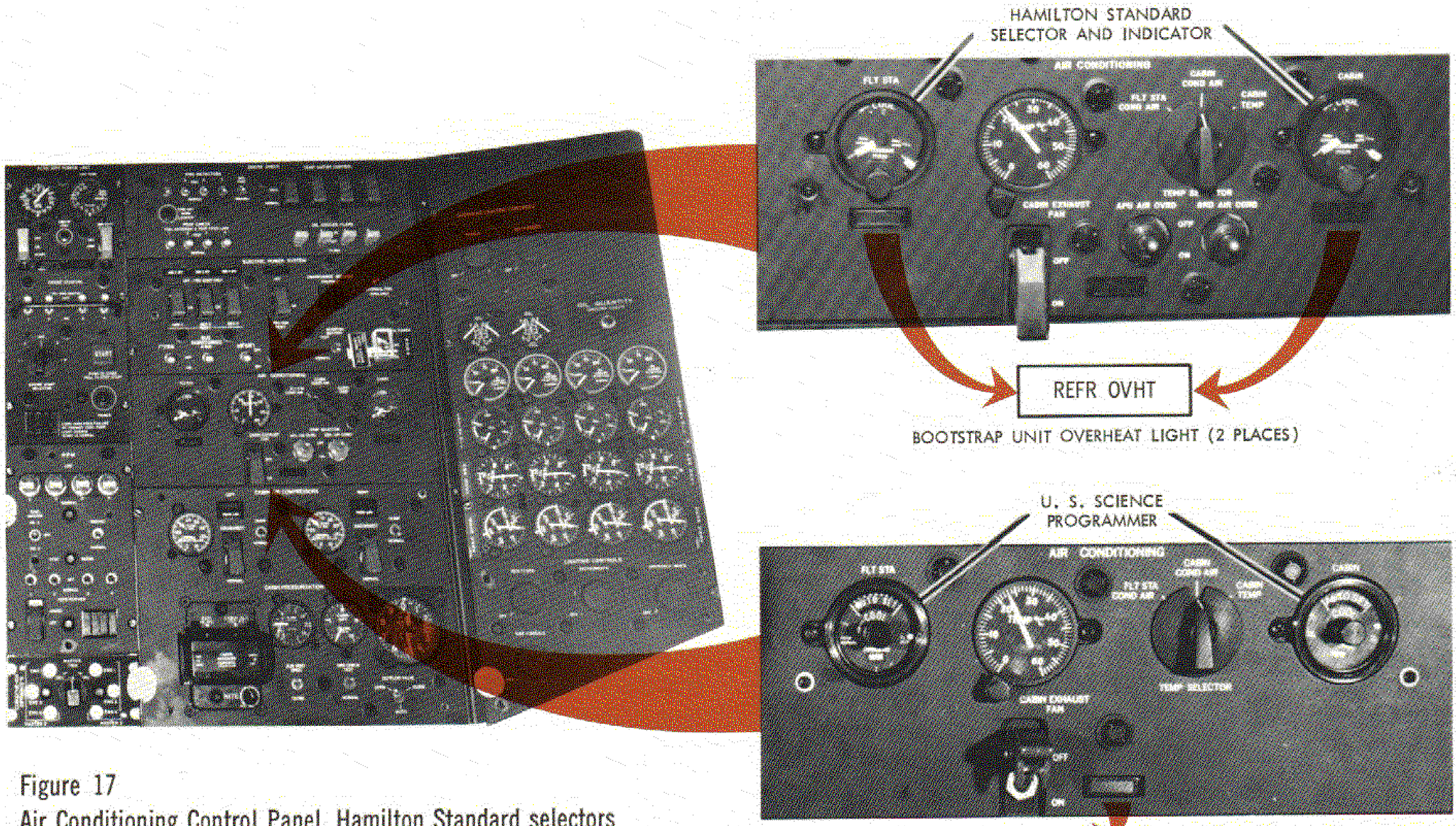


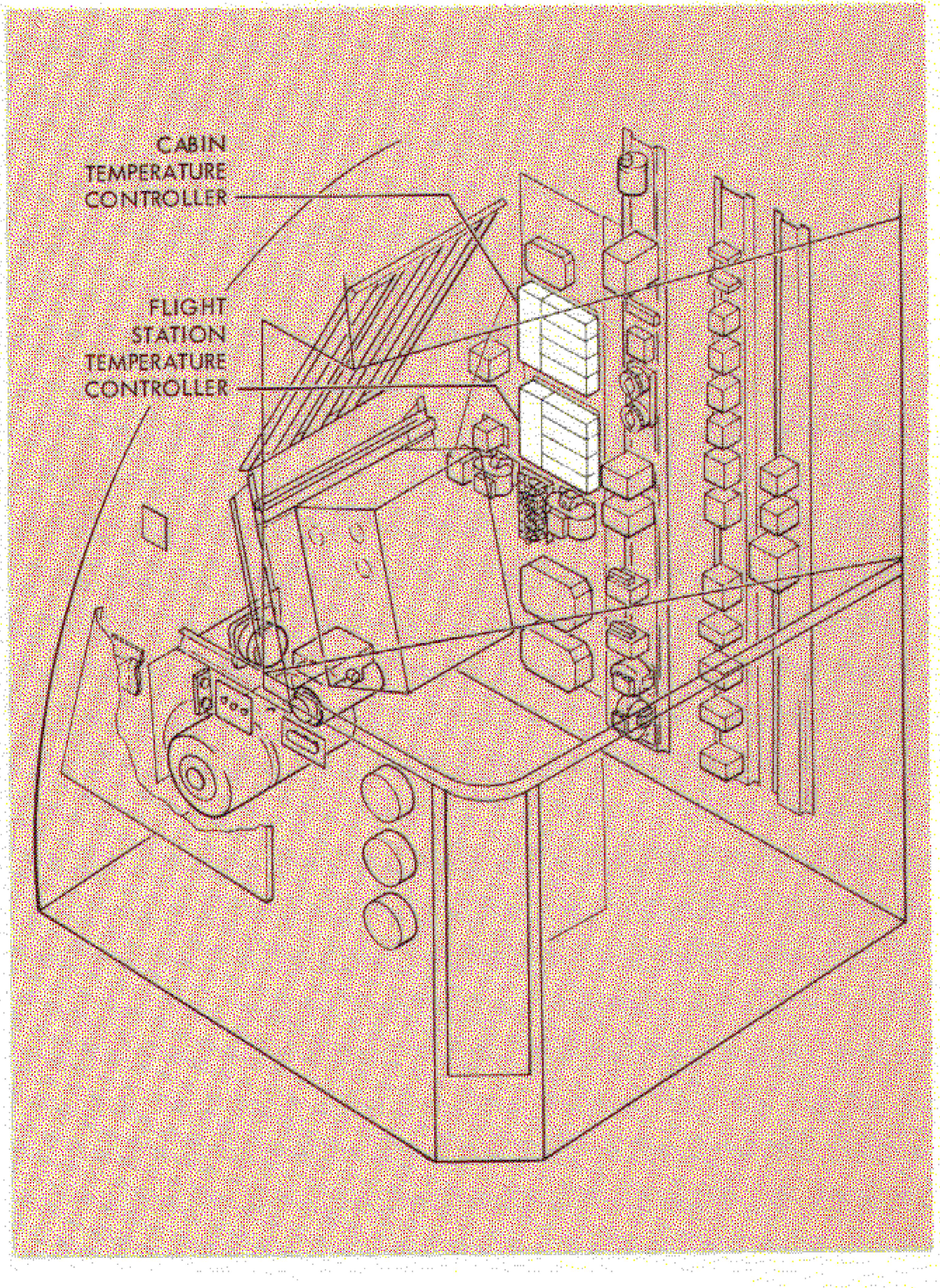
Figure 17
Air Conditioning Control Panel. Hamilton Standard selectors are installed on the upper panel; U.S. Science programmers are shown installed on the lower panel. Drawing of Forward Electrical Load Center shows location of the temperature controllers.

TEMPERATURE CONTROL

Hot compressed air from each engine-driven compressor is shunted around and/or through the air-cycle system refrigeration components by three airflow control valves, then the hot, tepid, and cold air is blended to the desired temperature. It is the job of the temperature control system to modulate these valves so that a selected air temperature may be attained and maintained.

There are two completely independent temperature control systems on each P-3 aircraft, one for the flight station air-cycle system and one for the cabin air-cycle system. Each system is composed of a temperature selector and indicator* (or temperature programmer**), a programming controller* (or temperature controller**), a master temperature sensor, a duct rate sensor assembly, an ice limiting sensor assembly, a pressure ratio limiter switch assembly, and the three airflow control valves.

The selector and indicator assemblies for both systems are located in the flight station on the Air Conditioning control panel (Figure 17), and the



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*Hamilton Standard nomenclature
**U.S. Science nomenclature

two programming controllers are located in the Forward Electrical Load Center. The flight station master temperature sensor is located in an exhaust duct aft of the pilot's left ear on the left side of the aircraft, and the cabin master temperature sensor is located in the exhaust duct above the work table between the navigator's and the Julie-ECM stations. The duct rate sensor assemblies, ice limiting sensor assemblies, and control valves are located in (or in the vicinity of) the airconditioning service center. Lastly, the two pressure ratio switch assemblies are part of the two EDC's on the inboard engines.

The P-3 Maintenance Instruction Manual shows that there are two different brands of temperature control system components. All Orions up to and including aircraft BUNO 150609 were production-equipped with U.S. Science temperature control systems. With the exception of the duct rate sensor, U.S. Science components are completely interchangeable between *U.S. Science* flight station and cabin temperature control systems. All subsequent aircraft have been equipped with Hamilton Standard temperature control systems which (again, with the exception of the duct rate sensor) are interchangeable between *Hamilton Standard* flight station and cabin systems. Unfortunately, corresponding U.S. Science and Hamilton Standard components will fit in the same hole or slot, but — with the exception of the ice limiting (non-ice) sensor — functionally they are not compatible.

Sometime during an Orion's service life it is conceivable that it may be fitted with one U.S. Science temperature control system and one Hamilton Standard system simultaneously. From a functional standpoint this configuration is perfectly satisfactory, but it gives maintenance personnel something additional to concern themselves about. Vigilance should be exercised when repairing or replacing temperature control system components to avoid the inadvertent creation of a hybrid U.S. Standard or Hamilton Science system, for such a system does not function correctly — it just ruins expensive components.

SYSTEM OPERATION The temperature control system has two modes of operation, manual and automatic. When the system is operated manually, the temperature can be varied anywhere from substantially below freezing (if the dew point is low enough) to over 200°F above the outside ambient temperature. On the other hand, in the automatic mode the system is limited to maintaining the temperature at a selected setting nominally between 65° and 85°F. In the manual mode, the temperature control system moves the three airflow control valves to positions that are determined by the selector setting, supplying air at a more or less constant duct temperature* regardless of the temperature within the aircraft. However, in the automatic mode the temperature control system modulates the output air temperature of the air-cycle system as necessary to attain and maintain a selected air temperature within the aircraft.

The mode of operation is chosen by moving a push-pull knob on the face of the selector and indicator (or temperature programmer, as the case may be) — push for the manual mode and pull for automatic. A flag on the face of the instrument indicates whether the "MAN" or "AUTO" mode has been selected. As long as the system is in the manual mode, the ice limiting and pressure ratio limiting protective circuits are disconnected. Any measures that are required to prevent ice formation within the air-cycle system or to compensate for pressure ratio irregularities within the system must be initiated by the man at the system control knob. During the automatic mode the temperature controller takes care of these chores.

Once the mode of operation has been chosen, the desired air-cycle system output air temperature is selected by rotating the selector's push-pull knob. This rotates potentiometers within the selector and indicator assembly, producing a command signal to the temperature controller, and positions a pointer on the instrument's face to indicate whether cooler or warmer air has been selected. In the manual mode this indication corresponds to the system's program position, but in the automatic mode the system's program position is indicated separately.

If the system is in the manual mode, the controller responds to the command signal by positioning the three servo-operated airflow control valves in the air-cycle system. Co-ordination of the three valves' positions is according to a predetermined schedule that is directly related to the temperature program command signal (0% program position equals maximum cooling, 100% equals maximum heating). Naturally, any changes or corrections of air-cycle system output temperature while the system is in the manual mode must be done manually.

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*_The constancy of the duct temperature depends upon th stability of the ambient atmospheric conditions when th system is operating in the manual mode._

During the automatic mode of operation, the controller compares the selector and indicator assembly's command signal with signals from the system's temperature sensors. Whenever the sensors signal that warming or cooling is required to restore the temperature within the fuselage to the selected temperature, the controller will modulate the airflow control valves in the proper direction. Setting the selector at the mid-point of the temperature range usually results in a comfortable environment.

When the automatic mode is initially selected, it may take several minutes for the temperature within the aircraft to stabilize at the selected temperature. During this time lag, the temperature of the processed air from the air-cycle system probably will be considerably warmer (or cooler) than the selected temperature. This normal condition will continue to exist until the temperature control system has matched the inside temperature with the selected temperature. Discourage impatient individuals from re-adjusting the temperature selector setting, otherwise the time required for the system to stabilize will be prolonged. If the system is switched to "manual," the temperature may never stabilize, and the two automatic airconditioning system protection circuits (PRL and ice-limiting) will be disconnected.

Ice Limiting Often, ice forms in the water separators during hot, humid days when the temperature control system is cranked all the way over to the full cold position. By the time the ambient moisture-laden air has been processed through the air-cycle system, it approaches the already-wet water separator liner in the form of an arctic blast. If the air temperature is below the dew point, the wet liner will freeze and restrict the flow of processed air to the air distribution ducting, creating back-pressure throughout the air-cycle system all the way back to the EDC discharge duct. The ice limiting sensor assembly signals the temperature control system when an icing condition within the water separator is imminent.

The ice limiting sensor assembly is situated upstream of the water separator (see Figure 15). It consists of a duct and flange assembly, upon which are mounted two bellows-operated switches (or a dual pressure switch assembly), and a tube that runs from the switch assembly to the downstream side of the water separator. Formation of ice on the liner increases the pressure drop across the water separator, causes the bellows to actuate the pressure switches, and sends a warning signal to the programming controller. The ice limiting circuitry parallels that of the pressure ratio limiter (see the discussion of pressure-ratio limiting in the section devoted to cabin air compressors).

However, when the system is in "manual," ice can also form on the expansion turbine blades and on sharp edges of the ducting. Rapid movement of air across these irregular ice accumulations may cause a howling or screaming noise, a noise that has been the subject of several field complaints. On many occasions the bootstrap unit has been unnecessarily removed, only to find that the evidence has melted. If a banshee-like noise issues from the air-cycle system, reset the selector to a warmer temperature and melt the ice. It is the opinion of Lockheed's Engineering Department that the frequency of icing in the air-cycle system is directly related to the frequency that the temperature control system is operated in the manual mode. Lockheed's Engineering prefers that the temperature control system be operated in the manual mode *only when the automatic mode is malfunctioning.*

The ice limiting sensor can differentiate between three conditions: no ice (green condition); some ice (yellow condition); and too much ice (red condition). The green condition exists until a pressure differential of 2.9" Hg occurs, then the bellows actuates the first (yellow) switch. This signals the controller that some ice is present in the water separator (condition yellow), causing the controller to respond only to those signals that would increase the temperature of the air-cycle system's output. The yellow switch re-opens when the pressure differential descends to 1.8" Hg. Figure 5 shows the ice limiting circuitry.

Sometimes, despite actuation of the ice limiter's yellow circuitry, ice may continue to form in the water separator. When this added ice accumulation causes the pressure drop to reach 4.1" Hg, the red condition is declared and the second pressure switch closes. This causes the controller to open the hot air bypass valve, allowing the hot air to circumvent the air-cycle system refrigeration components and go directly to the air mixing chamber. This influx of hot air is more than enough to melt the accumulation of ice in the water separator. As the ice melts, and when the pressure drop across the separator decreases to 3.1" Hg, the red switch re-opens to return the control circuit to the "yellow" condition.

REMEMBER: The ice limiting sensor will NOT work if the temperature control system is in the manual mode.

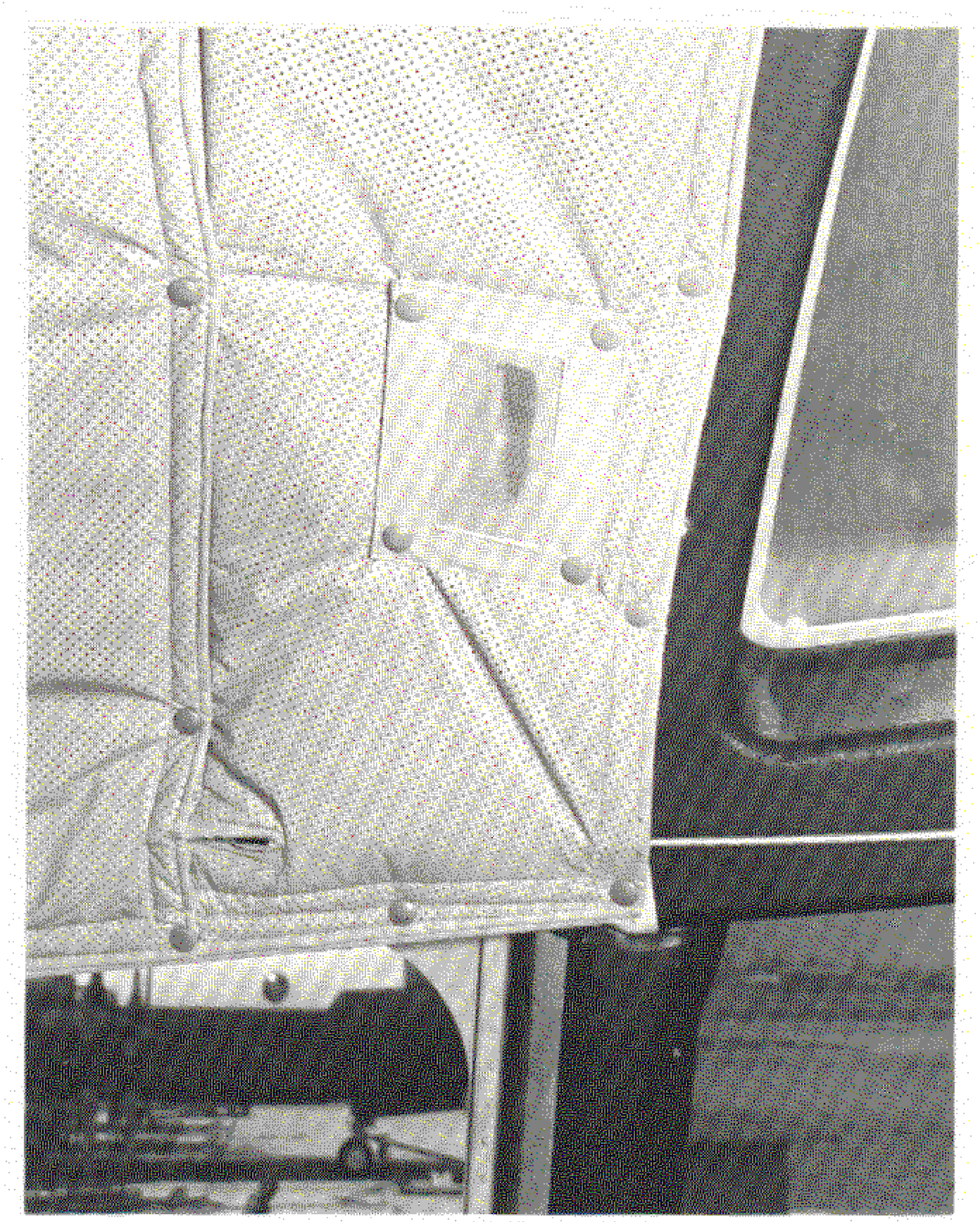


Figure 18 Flight Station Master Temperature Sensor

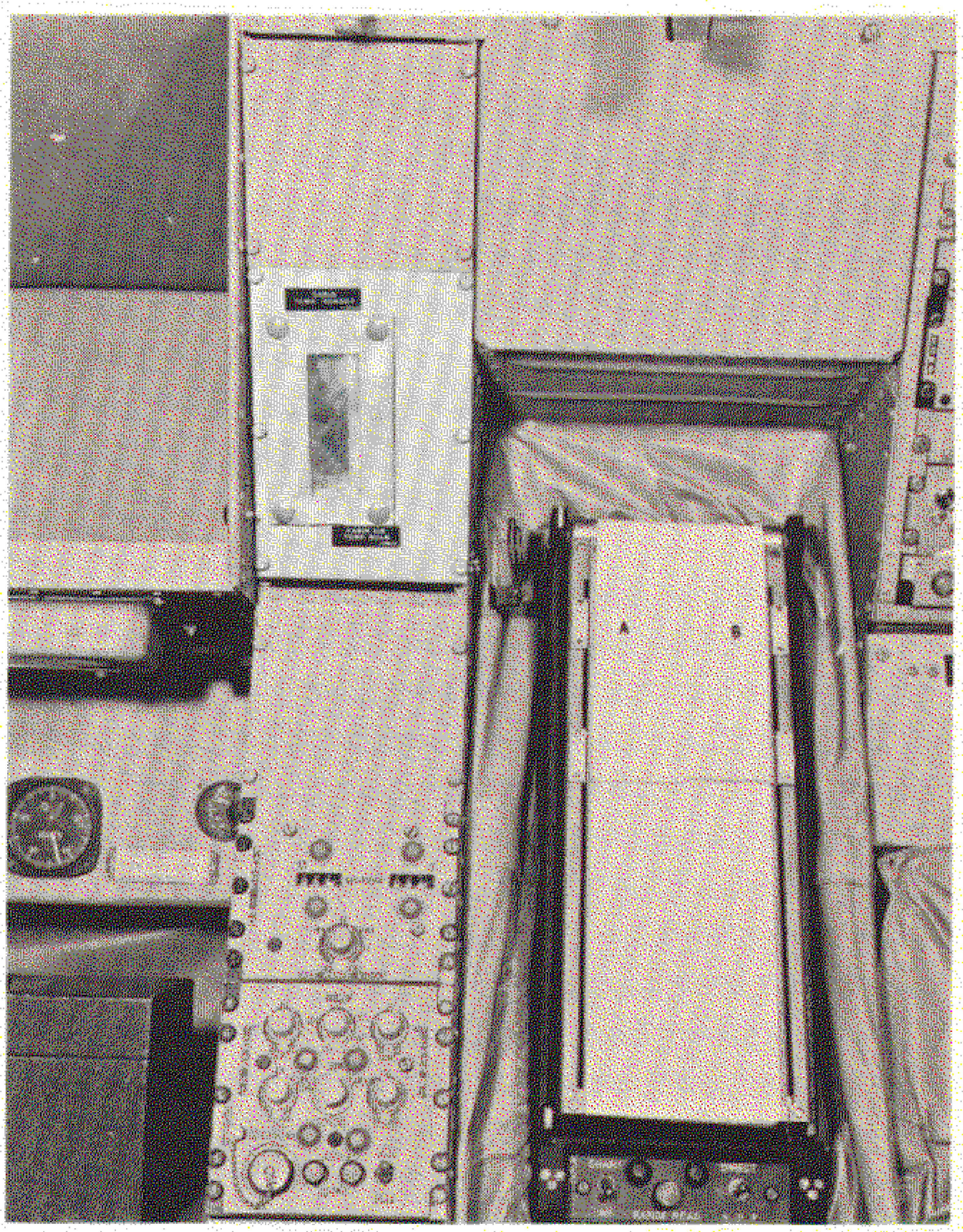


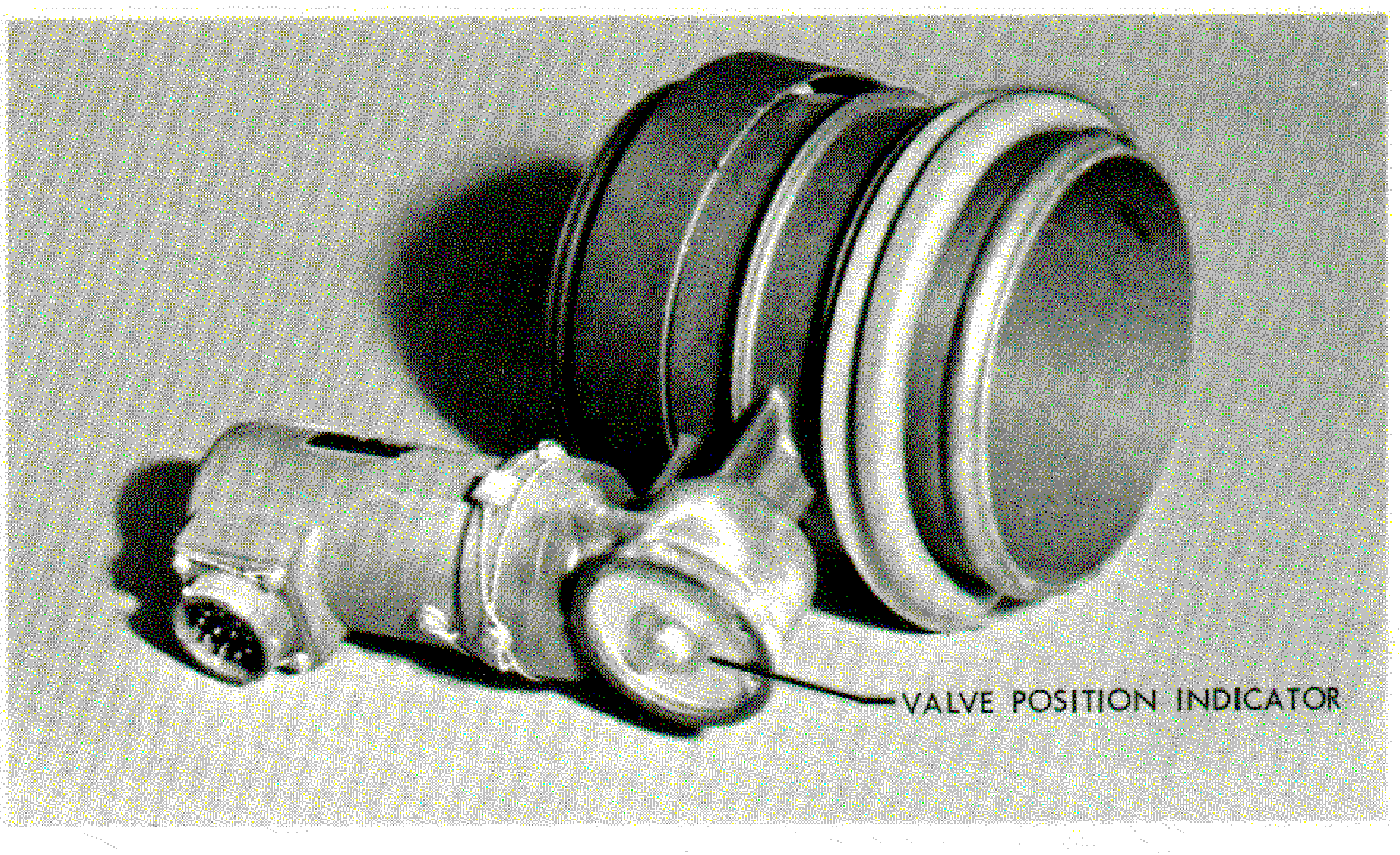
Figure 19 Cabin Master Temperature Sensor and Cabin Air Temperature Bulb.

Temperature Sensors During the automatic mode of operation, each temperature control system has two sources of temperature data — the reference signals from the duct rate sensor and those from the master temperature sensor. The duct rate sensor senses the temperature of the processed air immediately after it has left the air-cycle system, while the master temperature sensor senses the temperature of the air after it has circulated within the fuselage. The heart of both of these sensors is the thermistor, a device whose electrical resistance varies inversely with its temperature. When the temperature control system circuitry is energized, the changes of resistance provide reference signals to the system temperature (programming) controller. The controller combines these signals from the sensors with the temperature selector (programmer) signal and produces the temperature command signal. The command signal is subsequently used by the controller to regulate the temperature within the aircraft. Although the U.S. Science and Hamilton Standard temperature control systems do not employ the signals from the two system temperature sensors in precisely the same manner, both systems must rely upon the sensor signals as the source of temperature data for the automatic mode of operation.

The master temperature sensors are installed in exhaust ducts in the flight station (Figure 18) and the cabin (Figure 19) where the environment is dry, but the duct rate sensors are installed upstream from the water separators where the environment is frequently very hostile. On numerous occasions the duct rate sensors are exposed to humid, saline air, and often salt deposits accumulate upon the sensing elements and affect the sensor's performance. During air-cycle system icing conditions, duct rate sensors have been exposed to airborne bits and pieces of ice. Sensors that are not protected by the duct rate sensor guard* have emerged from these artificial hail-storms much the worse for wear. Whenever the opportunity presents itself, we recommend that the duct rate sensors be inspected and tested.

**Sensor guards have been installed during production beginning with P-3 aircraft BUNO 152886, and some earlier aircraft have had these guards installed during incorporation of Airframe Change No. 110. Although there is no program to retrofit all P-3's with duct rate sensor guards, units that wish to modify their aircraft should contact their Lockheed-California Co. Service Representative for further information.*

Figure 20
Turbine Bypass Valve



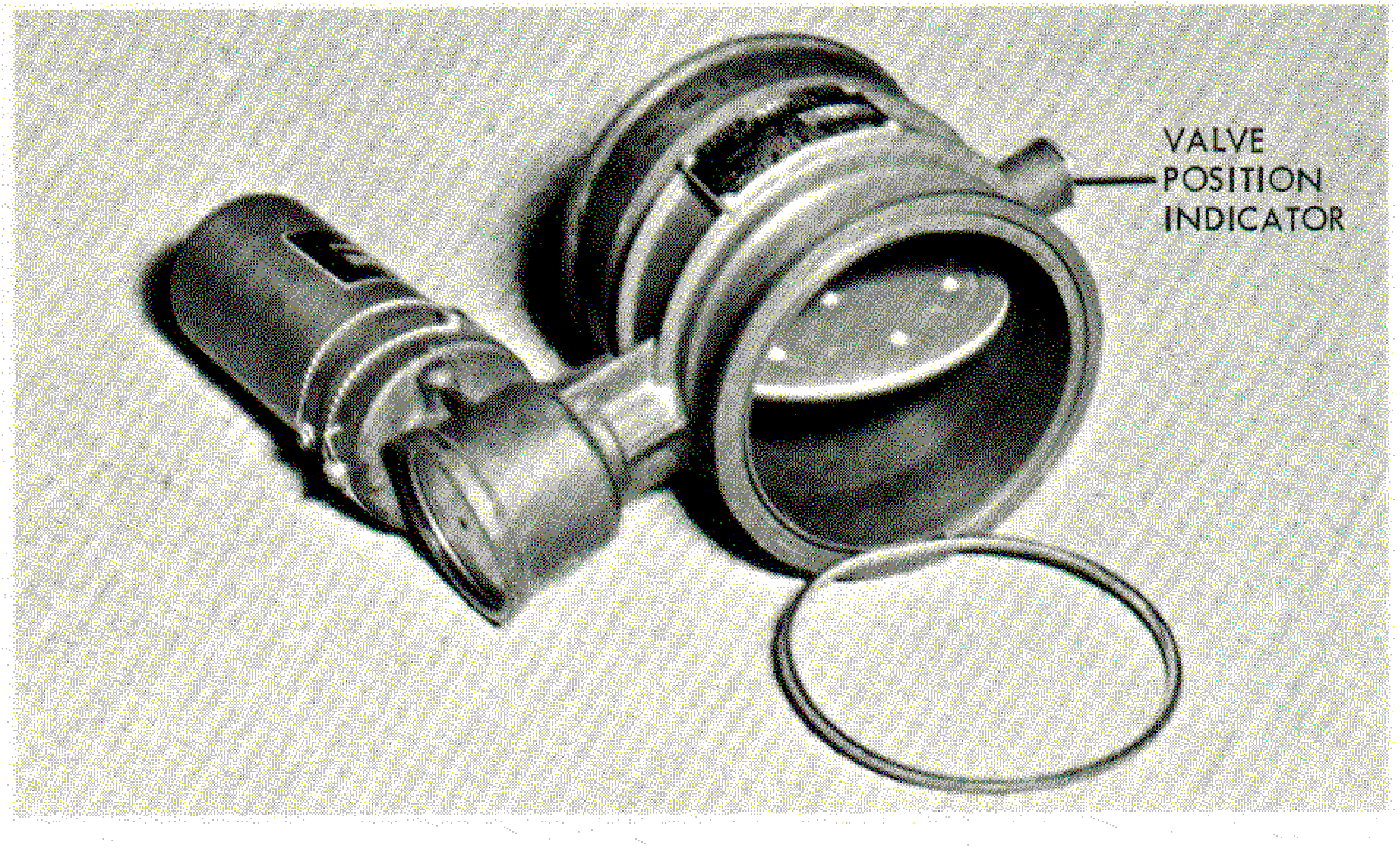


Figure 21
Hot Air Bypass Valve

It has already been stressed that components of one vendor cannot be substituted for those of another, but in the case of the duct rate sensors it is necessary to go one step further. Even if the components are the same brand, duct rate sensors for the flight station cannot be used in place of cabin system duct rate sensors or vice versa. The difference of volume between the flight station and cabin areas is so great that one type of sensor could not satisfy the requirements of both areas.

Airflow Control Valves The air-cycle system air output is regulated by three airflow control valves: the turbine bypass valve (Valve A), the turbine air shut-off valve (Valve B), and the hot air bypass valve (Valve C). Each valve assembly consists of a butterfly-type valve, an ac servomotor, planetary gears, and a follow-up potentiometer. The servomotor, planetary gears, and potentiometer are combined into one unit called a valve actuator assembly that is mounted on the valve housing.

Valves A and B are located in the nose wheel well area, and Valve C is in the airconditioning service center.* The turbine bypass valves (Valve A) on all aircraft are 4½" valves and the turbine shut-off valves (Valve B) on all aircraft are 3½" valves, but aircraft without the APU have 4½" hot air bypass valves (Valve C) while APU-equipped aircraft have 3½" hot air bypass valves. The interchangeability of these valves depends upon the valve size rather than the brand of temperature control system, hence U.S. Science and Hamilton Standard valves may be interchanged so long as they are physically compatible with the system.

**On APU-equipped aircraft this area is called the APU compartment.*

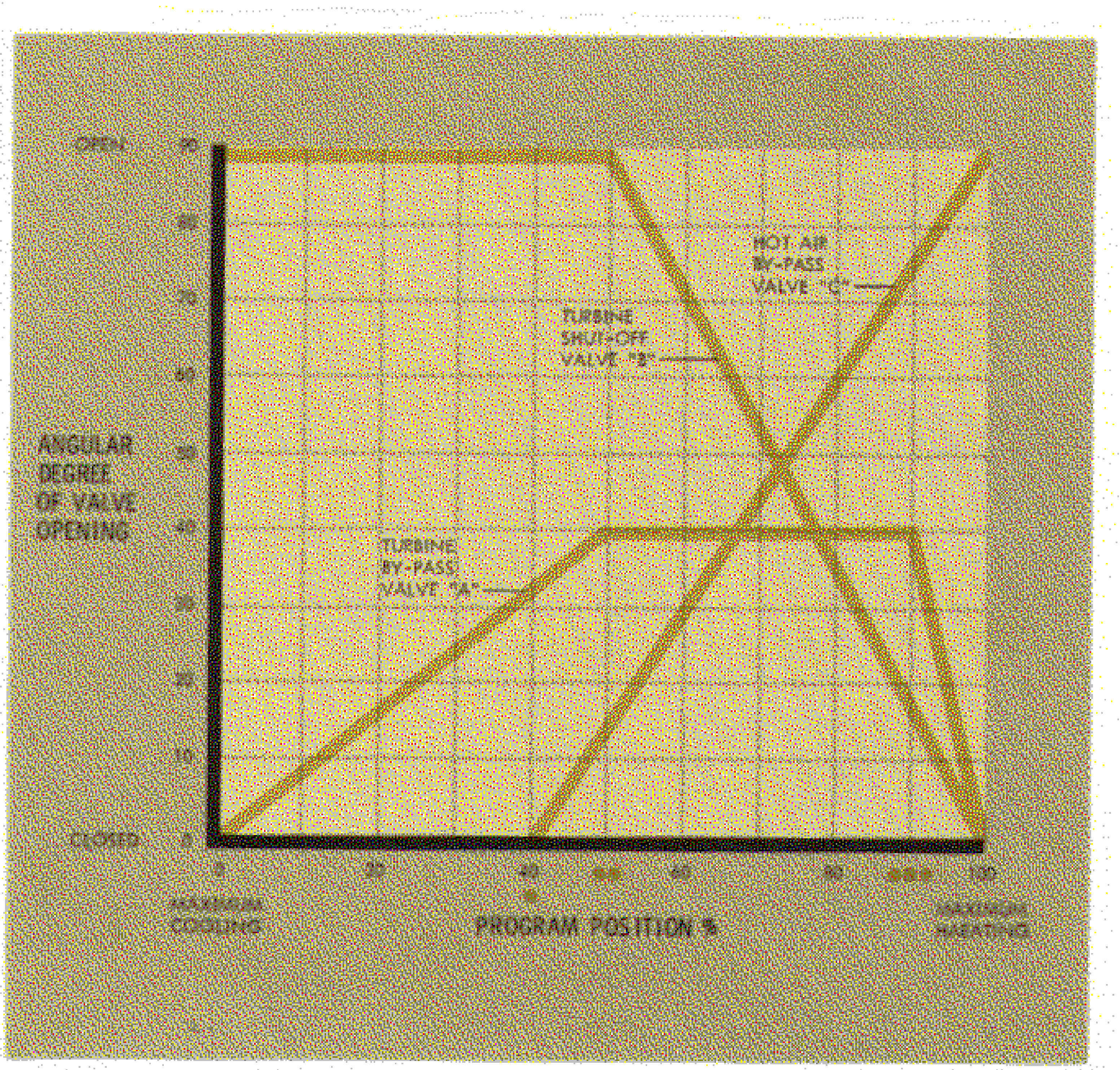


Figure 22 Air-Cycle System Valve Operating Schedule

The principles of operation are the same for all three valves. When a valve's servomotor receives a command signal from the temperature control system, it moves the valve until the follow-up potentiometer nullifies the command signal. The three airflow control valves function as a team according to the temperature control system's predetermined program schedule (see Figure 22). Referring to the program schedule, limits of valve opening or closing occur at the single dot (40%), double dot (50%), or triple dot (90%) program position. These dot markings are placed on the selector (programmer) face for reference purposes.

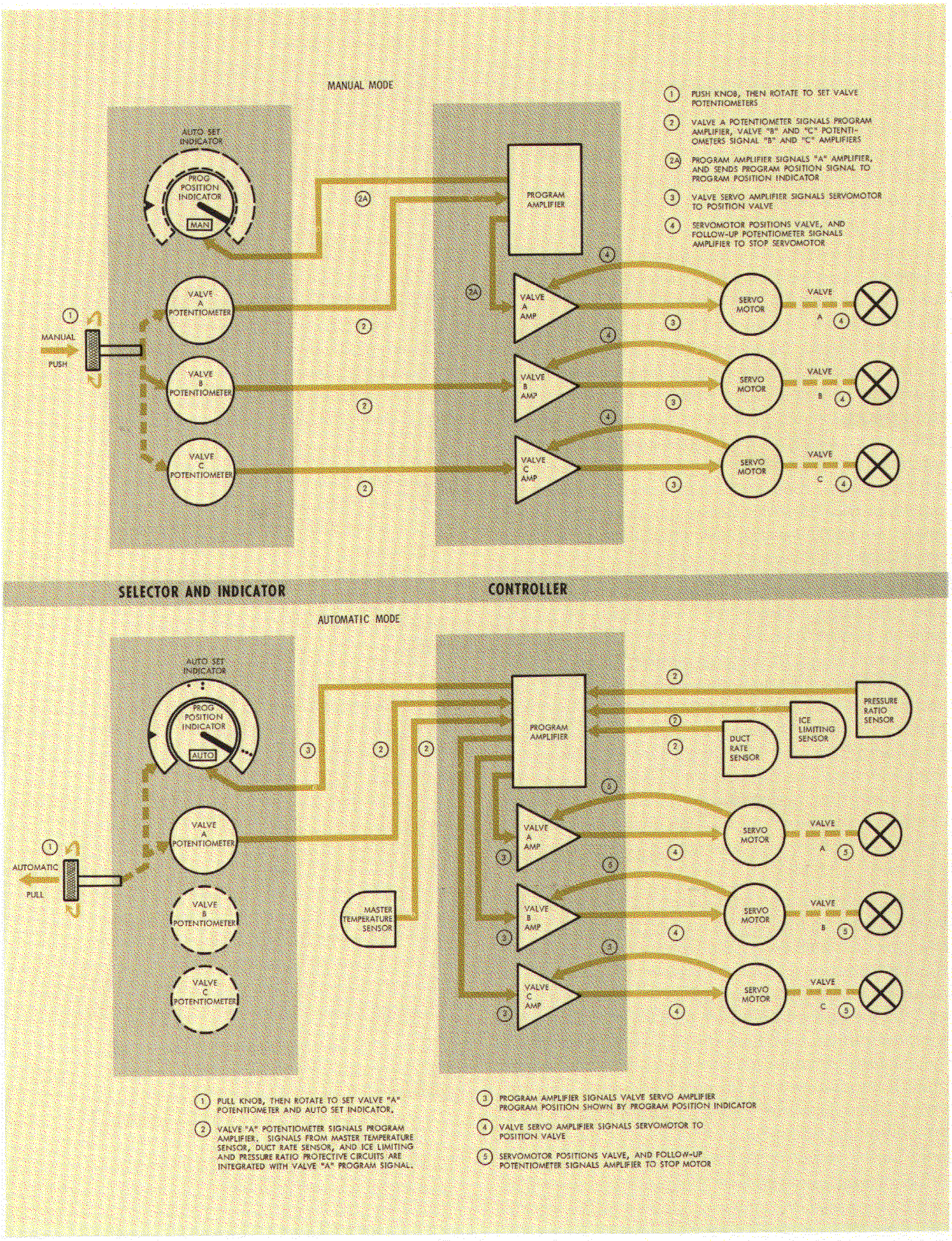
BLACK BOXES The selector and indicator assembly (temperature programmer) and the programming controller (temperature controller) are the temperature control system's little black boxes, both of which are powered from the Monitorable Essential AC Bus. The mode of operation, manual or automatic, and the desired temperature are chosen by either pushing or pulling the selector knob, and then rotating the knob to move the selector pointer to the desired temperature setting. This action produces a command signal that is sent to the controller. The controller receives the command signal, compares it with reference signals from the master temperature sensor and the duct rate sensor (if the system is in the automatic mode), determines what the proper airflow valve positions should be, and signals the valve servomotors to drive the valves toward the proper positions.

Selector and Indicator (Temperature Programmer) Assembly Each make of temperature control system has its own nomenclature for components whose function and appearance are quite similar. In the case of the component used to choose the operating mode and temperature setting, Hamilton Standard calls this device the selector and indicator assembly. U.S. Science's corresponding component is called the temperature control programmer, or temperature programmer for short. Physically the two brands of selector/programmers are interchangeable, but functionally they are not. The Hamilton Standard selector and the U.S. Science programmer both afford the means of choosing the mode of operation and selecting the temperature, but the U.S. Science system's programming is actually done by this instrument. Figure 17 shows the distinguishing features on the faces of the two brands of instruments, and the components are briefly compared in the following paragraphs.

The Hamilton Standard selector and indicator assembly has two pointers on the face of the instrument, one at the periphery and one at the center. The peripheral pointer gives an approximation of the temperature program command signal *that the instrument has been set to send to the temperature controller.* The pointer in the center of the dial is the indicator of a voltmeter that is connected to the temperature controller circuitry. This voltmeter indicates the magnitude of the program command signal that the controller *actually is sending* to the airflow valve servo amplifiers.

There are three potentiometers inside the Hamilton Standard selector assembly. During the manual mode of operation, each potentiometer provides a command signal to one of the three servo-operated airflow control valves (Valves A, B, and C) via the programming controller. When the automatic mode is selected, the "Valve A" potentiometer provides the temperature controller with the command signal for all three airflow control valves.

The U.S. Science temperature programmer also has two indicator pointers on the dial face. The upper gives an approximation of the temperature command signal that the temperature control system is being directed to attain and maintain automatically. The lower pointer indicates the command signal that the programmer actually is sending to the controller's valve servo amplifiers. The lower pointer's indication of system performance is valid for both the manual and the automatic modes of operation.



① PUSH KNOB, THEN ROTATE TO SET VALVE POTENTIOMETERS

② VALVE A POTENTIOMETER SIGNALS PROGRAM AMPLIFIER, VALVE "B" AND "C" POTENTIOMETERS SIGNAL "B" AND "C" AMPLIFIERS

(2A) PROGRAM AMPLIFIER SIGNALS "A" AMPLIFIER, AND SENDS PROGRAM POSITION SIGNAL TO PROGRAM POSITION INDICATOR

③ VALVE SERVO AMPLIFIER SIGNALS SERVOMOTOR TO POSITION VALVE

④ SERVOMOTOR POSITIONS VALVE, AND FOLLOW-UP POTENTIOMETER SIGNALS AMPLIFIER TO STOP SERVOMOTOR

① PULL KNOB, THEN ROTATE TO SET VALVE "A" POTENTIOMETER AND AUTO SET INDICATOR.

② VALVE "A" POTENTIOMETER SIGNALS PROGRAM AMPLIFIER. SIGNALS FROM MASTER TEMPERATURE SENSOR, DUCT RATE SENSOR, AND ICE LIMITING AND PRESSURE RATIO PROTECTIVE CIRCUITS ARE INTEGRATED WITH VALVE "A" PROGRAM SIGNAL.

③ PROGRAM AMPLIFIER SIGNALS VALVE SERVO AMPLIFIER PROGRAM POSITION SHOWN BY PROGRAM POSITION INDICATOR

④ VALVE SERVO AMPLIFIER SIGNALS SERVOMOTOR TO POSITION VALVE

⑤ SERVOMOTOR POSITIONS VALVE, AND FOLLOW-UP POTENTIOMETER SIGNALS AMPLIFIER TO STOP MOTOR

Figure 23 Signal Flow Diagram of the Hamilton Standard Temperature Control System. Broken lines denote mechanical operations.

The U.S. Science temperature programmer has three potentiometers and a rheostat. The three potentiometers function during both modes of system operation, each providing the temperature controller with the program command signal for one of the three airflow control valves. When the manual mode is engaged, the potentiometers are mechanically operated by rotating the push-pull knob, an act which also moves the lower pointer on the dial face.

When the system is in the automatic mode, the sequence of events is more complex. Rotation of the push-pull knob positions the programmer's temperature selector rheostat, providing the temperature controller with an "attain and maintain" temperature command signal. Simultaneously, this act positions the programmer's upper pointer. The controller integrates the command signal with the reference signals from the master temperature sensor and the duct rate sensor, then actuates the programmer servomotor to mechanically position the three potentiometers. The potentiometers then send valve position command signals to the controller (shown by the programmer's lower pointer), causing the controller to position servo-operated valves accordingly.

Programming Controller (Temperature Controller) The difference between the two brands of control units is comparable to that between the selector/programmers—both perform similar (but not identical) functions, although they differ in basic design and nomenclature. The Hamilton Standard programming controller is designed around transistorized servo amplifiers and solid state electronic programming circuitry. In contrast, the U.S. Science temperature controller design incorporates magnetic servo amplifiers and programming circuitry which supplements that of the temperature programmer previously discussed.

The programming (temperature) controller might be considered as the "brains" of the temperature control system. The controller receives and evaluates signals from the selector (programmer), master temperature sensor, duct rate sensor, ice limiting sensor, and the pressure ratio limiter sensor. The controller's servo amplifiers modulate the airflow control valves by actuating servomotors that move the valve assemblies. If the system is in the automatic mode, the controller also causes the valves to respond correctly to the yellow or red warning signals from the pressure ratio limiter sensor or ice limiter sensor.

The Hamilton Standard programming controller unit is composed of a programming amplifier module and three transistorized servo amplifier modules that plug into it. All three servo amplifier modules (one for each airflow control valve) are identical, and can be interchanged for trouble shooting purposes.

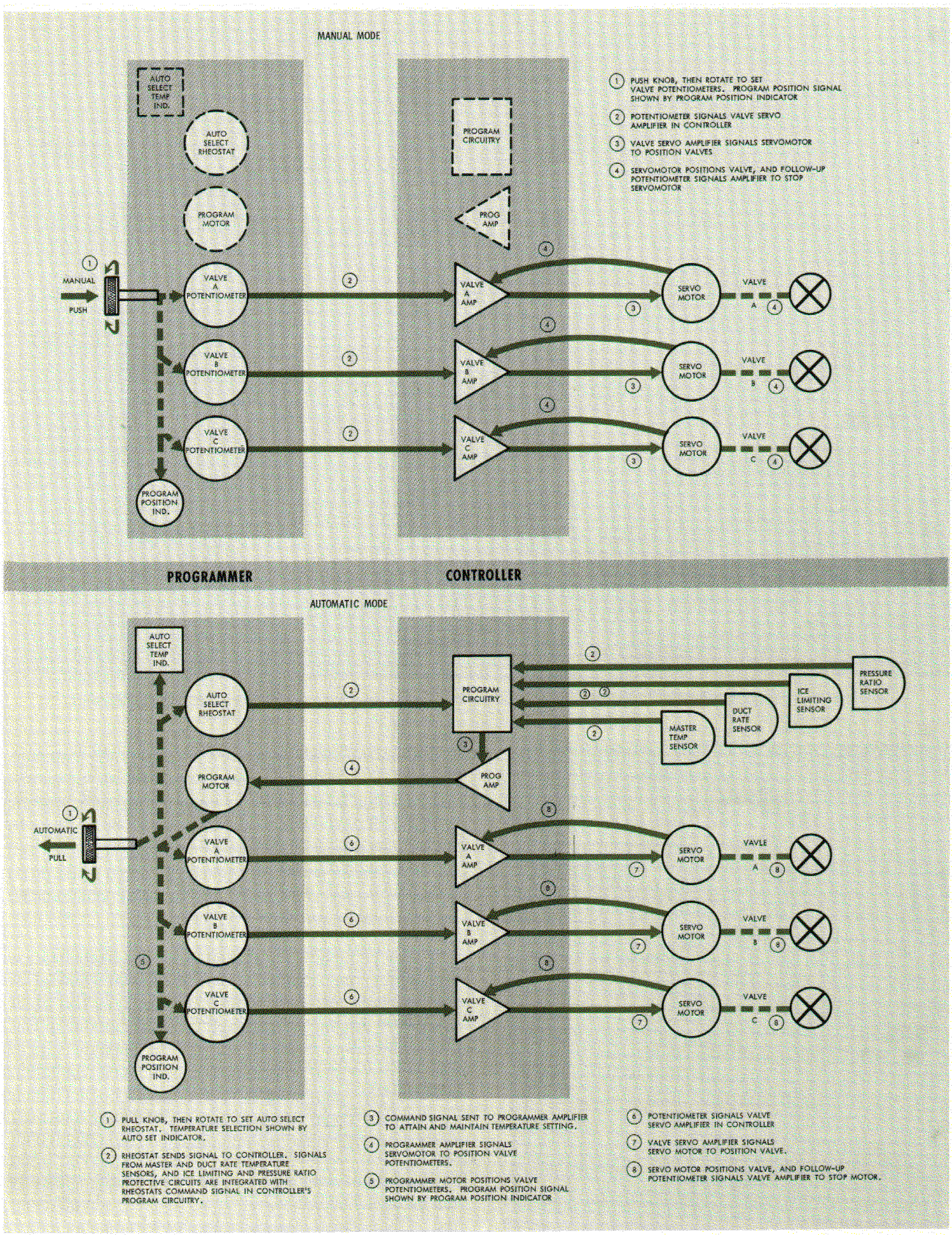
The programming amplifier contains the temperature control system's automatic mode control circuitry. When the automatic mode is engaged, this module integrates the sensor signals with the selector's command signal, and produces the appropriate command signals for the three servo amplifiers. During the manual mode, the programming amplifier contributes nothing to system operation.

The servo amplifiers control the operation of the airflow control valve assemblies, and are identified as the Valve A, B, and C servo amplifiers. During the manual mode the servo amplifiers respond to command signals from the three potentiometers in the selector assembly; in automatic the command signals come from the programming amplifier module.

The U.S. Science temperature controller is composed of a mounting base containing basic circuitry and four identical magnetic servo amplifiers. Three of the servo amplifiers control the movement of the airflow control valves in a manner similar to that of the Hamilton Standard system, but the application of the fourth servo amplifier (called the programmer magnetic amplifier) is peculiar to the U.S. Science system.

The fourth servo amplifier functions only during the automatic mode. Upon receipt of command signals from the programmer's temperature selector rheostat, it positions the three control valve potentiometers with a servomotor. Circuitry within the controller responds to signals from the duct rate and master temperature sensors, and cause the programmer magnetic amplifier to modulate the position of the three valve program potentiometers with the servomotor. This modulates the command signal to the three airflow control valve magnetic amplifiers, thereby regulating the operation of the control valve servomotors. The U.S. Science system automatically regulates the temperature of the air from the air-cycle system in this manner.

The U.S. Science controller has a separate circuit that bypasses the programmer's magnetic amplifier upon receipt of a "yellow" or "red" signal from the pressure ratio limiter or the ice limiter. This circuit provides power to the control windings of the programmer servomotor, causing the programmer to operate slowly towards WARM during the "yellow" condition and causing the programmer to operate towards WARM at maximum motor speed during the "red" condition.



① PUSH KNOB, THEN ROTATE TO SET VALVE POTENTIOMETERS. PROGRAM POSITION SIGNAL SHOWN BY PROGRAM POSITION INDICATOR

② POTENTIOMETER SIGNALS VALVE SERVO AMPLIFIER IN CONTROLLER

③ VALVE SERVO AMPLIFIER SIGNALS SERVOMOTOR TO POSITION VALVES

④ SERVOMOTOR POSITIONS VALVE, AND FOLLOW-UP POTENTIOMETER SIGNALS AMPLIFIER TO STOP SERVOMOTOR

① PULL KNOB, THEN ROTATE TO SET AUTO SELECT RHEOSTAT. TEMPERATURE SELECTION SHOWN BY AUTO SET INDICATOR.

② RHEOSTAT SENDS SIGNAL TO CONTROLLER. SIGNALS FROM MASTER AND DUCT RATE TEMPERATURE SENSORS, AND ICE LIMITING AND PRESSURE RATIO PROTECTIVE CIRCUITS ARE INTEGRATED WITH RHEOSTATS COMMAND SIGNAL IN CONTROLLER'S PROGRAM CIRCUITRY.

③ COMMAND SIGNAL SENT TO PROGRAMMER AMPLIFIER TO ATTAIN AND MAINTAIN TEMPERATURE SETTING.

④ PROGRAMMER AMPLIFIER SIGNALS SERVOMOTOR TO POSITION VALVE POTENTIOMETERS.

⑤ PROGRAMMER MOTOR POSITIONS VALVE POTENTIOMETERS. PROGRAM POSITION SIGNAL SHOWN BY PROGRAM POSITION INDICATOR

⑥ POTENTIOMETER SIGNALS VALVE SERVO AMPLIFIER IN CONTROLLER

⑦ VALVE SERVO AMPLIFIER SIGNALS SERVO MOTOR TO POSITION VALVE.

⑧ SERVO MOTOR POSITIONS VALVE, AND FOLLOW-UP POTENTIOMETER SIGNALS VALVE AMPLIFIER TO STOP MOTOR.

Figure 24 Signal Flow Diagram of the U. S. Science Temperature Control System. **Broken lines denote mechanical operations.**

Figure 25 Cabin Air Distribution System Discharge Vents, and Cooling Air Inlets in the Main Electrical Load Center

TEMPERATURE CONTROL SYSTEM TROUBLESHOOTING If a temperature control system should malfunction, most of the troubleshooting procedures are of the clean, inspect, adjust, tighten, and (if all else fails) remove and replace nature. These procedures are contained in the 01-75PAA-2-2.4 Maintenance Instruction Manual and the 01-75PAA-12 In-Flight Maintenance Manual. An operational check of the temperature control system can be performed electrically with the aid of the B092 test set. This set enables maintenance personnel to determine and isolate the problems without unnecessary removal of components. In view of the additional congestion in the airconditioning service center resulting from the installation of an auxiliary power unit on P-3 aircraft, this test set has proven itself a valuable time saver.

AIR DISTRIBUTION AND EXHAUST

Once the air has been processed by the air-cycle systems and blended by the temperature control systems, it must be distributed throughout the aircraft. As the fresh processed air enters the fuselage, "used" air is exhausted overboard. At all times the exhaust fan is activated to ensure that sufficient air is being drawn through the electronic components to cool them properly. When the fuselage is pressurized (as it normally is during flight), the cabin differential pressure causes the "used" air to enter the exhaust system intakes and flow overboard.

Fresh processed air is routed to the flight station through a riser that follows the circular contour of the fuselage. Most of the air delivered to the flight station is discharged through an oval duct atop this riser. This duct is above and on the forward side of the doorway that connects the cabin and the flight station. The remainder is routed through small ducts to the pilot's and copilot's gaspers and foot warmers, each of which may be individually controlled.

Fresh processed air is distributed to the cabin by an overhead longitudinal duct that extends aft from the cabin system vertical riser for almost the entire length of the fuselage. Openings along the length of

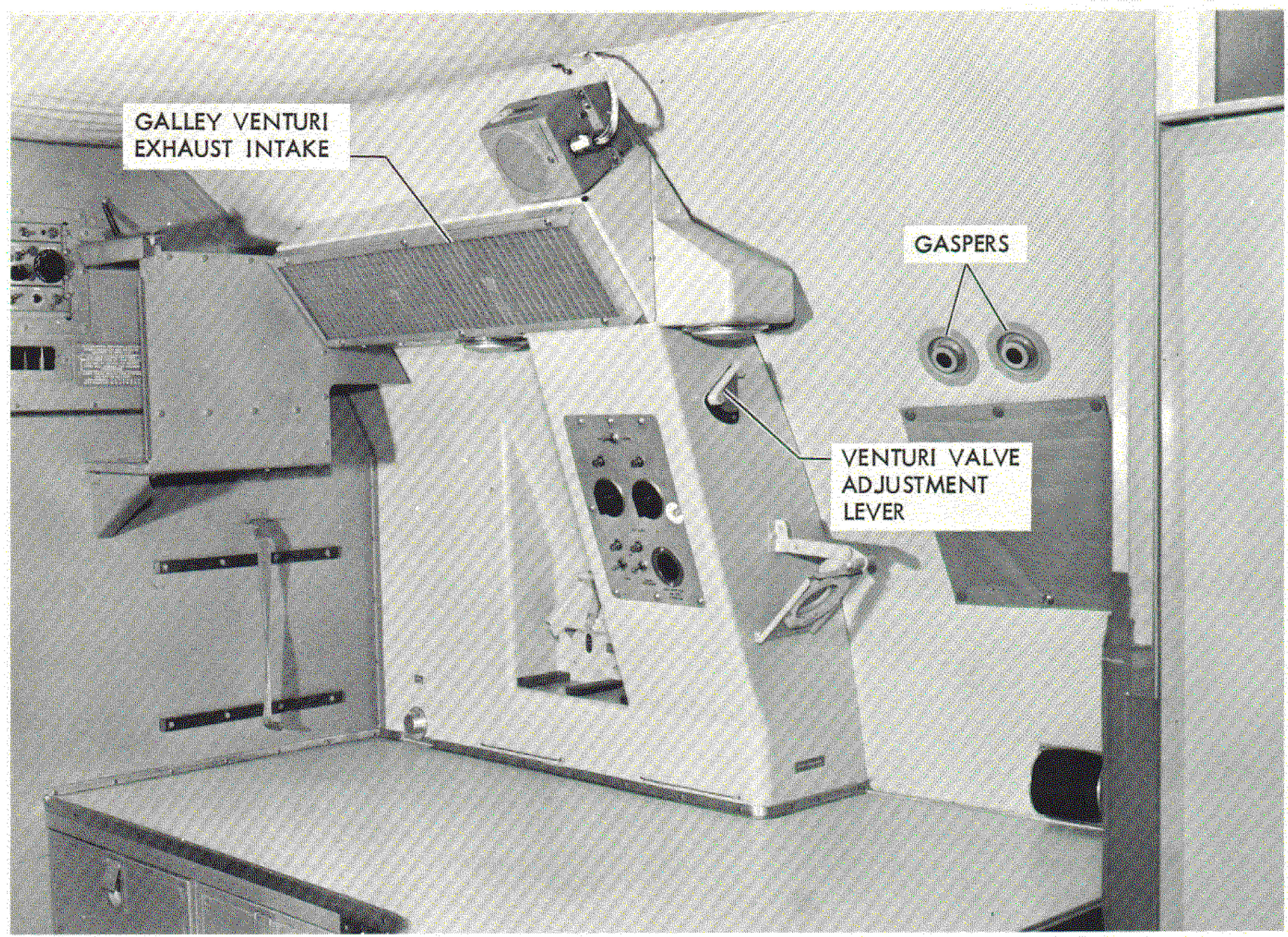
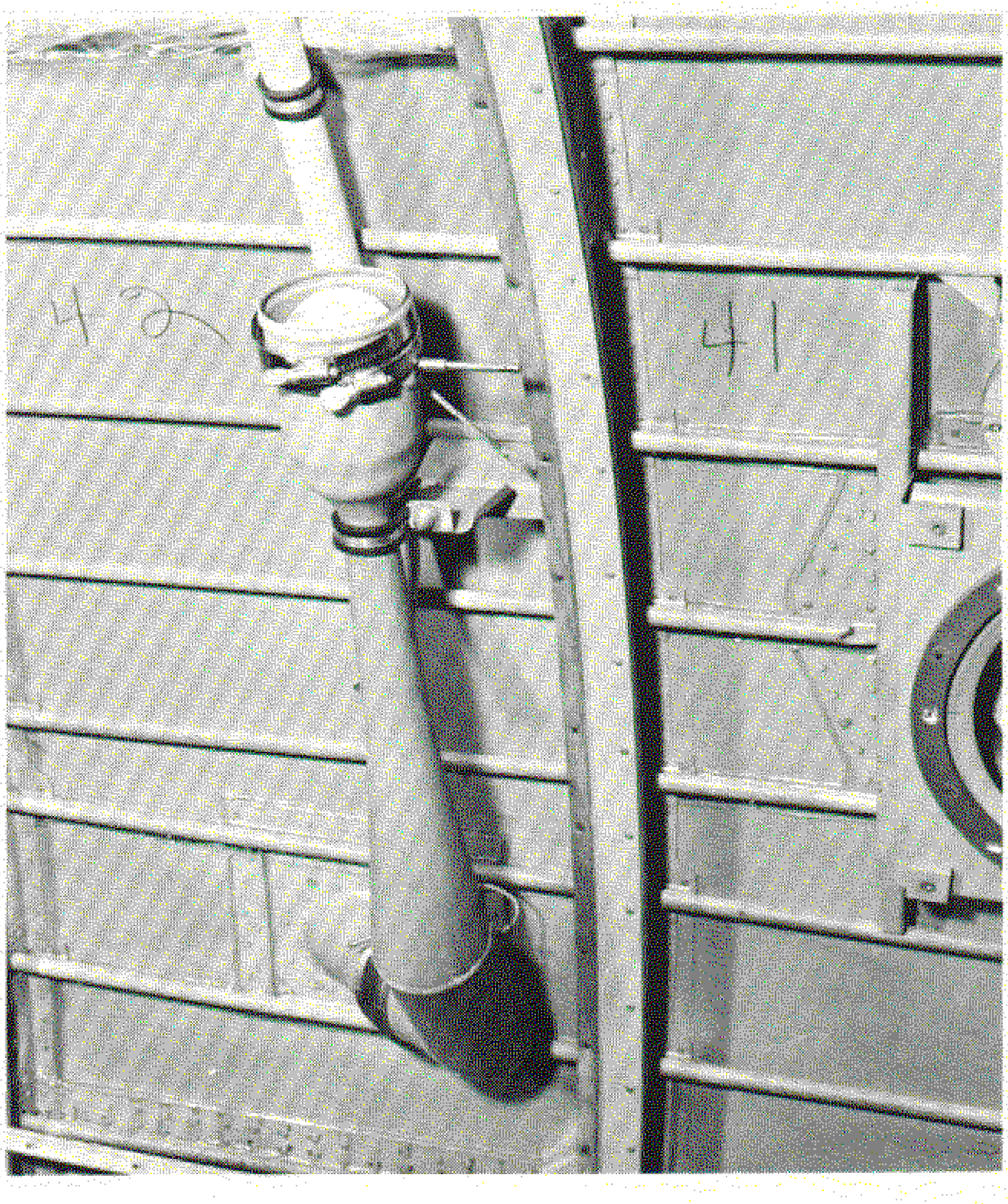


Figure 26 Galley Installation Showing Venturi Control Lever and Gaspers. Venturi prior to installation of galley shown below.

this duct permit fresh air to discharge downward into the cabin and mix with the cabin air to maintain the desired temperature within the aircraft. Air is also ducted laterally from the overhead distribution duct to individual controllable outlets (gaspers) located at the tactical stations and in the rest areas. The air distribution and exhaust system is depicted by Figure 16.

After the conditioned air has circulated through the inhabited portion of the aircraft, this same air is used to cool the aircraft's electrical and electronic equipment. The exhaust fan and (during flight) the build-up of air pressure within the fuselage draw the air through louvered openings of cabinets and enclosures, over and through electrical and electronic equipment, into the exhaust ducting, and finally exhaust the "used" air overboard. This makes room for more fresh processed air to be cycled through the fuselage. Small amounts of air are also vented directly overboard through venturis installed in the galley and lavatory areas. The galley venturi is adjustable, and should be closed when the galley is not in use.



CABIN EXHAUST FAN The cabin exhaust fan must be turned on whenever the aircraft electronics equipment is in operation to ensure that this equipment will be adequately cooled. The exhaust fan control switch is located on the Air Conditioning control panel, and it is guarded to the "ON" position to make certain that the fan is not inadvertently switched "OFF." The "FAN OUT" warning light, installed adjacent to the fan switch, illuminates when a pressure switch upstream from the fan closes due to lack of suction (less than cabin pressure) in the ducting. The cabin exhaust fan circuitry is shown in Figure 27.

TEMPERATURE INDICATOR The performance of the temperature control systems may be monitored by observing the temperature indicator. This instrument and its three-position selector switch are located on the Air Conditioning panel between the two selector and indicator (temperature programmer) assemblies. The temperature indicator, calibrated in degrees Centigrade, is supplied data from three temperature sensing elements, one in the flight station air-cycle system, one in the cabin air-cycle system, and one in the cabin exhaust system.

The three positions of the temperature indicator selector switch are labeled "FLT STA COND AIR," "CABIN COND AIR," and "CABIN TEMP." The FLT STA COND AIR and the CABIN COND AIR temperature bulbs sense the air temperature in their respective systems as the air approaches the distribution risers, immediately after it has been processed by the air-cycle and temperature control system components. The CABIN TEMP temperature bulb is installed at the mouth of the exhaust duct between the navigator's and Julie-ECM stations, and senses the air temperature as it leaves the tactical crew area. The cabin temperature control system's master temperature sensor is also located in this duct—don't mistake one for the other during maintenance activities.

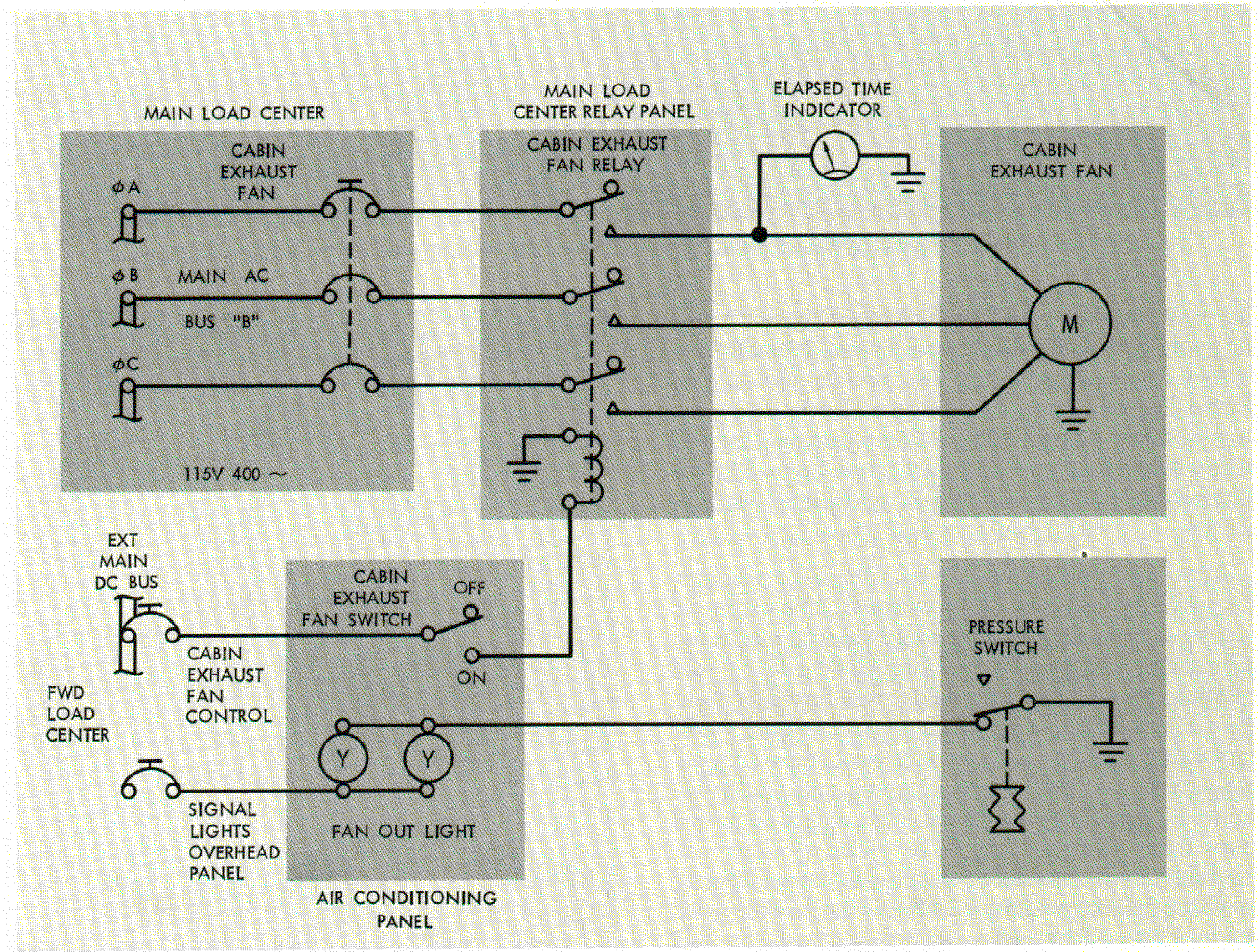


Figure 27 Cabin Exhaust Fan Circuitry

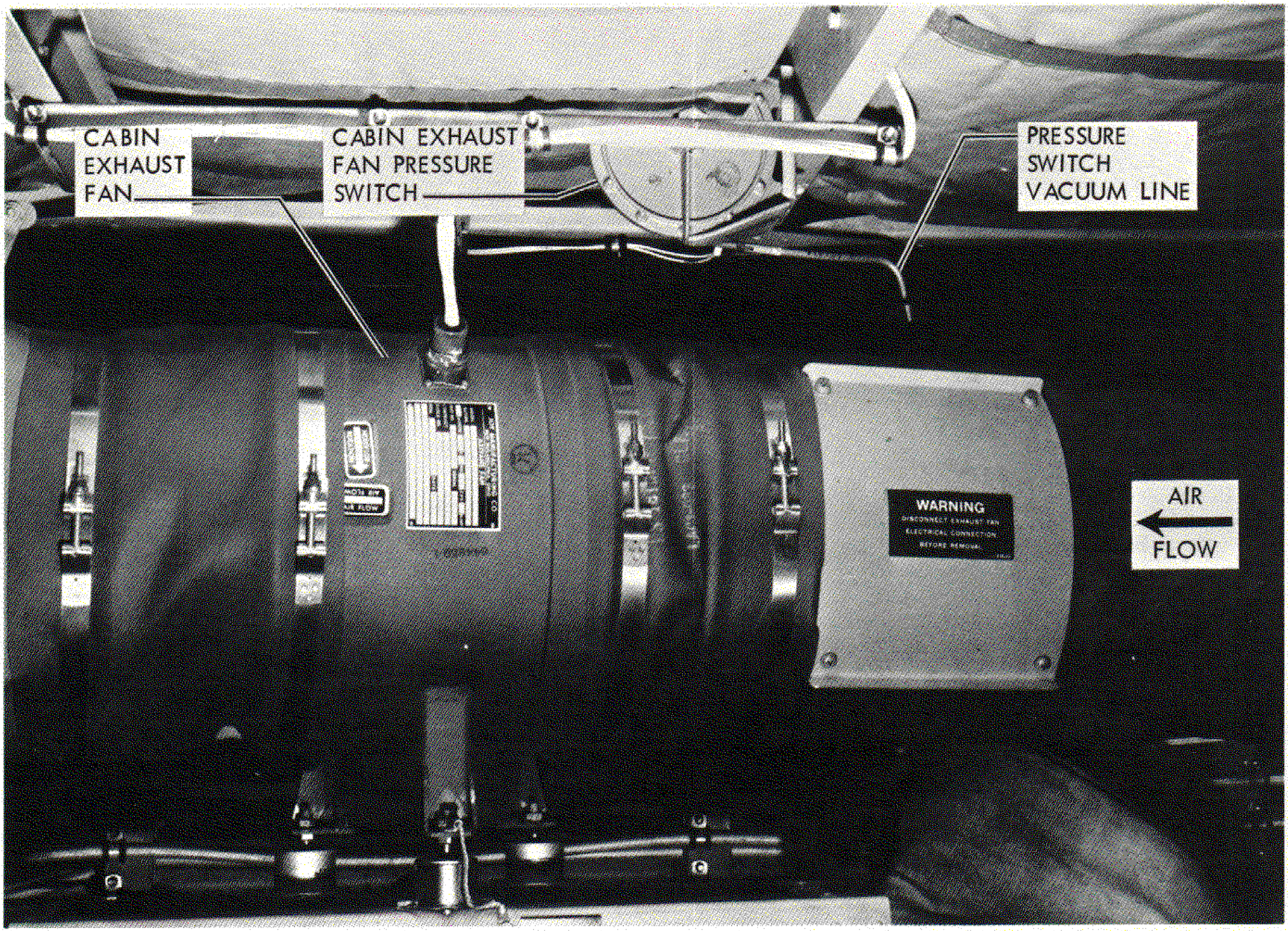


Figure 28 Cabin Exhaust Fan Installation

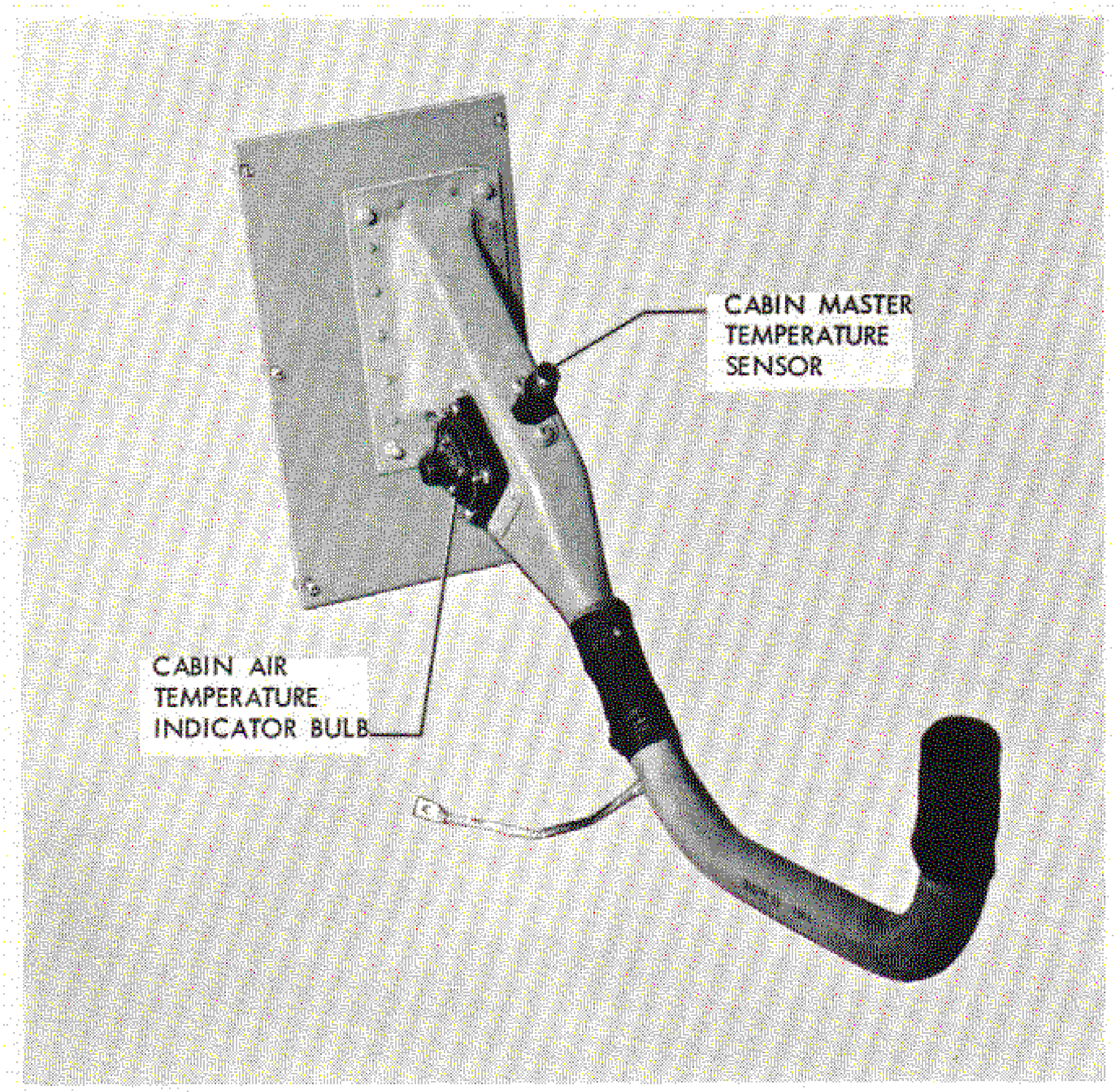


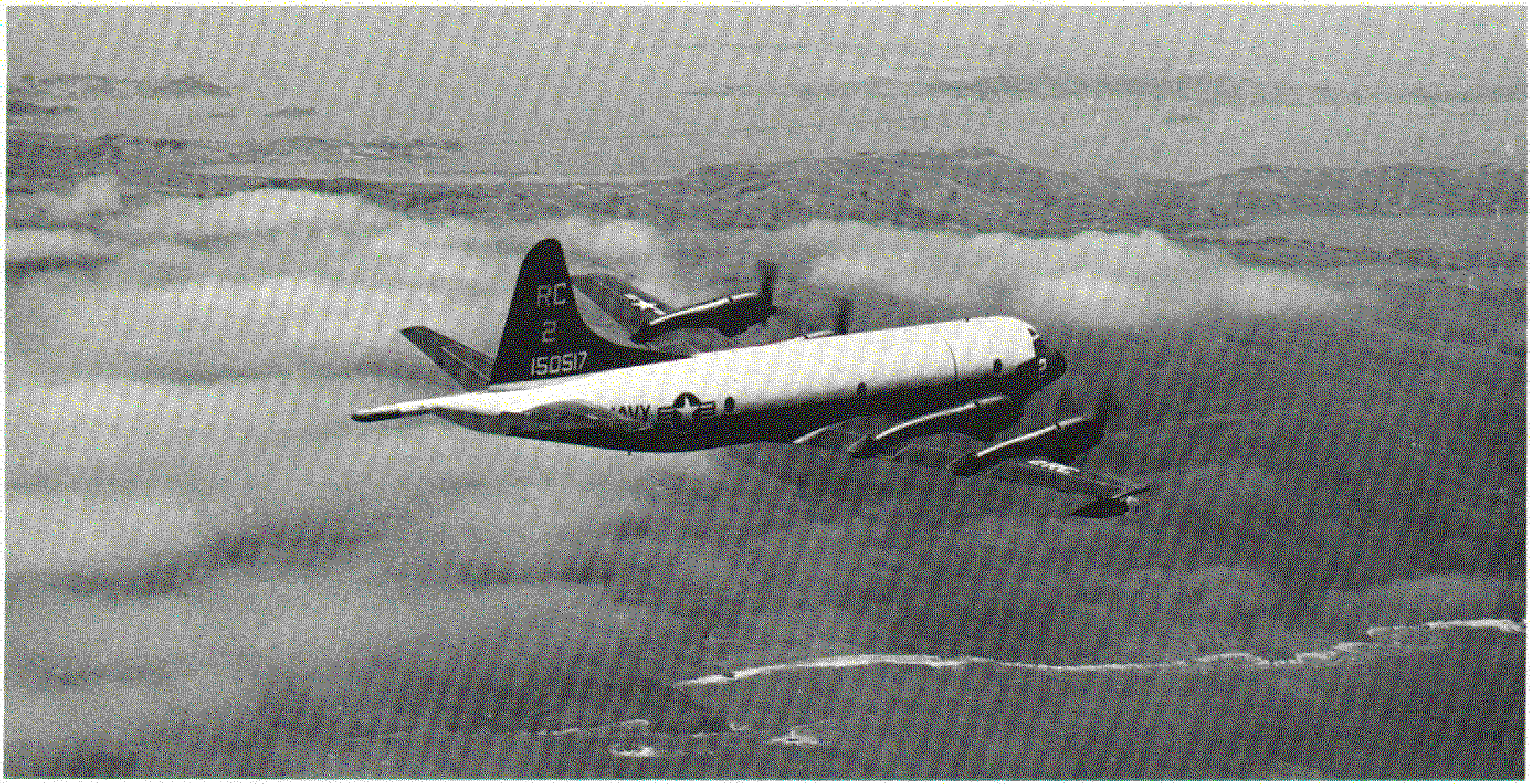
Figure 29 Cabin Temperature Indicator Bulb

SUMMARY

The airconditioning system supplies the aircraft interior with fresh air at a controlled temperature. This conditioned air is used to control the flight crew's environment and to cool the electronic equipment aboard the aircraft. Two separate fresh air-cycle air refrigeration systems, each regulated by its own temperature control system, are the source of this conditioned air. During flight, two engine-driven compressors supply the air to the air-cycle systems; on the ground, air is supplied to the air-cycle systems by the EDCs or (if the aircraft is so equipped) by the auxiliary power unit-air multiplier package. The temperature of the processed air may be regulated either manually or automatically, but extensive testing has revealed that the temperature control system's automatic mode of operation is preferred on most occasions. The manual mode's primary function is to provide an alternate mode of operation in case the automatic mode fails. ▲▲

NORMAL PRESSURIZED FLIGHT	NORMAL GROUND AIRCONDITIONING
SYSTEM UTILIZATION NORMAL CONTROL CONFIGURATION AND OPERATIONAL NARRATIVE	
EDC's OPERATING, DUMP AND DISCONNECT SWITCHES "NORMAL", TEMP SELECTOR AND OUTFLOW SELECTOR "AUTO", AUX VENT SELECTOR "CLOSE", GND CHECK SWITCH "NORM". EDC's supply rated flow. Their discharge pressures vary in unison as pressure altitude and cabin pressure varies, but will also reflect individual variable back-pressure due to boot-strap turbine load and cyclic variations due to ice-limiter operation. In some cases, ice may agglomerate on boot-strap turbine producing audible squeal. This can usually be rectified by selecting slightly warmer air. If "REFR OV'HT" light illuminates, related EDC should be dumped, related temp selector should be selected "MANUAL" at "2-dot" setting, and after "REFR OV'HT" light extinguishes, EDC Dump switch can be returned to "NORMAL".	APU OPERATING, EDC'S OPERATING OR NOT. ENGINE START SELECTOR BOMB BAY HEAT SWITCH, AND APU AIR O'VRD SWITCH "OFF". TEMP. SELECTOR AND OUTFLOW SELECTOR "AUTO", GROUND AIRCOND. SWITCH "ON", AND AUX VENT SWITCH "CLOSE". APU supplies both airconditioners with normal rated flow, dependent on: APU remaining above 95% rpm, APU generator load not becoming abnormally high, and no "REFR O'HT". Abnormal generator load will detract from bleed air supply to airconditioner; airconditioners will shut down entirely if APU drops underspeed or if "REFR O'HT" occurs. System malfunction must be corrected if "REFR O'HT" occurs; system can then be reactivated by selecting Ground Aircondition switch "OFF", then "ON". Shutdown due to overtemp or intake problems at the air multiplier also stops all airconditioner airflow, but "REFR O'HT" light does not illuminate. System can be reactivated by selecting "OFF", then "ON" position of the Ground Aircondition switch, or EDC's can be utilized by selecting "ON" at both the Ground Aircondition switch and the APU Air O'Vrd switch. EDC Discharge indicators will reflect variations as noted under "PRESS. FLIGHT" heading, and icing information noted there is applicable for ground operations too. If takeoff is made utilizing APU bleed air for airconditioning, system will transfer automatically to EDC discharge air supply at lift-off due to scissors switch action.
EFFECT OF DEVIATIONS FROM NORMAL CONTROL CONFIGURATION	
▲ DUMP 1 EDC: Discharge is dumped overboard, duct to fuselage is closed, related airconditioner is inoperative and its control valves are inoperative in "AUTO" mode. Opposite airconditioner system remains operable from EDC for air or ground operation; both systems operable from APU for ground use. ▲ DISCONNECT 1 EDC: EDC drive disconnects. Related airconditioner is inoperative for duration of flight, but airconditioner control valves will go to FULL HOT with U.S. Science control system; Valve A only goes to full open with Ham. Std. system. Opposite airconditioner remains operable from EDC for air or ground operation; both airconditioners are operable from APU for ground use. ▲ TEMP SELECTOR "MANUAL": Operator directly selects proportioning of air diverted through and/or around airconditioner components. Temperatures of air delivered to fuselage will vary according to changes in environmental conditions, necessitating periodic readjustment of temp selector setting. Ice limiter is inoperative. If ice restriction occurs, part or all of EDC air may spill through EDC dump valve, air flow delivered to fuselage may cycle, then stabilize at low flow. If cyclic/icing condition occurs, EDC Discharge pressure will read high, and condition can be rectified by selecting the "2 Dot" or the "1 Dot" position at Temp Selector.	▲ Engine Start Selector moved from "OFF": Air multiplier shuts down. ▲ Bomb Bay Heat switch set to "ON" or "O'VRD": APU bleed air start valve opens; bomb bay hot air solenoid valve opens, then cycles closed/open automatically to maintain bomb bay at correct temperature if switch is "ON". If switch is at "O'VRD", hot air flow to the bomb bay will be continuous. After takeoff, engine bleed air must be utilized to supply bomb bay heat. ▲ APU Air O'vrd switch "ON"; EDC's supply air if inboard engines are operating. ▲ Temp Selector MANUAL: See discussion under "NORMAL PRESS. FLIGHT" heading. ▲ Outflow valve Selector set to "OPEN" or "CLOSE": Has no effect unless Ground Check Test switch is moved to "TEST". ▲ Ground Check Test switch set to "TEST": Aux Vent valve closes and Outflow Valve selector becomes operational; fuselage pressure checks can be made utilizing either APU bleed air or EDC's (if inboard engines are operating and APU Air Ovrd is selected "ON").

Table 1 Recap of Operating Information for Ground and Airborne Use of P-3 Airconditioning system



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