ORION

SERVICE DIGEST

LOCKHEED
CALIFORNIA·COMPANY
issue 18 February 1968

ORION

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FRONT AND BACK COVER When Patrol Squadron FOUR began operating as VP-4D14 at Pearl Harbor in 1928, it had only 4 Douglas PD-1 patrol aircraft and shared Ford Island ground facilities with the U.S. Army. From this rather humble beginning came the multiple award winning "Skinny Dragon" Squadron of today.

The Squadron fortunes seem attached to the "4" in their designation. Their prosperity under the "Four Leaf Clover" emblem, while being redesignated as VP-4B and VP-4F, changed to disaster after the clover was abandoned in deference to a redesignation as VP-22 in 1935. Their entire complement of P2Y-3's, acquired at that time, was destroyed in the Pearl Harbor attack and, after being re-equipped with PBY-5's, the squadron lost all but one of these aircraft in the bitter Philippine defense action that followed, suffering such heavy casualties as to force the decommissioning of the squadron in early 1942.

Recommissioned in mid 1943 as VP-144, the squadron re-entered the war with vastly improved fortunes, carrying out strike missions as part of the torturous "island hopping" campaign through the Gilberts, Marshalls, and Eastern Carolines that marked the turn to victory in the War in the Pacific.

At the end of Pacific hostilities the squadron emerged as Patrol Squadron FOUR and moved to a new home base at Whidbey Island, Washington. After transitioning to P2V-2 Neptunes in 1947, VP-4 detachments conducted a South-Eastern Alaska aerial photographic survey from Annette Island and deployed to Adak, Alaska, Barbers Point, Hawaii, and Iwakuni, Japan.

Naha, Okinawa became the next home port for VP-4 in 1956, from which their reconnaissance and ASW coverage helped counter the Chinese Communist bombardment of the Nationalist Island of Quemoy. The year 1964 capped an unequalled record for excellence set by the squadron that, in four years' time, had amassed a total of three CNO Aviation Safety Awards, three COMNAVAIRPAC Battle Efficiency Awards, and four Arnold J. Isbell Awards for ASW excellence.

VP-4 returned to Hawaii in 1964, replaced their Neptunes with Orions two years later, and shortly thereafter deployed to Iwakuni, Japan for the first 6 months of 1967. A letter of commendation from the Seventh Fleet Patrol Force Commander attests to the proficiency already attained with their new equipment, as exhibited in flying Market Time and Yankee Team Patrols.

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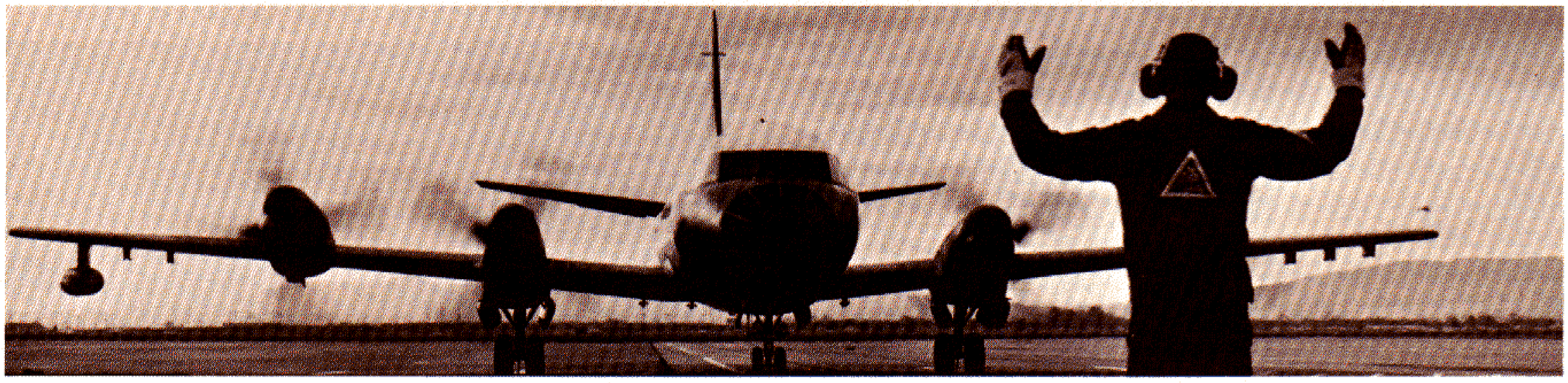


P-3 AUXILIARY POWER UNIT

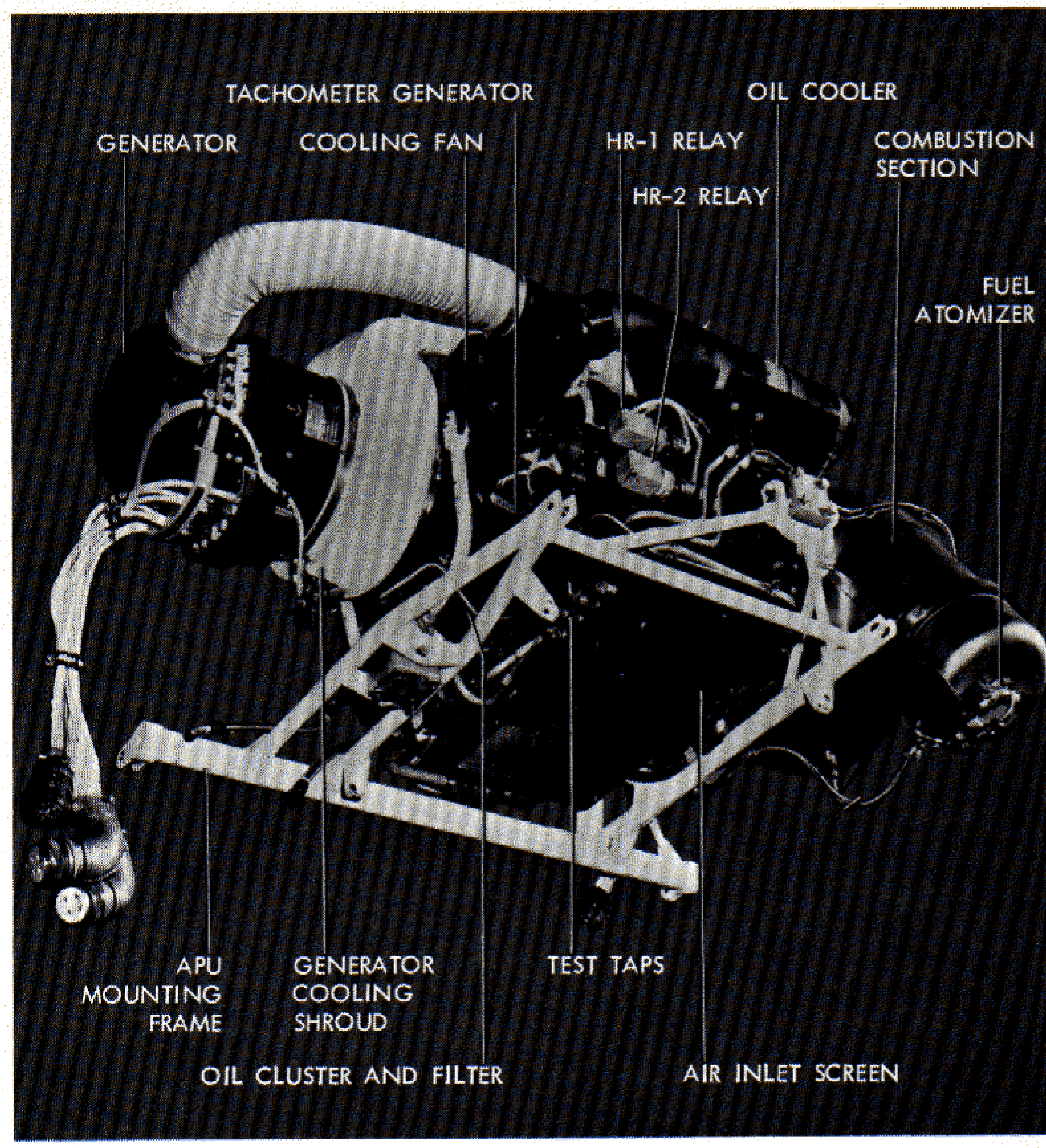
A FEW YEARS AGO the decision was made to equip all P-3 aircraft with a self-contained starting system, freeing the aircraft from dependence on ground power sources. The heart of this system is the GTCP95-2 turbine engine, manufactured by AiResearch, a Division of the Garrett Corporation. This engine can provide the aircraft with pneumatic power while it drives a 60-kva three phase ac electric generator mounted on its accessory case. The complete engine/generator assembly is called the Auxiliary Power Unit, the APU. The hot compressed air supplied by the APU can be used to drive any one of the main power plant pneumatic starter motors or it can be used to operate the P-3 air conditioning system during ground operations, and it can be used to heat the bomb bay in cold (sub-freezing) ground operation. Originally the APU installation was designed for use only while the aircraft is on the ground, but most early APU installations have been modified so that they can also supply the aircraft with emergency in-flight electrical power. All new P-3 aircraft are being delivered with APUs featuring in-flight operational capability.

This multi-purpose unit was phased into the Orion production line on P-3 aircraft BuNo 152141, 152164 and subsequent. All earlier P-3s are being retrofitted with APUs during Progressive Aircraft Rework (PAR) through incorporation of P-3 Airframe Change No. 110.

This article is devoted to describing the design, installation, and operation of the APU engine, the systems that support APU operation, and the APU compartment fire detection and extinguishing system. Although it is beyond the scope of this article to provide a detailed discussion of how the APU's pneumatic and electrical power is employed, the unit's uses and limitations will be reviewed briefly in the next few paragraphs. Further discussions of the use of the APU and its related systems appear in *Orion Service Digests,* Issues 15 and 16, and in the official publications listed in the latter part of this article.

GENERAL The APU is attached to a mounting frame and installed in the fuselage below the forward observer and radio operator stations, between the nose wheel well and the bomb bay. A fire barrier of elastomeric blankets installed on the APU compartment bulkheads and overhead isolates the area from the remainder of the aircraft. As a further precaution this compartment has its own automatic fire detection and extinguishing system. The APU draws fuel from the aircraft supply. During the APU starting cycle the unit draws electrical power from the aircraft's battery whenever power is not available from the aircraft's main electrical system or external sources. The controls for both the APU and its fire extinguisher system are located in the flight station. In view of the many functions involved, the controls are surprisingly few and simple, for operation of the APU is automatic after initiation of the unit's starting cycle.

USES OF THE APU Electrical power is available from the APU whenever the unit is operating above 95% rpm, but there are some limitations to the availability of APU pneumatic power. As it was originally conceived, the unit was intended for use only during ground operations. Most APU-equipped aircraft have an installation of improved design that permits in-flight operation of the APU to supply



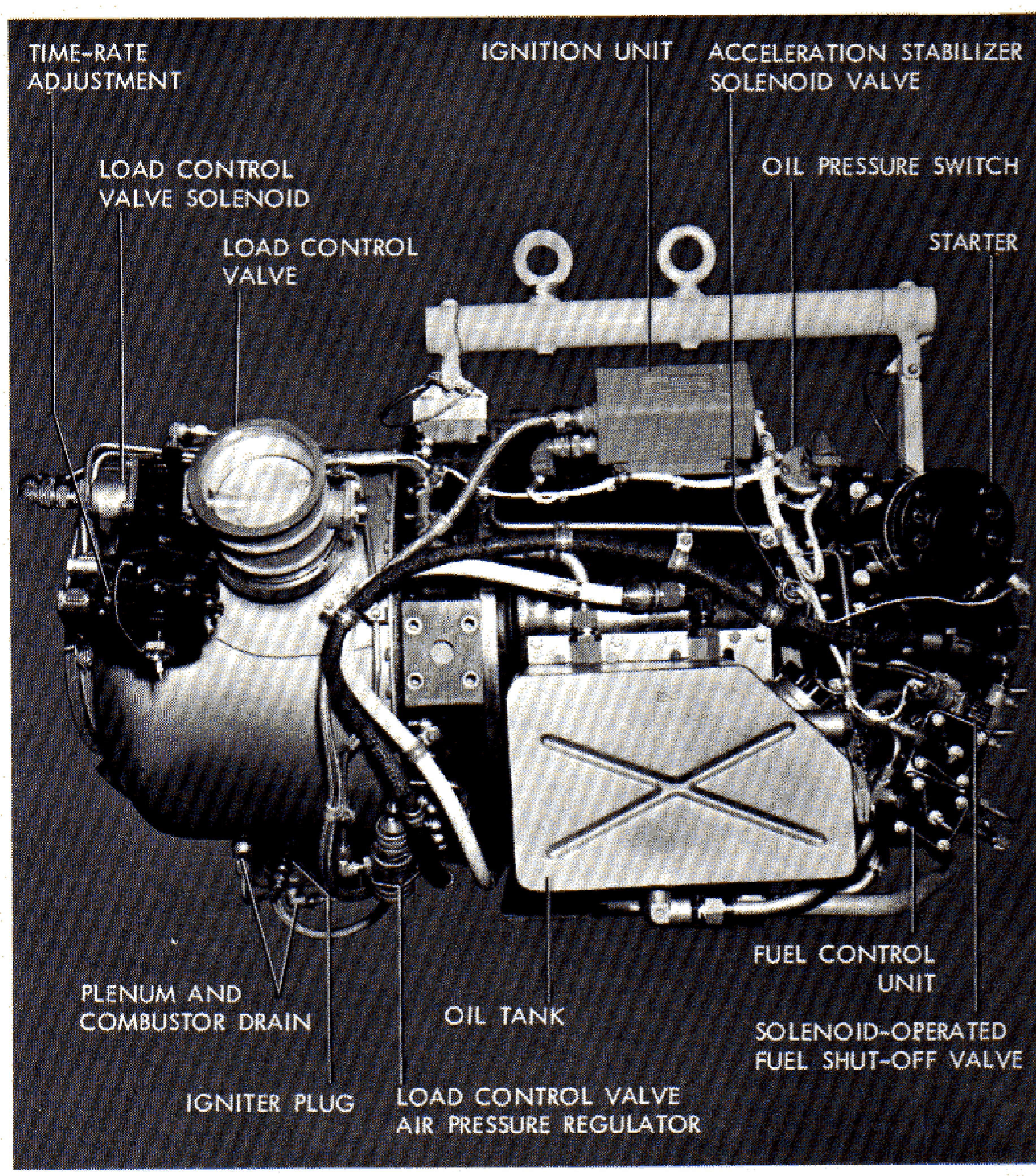


Figure 1 General Views of the APU

emergency electrical power,[1] but neither configuration permits the unit to supply pneumatic power during flight. During ground operations the APU can supply pneumatic power to *either* the aircraft engine starting system *or* the air conditioning system, but not to both systems at the same time. Whenever there is a simultaneous demand for pneumatic power, the engine starting system takes precedence. If there is a simultaneous demand for pneumatic and electrical power, the pneumatic power output will be limited as necessary to conserve APU horsepower to satisfy the electrical load demand.

The APUs on recent production aircraft also can supply hot bleed air to the aircraft's bomb bay heat system while pneumatic power is being supplied for starting or air conditioning. However, use of the bomb bay heat system during an engine start is not recommended because it reduces the pneumatic power available to the main power plant pneumatic starting system. Delivered aircraft will be modified to this configuration through incorporation of P-3 Airframe Change No. 142.

In-flight operation of the APU is intended solely to provide *emergency* electrical power to the aircraft after two engine-driven generators have failed. Airspeed should not exceed 225 knots, for at higher speeds the airloads could damage the open inlet and exhaust doors. The APU generator and the horsepower available to drive it are ample to supply the electrical loads of the entire aircraft at lower altitudes, but the available horsepower is directly associated with atmospheric density and it is necessary to dispense with progressively more aircraft electrical services at higher operating altitudes to ensure that the APU engine is not overburdened.[2] The P-3 NATOPS Flight Manual Emergency Operating Procedures lists a number of alternatives in this respect, and directs that above 10,000 feet the operator is to reduce the total load (dispensing with hydraulic motor pumps, avionics, deicing, or combinations of these services) as befits the mission circumstances before starting the APU. The Manual also directs that the APU is not to be started or operated above 20,000 feet altitude.

NOMENCLATURE For the benefit of those unfamiliar with our topic, we should point out that a number of abbreviations are associated with it in addition to the term "APU." Although we have used the general term "APU" almost exclusively in this article, other writings which treat on major components and services utilize more specific terminology. The most frequently used abbreviations are GTC, GTCP, APU, ISS, and IACS. The term "GTC" is short for gas turbine compressor, referring solely to the power unit's engine. When the engine is equipped with an accessory drive to provide shaft power, it is called a GTCP (gas turbine compressor, power). The combination of a GTCP and an electrical generator is usually called an auxiliary power unit, or APU. On other occasions the gas turbine compressor part of the GTCP provides pneumatic power to start the airplane's engines, thus becoming part of the integral starting system (ISS), or the compressor may supply compressed air to the ship's air conditioning system and become part of the integral air cycle system (IACS).

[1] *Earlier APU installations are being updated to give them in-flight capability through incorporation of P-3 Airframe Change No. 122.*

[2] *The present P-3 electrical power system is designed to give the APU generator priority over the No. 4 generator if generators Nos. 2 and 3 have failed. This priority has been reversed on P-3B aircraft BuNo 154592 and subsequent (and will be on all P-3C aircraft) so that No. 4 generator has priority over the APU generator during emergency in-flight operation. Earlier aircraft will be modified to this configuration through incorporation of P-3 Airframe Change No. 165. Another feature incorporated during this change is installation of circuitry to automatically monitor the electrical loads imposed upon the APU during in-flight operation.*

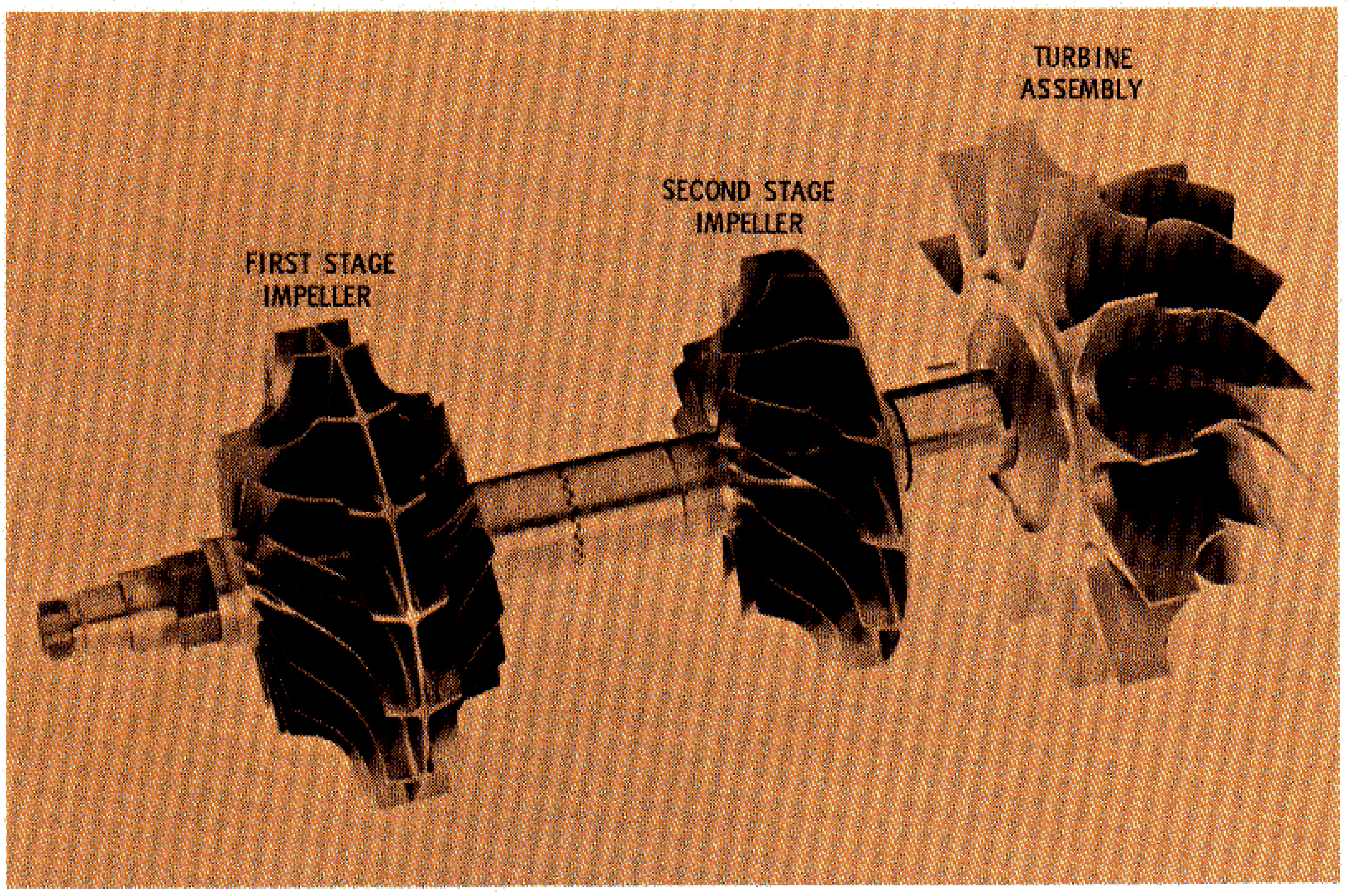


Figure 2
Compressor/Turbine
Assembly

Photo Courtesy of the Garrett Corporation

Figure 3
Diagram of the
GTCP95-2 Engine

ENGINE DESCRIPTION

The APU's engine is comprised of a compressor/turbine section, with attaching components that make up the unit's fuel, bleed air, lubrication, and electrical systems. The accessory section is mounted on the left side of the engine (as it is installed in the aircraft), and furnishes shaft power to drive the APU generator and the engine's accessories. The APU engine uses either JP-4 or JP-5 fuel, consuming it at a rate of approximately 270 pounds per hour[3] when the rated load is applied to the unit. Since this is the same type of fuel used by the aircraft's power plants, the APU draws its fuel from the aircraft's supply. MIL-L-23699 oil is recommended for lubricating the APU under all except the coldest of operating conditions when MIL-L-7808 oil might be used. The engine's controls and instrumentation are located on the APU panel in the flight station, a safety switch is located on the aircraft exterior, and the APU electrical system's circuit breakers are located on the forward electrical load center panels.

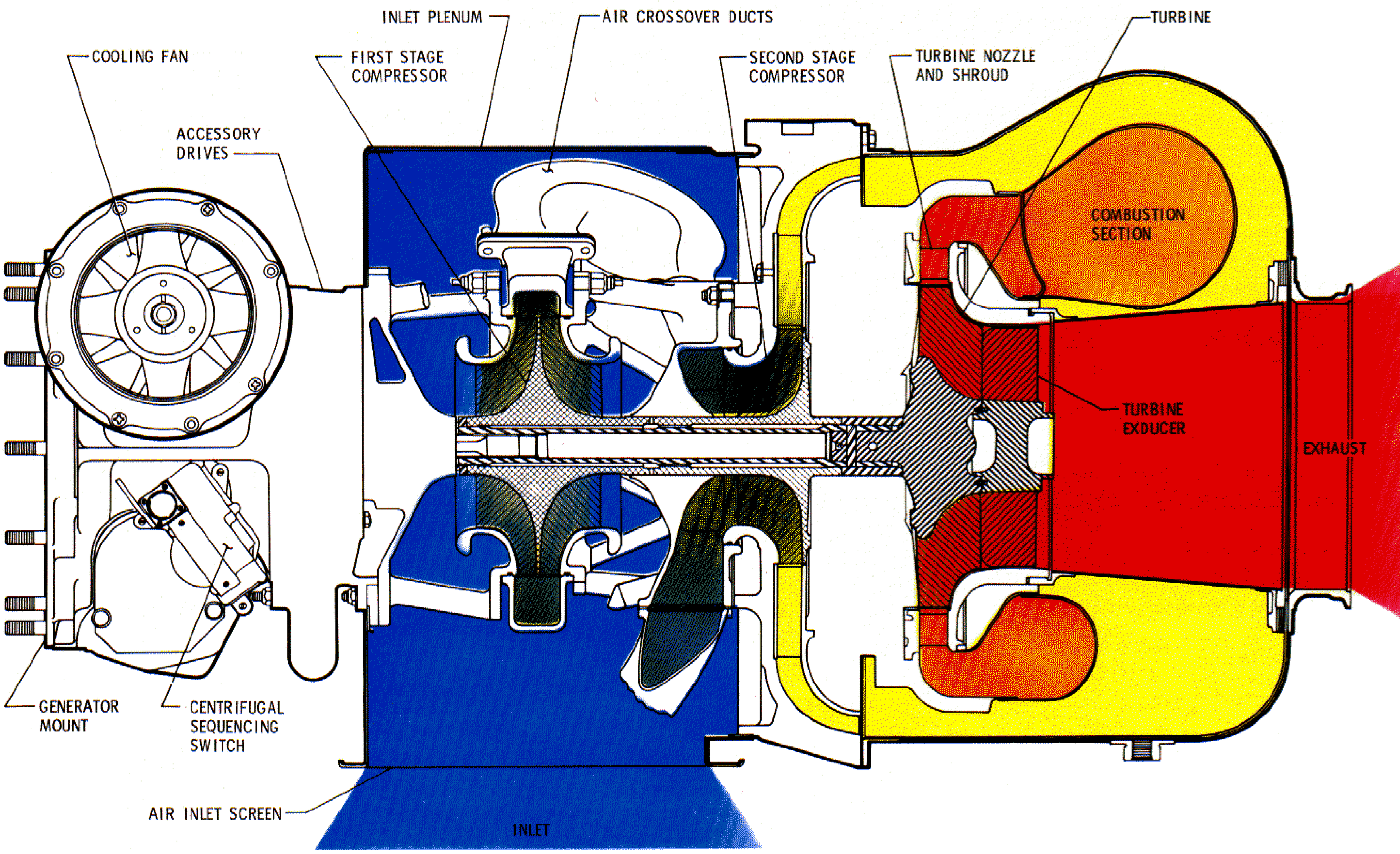
The engine's normal operating speed is 42,000 rpm (100%, nominal) ±2%. Under no-load operating conditions (idle) the APU's turbine wheel rotates up to 42,840 rpm (maximum), equivalent to 102% engine operating speed. Under full load conditions the minimum engine speed can be as low as 41,160 rpm (98% rpm). Turbine rotation is geared down at the accessory section main output drive pad to drive the 60-kva generator and the engine accessories. Clean, compressed air can be bled from the engine to supply the aircraft with pneumatic power. The engine's bleed load control and air shutoff valve located on the forward right side of the APU (as it is installed in the aircraft) is used to control the flow of APU bleed air or to shut it off entirely.

COMPRESSOR/TURBINE SECTION The APU compressor/turbine is composed of a two-stage compressor section and a single-stage turbine section. The compressor's two impellers and the turbine wheel are mounted on a common shaft and form the single balanced unit shown in Figure 2, supported by a ball bearing at the compressor end and a journal bearing at the turbine end. The sectional view in Figure 3 shows the location of the compressor/turbine shaft in the engine.

The two-stage compressor section is composed of the two impellers, their diffusers, and the ducting required to direct the air through the compressor section to the turbine section. These components are enclosed by a plenum assembly, part of which forms the engine air inlet. Several engine accessories are mounted on the compressor plenum, among which are the oil pressure switch, oil cooler, oil tank, engine ignition exciter unit, a differential air pressure regulator, the time totalizer (hourmeter), the ac generator cooling discharge duct, wiring, plumbing, and the two engine control relays.

The turbine section consists of the radial inward-flow turbine wheel assembly, its nozzle and shroud, the combustion chamber liner, cap and torus, and the exhaust pipe, most of which are also enclosed by a plenum assembly. Parts of the turbine section plenum and torus assemblies, in conjunction with the combustor cap and combustion chamber liner assemblies, form the combustion chamber. The turbine plenum shields the area in the vicinity of the engine hot section with relatively cool (up to 460°F) compressor discharge air. If a light-off does not

[3] *300 pounds per hour is used in NAVAIR 01-75PAA-1 for fuel management planning purposes.*



occur during the starting cycle, any fuel that has accumulated in the torus drains through a small hole into the plenum. When the plenum air pressure is low enough (approximately 9 psig), the plenum check valve opens and the fuel drains overboard.

ACCESSORY SECTION The engine accessory section provides the gear train for the starter to rotate the turbine and accessories during the first 35% of the starting cycle, and for the engine to drive the several accessories during the latter part of the starting cycle and during normal operation. At the output pad the engine speed of approximately 42,000 rpm is reduced to a nominal 6,000 rpm ±2% to drive the 60-kva ac generator. Other accessories driven by the accessory section are the oil pump, fuel control unit, centrifugal sequencing switch, and the fan that supplies air to cool the oil cooler and the generator. The engine's tachometer generator is mounted on the oil pump and it is driven in tandem with the oil pump from the accessory section.

ENGINE COMBUSTION Ambient air is compressed by the two-stage radial compressor, and directed into the turbine section. As compressed air enters the turbine section, it passes between the turbine plenum and the combustion chamber liner, and enters the combustion chamber through holes and slots in the liner. (The size of the holes and slots in the liner controls the airflow into the combustion chamber, creating the proper fuel-air mixture and cooling the chamber's combustion zone.) Simultaneously, fuel is injected into the combustion chamber through an atomizer assembly mounted on the combustor cap. The fuel-air mixture is ignited by the engine's igniter plug (also mounted on the combustor cap) during the starting cycle, and auto-ignition of the mixture occurs at engine speeds above 95% operating speed. Additional air is introduced downstream from the primary combustion zone and mixed with the hot combustion gases.

During the starting cycle the fuel flow and ignition are turned on at about 10% speed by a pressure switch in the engine oil system. As the engine accelerates past 35% the starter is disengaged, and when fuel combustion becomes self-sustaining at approximately 95% speed, the ignition is turned off. The fuel control unit will stabilize the engine speed at approximately 100% rpm.

APU FUEL SYSTEM

Presently the APU fuel system consists of six major components and the system plumbing: the fuel control unit, two fuel solenoid valves, the acceleration stabilizer solenoid, the fuel atomizer, and the acceleration and overtemperature thermostat. Some of these components are mounted on the APU, while others are mounted on the airframe and are connected to the aircraft fuel system. Until recently a seventh component, the APU fuel boost pump, was installed in the left wing fillet behind the wing rear beam. Service experience indicated that the system would be more reliable using the engine feed boost pump in No. 2 tank, so the system has been redesigned and the APU boost pump deleted from all aircraft so equipped by incorporation of P-3 Airframe Change No. 159.

Fuel is normally supplied to the APU from the aircraft's No. 2 fuel tank at the reduction tee in the No. 2 engine fuel supply line (see Figure 4). This tee is located downstream from the No. 2 boost pump discharge port and dual check valve, outside of the No. 2 tank's surge box. During a battery start (without external ac power) the No. 2 boost pump can not be energized, so fuel is *drawn* from the No. 2 tank surge box via the boost pump bypass line by the pump in the APU's fuel control unit. If ac electrical power is already available to the aircraft, the No. 2 boost pump can be energized and supply fuel to the APU under pressure, or fuel can be cross-fed from tanks Nos. 1, 3, or 4 to the reduction tee in the No. 2 engine fuel supply line.[4]

Fuel from the tank is routed through a manual shutoff valve and the first fuel solenoid valve, then through a 10-micron filter. The APU fuel line is routed from the filter through the No. 5 fuel tank forward to the fuel control unit in the APU compartment. The fuel control unit, which is a combination fuel pump/governor/acceleration limiter, supplies fuel to the fuel atomizer in the APU engine hot section according to a predetermined schedule. Operation of the fuel control unit is automatic, supplying the proper amount of fuel to start the APU and sustain its operation. The acceleration and overtemperature thermostat prevents excessive fuel flow to the engine, and a second fuel solenoid valve serves as the "on-off" valve for the APU.

[4]*If air has become entrained in the APU fuel lines during maintenance activity, apply external ac power to the aircraft and pressurize the APU fuel lines with one of the fuel boost pumps during the first APU start after the aforementioned maintenance activity.*

The amount of fuel that can be safely injected into the combustion chamber varies directly with the density and flow of air within the combustion chamber. At low engine speeds the compressor is very inefficient, and the density of the air in the combustion chamber is comparatively low. By the time the engine has accelerated to about 10% operating speed, the compressor discharge flow is sufficient to permit injection of fuel into the combustion chamber. The compressor discharge flow and pressure continue to increase as the engine accelerates, permitting more fuel to be added to the combustion chamber. The fuel control acceleration limiter schedules the fuel flow until the engine has accelerated to 95% operating speed, at which time the fuel governor takes over regulation of the fuel flow.

SOLENOID-OPERATED FUEL VALVE (WING FILLET) The first solenoid-operated valve that the APU fuel supply encounters is located in the rear of the left wing fillet. This normally closed valve's solenoid is powered through the FUEL VALVE circuit breaker (formerly the FUEL PUMP AND VALVE c.b. prior to removal of the APU boost pump) on the Ground Operating DC Bus. The solenoid opens the valve when the APU control switch is positioned "ON," and keeps it open as long as the APU's control circuitry remains energized.

FUEL CONTROL UNIT The fuel control unit adjusts fuel supply to hold engine speed within narrow limits, thereby matching automatically the APU power output to the demand made by the aircraft systems.

The fuel control unit assembly, often called the "fuel cluster," is mounted on the engine accessory drive housing. It is composed of the fuel governor, acceleration limiter valve, fuel pump, filter, and the high pressure relief valve. As the fuel enters the fuel control unit, the first component it encounters is the two-gear, positive-displacement type fuel pump. The fuel pump has a main drive gear and an idler gear, both of which are integral with their shafts. Each gear is sandwiched between two bronze bushings that are spring-loaded against the gears to maintain minimum clearances within the pump assembly. This keeps fuel pump internal leakage to a minimum and helps maintain the pump efficiency as the bushings wear. The fuel pump main gear is driven by the fuel cluster drive shaft, which is driven by the oil pump drive. The other end of the fuel pump main drive gear shaft drives the governor. The pump is lubricated solely by the fuel that passes through it. As the fuel passes through the pump, it also acts as a heat sink to carry away any heat developed by friction within the pump.

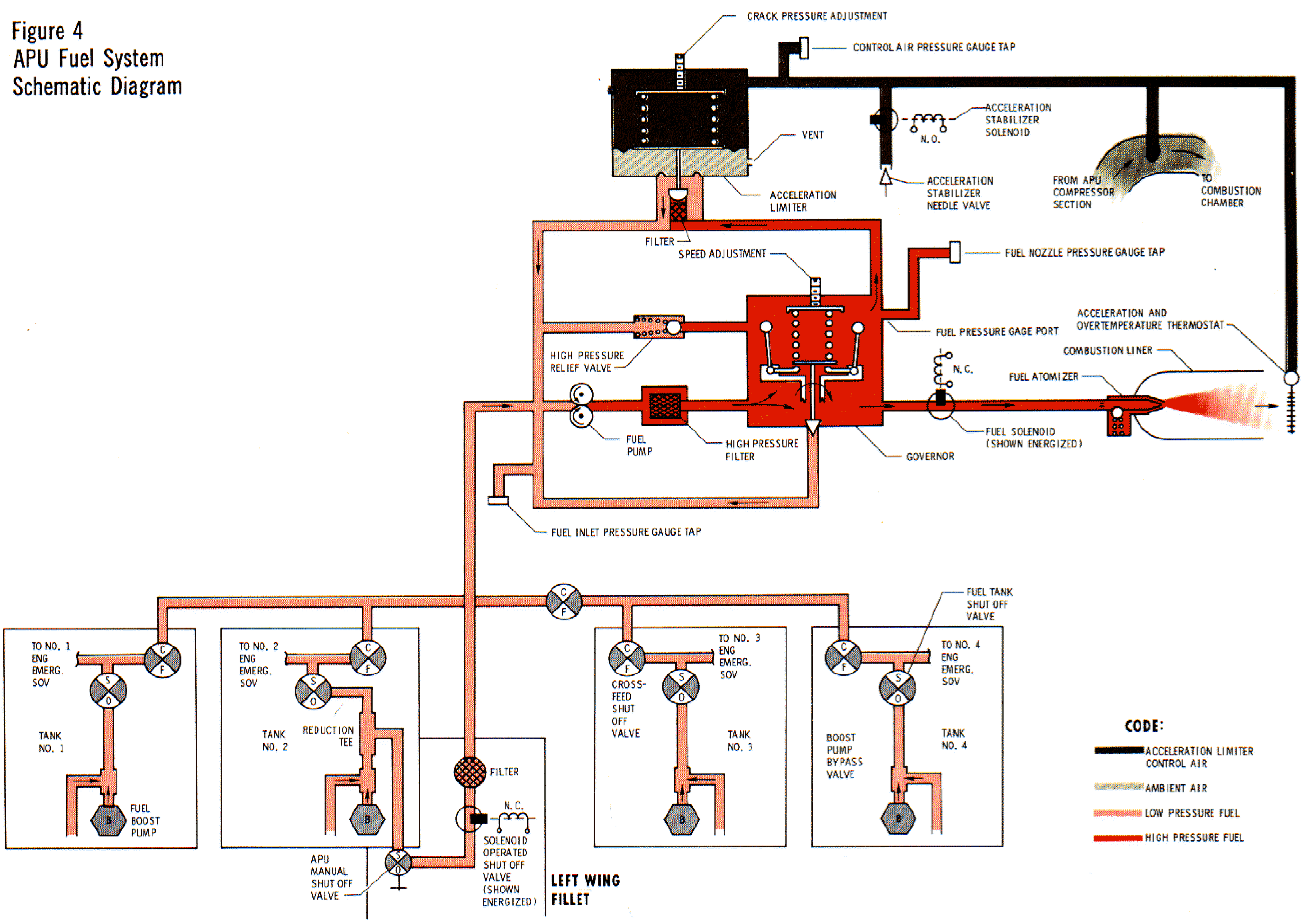
The fuel exits the fuel pump and is forced through a high pressure, paper cartridge-type filter. Although there are no provisions for a filter bypass in case the filter element becomes clogged, this should pose no problems because the fuel has already been filtered through the element in the left wing rear fillet. Both of these filter elements should be replaced at 200 hour intervals. After the fuel has been filtered, it is ported to the fuel control unit governor chamber.

During normal operation of the APU, the unit's fuel flow is regulated by the governor. The governor regulates the fuel flow by positioning a fuel control valve that bypasses fuel back to the inlet side of the fuel pump. The more fuel bypassed to the fuel pump inlet, the lower the fuel flow through the atomizer and into the combustion chamber.

The governor is composed of the fuel control valve sleeve, the governor drive shaft, two "L"-shaped flyweights mounted on the governor drive shaft, and a "speeder spring." It operates on conventional principles — rotation of the governor drive shaft (which is driven by the fuel pump drive gear shaft) causes the flyweights to rotate, and centrifugal force causes them to move radially outward. As the flyweights move outward, the toes of the flyweights move the sleeve-type fuel valve (that slides on the governor shaft) against the speeder spring force towards the open position to bypass fuel to the fuel pump inlet.

Thus, when the flyweight rotational speed decreases (and this is directly related to engine speed), the speeder spring force overcomes the centrifugal force of the flyweights, moves the valve towards the "closed" position, and less fuel is bypassed. The governor can be adjusted by varying the tension of the speeder spring. At speeds below 95% engine operating speed, the speeder spring force is greater than the flyweight centrifugal force and holds the governor valve closed.

Figure 4
APU Fuel System
Schematic Diagram



During the starting cycle (below 95% engine operating speed) the fuel governor is inoperative, and the acceleration limiter meters the fuel flow to the engine. The acceleration limiter senses how much fuel is required to accelerate the APU to operating speed (idle), then modifies the fuel flow accordingly by bypassing excess fuel back to the fuel pump inlet. Figure 4 shows that fuel pressure tends to force the limiter's bypass valve open; the pressure of air available for combustion, acting through the limiter's control system, tends to keep the valve closed.

The acceleration limiter control system applies engine compressor discharge air pressure to a diaphragm, and this force is applied to the bypass valve at a 15:1 pressure ratio (approx.). This means that the valve cracking pressure will vary with the compressor discharge pressure, and a 1-psi change of air pressure will result in a 15-psi change in fuel pressure. A minimum valve cracking pressure is set by adjusting the spring force applied to the diaphragm. At lower engine speeds, when compressor discharge pressure is extremely low, the spring pressure on the diaphragm prevents fuel from being bypassed freely through the relief valve back to the fuel pump inlet, and it ensures that there will be sufficient fuel pressure (34 ± 1 psig) for light-off. The tension of the spring can be adjusted and should be checked during routine inspections.

The acceleration limiter's control air pressure is "fine tuned" to the individual APU with an adjustable needle valve that bleeds control air from the limiter's system. The needle valve is adjusted to cause the fuel controller to supply the engine with fuel enough to obtain the fastest rate of acceleration that can be realized without compressor surge. A normally open solenoid-operated bleed air shutoff valve, called the acceleration stabilizer solenoid, is interposed between the control air line and the needle valve, and the two are combined into one assembly. Actuation of the centrifugal sequencing switch assembly (one of the APU's electrical components) opens the acceleration stabilizer solenoid valve between 35% and 95% engine operating speed, allowing control air to bleed through the needle valve during the latter part of the starting cycle, but not during the initial part of the starting cycle nor during normal engine operation when loss of control air might cause fuel starvation.

As the engine speed increases during the start cycle, the acceleration limiter establishes a fuel flow schedule that permits the engine to accelerate to normal operating speed without stalling or surging. At 95% engine speed the governor starts to control the fuel pressure, and the engine accelerates to 100% operating speed. As loads are applied to the APU, the governor allows an increase in fuel pressure to match the load requirements. The acceleration limiter does not interfere with the operation of the governor under normal operating conditions because the limiter's control air pressure sets the limiter bypass valve cracking pressure higher than the governed fuel pressure. It should be noted, however, that the limiter remains in a standby role, and will promptly reduce the fuel flow to the combustion section if control air pressure is reduced. This application of the limiter will be discussed later under the heading "Engine Overtemperature Protec-

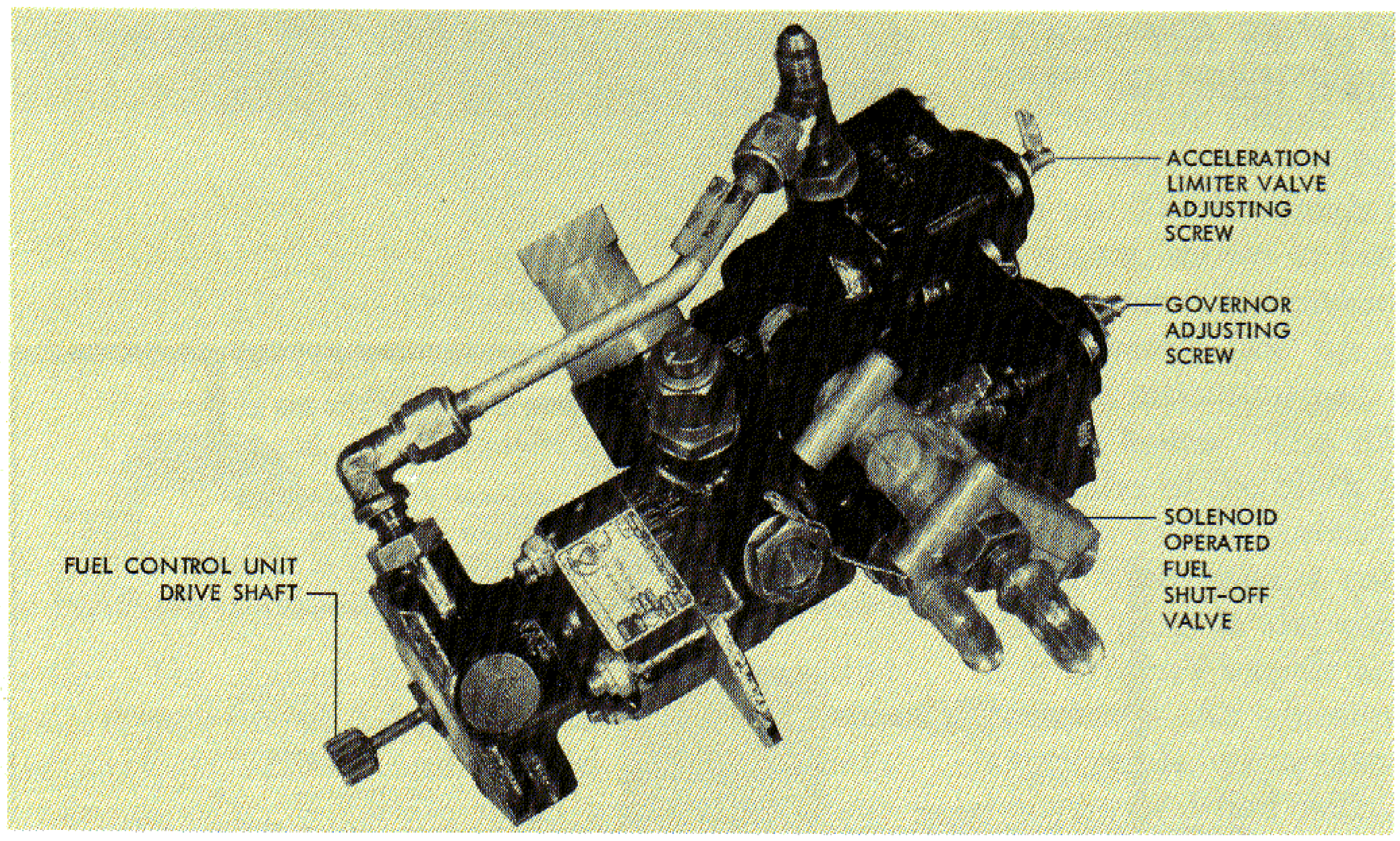


Figure 5
Fuel Control Unit
and Solenoid-operated
Fuel Shutoff Valve

tion System." This brings the discussion of the fuel control assembly to the high pressure relief valve.

Attached to the fuel control unit and situated immediately downstream from its outlet is the fuel system's other fuel solenoid valve. When the APU is shut down, the solenoid valve is de-energized and closes while the control unit's fuel pump is still operating, causing a sharp surge of pressure within the fuel control assembly. The control unit's high pressure relief valve cracks at approximately 490-540 psi and bypasses fuel from the governor chamber back to the fuel pump inlet, thereby preventing damage to the fuel control unit whenever the APU is shut down.

FUEL SOLENOID VALVE The fuel solenoid valve mounted on the fuel control unit is used to turn on or shut off the fuel to the fuel atomizer. It is a straight-through flow type valve that is electrically actuated, and is normally closed. Its components are a valve body, a movable plunger, a solenoid coil, and two spring-loaded carbon discs which are set in a hole in the lower end of the plunger and spring-loaded outward to contact the lapped faces of two seats in the valve body.

When the valve solenoid is de-energized, the plunger is positioned to interpose the discs in line with the holes in the valve seats. The incoming fuel pressure forces the downstream disc tightly against its seat and shuts off the fuel flow. When the solenoid is energized, the valve plunger is magnetically attracted upward. This upward movement of the plunger slides the discs over the seat faces until they clear the holes in the seats, allowing the fuel to pass through the valve body. An arrow on the valve body indicates the normal flow direction. If the arrow points in two directions, the valve is reversible; if not, observe the flow direction when installing the valve, otherwise it will leak internally.

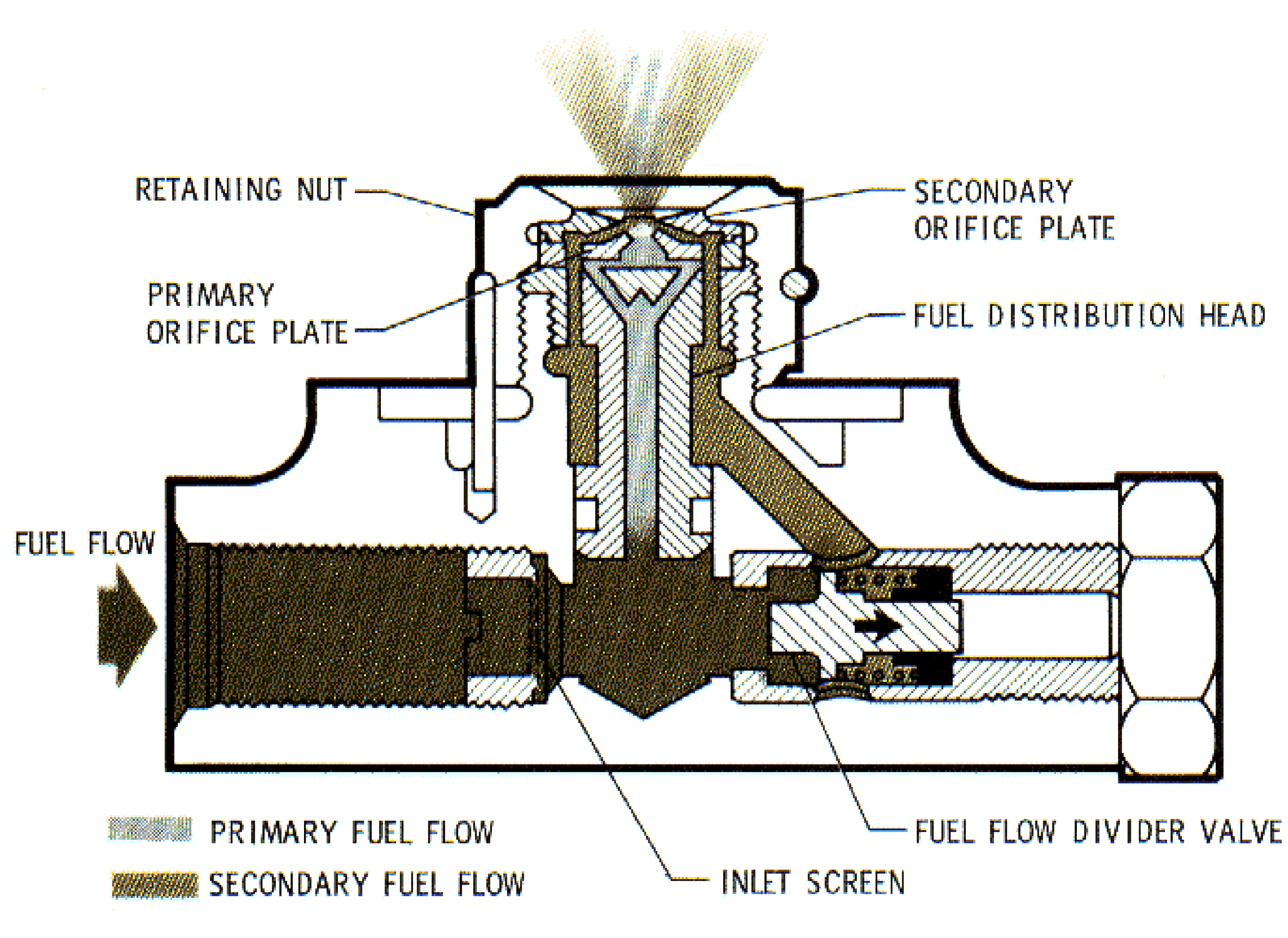


Figure 6 Fuel Atomizer

The fuel solenoid valve is energized during the APU starting sequence by actuation of the oil pressure sequence switch at approximately 10% engine rpm (2.5 - 3.5 psi oil pressure). This allows fuel to flow under pressure to the fuel atomizer in the combustion chamber. The valve can be de-energized to cut off the fuel flow by any of the following means: a) manual actuation of the control switch on the APU control panel to "OFF"; b) manual actuation of the APU safety switch to "SAFE"; c) manual or automatic actuation of the 106% overspeed switch in the centrifugal sequencing switch assembly; d) automatic actuation of the scissors switch at takeoff if the APU in-flight circuitry is not energized; e) automatic actuation of the oil pressure sequence switch; f) manual or automatic actuation of the APU fire detection circuit; g) manual actuation of the APU in-flight arming switch to "OFF" during in-flight APU operation.

FUEL ATOMIZER The fuel flows under pressure from the fuel control unit through the fuel solenoid valve to the fuel atomizer mounted on the cap of the engine combustion chamber. There the atomizer converts the fuel into a fine spray that is mixed with the air supplied by the engine compressor.

The atomizer is made up of three main parts: a dual orifice nozzle, a flow divider valve, and the atomizer body (see Figure 6). The dual orifice nozzle is actually two nozzles that are assembled concentrically, one inside the other. The center nozzle, the smaller of the two, is called the primary orifice and is specifically designed to atomize fuel supplied at low pressure, the condition present in the fuel system during engine light-off and during the early part of the starting cycle. As the engine accelerates, the fuel flow and pressure increase. Finally, when a predetermined pressure (40 psig ± 1) is reached, the pressure-sensitive flow divider valve cracks, porting fuel to the secondary orifice too. This supplies an increased volume of atomized fuel to the combustion chamber, permitting the engine to accelerate to normal operating speed.

The flow divider valve is preset at the factory or during overhaul, so no attempt should be made to adjust it in the field. However, the valve may be removed and its O-ring packings inspected to see if the valve is seating properly. Fuel leakage around the valve or premature valve opening will result in excessive fuel flow into the combustion chamber. This condition has little if any effect on engine

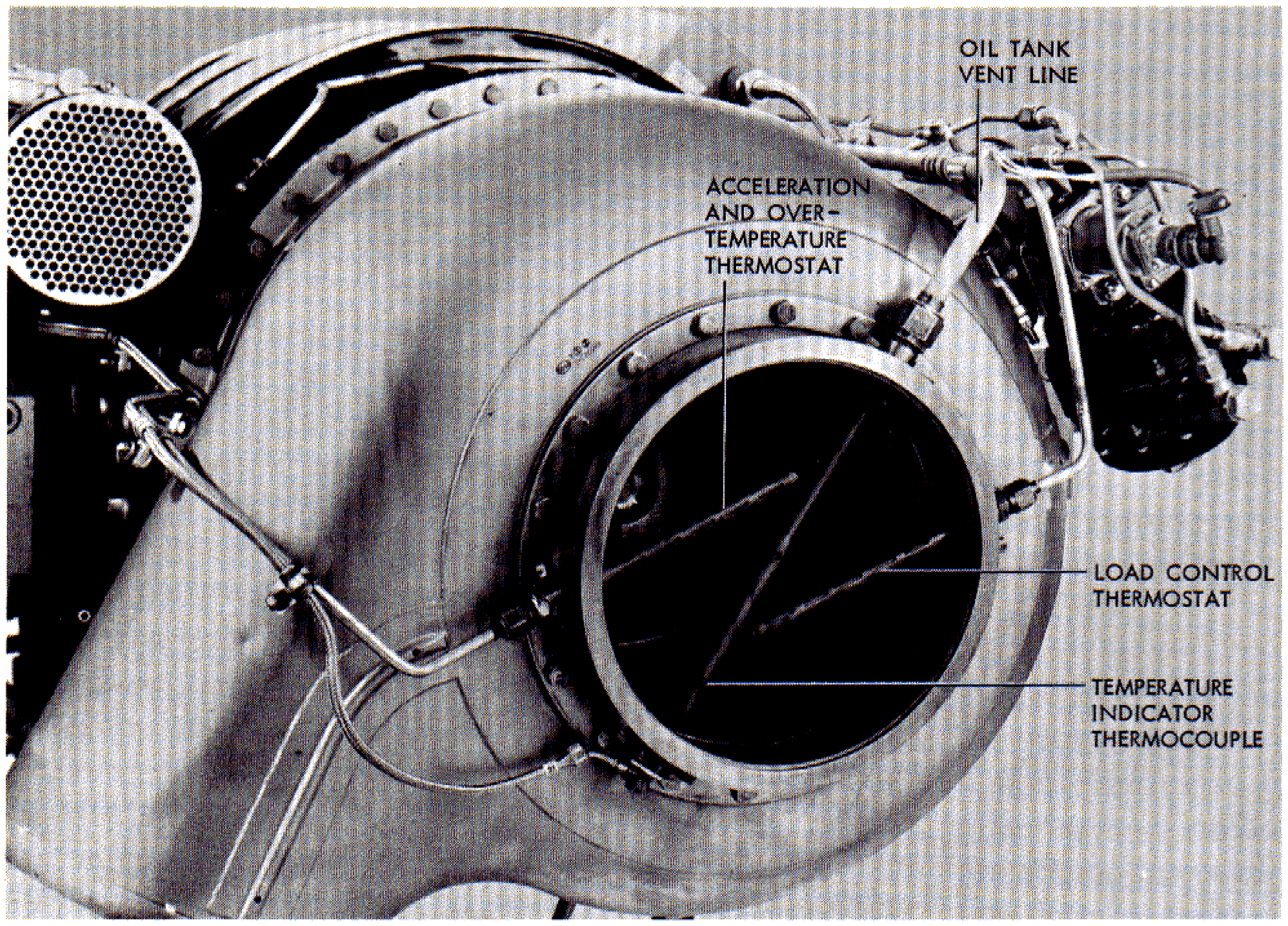


Figure 7
APU Exhaust Outlet

Photo Courtesy of the Garrett Corporation

operation at normal speed, but during the starting cycle the effects may be quite dramatic. During an APU start a small amount of fuel leakage may cause flames to shoot out the APU exhaust, perhaps there may be a booming sound at light-off, and the turbine could be subjected to excessive temperatures and suffer thermal damage. If the leakage around the valve is severe, the fuel igniter plug could be drowned in raw fuel, or the fuel-air mixture could be too rich to burn. It should be pointed out that the same conditions can be produced when misadjustment of its diaphragm spring sets the acceleration limiter valve's cracking pressure above 34 ± 1 psig.

ENGINE OVERTEMPERATURE PROTECTION SYSTEM

The engine overtemperature protection system monitors the APU exhaust temperature, and when an overtemperature condition is detected the fuel flow to the engine is reduced.[5] This system utilizes a pneumatic thermostat (Figure 7) in conjunction with the fuel control unit's acceleration limiter control valve. The acceleration and overtemperature thermostat, a normally closed, temperature-actuated air valve, is connected to the acceleration limiter's control system. When the thermostat senses excessive exhaust gas temperature, the difference of thermal expansion of the materials within the thermostat causes the valve to open and leak air from the limiter's control system. This decrease of control air pressure allows the acceleration limiter valve to bypass fuel more readily, lowers the fuel pressure to the atomizer, reduces the fuel supply to the engine, and lowers the temperature in the combustion chamber.

In practice the thermostat does not react immediately to a temperature change. When it does react, it acts as a variable-area bleed air valve in the acceleration limiter's control air line. To allow for its lag in reaction to temperature change, the thermostat is calibrated at a preselected rate of temperature increase to achieve fuel limiting action at an exhaust gas temperature of 1340°F - 1350°F (727°C - 732°C). This allows the acceleration limiter to smoothly adjust the fuel pressure, avoiding rapid transitions of engine temperature. The thermostat provides protection against overheat damage, both during the start cycle and during operation at normal speed.

The acceleration and overtemperature thermostat may be adjusted by varying the number and thickness of shims between the thermostat's ball seat fitting and its outer housing. Decreasing the number of shims raises the setting of the thermostat, while adding shims has the opposite effect. A change of .001 inch in the total shim thickness will result in a change of approximately 30°F in the thermostat's temperature setting.

[5]*The engine overtemperature protection system and the pneumatic load control system (described later in this article) complement each other in the primary function of preventing thermal damage to the APU engine.*

APU OIL SYSTEM

The GTCP95-2 oil system provides pressurized and splash lubrication for all engine gears, shafts, and bearings whenever the APU is in operation. MIL-L-23699 oil is recommended as the engine lubricant by both AiResearch and Lockheed.[6] This is a synthetic oil — under no circumstances should a petroleum-based oil be used in the APU. If the APU is to be operated in an extremely cold environment (—65°F to —40°F), MIL-L-7808 oil may be used.

The oil system's major components are the oil pump assembly, an oil tank, an oil cooler, the oil jet and scavenge fittings, and the oil pressure sequencing switch. The oil pump assembly is mounted on the engine accessory section and is composed of an oil pressure pump, a dual oil scavenge pump, a pressure regulating valve, a filter, and a filter relief valve. A pad on the oil pump housing mounts the APU tachometer generator. An auxiliary drive shaft (Figure 8) from the oil pump gear shaft drives the fuel control unit. Figure 9 shows a schematic of the APU oil system.

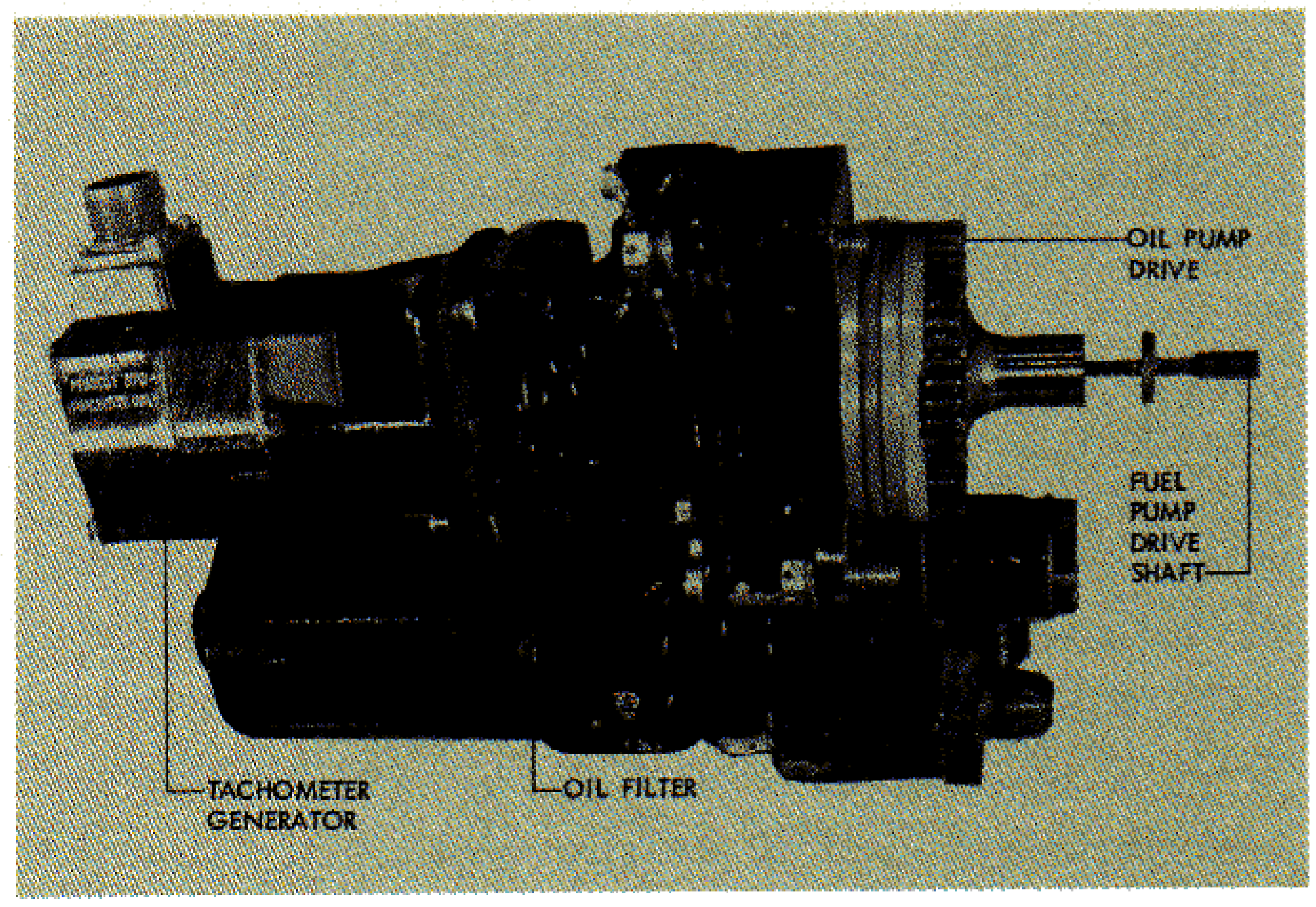


Figure 8 Oil Pump Assembly. APU tachometer generator is positioned on its mounting pad, but not installed.

[6]*See Qualified Products List 23699 for the approved brands of oil. Do not mix different brands of approved oils.*

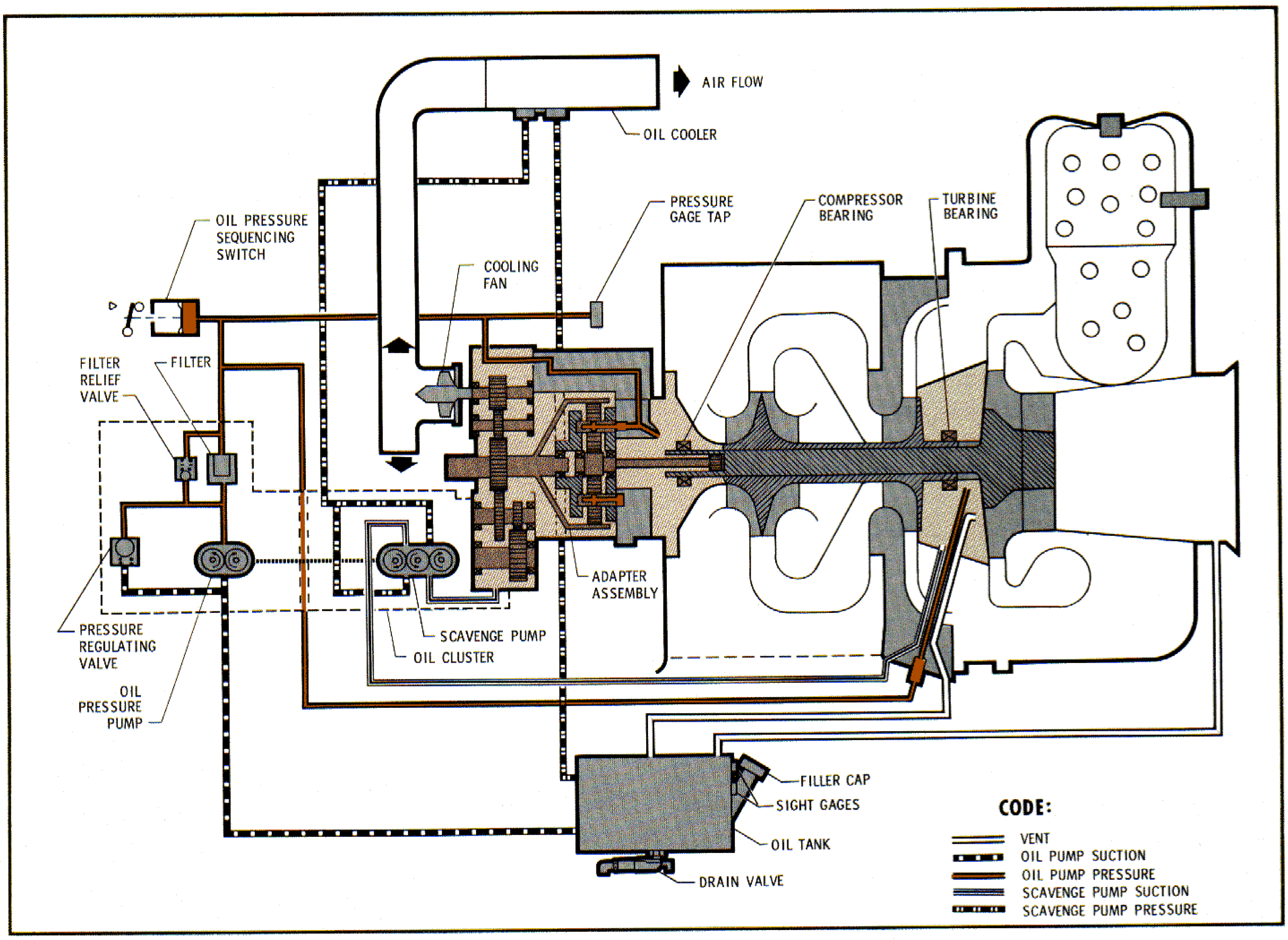


Figure 9 APU Oil System Schematic Diagram

The oil pressure pump is a gear-type lubrication pump with one drive gear and one idler gear. The oil scavenge pump is of similar design, except that it has an additional idler gear. Both pumps (and the tachometer generator) are driven by a common shaft from the engine accessory gear train. The oil pump supplies oil at a rate of about four gallons per minute, 2.5 gallons of which are forced through the system while the other 1.5 gallons pass through the oil pressure regulating valve and back to the oil pump inlet. The pressure regulating valve is set to maintain 90 ($\pm$10) psig at the pump manifold.

A re-usable metal filter element is installed downstream from the oil pressure pump. This filter will cause a drop of at least 10 psi of system pressure even when the filter is clean, but as the filter entraps contaminants the pressure drop increases. When the pressure differential across the filter reaches 40-60 psig, the filter bypass valve opens and allows unfiltered oil to flow through the system. The oil must be changed and the filter element cleaned about 20 hours after installation of a new or overhauled APU, and regularly thereafter at 200 hour intervals. After the oil has passed through the filter, it is routed to the oil pump manifold fitting.

Two lines are connected to the oil pump manifold fitting. One line leads directly to the turbine journal bearing oil fitting, while the other leads to the oil pressure sequence switch and to a tee mounted on top of the engine accessory drive case. One leg of the tee directs oil to the gears and bearings in the accessory case and to an oil jet that lubricates the compressor shaft ball bearing; the other leg has a 0.040-inch orifice and routes oil to an oil pressure gage quick-disconnect fitting that may be used during normal maintenance activity. The orifice prevents rapid loss of oil from the system if the quick-disconnect shutoff valve fails when the gage is removed. The normal oil pressure reading at this point in the system is 60 ($\pm$ 10) psig. The oil pump manifold fitting also has a boss that normally is plugged. The plug may be removed and a temperature bulb installed for test purposes.

After the oil has lubricated the bearings and gears, it flows to the bottom of the accessory assembly and to the bottom of the aft bearing cavity. Then the oil is removed from each of these sections by separate halves of the dual scavenge pump. Each pump-half operates at a speed that can displace about 4.5 gallons per minute from its respective section, exceeding the total flow through the oil filter (which is never more than 2.5 gallons per minute) by a wide margin. Thus, the scavenge pump removes air

Photo Courtesy of the Garrett Corporation

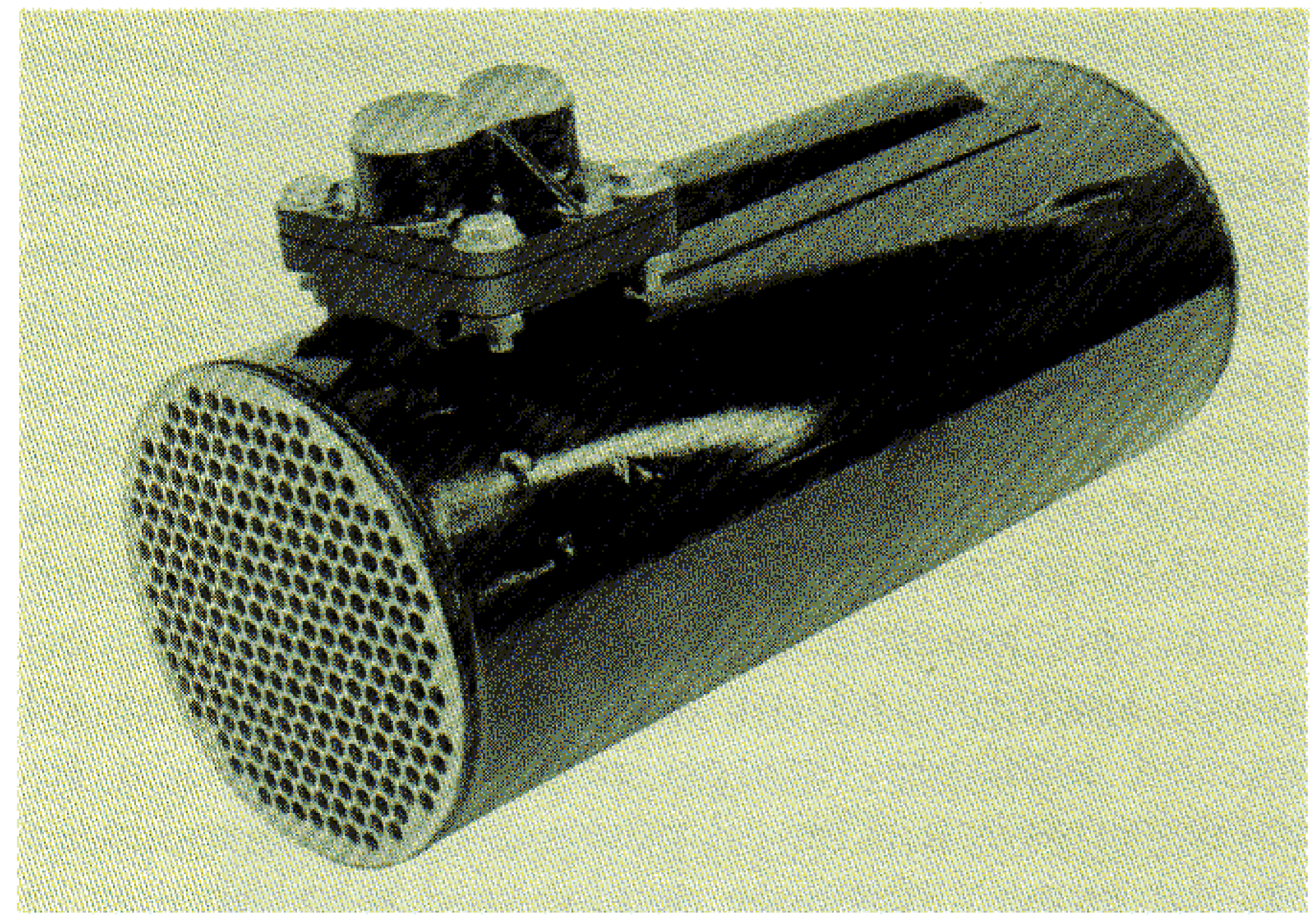


Figure 10 APU Oil Cooler

as well as oil from these sections, and creates a negative air pressure in both sections during engine operation. The hot foamy oil/air mixture is discharged from the scavenge pump and directed to the oil cooler (Figure 10).

As the oil/air mixture is passed through the oil cooler, heat is transferred from the mixture to air forced through the cooler's heat exchanger tubes by a fan. Next, this mixture is routed from the cooler to the oil tank where it is directed against an air-oil separator. This induces a whirling motion to the mixture that causes the heavy oil particles to cling to the separator wall and flow down into the tank where they again become part of the system oil

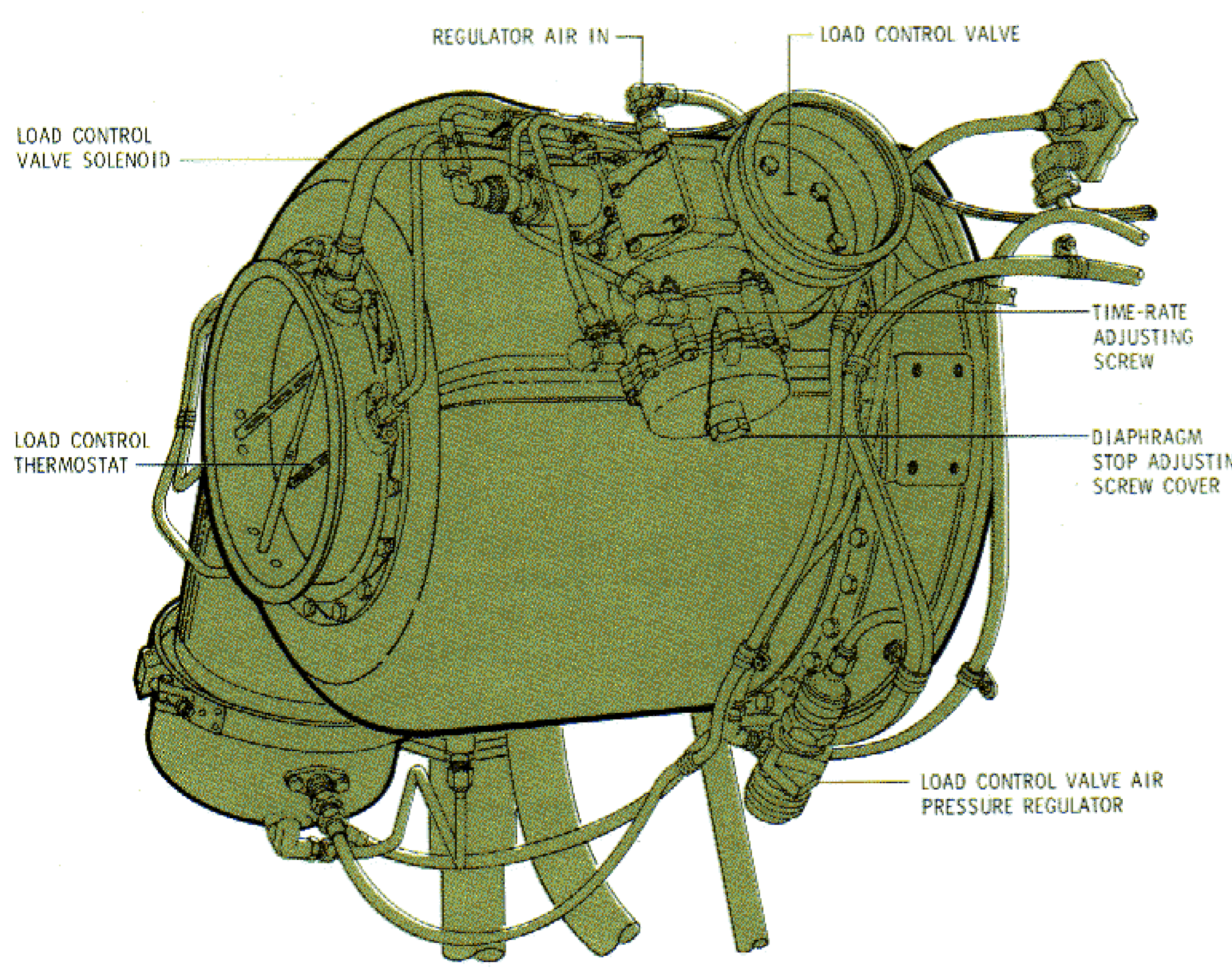


Figure 11 APU Pneumatic System Component Location

supply. The tank vent line ducts the air to the APU turbine exhaust to prevent the build-up of excessive pressure within the tank. Excessive oil vapor vented into the exhaust is indicated by blue smoke in the exhaust stream.

A separate line interconnects the turbine bearing cavity and the oil tank. The cavity is surrounded by compressed air, and if an engine housing seal were to leak, sufficient positive pressure could develop within this cavity to establish a flow which would carry entrained oil vapor into the compressor or turbine wheel areas. The interconnection ensures that such leakage will be ported to the oil tank, and then overboard into the exhaust. A major seal leak in the aft engine cavity would cause an excessive amount of oil vapor to be vented into the oil tank and some oil vapor will then escape into the exhaust.

The oil tank has a usable capacity of one U.S. gallon. The remainder of the space is allowed to accommodate the foaming oil that the scavenge pump returns to the tank via the oil cooler. Two sight gages are installed on the tank, the upper to indicate when the tank is full and the lower to indicate when the oil is two quarts low and must be replenished. A screen is installed on the filler tank neck to prevent large objects from inadvertently falling into the tank during oil replenishment. During normal engine operation the oil tank is slightly pressurized. Never remove the oil tank filler cap when the APU is running. To do so could spatter an individual with hot oil and cause serious injury.

PNEUMATIC LOAD CONTROL SYSTEM

Air can be bled from the APU compressor section to supply pneumatic power to the main engine starting system, to the air cycle refrigeration system, or to the bomb bay heating system. The quantity of air that may be bled from the unit varies, depending on the environmental conditions (ambient air pressure and temperature) and the loads imposed upon the unit by the 60-kva generator. The limiting factor is the engine exhaust gas temperature, for as more air is bled from the compressor there is less air available to "cool" the engine combustion section, so the exhaust gas temperature increases. If electrical loads are applied to the APU generator too, more fuel is supplied to the engine to produce the additional shaft power required to maintain engine rpm. This also results in an increase of engine temperature. The APU's pneumatic load control system senses the engine exhaust temperature and limits the amount of air that can be bled from the unit when the engine's thermal limit is approached.

The pneumatic load control system's major components are the bleed load control valve, the air pressure regulator, and a pneumatic thermostat, all of which are mounted on the APU turbine section (Figure 11). The bleed load control valve assembly is a pneumatically operated butterfly valve. The compressed air (control air) that operates this valve is tapped from the engine compressor and passed through a pressure regulator to reduce the air pres-

sure to approximately 20 psig. Figure 12 depicts how the solenoid-operated switcher valve routes this regulated compressed air to either the upper or lower side of a diaphragm and vents the other side of the diaphragm to atmosphere. This causes the diaphragm to move, mechanically actuating the butterfly valve. When air pressure is directed to the upper side of the diaphragm, the bleed load control valve opens; when air is directed to the lower side of the diaphragm, the valve closes.

The load control thermostat (Figure 7), a pneumatic thermostat actuated by rising APU exhaust temperature, is connected to the air line that leads to the upper side of the load control valve diaphragm. This thermostat bleeds air from the "valve open" side of the diaphragm as the engine exhaust temperature approaches 1240°F (672°C),[7] causing the butterfly valve to move toward the closed position. When the exhaust temperature subsides, the load control thermostat stops bleeding air from the "valve open" line, permitting control air pressure to increase and move the valve toward the open position.

[7] *1250°F (677°C) is the turbine discharge temperature limit for continuous operation, but individual APUs may be set at slightly lower temperatures when specification performance can be met.*

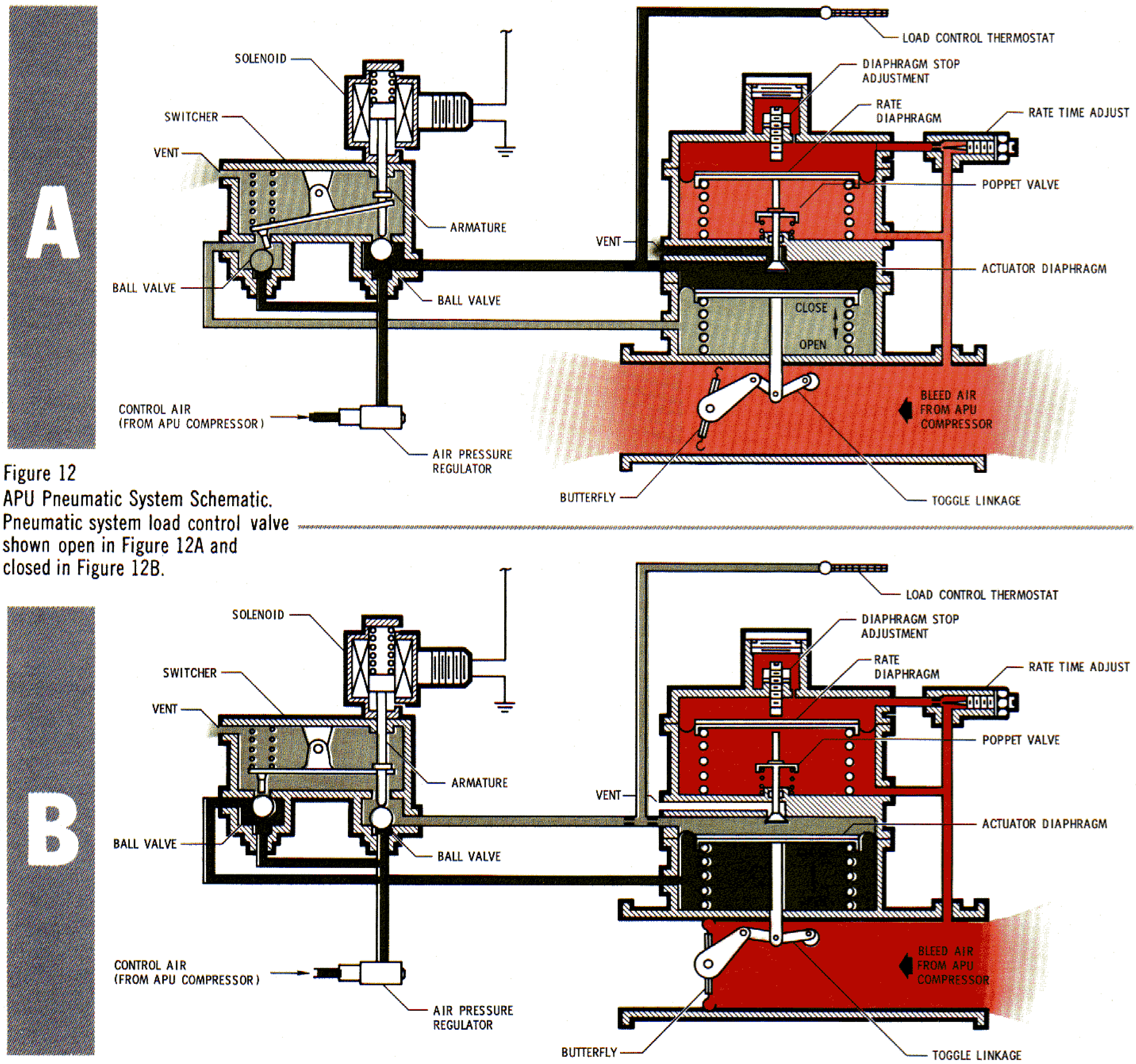


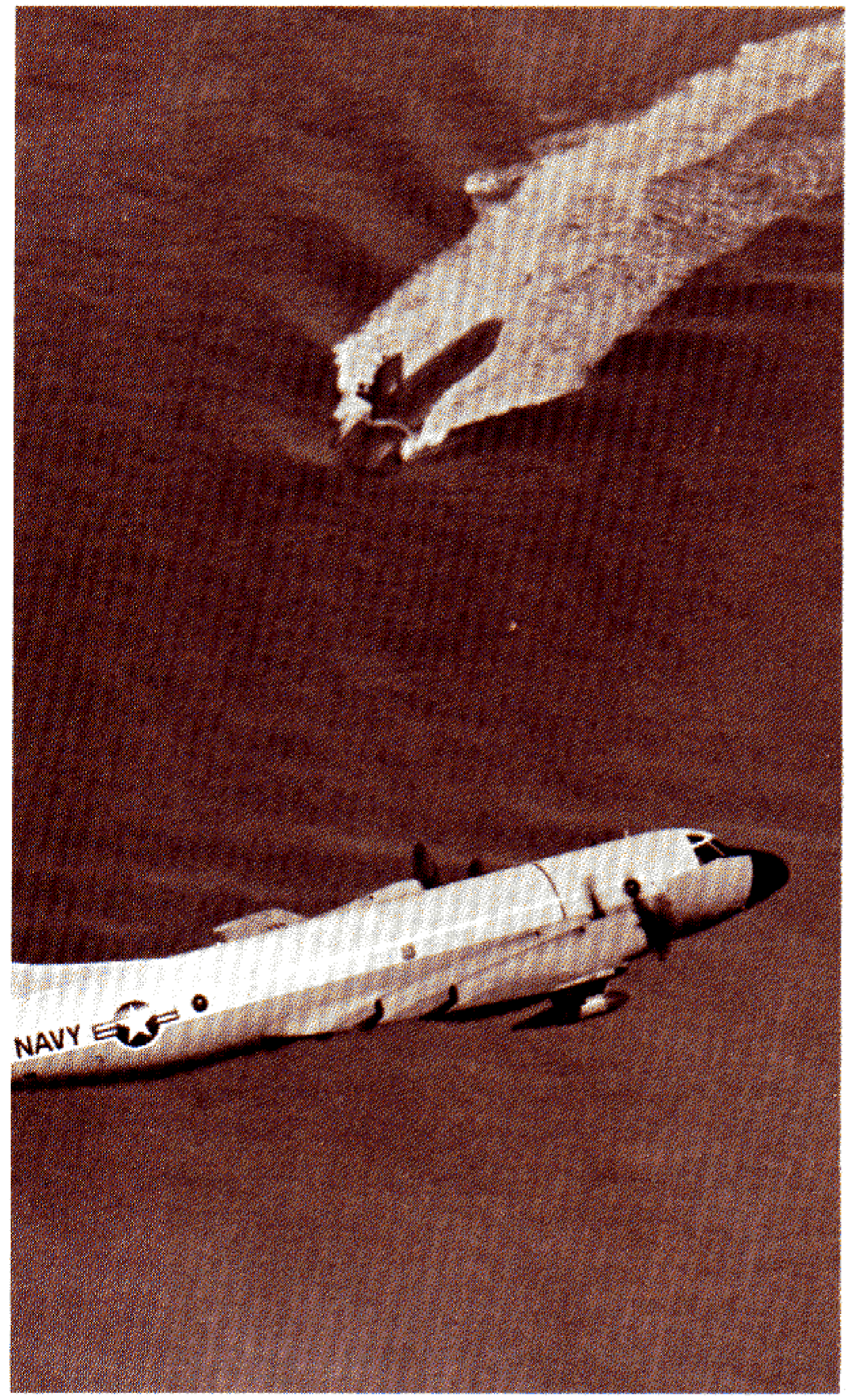
Figure 12
APU Pneumatic System Schematic.
Pneumatic system load control valve shown open in Figure 12A and closed in Figure 12B.

The load control thermostat (P/N 107658-17) and the acceleration and overtemperature thermostat (P/N 107658-18) are identical in appearance and function, differing only in the temperature at which they are set to open. Since there is a difference of approximately 100°F (56°C) between the actuation points of the two thermostats, use of the wrong thermostat could degrade APU performance. Always be certain that you have the proper thermostat before you install it. Acceptable alternates to these thermostats are the P/N 107966-17 load control thermostat and the P/N 107996-62 acceleration and overtemperature thermostat.

The load control thermostat reacts quite slowly to temperature changes, causing the load control valve's operating system to respond in a similar manner. If the load control valve were allowed to open too far, too fast, it would not react fast enough to modulate the valve when momentary excessive loads were imposed upon the APU. This might expose the engine to overtemperature conditions. A valve opening rate control device is incorporated into the design of the bleed load control valve to prevent it from opening too fast.

The valve opening rate controller has two chambers that are separated by a diaphragm. Downward movement of the diaphragm unseats a poppet valve and bleeds air pressure from the load control valve's control system. Air is ported from the upstream side of the butterfly valve directly into the rate controller's lower chamber, and is ported through an adjustable orifice into the controller's upper chamber. The pressure drop that occurs upstream of the butterfly valve when the valve opens causes air to flow back from both chambers, but, due to the presence of the adjustable orifice, the return flow of air from the upper chamber is much slower. This creates a pressure differential between the two chambers (the higher pressure being in the upper chamber), that forces the diaphragm to move downward and unseat the poppet valve. When the poppet valve is unseated, air is bled to atmosphere from the load control valve operating system. This lowers the air pressure on the upper side of the actuator diaphragm and stops the butterfly valve from opening further.

The rate at which the butterfly valve now opens is directly related to how much control air is vented through the poppet valve — the more control air vented, the slower the butterfly valve movement. The rate at which the poppet valve is allowed to seat (which determines how fast the butterfly valve will open) is set by adjusting the orifice to the upper chamber.



ELECTRICAL SYSTEM

The APU's electrical system provides the means of starting the APU engine, controlling the unit's fuel supply, igniting the fuel, controlling engine acceleration, and, after the starting cycle has been completed, monitoring the operation of the engine. Most of the APU electrical system components are located either in the APU compartment, just forward of the bomb bay, or in the flight station. 28-volt dc power is used to start, sustain, and control the APU'S operation, and power the unit's fire protection circuitry.

Since the primary intent of the APU installation is to provide the aircraft with self-contained operating capability, the APU's prime starting power source must be considered the aircraft's 34 ampere-hour battery. Naturally this does not preclude starting the APU with ground power or with power from the aircraft's generators, for in either case the power would merely be supplied through the air-

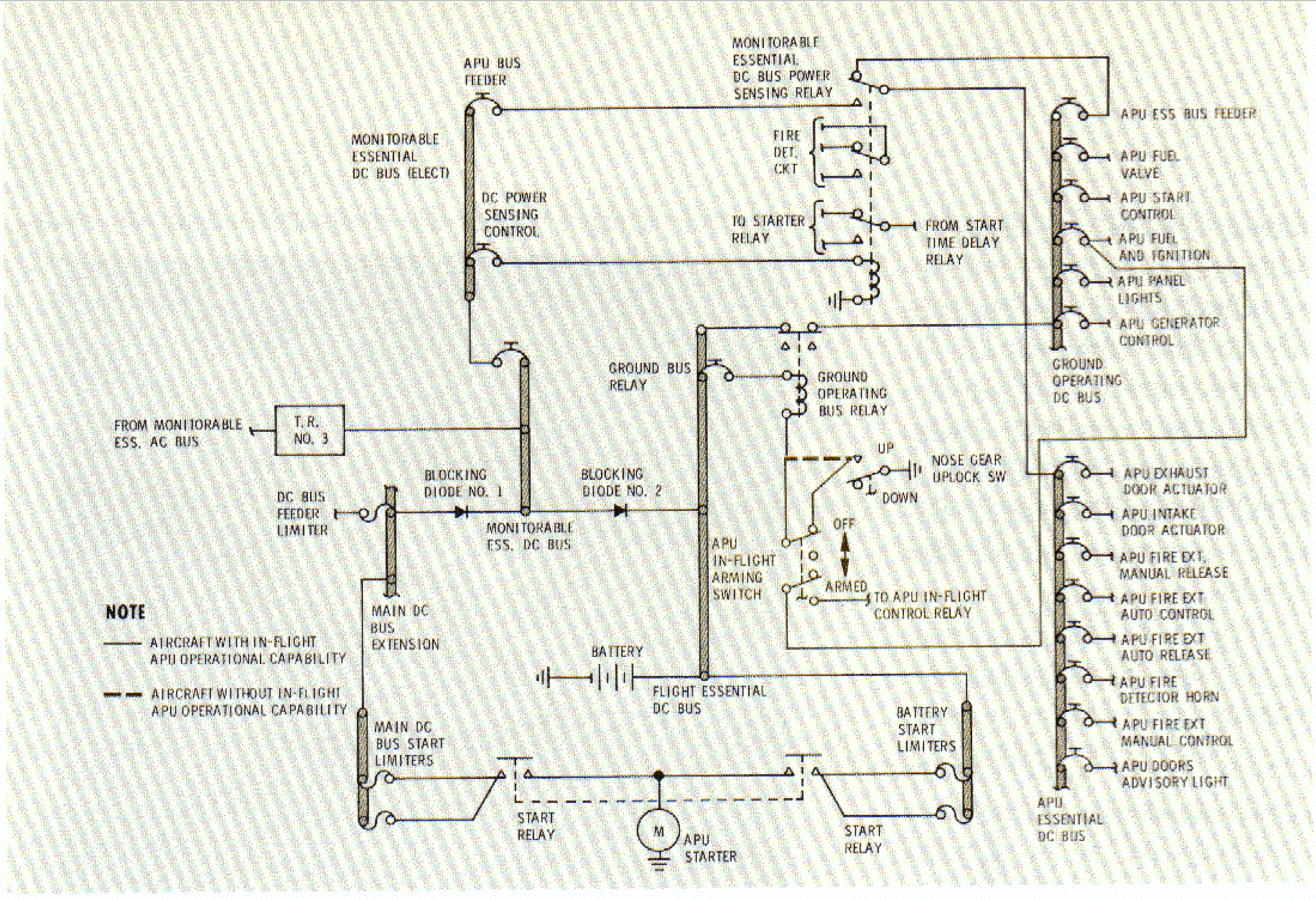


Figure 13
Schematic of
Electrical Power Distribution
to APU Control System

craft's power distribution system (Figure 13). Regardless of the power source employed to start the APU, once the starting sequence is complete, its 60-kva generator can supply electrical power to the aircraft's main electrical system and the APU can draw dc power from the aircraft's system to sustain the unit's operation.

The original concept was to use the APU to supply pneumatic and electric power only during ground operations, but this has been modified to permit the APU to serve as a source of emergency electrical power during flight as long as certain altitude and airspeed restrictions are observed. Later P-3 aircraft have had this feature incorporated during production, while the remainder of the aircraft are being retrofitted to this configuration. Both versions are shown on the simplified schematic of the APU control circuit (Figure 14), the schematic that will serve as the basis of the subsequent electrical system discussion.

SYSTEM DESCRIPTION AND FUNCTION In the following paragraphs the APU circuitry will be traced through the sequence of a battery start, with the assumption that the aircraft is on the ground. Starting the APU with external power or aircraft generator power, and in-flight starting of the APU will also be discussed briefly. During this discussion the significant electrical system components will be pointed out and their relationship to the starting circuitry as a whole will be indicated. After the relationship of the electrical system components has been so established, the major components will be discussed in greater detail.

Battery Start The APU controls are located on the AUXILIARY POWER UNIT panel in the flight station. Before attempting a battery start, make certain that all circuit breakers on the APU Essential Bus panel and those on the APU portion of the Ground Operation DC Bus are *in*. Check that the APU INFLIGHT ARMING switch is in the "OFF" position. This ensures that the APU in-flight circuitry is deactivated, and permits use of the APU's pneumatic power during ground operations. Move the APU fire detector test switch to the TEST position. If the APU fire detection system is functioning properly, the APU fire indicator light on the glareshield will be illuminated and the warning horns in the flight station and tactical area will sound. Return the APU fire detector test switch to the NORMAL position. Push the LIGHTS TEST button to check the operation of the "DOORS" and "ARMED" lights.

Next, move the APU control switch from "OFF" to "ON". This action applies power from the battery through the GROUND OPERATING DC BUS to energize the APU scissors switch relay, which in turn energizes the APU control relay. When the APU control relay is energized, it closes the circuits from the APU ESSENTIAL DC BUS to the APU's air intake and exhaust door actuators, causing the electric motor-driven actuators to open the APU compartment doors. As the doors begin to open, each door actuates a microswitch on the door sill, either of which illuminates the "DOORS" light on the APU panel. When the doors reach the "OPEN" position, a load-sensing device operates a switch within each actuator, opening the actuating circuit and turning off the motor. Two more switches in series (one per door frame) are actuated when the doors reach the full "open" position, and provide the ground for the APU start relay during initiation of the engine starting sequence.

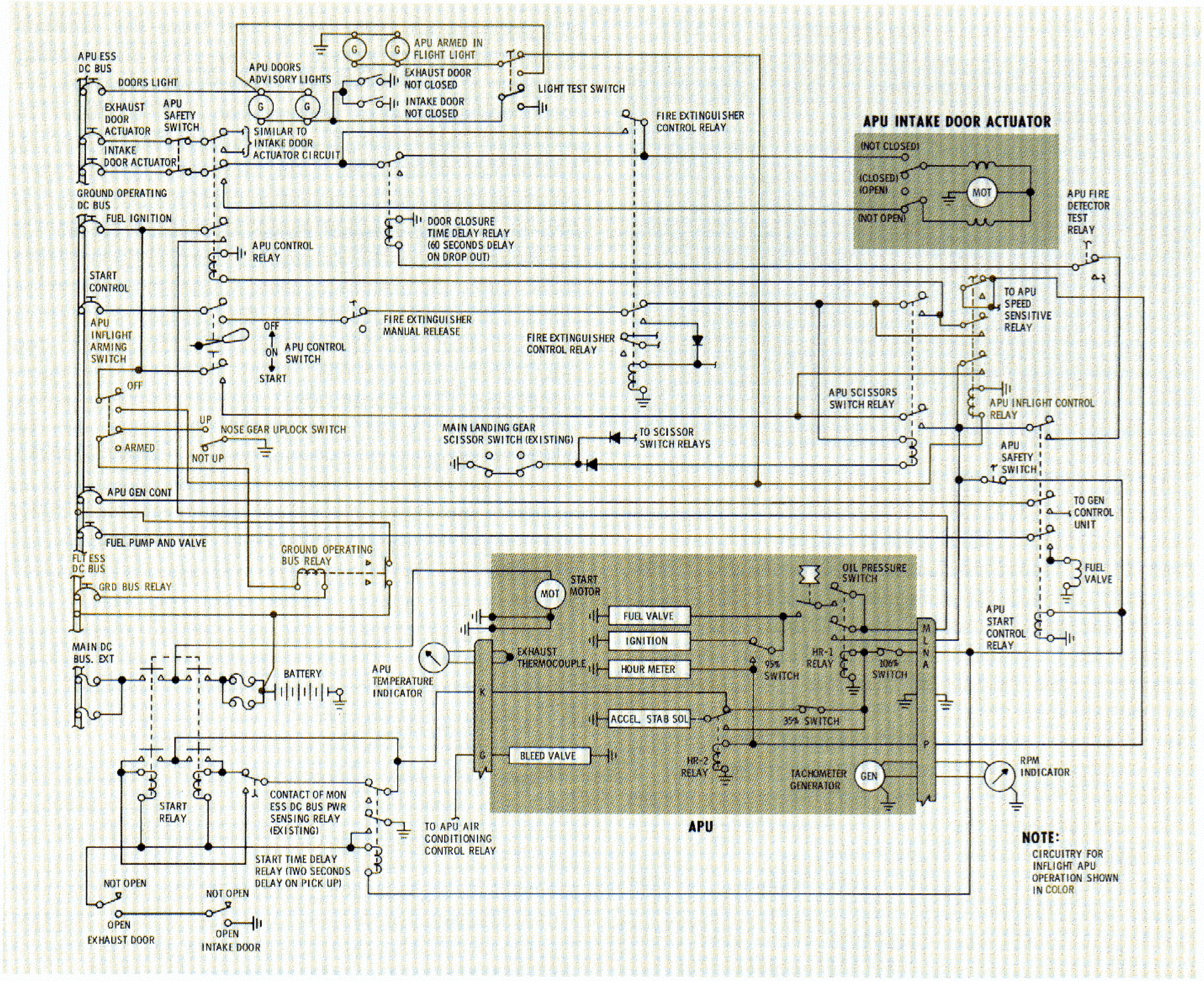


Figure 14 APU Control System Electrical Schematic

The starting sequence is set into motion by momentarily moving the APU control switch to the "START" position, then releasing it to "ON," thereby energizing the APU start control relay and the APU's HR-1 relay. The "battery start" coil of the start relay is also energized through the de-energized Monitorable Essential DC Bus power sensing relay. In the usual starting procedure listed in NAVAIR 01-75PAA-1, the APU control switch is moved momentarily to "START," then released to "ON." This simply energizes the APU start control relay and the HR-1 relay at the same time the APU compartment door actuation circuits are energized. The APU start relay cannot be energized until the compartment's "door open" switches are actuated to provide a ground for the relay.

Actuation of the start control relay energizes the APU fuel valve in the left wing fillet, and sets up the APU generator control circuit so that it can be completed when the generator is "on speed." Actuation of the HR-1 relay latches the fuel ignition circuit and sets up the circuitry to the fuel solenoid valve (mounted on the fuel controller) so that the valve will be energized when the oil pressure switch closes at about 10% engine rpm. When the start relay is energized, it closes the circuit between the APU battery start limiters and the starter motor. This energizes the starter, which begins to rotate the APU turbine. After a two-second delay, the start time delay latching relay is energized, latching the start relay circuitry through the 35% speed switch.[8] The acceleration stabilizer solenoid is also energized

[8]*This latching circuit prevents recycle of the starter by the 35% switch in the event of rpm decay below 35% (stagnated start). The "door open" limit switches are also bypassed to prevent an interrupted start due to door buffeting. Restart requires positioning the APU control switch to "OFF," then to "START."*

when the APU control switch is moved to "START," as are the air intake and the exhaust door closure relays which remain energized as long as the APU is in operation.

When the starter has accelerated to approximately 10% engine speed and the oil pressure reaches approximately 3.5 psig, the oil pressure sequence switch will close. This energizes (opens) the fuel solenoid valve to permit fuel to be supplied to the combustion chamber, and energizes the fuel ignition circuit until it is de-energized by the 95% switch, one of three switches of the centrifugal sequencing switch assembly. If pressure does not build up in the APU oil system, the oil pressure sequence switch will not actuate and the APU starting sequence cannot progress further.

At this point in the discussion we must stop for a moment to describe the centrifugal sequencing switch assembly.[9] This switch assembly, which is made up of three switches and a centrifugal actuating unit, controls the sequence of operation of the APU's electrical components. The unit's three switches are frequently denoted by the function they perform — the starter cutout switch (35% switch), the ready-to-load switch (95% switch), and the engine overspeed switch (106% switch). The centrifugal sequencing switch assembly's actuating unit is mechanically driven by the APU accessory drive train, and actuates the switches sequentially as the APU's speed increases or decreases.

Returning to the engine starting sequence, as the engine accelerates to 35% engine speed, the 35% switch is actuated and de-energizes the start relay and the acceleration stabilizer solenoid circuits. As the engine continues to accelerate and the de-energized starter begins to coast down, the starter's clutch automatically disengages from the engine gear train to prevent damage to the starter from overheating or overspeed. De-energizing the acceleration stabilizer solenoid permits control air to be bled from the limiter's control air system, enabling the fuel control unit to provide the most favorable fuel flow schedule during the 35% - 95% part of engine acceleration in order to prevent compressor surge.

When the engine has accelerated to 95% of its normal operating speed, the 95% switch is actuated. This causes several events to occur simultaneously: the ignition circuit is de-energized; the hourmeter is turned on; the APU speed sensitive relay is energized, thus energizing the APU's bleed air load control circuitry; the HR-2 relay is energized, which again energizes the acceleration stabilizer solenoid and prevents air from being bled from the limiter's pneumatic control system. At this point the starting sequence is concluded and engine operation has become self-sustaining. The engine will continue to accelerate until 100% engine operating speed is reached, at which speed the fuel control unit governor automatically maintains engine operation.

APU Start Using External Power or Aircraft Power If the aircraft is on the ground and power is available from either an external power source or is provided by the aircraft's generators, the MAIN DC BUS, MONITORABLE ESSENTIAL DC BUS, and the GROUND OPERATING DC BUS will be energized, and the monitorable essential dc bus power sensing relay will be actuated. Actuation of the power sensing relay will energize the APU ESSENTIAL DC BUS and switch the APU control start circuit to the "Main DC Bus Power" coil of the APU start relay. When the APU control switch is moved to "START," the start relay will actuate to supply power to the starter motor from the MAIN DC BUS. This prevents aircraft or ground power from being supplied to the starter motor through blocking diodes Nos. 1 and 2. With these exceptions, the APU control circuit operates the same as when power is supplied from the aircraft battery.

In-Flight APU Start Eventually all P-3 aircraft will have the capability of emergency APU operation during flight to supply electrical power. Those aircraft which already have this capability have a guarded in-flight arming switch on the APU control panel. By moving this switch to the "ARM" position during flight, the ground operating dc bus relay is de-energized so that power can be supplied to the GROUND OPERATING DC BUS, and the APU scissors switch relay circuit is bypassed through the APU in-flight control relay, which also has been actuated. This causes the "ARMED" light on the APU panel to be illuminated. The APU may now be started in the usual manner.

APU Start with Monitored Main Buses Although a flight crew may never need to start the APU after an emergency has necessitated de-energizing both MAIN AC BUS A and BUS B, all flight crews should be apprised that it will be necessary in this situation to manually de-energize Transformer Rectifier No. 3 before selecting "START" at the APU control switch. Otherwise, an attempt to start the APU will miscarry, as shown in Figure 15. In order to show more clearly the factors necessitating a non-standard start procedure in this isolated instance, we have *not* shown in Figure 15 the full extent of intricate interlocking circuitry involved, but have substituted elements which simulate the effect of that network.

[9] *Several publications refer to this unit as the multiple centrifugal switch.*

The APU starter represents an extremely heavy load, and its integration with the P-3 power distribution system is intended to ensure that the heavy starter amperage is *not* fed through the power diodes that support the Essential DC buses, for the diode capacity is marginal in this condition. On the other hand, it *is* preferable that power from a generator-supported bus be used by the starter whenever it is available rather than from a battery-supported bus. Therefore, the design provides a "selector" type of starter power relay that, when APU "START" is selected momentarily, detects power (if it is available) at the Monitorable Ess. DC Bus, switches the starter load on to the Extension Main DC Bus and latches it in position until APU rpm has advanced to 35%.

Due to the fact that starter power is taken from a bus supported via the Main Bus Transfer system (whereas power is sensed at a bus that can be supported via the Run-Around system after an emergency has forced the Main Bus Transfer system to be de-energized), the APU starter will be connected and latched to a de-energized bus if the Run-Around system is supporting Transformer Rectifier No. 3 and

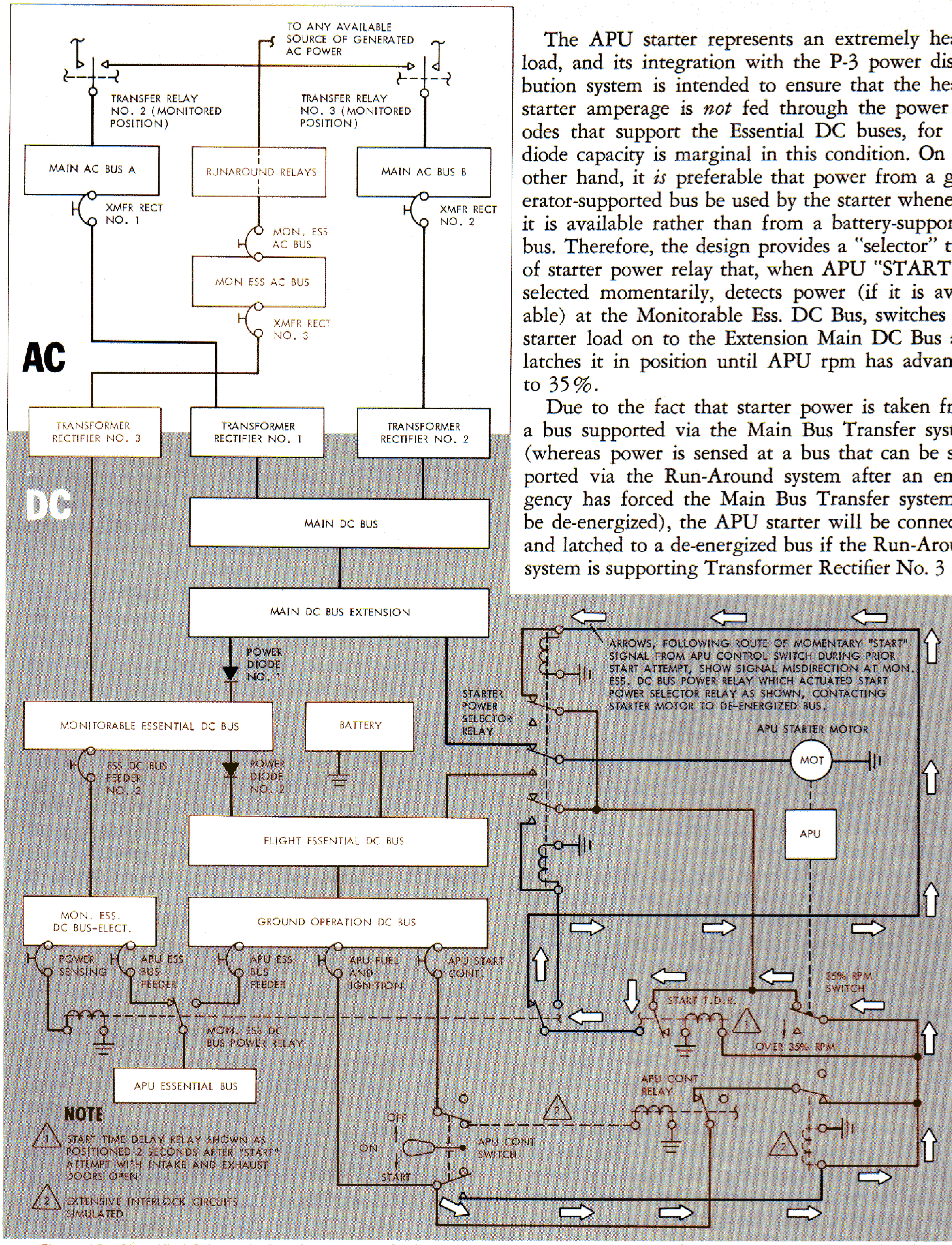


Figure 15 Simplified Schematic Showing Aberrant Configuration of Start Control Circuitry Inadvertently Induced by Attempting Normal APU Start with De-energized Main Buses. To enable battery start, open XMFR RECT. No. 3 Circuit Breaker and Select "OFF" at APU Control Switch (to disconnect starter from de-energized Main Bus) before re-selecting "START."

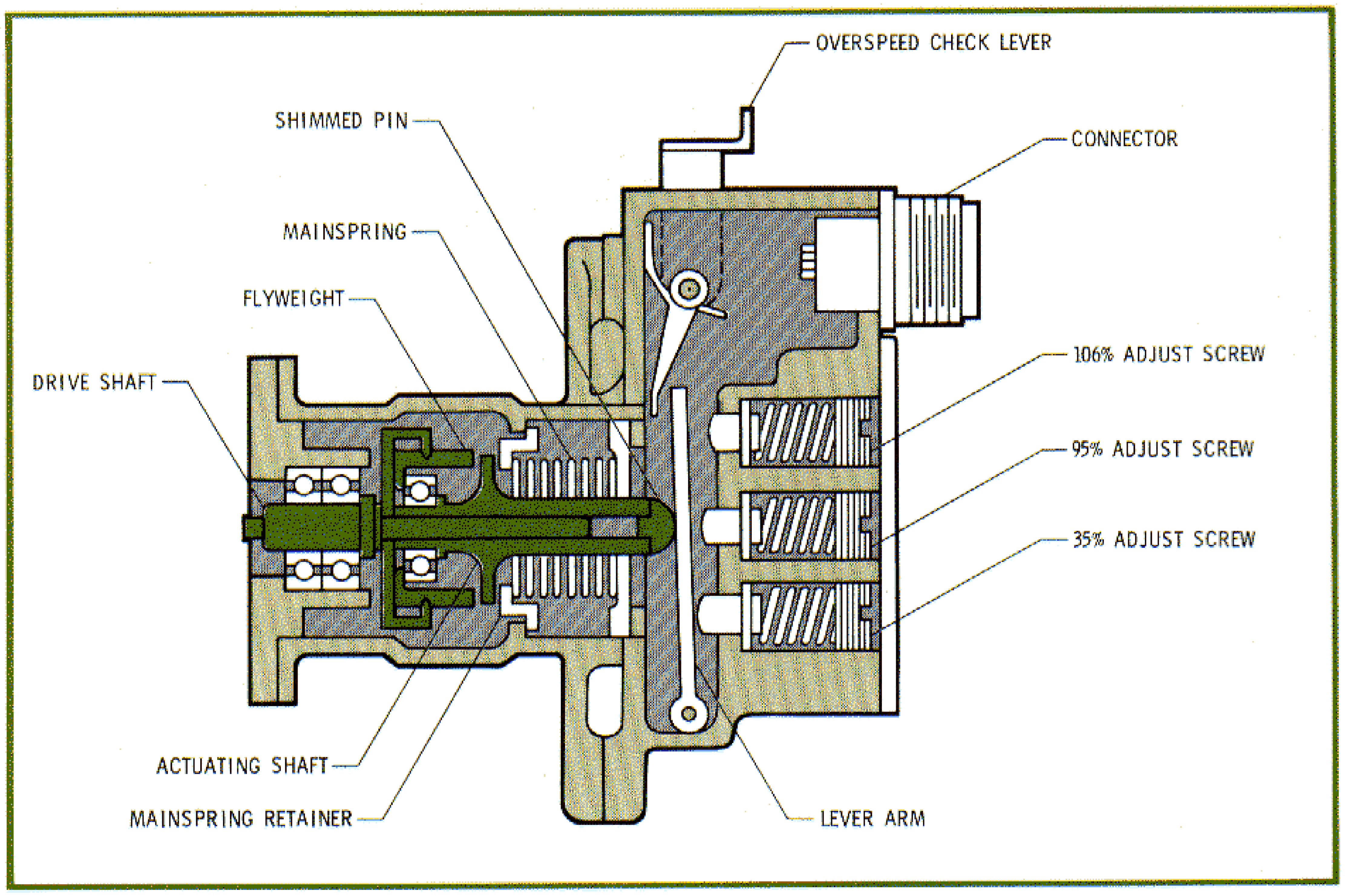
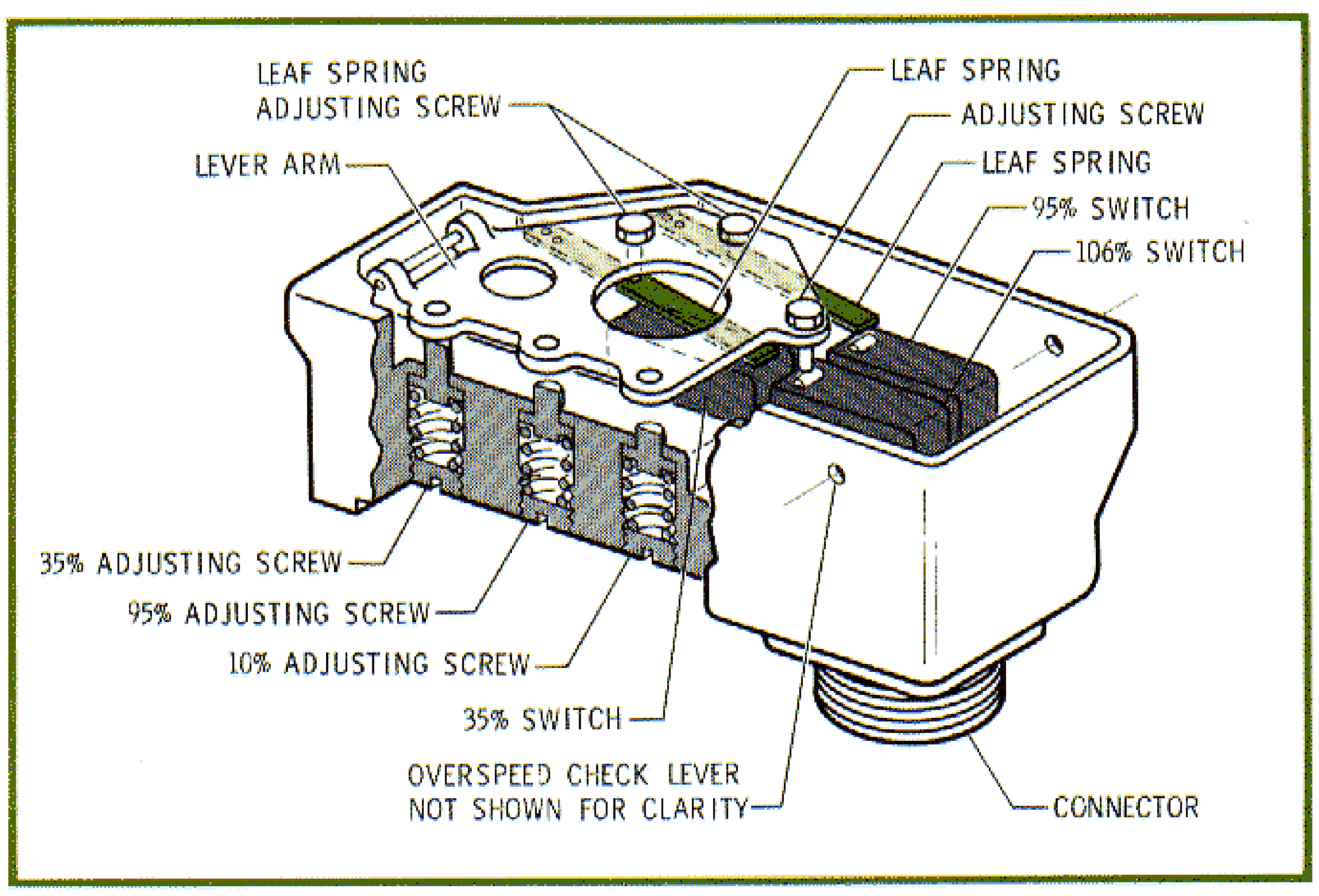


Figure 16
Centrifugal Sequencing
Switch Assembly



a normal In-Flight Start is attempted. This is the situation depicted in Figure 15.

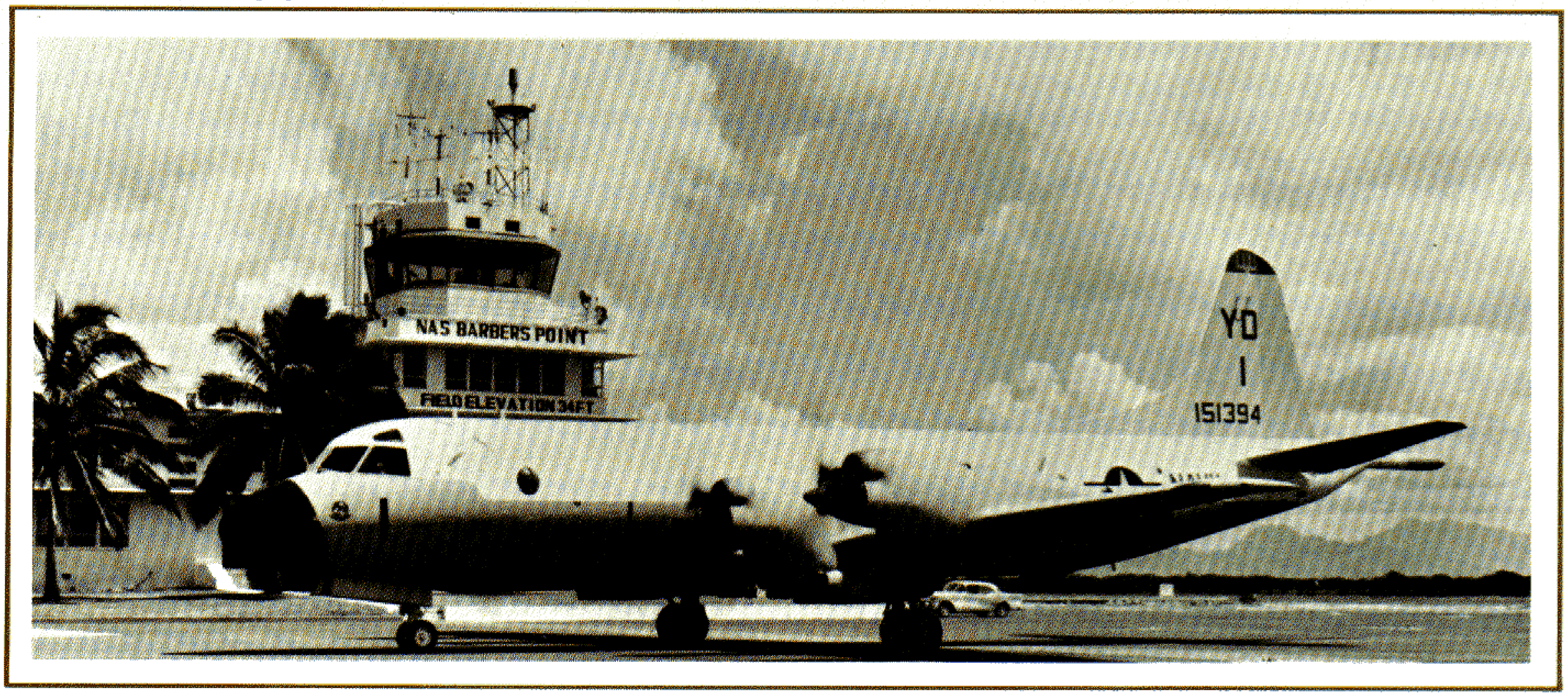
For this reason, after both Bus A and Bus B have been monitored, it is necessary to de-energize the Monitorable DC Bus by pulling the XMFR RECT No. 3 circuit breaker at the Monitorable Essential AC Bus *before* attempting to start the APU. The starter will then automatically utilize battery power and, after the APU has been started, Transformer Rectifier No. 3 can be re-energized to restore Monitorable DC Bus power and to replenish the battery charge.

Although it is possible to energize the starter from the battery-supported bus without de-energizing T.R. No. 3 (by opening either the Ess. DC Bus Feeder No. 2 or the Monitorable Ess. DC Bus Power Sensing Relay circuit breakers), it is most important that neither method be used, for if T.R. No. 3 remains energized, it will contribute heavily to the starter load through Power Diode No. 2. If the diode is damaged by the overload during the APU start, it may be impossible for generated power to supply the battery-supported buses afterwards, and the battery will be steadily discharged.

APU Shutdown During a normal APU shutdown *all* APU control power is turned off when the APU control switch is moved to "OFF." After a 60-second time delay the intake and exhaust door relay drops out and the door closure circuits are energized. When the doors close, they operate "door closed" position switches to extinguish the APU "DOORS" light on the APU control panel. The door actuator motors are turned off by integral load limit switches.

The APU engine speed is normally governed at 100% ± 2% (+3%, —2% in flight) rpm. If, due to a malfunction, the speed should exceed 106%, the 106% switch will be actuated and shut down the unit. When the 106% switch is actuated, it de-energizes the HR-1 relay, which interrupts the latching circuit created during the starting sequence, shuts off the APU fuel supply, and removes power from all the APU's control circuitry except the APU scissors switch circuit. As the engine coasts down, the three switches of the centrifugal switch assembly assume their positions prior to initiation of a start in reverse sequence, and as the engine decelerates through 10% (approx.) speed the oil pressure switch opens. The intake and exhaust door closure time delay relay, de-energized by actuation of the 106% switch, drops out 60 seconds after the latching circuit is broken and energizes the door closure circuit. The doors may be closed by moving the APU control switch to "OFF." When both doors are closed, the "DOORS" light on the APU panel is extinguished.

Official U.S. Navy Photograph



The APU can also be shut down by manually actuating the centrifugal switch overspeed simulation lever, tripping the 106% switch. This causes the APU control circuitry to behave exactly as if an actual overspeed condition caused switch actuation. Actuation of the main landing gear scissors switches will also de-energize the APU control circuitry and shut down the unit unless the INFLIGHT ARMING switch is "ON." Interruption of the scissors switch circuit de-energizes the scissors switch relay, which de-energizes the APU control relay. Another means of APU shutdown is to gain access to the APU safety switch (located on the left side of the fuselage), and position the switch to "SAFE." Keep in mind, though, that this not only de-energizes the APU control circuit, but it also de-energizes the APU door circuits and the APU HRD fire extinguisher circuit, rendering both systems inoperative.

If the APU fire detection and extinguishing system is actuated either automatically or manually, the APU will be shut down immediately. In addition, the compartment doors will immediately begin to close, and the fire extinguishing agent will be discharged into the APU compartment. This system should be used only in case of fire in the APU compartment. Further discussion of the APU fire detection and extinguishing system is included later in this article.

MAJOR ELECTRICAL COMPONENTS Among the APU electrical system's major components are the centrifugal sequencing switch assembly, the starter, and the ignition exciter. The centrifugal sequencing switch and the starter are mounted on the APU accessory section, and the ignition exciter is mounted on the upper forward side of the compressor plenum. The HR-1 and HR-2 holding relays are also mounted on the compressor plenum on the aft side near the centrifugal sequencing switch assembly.

Centrifugal Sequencing Switch Assembly This assembly, shown in Figure 16, is composed of three switches and a centrifugal actuating unit that is driven by the accessory drive compound idler gear shaft. The switch assembly's input shaft is supported by two ball bearings, mounts a knife-edge fulcrum that supports the centrifugal actuating unit's two flyweights, and serves as a guide for the switch actuating shaft. A ball bearing is mounted on the actuating shaft, with the toes of both flyweights lying under the bearing's outer race. As the APU engine accelerates, the input shaft rotates faster, the flyweights move outward, and the flyweight toes force the bearing and the actuating shaft to move along the axis of the input shaft. The tip of the actuating shaft moves a lever arm that actuates the assembly's switches.

Two leaf-springs and three set screws mounted on the lever arm are adjusted so that the three switches are actuated in proper sequence. Three adjustment spring/pistons of different length are mounted in the centrifugal sequencing switch assembly body and exert force on the lever arm in sequence and cumulatively; i.e., the first spring/piston acts on the lever at all times, the second spring/piston exerts force on the lever arm after actuation of the 35% switch but before actuation of the 95% switch, and the third spring/piston adds its spring force to that of the others after the 95% switch has been actuated. The switches are set to operate at 35%, 95%, and 106% turbine speed by adjusting the force of the lever arm with these spring pistons.

Another lever that is part of the centrifugal sequencing switch assembly enables the mechanic to check actuation of the overspeed switch while the engine is either stopped or running by creating an artificial overspeed signal in the APU control circuit. When this lever is pushed, the 106% switch is actuated, thereby de-energizing the HR-1 relay. (Actually all three switches are actuated, but the 106% switch is the only one of these three switches that controls the APU control system latching circuit.) Remember, this check can demonstrate that the 106% switch is functioning, *but it will not tell the mechanic if the switch is properly adjusted.*

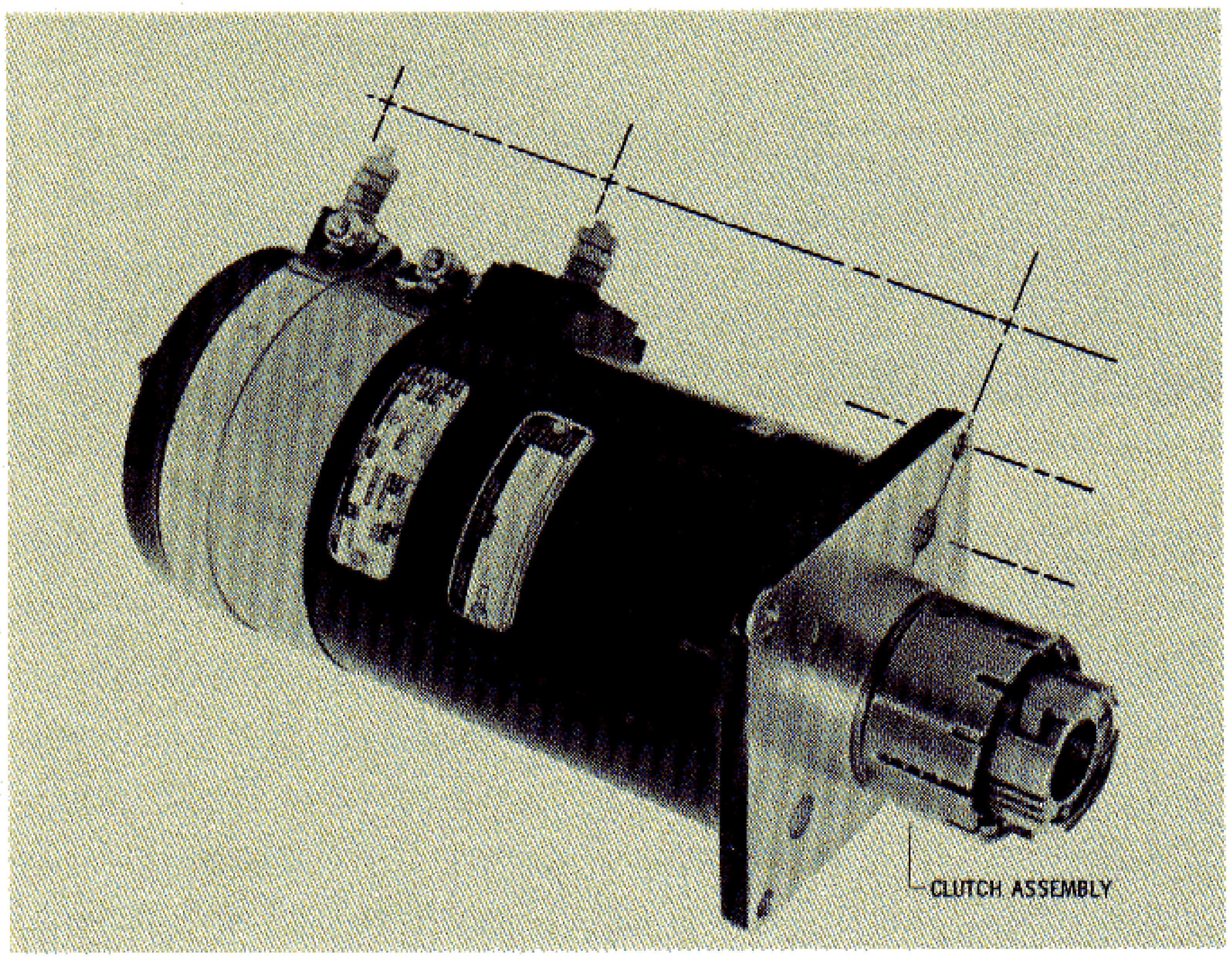


Figure 17 Starter and Clutch Assembly. Note that starter's electrical terminals are aligned with a corner of the starter's mounting pad. *Photo Courtesy of the Garrett Corporation*

Starter The starter has a 14-volt dc motor that produces 1.5 hp. at 5,500 rpm. The motor's armature shaft is splined and pinned to the starter's clutch assembly. A carbon faced seal on the armature shaft prevents engine accessory case oil from entering the starter motor, and prevents air from leaking into the accessory case via the starter. The O-ring packing between the starter mounting flange and the accessory case forms a seal, helping to maintain a negative pressure within the accessory case during engine operation.

The starter clutch assembly is a combination friction clutch and over-running clutch. The friction clutch, set to slip at approximately 135 to 145 inch-pounds torque, prevents excessive torque between the starter and the engine accessory drive gears, particularly during engagement of the over-running clutch with the accessory gear train. When the APU engine has accelerated to approximately 35% operating speed, it can continue to accelerate without further assistance from the starter, so the starter is de-energized. As engine acceleration continues, the accessory gear train ratchet speed exceeds the rotational speed of the starter's over-running clutch, causing the over-running clutch's pawls to disengage from the ratchet. This prevents the APU from driving the starter.

The starter has a duty cycle of one minute ON and four minutes OFF. This cycle allows enough time to dissipate the heat generated within the starter during the "ON" part of the starting cycle. If the starter is not permitted to cool for at least four minutes, it may suffer damage from overheating. Failure of the 35% switch to de-energize the starter circuit may also cause the starter to overspeed and fail due to overheating, or it may cause the starter to fail mechanically.

Maintenance personnel should be alerted to avoid another type of starter problem — inadvertently replacing a damaged starter with the *wrong* starter. The GTCP95-2 starter and the starters used on some models of GTCP85 series power units are similar in appearance, but they rotate in opposite directions. A simple means of differentiating them is to observe where the starter's electrical terminals line up. The terminals of the P-3's APU (GTCP95-2) starter, shown in Figure 17, line up with a corner of the starter's mounting pad; the terminals on the other starter line up *between* two corners of the starter's mounting pad.

Ignition Exciter The APU ignition exciter falls into the realm of the black (or in this case grey) box. The ignition exciter converts 28-volt dc power to a pulsating high voltage current, and transmits it to the igniter plug in the combustion chamber. The ignition system's exciter and igniter plug are shown in Figure 18. An aluminum housing contains the exciter's coils, capacitors, vibrator and wiring. The housing is filled with a compound to prevent the components from chattering when the exciter is exposed to vibration during APU operation. The housing is hermetically sealed to protect the exciter components from adverse environmental conditions, and is intended to remain that way, so under no circumstances should one attempt to open this unit.

If a unit proves defective, remove and replace it with an exciter that functions properly, and dispose of the malfunctioning unit in accordance with approved procedures. This unit is placarded with a warning that states, "THE OUTPUT OF THIS IGNITION UNIT IS SUFFICIENT TO CAUSE A DANGEROUS SHOCK," so treat it with respect. Always allow the unit's capacitors to discharge before working with it. If the APU circuitry is energized, under no circumstances should any exposed or live portion of the ignition exciter be touched.

APU COMPARTMENT DOORS

Two APU compartment doors — the compressor air inlet door and the turbine exhaust door — must be opened before the APU can function. Each of these doors is operated by an electro-mechanical actuator that obtains power from the APU Essential DC Bus. Each door installation has two switches which may arbitrarily be called the "door closed" switch and the "door open" switch. The function of these switches was described in the "Battery Start" segment of the article. Switches that are integral with each actuator assembly are used to control actuator motor operation, and will be discussed further in this section.

DOOR ACTUATORS The door actuators are electrically reversible, 24-volt dc electro-mechanically actuated jackscrews. The inlet door and exhaust door actuators are similar in design and function, but they are not identical. However, one item that is common to both units is the drive train. In both cases the actuator motor drives the jackscrew through a two-stage gear train that has a 149.7 : 1 reduction ratio. Integral with each actuator assembly are two torque-reaction switches, one to turn the motor off when the jackscrew is extended and the other to do the same when the jackscrew is retracted. The appropriate switch is actuated to shut off the motor when the opposing load against the jackscrew exceeds the switch's preset value. When the motor is turned off and the external load reduced, the switches are reset.

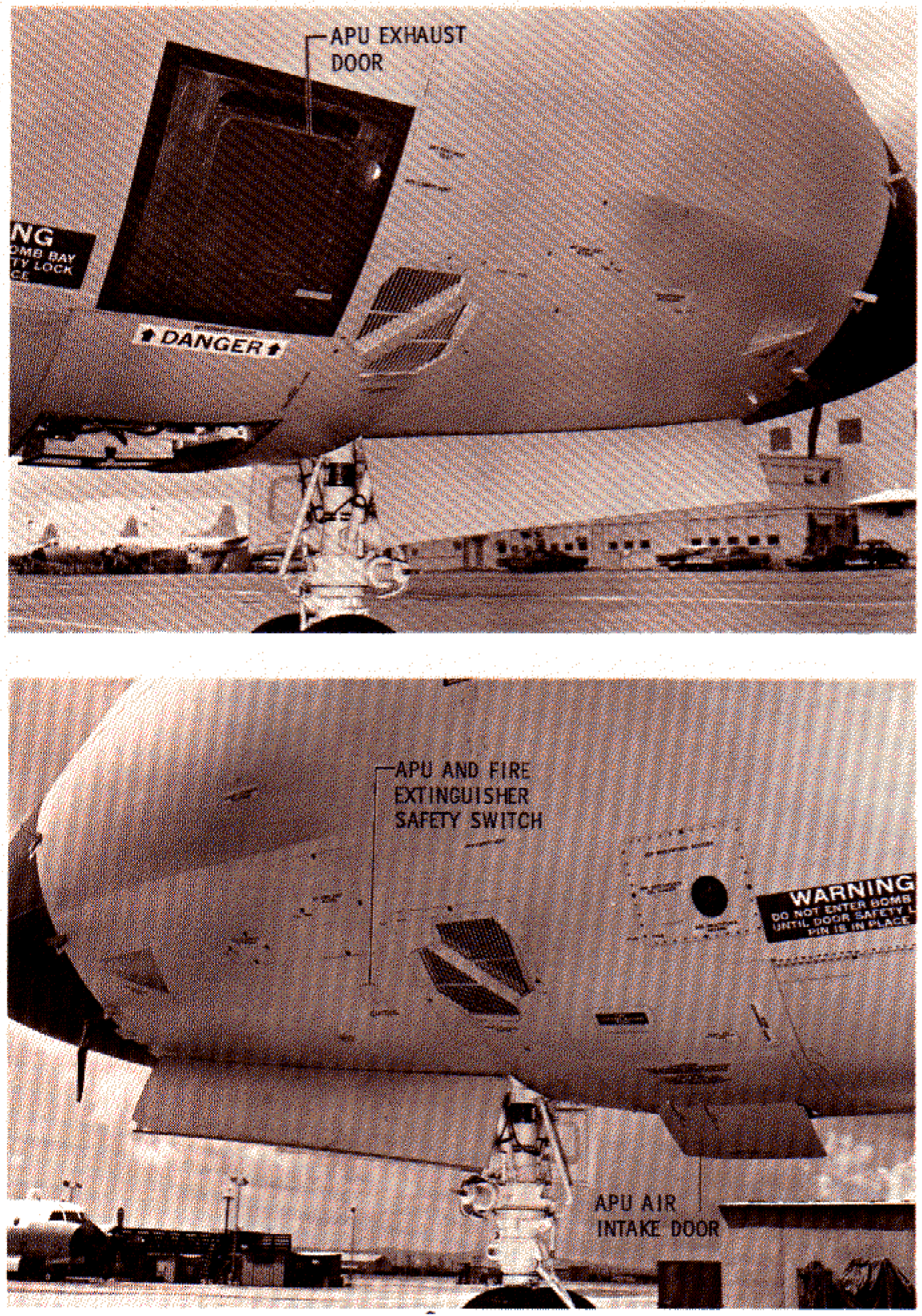


Figure 19 APU Compartment Doors

The inlet and exhaust door actuators differ in the adjustment of their torque-reaction switches and in the length of the jackscrew stroke. The inlet door actuator torque switches are adjusted to terminate jackscrew retraction upon application of from 275 to 475 inch-pounds of shaft load, and to terminate jackscrew extension upon application of from 540 to 740 inch-pounds of shaft load. Mechanical stops limit the inlet door's actuator stroke to 4.28 inches.

The exhaust door torque switches are adjusted to terminate jackscrew retraction upon application of from 540 to 740 inch-pounds of shaft load, and terminate jackscrew extension upon application of from 350 to 550 inch-pounds of shaft load. The exhaust door actuator stroke is limited to 1.71 inches by mechanical stops.

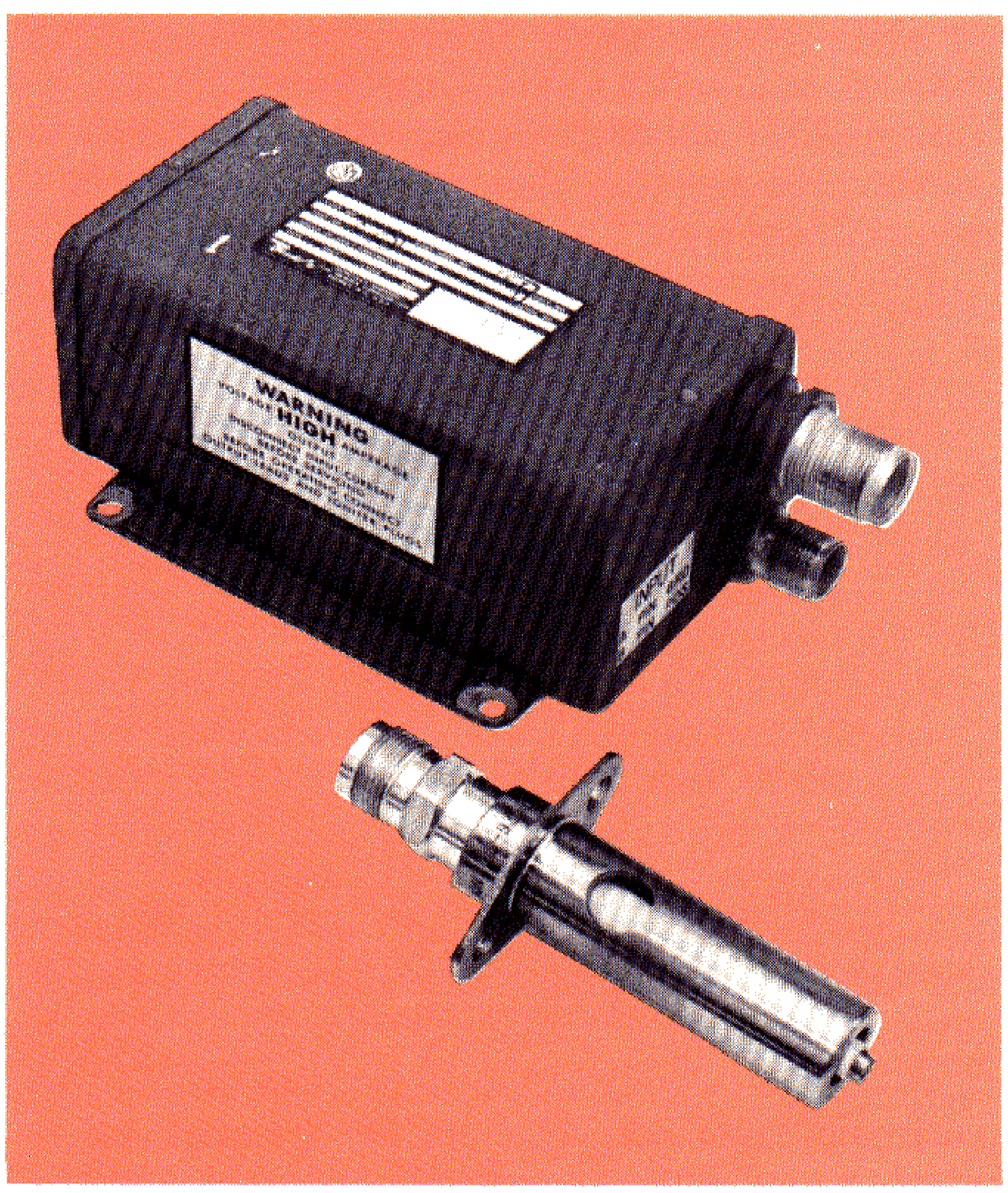


Photo Courtesy of the Garrett Corporation

Figure 18
Ignition Exciter Unit
and Igniter Plug

INSTRUMENTS

The APU has extremely simple instrumentation — an engine tachometer, an engine exhaust temperature gage, a "DOORS" light that illuminates when the APU's air intake and/or exhaust doors are not

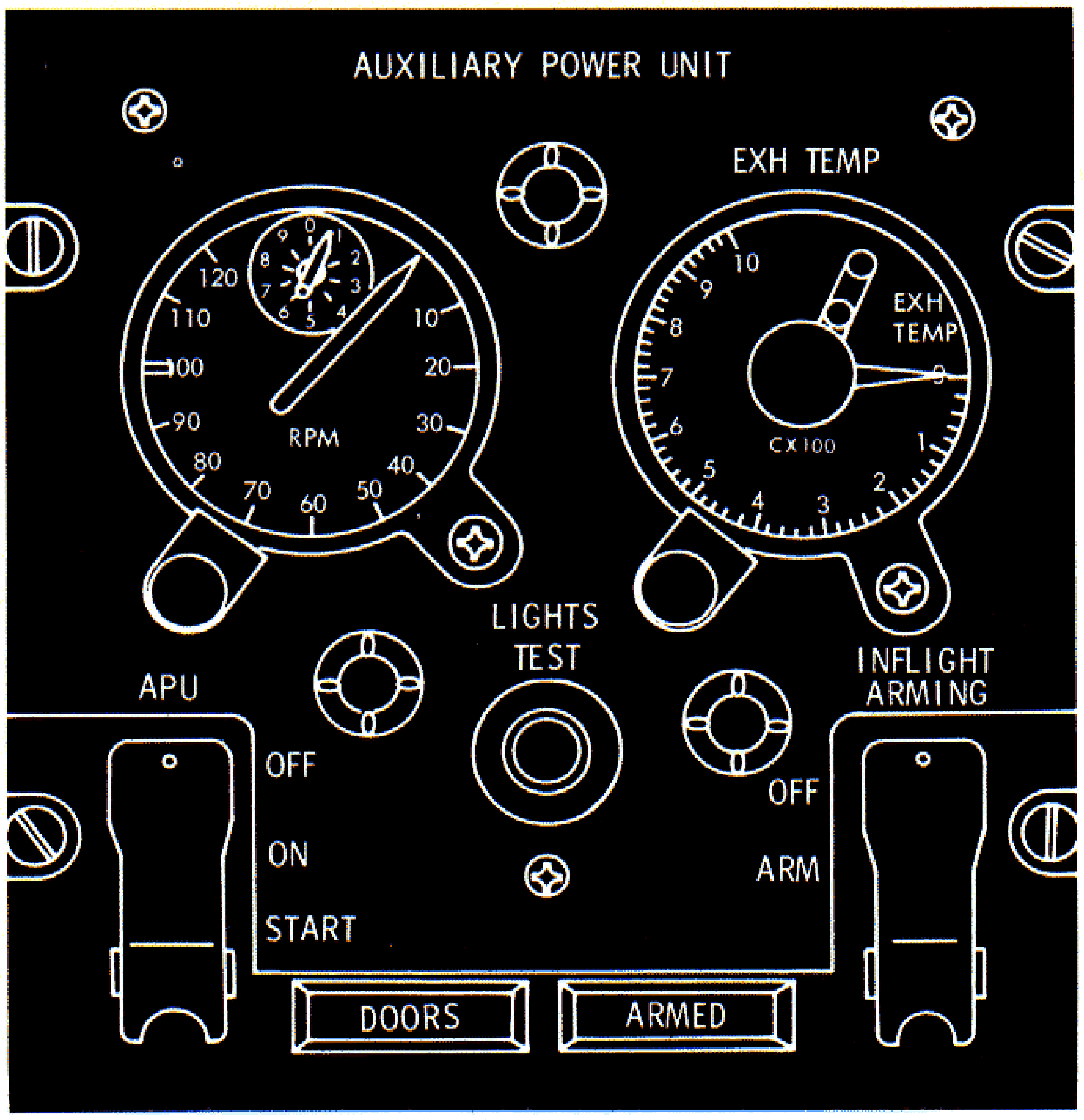


Figure 20 APU Control Panel

closed, and a light to indicate when the in-flight arming switch is in the "ARM" position. A press-to-test button is provided for the lights.

The APU tachometer is calibrated in percentage of engine RPM from 0 to 120%. The tachometer receives and repeats a signal sent from the APU tachometer generator mounted on the oil pump assembly. The tachometer generator is driven by the APU accessory drive through the oil pump assembly gear train.

The APU exhaust temperature indicator is scaled from 0°C to 1000°C. A thermocouple, located in the turbine exhaust stream (Figure 7), senses the exhaust temperature and provides a voltage signal that is sent through calibrated leads to the temperature indicator.

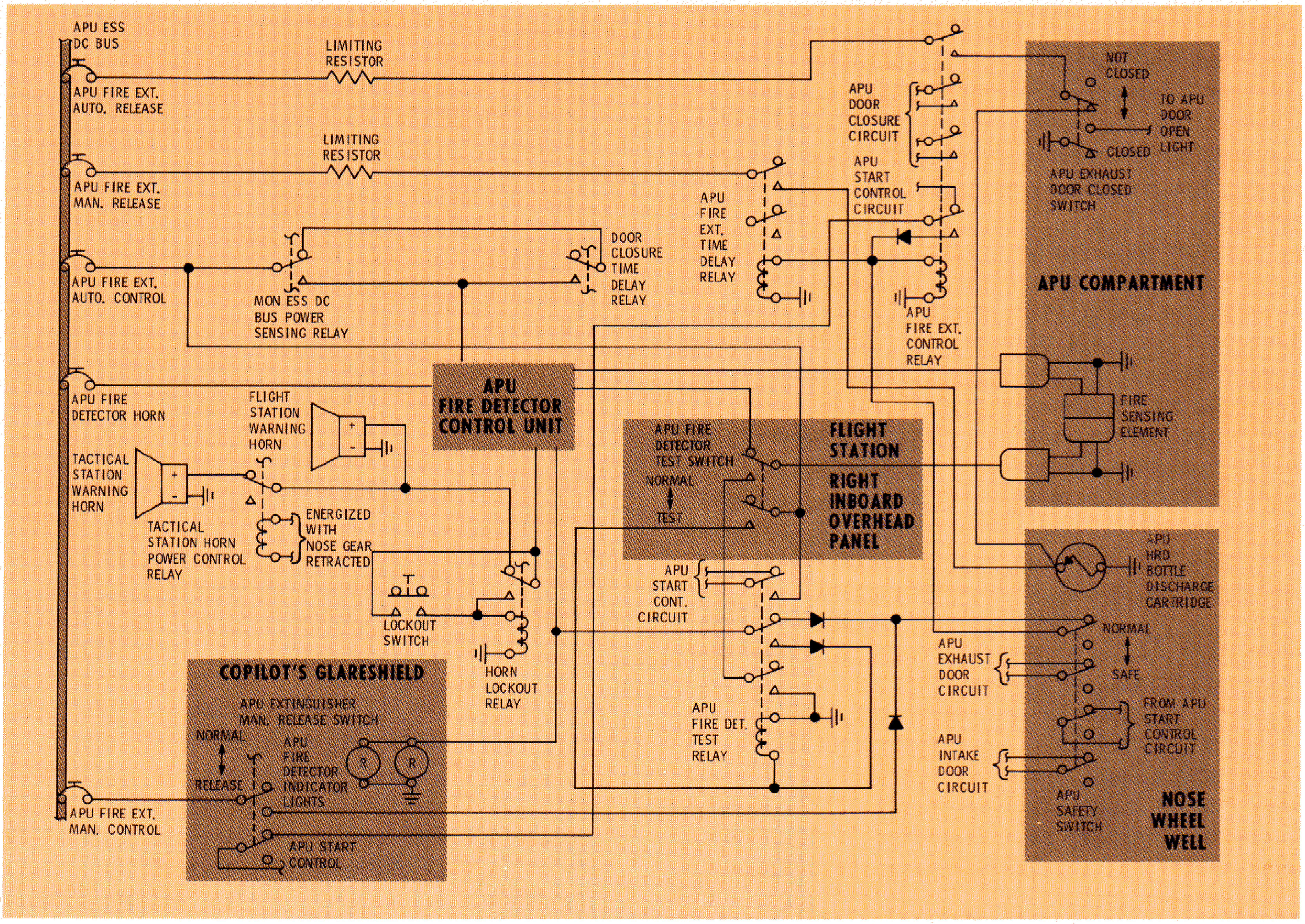
All these instruments are installed on the APU Control Panel (Figure 20), which is part of the Flight Station Overhead Panel. One more item, the hourmeter, indicates to the nearest tenth of an hour the elapsed time that the engine has run. The hourmeter is mounted on the gas turbine power unit, and it is operated by the APU electrical system.

APU FIRE DETECTING AND EXTINGUISHING SYSTEM

The APU fire detecting and extinguishing system is an automatic system that functions during ground operations and in flight, and the system can also be manually actuated from the flight station. The system is composed of the APU fire detection system control unit, located in the forward electrical load center; the flight station and the tactical station warning horns; the manual discharge switch and the system warning lights, mounted on the flight station glare-shield; the APU fire detector test switch, installed on the right inboard overhead panel in the flight station; the APU compartment temperature sensing element; the fire extinguisher container, mounted in the aft section of the nose wheel well; and the plumbing through which the extinguishing agent is routed from its container to the APU compartment.

The fire extinguishing agent is Spec. MIL-B-12218 liquid bromotrifluoromethane, a non-toxic agent that is stored in the system's 86-cubic inch container and pressurized to approximately 600 psig with Fed. Spec. BB-N-411 nitrogen (measured at 70°F). The extinguishing agent is released from the container by electrically detonating an explosive cartridge. This ruptures a frangible disc in the container's discharge valve, allowing the pressurized agent to escape through the discharge tubing into the APU compartment. When the bromotrifluoromethane reaches the APU compartment, it displaces the oxygen to smother the fire and reduces the compartment temperature below the ignition point of the combustibles.

This system (schematically depicted in Figure 21) is powered from the APU Essential DC Bus. Actuation of the system occurs when the sensing element detects a temperature of 400°F or more in the APU compartment for a period exceeding 1.5-2.0 seconds. When the system's control unit receives this signal, it completely de-energizes the APU control circuitry, thereby shutting down the APU. Simultaneously the fire extinguisher control relay is energized, causing the APU door actuation circuits to bypass the door closure time delay relay and immediately energize the door actuators to close the APU compartment doors. In approximately 15 seconds the exhaust door "closed" switch is actuated, and energizes the circuit that detonates the extinguisher cartridge. If closure of this circuit does not detonate the cartridge, 5 seconds later a time delay relay will close and detonate the cartridge via another circuit. When the system is manually energized



by actuating the guarded MAN. REL AUX PWR UNIT EXTINGUISHER switch, the fire detection part of the system's circuitry is bypassed.

While all this activity is taking place, there are accompanying visual and aural indications. In the flight station, the APU compartment fire warning lights will be illuminated, and the warning horn on the right overhead panel will be sounding. If the aircraft is on the ground, another warning horn in the tactical area will also sound. APU shutdown will be indicated on the APU instrument panel by decaying engine rpm and exhaust gas temperature.

A test switch for the APU fire protection system is mounted on the overhead panel above the copilot. When this switch is moved to "TEST," the continuity between the control unit and the sensing element is checked. A properly functioning system is indicated by illumination of the warning lights and by sounding the warning horns. When the test switch is energized, there will be a time delay of 1.5 to 2 seconds before the lights come on and the horns sound. This time delay is necessary to avoid sending a false fire signal to the control unit that would

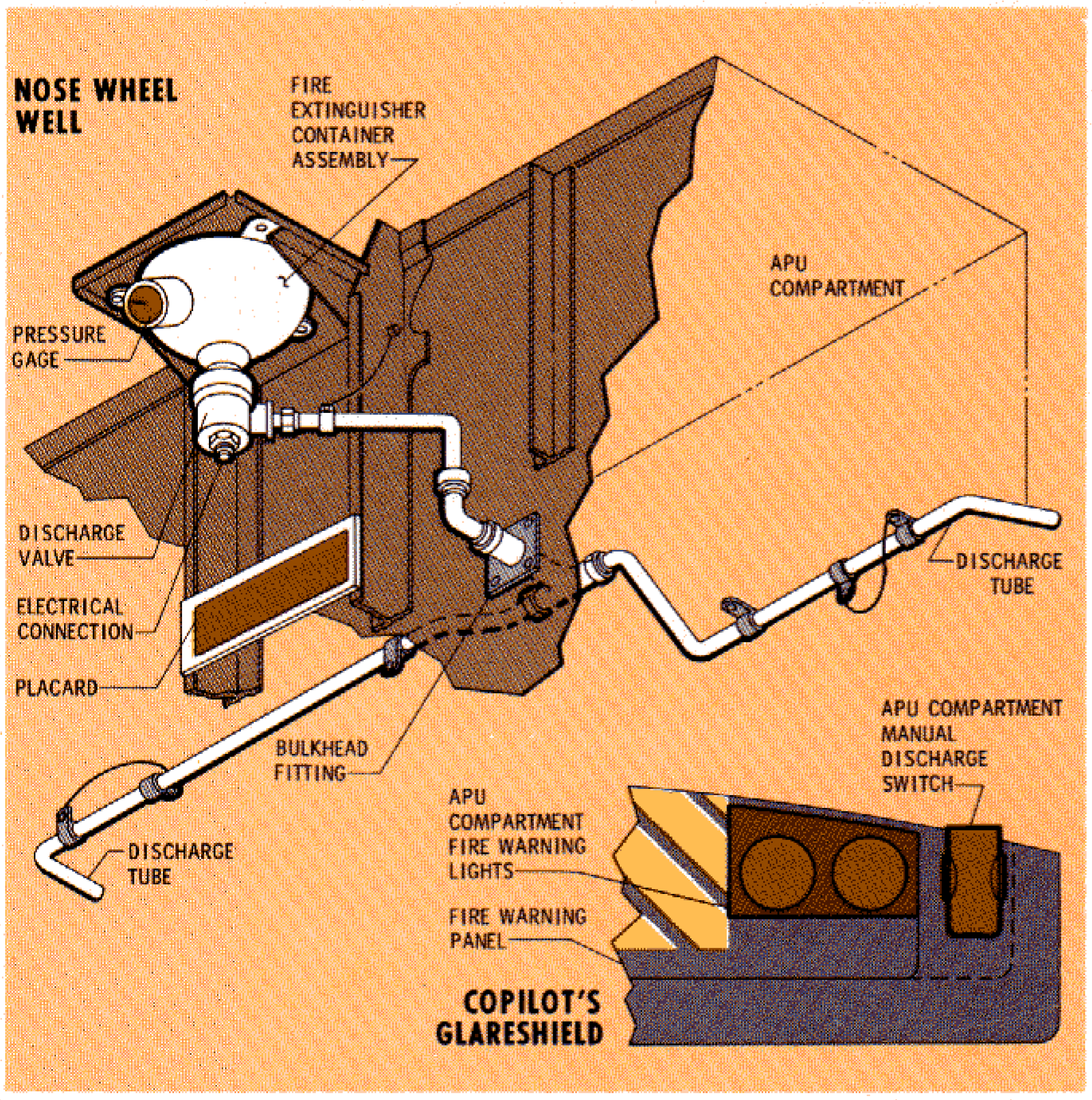


Figure 21 APU Compartment Fire Detection and Extinguishing System and Electrical Schematic

initiate the extinguishing sequence. The system should be deactivated when maintenance activities are conducted in the APU compartment. This can be done by positioning the APU safety switch (accessible from the aircraft exterior) to "SAFE." When the APU safety switch access door is closed, the safety switch is automatically returned to the "NORMAL" position.

The fire extinguishing agent container pressure should be periodically checked to determine if there is sufficient gas pressure in the container. By correlating the container gage reading with the container temperature, it can be determined whether or not the container is properly pressurized. A placard installed below the container discharge valve shows the proper pressure/temperature values.

If the container pressure is too low, it is necessary to ascertain how much fire extinguisher agent is in the container. The only way to determine this is to weigh the container. It must weigh within five percent of the actual weight shown on the container's data plate. If the weight differential is greater than five percent, replace the container.

The service life of the container's explosive cartridge is a maximum of three years from the date of manufacture stamped on the cartridge and its package, but no longer than 18 months after its moisture-proof package has been opened. If the cartridge has accumulated over 2000 hours in an environment

whose temperature ranges from 100°F to 158°F (38°C to 70°C), the cartridge must be replaced regardless of the age limit. Remember, these cartridges contain explosives and should be handled with the care and respect that is due such materials.

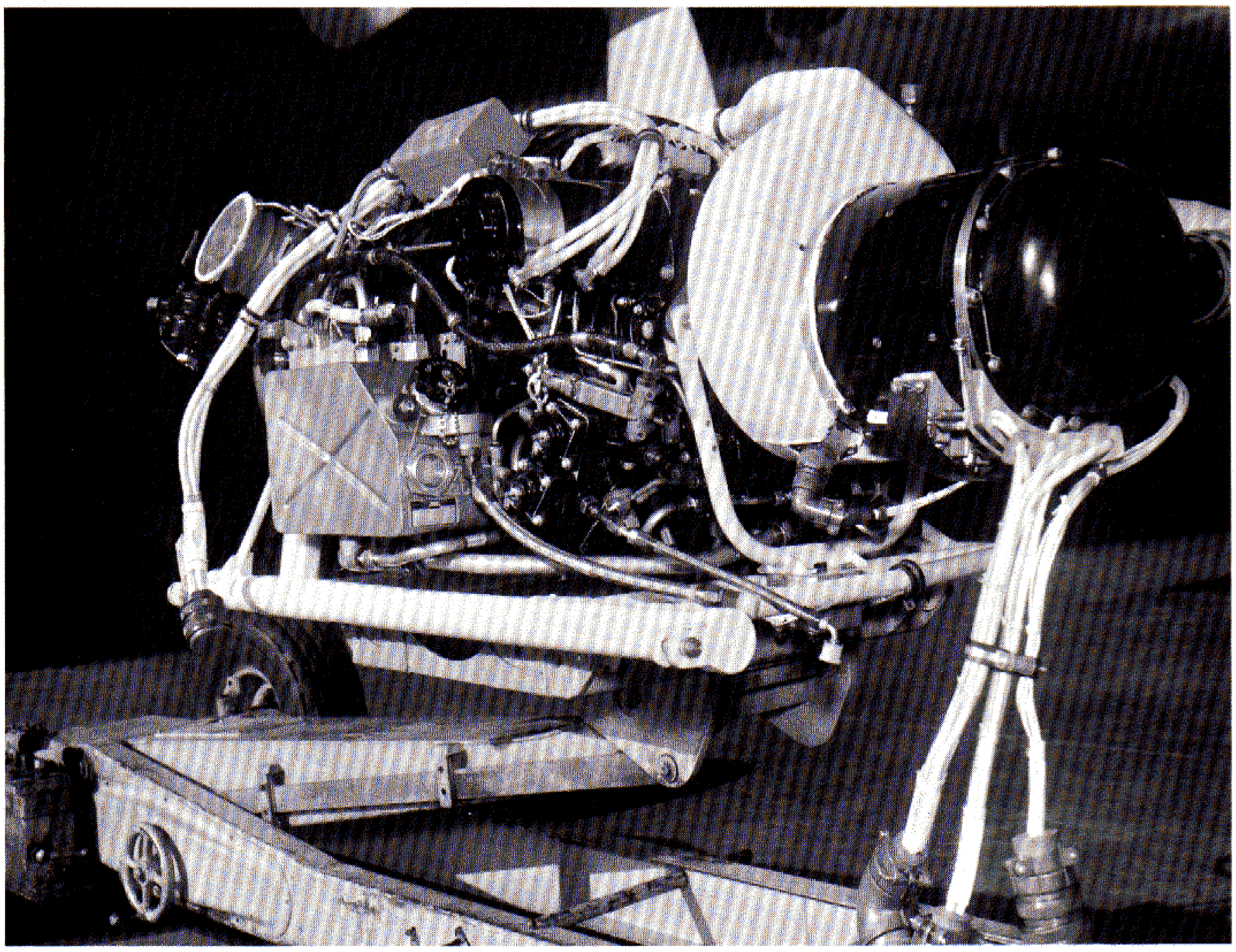


Figure 22
APU on Mark VII,
Model I Bomb Hoist

OPERATION AND MAINTENANCE

APU OPERATION All that is necessary to start and operate the APU is an adequately charged battery and sufficient fuel, so long as the ambient temperature limitations of —65°F to 130°F (±54°C) are observed. During the starting cycle fuel ignition should occur at approximately 10% rpm. The time it takes the engine to accelerate to 100% rpm will vary from approximately 20 seconds, when ambient temperature is warm, to about 50 seconds when the ambient temperature is exceedingly cold. As soon as the engine speed stabilizes at 100% rpm, loads may be applied to the APU. The APU operating range is between 98 and 102% engine rpm during ground operations, and between 98 and 103% engine rpm during in-flight operations. The absolute maximum APU engine speed is 106% rpm. Simplified instructions for starting and stopping the APU are contained in the P-3 NATOPS Flight Manual, NAVAIR 01-75PAA-1. More detailed instructions are contained in the P-3 Maintenance Instruction Manual, NAVAIR 01-75PAA-2-4, Sections II and III, and the recommendations of AiResearch are contained in Section III of the NAVWEPS 03-105CA-13 Operation and Maintenance Manual.

Once the engine speed has stabilized, the APU may be used to supply electrical power to the aircraft, supply pneumatic power to the integrated air cycle system, supply pneumatic power to the integrated starting system, or supply heated air to the bomb bay. When loads are applied to the APU, the exhaust temperature will rise. Normally, bleed air loads will cause a greater exhaust temperature rise than loads applied to the APU generator. Under normal operating conditions the exhaust gas temperature should not exceed 1250°F (677°C). Any continuous temperature above this point is evidence of malfunction. According to the NATOPS Flight Manual, the APU's maximum peak exhaust gas temperature limit is 1320°F (715°C).[10]

It is preferable to utilize fuel from No. 2 Tank for prolonged ground operation of the APU, but 1000 lbs. of fuel should be retained in No. 2 Tank as a heat sink for the heat exchanger of the No. 1 Hydraulic system (which should not be operated more than 10 minutes at lower fuel levels). If the No. 2 Tank is reduced to or near this level, fuel can be crossfed to the APU from Tank 1, 3, or 4.

During crossfeed operation, some fuel will enter Tank 2 via a tiny thermal relief orifice in the dual check valve's connection to the inoperative No. 2 Tank boost pump. Normally the small quantity of fuel introduced in this way is negligible, but if No. 2 Tank is already full or nearly so, fuel will eventually be expelled through the No. 2 Tank vent system.

If the APU is to be operated in flight, there are several restrictions placed upon the unit's operation. Foremost are those limiting APU operation to altitudes below 20,000 feet and at airspeeds less than 225 knots IAS. At altitudes above 10,000 feet, some of the aircraft's electrical loads may have to be monitored. At present, the operator must choose which loads to de-energize from a number of alternatives given in the P-3 NATOPS Flight Manual, NAVAIR 01-75PAA-1. In the near future, production aircraft will be equipped to automatically monitor the aircraft's electrical loads in flight when the APU is the sole source of electrical power at altitudes above 8,000 feet. Delivered aircraft will be retrofitted to this configuration through incorporation of P-3 Airframe Change No. 165, which will be released later this year.

When the APU is shut down, the engine rpm will begin to drop immediately, and the APU exhaust temperature will also drop. It will take at least 30 seconds for the turbine to decelerate, and twice that time is allotted before the doors begin to close. The APU can be shut down by using the APU safety switch on the left side of the fuselage, but if the APU is shut down in this manner when the battery is the only available aircraft power source *the APU control switch in the flight station must be moved to "OFF" shortly thereafter.* This rule must be followed to prevent depletion of the aircraft's battery by the APU control system's still-active components. Finally, if an APU re-start is attempted, remember that the "1 minute ON - 4 minutes OFF" starter duty cycle must be observed.

MAINTENANCE Maintenance information related to the P-3 APU and its associated systems is not consolidated into one manual, rather it is dispersed throughout several. The basic references for the APU's turbine engine and its accessories are contained in the NAVAIR 01-75PAA-2-4 and -4-5 manuals, and the NAVWEPS 03-105CA-13, -14, and -15 manuals. Supplementary information on the APU and its related systems is also contained in the NAVAIR 01-75PAA-2-2.4, -2-13.2, -4-4, -4-5, and -4-8 manuals, and in the NAVAIR 01-75PAA-6 series of maintenance requirements cards.

Clearance within the APU compartment is scant at best, so it may be necessary to remove the APU from the aircraft in order to perform maintenance on some of its components. If such is the case, the Mark VII, Model 1 bomb hoist may be used to remove and replace the APU. Extreme care must be exercised so that neither the APU nor the aircraft structure is inadvertently damaged during removal or installation procedures.

[10] *Shortly before press time AiResearch reported that the maximum peak exhaust gas temperature limit on GFAE APUs is now set at 1340-1350°F (727-732°C).*

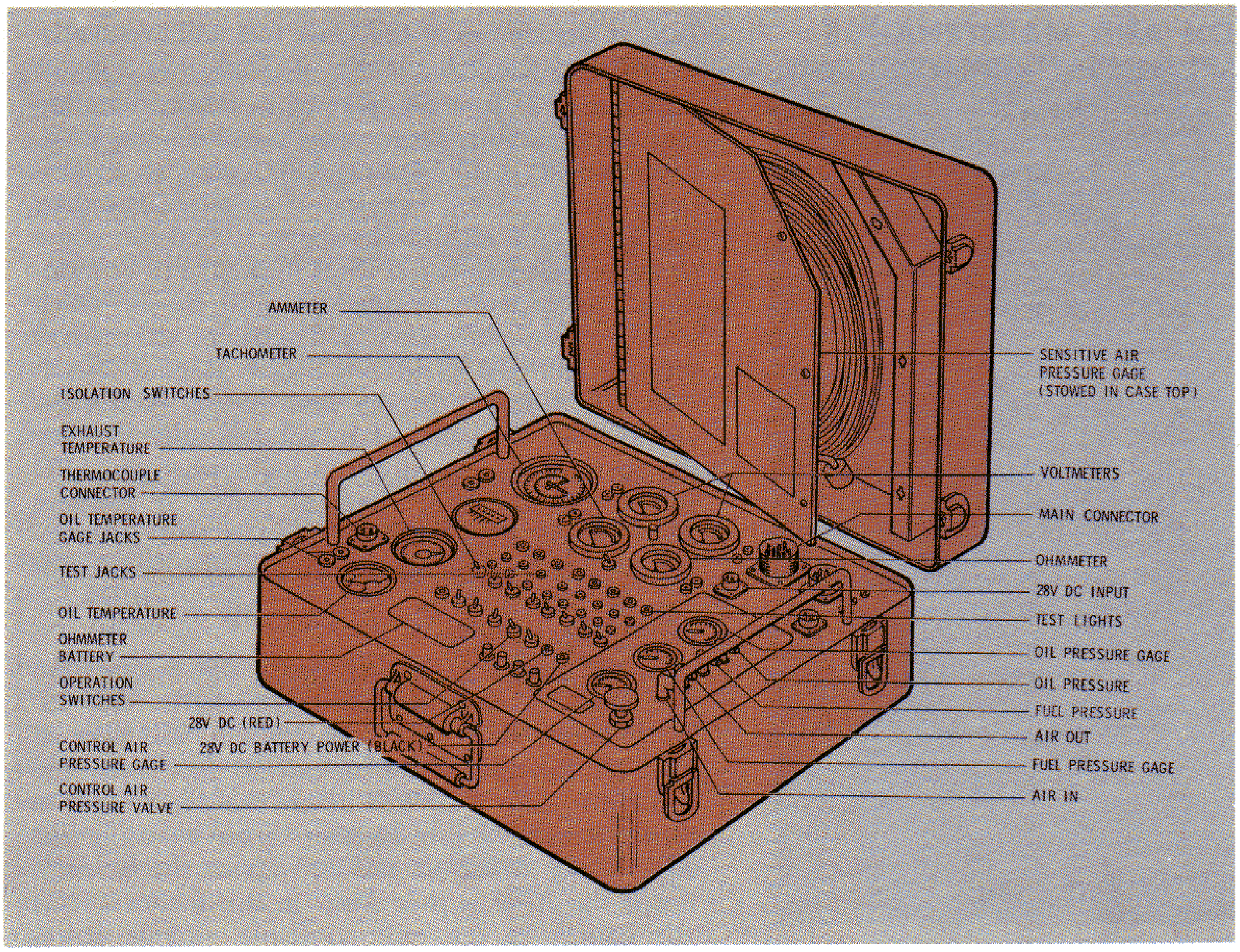
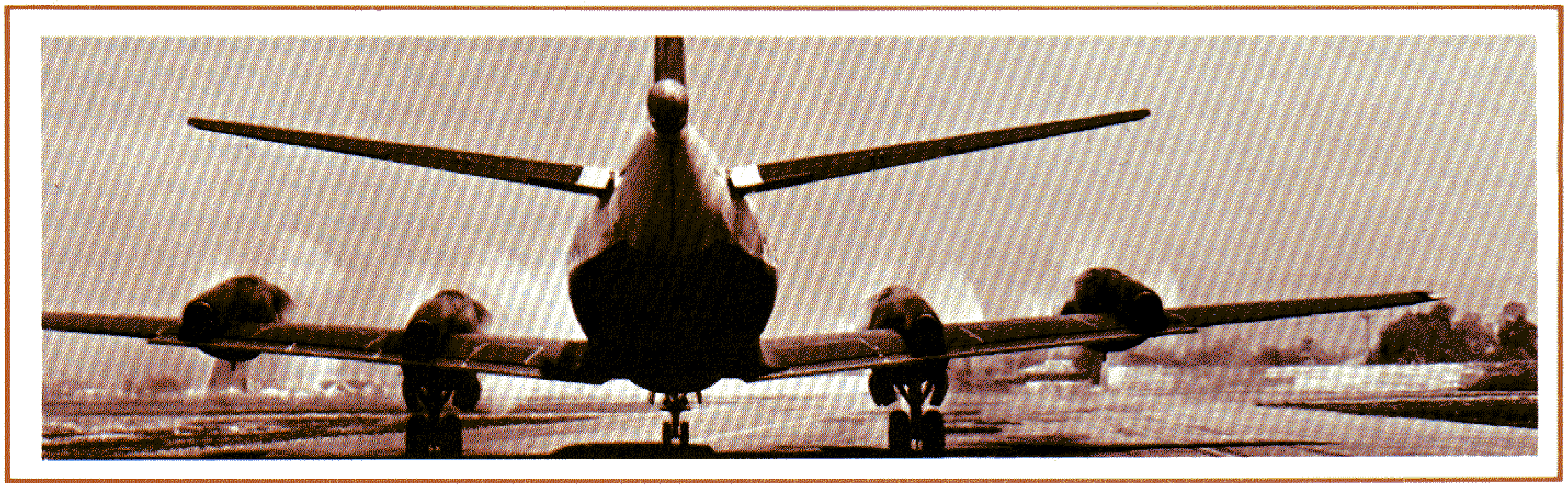


Figure 23 APU Analyzer

APU Analyzer The electrical continuity and the performance of the APU may be checked with the AiResearch P/N 281069 Analyzer (Figure 23) without removing the APU from the aircraft. In addition to the analyzer, a special cable assembly is required to connect the analyzer to the APU electrical system, and a special hose kit is needed to connect the analyzer to the APU test taps. The analyzer also requires an external power source. Since this analyzer was designed for use on other APUs and ground power units as well as the P-3's APU, there are some differences in calibration between the aircraft's APU instrumentation and the analyzer's instrumentation, two of which are quite apparent. The aircraft's APU tachometer is calibrated in percentage of APU rpm, and the APU temperature gage is calibrated in degrees Centigrade. Conversely, the analyzer's tachometer gives a direct reading of engine rpm and its temperature gage is calibrated in degrees Fahrenheit. The requirement for the proper conversion tables is obvious. ▲▲



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