ORION

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ORION

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FRONT AND BACK COVERS Traditionally a seaplane squadron, PATRON Forty-Eight now flies P-3B Orions and has its home port at NAS Moffett Field. Its history can be traced back to 1950 when, as Reserve Squadron VP-731, it was activated to serve in the Korean Theater. During this conflict the squadron flew PBM Mariners from Iwakuni, Japan and earned the Korean Presidential Unit Citation. Early in 1953 the squadron was redesignated VP-48.

In the years that followed, PATRON Forty-Eight continued to patrol the Pacific pond, trading its ancient Mariners for P5M-1s in 1954 and switching to the advanced P5M-2 aircraft in 1960. During the early 1960's the squadron made its home port at NAS North Island and performed a variety of assignments. While on deployment in Southeast Asia during the Gulf of Tonkin crisis in 1964, VP-48 set an all-time seaplane record by amassing 1585 flight hours during a single month of ASW operations. One year later the squadron deployed a detachment to Sangley Point, R. P. and operated from seaplane tenders at Cam Rahn Bay, Republic of Vietnam and Buckner Bay, Okinawa, flying "Market Time" patrols along coastal Vietnam.

Late in 1966 VP-48 began the transition to land-based P-3 Orions, shifting its home port from North Island to Moffett Field. Newly equipped, the squadron has since deployed to Iwakuni, Adak, and Southeast Asia. Recently it was the last VP squadron to check out of Sangley Point, as the base was returned to the Philippine Government in June 1971. Undaunted, the Boomerangers resumed their "Market Time" activities from other sites in Southeast Asia.

During its career, Patrol Squadron Forty-Eight has won its share of kudos, amongst which are the Isbell Trophies for ASW excellence in 1959, 1960 and 1965-66. It also has netted Battle Efficiency "E"s in 1960, 1966, 1970 and 1971, Aviation Safety Awards in 1959, 1960 and 1969, and has received the Meritorious Unit Commendation in December 1969.

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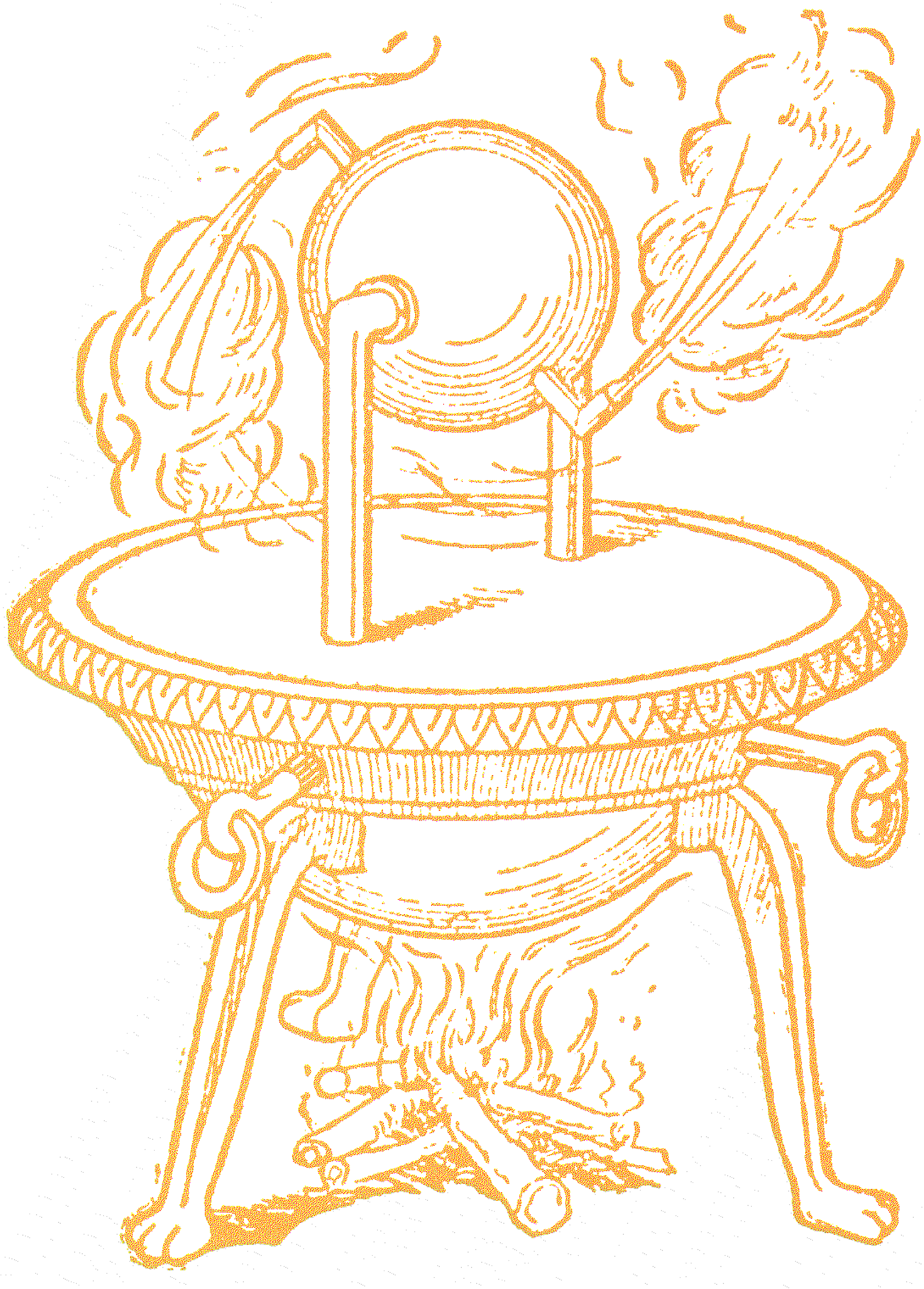


Figure 1. Hero's Aeolipile

THE T-56 ORION ENGINE

Nearly twenty centuries ago an Alexandrian philosopher named Hero demonstrated the principle of jet reaction with an apparatus called an aeolipile. This machine consisted of a hollow sphere mounted to rotate between two pillars, one of which was hollow and served to transmit steam from a closed vessel supported over the fire. Two pipes with right-angled ejection nozzles were mounted opposite one another on the sphere in a plane normal to the axis of rotation, and the reaction of the issuing steam jets caused the sphere to revolve. Hero's aeolipile is reputed to be the first apparatus on record that could convert steam pressure into mechanical power.

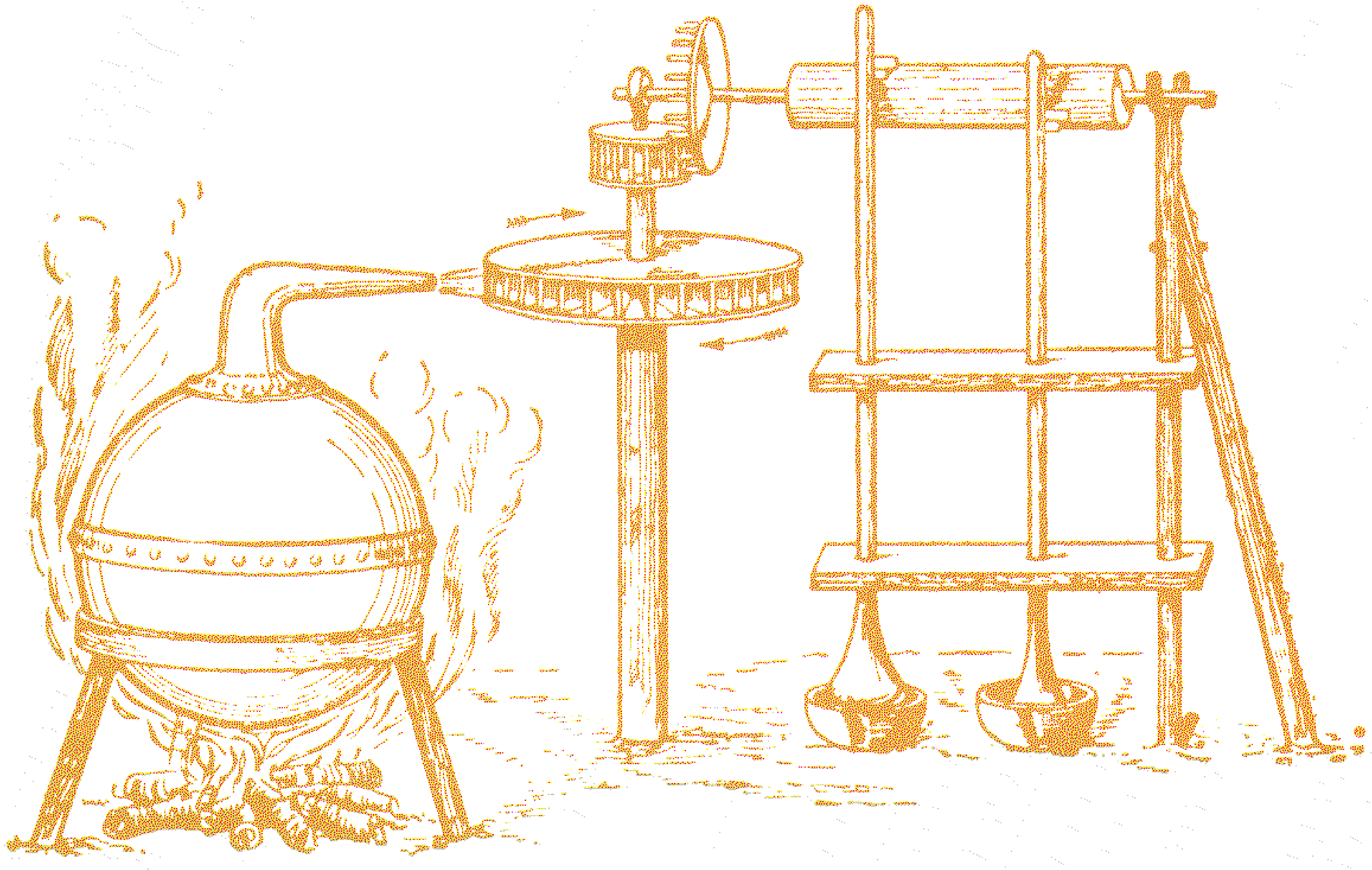


Figure 2. Steam Turbine Proposal by Giovanni Branca – 1629

It was not until 1629, when the Renaissance was in full swing, that we find the first suggestion of the steam turbine. The inventor was an Italian engineer named Giovanni Branca, and his idea was to direct a powerful jet of steam tangentially against open vanes formed on the circumference of a fan wheel mounted on a vertical spindle. Other mechanisms were to be driven from this spindle at reduced speed through crude cogwheel gearing. Less than sixty years later the famous English scientist Sir Isaac Newton had recognized the possibilities of jet propulsion, as is evident by the formulation of his third law of motion which states that action and reaction are equal in magnitude and opposite in direction.

Near the end of the eighteenth century, the year 1791, an Englishman named John Barber took out the first patent for a gas turbine. The proposed plant had a gas producer, a gas receiver, gas and air compressors, a combustion chamber, a turbine wheel, and speed-reducing gearing. This was the time of the industrial revolution when the substitution of mechanical power for human energy had become an economic necessity, but unfortunately for Mr. Barber the steam engine of this period was more efficient than his turbine machine.

Only a few years before Barber received his patent, man had left the confines of earth in hot air and hydrogen-filled balloons. Successful ascents and (more often than not) descents in lighter-than-air craft prompted experiments with heavier-than-air craft. It was not long until aerophiles began seeking a means of propelling their gliders and gas bags, but it was not until 1903 that man was able to achieve manned, powered flight. History credits the Wright brothers with this feat, although some historians are inclined to accept the claims of Clement Ader who conducted manned, powered flight experiments a few years before the Wright brothers' successful efforts at Kitty Hawk. At any rate, it is purely academic who flew the first powered heavier-than-air craft, for there were many others who were soon to follow.

The Wright brothers and their contemporaries found that the internal-combustion reciprocating engine was the answer in their quest for a power source for manned flight, for steam plants – the only really proven mode of power at the turn of the last century – were too heavy and cumbersome to power flying machines. Nevertheless, jet propulsion, gas turbines, ramjets, and thrust augmentors were visualized by the aircraft pioneers.

One of the earliest schemes to power an aircraft by jet propulsion was devised by a French engineer, Lorin, in 1908. His concept employed an orthodox internal-combustion engine, directing its hot gas exhaust through a divergent nozzle to produce a propulsive jet. The inventor envisaged multi-cylinder units of this type installed in the wings of aircraft. The idea suffered, of course, because of the inadequate mass of air handled, which could be no more than that required to produce a combustible mixture in the engine cylinder. But still, it was a step in the right direction.

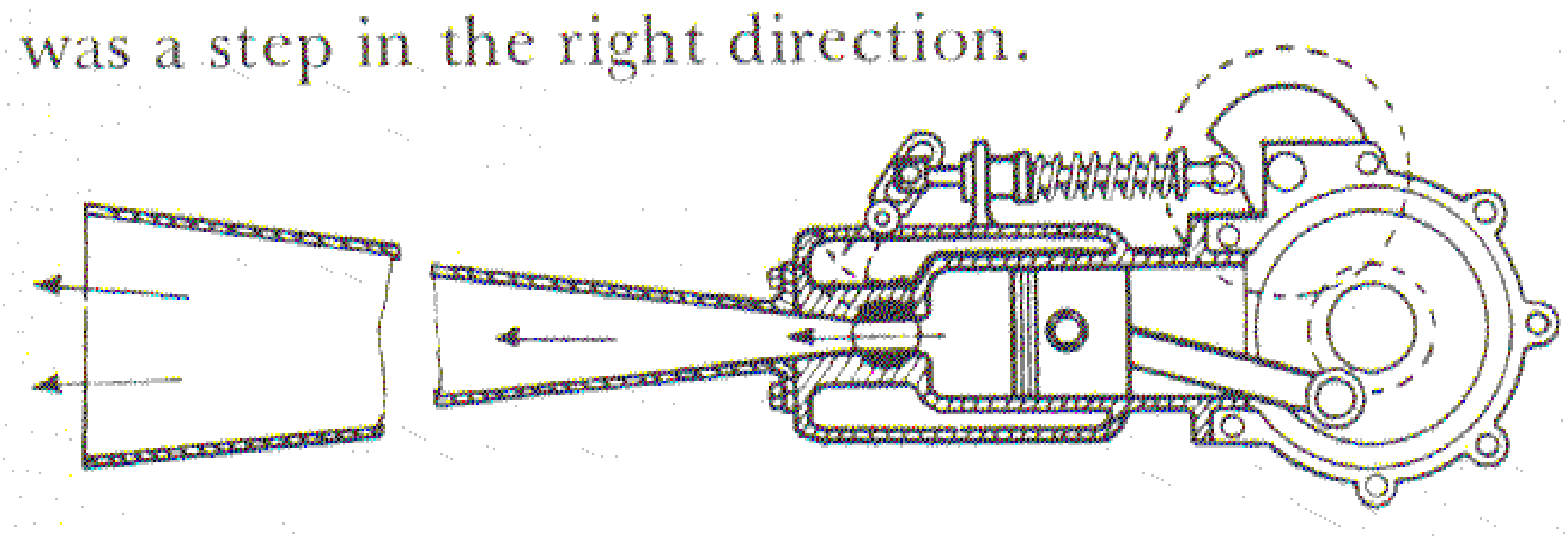
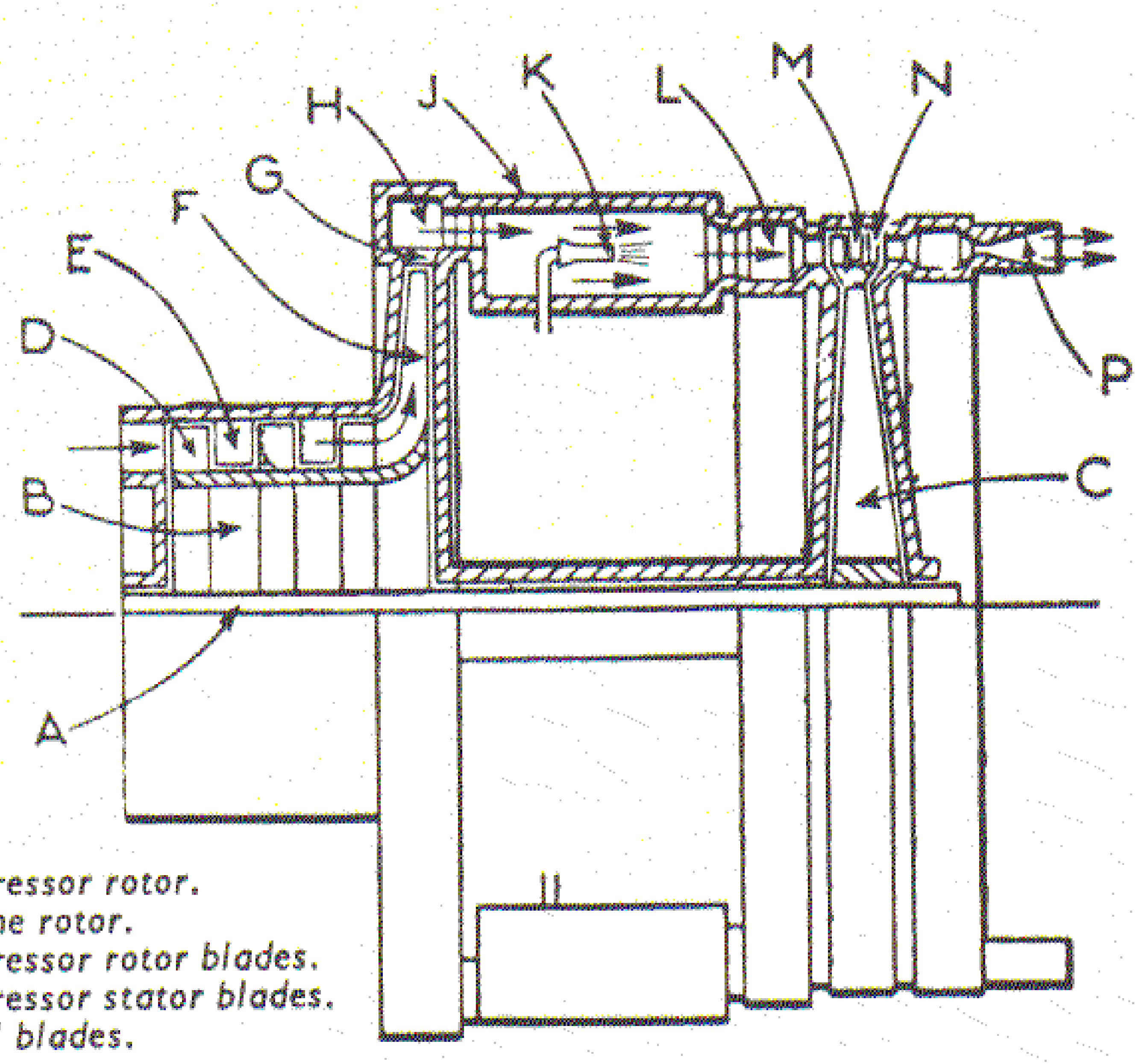


Figure 3. Concept of Lorin to Produce a Propulsive Jet with an Orthodox Internal Combustion Engine – 1908

Early efforts to overcome the handicap of Lorin's design led to ingenious schemes to increase the mass of air and thus "augment" the thrust. One such effort was devised by a Frenchman named Morize in 1917, while in the same year an Englishman named Harris developed another means of augmentation. Yet another "thrust augmentor" was invented during the same period by yet another Frenchman named Melot. Although all of these schemes were successful to some degree, they were still unable to challenge the efficiency of the piston engine-airscrew combination of that day.

The first real breakthrough to the era of turbine-powered aircraft occurred in England in 1930 when Frank Whittle filed the application for his first jet propulsion patent. Although the gas turbine and the concept of jet propulsion were by no means new, Whittle's idea of using the gas turbine for jet propulsion was. However, there was no flurry of activity to turn the concept into workable hardware, for when Whittle presented his patent to the British Air Ministry it was rejected on the ground that development of a gas-turbine aircraft engine presented too many practical difficulties.



A. Shaft.
B. Compressor rotor.
C. Turbine rotor.
D. Compressor rotor blades.
E. Compressor stator blades.
F. Radial blades.
G. Diffuser vanes.
H. Air collecting ring.
J. Combustion chamber.
K. Fuel jet.
L. Gas collector ring.
M. Turbine stator blades.
N. Turbine rotor blades.
P. Discharge nozzle.

Figure 4. Gas Turbine Engine Design Patented by Whittle in 1930

In 1935 Whittle received financial backing from private interests, enabling him to design a gas-turbine engine and have it built to his specifications. Tests on the engine began in April 1937, and although its performance did not meet expectations, the results were successful enough to generate financial backing from the British government for further research.

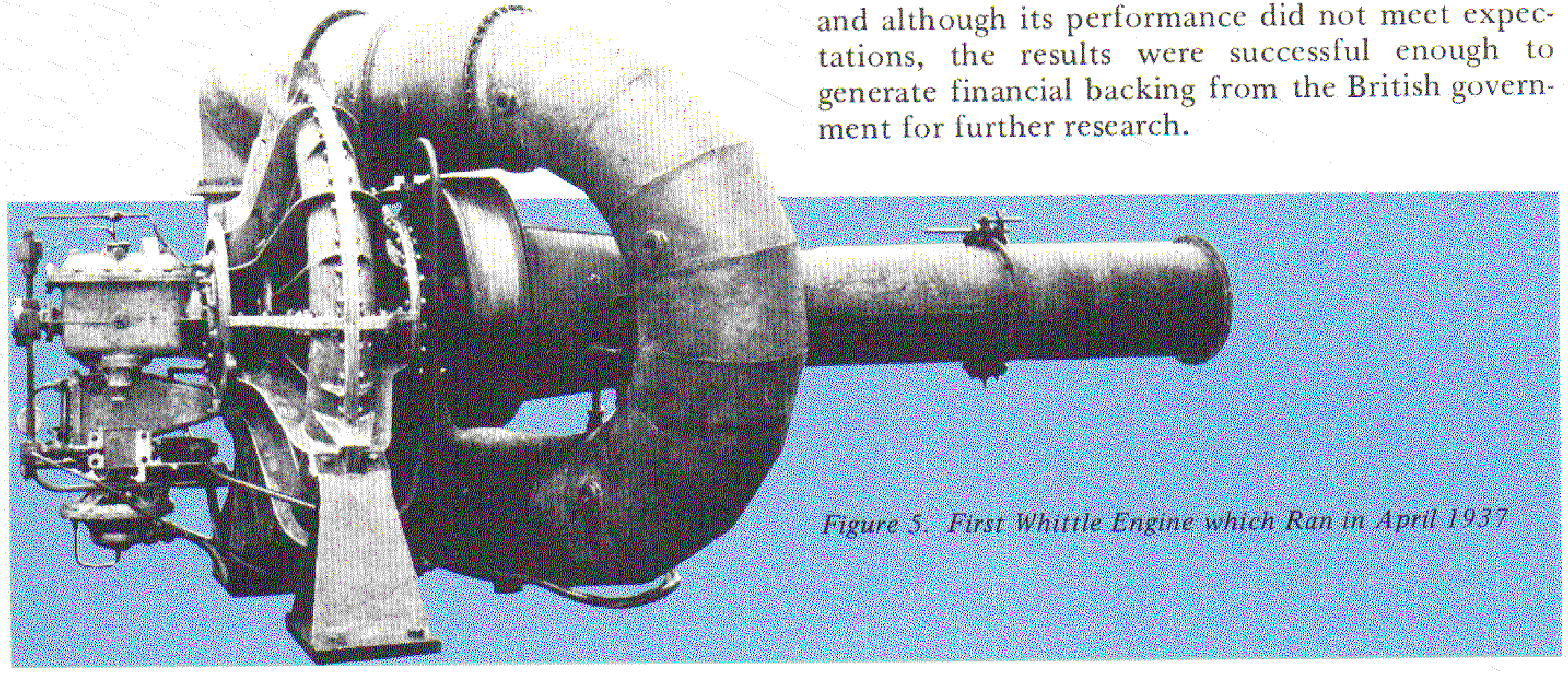


Figure 5. First Whittle Engine which Ran in April 1937

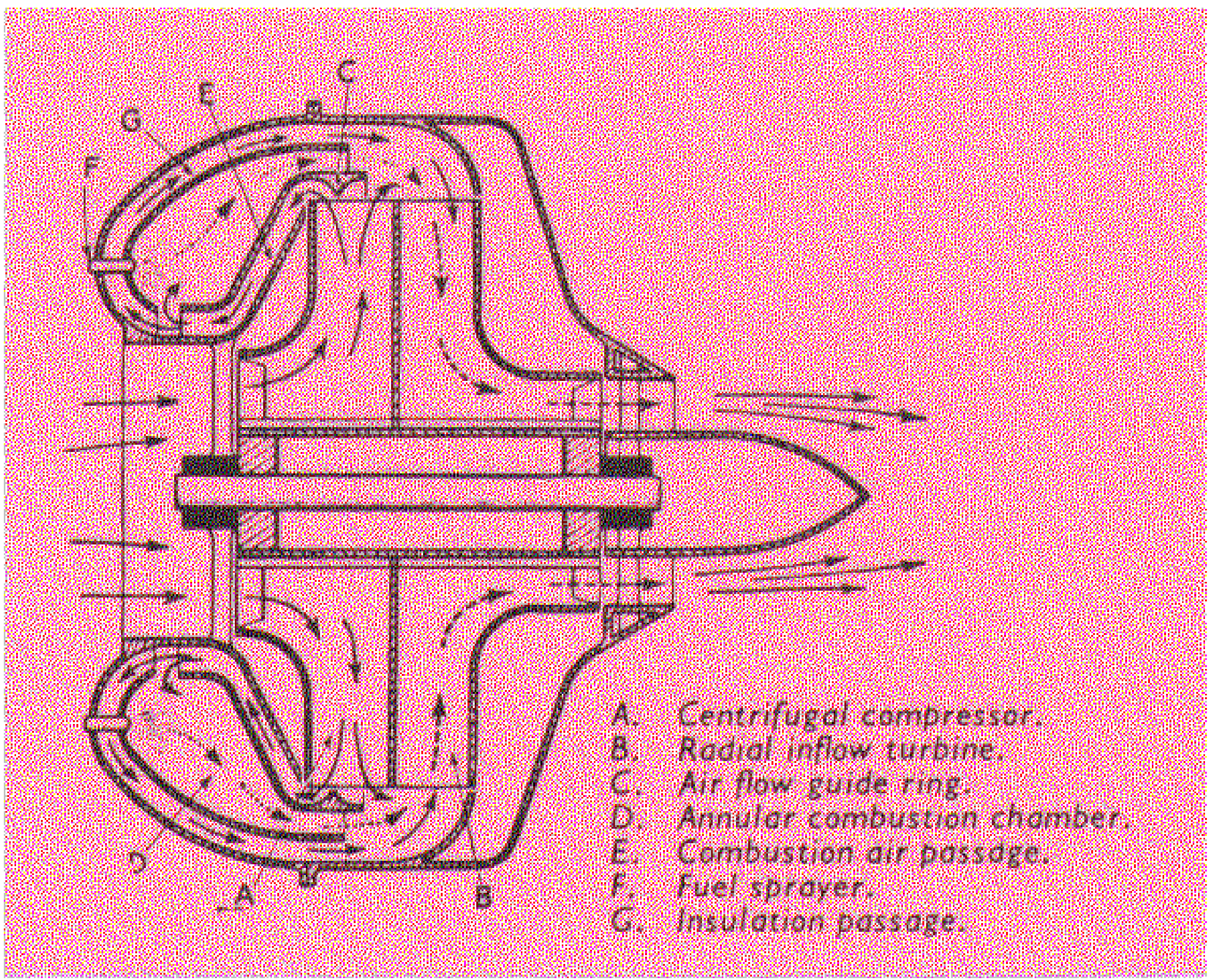


Figure 6. Von Ohain Gas Turbine Engine Design Patented in 1935

However, credit for building the first gas-turbine engine to actually operate must go to a young German named Hans von Ohain. About the time that Whittle began his engine development, von Ohain patented a turbojet unit and with the backing of the Heinkel aircraft company he built a demonstration unit that was run on a test bed in March 1937 and produced a thrust of 550 lb. Two years later, on August 24, 1939, Captain Warsitz made the world's first turbojet-powered flight in a Heinkel He-178 airframe powered by a He S-3B von Ohain-type engine that weighed slightly less than 800 pounds and delivered a static thrust of 1100 pounds. Thus, the jet age began, and during April 1941 an experimental Gloster fighter powered by the Whittle W1X engine became airborne during taxiing trials, rewarding the perseverance of the British inventor.

In 1929 an Englishman named Dr. A. A. Griffith, head of the Royal Aircraft Establishment engine department (and whose theories inspired Frank Whittle), presented in an official paper the prospects of an internal-combustion turbine driving a propeller. He concluded that the unit would be lighter, smaller, and more efficient than a piston engine, a conclusion that has long since been fully verified. By 1936 a Swedish firm had patented a turboprop unit with a multi-stage centrifugal compressor, in the late 1930's the British were experimenting with turboprop engine components, and in 1939 a Swiss firm also applied for a turboprop engine design. During 1939 Northrop Aircraft began design studies in the United States on a large turboprop engine called the Turbodyne which had been proposed by a Czech engineer, V. H. Pavlecka. In Hungary, Jendrassik began detailed studies of gas turbines in the early 1930's, built and tested a gas turbine in 1937, and began bench tests of a turboprop of 1000 shaft horsepower in 1941. Nevertheless, wartime priorities demanded that emphasis be placed upon development of

Figure 8. Sketch of the He S-3B Engine

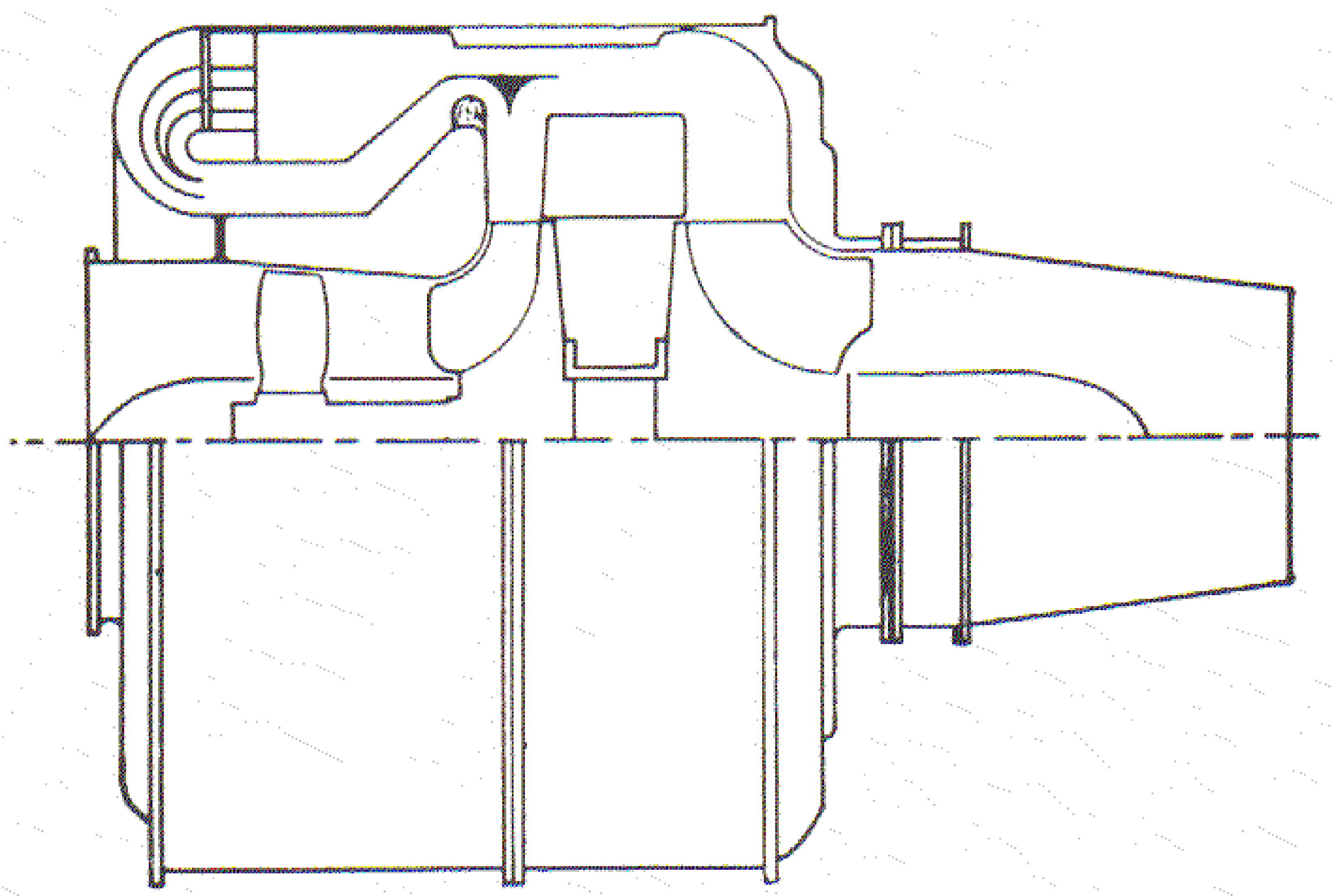
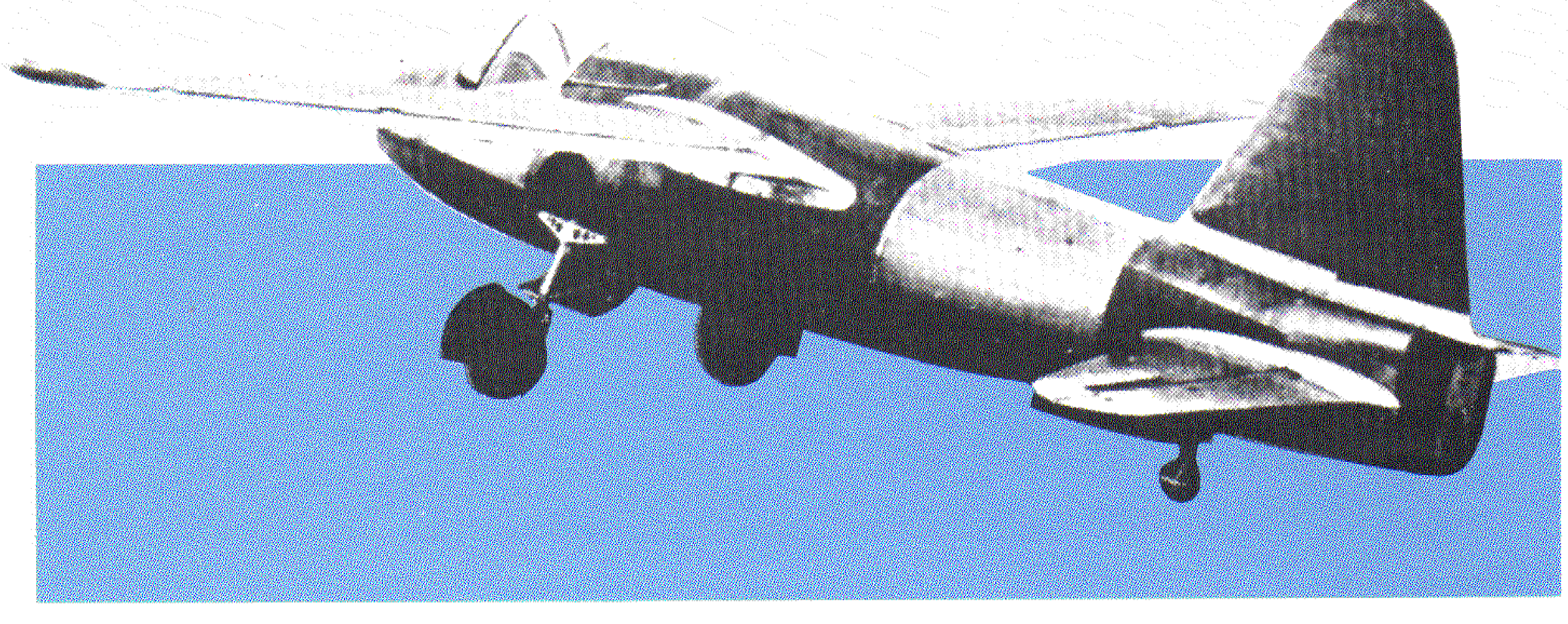


Figure 7. Heinkel He-178, the World's First Turbojet-powered Aircraft to Fly



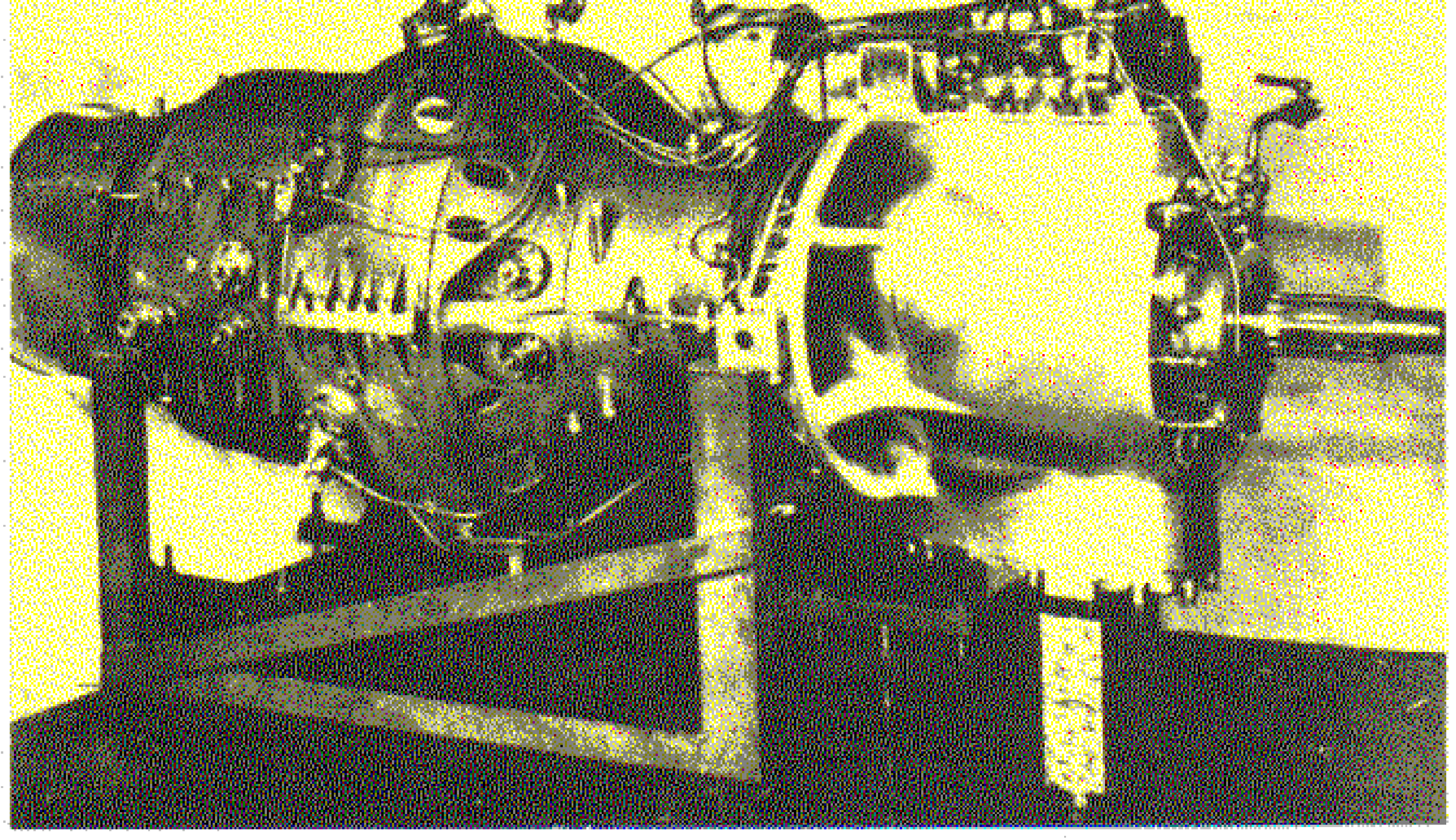


Figure 9. Jendrassik's Turboprop – 1941

turbojet aircraft engines, thus it was not until September 1945 that an aircraft fitted with Rolls Royce Trent turboprop engines became the first turboprop-powered aircraft to fly.

After the conclusion of World War II more interest was devoted to the development of turboprop engines. Among the turboprop power plants produced in the United States during this period were the General Electric T31, the Pratt and Whitney T34 used on some military variations of Lockheed Constellation aircraft, and the Allison T38 and T40 engines which were the predecessors of the Allison T56 engine, the subject of this article.

Figure 10. Rolls Royce Trent Turboprop Engine

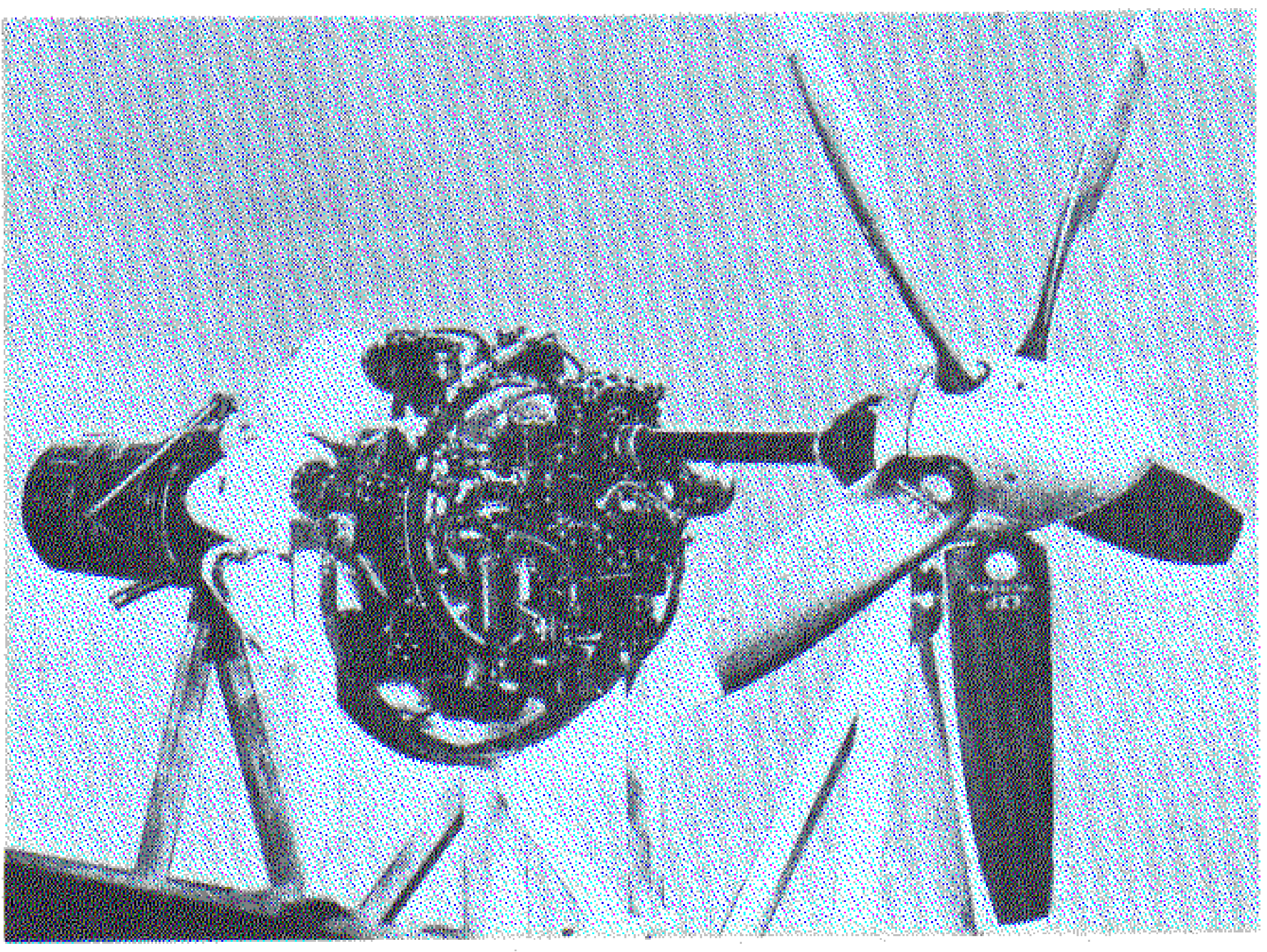


Figure 11. Lockheed R7V-2 Constellation Equipped with T34 Turboprop Engines

JET ENGINE THEORY

Turboprop and turbojet airplane engines both operate on the same basic principle, hot gas stream flow, for the development of propulsion force. The only difference between the two engine types is in their method of converting the hot gas energy into propulsion force. The basic operational processes in either engine include the following:

(a) Intake of atmospheric air

(b) Compression, with attendant heating, of the intake air stream in a turbine-driven compressor section

(c) Mixing the compressed air stream with atomized fuel and burning the mixture in a combustion (hot) section

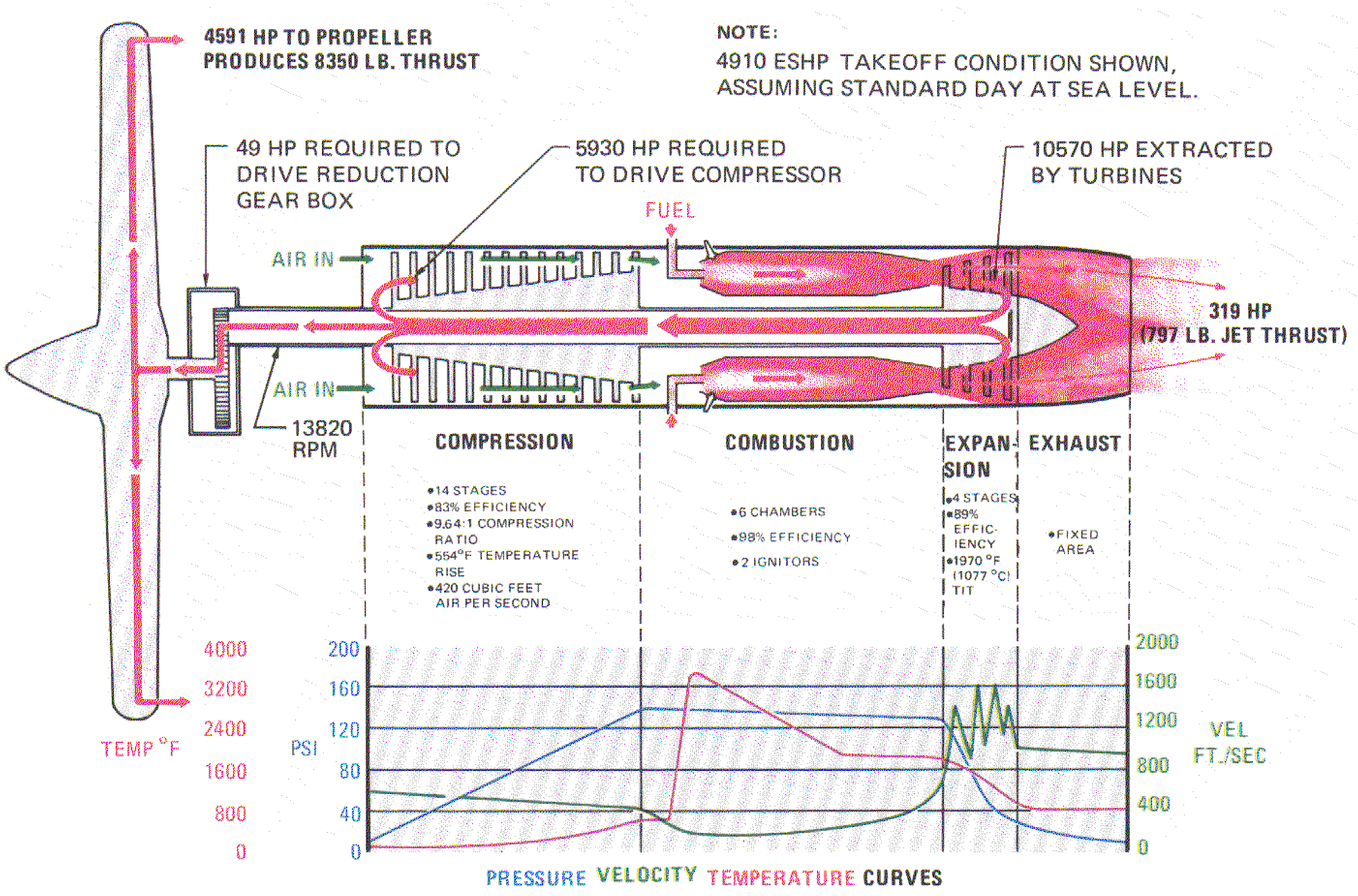
(d) Extracting a portion of the hot gas energy from the combustion section hot gas output and converting the extracted energy to mechanical power in a turbine section

(e) Passing the turbine exhaust stream through a jet nozzle, or tailpipe for further extraction of energy.

In a pure turbojet airplane engine, all of the propulsive force is derived from jet exhaust thrust, and the turbine only extracts sufficient hot gas energy from the hot section output to drive the compressor and engine accessories. On the other hand, a turboprop engine turbine section is designed to extract the maximum possible amount of energy from the hot gas stream for conversion to shaft mechanical power; the mechanical power thus generated which is in excess of the compressor and accessory requirements is used to drive a propeller for production of propulsive force. In a turboprop engine, only a small portion of the total propulsive force is derived from the turbine exhaust.

Basically, the two engine types are mechanically similar, the only real difference is that the turboprop engine includes a reduction gear arrangement in the propeller drive train; such an arrangement is not required in a pure turbojet engine. Both engine types include an air inlet, compressor section, combustion section, and turbine section. Also, both types have about the same requirements in the way of accessories, systems, and control functions.

Figure 12. Allison T56 Engine Schematic



Air Inlet

As its name implies, the air inlet is a fairly simple duct arrangement which admits and induces air stream flow from ambient atmosphere into a jet engine. Although its description and function are simple, its design details can be quite complex because the air inlet must function efficiently to provide the engine with sufficient air supply for optimum operation over a wide range of atmospheric conditions of pressure, temperature, humidity, and wind direction and velocity. Also, it must compensate for variations in airplane on-the-ground or in-flight operating conditions such as aircraft velocity and engine speed, accelerating or decelerating, takeoff climbout or landing approach, altitude, and airplane heading with respect to wind direction (especially during ground operations). The air inlet must be capable of preventing formation and ingestion of ice into the engine. Also, the air inlet installation must be designed to prevent, as much as possible, the ingestion of foreign objects during ground operations. Air inlet system design can provide a certain amount of air stream compression, designated as ram recovery, ahead of the compressor section.

Compressor Section

The compressor section is the most forward part of the basic engine. It receives the airstream flow from the air inlet, compresses it through several stages, and passes the compressed air to the combustion section. Aircraft jet engine compressors of modern design are usually axial-flow rotary units and may contain up to about 19 stages. Some engines have compressors that are constructed as radial-flow machines while others use a combination of axial flow and radial flow. Each stage of an axial-flow compressor section includes airfoil-shaped stator vanes and rotor blades. The rotor blades for each stage are installed around the periphery of a wheel, or disc, and the several wheels (one for each stage) are installed on a common driving shaft that extends back through the engine to the turbine section where it receives rotational mechanical force from the turbine to drive the compressor. The shaft includes gear drives or other means for transmitting power to various engine accessories.

The stator vanes are installed radially in the compressor casing. The vanes function to straighten the air stream flow between compressor stages and direct air flow into the next compressor stage for maximum efficiency. As the air flow passes through each rotor stage, swirling and turbulence is induced in the air stream. Also, centrifugal effect of the rotor blades tends to direct the air stream outwards to the periphery of the casing. The stator vanes of the succeeding stage tend to cancel these effects. The final compressor element to act on the air stream is the diffuser, a final stator stage, which distributes the compressed air evenly to the combustors.

Combustion Section

The combustion section of a jet engine usually consists of a series of burner units arranged radially just behind the compressor. The burner units receive the heated, compressed air from the compressor section and each unit incorporates a nozzle or orifice through which fuel is sprayed into the interior and mixed with the air. Each unit also has a spark igniter, or other suitable device, to initiate burning of the fuel-air mixture. Engines with multiple burner units usually employ igniters in only one or two units with a crossover tube system between the units to propagate combustion into all units. Most engines being built today are designed so that the burner units can be replaced with the engine installed on the airplane.

The burning fuel-air mixture produces a high-temperature gas flow out of the burner units, and this gas flow is induced directly into the turbine where a portion of the potential energy is extracted. Since energy potential of a given mass gas flow is directly proportional to its temperature, i.e., higher temperature produces greater energy, the optimum situation is when the output is heated to the maximum temperature that turbine materials and design will allow. Since the gas cools as energy is extracted by the turbine, the critical gas flow temperature is that which can be tolerated at the point of entry into the turbine first stage, or Turbine Inlet Temperature (TIT).

Since the total energy potential of the hot gas stream is exponentially proportional to the mass flow, it follows that the greatest overall engine output is produced when the maximum mass of gas, heated to the critical temperature, is produced in the burners by combustion of the fuel-air mixture. And, it is only logical that if more (a greater mass) of the combustion materials, fuel and air, is introduced into the burner units, a greater mass of heated gas will be produced by combustion. Air, because of its much lower density than fuel, is the critical element in this situation. So the problem becomes that of packing as much (mass) air as possible into the burner units. Air, as with all gases, increases in density as its temperature is lowered, so it is desirable that the air stream be introduced into the burner units at the lowest possible temperature. It has been found that the air stream can be cooled by injecting a small amount of water-alcohol into the air stream, and that an appreciable increase in engine power output results.

Turbine Section

A gas turbine is a precision machine which extracts energy from a high-velocity hot-gas flow and converts it to mechanical power. The gas turbine section of a jet engine consists basically of two elements, a rotor and a casing, or stator similar to the corresponding elements in the compressor section. The rotor is installed on a shaft which is mounted in bearings supported by a part of the stator structure. Some turbines are single-stage machines, that is, they have only one row of blades on the rotor and one row of vanes in the stator. Other units may have several stages, each a complete entity with its own single row of rotor blades and stator vanes. However, the blade wheels for the several stages are installed on a common shaft and the stator vanes are installed in a common casing.

The high-velocity hot-gas stream produced by the combustion section is directed into the turbine section where it impinges on the first stage rotor blades. Most turbines are of the axial-flow variety, although examples of radial-flow machines have also been used. As the hot gas stream passes through the turbine, it expands and cools. More pertinent to this discussion, it gives up a part of its energy to the turbine causing the integral rotor and turbine shaft to spin. In a pure jet engine, the turbine extracts only enough energy to provide rotary mechanical power to drive the compressor and engine accessories. But, in a turboprop engine, the turbine is designed to extract the maximum possible amount of hot gas energy for development of mechanical power. In a turboprop engine, the turbine drives the compressor directly, and the propeller and engine accessories through a gearbox arrangement.

The gas stream leaving the last turbine stage, now much cooled and expanded, is exhausted from the engine through a jet tailpipe, or nozzle. In most cases this nozzle is especially designed to recover, as jet thrust, as much as possible of the energy remaining in the turbine exhaust gas stream. With a turbojet engine, all of the propulsion force is developed from the jet exhaust while in a turboprop application, the jet stream provides only a small percentage of the total effort.

Even a truly expert jet engine technician would be hard put to name the most important functional element of a jet engine. All elements are important unto themselves, but even more so as an integral part of the overall engine design. The turbine section is, without a doubt, the most critical element of the entire engine and requires the most serious design study. The criticality factor is the sum total of several individual conditions and requirements. The turbines in some engines operate at rotational speeds up to 50,000 rpm in gas stream temperatures which exceed 1000° C. The gas stream contains chemical compounds that are highly corrosive and erosive to turbine materials, and at the high temperatures, this effect becomes seriously intensified. In order to be most efficient, the turbine must operate with extremely close dimensional clearances; turbine components, especially rotor blades and stator vanes must be made of materials that have maximum dimensional stability to limit expansion in high temperatures and with centrifugal forces that can equal thousands of g's.

Reduction Gear Box

In all gas-turbine engines, the compressor and turbine rotors are installed in-line on a main shaft and some sort of gearing arrangement is used to take mechanical power from the main shaft to drive engine accessories such as fuel and oil pumps, electrical generators, engine condition and status sensors, and control devices, etc. It is most likely that each of these accessories operate most efficiently at a particular speed which is peculiar to the individual accessory. Therefore, the gearing arrangement must be designed to accommodate these requirements. In turbojet engines, accessory drive power is usually taken off the main shaft at some point between the compressor and turbine, and the gearing arrangements can range from simple to complex depending upon the individual engine and accessory design requirements.

For turboprop applications, the gearing arrangement requirements are expanded as some means for driving the propeller must be provided. It is readily apparent that a large-diameter propeller cannot be driven at the high rotational speeds at which turbines operate. The propeller drive gearing arrangement, then, must provide a fairly large speed reduction, and it must be capable of transmitting power at high torque levels. In most cases, it must also provide a propeller drive disconnect capability and some means for accommodating conditions of negative torque.

These propeller drive requirements, especially with respect to the large-ratio speed reduction and high torque capacity, dictate the need for a large gearbox of rugged design. Because of these factors, it is highly impractical to take gearbox input power from a midpoint of the turbine shaft. The solution, then, is to extend the turbine shaft forward through the compressor section and straight into the gearbox. This, in turn, necessitates refinements in air inlet design and installation. The gear box is directly in front of the engine and of necessity must be reasonably close to the engine; the air inlet must route air around the gearbox into the compressor section.

P-3 ORION ENGINES

The P-3 Orion airplanes utilize Allison T56 engines designed especially for turboprop applications. These engines are derivatives of the earlier T56 engine used on the C-130 Hercules. A commercial derivative, the Allison Model 501-D13 engine, is used on the Orion's predecessor, the Lockheed Electra. The A-series P-3's were designed and built with the T56-A-10W engines which were rated at 3755 SHP (Shaft Horsepower) at Standard Day Conditions (59°F, Sea Level), unaugmented, at 100 percent (13,820) rpm and TIT of 971°C. This engine uses water-alcohol injection for short-duration (approximately 1-1/2 minutes) power augmentation and, in this mode, develops 4200 SHP at the stated rpm, TIT, and atmospheric conditions. Starting with the first B-series airplane, the -10 engines were replaced by uprated engines designated as the T56-A-14. These engines were designed to operate at the same rpm, but at higher TIT (1077°C). The higher TIT enables the -14 engine rating of 4591 SHP, unaugmented.

Figure 13a. P-3 Power Plant Installation - Left Side

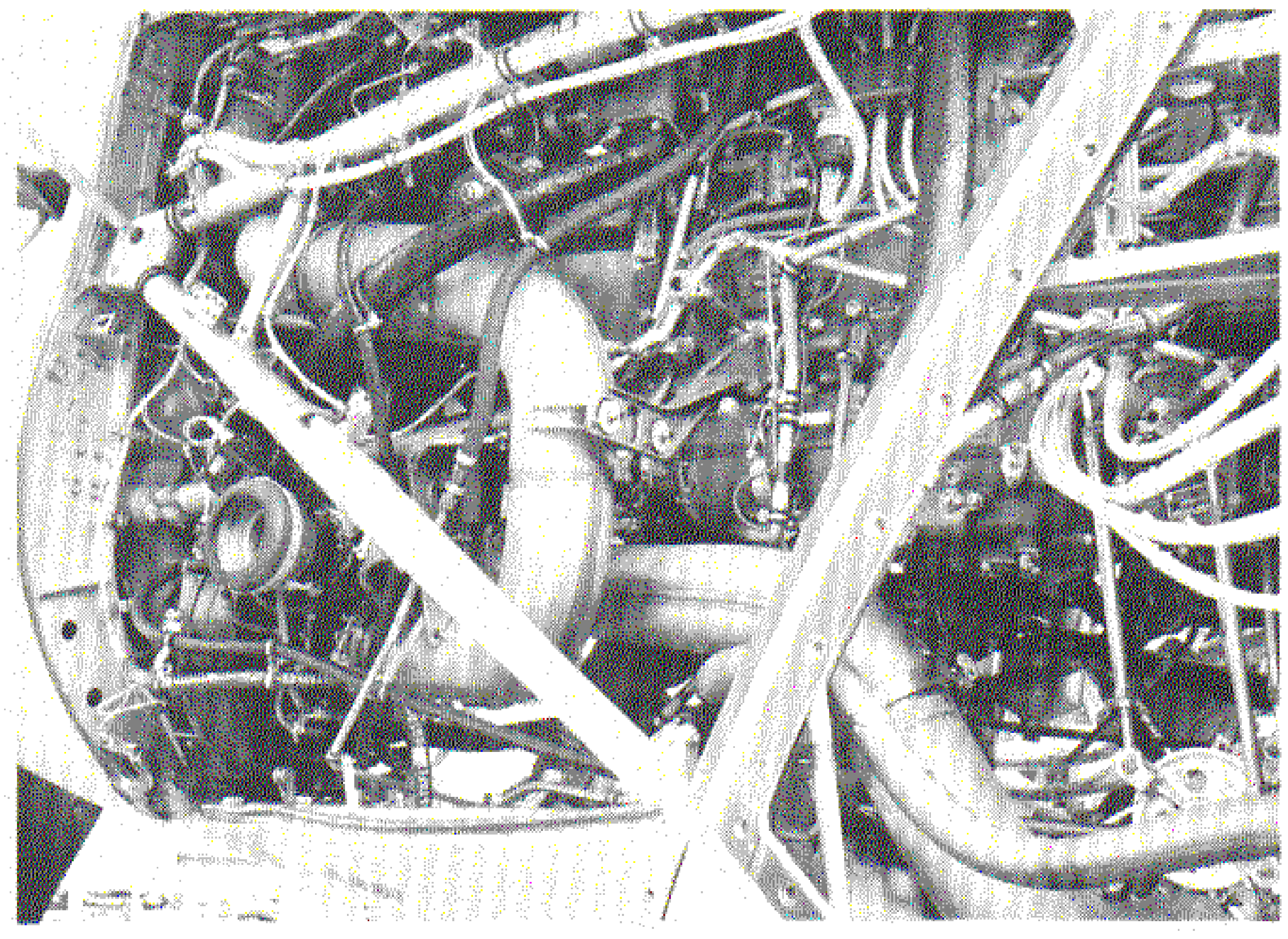
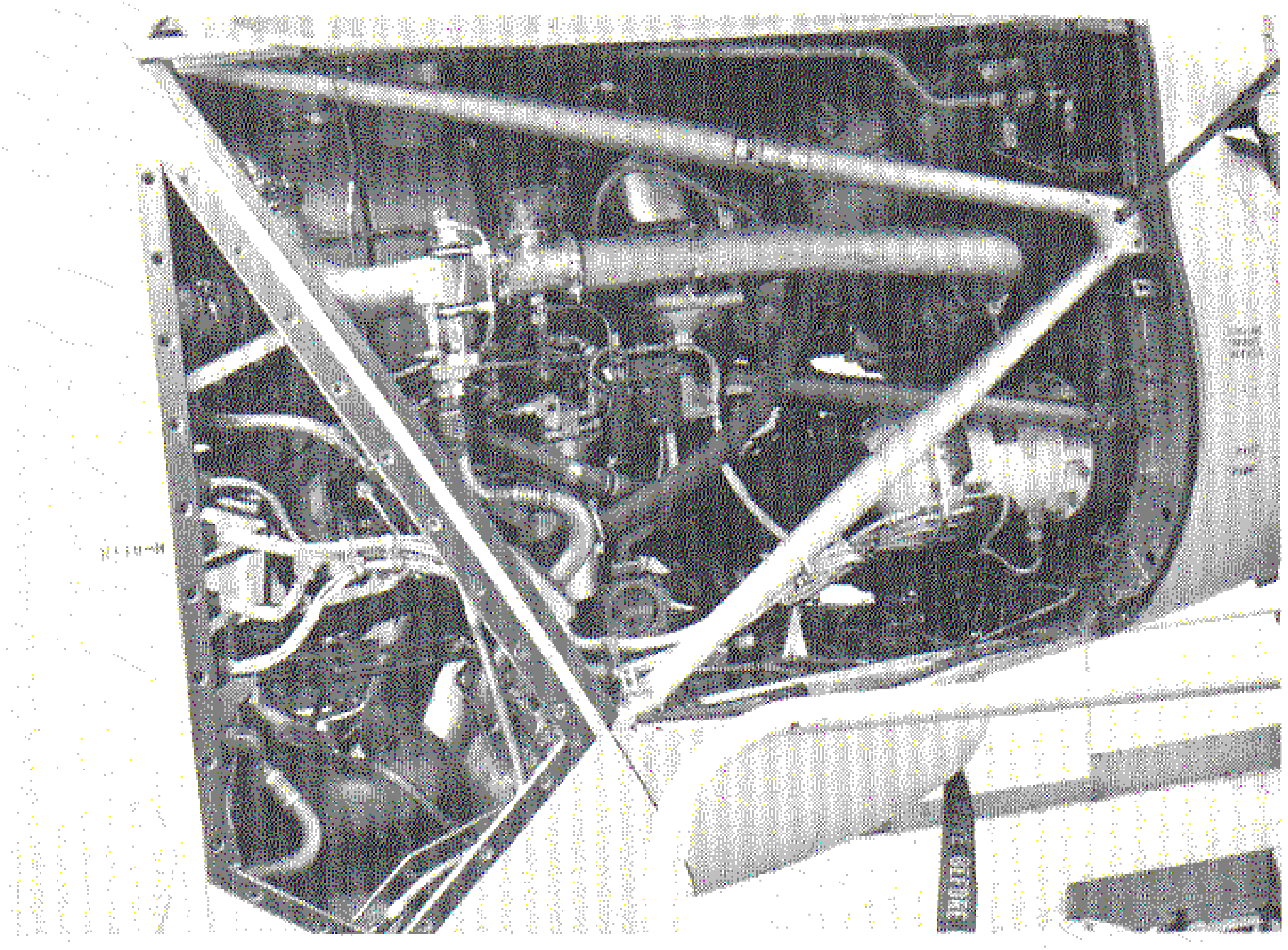


Figure 13b. P-3 Power Plant Installation - Right Side



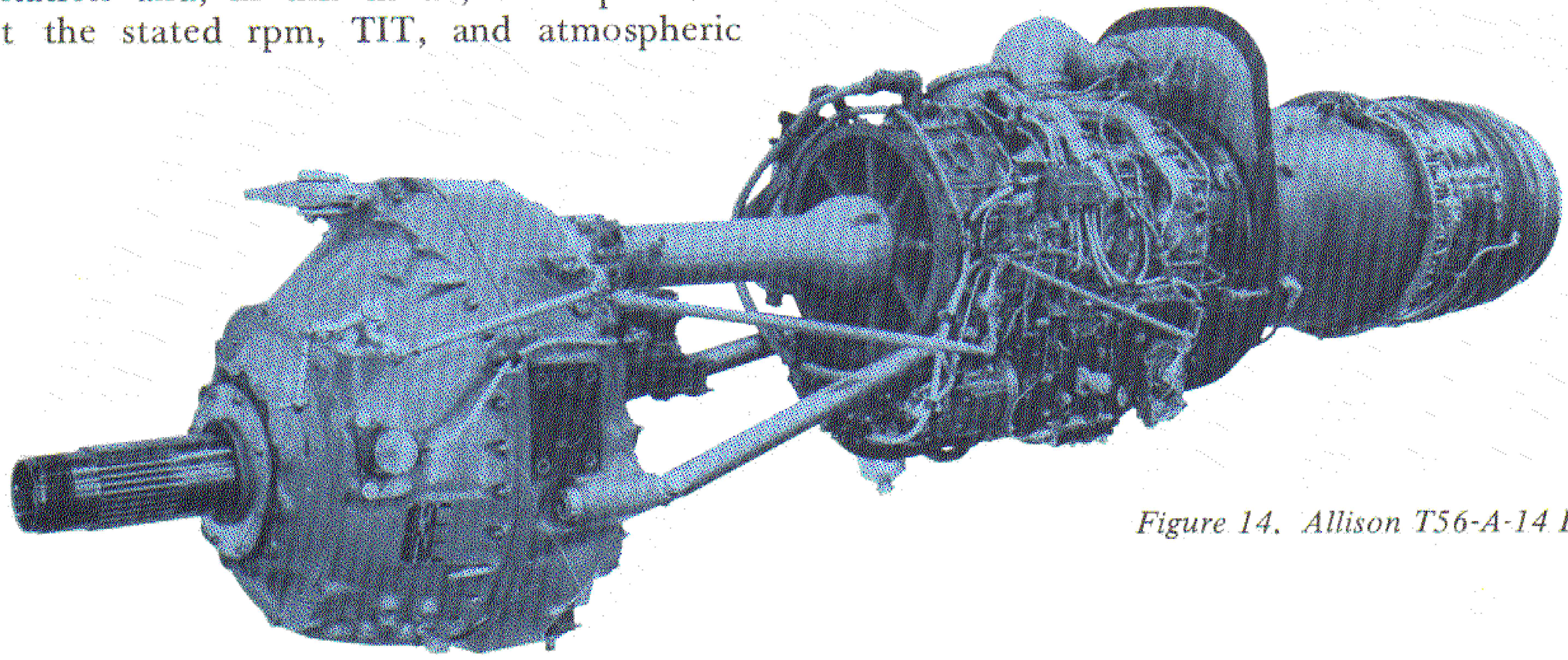


Figure 14. Allison T56-A-14 Engine

Table 1. T56-A-10W and -14 Static Rated Performance Specification Comparison

POWER CONDITION	T56-A-10W		T56-A-14	
	SHP	TIT	SHP	TIT
TAKEOFF	4200 (WET)	971°C	4591	1077°C
MILITARY	3755	971°C	4368	1049°C
NORMAL	3443	932°C	4061	1010°C

This article on P-3 engines, then, is addressed to both engines. Generally, it describes and defines the -14 engine, with explanations of the differences between the two engines, where applicable. Table 1 gives the static-rated performance specifications for both engines, while Table 2 gives their actual performance characteristics. Note that, contingent upon atmospheric conditions, actual performance can exceed specified values.

In this article we will discuss two models (T56A-10W and T56A-14) of the Allison T56 turboprop engine and their manual and automatic controls. We will explain the features and procedures most important to this closely integrated part of the Orion power plant. With such a broad scope, it will not be possible to provide the sort of accurate detailed descriptions suitable for the engine specialist, and the reader is forewarned that, in order to show the scheme of the operation clearly, we have greatly simplified the schematic illustrations and foreshortened many descriptions.

We have deliberately avoided citing specific measurements, adjustments, maintenance procedures, and operating procedures wherever it is possible to do so without obscuring the logic of the design and the operational function. In some cases, it is not possible to impart information and ignore tolerances or the sequence of operational steps, and in such cases the information reflects that given in the current Navy documents at the time of writing. Of course, we cannot forecast modifications which may be made hereafter, nor can we foresee the procedural changes that modifications or the necessity for non-standard operation may dictate. Readers are urged *not* to act on any of the information herein without first consulting the current official Navy document.

Table 2. T56-A-10W and -14 Engine Operating Limits Comparison

POWER CONDITION	T56-A-10W		T56-A-14	
	SHP	TIT	SHP	TIT
TAKEOFF	4300 - 4500 (3 SECONDS)	977°C (5 MINUTES MAX., DRY; 3 MINUTES MAX., WET)	4600 (AIRCRAFT LIMITING, 5 MINUTES) —— 5300 (ENGINE LIMITING, 3 SECONDS)	1083°C (5 MINUTES, MAX.)
MILITARY	3950 - 4300 (30 MINUTES) —— 4300 - 4500 (3 SECONDS)	977°C (30 MINUTES)	4600 (30 MINUTES)	1049°C (30 MINUTES)
NORMAL/ MAXIMUM CRUISE	3950 (CONTINUOUS OPERATION)	932°C	4600 (CONTINUOUS OPERATION)	1010°C
	DURING GROUND OR AIR STARTS WHEN THE ENGINE POWER SECTION OIL TEMPERATURE IS BELOW 0°C, LEAVE THE POWER LEVERS AT THE START (MINIMUM TORQUE) POSITION; WITH OIL TEMPERATURE BETWEEN 0° AND 40°C, POWER LEVERS MAY BE SET TO 1000 HP MAXIMUM DURING WARMUP.			

POWER PLANT DESCRIPTION

In the past the term "power plant", when referenced to propeller-driven aircraft, meant a reciprocating engine upon which was mounted a suitable propeller, these two principal components being – apart from suitable blade angle changes – largely independent of each other. This is not the case with the turboprop of today since, while the reciprocating engine uses separate rpm and throttle levers, the turboprop must necessarily combine both functions in a single control and it is well to understand this important fact thoroughly. The distinguishing characteristics of the single-spool, axial-flow Allison T56 engine and Hamilton Standard 54H60-77 propeller combination are:

(a) Arrangement of engine with a drive shaft and separate reduction gear permitting high ram recovery air intake and providing a direct drive accessory section.

(b) Automatic propeller blade pitch adjustment that varies engine load to maintain speed constant at 13,820 rpm during all takeoff, climbout, cruise, and descent operations.

(c) Automatic fuel trimming control which electronically refines the basic hydromechanical fuel metering and makes practicable the simple single lever power control.

(d) Coordinated propeller-engine power lever control of thrust output; the taxi-range thrust is controlled by movement of the power lever, and flight-range thrust is controlled by turbine inlet temperature.

(e) Safety devices to enhance airplane handling control and to preserve structural integrity in case of a sudden engine failure in flight. These include a negative torque system (NTS), an automatic engine safety coupling (Decoupler), a conventional low-pitch stop, and a variable low-pitch stop (Beta followup). Other safety devices include auto-feathering, ability to feather electrically or mechanically, propeller blade pitch lock, a propeller brake, and engine fuel governor overspeed control.

T56 ENGINE DEVELOPMENT

The Allison T56 engine has quite a long family ancestry beginning with the military T38 and T40 turboprop engines and continuing through eight different dash numbers of the T56 engines. When the engine was first put into military service it was apparent that certain changes would have to be made for the different aircraft installations, none of them fortunately being of major character. The compressor and turbine characteristics were, however, unchanged so the constant turbine speed of 13,820 rpm was retained.

Principally there was the problem of high noise levels on the ground, since the original military engine propeller had a much higher rotational speed of 1106 rpm for takeoff and 1080 rpm – actually some 97 percent – for ground idle. The original reduction gear ratio in the T56 engine was 12.5:1 whereas the present series II and series III engines use 13.54:1, thus giving a takeoff value of 1020 propeller rpm and a ground idle of approximately 992 rpm. This represented an improvement although the ground idle noise level was still not considered satisfactory for continuous use on the flight line. Allison then went to work to define a very low ground idle position consistent with minimum stable running and satisfactory operation speeds. This turned out to be 10,000 rpm, now known as "low ground idle," and resulted in a propeller shaft speed of 738 rpm. Normal ground idle, or "high ground idle" as it is now more frequently called, of approximately 13,450 rpm was retained and is used for fast taxiing or engine run-up purposes, in fact for anything requiring more thrust or more rpm.

ENGINE DESCRIPTION

Reference to the center spread showing a cutaway view of the engine reveals that it is made up of three main assemblies:

(a) Propeller reduction gear and torquemeter (engine drive shaft).

(b) Engine compressor together with engine fuel, oil, and ignition accessories.

(c) Turbine section including the combustion section, turbine, and expansion area.

This latter assembly is often known as the "hot section." The engine configuration is unique and very flexible in that it can be obtained with the gearbox offset up for a high wing airplane or offset down as in the case of the Orion installation for better layout in a low wing configuration. The propeller reduction gearing is in two stages, the first

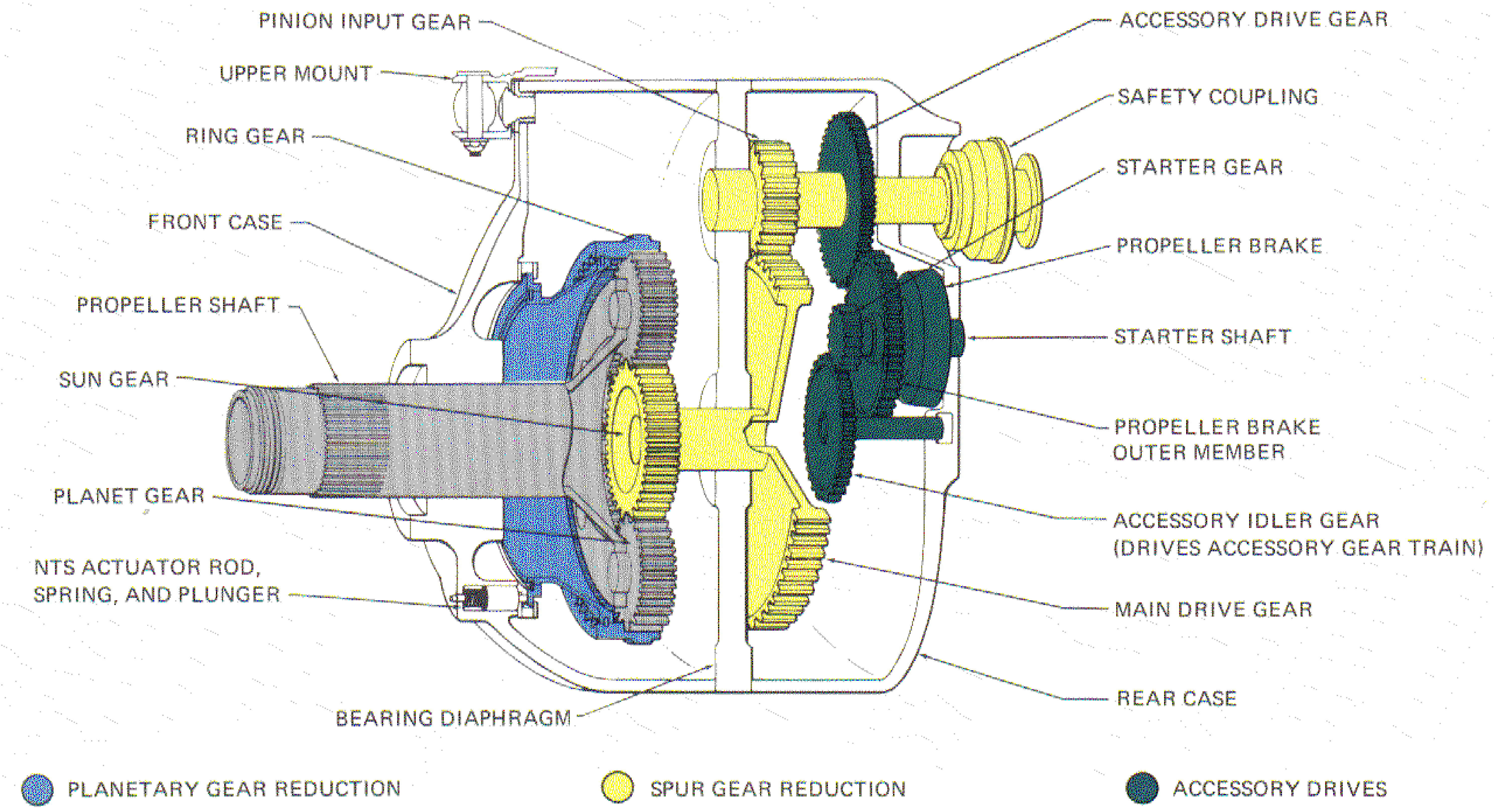
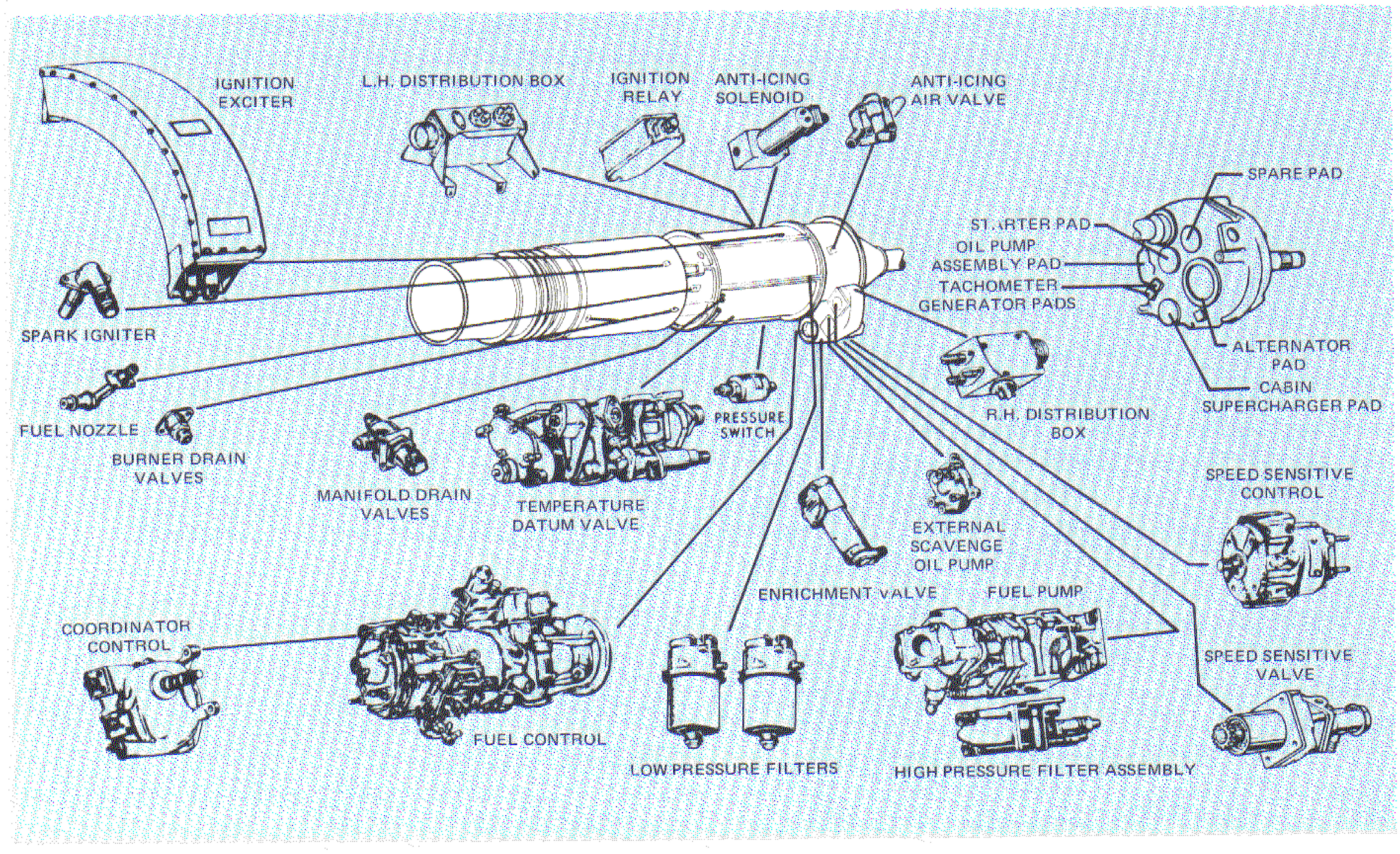


Figure 15. Engine Reduction Gear Schematic

Figure 16. Engine Accessories Location



being a spur-gear step down from the engine and the second a planetary gearset. Several of the engine safety devices are located in the reduction gear assembly. The torquemeter assembly is comprised of an inner torque shaft (engine drive shaft), a concentric outer shaft (torquemeter reference shaft), the torquemeter pickup located in the forward end of the assembly, and a housing. The torque shaft assembly transmits torque from the power section to the reduction gear assembly, and the assembly measures the torque produced by the power section by electrically detecting the torsional deflection of the inner shaft with respect to the outer shaft. The torquemeter assembly is the primary supporting structure between the power section and the reduction gear assembly. Below the shaft drive connection on the rear face of the gearbox are mounted the engine driven accessories, such as the pneumatic starter, cabin supercharger, AC generator, and the tachometer generator. The reduction gear has its own dry sump oil system fed from the main engine oil tank.

Inlet struts and guide vanes in the compressor air inlet are hollow and are anti-iced with air bled from the compressor. The torquemeter shroud and drive shaft housing are similarly protected from icing. The compressor has 14 stages and operates at a compression ratio of 9.25:1 in the -10 engine and 9.64:1 in the -14 engine. Annular bleed ports together with acceleration bleed valves are provided at the 5th and 10th compressor stages for unloading in the surge range, which is roughly 7,000 to 12,500 rpm. The acceleration bleed valves are an alternative method to the use of variable angle inlet vanes for compressor surge control purposes, and they are open at the 10,000 rpm (low ground idle) position. At the 14th stage, bleed ports are provided for hot air to be used for airframe anti-icing and other purposes. Below the compressor case is an engine accessory drive section carrying the fuel control, fuel pumps, filters, oil pump, speed sensitive control, etc. Aft of this is the coordinator control which is mechanically linked to the power lever and emergency handle.

The air from the compressor enters the diffuser section which distributes it equally to the six burner cans in the combustion section, which is of the "canannular" type. A large proportion of the air flows outside of the burner cans as secondary air and enters through slots to control the flame pattern. Each burner can is fed fuel by a nozzle and two of the cans have ignitors, the flame being carried during starting to the other four cans by crossover tubes. Moving aft, the hot gases from the burner cans combine in an annular area and feed between stator vanes into the four-stage turbine assembly. It is at this position that the 18 dual thermocouples are mounted to measure TIT. This provides much more accurate control than when the exhaust gas temperatures are measured, as in some other engines.

A relatively small amount of the energy from the last stage of the turbine leaves the tailpipe in the form of jet thrust. Actually the 4910 ESHP (equivalent shaft horsepower) of the T56A-14 engine is made up of 4591 SHP (shaft horsepower) plus 797 pounds jet thrust. The jet thrust is divided by 2.5 to approximate ESHP so that 319 HP is added to the propeller shaft power to obtain the take-off power rating. The reason for using four turbine stages – unlike a turbo-jet engine which normally uses fewer – is that the maximum energy is extracted as shaft power for the propeller, rather than in the form of jet thrust. This is illustrated in Figure 12 which shows typical power, temperature, velocity and pressure relationships. In general terms some 10 percent of the total thrust comes from the jet exhaust nozzle at the cruise condition.

Engine starting is accomplished by a pneumatic starter which in reality is a small high-speed air turbine capable of very high power output. It is necessary to extend the cranking range of the starter to an engine speed of 8,000 rpm to avoid "hot starts" and to ensure positive engine acceleration. Several things happen automatically in the sequence of starting, including turning on fuel and ignition, controlling fuel pump output, and operating the acceleration bleed valves. Most of these functions are controlled by the speed-sensitive control unit. The igniter plugs are energized during the starting sequence only and combustion is self-propagating after engine conditions stabilize.

The engine can, of course, be air started by windmilling after an in-flight engine shutdown. A propeller brake is provided to eliminate windmilling after feathering in flight and also to prevent engine rotation in a strong wind on the ground. It also assists in slowing the engine down at shutdown. The brake is mounted in the accessory section of the propeller reduction gearbox just behind the starter pad and is operated automatically by engine oil pressure. The propeller can be pulled by hand against the brake if necessary for maintenance purposes, but in one direction only since it prevents reverse rotation.

POWER PLANT INSTALLATION

Review of the engine would not be complete without briefly considering how it is installed in the airplane. The choice of the low-wing airplane configuration dictated, for propeller tip clearance and landing gear installation reasons, that the engine centerline be higher than the wing. The reduction gearbox on such an installation must necessarily be offset downwards to obtain, as nearly as possible, alignment of the propeller thrust line with the chord line of the wing. This configuration in turn, established the over-wing arrangement of the exhaust tailpipe as well as the high air intake position. After consideration of the possible adverse drag effect of short tailpipes it was decided that they should extend to the trailing edge of the wing.

Whereas in earlier reciprocating engine intake design practice, ram pressure recovery values of 75 to 85 percent were acceptable, the design objective in the case of the Orion was 98 percent in order to meet the specification requirements for speed and range. Careful design was necessary to achieve this together with a good ram pressure recovery ratio, the latter being an important measure of the overall engine inlet-outlet efficiency. In practice the design objectives have been exceeded and more than 100 percent total pressure recovery ratio is available at the cruise condition due to the pumping action of the propeller coupled with the suck-down effect of the exhaust ejector at the engine outlet. In practical terms this amounts to an increase in available power under cruise conditions of approximately 3 percent and for takeoff, some 5 percent increase.

The exhaust ejector consists of a bell-mouth section which induces air into the tailpipe, and forward of this are the anti-swirl vanes which straighten the engine exhaust gas thus increasing the axial component of jet thrust. Cooling airflow is provided around the tailpipe, being introduced through an NACA flush-type inlet on the top of the tailpipe forward door. In later P-3's (starting with the 52nd C-series airplane), additional cooling is provided by compressor 10th stage bleed air which is dumped into the tailpipe zone when the engine is operating below 10,000 rpm. Cooling air for the turbine zone is provided through flow distribution ducts from a similar flush inlet which also serves as a secondary cooling air source for the ejector. The upper wing surface is cooled by ram air flow from a system with inlets in the lower wing surface just outboard of the nacelle.

The propeller spinner contour, which is a modified conical form, was chosen because of its compatibility with the critical air intake flow requirements, and a labyrinth seal is used to prevent excessive propeller cooling air spillage between the fixed and rotating sections which would upset the boundary layer flow. The cooling air from the propeller passes into the accessory zone under normal flight conditions and, when propeller feathering occurs, is shut off automatically by a mechanical closure system. The boundary layer lip on the engine air intake is designed for optimum ram recovery even at the higher angles of attack common to takeoff and initial climbout conditions. Both the intake lip and the top of the intake duct are anti-iced by air bled from the 14th stage of the compressor. The tailpipe diameter of 19 inches was finally arrived at after a careful study to determine the optimum arrangement for the engine versus the lowest drag penalty from the aerodynamic viewpoint.

Several miscellaneous points are of interest in the power plant installation. For example, the engine ground running condition requires a propeller blade angle which is negative at the propeller tips in order to offset the static thrust of the jet exhaust. This results in very low airflow over the oil cooler so an airflow inducer rake, or augmentor, is fitted on the aft side which uses bleed air exhausted through nozzles to draw cooling air over the matrix, thus providing adequate cooling irrespective of the airplane's orientation with respect to the wind. Another interesting point is the use of an oil-to-oil accessory heat exchanger in the engine oil cooler outlet line for cooling the cabin supercharger oil. This provides accessory cooling without the complexity and drag penalty which would be associated with a separate cooler mounted in the airstream while, at the same time, preserving the individual identity of main engine and accessory lubrication systems.

The most notable aspect of the overall power plant installation is that the engine provides more power when installed than when running at 100 percent performance on the manufacturer's dynamometer. The attention paid to the details of propeller and induction system design and exhaust system configuration has paid off in the dividends of power available to more than meet performance guarantees.

ENGINE OIL SYSTEM

The T56 engine includes a completely self-contained oil system, shown schematically in Figure 17, for lubrication of the power section and the reduction gear. The engine oil system includes a supply tank, supply lines to the two engine units, individual internal oil systems in the power section and in the reduction gear, a fuel heater (oil-to-fuel heat exchanger), an oil cooler (air-to-oil heat exchanger), return lines from the two engine units to the tank, and system status (quantity, temperature, and pressure) transmitters and sensors. System status indicators and warning lights, activated by the transmitters and sensors, are located on instrument and control panels in the flight station. The engine oil system for either inboard engine includes an accessory cabin air compressor oil cooler (oil-to-oil heat exchanger).

Oil Supply Tank

The stainless steel tank, installed in the engine top cowl panel, has a total volume capacity of 15.75 gallons, although it contains only 8.65 gallons of usable oil; the remaining volume is taken up by 1.4 gallons of unusable oil and 5.7 gallons of foaming space. It is designed with a flexible internal pickup tube to ensure oil delivery to the engine regardless of airplane attitude. The tank is pressurized to 4.5 psig above ambient from a pressurizing valve which also serves as an inlet fitting for the vent line from the power section air-oil separator breather to ensure a positive, continuous supply of oil for the engine at all operating altitudes. The tank has a deaeration baffle and the oil return fitting has a deaeration nozzle to defoam the return oil flow. A normally-open, electrically-closed, oil shutoff valve in the sump at the bottom of the tank can be closed to stop flow of oil from the tank in case of emergency. The valve is actuated by a signal which results from emergency handle actuation.

The supply tank contains an oil quantity transmitter which provides tank oil-fill level signals to one side of a dual quantity gage – each gage serves two engines – located on the right outboard overhead panel. The gage, calibrated from 0 to 8 (full-scale reading of approximately 9) U.S. gallons, indicates the quantity of usable oil in the tank. In addition, the tank has a direct-viewing, oil-level indicator at the filler cap. The tank sump includes fittings for an oil-temperature sensing bulb and a normally-open temperature switch. The bulb pro-

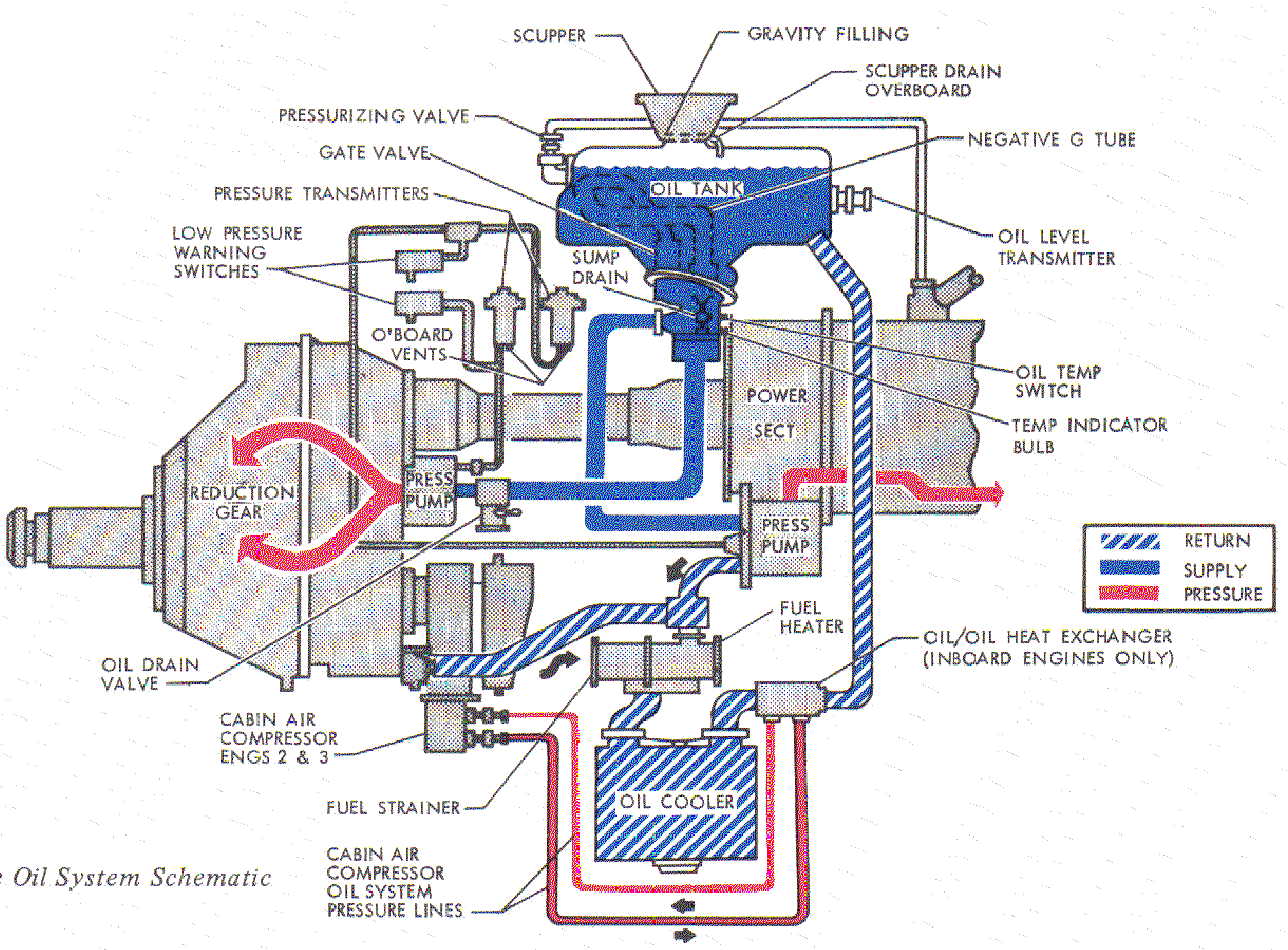


Figure 17. Engine Oil System Schematic

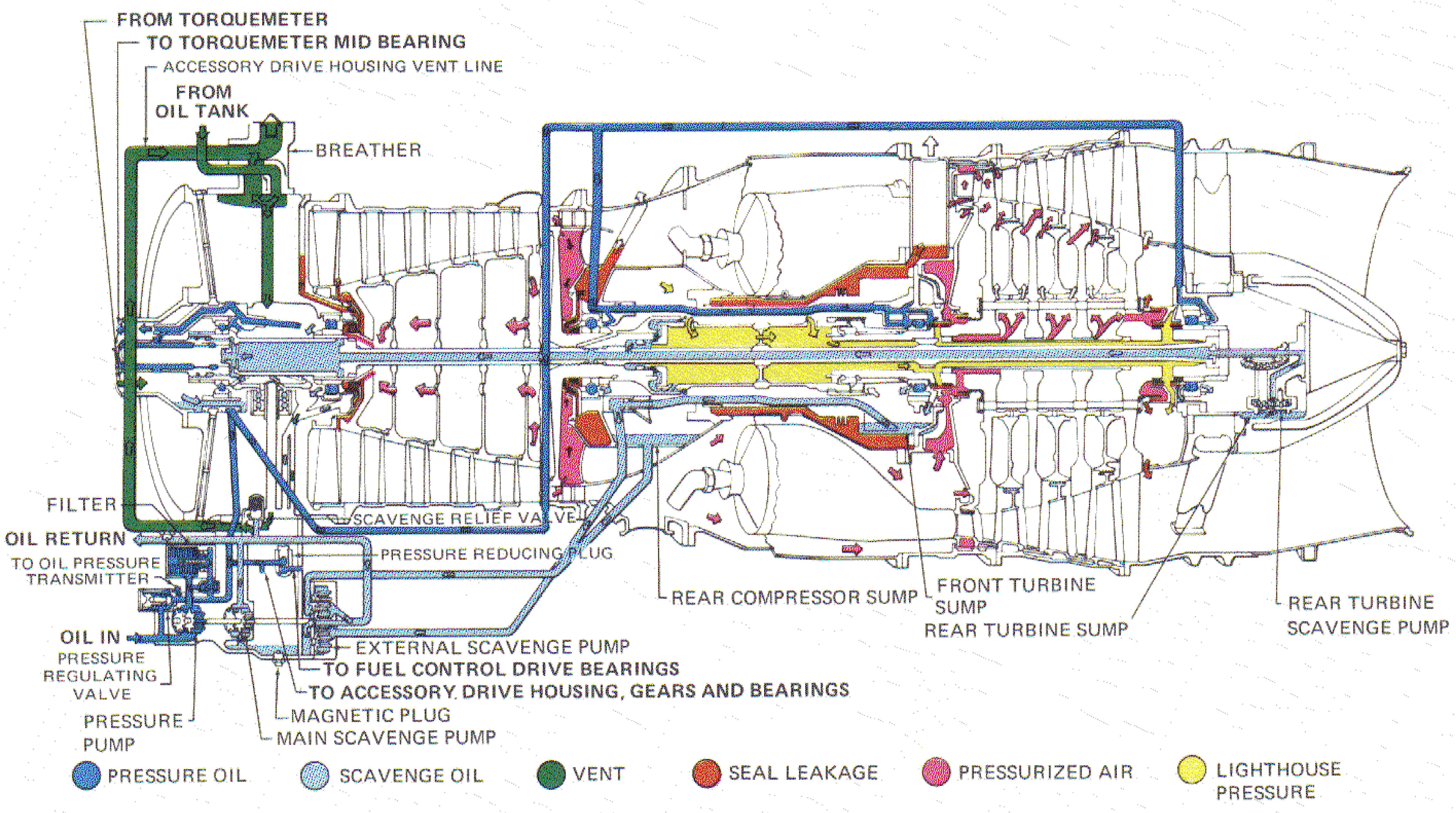
vides an electrical signal to a dial-type temperature indicator, calibrated from -50°C to 150°C, located on the right outboard overhead panel. When oil temperature reaches approximately 100°C (212°F), the switch closes to provide a signal that illuminates an OIL HOT warning light located on the center instrument panel.

Power Section Oil System

The power section incorporates an independent, dry-sump oil system which includes a combination main pressure pump and scavenge pump assembly, a high-pressure filter assembly, a pressure-operated check valve, a pressure transmitter and a pressure switch, separate independent scavenge pumps, a magnetic-chip detector drain plug, a scavenge relief valve, an air-oil separator breather, and the necessary plumbing lines and electrical circuitry. The fluid portion of the T56-A-14 power section oil system is shown schematically in Figure 18. The T56-A-10W power section oil system is schematically identical except in the scavenge pump arrangement.

Oil from the supply tank goes directly into the main pressure pump mounted on the front of the accessory drive assembly housing. The gear-type main pump, during normal operation, pumps more oil to the high-pressure filter than is required for power section lubrication. The pump contains a pressure-regulating valve which senses pressure at the filter outlet and bypasses the excess pump output back to the pump inlet port. The pump output is routed through the 170-micron, high-pressure filter which contains a pressure drop-sensitive filter bypass valve that opens to route pump discharge flow around the filter to ensure power section lubrication in the event the filter becomes clogged or obstructed. The filter bypass valve also prevents excessive back pressure at the pump discharge. During normal operation at 100 percent engine rpm, system oil pressure is maintained between 50 and 75 psi in the T56-A-10W engine power section, and between 50 and 60 psi in the T56-A-14 unit. The pressure-operated check valve, located just down-stream from the filter, opens at 6 to 10 psi to permit system oil flow, and closes upon engine shutdown to prevent oil seepage into the power section.

Figure 18. Engine Power Section Oil System Schematic

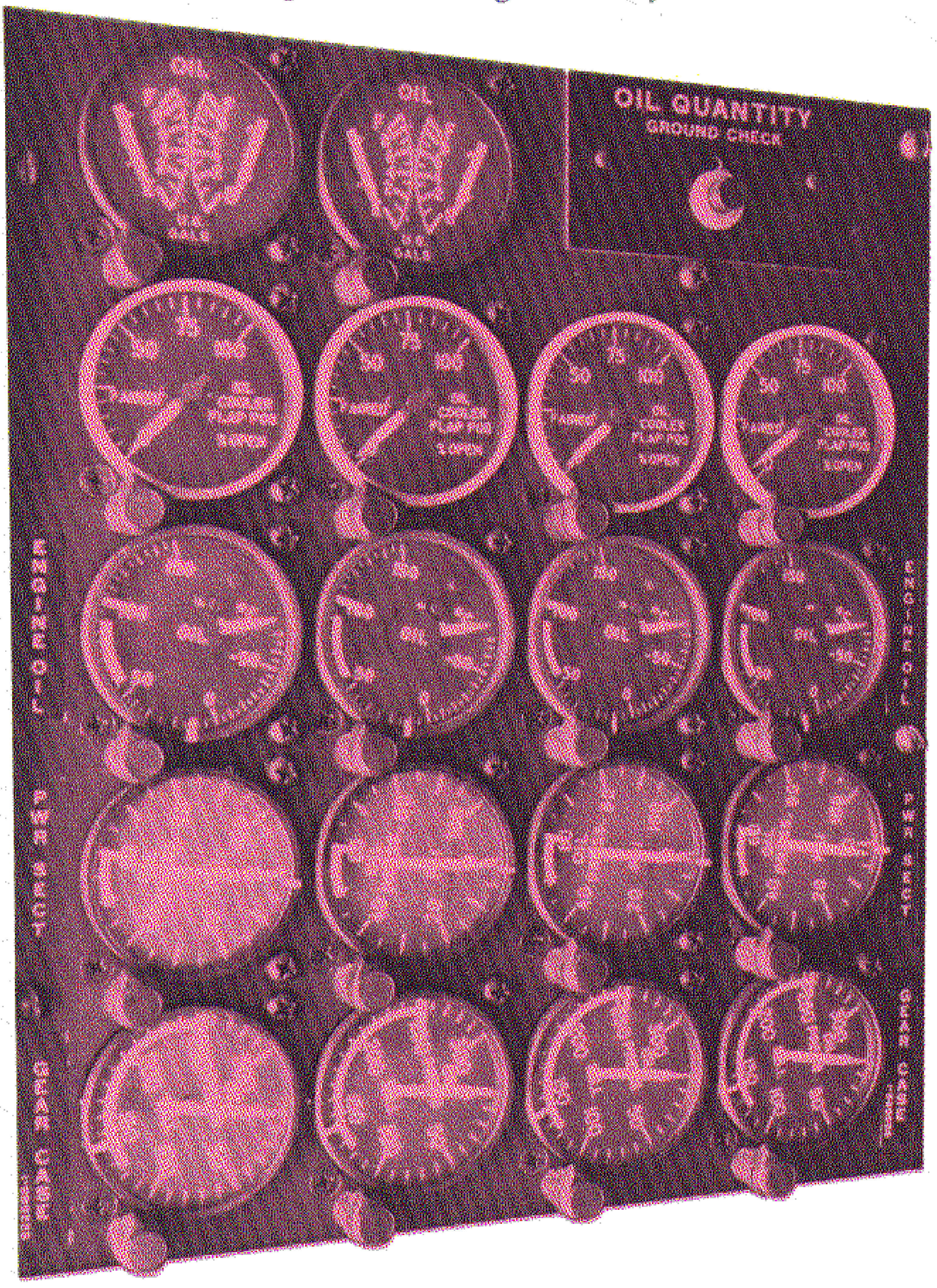


From the high-pressure filter, oil is directed to the various power section elements requiring lubrication, and to a pressure switch and a pressure transmitter. The front extension shaft bearing, front and rear compressor bearings, front and rear turbine bearings, fuel control bearings, and the main fuel pump drive gear and bearings in the T56-A-10W and T56-A-14 engines are all pressure lubricated, as are the speed-sensitive valve drive gear and bearings for the -14 unit. All other power section components are splash or spray lubricated.

The pressure transmitter senses system oil pressure and transmits a corresponding signal to activate a 0-to-100 psi, dial-type pressure gage located on the right outboard overhead panel to provide visual indications of system operating pressure. The normally-open pressure switch closes when system pressure falls below 40 psi (±5 psi) to energize an OIL PRESS warning light (common to the power section system and the reduction gear system) located on the center instrument panel to provide visual warning of the low-pressure situation.

An air-oil separator breather is installed on top of the air inlet housing to vent the forward portion of the power section. The front compressor bearing and the accessory drive assembly are vented direct-

Figure 19a. Engine Oil System Instruments



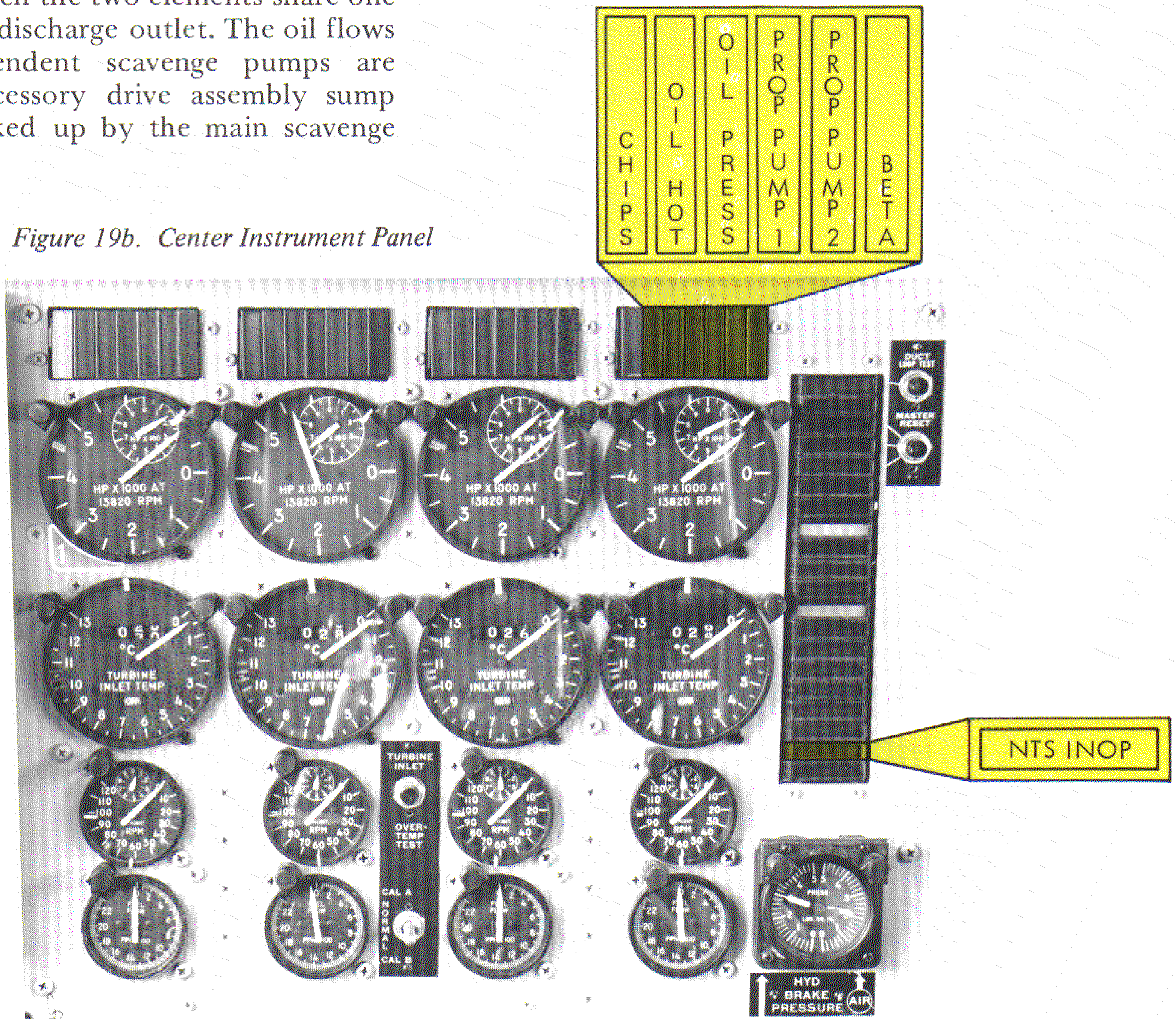
ly to the breather. The oil supply tank is vented through the pressurization valve and the vent line connected to the breather. Free oil collected by the breather is drained back into the accessory drive assembly sump. The rear compressor bearing and front turbine bearing sumps are vented through the turbine coupling and turbine rotor shafts to the rear turbine bearing oil seal vent outlet on top of the turbine case; the rear turbine bearing sump is also vented through the same vent fitting.

In addition to the scavenge pump element in the main oil pump assembly which scavenges oil from the accessory drive assembly, there are three independent gear-type scavenge pumps in the T56-A-10W engine power section: one is installed in the compressor diffuser housing to scavenge oil from the rear compressor bearing, and one each to scavenge oil from the front and rear turbine bearings. In the T56-A-14 engine power section, the scavenge pump arrangement is similar except that oil is scavenged from the rear compressor bearing and the front turbine bearing by a single dual-element pump in which the two elements share one gear and a common discharge outlet. The oil flows from these independent scavenge pumps are returned to the accessory drive assembly sump where they are picked up by the main scavenge pump and returned, through the fuel heater and oil cooler (and for inboard engine installations, through an accessory oil cooler), to the oil supply tank. A magnetic drain plug is installed in the accessory drive assembly sump to detect and collect particles of magnetic material in the scavenge oil flow. The drain plug, when magnetic particles are present, provides a signal that energizes the CHIPS warning light (common to the power section system and the reduction gear system) on the center instrument panel. A scavenge relief valve in the output line relieves excessive scavenge pump pressure back into the accessory drive assembly.

Reduction Gear Oil System

The reduction gear, like the power section, incorporates an independent, dry-sump oil system which includes a main pressure pump and high-pressure filter assembly, a pressure-relief valve, a pressure transmitter and a pressure switch, two separate and independent scavenge pumps, a scavenge relief valve, a magnetic-chip detector drain plug, and the necessary plumbing lines and electrical circuitry.

Figure 19b. Center Instrument Panel



The fluid portion of the reduction gear oil system is shown schematically in Figure 20.

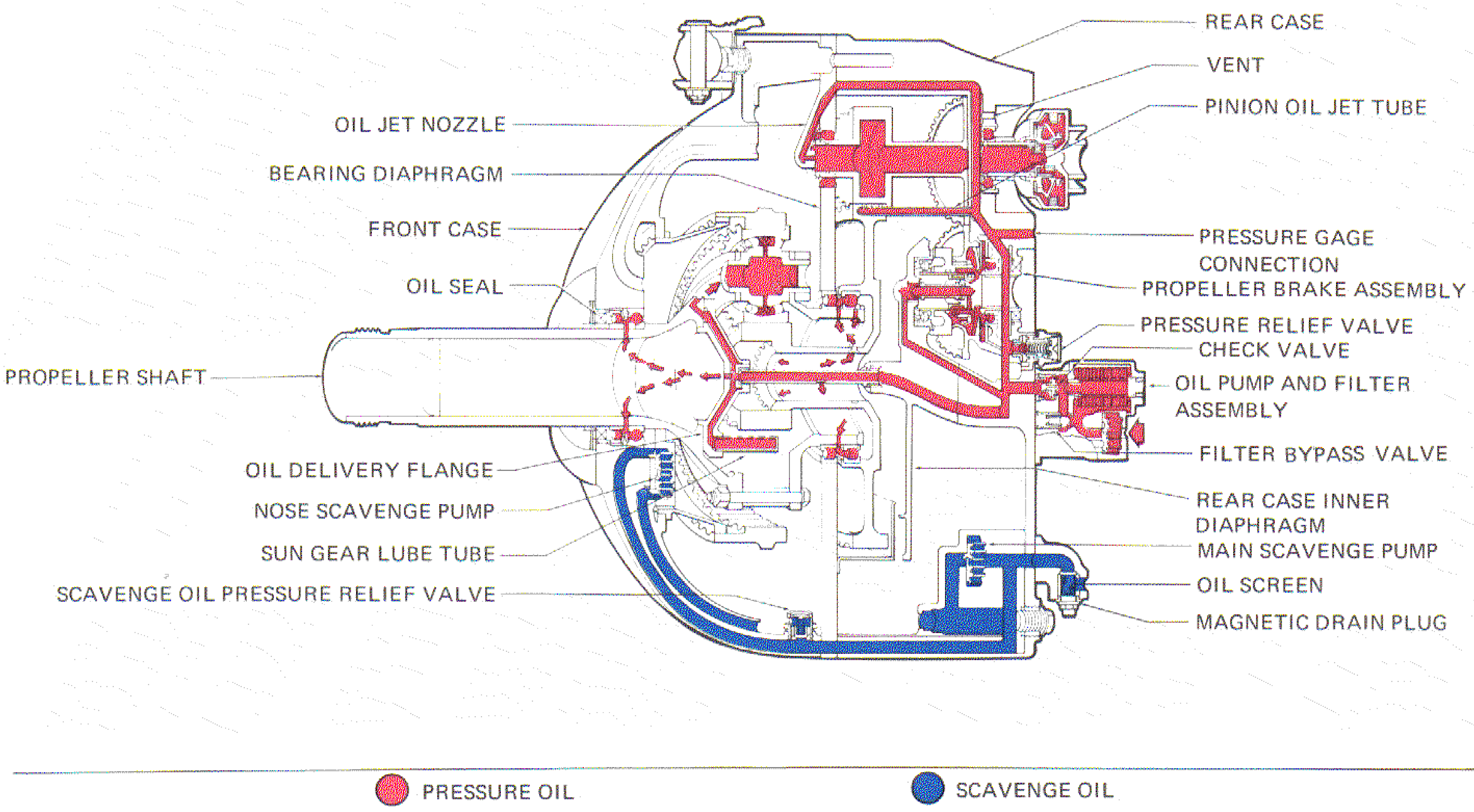
Oil from the supply tank goes directly into the inlet of the pressure pump and filter assembly mounted on the rear face of the reduction gear housing. Output of the gear-type pump is routed directly to the high-pressure filter and to a pressure drop-sensitive filter bypass valve that opens to route pump discharge flow around the filter to ensure reduction gear component lubrication in the event the filter becomes clogged or obstructed. The pump, during normal operation at 100 percent engine rpm, pumps more oil through the high-pressure filter than is required for reduction gear lubrication. A pressure-operated relief valve located just downstream from the filter opens to limit system pressure to 250 psi in the T56-A-10W reduction gear and to 260 psi in the T56-A-14 unit. Excess pressure is relieved back into the reduction gear rear case. The reduction gear oil system is vented through a fitting on the reduction gear case.

From the high-pressure filter, oil is directed to the various reduction gear and accessory elements requiring lubrication, and to a pressure switch and pressure transmitter. The input pinion shaft bearings, safety coupling mechanism, pinion and main drive gear tooth faces, propeller brake assembly, main drive gear and sun gear bearings, propeller shaft bearings, and all parts of the planetary gear system are pressure lubricated. Other components within the reduction gear case are splash and spray lubricated.

The pressure transmitter senses system oil pressure and transmits a corresponding signal to activate a 0-to-300 psi, dial-type pressure gage located on the right outboard overhead panel to provide visual indications of system operating pressure. The normally-open pressure switch closes when system pressure falls below 130 psi (±5 psi) to energize an OIL PRESS warning light (common to the reduction gear system and the power section system) located on the center instrument panel to provide visual warning of the low-pressure situation.

Oil is scavenged from the reduction gear case by the two gear-type scavenge pumps, one in each case segment. An internal scavenge relief valve opens to relieve excess scavenge pump discharge pressure back into the front case. A magnetic drain plug is installed in the outlet fitting (common to both pumps) to collect and detect particles of magnetic material in the scavenge oil flow. The drain plug,

Figure 20. Reduction Gear Oil System Schematic



when magnetic material is collected, provides a signal that illuminates a CHIPS warning light (common to the reduction gear system and the power section system) on the center instrument panel. Scavenge pump discharge flows are directed past the magnetic drain plug and through a common line to the fuel heater inlet where reduction gear and power section return flows are combined.

Fuel Heater

The fuel heater, an oil-to-fuel heat exchanger which is actually a component of the engine fuel system, provides the means for transferring waste heat from the power section and reduction gear oil return flows into the incoming fuel to prevent crystals of ice and water droplets from entering the fuel system components, and to improve fuel flow characteristics by lowering fuel viscosity during extreme ambient low-temperature conditions. The oil return flows are combined and enter the fuel heater through a dual-inlet fitting on the heater. A thermostatically-controlled valve in the heater senses fuel temperature and, when fuel heating is not required, operates to bypass return oil flow around the heater and on to the oil cooler. Also, the oil bypass valve is sensitive to oil pressure and operates at 30 psi inlet pressure to protect the heater by routing the oil flow around the heater.

Oil Cooler

The oil cooler, an oil-to-air heat exchanger mounted in the engine lower cowl area, is used to remove excess heat from the oil return flow from the fuel heater. It utilizes a flow of air from ambient atmosphere to maintain engine oil operating temperature between 60°C (140°F) and 90°C (194°F), as sensed by the oil-temperature sensing bulb in the tank sump. Air flow quantity is regulated by a manually-controlled, electric motor-actuated cooler flap. A three-position (OPEN, CLOSED, OFF) switch on the right inboard overhead panel controls flap actuator motor operation, and a 0-to-100 percent (flap opening), dial-type flap position indicator is located on the right outboard overhead panel.

During stationary ground operations, or low-speed taxiing, atmospheric air flow through the unit may be insufficient for adequate cooling. In such cases, increased air flow is induced by action of the jet-type augmentor which utilizes a flow of bleed air from the compressor 14th stage.

Accessory Oil Cooler

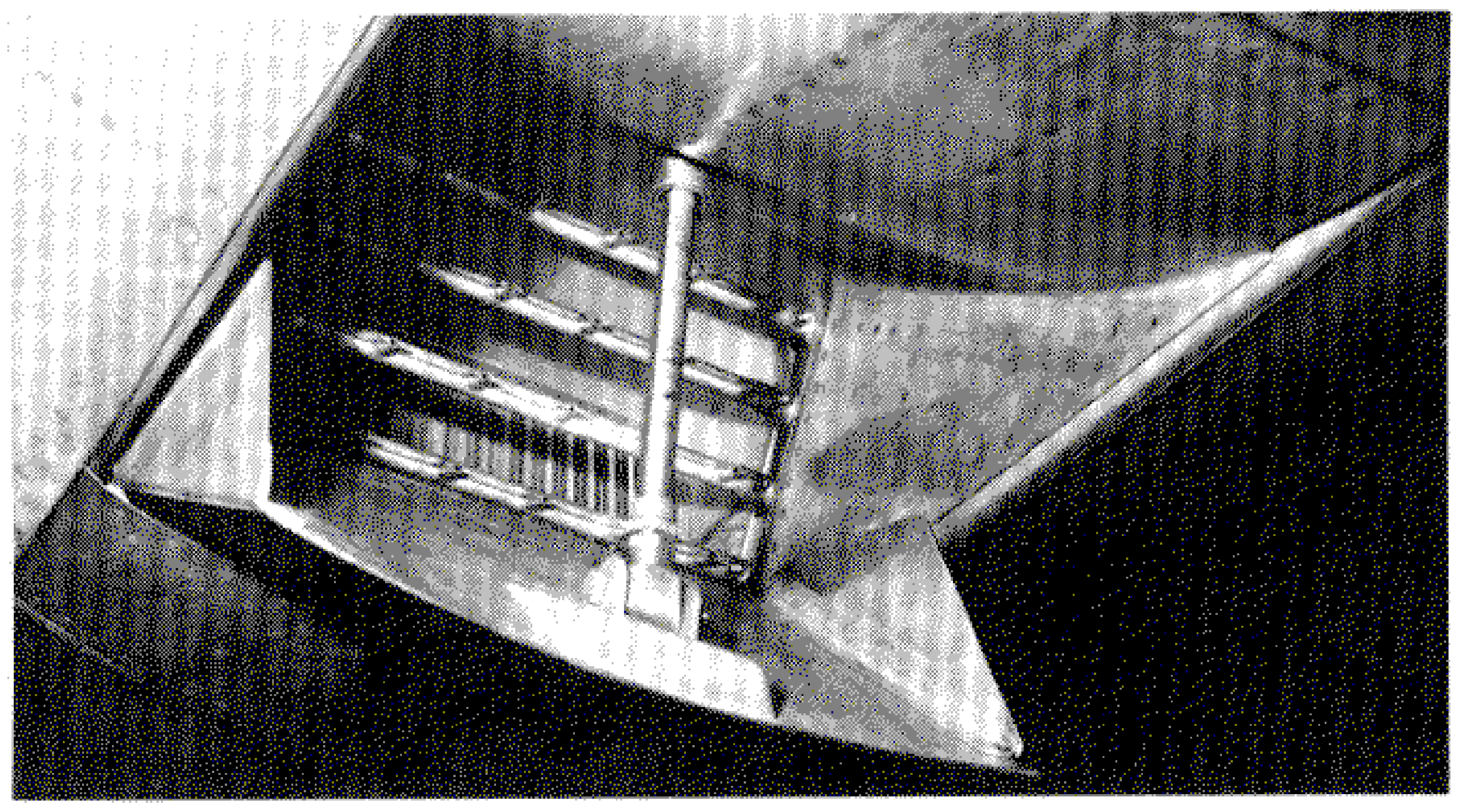
The accessory oil cooler, an oil-to-oil heat exchanger, is used to remove excess heat from the lubricating oil for the cabin air compressor used on inboard engine installations only. This unit utilizes the cooled oil flow from the oil cooler as the cooling medium. The accessory oil cooler does not contain any bypass valves so that the total engine oil return flow is routed through the accessory oil cooler.

ENGINE FUEL SYSTEM

The T56 engine, as used on the P-3 Orion, includes a fuel system (see Figure 22) that is completely self-contained within the engine installation, except for the fuel supply interface with the airplane fuel system and the control interface with the flight station. The integral engine fuel system contains all the elements necessary for pressurizing, filtering, and heating the fuel supplied from the airplane system, and for controlling its flow (at rates up to about 2500 pounds per hour) into the engine combustion chambers as required for engine power output in response to pilot commands (engine switches, power lever, and emergency handle actuation). The airplane fuel system, including the engine fuel system interface, is described in detail in ORION Service Digest, Issue 19.

This section describes the engine fuel system components, their functions in the various phases and modes of engine and airplane operation, and their interrelationship with components of other P-3 systems. This discussion is based on the schematic diagram shown in Figure 23 and other illustrative material presented, or referenced herein. By reference to the diagrams, we can quickly trace the fuel flow path from entrance into the fuel heater and strainer through the boost pump, low-pressure filters, secondary and primary

Figure 21. Jet-pump Type Engine Oil Cooling Augmentor



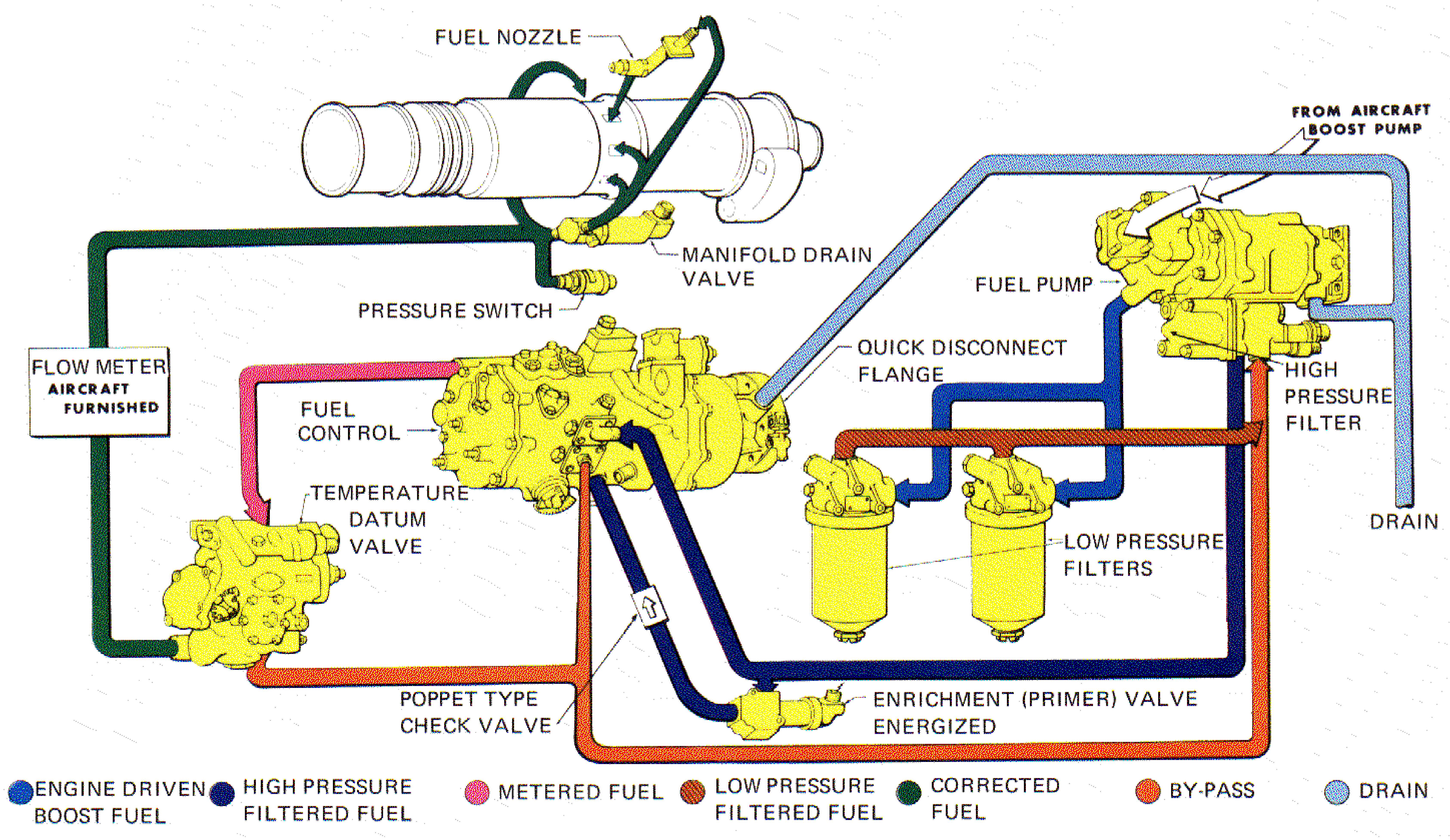


Figure 22. T56 Engine Fuel System Schematic

pressure pumps, paralleling valve, high-pressure filter, enrichment (primer) valve, fuel control, temperature datum valve, flowmeter, fuel manifold, and finally the fuel nozzles. Detailed description of the flow sequence and control actions is presented in the following paragraphs.

Although the engine coordinator, speed sensitive control, and thermocouples (TIT) are not specifically included in the engine fuel system, they are directly involved in fuel system operation and control as shown in Figure 24. The engine coordinator provides the primary means for relaying pilot commands (power lever movement and emergency handle actuation) to the fuel control. The speed sensitive unit controls certain functions within the fuel system, primarily the switching of fuel pump operational modes (series or parallel operation of the secondary and primary pressure pumps) as a function of engine rpm. The thermocouples provide the fuel control elements with TIT signals which are used to regulate fuel flow.

In addition to these related engine components, other parts of the engine installation play an important role in engine fuel system operation, primarily as engine protective devices. The thrust sensitive signal (TSS) system, which includes the auto-feather system, contains electrical circuitry that cuts off the engine fuel supply in case positive propeller thrust drops below 500 pounds during takeoff. The propeller pitch-lock mechanism actuates to limit engine speed to a safe rpm value in the unlikely event of simultaneous failures in the propeller governor and the overspeed limiting governor in the fuel control.

Coordinator

According to Webster, a coordinator is a person or thing (unit) that coordinates, and to coordinate means to bring into proper order or relationship. The coordinator used in P-3 engine installations is a unit that coordinates the actions of the propeller, temperature datum (TD) control, and fuel control to obtain the desired engine response to movement of the power lever or emergency handle by the pilot. The coordinator receives the pilot command inputs through separate power lever and emergency handle mechanical linkage systems. It produces mechanical outputs through other linkage systems to the fuel control and to the propeller linkage system. The coordinator also receives electrical signal inputs from, and returns electrical signal outputs to, the TD control. The coordinator is mounted on the aft end of the fuel control. It includes a discriminator assembly, a shaft position indicator and dial, a gear-driven potentiometer, and a cam-operated switch.

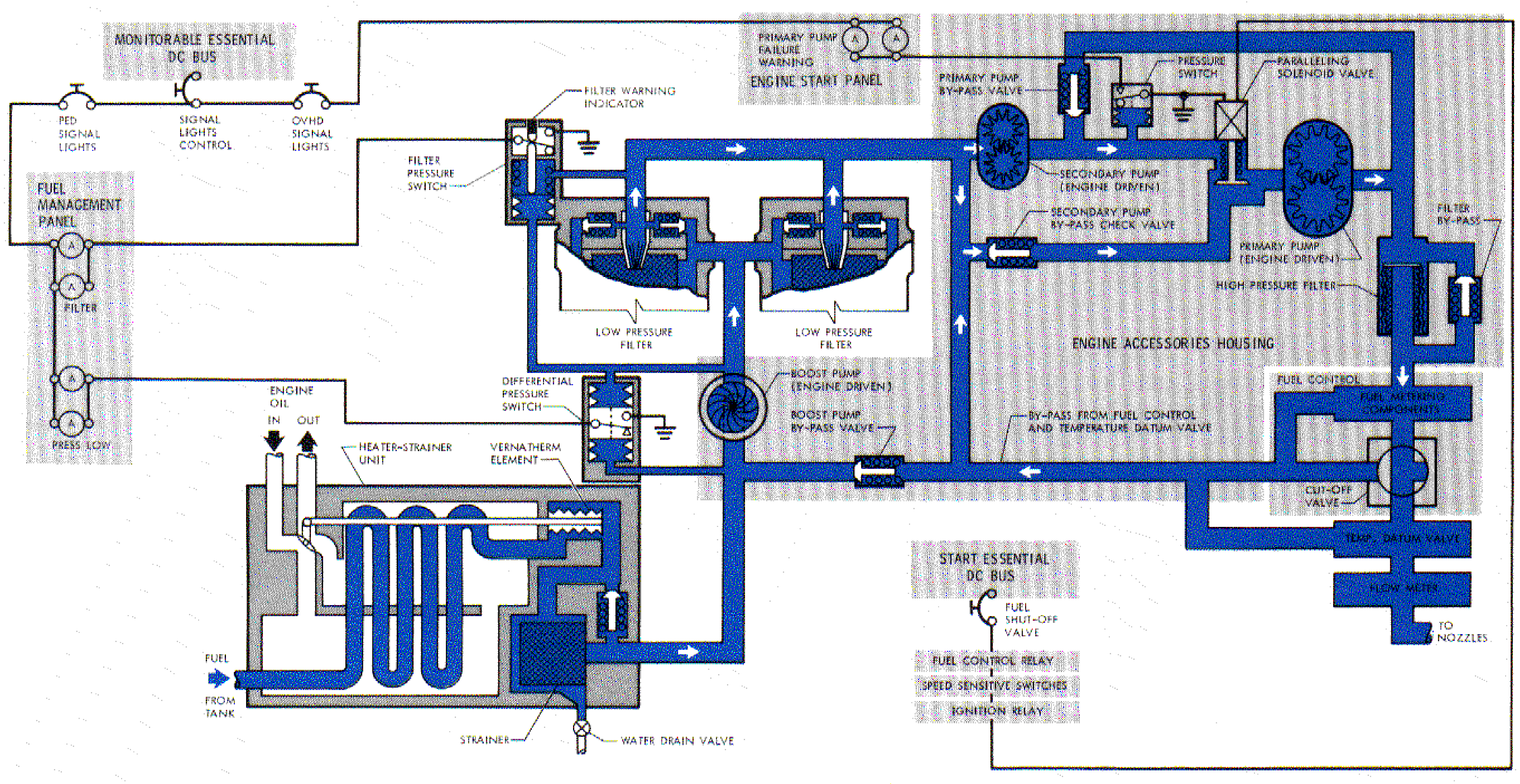
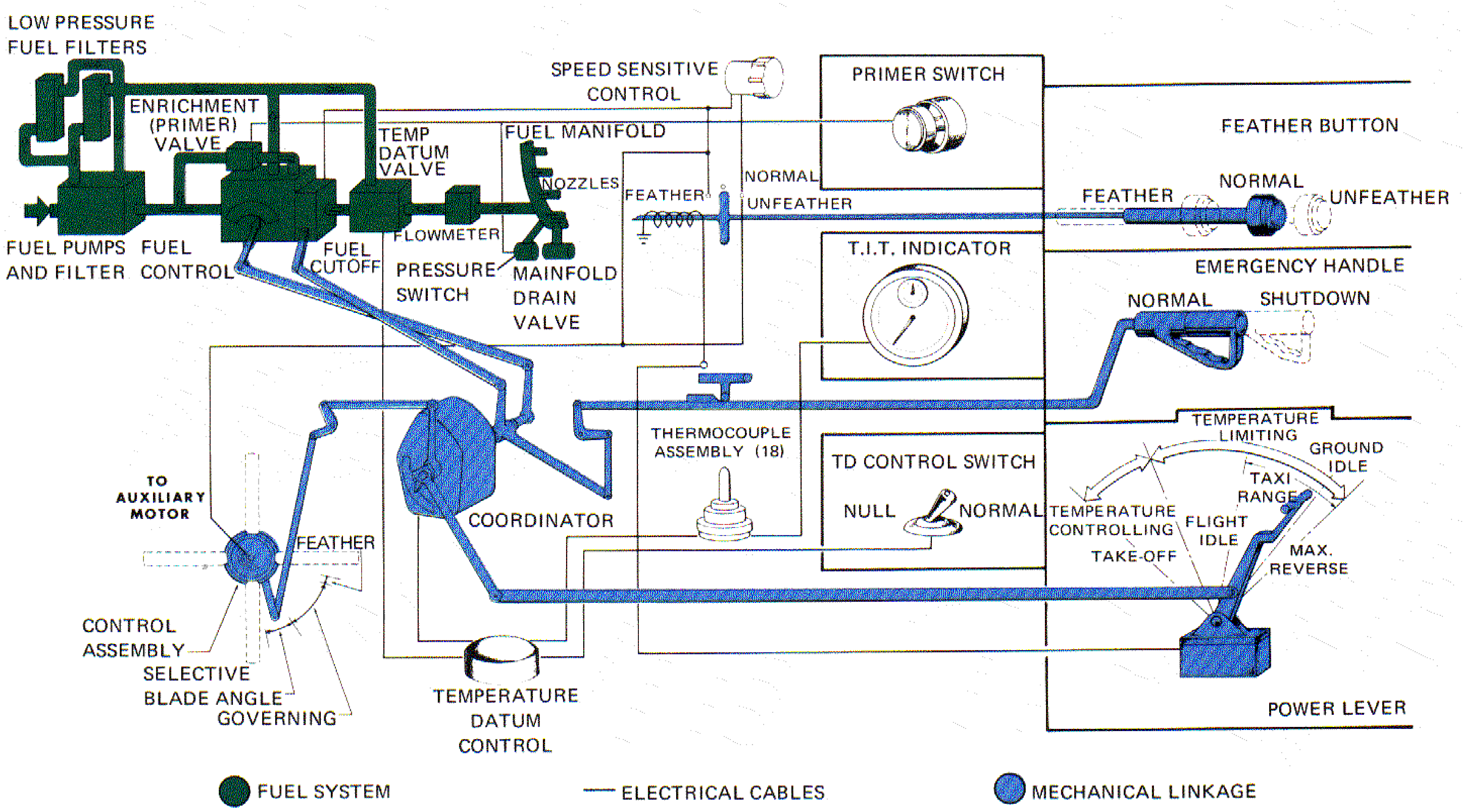


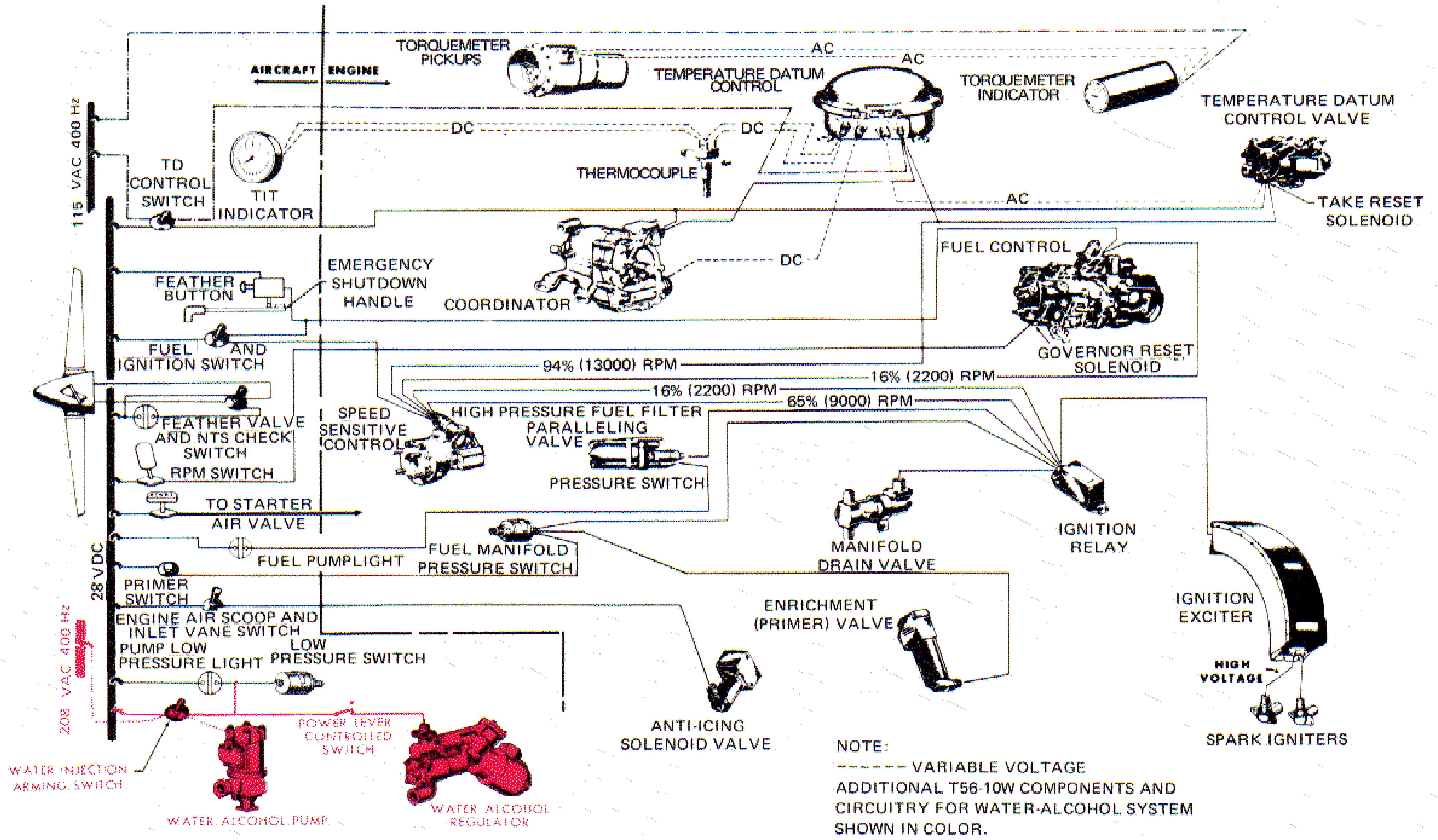
Figure 23. Engine Fuel System Flow Schematic

The discriminator assembly consists of a propeller coordinator shaft assembly, a feathering shaft assembly and helical spring, and a main shaft and gear assembly. The discriminator assembly permits control of the propeller linkage system by either the power lever or the emergency handle. During normal operation with the emergency handle pushed in, the power lever has complete control.

However, when the emergency handle is pulled, the discriminator overrides the power lever regardless of its position. Figure 26 shows that the power lever always has control of the fuel scheduling linkage and the emergency handle always has control of the fuel cutoff valve linkage. Therefore, it is apparent that no fuel can flow unless the emergency handle is pushed in.

Figure 24. T56 Engine Fuel and Control System Schematic





NOTE:
------ VARIABLE VOLTAGE
ADDITIONAL T56-10W COMPONENTS AND CIRCUITRY FOR WATER-ALCOHOL SYSTEM SHOWN IN COLOR.

Figure 25. T56 Engine Electrical System Schematic

The shaft position indicator dial is graduated in degrees (0 to 90), and full-scale movement of the indicator pointer corresponds to the full-travel (51-3/4 degrees) movement of the power lever. Thus, when we speak of power lever position in terms of degrees, we refer to the corresponding coordinator scale reading. For example, the pointer indicates 0 degrees when the power lever is at the full reverse position, 34 degrees with the power lever at flight idle, and 90 degrees with the power lever at the takeoff position.

The TD control operates in two modes with respect to TIT, temperature limiting and temperature controlling, and these modes are established as a function of power lever position (coordinator switch status) and engine rpm (speed sensitive control switch status). Detailed descriptions of the speed sensitive control and TD control system operations are presented in later paragraphs. With the power lever below 66 degrees coordinator, the coordinator switch is closed as shown in Figure 26. The closed switch contacts complete a circuit to energize the two TD control limiter selector relays and the TD control operates in the temperature-limiting mode to maintain TIT below 830°C until engine speed reaches 94 percent rpm and the speed sensitive control high-speed switch is actuated. With the power lever above 66 degrees coordinator, the switch is held open by a cam assembly on the discriminator assembly main shaft and the TD control then operates in the temperature-controlling mode.

Although any movement of the power lever results in actuation of the coordinator potentiometer, the potentiometer signals are not used by the TD control in the temperature-limiting mode of operation. At 66 degrees coordinator, and above, the potentiometer signals, representing the desired TIT as scheduled by power lever position (760°C to 977°C for the T56-A-10W engine and 819°C to 1083°C for the T56-A-14 engine), are used by the TD control for comparison with the actual TIT signals which are produced by the turbine inlet thermocouples.

Speed Sensitive Control

The speed sensitive control, while not actually a part of the engine fuel system in the strict sense, is quite involved in fuel control operations, and a good understanding of its functions is quite valuable in gaining knowledge of the total engine fuel system operation. It is an engine-driven electromechanical device mounted on the forward side of the accessory drive assembly which automatically energizes or de-energizes certain electrical circuits as a function of engine rpm during the engine starting and acceleration sequence. The control includes, in addition to a driven shaft, a flyweight and switch actuator mechanism, three (low, intermediate, and high speed) helical compression springs installed coaxially on the shaft, three (16, 65, and 94 percent engine rpm) normally-open microswitches, and associated electrical circuitry. The speed sensitive control functions to:

(a) Energize and de-energize the ignition relay located in the main load center. The relay, in turn, energizes and de-energizes the ignition exciter, manifold drip valve solenoid, primer valve solenoid, and paralleling valve solenoid. The paralleling valve position establishes the mode (series or parallel) of operation for the secondary and primary fuel pressure pumps.

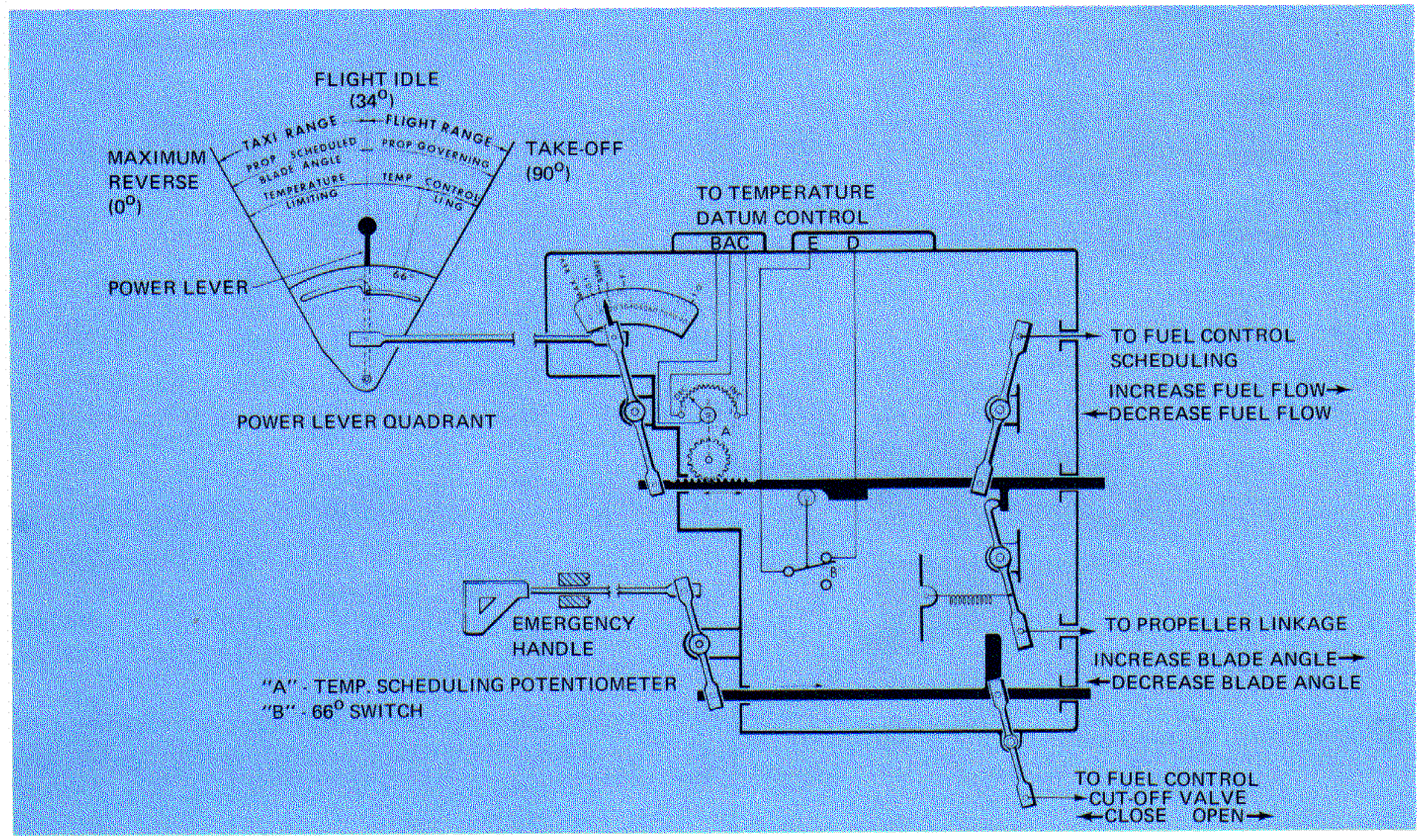
(b) Energize the fuel cutoff valve (fuel control) actuator motor to open the valve.

(c) Energize and de-energize the TD control speed sensitive relay and limiter selector relays (two) to enable operation of the TD control in either the temperature-limiting or temperature-controlling mode.

(d) Energize and de-energize the TD valve "take" solenoid.

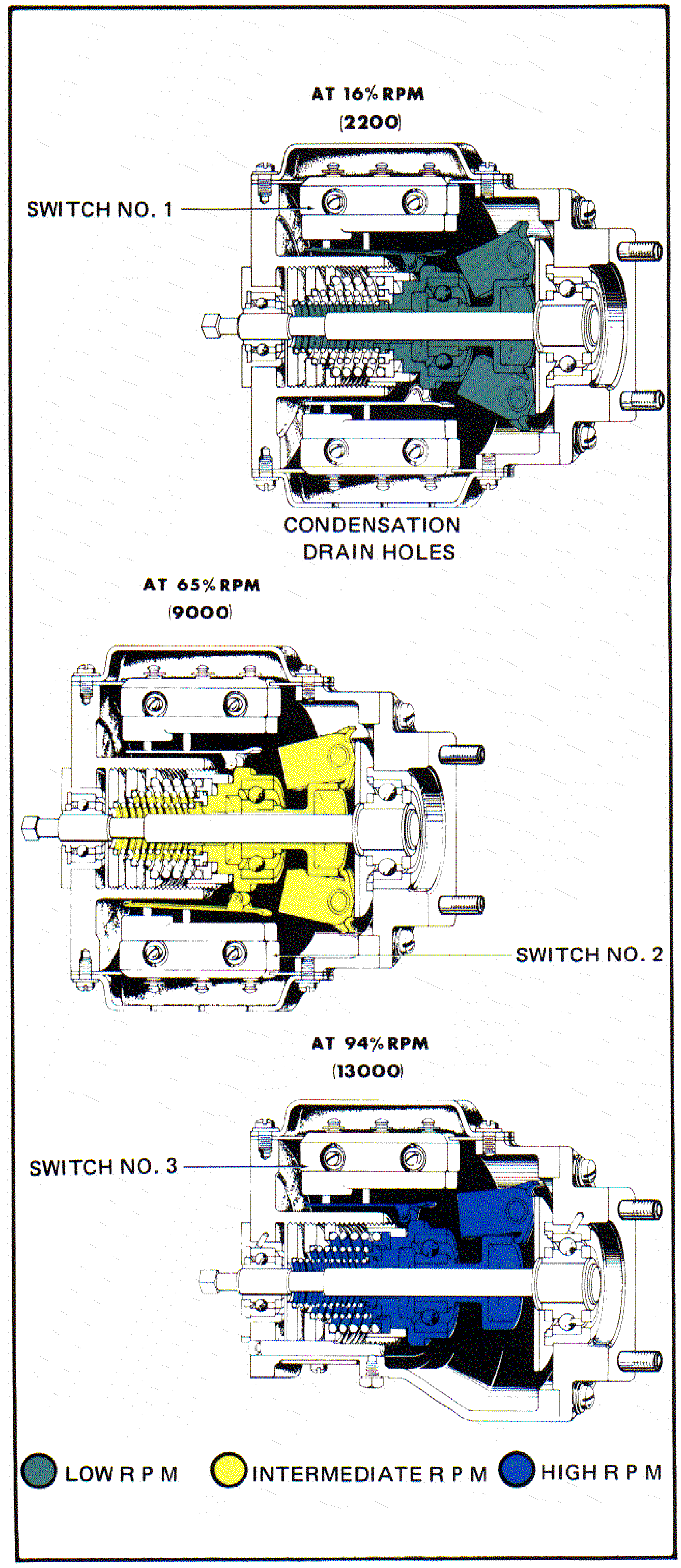
The speed sensitive control is driven from gears in the accessory drive assembly so that when engine speed is 100 percent (13,820) rpm, the control shaft turns at 4215 rpm. At engine speeds less than 16 percent rpm (see Figure 28a), the three microswitches are unactuated. The normally-open paralleling valve allows the secondary and primary fuel pressure pumps to operate in series, and the fuel cutoff valve is closed to prevent flow of fuel from the fuel control to the TD valve. A detailed description of the fuel pressure pumps operating modes (series and parallel) is presented in a later discussion. A set of normally-closed contacts in the 16 percent switch completes a circuit through normally-closed contacts in the fuel control relay located in the main load center, through the normally-closed fuel manifold pressure switch to energize the fuel enrichment control relay. The enrichment control relay, when energized, closes a parallel circuit through a set of contacts in the fuel manifold pressure switch so that when the 16-percent switch contacts open, the control relay will remain energized until fuel pressure opens the pressure switch at 50 psi. A second set of normally-open contacts in the fuel enrichment control relay completes a circuit from the fuel and ignition switch on the center overhead panel through a set of contacts in the primer relay (closed only when the relay is energized from the closed momentary primer switch on the center overhead panel) to energize the normally-closed enrichment valve.

Figure 26. Coordinator Control Schematic



From the initiation of the start sequence until the engine reaches 94 percent rpm, the normally-closed contacts of the 94-percent switch complete circuits to energize the TD valve "take" solenoid and the TD control speed sensitive relay directly and, through a diode, the two TD control limiter selector relays. Closed contacts of one relay complete a circuit through the contacts of the speed sensitive relay from the temperature reference regulator to the start potentiometer; contacts of the second relay are open.

Figure 27. Speed Sensitive Control Schematic



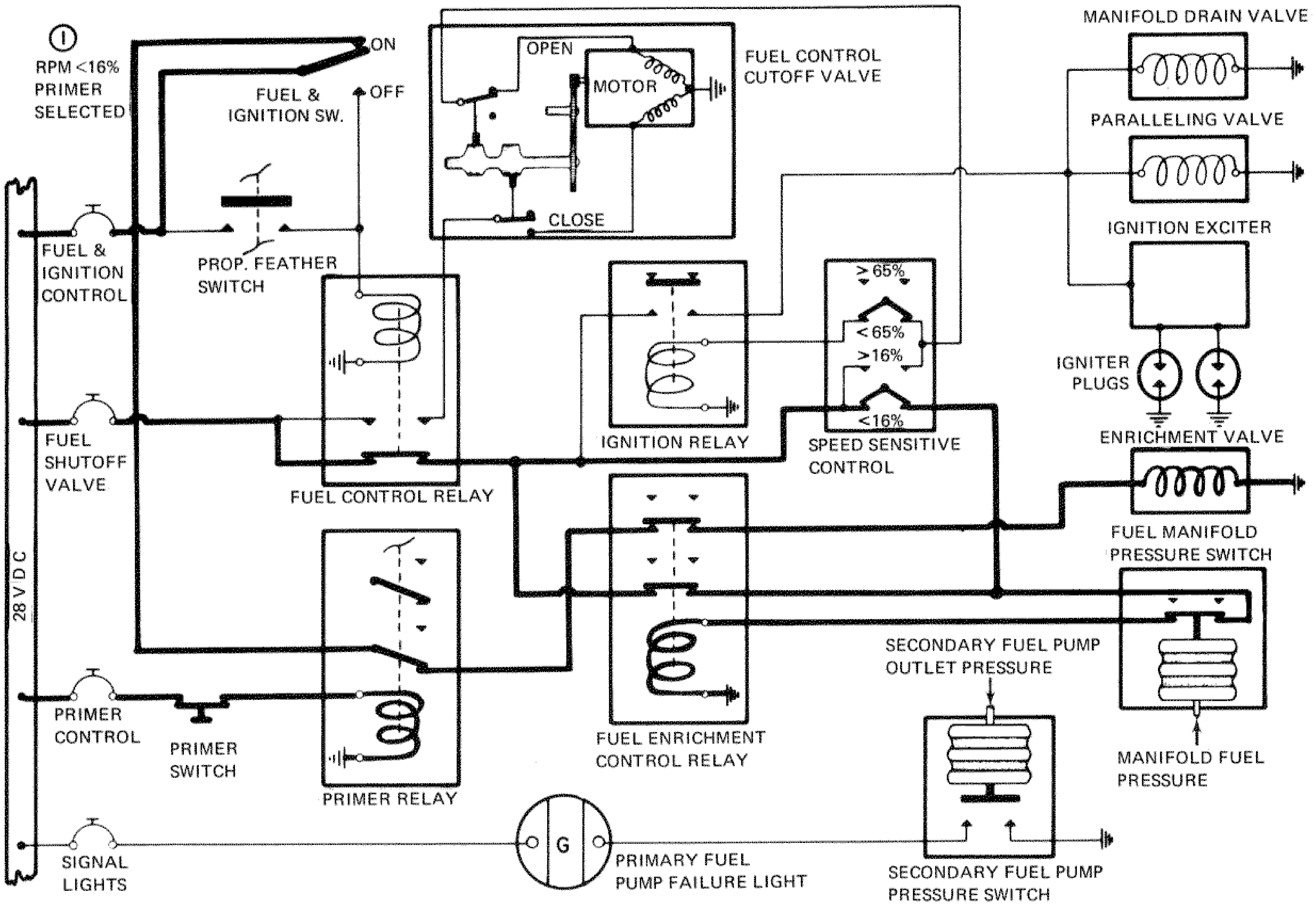
When engine speed reaches 16 percent rpm (see Figure 28b), centrifugal force exerted by the speed sensitive control flyweights acting through a switch actuator is sufficient to overcome the low-speed spring force and actuate the 16-percent switch, opening one set of contacts and closing another. Both sets of contacts are jumpered together to share a common circuit from normally-closed contacts in the fuel control relay. The opened contacts interrupt the circuit through the switch to the fuel enrichment control relay but the relay remains energized through the alternate holding circuit explained above. The closed contacts complete a circuit (from the fuel control relay) to energize the fuel control cutoff valve actuator motor, opening the valve to permit fuel flow to the TD control valve. The enrichment valve, being held open by the circuit through the fuel enrichment control relay, receives fuel flow directly from the high-pressure filter (pressure pumps) and routes it through the cutoff valve to the TD control valve. Complete descriptions of the fuel flow sequence to, and through, the TD control and enrichment valve are given in appropriate paragraphs later in this article.

The closed contacts in the 16-percent switch also complete a circuit through the normally-closed 65-percent switch contacts to energize the ignition relay. A set of normally-open contacts in the relay closes to complete circuits from the normally-closed contacts in the fuel control relay to:

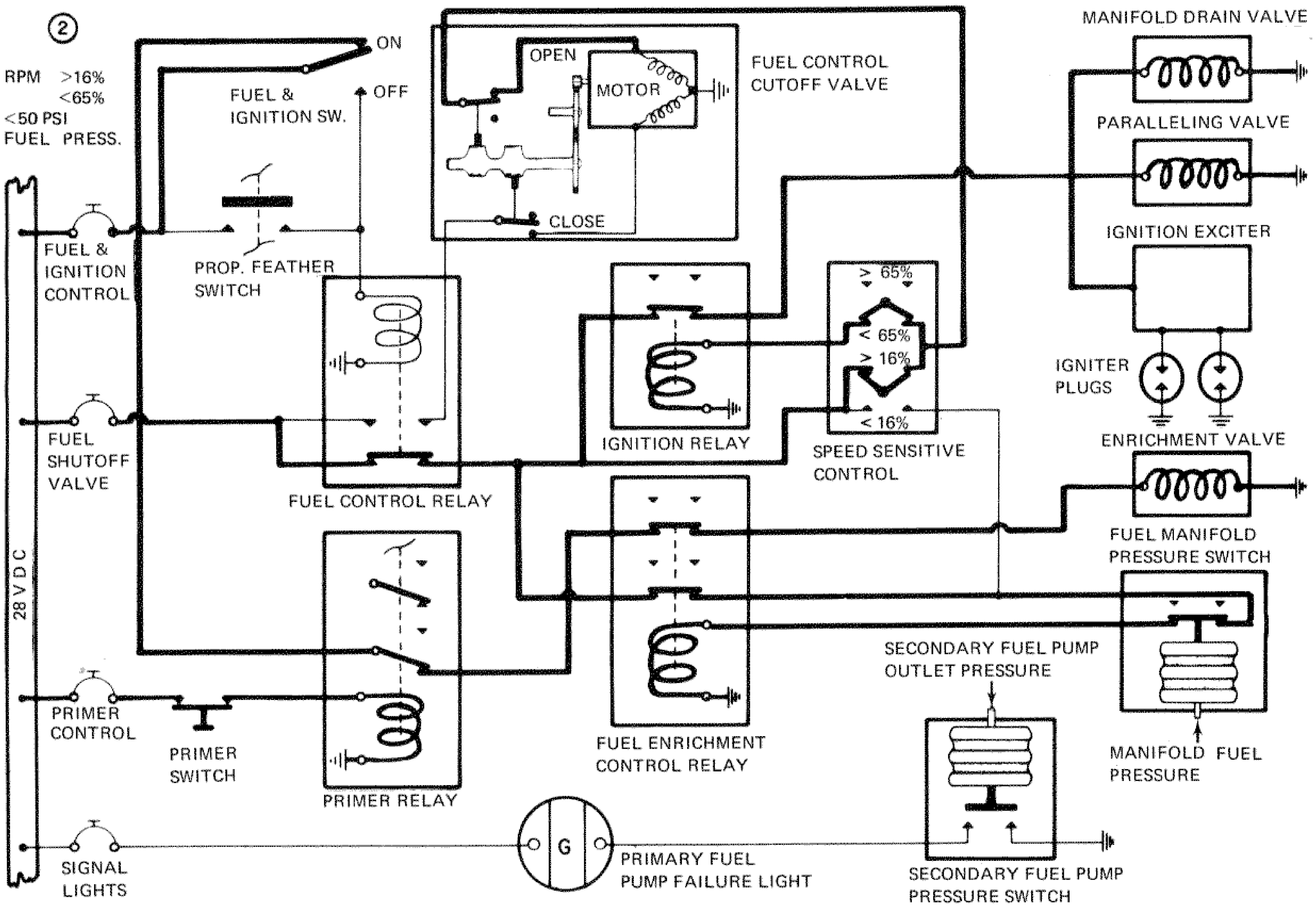
(a) Energize and close the solenoid-operated, normally-open manifold drain valve.

(b) Energize and close the solenoid-operated, normally-open fuel pressure pumps paralleling valve causing the secondary and primary fuel pressure pumps to operate in the parallel mode.

(c) Energize the ignition exciter causing it to produce high-energy sparking by the igniter plugs in No. 2 and No. 5 combustion cans.



Figures 28a (above) and 28b (below). Engine Starting Fuel and Ignition Schematic



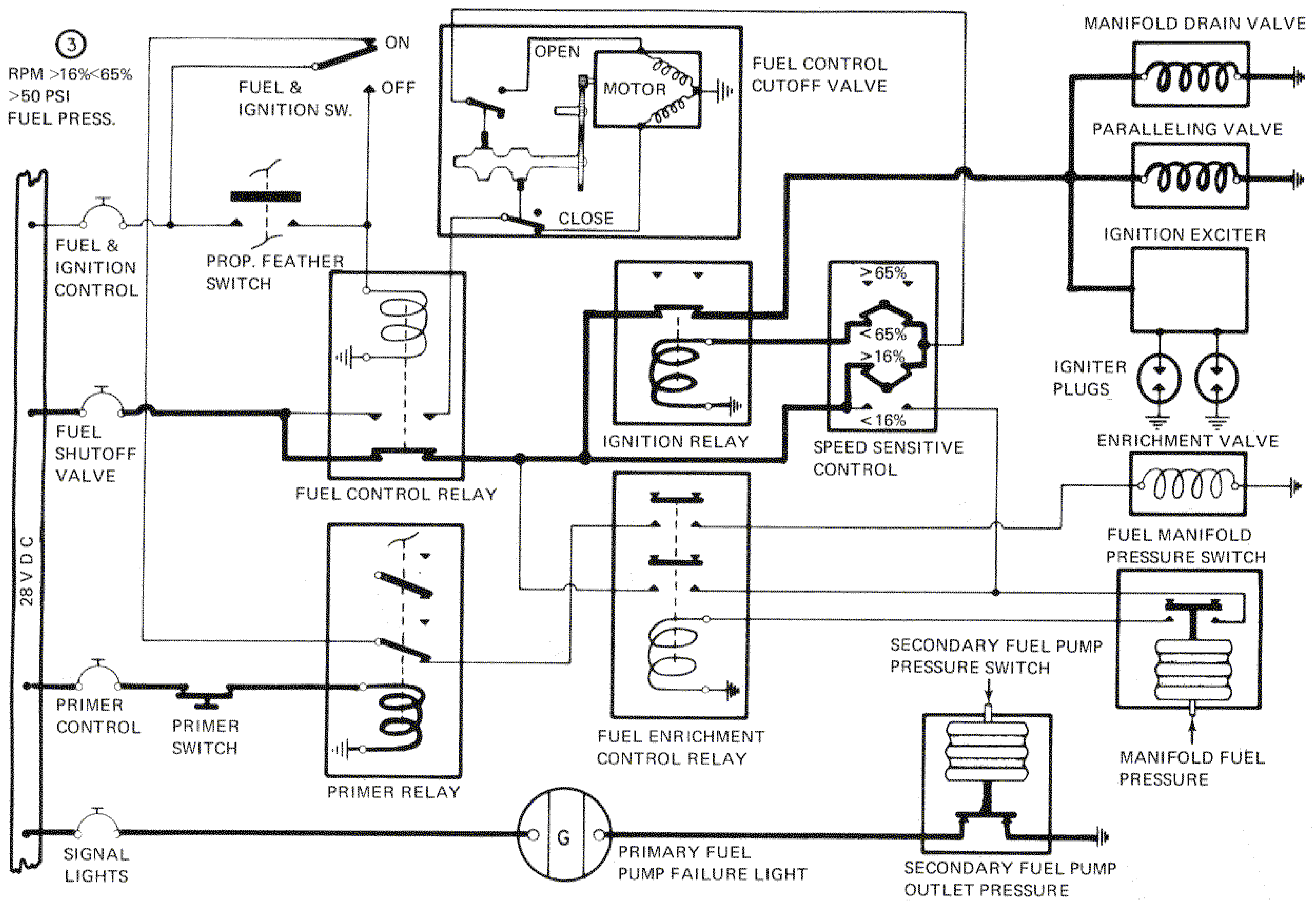


Figure 28c. Engine Starting Fuel and Ignition Schematic

As the engine accelerates above 16 percent rpm, fuel pressure sensed by the normally-closed manifold pressure switch increases. When the fuel pressure reaches 50 psi (see Figure 28c), the switch opens and interrupts the circuit to the fuel enrichment control relay, causing the relay to drop out. This, in turn, interrupts the circuit to the enrichment valve; the valve closes to shut off enrichment fuel flow through the valve.

When engine speed reaches 65 percent rpm, centrifugal force exerted by the flyweights acting through the switch actuator is sufficient to overcome the combined low-speed and intermediate-speed spring forces to open the normally-closed 65-percent switch contacts, de-energizing the ignition relay. The relay drops out and interrupts the circuits to the manifold drain valve which is held closed by fuel pressure in the manifold; to the paralleling valve which opens to permit secondary and primary fuel pressure pump operation in series (the secondary pump discharge pressure falls off because of the primary pump's greater capacity, the secondary pump pressure switch contacts open and the paralleling light is extinguished); and to the ignition exciter which stops producing energy for the igniter plugs.

The starting sequence is now complete and the engine continues to accelerate. When it reaches 94 percent rpm, flyweight centrifugal force is great enough to overcome the combined force of all three springs and open the normally-closed 94-percent switch. This de-energizes the TD valve "take" solenoid (Refer to TD control operational description presented later in this article) and the TD control speed sensitive and limiter selector (two) relays. However, when the power lever is below 66 degrees coordinator (Refer to the detailed coordinator operational description previously presented), the closed coordinator switch completes circuits that energize the limiter selector relays to prevent them from dropping out. The speed sensitive relay does drop out and switches the temperature reference regulator circuit from the start potentiometer to the normal potentiometer. The TD control is still operating in the temperature-limiting mode, but the TIT limit is increased from 830°C to 977°C for the T56-A-10W engine and to 1083°C for the T56-A-14 engine because of the potentiometer switching.

Fuel Heater and Strainer

This unit is installed below the engine near the oil cooler. It receives the incoming fuel flow, under pressure from the fuel tank boost pump, from the airplane fuel system. Its primary function is to remove water droplets and ice crystals from the fuel. The heater utilizes waste heat from the engine oil return flow to maintain fuel temperature above 40°F which is sufficient to melt existing ice crystals and to prevent further ice formation. As shown in Figure 23, fuel enters the unit and passes through tubes in a heat exchanger cavity into a second cavity containing a vernatherm (temperature-sensing) element and then through a strainer (or strainer bypass valve) out of the unit. The heat exchanger cavity has inlet and outlet ports through which the oil flow enters and leaves the cavity.

The vernatherm element is connected mechanically to an oil bypass valve just inside the heater oil inlet and outlet ports connected into the engine oil return plumbing. When the fuel temperature, as sensed by the element is below 40°F, the valve is opened fully to route the entire oil flow into the heat exchanger cavity where the hot oil completely surrounds the fuel tubes. As fuel temperature rises, the vernatherm modulates the valve to bypass a portion of the oil flow. And when fuel temperature reaches 70°F, the valve bypasses the entire oil flow directly to the outlet port. The oil bypass valve also acts as a relief valve to protect the heater from excessive oil pressure. It opens at 30 psi inlet oil pressure to bypass oil flow out of the unit.

The 60-mesh strainer removes water droplets, as well as other foreign material, from the fuel. Material removed by the strainer is collected in a sump (14 cubic inches capacity) below the strainer. The sump is fitted with a drain plug for removal of the material. A strainer bypass valve opens to route fuel flow directly to the outlet port in case the strainer becomes clogged.

Fuel Pumps and Filters

The fuel pump assembly, mounted on the engine accessory drive assembly, consists of two housings bolted together with each housing containing certain interrelated elements pertinent to engine fuel pumping. The primary purpose of the fuel pump assembly is to receive fuel flow, under relatively low pressure, from the airplane fuel system boost pump (Refer to ORION Service Digest, Issue 19) and direct the fuel, under increased pressure, to the engine fuel system flow metering and control components. Although not a part of the pump assembly, two separately-mounted, low-pressure filters are so involved in the fuel pumping phase (their total function) that they are included in this section.

During normal operation at high engine speeds, the pump assembly discharges considerably more fuel than the engine requires for operation. The total discharge flow is routed to the fuel control. The control bypasses a part of the excess back to the pressure pumps inlet (low-pressure filter return line) and supplies the TD valve with 120 percent of engine requirements. The TD valve, with up to 50 percent of flow "take" capability in the temperature-limiting mode, then trims the fuel flow as required to maintain TIT within established limits at all engine speeds. A complete operational description of the TD control is presented later in this article. Above 94 percent rpm engine speed, the speed sensitive control high-speed switch is actuated, and if the power lever is advanced beyond 66 degrees coordinator, the TD control is switched to a temperature-controlling mode with "take" capability limited to 20 percent, but with the added capability to "put" fuel up to 20 percent of flow. In either mode, the fuel trimmed (taken) by the TD valve is returned to the pump inlet and the exact amount of fuel required by the engine is routed to the fuel manifold and nozzles.

The upper fuel pump assembly housing contains three independent, engine-driven pump elements all driven from a common input shaft, an impeller-type boost pump and two (secondary and primary) gear-type fuel pressure pumps. The boost pump bypass valve is included in this part of the assembly. The lower housing shown in Figure 29a contains a secondary pump discharge pressure switch, two (secondary and primary pump bypass) check valves, a paralleling valve, and a high-pressure filter and filter bypass valve.

The engine-driven, impeller-type boost pump receives fuel from the airplane fuel tank boost pump and discharges it to the low-pressure filters. Note that the engine boost pump has sufficient suction capacity to draw fuel from the wing tank to supply the engine in case of tank boost pump failure. The boost pump inlet and discharge pressures act on the two sides of a differential-pressure switch, installed near (aft) the fuel heater to sense boost pump pressure increase. When boost pump-induced pressure rise is 19 psi or less, the switch closes and energizes a PRESS LOW warning light on the fuel management panel. When pressure rise is 23 psi or more the switch is open and the light is extinguished. The boost pump bypass valve opens to permit fuel flow from the airplane system directly into the secondary pressure pump inlet in the event of boost pump failure and the PRESS LOW warning light illuminates as a malfunction warning. Note that the secondary pressure pump suction capacity, combined with the tank boost pump discharge pressure, is sufficient to draw fuel from the wing tank and provide the engine with adequate fuel supply.

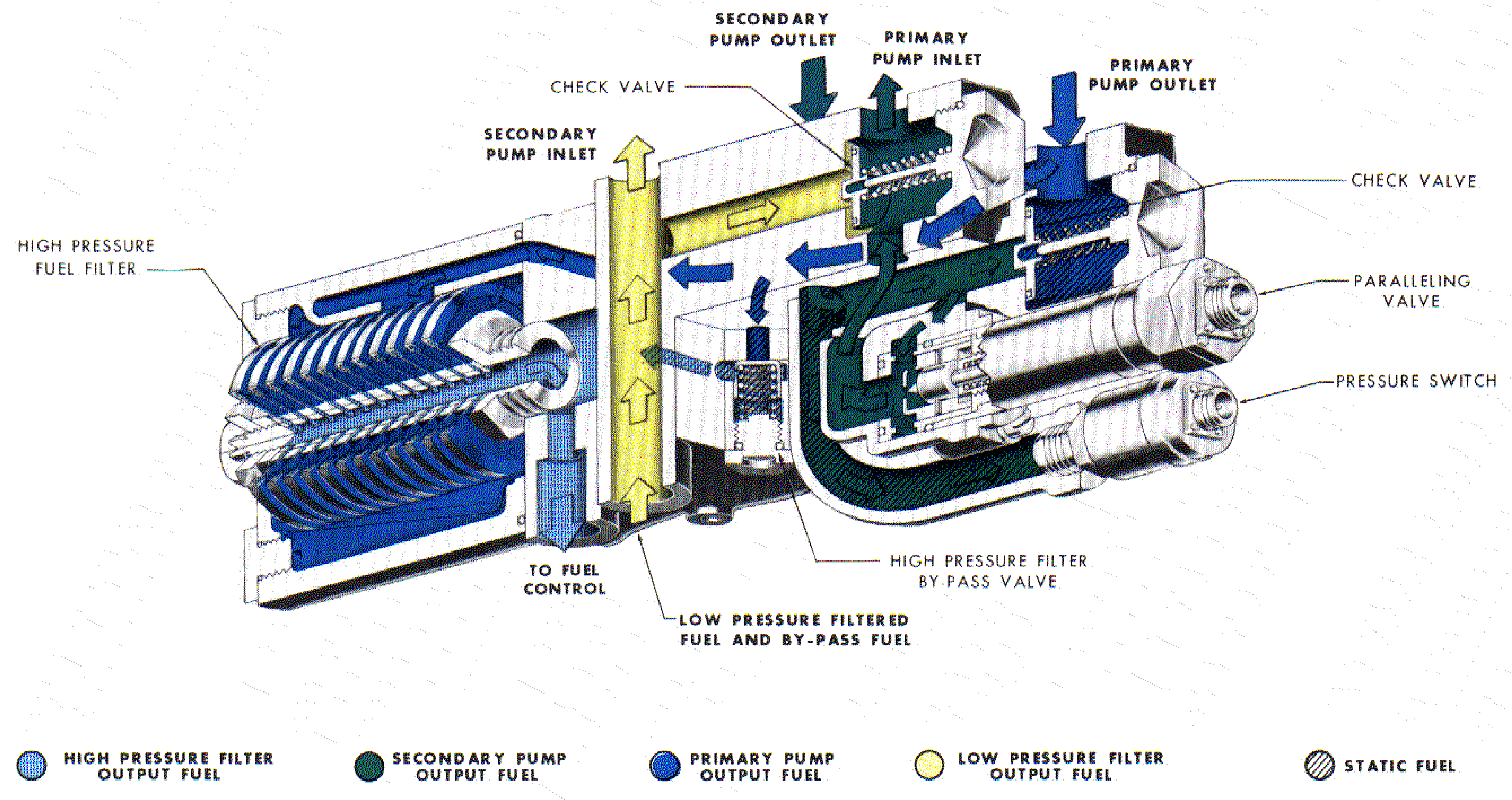
The two dual paper element, 5-micron, low-pressure filters, which receive the flow discharge from the boost pump, are connected in parallel, and each element contains two bypass valves that open to permit fuel flow around the filter when pressure drop across the element, due to filter clogging or obstruction, exceeds 5 psi. A pressure-sensing line tapped off the boost pump discharge and connected into the low-pressure filter return senses the clogged filter condition and energizes a FILTER warning light on the fuel management panel. Filter return flow is routed to the pressure pump inlets.

The secondary and primary fuel pressure pumps operate in one of two modes, series or parallel, under control of the paralleling valve in the secondary pump discharge line. This dual-mode design was developed to ensure adequate fuel quantity for reliable engine starting. At low speeds (as in beginning the start sequence), efficiency of the gear-type fuel pressure pumps is greatly reduced, and the output of a single pump may not be adequate to meet the demand. By operating the pumps in parallel, that is, by supplying both pump inlets with the low-pressure filter return flow and with the fuel control and TD valve bypass flow, and by directing the discharge flows from both pumps into the fuel system, total fuel output is greatly increased.

The entire fuel discharge flow from the fuel pressure pumps goes through the 33-micron, disc-type, high-pressure filter. The filter includes a bypass valve that opens at 120 psi to route fuel flow around the filter and ensure an adequate fuel supply to meet engine demands in case the filter becomes clogged or obstructed.

A pressure switch is installed in the secondary pump discharge line just ahead of the paralleling valve to detect, through line pressure variations, paralleling valve position and, thus, the pressure pumps operating mode. When the paralleling valve is closed, secondary pump discharge pressure closes the pressure switch and, through the switch action, energizes a circuit to a dual-purpose (paralleling valve closed/primary pump failure) warning light on the ENGINE STARTING (center overhead) panel. The normally-open, solenoid-operated paralleling valve is energized and de-energized by a circuit from the ignition relay as described in the previous discussion of speed sensitive control operation.

Figure 29a. High-Pressure Fuel Filter Diagram



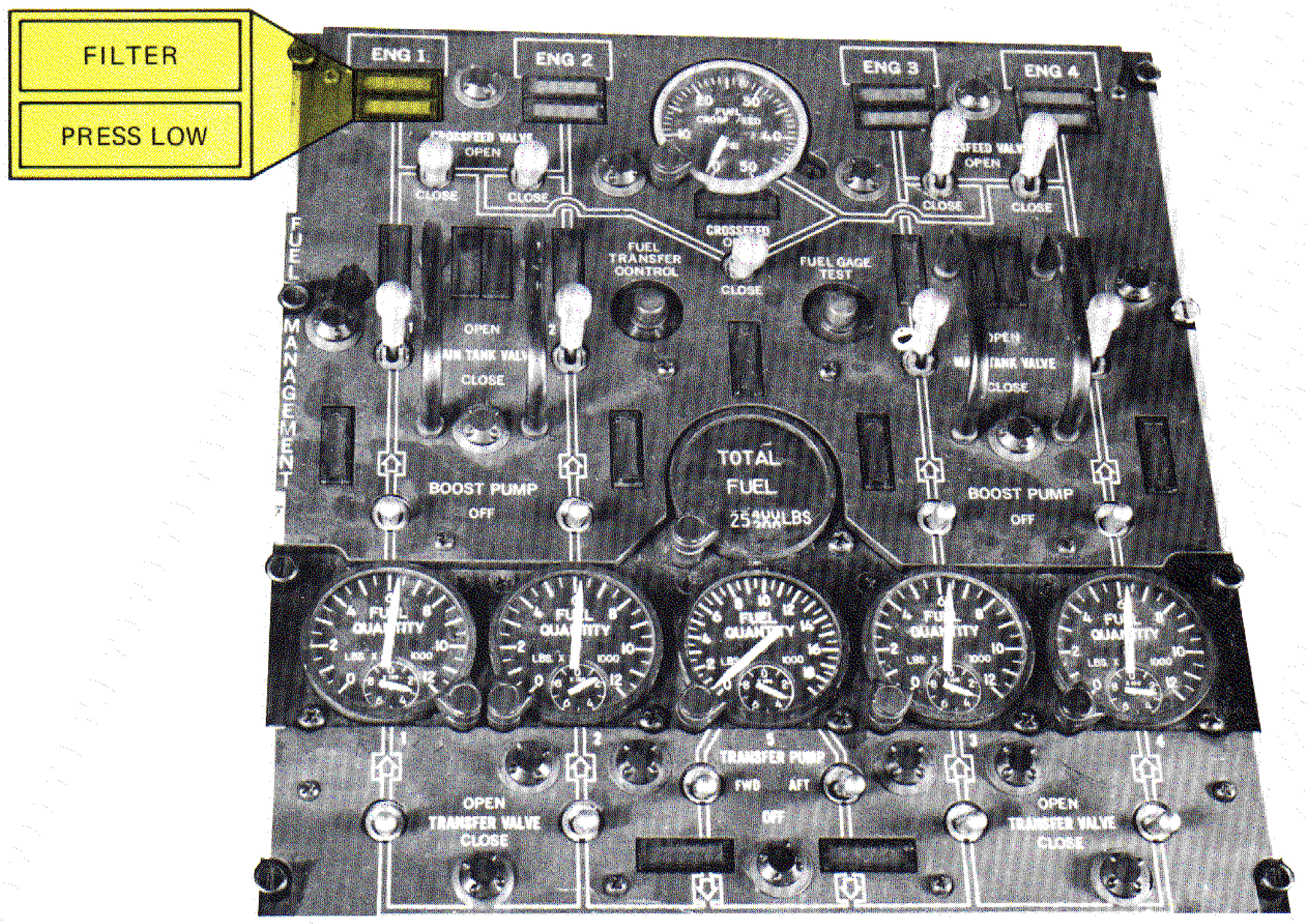
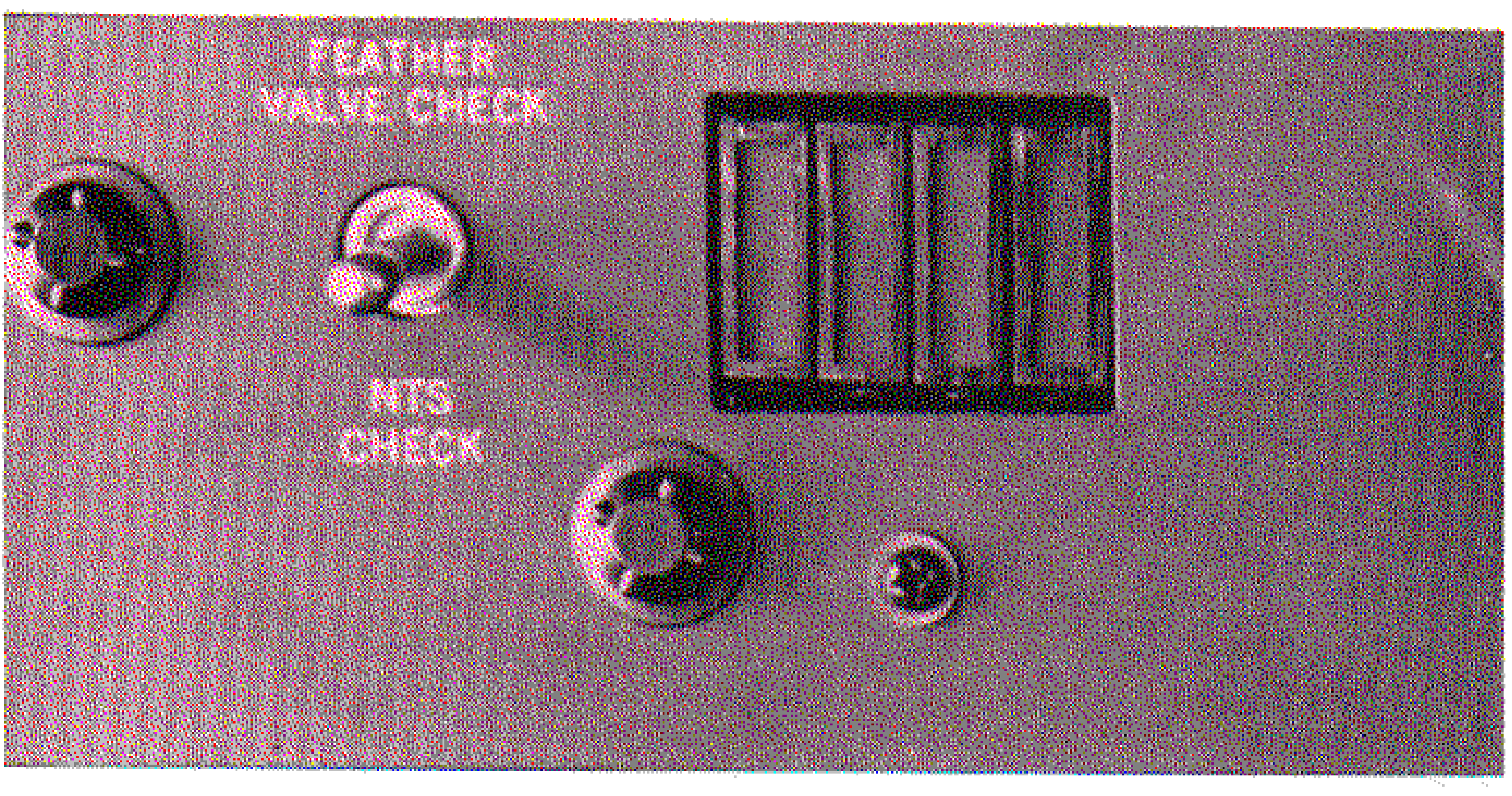


Figure 29b. Fuel Management Panel

As explained previously, when engine speed is less than 16 percent rpm, the fuel control cutoff valve is closed and there is no fuel flow out of the control to the TD valve. The paralleling valve is deenergized open and the pumps operate in series, i.e., the discharge flow from the secondary pump is routed to the inlet of the primary pump. Because the capacity of the primary pump is 10 percent greater than that of the secondary pump, the latter's discharge flow is not pressurized, the pressure switch is not actuated, and there is no signal flow in the indicator light circuit. Primary pump discharge flow goes directly to the inlet of the high-pressure filter and holds the secondary pump discharge-to-high pressure filter check valve closed. Because the fuel control cutoff valve is closed, all fuel flow to the fuel control is bypassed back to the pressure pump inlets.

And, when engine speed reaches 16 percent rpm, the paralleling valve is energized closed by the ignition relay as explained previously, and the pressure pumps operate in parallel. The secondary pump discharge flow, being blocked from the primary pump inlet by the closed paralleling valve, now builds up pressure sufficient to open the primary pump bypass check valve and permit secondary pump discharge flow direct to the high-pressure filter inlet. Also, the pressure switch is actuated and the paralleling light illuminates. The primary pump suction now opens the secondary pump bypass check valve in the low-pressure filter return line and the pump takes its inlet flow directly from the low-pressure filter, fuel control, and TD valve return flows. Secondary pump discharge flow goes directly to the high-pressure filter inlet where it joins the discharge flow from the primary pump.

When the accelerating engine reaches 65 percent rpm, the paralleling valve is de-energized by ignition relay dropout as explained previously and the pressure pumps revert to the series mode of operation. Because of the primary pump's greater capacity, pressure in the secondary pump discharge is reduced, the pressure switch is opened, and the paralleling light is extinguished. This status is maintained throughout the remainder of the engine operating regime unless a primary pump failure occurs.



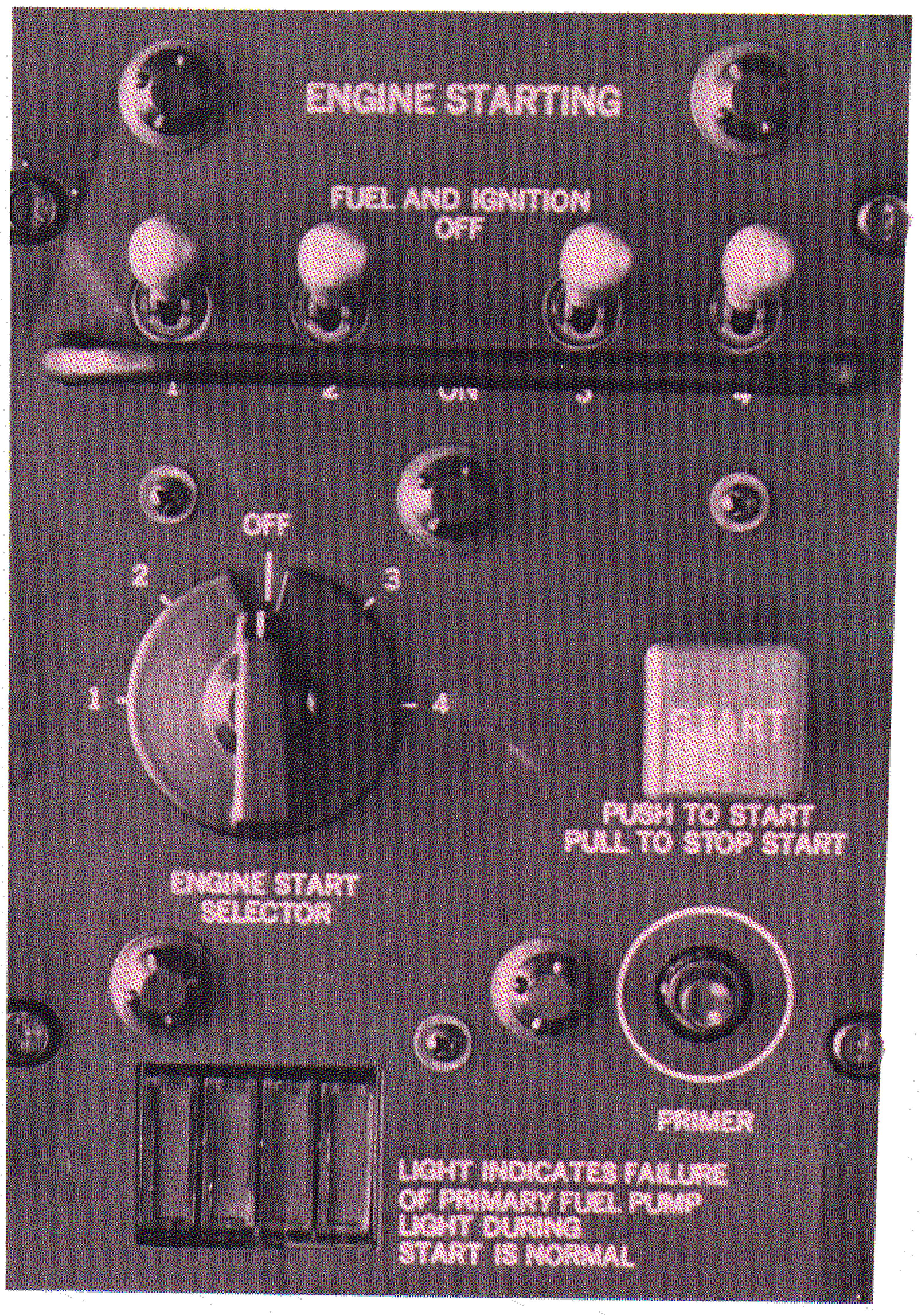


Figure 29c. Feather Valve – NTS Check Panel (above) and Engine Starting Panel (right)

As stated earlier, each fuel pressure pump is designed with sufficient capacity, when operating at the higher rotational speeds provided in the higher engine rpm range to pump all the fuel required to maintain engine operation, i.e., either pump can fail and the other will continue to carry the fuel pumping load. If the secondary pump fails, the primary pump continues to draw its fuel inlet flow from the low-pressure filter return, and to supply discharge flow to the high-pressure filter. The primary pump bypass check valve between the secondary pump discharge port and the high-pressure filter remains closed and prevents back-flow into the secondary pump.

And, if the primary pump fails, the secondary pump discharge pressure rises (because of loss of primary pump suction), the pressure switch closes, and the primary pump failure (paralleling valve) warning light is energized. The secondary pump discharge pressure opens the primary pump bypass check valve to the high-pressure filter, and the secondary pump continues to carry the entire fuel pumping load.

Fuel Control Assembly

The fuel control assembly is mounted on, and receives mechanical shaft power for its centrifugal flyweight-type governor mechanism from, the accessory drive assembly. It functions, under manual and automatic control, to receive the pressurized fuel flow from the high-pressure filter at a rate which is considerably higher than the momentary engine demand. It coordinates the several input signals to sense the amount of fuel required for engine operation, and meters its fuel output to the TD control at 120 percent of engine requirements; fuel received by the control which is in excess of the output is bypassed back to the fuel pressure pumps inlet. The control accommodates engine demand and responds to pilot commands during all phases of engine operation: starting, acceleration, low ground idle at 72.5 percent rpm, Beta range operation at 97.5 percent rpm, takeoff, climb, cruise, flight idle, and shutdown. In addition, it provides engine overspeed governing.

The fuel control assembly is a hydromechanical device shown schematically in Figure 30b, the basic purpose of which is to meter fuel flow to the engine by maintaining a constant pressure drop through a variable-orifice metering valve. The metering valve is designed so that both radial and axial movements result in orifice size modulation.

Hydraulic components — components through which the fuel flows and by which the flow is regulated and controlled — in addition to the metering valve include a fuel bypass valve, a servo-pressure regulator, a pressurizing valve, and a cut-off valve. These components are actuated and positioned by a mechanical system of shafts, levers, cams, gears, pressure diaphragms and bellows, and springs. The interaction of all components in an extremely precise manner enables the fuel control to perform its functions with great accuracy.

The basic command input to the fuel control and, in fact, to the entire engine fuel system is through movement of the power lever. Power lever movement is relayed by mechanical linkage through the coordinator to the fuel control input lever as explained in the coordinator discussion. Also, as explained in the speed sensitive control discussion, when engine speed reaches 16 percent rpm, closing contacts in the control complete an electrical circuit that energizes the fuel control cutoff valve actuator motor to open the valve.

Power lever movement to commence engine operations rotates the fuel control input lever shaft, and this motion is transferred through bevel gears to the governor cam shaft on which the governor scheduling cam and the part-throttle scheduling cam are installed. The governor scheduling cam, acting through a lever system, establishes the basic governor spool position and thus, the governor schedule for that particular power lever setting.

Rotation of the governor cam shaft (and the part-throttle scheduling cam) results in a sliding movement of the follower on its shaft and movement of the follower on the part-throttle setting cam on the speed temperature shaft. Contour of the grooved part-throttle scheduling cam is such that power lever movement in either direction from the START position (15 degrees coordinator) commands increased engine power and fuel control mechanism follow-up action. The part-throttle cam follower moves toward the small end of the part-throttle setting cam, causing the part-throttle shaft to rotate. This rotation, through action of the acceleration cam follower, is translated into lateral movement of the metering valve shaft away from the valve. This movement permits the metering valve spring to open the valve. Note that spring force is the only means by which the metering valve is opened axially. Although the spring always exerts opening force, the valve is restrained from opening by the metering valve shaft.

Pressurized fuel flow from the high-pressure filter (pressure pumps discharge flow) is received into the fuel control bypass valve chamber, flows through the hollow stem of the bypass valve, exerts opening force (related to pump discharge pressure) on one side of the bypass valve diaphragm to overcome spring closing force, and flows on to the metering valve. The bypass valve spring exerts a force equivalent to that which would be exerted by fuel pressure of 22 psi (the spring includes an adjustment screw). Because the incoming fuel flow is greater than engine demand, only a portion of the flow can pass through the metering valve. The bypass valve is opened by inlet pressure to route excess flow back to the pressure pumps inlet. Metering valve downstream pressure is routed to the closing (spring) side of the bypass valve diaphragm. The combined bypass valve closing force exerted by the spring and metered fuel pressure acting on one side of the diaphragm and the opening force exerted on the other side by the inlet pressure allows the valve to bypass only sufficient fuel flow to maintain the 22 psi pressure drop across the metering valve. This balance is maintained so long as operating conditions remain stable.

Figure 30a. Autofeather and RPM Control Panel

As explained above, advancing the power lever to increase thrust, as in the transition from low ground idle to takeoff for instance, causes the metering valve to open and permit greater fuel flow through the valve to the engine. The increased fuel flow through the valve causes an immediate rise in downstream (metered fuel) pressure. This increased

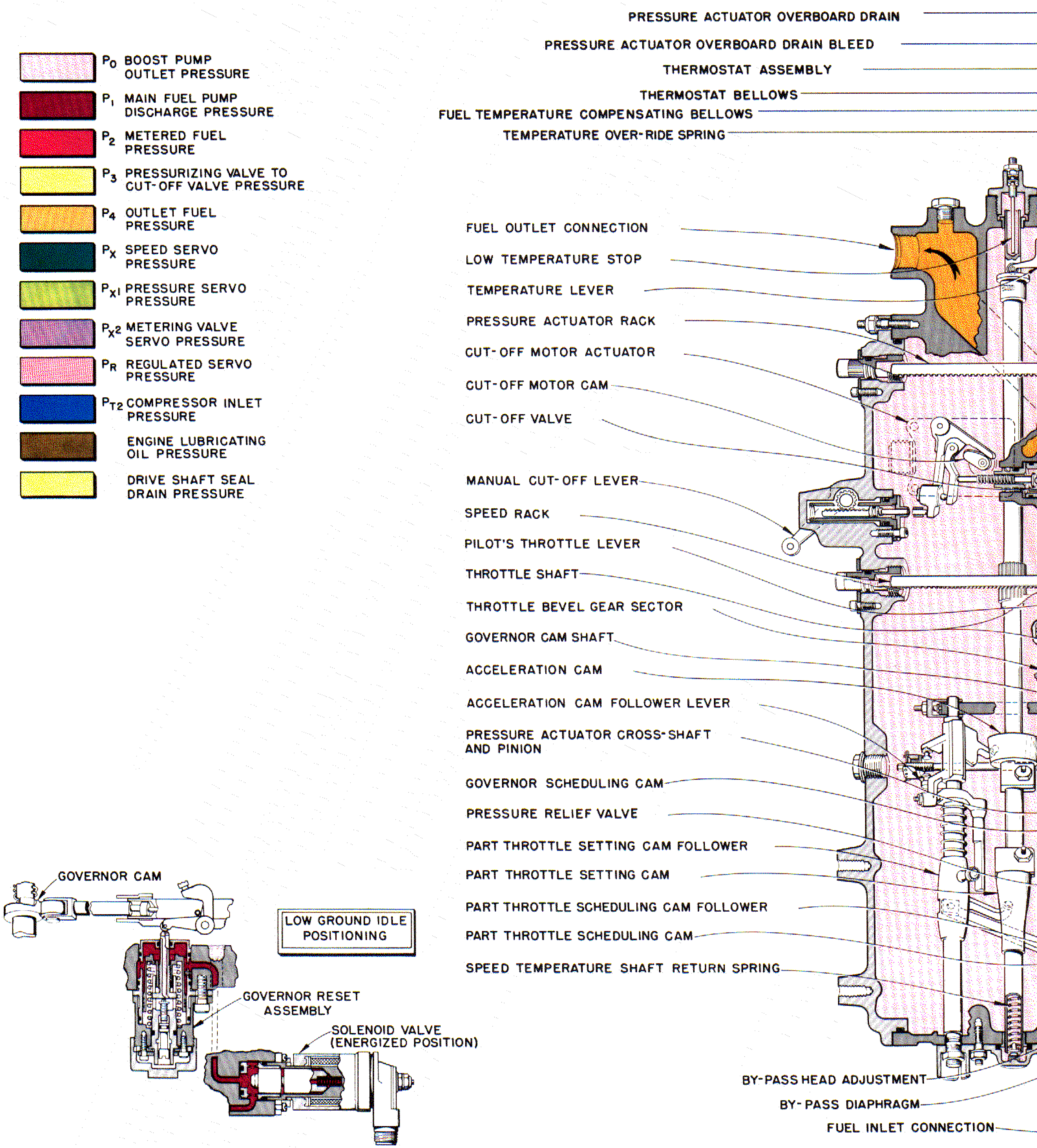
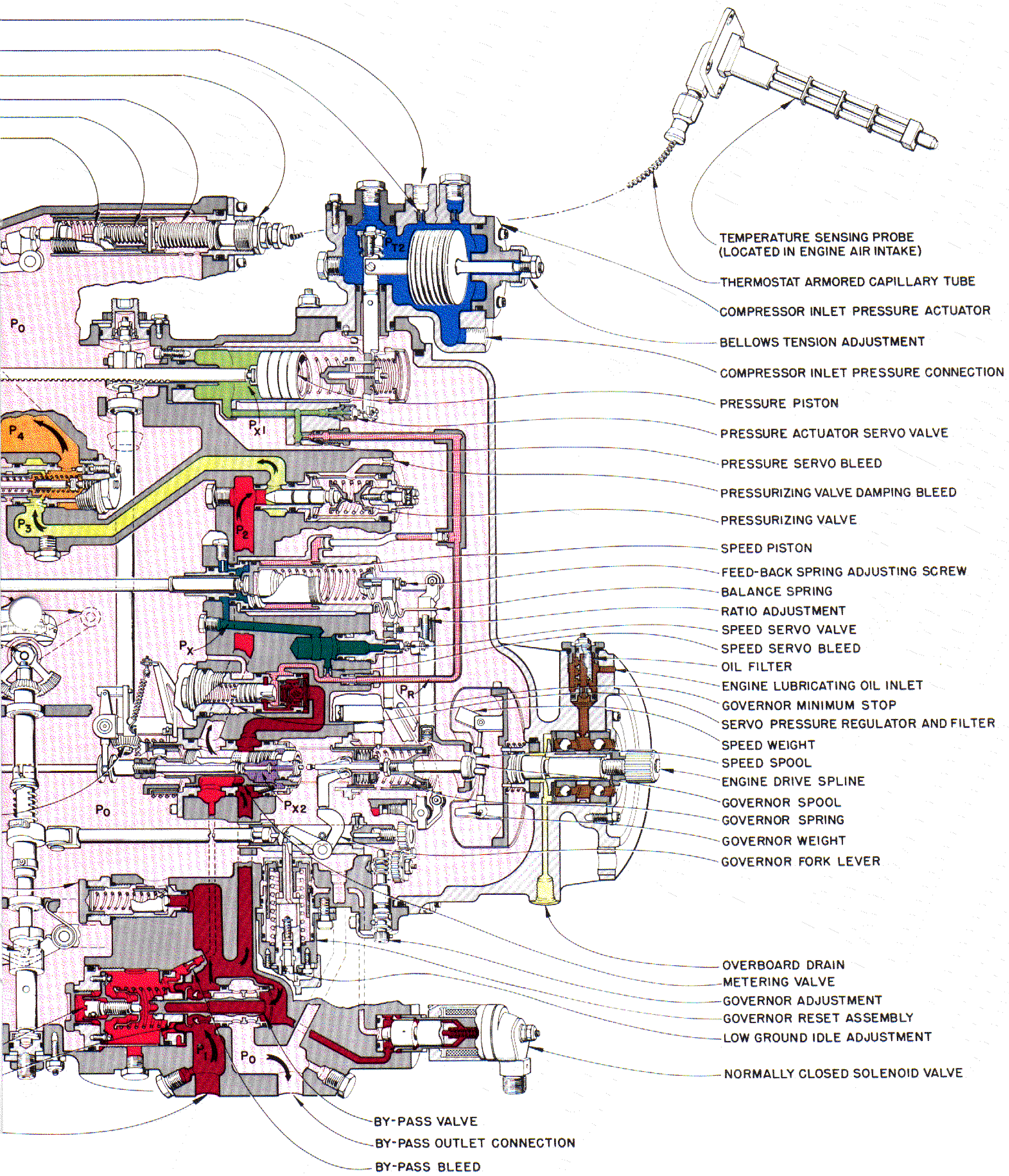
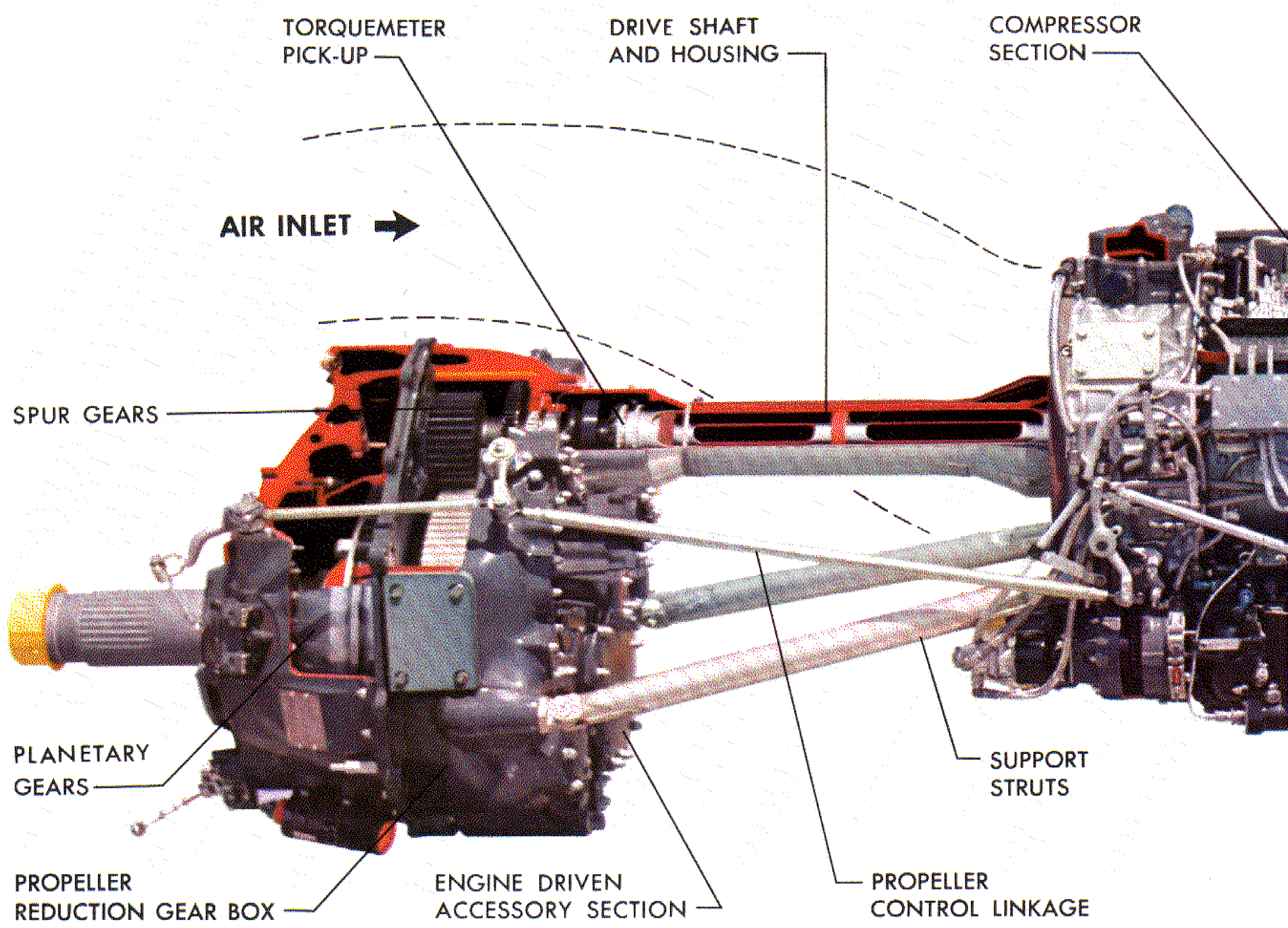


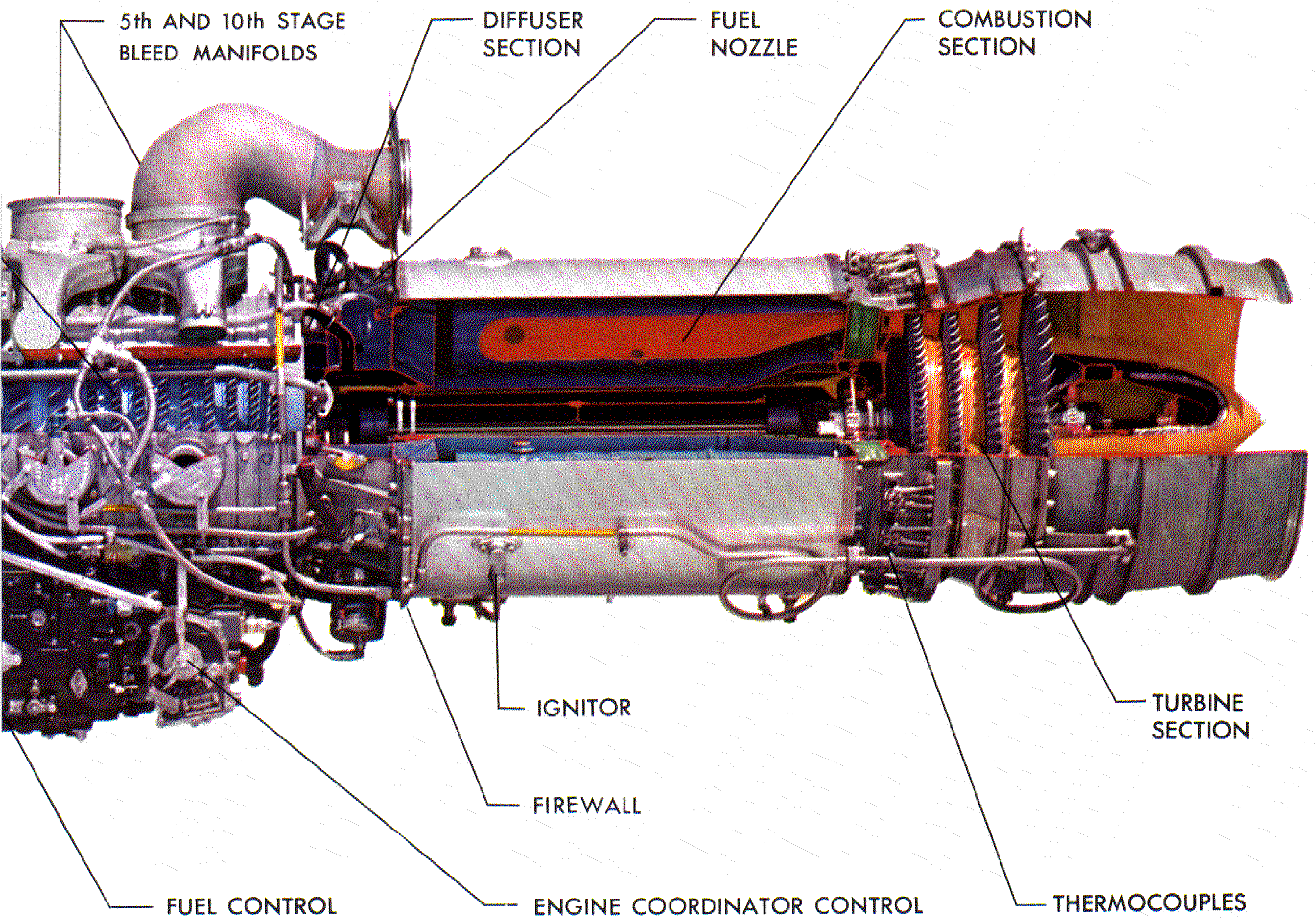
Figure 30b. Fuel Control Schematic


TEMPERATURE SENSING PROBE (LOCATED IN ENGINE AIR INTAKE)
THERMOSTAT ARMORED CAPILLARY TUBE
COMPRESSOR INLET PRESSURE ACTUATOR
BELLOWS TENSION ADJUSTMENT
COMPRESSOR INLET PRESSURE CONNECTION
PRESSURE PISTON
PRESSURE ACTUATOR SERVO VALVE
PRESSURE SERVO BLEED
PRESSURIZING VALVE DAMPING BLEED
PRESSURIZING VALVE
SPEED PISTON
FEED-BACK SPRING ADJUSTING SCREW
BALANCE SPRING
RATIO ADJUSTMENT
SPEED SERVO VALVE
SPEED SERVO BLEED
OIL FILTER
ENGINE LUBRICATING OIL INLET
GOVERNOR MINIMUM STOP
SERVO PRESSURE REGULATOR AND FILTER
SPEED WEIGHT
SPEED SPOOL
ENGINE DRIVE SPLINE
GOVERNOR SPOOL
GOVERNOR SPRING
GOVERNOR WEIGHT
GOVERNOR FORK LEVER
OVERBOARD DRAIN
METERING VALVE
GOVERNOR ADJUSTMENT
GOVERNOR RESET ASSEMBLY
LOW GROUND IDLE ADJUSTMENT
NORMALLY CLOSED SOLENOID VALVE
BY-PASS VALVE
BY-PASS OUTLET CONNECTION
BY-PASS BLEED
PT2
Po
PX1
P4
P3
P2
PX
PR
Po
PX2
P1
Po

ALLISON TURBOPROP ENGINE.

This demonstration engine does not have accessories or modifications for P-3 Orion installation.



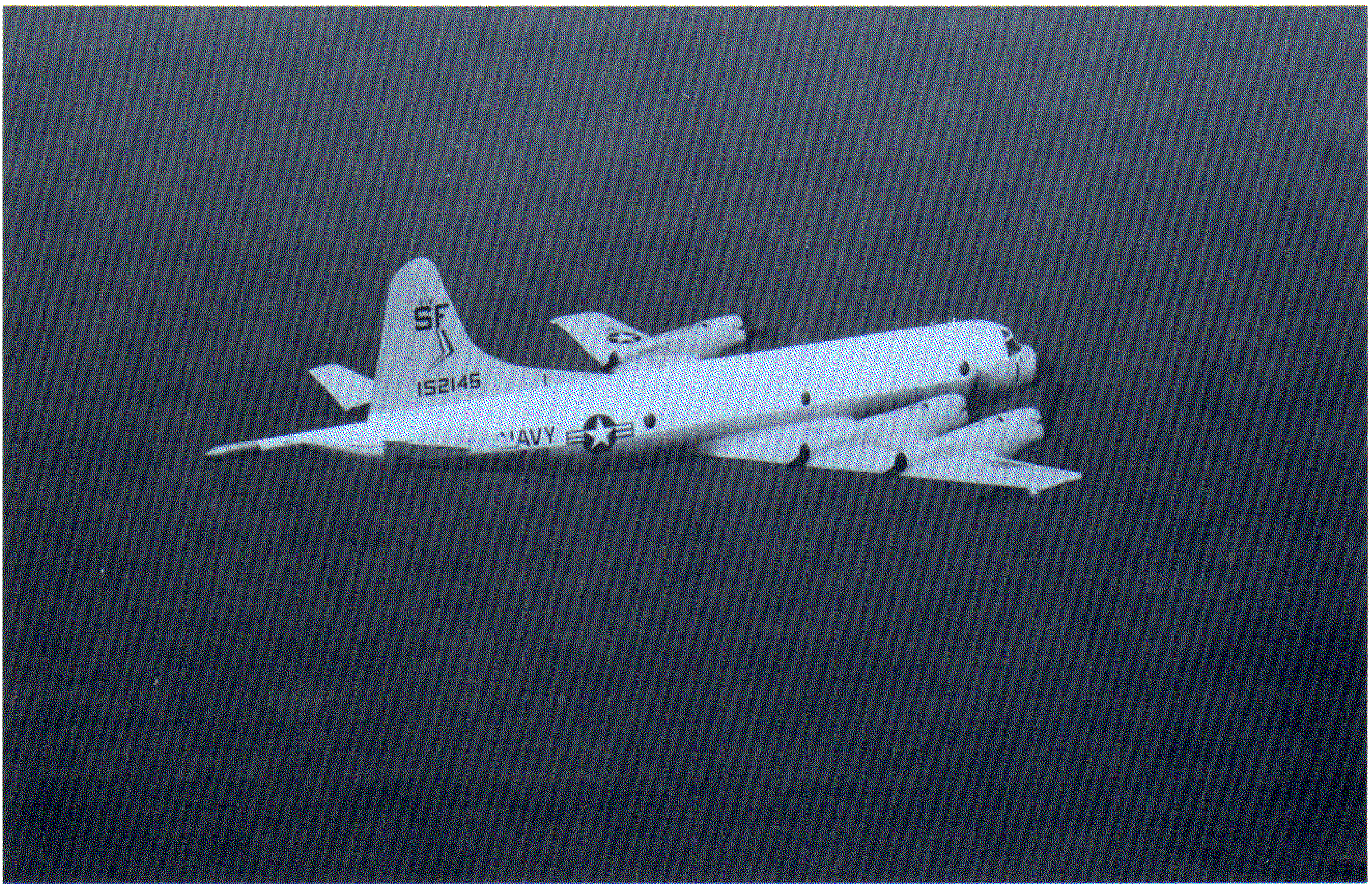

5th AND 10th STAGE BLEED MANIFOLDS
DIFFUSER SECTION
FUEL NOZZLE
COMBUSTION SECTION
IGNITOR
TURBINE SECTION
FIREWALL
FUEL CONTROL
ENGINE COORDINATOR CONTROL
THERMOCOUPLES

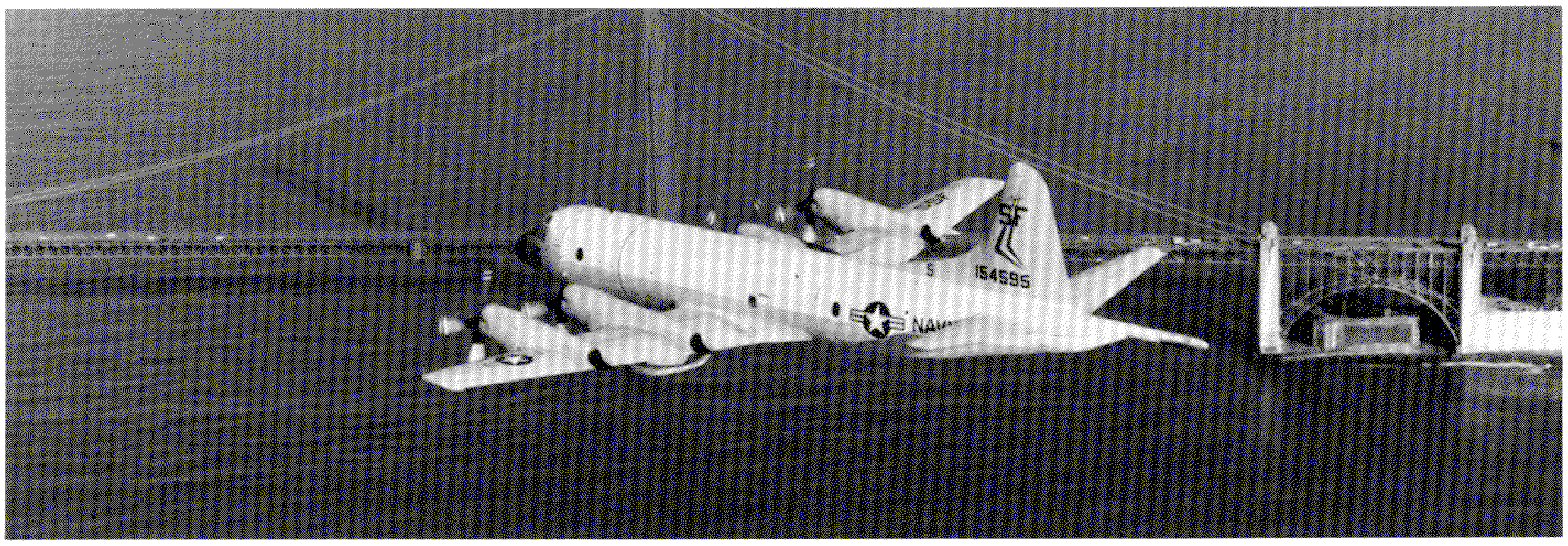
pressure acting on the closing side of the bypass valve diaphragm – inlet pressure does not change – moves the bypass valve toward close, and reduces the bypass flow. With restricted bypass flow, more fuel goes to the metering valve and the 22 psi pressure drop across the valve is regained with greater fuel flow to the engine and a resulting increase in thrust output.

Conversely, when the power lever is retarded to decrease thrust, e.g., from takeoff power to cruise, the action of the fuel control mechanical components is exactly the opposite of that described for power lever advance (thrust increase), except that the coordinator does not signal the cutoff valve actuator motor to close the valve. The metering valve orifice is closed slightly and the engine demands less fuel. This results in a momentary increase in pressure in the bypass valve chamber and upstream (inlet side) of the metering valve with very little increase in metered fuel pressure. Thus, the pressure drop across the metering valve rises. The increased force applied to the bypass valve diaphragm by the inlet fuel opens the bypass valve to allow a greater bypass flow until a stable condition (22 psi pressure drop across the metering valve) is again reached.

The foregoing discussion on metering valve action was much more simplified than is actually the case in operation for the sake of ease in understanding fuel control function (which is always based on the relationship between the bypass valve and the metering valve). Only the metering valve action with respect to power lever movement was discussed, and all aspects of fuel control action such as metering valve response to variations in other operating conditions were left out. In reality, metering valve position is modulated by a number of conditions, either singly or in any combination. Any change in condition that causes a change in engine fuel demand, except power lever movement, results in metering valve modulation through a precise system of servo biasing. The following paragraphs discuss fuel control operation to accommodate engine acceleration demands, engine rpm governing (overspeed, Beta-range, low ground idle), and variations in compressor air inlet pressure and temperature.

The metering valve orifice opening is modulated to answer engine demands in response to operating condition variations by a precise system of servo positioning which utilizes fuel pressure as the power source. In order for the system to operate





with the required degree of precision, the pressure must be regulated within close limits. The servo pressure regulator receives fuel (not pressure regulated) from the fuel control inlet supply and delivers it at a lower (but now closely-regulated pressure) to the speed piston, pressurizing valve, and pressure piston for use in metering valve servo-positioning. Pressure-regulated fuel flow, after being utilized by the servos, is ported into the fuel control housing interior which is open through the bypass return port to the pressure pumps inlet.

Acceleration control during the light-off and acceleration phases of the engine starting sequence requires precise fuel metering to ensure sufficient fuel flow for engine speed increase and, at the same time, to prevent excessive TIT which would result in engine hot section damage. The speed sensitive control works in conjunction with the TD control, as explained previously, to establish TIT limits. Later, the TD control action will be explained in detail. For the purposes of this immediate discussion, an assumption is made that the TD control modulates the fuel flow supplied by the fuel control to accomplish TIT limiting. Fuel flow changes pertinent to speed buildup are initiated by action of the fuel control governor assembly which senses engine rpm.

Regulated fuel pressure is directed from the servo pressure regulator through the speed servo valve. When the valve is open, fuel flow is through the valve into the fuel control housing. As engine (and governor) speed builds up, centrifugal force produced by the governor speed weights, acting through the speed spool, gradually closes the servo valve. As the valve closes, fuel flow is diverted to the speed servo piston chamber. Fuel pressure buildup in the chamber moves the piston and speed rack piston rod against the force of a spring installed on the opposite side of the piston. Note that the governor spool movement also serves to increase spring force slightly as a speed bias factor. The piston and speed rack move laterally; the rack engages a pinion on the speed temperature shaft. As the rack moves, the shaft (and the acceleration cam installed on the shaft) rotates. The acceleration cam follower lever moves the metering valve shaft away from the valve, permitting the spring to open the valve in relation to engine rpm increase.

Metering valve control remains with the acceleration cam follower until the part-throttle cam follower contacts the part-throttle cam and takes over control of the metering valve as the acceleration cam moves away from its follower. This transfer of control occurs at about 94 percent rpm and, at this time, engine fuel flow is on a schedule that is considerably above the engine demand for steady state operation at normal idle speed (97.5 percent rpm). Speed temperature shaft rotation continues until engine speed stabilizes. Because of the part-throttle cam shape, the metering valve is modulated toward close while the engine continues to accelerate. When normal idle speed is reached, fuel flow through the metering valve is on the schedule required for steady-state operation.

Overspeed governing limits engine speed at 104 to 106 percent rpm by reducing the metering valve opening to reduce fuel flow. The metering valve incorporates a poppet-type servo valve in the end toward the governor. During normal (speed stabilized) operation, the metering valve is positioned such that there is no contact between the normally-open servo valve and the governor spool. Fuel control internal pressure (bypass to engine pressure pumps inlet) is admitted across the servo valve to unequal areas of the metering valve. When the engine overspeeds to the governor setting, centrifugal force acting through the governor flyweights and governor spool closes the poppet valve. This causes hydraulic unbalance and the metering valve moves towards the close position, reducing fuel flow (and engine speed) until hydraulic balance is restored. As engine rpm decays, the governor shaft retracts, the servo poppet valve opens, and governing capability is again enabled.

When the metering valve moves toward the close position, its shaft is moved away from the acceleration cam follower lever which mechanically positions the valve in response to power lever movement. In this situation, then, further opening of the metering valve by power lever movement or by the normal automatic functions is prevented. If the power lever is retarded to reduce power, the metering valve is mechanically closed and fuel flow is reduced.

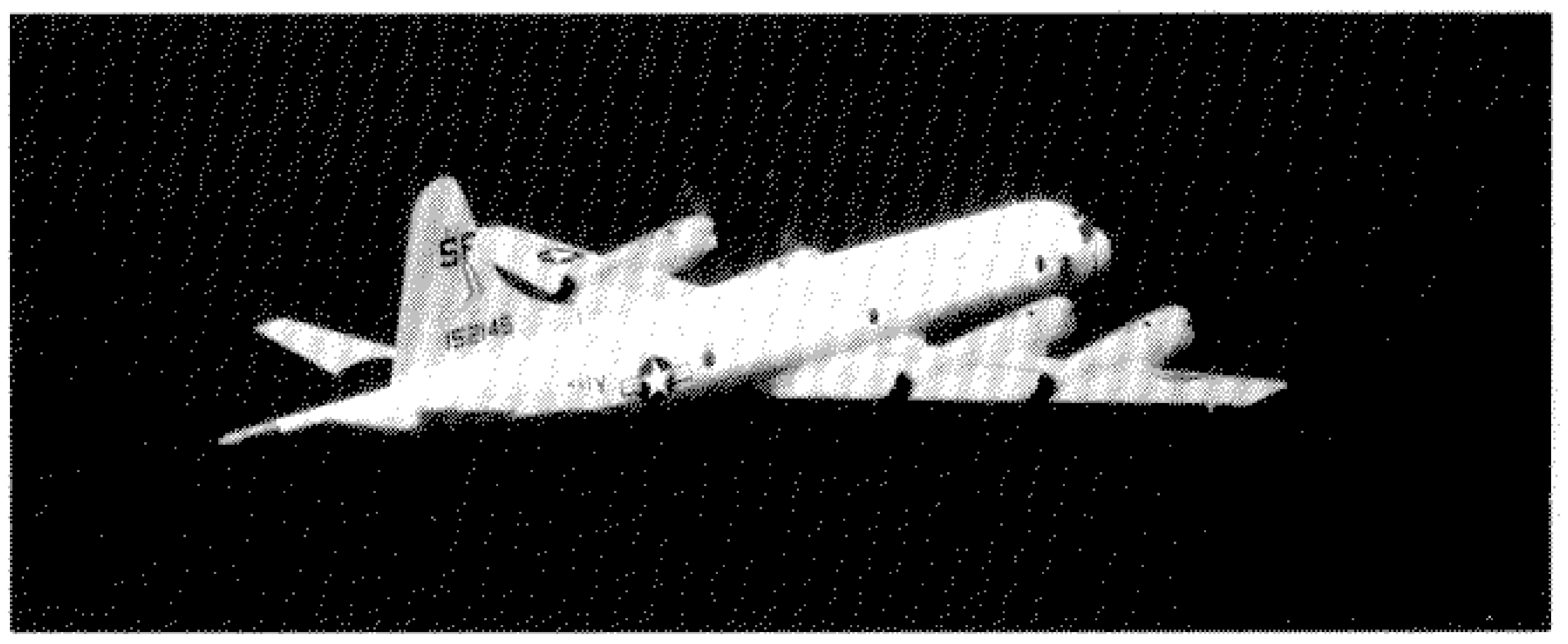
Beta-range governing is a procedure in which the fuel control schedules fuel flow to govern engine speed at approximately 97.5 percent rpm over the portion of the Beta range with power lever settings between 15 and 34 degrees coordinator. Note that while the term "Beta range" defines the range of power lever positions between 0 and 34 degrees coordinator, speed governing in the reverse thrust range (15 to 0 degrees coordinator) is a function of the fuel control overspeed governor, and for full-reverse thrust, engine speed can go to the normal (104 to 106 percent rpm) governed limit.

Beta-range governing is accomplished within the fuel control in the same manner as overspeed governing, i.e., maximum fuel flow is limited to prevent engine overspeed beyond the preset limit. Because power lever movement is not so great, corresponding follow-up actions of the fuel control components are limited. Thus, the metering valve shaft is not pulled away from the valve quite so far as in over-speed operation, valve opening is restricted, and fuel flow is less.

Low ground-idle governing, a fuel-scheduling procedure which limits engine speed to 72.5 percent (10,000) rpm, may be used during certain ground operations – usually on the flight line. Although the power plant can produce sufficient thrust for low-speed taxiing, the engine-driven generator (on engines so equipped) does not produce electric power at this low rpm and engine needs must be supplied from an outside source such as the APU or another engine which is producing electric power. This operational mode, initiated when the RPM switch on the center instrument panel is moved, to LOW, is enabled only when the power lever (in taxi range) holds the lockout switch closed.

The RPM switch completes a circuit through the closed lockout switch (actuated by the power lever) to energize the normally-closed solenoid valve in the fuel control to port inlet fuel pressure from the bypass valve chamber to the governor reset piston chamber. The piston acts through a bellcrank and lever mechanism to lengthen the governor spring and thus lighten its force on the governor spool. This enables the governor flyweights to move the spool at lower engine speed. The fuel control contains a pushrod arrangement (mechanical backup for the power lever operated switch) which is actuated by the governor scheduling cam to reset the governor spring load to normal if the power lever is moved into the flight range while the solenoid is energized.

The fuel control governs engine speed by regulating fuel flow through metering valve action just as in overspeed governing, except that power lever movement in the taxi range does not signal a change in thrust output and thus a change in fuel flow, by changing the TIT schedule (the TD control operates in the temperature-limiting mode). Power lever movement in this range signals thrust output changes by changing the propeller blade angle. This changes the engine load and the fuel control modulates the metering valve opening (fuel flow) as required to limit engine speed to the 72.5 percent rpm value.



Compressor air inlet temperature changes result in changes in mass air flow through the engine, and fuel flow is controlled to compensate for such changes in order to maintain TIT within specified limits. Inlet temperature changes result in corresponding but inverse changes in mass flow, power output, and fuel flow. When air temperature increases, its density becomes less. Thus, mass flow through the engine is reduced. With less mass flow, less fuel is required to heat the air to the same TIT. Power output is also a function of mass flow – a decrease in mass flow results in decreased power. And the exact converse of the above is true – mass flow, power output, and fuel flow all increase when air temperature decreases. Again, with decreasing inlet air temperature, the air is denser and greater mass flow results; the greater mass flow requires more fuel to raise the temperature to the specified TIT and more power is produced.

Compressor air inlet temperature changes are accommodated in the fuel control by action of a thermostat assembly containing an alcohol bellows which responds to air inlet temperature signals received from the temperature sensing probe located in the engine air inlet duct. The thermostat assembly also includes a fuel-temperature compensating bellows, a temperature override spring, and a bellows-operated pushrod and bellcrank mechanism. The assembly is installed in the fuel control case and is submerged in fuel. Because fuel density and mass change quite significantly with temperature changes, the fuel temperature compensating bellows expands or contracts as a function of fuel temperature to bias operation of the thermostat bellows. The temperature override spring provides a secondary bias to balance the spring load on the speed-temperature shaft which is actuated axially, by bellows expansion.

When inlet air temperature increases, the thermostat bellows expands and causes the bellcrank lever assembly to rotate about its pivot. The bellcrank moves the speed-temperature shaft against the force of its spring to carry the acceleration and part-throttle setting cams past their respective followers, in effect moving the followers onto the larger diameters of the cams. Depending on power lever setting and engine rpm, one or the other of the followers actuate the metering valve shaft to pull the metering valve towards the closed position, thereby reducing fuel flow.

When inlet air temperature decreases, the mechanism acts in reverse to open the metering valve and increase fuel flow, except that opening of the metering valve and movement of the speed-lever shaft are effected through spring action rather than mechanical force of the cams and bellcrank mechanism.

Compressor air inlet pressure changes, like temperature changes, result in changes in mass air flow through the engine, and fuel flow is controlled to compensate for such changes in order to maintain TIT within specified limits. The principal causes of air pressure changes are altitude changes and, of course, the ram air effect which is a function of airplane speed. Atmospheric air pressure decreases with a gain in altitude and ram air pressure increases with increase in airplane speed (generally associated with altitude gains). The fuel control action integrates these factors and controls fuel flow as required. Increased inlet pressure is equivalent, in effect, to an increase in density and results in an increase in mass air flow through the engine, and vice versa. The fuel control reacts to these changes by increasing or decreasing fuel flow as required to maintain TIT at the specified value; increasing fuel flow results in an increase in engine power output while decreasing fuel flow has just the opposite effect.

Compressor air inlet pressure is sampled by a ram air pickup tube located in the engine air duct and connected to the aneroid assembly (pressure bellows) in the fuel control by a capillary tube. When inlet air pressure increases, the bellows expands and, acting through a lever, opens the pressure actuator servo valve to admit regulated fuel pressure to the back side of a spring-loaded piston. At the same time, the lever increases spring force on the piston as a pressure increase bias. Fuel pressure acts on the piston to overcome force of the spring and moves the piston and its pressure actuator rack (piston rod). Rack motion is translated through the pinion gear into rotary motion of the pressure actuator cross shaft and a bevel gear on the end of the shaft imparts rotary motion to the metering valve sleeve through the sleeve sector gear to increase fuel flow and engine power output. Note that all other conditions cause axial movement of the metering valve; air pressure changes are the only means by which the valve is opened or closed by radial action.

When air inlet pressure decreases, fuel control actions to actuate the metering valve toward the closed position are the reverse of those explained above.

Fuel flow cutoff to the engine is effected by the electric motor-operated fuel control cutoff valve which provides positive on-and-off fuel flow control for normal engine operations. Valve action is enabled by two (open and closed) cam-operated switches in the valve actuator. Switch and system status at initiation of the engine start sequence (valve closed) is shown in Figure 28a. Note that the "open" switch is closed, but that the motor power circuit from the de-energized fuel control relay is incomplete through the unactuated speed sensitive control. The closed fuel cutoff valve bypasses fuel flow into the fuel control interior cavity which is connected through the bypass port to the pressure pumps inlet. When engine speed reaches 16 percent rpm (Figure 28b), the speed sensitive control low-speed switch actuates to energize the valve motor in the "open" direction. The valve motor runs until the "open" switch trips (Figure 28c) to interrupt power to the motor when the valve is fully open; the "close" switch also trips to enable valve closing at engine shutdown. Fuel flows through the cutoff valve to the TD valve which routes a portion of the fuel flow to the fuel manifold. When the FUEL AND IGNITION switch on the ENGINE STARTING panel is moved to OFF, the fuel control relay is energized, permitting current flow through the "close" switch to energize the valve motor. The motor runs until the "close" switch (and "open" switch) is tripped to interrupt power to the motor when the valve is fully closed. When the valve is open, it can be manually closed by emergency handle actuation.

Starting fuel enrichment, available in the initial phase of the engine start sequence, is a procedure which provides an additional supply of fuel to the engine to ensure reliable starting. Enrichment is accomplished by routing fuel flow directly from the high-pressure filter through the normally-closed, solenoid-operated enrichment valve to the fuel cutoff valve, bypassing all other components and functions of the fuel control. Enrichment is initiated (Figure 28a) when the PRIMER button on the ENGINE STARTING panel (FUEL AND IGNITION switch ON) is depressed. This energizes the primer relay and completes the enrichment valve energizing circuit through the fuel enrichment control relay which is energized through the normally-closed (unpressurized) fuel manifold pressure switch. The enrichment valve opens to permit fuel flow to the cutoff valve which is closed with engine speed below 16 percent rpm. The closed cutoff valve bypasses the fuel flow through the fuel control and back to the pressure pumps as explanined previously. When the speed sensitive control low-speed switch is actuated (engine speed reaches 16 percent rpm), the cutoff valve opens. Fuel then flows through the cutoff valve to the TD valve, and through the TD valve to the fuel manifold. When manifold fuel pressure builds up to 50 psi, the pressure switch opens. The fuel enrichment control relay now drops out and interrupts power to the enrichment valve. The spring-loaded valve closes and shuts off the enrichment fuel flow.

Temperature Datum System

Whereas, the fuel control might be considered to be the heart of the P-3 fuel system, the TD (temperature datum) system constitutes the brains. The TD system, which includes the TD valve, electronic TD control/amplifier, the thermocouples which measure TIT, fuel plumbing, and associated electrical circuitry, receives fuel flow from the fuel control at 120 percent of engine demand throughout the entire operating range. The TD control senses TIT and coordinator (power lever) position, and uses this intelligence to control the TD valve. The TD valve trims the fuel flow oversupply to the exact quantity required to produce the thrust output commanded by the pilot. By regulating fuel flow, the TD system limits or controls TIT to an extremely close degree. The excess fuel flow delivered to the TD valve, but not required by the engine, is bypassed back to the fuel pressure pumps inlet where it joins the bypass return from the fuel control. Note that while the fuel control delivers 120 percent of engine demand fuel flow to the TD valve, the pumps deliver fuel at a rate in excess of 120 percent engine-required-to-run flow to the fuel control. The excess at this stage is also bypassed back to the pumps inlet.

The TD system plays a sophisticated game of "put-and-take" to regulate fuel flow to the engine. In TD system language, the term "put" means that the TD valve, under command of the TD control, uses a part of the 20 percent excess fuel flow which would normally be bypassed back to the pumps to add to the 100 percent normal engine fuel flow for meeting momentary engine demands. "Take" means that the TD valve trims the 120 percent of engine requirements flow from the fuel control by as much as 50 percent to supply the engine with its exact momentary requirements. In the case where the TD valve supplies 100 percent to the engine and bypasses 20 percent back to the pumps, the system is neither "putting" fuel nor "taking" fuel, and the valve is said to be in the "null" or neutral position. As a point of fact, the TEMP DATUM CONTROL switch markings on the right inboard overhead panel are NORMAL (system operative) and NULL (system off). With the switch at NULL, engine parameters (especially TIT) must be monitored very carefully, and in the event of overtemperature (or undertemperature) manual means must be exercised to trim (reduce or increase) fuel flow. (See Figure 31b.)

The TD system operates in either of two modes, temperature-limiting or temperature-controlling. The mode of operation is determined by engine rpm and power lever position.

(a) In the temperature-limiting mode with engine speed below 94 percent rpm and the power lever below 66 degrees coordinator, the 5th and 10th stage compressor bleed valves are open and the TD system maintains a TIT* upper limit of 830°C and has up to 50 percent "take" capability.

(b) Also, in the temperature-limiting mode with engine speed above 94 percent rpm and the power lever below 66 degrees coordinator, the bleed valves are closed and the TD system maintains a TIT limit of 977°C (T56-A-10W engine) or 1083°C (T56-A-14 engine) with "take" capability restricted to 20 percent.

(c) In the temperature-controlling mode, power lever position represents a specific TIT schedule for which the TD control

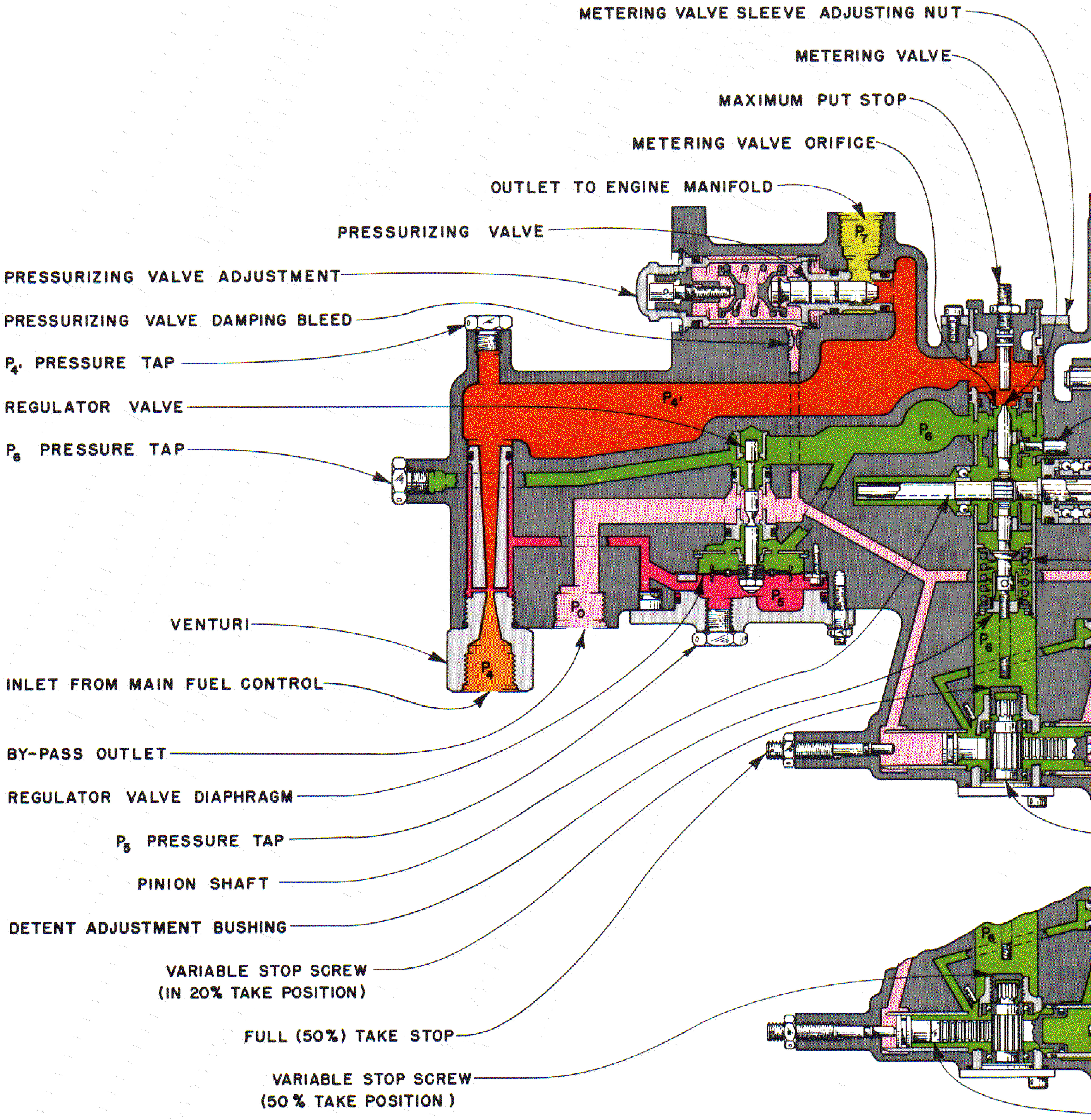
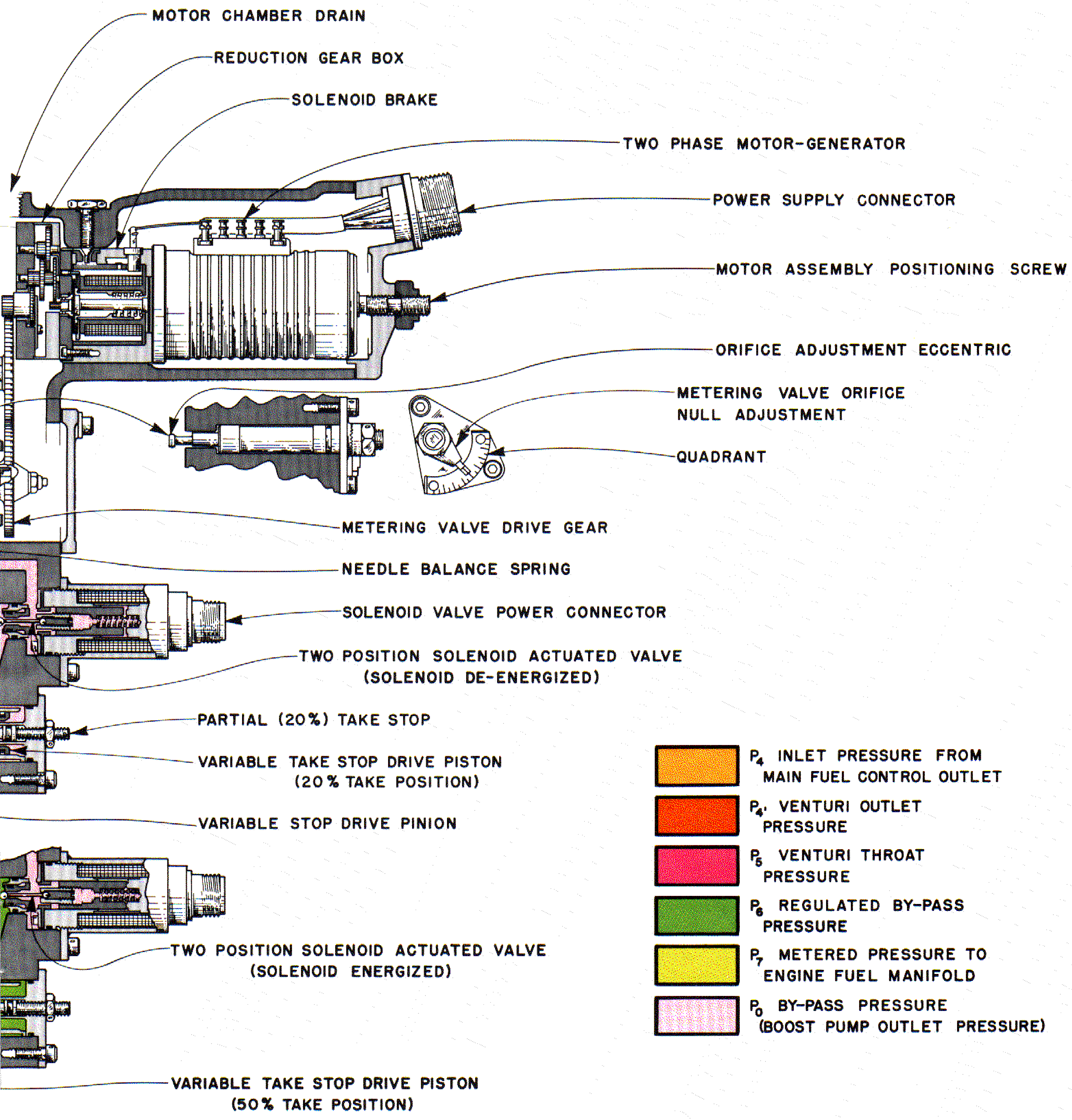


Figure 31a *Temperature Datum Valve Schematic*


MOTOR CHAMBER DRAIN
REDUCTION GEAR BOX
SOLENOID BRAKE
TWO PHASE MOTOR-GENERATOR
POWER SUPPLY CONNECTOR
MOTOR ASSEMBLY POSITIONING SCREW
ORIFICE ADJUSTMENT ECCENTRIC
METERING VALVE ORIFICE NULL ADJUSTMENT
QUADRANT
METERING VALVE DRIVE GEAR
NEEDLE BALANCE SPRING
SOLENOID VALVE POWER CONNECTOR
TWO POSITION SOLENOID ACTUATED VALVE (SOLENOID DE-ENERGIZED)
PARTIAL (20%) TAKE STOP
VARIABLE TAKE STOP DRIVE PISTON (20% TAKE POSITION)
VARIABLE STOP DRIVE PINION
TWO POSITION SOLENOID ACTUATED VALVE (SOLENOID ENERGIZED)
VARIABLE TAKE STOP DRIVE PISTON (50% TAKE POSITION)
🟧 P_4 INLET PRESSURE FROM MAIN FUEL CONTROL OUTLET
🟥 $P_{4'}$ VENTURI OUTLET PRESSURE
🟪 P_5 VENTURI THROAT PRESSURE
🟩 P_6 REGULATED BY-PASS PRESSURE
🟨 P_7 METERED PRESSURE TO ENGINE FUEL MANIFOLD
⬜ P_0 BY-PASS PRESSURE (BOOST PUMP OUTLET PRESSURE)

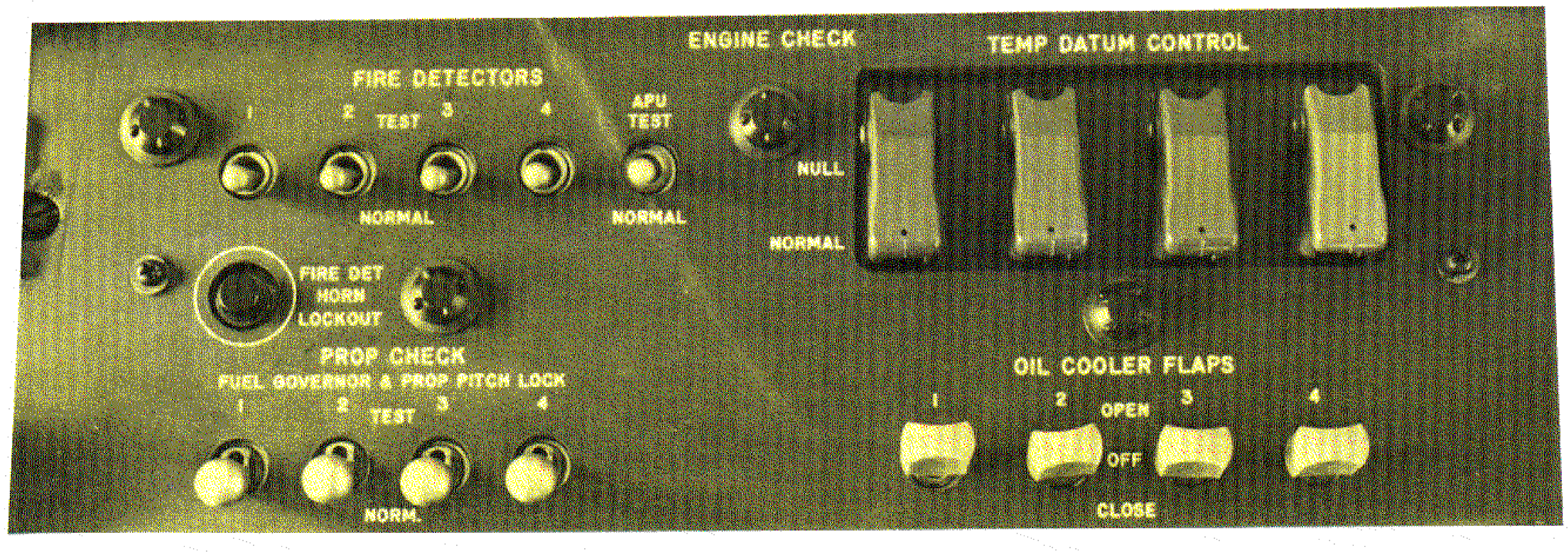


Figure 31b. Engine Check Panel

trims or modulates fuel flow to control TIT. For the T56-A-10 engine, the TIT range is between 760°C at 66 degrees coordinator, and 977°C at 90 degrees coordinator; these TIT range limits are raised for the T56-A-14 engine to 819°C and 1083°C with the power lever at 66 degrees and 90 degrees coordinator, respectively.

The TD valve, shown schematically in Figure 31, is the fuel flow element of the TD system and, as such, it receives the total flow output of the fuel control (120 percent of engine requirements) and divides the flow, as required, between a fuel flow to the engine and a bypass flow back to the pressure pumps inlet. The valve operates to regulate fuel flow as directed by the TD electronic control when the TEMP DATUM CONTROL switch is in the NORMAL position. The valve trims fuel flow by as much as 50 percent as the system responds to varying engine operating conditions.

Fuel flow from the fuel control enters the TD valve through the venturi, and a pressure tap ports venturi throat pressure to one side of the regulator valve diaphragm to provide a regulator valve positioning force that is inversely proportional* to the amount of TD valve inlet fuel flow. Fuel flow from the venturi goes to the pressurizing valve (actually a spring-loaded bypass valve) and to the metering valve. Fuel pressure, acting on the pressurizing valve poppet, overcomes the spring force and opens the valve; a portion of the inlet fuel flow passes through the valve to the TD valve outlet port and fuel flow to the engine is initiated. The pressurizing valve chamber behind the poppet is vented by means of an orificed dampening bleed connection into the bypass flow side of the regulator valve, and then to the TD valve bypass outlet.

The metering needle, in the absence of a motor-operating signal from the TD control, is at the "null" (neutral) position, and thus has a 20 percent "take" capability. This means that 20 percent of the inlet fuel flow passes through the metering valve orifice and experiences a drop in pressure as the result. For purposes of this discussion which describes how the "null" position is attained, fuel flow through the orifice is designated as metered fuel flow.

Metered fuel flow goes to the regulator valve, which is closed because of venturi throat pressure acting on the diaphragm, and to the other side of the diaphragm where its opening force (because of greater pressure) overcomes the closing force exerted by venturi throat pressure and opens the regulator valve to bypass the fuel "taken" by the metering valve to the TD valve bypass outlet. With bypass flow established, metered fuel pressure is further reduced and the regulator valve modulates in response to the balance of forces (metered fuel pressure versus venturi throat pressure) acting on the diaphragm to permit bypass fuel flow from the TD valve. When the forces are in balance, a regulated orifice-to-bypass excess fuel flow through the

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**Venturi throat pressure decreases as fuel flow (pressure) through the venturi increases. In this discussion, no attempt has been made to follow venturi throat pressure fluctuations and their interrelationship with other TD valve components and conditions even though, in reality, these fluctuations are quite important in TD valve operation.*

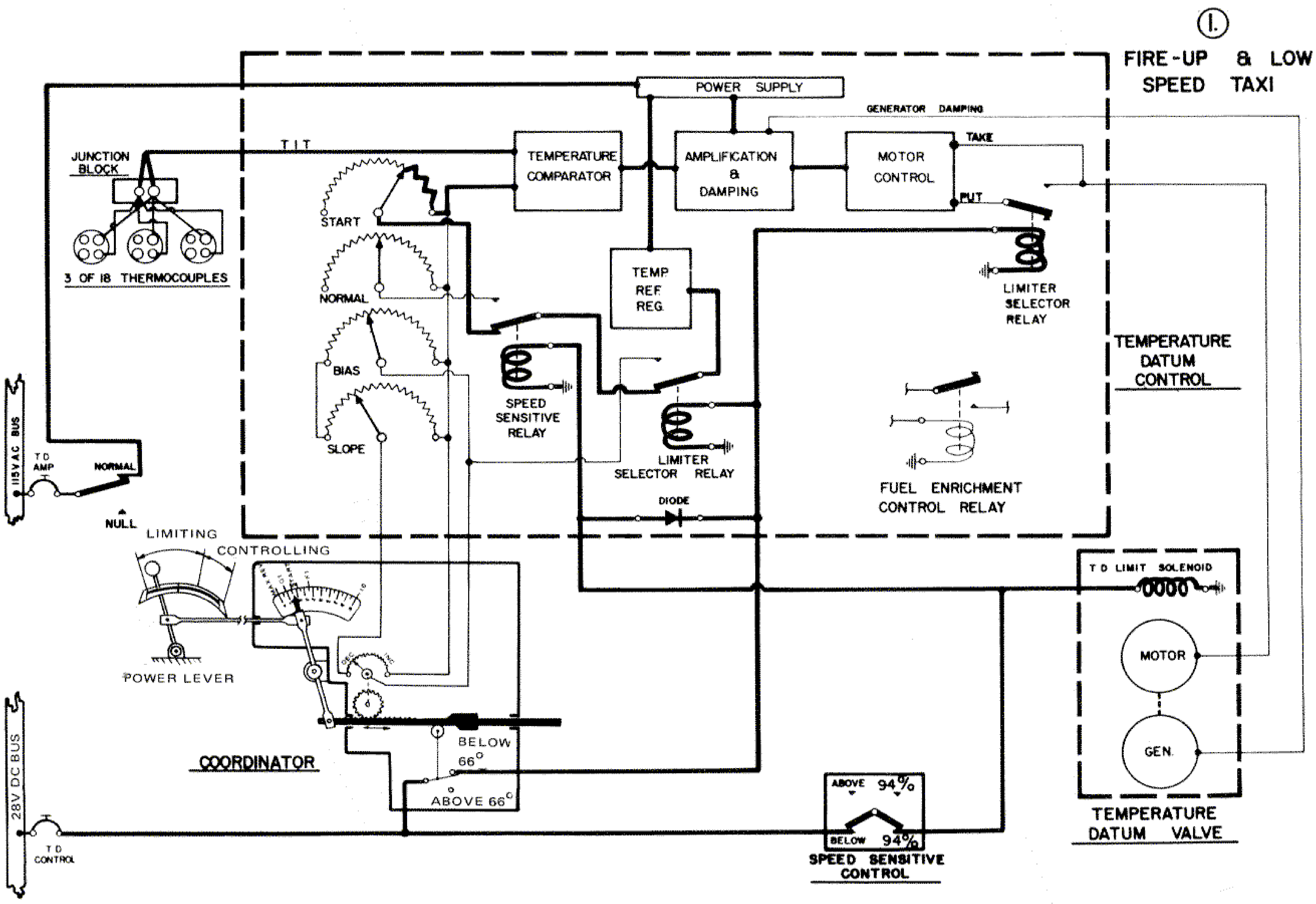
regulator valve and the required pressure drop across the metering valve to trim off excess fuel flow are established. At this balanced condition, the pressure rise from the venturi throat to the venturi exit equals the pressure drop across the metering valve and 20 percent of the TD valve inlet fuel flow from the fuel control is bypassed back to the pressure pumps inlet.

Fuel flow through the metering valve also goes to one side of the solenoid valve and to one side of the "take" stop drive piston. The solenoid valve is closed when de-energized, and metered fuel pressure acting on the drive piston forces it against the adjustable 20-percent "take" stop. The drive piston incorporates gear rack teeth which engage a pinion that has a threaded shaft. The shaft is threaded into the variable-stop screw which is held from rotating as the pinion rotates when the piston moves. With the piston against the 20-percent "take" stop, the stop screw is extended to its limit, applying the maximum preload to the needle balance spring and restricting metering needle movement (metering valve orifice opening), and thus the amount of fuel that can be "taken" from the engine fuel flow (flow through the metering valve orifice) and bypassed to the pressure pumps is limited to 20 percent of the TD valve inlet flow.

In the starting and acceleration phases of engine operation, the solenoid valve is energized through the high-speed (94-percent rpm) switch in the speed sensitive control as shown in Figure 32a. The solenoid valve opens permitting the flow of metered fuel to the other side of the "take" stop drive piston, moving the piston against the adjustable 50-percent "take" stop. The piston, through its gear rack, rotates the pinion threading it into the variable-stop screw. The stop screw is now retracted to its limit, lightening the preload on the needle balance spring and permitting the metering needle to move away from the orifice so that up to 50 percent of the TD valve inlet flow can be "taken" and bypassed back to the fuel pumps.

The TD control includes an internal power supply and four electronic boxes, temperature comparator, temperature reference regulator, amplification and damping unit, and TD valve motor control. In addition to the electronic elements and associated wiring, the control also includes:

Figure 32a. Engine Turbine Inlet Temperature Trim System Schematic



(a) Four potentiometers (start, normal, bias, and slope) which assist in determining the operational mode, temperature limiting or temperature controlling; the potentiometers establish the TIT limit during the limiting mode and the TIT schedule to be maintained during the controlling mode.

(b) A speed-sensitive relay which routes temperature reference regulator signals to the start potentiometer or normal potentiometer, depending upon coordinator position (power lever setting) and speed sensitive control status (engine speed).

(c) Two limiter selector relays. One, when energized, routes the temperature reference signal to the speed sensitive relay, or when de-energized, directly to the movable contact of the bias potentiometer. The second relay, when energized, completes the "put" circuit from the motor control to the TD valve motor.

(d) A fuel enrichment control relay which controls the enrichment valve but is not used for TD operation in either temperature limiting or temperature controlling.

The TD control power supply is energized from the 115-volt MONITORABLE ESSENTIAL AC BUS through the two-position (NORMAL, NULL) TEMP DATUM CONTROL switch on the right inboard overhead panel to provide electrical power to the temperature reference regulator and the amplification and damping unit, and through the latter, to the TD valve and TD motor control.

The temperature reference regulator is energized from the power supply and provides a signal to appropriate potentiometers. The signal circuits are controlled by the limiter selector relay and the speed sensitive relay.

The amplification and damping unit is energized directly from the power supply, receives control signal inputs from the temperature comparator, and produces actuation signals to the TD valve motor.

The temperature comparator receives input signals representative of the actual momentary TIT from the thermocouples. Simultaneously, it receives signals from the coordinator potentiometer and the TD control potentiometer which represent either the TIT limit (temperature-limiting mode) or the desired TIT schedule (temperature-controlling mode). The unit compares these signals and outputs a control signal to the amplification and damping unit.

The TD control operates in the temperature-limiting mode during the engine starting and acceleration phase until engine speed reaches 94 percent rpm. Figure 32a illustrates TD control circuitry status during engine starting. Temperature limiting is desirable in these operational phases because overrich fuel mixtures could result in excessive TIT and damage to the engine "hot" section. TIT limits are lower for the initial phases of engine operation than they are after the engine has thoroughly warmed up; excessive TIT impinging on relatively cool parts or on parts at uneven temperatures, e.g., first stage turbine blades, can result in distortortion and serious damage. Also, because the 5th and 10th stage bleed valves are held open to permit faster engine acceleration, the mass air flow through the combustors and turbine is less and the turbine components are much more vulnerable to excess TIT than is the case where the bleeds are closed. Therefore, the TD system limits TIT to 830°C. Even after engine speed reaches 94 percent rpm, the TD control continues to operate in the temperature-limiting mode as shown in Figure 32b until the power lever is advanced beyond the 66 degree coordinator position when actuation of the coordinator switch initiates the transition to the temperature-controlling mode.

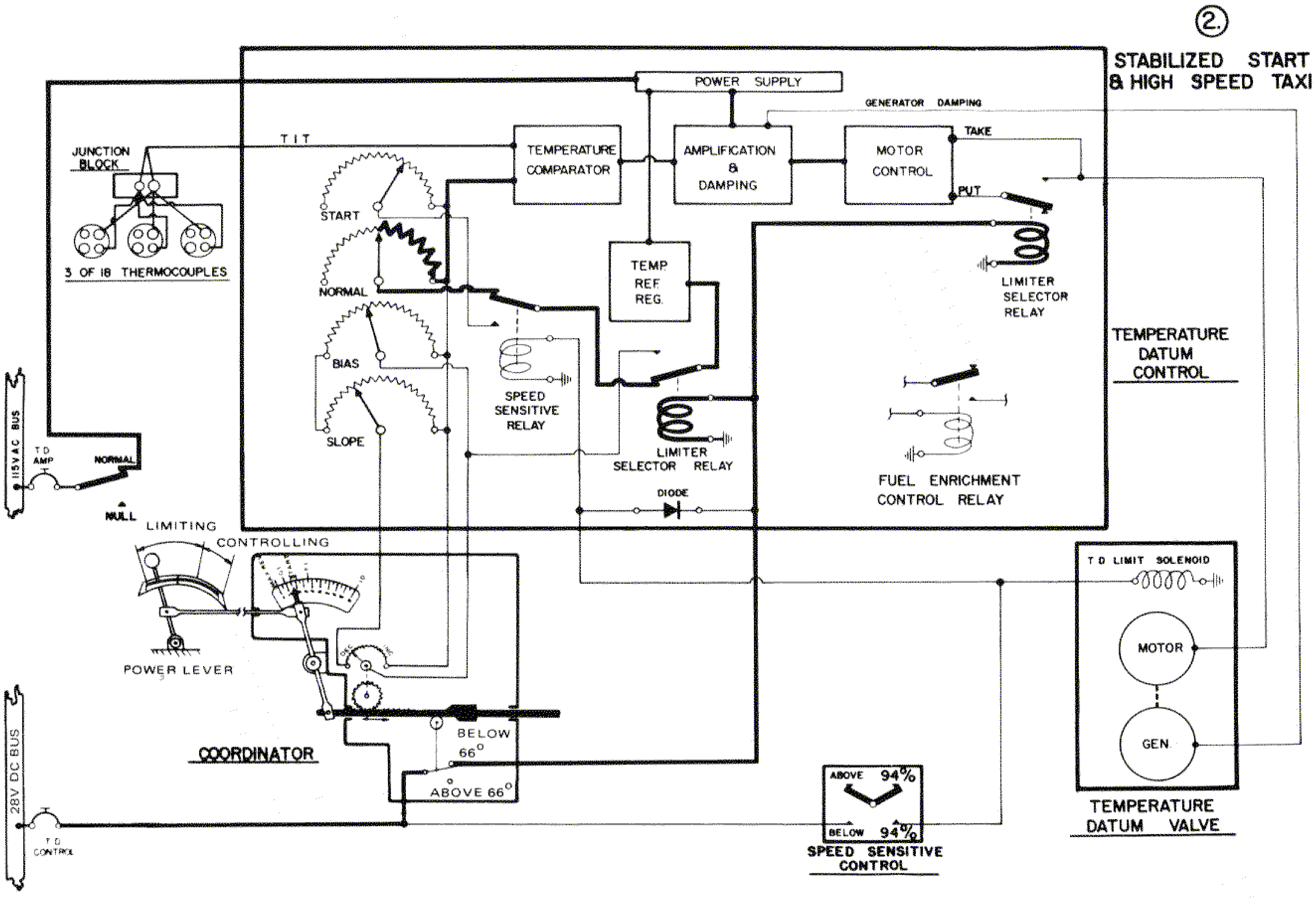
TD control system operation with the TD control switch at NORMAL (Figure 32a), the TD limit solenoid and the speed sensitive relay are energized from the 28-volt START DC BUS through the high-speed (94 percent rpm) switch in the speed sensitive control. And, with the power lever retarded below the 66-degrees coordinator position, the limiter selector relays are energized from the same bus through the coordinator switch. The first limiter selector relay routes a temperature reference signal through the speed sensitive relay to the movable (adjustable) contact of the start potentiometer. The potentiometer is adjusted so that its effective resistance represents the 830°C TIT limit to be maintained until engine speed reaches 94 percent rpm and its output signal is sent to the temperature comparator. The thermocouples produce continuous signals which reflect actual momentary TIT; this signal is also sent to the comparator unit. The second limiter selector relay interrupts the motor control "put" signal to the TD valve motor; therefore, the TD control has no "put" capability while operating in the temperature-limiting mode although it does have up to 50 percent "take" capability when the TD valve is energized. Note that the motor control "take" circuit to the TD valve motor does not include a switch.

If the temperature comparator determines from the thermocouples signal that the actual TIT is 830°C, or less, there is no control action, the TD metering valve is "nulled" (neutral), 20 percent of the TD valve input fuel flow from the fuel control is bypassed back to the pressure pumps inlet, and 100 percent fuel flow is routed to the engine to meet its demands.

However, if actual TIT is higher than the preset limit, the comparator produces a "take" fuel signal output to the amplification and damping unit which amplifies the signal and transmits it as a metering valve opening signal to the motor control. This unit then signals motor operation to open the metering valve and bypass more fuel (up to 50 percent of the TD valve input flow) to the pressure pumps inlet, thereby reducing flow to the engine with a consequent reduction in TIT. As the motor runs to open the metering valve, the generator produces a feedback signal to the amplification and damping unit. This signal is used by the amplification and damping unit to modulate motor speed, and to prevent motor overrun and hysteresis as TIT is reduced. When TIT is reduced to 830°C, the TD control circuitry "nulls" the metering valve and bypass fuel flow is once more at the normal 20 percent level.

When engine speed reaches 94 percent rpm with the power lever below 66 degrees coordinator as shown in Figure 32b, the speed sensitive valve high-speed (94 percent rpm) switch opens interrupting the energizing circuit to the TD limit solenoid and the speed sensitive relay. The de-energized limit solenoid reduces the "take" fuel capability to 20 percent. The speed sensitive relay drops out and switches the temperature reference signal to the sliding (adjustable) contact of the normal potentiometer. This introduces a new and higher TIT upper limit (977°C for the T56-A-10W engine and

Figure 32b. Engine Turbine Inlet Temperature Trim System Schematic



1083°C for the T56-A-14 engine). Again, when actual TIT is at, or below, the established limit, there is no control action and the TD valve bypasses 20 percent of the inlet fuel flow from the fuel control back to the pressure pumps inlet.

If actual TIT exceeds the established limit, the TD control operates to reduce TIT by "taking" fuel from the engine flow and bypassing the "taken" fuel, along with the normal 20 percent bypass flow, back to the pressure pumps inlet. The operation is identical to that described previously except that the "take" capability is limited to 20 percent of the TD valve inlet fuel flow from the fuel control.

Now, with engine speed above 94 percent rpm, the TD control system is transitioned to the temperature-controlling mode (Figure 32c) when the power lever is advanced beyond the 66 degrees coordinator position and the following system conditions are set up:

(a) The coordinator switch is opened.

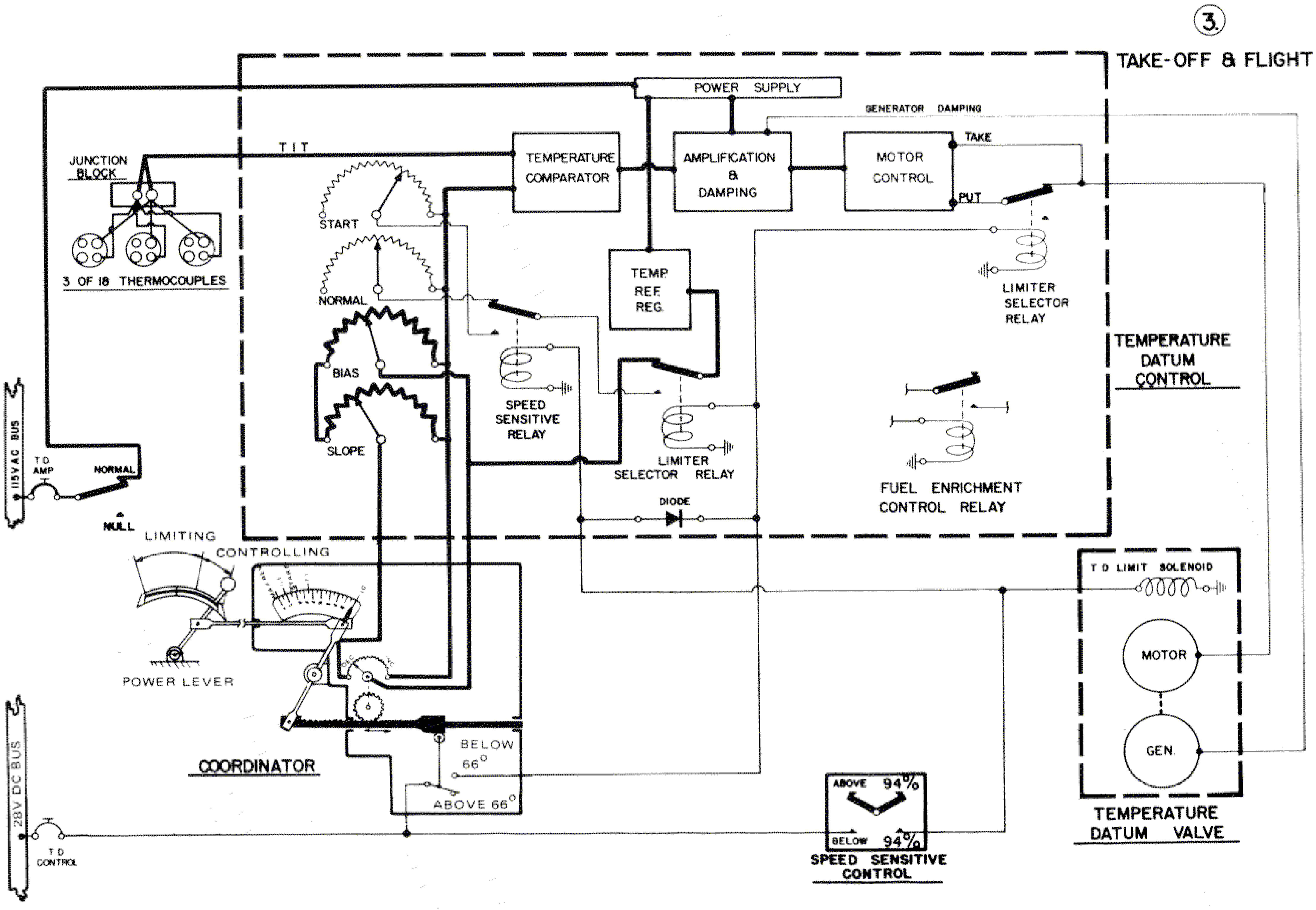
(b) The limiter selector relays are de-energized.

(c) The temperature reference regulator output signal is removed from the normal potentiometer and is applied, through the first limiter selector relay contacts, to the sliding contacts of the coordinator potentiometer and the TD control bias potentiometer.

(d) Fixed contacts of the bias, slope, and coordinator potentiometers are connected in parallel to provide a variable TIT schedule which is related to power lever positions between 66 degrees and 90 degrees coordinator for use by the temperature comparator as a control reference. The potentiometer signal at the time of coordinator switch actuation (66 degrees) represents a TIT of 760°C for the T56-A-10W engine and 819°C for the T56-A-14 engine. The upper limits with the power lever at 90 degrees coordinator are 977°C and 1083°C, respectively for the two engines.

(e) The motor control "put" signal circuit is completed through the second limiter selector relay contacts to the TD valve

Figure 32c. Engine Turbine Inlet Temperature Trim System Schematic



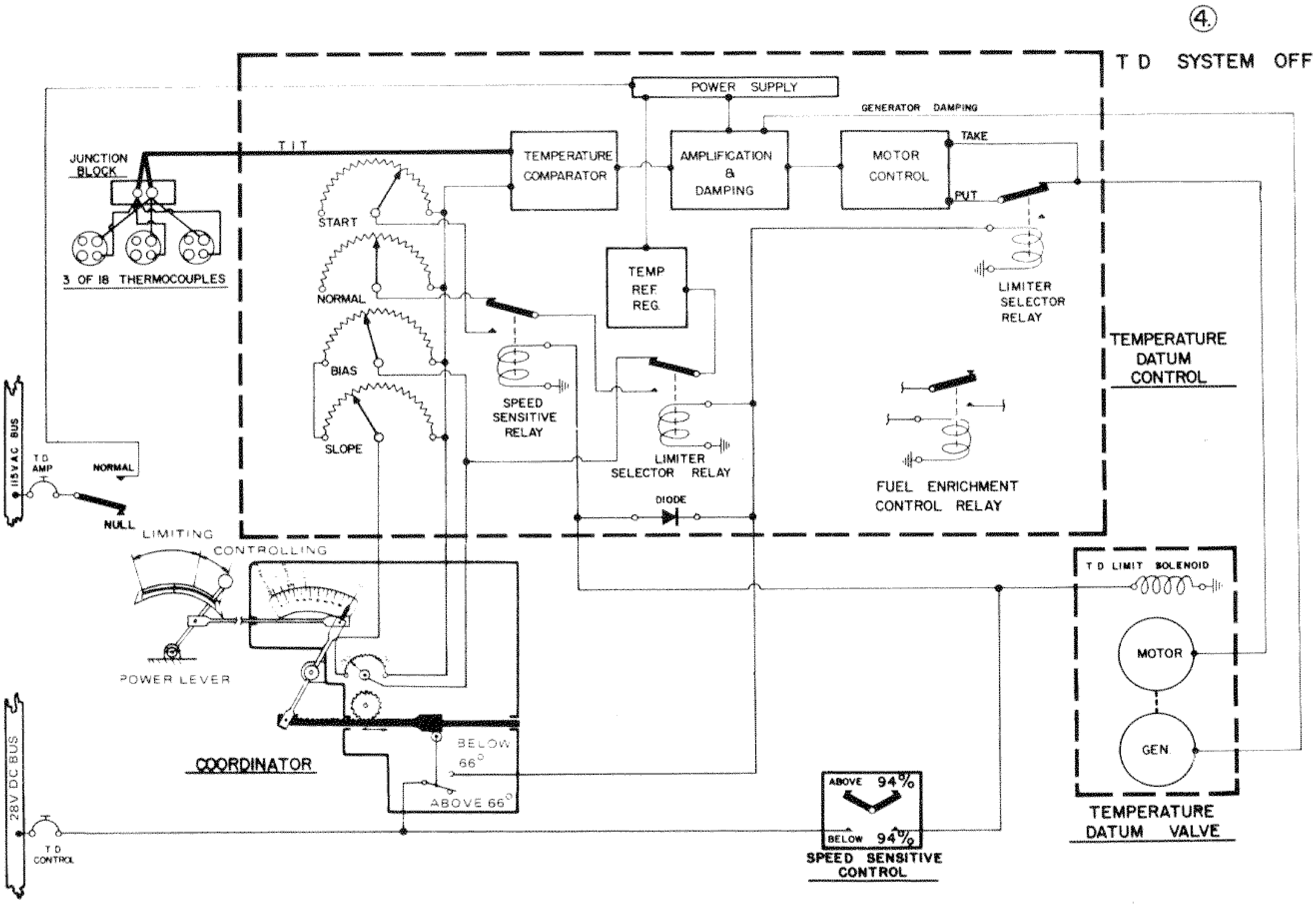


Figure 32d. Engine Turbine Inlet Temperature Trim System Schematic

motor. This enables the system to "put" or add fuel from the normal 20 percent bypass flow into the engine fuel flow to correct a low TIT condition. The "put" capability is limited to 15 percent to ensure that fuel flow from the fuel control, at 120 percent of engine demand, is always in excess of the actual amount being supplied to the engine. Note that transition to temperature-controlling operation does not change the "take" capability.

When the temperature comparator determines that actual TIT is below the scheduled value for any power lever position between 66 degrees and 90 degrees coordinator, it produces a "put" fuel signal to the amplification and damping unit which amplifies the signal and transmits it as a metering valve closing signal to the motor control. This unit then signals motor operation to close the valve and reduce bypass fuel flow to the pumps inlet, thereby increasing fuel flow to the engine by as much as 15 percent with a consequent increase in TIT. As the motor runs to close the metering valve, the generator produces a feedback signal which is used by the amplification and damping unit to modulate motor speed (valve change rate), prevent motor overrun, and control hysteresis as the TIT deficiency is corrected. When TIT is increased to the scheduled value, the TD control circuitry "nulls" the metering valve and bypass fuel flow is once more at the normal 20 percent level.

When the actual TIT is equal to the scheduled value there is no control action, the TD valve is "nulled", 20 percent of the TD valve inlet fuel flow from the fuel control is bypassed back to the pressure pumps inlet, and 100 percent fuel flow is routed to the engine to meet its operating demands.

If the actual TIT exceeds the scheduled value, the comparator produces a "take" signal output to the amplification and damping unit. Subsequent functioning of the TD control system is the same as for the low TIT condition, except that the metering valve is opened to increase the bypass fuel flow by "taking" up to 20 percent of the engine fuel flow. As the engine fuel flow is decreased, TIT is reduced.

The engine can be operated in all its phases from startup to shutdown with the TD control system inoperative (Figure 32d), in the event of TD system malfunction. The TEMP DATUM CONTROL switch is placed in the NULL position to interrupt electrical power to the system. The thermocouples supply a TIT signal to the combination dial-type and digital-reading indicator (calibrated in degrees Centigrade) on the center instrument panel. Control of engine fuel flow, and thus TIT, is accomplished by power lever manipulation. Movement of the power lever results in movement of the fuel control input lever to increase or decrease fuel flow output to the TD valve. Even with the electronic elements shut down, the TD valve bypasses the normal 20 percent of the fuel flow it receives from the fuel control back to the pumps inlet, and provides the engine with 100 percent for its operational needs.

Thermocouples and Harness

The engine incorporates a thermocouple sensing system. Signals from this system are utilized by the electronic trimming system and by the flight deck TIT indicating system.

Eighteen dual thermocouple assemblies attached to the turbine inlet casing extend into the outlet of the combustion liners. Therefore, there are three thermocouple assemblies for each combustion liner. The location and number provide a good sampling of the gas temperature.

The shrouded type thermocouples contain two separate but identical thermocouple junctions. Two holes in the probe allow hot gasses to enter, flow over the junctions and exit through one hole. Thus hot gasses don't impinge directly on the junctions.

A thermocouple may be described as a thermoelectric generator. The junctions consist of dissimilar metals and when heat is applied, a small electromotive force is generated. And as temperature increases, the EMF increases. One of the junctions sends a signal to the TIT indicator while the other sends a signal to the TD control (amplifier). The thermocouples are wired in parallel to produce an average TIT signal.

A harness provides a means of connecting the thermocouples in parallel. For ease of removal and installation, it is divided into LH and RH harness assemblies. The LH harness receives its signals from the thermocouples in combustion liners 4, 5 and 6, while the RH harness receives its signals from the thermocouples in combustion liners 1, 2 and 3.

A terminal block connects the LH and RH harness assemblies completing the circuits, with each circuit having 18 thermocouples connected in parallel. From the terminal block one set of leads goes to the TIT indicator and the other set is connected to the temperature datum amplifier.

Flowmeter

The fuel flow indicating system installed on the P-3 is quite accurate, and measures the mass of flow rather than volume. Consequently, it reports the weight of flow per hour to the engine regardless of the density of the fuel, or which fuel is being used. (See Figure 33).

All components are energized from phase B of MAIN AC BUS A through the FUEL FLOW IND circuit breaker. The four synchro transmitter/indicator branches of the system utilize the power directly and in conventional fashion. However, the 400 Hz bus power is altered by the fuel flow power supply unit in the main load center to provide a 6 Hz output* which is used to drive a low-speed motor in each transmitter assembly, one of which is mounted at the right side of each engine.

The transmitter motor turns an impeller turbine near the inlet of the assembly at constant rpm. The impeller is not a pump, that is, it does not produce a flow, but it does impart a swirl to the fuel flow. The swirling fuel impinges on the blades of a stator turbine downstream of the impeller, and the helical flow is straightened in passing through the stator turbine. As its name implies, the stator turbine does not revolve, but it is restrained only by a torsion spring so it can yield to the momentum of the swirling fuel, rotating and coming to rest at whatever position the torque imparted by the swirling fuel is balanced by spring force. The synchro system senses the angular displacement of the stator turbine and reflects the displacement at the indicator hand of the fuel flow gage in the flight station. Gage calibrations range from 0 to

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**Beginning with BUNO 152187, the 6 Hz power is obtained by use of transistor-switching circuits instead of the motor-driven, commutator-switching arrangement used previously. The two types of power supply units are both physically and functionally interchangeable, the only difference being the substitution of solid-state components for the moving components in the earlier model.*

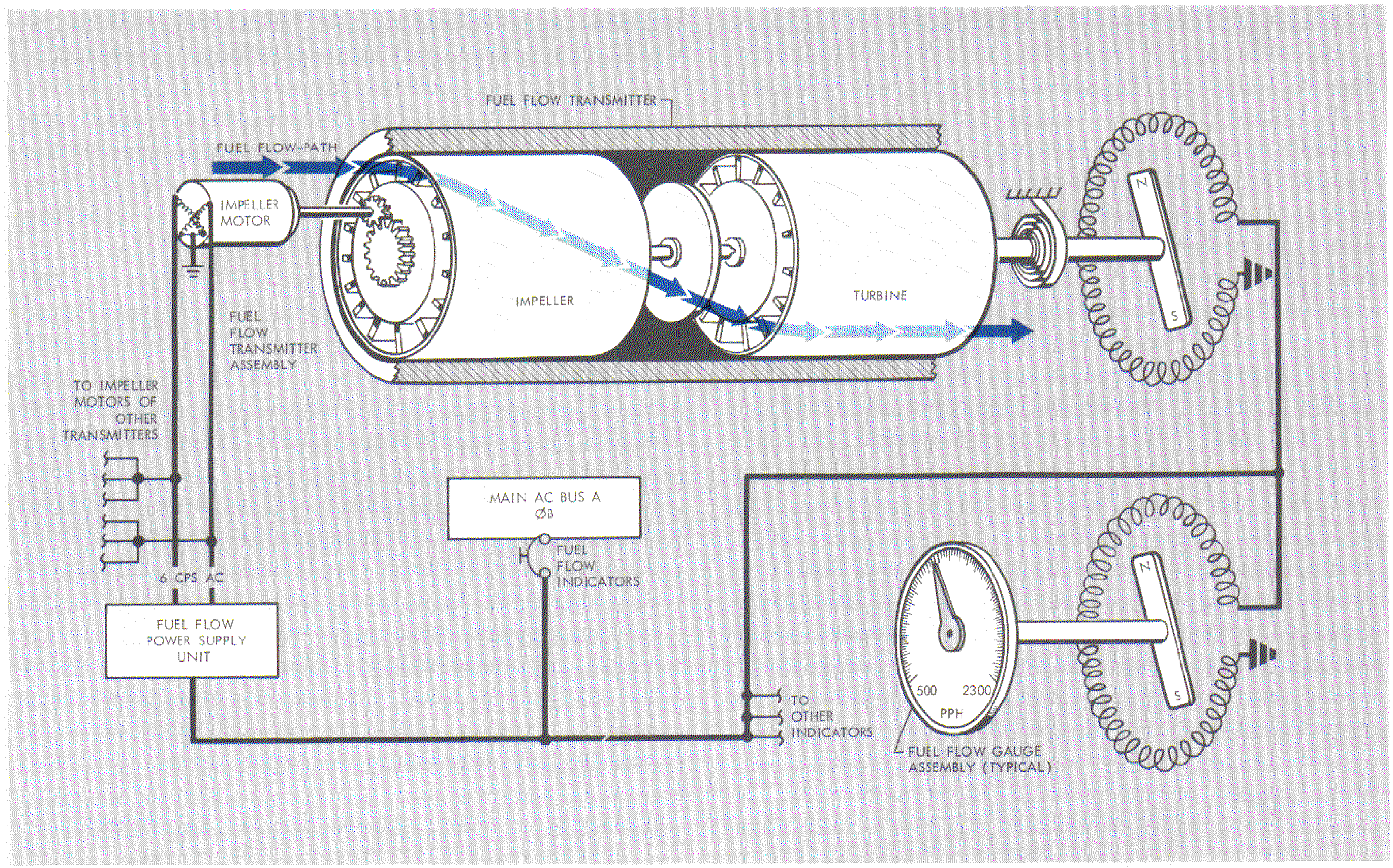


Figure 33. Fuel Flowmeter Power, Transmitter, and Indicator Schematic.

2300 pounds per hour. The system requires little regular maintenance, but it should be noted that the entire system remains operational and the motor-impeller assembly rotates continuously so long as MAIN AC BUS A is energized. The flowmeter is cooled and lubricated by fuel and can be damaged if operated without it. For this reason it is necessary that the power unit be de-energized by pulling the FUEL FLOW IND circuit breaker when maintenance requires draining any transmitter.

Fuel Manifold and Nozzles

The fuel manifold consists of a Y-fitting and short sections of flexible high-pressure hose connecting the nozzles in two series of three each. A drain valve in the bottom of the manifold is spring-loaded open and solenoid closed. The solenoid is energized closed by the 16-percent switch (in the speed sensing control) and de-energized by the 65-percent switch. However, the valve will remain closed by pressure in the manifold. During shutdown, when the pressure in the manifold decreases, the spring force will open the drain valve, clearing the manifold of all fuel and pressure.

Single-entry, dual-orifice fuel nozzles are provided to properly atomize and inject fuel in all ranges of fuel flow from "light off" to maximum power. This is accomplished by the dual orifice design. The primary orifice has fuel delivered to it at any manifold pressure; the secondary orifice receives fuel only after a predetermined pressure is reached. The metering-valve type, secondary passage opening varies directly with volume flow. The combination of the primary and secondary orifices provides excellent atomization at all rates of delivery without the necessity of utilizing abnormally high pressures. An air shroud, attached to the fuel nozzle body collects air and directs it to numerous holes in the face of the shroud. Air flow through these holes reduces the possibility of soot and carbon buildup around the primary and secondary orifices.

Two spring-loaded burner drain valves (one forward and one aft) are located at the bottom of the combustion liner assembly to prevent the accumulation of fuel in the burner section after shutdown or in the event of an unsuccessful start attempt.

ACCELERATION BLEED SYSTEM

The acceleration bleed system, shown schematically in Figure 34, functions automatically to unload the compressor during the acceleration (engine speed below 94 percent rpm) phase of the engine starting sequence and during low ground idle operations to prevent compressor surge or stall. Compressor unloading also lightens the starter load and enables faster engine spinup. The system consists of an engine-driven, flyweight-actuated speed sensitive valve installed on the forward face of the accessory drive housing, eight (four each for the 5th and 10th compressor stages) pneumatically-operated bleed air shutoff valves installed on the compressor case, and the connecting plumbing.

At engine speeds below 94 percent rpm, the bleed valve piston chambers are vented into the nacelle interior through the open speed sensitive valve. Compressor (5th and 10th stage) bleed air pressure opens the bleed valves and bleeds air through the open valves into the nacelle interior.

When engine speed reaches 94 percent rpm, flyweight centrifugal force actuates the speed sensitive valve, routing control air pressure (bled from the 14th compressor stage) to the bleed valve piston chambers. Because 14th stage bleed pressure is greater than that from the earlier stages, it forces the bleed valves closed to shut off the compressor bleed.

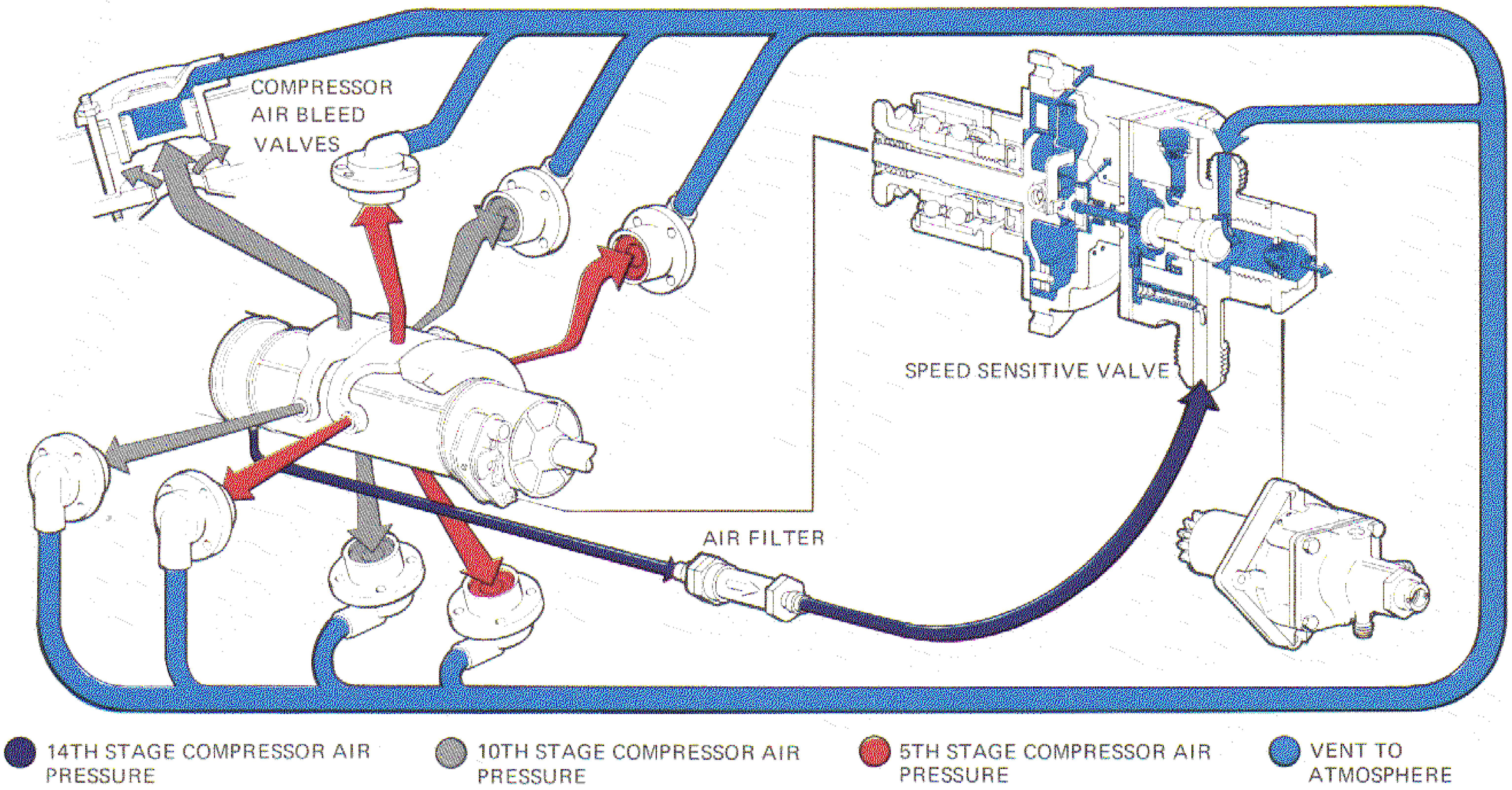
When engine speed decays below 94 percent rpm (e.g., for low ground idle operations), the decrease in flyweight centrifugal force actuates the speed sensitive valve to shut off the flow of control pressure to the bleed valves, and the bleed valves again open to permit bleed.

ENGINE BLEED AIR SYSTEM

T56 engine installations on the P-3 airplane include an engine bleed air system that provides heated, pressurized air from the 14th compressor stage bleeds for bomb bay heating, wing anti-icing, oil cooler flow augmentation, and cross-bleed engine starting. This system, independent of the acceleration bleed system, includes a cross-ship manifold duct system and electrically-operated shutoff and isolation valves which can be actuated individually to control air flow from, or to, any engine. This system enables the use of any operating engine to supply a pressurized air flow as the energy source for the air-turbine starters of the other three engines. Engine anti-icing is the function of an independent subsystem for each engine.

Issue 16 of the ORION Service Digest provided details of the P-3 Air Conditioning System, including the functions of the engine-driven compressors which are installed on engines No. 2 and No. 3. Issue 21 covered the P-3 Ice Control Systems. Both issues contained references to the engine bleed air system.

Figure 34. Engine Air Bleed System Schematic – Operation shown at less than 94% rpm



IGNITION SYSTEM

Capacitor-discharge ignition system operation is enabled when the FUEL AND IGNITION switch on the ENGINE STARTING panel (Figure 29c) is moved to ON. However, the system does not function until 16 percent rpm engine speed actuates the speed sensitive control low-speed switch (Figure 28b) closed to complete a 28-volt DC circuit from the de-energized fuel control relay closed contacts through the closed (unactuated) speed sensitive control intermediate-speed switch and energize the ignition relay. Note that from here on there are two independent subsystems. Power is routed to the two ignition exciters (transformers) which build up high-voltage charges in the storage capacitors. When the capacitor charges are sufficiently high, they bridge the calibrated spark gaps and are dissipated as high-intensity sparks across the electrodes of the igniter plugs installed in No. 2 and No. 5 burner cans. The charge and discharge sequence cycles at between 4 and 8 times per second (depending on input voltage) so long as power is supplied to the exciters.

When 65 percent rpm engine speed actuates the speed sensitive control intermediate-speed switch, its open contacts de-energize the ignition relay. Open relay contacts interrupt power to the ignition exciters, causing system shutdown. If the emergency shutdown handle is pulled while the system is operating, the fuel control relay is energized and its open contacts interrupt the ignition relay energizing circuit and the system is shut down.

WATER-ALCOHOL INJECTION SYSTEM

A water-alcohol mixture (2 to 1 by volume) injection system is provided for the four T56-A-10W engines used on P-3A airplanes for approximately 1.2 minutes takeoff thrust augmentation. Water-alcohol, especially beneficial on hot days, cools the inlet airflow and results in approximately 11 percent (Standard Day) thrust increase. The mixture is injected into the inlet air flow of each engine through a flow regulator/shutoff valve and eight nozzles which are equally spaced in a circular array around the aft end of the torquemeter shroud.

A bladder-cell tank, installed between the two fuselage fuel tanks for accessibility through a belly hatch, supplies the 38.5 gallons of water-alcohol mixture required for one takeoff cycle through a distribution manifold to the four solenoid-operated regulator shutoff valves. When the tank is filled, an internal float switch energizes a FULL indicator light on the WATER INJECTION panel located on the control pedestal.

Two explosion-proof, AC motor-driven pumps, each capable of developing the full system flow of 8 gallons per minute per engine, are located near the tank and are plumbed in parallel to the manifold. Individual thermal switches shut off motor power 204°C (400°F) and automatically reset at 74°C (165°F) for motor overheat protection.

Each pump discharge line contains a bypass/check valve and a pressure switch. The valve bypasses excess pump output flow back to the tank and, as a check valve, it permits system drain back to the pump at gravity pressure but closes at 4 psi to prevent pressure backflow through a failed pump. The pressure switch opens on rising pressure at 132 psi and closes on falling pressure at 127 psi. Each switch is connected to an individual PRESS LOW indicator light on the injection panel; when the switch is closed, the light is energized.

Prior to takeoff, the panel arming switch is moved to ON to energize a pump motor relay, completing the pump motor power circuits. The two pumps pressurize the system against the closed regulator shutoff valves. The arming switch also energizes a signal light control box relay which completes the PRESS LOW indicator light circuits. The indicators are illuminated until the pressure switches are opened by rising system pressure.

With power lever advance past 75 degrees, power lever switch No. 5 is closed to complete a circuit through the de-energized emergency shutdown relays and the water injection low rpm interlock relay, and energize the shutoff valve solenoid. The valve opens and fluid is metered to the nozzles by the valve regulator element at 1 gallon per minute per nozzle. When the fluid supply is depleted, pump discharge pressure falls off and the PRESS LOW indicator lights illuminate.

Fluid injection is stopped when the arming switch is moved to OFF, or when the power lever is retarded below 75 degrees to open switch No. 5. Either action de-energizes the shutoff valve closed, shutting off fluid flow. Shutdown is also effected when the emergency shutdown handle is pulled, energizing the emergency shutdown relays; the shutoff valve solenoid is de-energized, causing the valve to close.

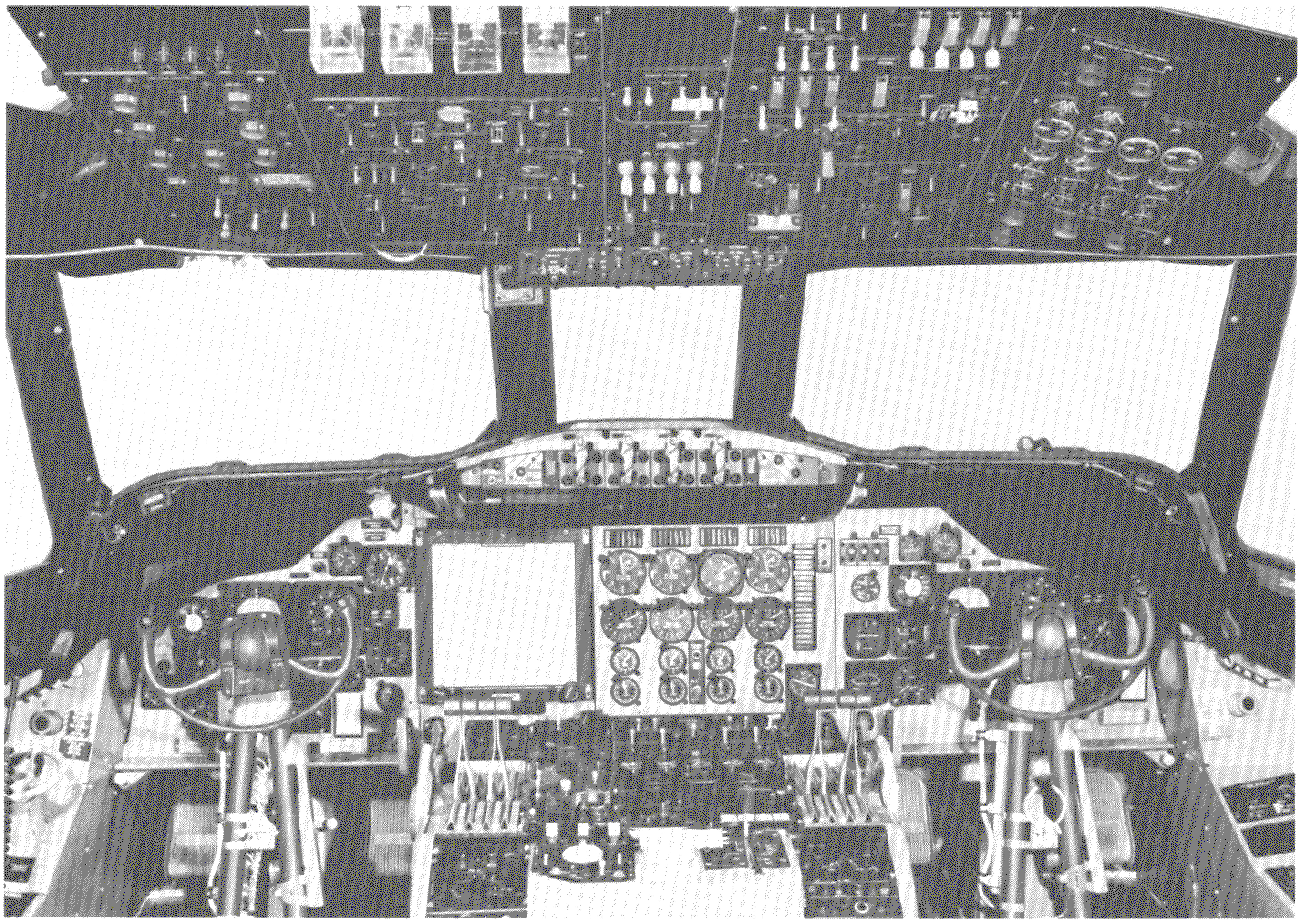


Figure 35. P-3 Flight Station

POWER PLANT CONTROL

The P-3 flight station (Figure 35) was designed to provide a comfortable and highly-functional working environment for the personnel who spend many hours in its close confines during extended overwater patrol missions. The flight station contains the power plant instrument and circuit breaker panels, display and annunciator devices, and manual controls. Most of these items have been defined in the descriptions of the engine components with which they are most closely associated.

Control of the Orion turboprop power plant over the entire range of airplane operation requires only the monitoring of a few instruments and indicators, manipulation of a minimum of switches and controls, and movement of the power lever. Power lever operation is almost instinctive – it is advanced when more speed (power) is desired and retarded when less power is needed. These movements, sometimes coordinated with manual switch actuation, automatically actuate several switches to initiate followup actions within the powerplant systems to control or regulate fuel flow, TIT, and propeller blade pitch.

Power lever movements, transmitted through a mechanical linkage arrangement to the coordinator, are relayed to the fuel control and the propeller control. These devices, using signal inputs from subordinate or related devices, either perform the required actions or signal other control components to perform them. The net result is that power lever movement achieves nearly-total power plant control.

P-3 power production is a highly-complex process – more correctly, a precise integration of several highly-complex processes – even though its manual control is relatively simple. Fuel flow regulation, TIT control, and propeller blade angle adjustment require quite sophisticated hardware to accomplish the nearly automatic power plant control characteristic of the P-3.

A good many power plant safety devices operate automatically when conditions require their use. However, during emergencies which require that the power plant be secured immediately, the emergency shutdown handle combines all shutdown functions in a single manual action.

Even though basic control of the P-3 turboprop unit appears to be fairly simple, all flight crew members should have a comprehensive "working knowledge" of the power plant installation and the engine systems, subsystems, and safety devices. This knowledge is helpful for quick, accurate identification of malfunctions and the appropriate corrective action to be applied. In some instances, erroneous corrective action can be worse than no action. All flight crew members, even though their normal assignments and duties are not concerned with the power plant, are urged to become familiar with the official Maintenance and NATOPS manuals. It is equally important for maintenance personnel to know the equipment in order to maintain it properly.

Power Lever System

The Orion's engines and propellers are controlled by coordinated, semi-automatic operation of the fuel, propeller, and electrical systems – primarily in response to manual actuation of the power levers. Subordinate control items which work in conjunction with the power levers have been discussed previously. Therefore, the following paragraphs will discuss only the power lever system.

The P-3 power lever system consists basically of four independent subsystems, one for each engine. The basic element of each subsystem is a pair of power levers, one each for the pilot and copilot. The four pilot levers are installed as a group on top of the control pedestal at the left end and the copilot levers are similarly grouped at the right end. Corresponding pilot and copilot levers are coupled by a torque tube so that movement of either lever results in identical movement of its counterpart. The levers for any engine can be moved without moving those for the other three engines.

Each power lever pair is connected to the coordinator by a linkage-cable mechanism so that power lever movement through an arc of approximately 52 degrees results in coordinator shaft rotation of 90 degrees. For clarity, power lever positions and control event timing are given in degrees of coordinator shaft rotation.

The power lever quadrant is marked at the GROUND IDLE, START, and AIR START (9, 15, and 48 degrees, respectively) positions. There are two operating ranges (Figure 36), taxi or ground operating (Beta) range and flight (Alpha) range. The 34-degree position (flight idle gate) separates the two ranges. The quadrant has a ramp at the gate to prevent unintentional movement of the power lever through the gate from the flight range into the taxi range; the lever must be lifted onto the ramp as it is pulled back.

Beta-range operations, including reverse thrust braking, are conducted with the power lever between 0 and 34 degrees. Engine speed is governed at 97.5 percent rpm with the RPM switch (Figure 30a) at NORMAL, or at 72.5 percent rpm (ground-idle governing) with the switch at LOW, by the fuel control. Engine control is a total power lever function in this range because fuel flow and propeller blade angle are controlled directly by power lever position and movement. Propeller blade angle is 11 degrees (power lever advance) or 13 degrees (power lever retard) at the flight idle gate, 10 degrees at the 27-degree position, 0 at START (the point of minimum fuel flow – power lever movement in either direction changes propeller blade angle and increases fuel flow), and -6 degrees at GROUND IDLE. When blade angle is 10 degrees or less, the BETA indicator light on the center instrument panel is energized by a propeller control Beta shaft cam-operated switch.

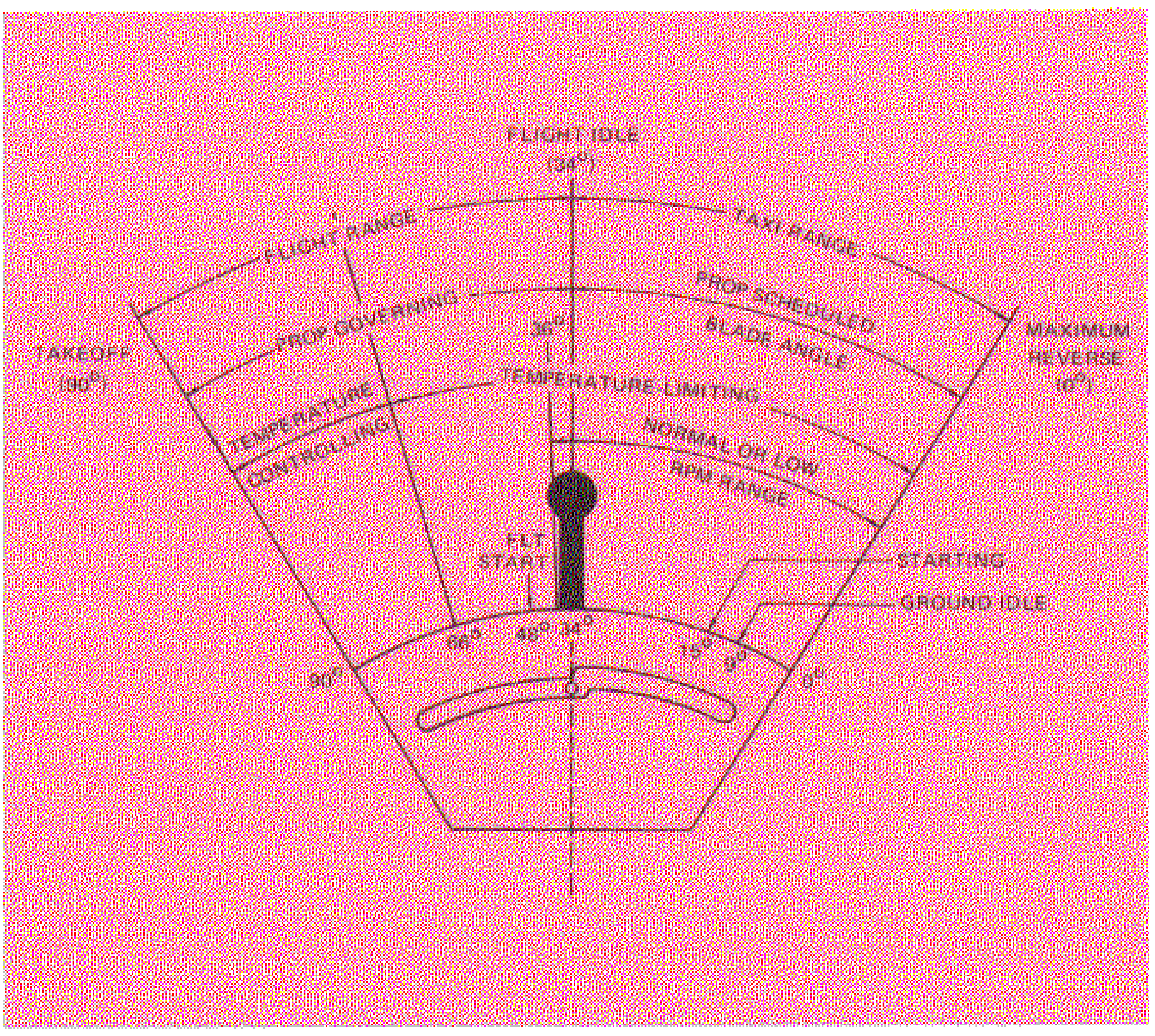


Figure 36. Engine Power Lever Quadrant

Reverse thrust is produced when the power lever is between 15 degrees and 0. At 10 degrees (blade angle at -6 degrees), just enough reverse thrust is produced to offset the slight forward thrust of the jet exhaust. Maximum reverse thrust is produced at 0 degrees with the blade angle at -13 degrees. Because blade angle is fixed in relation to power lever position during Beta-range operations, propeller governing is not possible; the fuel control regulates fuel flow to govern engine speed between 104 and 106 percent rpm.

Flight-range operations are conducted with the power lever between 34 degrees (flight idle) and 90 degrees (takeoff). Fuel flow is regulated to produce the desired power (related to TIT) as blade pitch is adjusted by the propeller governor to maintain engine speed constant at 100 percent (13,820 rpm). The propeller governs overspeed to 103.5 percent rpm, and fuel control overspeed governing between 104 and 106 percent rpm only occurs in the event of propeller governor failure. The TD control operates in the temperature-limiting mode until the power lever is advanced past 66 degrees, when temperature-controlling is initiated. From 66 degrees to 90 degrees, power lever position establishes the TIT schedule required to produce the desired power.

Power Lever Switches A switch assembly, containing six separate switches, and its pushrod actuating mechanism are installed in the pedestal for each pair of power levers. The individual switches are actuated at different power lever travel points.

Switch No. 1, closed when the power lever is in taxi range, is opened by power lever advance past 36 degrees. Its closed contacts complete a series circuit through the energized *(only when the airplane is on the ground and both MLG scissors switches are closed)* No. 4 scissors switch relay closed contacts to energize the fuel control solenoid when the RPM switch (Figure 30a) is moved to LOW, enabling low-speed (72.5 percent rpm) engine operation.

Switch No. 2, open with the power lever back of 32 degrees, locks out propeller synchrophasing and electronic governing during Beta-range operations. The switch, closed by power lever advance past 32 degrees, completes the energizing circuit from the SYNC SERVO switch (Figure 30a) to the propeller speed bias servo motor reference winding. This enables propeller systems operation when the SYNC SERVO switch is moved to NORMAL.

Switch No. 3, open when the power lever is back of 75 degrees (T56-A-10W) or 60 degrees (T56-A-14), is closed by power lever advance to prearm the auto-feather relay energizing circuit when the AUTO-FEATHER switch (Figure 30a) is moved to ARMED. With the circuit armed, the relay is energized through the propeller TSS device to initiate autofeathering action if propeller thrust drops below 500 pounds.

Switch No. 4, closed with the power lever back of 32 degrees, completes a series circuit through the energized *(when either MLG scissors switch closes on touchdown)* flight idle stop relay closed contacts to energize the propeller control flight idle stop solenoid. The solenoid retracts the spring-loaded mechanical flight idle stop. The switch, opened by power lever advance past 32 degrees, de-energizes the solenoid and the stop extends to prevent the power lever from being unintentionally retarded from the flight range until the airplane is on the ground. *NOTE: The stop can be collapsed by application of extra manual effort to the power lever.*

When the switch is closed, its contacts complete a series circuit through energized *(when the ENGINE START SELECTOR switch shown in Figure 29c is OFF)* oil cooler flaps interlock relay closed contacts to energize the inducer valve control relay. This enables operation of the oil cooler inducer valve and oil cooler flaps when the OIL COOLER FLAPS switch (Figure 31b) is moved to OPEN or CLOSED.

Switch No. 5 (T56-A-10W engines only), open with the power lever back of 75 degrees, is closed by power lever advance. Its closed contacts complete a series circuit with the WATER INJECTION PANEL (not illustrated) ARMING switch closed (ON) contacts and closed contacts of de-energized emergency shutdown relays (Nos. 3, 4) and engine low rpm interlock relay to energize the water-alcohol shutoff valve solenoid. The valve opens to permit fluid flow to the injection nozzles.

Switch No. 6, open with the power lever above 28 degrees, closes when the power lever is retarded. Its closed contacts, in series with propeller control pitchlock reset switches (Alpha and Beta shafts cam-actuated) closed contacts, energize the pitchlock reset solenoid. This resets the system to pitchlock at 109 (instead of 103.5) percent rpm to ensure availability of full reverse thrust for maximum reverse thrust braking.

SAFETY DEVICES

Early in 1953, in a program to develop a prototype YC-130 military transport using the T56 engine, Lockheed conducted extensive safety analysis investigations based on the premise that a turboprop-powered airplane should have an inflight safety level at least equal to, or preferably better than, that of an equivalent reciprocating engine-powered counterpart. The test work included an extensive full-scale T56 engine program in the power plant wind tunnel at Ames Aeronautical Laboratory and considerable flight testing in a Constellation flying test-bed airplane. Program results and data developed from use of Pratt & Whitney T34 engines on the YC-121F (U.S. Air Force) and R7V-2 (U.S. Navy) turboprop versions of the 1049 Constellation enabled Lockheed to develop several entirely new safety concepts. Later programs have developed the hardware to implement these concepts.

Use of these developments in the P-3 Orion has proven their soundness. In addition, the reader is reminded that the P-3 airframe was designed to survive the most improbable compounding of engine and safety device failures even if they were to occur under the most unfavorable operating conditions.

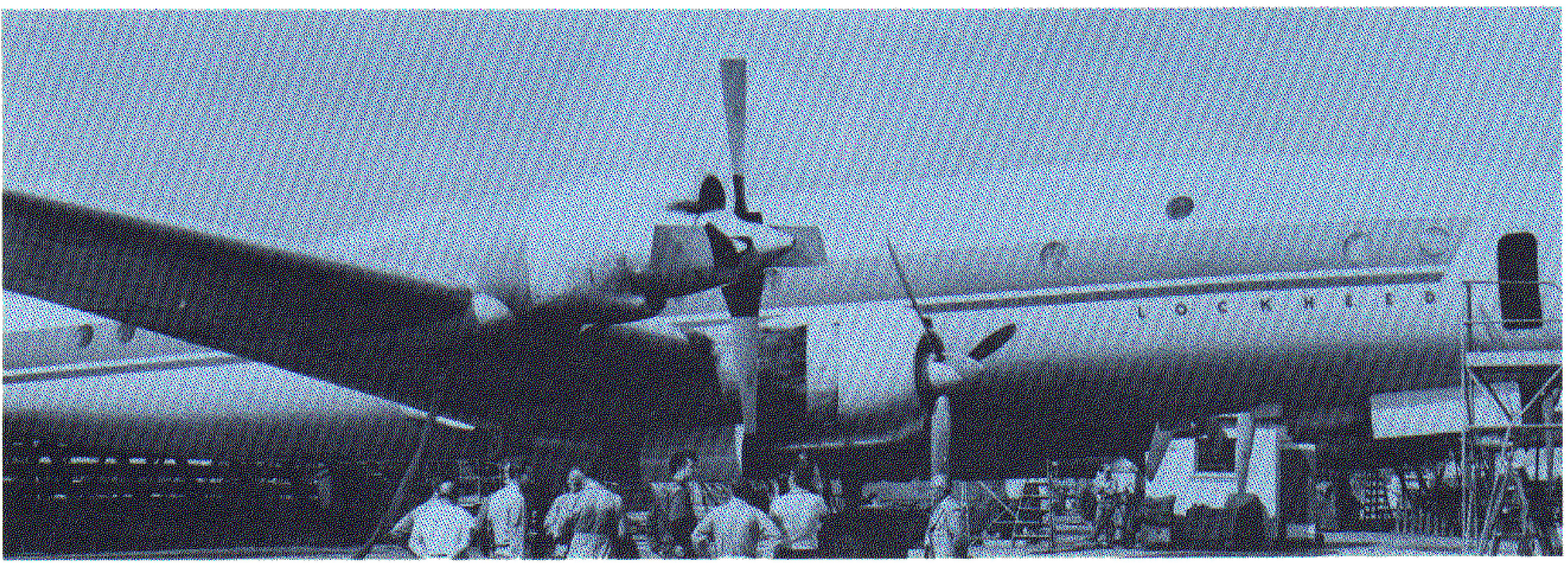
Generally, when the power output of any propeller-engine combination fails, the propeller attempts to continue rotation at the governed speed. It reduces blade pitch and acts as a windmill to take sufficient energy from the airstream to motor the "dead" engine. With a reciprocating engine, the load is relatively light; the propeller only has to supply sufficient power to overcome pumping and friction losses and engine-driven accessory loads in order to maintain rotational speed. On the other hand, with a single-spool turboprop engine such as the T56, the power required to drive the compressor, when added to engine accessory loads (the T56 gearbox requires about 50 SHP) and friction losses, represents an impressive figure. It has been estimated that a turboprop engine would require about ten times the "motoring power" of an equivalent reciprocating engine.

In the Allison T56-A-14 engine about 57 percent of the total horsepower developed by the turbine is used to drive the compressor. In other words, the compressor requires approximately 6000 SHP when it is being driven at 100 percent (13,820) rpm. And, in the event of sudden inflight engine power loss, a large portion of this quite considerable load is assumed by the propeller and instead of the propeller being driven by the engine (positive torque) the propeller tends to maintain its speed as previously explained and drives the engine (negative torque), decreasing blade pitch angle as the negative torque load increases. From the foregoing, it is readily apparent that unless means are provided to control negative torque – more correctly, the propeller's reaction to it – results can be nothing less than catastrophic.

Two types of engine power failure can be cited to define the minimum and maximum negative torque loads absorbed by the propeller of an unprotected P-3 system. The most simple case, and the most probable, is the one of engine flameout due to fuel flow failure. The most severe case is the result of multiple turbine blade failures.

In the first case, the engine is undamaged and the "windmilling" propeller, in its attempt to maintain the 1020 rpm governed speed, absorbs sufficient

Figure 37. Flying Test Bed for Allison Turboprop Engine



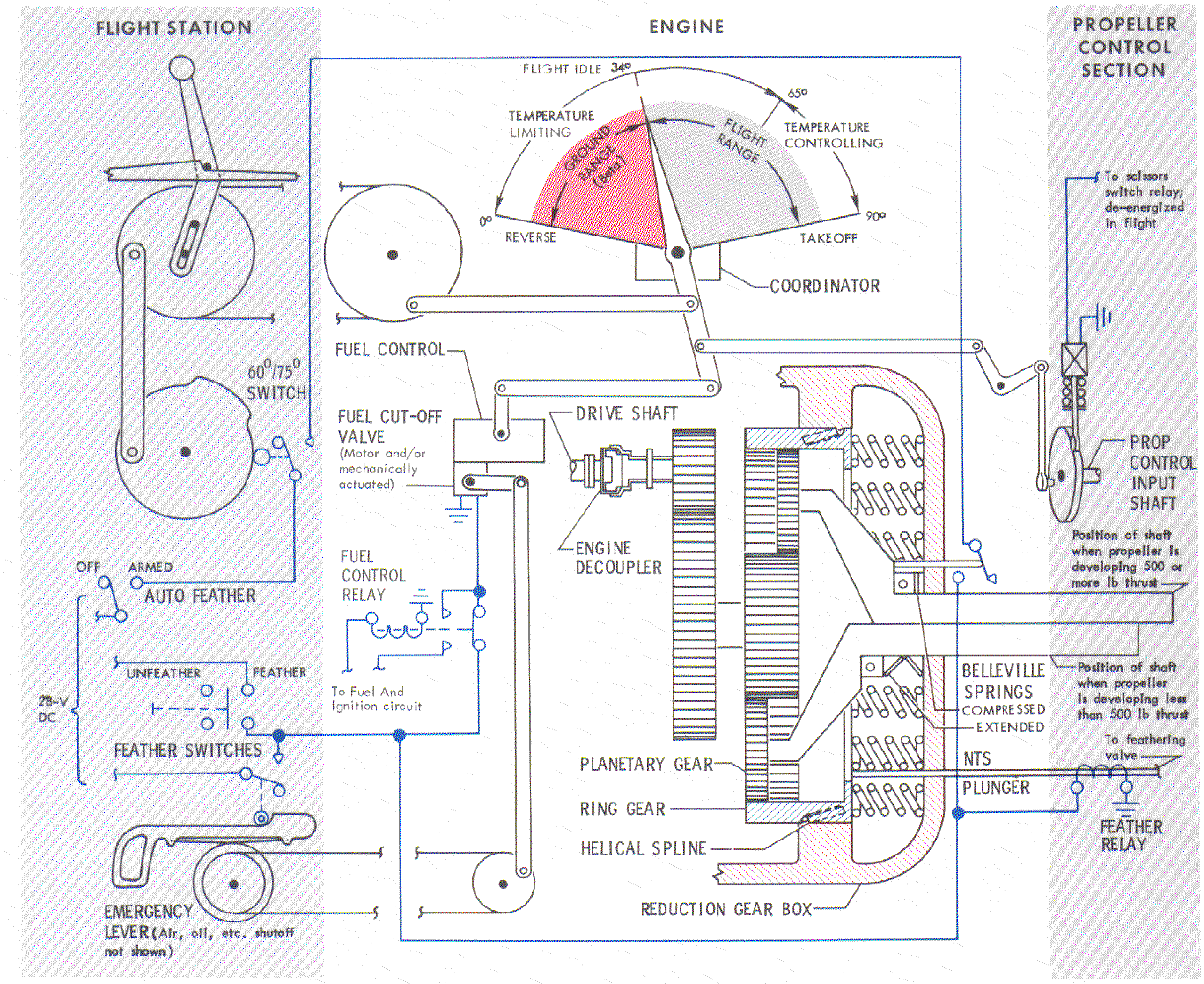


Figure 38. Schematic of Propeller and Engine Controls and Some Related Safety Devices

negative torque from the airstream to motor the engine. In effect, the engine is partially in "bootstrap" operation. In other words, airflow through the engine gains energy from ram recovery and from compression; a major portion of the energy is then recovered by the turbine from airflow expansion. The net negative torque, i.e., the negative torque absorbed by the propeller to motor the engine at normal rpm is about 1800 SHP at typical conditions of about 300 knots at sea level.

In the most severe case, the failed engine does not produce any power and the propeller absorbs the full 6000 SHP load. This load, by itself, is within the propeller's capabilities but when the additional load imposed by drag forces is added, the total is formidable. For example, at the 300-knot sea level conditions, drag imposed by an outboard engine (out because of fuel failure) is about 1000 pounds. With a failed turbine, drag is about 16,000 pounds. And, asymmetric drag (three engines working) increases the total to about 5500 and 18,500 pounds, respectively for the two failure cases.

It is apparent, then, that negative torque protection is imperative. The P-3 power plant has several protective devices to prevent negative torque situations such as those described. In addition, the airplane's vertical tail has sufficient structural strength to accommodate the yaw loads imposed by total failure of the protective devices, and by the pilot's corrective actions in such event.

Negative Torque Signal Device

The negative torque signal (NTS) device, in the reduction gearbox, automatically limits the negative torque absorbed from the airstream by the propeller in case of engine failure or during air starts. It also functions when abnormal situations such as steep approaches, severe air gusts, etc. create negative torque loads.

The device (Figures 15, 38 and 39) utilizes the tendency of two mated, helically-splined members to be displaced axially from each other by application of torque when one member is fixed. The internally-splined ring is bolted between front and rear plates (rings with smaller ID than the spline ring) to the gearbox case so that it cannot move. The other member, an externally-splined coupling and a planetary ring gear joined by a ring gear coupling, is free to rotate except for spline engagement with the spline ring. It can move axially as it rotates, but travel is restricted because the splines are mated between the two plates. Also, this member is spring-loaded against the rear plate. During normal operation with the engine delivering power to the propeller, helical spline action tends to force the spline coupling tighter against the rear plate. An NTS actuator rod is installed through the case so that it is spring-loaded against the spline coupling; axial coupling travel moves the rod.

Spline action, in response to negative torque, tends to move the coupling against spring force toward the front plate. With 100 to 500 negative SHP (depending on spring force) applied, the coupling moves to the front plate and extends the actuator rod. The rod actuates the propeller control linkage which overrides propeller governor pitch control authority and moves the feather valve in the increase pitch direction. The propeller hydraulic system increases blade pitch to reduce negative torque. Reduced negative torque permits spring force to move the spline coupling to the rear plate; the actuator rod follows spline coupling movement and returns pitch control authority to the propeller governor.

The above description of an NTS cycle assumed a momentary negative torque situation. If the condition persists, as in engine power loss or an air start sequence, NTS action is cyclic until propeller feathering or engine restart is accomplished. In either case, negative torque is indicated by a negative horsepower reading on the horsepower indicator (Figure 19b).

When the feather button on the PROPELLER feather panel is held out (PULL TO UNFEATHER) for an air start, a 45-degree blade angle circuit in the propeller control is enabled. If the NTS does not actuate by the time blade angle reaches 45 degrees, the propeller is driven back toward feather and the NTS INOP warning light (Figure 19b) is energized. This signals the crew to abort the air start and initiate immediate engine shutdown.

The NTS is automatically disabled by an Alpha shaft cam-operated pushrod linkage in the propeller control when the power lever is retarded back of 24 degrees. This permits the propeller to go into reverse pitch for landing rollout braking. The Beta indicator light (Figure 19b) is energized through a Beta shaft cam-operated switch which is closed when blade angle is 10 degrees or less.

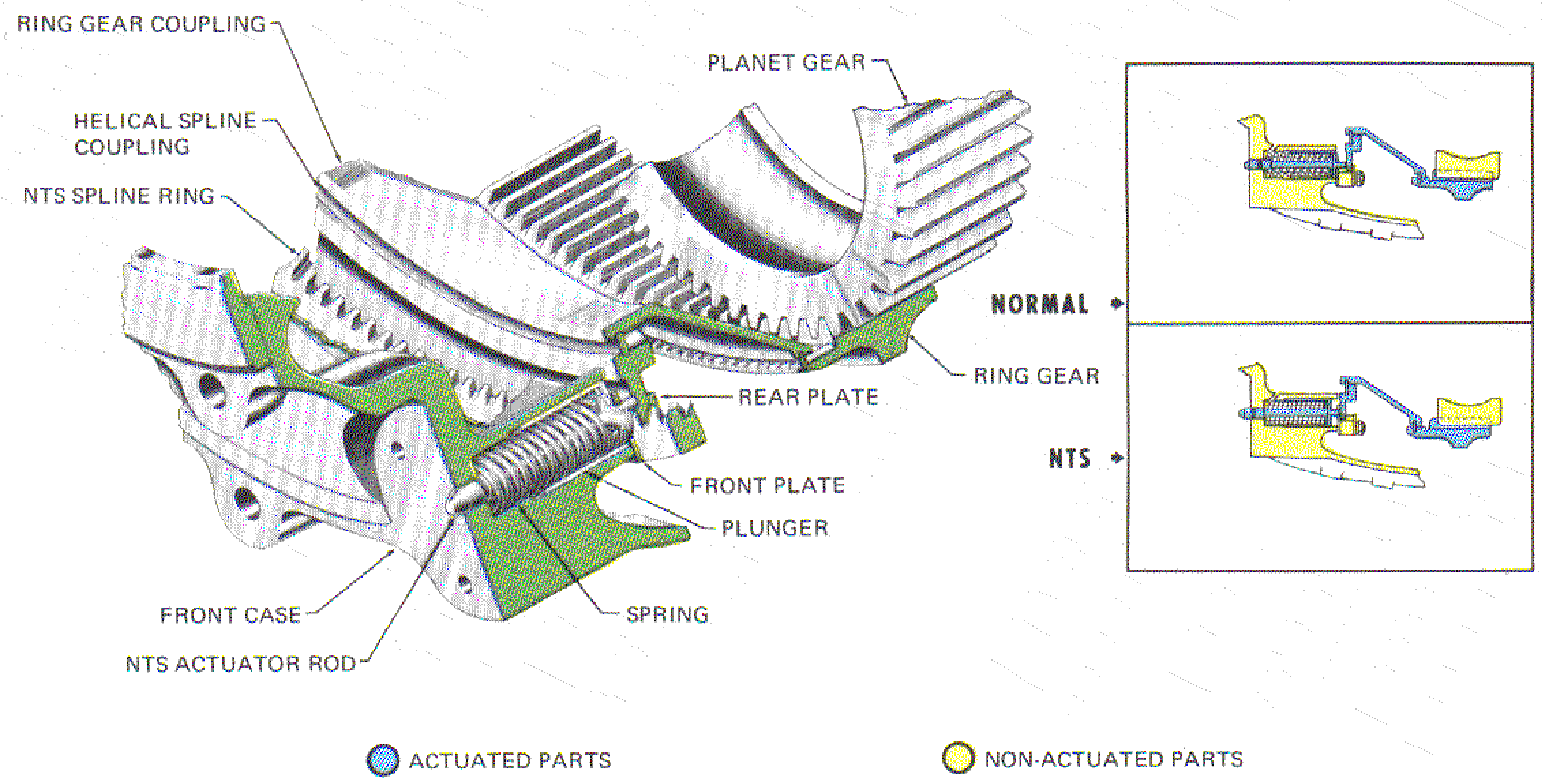


Figure 39. Negative Torque Signal (NTS) Device

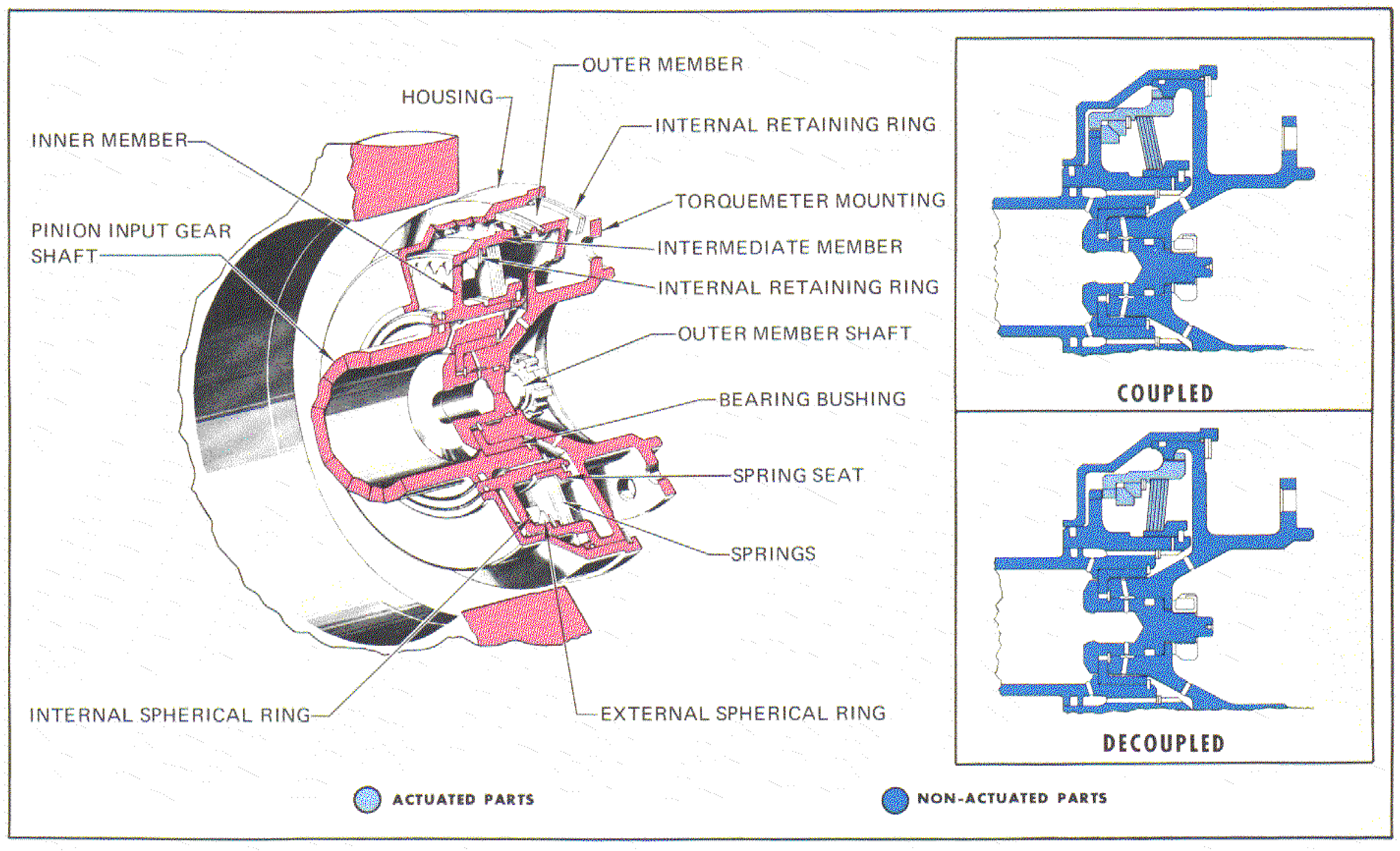


Figure 40. Engine Safety Coupling

Engine Safety Coupling

The self-contained engine safety coupling (Figure 40) is installed at the rear face of the reduction gearbox to transmit power from the engine drive shaft (power section) to the reduction gear input pinion. It functions as a safety backup for the NTS, decoupling automatically when negative torque reaches approximately 1700 negative SHP.

The safety coupling, like the NTS device, operates on the principle of axial displacement of helically-splined mating members when torque is applied. It consists of an outer member bolted to the front of the inner torquemeter shaft, an inner member mounted on the reduction gear input pinion shaft, and a sliding intermediate member which mechanically connects the other two members. The outer member has straight internal splines in which the intermediate member slides. The intermediate member has internal helical splines which mate with external splines on the inner member. It contains a pair of mating spherical rings to maintain concentricity between it and the inner member. Five Belleville spring washers, whose force determines the negative torque at which the coupling disengages, tend to keep the helical splines engaged.

In normal operation, force of the helical splines holds the intermediate and inner members in full engagement, and shaft power is transmitted through the coupling to the input pinion gear.

In case of engine power failure and simultaneous NTS failure (an exteremely unlikely coincidence), the coupling is subjected to negative torque. When this torque (translated into axial force by helical spline action) becomes sufficient to overcome the force of the Belleville spring washers, the intermediate member moves aft until the helical splines are disengaged from the inner member. The input pinion gear and the drive shaft are now decoupled and this condition, indicated by a "0" reading on the horsepower indicator (Figure 19b), calls for immediate propeller feathering.

As soon as decoupling occurs, spring force tends to re-engage the splined members. If the propeller is feathered to reduce its rotational speed, the coupling re-engages when speed of the mating members are equal. In effect, the mating members of the coupling "ratchet" on each other until re-engagement is effected. If the ratcheting action is allowed to continue, spline damage may make re-engagement impossible.

Propeller Brake

The propeller friction brake is installed in the reduction gearbox (see Figure 15) as a part of the starter shaft assembly. It automatically prevents propeller rotation when the propeller is feathered for an in-flight shutdown or when the airplane is parked with the engine stopped. It also shortens the deceleration time after shutdown. The brake, like the NTS device and the engine safety coupling, uses helically-splined mating members (assisted by Belleville spring washers and centrifugal force-induced pressure of the gearbox lubricating oil for its actuation). Figure 41 shows a cutaway section through the brake mechanism and schematic diagrams to illustrate its three operating modes, released, applied, and locked.

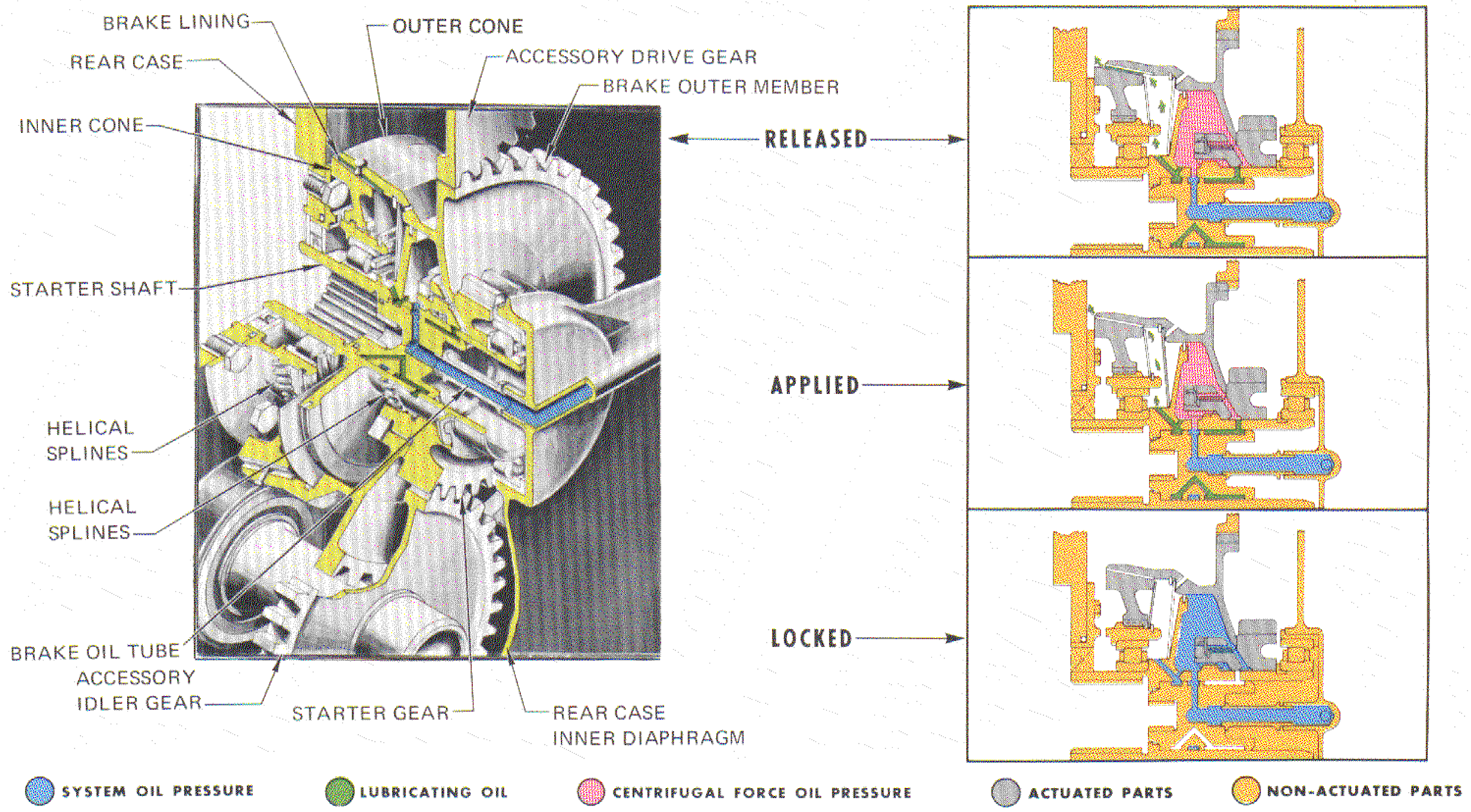
The brake consists principally of an inner friction cone installed on the starter shaft bearing flange by mating helical splines and a matching outer cone (with a sintered bronze friction surface) attached to the starter gear. The gear and cone assembly are installed on the starter shaft by mating helical splines, and in such fashion that an oil chamber is created. Thus, both cones can move axially when torque is applied. Each cone is spring-loaded aft by Belleville spring washers.

The brake is applied (both cones held aft by their respective spring washers) to prevent random propeller rotation when the aircraft is parked with the engine stopped. However, the propeller can be turned by hand in the normal direction of rotation. When forward rotational force is applied to the propeller, helical spline action moves the outer cone forward to decrease brake friction.

When starter torque is applied to start the engine, helical spline action moves the outer cone forward (against spring washer force) to release the brake. At engine speeds above approximately 21 percent rpm, centrifugal force acting on the lubricating oil in the brake chamber creates sufficient force to hold the outer cone forward against spring washer force. The helical spline actuating force is removed when starter operation is discontinued at approximately 59 percent rpm.

When the propeller is feathered in flight, the brake is locked to prevent propeller and engine rotation. As engine speed decays, oil pressure in the brake chamber decreases until, at about 21 percent rpm, spring washer force moves the outer cone aft so that the brake friction surfaces are in contact. Because the feathering mechanism is set to provide a slight overfeather, the propeller tends to “wind-

Figure 41. Propeller Brake



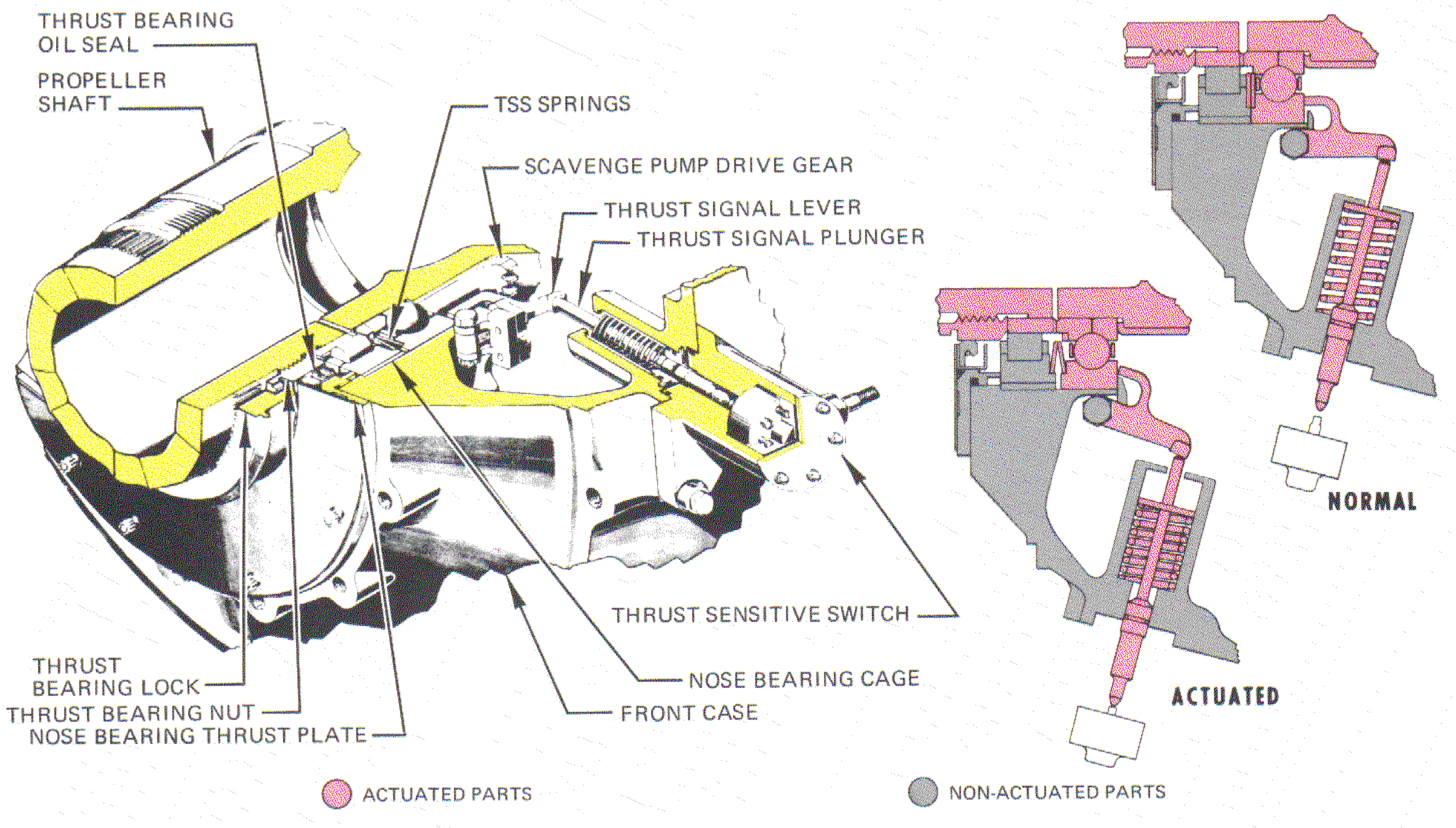


Figure 42. Thrust Sensitive Signal (TSS) Device

mill" in reverse after its forward rotation has stopped. As the propeller (and outer cone) reverses, brake friction rotates the inner cone causing it to move forward by helical spline action – the brake is self-energized to the locked position.

When the propeller is unfeathered for a flight start, it "windmills" in the normal direction and rotates the gearbox components and engine. The forward rotation relieves the helical spline loading on the inner cone and both cones move to the brake applied position. The propeller accelerates the engine and gearbox components against drag of the applied brake until oil pressure again becomes sufficient (at approximately 21 percent rpm) to release the brake.

During engine shutdown deceleration, oil pressure holds the brake in the released position until pressure decay at approximately 21 percent rpm allows the outer cone to be moved forward to the brake applied position because of spring washer force.

Automatic Feathering System

The automatic feathering system (AFS), when manually armed, automatically initiates propeller feathering and fuel flow shutoff action for any one of the four power plants in case of power loss (Propeller thrust below 500 pounds). This reduces drag and asymmetric flight characteristics.

AFS functions are based on operation of the thrust sensitive signal (TSS) device (Figure 42), basically a propeller shaft cam-operated switch in the reduction gearbox. It is connected in a series circuit (auto-feather relay energizing) with the AUTO-FEATHER switch (Figure 30a) and power lever switch No. 3. The shaft, spring-loaded aft by Belleville spring washers with 500 pounds force, can move axially (Figure 38) approximately 0.10 inch.

The AFS is prearmed during takeoff preparation when the guarded AUTOFEATHER switch is moved to ARMED, and is disabled after takeoff when the switch is moved to OFF. Four (one for each engine) indicator lights on the switch panel are illuminated when the system is prearmed. Final arming of each engine subsystem occurs when power lever advance (to start the takeoff run) past 75 degrees (T56-A-10W engine) or 60 degrees (T56-A-14 engine) closes power lever switch No. 3.

Propeller thrust over 500 pounds overcomes spring force and moves the shaft forward to hold the TSS switch open. When propeller thrust drops below 500 pounds, spring force moves the shaft aft, allowing the switch to close and energize the auto-feather relay. Relay closed contacts energize the PROPELLER feather button "pull in and hold in" solenoid which opens and closes contacts to initiate propeller feathering, as described in Issue 11 of this magazine, and to energize the fuel control relay (Figure 28). Relay closed contacts energize the fuel control cutoff valve actuator to close the valve and shut off engine fuel flow.

AFS interlock circuitry limits system action to only one engine with priority as follows: No. 4, No. 1, No. 3, and No. 2. When action occurs, the indicator light for that engine stays illuminated and the other three lights are extinguished.

Emergency Shutdown Handle

The emergency shutdown handle, commonly called the E-handle, is a safety device that provides a single-control engine shutdown capability in case of an emergency that demands immediate attention, and it can be used during any phase of engine operation. During normal operation, the E-handle is all the way in and does not function in power plant control.

First consideration in an engine emergency, after engine shutdown, is for the prevention or control of fire. Therefore, the supply of combustibles (fuel, oil, and oxygen) must be cut off immediately. Use of the E-handle accomplishes eight (nine for the T56-A-10W engine) mechanical and electrical functions that shuts down the engine and cuts off the combustible material supply.

The P-3 emergency shutdown system is comprised of four independent subsystems, one for each power plant. Each subsystem includes an E-handle and two E-handle cam-actuated switches, a cable-pulley and connecting rod mechanical linkage, four emergency shutdown relays, and associated electrical circuitry. The E-handles and switches are installed in a common housing (Figure 43) at the center of the glareshield for access by the flight station crew members. Each E-handle is installed between guide rollers so that it can be pulled straight out from the panel. Each handle shaft incorporates two identical cams, one on each side; one switch is installed with each cam so that both switches are operated simultaneously when the E-handle is actuated. A cable pulley, installed in the housing, rotates as the handle is actuated. A continuous cable loop transmits pulley rotation to a fuel tank emergency shutoff valve operating quadrant and to a coordinator control pulley on the front side of the engine firewall. A connecting rod between the valve quadrant and the fuel tank emergency shutoff valve closes the valve when the E-handle is pulled, and vice versa. A similar connecting rod transmits rotation of the coordinator control pulley to the coordinator input shaft. The coordinator discriminator assembly, acting through its mechanical output linkage system, closes the fuel control shutoff valve and actuates the propeller control linkage to feather the propeller. On engine No. 2, No. 3, and No. 4 installations, a second connecting rod from the coordinator pulley closes the generator cooling air shutoff valve.

The switches and emergency shutdown relays are connected as two independent, redundant circuits – two parallel-connected pairs of relays with each pair performing identical functions under single-switch control – either circuit can perform the required electrical switching. Thus, component failures in either circuit do not degrade emergency shutdown system operation.

When the E-handle is pulled, the switches are closed and each switch energizes its pair of relays. One set of relay closed contacts energizes the PROPELLER feather button "pull in and hold in" solenoid, causing the feather switch to be actuated and latched in the "feather" position. Ensuing action is just as if the feather button were manually depressed to PUSH TO FEATHER. Issue 11 of this magazine described propeller feathering functions.

One set of feather switch closed contacts energizes the fuel control relay (Figure 38); relay closed contacts energize the fuel control cutoff valve actuator motor to close the valve and shut off engine fuel flow. If engine speed is between 16 and 65 percent rpm, fuel control open contacts de-energize the ignition relay to shut down ignition system of operation. Other feather switch contacts control circuits that cause propeller feathering by the propeller

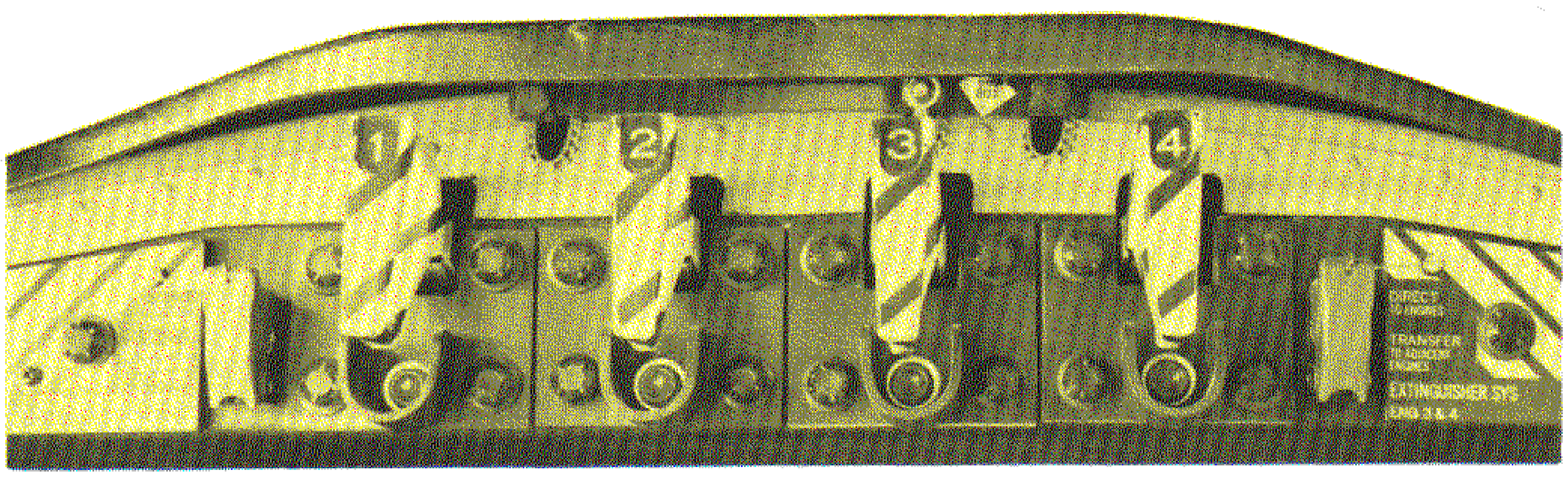


*Figure 43.
Glareshield
Panel*

control. *NOTE: E-handle actuation causes both mechanical and electrical cutoff valve closing and propeller feathering.*

Other emergency shutdown relay contacts energize the bleed air shutoff valve actuator, closing the valve; the bleed air valve OPEN indicator light on the left inboard overhead panel is extinguished. Other closed relay contacts energize the motor-driven oil tank shutoff valve closed to shut off all oil flow to the engine. For engine No. 2 and No. 3 engine-driven compressor (EDC) installations, closed relay contacts energize the EDC discharge duct air shutoff valve actuator, closing the valve; this circuitry also energizes the EDC dump solenoid valve open to dump discharge air overboard.

All E-handle shutdown functions, except mechanical propeller feathering, are completely reversible. The E-handle can be pushed in, after resolution of the emergency situation, to enable engine restart. The PROPELLER feather button remains latched in the feather position and must be pulled to unfeather the propeller and accomplish an air start.

Overspeed Governing

Three methods of engine overspeed governing are provided for the P-3 power plant. Propeller governing is performed as a basic function of propeller operation. During normal operation, the propeller maintains engine speed constant at 13,820 rpm by automatically changing its blade pitch as a function of minute speed variations. Propeller action in this method was described in detail in ORION Service Digest, Issue 11. The second method is accomplished, as described previously, by action of the fuel control governor in case propeller governing fails, or during reverse thrust operations when propeller governing is not effective. In case these two methods both fail, the overspeed limiting pitch lock mechanism in the propeller control functions, as described in Issue 11, as the third method.

Propeller Safety Devices

In addition to the safety devices and functions previously described, the propeller includes other integral devices (primarily for its own protection) which provide varying measures of safety for the engine, and the airplane. The most notable of these devices, described in ORION Service Digest, Issue 11, are the variable hydraulic low-pitch stop (Beta followup), mechanical low-pitch stop, and the propeller synchrophasing system.

NACELLE FIRE PROTECTION SYSTEM

The P-3 nacelle fire protection system includes an automatic, full-time, temperature-sensitive, detection and indication system and a manually-controlled, electrically-fired, explosive cartridge-initiated, extinguishing system. The detection and indication system automatically monitors temperatures in three separate zones of each nacelle continuously and, when temperature in any nacelle exceeds a predetermined alarm point, provides visual and audible fire warning indications. The extinguishing system enables selective HRD (high rate discharge) of bromotrifluoromethane (CF_3Br) fire extinguishing agent into any nacelle where excess temperature is detected.

Fire Detection and Indication System

The detection and indication system consists of four independent subsystems, one for each nacelle. Each subsystem includes a segmented detector element, a control unit, two (visual and audible) warning circuits, and a test switch circuit. The interior of each nacelle is divided into three zones, as shown in Figure 44, for temperature monitoring. Zone 1 includes the area aft of the firewall enclosing the engine combustion and turbine sections and the tailpipe shroud. Zone 2 is the space forward of the firewall and includes the engine compressor section, drive shaft, and reduction gearbox. Zone 3 is aft of the firewall and forward of the wing beam; it includes the main landing gear wheel well in the inboard nacelles. Although each nacelle is divided into three zones, temperatures in all three zones are monitored by a single, continuous-loop fire detector element. The detector loop for each nacelle is connected to an individual hermetically-sealed control unit in the forward electrical load center. Thus, each nacelle is provided with an independent fire detection system. Each fire detection loop consists of ten semi-flexible detector tube segments connected in series with one segment in Zone 1, six segments in Zone 2, and three segments in Zone 3. The loop is routed through the spaces so that each zone is completely protected.

Operation of the detection and indication system is based on the inverse resistance-temperature characteristic of the detector element – its resistance decreases with increase in temperature. Each detector loop is connected to the corresponding control unit as one leg of a resistance-bridge network. When the temperature environment of the detector element (and its resistance) is normal, the bridge

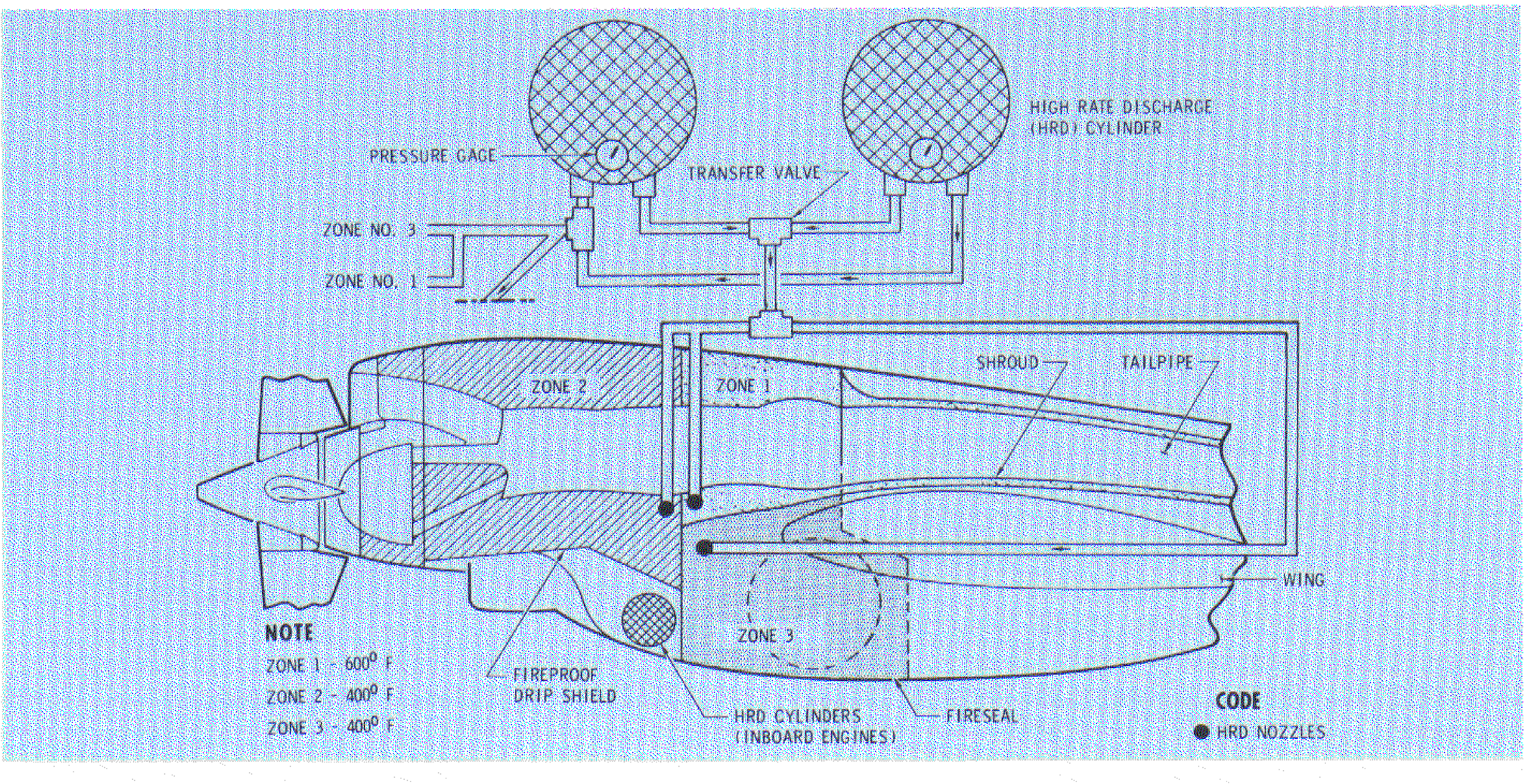


Figure 44. Nacelle Fire Protection System Schematic

circuits are in balance and the control unit relay is de-energized. However, when temperature increase reduces element resistance to a predetermined point, the resulting bridge network unbalance energizes the relay; relay closed contacts energize the visual and audible fire warning circuits. The control unit incorporates a time-delay circuit to prevent false alarm indications in case of a momentary short in the detector element. Design of the detection system is such that it will function normally for heat detection in case the element is broken; however the element test will reveal the discontinuity resulting from the break.

The detector element resistance is reduced to the alarm point when the total length of the detector element in any zone senses a certain temperature, or when a shorter portion of the element senses a higher temperature. Alarm annunciation is initiated when the entire length of detector element in Zone 1 is heated to 316°C (600°F) or when any one-foot length of the element is heated to 552°C (1025°F). In Zone 2 or Zone 3, the values are 204°C (400°F) for the entire length and 377°C (710°F) for a one-foot segment.

Control unit circuitry is such that it detects, and reacts to, unusually rapid rates of detector element resistance decrease (temperature increase) such as might be caused by an intense fire. In such case, the relay (and warning circuits) are energized even before the previously stated alarm temperatures are reached. However, the circuitry will not react to an instantaneous decrease in the element's resistance such as would result from a momentary short circuit.

Visual fire warning indications are provided by sixteen (four for each nacelle) red warning lights. The four lights for a single nacelle are installed to form a square around the corresponding emergency shutdown handle (and the extinguishing system discharge button) on the glareshield panel as shown in Figure 43. Each set of four lights is installed in a separate subpanel so that when the light circuit is energized, the entire subpanel lights up. *NOTE: The warning lights have no significance with respect to nacelle zones.* In other words, an overheat condition in any zone causes all four lights for the nacelle to be illuminated.

Audible fire alarm warnings are sounded by two warning horns, one in the flight station and one in the tactical area. *NOTE: The tactical area horn sounds only when the airplane is on the ground and the nose landing gear uplock switch is closed.* The warning horns are silenced when the FIRE DET HORN LOCKOUT button on the ENGINE CHECK panel (Figure 31b) is actuated momentarily to energize the warning horn lockout relay (latching), interrupting the warning horns power circuit. After being silenced, the warning horn system is automatically reset (lockout relay de-energized) for subsequent operation when the fire (or overheat) condition is removed and the control relay is de-energized.

When the fire (or overheat) condition that activated the system is removed, resistance of the detector element increases as the element cools. The system returns to normal with the bridge circuit in balance and the control relay and warning circuits de-energized in readiness for subsequent operation.

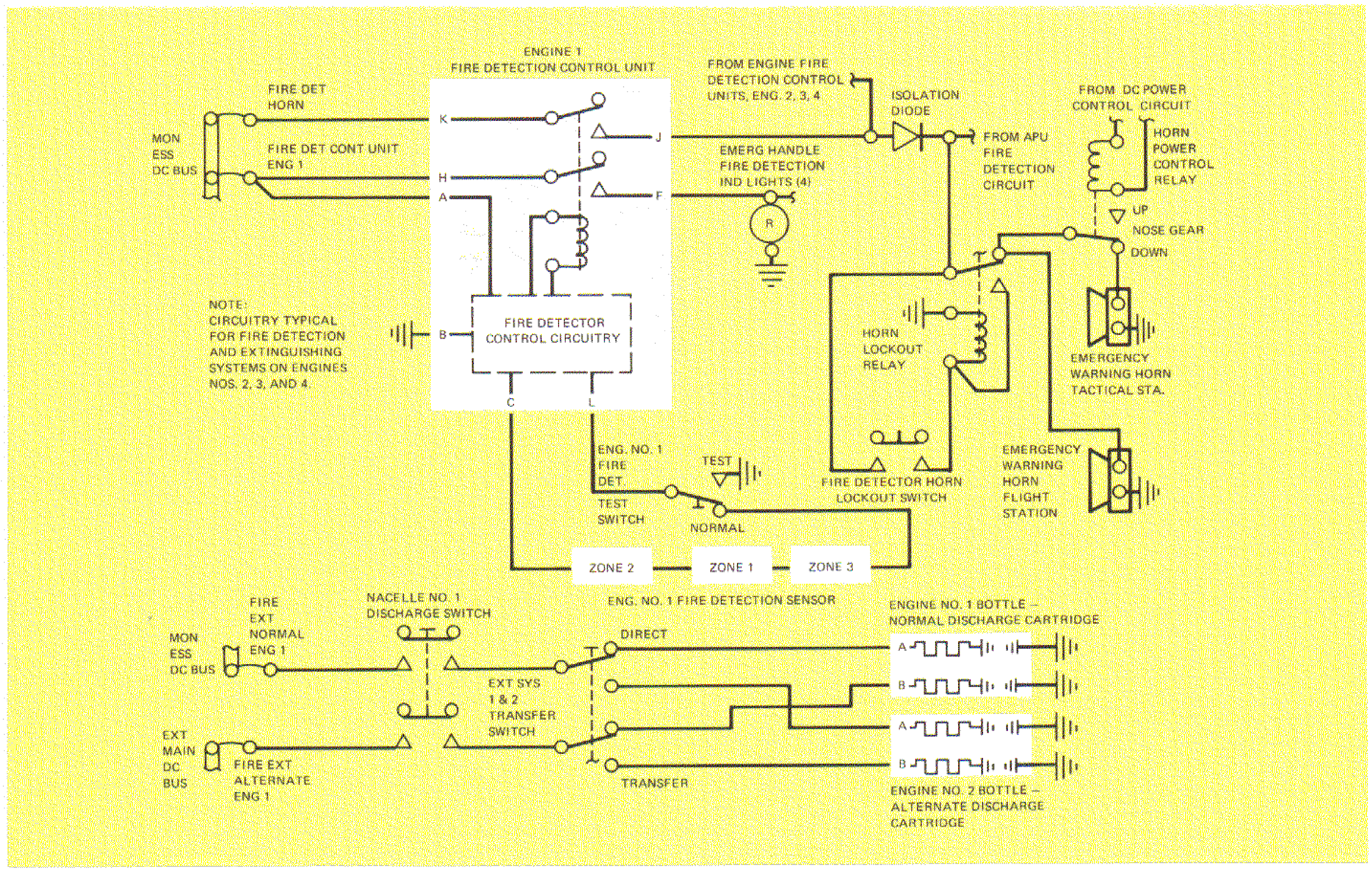
An individual (for each nacelle subsystem) test switch is installed on the ENGINE CHECK panel (Figure 31b) to test continuity of the detector element loop and operation of the warning circuits and devices. The switch, when actuated to TEST, grounds the detector element loop to simulate a fire (or overheat) condition. If the system is fully operational, all four warning lights for the individual nacelle will illuminate and both warning horns will sound.

Fire Extinguishing System

The fire extinguishing system consists of two independent HRD subsystems, one for each side of the airplane. Each subsystem, shown schematically in Figures 44 and 45, includes two CF_3Br pressure bottles installed on the forward side of the firewall in the inboard nacelle, two transfer check valves to connect both bottles to both nacelles, plumbing lines from the transfer check valves to each zone of both nacelles, six (one in each nacelle fire zone) discharge outlets, and two (one for each nacelle) guarded discharge buttons and a two-position (DIRECT TO ENGINES, TRANSFER TO ADJACENT ENGINES) system transfer switch on the glareshield panel (Figure 43). Each discharge button is located under the corresponding emergency shutdown handle to prevent inadvertent system activation. The transfer switch enables selective discharge of either bottle into either nacelle, or of both bottles into one nacelle.

Each welded-steel, spherical pressure bottle, of approximately 400-cubic inch capacity, is fitted with two (one for each nacelle) discharge valve assemblies, a pressure gage, and an overboard discharge port (also used as a fill fitting) which are accessible from the wheel well through a firewall access door. The bottle, when charged with approximately 10.5 pounds of CF_3Br, is pressur-

Figure 45. No. 1 Nacelle Fire Protection System Electrical Schematic (Typical)



ized with nitrogen to approximately 600 psi. A safety rupture disc in the overboard discharge port bursts at approximately 1400 to 1800 psi to relieve excess bottle pressure.

Each discharge valve assembly contains a dual-squib explosive cartridge which is electrically fired, when the discharge button is depressed, by two (one for each squib) independent power sources through separate sets of transfer switch closed contacts. The explosive cartridge (both squibs) of each valve assembly is fired from its appropriate (DIRECT TO ENGINES, TRANSFER TO ADJACENT ENGINES) transfer switch position. When discharged, the explosive cartridge drives a slug through a frangible disc in the bottle outlet to release the pressurized CF_3Br through the plumbing lines and discharge outlets into the selected nacelle.

The transfer check valves are T-fittings, each with one outlet port and two inlet ports. The outlet port is connected by plumbing lines to the three discharge outlets of a single nacelle. One inlet port is normally closed (other inlet port is open) by a spring-loaded poppet in the valve; inlet port status is reversed when bottle discharge pressure applied to the normally-closed port actuates the poppet. The inlet ports of each transfer check valve are connected by plumbing lines to two (one on each pressure bottle) discharge valve assemblies. The normally-open ports are connected to the valve assemblies controlled through the DIRECT TO ENGINES transfer switch position, and the normally-closed ports are connected to the valve assemblies controlled through the TRANSFER TO ADJACENT ENGINES position. Thus, each pressure bottle is connected to one nacelle system through one (direct-to-engines) of its discharge valve assemblies and one (normally-open inlet port) transfer check valve, and to the other nacelle system through the second (transfer-to-adjacent-engines) discharge valve assembly and the other (normally-closed inlet port) transfer check valve.

Drain valves (spring-loaded open at gravity pressure, bottle discharge pressure-closed) are installed in each discharge valve assembly-to-transfer check valve plumbing line, and at appropriate locations between the transfer check valves and the discharge outlets to drain condensed moisture from the system.

During normal standby (system ready) operation, the guarded transfer switch is in the DIRECT TO ENGINES position. When the discharge button for a particular nacelle is pressed, the squib cartridge in the corresponding discharge valve assembly is fired and the pressurized CF_3Br is discharged into the selected nacelle in about 0.4 second. The other bottle can be discharged into the other nacelle without moving the transfer switch. However, if both bottles are to be used for one nacelle, the transfer switch must be moved to the TRANSFER TO ADJACENT ENGINES position before the second bottle is discharged.

Maintenance Precautions

Certain precautions must be observed during fire protection system maintenance and servicing. Maintenance of this system, as with all P-3 systems, must be performed in strict accordance with the procedures specified in the official maintenance instruction manuals.

It should be emphasized that the explosive cartridges used to activate the fire extinguishing system are capable of inflicting serious injury and must be handled with extreme care. The system circuit breakers must be opened and tagged to prevent the cartridges from being discharged inadvertently. For further guidance on the service life, shelf life, disposition of overage explosive cartridges, and special safety precautions to be observed, NAVAIR 11-100-1, "Cartridges and Cartridge Actuated Devices for Aircraft and Associated Equipment," should be consulted.

Observance of special safety precautions in handling the fire extinguishing agent should be emphasized. Bromotrifluoromethane (BF_3Br), in its liquid state, is nontoxic; it is classed as a non-poison. However, it is a highly-volatile substance, not easily detected by odor, that can be harmful to personnel if carelessly handled. *The liquid can cause frostbite of skin tissue* with which it comes in contact because of its low boiling point. When vaporized, it presents about the same personnel hazards as carbon dioxide or the other freons, because its presence in a given space reduces the oxygen concentration. *Suffocation can result from breathing the vapor.* Personnel should not enter a closed space where CF_3Br leakage is suspected until the space has been thoroughly ventilated and a halide detector check indicates that the vapors have been dissipated. Containers from which leakage is either known or suspected should not be stored or used; they must be discharged immediately by use of approved safety procedures.

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