ORION

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FRONT AND BACK COVERS Originally commissioned Patrol Squadron 205 at Norfolk a few months after the U. S. entered World War 2, the squadron that is now VP-45 schooled 21 years in the jack-of-all-trades duties of a seaplane squadron. Operating PBM3 equipment the first 2 years, PBM5's the next 10, and P5M's the next 9 years, the squadron saw only brief Convoy Coverage duty (flying from Guantanamo Bay) as Patrol Squadron 205. After re-training and re-commissioning as Patrol **Bombing** Squadron 205, they joined the Pacific Fleet; island-hopping from Hawaii to Saipan to Okinawa to Japan in 1945, their duties including ferry service, Search and Rescue, Area-search, Barrier Patrol, Anti-submarine Patrol-Convoy Coverage, and Surveillance in the latter days of the war.

Shortly after the war, they resumed Carribean patrol duties (as Patrol Squadron 5 — re-designated Patrol Squadron 45 in 1948) from Coco Solo, Bermuda, and San Juan, working with Seaplane Tender "USS Albemarle" and at various times with NORTC Midshipmen, for whom they provided extensive ground training in addition to flying experience. VP-45 participated in "Springboard '60" and worked, in 1961 and 1962, with Task Group Delta in the development of both new equipment and new tactics for Anti-Submarine Warfare.

Seven VP-45 aircraft were detached to Guantanamo Bay in early 1963 to observe some highly interesting cargo Cuba exported to USSR that year, and of course they pulled intermittent life-guard duty for the Project Mercury Astronauts who splashed in VP-45's pond during this period.

Given 9 new Orions in their twenty-first year and assigned to NAS Jacksonville as part of Fleet Air Wing 11, VP-45 became operational with the P-3 in May 1964, and promptly detached 5 aircraft to Argentia, Newfoundland. There they are again proving themselves "specialists in everything" by carrying out Ice Reconnaissance and Air Surveillance duties efficiently and concurrently with their ASW work.

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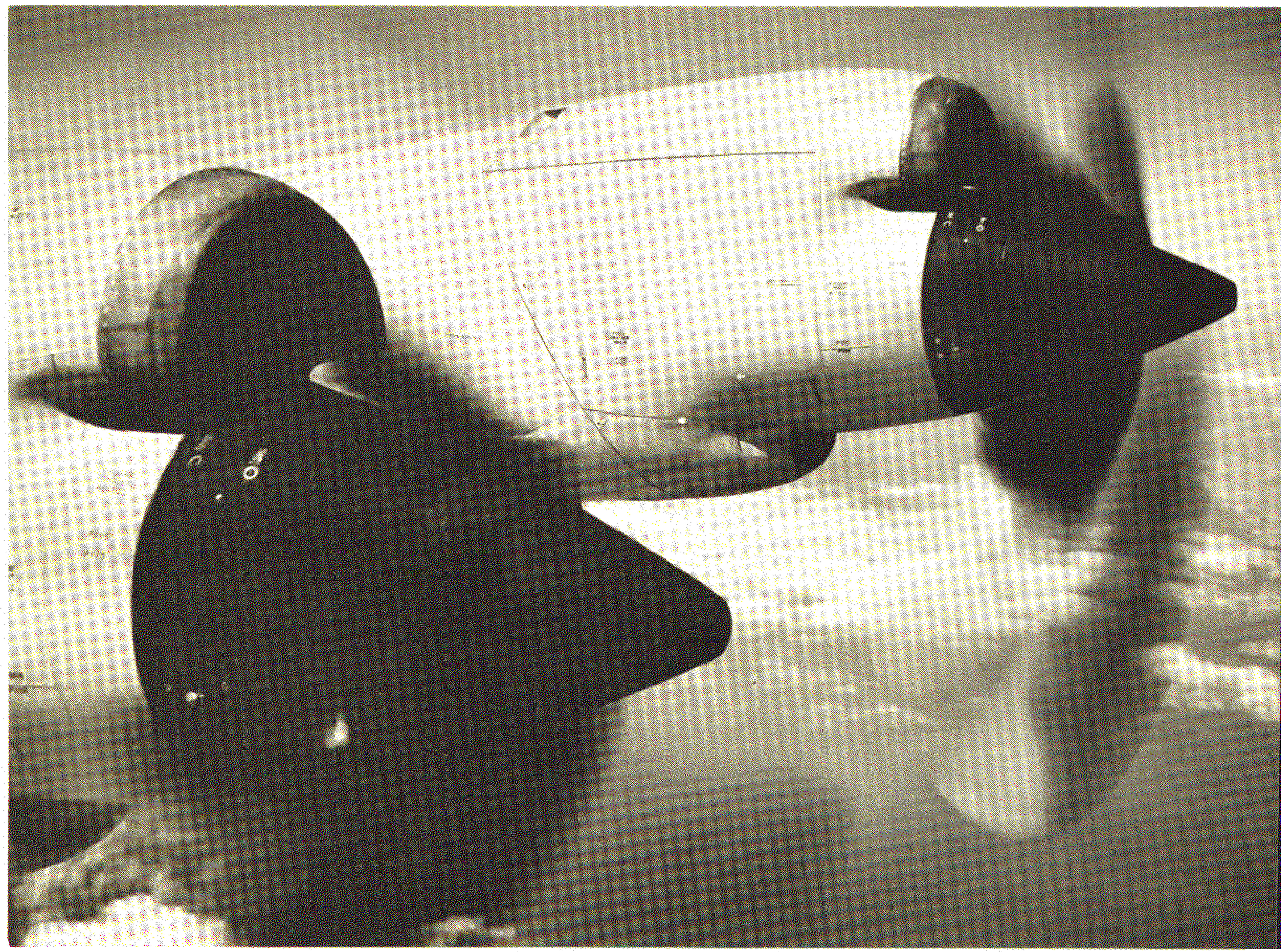

P-3 PROPULSION

PROPELLER UTILIZATION OF TURBINE POWER

WHEN THE FIRST POWERED GLIDER staggered into the air, the propellers that pulled it aloft were, of necessity, remarkably efficient and highly developed aerodynamic components. Its predecessor in the wind-and-shaft power business—the windmill—had served man since antiquity, but considerable modification was needed to reverse the windmill's function and reduce its huge sails and shaft to feasible proportions. The high degree of refinement achieved in the 1903 model propellers is indicated by their close similarity to propellers still in use more than a half-century later. And it is doubtful if any appreciable design improvement will ever appear on the fixed-pitch propellers of future generations of low-powered, low-speed aircraft, for it would be difficult to conceive a more utilitarian device for such craft, or one less costly or easier to maintain.

But a propeller with a fixed pitch is confined to a narrow scope of operation, and an aircraft fitted with such an inflexible drive is much like an automobile with direct drive. If there is no means of altering the ratio between the rotational speeds of crankshaft and wheels, the only alternative is to utilize an optimum gear ratio approximating the second gear of a 3-speed transmission. Aircraft with fixed-pitch propellers are handicapped in the same way by the limited range of operating conditions in which thrust is produced with reasonable efficiency.

To escape this inherent limitation, the obvious solution was to mechanize the propeller so that the angle at which the blades meet the air could be varied. This was done in a number of different ways, one of the most successful being a 2-position propeller that allowed the engine to be reasonably efficient in two operating regimes; a "fine" pitch (low blade angle) allowing the engine to develop high rpm for best power at takeoff, and a coarser pitch (high blade angle) better suited to flight.

Since the propeller must convert varying increments of torque into thrust in such a variable medium as air, it is obvious that the propeller should have more than two operating positions. It must, ideally, assume *whatever* position these variables dictate.

This goal was realized in the variable pitch, constant-speed propeller by building into the propeller certain faculties to receive information and act accordingly; in short, the propeller was given the traits of a servo-mechanism. With this type of propeller, the operator commands a certain rpm and the propeller control continually senses its own rpm, and acts automatically to correct any off-speed discrepancy—either relieving the engine load (decreasing prop pitch) if too slow, or burdening it (increasing prop pitch) if too fast.

Aircraft with powerful reciprocating engines and constant speed propellers are able to approach Mach 1, but in this range any and all propellers encounter a natural (and apparently insurmountable) obstacle due to the fact that the blade tips inevitably reach sonic speed before the aircraft does. The supersonic segment of the blades incur such a variety of aerodynamic penalties that it is practically impossible to obtain additional thrust for further acceleration.

A final development in the exploitation of the variable-pitch propeller was the "reversible" propeller, a propeller whose blades assume negative angles and supply reverse thrust to supplement braking in the landing roll.

Inevitably, the propeller became more complex with each evolutionary step. Any variable-pitch propeller whose pitch range includes very low positive and even negative blade angles could produce an excessive drag or "windmill" at hazardous rpm if malfunctions occur during flight. Consequently, the designer must first devise a control that is exceptionally sure and positive, then assume that it is neither fail-proof nor foolproof and incorporate a variety of safeguards to ensure that the propeller will not unduly handicap a flight in any event. A dependable "feathering" capability should also be provided, whereby the entire power plant can be secured after an in-flight failure so that it does not encumber the aircraft or suffer further damage due to "windmilling" propeller rotation.

With these basic control capabilities plus refinements (de-icing, synchronization, etc.) the propeller matured into the near-ideal thrust converter for use with the reciprocating engine.

The turbine engine was developed for aircraft use because the jet-thrust principle offered a means of overcoming the natural limitations of the reciprocating power plant. In the latter part of World War II, turbo-jet aircraft demonstrated a marked superiority in terms of altitude and top speed. Its inherent properties are ideally suited for these criteria, but the turbo-jet does not produce thrust efficiently at low altitude or low speed and it is very difficult to obtain the adroit thrust control needed for good airport performance with turbo-jet powered aircraft.

HAMILTON STD./ALLISON PROP-JET

The prop-jet power plant was developed to combine the superior qualities of the turbine engine with the superior qualities of the propeller. This entailed no really drastic change in the turbine engine. Examining the internal structure of the Orion's Allison engine reveals conventional compressor and combustion sections; the turbine is somewhat enlarged to convert more heat energy to torsion, and a drive-line incorporating a decoupler and a large reduction gear box is added. The gear box provides mounting facilities with various drive ratios for engine-driven accessories—the principal "accessory" being the propeller. The ratio of the prop-shaft drive is sharply reduced (13.54 to 1) to allow both components to turn at the widely diverse speeds they require for efficient operation.

The propeller designer faced a more challenging job in adapting the propeller to this new power source. The range of every factor that affects propeller design was larger with the single exception of rpm, which for the first time was fixed*, but this was not an unmixed blessing. To permit the airplane to attain speeds near Mach 1, the prop drive shaft is geared to turn at the lowest practicable rotational speed, 1020 rpm, and since the propeller cannot work faster (increase rpm) to do more work (produce more thrust), a very broad blade is needed to obtain high thrust at low airspeed. The turbine engine develops shaft power in excess of 4000 hp, and power changes may be made very rapidly. This requires a stronger, more massive propeller, capable of fast pitch-changes in response to fast power changes.

Due to the inherent differences between piston and turbine engines, there is need for an exceptionally positive and dependable prop control. Since the turbine must have a quick responding, broad-bladed propeller, and since the control of any "constant-speed" propeller is basically a device that increases the blade angle when shaft power increases and decreases blade angle when shaft power decreases, this highly efficient thrust producer has the potential to quickly present a very effective windmill to the slip stream if an engine fails. As this windmill attempts to "crank" the engine back up to "on speed" rpm, the energy extracted from the slipstream represents drag on the airframe. The drag of a defunct reciprocating engine, due mostly to its running friction, is little more than a nuisance compared to the many thousand shaft horsepower needed to keep the Allison compressor section "on speed", and if the prop-to-compressor drive line remains intact, the wide-bladed windmill could produce such a high drag that the airplane would be uncontrollable.

To protect against such a contingency, an automatic mechanical device is incorporated (the Negative Torque System) that can override the constant speed governor control if an appreciable windmilling tendency develops. In case the NTS cannot control the windmilling tendency, the Allison engine drive shaft is fitted with the "de-coupler," a sort of clutch that disconnects the prop-to-compressor drive line automatically when a high negative torque is developed by the propeller, and the prop is let to turn free of the cranking drag. Many additional safeguards are provided in the propeller design to protect against diverse types of failures.

For all these reasons and more, the prop-jet propeller is radically different from the piston engine propeller. Coupled to a turbine, the propeller becomes a more useful device, but it also is necessarily more complex.

POWER PLANT CONTROL Despite this additional complexity, the Orion power control system is fundamentally simpler than most reciprocating engine controls insofar as the flight crew is concerned, for there is no occasion to "juggle" rpm, mixture, and throttle. The factors that determine thrust are synchronously adjusted by the simplest and most instinctive type of control—one lever per engine that is pushed forward to go faster and pulled aft to go

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**Although most turbo-prop power plants have a rather wide operating-rpm range, the Allison T-56 Series engines vary so little that they are considered to be constant speed engines with a special provision for "LOW" (72.5%) rpm operation. It should be noted, however, that there will be minor fluctuations when abrupt power changes are made during "NORMAL" rpm operations, and also that the fuel governor schedules speeds slightly below 100%, generating tachometer readings of 96 to 99% during some operating phases, described later in this article, when the propeller governor does not have full control of blade angle.*

slower. Through this simple and instinctive action on the pilot's part signals are transmitted mechanically to both the engine and the propeller controls, and through purely mechanical and self-generated hydraulic means the fuel control and the propeller control re-adjust fuel flow and propeller pitch as necessary to provide the demanded thrust. There are so many variable factors which affect power development on aircraft that the fuel control and prop control are necessarily very complex servo-mechanisms, and to provide extremely accurate control, electrical and electronic components are added to both. These are normally used, but they are *not* essential to safe operation.

Although the pilot routinely positions a few switches and uses only the power levers to control thrust, a multitude of devices are involved, and if a malfunction occurs the flight crew must be prepared to quickly identify the character of the trouble in order to act appropriately. This requires more than a casual acquaintance with the various systems, and with the protective devices built into these systems, for in some circumstances the situation will deteriorate if the wrong action is taken. Maintenance crews, too, must know and understand the controls in order to trouble-shoot and repair the systems efficiently. Of course, both the Maintenance Instruction Manual and the NATOPS Flight Operating Manual contain procedural instructions for various circumstances, but it is difficult to foresee every contingency and memorize lengthy procedures without some "working" knowledge of the design.

In this article we will describe the Hydromatic propeller, its manual and automatic controls, and 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 propeller 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. The center-fold pages of this magazine contain a Master Schematic which integrates all the major electric, hydraulic, and mechanical components. Supplementary schematics attend the various discussions in the text, but readers are urged to refer to the Master Schematic frequently to become familiar with the integration of functions and components.

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.

HYDROMATIC PROPELLER OPERATING PRINCIPLES

Despite the array of control changes that have been implemented, the fundamental design concept of the mechanism that changes the pitch on the Hamilton Standard 54H60-77 propeller is not greatly different than that used on their reciprocating engine propellers with which many readers are familiar. Heavy, beveled gear teeth on the four blade butts are meshed to a single ring gear inside the hub. The ring gear has a cylindrical skirt that extends forward into the propeller dome. Spiral cam tracks in the walls of the skirt convert the linear travel of a large hydraulic piston into rotary motion of the ring gear. The relationship of the pitch control piston to blade angle is such that aft motion of the piston drives the blades towards higher pitch, ending with the propeller feathered; forward motion drives the blades towards lower pitch, ending with the propeller in negative (reverse) pitch. Mechanical stops limit the travel of the pitch-change mechanism to 86.65° (feather) and minus 14.5° (reverse) as measured at

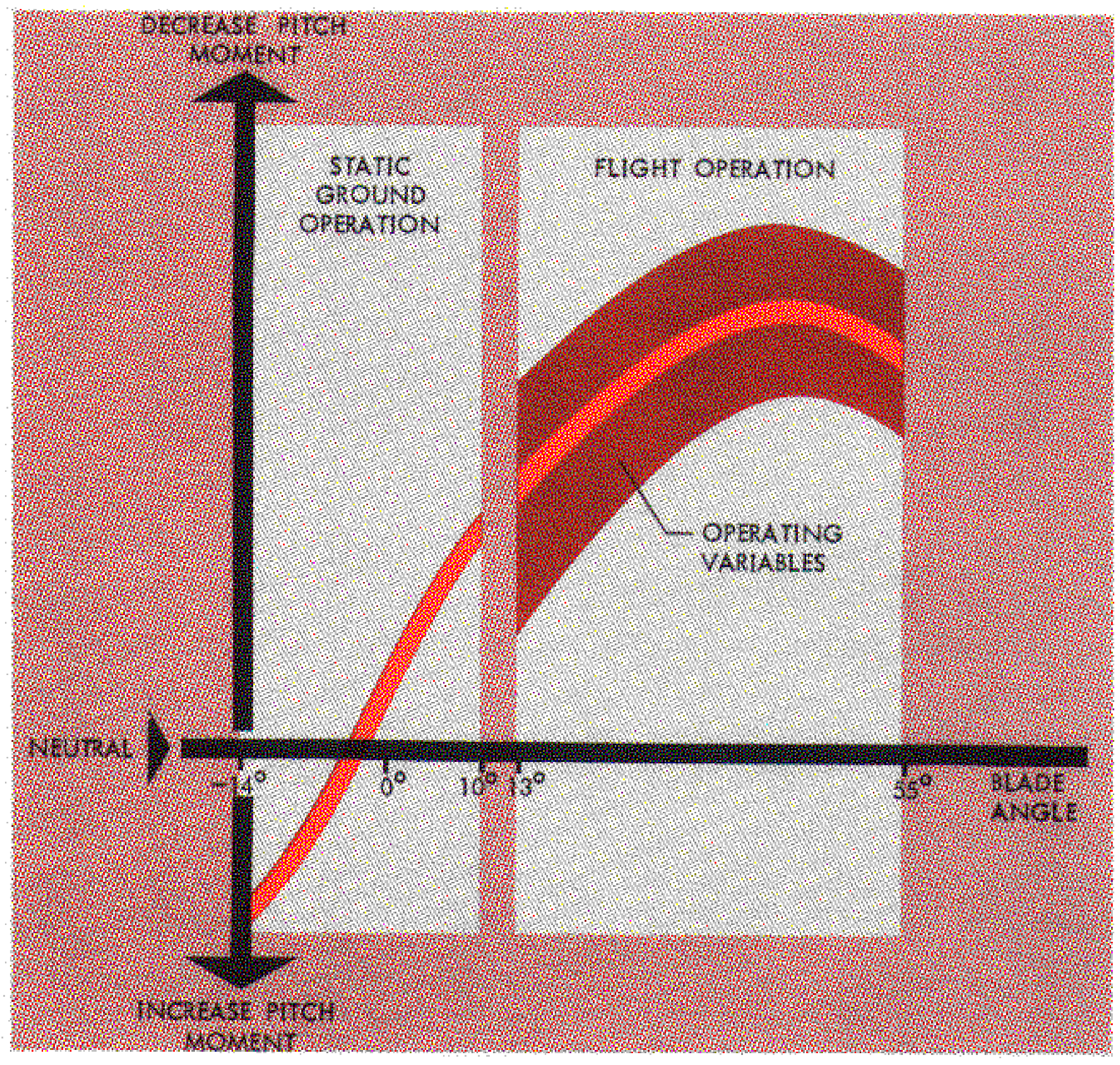

Figure 1 Net Effect of Twisting Moments on Blades During Static Ground Running and Typical Flight Operation

the blade index point. This point marks a chord-section of the blades, 54 inches from the center of the hub, that is approximately parallel to the plane of rotation when the propeller is producing no thrust at zero airspeed. Prop span is 13 ft., 6 inches.

When a propeller rotates at normal operating speed, its blades experience a stress that tends to twist them towards flat pitch. This twisting moment is a natural dynamic phenomenon that affects blades of every design, and its total effect is the sum of prop speed, load, and friction factors. It is more directly related to the centrifugal forces generated by the whirling mass than to aerodynamic loads, but with the reversible propellers the blades tend to pivot from either positive or negative pitch towards the zero-moment blade angle as shown by the curve in Figure 1. This force is generally identified only with its chief contributing factor—the Centrifugal Twisting Moment; abbreviated as "CTM." However, the variable airload moment is of major importance to the control of a propeller which has a fixed operating rpm. Therefore this discussion must consider the total Twisting Moment and use the shorter abbreviation "TM."

In self-governing operation, the rotational speed of the propeller is sensed by a fly-weight assembly in the governor that converts the fly-weights' centrifugal force into linear force. This linear force acts on a sliding "pilot" valve against the opposing force of an extremely sensitive spring, known as a speeder spring, that is carefully calibrated so that a given rotational speed of the propeller results in the spring being compressed to a predictable position. In the Orion Hydromatic propeller, an excursion of the pilot valve re-positions a servo valve, and the servo valve controls and directs hydraulic flow to the pitch control piston in the propeller dome. On Hydromatic governors used with reciprocating engines, the speeder spring can be re-adjusted to varying degrees through a manual flight station control to establish a desired engine speed. There is no such direct control on the Orion, for the engine speed need not be varied to obtain better power or better efficiency for any phase of flight. The pilot valve in the Orion governor has a single "ON SPEED" position, where it stabilizes when the TM, acting to force the pitch control piston towards low pitch, is exactly countered by hydraulic force on the front (increase pitch) side of the pitch control piston. Of course, this pressure is made to increase and overcome the TM when the slightest over-speed causes the pilot valve to move against the speeder spring. Conversely, a small underspeed sensed by the governor relaxes the "increase pitch" hydraulic force and allows the TM to move the blades towards low pitch until the propeller returns to "ON SPEED". In a more severe underspeed, the governor can augment the TM with "decrease pitch" hydraulic power.

From the start of the take-off roll to touch down, the Orion propeller functions as a self-governing unit at all times, and in governing its own speed it automatically governs engine speed as well. For ground operation, the pilot valve is "trapped" by a mechanical linkage that leads the pilot valve as necessary to produce specific blade angles, and the propeller is neither self governing nor speed sensitive except for severe overspeed during ground operation.

During flight, the propeller operates always in a fairly high pitch range (13 to about 55 degrees). Blade angles lower than this are plainly not compatible with the flight speed range of the Orion, and a mechanical "low pitch stop", very similar to those used with piston engine propellers, is incorporated in the propeller dome to ensure that the TM cannot reduce propeller pitch to a lower level in the event that either engine power or hydraulic control power is lost.

DESIGN CONSIDERATIONS As noted earlier, there are many inherent traits in the turbine engine which require that the propeller be very closely integrated in order to hold the engine on speed and to preserve the aircraft's controllability if malfunctions and failures occur. In some respects there is a resemblance to the reciprocating engine power control, but in the main the turbo-prop is unique.

It will greatly facilitate the later discussions, which describe the mechanics of the propeller, to first review the over-all design concept and identify the components and sub-systems as to the purpose they serve in both normal and emergency situations.

As noted previously, it is essential for safety's sake that the engine be de-coupled from the propeller automatically in the event a series of malfunctions result in the propeller "motoring" the engine compressor to the point that drag becomes excessive. In such a case, it could happen that the engine, the propeller, or both may continue to revolve for an indeterminate time. To ensure that the separated components are not subject to further damage, it is obviously necessary for each to be self governing and self lubricated. For this reason, the engine has its own speed governor and lubrication system, both of which operate from direct mechanical gear drives. Similarly, the power plant segment forward of the de-coupler can operate indefinitely as an autonomous unit, driven by the airstream. The reduction gear box has a gear driven lubrication system pump that is completely separate from the engine system except that they share a common reservoir. The propeller has its own hydraulic oil supply and gear driven pumps that provide the necessary lubrication and the hydraulic power for pitch controlling.

In addition to the normal speed-governing flyweight assembly, the propeller incorporates a speed sensitive safety mechanism, known as the pitch lock assembly, attached directly to the propeller pitch-change mechanism. This device also has the faculty to sense the operability of the propeller's hydraulic power system. If the propeller's hydraulic power system fails to maintain pitch control pressure, or if the propeller overspeeds for whatever reason at normal flight speeds and power settings, the pitch lock assembly blocks the pitch change mechanism against travel towards low pitch at a blade angle well within the range compatible with P-3 flight speed; before it reaches the low-pitch stop at 13°.

A mechanical coordinating linkage, operated by the power lever cable system, interconnects the primary engine control, the fuel control assembly, and the primary prop control component, a cam shaft in the control assembly known as the "alpha shaft" (see Figure 2). This positive inter-locking control is linked to the pointer of a coordinator quadrant on the engine fuel control assembly which is graduated from 0° to 90° and serves as the primary index to which the power control system is related as follows:

1. At 0°, the power lever is at its aft extreme. The normal speed sensing faculty of the propeller governor is blocked by a cam on the alpha shaft which artificially induces a "decrease pitch" signal until the prop reaches its full reverse position and the fuel control will automatically supply as much power as is needed to maintain the selected engine speed. As the power lever is advanced through the first 33° of coordinator travel, control cams cause the propeller pitch to traverse from its maximum negative angle (minus 14°) through 0° (marked "START" on the power lever quadrant) to about plus 10°, and the fuel control continuously furnishes whatever increment of fuel flow is needed to maintain engine speed.
2. At 34° coordinator, the power lever drops down a ramp into the flight operating range. In this range, the request for power is sensed initially by the fuel control, and the propeller pitch changes automatically to utilize the power and maintain engine speed. The pitch angle is not predictable, for it varies with power and airspeed, but after sufficient power has been applied to advance blade angle past the point at which the low pitch stop levers latch, blade angle will be no less than the low pitch stop position (13°), and at top speed and power the blade angle will be approximately 55°. With the power lever full forward at TAKEOFF position, the coordinator will be at 90°.
3. The power lever/fuel control/coordinator linkage cannot be moved past TAKEOFF position, but the propeller control, that is, the linkage from the coordinator to the "alpha" shaft, can be turned past this position by the Emergency Engine Shutdown control. When the shutdown handle is pulled, a cam on the alpha shaft mechanically positions the feather valve in the propeller control, and a separate mechanical linkage, independent of the normal fuel control, mechanically closes the fuel shut-off valve.

Thus, there are two ranges of propeller pitch control divided by the low pitch stop;* ground operating range and flight operating range. The propeller pitch is not controlled directly by the power lever in flight range, this being a function of airspeed and power, but there is a lower limit established by the low pitch stop. Actually, if the propeller pitch is reduced this far in flight, it is due to the fact that the engine is not producing enough power to drive the compressor, and the propeller is windmilling to supply the balance, thus producing a small drag. This drag is most useful to offset the tendency of the aircraft to accelerate during descent, especially during the final approach, but it is extremely important that the power control *not* be reduced into the ground operating range during flight. In ground range, the propeller is made to assume such low blade angles that at flying speeds it will produce a windmilling drag, possibly over-speed, probably decouple, and certainly prejudice the controllability of the aircraft.

Once the airplane touches down, however, windmilling drag is very useful, for it acts simultaneously as a brake and as a spoiler of wing lift, allowing the aircraft weight to settle on the wheels so that wheel braking is effective early in the landing roll.

The power control system is blocked mechanically in two places to ensure that the power lever is not retarded into ground range during flight. The lever linkage in the flight station has a ramp stop that requires the pilot to lift the lever to retard it

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**Note that there is a 3-degree increment between the highest positive blade angle directly scheduled for ground operation (+10°) and the lowest angle permitted for flight operation (+13°). This range is proper for neither operation, and operation here is transitory.*

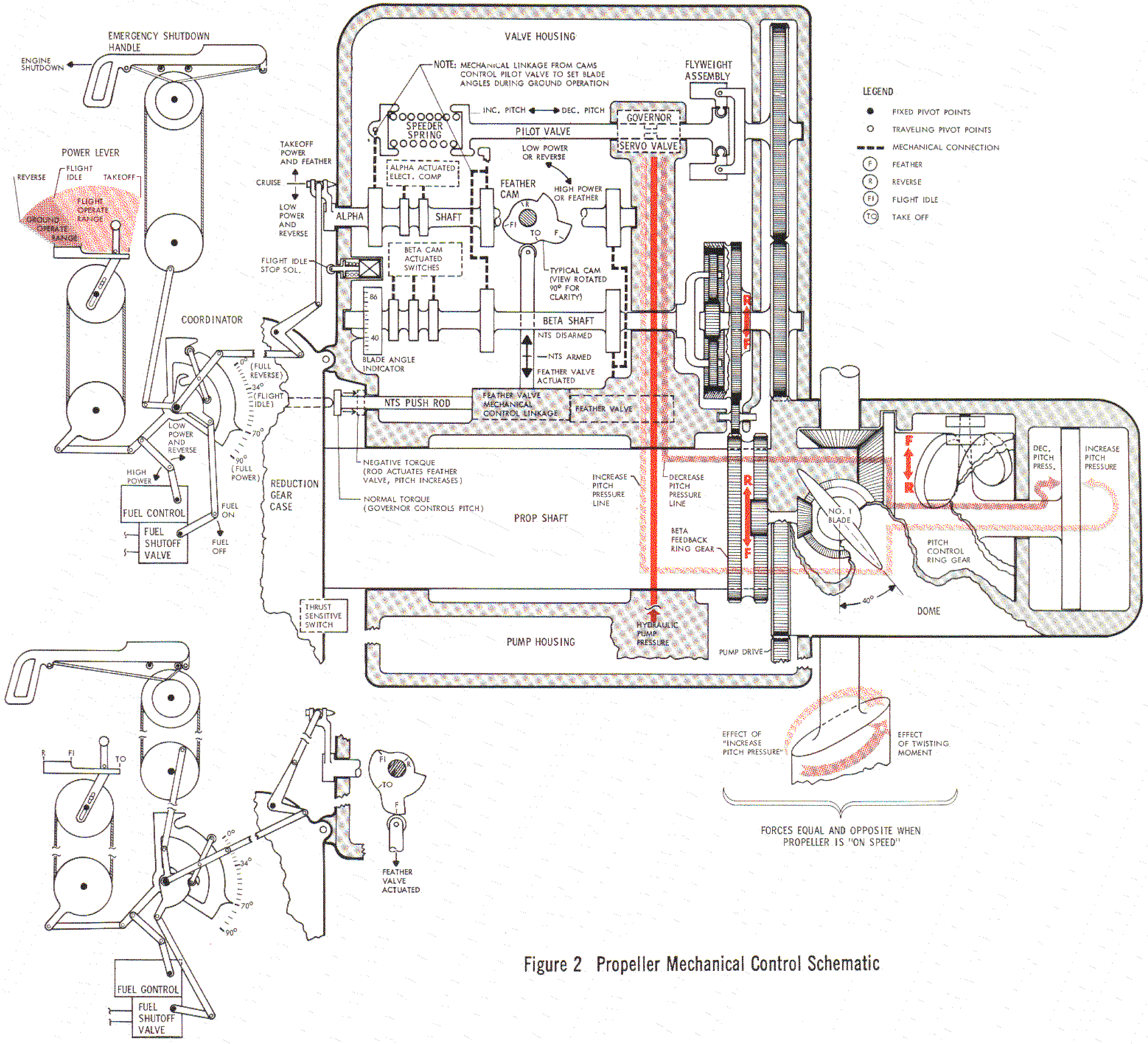


Figure 2 Propeller Mechanical Control Schematic

into ground range, and the propeller linkage at the alpha shaft has a solenoid operated "flight idle stop" that operates from the MLG shock strut scissors switch. The flight idle stop is actually a spring-loaded detent, designed so the pilot can over-ride the stop by applying about a 12-lb. pull at the power lever in the event that the electrical signal from the scissors switch does not materialize when the aircraft touches down.

When the propeller pitch enters the ground operating range at +10°, a switch in the propeller assembly actuates, illuminating an advisory light identified "BETA" in the flight station. In aerodynamic calculations, the Greek letter Beta is used as a symbol of propeller blade angle, and this nomenclature is carried over into the advisory light identification. The term is also applied to the nomenclature of many components and is used in functional descriptions to indicate that the subject component, system, or function is directly concerned with propeller pitch. Thus, the Beta operating range is the ground operating range of the power controls in which the positioning of the control sets the blade angle. Similarly, a cam shaft in the propeller control is geared to the No. 1 blade butt, and since its position is a direct indication of propeller pitch, it is known as the Beta shaft. It should be noted, however, that this shaft operates throughout the full range of pitch control, and it is *not* exclusively associated with the Beta (ground operating) pitch control range.

The reduction gear box incorporates two devices that react to deviations from the normal development and transmission of power from engine to propeller.

One device actuates the Thrust Sensitive Switch when propeller thrust drops to less than 500 lb., thereby triggering an automatic engine shutdown and feathering cycle, if this system is armed and if the power lever is at or near take-off position.

The other device is the NTS mechanism mentioned earlier that responds to negative torque, that is, when the propeller begins to turn the prop shaft. When negative torque reaches a pre-set value, a ring gear inside the gear box is forced forward against a spring load, driving a mechanical linkage against the striker of the NTS push rod in the propeller control. If the power lever is in flight range, the NTS rod engages an internal linkage in the prop control assembly that levers the feather valve towards feather position. All available hydraulic power is diverted by the feather valve into the "increase pitch" lines until the excessive negative torque is relieved, at which point the NTS plunger retracts and the propeller becomes self-governing again. If engine power is still too low for the prevailing air speed, prop pitch will decrease, windmilling will resume, and the NTS will repeat its cycle.

At all times during flight, the NTS serves as an automatic protective device that prevents the propeller from imposing a serious drag due to a diminution of engine power, regardless of the cause of the power reduction. Note that if the engine actually dies, the NTS has the capability to continually increase propeller pitch to the point that the prop's rotational speed and the resultant windmilling drag are both held to safe, low values—incurring just enough windmilling drag to produce NTS actuation. In this respect, the NTS has the nature of a completely automatic, purely hydro-mechanical auto-feather system. Since it serves also to limit drag due to a deliberate reduction of power through the flight station control, *the NTS is one of the most important features in the adaptation of the engine and propeller to the needs of the airframe.*

PROPELLER ASSEMBLY

Ignoring the spinner and the stationary afterbody fairing, the propeller comprises three main subassemblies: the barrel assembly, the dome assembly, and the control assembly.

The barrel assembly is the hub of the propeller which is mounted on the propeller drive shaft at the front of the reduction gear box. It serves as a structural foundation for the propeller blades (which

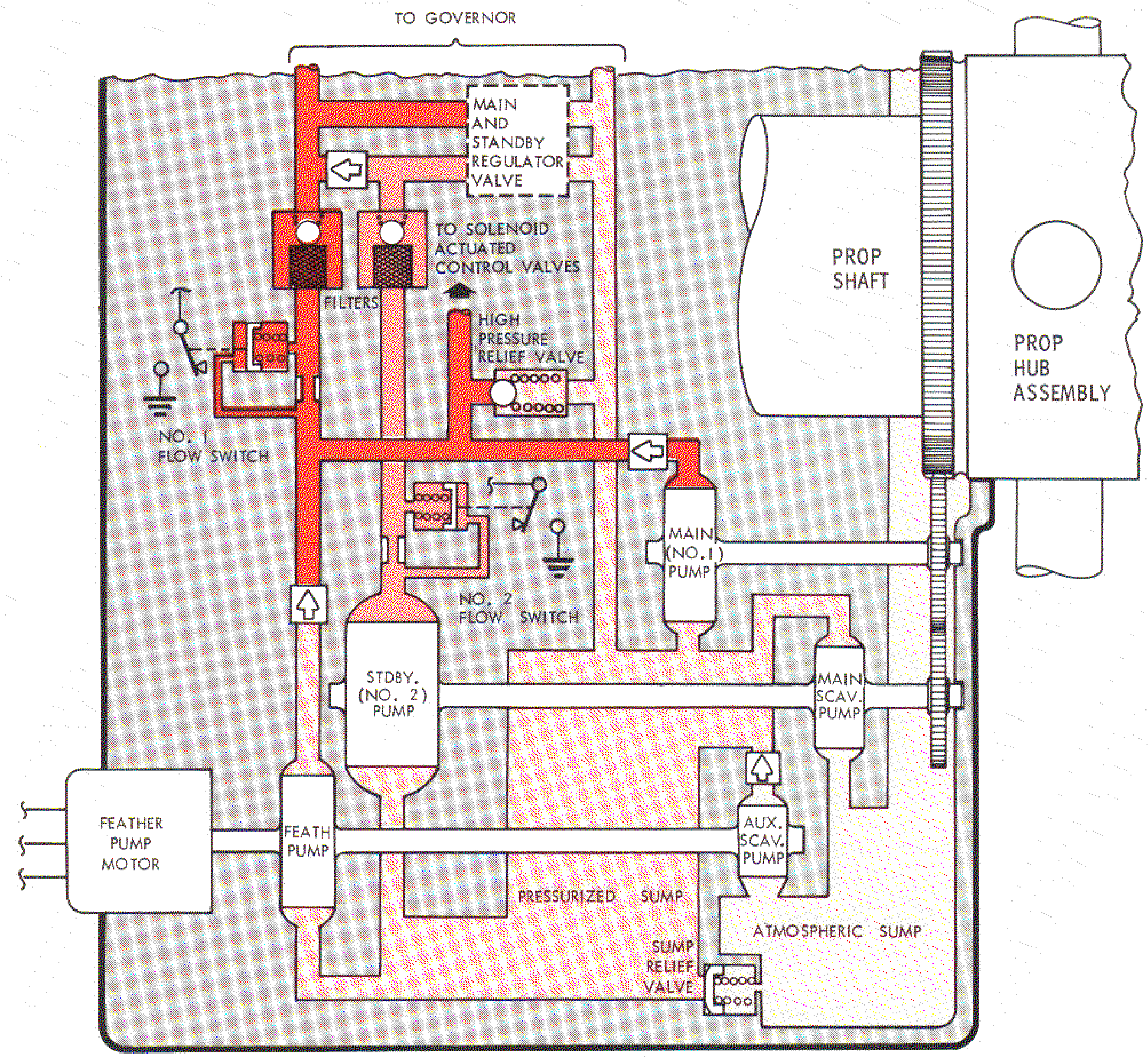


Figure 3
Prop Hydraulic
Pumping Configuration

are the only moving parts of this assembly) and for the dome and the control assemblies. The hub is mounted on centering cones, and retained by a splined-wrenching nut. The pitch lock assembly is mounted in the center of the hub. The nut and pitch lock assemblies provide the oil passages needed to transmit hydraulic power from the control assembly to the dome.

The dome assembly incorporates the pitch control piston and the cam-and-gear train which converts linear travel of the piston into rotary motion to drive the bevel gears on the four blade butts.

Although the control assembly is mounted on the aft side of the propeller hub, it does not turn with the hub, being held stationary by a torque retainer fixed on the front housing of the reduction gear box. The control assembly is roughly cylindrical, and is divided into top and bottom housings. The lower housing, known as the pump housing, contains two oil sumps (one "dry" sump known as the atmospheric sump, one "wet" sump known as the pressurized sump) and it contains five separate gear-type pumps. Three are driven by rotation of the prop hub; two (which are actually combined in a single stacked unit) are motor powered. The pump housing also contains relief valves, filters, flow sensing devices and all the other components necessary to a hydraulic power pumping system.

The upper part of the control housing is detachable—without removing the propeller. It is known as the "valve housing," and it contains the governor and all the valves needed to regulate the hydraulic power system and to direct the pitch-control flows. The alpha shaft, which is actuated by the power lever and emergency shut-down controls, is located in this assembly adjacent to the Beta shaft, which feeds-back an indication of blade angle to the control.

The hub assembly and the dome assembly are similar in their operation to the reciprocating engine design which has been in use for years. The control assembly and the pitch-lock mechanism are unique, however, and we will discuss them here in some detail.

MAJOR CONTROL ASSEMBLY COMPONENTS

The pump housing assembly, comprising the lower part of the control assembly, has one gear-driven pump that scavenges the "dry" atmospheric sump and maintains a constant pressure of about 20 psig in the pressurized sump to ensure against cavitation within the hydraulic power system.

The atmospheric sump simply acts as a scupper to collect oil which leaks or is bled from the pressurized components. In Figure 3 we have portrayed the *scheme* of the hydraulic pumping system. Its total capacity is 25 quarts of MIL-H-6083, Type 1. Alternatively, equal parts of MIL-H-6083, Type 2 and MIL-H-5606 may be used.

All the pumps in the control section are positive displacement, and output flow does not vary except that the pumps that are gear-driven from the propeller shaft will only produce 72% of rated flow during "LOW" (72%) rpm engine operation. Aside from a small metered bleed flow and normal leakage, the hydraulic power system constitutes a "closed" system in connection with the pressurized sump. The capacity of the scavenge pump is more than adequate to return these normal losses. The excess scavenge flow is bypassed back to the atmospheric sump through a pressurized sump relief valve, set at approximately 20 psi.

There are two mechanically driven power pumps, a main and a standby pump, that operate in parallel. A constant output flow is proof of pump operability, and the output is monitored continually by individual flow-sensitive switches that close and illuminate the associated "PROP PUMP" light on the center instrument panel in the flight station if pump flow deteriorates below a pre-set quantity. The warning lights, identified No. 1 for the main pump, No. 2 for the standby, do not pinpoint the reason for flow loss, but it must be assumed that a serious malfunction is indicated if one or both lights illuminate for any appreciable length of time during "NORMAL" rpm operation.

The term "main pump" denotes the duty of this pump, not its capacity. Actually, the main pump produces only half as much flow (5 gpm) as the standby pump (10 gpm). In normal operation, the main pump flow is more than sufficient for propeller control unless a sharp power transient requires a substantial pitch change. In such a case, as much of the standby pump flow as is needed is channeled to the pitch change piston, and when the propeller comes back "ON SPEED", the standby pump flow is phased out and the main pump maintains the pressure needed to hold the propeller in its new attitude.

As shown in Figure 3, the other two pumps in the lower part of the control section are motor-driven. One pump element, known as the auxiliary scavenge pump, is plumbed in parallel with the gear driven scavenge pump. The other pump is known as the feather pump, and it is plumbed in parallel with the main and standby pumps. The motor that drives these pumps is generally referred to as the feather pump motor, although some documents term it "auxiliary" motor, and properly so, for it is routinely used as an auxiliary source of hydraulic power to cycle the propeller when the engine is not operating, thus allowing a great deal of check-out work to be carried out without running the engine. It is used inflight for both unfeathering and feathering, serving to complete the feather operation after the propeller has nearly stopped. (A motor-driven pump is needed to stop windmilling completely, for obviously the output of the mechanically driven pumps is reduced in proportion to rpm.) The feather motor power control circuit is routed through a pressure sensing switch that de-energizes the motor automatically when a sharp pressure rise in the "increase pitch" hydraulic power line indicates that the pitch control piston has bottomed at its full-feather position.

There is no fixed operating pressure in the hydraulic power system of the propeller. The system has a demand type regulator—the main and standby regulator valve—that maintains pressure in the pump manifold 150 psi higher than the pressure required for pitch control. There is a high pressure relief valve, but it is set to relieve at a pressure well above the normal operating range, and serves only to protect against the development of destructive pressures due to a malfunction.

The valve housing, comprising the top part of the control unit, contains the propeller's "brains", that is, those components which sense the pilot's command and the propeller's condition and convert any disparity between the two into hydraulic actuation to restore the balance.

The command is delivered mechanically via the power lever control which positions the alpha shaft.

The condition is sensed, 1), as rotational speed by the governor fly-weight assembly, which has a fixed-ratio gear drive from the prop shaft, and 2), as pitch angle by the Beta shaft, which is turned by a complex differential gear train driven by a gear segment on the butt of No. 1 blade.

The actuation hydraulic power is directed either to the "increase" or the "decrease" pitch line by the governor servo valve assembly, but the effectiveness of the controlling power (rate and pressure) is determined by main-and-standby regulator.

FLIGHT OPERATION — SELF GOVERNING To describe the inter-action of the various components in the course of normal flight operation, we will follow the train of events that occur from the initial cause to final effect. Figure 4 is arranged to illustrate the function of the various basic components clearly, and it should be noted that we have made no effort to portray the actual components.

Also, for purposes of illustration, we will assign certain arbitrary values to the hydraulic forces which prevail at certain points in the system when the propeller is stabilized "ON SPEED", that is, when the hydraulic pressure acting on the "increase pitch" face of the pitch control piston is exactly countered by the TM tending to decrease the pitch. For simplicity, we will refer to this as "demand" pressure.

If this "demand" is known to be 300 psi, the pressures at the other key points are predictable.

Power system pressure will be 150 psi higher than demand, due to the metering piston in the main and standby regulator valve. Note that demand pressure plus a spring force equal to 150 psi acts on one face of the metering piston; pressure in the pumping system acts on the other face, and a stable condition is achieved only when these forces cancel, that is, pump pressure is 150 psi above demand.

The pump pressure, 450 psi, in turn, is utilized as a reference by the servo spool in the governor valve assembly; one face of the spool is always under pump pressure, the other—and larger—face is under "balance" pressure. For simplicity, we will assume the larger end of the servo to be precisely twice the area of the smaller, and therefore the balance pressure must be 225 psi (450x.5) in the stable "ON SPEED" conditions of our example. The pilot valve's sole function is to control this balance pressure. Speed variations alter the balance, and as the pilot valve seeks always to re-establish the balance, pitch control pressure is altered as necessary to eliminate the speed error.

Assuming, now, that the pilot has just pulled the power lever back to the flight idle ramp, so that engine power is too low to sustain the propeller at normal speed at the high pitch angle shown:

1. The fly-weight assembly loses rpm as the engine drops slightly underspeed, and the diminished centrifugal force allows the speeder spring force to move the pilot valve to the right.
2. This shift causes balance pressure to drop below 225 psi, and the opposing 450-psi pump pressure shifts the servo towards the right also.
3. This shift causes a severe pressure drop in the "increase pitch" line which has two effects:
    - A. The main-and-standby regulating valve senses that the demand (previously 300 psi) is less, and pump pressure (450 psi) shifts the regulating piston against the diminishing force of its demand reference, thereby

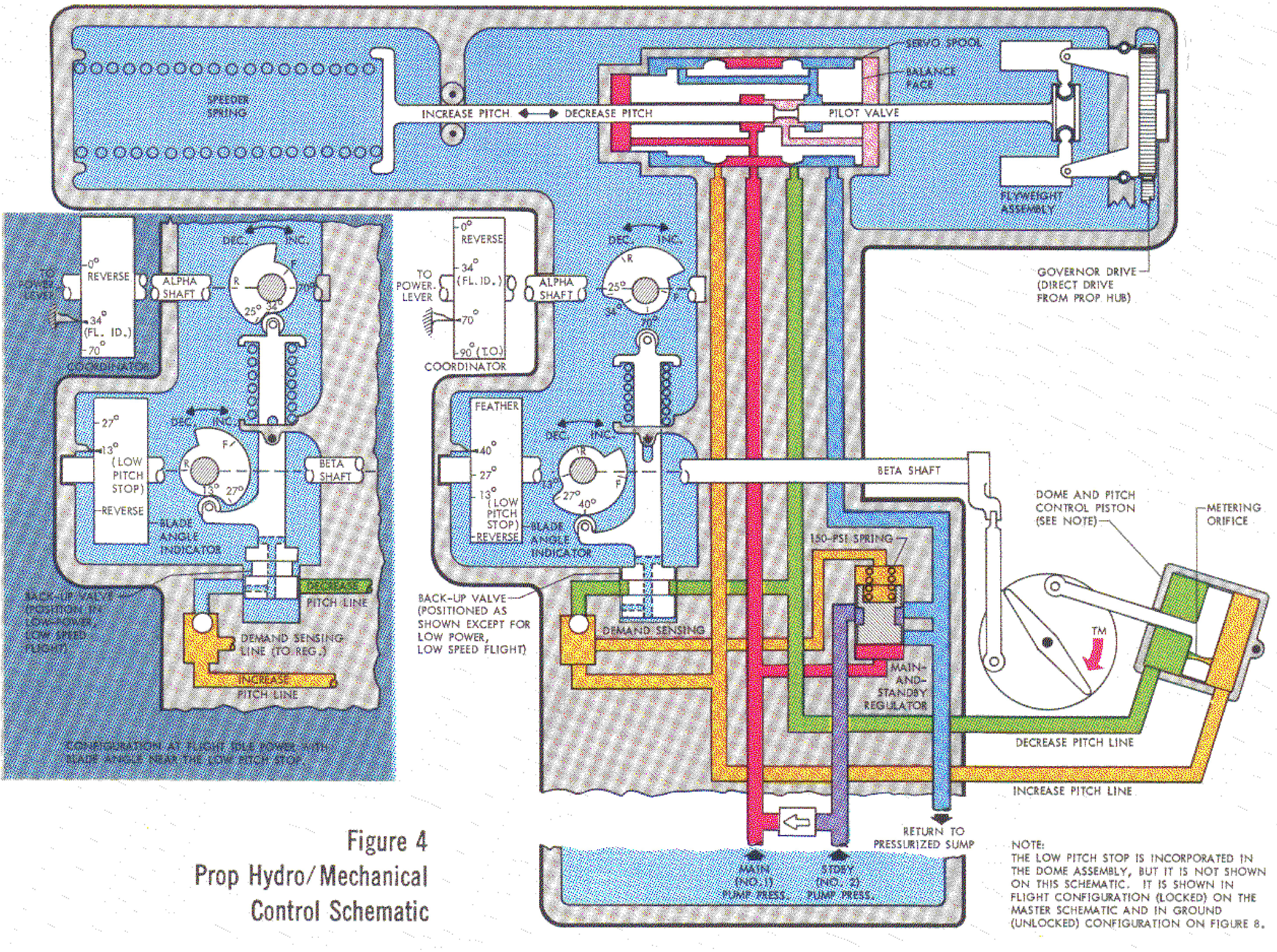


Figure 4
Prop Hydro/Mechanical
Control Schematic

by-passing more pump output to return so that pump pressure falls below its previous value of 450 psi.

B. TM drives the pitch control piston towards the relaxed force of "increase pitch" pressure, the decreasing pitch begins to relieve the over burdened engine and its speed begins to increase. Note that, if the underspeed is sudden and severe, the servo may eliminate "increase pitch" pressure altogether and divert pressure to the "decrease pitch" lines to augment the TM effect and facilitate the pitch change. However, this supplemental pressure is limited sharply when the blade angle drops below about 27 degrees, for at this point a cam-operated valve, known as the "back-up" valve, closes, and reference pressure from the "decrease pitch" lines to the main and standby regulator is blocked. In effect, the regulator senses that demand has dropped to zero, and at zero demand the spring force alone will create only 150 psi pump pressure. Therefore with the power lever at Flight Idle, even though the servo shifts to its extreme "decrease pitch" position, it cannot port more than 150 psi to the "decrease pitch" lines while blade angles are in the low flight operating range for the simple reason that the regulator is insensitive to the demand, and the pumping system cannot produce more than 150 psi unless a hydraulic pressure "demand" signal augments the regulator spring force.

4. When the engine returns to normal speed, the pilot valve returns to its "ON SPEED" position, but when it stabilizes there, the servo valve remains shifted slightly to the right of its previous position, creating a new set of pressure values throughout, keyed to the lower "increase pitch" demanded to counter the lower TM at reduced power.

If we assume the lower TM is exactly countered by 50 psi in the "increase pitch" line, the other key pressures are altered thus:

1) Power system pressure will be reduced the same value as demand. Demand is now 50 psi, therefore power system pressure is now 200 psi (150 plus 50).

2) The power system pressure, acting on one end of the servo spool, is countered by a balance pressure of exactly ½ acting on the larger face of the spool (200x.5=100).

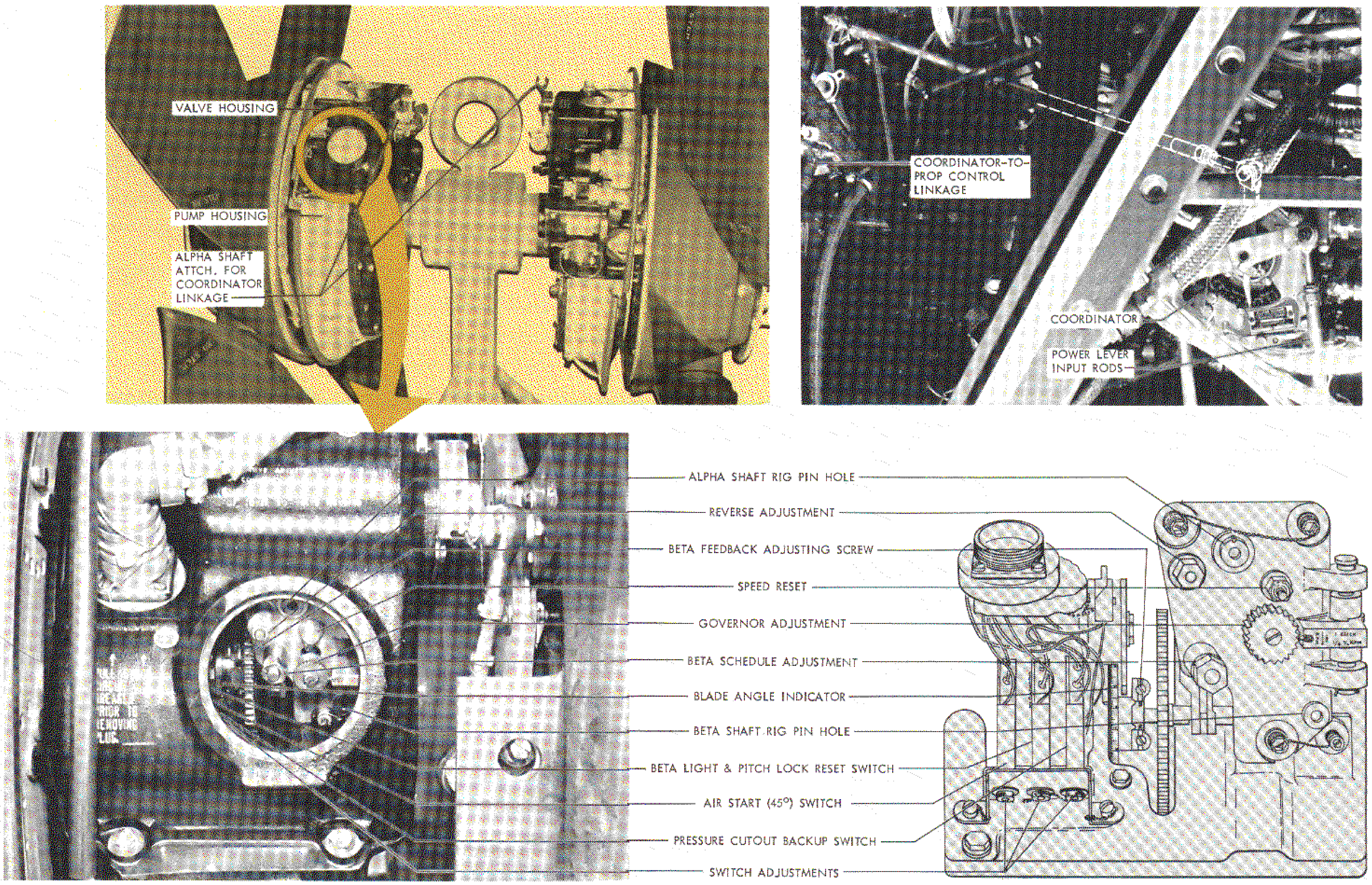
In summation, it can be said that when the propeller control is in its "speed governing" (flight operating) range, it governs power plant speed by providing the exact "increase pitch" hydraulic pressure needed to counter the propeller's TM. In the foregoing example, the TM/"increase pitch" balance was destroyed by a reduction in engine power, but it should be noted that if aircraft speed is reduced by adding drag with the flaps or by inducing a climb, the underspeed will occur and the "increase pitch" pressure will be reduced by the governing system in exactly the same way.

If the reverse situation occurs, that is, if the engine overspeeds slightly due to increased power or increased airspeed, the entire process is reversed, and when the power plant comes back "ON SPEED", pump pressure, balance pressure, and "increase pitch" pressure will all be elevated in proportion to the increase in the twisting moment of the propeller blades.

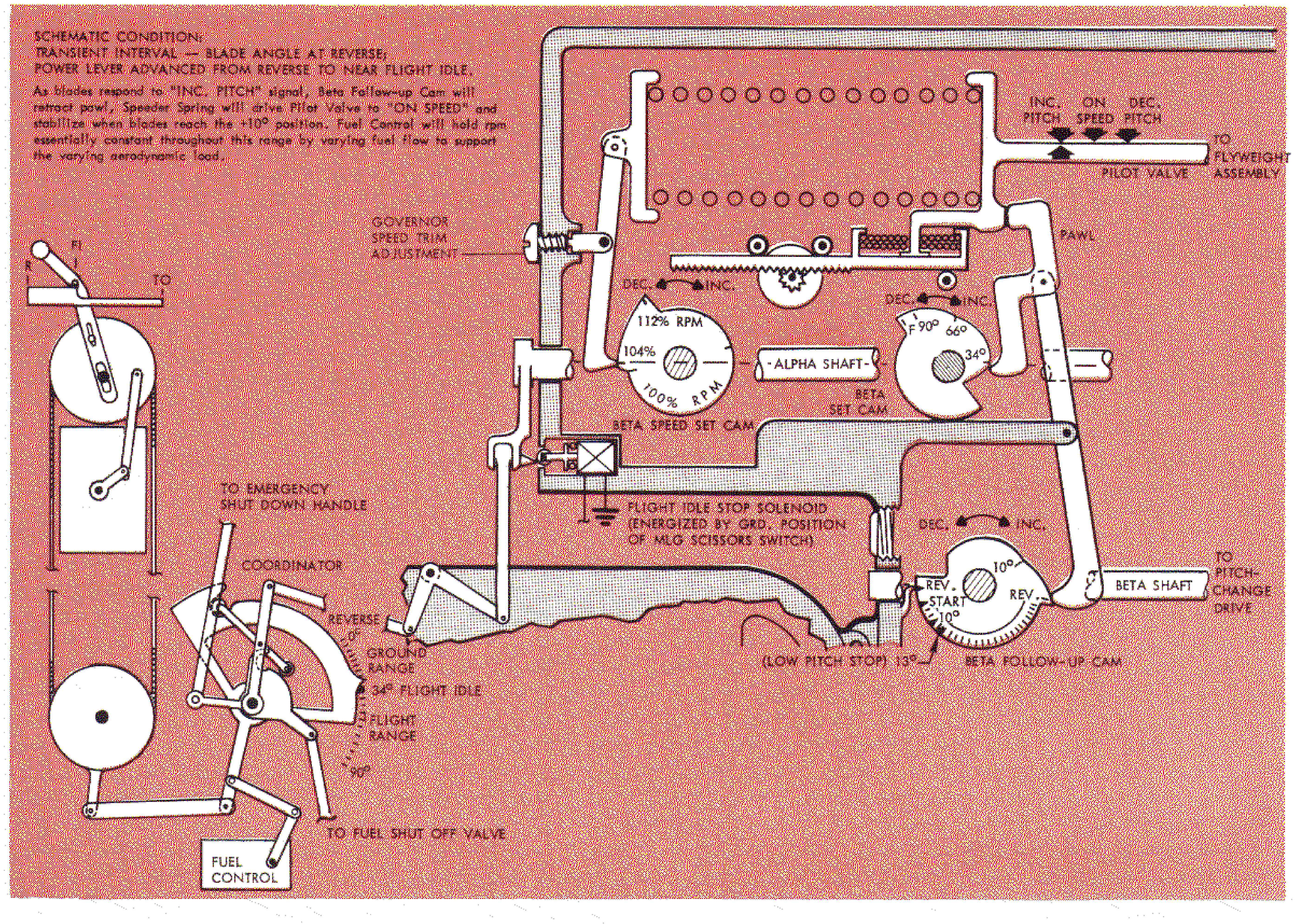
The foregoing step-by-step explanation is apt to be misleading, for it gives the impression that there is a substantial lag in propeller response. Actually, the corrective action begins immediately; in fact, the control has a faculty (which we will describe later) to sense that an off-speed condition is imminent and to initiate the proper corrective action before the off-speed occurs. The high order of sensitivity in prop control allows design simplification elsewhere, for example, the ac generators can be driven directly from the engine without fear of damaging electrical components with alternating current too high or too low in frequency.

GROUND OPERATION—MANUAL BETA CONTROL The propeller's hydraulic power control system functions exactly the same during ground operation as it does during flight operation, except that the governor pilot valve is under direct manual-mechanical control and cannot respond to rpm variations, except for extraordinarily high over-speed.

The highly simplified schematic in Figure 5 shows the general "plan" of mechanical pilot valve control. Note that during all operation with the power lever in ground range, the speeder spring on the governor pilot valve is "trapped" between a pawl operated by the Beta Speed Set cam (which "resets" the spring, making the governor steadily less sensitive to overspeed as the Alpha shaft turns towards reverse) and a pawl whose position is a function of both demand (indicated by the Beta Set cam on the Alpha shaft) and response (indicated by the Follow-Up cam on the Beta shaft).



Control Housing — Rigging and Adjustment Points



SCHEMATIC CONDITION:
TRANSIENT INTERVAL — BLADE ANGLE AT REVERSE;
POWER LEVER ADVANCED FROM REVERSE TO NEAR FLIGHT IDLE.

As blades respond to "INC. PITCH" signal, Beta Follow-up Cam will retract pawl, Speeder Spring will drive Pilot Valve to "ON SPEED" and stabilize when blades reach the +10° position. Fuel Control will hold rpm essentially constant throughout this range by varying fuel flow to support the varying aerodynamic load.

Figure 5
Hydro-Mechanical
Blade Angle Control
in Ground Operation

When the power lever is advanced as shown in Figure 5 to near Flight Idle, the Beta Set cam action drives a pawl against the pilot valve "bridle" and compresses the speeder spring, thus inducing a spurious "overspeed" motion of the pilot valve, that is, the pilot valve is displaced from "ON-SPEED" towards "INCREASE PITCH" position. Just as in flight operation, this upsets the hydraulic pressure balance across the servo spool, hydraulic force moves the spool to follow the pilot valve, and pressure builds up in the "increase pitch" lines.

As the prop moves towards a higher pitch, the Beta Follow-Up cam action withdraws the pawl that induced the "overspeed" motion, and the highly compressed speeder spring returns the pilot valve towards its "ON SPEED" position. The increasing propeller pitch tends to slow the engine, but the fuel control governor meters more fuel to recover the lost speed, and eventually a stable condition will be reached in which the higher blade angle selected by the operator has induced higher TM, and this is exactly countered by a pressure increase in the pumping system.

For quieter, more economical operation on the ground, the operator can select "LOW" (72.5%) engine speed during ground operation. This is done electrically, by re-adjusting the fuel governor speeder spring, and since the propeller has no speed sensing faculties while the power lever is in ground range, "LOW" rpm engine operation has no effect on the propeller except to reduce rpm and thrust.

When the power lever is moved out of ground operating range, Alpha shaft cam action releases the prop governor's speeder spring from entrapment, and the free-floating pilot valve can respond to "OFF SPEED" rpm. Whereas the fuel control governor holds rpm within about 4%, that is, between 96 and 105% at "NORMAL" speed, the propeller governor is much more sensitive. It will seldom permit rpm to deviate more than about 2% (98 to 102%)* while the power lever is in flight range, and therefore it serves as the "prime" control for the entire power plant, and the fuel control governor serves as a "standby", during flight range operation.

**The Speed Trim adjustment of the prop governor allows governing control speed to be pre-set to within 0.20% of "NORMAL" rpm, and the hydro-mechanical governor will hold rpm almost exactly at the pre-set speed except for brief excursions when abrupt power and airspeed transients occur. A strobe light or comparably accurate laboratory equipment will usually be required to determine the remaining small off-speed increment, or to detect the brief excursions which normally occur. Speaking practically, however, since tachometers are allowed an accuracy tolerance of plus or minus 1%, and since their readings reflect small surges when abrupt power changes are made, a spread of about plus or minus 2% might be observed at some stage of any flight. We have adopted this APPARENT range in this article simply to further the discussion without precipitating a flood of unwarranted prop and/or tach rejections.*

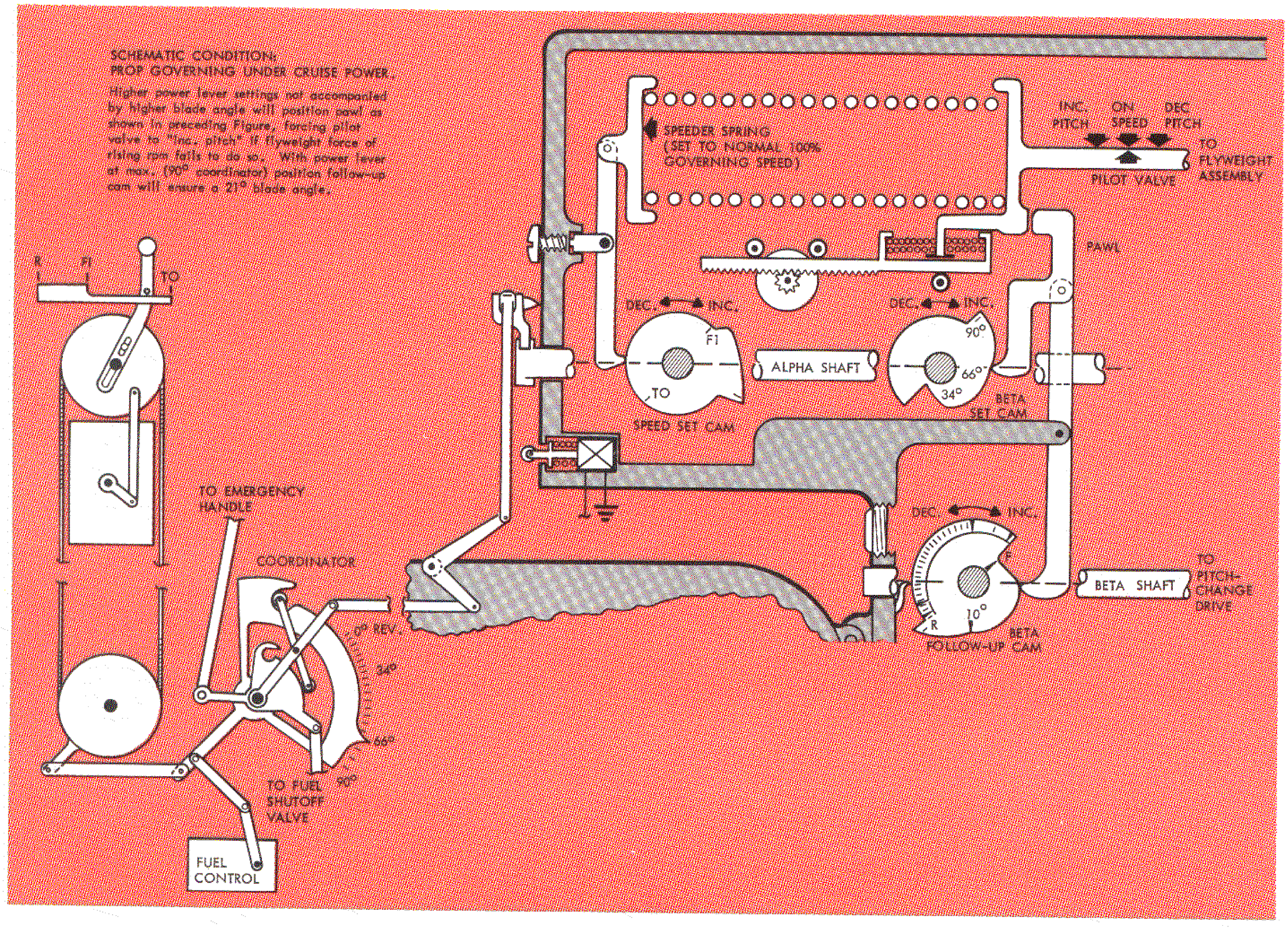

SCHEMATIC CONDITION:
PROP GOVERNING UNDER CRUISE POWER.
Higher power lever settings not accompanied by higher blade angle will position pawl as shown in preceding Figure, forcing pilot valve to "inc. pitch" if flyweight force of rising rpm fails to do so. With power lever at max. (90° coordinator) position follow-up cam will ensure a 21° blade angle.

Figure 6 Flight Operating Configuration at Threshold of Beta Follow-up Actuation

BETA FOLLOW-UP

The cam-and-lever arrangement in the control assembly that "captures" the governor pilot valve during ground operation and "leads" it as necessary to obtain a specific pitch angle for any given power lever position also serves a dual purpose during flight. In these flight range roles, it is referred to as the "Beta follow-up system".

As can be seen in Figure 6, when the power lever is advanced through the flight-idle ramp, the speeder spring tension is set to command 100% rpm. When sufficient power has been applied to turn 100% at 10° plus blade angle, fly-weight force will move the pilot valve away from the leverage control pawl to its "ON SPEED" position, and the free floating valve gains full control of power plant rpm. Thereafter, the leverage action will react to changes in power demand and pitch response in the higher power and blade angle ranges, but under normal circumstances it does not take an active part in the control. However, at any time during high power operation in flight range, if the propeller pitch angle (as sensed through the Beta shaft) becomes excessively low in comparison to power demand (as sensed by the Alpha shaft), the pawl action will intercede, and force the governor pilot valve towards "INCREASE PITCH" position.

To ensure that Beta follow-up action does not interfere with ground checks of flight range operation, the effectivity of the Beta follow-up system, that is, the angular variation it will allow before it nudges the pilot valve, is calculated to make allowance for the effects that air speed, density, and/or reasonable engine inefficiencies have in determining pitch. For example, a specific power lever setting applied to an engine of minimum efficiency while parked in a tail wind at sea level will require a much lower blade angle than results when the same power lever setting is applied to a highly efficient engine in high-altitude, high-speed flight, and the Beta follow-up is designed to tolerate the lowest blade angle that might reasonably result in the former instance.

If the pitch is *obviously* too low, the Beta follow-up will take effect in response to:

1) A rapid power lever advance. In this case, the system is said to "anticipate" the imminent power surge, and by mechanically dumping the full capacity of the hydraulic pumping system into the "increase pitch" lines before the governor actually has any off-speed tendency to rectify, the propeller is enabled to contain the power burst without overspeeding.
2) A sharp drop in pitch, not accompanied by a reduction in power setting. In this circumstance, the Beta follow-up system serves as a sort of adjustable low pitch stop. At take-off power setting this system becomes effective at about the 21° blade angle—8° before the mechanical low pitch stop.

In its function as a stop, the Beta follow-up system control of blade angle is not purely mechanical, as the low pitch stop is, for it is dependent on a functional hydraulic power and control system. Its special purpose is to stop the controlled deterioration of pitch caused by a relatively gradual loss of engine power from a fairly high power setting. The follow-up stop can be advanced well into the pitch range normal to low power, low speed flight, and for ground-check of the propeller it provides a measure of manual pitch control whereby the blades can be cycled in the lower flight range angles (up to 21°) just as they are throughout the ground range, without running the engine.

In the event of a fast power loss in flight, it is more likely that the propeller will begin to windmill, and the negative torque mechanism will limit the decline by sporadically activating the feather system.

TRANSITION FROM FLIGHT TO GROUND OPERATION

In the ground range of operation, the prop's braking capability is as important as its capability to produce positive thrust, and after touchdown the windmilling drag potential of the propellers becomes a most valuable asset. This form of braking is particularly well suited for the landing roll-out because its effectiveness is directly proportional to speed, and the pilot who lands a little hot, either through necessity or inadvertently has the benefit of more effective propeller braking.

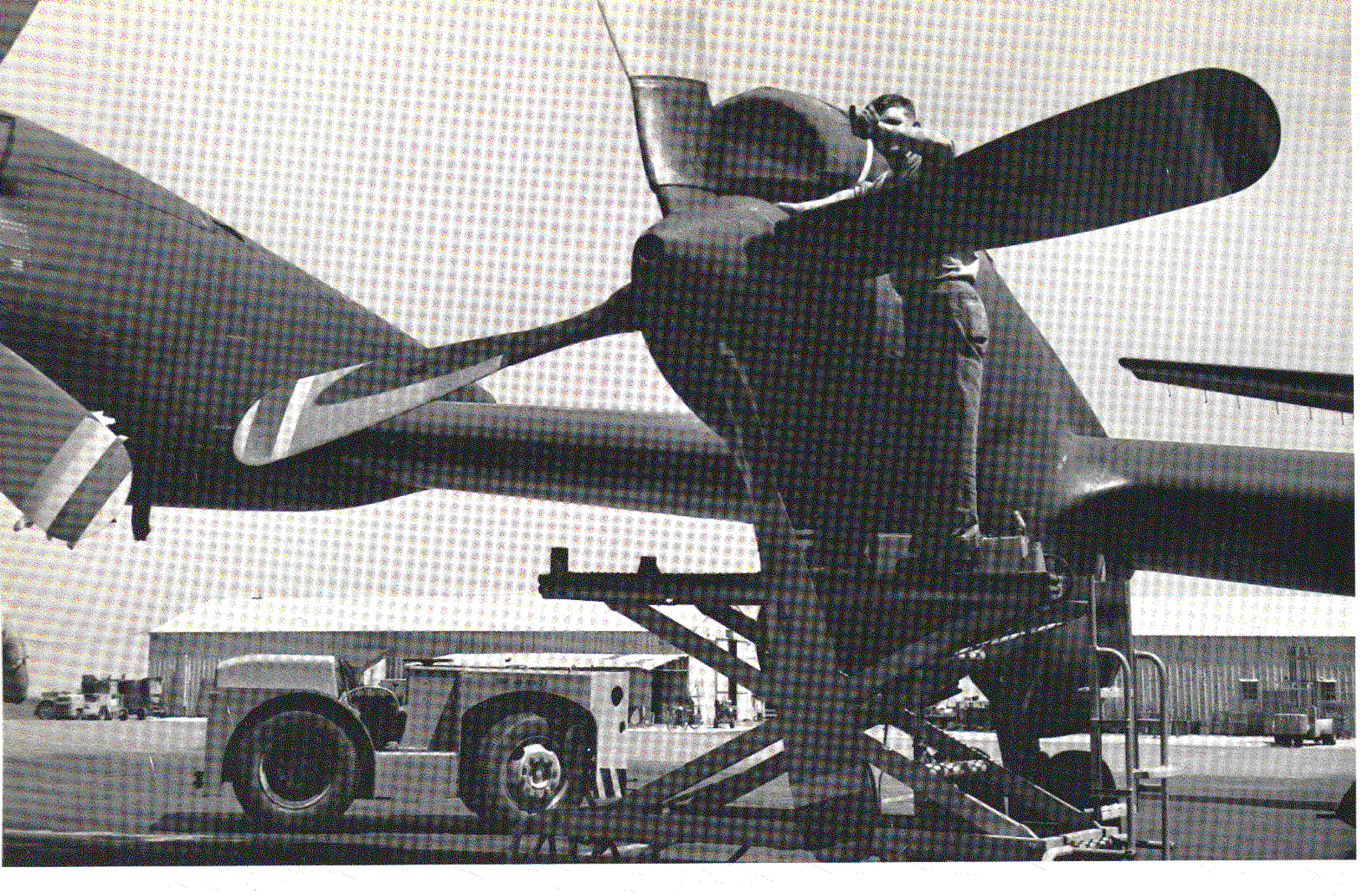
After touch-down it is necessary to disarm the NTS — which functions to limit windmilling drag during flight — to ensure that the propeller is not prevented from following the power-lever commands for pitch changes during roll-out. Obviously, if windmilling were to cause the NTS to operate the feather valve, it would override the power lever demand for "decrease pitch" toward reverse range and propeller braking would be badly impaired.

The NTS is disarmed by a cam on the alpha shaft, which mechanically extracts a vital link from the actuating linkage of the NTS when the power lever is brought past the flight idle stop into ground operating range. Simultaneously, rotation of the two mechanical control cams on the Alpha shaft — Speed Set and Beta Set — increases the Speeder Spring tension and retracts the pawl so the pilot valve is forced to an extreme "under-speed" position. This results in the full power of the pumping system being ported into the "decrease pitch" lines, driving the propeller back below its normal flight range towards the low pitch stop. As mentioned previously, at low flight-range blade angles, the main and standby regulating valve is prevented from developing more than 150 psi "decrease pitch" pressure while the power lever is in flight range. This is but a fraction of the pressure required to unlatch the low pitch stop. Therefore, when the power lever is brought back into ground operating range, a cam on the Alpha (demand sensing) shaft will re-open the Back-up valve as the Figure 4 Inset shows, permitting the regulating valve to sense the demand for elevated pressure in the "decrease-pitch" lines. Thus, when the pitch control piston encounters the obstruction of the low pitch stop, the hydraulic power system pressure rises sharply, the extraordinarily high "decrease pitch" pressure automatically unlatches the low pitch stop, and the propeller is permitted to enter the low-angle ground operating range. (The low pitch stop actuation is schematized in Figure 8.)

The propeller will move rapidly to the angle requested by the power lever position, and when the response, as indicated by the cam on the Beta shaft, satisfies demand, as indicated by the cam on the Alpha shaft, the pawl will have advanced sufficiently to retrieve the governor pilot from the induced underspeed (decrease pitch) excursion and the pilot valve will be exactly at its "ON SPEED" position.

The Pilot should have a sure indication of the prop blades' successful transition from one operating range to the other, and this is furnished by a Beta shaft cam-operated switch that illuminates an advisory light on the center instrument panel (marked "BETA") when the propeller is in the ground operating range, below 10° blade angle.

The switch that illuminates the Beta light when the propeller transits from flight to ground operating range is also instrumental in the automatic pitch-lock safety mechanism, but before discussing pitch-lock in connection with this transient phase of operation, we will describe its principal operating function.



THE PITCH-LOCK

GENERAL The pitch-lock provides the surest type of automatic, mechanical protection against the hazard of an uncontrollable, runaway propeller. Its fundamental components are two gears; one is splined to the ring gear that drives (or is driven by) the blades during pitch change, the other is splined to the barrel so that it turns with the prop shaft but is not affected by the pitch change. The gear turned by the pitch change mechanism is spring loaded to mesh with its mate, and since the mating teeth are raked, the gears provide a ratchet type of coupling when they mesh which does not prevent the pitch-change mechanism from turning towards high pitch, but positively blocks rotation towards low pitch.

Cams are machined on the mating faces of the gears, and at both the high and low extremes of the pitch-change range these cams overlap, presenting a positive inteference which prevents the ratchet halves from engaging. In these pitch ranges the pitch lock is said to be "cammed-out." Pitch control hydraulic power enroute to the dome is fed into an annular pitch lock control actuator that provides the force necessary to prevent pitch-lock engagement in the median range, the range normal to flight operation.

Obviously, if *all* pitch control power is lost during flight, the pitch lock control actuator will be depressurized, the lock will engage and prevent the TM from turning the blades to a dangerously low angle.

A valve operated by a fly-weight assembly is incorporated in the pitch lock. If the propeller overspeeds beyond its normal governing range, the fly-weight valve opens, the pitch lock actuator is depressurized and the pitch change mechanism is blocked just as effectively as when all pitch control power is lost.

It is important to understand the simple schematic of the pitch lock shown in Figure 7 to understand its capabilities and reactions.

A small valve, known as the pressurizing and regulating valve, creates a small constant pressure in the fly-weight cavity, drawing on either the "increase" or "decrease" power line for the purpose. The pitch lock actuator piston also receives the full pressure of either control power line through a 2-position servo valve. It can be seen that when the fly-weights overspeed, the fly-weight cavity pressure is dumped against the servo and as the servo shifts it blocks the pressure supply line to the pitch lock actuator piston and ports it to return.

Thereafter, the spring load on the pitch-lock gear will keep the ratchet engaged until, 1) "increase pitch" pressure is provided by the governor, and, 2) the prop rpm comes back to normal so fly-weight cavity pressure is removed from the servo.

At first glance, it would seem that if the propeller dropped slightly underspeed causing the governor to supply "decrease pitch" pressure, this pressure would unlatch the pitch-lock and the propeller would again be self-governing. Actually this cannot occur, for the pitch-lock teeth are slightly undercut, and the torque given the rotatable gear (by both TM and "decrease pitch" pressure acting on the pitch change piston) tends to secure the lock so strongly that it cannot be forced by the "decrease pitch" pressure on the pitch lock actuating piston.

The reason that the pitch lock is "cammed-out" in the high pitch-angle range is now obvious. It would be impossible to unfeather the propeller in flight if the pitch lock was engaged, because "decrease pitch" pressure cannot disengage the interlocked gear teeth.

The logic of the pitch-lock design is based on the premise that the propeller should be blocked promptly from going to low pitch at the first sign of control loss during flight, and it should remain blocked until the power and control systems demonstrate a positive ability to resume control.

To ensure that pitch lock will occur promptly after normal governing malfunctions, the pitch lock flyweight is set to initiate the pitch lock about 3% above normal prop governing rpm. However, the pitch lock teeth will permit pitch angle to deteriorate a few degrees as they mesh, and if an in-flight pitch lock occurs it is to be expected that rpm will rise further, to the point at which the fuel governor becomes effective and reduces engine power to control rpm.

The pitch lock is cammed-out in ground operation. These cams become effective at the lower flight range angles, actually, disarming the pitch-lock mechanism so it cannot engage after blade angle is reduced to within a few degrees of the low pitch stop. Normally, the propeller reaches this minimum position during final approach, when power and airspeed are both very low. However if a takeoff is aborted or if a "power-on" or high speed approach is made, the propeller may be well up into its normal flight operating range at the time the pilot quickly pulls the power lever back into ground operating range. This puts the fuel governor in control of rpm, and since the fuel governor allows speed to vary much more than the propeller governor does, the propeller may overspeed enough to trigger the pitch lock. If the pitch lock should engage, locking the blades in flight range while the power control is in ground range, the fuel control will blindly supply high power to maintain engine speed, and the propeller will produce a high positive thrust at the very time maximum propeller braking is most sorely needed.

To prevent this nasty situation from developing, the pitch-lock governor is "reset" during the transition period, so that it is more tolerant of overspeed.

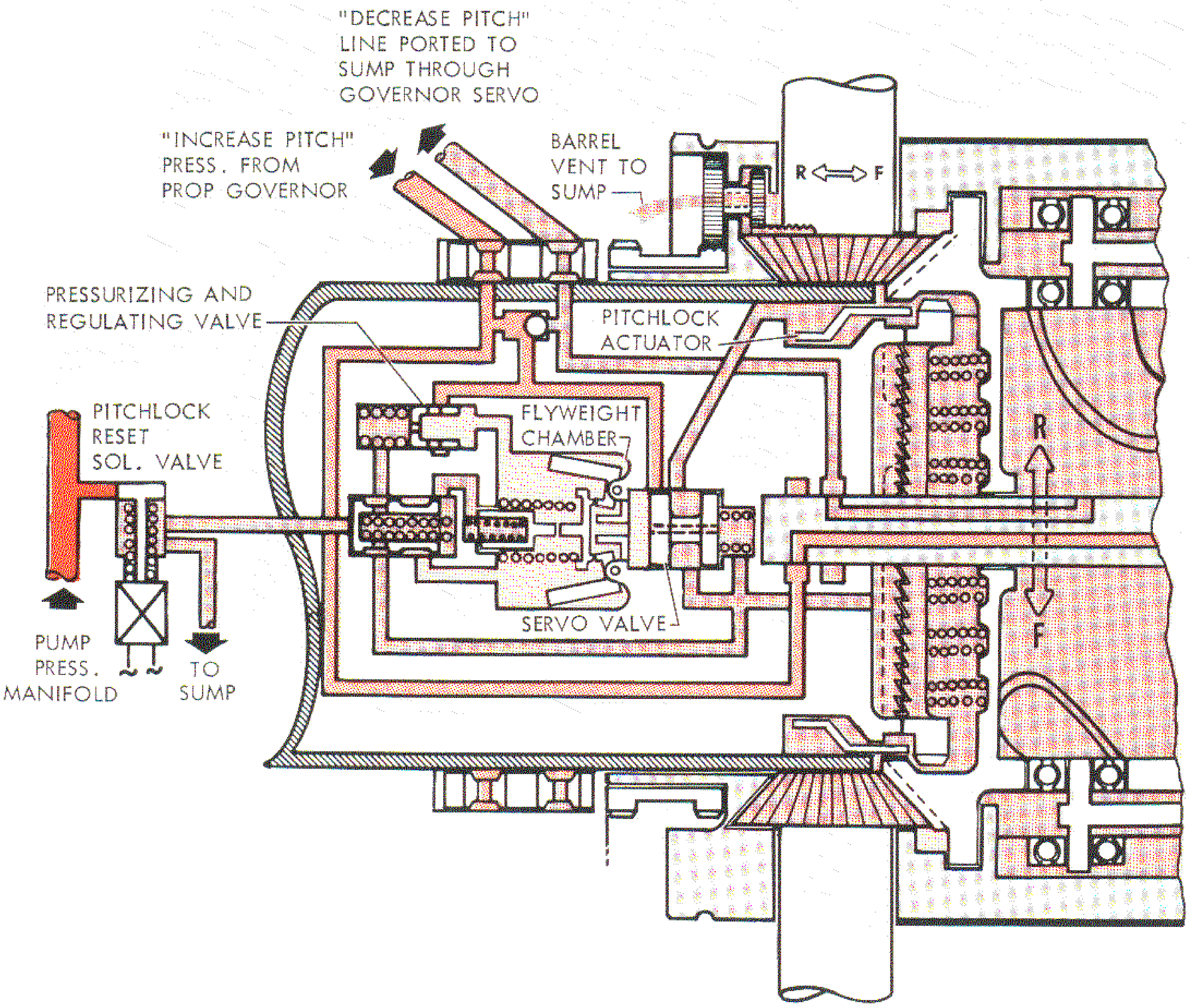
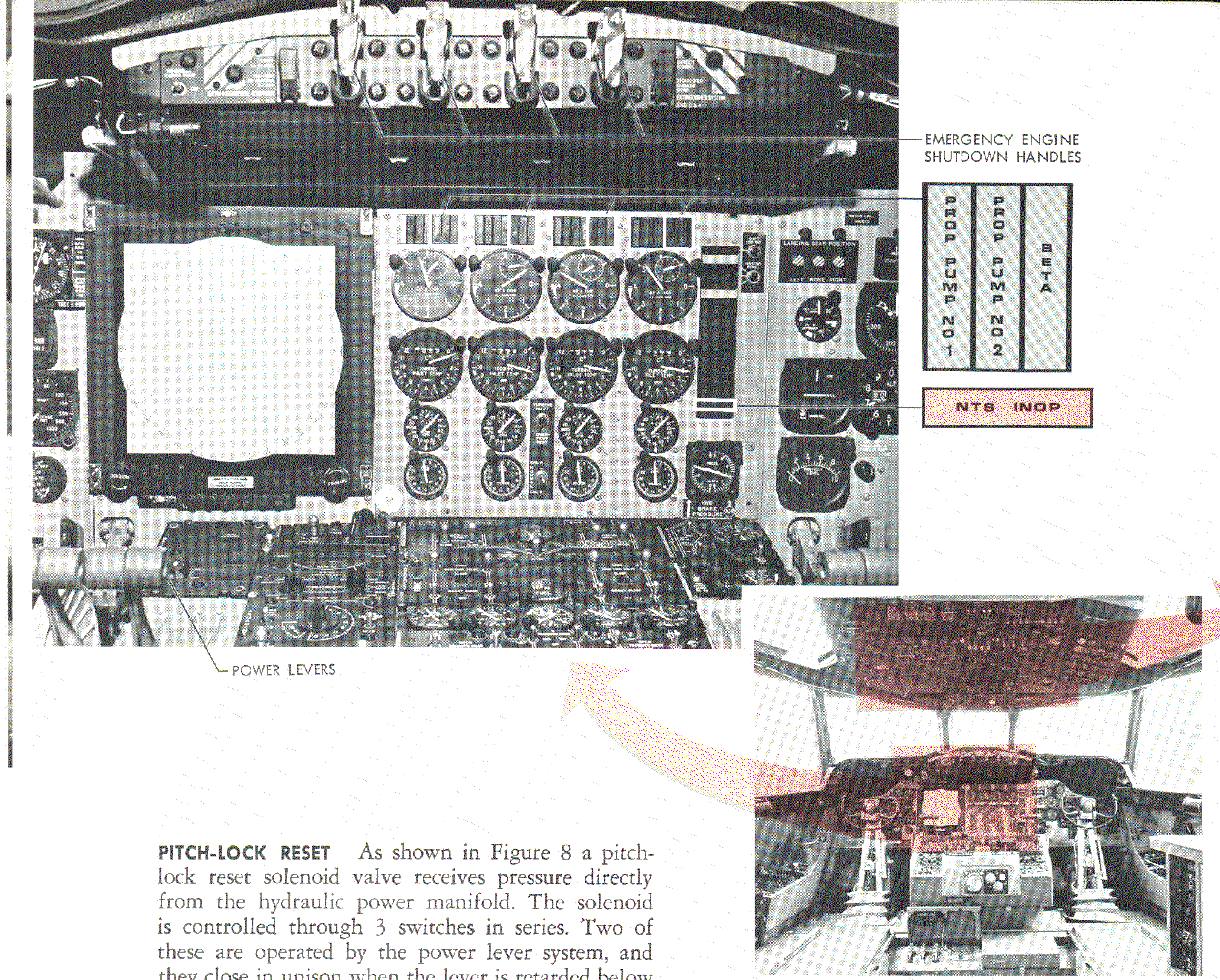


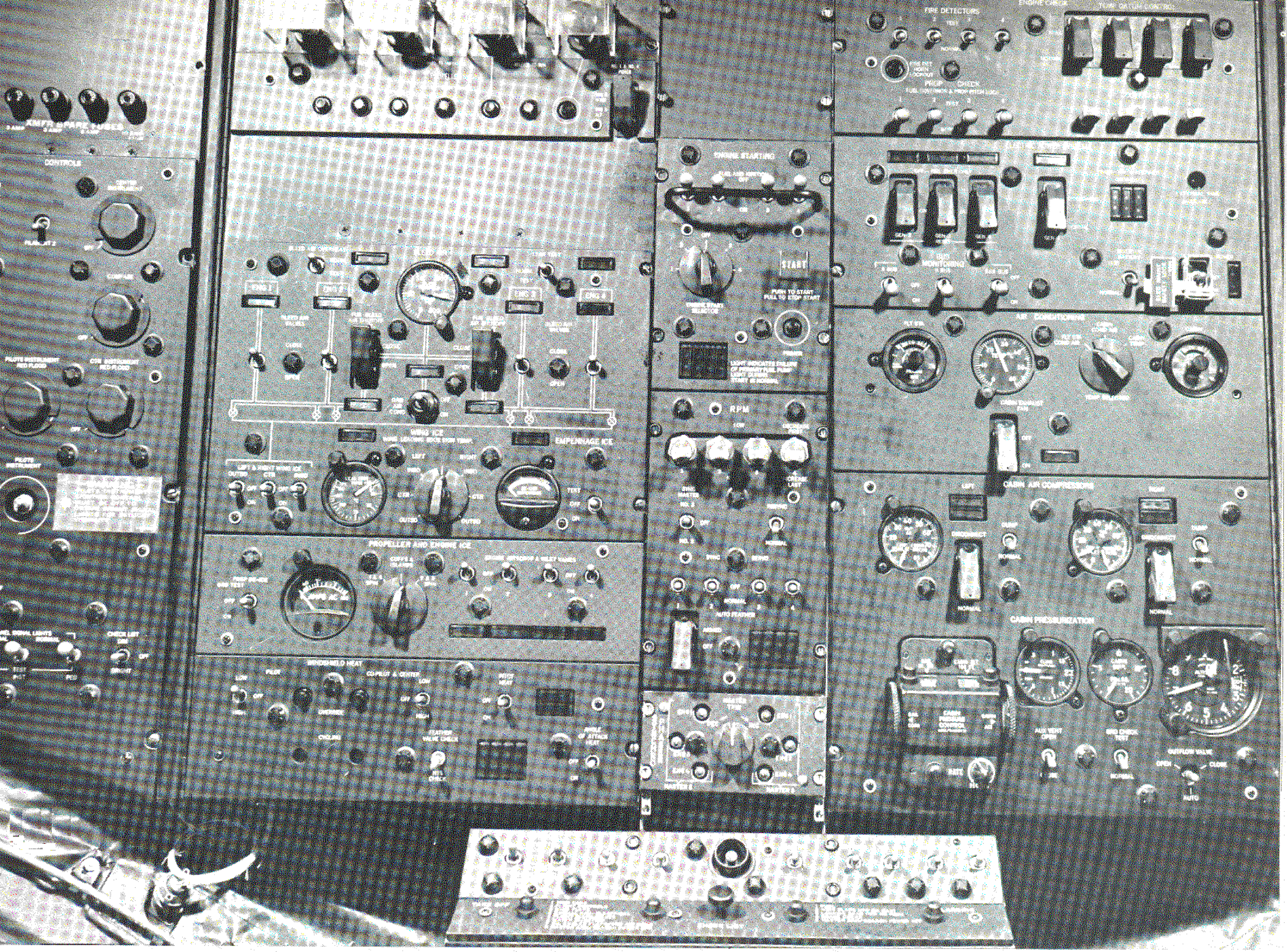
Figure 7
Pitchlock Engaged
due to Overspeed
During Flight Without Loss
of Hydraulic Power



PITCH-LOCK RESET As shown in Figure 8 a pitch-lock reset solenoid valve receives pressure directly from the hydraulic power manifold. The solenoid is controlled through 3 switches in series. Two of these are operated by the power lever system, and they close in unison when the lever is retarded below Flight Idle.* The third switch is a double-throw switch that is actuated by a Beta shaft cam just as the blade angle enters the ground operating range; opening the pitch-lock reset circuit and coincidentally closing the "BETA" advisory light circuit mentioned previously.

Thus, the solenoid is energized when the power lever is in ground operating (fuel governing) range unless or until the blade angle is also within the ground operating range, that is, 10° or less. The opening of the solenoid valve ports a high hydraulic pressure to a small 2-position servo valve, known as the pitch lock reset actuator. When the servo shifts, it ports fly-weight chamber pressure to a small "bias" piston, and the force of a small supplementary spring is added to the normal speeder spring. The added spring force "resets" the governor, and the pitch-lock will tolerate an overspeed of about 9% until the fly-weight chamber pressure is removed from the bias piston. Of course, this is done automatically by operation of the "BETA" switch as the propeller is forced rapidly down into ground operating range, and the total duration of the "reset" operating cycle is very short. During this interval, if the pitch lock rachets have not reached their cam-out range the pitch lock will operate as usual in response to a total loss of pitch-control hydraulic power, but it will not be triggered by the less stringent speed governing of the fuel control during the critical transition period unless rpm exceeds 109%.

**This 2-switch arrangement provides a safety factor. If only one switch was provided, a single mal-adjustment or switch malfunction could result in the pitch lock operating "reset" constantly. If the pitch lock is not triggered in high speed flight before rpm reaches 109%, the blade angle, which is already far below normal, will be so far reduced before the ratchets engage as to permit a truly serious overspeed.*



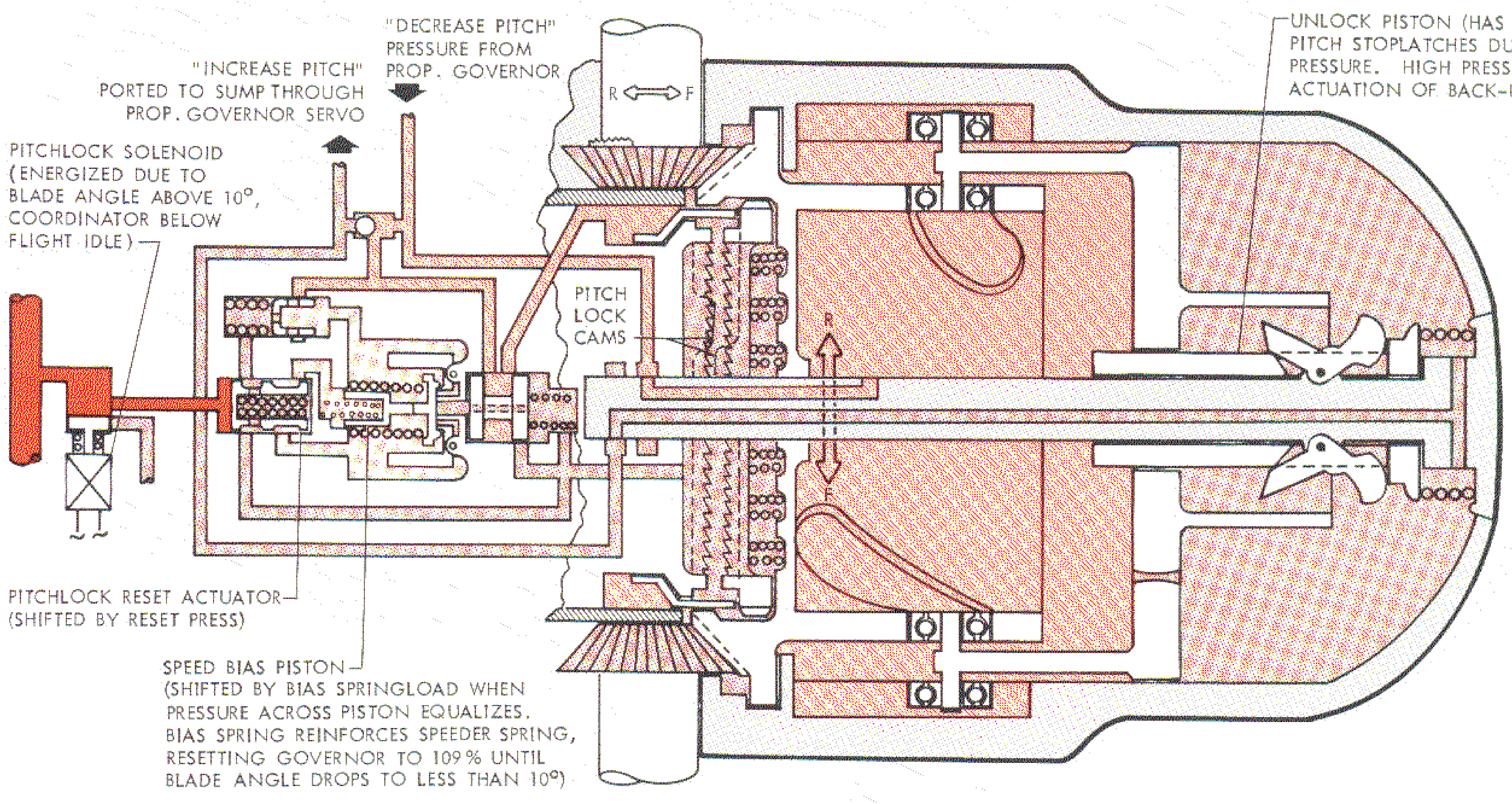


Figure 8
Transient Control Configuration — After Power Lever is Retarded Below 25° Coordinator; Before Blade Angle is Reduced to 17°. Note that pitchlock cams will overlap when blades rotate further towards R (reverse).

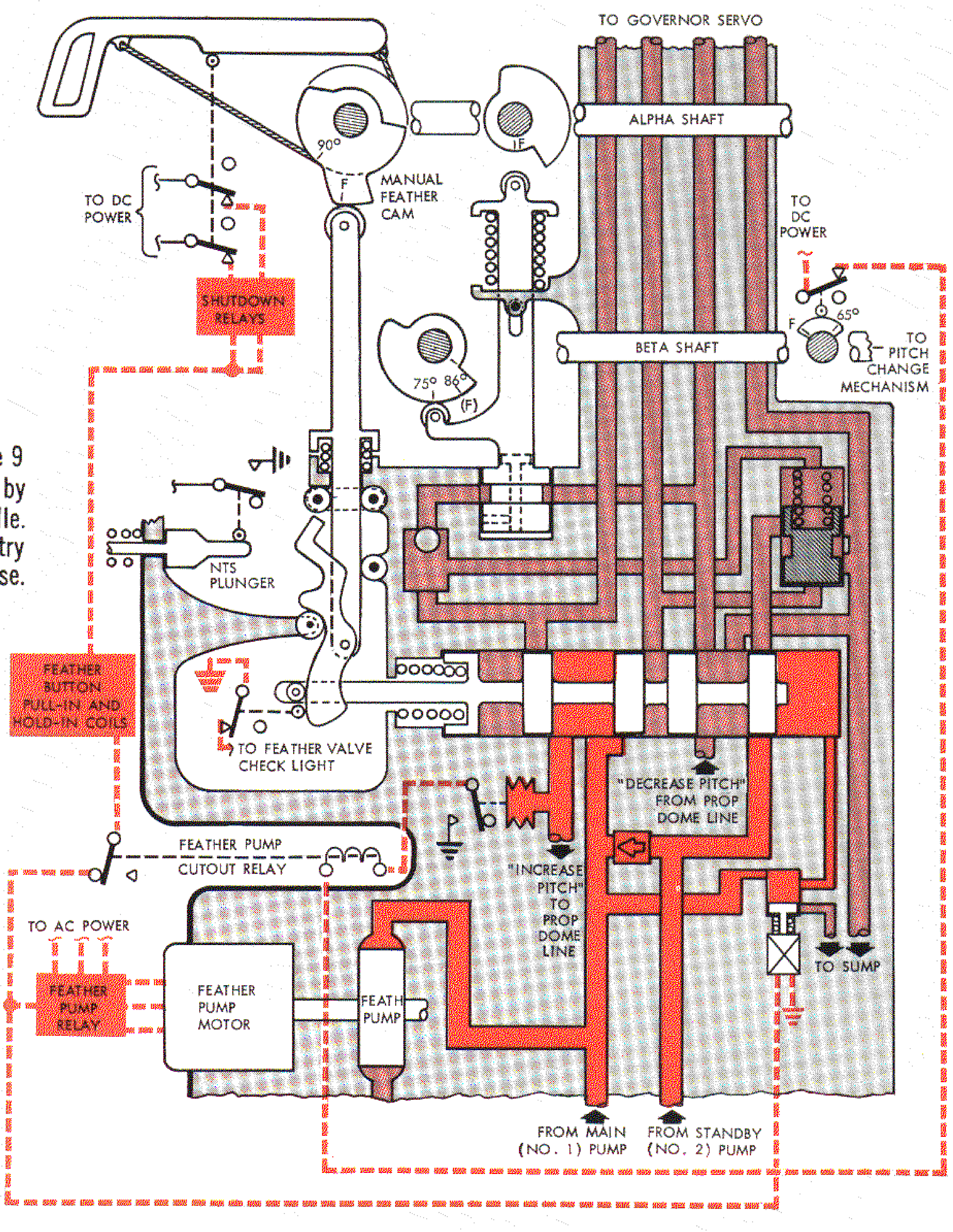


Figure 9
Feathering Operation Initiated by Pulling Emergency Engine Shutdown Handle. Colored phantom circuitry indicates electrical response.

NTS AND MANUAL FEATHERING

Both of these functions mechanically operate the feather valve. The subsequent operation is identical, but due to the different means by which they are actuated the NTS is generally cyclic whereas feathering is, of course, sustained until the blades are "stream-lined".

As mentioned previously, the reduction gear box is designed to react to a reversal of power flow, and position a simple mechanical linkage that bridges the gap between engine gear box and propeller control. This reactive signal is derived, as shown in the Master Schematic, by providing a flexible coupling between the gear case and the large ring gear that serves as a race for three planetary gears which drive the prop shaft. The ring gear is mated to the gear case with helical splines, that is, the splines are broached at an angle, so that the ring gear is permitted a short "spiraling" travel fore and aft. Springs load the ring gear aft, and normal "positive" power flow from drive shaft-to-prop shaft supplies a torque to the ring gear that also forces it to its aft extreme. When the power flow is reversed (prop shaft-to-drive shaft), the torque applied to the ring gear by the planetary gears is also reversed and, at about 325 hp negative,* the

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**Although the negative torque required of the propeller to operate the NTS is held to a narrow tolerance, and does not vary according to engine position, the range (as shown on the HP Indicators in the flight station) can vary from minus 150 to minus 500, and generally outboard engines will NTS nearer to 500 than the inboard engines. It should be noted that the hp indicator only reflects torque transmitted through the engine drive shaft and is accurate only at 100% rpm. Therefore, when the propeller windmills, the power required to drive the engine accessories is not sensed at the drive shaft torquemeter, and the amount of unregistered power varies with the number of accessories and the load on them, producing the wider* apparent *range at the H.P. Indicators when the system is tested in flight.*

ring gear spirals forward against its spring load, driving forward a plunger that protrudes an "NTS actuator rod" through the front gear case wall. This action is carried through an adjustable leverage system into the propeller control as a probing motion of a push rod that cams a limit switch closed and strikes a stepped pawl, forcing the feather valve spool from "normal" to "feather" position. The NTS check switch is closed in all cases, illuminating the individual "NTS" advisory light in the flight station, but the stepped pawl will be contacted and made to operate the feather valve only if the power lever is in flight range, as shown in the Master Schematic.

The stepped pawl is moved into position by a cam when the Alpha shaft is turned into flight range and, as mentioned in the Touchdown-Transition discussion, this pawl is withdrawn when in ground range to a position beyond the reach of the NTS "probe".

As shown in Figures 2 and 9, another lobe on this Alpha shaft cam drives the pawl to a third position, where it operates the feather valve, with or without the aid of the NTS probe. This is effected at the extreme position of the Alpha shaft, beyond the range of power lever control, obtained only by operation of the emergency engine shutdown lever. This arrangement provides the Orion with a positive, hydro-mechanical manual feathering cycle that is not dependent on power except the propeller's self generated hydraulic power system.*

The feather valve controls the line between the pump pressure manifold and the governor servo, and also the pitch control lines between the governor servo and the dome. In its normal position the feather valve has no effect on these flows, but when it is shifted to feather position it blocks all pump pressure flow to the main-and-standby regulator and the prop governor, and dumps the full pump flow directly into the "increase pitch" line. At the same time, it connects the "decrease pitch" line to return. Since it eliminates the possibility for oil to by-pass through the pressure regulator, the full, unregulated power of the pumping system works to produce a high-rate pitch change towards feather. The pressure relief valve, which is tapped off the pump manifold, will prevent excessive pressure buildup.

The mechanical actuation of the feather valve to "feather" position closes a limit switch that is connected to the NTS advisory light circuit (see Figure 10). A 2-position switch (NTS CHECK/FEATHER VALVE CHECK) is located adjacent to the indicator lights on the pilot's overhead control panel. When in its NTS CHECK position, the switch directs the check circuit through a self-holding relay to the *NTS-operated* switch in the propeller control, and the light provides a lasting record of any NTS operation, no matter how fleeting. When the switch is moved to the FEATHER VALVE CHECK position, the NTS holding relay is de-activated and the light circuit is directed to the feather valve operated limit switch, providing a direct indication of mechanical valve operation (cyclic during NTS, steady after the Emergency shutdown handle is pulled).

**As indicated on Figure 9, pulling the Emergency Shut down handle also initiates the Hydro Electric feather cycle discussed in the next chapter.*

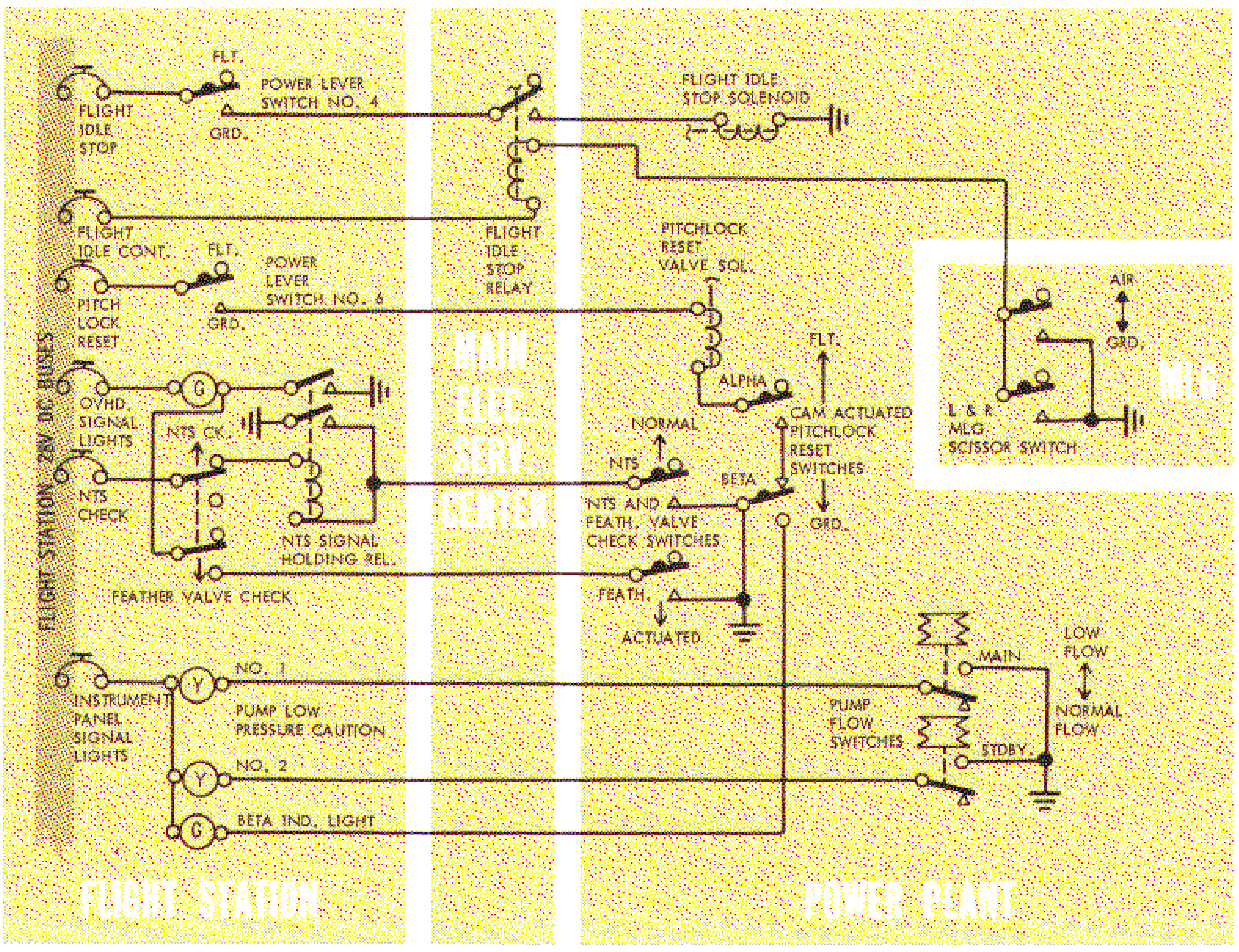
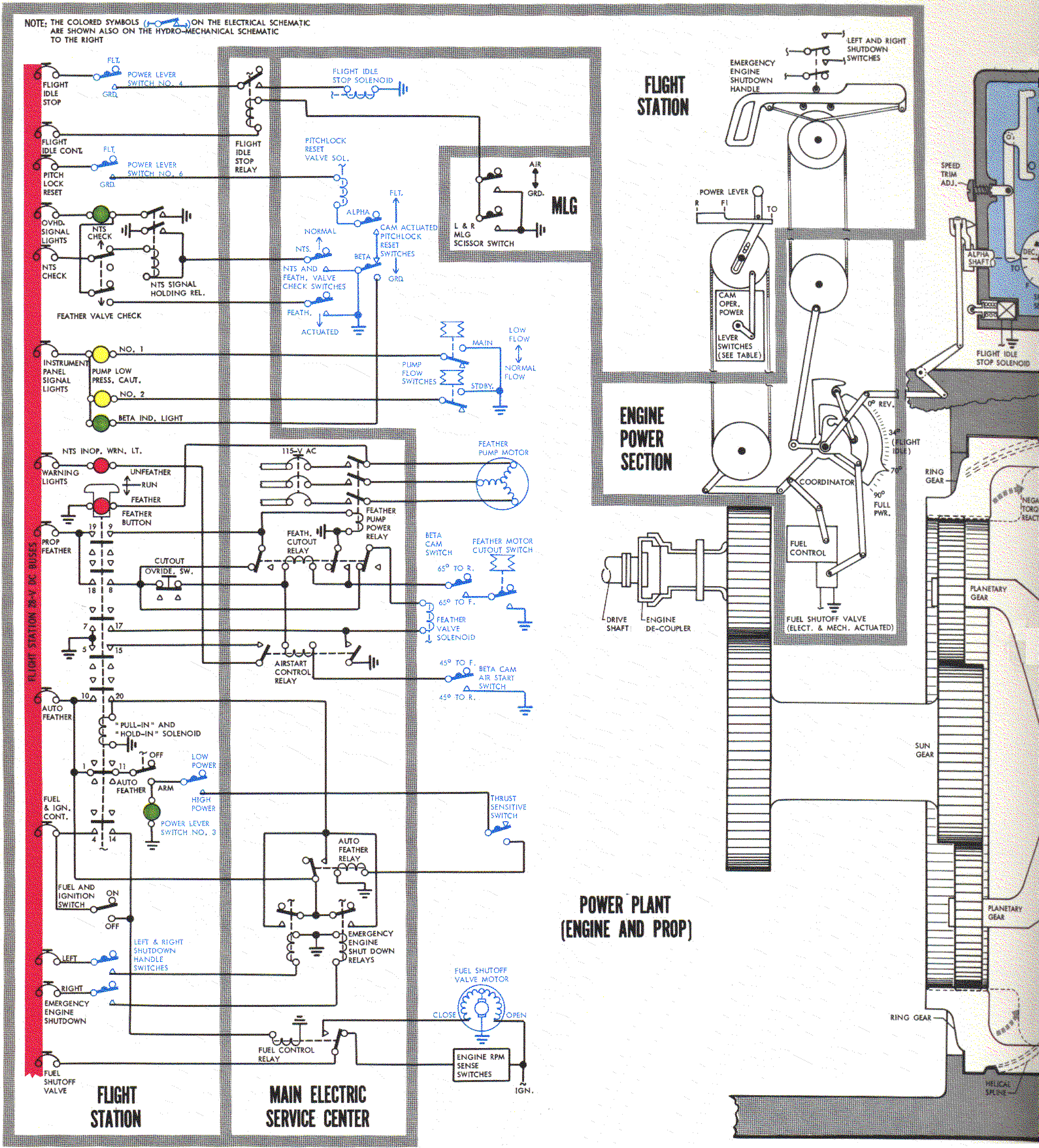
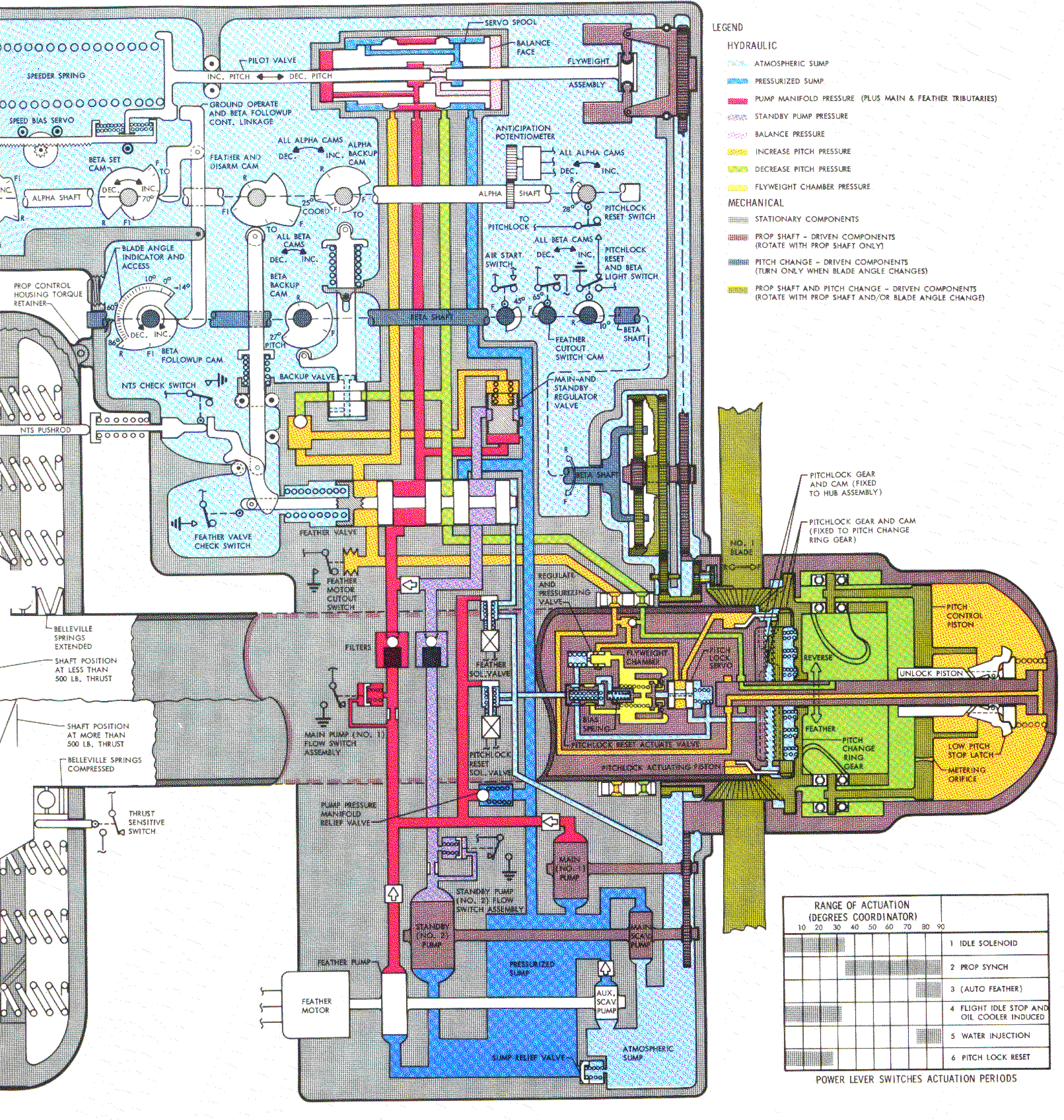


Figure 10
Miscellaneous Monitoring and Control Circuitry


NOTE: THE COLORED SYMBOLS ON THE ELECTRICAL SCHEMATIC ARE SHOWN ALSO ON THE HYDRO-MECHANICAL SCHEMATIC TO THE RIGHT

Prop Control Master Schematic. The schematic configuration sho flight operating range to illustra



RANGE OF ACTUATION (DEGREES COORDINATOR)									
10	20	30	40	50	60	70	80	90	
▨	▨	▨	▨						1 IDLE SOLENOID
			▨	▨	▨	▨	▨	▨	2 PROP SYNCH
							▨	▨	3 (AUTO FEATHER)
▨	▨	▨	▨						4 FLIGHT IDLE STOP AND OIL COOLER INDUCED
							▨	▨	5 WATER INJECTION
▨	▨	▨							6 PITCH LOCK RESET

POWER LEVER SWITCHES ACTUATION PERIODS

is normal to cruise except that blade angle is higher than normal
cam-out of the pitch lock ratchets when blades advance towards feather.

HYDRO-ELECTRIC FEATHERING

The feather motor-pump provides hydraulic power for pitch control when the propeller is static or turning so slowly that its gear driven pumps may be ineffective. The feather pump motors are powered by the Main AC Buses; Engines 2 and 3 pumps from Main AC Bus A, Engines 1 and 4 from Bus B, except that if necessary the pilot can transfer the 1 and 4 loads to Bus A by actuating a guarded selector switch adjacent to the feathering buttons. This transfer capability is given the outboard powerplants because they are routinely feathered during "loiter" operation and loss of power at Bus B would otherwise prevent "air start".

Control power for feathering the outboard propellers is taken from the Monitorible Ess. DC Bus, and from the Extension Main DC Bus for the inboard propellers.

A single relay is used in each motor power circuit, but the control of these relays is quite involved, for there is need for an intricate system of interlocking circuits to ensure that the feather pumps can be used only under the proper operational circumstances. We have not discussed all the intricacies of the circuits, but the following pages describe the fundamental logic of the circuit as shown in the Figure 11 schematic.

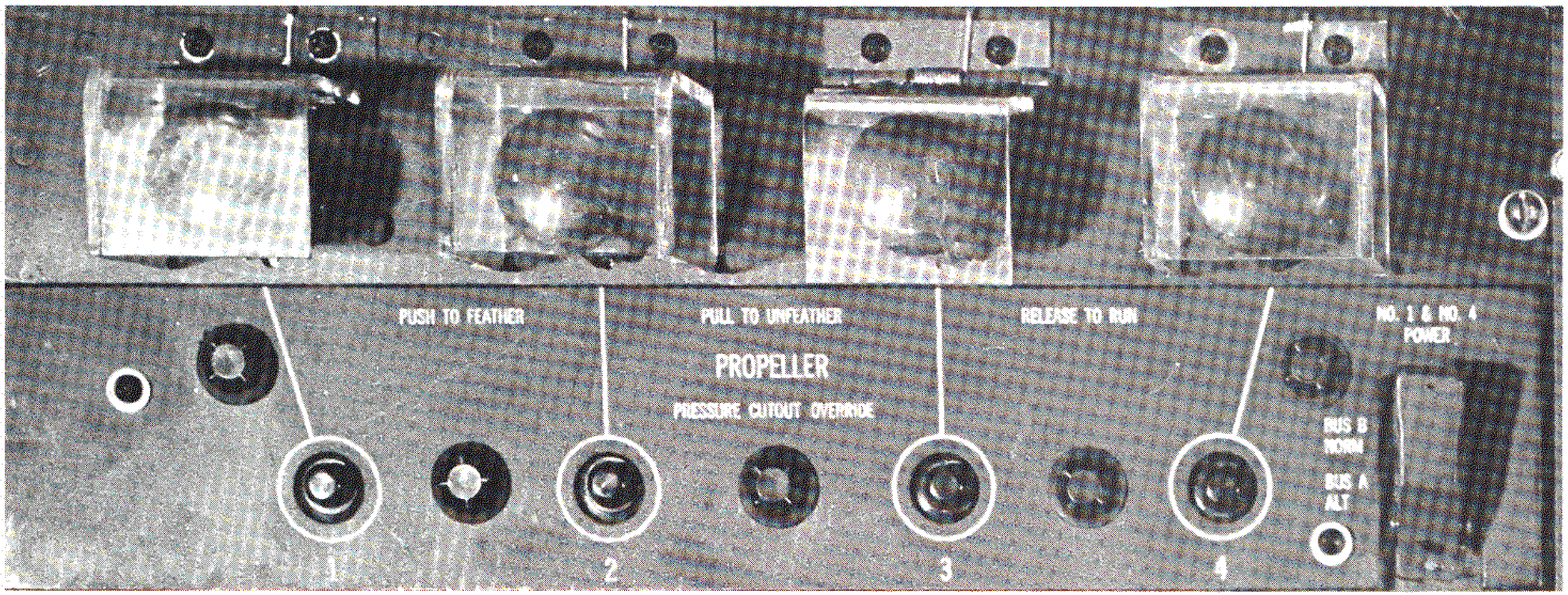
The feathering cycle is initiated for a routine (loiter) engine shut down by pushing the feathering button. Note that the feather switch has a solenoid that becomes energized (through feather switch contacts 10-20) when the button is pushed, and the switch is magnetically (and also mechanically) "latched" in feather position until the button is manually pulled back to "NORMAL" or beyond to "UNFEATHER". Switch contacts 18-8 transfers dc power to the feather pump power relay, the relay closes, energizing the feather pump motor and illuminating a red light in the feathering button. Another branch of the 18-8 circuit energizes the feather solenoid; the solenoid circuit finding a certain ground through contacts 17-7 of the feather switch and possibly through the contacts of the air start control relay also, depending upon the pitch angle of the blades.

The feather solenoid valve ports pressure from the pump manifold to one end of the feather valve spool, forcing it to "feather" position, and feathering proceeds exactly as described previously in the "Manual Feathering" discussion.* However, there is one additional hydraulic system factor to consider in the electro-hydraulic feathering cycle which does not affect the manual-mechanical cycle because the mechanically driven pumps stop automatically as prop shaft rotation stops. The auxiliary pump motor is not designed for continuous and prolonged operation, and it is necessary to provide a "cut-out" circuit to retire the pump automatically when the cycle is complete. As can be seen on Figure 9 schematic, the cut-out relay provided for this purpose will be actuated: 1 — after the blade pitch reaches a point well above the normal flight range and actuates a limit switch, and 2 — when a steep rise in "increase pitch" pressure occurs (indicating that the pitch change mechanism has bottomed on the full feather stop), closes a pressure switch and completes the cut-out circuit. Relay actuation de-energizes the feather pump power relay, the feather button light, and the feather valve solenoid. Note that the cut-out relay (see Figure 11) has a self-holding solenoid similar to the feather button switch, and even though the declining hydraulic pressure allows the original "cut-out" circuit to re-open, the cut-out relay will remain actuated until its source of dc power is removed. A Pressure Cutout Override button switch, adjacent to each feather button on the pilot's overhead panel, performs this function, allowing the crew to continue operation of the feather pump should the automatic control actuate before windmilling stops completely.

Obtaining the exact feathering angle is more difficult with the turbo-propeller than with the reciprocal power plant due to the larger blade dimensions and the turbine's low break-away torque. A prop shaft brake in the reduction gear box is applied automatically when lubrication pressure dissipates, but it cannot be too positive, for it would interfere with starting. A mechanical detent in the dome assembly engages the pitch change mechanism and retains it in feather position.

Unfeathering is accomplished by pulling and holding the feather button switch. Assuming that the feather button has been "latched" in its feather position, and that the cut-out relay has been "latched-in" also, it can be seen that the cut-out relay will be de-energized when the feather button is pulled from "FEATHER" to "NORMAL", enabling the feather pump power relay to be energized through feather switch contacts 19-9 when the button is pulled from "NORMAL" to "UNFEATHER". The governor pilot valve will be at its extreme underspeed (decrease pitch) position, and full pump power will be ported to the "decrease pitch" line, forcing the pitch change mechanism through the feather position detent. Subsequent events are closely related to the "Flight-Start" cycle, and we will discuss them in this connection.

**Due to the fact that the Feather valve check switch is operated by the linkage that mechanically actuates the feather valve, it is not actuated during hydro-electric feathering, and therefore the advisory light in the flight station cannot be utilized to check the performance of the feather valve if the electrical feather cycle is initiated by pushing the feather button.*



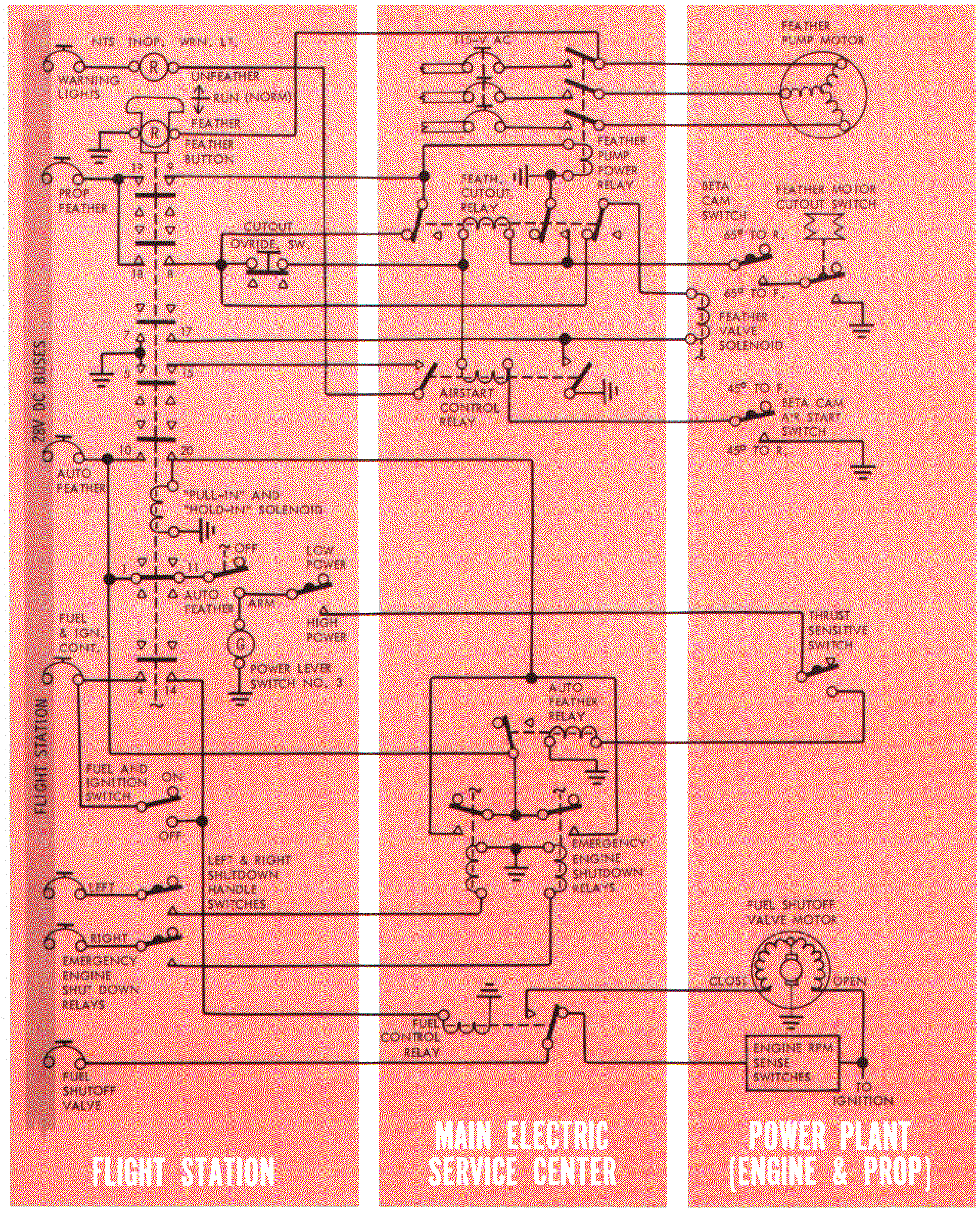


Figure 11
Feather, Auto-Feather, and Engine Shutdown Circuitry

NOTE

MANY OF THE FOLLOWING DISCUSSIONS DEAL WITH VERY IMPORTANT IN-FLIGHT FUNCTIONS. THE TEXT WAS CAREFULLY AUTHENTICATED BEFORE PUBLICATION, BUT IT SHOULD BE REGARDED ONLY AS A SOURCE OF GENERAL INFORMATION, NOT TO BE APPLIED UNLESS BORNE OUT IN OFFICIAL NAVWEPS DOCUMENTS CARRYING THE LATEST REVISIONS.

FLIGHT STARTING

(See NATOPS procedure, Figure 12) The integrity of the system is partially demonstrated *before* unfeathering by pressing the Cut-out Override (thus operating the feather pump) for a few seconds with the Feather button in "FEATHER" position. The output of the feather pump is routed through the NO. 1 (Main) PUMP flow switch, and it will provide sufficient flow to extinguish the related caution light on the center instrument panel. Thus it is proven that the oil reserve has not been depleted through an external leak during the shut-down period, and a few seconds of pump operation will circulate oil through the dome to "bleed" off any vacuities caused by internal leakage. This ensures that the propeller will have positive hydraulic power for pitch control, and the feather button should be pulled to "UNFEATHER" immediately *after* releasing the Cut-Out Override button.

The acceleration of the engine provided by the wind-milling propeller must be carefully controlled and gradual. Since the nature of the propeller governor is to drive the propeller rapidly towards low-pitch until the propeller comes "ON SPEED" and TM also supplies an ever-increasing "decrease-pitch" force as the propeller accelerates, it can be seen that the cranking torque of the propeller would build up at an explosive rate if normal speed governing prevailed during the flight start.

The NTS overrides the governor and provides the necessary restraint during this critical period, and the operator should select "FEATHER VALVE CHECK" position of the test switch in order to monitor the operation. When the propeller's cranking torque surpasses the NTS tolerance, the reaction of the NTS linkage mechanically repositions the feather valve to "feather". As the propeller pitch increases, cranking torque decreases, the NTS rod is withdrawn, and the propeller is permitted another slight pitch reduction. The cycle is indicated by the flashing check light, and it repeats continuously as the propeller accelerates and stabilizes at the maximum speed it can attain through negative-torque cranking. No specific value can be given for either the rpm or the blade angle at which the balanced condition will occur, for the density altitude and many other factors influence this. However, in the speed range recommended for air starting, 170 to 210 knots, the blade angle will be more than 50° when the engine reaches a "stable" motoring speed (generally between 35% and 45% rpm) and the fuel and ignition can be turned on with full assurance that the propeller control is operable.

If the NTS does not effectively control the acceleration rate during air start, there is every likelihood that the hydraulic power system is seriously at fault. If propeller control seems questionable, the engine should not be started and every effort should be made to arrest the blade angle decline and to return the propeller to feather. This action is initiated automatically if the blade angle drops as low as 45°, for at this point the air-start switch (shown in the Master Schematic) will close; actuating the air start control relay which energizes the feather solenoid valve and illuminates a red "NTS INOP" warning light in the flight station.

This reverses the unfeather cycle and the entire hydraulic power resources of the propeller are directed to hydro-electric feathering. Of course, with the feather button held in "UNFEATHER", the air-start switch will open and interrupt feathering as the blades pass 45°, and it is essential to pull the Emergency Shutdown handle immediately, if the "NTS INOP" light illuminates, to ensure a positive and permanent displacement of the feather valve to feather position. Otherwise even if the feathering capability is perfectly operable, the prop can only cycle around the 45° blade angle position as long as the feather button is held at "UNFEATHER."

The propeller can be feathered, unfeathered and then returned to ground operating range for ground check out purposes by pressing the Cut Out Override button (thus de-energizing the Air Start Control Relay) after the blades reach the 45° position. Obviously, the Override button should *not* be held in during Flight Start, for this would defeat the automatic safety feature of the air start control relay. When it is necessary to use the feather pump to check the power lever control of blade angle in the ground operating pitch range and the low flight pitch range, it is essential to hold the Override button in and the feather button at "UNFEATHER." If the Override button is not held in, the blades will go to 45° and cycle around that position.

ENGINE RESTART DURING FLIGHT.

WARNING

If an engine has been shut down because of a malfunction, do not attempt to unfeather the propeller or restart the engine unless a greater emergency exists.

CAUTION

In case of engine failure during two-engine loiter, restart No. 4 engine first to provide additional generator output.

Recommended airspeed for normal airstart is 170 to 210 knots. The Engine Restart During Flight checklist will be accomplished step by step as each item is read.

1. Airspeed 170 to 210 knots.
2. Fuel and ignition switch—OFF (E).
3. Fuel main tank valve switch(es)—OPEN (E).
4. Fuel boost pump switch(es)—ON (E).
5. Emergency shutdown handle—IN (E).
6. Power lever—FLT START position (E).
7. NTS Feather valve switch — FEATHER VALVE position (E).
8. Temperature datum control switch—NORMAL (E).
9. Feather button—IN (E).
10. Pressure cutout override switch — PUSH and hold for 10 seconds. Propeller pump No. 1 light should go out (E).
11. Feather button—UNFEATHER immediately after release of pressure cutout override switch and *hold until rpm stabilizes* and the feather valve light cycles indicating normal operation of the NTS. Continue to hold feather button (E).

WARNING

- If the NTS INOP light illuminates, continue holding out on feather button and secure engine by means of the emergency shutdown handle. Push in feather button *after* emergency shutdown handle has been pulled. Do not attempt to restart engine.
- If the propeller does not rotate as blades unfeather (because of the propeller brake), push feather button. Use engine starter until propeller rotation begins. Continue unfeathering procedure starting with step 10. Do not energize the starter if the propeller is rotating.

12. Reduction gear and power section oil pressure—Oil pressure rising (E).
13. Fuel and ignition switch—ON (after rpm has stabilized) (E).

CAUTION

If no light-off occurs within 10 seconds, push in feather button and secure the engine. If desired, an additional attempt may be made to start the engine using same procedure as outlined above.

14. Feather button—Release at light-off.

Note

- If feather button is not released, NTS INOP light will cycle and blade angle will remain at 45 degrees.
- The number one pump light may come on momentarily when the feather button is released. If either pump light remains on above 55% rpm, feather the propeller and do not attempt restart.

Note

Stand by to shut down engine if any of the following occurs:

a. No oil pressure indication prior to reaching 35 percent rpm.
b. T.I.T. exceeds 850°C.
c. Engine rpm stagnates or begins to decay.
d. RPM increases beyond 104 percent and remains off speed.

15. Oil pressure—Normal.
16. Oil cooler flap—Set as required (E).
17. Electrical panel—Set (E).
18. Sync servo switches—NORMAL (E).
19. NTS/Feather Valve switch—NTS.

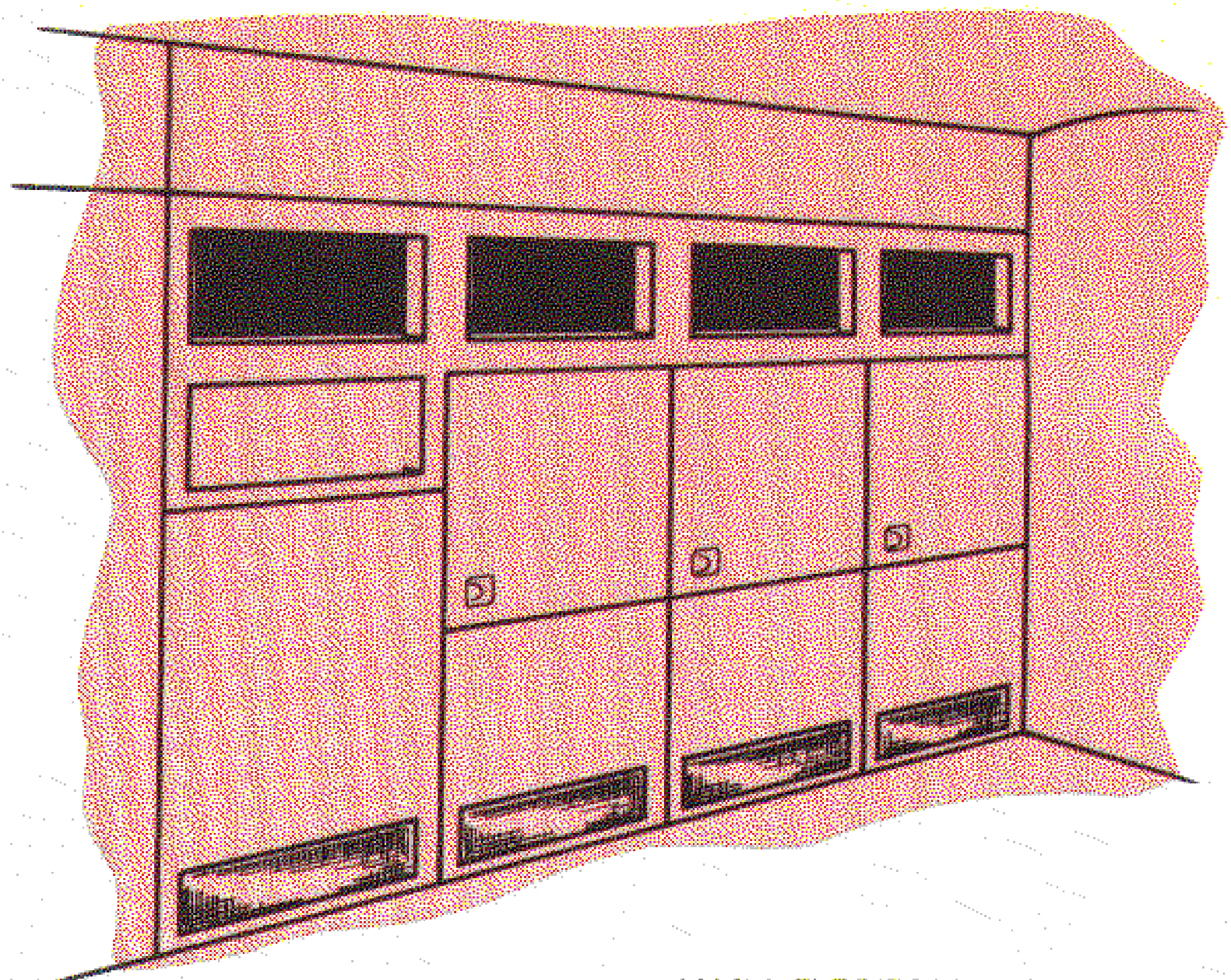
Figure 12 Flight Start Procedure — NATOPS, Current as of June 1965

AUTOMATIC FEATHERING As shown in the Master Schematic, once the system is armed the auto-feather cycle will be triggered by a Thrust Sensitive Switch on the forward face of the reduction gear box if thrust falls to less than 500 lbs. while the power lever is at or near take-off position. If thrust drops this low, Belleville springs inside the gear box actually retract the propeller shaft about .10 in., the Thrust Sensitive Switch closes, and if the power lever is forward of the 75° coordinator position, this energizes the Auto Feather Relay and, in turn, the feather button "Pull-in and Hold-in" solenoid. Thereafter, the feather cycle proceeds as described under "Hydro-Electric Feathering."

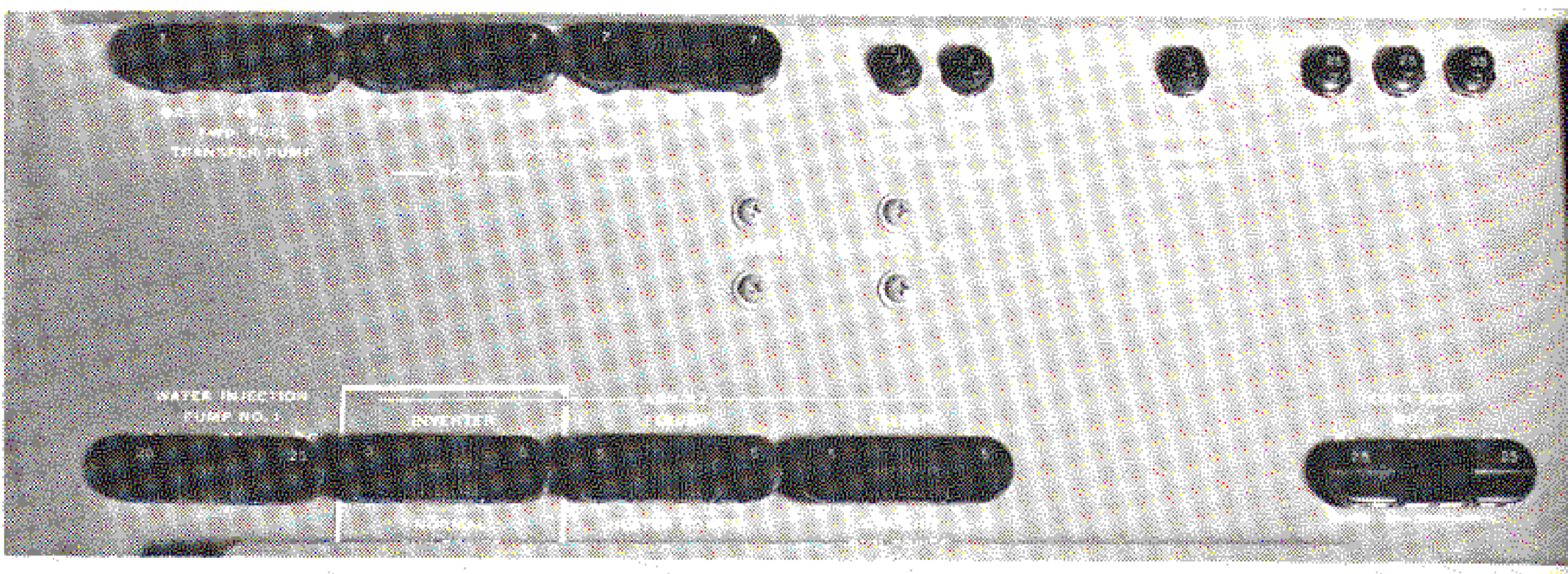
Although it is not shown on the Figure 11 or the Master Schematic, there is a complex network of inter-locking circuits through other (not shown) contacts of the feather button switches. The arrangement is such that: 1) if any single engine receives an auto-feather signal, or if it receives a signal in advance of signals from other engines, it will auto-feather and disarm the auto-feather system; 2) if thrust switches on more than one engine close simultaneously, the inter-lock of the auto-feather circuits establishes a priority sequence (4, 1, 3, 2), only one engine will auto-feather, and the others must be feathered manually just as if the signals had been triggered sequentially rather than simultaneously.

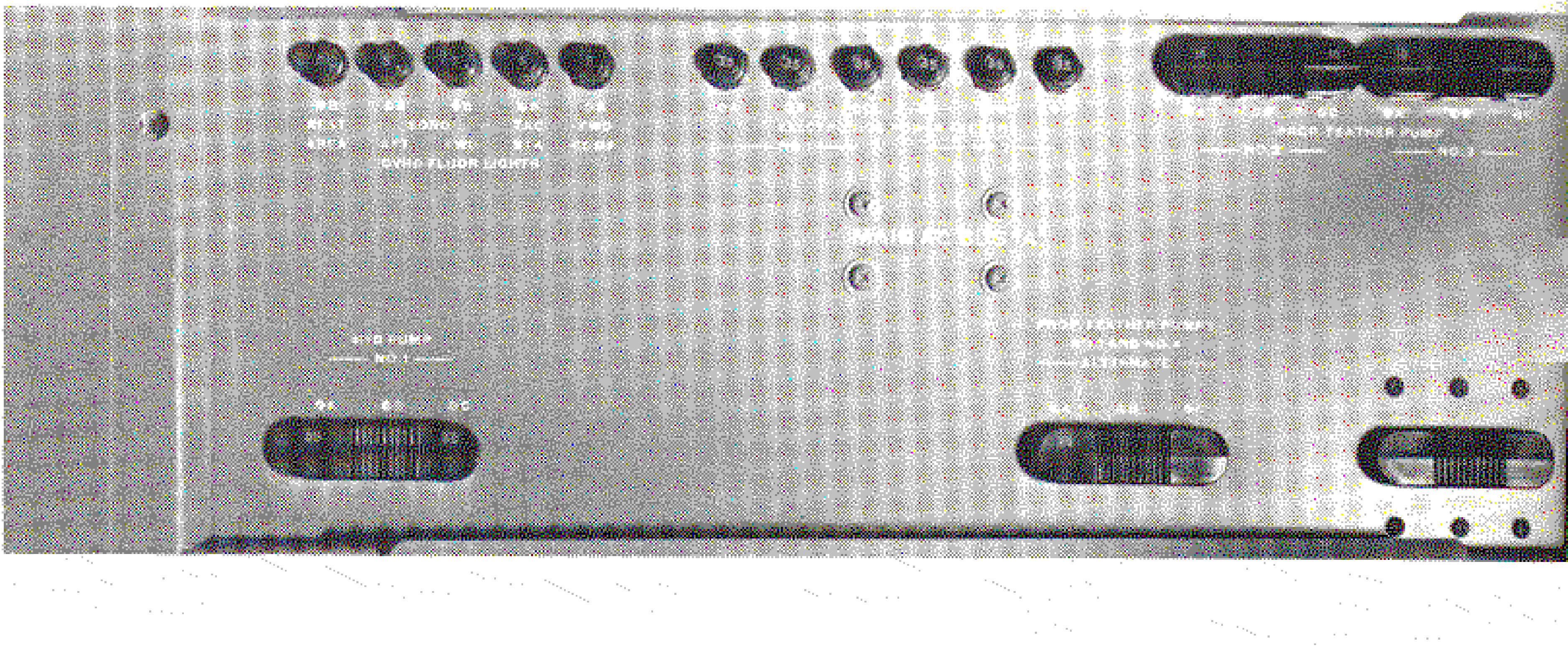
It is considered very unlikely that a situation will arise that requires more than one engine to be feathered during takeoff, but some malfunction, possibly of a minor and transitory nature, could conceivably "trick" the auto-feather system into feathering more than one engine if it were not for the inter-lock arrangement. The auto-feather sequence gives least priority to the inboard engines, for they do not present as serious an asymmetric-thrust problem prior to feathering, and if an inboard engine were to be auto-feathered inadvertently and unnecessarily, one normal source of electrical power would be lost. Of course, the automatic and excellent control of prop "drag" provided by the NTS makes auto-feathering less imperative on the Orion than it is on reciprocating multi-engine aircraft.

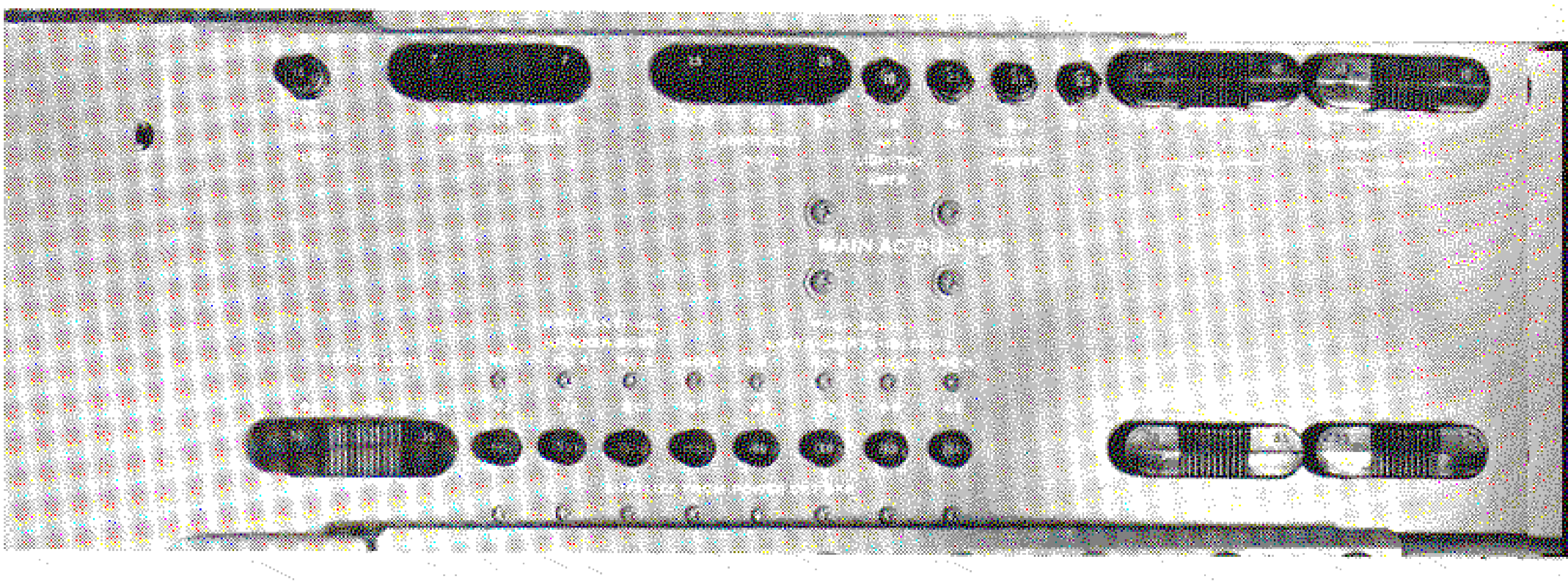
The auto-feather system will usually be "armed" during the take-off period, but it should be manually disarmed during climb-out. If the system is not disarmed, any situation such as a refused landing which requires a fast power lever advance from Flight Idle to Take-off may close one or more of the "75°" switches before enough thrust has developed to compress the Belleville springs, and one engine will auto-feather at a most inopportune time.

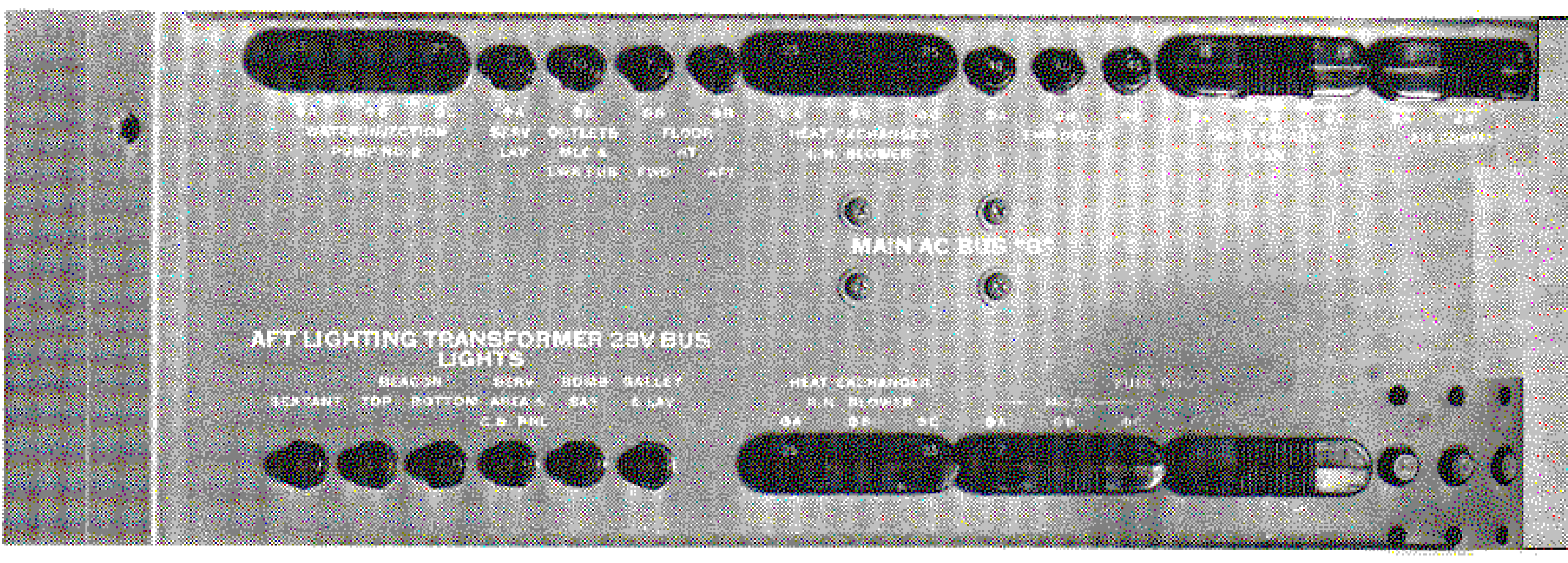


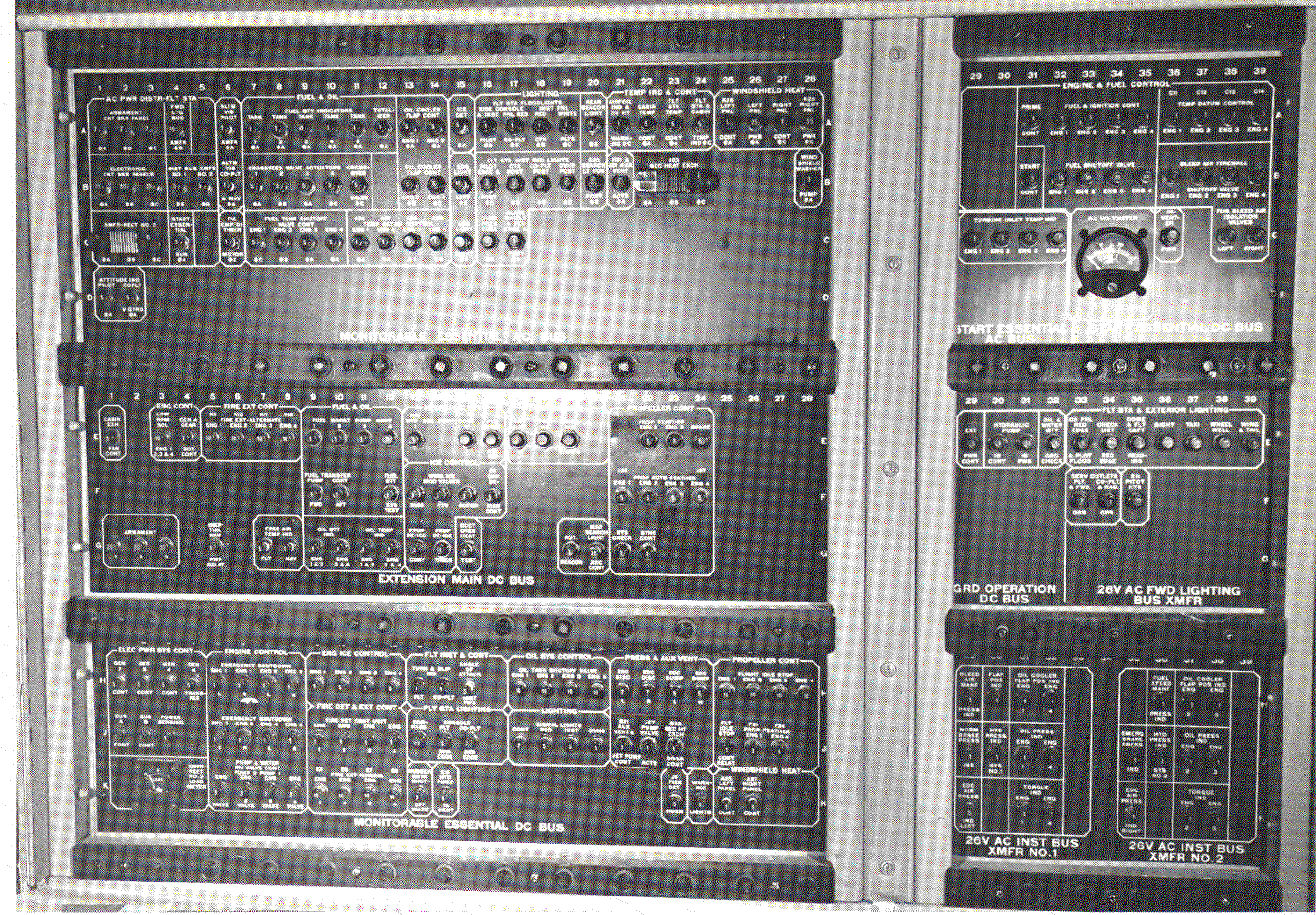
MAIN ELECTRICAL
LOAD CENTER

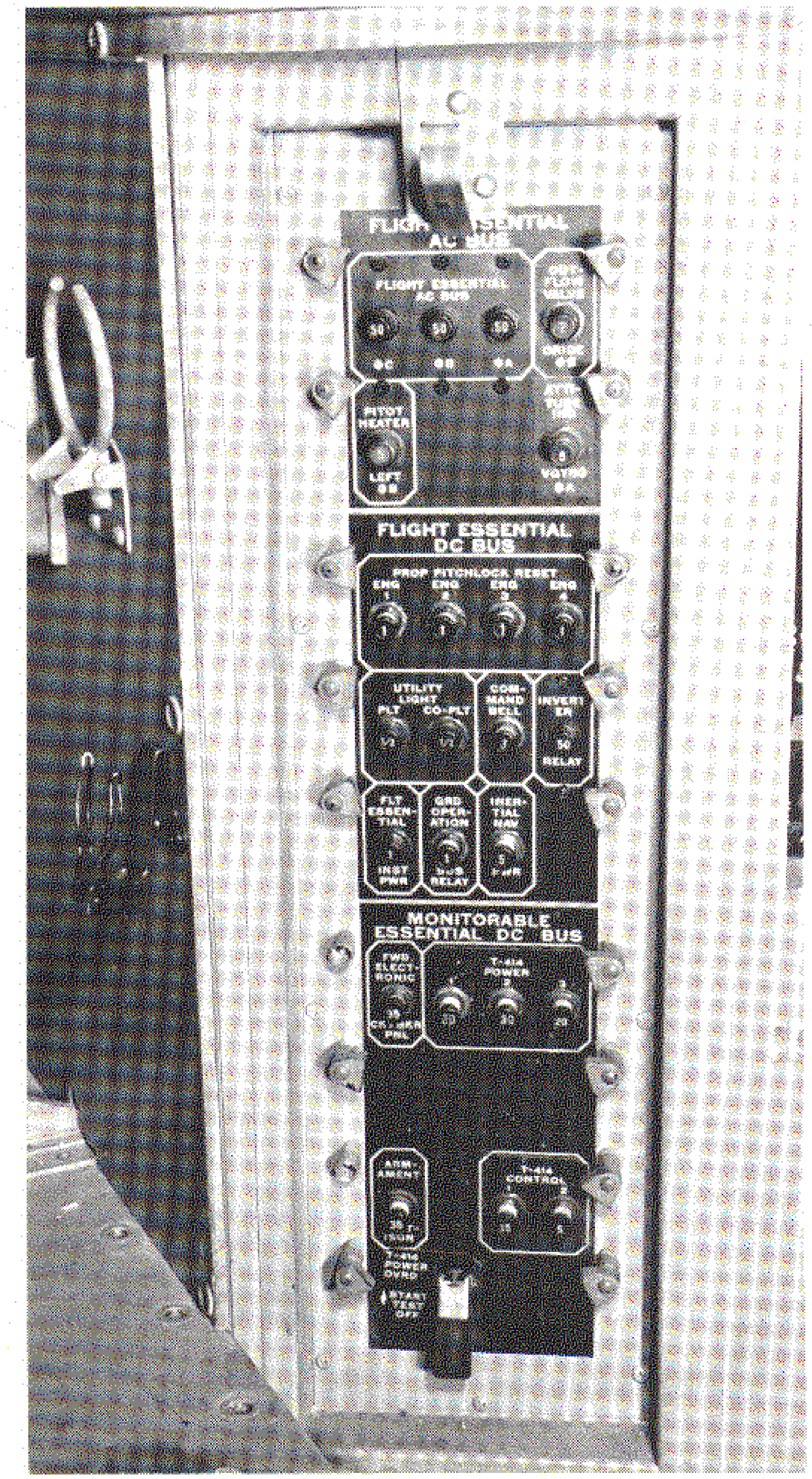












THE ELECTRONIC "FINE TUNING" PROP GOVERNOR SYSTEMS

With a properly adjusted speeder spring (see "Speed-Trim Adjust" in the Master Schematic), the hydro-mechanical governing system described to this point will hold engine speed practically constant and very near 100% during flight in reasonably smooth air with reasonably smooth power lever manipulation. In fact, electrical power is not required for safe control during any phase of operation from full reverse to full take-off power under normal circumstances.* Even closer speed tolerances are obtained by use of the small "Speed Bias" motor (see Figure

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**Of course, the pitch-lock reset function, which ensures against an inadvertent pitch-lock being induced by a too-rapid transition from high power to ground range operation, may be important in special circumstances and does require 28-V power. For this reason, the pitch-lock reset power is taken off the surest bus in the airplane — the Flight Essential DC Bus, which is connected directly to the battery. Of course, if the battery is the only source of power and its charge is questionable, the pilot should be particularly circumspect when transitioning from flight to ground range, and not make the transition until airspeed is below 125 knots. At this speed, the pitch lock will be cammed out.*

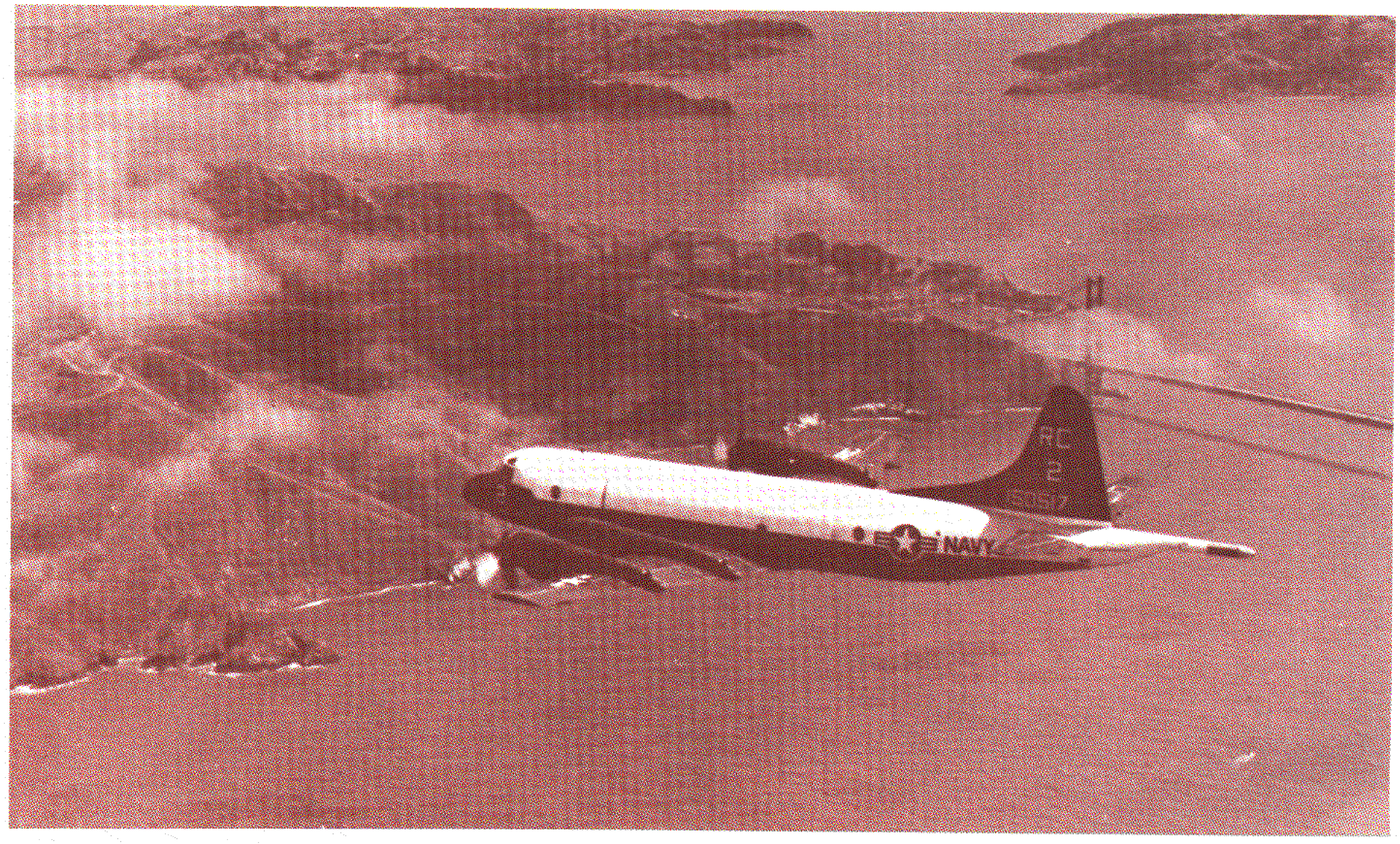
13 and the Master Schematic) mounted inside the prop control housing, and it is normally used constantly after takeoff. This is a reversible, ac servo motor which can quickly add a small and varying supplemental spring force to the governor speeder spring or subtract a like force. As its name implies, this servo-mechanism can bias the nominal control speed of the prop governor, that is, it can hold the governor slightly off the mechanically pre-set control speed, and it also receives and acts upon transitory control signals to improve prop reactions in unstable operating conditions.

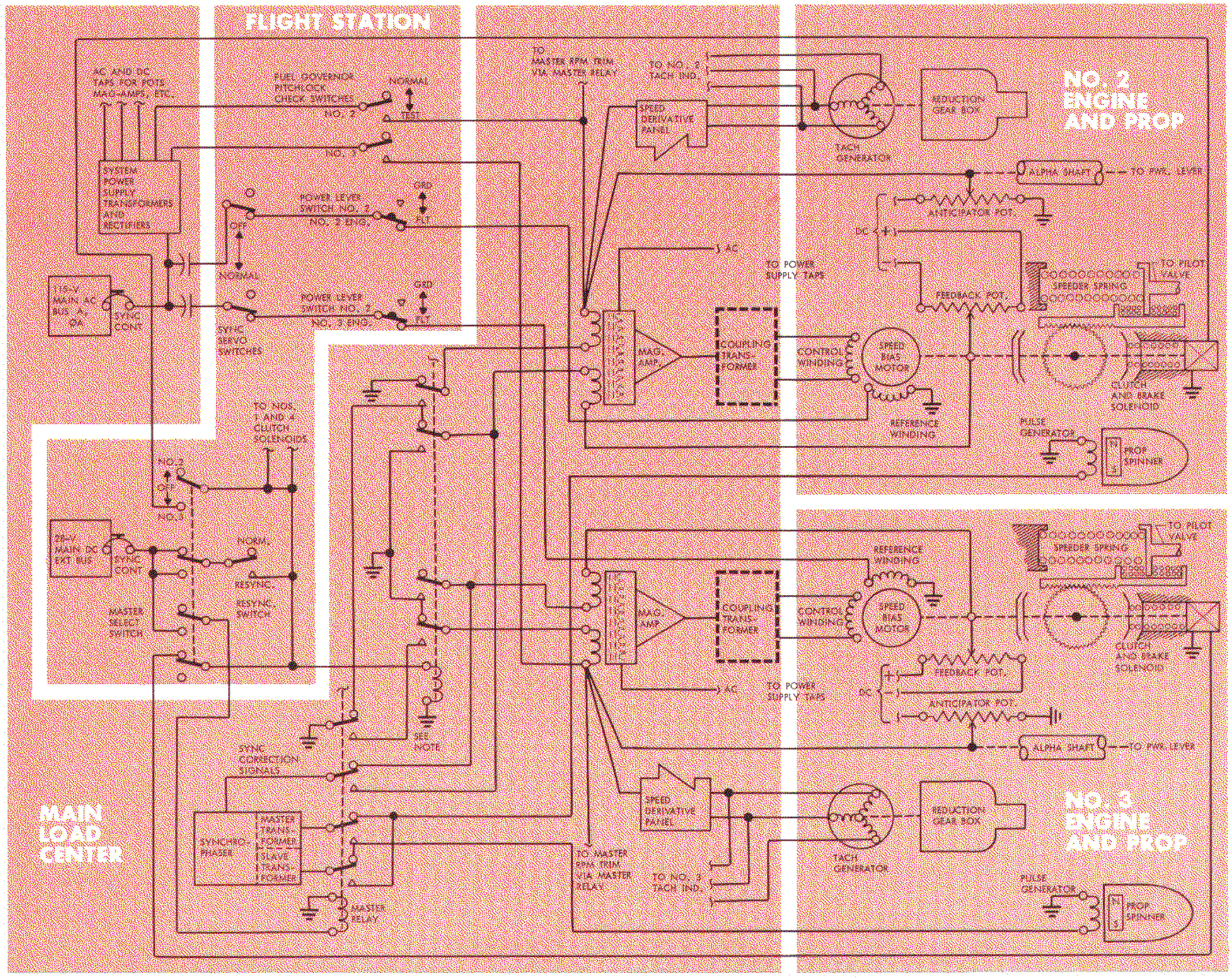
We will discuss the various sources of servo-control signals only briefly here, for it is beyond the scope of this article to explain all the electronic intricacies of these sub-systems. As shown on the Figure 13 Simplified Schematic, the "reference winding" of each speed-bias servo is energized from Main AC Bus A through two switches in series: a manually actuated Sync-Servo switch (shown also in Figure 14) that is closed when in "NORMAL" position, and a power lever actuated switch that is closed when the power lever is forward of Flight Idle. *When either of these switches are open, the speed bias servo is ineffective and prop governing is purely hydro-mechanical.*

If it is necessary for test purposes, electronic governing can be utilized with the airplane parked, but it is primarily intended for in-flight use and its function should, in most cases, be tested in flight. The performance of electronic governing on a parked aircraft is not representative of its performance in flight, for the close proximity of the ground causes aerodynamic disturbances at the blade tips which do not otherwise occur.

In normal flying operations, electronic governing is put into service (by a set procedure described under the "Propeller Indexing" heading) during climb-out after takeoff.

The Speed-Derivative Governor Damping System. As noted previously, hydro-mechanical governing holds quite close tolerances on engine rpm, and to simplify the discussion we have portrayed it as capable of holding steadily "ON SPEED" when power and airspeed are constant. Actually, the propeller may deviate a fraction of a percent within its narrow tolerance range. Obviously, when *any* power or air-speed transient occurs, an off-speed excursion of rpm must occur before the governor can begin to compensate, and sensitive though it is, the governor cannot instantly eliminate the compensating pressure when the





NOTE: THE FUNCTIONS OF TWO RELAYS (RESYNC AND DERIVATIVE) ARE COMBINED IN A SINGLE RELAY SYMBOL ON THIS SCHEMATIC. MOST INTERCONNECTIONS FOR THE NO. 1 AND NO. 4 ENGINES HAVE BEEN OMITTED FOR SIMPLIFICATION.

Figure 13 Speed Bias Servo Control Schematic. Inboard engines are shown, with No. 2 selected as master.

prop comes back "ON SPEED", and diminutive rpm excursions normally occur. Generally such excursions as do occur during "steady state" operations will be too small to produce any visible fluctuation of the tachometer indicator.

These indicators "count" the frequency of current alternations generated by a small 3-phase generator driven by the engine's reduction gear box. Two phases are tapped and utilized as a reference by a segment of the bias motor control known as the "speed derivative" system. This system translates a frequency change (caused by a fluctuation in engine rpm) into a corrective signal to the speed-bias motor. The signal is sustained as long as rpm is changing and when the change stops and reverses, a reverse corrective signal is instantly fed to the speed-bias motor.

The electrical sensing of rpm changes is more acute than the flyweight sensing mechanism and the bias motor response is fast and effective enough that governor reflex is much accelerated. Thus during steady state flight the Orion has a near-perfect constant speed power plant.

The speed derivative system functions continuously as an adjunct of the Synchrophasing system, but its signals are weak in comparison to the signals derived from other control circuits which may be impressed on the servo control windings, and any given speed damping cycle may be cancelled, reversed, or augmented by an over-riding signal. Both the "Speed Derivative" circuit and the "Power Change Anticipation" circuit (discussed later) are activated by turning the Sync-Servo switch for the individual engine to "NORMAL."

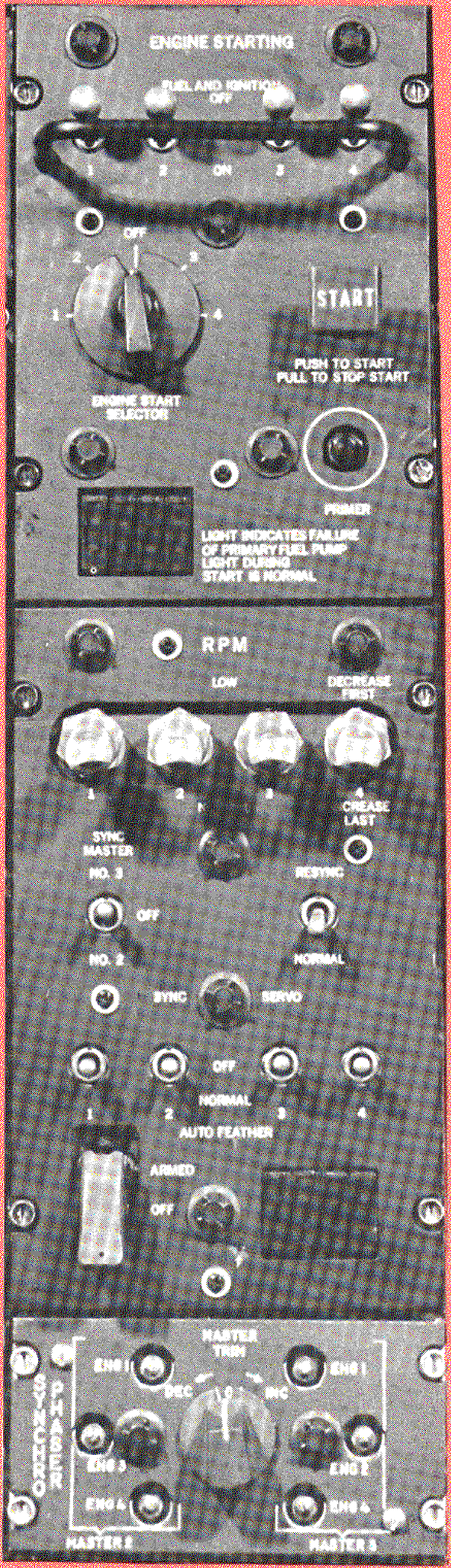
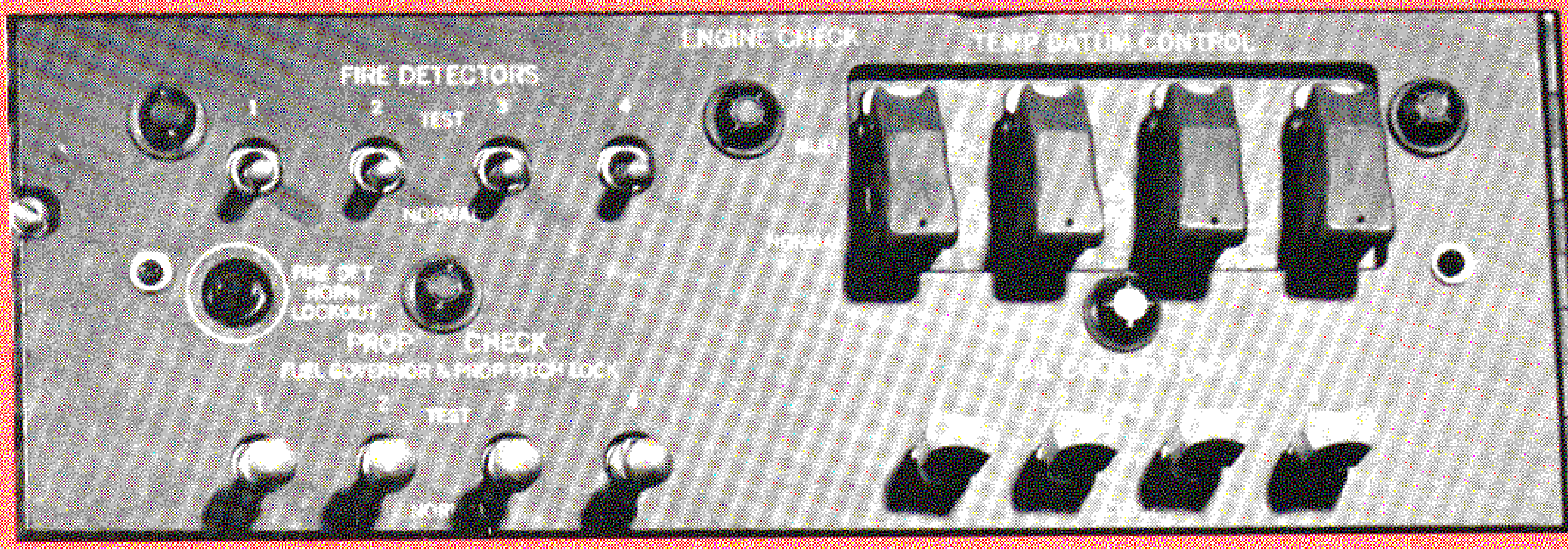


Figure 14
Synchrophaser Controls — Center Overhead Control Panel



The Synchrophasing System. This system, whose controls are shown in Figure 14, has the capability of bringing three "slave" engines to exactly the same speed as a "master" engine; either engine No. 2 or No. 3 may be chosen as "master" by use of the selector.

With Synchrophase control, the speed bias motor can produce such infinitely small increments of tension at the prop governor speeder springs that they are not only able to keep all four propellers turning at the exact same rpm, but also exactly "in phase" with the master. The Synchrophasing system becomes fully operational when a master engine is selected, (assuming Sync Servo switches are at "NORMAL" and power levers are in Flight Operating range) and its persistent signals bring the slave propellers into phase with the master so closely that they turn as if driven by a drive line from the Master. The system orients the props so the inboard and outboard blade tips interact aerodynamically very little, sparing both the airframe and its crew from the fatiguing effects of vibration.

The Synchrophasing system receives an electrical pulse (one pulse per revolution, produced by a single-magnet magneto on each propeller) from each engine. The Master pulse provides an index, and corrective signals are fed to the slave engine servos until their pulse frequency, which is to say engine rpm, exactly matches the master. Slaved engine speeds may be automatically increased or decreased no more than 2% during synchronization, for the servo-motor gear train drives the wiper of a "feed-back potentiometer" that automatically cancels further signals when a 2%

speed change has been made. This limitation is imposed to prevent a malfunction that affects Master engine rpm from severely influencing slave engines. The nominal control speeds of the four engines will rarely be beyond this range, but if one or more slave engines do not automatically come into synchronization with the Master after a few seconds operation, the pilot can obtain a second 2% corrective increment by actuating the "RESYNC" switch.

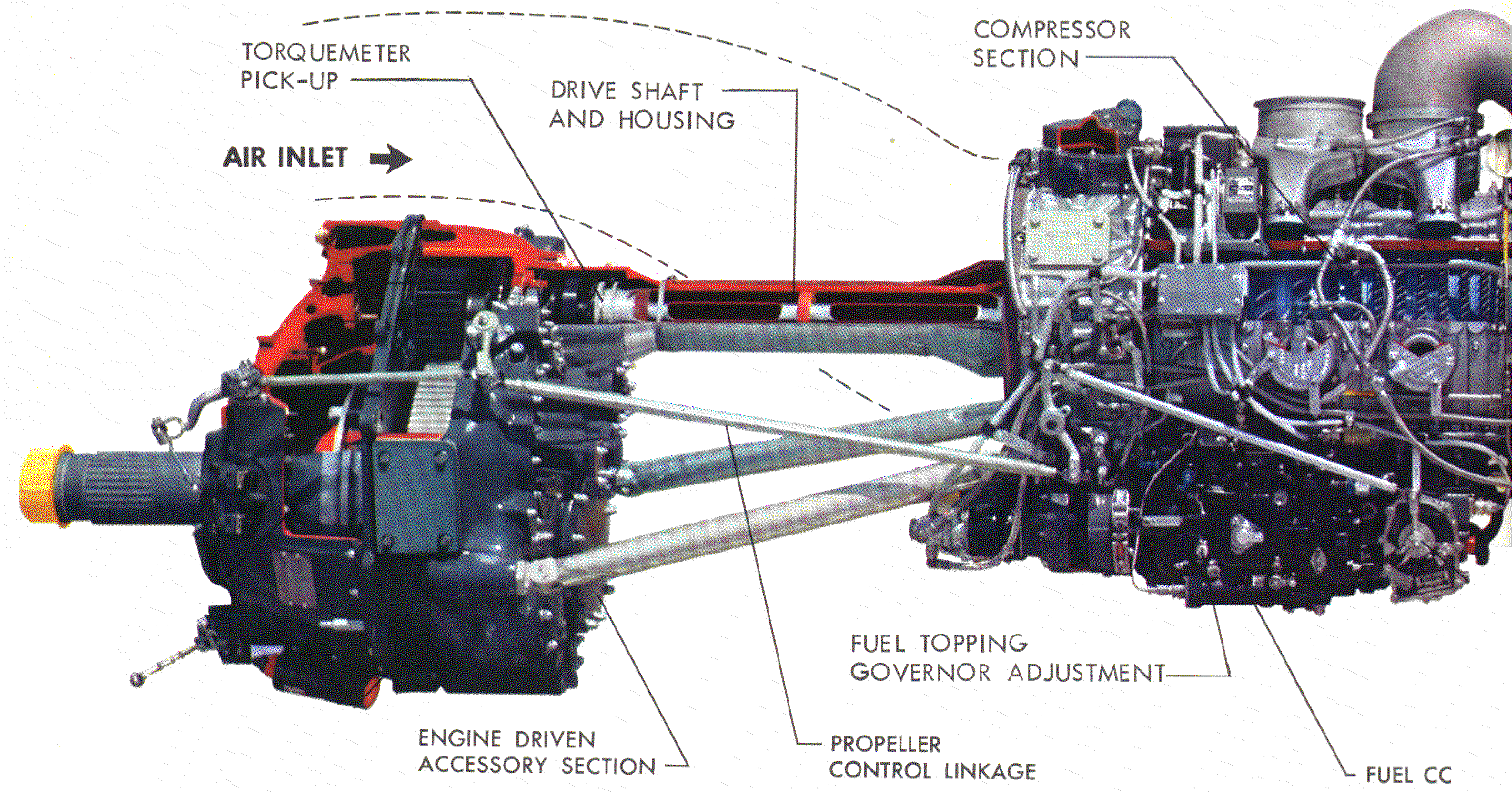
When the "RESYNC" switch is actuated, the magnetic clutches of the three slaved speed-bias servos are actuated. This locks the biasing mechanism, (thus retaining the incremental spring force adjustments that have been achieved) and disconnects the servo motor from the mechanism, allowing it to run free in response to control signals. However, the "Resync" actuation also interrupts all control signals from the sync (magneto-pulse) systems, and the remaining principal control signal for each servo will originate from its own feed-back potentiometer. If the feed-back potentiometer wiper of any slave has been driven off center by the preceding synchronization period, the wiper will supply a potential to the servo motor that will run the motor, and thereby return the potentiometer wiper back to center, at which point resync potential drops to zero. This will require about 2 seconds if the feed-back potentiometer was full travel off-center (a 2% rpm correction had already been made) and therefore, it is customary in such a circumstance to hold the Resync switch at least 2 seconds to ensure that all slave feed-back potentiometers are returned to neutral.

When the Resync switch is released, the servo motors are re-connected to the biasing mechanism, the Synchrophasing circuits are reconnected to the servo motors, and slave correction will resume.

The resync operation can be repeated as required, but note that mechanical stops prevent the speed-bias mechanism from driving the governor speeder spring tension more than plus 6 or minus 4% off its pre-set (ground adjusted) value. This range (10% total) is many times as wide as is required with properly adjusted and indexed propellers under any normal circumstance, but the power-plant can operate safely in this range and in fact the servo is deliberately run to the 106% stop to make the "Fuel Governor/Pitch-lock" check discussed later.

After the slave engines' rpm is synchronized with the master, the proper phase relationship is attained by a separate Synchrophaser circuit that operates by sensing the slave pulse lag or lead in respect to the master pulse.

The speed-bias servos for individual engines are de-activated automatically by Power Lever Switch No. 2 when the power levers are retarded into Ground Operating range. Turning "OFF" the individual Sync Servo switches, mounted adjacent to the Sync Master selector switch, performs the same function. By use of these switches during Flight Range operation, the control can be switched from servo-bias control to purely hydro-mechanical governing. Thus, it is possible to compare the performance of prop governing with speed-bias to the performance without it, or a single propeller with a malfunctioning speed-bias control can be "isolated" from the others and operated on hydro-mechanical governing alone.



Fuel "Topping" Governor (RPM Limiting) Adjustment

Power-Change Anticipation. As shown in Figure 13 and the Master Schematic, an "anticipation potentiometer" is connected directly to the alpha shaft, and every motion of the power lever moves the wiper. Movement of the wiper produces an actuation signal at the servo motor whose intensity, polarity, and duration are directly proportional to the speed, direction, and amount of change in power setting. A slow advance may not produce any noticeable effect, but a fast change to high power will produce an instant and equally fast action of the governor pilot valve towards "increase pitch", blade angle will begin to increase before the engine power actually increases, and, thus prepared, the propeller is enabled to absorb the rising torque without a substantial overspeed. Retarding the power lever has the opposite effect.

By anticipating abrupt power changes, the prop governor control of engine speed is well stabilized as the changes develop, but it should be noted that the pilot valve action is *not* actually a result of speed changes, and the natural reaction of the hydro-mechanical governor is being interfered with. If the power lever is rapidly advanced and immediately retarded, the power burst may not develop until *after* the anticipation system has produced a strong control signal to decrease pitch. The propeller is thus prevented from absorbing the high power, and a momentary over-speed may trigger the pitch-lock. If this occurs, the engine will subsequently drop underspeed, and the pilot must either increase power on the pitch-locked engine or increase air speed (thereby regaining rated rpm) to regain propeller control. As described in the previous discussion of the pitch lock, "decrease-pitch" pressure will not disengage the pitch-lock ratchet.

Fuel Governor/Pitch Lock Check. (see NATOPS procedure, Figure 15.) The propeller governor normally prevents engine speed from exceeding 102% during operation in the flight range, but if it fails to do so the pitch-lock will trigger at about 103%, preventing the propeller from further reducing the engine load, and at about 104% the fuel governor will begin to trim fuel flow to reduce engine power as necessary to prevent further rise in rpm. These stand-by safeties are extremely important, and their operability should be ground-checked regularly. Obviously, it is necessary to turn the engine faster than normal prop-governing will allow to test the standby controls, and the individual Fuel Governor/Pitch Lock check switches provide this capability. This check is made with the aircraft parked and the engine operating, initially, at Flight Idle. When the check switch is actuated, the speed-bias servo motor receives a continuous overriding signal which drives the mechanism full travel towards "decrease pitch", and the prop governor's speed-sensing mechanism cannot create "increase-pitch" pressure unless rpm reaches about 106%.

FUEL GOVERNOR, PITCH LOCK, AND REVERSE HORSEPOWER CHECK.

The purpose of this check is to ensure that the fuel control governor will limit engine speed if the propeller governor fails. Also, that the propeller pitch lock will engage to prevent the propeller from going to a lower blade angle and that REVERSE HORSEPOWER is checked.

1. RPM switches—NORMAL.

2. Temperature datum control switches — NORMAL.

3. Propeller servo switches—NORMAL.

4. Propeller sync master switch—OFF.

Note

- **Perform steps (5) through (12) on two engines at a time (1 and 4, 2 and 3).**

5. Power levers—FLIGHT IDLE.

6. Fuel governor check switches for engines being checked—Hold in TEST.

7. Power levers — Advance to maximum power position and observe fuel governor rpm (103.8 to 106.0 percent).

Note

- **If rpm is between 105.5 and 106 percent investigate to determine that propeller governor is not controlling rpm.**

8. Power levers—Retard to 100 percent rpm; horsepower should be 1500 minimum.

CAUTION

Do not permit the rpm to drop below 95 percent or the engine bleed valves may open and an overtemperature occur.

9. Fuel governor check switches—NORMAL.

10. Power levers—Advance to a minimum of 900°C. As power lever is advanced, torque should increase and rpm should remain fairly constant.

11. Power levers—MAX REVERSE; check horsepower.

  a. Engines 2 and 3 should be 1200 (±150) hp.

  b. Engines 1 and 4 should be 1100 (±150) hp.

12. Power levers—START.

13. Repeat steps 5 through 12 with the remaining two engines.

Figure 15
Fuel Governor, Pitchlock, and Reverse
Horsepower Check Procedure — NATOPS, Current as of June 1965

Next (Step 7 on Figure 15), the power lever is advanced to maximum power position. At this point in the procedure the pitch lock should have triggered (at about 103%), the fuel governor should be controlling rpm (at less than 106%) and the Beta follow-up system should have mechanically manipulated the pilot valve and increased the blade angle to 21 to 22° —well into the normal flight range where the pitch-lock is effective. Of course, if the fuel governor fails to assume control, the propeller governor will regain control at about 106%. The upper fuel governor tolerance may be so near 106% that the rpm indicator cannot be trusted to show which governor is controlling, but in such a case the fuel flow, which should be far below normal, provides the most reliable indication of fuel governor control. If the fuel governor is controlling in the 105.5 to 106% range, the indicated fuel flow will be substantially lower than when the propeller is governing engine speed at the 90° coordinator position. The MIM (July 1963 revision) specifies that fuel flow should not exceed 1650 pph while rpm is 105.5%, and should not exceed 1250 pph while rpm is 106%.

There is no indication of pitch-lock engagement at the take-off power setting. Therefore, the power lever must be retarded until rpm deteriorates to 100% to complete the check. With the pitch lock engaged, holding the propeller at about 21°, and with fuel governor control the engine will produce about 1800 hp at 100% rpm. Variables, chiefly environmental, may subtract as much as 300 hp from the normal, but if the pitch-lock has not engaged, the propeller will come back beyond 21° towards the low pitch stop (13°), and hp will be substantially less than 1500 at 100% rpm. Any hp indicated in excess of 1500 proves the operability of the pitch lock mechanism.

Thereafter, the Test switch is returned to "NORMAL" (the overriding 106% signal is removed from the speed-bias servo) and the power lever is once again advanced towards high power to ensure that the pitch lock disengages and the prop governor maintains 100% rpm in normal fashion. The procedure at this point (Step 10) calls for the power lever to be advanced to at least 900°C on the TIT indicator.

The remainder of this procedure (see Figure 15) merely tests that the power plant's capability to produce reverse thrust is within tolerance—it has no direct connection with the Fuel Governor/Pitch Lock check.

OPERATING PRACTICES

NTS CHECK The operability of this important function is to be checked during engine shutdown at the end of each flight, and an in-flight check is to be made prior to feathering a propeller in-flight for any reason except emergencies.

The ground check is performed simply and automatically at shutdown by turning "OFF" the Fuel and Ignition switch with the power lever at ground START position and the NTS/Feather Valve Check switch at NTS CHECK position. With the power lever at START there is very little air drag to stop prop rotation. When the fuel is shut off, the prop's inertia will be immediately braked by the engine compressor and generally enough negative torque will develop to produce actuation of the NTS rod. Even a brief rod actuation will momentarily close the NTS check switch in the propeller control housing, the appropriate self-holding relay will close and the engine's individual advisory light will glow continuously until its power supply is interrupted.

Note that, when the engine is shut down at Low (72.5%) RPM, the amount of negative torque created by propeller inertia is marginal, and in some cases the NTS may not actuate. In such cases the engine should be re-started to Normal RPM and shut down again. If the additional inertia does not produce an NTS actuation, it must be assumed that the system is not airworthy.

Since the NTS is disconnected from the feather valve while the power lever is in ground operating range, the NTS rod actuation will not affect blade-angle when the ground check is made.

The in-flight check (see NATOPS procedure, Figure 17) is to be made below 8000 ft. at 170 knots. Since the power lever is in flight range, the NTS should actuate the feather valve, and therefore the check switch should be selected to "FEATHER VALVE CHECK" position beforehand. Then, with the power set to 800 hp or more, all the wing de-icer switches

re turned to "ON," the engine's anti-ice switch is turned to "ON," and its bleed-air switch is turned to "OPEN." A high-rate air bleed from the compressor results, which has the net effect of sharply reducing the hp delivered to the propeller, and by cautiously retarding the power lever towards Flight Idle, the HP Indicator will quickly drop below zero into the minus (negative torque) hp range as the propeller begins to windmill. At some point between minus 150 and minus 500 hp, the HP Indicator should begin to cycle and the Feather Valve advisory light should begin flashing, indicating that the NTS is intermittently actuating the feather valve. If there is no NTS reaction before reaching minus 500 hp, the check should be discontinued, for the NTS is not operating properly. Since it is unsafe to air-start an engine with an inoperable NTS, the engine should never be shut-down deliberately with the intent of re-starting it before landing. Of course, the engine can be shut down in an emergency.

ENGINE SHUTDOWN.

1. Engine start selector—Any engine (E).
Selecting one of the four placarded engine positions will allow the emergency inverter to power the T.I.T. after ac generators have gone off the bus.

2. Power levers—START (P).

3. Fuel and ignition switches—1, 2, 3, OFF (E).

CAUTION

When the fuel and ignition switch has been placed to OFF, it must remain there until the rpm has decayed to zero. Closely monitor engine instruments during coastdown, especially engine speed and T.I.T. Stop the engine by pulling the emergency handle if abnormal operation occurs.

4. Ground power—As desired (E).

5. Fuel and ignition switch 4—OFF (E).

6. NTS lights—Checked (E).
Each engine NTS light should come on when its fuel and ignition switch is positioned to OFF. If a satisfactory NTS check is not obtained at low rpm, recheck at normal rpm. Maintenance is required if a satisfactory check is not obtained at normal rpm.

IN-FLIGHT NTS CHECK.

When test flights, training flights, or mission flight plans call for feathering shutdown and subsequent air start of an engine or engines, a functional test of the NTS of those engines will be accomplished in flight prior to engine shutdown. If the NTS check is not successful, do not shut down the engine except in an emergency. Check as follows:

1. Perform at any altitude below 8000 feet at 170 knots.

2. Set power at a minimum of 800 horsepower.

3. NTS-feather valve switch—FEATHER VALVE position.

4. Wing deicer switches—All three ON.

5. Engine anti-ice switch—ON.

6. Engine bleed air valve switch—OPEN.

7. Power lever — Retard slowly, observing horsepower indicator. NTS action should occur between 150 and 500 negative horsepower and the feather valve light should flash intermittently. Do not exceed 500 negative horsepower.

Note

- **It is necessary that the NTS check be completed before the wing deicers start modulating, otherwise insufficient bleed may prevent reaching NTS horsepower.**
- **If NTS action does not occur prior to attaining negative 500 hp, advance power lever and record. Do not shut down and attempt to restart this engine unless an emergency exists.**

8. Engine bleed air valve switch—CLOSE.

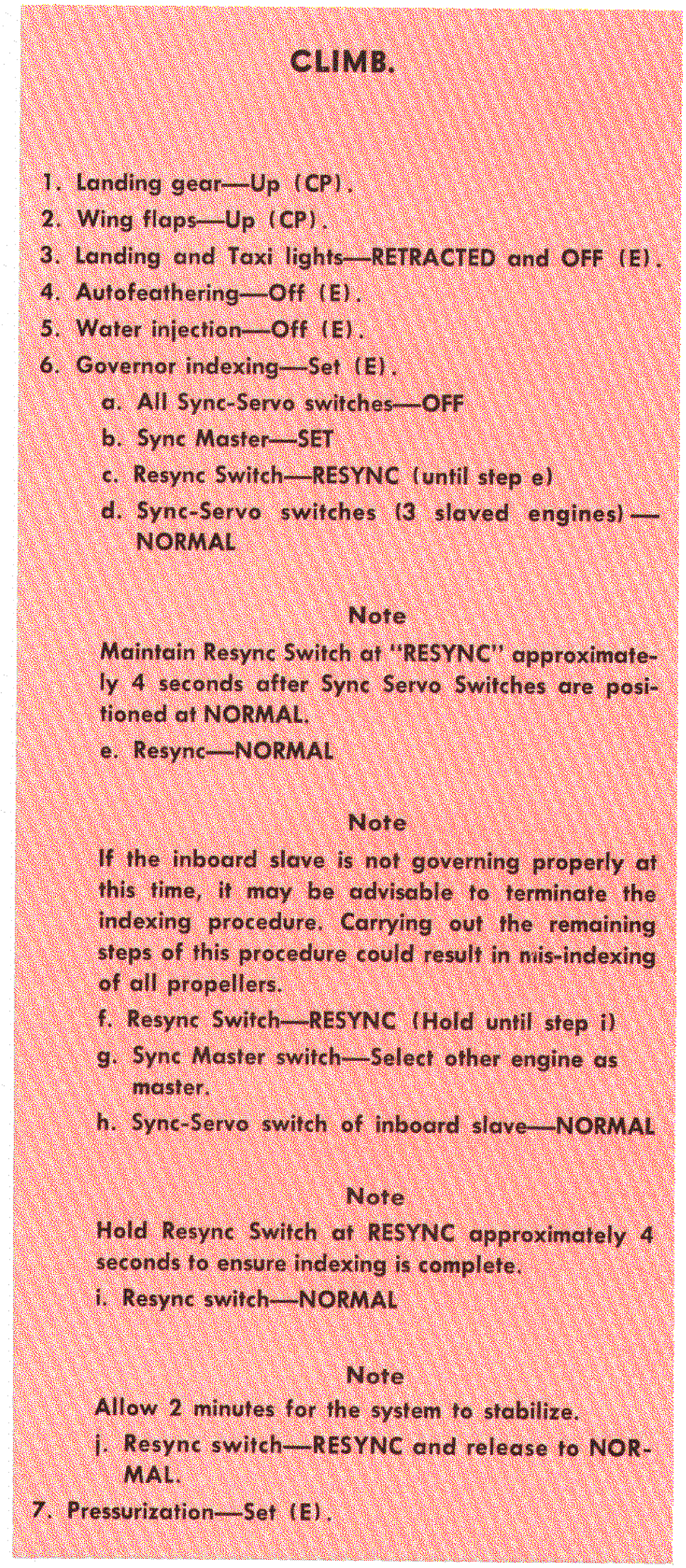
9. Engine anti-ice switch—OFF.

10. Repeat on other engine to be shut down.

11. Wing deicer switches—OFF.

Figure 17
In-Flight NTS Check Procedure — NATOPS,
Current as of June 1965

Figure 16
Engine Shutdown Procedure —
NATOPS, Current as of June 1965.
The "After Landing" Procedure, just prior to this
in the NATOPS Manual, includes step
"8. NTS-FEATHER VALVE SWITCH — NTS (E)."



CLIMB.

1. Landing gear—Up (CP).
2. Wing flaps—Up (CP).
3. Landing and Taxi lights—RETRACTED and OFF (E).
4. Autofeathering—Off (E).
5. Water injection—Off (E).
6. Governor indexing—Set (E).
    a. All Sync-Servo switches—OFF
    b. Sync Master—SET
    c. Resync Switch—RESYNC (until step e)
    d. Sync-Servo switches (3 slaved engines)—NORMAL

    Note

    Maintain Resync Switch at "RESYNC" approximately 4 seconds after Sync Servo Switches are positioned at NORMAL.

    e. Resync—NORMAL

    Note

    If the inboard slave is not governing properly at this time, it may be advisable to terminate the indexing procedure. Carrying out the remaining steps of this procedure could result in mis-indexing of all propellers.

    f. Resync Switch—RESYNC (Hold until step i)
    g. Sync Master switch—Select other engine as master.
    h. Sync-Servo switch of inboard slave—NORMAL

    Note

    Hold Resync Switch at RESYNC approximately 4 seconds to ensure indexing is complete.

    i. Resync switch—NORMAL

    Note

    Allow 2 minutes for the system to stabilize.

    j. Resync switch—RESYNC and release to NORMAL.
7. Pressurization—Set (E).

Figure 18 Climb Procedure — NATOPS, Current as of June 1965

PROPELLER INDEXING. It sometimes happens, either inadvertently or through necessity, that all the propellers' nominal control speeds for Synchrophase operation will be driven far below normal while the airplane is parked. This occurs when the Synchrophaser system is energized while the engines are not operating. If the Master Engine Selector is alternated (each inboard engine is repeatedly made master, then slaved) and the Resync switch is toggled, both inboard (potential Master) propeller governors will be re-set progressively towards "increase pitch" during their slave service as the system attempts to match the slave's speed to a zero-rpm master. The system is said to be misindexed when this occurs, meaning that one or more speed-bias servo system is disoriented in respect to normal rpm.

Of course, so long as the Sync-Servo switches are "OFF," the misindexed servo control has no effect on propeller governing. When the engine is started and run with sufficient power to reach 100% rpm, the hydro-mechanical governor will assume control and hold rpm very near that point, but in so doing it carries the de-energized servo-mechanism to a position where the feed back potentiometers are far off their "null" point. If the Speed-bias Servos were made operative (Sync-Servo switches "NORMAL") at this time, the servo motors would run and inflict a steady "bias" on the governor speeder spring, driving propeller rpm appreciably off 100%.

Therefore, it is standard procedure to start and run the engines with the Sync-Servo switches at "OFF" position until the aircraft is well established in climb-out after takeoff and then to carry out a 10-step procedure, which puts the Synchrophaser into operation, but ensures that the servo control is properly re-indexed before it is made effective. The steps of this procedure are shown in Figure 18 as they appear in the June 1965 Revision of the NATOPS "CLIMB" Procedures, and are listed below also, together with brief descriptions of the effects of each procedural step.

a. All Sync-Servo switches — OFF

All electronic "fine tuning" of the propeller governors is de-activated when the Sync-Servo switches are "OFF"; thus initially, all engines are operating with hydro-mechanical governing only, and during steady-state operation they will hold rpm to the pre-set value (100% plus or minus 0.20%).

b. Sync Master — SET

Selecting a master engine enables Resync and Synchrophasing signals to be routed to specific slave propellers, but all speed-bias motors remain ineffective (the Sync-Servo switches are holding open the circuit to the reference winding of all servo motors, therefore control signals cannot run them).

c. **Resync Switch — RESYNC (until step e)**

This energizes the clutch solenoids of the three slaved servo-motors (they are disengaged from the speed bias spring mechanism), and blocks all Synchrophaser control signals to the servo-motors, but the circuit from the feed back potentiometer of each slave to its own servo motor remains closed.

d. **Sync-Servo switches (3 slaved engines) — NORMAL**

This provides a "reference" potential to the slave servo-motors, and any slave feed back potentiometer which is not at "NULL" position will provide control potential (of the correct polarity) to run its servo-motor. The servo will drive the wiper of the feed-back potentiometer to "NULL," thus eliminating its own control signal. If slave feed-back potentiometers are full travel off null, it will require a few seconds for them to reach that position, and it is best to:

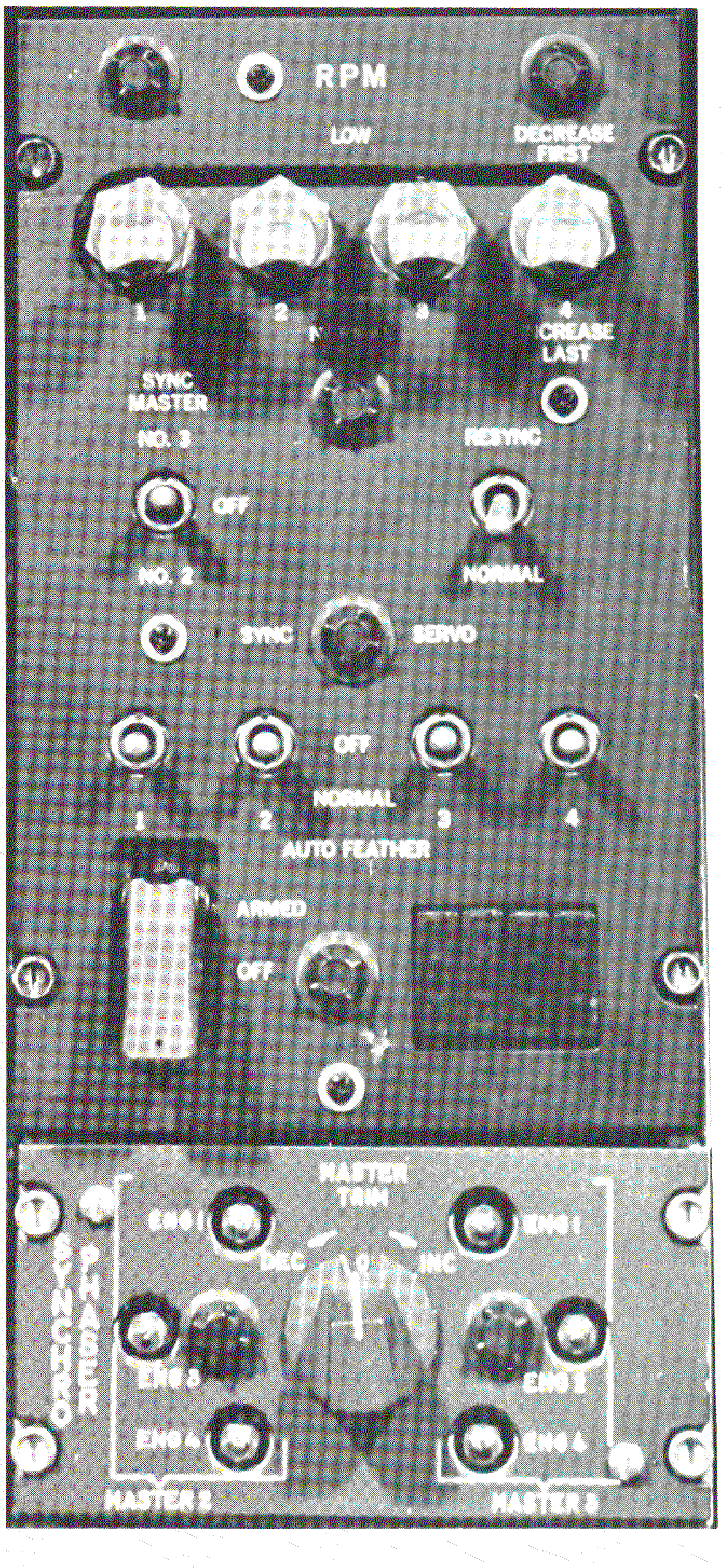
NOTE

Maintain Resync Switch at "RESYNC" approximately 4 seconds after Sync Servo Switches are positioned at NORMAL.

Due to the fact that the servo is declutched, the motor action has no effect on any of the prop governor speeder springs, and the propellers continue to control themselves with hydro-mechanical governing at 100%, plus or minus 0.20%. Note that, although the slave bias springs are still disconnected from their servo-mechanisms, at this point in the procedure all speed-bias springs are nulled and the *slaved* servo-bias mechanisms are also nulled.

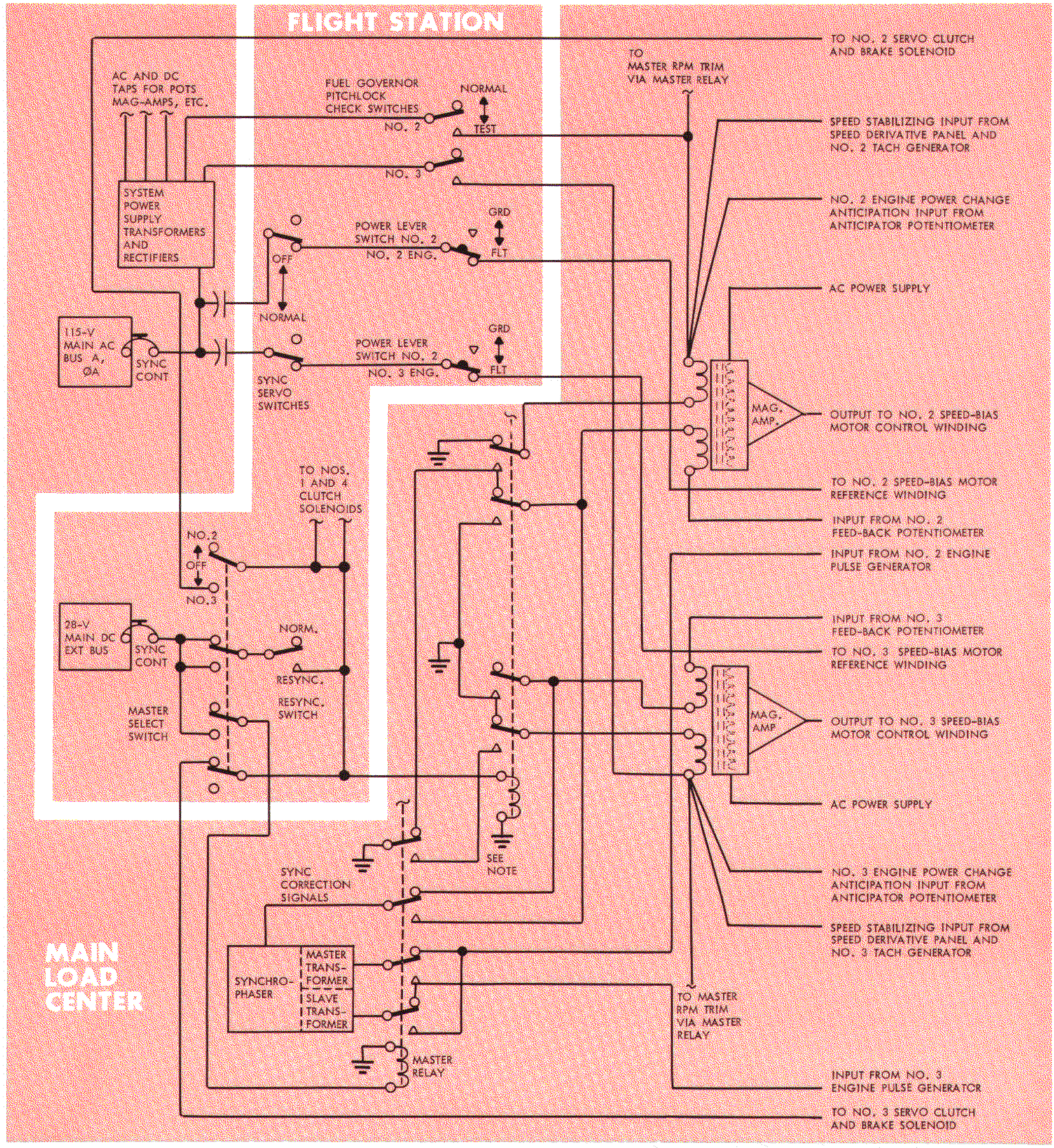
e. **Resync — NORMAL**

This engages the slave clutches (connecting the nulled bias spring mechanisms to the nulled servo-mechanisms on the three slaved prop governors) and re-establishes all tributaries of the servo-control circuit for the slave prop governors. At this point in the procedure, three propellers are slaved to a master which is being controlled by hydro-mechanical governing, and local turbulence or Master engine power lever manipulation may produce small fluctuations of all tachometers. If any slave tachometer is widely at variance with the master, it is good technique to return the Resync Switch to "RESYNC" briefly, but if there is no improvement it will be best to turn the slave's Sync-Servo switch to "OFF" and proceed without electronic governing on that propeller.



NOTE

If the inboard slave is not governing properly at this time, it may be advisable to terminate the indexing procedure. Carrying out the remaining steps of this procedure could result in mis-indexing of all propellers.



NOTE: THE FUNCTIONS OF TWO RELAYS (RESYNC AND DERIVATIVE) ARE COMBINED IN A SINGLE RELAY SYMBOL ON THIS SCHEMATIC. MOST INTERCONNECTIONS FOR THE NO. 1 AND NO. 4 ENGINES HAVE BEEN OMITTED FOR SIMPLIFICATION.

Figure 19 Abbreviated Synchrophaser Control Schematic

f. **Resync Switch — RESYNC (Hold until step i).**

The three slave propeller speed-bias clutches are disengaged, and all engines are again operating on independent, hydro-mechanical governing.

g. **Sync Master switch — Select other engine as master.**

The new Master propeller has heretofore been slaved, but when it is selected as Master its clutch is automatically engaged and the clutch of the former Master is disengaged. The servo-bias control of the former Master engine is not operative as yet because its Sync-Servo switch is "OFF."

h. **Sync-Servo switch of inboard slave — NORMAL**

At this point, the servo-motor of the former Master (which is now slaved and de-clutched) will receive a "reference" potential, and the motor will act upon the control signal from its own feed-back potentiometer if it is off "NULL." The motor will run the feed-back potentiometer as necessary to "NULL" position.

NOTE

Hold Resync Switch at RESYNC approximately 4 seconds to ensure indexing is complete.

i. **Resync switch — NORMAL.**

This puts the entire system into normal operation, and all engines should come into synchronization with the Master. The actual reading on one or more slave tachometers may be slightly at variance with the Master due to the fact that the tachometers are allowed a plus or minus 1% tolerance, but the apparent variation should not exceed 2% and there will generally be an audible improvement in the sound of the engines shortly after the Resync switch is released to "NORMAL" as the Synchrophaser system brings the individual propellers into synchronization.

NOTE

Allow 2 minutes for the system to stabilize.

j. **Resync switch — RESYNC and release to NORMAL.**

This step is necessary because the feed back potentiometers of the slave engines will be driven slightly off "null" during the synchronization cycle. This feeds-back a small confusion factor into the synchrophaser system and, although the propellers will synchrophase, the blades will probably not be at the optimum angle for minimum "noise." A brief "RESYNC" interval will essentially eliminate the troublesome feed-back signal. When the switch is returned to "NORMAL," the blades will assume their correct relationship, and generally there will be audible improvement in the sound of the propellers.

It is good technique to repeat Step (j) occasionally on long flights to realign slaves with the master engine, for the master may "drift" slightly off its original rpm and regenerate a small confusion factor in the Synchrophaser circuits.

PITCH-LOCKED OPERATION. Since the pitch-lock feature protects against such a variety of propeller control malfunctions, pilots should have a thorough grasp of its operating details and understand both the direct effects that a pitch-locked propeller will have on power control and the indirect effects on aircraft control.

If a pitch-lock occurs on the runway, there will be obvious indications that the propeller has been locked in flight-range when the power lever is retarded into ground range. In fact, if a pitch-lock has occurred in flight, the yawing tendency due to asymmetric power will probably be evident in final approach, and certainly so when the power levers are brought back to low flight power or ground operating positions. The abnormally high power and the failure of a Beta light to illuminate will further identify the pitch-locked propeller and, if the aircraft is to be stopped, it is imperative to shut off fuel to the engine by pulling the Emergency Handle. Of course, this will also operate the manual feather mechanism, but in this circumstance it is of little note whether or not the propeller feathers successfully. The primary concern is to shut off the fuel to the power plant whose propeller is locked at high pitch, and the Emergency Handle shutdown is preferred because it closes the fuel shut-off valve by both electrical and mechanical means. Even at the lowest possible pitch-locked blade angle, a power plant can produce about 1700 hp at zero airspeed, and the threat to controllability is obvious.

When a pitch-lock occurs during flight, there is more opportunity (and more reason) to analyze the indications and plan remedial action.

If rpm tends to follow the power lever, power does not respond normally to power lever *advance,* and no pump flow warning lights are illuminated, a pitch lock due to malfunction of the prop governor or the pressure regulating system is indicated.

PROPELLER MALFUNCTIONS.

The more serious propeller malfunctions generally result in some degree of offspeed. Normally, under conditions of overspeed the propeller should be feathered. Conditions may arise, however, when feathering should not be attempted. When loss of control oil pressure occurs, feathering and NTS capabilities are lost. Under these circumstances, an attempt to feather may result in engine decoupling and may be followed by a greater overspeed even though the pitchlock is engaged. The only indication of a loss of oil pressure is given by the propeller pump warning lights. If either or both of these lights are on during an overspeed, feathering should not be attempted.

Following are detail procedures for various propeller malfunctions.

Propeller Overspeed During Takeoff.

If engine rpm exceeds 104 percent and remains off speed before reaching V_R (refusal speed):

1. Abort the takeoff.
2. Pull emergency shutdown handle.

If overspeed occurs after V_R, not accompanied by propeller pump warning lights, continue the takeoff.

1. Pull emergency shutdown handle.
2. If propeller fails to feather, leave power lever in the takeoff position so that the Beta Follow-Up system will maintain the higher blade angle setting. Maintain airspeed not above 150 knots by retarding the power levers of the remaining engines. Proceed as follows:

   1. Turn off fuel and ignition switch.
   2. Push in emergency shutdown handle to provide oil for the engine and gear box lubrication.
   3. Pull oil shutoff valve circuit breaker.
   4. Pull emergency shutdown handle.

Propeller Overspeed During Flight.

If engine rpm exceeds 104 percent with sync servo switches in NORMAL and remains off speed with propeller pump warning lights not on, proceed as follows:

1. Sync servo switch—OFF (on affected engine).

   If rpm returns to normal governing range, continue operation with propeller in mechanical governing. If the above procedure does not correct the overspeed:

2. Emergency shutdown handle—Pull.

If engine rpm exceeds 104 percent and remains off speed, and either propeller pump warning light is on, the propeller is pitchlocked. Do not feather.

Note

An attempt to feather the propeller with insufficient oil pressure after overspeed and pitchlock may not be successful and may result in engine decoupling. This could result in excessive overspeed and high windmilling drag.

Operation With Pitchlocked Propeller (With One or More Propeller Pump Lights On).

1. Maintain engine operation at fuel governing rpm (above 104 percent) by use of the power lever.
2. Do not allow indicated horsepower to become negative. (Horsepower will increase with a reduction in speed or altitude.)
3. Proceed to nearest available airport.
4. Before landing, as airspeed and power become insufficient to maintain more than 95 percent rpm, or, when airspeed is down to approximately 130 knots, move fuel and ignition switch to OFF.

Note

This should be accomplished far enough from the runway so that power and control changes can be established before touchdown.

Methods of Detecting a Pitchlocked Propeller.

a. RPM stabilizes at higher than governing limit (above 103.5 percent).

b. RPM increases and decreases with power lever movement.

c. RPM increases and decreases with changes in altitude and airspeed.

Propeller Pump Warning Lights.

If either No. 1 or No. 2 propeller pump warning light comes on, not accompanied by overspeed or surging, pull emergency shutdown handle.

If propeller fails to feather, proceed as follows:

1. **Commence reducing airspeed by retarding power on remaining engines.**
2. **Turn off fuel and ignition switch.**
3. **Push in emergency shutdown handle to provide oil for the engine and gear box lubrication.**
4. **Pull oil shutoff valve circuit breaker.**
5. **Pull emergency shutdown handle.**

Decoupling.

If decoupling occurs shut down engine with emergency shutdown handle.

Note

The tachometer is driven through the propeller gearbox and does not reflect engine power section rpm while engine is decoupled.

RPM Fluctuation in Flight (With Propeller Pump Warning Lights Out).

1. **If engine rpm fluctuates during flight move propeller sync servo switch to OFF.**
2. **If condition persists move temperature datum control switch to NULL.**
3. **If condition still persists pull emergency shutdown handle.**

WARNING

If one or both propeller pump warning lights *are* on, *do not feather*, but monitor the propeller closely.

It should be noted that pitch-lock trigger speed, 103.5% rpm, is within the control range of the speed-bias servo, and before feathering it is always best to de-activate the servo control (by turning "OFF" the Sync Servo switch) to test that the servo-motor has not malfunctioned and set the nominal governing speed beyond pitch-lock range. If this fails to correct the situation and if there is no reason to question the feathering capability, the simplest course is to shut-down with the Emergency Handle.

Note that stable governing at about 106% is not in itself a compelling reason to feather the engine, indeed, if either pump flow warning light is illuminated, the feathering capability is highly suspect and attempting to feather may worsen the situation. If the pumping system supplies a sporadic flow and does not complete the feather cycle cleanly, short bursts of "increase pitch" pressure may reach the pitch change mechanism, providing sufficient force to disengage the pitch-lock ratchets briefly but not sufficient force to overcome the TM. Thus the blade angle is permitted to deteriorate, possibly to the point at which windmilling will commence. If the negative torque becomes severe, the de-coupler may operate and, although the drag will be substantially alleviated when the propeller is relieved of the braking effect of the engine, it may go appreciably overspeed if airspeed is high.

Therefore, it is best to *prevent* operation of the feather valve if there is evidence of a hydraulic power fault until favorable circumstances are obtained. The engine can be used to reach the vicinity of the nearest suitable airport by manipulating the power lever as necessary to maintain engine speed at fuel governing rpm (about 104% or more), preventing the NTS from operating the feather valve. The pitch-locked engine will labor increasingly as speed and altitude are reduced, and eventually it may not be possible to prevent the engine from dropping underspeed if pitch-locked at a high blade angle. When the point is reached at which it is not possible to maintain 95% rpm, the engine should be shut down with the Fuel and Ignition switch. If pitch-locked at a low blade angle, the effects of descent and decelleration on rpm can be off-set with the power lever, and the Fuel-and-Ignition shutdown should be made at 130 knots. When shut down in this way, engine lubrication is not interrupted, and the NTS will automatically streamline the prop blades to the extent of its ability. The low airspeed is not likely to induce decoupling or a high drag that would be bothersome, and the aircraft can be re-trimmed for a 3-engine landing, unencumbered by an engine that produces more and more thrust as airspeed diminishes.

The airspeed/power situation is extremely important at the time of shutdown. If a pitch locked engine is at high power when it is shut down, the blades are obviously at a relatively high angle for the prevailing airspeed, windmilling drag will be moderate after shutdown, and the prop will windmill at less than 100%. Conversely, if little or no power is required to maintain rpm, the blade angle is relatively low for the prevailing flight speed and windmilling drag could be severe (assuming the NTS does not succeed in advancing the blade angle after the fuel is shut off) unless airspeed is low. If windmilling is quite severe, the de-coupler may operate, and the prop may overspeed.

Incidentally, we must emphasize one effect of an Emergency shutdown that differs from shut-down via the Feather button or Fuel and Ignition switch. The oil supply to both the engine lubrication system and the reduction gear box system is shut off at the oil reservoir when the Shut-down handle is pulled. If feathering is not completed and the engine and/or the reduction gearbox are driven by propeller windmilling, it is essential to restore engine lubrication. If the engine was shut-down with the Emergency handle, it will be necessary to turn "OFF" the Fuel and Ignition switch, push the Shutdown handle in (thus opening the oil shut-off valve), pull the Oil Shut-off Valve circuit breaker, and then pull the Emergency Shut-down handle again in order to restore and preserve the necessary lubrication. ▲ ▲

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