ORION • SERVICE digest

issue 42 JULY 1984
LOCKHEED • CALIFORNIA COMPANY

P-3 PROPULSION

ISSUE 42 JULY 1984
LOCKHEED-CALIFORNIA COMPANY

editor | WAYNE CRADDUCK
art and production by | ALLEN LUDLOFF

TABLE OF CONTENTS

NOT FOR PUBLIC RELEASE

The Lockheed Orion Service Digest is published by Lockheed-California Company, Burbank, California. Material is not officially approved by the FAA, CAB, or any of the military services unless specifically noted. Military personnel are advised that direct use of the information in this publication may be restricted by directives in their organization. Material contained herein is not classified, but strictures against unauthorized and indiscriminate dissemination of military information apply. Republication of material is mpy sanctioned unless written permission is granted by Lockheed-California Company. Regulations require that republished material conform to the latest information and changes.

COPIES REQUIRED OR CHANGE OF ADDRESS – Please send your name; present address; occupation; your organization's name; and, if applicable your address as imprinted on a Digest envelope to:

LOCKHEED ORION SERVICE DIGEST, BURBANK, CALIFORNIA 91520-6418, OR YOUR LOCAL LOCKHEED-CALIFORNIA COMPANY SERVICE REPRESENTATIVE.

Cover Photo Credit:
LAC Robin Menzel,
No. 492 Squadron
Photographic Section
RAAF

FRONT AND BACK COVERS

No. 92 Wing, Royal Australian Air Force, is an operational organization that consists of four squadrons — two operational flying squadrons equipped with P-3 aircraft (Nos. 10 and 11), a training and support squadron (No. 292) and a centralized maintenance squadron (No. 492). All squadrons are home-based at RAAF Base Edinburgh, located about 25 kilometers north of Adelaide, South Australia. Edinburgh is reasonably central, and a P-3 aircraft can be on task off any part of the Australian coastline within 4 hours of takeoff.

When No. 10 Squadron was equipped with P-3C aircraft in the latter 1970s, the RAAF took the opportunity to realize a saving in manpower and support costs by collocating No. 10 Squadron with No. 11 Squadron, which was already operating P-3B aircraft at Edinburgh. Moreover, the most appropriate way of operating the Australian maritime patrol force was judged to be by a Wing organization. Thus, No. 92 Wing was formed at RAAF Base Edinburgh in July 1977.

The motto on the No. 92 Wing Crest is "Watch and Ward", which describes the roles of the Wing. Surveillance of both surface and subsurface, maritime interdiction, minelaying, and search and rescue are all part of its responsibilities. Like most maritime patrol forces, No. 92 Wing conducts operations world-wide. It is not uncommon to encounter an Orion, adorned with the red kangaroo, at some unusual places in the world.

No. 10 Squadron was formed at the birthplace of the RAAF, Point Cook, Victoria on 1 July 1939, with the Seaplane Training Squadron of RAAF No. 1 Flying School and two of that unit's Supermarine Seagull V amphibians serving as its nucleus. That same month, a party of No. 10 Squadron officers and airmen were sent to the United Kingdom to take delivery of the squadron's new Short S.25 Sunderland Mk 1 flying boats and ferry them back to Australia. However, the outbreak of World War II soon followed, which prompted Australia to place the Sunderlands and their crews at the disposal of the British Government in the United Kingdom. The arrival of 185 officers and airmen from Australia in December 1939 brought No. 10 Squadron to full strength.

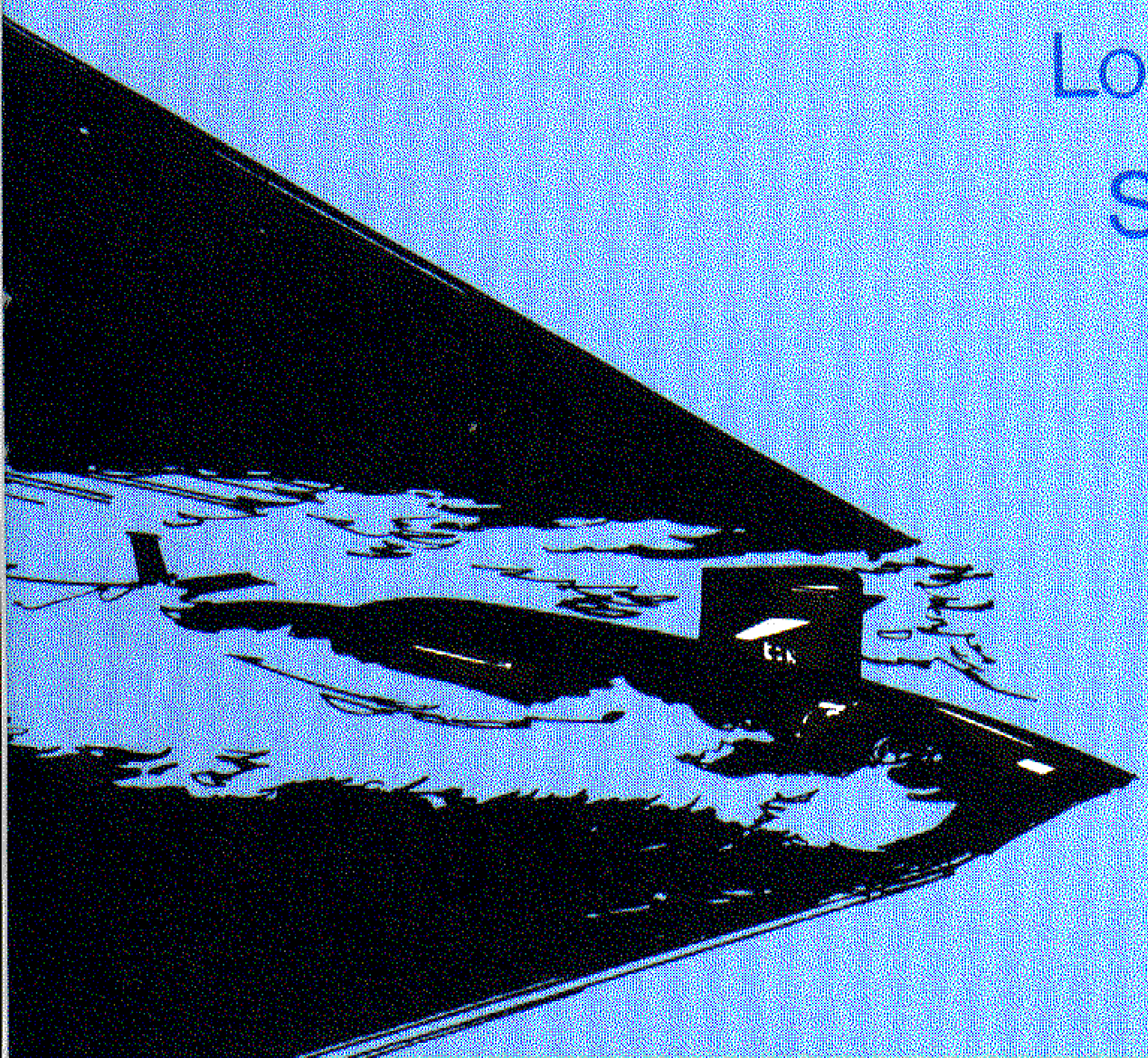
In February 1940, No. 10 Squadron began wartime operations with No. 15 Group of the RAF Coastal Command, becoming the first Dominion squadron to enter active service in World War II. During the war the squadron engaged in all forms of maritime operations from home stations at Pembroke Dock, South Wales, and at Mount Batten, Plymouth, England, and from detachments located as far apart as Oban, Scotland and the Island of Malta. By the time that the Battle of the Atlantic was at peak intensity, No. 10 Squadron was operating with No. 19 Group of the Coastal Command. Between April and August 1943, the squadron destroyed three U-boats; during this period, squadron personnel received five awards for gallantry.

Following the end of hostilities in Europe, the squadron ceased operations in June 1945 and reverted to detachment status at Mount Batten. Meanwhile, No. 466 Squadron (RAAF) of the RAF Transport Command (formerly of No. 4 Group, RAF Bomber Command) was renamed No. 10 Squadron on 20 June 1945. Plans to use the "new" No. 10 Squadron for long-range transport duties did not materialize, and in October 1945 both the "new" No. 10 Squadron stationed at Bassingbourn and the detachment at Mount Batten disbanded.

No. 10 Squadron reformed at Townsville, Queensland in March 1949 to help fulfill Australia's need for an increased RAAF general reconnaissance capability. Initially, the squadron operated GAF Lincoln Mk. 30 aircraft, but later it was re-equipped with the Australian-designed Lincoln Mk. 31 (MR) and reverted to its former role of maritime reconnaissance. A search and rescue capability was maintained, as well as a permanent detachment at Darwin, Northern Territory.

(Continued next page)

Lockheed
ORION
Service
Digest



In 1962, the squadron again re-equipped, this time with Lockheed P2V-7S aircraft. With these advanced anti-submarine warfare aircraft, the squadron extended its range of operations into the SEATO area and as far afield as Hawaii. On 15 September 1969, No. 10 Squadron was presented the Standard, an award by the Queen, for outstanding operations and for completing 25 years of operational service.

Mid-1977 saw No. 10 Squadron transfer to RAAF Base Edinburgh and begin conversion training leading to the squadron's re-equipment with Lockheed P-3C Update II Orion aircraft. The squadron received their tenth Orion in January 1979, to complete their complement of the new aircraft. During the next two years, all of the squadron's Orions were fitted with the AQS-901 Acoustic Processor and with the Australian-developed SSQ-801 Barra sonobouy. Acquisition of the AGM-84 Harpoon Weapons System in mid-1981 also gave the P-3C Update II aircraft a stand-off missile capability. No. 10 Squadron, whose motto is "Strike First", is featured on our front cover.

No. 11 Squadron was formed as a general reconnaissance squadron at RAAF Base Richmond, New South Wales in September 1939 at the outbreak of World War II, and promptly proceeded to Port Moresby, New Guinea equipped with two ex-QANTAS "Empire"-type flying boats. The squadron conducted surveillance patrols in the Thursday Island, Solomon Islands, and New Zealand areas from this base through 1941. During this period, the squadron also re-equipped with Catalina aircraft. In addition to patrol activities, the squadron flew bombing missions over Japanese-held Guadalcanal, Kavieng, and Rabaul.

In 1942, No. 11 Squadron moved to Cairns, Queensland. From that location, it carried out long-range patrols over the Coral Sea and Indian Ocean and took part in a successful mine-laying campaign in the Southwest Pacific area. The squadron moved again in late 1944 to Rathmines, near Newcastle, New South Wales. In December 1944 the squadron performed one of its most successful missions, when three No. 11 Squadron aircraft flew to the Philippines and mined Manila Harbor.

Soon after the war No. 11 Squadron disbanded, but it re-formed in 1948 and was subsequently equipped with Lincoln Mk. 30 aircraft. The squadron again disbanded in 1950, but re-formed the same year at RAAF Base Pearce, Western Australia and began transition to P2V-5 Neptune aircraft the following year. The squadron returned to RAAF Base Richmond in 1953, and operated from that site for the next 14 years.

No. 11 Squadron performed Operation West Bound in 1957, one of the RAAF's most ambitious peacetime exercises. This operation saw three of the squadron's P2V-5s fly 30,000 miles around the world during a six-week period, crossing the equator on four separate occasions — the first time that a formation of RAAF aircraft had circled the world. In 1959 the squadron again travelled afar, this time to the U.S.A. where they had their Neptune aircraft modified to the P2V-5F configuration with the installation of wing-mounted jet pods.

The Squadron operated its Neptunes until 1968, when it transitioned to Lockheed P-3B Orions. No. 11 Squadron trained with USN Squadron VP-31 at NAS Moffett Field while mastering the P-3B, then returned to Australia and moved from Richmond to its present home at RAAF Base Edinburgh. In 1970, HRH Price Philip presented the squadron with its own Standard for 25 years of meritorious service. The next year brought No. 11 Squadron further recognition, when it was the co-winner (with a Canadian Squadron) of the coveted Fincastle Trophy, awarded for ASW proficiency.

Through its participation in SEATO and Operational Readiness Exercises, No. 11 Squadron is well-known to American, British and New Zealand maritime bases in the Pacific and Southeast Asia. Exchange tours of duty by RAF, USN, and Canadian Armed Forces officers have also given the squadron an international flavor. This year is yet another high point for No. 11 Squadron as it transitions from the P-3B to the P-3C Update II Orion aircraft and prepares, as the motto on the Squadron Crest states, to "Shepherd or Destroy".

No. 292 Squadron was formed from the training flights of Nos. 10 and 11 Squadrons on 1 January 1977. This squadron is responsible for the conversion of aircrew members to the P-3 Orion aircraft. All such conversions include ground lectures, simulator training, and flying. The flight training ranges from basic aircraft and equipment handling to performing actual operational missions under the supervision of No. 292 Squadron staff. The Squadron is also responsible for the detailed analysis of inflight records, particularly acoustic data, and the investigation and formulation of new tactics. "Prepare the Hunter", the motto on the Squadron Crest, aptly describes the function of No. 292 Squadron.

No. 492 Squadron was formed on 1 July 1977 to maintain Wing No. 92 P-3 Orion aircraft and to provide limited maintenance support to RAAF Base Edinburgh units. This new squadron replaced the separate maintenance flights of Nos. 10 and 11 Maritime Squadrons, and used as its operational basis the former maintenance facilities of No. 11 Squadron. These facilities were expanded to enable No. 492 Squadron to support No. 10 Squadron's P-3C Update II Orions, as well as No. 11 Squadron's P-3B aircraft.

Since No. 492 Squadron's formation, its facilities have continued to expand. Most recently, a multi-trade avionics workshop was opened by the Minister of Defence on 12 November 1982. The combination of skilled tradesmen, modern equipment and facilities, dedication, and energetic management enabled No. 492 Squadron to win the RAAF Maintenance Trophy in 1983. By the end of 1985, No. 11 Squadron will have turned in the last of its P-3B Orions, and its complement of new P-3C Update II aircraft will almost be complete. No. 492 Squadron will then maintain a fleet comprised solely of P-3C aircraft. No. 492 Squadron's Crest, shown on the back cover, features their motto "Support for the Lion".

Lockheed
ORION
Service
Digest

FOREWORD

Orion Service Digest No. 11, March 1965, featured an article that described the function of the 56H60-77 propeller, with which the P-3 Orion is equipped. The original article was prepared by the late Donald F. Wadsworth, editor of the Orion Service Digest from 1964 to 1969. Since its initial publication, continuing demand has prompted us to reprint OSD No. 11 several times. However, a recent review of the original article revealed that it would be beneficial to revise the article to incorporate the latest available accurate information. In this revision, we have attempted to retain Mr. Wadsworth's approach to the subject, while revising or restructuring the text and illustrations as necessary to present this updated material.

The changes most apparent in this revision are the deletion of several operating and maintenance procedures from the original article, for such material is most appropriately presented in official technical publications that are subject to periodic review, update and revision. In a few instances abbreviated procedures have been retained for the purpose of illustration, but in such cases the reader is alerted and urged to consult the official technical publications for the approved procedure. Finally, the Synchrophaser discussion has been revised extensively to incorporate the recommendations of reviewers from the Hamilton Standard Division, United Technologies, the company that manufactures the 56H60-77 propeller.

The editor would like to acknowledge the assistance of the following individuals, whose efforts were instrumental in revising and updating the P-3 Propulsion article.

Sheldon Bloedorn
J. J. Brimlow
Dennis A. Carroll
Hal Guttman
James K. Lee
Carl Malkow

of the Lockheed-California Company,
and

Steve Josephson
R. D. Kaddy
Bob Madsen

of the Hamilton Standard Division, United Technologies.

Editor

P-3
Propulsion
Propeller Utilization of Turbine Power

INTRODUCTION

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 — has 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 three-quarters of a 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.

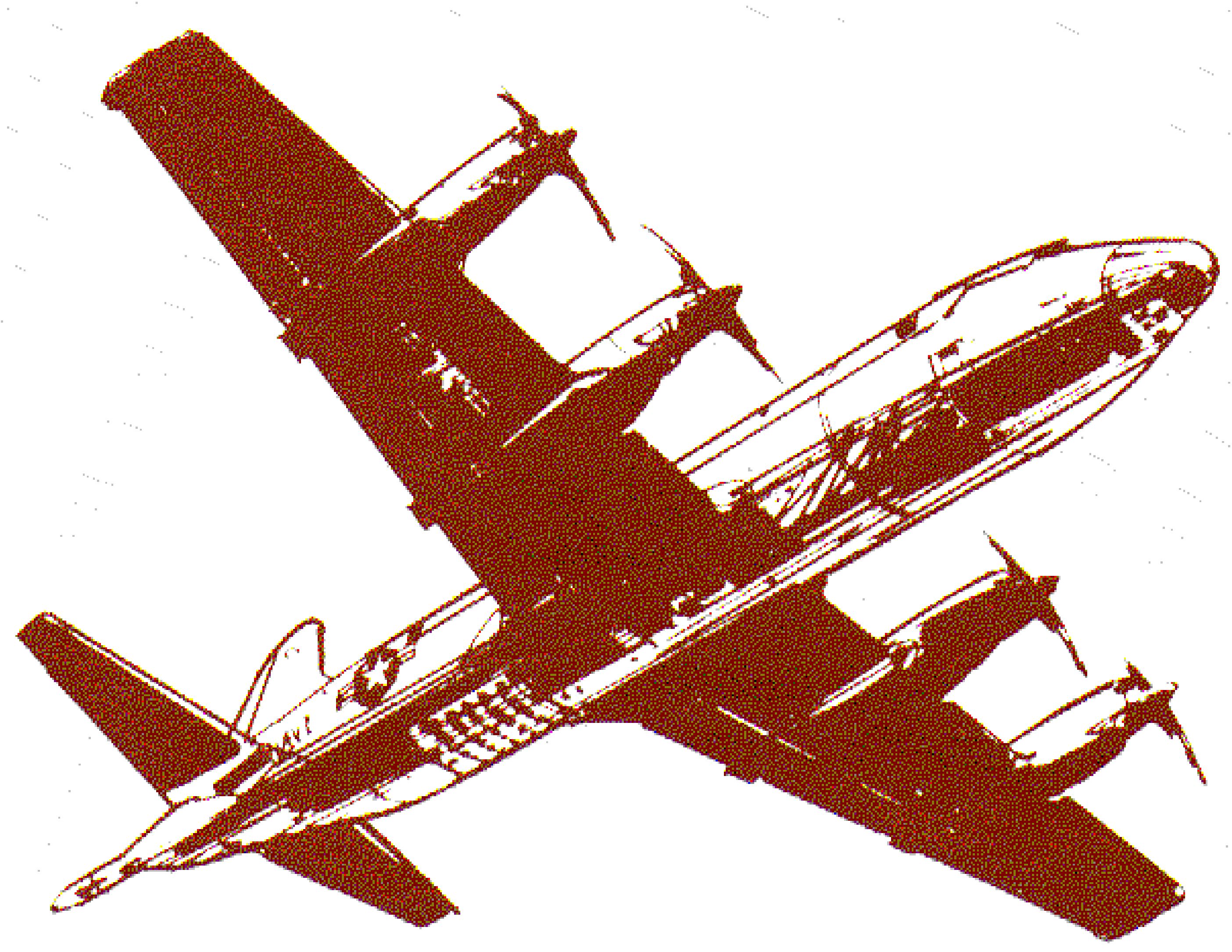
Since the propeller must convert varying increments of torque into thrust in such a variable medium as air, it is obvious that the propeller should have more than two operating positions. It must, ideally, assume *whatever* position these variables dictate.

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 propeller pitch) if too slow, or burdening it (increasing propeller pitch) if too fast.

Aircraft with powerful 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 incurs 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 excessive 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 fool-proof 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 malfunction so that it does not encumber the aircraft or suffer further damage due to "windmilling" propeller rotation.

With these basic control capabilities plus refinements (deicing, 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, turbojet aircraft demonstrated a marked superiority in terms of altitude and top speed. Its inherent properties are ideally suited for these criteria, but the turbojet does not produce thrust response efficiently at low speed, and it is very difficult to obtain the adroit thrust control needed for good airport performance with turbojet powered aircraft.

HAMILTON STANDARD/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 T56 Allison engine reveals conventional compressor and combustion sections. The turbine is somewhat enlarged to convert more heat energy to torsion, and the drive line incorporates a decoupler and a large reduction gear assembly.

The T56 turbine engine develops shaft power in excess of 4000 hp and is designed to accommodate very rapid power changes. The reduction gear assembly has mounting facilities with various drive ratios for engine-driven accessories – the principal "accessory" being the propeller. The speed of the propeller shaft drive is sharply reduced (13.54 to 1) to allow operation of the propeller at its most efficient speed of 1020 rpm while maintaining efficient engine speed.

The prop-jet propeller, coupled to a turbine, becomes a more useful device but it is also necessarily more complex. Thus, the propeller designer faced a challenging job in adapting the propeller to the T56 turbine engine power source. Every factor that affects propeller design increased, with the single exception of rotational speed which for the first time was fixed. Because of the fixed engine speed, a stronger, more massive and more responsive propeller was necessary to accommodate the increased thrust, thrust variation and response demands of the propulsion system.

The inherent operating characteristics of the turbine engine require an exceptionally positive and dependable propeller control to make quick blade angle changes in response to power changes. Should engine failure occur, the propeller – which is a highly efficient thrust-producer – acts as a windmill in the slipstream to produce drag on the airframe. A windmilling propeller on a turbine engine also attempts to extract enough energy from the slipstream to drive the engine compressor "on-speed." This could produce sufficient drag to compromise aircraft controllability.

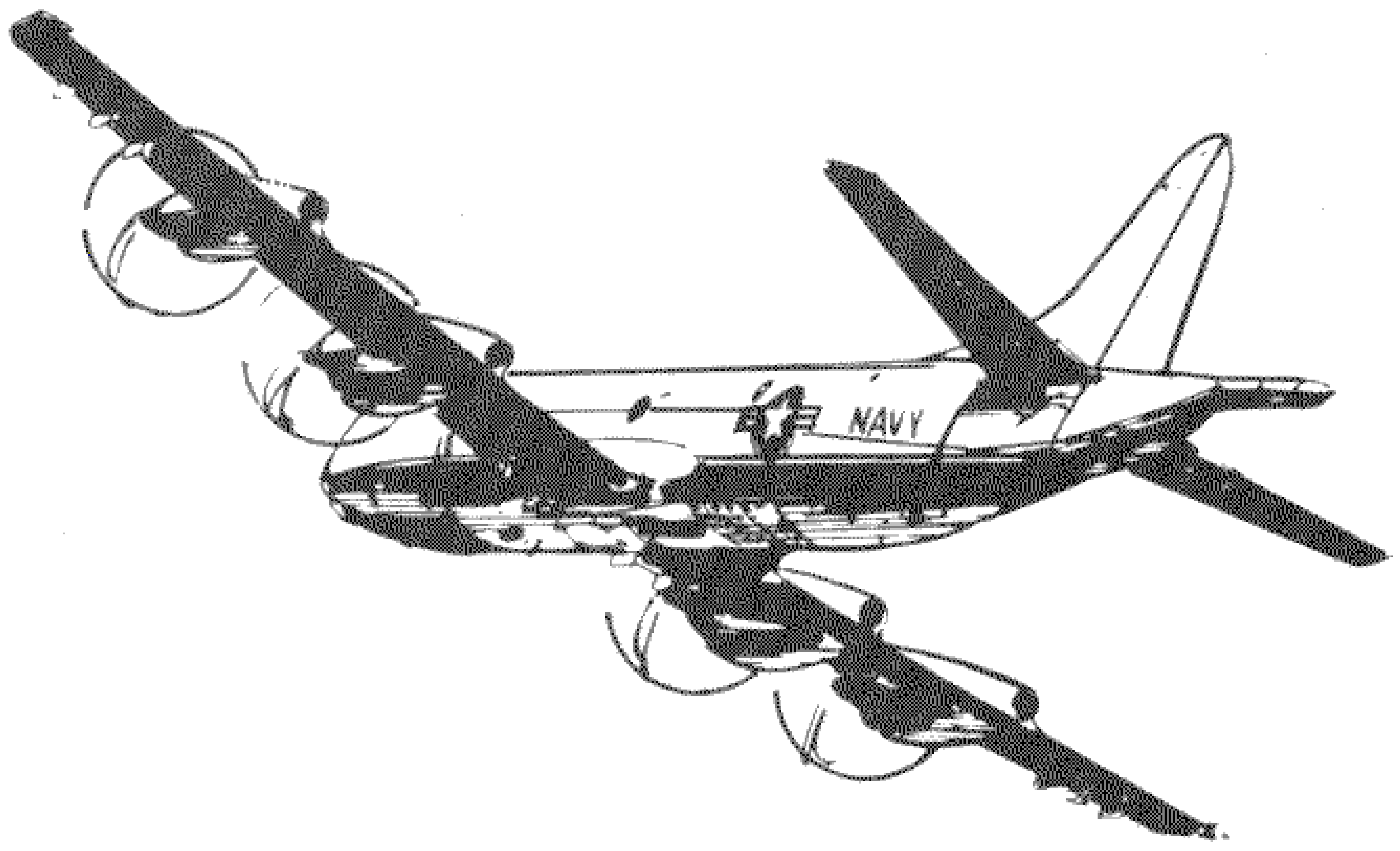
To protect against such a contingency, the T56 prop-jet power plant has an automatic mechanical device called the Negative Torque Signal System (NTS System) that overrides the propeller's constant speed governor control if the propeller develops an appreciable tendency to windmill. The Allison T56 engine drive shaft is fitted with a safety coupling that disconnects if the NTS System cannot control the windmilling tendency. This safety coupling is a sort of clutch that automatically disconnects the propeller-to-compressor drive shaft when a high negative torque is developed by the propeller, and lets the propeller turn free of engine compressor cranking drag. The propeller has many additional safeguards to protect against diverse types of failure.

POWER PLANT CONTROL Despite its apparent complexity, the Orion power control system is fundamentally simpler than most reciprocating engine controls insofar as the flight crew is concerned. 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 slower. There is no need to "juggle" rpm, mixture and throttle as is necessary for controlling a reciprocating engine. By this simple and instinctive action on the pilot's part, signals are transmitted mechanically to both the engine and the propeller controls. Through purely mechanical and self-generated hydraulic means, the fuel control and the propeller control readjust fuel flow and propeller pitch as necessary to provide the demanded thrust. Because so many variable factors affect power development on aircraft, the fuel and propeller controls are necessarily very complex servo-mechanisms. Electrical and electronic components are added to both the fuel and propeller controls to provide extremely accurate power control. These components 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. Thus, 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 an in-depth knowledge of the engine and propeller systems and their protective devices. Maintenance crews also must understand the propeller and engine systems in order to troubleshoot and repair the systems efficiently. Both the Maintenance Instruction Manual and the NATOPS Flight Manual contain procedural instructions for various circumstances, but it is difficult to foresee every contingency. Furthermore, lengthy procedures are difficult to memorize without some "working" knowledge of the system and its components.

In this article we will describe the Hydromatic propeller and its controls, and explain the basic features related 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. Thus, 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. This magazine contains a master schematic that 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 wherever it is possible to do so without obscuring the logic of the design and the operational function. However, 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 which was available *at the time of writing.* Of course, we cannot forecast all modifications which may be made in the future, nor can we foresee the procedural changes that such modifications or deviation from standard operation may dictate. Consequently, readers are urged *not* to act on any of the information herein without first consulting the current official Navy document for procedural requirements.



VARIABLE PITCH AIRCRAFT PROPELLER OPERATING PRINCIPLES

The basic function of the Hamilton Standard 54H60-77 propeller system is to convert the power developed by the engine into thrust. The pitch changing mechanism converts hydraulic pressure into mechanical torque. Its main parts are a double-acting piston assembly, a stationary cam, a rotating cam, and a dome shell. The piston fits over the two cams within the dome shell and is held in place by rollers that traverse in diagonally opposed spiral tracks of the cams. The rear of the rotating cam incorporates an integral bevel gear that meshes with bevel segment gears, one attached to each of the blades. As hydraulic pressure is applied to the piston, the piston moves, causing the rollers to turn the rotating cam and change the blade angle. The low pitch stop in the dome mechanically stops the piston from decreasing the blade angle below a preset value during flight, but the low pitch stop may be retracted during ground operation to allow lower blade angles.

The relationship of the pitch control piston motion to blade angle is: (a) aft piston travel drives the blades towards higher pitch, ending with the propeller feathered; and, (b) forward piston travel 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 plus 86.65 degrees (feather) and minus 14.5 degrees (reverse) as measured at the blade reference station. This reference station is 54 inches from the center of the propeller hub, approximately parallel to the plane of rotation when the propeller is producing no thrust at zero airspeed. The propeller diameter is 13 feet, 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 propeller 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 (CTM). However, the variable airload moment is of major importance to the control of a propeller that has a fixed operating speed. Therefore this discussion must consider the *total* Twisting Moment (TM).

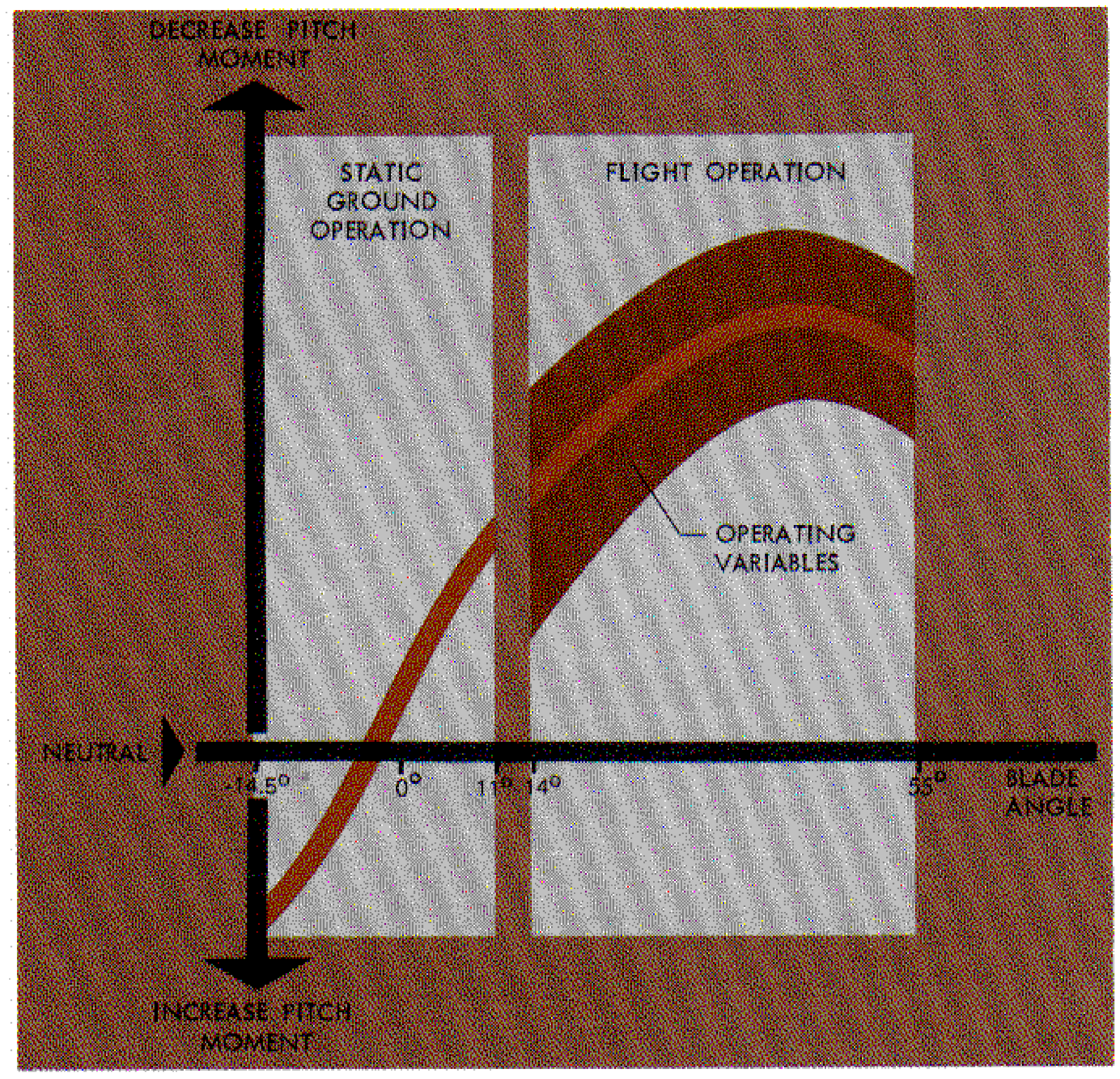


Figure 1. Net Effect of Twisting Moments on Propeller Blades During Static Ground Operation and During Flight Operation

In self-governing operation, the rotational speed of the propeller is sensed by a flyweight assembly in the governor that converts the flyweights' 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. The speeder spring is carefully calibrated so that at a given propeller rotational speed, the spring is compressed to a predictable position. Excursion of the pilot valve repositions the governor servo valve, causing the servo valve to control and direct hydraulic flow to the pitch control piston in the propeller dome.

The pilot valve in the propeller 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. This pressure is made to increase and overcome the TM when the slightest overspeed 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 takeoff roll to touchdown, 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 controlled by a mechanical linkage that positions the pilot valve as necessary to produce specific blade angles. As the blade angle changes, mechanical feedback signals move a cam to reposition the pilot valve at the null position. This scheduling of blade angle by the power lever in the ground operating range (below flight idle) is called the *Beta* operating schedule. Engine fuel flow is also scheduled in the ground operating range. During ground operation, both the fuel flow and the blade angle schedules are tailored to keep the engine rpm within a narrow operating band.

During flight, the propeller always operates in a fairly high pitch range (14 to about 55 degrees). Blade angles lower than this are plainly not compatible with the flight speed range of the Orion. A mechanical low-pitch stop is incorporated in the propeller dome to ensure that the TM cannot reduce propeller pitch to a lower level if either engine power or propeller hydraulic pressure is lost.

DESIGN CONSIDERATIONS The turbine engine has many inherent traits which require that the propeller and engine controls be very closely integrated in order to hold the engine on-speed and to preserve aircraft controllability if malfunctions and/or failure occur. In the following paragraphs, we shall discuss the over-all design of the propeller, identifying its components and subsystems and the purposes they serve in both normal and emergency situations. This will give the reader background for later discussions that describe the mechanics of the propeller.

It is essential for safety's sake that the engine be decoupled from the propeller automatically if a series of malfunctions cause the propeller to "motor" the engine compressor to the point that drag becomes excessive. In such a case, the engine, the propeller, or both could continue to rotate. To ensure that the decoupled components are not subjected to further damage, each must be self-governing and self-lubricated. For this reason, the engine has its own speed governor and lubrication systems, both of which operate from direct mechanical gear drives. Similarly, the power plant segment forward of the decoupler can operate indefinitely as a self-contained unit, driven by the airstream. The reduction gear assembly lubrication system has an integral mechanically-driven gear-type pump that is completely separate from the power section lubrication system, except that they share a common oil tank. The propeller has its own hydraulic oil supply and integral mechanically-driven gear-type pumps that provide the necessary lubrication and the hydraulic power for pitch control.

In addition to the normal speed-governing flyweight assembly, the propeller has a speed sensitive safety mechanism called the pitchlock assembly that is attached directly to the propeller pitch change mechanism. This device also senses whether the propeller's hydraulic power system is operable. If the propeller's hydraulic power system fails, or if the propeller overspeeds for any reason at normal flight speeds and power settings, the pitchlock assembly will lock the pitch change mechanism against travel towards low pitch. However, note that if – during an overspeed – the normal propeller governing operation is attempting to increase the blade angle, the pitchlock assembly will *not* lock and the propeller rpm will decrease as the blade angle increases until the rpm is below the speed at which the pitchlock is active.

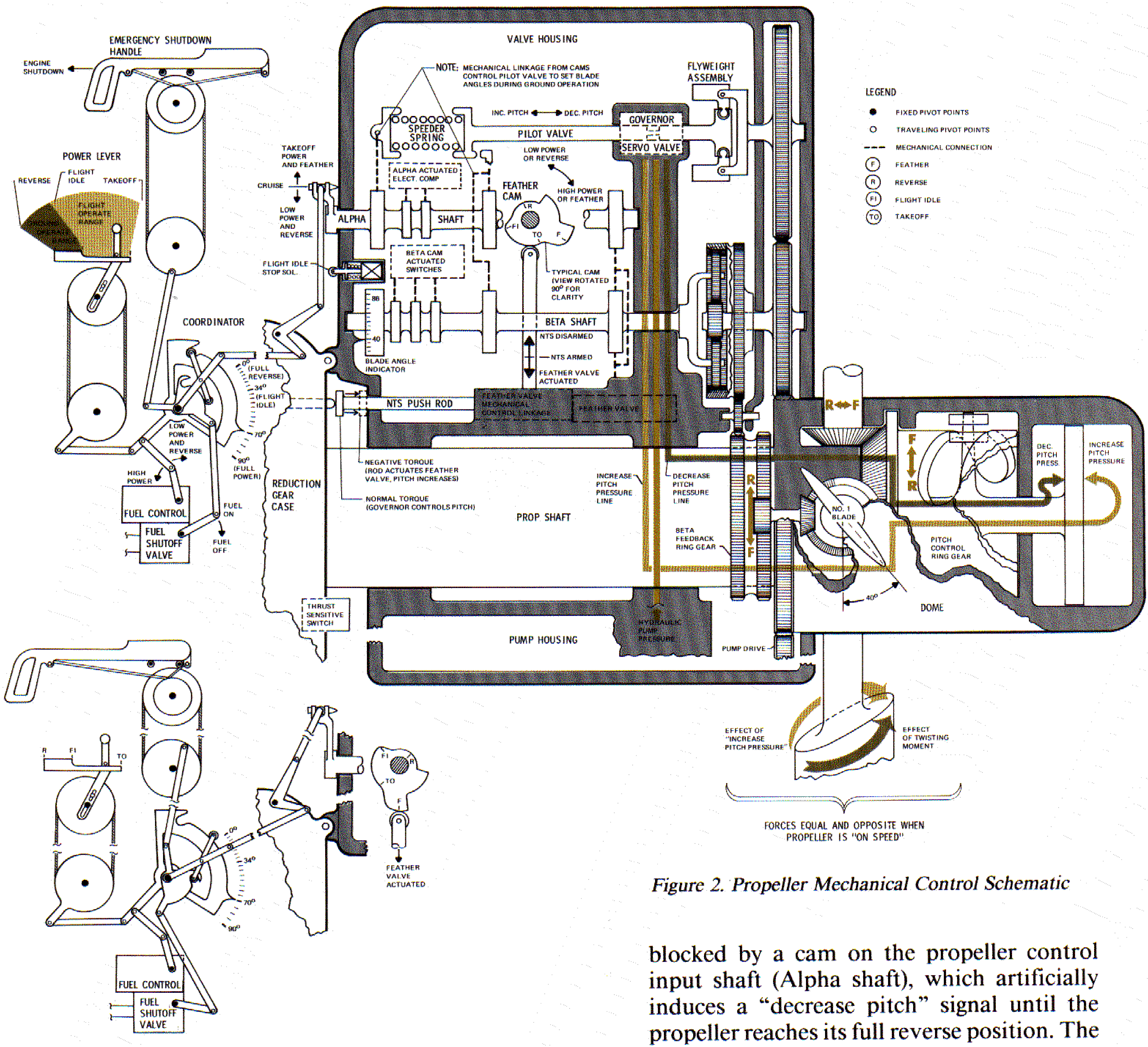


Figure 2. Propeller Mechanical Control Schematic

Figure 2 shows a mechanical coordinator operated by the power lever cable system. The coordinator is mounted on the engine fuel control assembly. The coordinator interconnects the power lever cable system (primary power control) with the fuel control assembly and the propeller control. This positive interlocking control system is linked to the pointer of the coordinator quadrant. The coordinator quadrant is graduated from 0° to 90°, and serves as the primary index to which the power control is related as follows:

1. At 0 degrees on the coordinator, the power lever is at its aft extreme. The normal speed sensing capability of the propeller governor is blocked by a cam on the propeller control input shaft (Alpha shaft), which artificially induces a "decrease pitch" signal until the propeller reaches its full reverse position. The fuel control will automatically supply the fuel required to maintain the selected engine speed. As the power lever is advanced through the first 34 degrees of coordinator travel, control cams cause the propeller pitch to traverse from its maximum negative angle (minus 14.5 degrees), through flat pitch (marked START on the power lever console in the flight station), to about plus 11 degrees. The fuel control will continuously furnish whatever increment of fuel flow is needed to maintain engine speed.

2. At 34 degrees on the 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 use the power and maintain engine speed. The resulting blade angle is not predictable, for it varies with power requirement. But, after sufficient power has been applied to advance blade angle past the point at which the low pitch stop levers engage, the blade angle will be no less than the low-pitch stop position (14 degrees). At top speed and power, the blade angle will be approximately 55 degrees. With the power lever full forward at TAKEOFF position, the coordinator will be at 90 degrees.

3. The power lever and fuel control linkage cannot be moved past the takeoff position, but the propeller control linkage (the linkage from the coordinator to the propeller Alpha shaft) can be turned past this position by pulling the engine emergency shutdown control handle (commonly called the "E-handle"). When the E-handle is pulled, a cam on the Alpha shaft mechanically positions the feather valve in the propeller control to "feather," and a separate mechanical linkage (independent of the normal fuel control) mechanically closes the fuel shutoff valve on the engine fuel control. This shuts down the engine and feathers the propeller.

Thus, there are two ranges of propeller pitch control separated by the low-pitch stop – ground operating range and flight operating range.[1] The propeller pitch is not controlled directly by the power lever in the flight range, this being a function of airspeed, power, and propeller governing. If the propeller pitch is reduced far enough in flight, the propeller will windmill, 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. In the ground operating range, the propeller is made to assume such low blade angles that during flight it would produce an extremely high windmilling drag, possibly overspeed, possibly decouple, and certainly adversely affect aircraft controllability.

Once the airplane touches down, however, windmilling drag is very useful. 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 power lever linkage in the flight station has a ramp stop that requires the pilot to lift the lever to retard it into ground range, and the propeller linkage at the Alpha shaft has a solenoid-operated flight-idle stop that is activated through the scissors switch on the main landing gear shock strut. The flight-idle stop is actually a spring-loaded detent, designed so that the pilot can override the stop by applying about a 12-pound pull at the power lever if the solenoid does not operate when the aircraft touches down.

When the propeller pitch enters the ground operating range at plus 10°, a switch in the propeller assembly actuates, illuminating an advisory light identified as "BETA" in the flight station.[2] The Beta operating range is the ground operating range of the power controls in which the positioning of the power lever sets the propeller blade angle. Similarly, a cam shaft in the propeller control is geared to the No. 1 blade butt. Since its position is a direct indication of propeller pitch, it is known as the Beta shaft. Note, 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 assembly 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 pounds. This triggers automatic engine shutdown

---

[1] There is a slight increment between the highest positive blade angle directly scheduled for ground operation and the lowest blade angle permitted for flight operation. Operation in this incremental range is transitory and is not proper for either ground or flight operation.

[2] In aerodynamic calculations, the Greek letter Beta (β) 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.

and feathering if the auto-feather system is armed and if the power lever is at or near takeoff position.

The other device is the NTS mechanism mentioned earlier that responds to negative torque – that is, when the propeller begins to drive the propeller shaft. When negative torque reaches a preset value, a ring gear inside the reduction gear assembly is forced forward against a spring load, driving a pushrod to actuate the NTS linkage in the propeller control. If the power lever is in the flight range, the NTS linkage in the propeller control assembly moves the feather valve towards the feather position. All available hydraulic power is then diverted by the feather valve into the increase-pitch lines to increase the blade angle until 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, propeller pitch will decrease, windmilling will resume, and the NTS system will repeat its cycle until the condition is corrected.

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. If the engine loses *all* power, the NTS system will increase propeller pitch to the point where the propeller rotational speed and the resultant windmilling drag are both held to safe, low values – incurring just enough windmilling drag to maintain NTS system actuation. In this respect, the NTS has the nature of a completely automatic, purely hydro-mechanical system. Since it serves to limit drag when power is deliberately reduced with the flight station control, the NTS system 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 consists of four main subassemblies: the barrel assembly, the dome assembly, the blade 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 assembly. It serves as a structural foundation for the propeller blades, and for the dome and the control assemblies. The only moving parts in the barrel assembly are the propeller blades and the Beta feedback shaft. The hub is mounted on centering cones and is retained by a splined-wrenching nut. The pitchlock regulator assembly is installed in the hub retaining nut. The hub retaining nut and pitchlock regulator assembly contain oil passages through which hydraulic power is directed from the control assembly to the dome.

The dome assembly includes the pitch control piston and a cam-and-gear train. The cam-and-gear train converts linear travel of the pitch control piston into rotary motion to drive the segment gear on each of the four propeller blades.

The propeller control assembly is mounted on the aft extension of the propeller barrel, but is prevented from rotating by the propeller torque retainer which is attached to the front of the engine reduction gear assembly. The propeller control assembly is roughly cylindrical and is divided into top and bottom housings. It contains the oil reservoir, pumps, valves, and control components that supply the pitch changing mechanism with hydraulic pressure to vary propeller pitch. The control assembly hydraulic supply is self-contained.

The upper section of the propeller control is called the valve housing assembly. It contains the governor and all valves needed to regulate the propeller hydraulic power system and to direct the pitch control flows. The Alpha (control input) shaft and Beta (blade feedback) shaft are also contained within the valve housing assembly. The valve housing can be removed from the power plant without removing the propeller.

The lower section of the propeller control is called the pump housing assembly. It contains three mechanically-driven pumps (main, scavenge, and standby) and an electrically-driven double-element auxiliary pump. The main and standby pumps and the main element of the auxiliary pump supply hydraulic oil pressure to the propeller's rotating barrel assembly through a transfer bearing that consists of rotating and stationary sleeves. The scavenge pumps transfer spent oil from the propeller's atmospheric sump to the pressurized sump to maintain a positive pressure head on the main and standby pumps, and to provide a constant pressure reference for the hydraulically-operated valves. The pump housing assembly also contains flow control valves, flow sensing devices and the oil sumps (atmospheric and pressurized) for the hydraulic source.

All mechanical and electrical connections necessary for propeller operation are made through the control assembly. The mechanical connections consist of linkages between the engine control system and the NTS system. The electrical connections are for the pulse generator coil, auxiliary pump motor, synchrophasing system, anti-icing and deicing systems, the flight idle stop solenoid, and the electrical feathering system.

PROPELLER CONTROL

In this section we shall describe the function and operation of the propeller control system components contained in the control assembly pump and valve housings. Following these descriptions, we shall discuss how the propeller control system functions as a self-governing system during flight operation and as a manually-controlled system during ground or Beta range operation.

PUMP HOUSING ASSEMBLY The pump housing assembly is the lower part of the propeller control assembly. Figure 3 portrays the *scheme* of the propeller's hydraulic pumping system. Its total

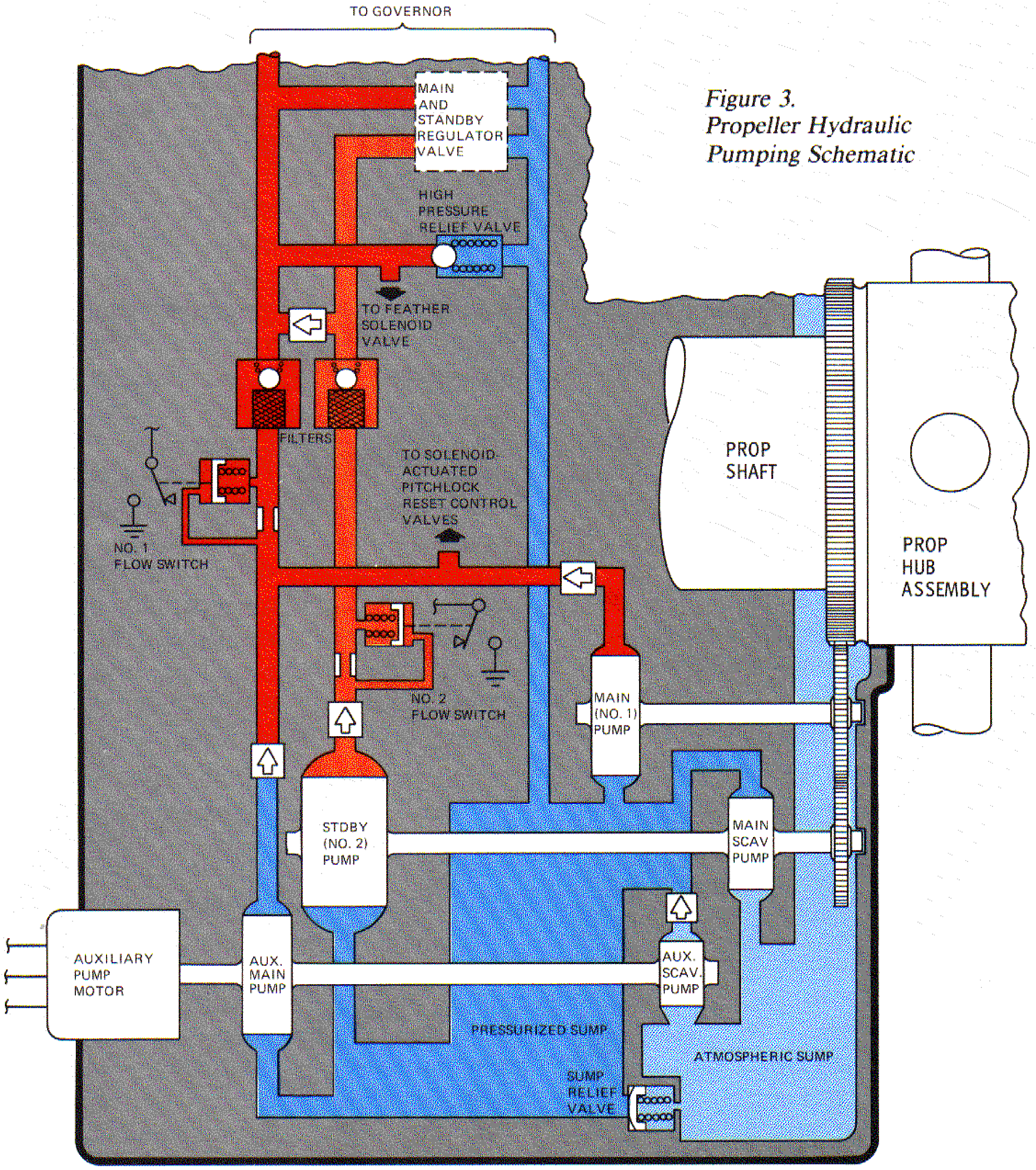
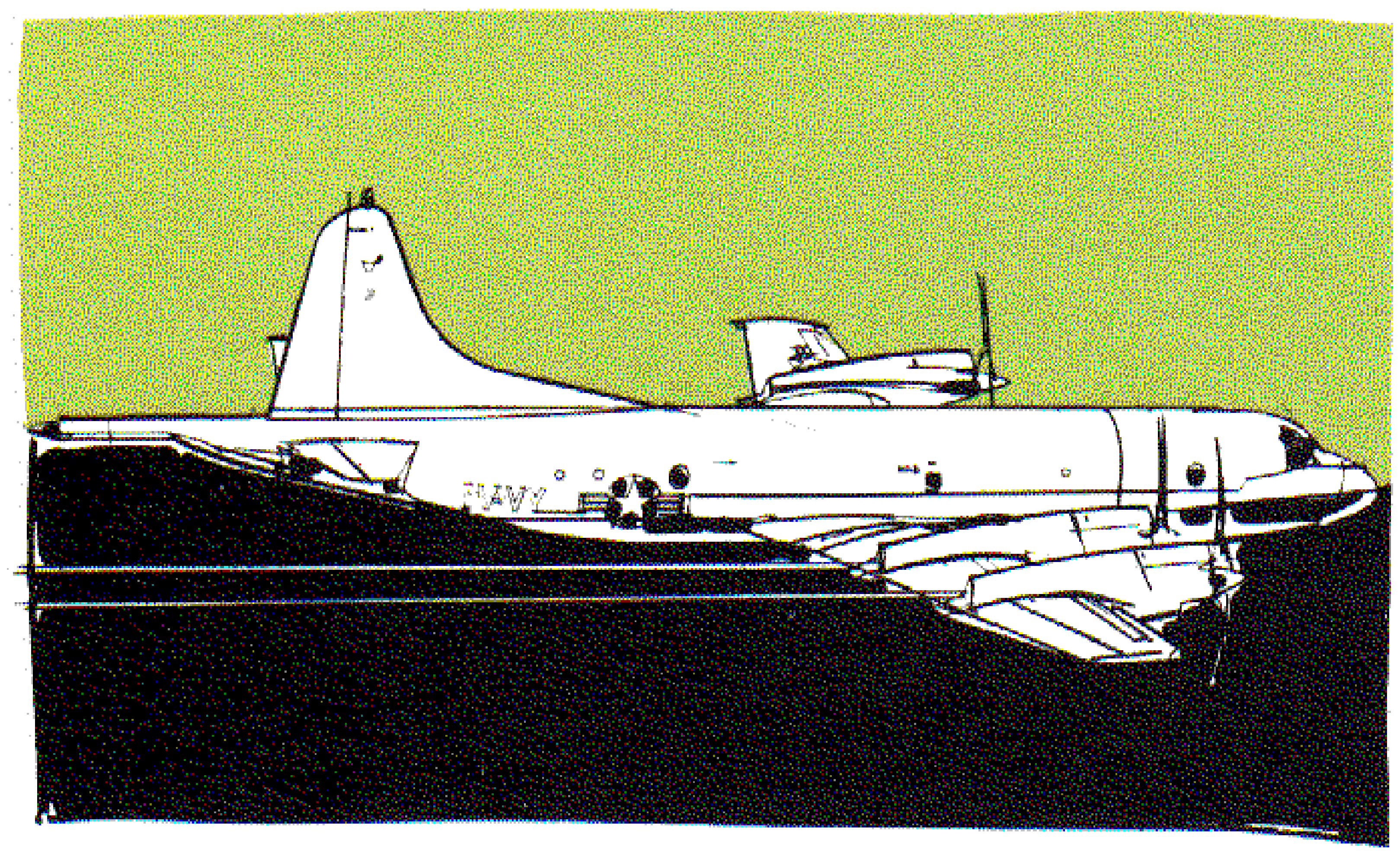


Figure 3.
Propeller Hydraulic
Pumping Schematic

capacity, including the propeller, is approximately 25 quarts of MIL-H-5606 or MIL-H-83282 hydraulic fluid. (Consult the official maintenance publications for the specification of the appropriate hydraulic fluid before servicing the propeller.) All the pumps in the control section are positive displacement-type pumps. These pumps are all driven mechanically from the propeller shaft, except for the electrically-powered auxiliary pump. The outputs of the mechanically-driven pumps vary as a function of propeller speed — i.e., reverse, low speed ground idle, high speed ground idle, takeoff, overspeed, etc. For example, the mechanically-driven pumps will produce only 72 percent of their rated flows during "LOW" (72 percent) rpm engine operation. On the other hand, since the auxiliary pump is powered by an electric motor, its output does not vary as a function of propeller speed.

The propeller's hydraulic power system constitutes a "closed" system. The spent oil that leaks within the control assembly is collected in the atmospheric sump and transferred by the scavenge pump to 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. The pressurized sump is maintained at approximately 20 psig by the sump relief valve to ensure that cavitation will not occur within the hydraulic system and to provide consistent reference pressure on the hydraulically-operated valves.

Two mechanically-driven propeller power pumps, a main and a standby pump, operate in parallel. Their outputs are monitored continually by individual flow-sensitive switches. If the pump flow falls below a preset quantity, that pump's flow switch will close and illuminate the associated PROP PUMP light on the center instrument panel in the flight station. The advisory lights are identified as PROP PUMP NO. 1 for the main pump and PROP PUMP NO. 2 for the standby pump. Illumination of a PROP PUMP advisory light does not pinpoint the reason for flow loss, but it must be assumed that a serious malfunction is indicated if one or both lights illuminate during "normal" rpm operation. A momentary advisory light illumination can occur during high power transients due to the sudden increase in oil flow demand; this should not be considered an indication of a malfunction.



The term "main pump" denotes the duty of this propeller pump, not its capacity. Actually, the main pump produces only half as much flow (20 qts/min) as the standby pump (40 qts/min). 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 at its new blade angle.

As shown in Figure 3, the dual-element pump in the lower part of the propeller control section is electric motor-driven. One pump element, known as the auxiliary scavenge pump, is in parallel with the mechanically-driven scavenge pump. The other pump element is known as the auxiliary or "feather" pump, and it is in parallel with the main and standby pumps. The motor that drives this dual-element pump is generally referred to as the feather pump motor. Some documents term it the "auxiliary" motor, and properly so, for the feather pump that it drives 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 ground check-out work to be carried out without running the engine. The feather pump is also used inflight for both unfeathering and feathering, serving to complete the feather operation after the propeller has nearly stopped. An electric motor-driven pump is needed to complete the feather cycle, for the output of the propeller's mechanically-driven pumps is reduced in proportion to propeller rpm. The feather motor

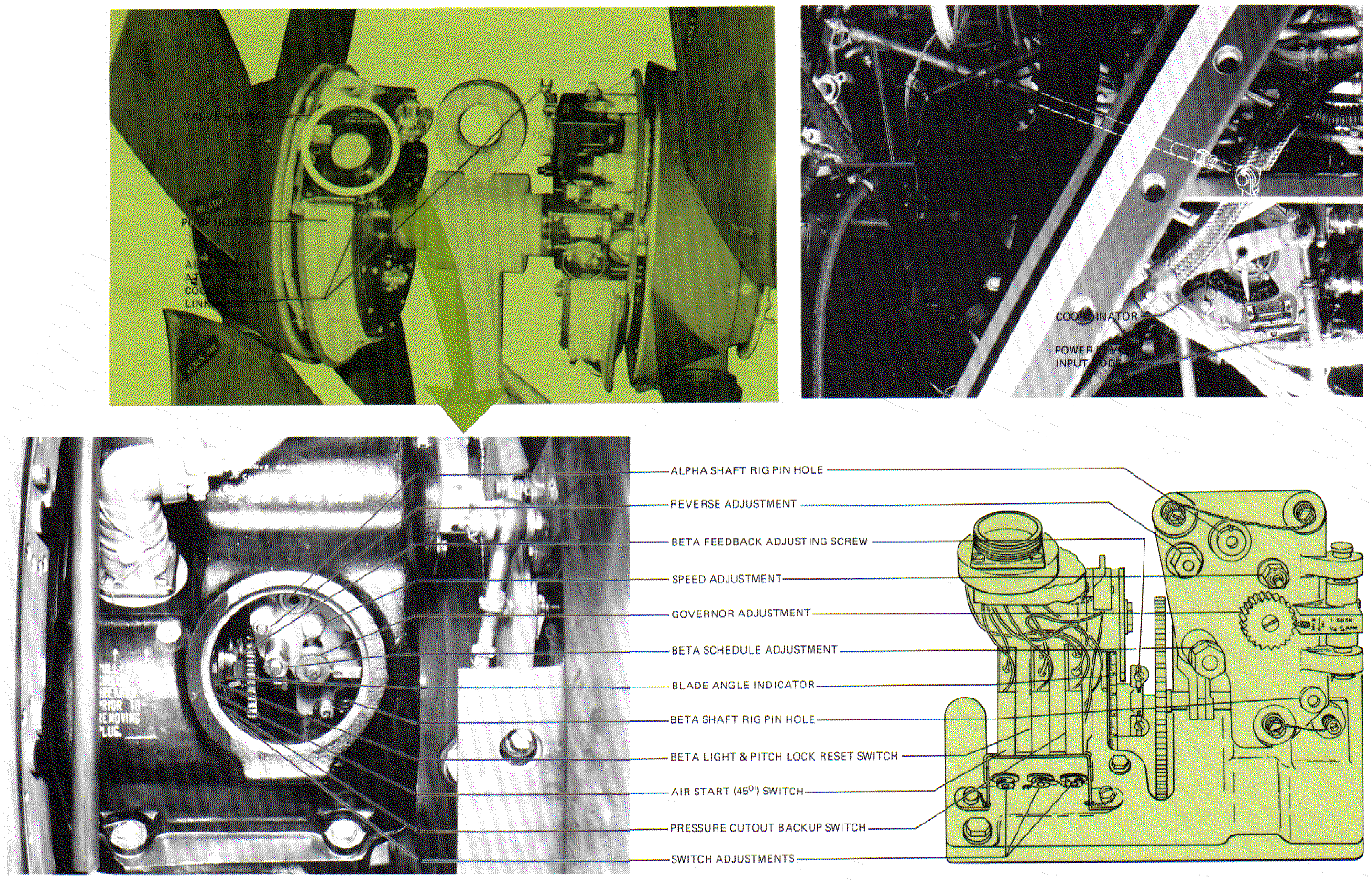


Figure 4. Propeller Control Housing — Rigging and Adjustment Points

power control circuit is routed through a pressure sensing switch that automatically de-energizes the motor when a pressure rise in the increase-pitch hydraulic power line indicates that the pitch control piston has bottomed at its full-feather position (see the Propeller Control Master Schematic).

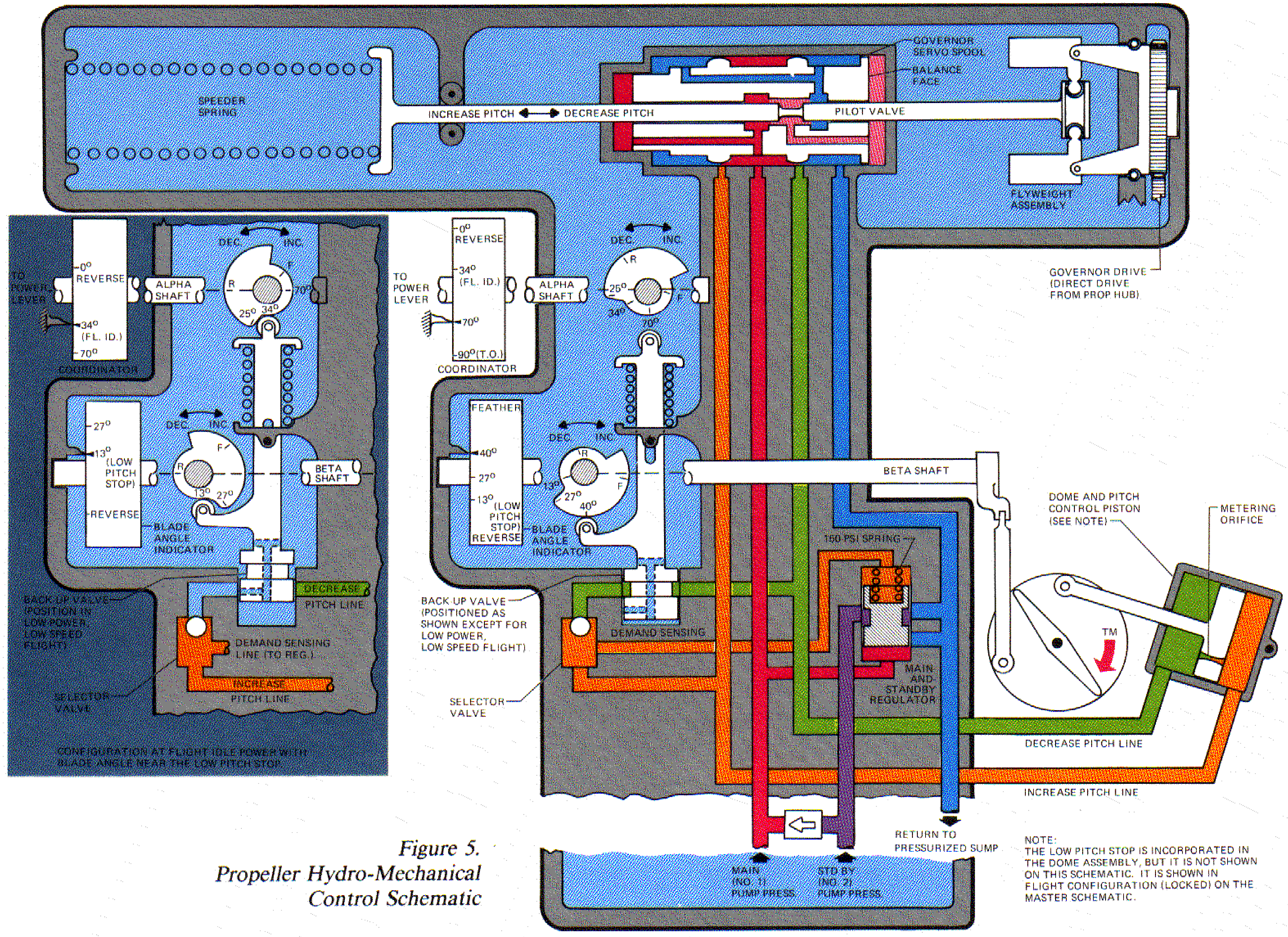
There is no fixed operating pressure in the hydraulic power system of the propeller. The system has a demand-type regulator — the main and standby regulator valve — that maintains pressure in the pump manifold 150 psi higher than the pressure required for pitch control. There is a high pressure relief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

VALVE HOUSING ASSEMBLY The valve housing is the upper part of the propeller control unit (see Figure 4). It contains the propeller's "brains," those components that sense the pilot's command and the propeller's condition and then convert any disparity between the two into hydraulic actuation to restore the balance.

The pilot's command is delivered mechanically via the power lever control, which positions the Alpha shaft. The propeller's condition is sensed (1) as rotational speed by the propeller governor flyweight assembly, which has a fixed-ratio gear drive from the propeller 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-pitch line or the decrease-pitch line by the governor servo valve assembly, but the effectiveness of the controlling power (rate and pressure) is determined by the main-and-standby regulating valve.

FLIGHT OPERATION - SELF-GOVERNING To describe the interaction of the propeller's various components during normal flight operation, we will follow the train of events that occur from the initial



NOTE:
THE LOW PITCH STOP IS INCORPORATED IN THE DOME ASSEMBLY, BUT IT IS NOT SHOWN ON THIS SCHEMATIC. IT IS SHOWN IN FLIGHT CONFIGURATION (LOCKED) ON THE MASTER SCHEMATIC.

Figure 5.
Propeller Hydro-Mechanical Control Schematic

cause to final effect. Figure 5 is arranged to illustrate the function of the various basic propeller components, but no effort has been made 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 operation is stabilized on-speed. The on-speed condition exists when the hydraulic pressure acting on the increase-pitch face of the pitch control piston is exactly countered by the TM that is tending to decrease the pitch. For simplicity, we will refer to this as "demand" pressure. If this demand pressure is some known value, the pressures at the other key points are predictable.

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

The pump pressure, in turn, is used as a reference by the servo spool (pitch change) valve in the governor valve assembly; one face of the pitch change valve is always under pump pressure, the other (and larger) face is under "balance" pressure. For simplicity, we will assume the larger end of the valve to be precisely twice the area of the smaller. Therefore, for a demand pressure of 300 psi, the pump pressure is 450 psi and the balance pressure will be 225 psi (450 x 0.5) in the stable on-speed conditions of our example. The sole function of the pilot valve is to control this balance pressure. Speed variations alter the balance, and as the pilot valve seeks always to reestablish the balance, pitch control pressure is altered as necessary to eliminate the speed error.

Assume, 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 in Figure 5:

1. The flyweight 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 the balance pressure to drop below 225 psi, so the opposing 450 psi pump pressure shifts the pitch change valve towards the right.

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 pressure (previously 300 psi) is less, so pump pressure (450 psi) shifts the regulating piston against the diminishing force of its demand reference pressure. This causes the regulating valve to bypass more pump output to the pressurized sump so that pump pressure falls below its previous value of 450 psi.

    b. TM drives the propeller blades toward decrease-pitch, moving the pitch control piston against the relaxed force of increase-pitch pressure. The decreasing pitch begins to relieve the overburdened engine, and engine speed begins to increase. Note that if the underspeed is sudden and severe, the pitch change valve 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 or when the power lever is above 30 degrees to prevent inadvertant retraction of the low-pitch stop assembly, for at these points the cam-operated backup valve closes and reference pressure from the decrease-pitch lines to the main-and-standby regulating valve is blocked. In effect, the main-and-standby regulating valve senses that demand has dropped to zero, and at zero demand the regulating valve spring force alone will create only 150 psi pump pressure. Therefore, with the power lever at Flight Idle, even though the pitch change valve shifts to its extreme decrease-pitch position, the pitch change valve cannot port more than 150 psi to the decrease-pitch lines while blade angles are in the low flight-operating range because the regulating valve is insensitive to the demand. Also, the pumping system cannot produce more than 150 psi (which is less than the pressure required to retract the low pitch stop assembly), unless a hydraulic pressure "demand" signal augments the regulating valve spring force.

4. When the engine returns to normal speed, the pilot valve returns to its on-speed position. After the propeller governor pilot valve position stabilizes, the pitch change valve remains shifted slightly to the right of its previous position, creating a new set of pressure values throughout the propeller control system. These new pressure values are keyed to the lower increase-pitch pressure demand 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 change by the same value that demand pressure changes. Demand pressure is now 50 psi; therefore, power system pressure is now 200 psi (150 plus 50).

2. The power system pressure of 200 psi, acting on the smaller face of the pitch change valve, is countered by a balance pressure acting on the larger face of the pitch change valve that is exactly one-half the power system pressure (200 x 0.5 = 100).

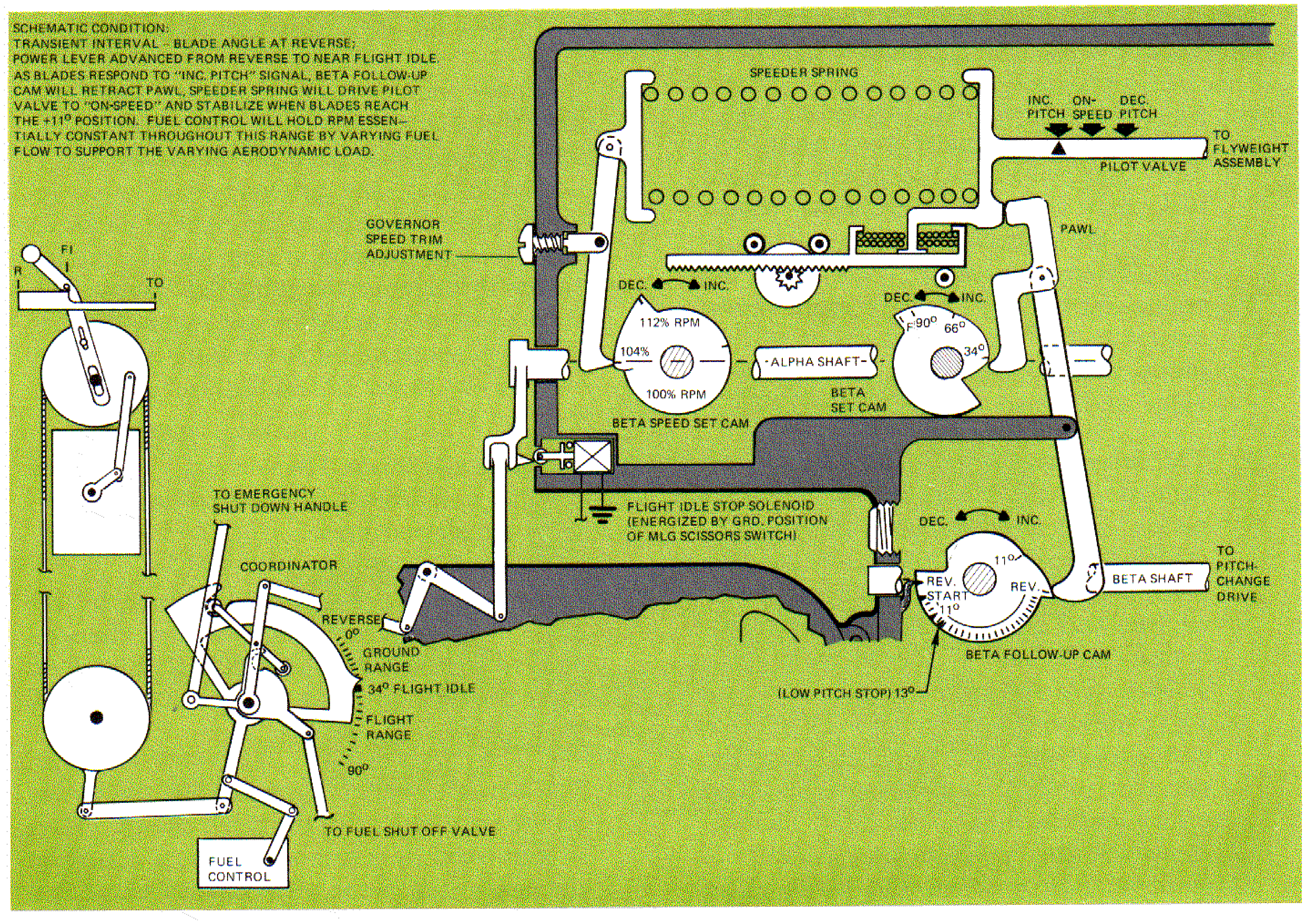
In summation, it can be said that when the propeller control is in its speed-governing (flight operating) range, it governs power plant speed by providing the exact increase-pitch hydraulic pressure needed to counter the propeller's TM. In the foregoing example, the TM/increase-pitch balance was destroyed by a reduction in engine power. However, if aircraft speed is reduced by adding drag with the flaps or by inducing a climb, engine 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. 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 propeller control has a device (which will be described later) to sense that an off-speed condition is imminent and to initiate the proper corrective action before the off-speed condition occurs.

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 in case of extraordinary high overspeed.

The highly simplified schematic in Figure 6 shows the general "plan" of mechanical pilot



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 +11° POSITION. FUEL CONTROL WILL HOLD RPM ESSENTIALLY CONSTANT THROUGHOUT THIS RANGE BY VARYING FUEL FLOW TO SUPPORT THE VARYING AERODYNAMIC LOAD.

Figure 6. Hydro-Mechanical Blade Angle Control During Ground Operation

valve control. 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 another 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).

When the power lever is advanced as shown in Figure 6 to near flight idle, the Beta set cam action positions a pawl against the pilot valve "bridle" to compress the speeder spring, thus inducing a spurious "overspeed" motion of the pilot valve. That is, the pilot valve is displaced from on-speed toward the increase-pitch position. Just as in flight operation, this upsets the hydraulic pressure balance across the pitch change valve, hydraulic force moves the pitch change valve spool to follow the pilot valve, and pressure builds up in the increase-pitch lines.

As the propeller 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. Thus, eventually a stable condition will be reached in which the higher set blade angle has induced higher TM, and the higher TM will be countered by a pressure increase in the propeller pumping system.

For quieter, more economical operation on the ground, the operator can select LOW (72.4 percent) engine speed during ground operation. This is done electrically, by readjusting the fuel governor speeder spring, and since the propeller has no speed sensing capability 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 the ground operating range, Alpha shaft cam action releases the propeller governor speeder spring from entrapment, and the freed pilot valve can respond to off-speed rpm. It will seldom permit rpm to deviate more than about plus or minus 2 percent (between 98 and 102 percent)[3] while the power lever is in the flight range. For this reason, during flight range operation the propeller governor serves as the "prime" rpm control for the entire power plant.

BETA FOLLOW-UP

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

---

[3] The Speed Trim adjustment of the propeller governor allows governing control speed to be preset to within 0.20 percent of NORMAL rpm, and the hydro-mechanical governor will hold rpm almost exactly at the preset speed except for brief excursions when abrupt power and airspeed transients occur. A strobe light or comparable accurate laboratory equipment will usually be required to determine the remaining small off-speed increment, or to detect the brief excursions that normally occur.

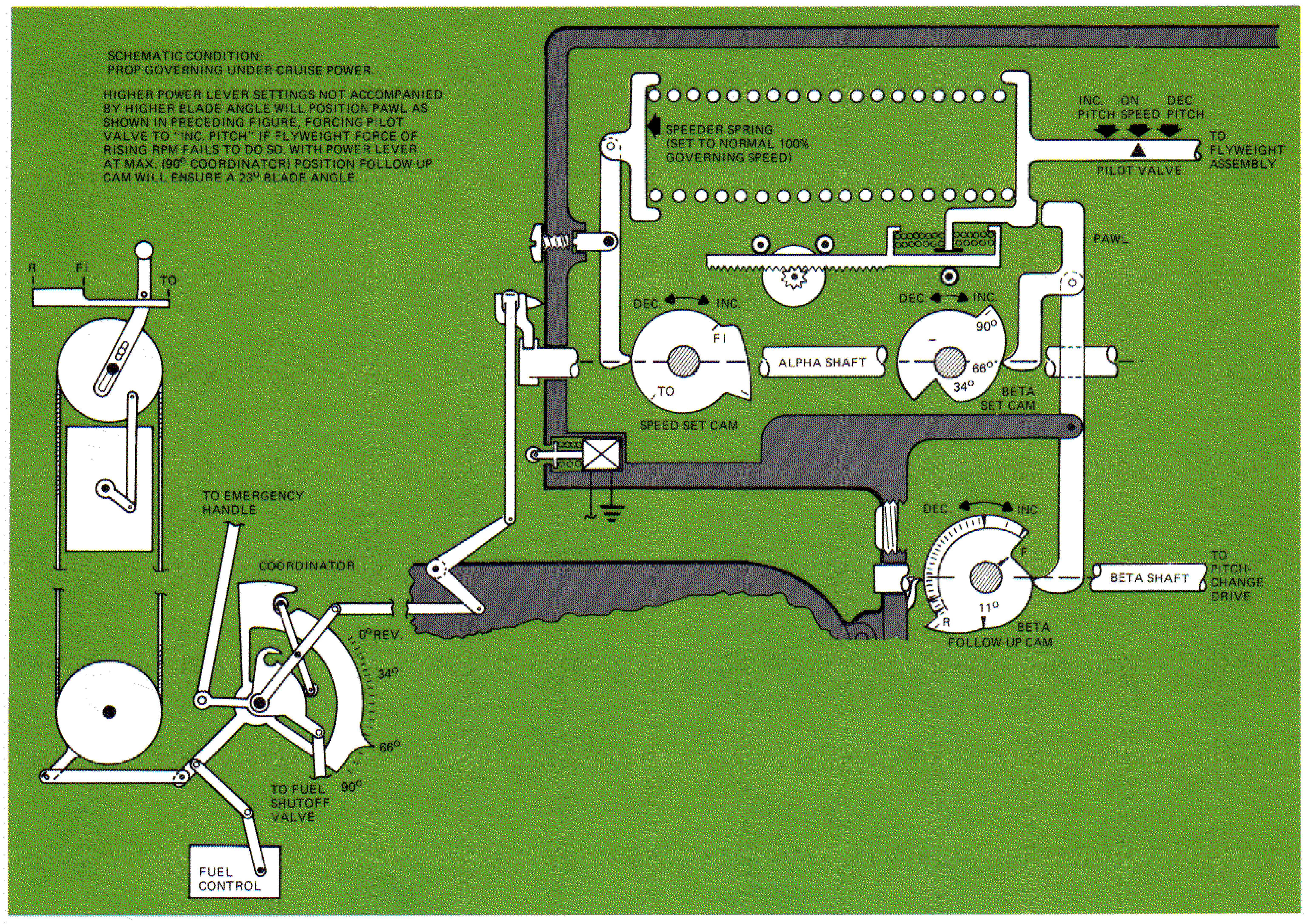


Figure 7. Blade Angle Control In Flight Operation Configuration at Threshold of Beta Follow-up Actuation

As can be seen in Figure 7, when the power lever is advanced through the flight-idle gate, the speeder spring tension is set to command 100 percent rpm. When sufficient power has been applied to produce 100 percent rpm at plus 11 degrees blade angle, flyweight force will move the governor pilot valve away from the leverage control pawl to its on-speed position, and the free floating pilot 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 propeller pitch control. However, at any time during high power operation in the 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 the increase-pitch position.

The Beta follow-up system is designed so that it will not interfere with ground checks of power plant flight range operation. It permits a limited amount of blade angle variation before the Beta follow-up control linkage nudges the governor pilot valve toward the increase-pitch position. This accomodation makes allowance for the effects that air speed, air density, and/or reasonable engine inefficiencies have in determining blade pitch. For example, a specific power lever setting applied to an engine of minimum efficiency while the aircraft is parked in a tail wind at sea level will require a much lower blade angle than that which results when the same power lever setting is applied to a highly efficient engine in high-altitude, high-speed flight. The Beta follow-up system is designed to tolerate the lowest blade angle that might reasonably result in the former instance.

If the blade 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. By mechanically dumping the full capacity of the hydraulic pumping system

in the increase-pitch lines before the governor actually has any off-speed tendency to rectify, the Beta follow-up system enables the propeller 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 takeoff power setting, this system becomes effective at about 23-degrees blade angle — 10 degrees before the mechanical low-pitch stop.

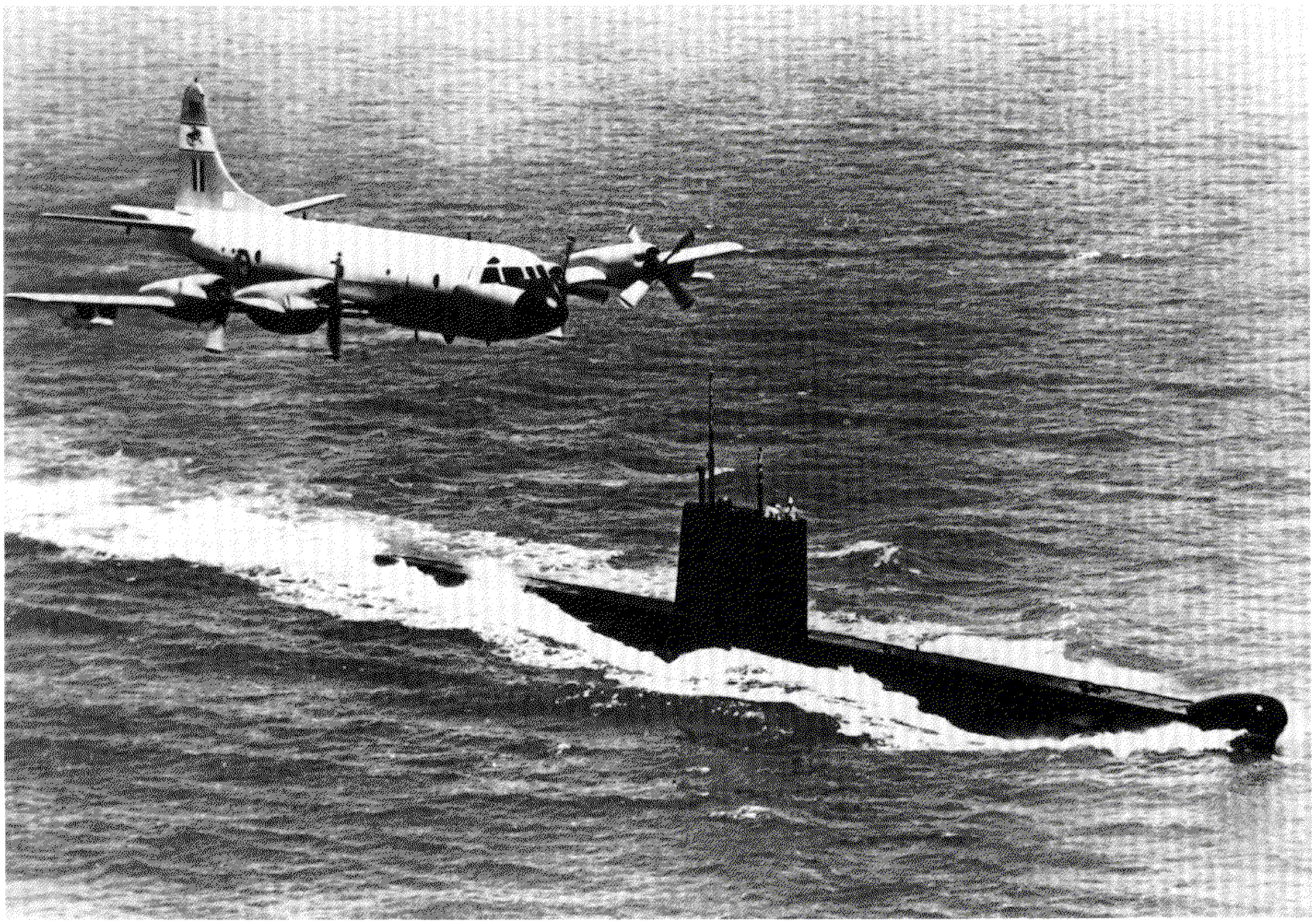
In its function as a stop, the Beta follow-up system's control of blade angle is not purely mechanical (as the low-pitch stop is), for it is dependent on a functional hydraulic power and control system. Its special purpose is to stop the controlled deterioration of pitch caused by a relatively gradual 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. 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 23 degrees) just as they are throughout the ground range, without running the engine.

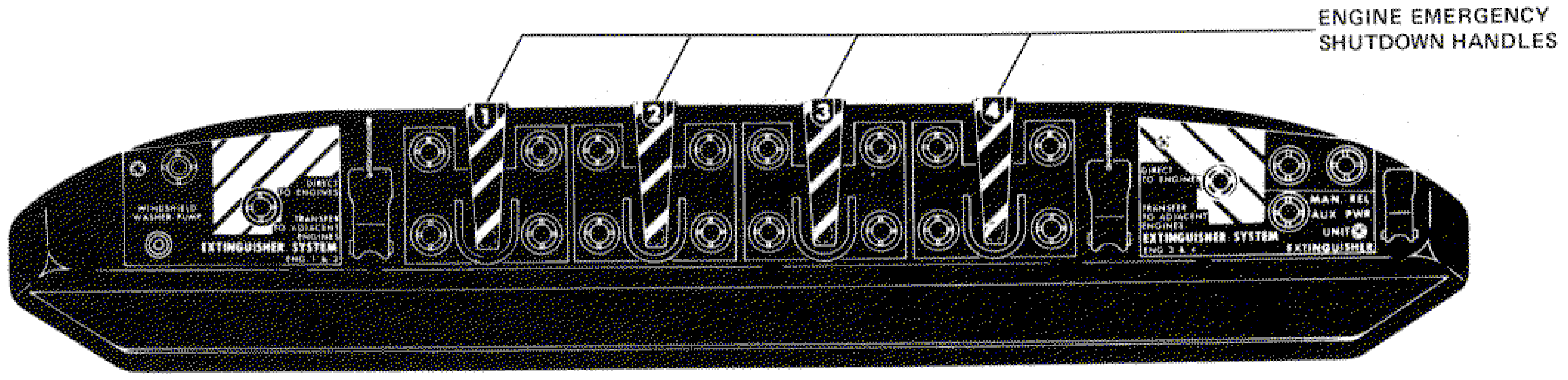
If there is a fast power loss in flight, it is more likely that the propeller will begin to windmill, and the negative torque mechanism will limit pitch deterioration by sporadically activating the feather system.

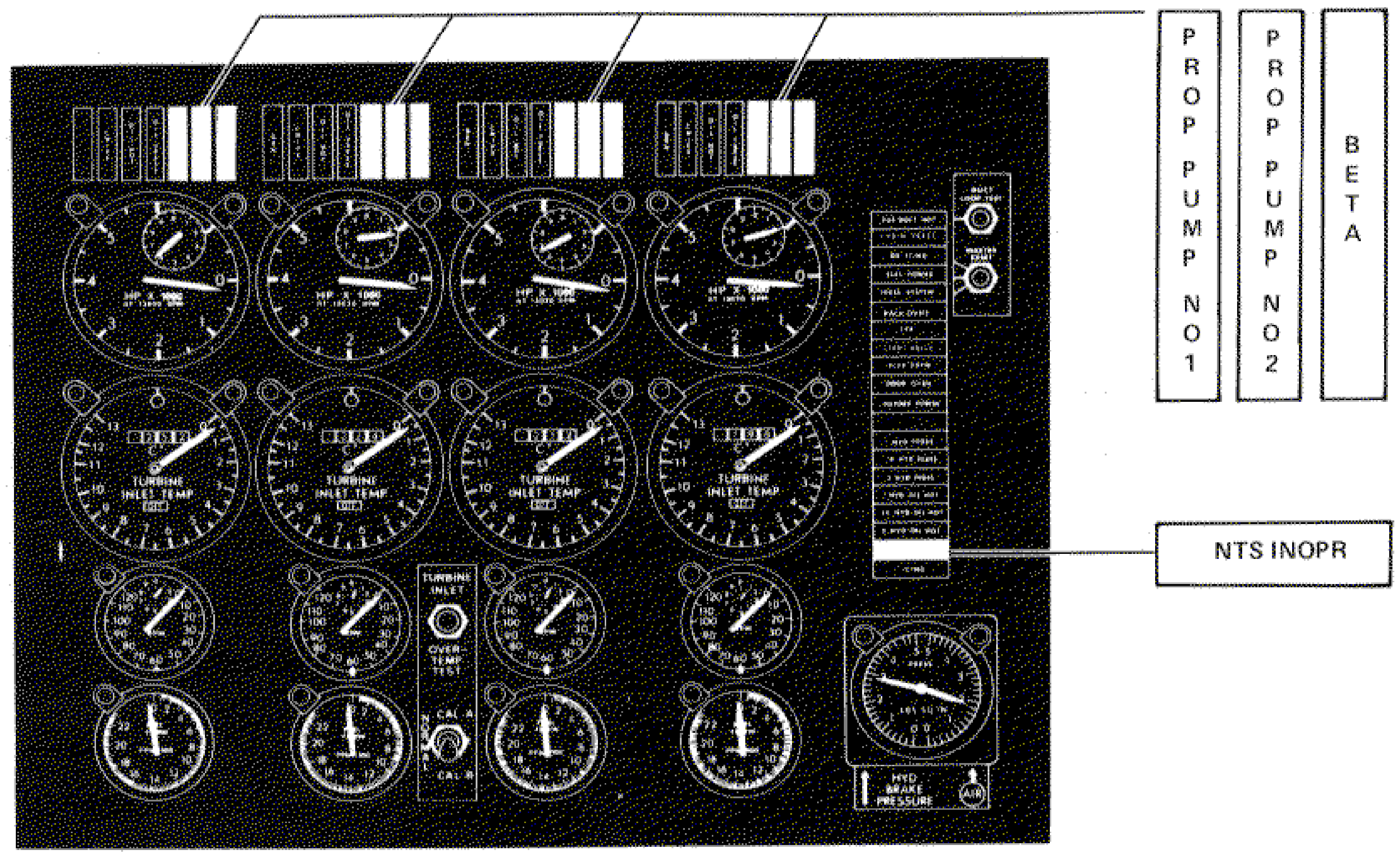
TRANSITION FROM FLIGHT TO GROUND OPERATION

In the ground range of operation, the propeller's braking capability is as important as its capability to produce positive thrust, and after touchdown the drag potential of the propeller becomes a most valuable asset. This form of braking is particularly well suited for the landing roll-out because its

Photo Courtesy Royal Australian Air Force







effectiveness is directly proportional to speed, and the pilot who lands a little hot — either through necessity or inadvertantly — has the benefit of more effective propeller braking.

After touchdown, it is necessary to disarm the NTS system (which functions to limit wind-milling 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 reversing propeller pitch were to cause the NTS system to operate the feather valve, it would override the power lever demand for decrease pitch toward the reverse range and propeller braking would be badly impaired.

The NTS system is disarmed by a cam on the Alpha shaft, which mechanically extracts a vital link from the NTS system actuating linkage when the power lever is retarded past the flight-idle stop into the ground operating range. Simultaneously, rotation of the two mechanical control cams on the Alpha shaft — the speed set and Beta set cams — increases the speeder spring tension and retracts the ground operation and Beta follow-up control linkage so that the pilot valve is forced to an extreme underspeed position. This causes the full power of the pumping system to be ported into the decrease-pitch lines, driving the propeller blade angle 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 the 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 the ground operating range, a cam on the Alpha (demand sensing) shaft will reopen the backup valve as the Figure 5 inset shows, permitting the main-and-standby 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 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 ground operation and Beta follow-up control linkage pawl will have advanced sufficiently to retrieve the governor pilot valve from the induced underspeed (decrease pitch) excursion. The pilot valve will then be exactly at its on-speed position.

The pilot should have a sure indication that the propeller blade angle has transitioned successfully from one operating range to the other. This is furnished by a Beta shaft cam-operated switch that illuminates the BETA advisory light on the pilot's center instrument panel (see Figure 8) when the propeller is in the ground operating range, below 10 degrees blade angle.

The switch that illuminates the BETA light when the propeller transits from flight to ground oper-

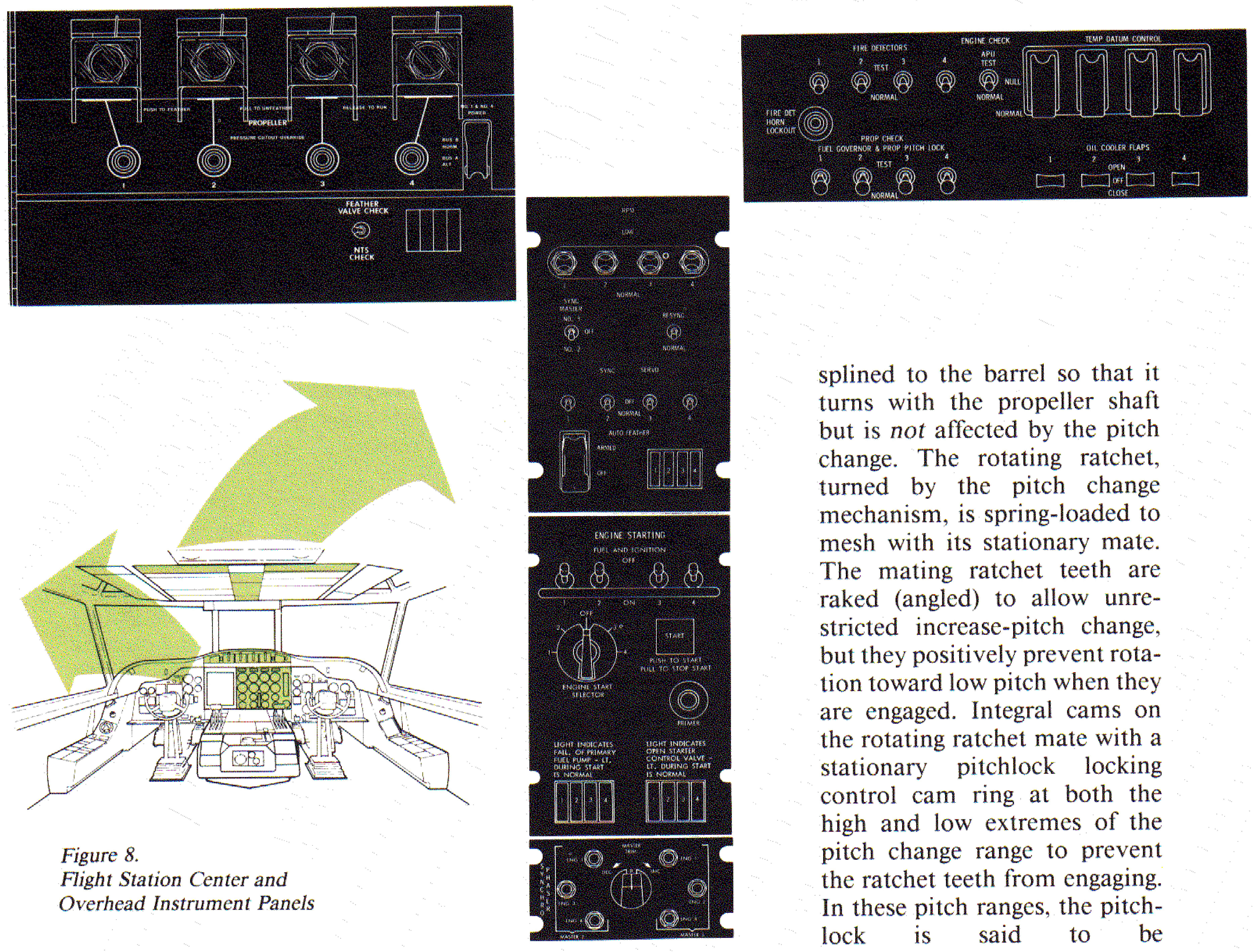


Figure 8.
Flight Station Center and Overhead Instrument Panels

ating range is also instrumental in the automatic pitchlock safety mechanism. However, before discussing the pitchlock in connection with this transient phase of operation, we will describe its principal operating function.

THE PITCHLOCK

GENERAL The pitchlock provides the surest type of automatic, mechanical protection against the hazard of an uncontrollable, runaway propeller. Its fundamental components are two sets of ratchet teeth. One ratchet, called the rotating ratchet, is splined to the dome rotating cam that drives (or is driven by) the blades during pitch change. The other ratchet, called the stationary ratchet, is splined to the barrel so that it turns with the propeller shaft but is *not* affected by the pitch change. The rotating ratchet, turned by the pitch change mechanism, is spring-loaded to mesh with its stationary mate. The mating ratchet teeth are raked (angled) to allow unrestricted increase-pitch change, but they positively prevent rotation toward low pitch when they are engaged. Integral cams on the rotating ratchet mate with a stationary pitchlock locking control cam ring at both the high and low extremes of the pitch change range to prevent the ratchet teeth from engaging. In these pitch ranges, the pitchlock is said to be "cammed-out." Pitch control hydraulic power enroute to the dome is fed into an annular pitchlock control actuator that provides the force necessary to prevent pitchlock engagement in the median range, the range normal to flight operation.

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

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

It is important to understand the simple schematic of the pitchlock shown in Figure 9 to understand its capabilities and reactions.

A small valve, known as the regulating and pressurizing valve, creates a small constant pressure in the flyweight cavity, drawing on either increase-pitch or decrease-pitch pressure for the purpose. The pitchlock actuator piston also receives actuating pressure through the two-position pitchlock servo valve as shown in the Propeller Control Master Schematic. When the flyweights overspeed, the flyweight cavity pressure is dumped against the servo valve to equalize the pressure across the servo valve. As the servo valve shifts by spring force, it blocks the pressure supply line to the pitchlock actuator piston and ports the pressure from the actuator piston to return.

Thereafter, the spring load on the pitchlock ratchet will keep the ratchet engaged until (1) increase-pitch pressure is provided by the governor, and (2) the propeller rpm comes back to normal so flyweight cavity pressure is removed from the servo valve.

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 pitchlock and the propeller would again be self-governing. Actually, this does not occur, for the pitchlock ratchet teeth are raked or undercut so that any force attempting to drive the blades toward decrease-pitch drives the pitchlock into a tighter lock position. Conversely, any momentary overspeed into the pitchlock range will not lock the pitchlock mechanism, provided that the normal governing signal is providing a compensating increase of blade angle at that time.

The reason that the pitchlock is cammed-out in the high pitch-angle range should now be apparent. It would be impossible to unfeather the propeller in flight if the pitchlock was engaged, because decrease-pitch pressure cannot disengage the interlocked ratchet teeth. The logic of the pitchlock 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 pitchlock will occur promptly after normal governing malfunctions, the pitchlock flyweight is set to initiate the pitchlock about 3 percent above normal propeller governing rpm.

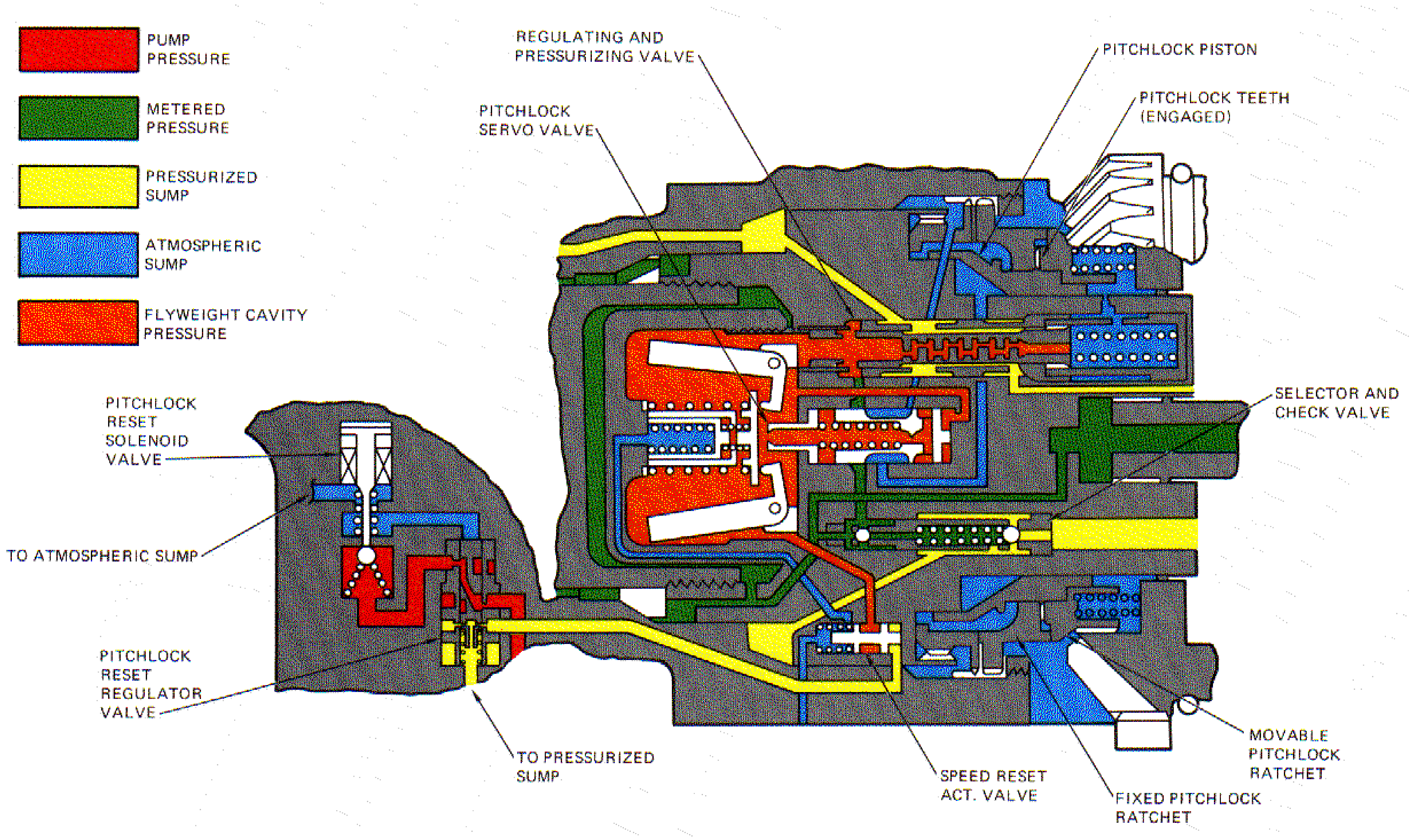


Figure 9. Pitchlock Engaged During Flight Due to Overspeed Without Loss of Hydraulic Power

However, the pitchlock teeth will permit the blade angle to deteriorate a few degrees as they mesh. If an in-flight pitchlock occurs, rpm could be expected to rise further, to the point at which the fuel governor may become effective and reduce engine power to control rpm. This would be determined by the dynamics involved in the pitchlock incident.

The pitchlock is cammed-out in ground operation. These cams become effective at the lower propeller blade angles, disarming the pitchlock mechanism so it cannot engage after the blade angle is reduced to within a few degrees of the low pitch stop. Normally, the propeller reaches this minimum position after touchdown when power and airspeed are both very low. However, if a takeoff is aborted, the propeller pitch will 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 pitchlock. If the pitchlock 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 that maximum propeller braking is needed most.

To prevent this undesirable situation from developing, the pitchlock governor is reset at 109 percent rpm during the transition period, so that it is more tolerant of overspeed. Since the pitchlock protects against a variety of propeller control malfunctions, pilots should have a thorough grasp of its operating details and understand both the direct effects that a pitchlocked propeller will have on power control and the indirect effects it will have on aircraft control.

If a pitchlock 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. If a pitchlock has occurred in flight, the yawing tendency due to asymmetric power will be evident, and certainly so when the power levers are brought back to the low flight power or ground operating positions. The abnormally high power and the failure of a Beta light to illuminate will further identify the pitchlocked propeller.

PITCHLOCK RESET As shown in Figure 10, a pitchlock reset regulator valve receives pressure direct-

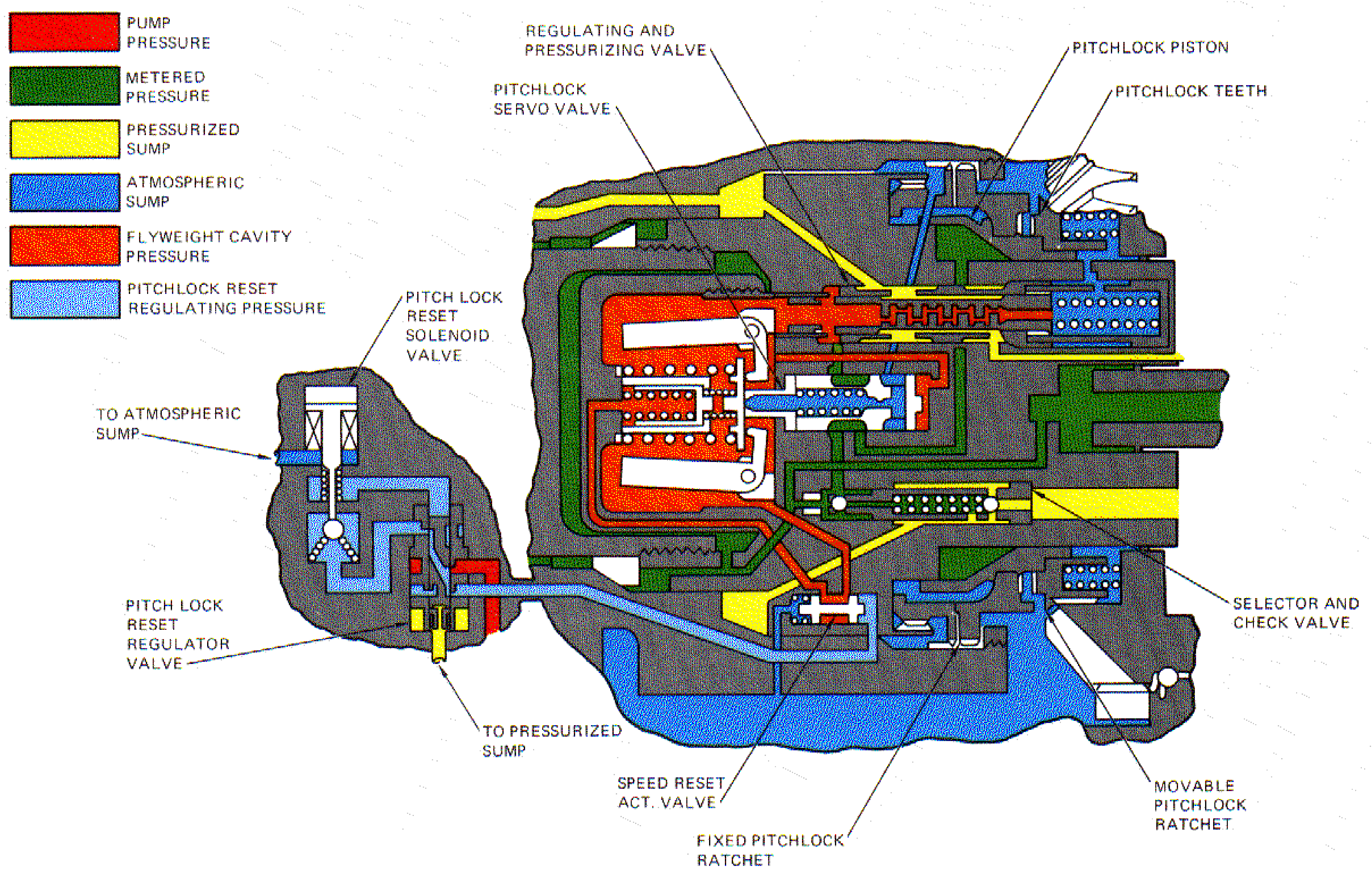


Figure 10. Pitchlock Reset Control Configuration

ly from the hydraulic power manifold, and operation of this regulator valve is controlled by the pitchlock reset solenoid valve. The pitchlock reset solenoid is controlled through three switches in series. Two of these switches are operated by the power lever system, and they close simultaneously when the lever is retarded below flight idle.[4] 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. When actuated, it simultaneously opens the pitchlock reset circuit and closes the BETA advisory light circuit.

The pitchlock reset solenoid valve is energized open when the power lever is in the ground operating (fuel governing) range and the blade angle is greater than 10 degrees. When the pitchlock reset solenoid valve is energized open, it ports hydraulic pressure back to the pitchlock reset regulator valve, which actuates this valve. When actuated, the pitchlock reset regulator valve directs regulated hydraulic pressure through a passage in the propeller transfer bearing to the two-position speed reset actuating valve in the pitchlock regulator assembly. This shifts the plunger of the speed reset actuating valve to direct regulated pressure from the pitchlock regulator's flyweight chamber to the reverse side of the regulator's speed bias plunger and equalize the pressure across the plunger. When the pressure across the speed bias plunger is balanced, the force of a small supplementary spring applied to the speed bias plunger is added to the force of the pitchlock regulator's normal speeder spring. This added spring force resets the pitchlock governor to a higher propeller speed. The pitchlock will tolerate an overspeed of about 9 percent before the flyweight chamber pressure is removed from the speed bias plunger.

Lockheed
ORION
Service
Digest

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 system operation is cyclic while feathering is sustained until the propeller blades are streamlined.

As mentioned previously, the reduction gear assembly reacts to a reversal of power flow by positioning a simple mechanical linkage that bridges the gap between the reduction gear assembly and the propeller control. This reactive signal is produced, as shown in the Master Schematic, by movement of a splined coupling between the gear case and the large ring gear that serves as a race for three planetary gears which drive the propeller shaft. The ring gear is mated to the gear case with helical splines so that the ring gear is permitted a short "spiraling" travel fore and aft. The ring gear is spring-loaded aft, and normal "positive" power flow from the drive shaft-to-propeller shaft supplies a torque to the ring gear that also forces it to its aft extreme.

When the power flow is reversed (propeller shaft-to-drive shaft), the torque is applied to the opposite face of the ring gear teeth by the planetary gears. At about 325 hp negative,[5] the ring gear spirals forward against its spring load, driving a plunger forward to position the NTS actuator rod through an opening in the front gear case wall. This mechanical signal is carried through an adjustable leverage system into the propeller control unit as a probing motion of the control unit's NTS

---

[4] This two-switch arrangement provides a safety factor. If only one switch was provided, a single misadjustment or switch malfunction could result in the pitchlock operating "reset" constantly. If the pitchlock is not triggered in high-speed flight before rpm reaches 109 percent, the blade angle (already far below normal) would be so far reduced before the pitchlock ratchets engage that a truly serious overspeed condition could occur.

[5] 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 100 hp to minus 500 hp. Note that the hp indicator only reflects torque transmitted through the engine drive shaft, and it is accurate only at 100 percent 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. This produces the wider apparent range at the hp indicators when the system is tested in flight.

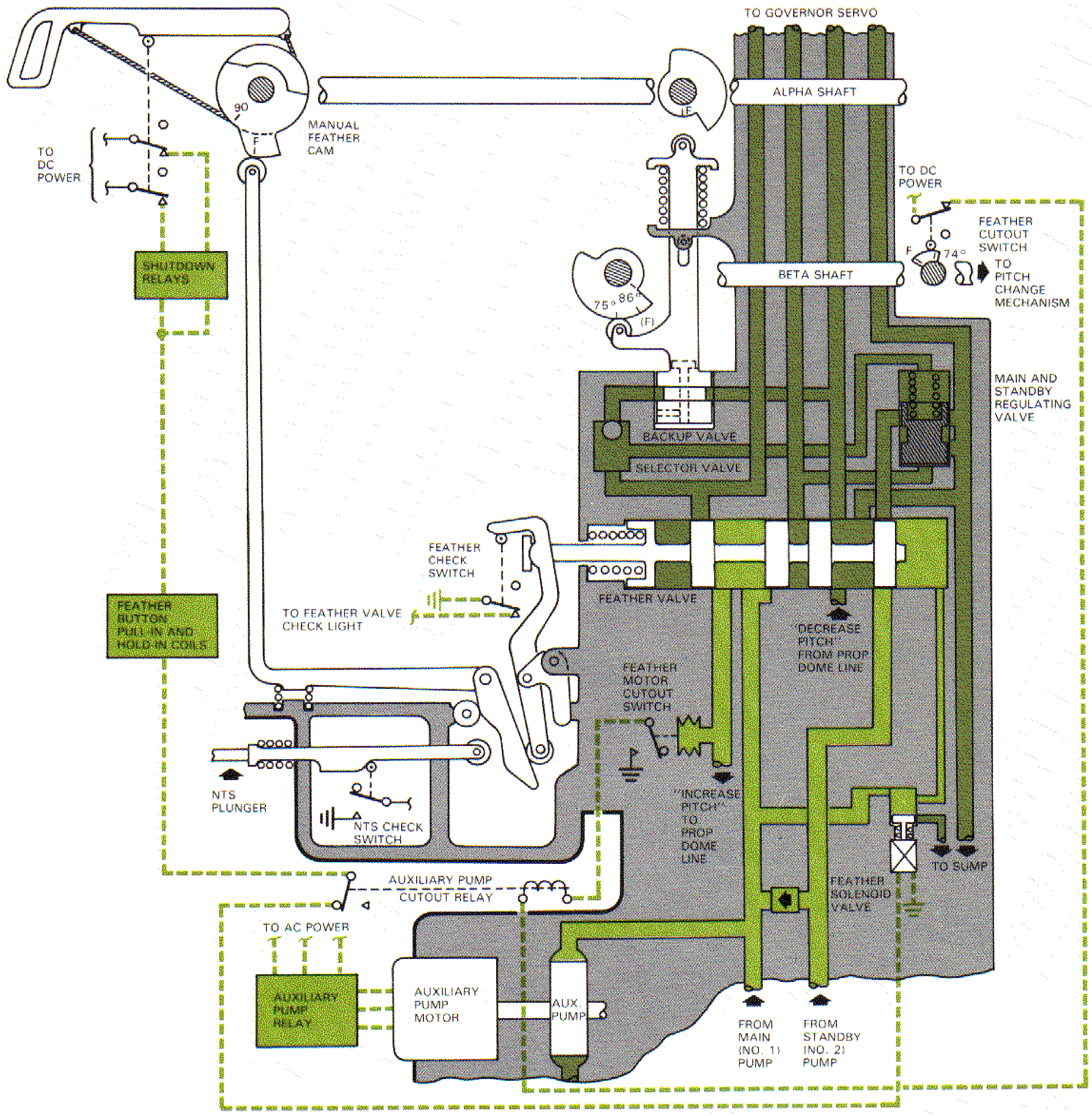


Figure 11.
Feathering Operation Initiated by Pulling the Engine Emergency Shutdown Handle. Colored phantom circuitry indicates electrical response.

plunger. This probing motion causes the NTS plunger to strike a stepped pawl, which mechanically forces the feather valve spool from the normal to the feather position (see the Master Schematic). The probing motion of the NTS plunger also cams the NTS check switch closed. This energizes the NTS signal holding relay when the feather valve check/NTS check switch next to the advisory lights is in the NTS CHECK position, and illuminates the propeller's individual NTS advisory light on the pilot's overhead control panel. If this switch in the flight station is selected to the FEATHER VALVE CHECK position, actuation of the feather valve to "feather" will actuate the feather valve check switch in the propeller control unit and illuminate the NTS advisory light on the pilot's overhead control panel each time that negative torque is sensed.

The NTS plunger will contact the stepped pawl and cause it 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 the manual feather cam when the Alpha shaft is turned into flight range. However, as mentioned in the Touchdown-Transition discussion, this pawl is withdrawn beyond the reach of the NTS plunger when the Alpha shaft is turned into the ground operating range.

As shown in Figures 2 and 11, another lobe of 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 plunger. This is effected at the extreme position of the Alpha shaft, beyond the range of power lever control, and is obtained only by operation of the emergency en-


NAVY
NAVY

gine shutdown lever. This arrangement provides the Orion with a positive, hydro-mechanical manual feathering cycle that is not dependent on power, except for the propeller's self-generated hydraulic power system.[6]

The feather valve controls the line between the pump pressure manifold and the governor servo valve and also the pitch control lines between the governor servo valve and the propeller 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 propeller 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 bypass through the pressure regulator, the full, unregulated power of the pumping system works to produce a high-rate pitch change towards feather. The high pressure relief valve, which is tapped off the valve housing manifold, will prevent excessive pressure buildup.

Mechanical actuation of the feather valve to the feather position closes the feather check limit switch on the valve housing, which is connected to the NTS advisory light circuit (see Figure 12). The two-position feather valve check/NTS check switch, located next to the indicator lights on the

---

[6] As indicated on Figure 11, pulling the emergency shutdown handle also initiates the hydro-electric feather cycle discussed in the next section.

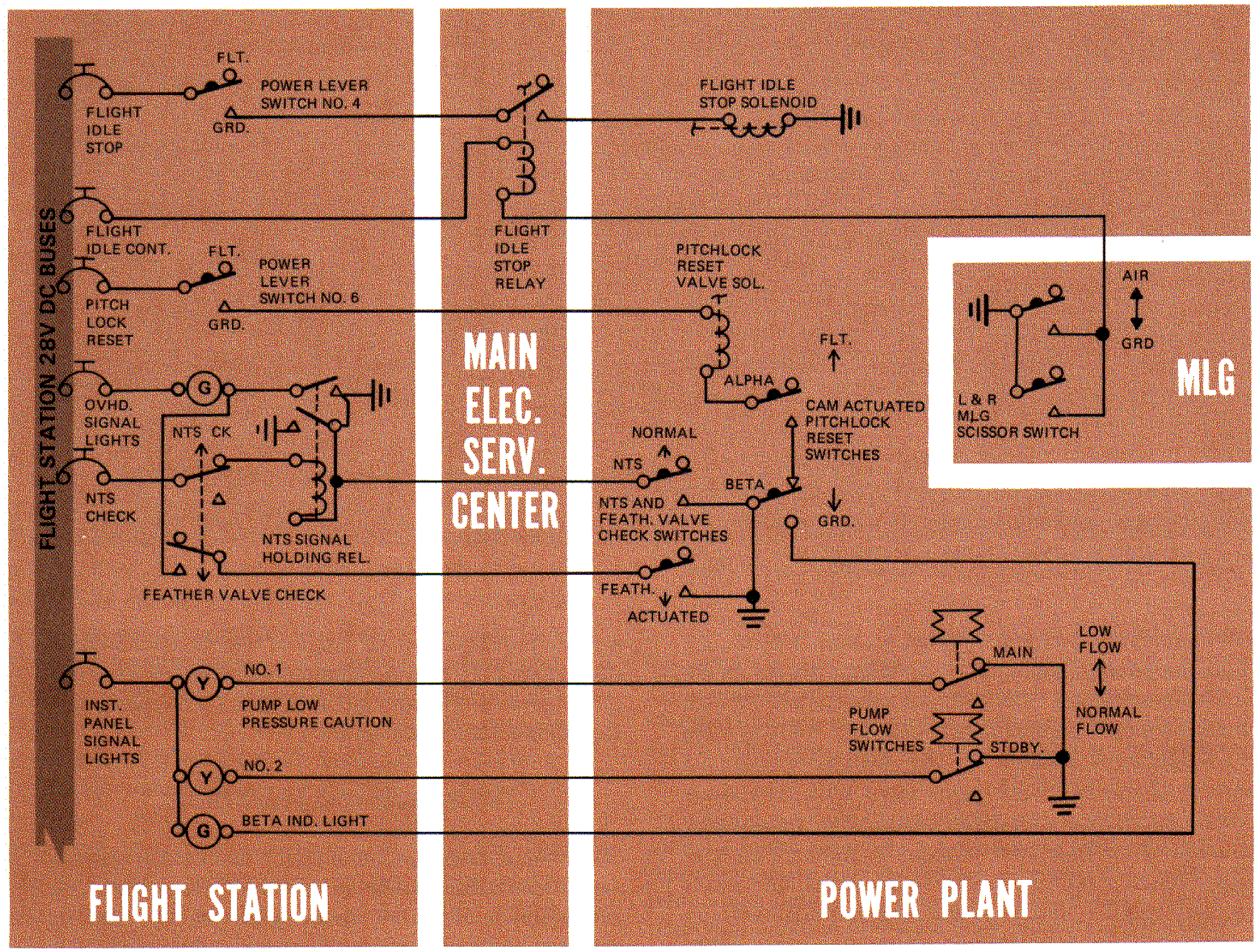


Figure 12. Miscellaneous Monitoring and Control Circuitry.

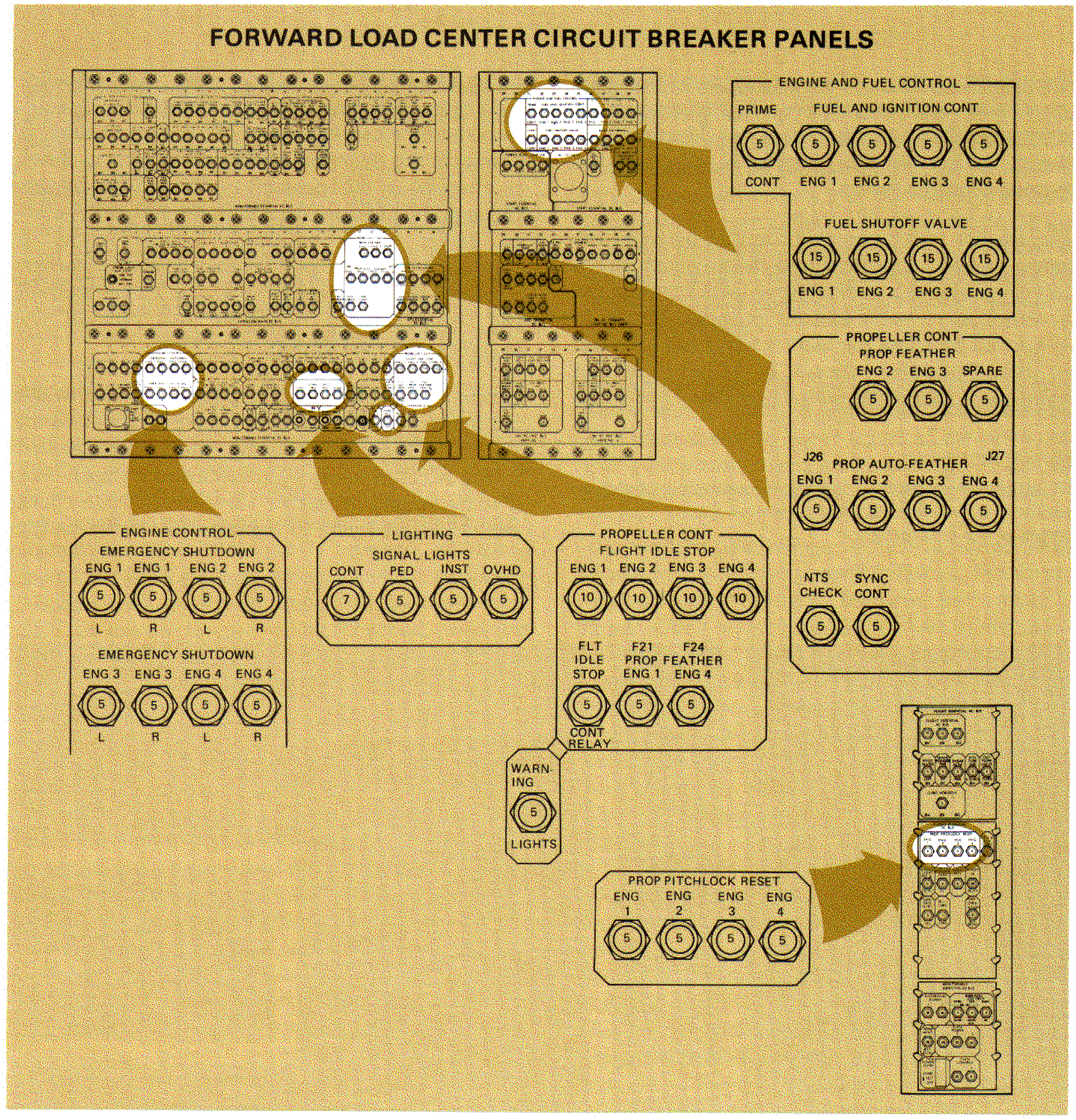
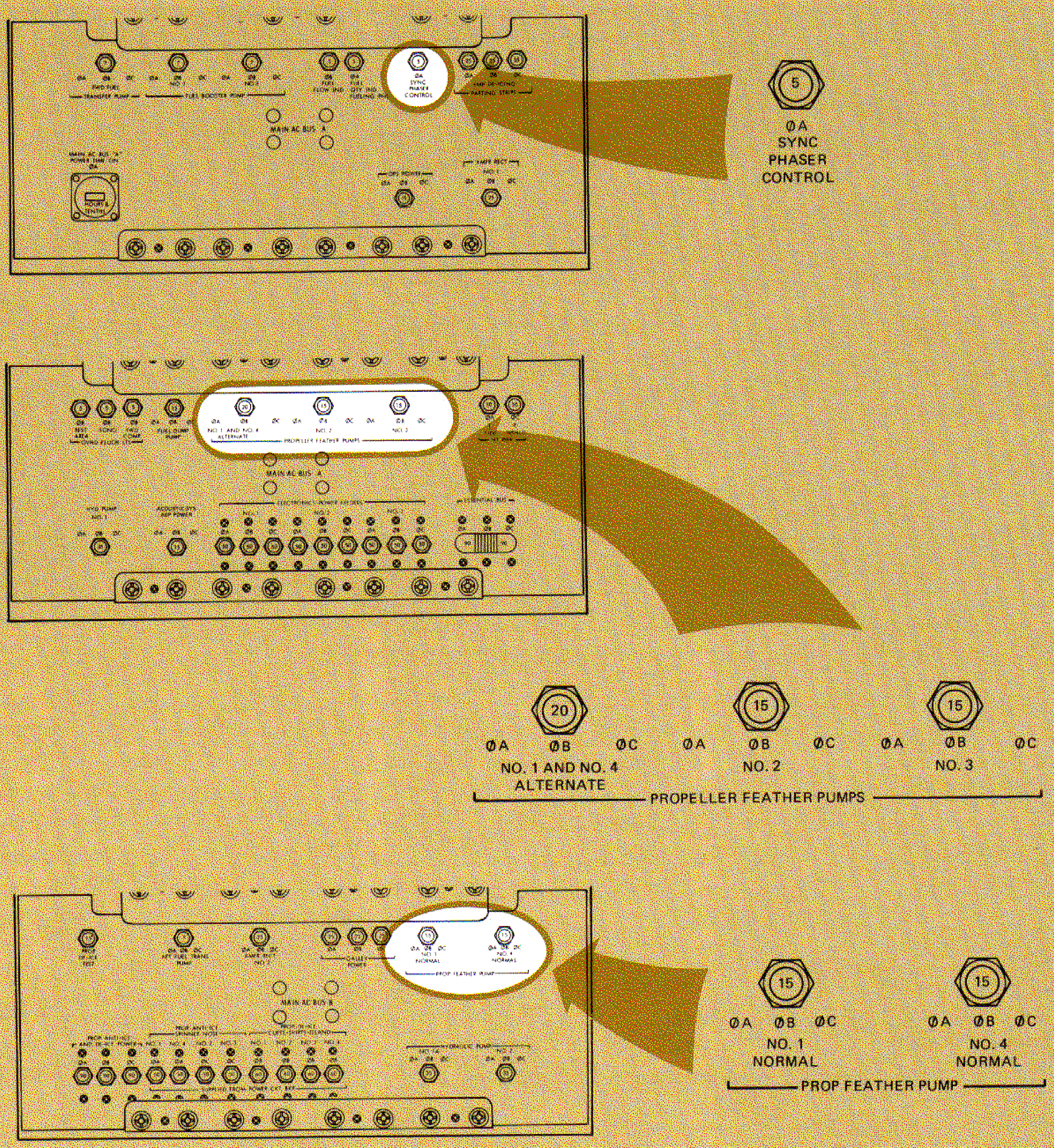


Figure 13. Forward and Main Electrical Load Center Panels

pilot's overhead control panel, is also part of the NTS advisory lights circuit. When in its NTS CHECK position, this second switch directs the check circuit through a self-holding relay to the *NTS-operated* switch in the propeller control unit, and the NTS advisory light will provide a lasting record of any NTS operation, no matter how brief. When the switch is moved to the FEATHER VALVE CHECK position, the NTS holding relay is deactivated and the light circuit is directed to the feather valve-operated limit switch, and the NTS advisory light will provide a direct indication of feather valve mechanical operation (cyclic illumination during NTS operation, steady illumination after the emergency shutdown handle is pulled).

HYDRO-ELECTRIC FEATHERING

GENERAL The propeller feather motor pump provides hydraulic power for pitch control when the propeller is static or turning so slowly that its mechanically-driven pumps are ineffective. The feather pump motors are powered by the Main



MAIN LOAD CENTER CIRCUIT BREAKER PANELS

AC Buses (see Figure 13). The feather pumps for Propeller Nos. 2 and 3 are powered from Main AC Bus A, while the feather pumps for Propeller Nos. 1 and 4 are powered from Main AC Bus B, except that if necessary, the pilot can transfer Propeller Nos. 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 power plants because their propellers are routinely feathered during loiter operation, and loss of power at Main AC Bus B would otherwise prevent an air start.

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

A single relay is used in each feather pump 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 cannot discuss all the features of these circuits, but the following

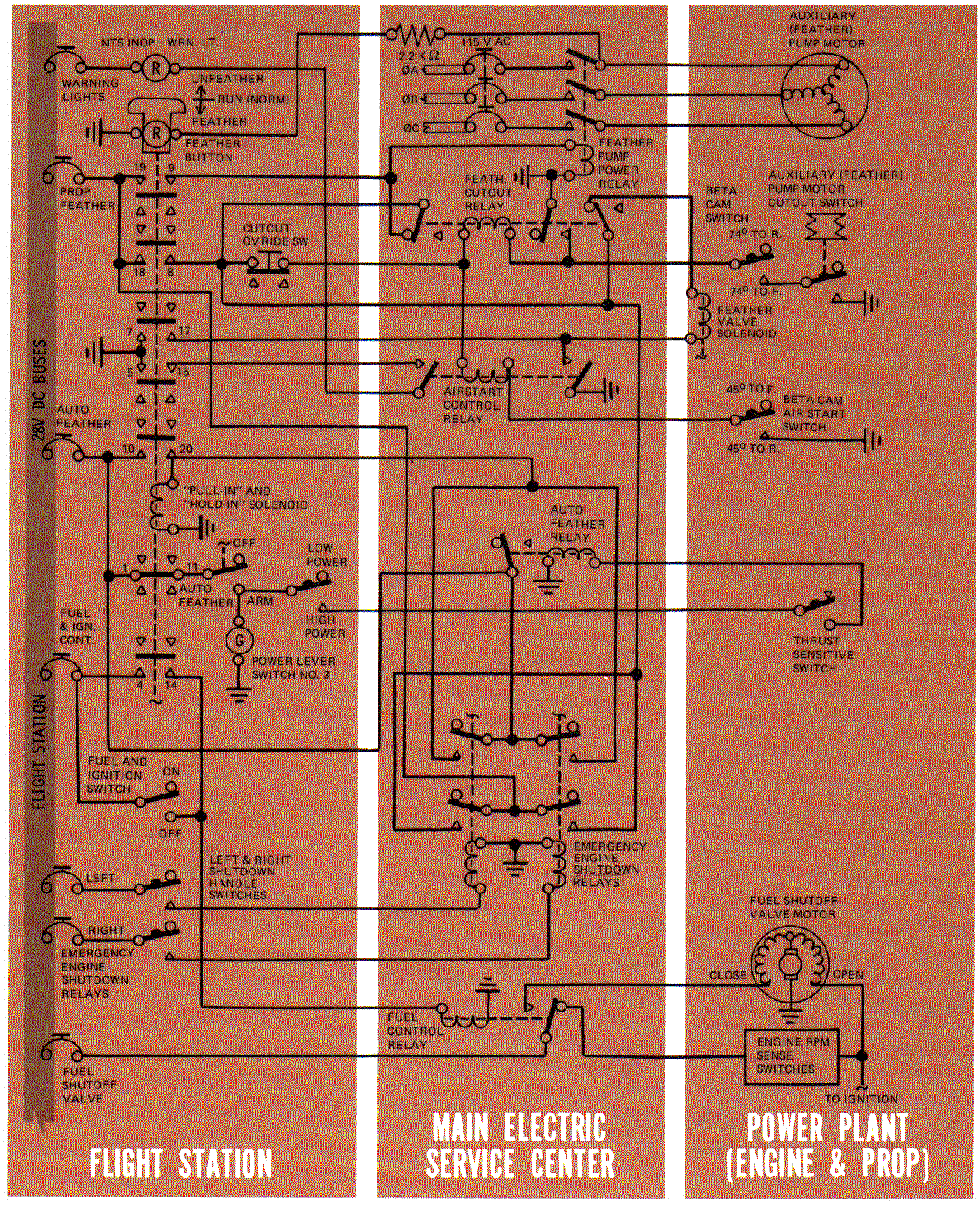


Figure 14. Feather, Autofeather, and Engine Shutdown Circuitry

paragraphs describe the fundamental logic of the circuit as shown in the Figure 14 schematic.

FEATHERING The feathering cycle is initiated for a routine (loiter) engine shutdown by pushing the feathering button. Note that the feather switch has a solenoid that becomes energized (through feather switch contacts 10 and 20) when the feather button is pushed, and the switch is magnetically (and also mechanically) latched in the feather position until the feather button is manually pulled back to NORMAL or beyond to UNFEATHER. Switch contacts 18 and 8 transfer dc power to the feather pump power relay, then the relay closes, energizing the feather pump motor and illuminating a red light in the feather button. Another branch of the circuit leading from feather switch contacts 18 and 8 energizes the feather solenoid; the solenoid circuit finds a certain ground through feather switch contacts 17 and 7, and possibly a ground through the contacts of the air start control relay (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 the feather position, and feathering proceeds exactly as described previously in the Manual Feathering discussion.[7]

One additional factor to consider during the electro-hydraulic feathering operation is that the feather pump motor is not designed for continuous and prolonged operation. Consequently, a cutout circuit has been provided to deenergize the pump automatically when the feather cycle is complete. This is not a factor during the manual-mechanical feathering cycle because the mechanically-driven pumps stop automatically as propeller shaft rotation stops. As can be seen on Figure 14 schematic, the feather cutout 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), which closes a pressure switch and completes the cutout circuit. Feather cutout relay actuation deenergizes the feather pump power relay, the feather button light, and the feather valve solenoid. Note that the feather cutout relay (see Figure 14) has a self-holding solenoid similar to the feather button switch, and even though the declining hydraulic pressure allows the original cutout circuit to reopen, the cutout 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 if the automatic control actuates 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 breakaway torque. A propeller shaft brake in the reduction gear assembly is applied automatically when lubrication pressure dissipates, but it cannot be too positive, for it would interfere with engine starting. A mechanical latch in the dome assembly engages the pitch change mechanism and retains it in the feather position.

UNFEATHERING Unfeathering is accomplished by pulling the feather button switch and holding it "out." Assuming that the feather button has been latched in its feather position, and that the cutout relay has also been latched-in, the cutout relay will be deenergized when the feather button is pulled from FEATHER to NORMAL. This enables feather pump power relay to be energized through feather switch contacts 19 and 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 respect.

NOTE

Much of the following discussions deals with the very important in-flight functions. The text was carefully authenticated before publication, but it should be regarded only as a source of general information. Refer to the official NAVAIR documents for the approved operating procedures.

FLIGHT STARTING

The integrity of the propeller's hydraulic power and control system is partially demonstrated *before* unfeathering by pressing the pressure cutout override button (thus operating the feather pump) for a few seconds with the feather button in the FEATHER position. The output of the feather pump is routed to the No. 1 (Main) Pump flow switch, and it will provide sufficient flow to actuate this switch (see Figure 12) and extinguish the related caution light on the center instrument

---

[7] Because the feather check switch is operated by the linkage that mechanically actuates the feather valve, it is not actuated during hydro-electric feathering. Therefore, the NTS advisory light in the flight station cannot be used to check the performance of the feather valve if the electrical feather cycle is initiated by pushing the feather button.

panel. A few seconds of pump operation will supply oil under pressure to the high-pitch side of the propeller dome to replenish any voids or air pockets on that side of the dome caused by internal leakage. This ensures that the propeller will have positive hydraulic power for pitch control, and illumination of the caution light indicates that the oil reserve has not been depleted through an external leak during the shutdown period. The feather button should be pulled to UNFEATHER after releasing the pressure cutout override button.

The acceleration of the engine provided by the windmilling 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 decreasing-pitch force as the propeller accelerates, it can be seen that the cranking torque of the propeller would build up at an alarming rate if normal speed governing prevailed during the flight start.

The NTS overrides the governor and provides the necessary restraint during this critical period. 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 operator can monitor this operation by positioning the feather valve check/NTS check switch to FEATHER VALVE CHECK. The cycle is indicated by the flashing NTS check advisory light, and it repeats continously as the propeller accelerates and stabilizes at the maximum speed it can attain through negative-torque cranking. As rpm stabilizes, the NTS check advisory light may cease flashing. 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, at the speed recommended for air starting, the blade angle will be more than 50 degrees when the engine reaches a stablized speed controlled by the NTS system (generally between 35 and 45 percent rpm). The fuel and ignition can be turned on with full assurance that the NTS system will control propeller rpm and blade angle until the propeller reaches normal rpm and governing occurs.

If the NTS does not effectively control the acceleration rate during air start, it is likely that the propeller NTS operation is seriously at fault. If the blade angle drops to 45 degrees while the feather button is in the UNFEATHER position, the air start switch (shown in the Master Schematic) will close and actuate the air start control relay. This will energize the feather solenoid valve and illuminate the red NTS INOPR warning light on the pilot's center instrument panel. (The flashing or blinking NTS INOPR warning light indicates that the NTS system is functioning abnormally and that an inflight start should *not* be attempted.) This operational sequence reverses the unfeather cycle and directs the entire hydraulic resources of the propeller to increase the blade angle above 45 degrees.

With the feather button held in UNFEATHER, the air start switch will again open and interrupt feathering as the blade angle increases past 45 degrees. Therefore, the operator should pull the emergency shutdown handle if the NTS INOPR warning light illuminates, which will cause the positive and permanent displacement of the feather valve to the feather position.[8] Otherwise, even if the feathering capability is perfectly operable, the propeller can only cycle around the 45-degree blade angle position as long as the feather button is held at UNFEATHER.

The propeller can be feathered, unfeathered, and then returned to the ground operating range for ground checkout purposes by pressing the propeller's pressure cutout override button (thus deenergizing the air start control relay) after the blade angle reaches the 45-degree position.

AUTOMATIC FEATHERING As shown on the Master Schematic, once the automatic feathering system is armed, the auto-feather cycle will be triggered by the thrust sensitive signal switch on the forward face of the reduction gear assembly if thrust falls to less than 500 pounds while the power lever is at or near takeoff position. When thrust drops

---

[8] The oil supply to both the engine lubrication system and the reduction gear assembly lubrication system is shut off at the oil tank when the emergency shutdown handle is pulled. If feathering is not completed and the engine and/or the reduction gear assembly are driven by propeller windmilling, it is essential to restore engine lubrication.

this low, Belleville springs inside the reduction gear assembly actually retract the propeller shaft about 0.10 inch, closing the cam-actuated thrust sensitive signal switch. If the power lever is forward of the 75-degree coordinator position on aircraft equipped with the T56-A-10WA engine or 60 degrees on aircraft equipped with the T56-A-14 engine, the power lever No. 3 switch will be closed. This will complete the circuit through the closed thrust sensitive signal switch, which will energize the auto-feather relay and, in turn, the feather button "pull-in and hold-in" solenoid. Thereafter, the feather cycle proceeds as described under the Hydro-Electric Feathering discussion.

Although it is not shown on the Figure 14 or the Master Schematic, there is a complex network of interlocking circuits through other 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, its propeller will auto-feather and disarm the auto-feather system; (2) if thrust sensitive signal switches of more than one engine close simultaneously, the interlock of the auto-feather circuits will establish a priority sequence (4, 1, 3, 2), only one propeller will auto-feather, and the others must be feathered manually just as if the thrust sensitive signals had been triggered sequentially rather than simultaneously.

It is very unlikely that a situation will arise that requires more than one propeller 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 propeller if it were not for the interlock arrangement. The auto-feather sequence gives least priority to the inboard propellers, for they do not present as serious an asymmetric-thrust problem prior to feathering, and if an inboard propeller were to be auto-feathered inadvertently and unnecessarily, one normal source of electrical power would be lost.

The auto-feather system will usually be armed during takeoff and manually disarmed during climbout. If the auto-feather system is not disarmed, any situation that requires a fast power lever advance from flight idle to takeoff (such as a refused landing) may close the power lever No. 3 switch of one or more propellers *before* enough thrust has developed to compress the Belleville springs in the power plant's reduction gear assembly and open the thrust sensitive signal switch. This would cause a propeller to feather at a most inopportune time.

ELECTRONICALLY FINE-TUNING THE PROPELLER GOVERNING SYSTEM WITH THE SYNCHROPHASER®

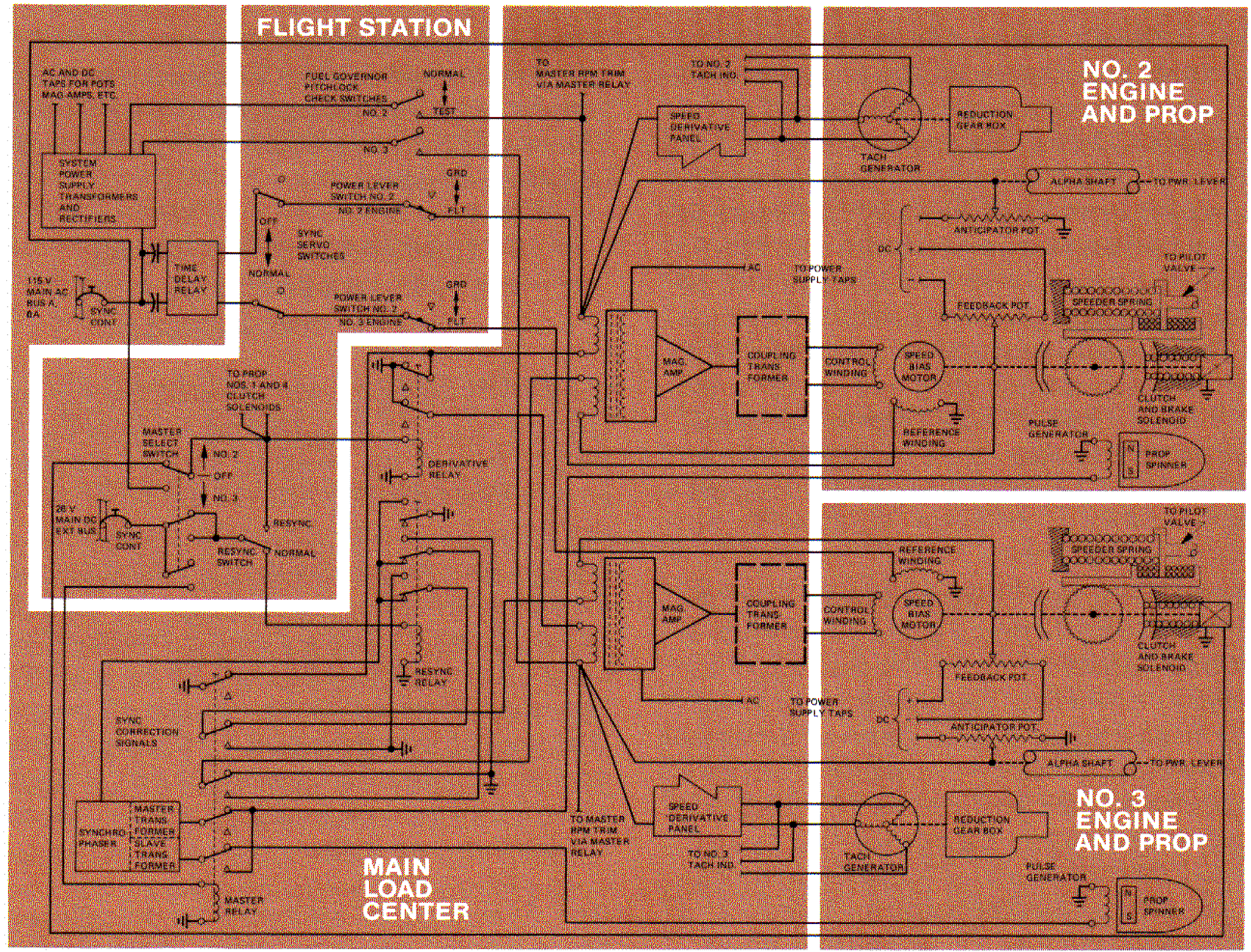
GENERAL With a properly adjusted speeder spring (see the "speed trim" adjusting screw in the Master Schematic), the propeller's hydro-mechanical governing system described to this point will hold the propeller speed practically constant at 100 percent rpm during flight in reasonably smooth air with reasonably smooth power lever manipulation. In fact, electrical power is not required for safe power control during any phase of propeller operation, from full reverse to takeoff power under normal circumstances.[9] However, through use of the propeller Synchrophaser system, an even finer degree of propeller rpm control can be obtained during flight.

The Syncrophaser system electronically senses the rotational position (phase) of the propellers' blades and their rpm, then signals the propeller control units to maintain the same propeller rpm as that of a selected "master" propeller and maintain the blade phase relationship of the propellers within close limits. This reduces airframe vibration and noise variation (propeller beat). Signals from the Synchrophaser also enable the propeller control system to respond faster to rpm variations due to power lever movement and changing power plant loads.

To provide this electronic assist, the Synchrophaser system sends control signals to the small

---

[9] The pitchlock reset function, which ensures against an inadvertant pitchlock being induced by a too-rapid transition from high power to ground range operation, may be important in special circumstances and does require 28-VDC power. For this reason, the pitchlock reset power is taken from the surest electrical bus on the airplane — the Flight Essential DC Bus — which is connected directly to the battery. However, if the battery is the only source of power and its charge is questionable, the pilot should consider the consequences of electrical power failure when transitioning from flight to ground range and not make the transition until airspeed is below 125 knots.



NOTE: MOST INTERCONNECTIONS FOR THE NO. 1 AND NO. 4 ENGINES HAVE BEEN OMITTED FOR SIMPLIFICATION.

Figure 15. Speed-Bias Servo Control and Synchrophaser Schematic. Inboard engines are shown, with engine no. 2 selected as the master.

speed-bias motor (see Figure 15 and the Master Schematic) mounted inside each propeller control housing. The speed-bias motor is the interface between the Synchrophaser and the propeller flyweight governor. It is a reversable AC servo motor that can quickly add a small and varying supplemental 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 propeller governor; that is, it can hold the propeller governor slightly off the mechanically preset control speed.[10] Thus, it receives and acts upon transitory control signals from the Synchrophaser to improve the propeller governor reactions to unstable operating conditions. The Synchrophaser system is normally used constantly after takeoff, throughout flight.

We will discuss the various sources of the servo-controls only briefly, for it is beyond the scope of this article to present a comprehensive description of electronic propeller governing. The simplified schematic in Figure 15 shows that the reference winding of each speed-bias motor is energized from Main AC Bus A through two switches in series: (1) the manually-actuated sync-servo switch that is closed when it is in the NORMAL position, and (2) power lever switch No. 2 that is closed when the power lever is in the flight range. *When either of these switches is open, the governor's speed-bias motor is ineffective and propeller governing is purely hydro-mechanical.*

If necessary, electronic governing can be used for ground test purposes with the airplane parked. However, the performance of electronic governing on a parked aircraft is not representative of its performance during flight, for the close proximity of the ground causes aerodynamic disturbances at the propeller blade tips that do not otherwise occur. The Synchrophaser system is intended for

---

[10] The linkage between the speed-bias motor and the governor speeder spring is mechanically limited to a maximum reset of plus 6 to minus 4 percent of the propeller speed setting.

in-flight use and its normal function should, in most cases, be tested in flight.

SYNCHROPHASER SYSTEM The Syncrophaser system supplements the aircraft's hydro-mechanical, constant-speed propeller governing system by employing two electronic governing modes — normal governing and synchrophasing — thus giving the propeller control system three modes of speed governing. In the following paragraphs we shall discuss these electronic governing modes. We shall also briefly examine propeller indexing, resyncing, and the function of the Synchrophaser system in the fuel governor/pitchlock check.

Normal Governing The hydro-mechanical governor regulates propeller rpm by maintaining a balance between its flyweight force and its speeder spring counterforce. The speed at which the propeller is governed is set mechanically by adjusting the governor's speed trim screw, with one "click" equal to a 0.25 percent change in rpm. In the normal governing mode, the Synchrophaser system enables the propeller governor to respond faster to transient propeller rpm variations. These rpm variations can be caused by changes in power plant loads, such as those that occur during initiation of aircraft climb or descent maneuvers, or by movement of the power lever. The normal governing mode is selected individually for each propeller when the power lever for that propeller is set at or above flight idle *and* the sync-servo switch for that power plant is positioned at NORMAL.

During Synchrophaser operation in the normal governing mode, the Synchrophaser's *speed-derivative governing damping control circuit* regulates rpm variations that are caused by changes in power plant loads. The speed-derivative circuit receives a reference signal from the power plant tachometer signal generator, located on the reduction gear assembly. When rpm changes, the speed-derivative circuit senses the rate and amount of rpm change and signals the governor speed-bias motor to change the speeder spring force, which temporarily resets the propeller governor. This operation occurs as the propeller rpm is changing. The result is faster governor response, which produces a smaller increase or decrease in propeller rpm than would occur during hydro-mechanical governing.

When propeller rpm is regulated only by hydro-mechanical governing, rapid power lever advance causes the rpm to overshoot and then undershoot. During Synchrophaser operation in the normal governing mode, the Syncrophaser's *power lever anticipation circuit* enables the governor to respond faster to transient speed changes caused by rapid movement of the power lever. Within the flight idle to takeoff operating range, power lever movement actuates the power lever anticipation potentiometer, which is located within the propeller control unit. This moves the potentiometer wiper, which changes the voltage output from the potentiometer to the Synchrophaser. The rate of change causes the Synchrophaser to respond by signaling the speed-bias motor to change the speed-bias spring force, which temporarily resets the propeller governor. During a power lever advance when in the "normal" governing mode, initial rpm overshoot may be the same as that during hydro-mechanical governing, but the governor's response to the Synchrophaser power lever anticipation and speed derivative signals will reduce rpm undershoot substantially. Similarly, when the power lever is retarded during operation in the normal governing mode, initial rpm undershoot is about the same but subsequent overshoot is much less.[11]

The Synchrophaser system responds to changes of propeller rpm in both its normal governing and synchrophasing modes. During hydro-mechanical governing, the signal inputs from the power lever potentiometer and the tachometer generator are connected to the Synchrophaser, but the Synchrophaser system cannot respond because there is no power to the reference winding of the governor speed-bias motor.

Synchrophasing In the synchrophasing mode, the Synchrophaser integrates the hydro-mechanical and "normal" electronic governing functions of all four power plants. The governors of all four propellers are regulated by control signals from the Synchrophaser, causing three slave propellers to operate at the same rotational speed as a se-

---

[11] It is possible for one or more propellers to operate in the normal governing mode while the others are operating in the hydro-mechanical governing mode. This occurs because of differences in power lever settings (ground operation) or because one or more of the power plant sync-servo switches are not set at NORMAL.

lected master propeller. Either propeller No. 2 or No. 3 may be selected as the master propeller. In this mode, the Synchrophaser also causes the propellers to maintain a constant rotational or phase relationship with one another that keeps the aerodynamic interaction of the inboard and outboard propeller's blade tips to a minimum. This reduces airframe vibration and the noise variation that is commonly referred to as propeller "beat." The synchrophasing mode becomes operational when the Synchrophaser system is in the normal governing mode (power levers at or above flight idle, and the sync-servo switches in the NORMAL position) *and* when a master engine is selected (sync-master switch in either the No. 2 or No. 3 position).

The Synchrophaser receives one electronic pulse per revolution from each propeller. This signal pulse is generated by a magnet on the propeller slip ring assembly as its magnetic field passes through a coil that is mounted on the propeller control unit. The pulse from the master engine provides the Synchrophaser with an "index," which it uses as a reference for generating corrective signals that it sends to the slave propeller's speed-bias motors. The Synchrophaser compares the frequency and the relative times of the pulses from the slave propellers with that of the index pulse from the master propeller. A difference in frequency indicates that the hydro-mechanical governor of the slave propeller is controlling it at a different rpm than that of the master propeller. When this occurs, the Synchrophaser signals the slave propeller's speed-bias motor to "fine tune" the tension on the governor speeder spring so that the governor will adjust the slave propeller's rpm to that of the master propeller. The rpm of the slave propeller is now "synchronized" with that of the master propeller.

During hydro-mechanical governing, the differences in rpm of the propellers produce increases and decreases in sound levels. When the rpm of all propellers are synchronized, the sound level is constant. However, this sound level may not be a minimum value. The Synchrophaser makes a further comparison of the propeller timing pulses, which determines the relative angular positions (phase angles) of the propellers as they rotate. The Synchrophaser then compares these phase angles with preset optimum phase angle values, and further controls the propeller governors to obtain and maintain optimum phase angle conditions for a constant, lower sound level under constant operating conditions. The result is called synchrophasing.

Changes in operating conditions may temporarily upset the phase angle or rpm relationship, but as soon as conditions are again stable, the Synchrophaser will re-synchronize the propellers' speed and restore their operation to the optimum phase angle values. The operator should note that if the sync-servo switch for a slave propeller is positioned OFF, operation of that propeller is switched to the hydro-mechanical governing mode and it cannot be synchronized or phase-controlled by the Synchrophaser.

Propeller Indexing For efficient Synchrophaser system operation, the normal mode governing speed of each propeller should be as close as possible to the propeller's 100 percent hydro-mechanical governing speed. This is necessary because the Synchrophaser is most sensitive when the propeller governor's speed-bias motor feedback potentiometer is positioned close to the zero-volt feedback point. It is also important because, in the normal governing mode, the speed-bias motor feedback potentiometer will drive the motor until the potentiometer is positioned back to the zero-volt point. By use of the Synchrophaser, the propeller's normal mode governing rpm can be set or *indexed* to correspond with its hydro-mechanical governing rpm. This is achieved by performing the propeller governor indexing procedure presented in the P-3 NATOPS Flight Manual.

During the propeller governor indexing procedure, all of the propellers are allowed to operate at 100 percent rpm in the hydro-mechanical governing mode. The propeller governor speed-bias motors are then decoupled from the governor and allowed to run until their feedback potentiometers are reset at the zero-volt feedback position, which corresponds to a no-bias condition relative to the propeller's 100 percent rpm hydro-mechanical governing set point. A system is indexed if there is no change in propeller rpm when the sync-servo switch for that propeller is moved from OFF to NORMAL, or the reverse.

Resyncing As phase angle errors occur, the Synchrophaser signals each slave propeller's speed-bias motor to adjust its governor to restore the master and slave propellers to their proper phase angle relationship. During this operation, the speed-bias motor drives its feedback potentiometer so that a portion of the error signal from the Synchrophaser is cancelled. As the phase angle error is corrected, the error signal decreases until it matches the feedback signal. When this occurs, the potential at the signal summing point is zero and the speed-bias motor stops running, leaving a small portion of the phase angle error uncorrected.

Usually, phase angle errors tend to lead and lag about a set value, and because of this, they tend to cancel one another. However, sometimes phase angle errors will accumulate in one direction, causing the slave propeller speed-bias motor to position its feedback potentiometer off-center from the zero-volt feedback position. By performance of the *resyncing* procedure presented in the P-3 NATOPS Flight Manual, the slave propeller speed-bias motor can be temporarily decoupled from its hydro-mechanical governor and its feedback potentiometer recentered to the zero-volt feedback position. When the resyncing procedure is completed, all circuits return to the synchrophasing mode and the Synchrophaser can then correct the accumulated phase angle error.

Misindexing A propeller is *misindexed* when its rpm in the normal governing mode does not correspond with its preset (ground adjusted) rpm for the hydro-mechanical governing mode. This condition can occur either during flight or on the ground when the Synchrophaser system is turned on. In addition, actuation of the resync switch purposely misindexes the slave propellers to match the master propeller. Although misindexing is generally undesirable, a propeller can be operated safely with a misindexed governor because the mechanical stops mentioned earlier in this article prevent the speed-bias motor from driving the governor speeder spring more than plus 6 or minus 4 percent off its preset hydro-mechanical governing value. Indeed, during the Fuel Governor/Pitchlock Check that we shall discuss subsequently, it is necessary to run the propeller to the 106 percent rpm stop to perform the check.

During flight, if the resync switch is actuated while the Synchrophaser system is operating in the synchrophasing mode, each slave propeller will be indexed so that its rpm in the normal governing mode will correspond with the master propeller's rpm in the hydro-mechanical governing mode. By this resyncing operation, the slave propellers have been misindexed by the difference between the master and slave propeller hydro-mechanical governing mode rpm settings. If the normal governing mode is subsequently selected by positioning the sync-master switch OFF, all four propellers will maintain the rpm set when the resync switch was actuated. Later, if there is a significant difference in propeller rpm when its operation is switched between normal and hydro-mechanical governing, the propeller is misindexed to the degree that it should be reindexed.

Sometimes, either inadvertantly or through necessity, all of the propeller's nominal control speeds for synchrophasing operation are driven far below normal when the airplane is parked. This occurs when the Synchrophaser system is energized when the engines are not operating. If the sync-master switch is alternated (each inboard propeller is repeatedly made master, then slaved) and the resync switch actuated, both inboard (potential master) propeller governors speed-bias motor feedback potentiometers will be reset and misindexed progressively toward increase-pitch. The misindexing will occur while the inboard propeller is functioning as a slave, as the Synchrophasing system attempts to match the slave propeller's speed with that of the zero-rpm master propeller.

As long as the sync-servo switches are OFF, the misindexed speed-bias controls will have no effect on propeller governing. When the engine is subsequently started and run with sufficient power to reach 100 percent rpm, the propeller's hydro-mechanical governor will assume control and hold propeller rpm very near that point. However, in so doing, the governor will carry the de-energized speed-bias control mechanism to a position where the feedback potentiometer is far off its zero-voltage null point. If the speed-bias motor was made operative (sync-servo switch moved to NORMAL) at this time, the servo motor would run and apply a steady bias on the governor speeder spring, driving propeller rpm appreciably off 100 percent. For this reason, it is standard procedure to start and run the engines with the sync-servo switches OFF until the aircraft is well established in climbout after takeoff, and then perform the propeller governor indexing procedure presented in the P-3 NATOPS Flight Manual.

Fuel Governor and Propeller Pitchlock Check The propeller governor normally prevents the propeller speed from exceeding 102 percent rpm during operation in the flight range. If it fails to do so, the pitchlock will trigger at about 103 percent rpm to prevent the propeller from further reducing the engine load, and at about 104 percent rpm the fuel control governor will begin to trim fuel flow to reduce engine power as necessary to prevent further rise in rpm. These standby safety features are extremely important, and their operability should be ground-checked regularly.

Obviously, it is necessary to turn the engine and propeller faster than normal propeller governing will allow to test these standby controls. The individual fuel governor and propeller pitchlock check switches provide this capability. The fuel governor and propeller pitchlock check procedure is presented in the P-3 NATOPS Flight Manual. In the following paragraphs, we shall highlight portions of this check procedure, but we emphasize that the reader must refer to the P-3 NATOPS Flight Manual for the complete test procedure and for the various check values.

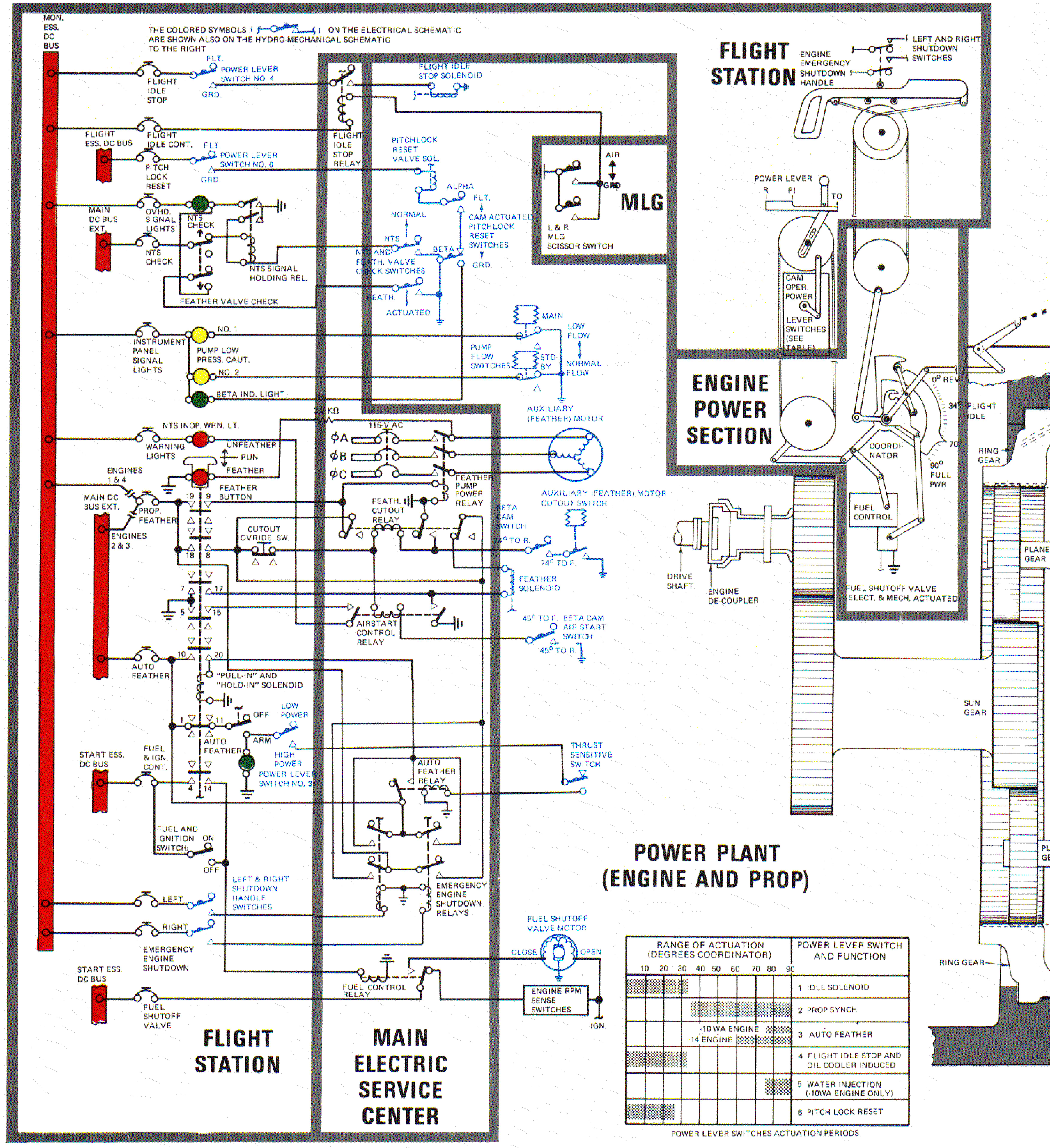
This check is performed with the aircraft parked and the engine operating, initially, at flight idle. When the check switch is actuated, the speed-bias control assembly receives a continous overriding signal that drives the mechanism full-travel towards decrease-pitch. Under these operating conditions, the propeller governor's speed-sensing mechanism cannot create increase-pitch pressure unless the propeller rpm reaches about 106 percent.

When the power lever is subsequently advanced to the maximum power position, the pitchlock should trigger at about 103 percent rpm, the fuel governor should begin controlling rpm at about 104 percent, and the Beta followup system should manipulate the propeller governor pilot valve to increase the blade angle into the normal flight range where the pitchlock is effective (above 17 degrees). If the fuel control governor fails to assume control, the propeller governor will regain control of rpm at about 106 percent.

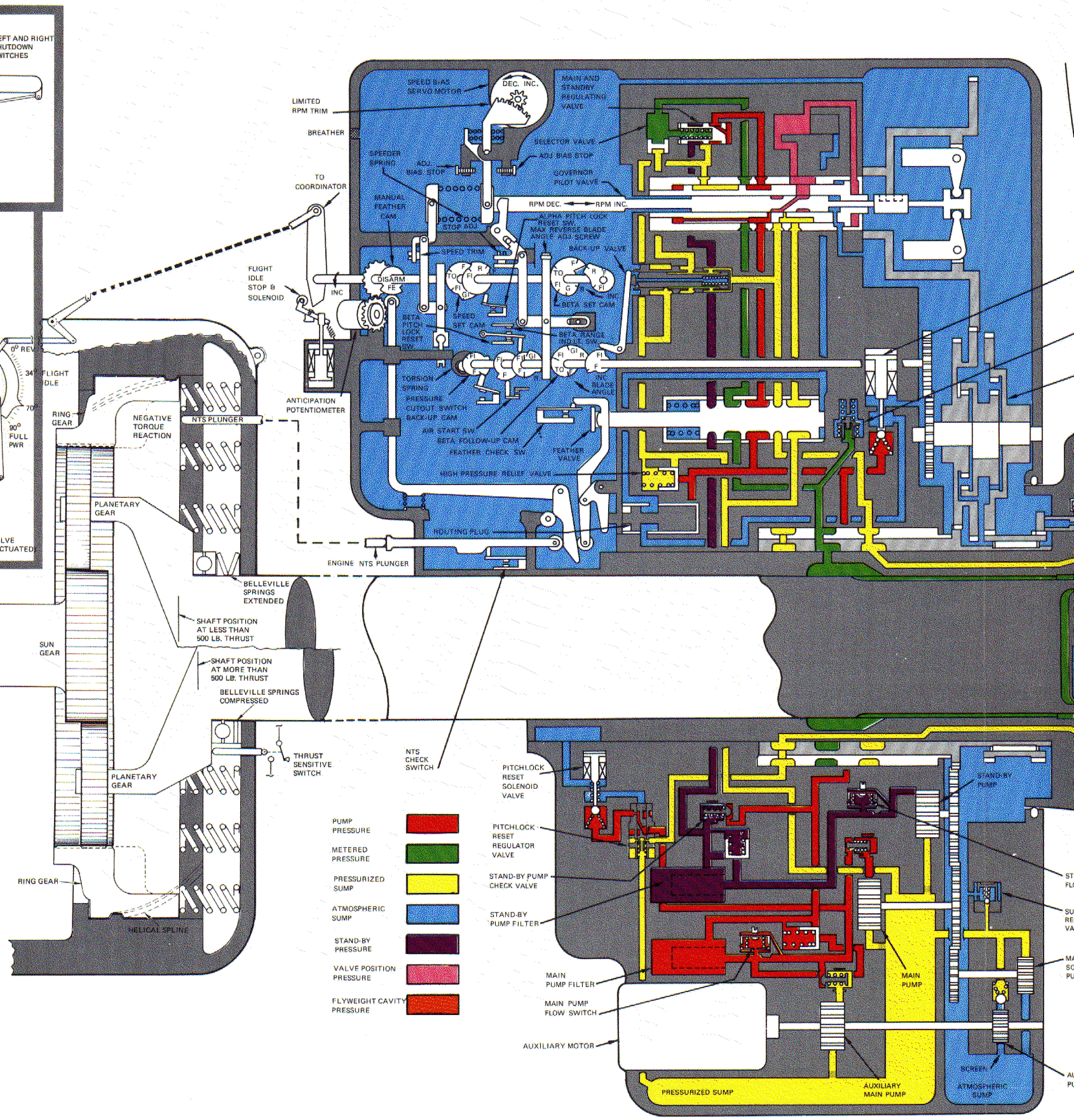
The upper tolerance at which the fuel control governor may assume rpm control may be so near 106 percent rpm that it may be difficult to tell by the tachometer indicator which governor is actually controlling the power plant rpm. In such a case, the fuel flow (which should be far below normal) provides the most reliable indication of fuel governor control. If the fuel control governor is controlling in the 105.5 to 106 percent rpm range, the indicated fuel flow will be substantially lower than when the propeller governor is controlling power plant rpm at the 90° coordinator position. Refer to the P-3 Maintenance Instruction Manual, which specifies fuel flow at various rpm when the fuel control governor is controlling power plant rpm.

Since there is no indication of pitchlock engagement at the takeoff power setting, the power lever must be retarded until rpm decreases to 100 percent rpm to complete the check. With the pitchlock engaged and with the fuel control governor in control, the engine will produce about 1800 hp at 100 percent rpm. Variables, chiefly environmental, may subtract as much as 300 hp from this value. However, if the pitchlock is not engaged, the propeller angle will return back towards the low pitch stop and engine horsepower will be substantially less than 1500 hp at 100 percent rpm. Any indication in excess of 1500 hp proves that the pitchlock mechanism is operable. Again, refer to the P-3 NATOPS Flight Manual for the official check values and check procedure.

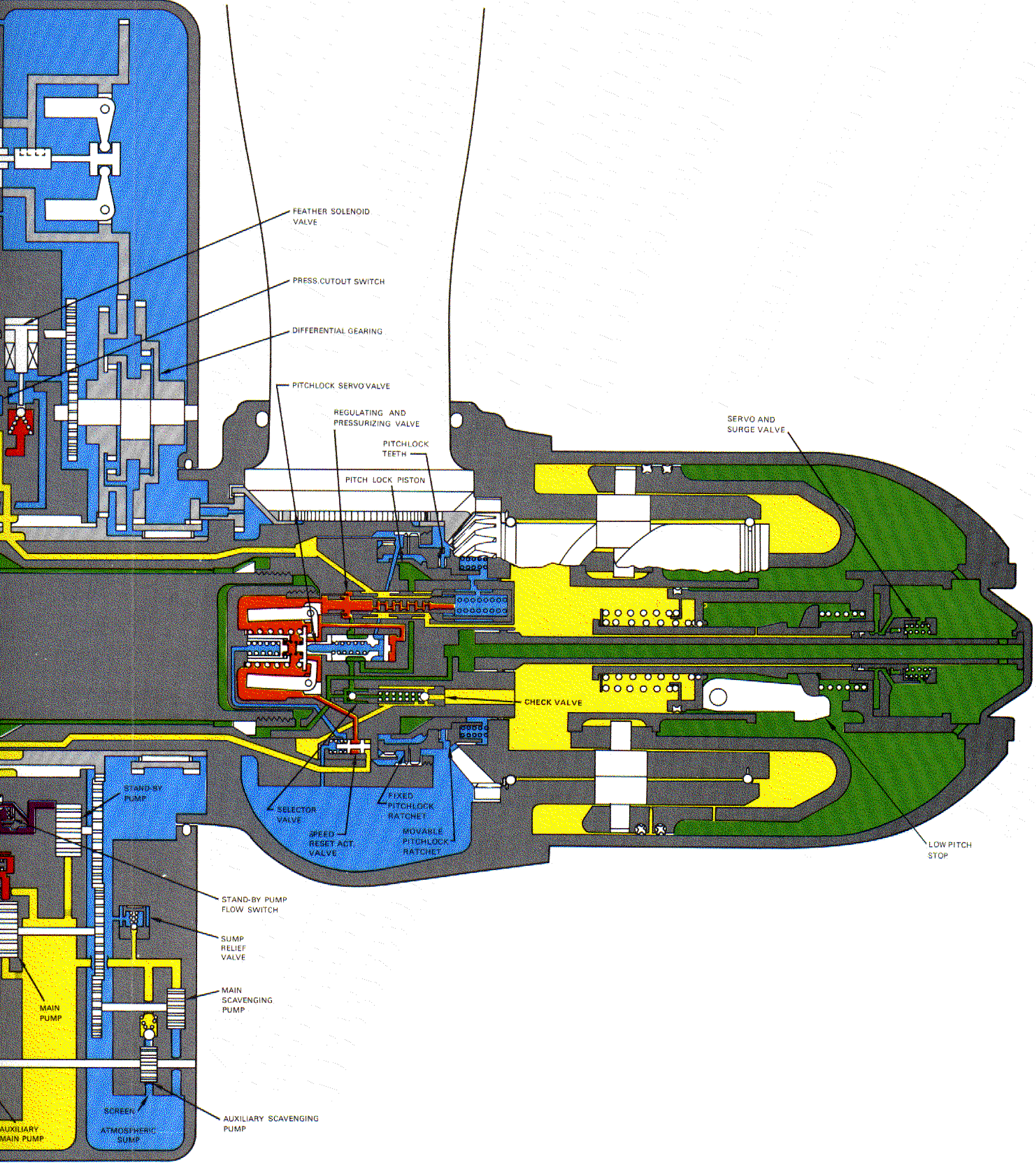
Lockheed ORION Service Digest



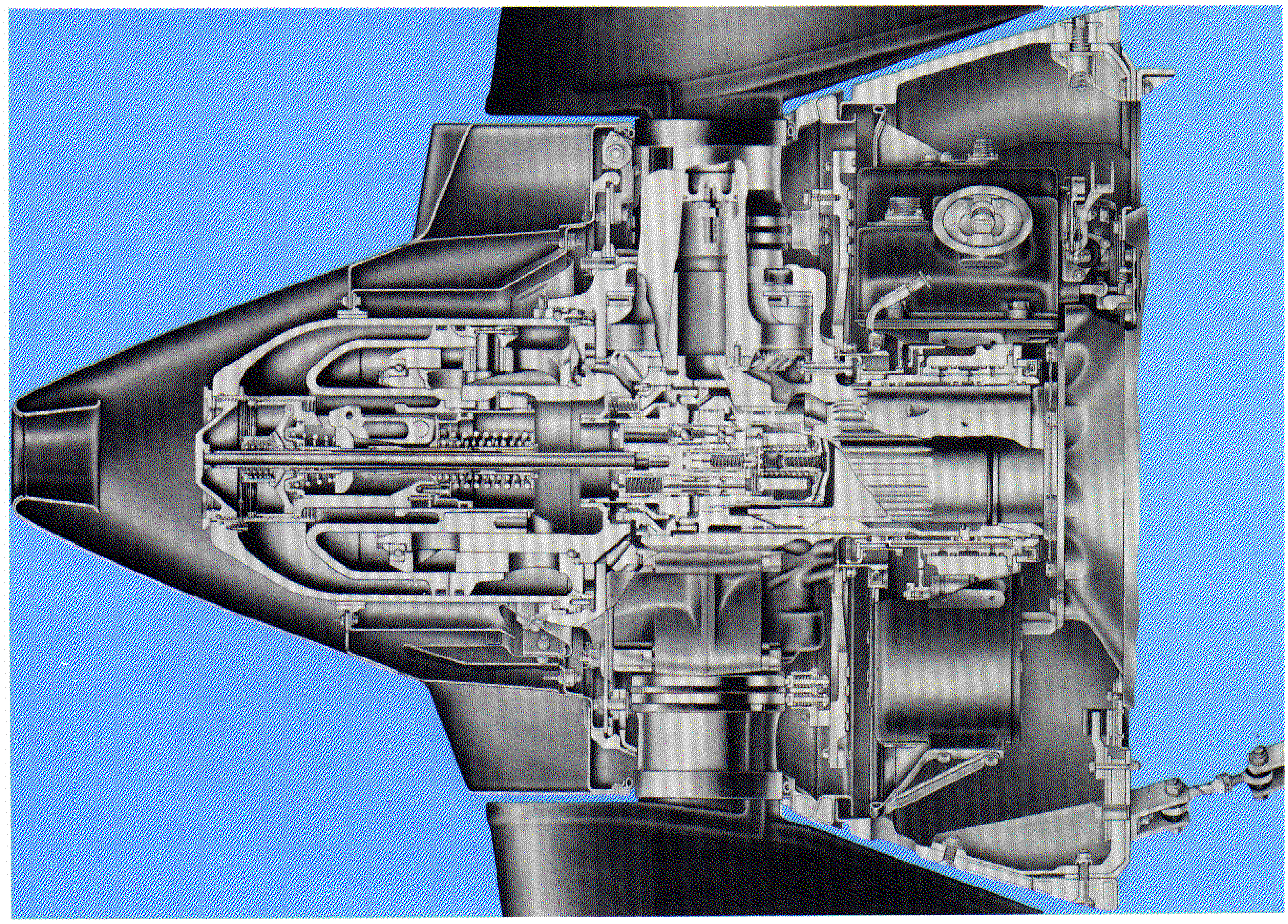
Propeller Control Master Schematic — Propeller Shown in On-Speed Condition



SPEED BIAS SERVO MOTOR
DEC. INC.
LIMITED RPM TRIM
BREATHER
MAIN AND STANDBY REGULATING VALVE
SELECTOR VALVE
ADJ BIAS STOP
SPEEDER SPRING
ADJ. BIAS STOP
GOVERNOR PILOT VALVE
TO COORDINATOR
MANUAL FEATHER CAM
STOP ADJ.
RPM DEC.
RPM INC.
ALPHA PITCH LOCK RESET SW.
MAX REVERSE BLADE ANGLE ADJ SCREW
SPEED TRIM
BACK-UP VALVE
DISARM
FE
INC
FLIGHT IDLE STOP & SOLENOID
TO
F
R
FI
GI
G
BETA SET CAM
SPEED SET CAM
BETA PITCH LOCK RESET SW.
BETA RANGE IND. LT. SW.
TORSION SPRING
PRESSURE CUTOUT SWITCH BACK-UP CAM
AIR START SW.
BETA FOLLOW-UP CAM
FEATHER CHECK SW.
FEATHER VALVE
INC BLADE ANGLE
HIGH PRESSURE RELIEF VALVE
ROUTING PLUG
ANTICIPATION POTENTIOMETER
ENGINE NTS PLUNGER
0° REV
34° FLIGHT IDLE
70°
90° FULL PWR
RING GEAR
NEGATIVE TORQUE REACTION
NTS PLUNGER
PLANETARY GEAR
BELLEVILLE SPRINGS EXTENDED
SHAFT POSITION AT LESS THAN 500 LB. THRUST
SUN GEAR
SHAFT POSITION AT MORE THAN 500 LB. THRUST
BELLEVILLE SPRINGS COMPRESSED
THRUST SENSITIVE SWITCH
PLANETARY GEAR
NTS CHECK SWITCH
RING GEAR
HELICAL SPLINE
PITCHLOCK RESET SOLENOID VALVE
PITCHLOCK RESET REGULATOR VALVE
STAND-BY PUMP CHECK VALVE
STAND-BY PUMP FILTER
MAIN PUMP FILTER
MAIN PUMP FLOW SWITCH
AUXILIARY MOTOR
STAND-BY PUMP
MAIN PUMP
AUXILIARY MAIN PUMP
PRESSURIZED SUMP
SCREEN
ATMOSPHERIC SUMP
PUMP PRESSURE 🟥
METERED PRESSURE 🟩
PRESSURIZED SUMP 🟨
ATMOSPHERIC SUMP 🟦
STAND-BY PRESSURE 🟪
VALVE POSITION PRESSURE 🟥
FLYWEIGHT CAVITY PRESSURE 🟧


FEATHER SOLENOID VALVE
PRESS.CUTOUT SWITCH
DIFFERENTIAL GEARING
PITCHLOCK SERVO VALVE
REGULATING AND PRESSURIZING VALVE
PITCHLOCK TEETH
PITCH LOCK PISTON
SERVO AND SURGE VALVE
CHECK VALVE
STAND-BY PUMP
SELECTOR VALVE
SPEED RESET ACT VALVE
FIXED PITCHLOCK RATCHET
MOVABLE PITCHLOCK RATCHET
LOW PITCH STOP
STAND-BY PUMP FLOW SWITCH
SUMP RELIEF VALVE
MAIN SCAVENGING PUMP
MAIN PUMP
AUXILIARY MAIN PUMP
SCREEN
ATMOSPHERIC SUMP
AUXILIARY SCAVENGING PUMP

Courtesy of Hamilton Standard Division, United Technologies



Hamilton Standard 54H60-77 Propeller System

LOCKHEED-CALIFORNIA COMPANY
PRODUCT SUPPORT – GOVERNMENT PROGRAMS

R. L. MOORE, VICE PRESIDENT

DIRECTOR
INT'L SUPPORT PROGRAMS
A. B. Stacey

DIRECTOR
P-3 SUPPORT
H. A. Franck

DIRECTOR
S-3 SUPPORT
A. J. Neibauer

FIELD SERVICE DIVISION – D.R. STEELE, MANAGER

P-3 Field Service	**J.R. Mercer, Manager**
S-3 Field Service	**R.D. Wade, Manager**
Military Field Modifications	**C.A. McLeish, Manager**

FIELD SERVICE OFFICES

MAJOR LOCATION	MAILING ADDRESS AND BUSINESS TELEPHONE
NARF Alameda P. H. Gerard	P.O. Box 1363 NAS Alameda, CA 94501 (415) 869-4696/521-2283
NAVAIRSYSCOM, Arlington E. O. Skidmore F. A. Warner (PMA-240)	Lockheed-California Co. 1235 Jefferson Davis Hwy Suite 1200, Crystal Gateway Arlington, VA 22202 (202) 872-5929
NAS Barbers Point A. W. Vitaglin	P.O. Box 268 NAS Barbers Point, HI 96862 (808) 681-3444/682-3671
NAS Brunswick W. J. Biggs	P.O. Box 38 Brusnwick, ME 04011 (207) 921-2472/921-2521
NAS Cecil Field E. S. Skultety	P.O. Box 162 NAS Cecil Field Jacksonville, FL 32215 (904) 772-8517/772-0369
NS Cubi Point, R.P. D. L. Lannigan	P.O. Box 47 FPO San Francisco, CA 96654 Cubi Point 63-8-885-6163
NAS Jacksonville S. L. Solomon	P.O. Box 31300 Jacksonville, FL 32230 (904) 772-3535/772-1527
NAS Moffett Field K. M. Prideaux	P.O. Box 159 Moffett Field, CA 94040 (415) 966-5461

MAJOR LOCATION	MAILING ADDRESS AND BUSINESS TELEPHONE
NS Naples, Italy H.S. Mattox	Lockheed-California Co. COMFAIRMED/NSA Box 2 FPO New York NY 09521 Naples 081-724-5359
CNAVRES New Orleans R.G. Baumgarten	P.O. Box 3906 New Orleans, LA 70177 (504) 948-1220
NAS Norfolk W. H. Beydler	P.O. Box 15148 U.S. Naval Base Norfolk, VA 23511 (804) 423-8321
NAS North Island D. K. Payne	P.O. Box 5, NAS North Island San Diego, CA 92135 (619) 435-8910
Ottawa, Canada H.W. Heintz	LAC of Canada, Ltd. 255 Albert St. – Suite 603 Ottawa, Ontario Canada K1P 6A9 (613) 238-8141
NATC Patuxent River M. D. Garino	P.O. Box 218 NATC Patuxent River, MD 20670 (301) 863-8186
ASO Philadelphia J. P. Murphy	P.O. Box 7051, Blvd Station Philadelphia, PA 19149 (215) 697-3287
NADC Warminster G. Sink	196 West Street Rd. Warminster, PA 18974 (215) 674-3550

LOCKHEED-CALIFORNIA COMPANY • A DIVISION OF LOCKHEED CORPORATION