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ORION

ELECTRIC SYSTEM — PART ONE

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FRONT AND BACK COVERS Patrol Squadron Eight (VP-8) has been in the ASW game since the squadron was first formed during World War II—flying PBM Mariners, P-2 Neptunes, and now P-3A Orions. Based at NAS Patuxent River, Maryland, VP-8 was the first operational squadron to be equipped with the P-3 Orion. On 8 August 1962, Commander C. W. Cook, then VP-8's commanding officer, flew the Navy's new ASW aircraft on its first operational mission—some five days before the Orion was officially inducted into the Navy.

VP-8 was scheduled to become fully operational with the Orion on 1 January 1963, but it is a measure of both the squadron and the P-3 airplane that this deadline was bettered by a considerable margin. The original program was accelerated, partly due to the rising crisis in Cuba, and October 1962 found VP-8 in active support of the Cuban quarantine operation with aircraft deployed to Bermuda and the Azores. From these islands, VP-8 flew about 1,000 hours in all weather conditions, providing surveillance of shipping bound to and from Cuban ports, and undertaking various anti-submarine tasks — a meritorious achievement considering the squadron was operating a new type aircraft from advanced bases with a minimum of support.

Since the Cuban crisis, VP-8 has completed training exercises at the Naval Air Station, Roosevelt Roads, Puerto Rico and has participated in a major NATO exercise, operating from a Royal Air Force base at Ballykelly in Northern Ireland. At present the squadron is operating as a part of Task Group Delta, one of four special U.S. Navy ASW groups — which may comprise carriers, destroyers, and patrol planes — operating in and over the Atlantic. Task Group Delta, including VP-8, has a primary responsibility to keep watch on the Atlantic sea lanes, but is also active in developing new ASW tactics and operating procedures for patrol aircraft in the surveillance and barrier areas of the Navy's ASW effort.

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Foreword

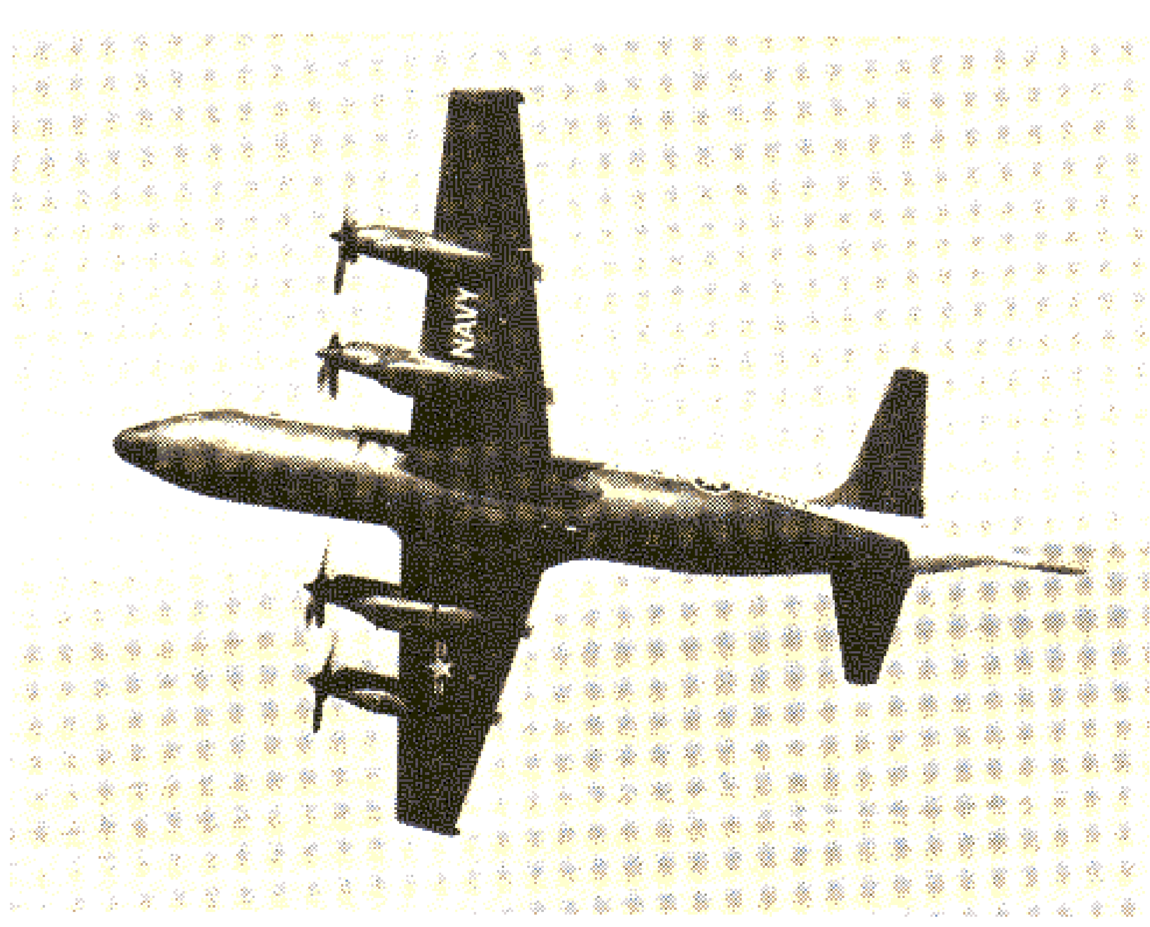
The ever-increasing complexity of aircraft — and ASW aircraft in particular — puts a similarly-increasing burden on both maintenance and flight crews. The human mind has its limitations, and whereas in the past one or two persons could attempt to learn and retain most of the knowledge required for efficient aircraft operation, progress in airplane design has radically changed this situation. Today we have multi-member flight crews, and large numbers of maintenance specialists.

However this development in specialization of knowledge is not, in itself, the complete solution to the operation of present-day aircraft. It is extremely desirable that any flight or ground crew member should have at least a general knowledge of the complete aircraft with particular emphasis on those functional systems with which his own "specialty" is interconnected. In regard to the latter point, the Orion's electric system is unique among the aircraft systems. It is interconnected in some way with all the other aircraft systems and, further, is the prime power source for nearly all functions on the airplane. It follows that a working knowledge of the electric system should be a mandatory requirement for all who work on the Orion.

Thus the primary purpose of this first part of the article is to provide a basic description of the Orion's electric power system in a form which will render the task of learning the system somewhat more palatable to the reader. The principal illustration, Figure 17, is a schematic of the electric power system. The content and layout of the article is to a large extent based on describing the operation of the system as it is depicted in this schematic, although other supporting information is presented while following this procedure. Since Figure 17 is on a fold-out page near the end of the book, the reader is enabled to refer to it conveniently while reading the foregoing text.

As a further aid in learning the system, a limited number of enlargements of the Figure 17 schematic are available to readers for use as wall charts. Navy personnel working on the Orion and desiring copies of the wall chart should preferably request them from the nearest Lockheed-California Service Representative. Otherwise, copies can be obtained by writing to the address given on page 2 of this magazine.

Editor



the ORION electric system - part one

BASIC POWER SYSTEM LAYOUT

FOR ALL FLIGHT conditions, and with the exception of an 11-amperehour, 24-volt battery, all electric power on the Orion is derived from three 60-kva, 120/208-volt, 3-phase, 400-cps, alternating-current generators. These identical generators are installed on engine Nos. 2, 3, and 4 and are numbered correspondingly. An automatic transfer system determines the availability of the generators and connects them to (or disconnects them from) two separate groups of loads (buses) in accordance with a predetermined plan. The various generator/bus connections allowed for by the plan are depicted in Figure 1, which shows pictorially the action of the main ac bus transfer system. The meaning of some of the terms on this illustration may not be apparent to the reader at this stage, but they are explained later in the article. It will be noted that the generators are never paralleled or, to put it another way, a bus is never connected to more than one generator at a time.

The normal flight operation of the system is depicted in Figure 1a where generator Nos. 2 and 3 are operating independently, and each is powering one of the two ac buses, which are called the Main AC Bus A and the Main AC Bus B; generator No. 4 is energized but on standby. This particular configuration of the transfer system is also depicted in Figure 2 by showing the "normal" connections in black. On the other hand the grey lines on this illustration depict the various alternative connections available should one or more generators be inoperable; in effect, the various generator/bus configurations depicted in Figures 1b through 1h are all superimposed on Figure 2. The remaining black lines on Figure 2 show how the other principal power system components are connected in normal operation.*

The Essential AC Bus feeds a selected group of services which, generally speaking, are of primary importance to the airplane's operation. The same statement can also be applied to the Essential DC Bus which carries the most important direct-current services. Both these essential buses actually consist of several buses with interconnecting circuitry but, for simplicity, they have been depicted as single blocks on Figure 2.

Each of the three ac buses powers one of three transformer-rectifiers, and these provide the Orion's 28-volt dc power requirements. Transformer-rectifier Nos. 1 and 2 both supply the Main DC Bus and they are also connected to the Essential DC Bus via a power diode, which allows current to flow from the Main DC Bus to the Essential DC Bus but not in the reverse direction. Because of the power diode, the output of transformer-rectifier No. 3 is restricted to the Essential DC Bus. The battery is connected to the Essential DC Bus and is maintained in a charged condition whenever there is a source of ac power for the aircraft. It should be noted that all three transformer-rectifiers are available even if only one generator is operating.

The red lines on Figure 2, connected just below each generator, depict the possible emergency lines of supply to the Essential AC Bus. This run-around or bypass transfer system ensures that the essential aircraft services are available even in the event of a complete breakdown of the main ac bus transfer system. Again, only one generator can supply the Essential AC Bus at one time, but the generator selection depends upon a comparatively simple automatic circuit that does not involve additional control circuits. With power on the Essential AC Bus, the Essential DC Bus is also energized via transformer-rectifier No. 3 and, under these emergency conditions involving a partial or total loss of power from the main ac buses, the importance of the power diode becomes more apparent — the dc output of transformer rectifier No. 3 is restricted to the essential dc loads on the aircraft and is blocked in the direction of the Main DC Bus.

**Deviations from the layout in Figure 2 will be apparent to the reader as this article progresses. However, the connections as shown are as accurate as this simplified block diagram permits.*

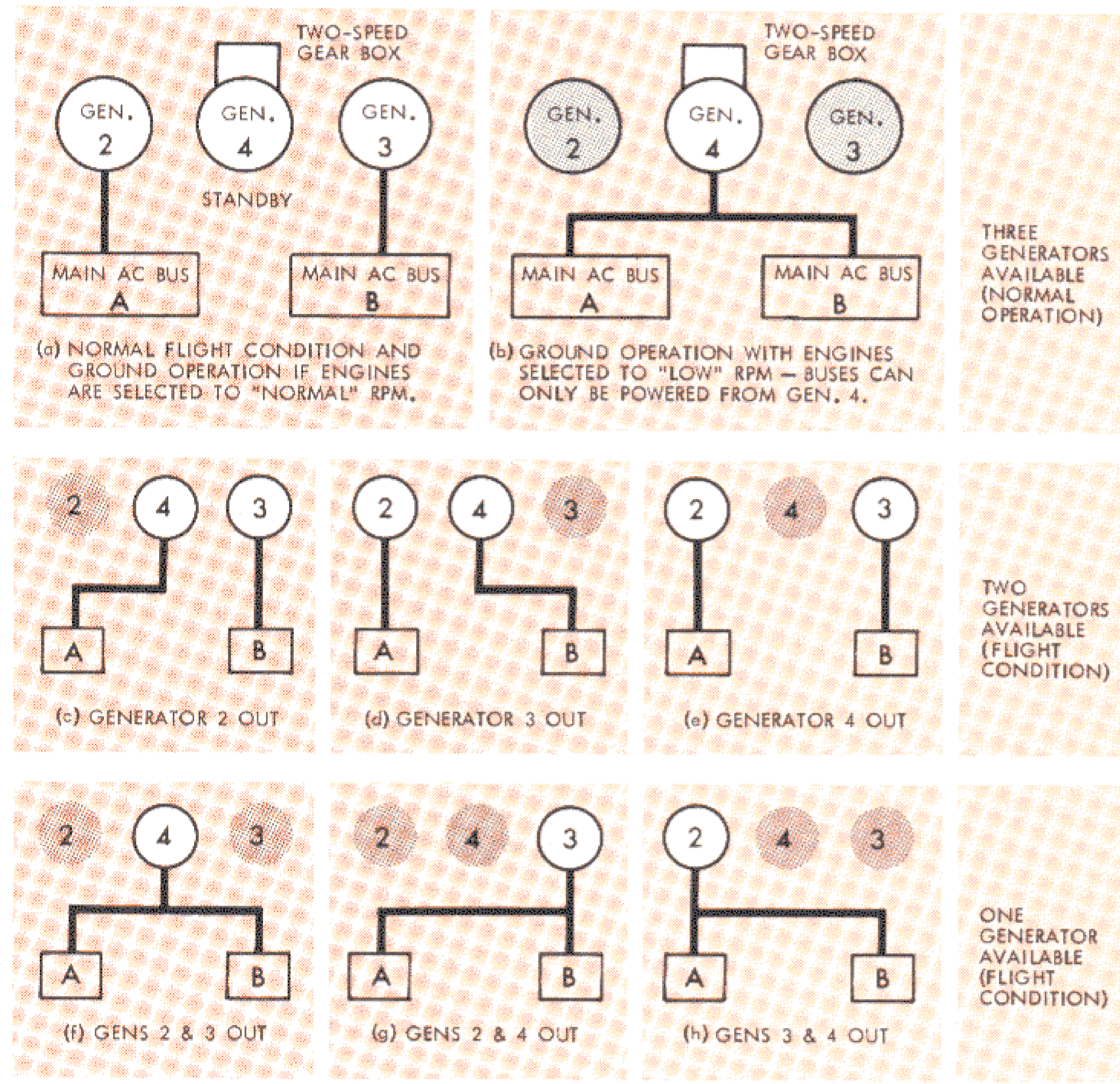


Figure 1 Generator/Bus Support Diagram

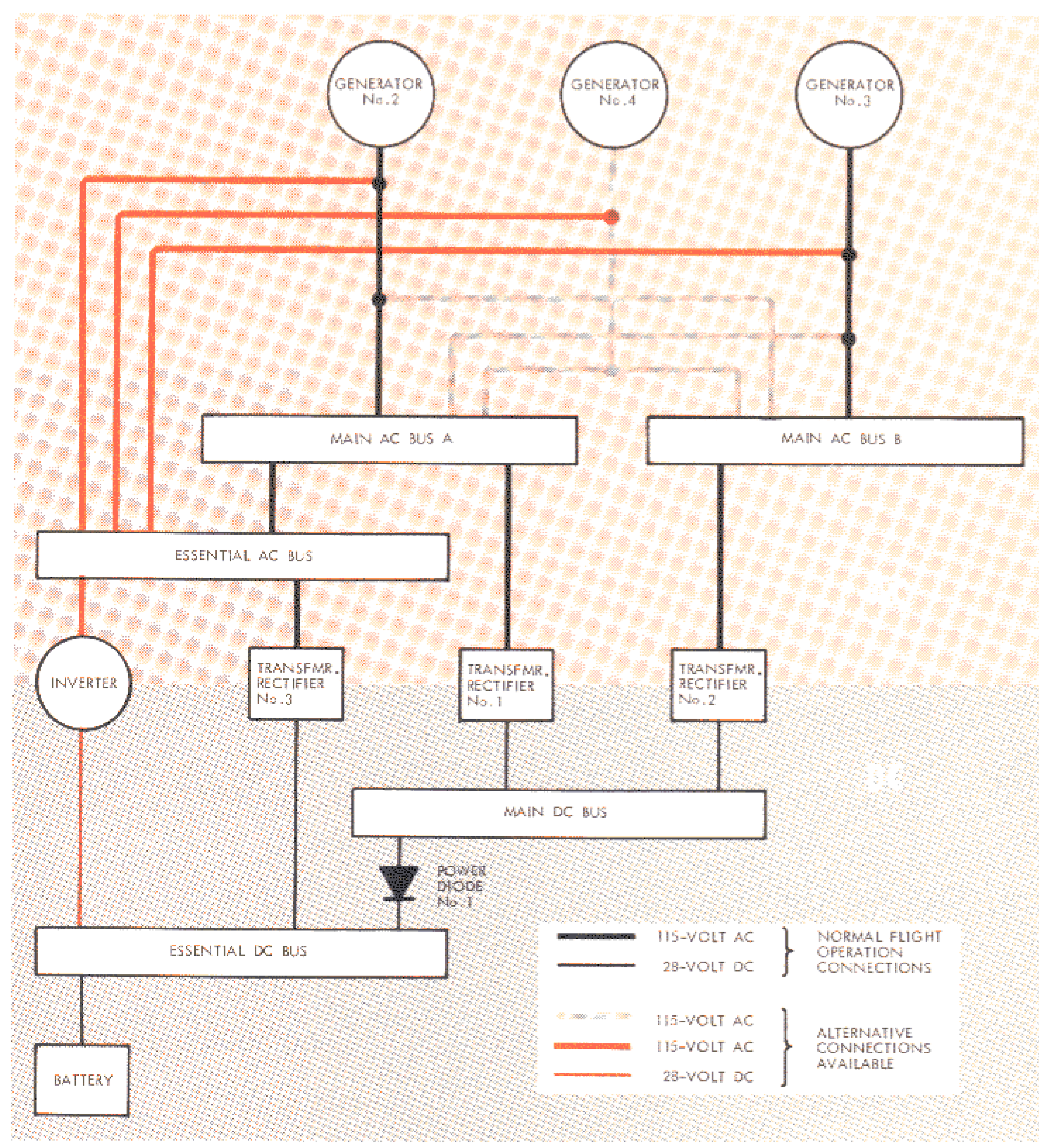


Figure 2 Basic Power System Layout

The battery, in conjunction with the inverter, supplies the minimum ac and dc loads necessary for ground and emergency situations when no other power source is available. The connections of the inverter and battery are shown on Figure 2, but it should perhaps be pointed out that the inverter and the battery would only be connected to a few essential loads and not the complete essential buses as shown.

The last remark again draws attention to the fact that Figure 2 is a very simplified block diagram, but it does give a helpful picture of the basic layout of the electric power system and, if committed to memory, is an aid in following all the subsequent refinements.

One simplification on Figure 2 which has already been pointed out is that, for reasons of geographic location and for purposes of load monitoring, some of the buses are actually broken down into several sub-buses which can be referred to collectively by the name given to them in Figure 2. For example, the Essential AC Bus actually consists of three sub-buses: the Start Essential AC Bus, the Monitorable Essential AC Bus, and the Flight Essential AC Bus. The names of these sub-buses are found on the circuit breaker panels in the aircraft and the reader might find it advantageous at this stage to glance at Figures 14 and 15 and compare the bus arrangements on these illustrations with those on Figure 2.

LOCATION OF PRINCIPAL COMPONENTS

The majority of the electric power system components are distributed between three main locations which can be seen in Figure 3 and are identified as follows:

1. Powerplants — generator installations.
2. Main Load Center — sometimes referred to as the main service center.
3. Forward Load Center — sometimes referred to as the flight station load center.

Slight deviations from this basic scheme are brought out in the following discussion:

POWERPLANTS With the exception of engine No. 1, a 60-kva generator is mounted on the aft righthand side of each engine/propeller reduction gear box. The No. 4 generator installation differs from the Nos. 2 and 3 generator installations in that it is driven through a two-speed gear box (see Figures 4 and 5). The necessity for and the operation of the gear box is explained later in the "AC Power Transfer and

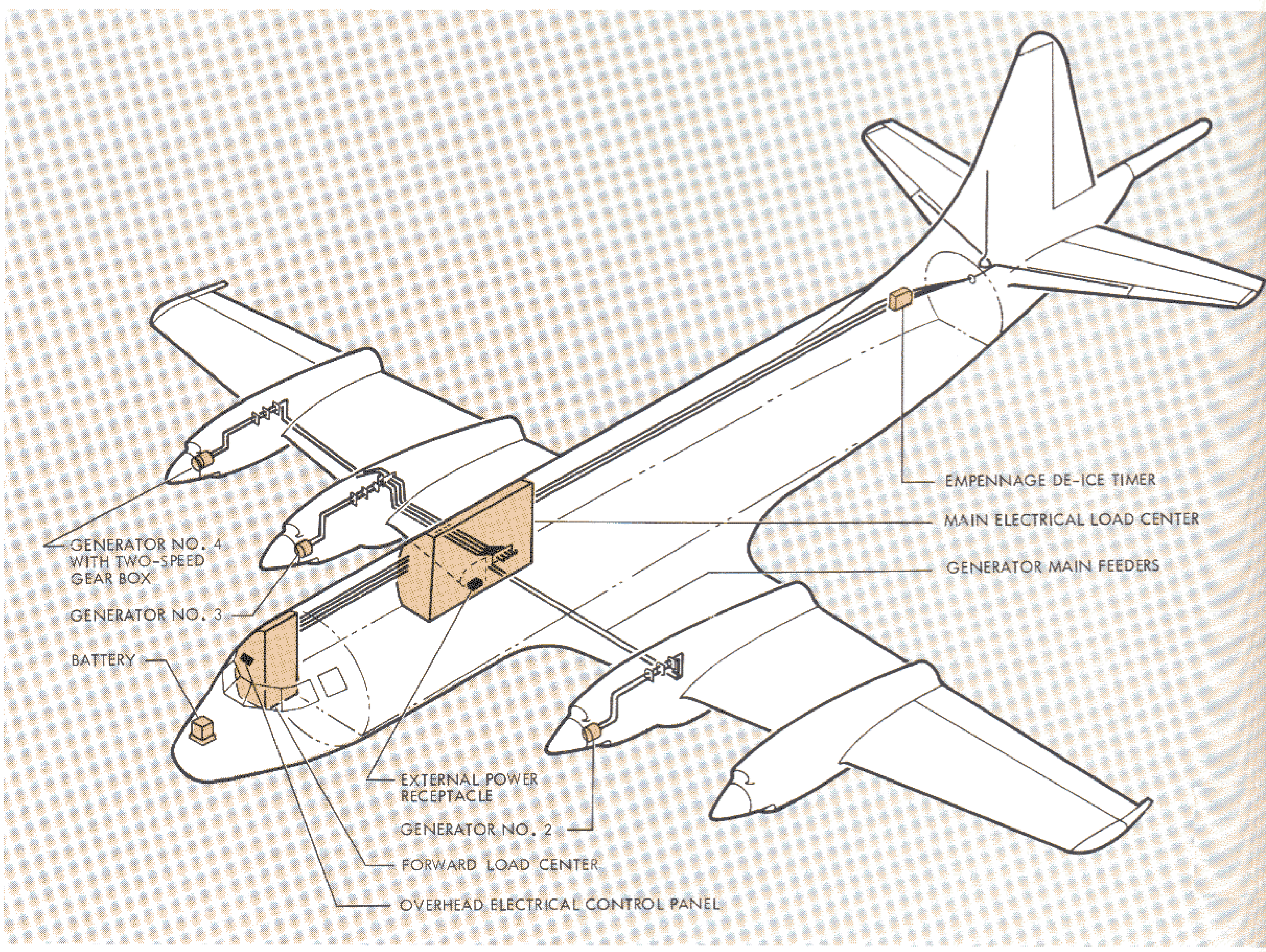


Figure 3
Location of
Electrical Equipment

Distribution" section. The gear box has its own oil lubrication system; the oil filler, sight-gauge, and filter can all be seen in Figure 5. In order to maintain as far as possible interchangeability of powerplants, each one (including No. 1) is provided with identical electric harnesses equivalent to a generator No. 4 installation. Where particular wiring is not required on the other engines, it is stowed in specially provided stowage brackets.

Each of the three generators is cooled by air which is tapped from the engine oil cooler scoop and directed to the aft end of the generator through a 4-inch flexible duct. On engine No. 1 a blast cap is installed instead of a flexible hose, which discharges air directly into the nacelle. A mechanically operated shutoff valve, located at the intake of each duct or blast cap, is one of many items controlled by an emergency engine shut-down handle. There are four such handles, one per engine, and they are located below the center windshield in the flight station (see Figure 13).

There are fins on the forward end of the generator rotor, but a fan attached to the aft end does most of the work in maintaining the cooling air flow through the duct and generator, and exhausting it through openings in the forward end. The fans enable slightly in excess of rated power to be obtained on the ground and, in flight, the additional ram effect from the oil cooler scoop provides sufficient cooling for the overload ratings. The aft fan, in conjunction with baffles built into the generator aft cover, also serves to deflect moisture in the air away from the brush assembly, thus avoiding any possible brush icing problems. It should be noted that by removal of the two-piece cover which is held in place by a clamp, the brush assembly, slip rings, and the aft fan are all completely exposed for inspection.

Each generator weighs about 100 pounds and although this is extremely light in relation to its output (its commercial equivalent would weigh about half a ton) it is still rather heavy for handling during installation and removal. However, either task can be accomplished by two men without too much difficulty provided a workstand of suitable height is used and the generator installation nuts are left on the studs (tops of nuts flush with tops of studs) when removing or replacing the generator. The latter proviso permits easy rotation of the generator, which has keyhole type mounting holes in the attachment flange. A wrench kit is available for use on the generator and two-speed gear box attachment nuts. The placement of a one-inch thick board (1 ft. by 4 ft. approx.) across the lower cowl panel will also facilitate generator handling.

Two 6-gauge wires are used for each phase out-

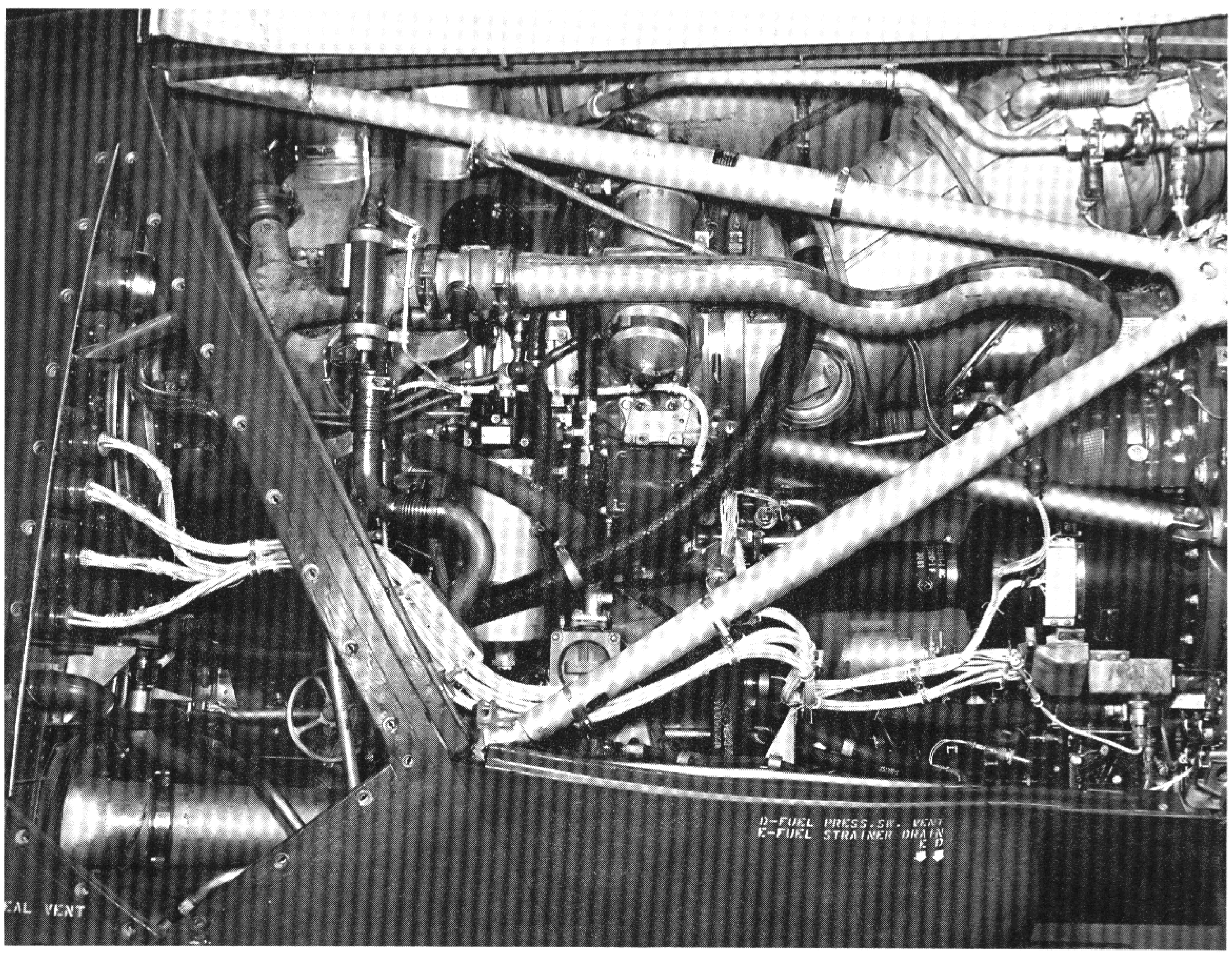


Figure 4
Generator Nos. 2 or 3
Installation

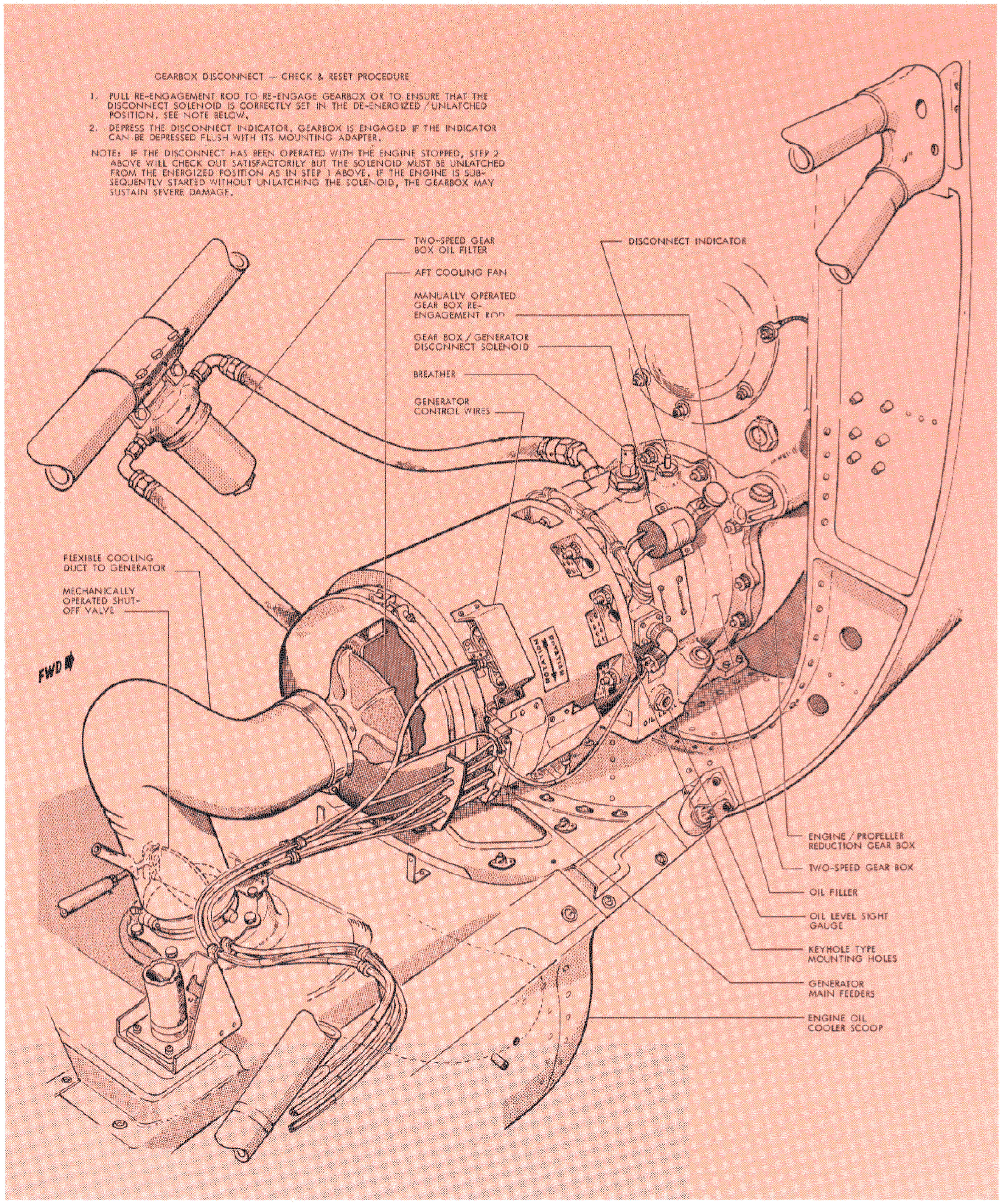
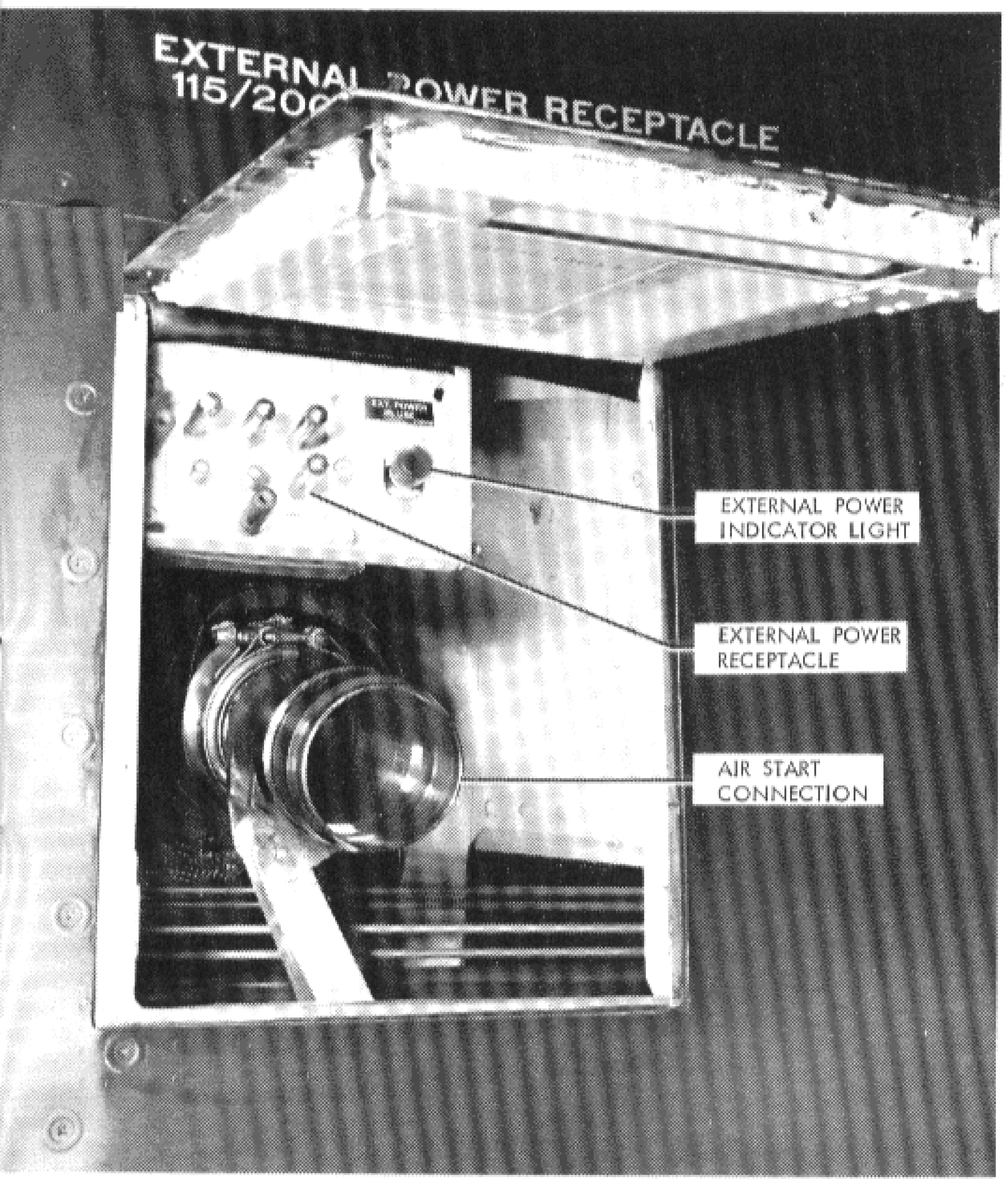


Figure 5
Generator No. 4
Installation

put from the generator rather than a single heavier gauge wire. Thus each of the 3-phase generators has a total of six main feeder wires, and a single 4-gauge wire serves as the generator neutral or ground. To minimize the possibility of crossed wires, the wiring and the terminals of each generator are color coded, and this practice has been used on many of the 3-phase circuits on the airplane.

Each generator installation includes the smaller wires of various warning and control circuits, which are as far as practicable routed separately from the power wiring. However, all generator wiring passes through the engine firewall and all the ground wires including the generator neutral are terminated on the nacelle structure aft of each engine firewall. The remainder of the wiring progresses inboard inside the wing leading edge (see Figure 6), enters the pressurized fuselage shell through pressure seals, and thence into the main load or service center (see Figure 7). Between the generators and the service center, the only break in the main feeder wires is at the engine firewalls, where fireproof connectors are provided for all wires to facilitate powerplant removal.



External Ground Power Receptacle

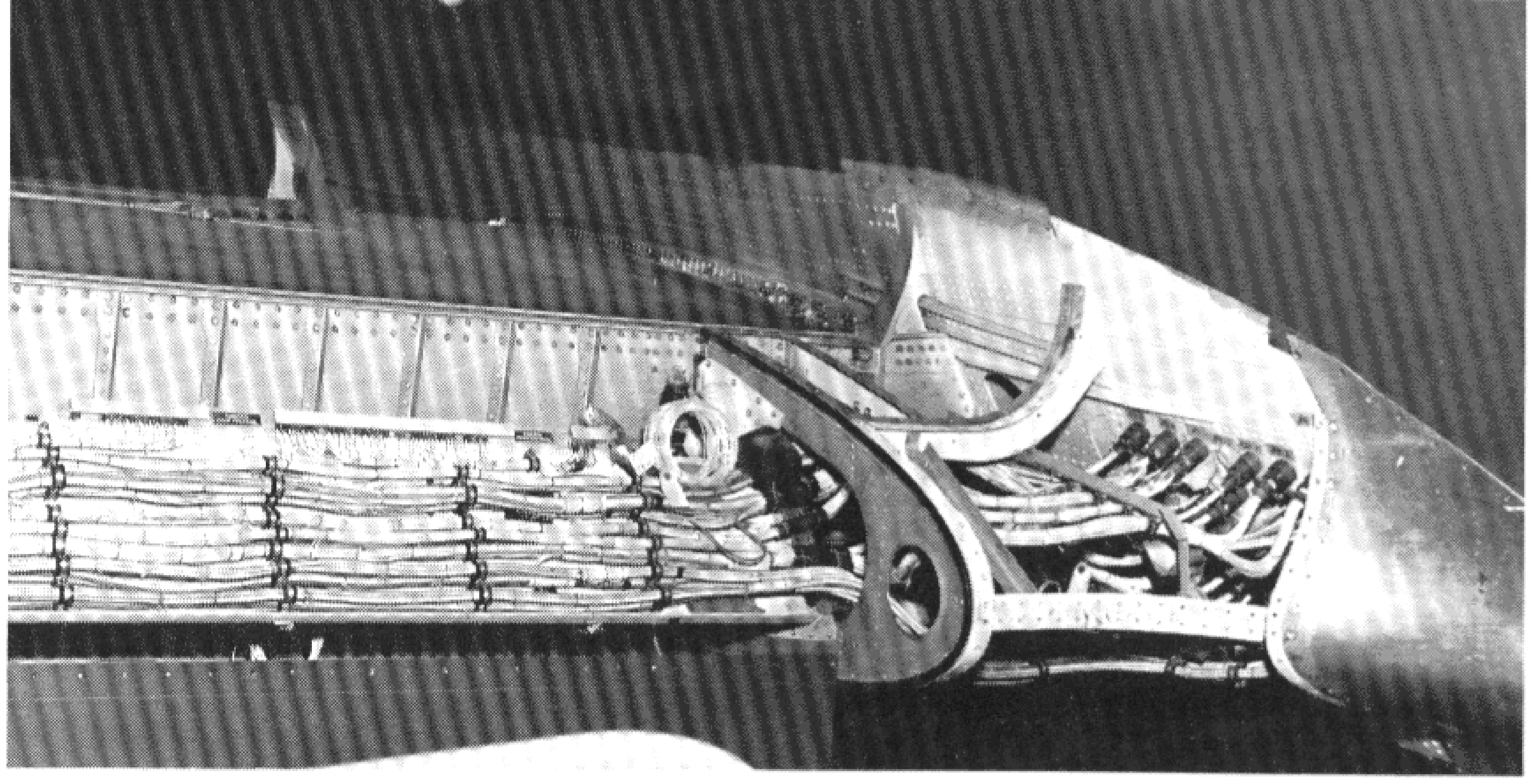


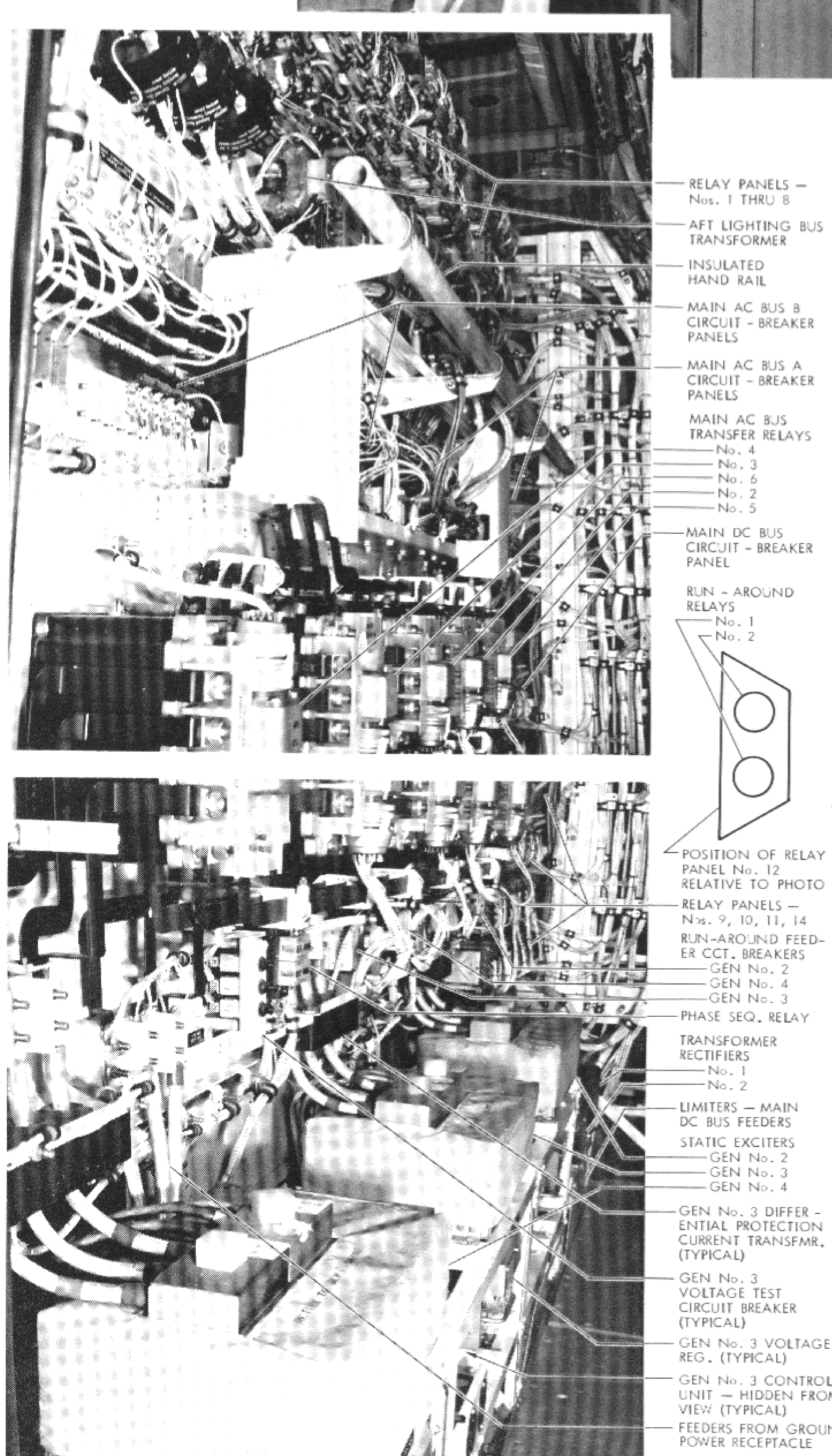
Figure 6 Wire Runs in Wing Leading Edge

Figure 7 Main Load Center

MAIN LOAD CENTER This compartment is located just forward of the wing center section on the starboard side of the cabin. It may be considered as the nerve center of the Orion's electric system since all the components which control and protect each of the generators are found here, together with both main ac buses and their associated circuit breaker panels, and the main ac bus transfer system — consisting of five large relays and the automatic transfer control circuitry.

The Nos. 1 and 2 transformer-rectifiers are also located in the main load center. Separately powered from the two main ac buses, these two transformer-rectifiers, as previously mentioned, supply 28-volt dc power to the Main DC Bus. This bus with its associated circuit breaker panel is found in the main load center, but an *extension* of the Main DC Bus (and so named) is located in the forward load center.

Although there are many more miscellaneous relays and other equipment, the above accounts for all the major components in the main load center. Advantage has been taken of the ample cabin space available on the Orion to install all the various electrical units neatly along one side of the compartment leaving room for a person to walk between them and the fuselage side (see Figure 7). There is an entry door at the aft end of the load center and an insulated hand rail has been provided so that, in an emergency, the compartment may be entered during flight. The arrangement of equipment gives the maximum in accessibility. All units can be removed and installed without unduly disturbing others; in particular, the



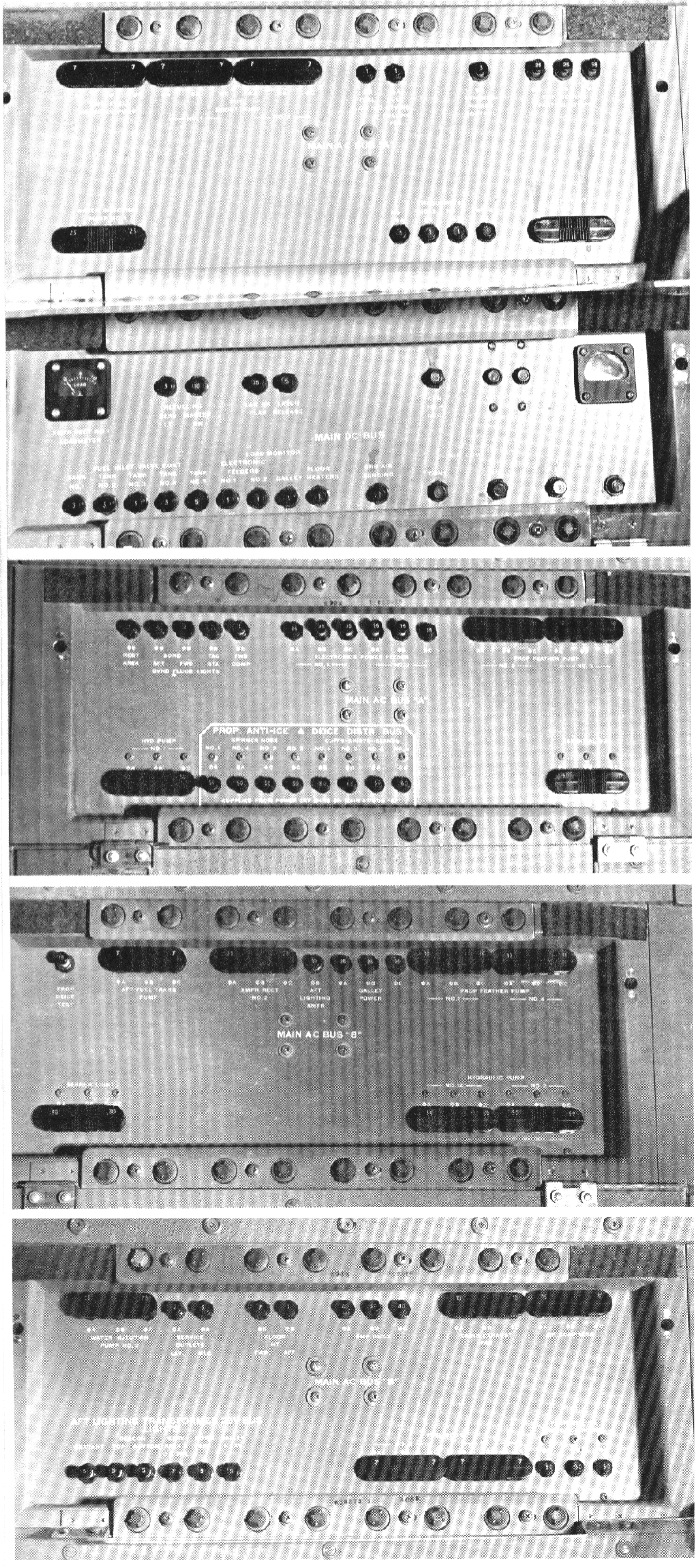


Figure 8
Main Load Center
Circuit-Breaker Panels

main transfer relays have been mounted on panels allowing relay removal from outside the compartment after relay electrical disconnections have been made, and making it unnecessary to dismantle the bus bar connections on nearby components.

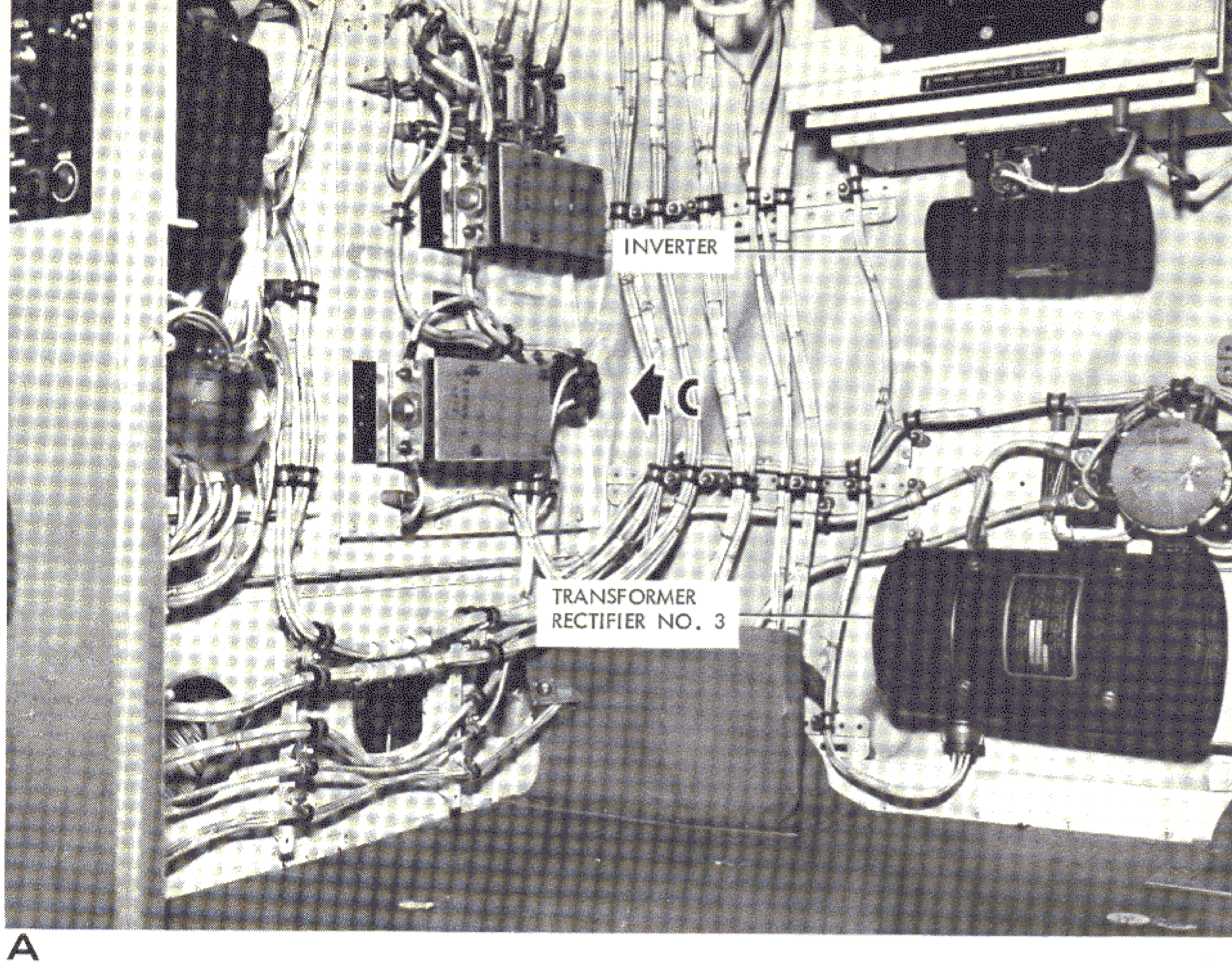
Like other major service centers in the main cabin, a cooling system is provided for the main load center to maintain temperatures below 130°F under the most adverse conditions. Cabin air enters the bottom of the equipment racks, rises through the various units, and is drawn off at the top into a trunk line that ducts the air overboard through the cabin pressure outflow valve. Whenever electric power is on, an exhaust blower near the outflow valve operates constantly and maintains the necessary cooling flow for the electrical equipment even if the cabin is not pressurized.

Each set of generator main feeders is first routed to its associated control components and then branch feeders go to the transfer system of the Main AC Buses and also to the Essential AC Bus transfer system — the latter being more generally known as the run-around system. An external ground power socket is located in the lower leading edge fillet area of the starboard wing, immediately below the main load center, and ground power feeders from the receptacle are also directed to the main ac bus transfer relay system.

FORWARD LOAD CENTER A compartment located on the right hand side of the flight station, the forward load center contains principally the Essential AC Bus, the Extension Main DC Bus, and the Essential DC Bus together with their associated circuit breaker panels. Transformer-rectifier No. 3, the inverter, a signal light control box, and various relays are also contained in this compartment (see Figures 9 and 10).

Two sets of 3-phase feeders to the Essential AC Bus and three direct-current feeders to the Extension Main DC Bus supply power from the main load center to the forward load center. These power feeders and other wiring runs are installed on the right side of the fuselage behind readily removable access panels.

The equipment installed in the forward load center is accessible through the hinged circuit breaker panels and the removable lower panel. A fixed panel near the floor carries the Flight Essential AC and DC Buses so that they are, as far as possible, physically



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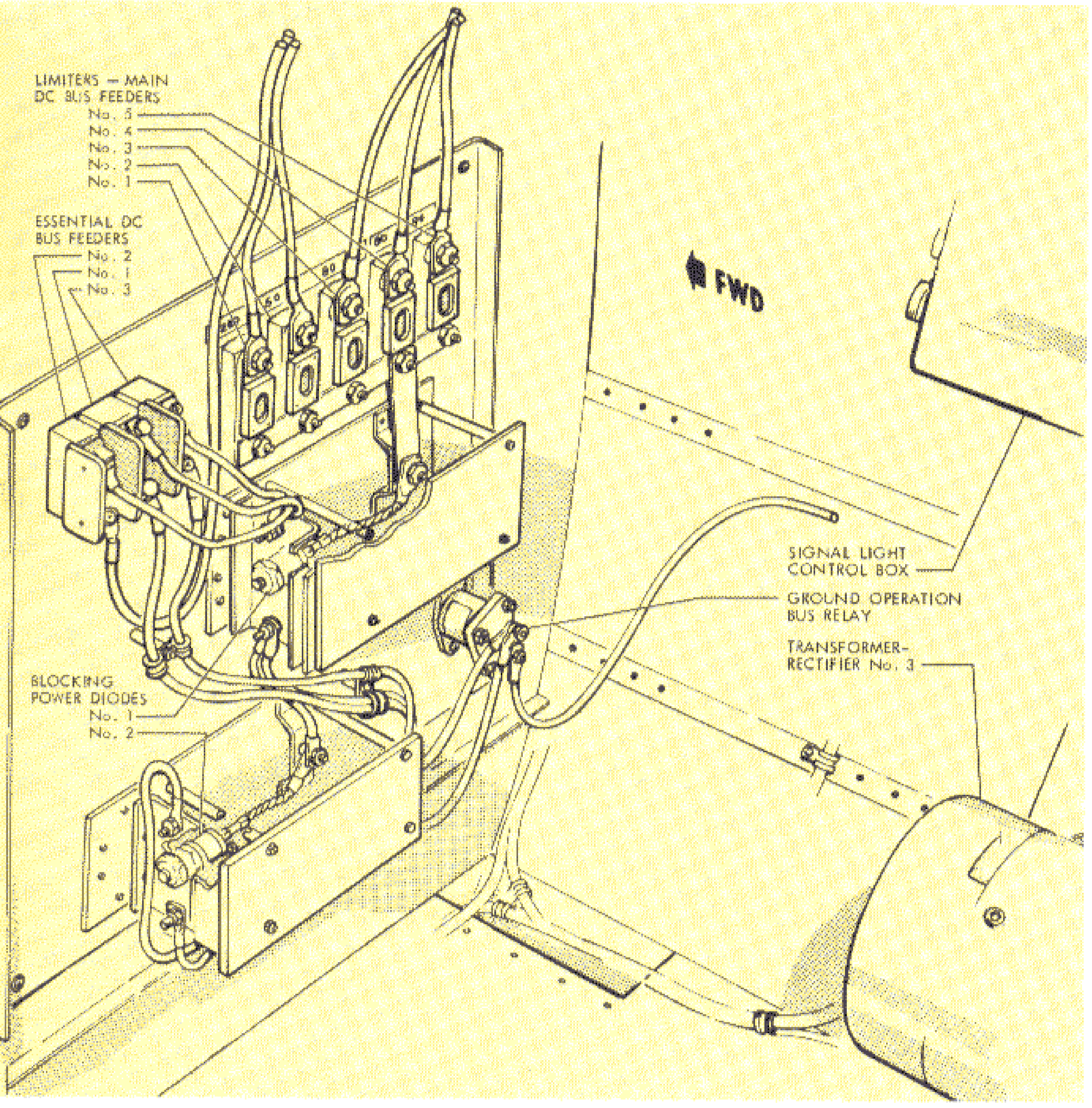

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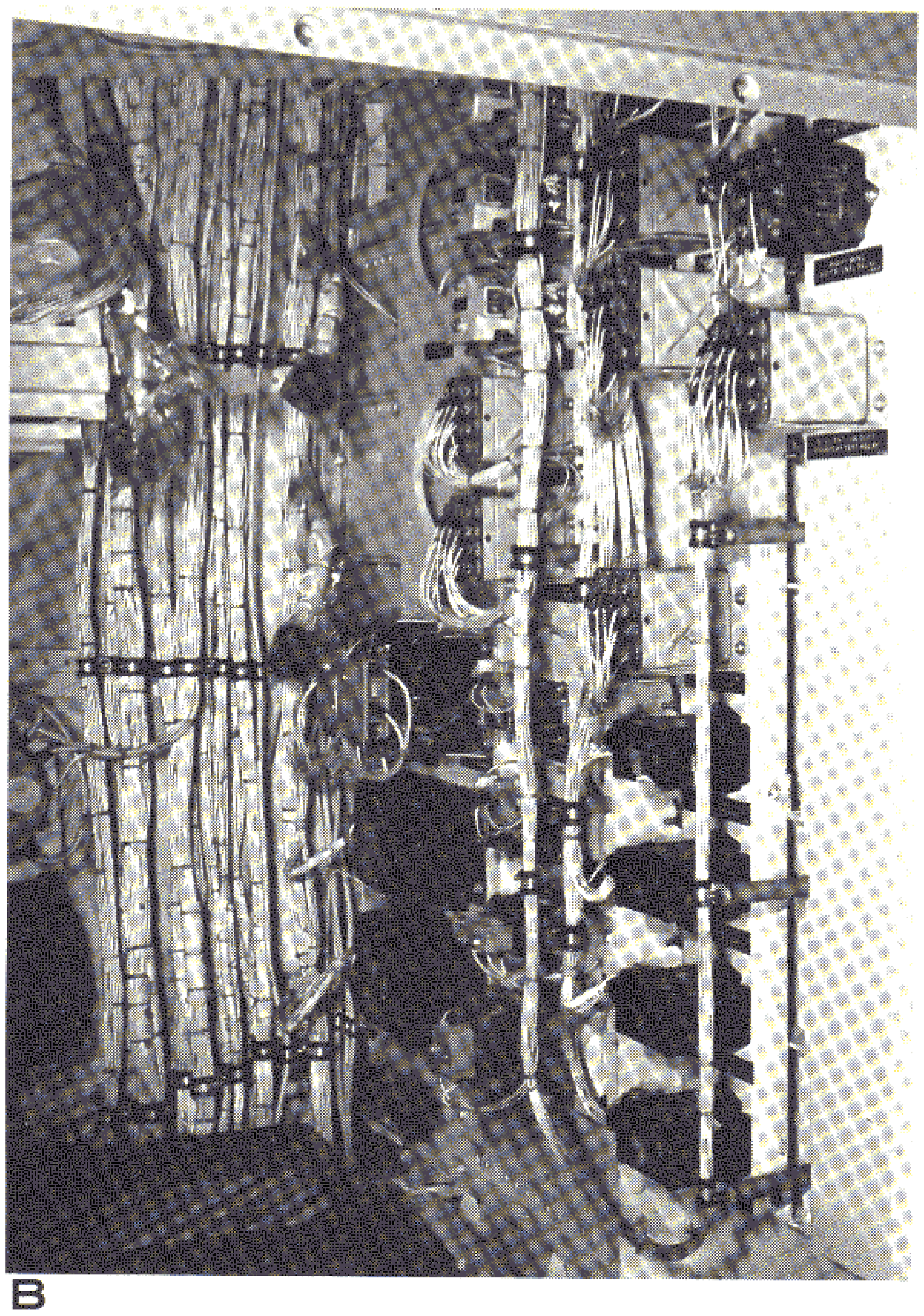

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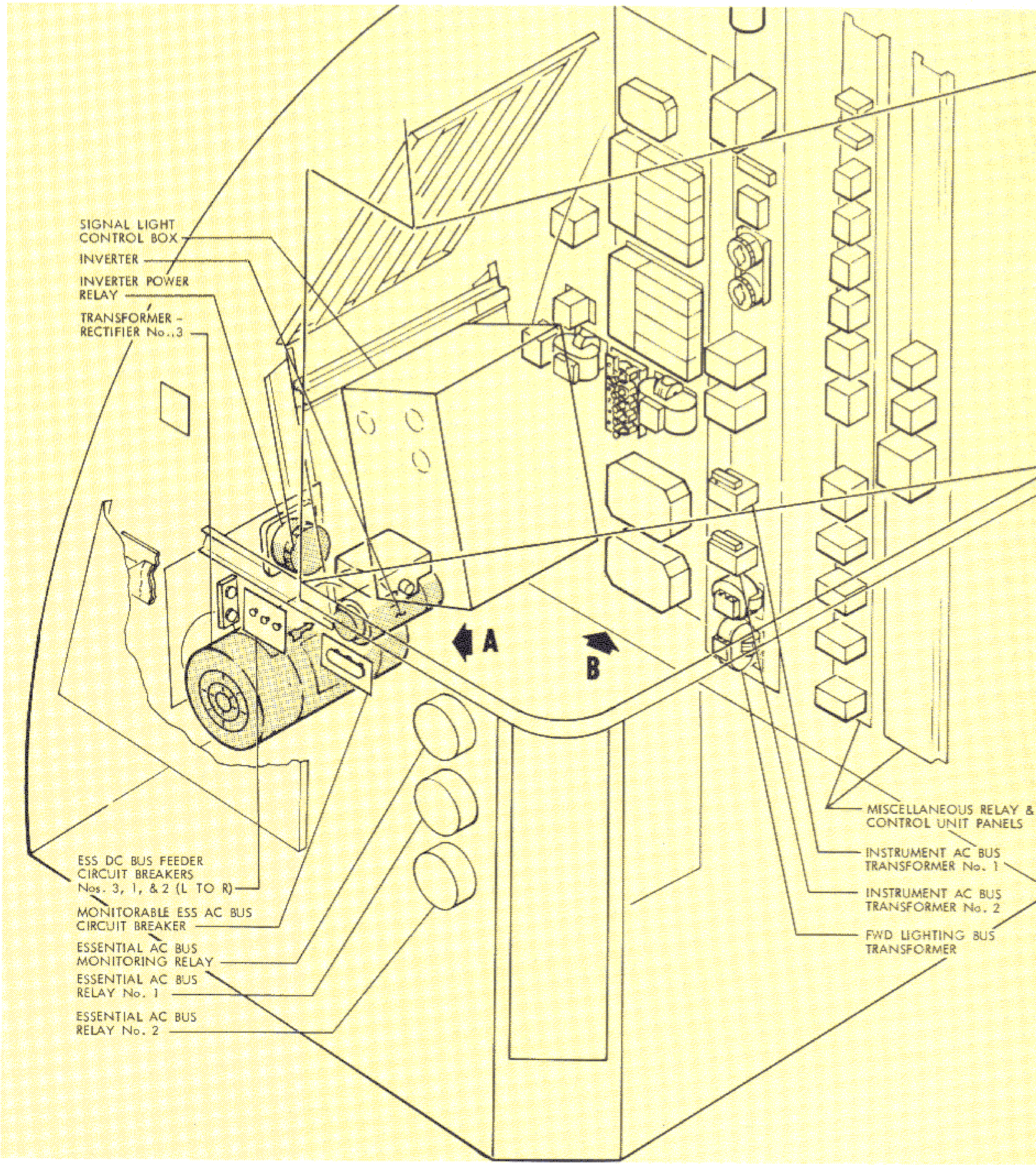
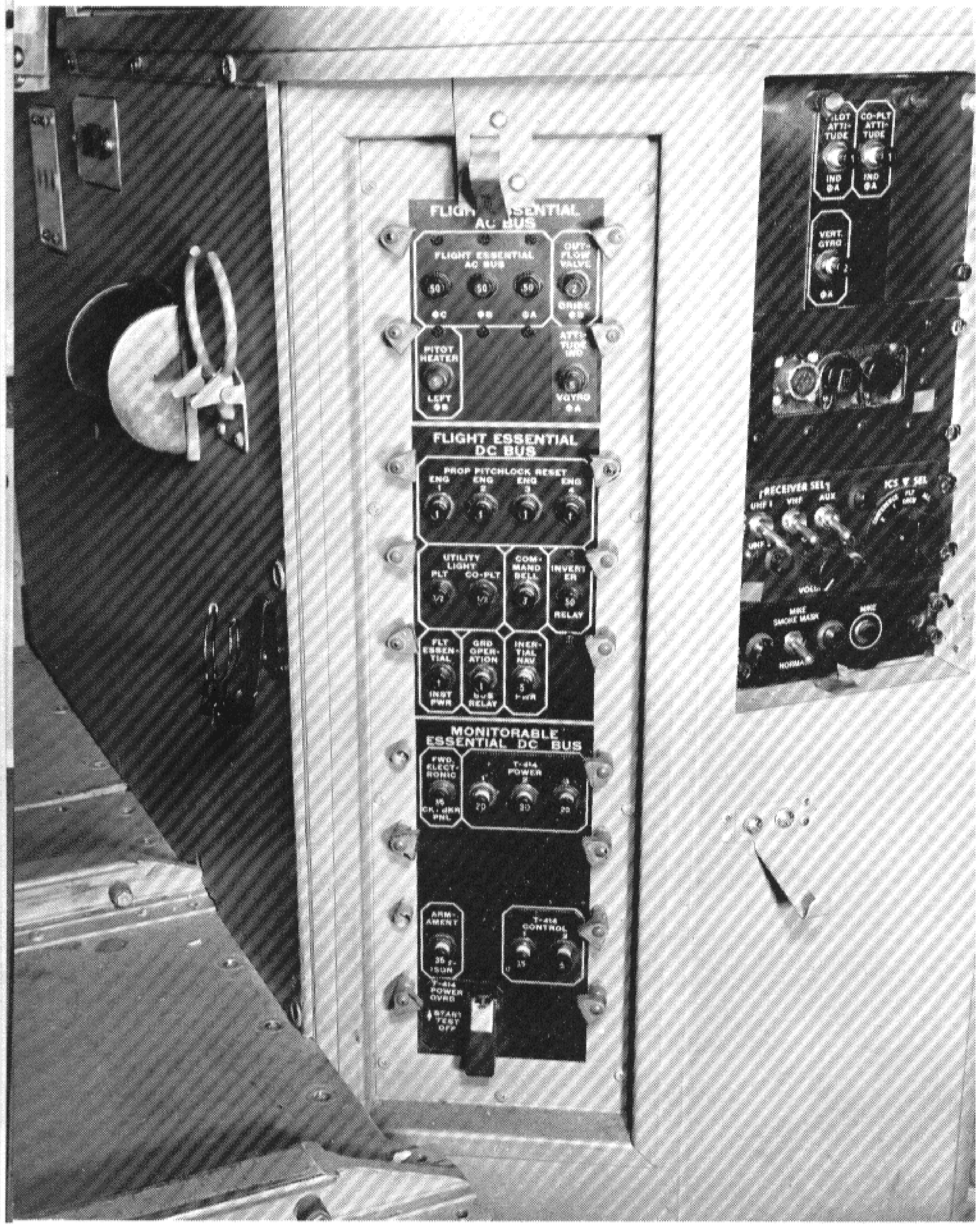
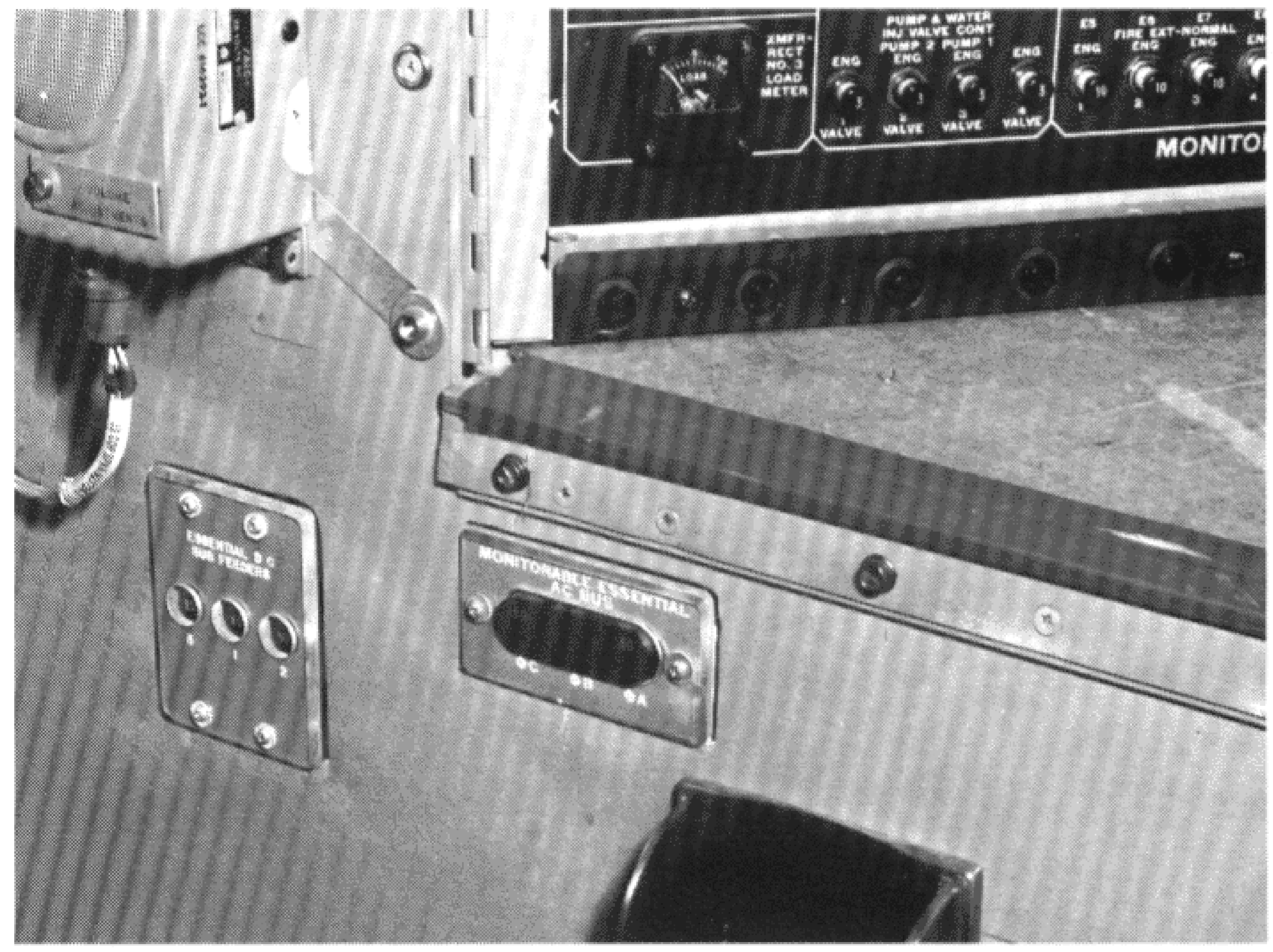
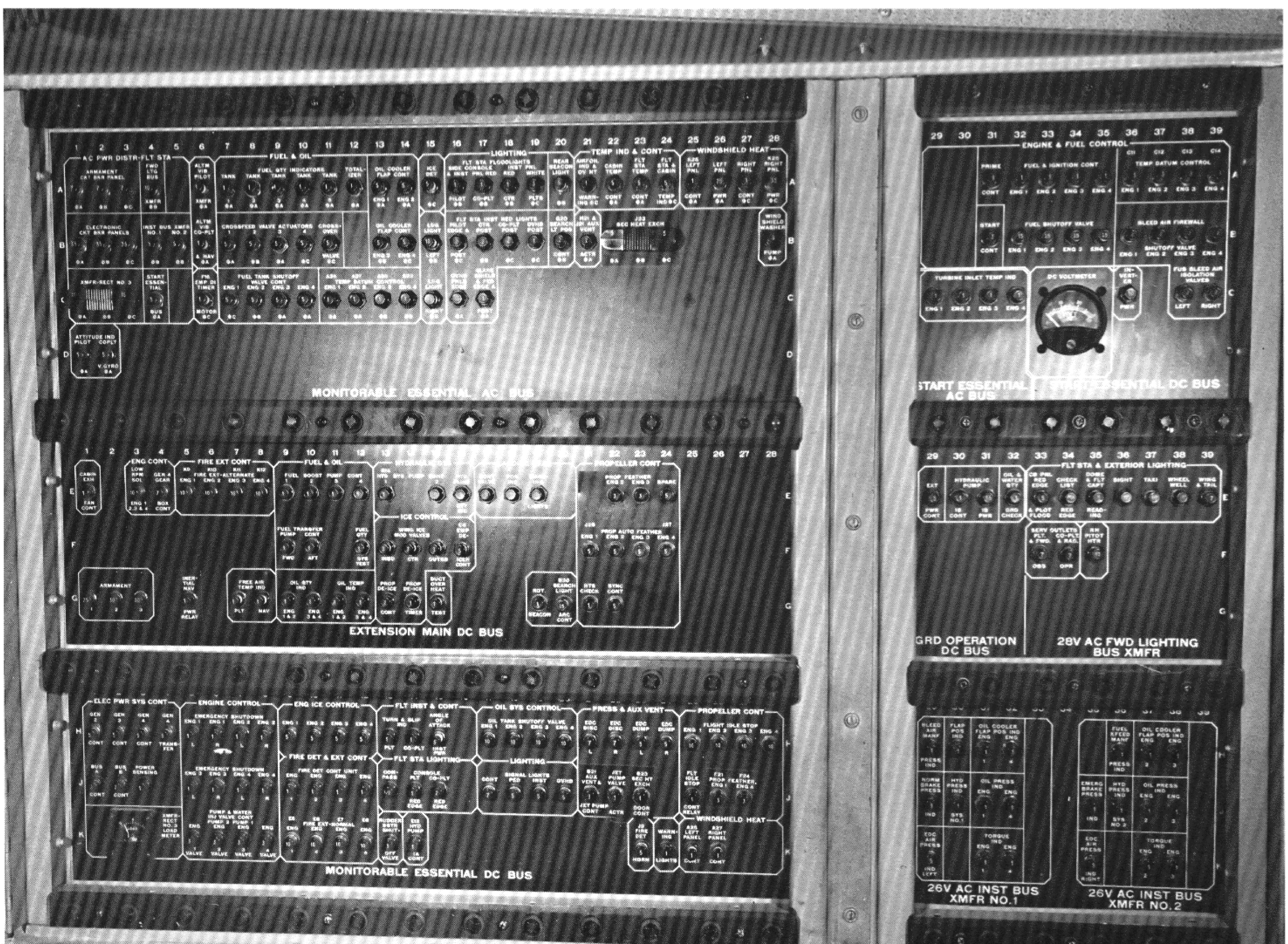


Figure 9 Forward Load Center

Figure 10
Forward Load Center Circuit-Breaker Panels







and electrically isolated from the other buses and components. This location of the essential buses also provides minimum wire length between them and the battery and inverter.

The AN 3154-1A lead-acid battery is located just below the forward load center, on the right side of the nose gear wheel well (see Figure 11). Here it is almost ideally situated, being readily accessible for maintenance from the ground as well as being close to its associated bus. Rated at 24-volts dc with an 11-amperehour capacity, the battery is provided with a quick disconnect fitting for both positive and negative leads.

Most of the power system control switches and indicator lights are mounted on a small electrical control panel, which is located overhead between the plane captain (flight engineer) and copilot positions, but is also accessible to the pilot. The control panel reflects the efforts of the designers to keep the number of control switches, meters, and so forth of this essentially automatic system to a minimum (see Figure 13). Also shown in the illustration are the engine low rpm switches, the engine start selector, and various caution and warning lights, which are also associated with the electric power system.

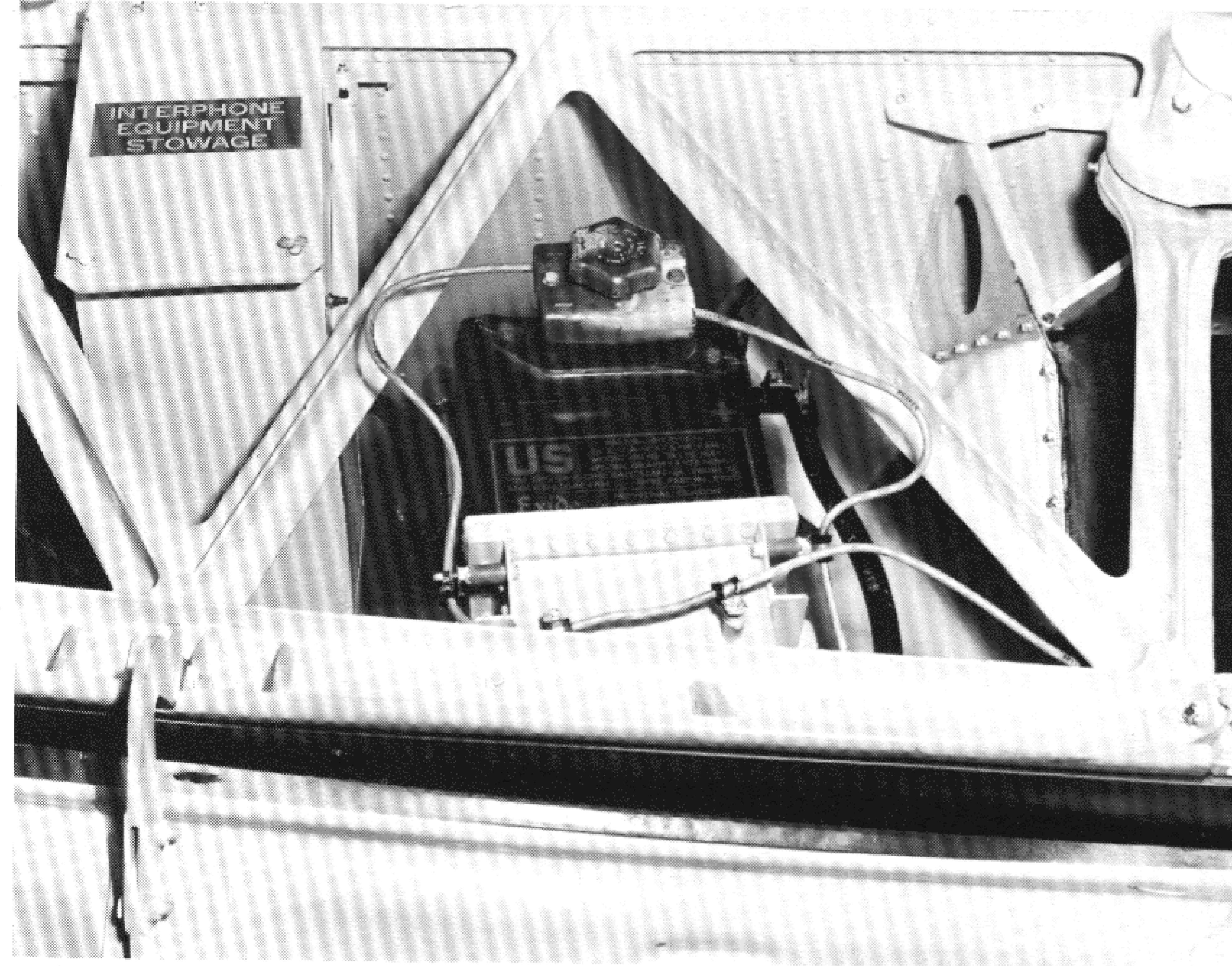


Figure 11 Battery Installation in Nose Gear Wheel Well — Cover Removed

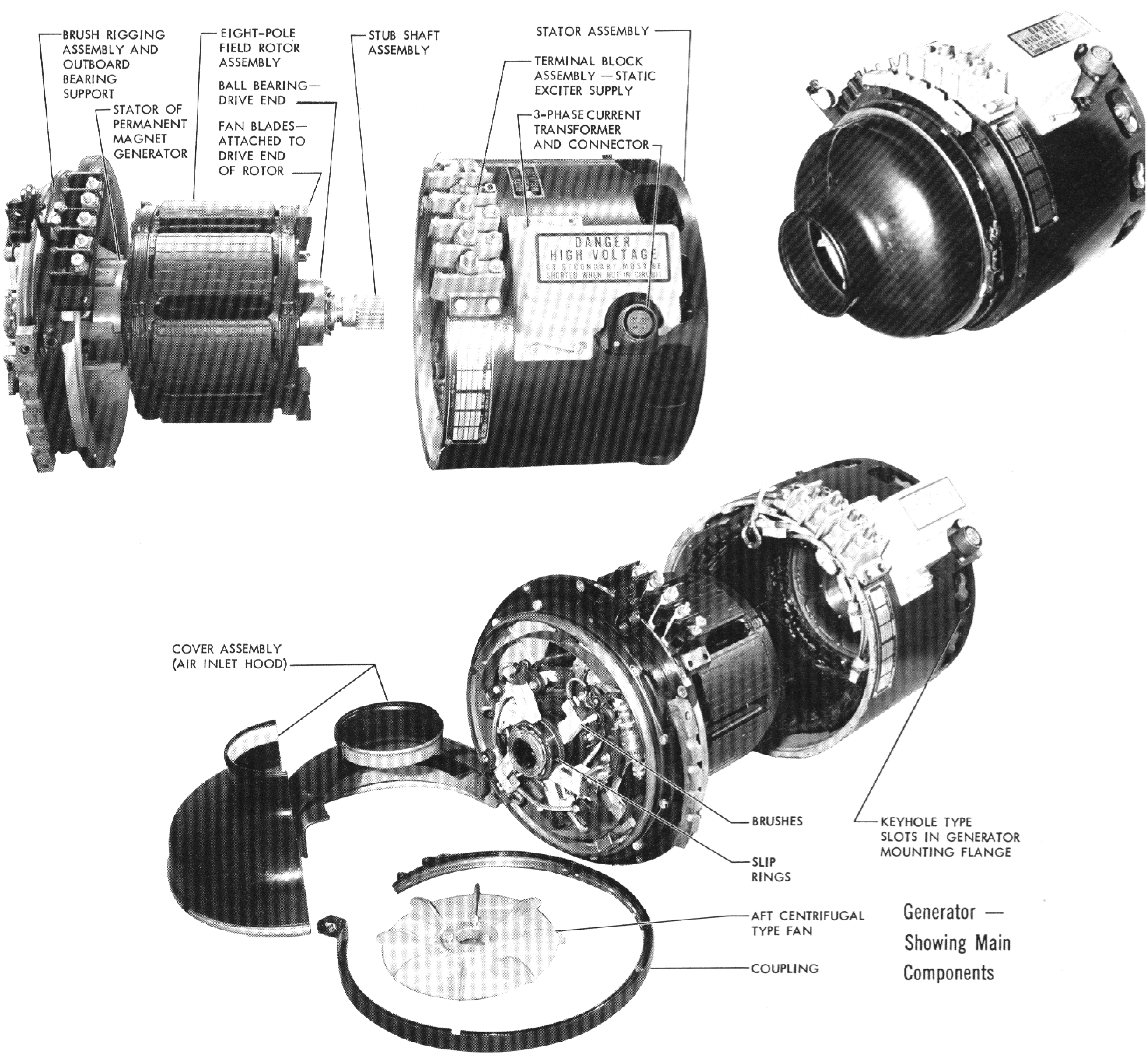
POWER CIRCUIT DESCRIPTION

Having now discussed the basic design concepts of the electric power system and briefly described the physical locations of the principal electric components, we shall now describe the system in more detail. A complete, although still rather simplified, electric power circuit is depicted in Figure 17, and it will be noted that as a further aid in creating a mental picture of the power system, this illustration has the same subdivisions with regard to component location as the "Location of Principal Components" section.

Much of the following text is devoted to explaining this schematic, although there are a few intervening diagrams to help the explanation. Figure 17 shows a bare minimum of the various components which comprise each of the three generation systems. The operation of these will be described in detail in a future issue of the *Digest*, but the following brief description is included here in order to facilitate the discussion of the rest of the power system.

GENERATION SYSTEM The General Electric generation system was designed and developed for the Electra commercial transport, which actually uses four such systems to the Orion's three. Since proven unusually successful with many years of service experience, each of the three generation systems is basically unchanged in the Orion application and consists of four main components: a generator, a static exciter, a voltage regulator, and a control unit. The general arrangement of these units can be seen in the block diagram (Figure 12) and, with the exception of the generator, they are all located in the main load center. The two-speed gear box, which is closely associated with the No. 4 generation system, is also shown in Figure 12, but its function is described later.

Each 3-phase, wye-connected generator is rated at a nominal 60-kva, 120/208-volts ac, 380/420 cps, at 5,700/6,300 rpm and, allowing about a 3-percent voltage drop, this output results in a minimum bus voltage of 117/202 volts. Although nominally rated at 60 kva, the generator, with the ram air cooling available in flight, is capable of supplying a 90-kva overload rating continuously without reducing the service life. On the ground, the cooling induced by the integral fans allows continuous operation at 70 kva. One interesting design feature is the provision of a mechanical-failure warning light for each generator. Should the rotor contact the stator, due to a



Generator — Showing Main Components

bearing or other mechanical failure, a circuit is completed to ground which illuminates the pertinent red warning light on the center instrument panel (see Figure 13).

The generator's 3-phase output is fed through the static exciter, which uses both a voltage and a current signal from each phase to supply dc power for excitation of the generator field. The amount of this feedback or field excitation power is closely governed by the voltage regulator which, in effect, makes the static exciter more responsive to sudden changes in load and, under steady operating conditions, acts as a trimming or vernier device. The control unit contains control and protective circuitry, and also supplies the necessary signals for operation of the main bus transfer system.

Also shown in Figure 12, the permanent magnet generator (PMG) is an integral part of the main generator and rotates on the same shaft. As its name implies, the PMG has a permanent-magnet rotating field and it is therefore self exciting. In conjunction with a transformer rectifier in the generator control

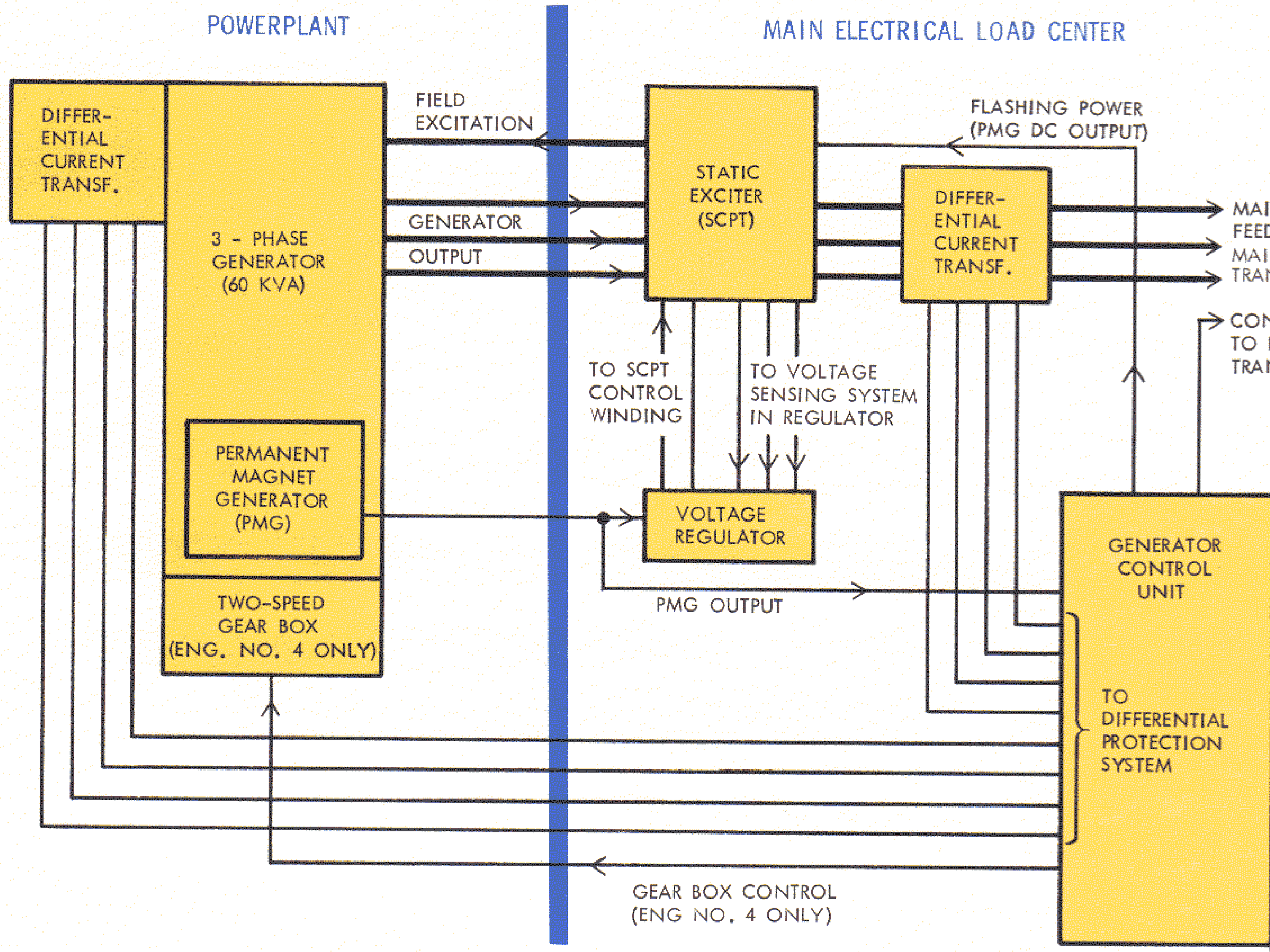


Figure 12
Generation System Block Diagram

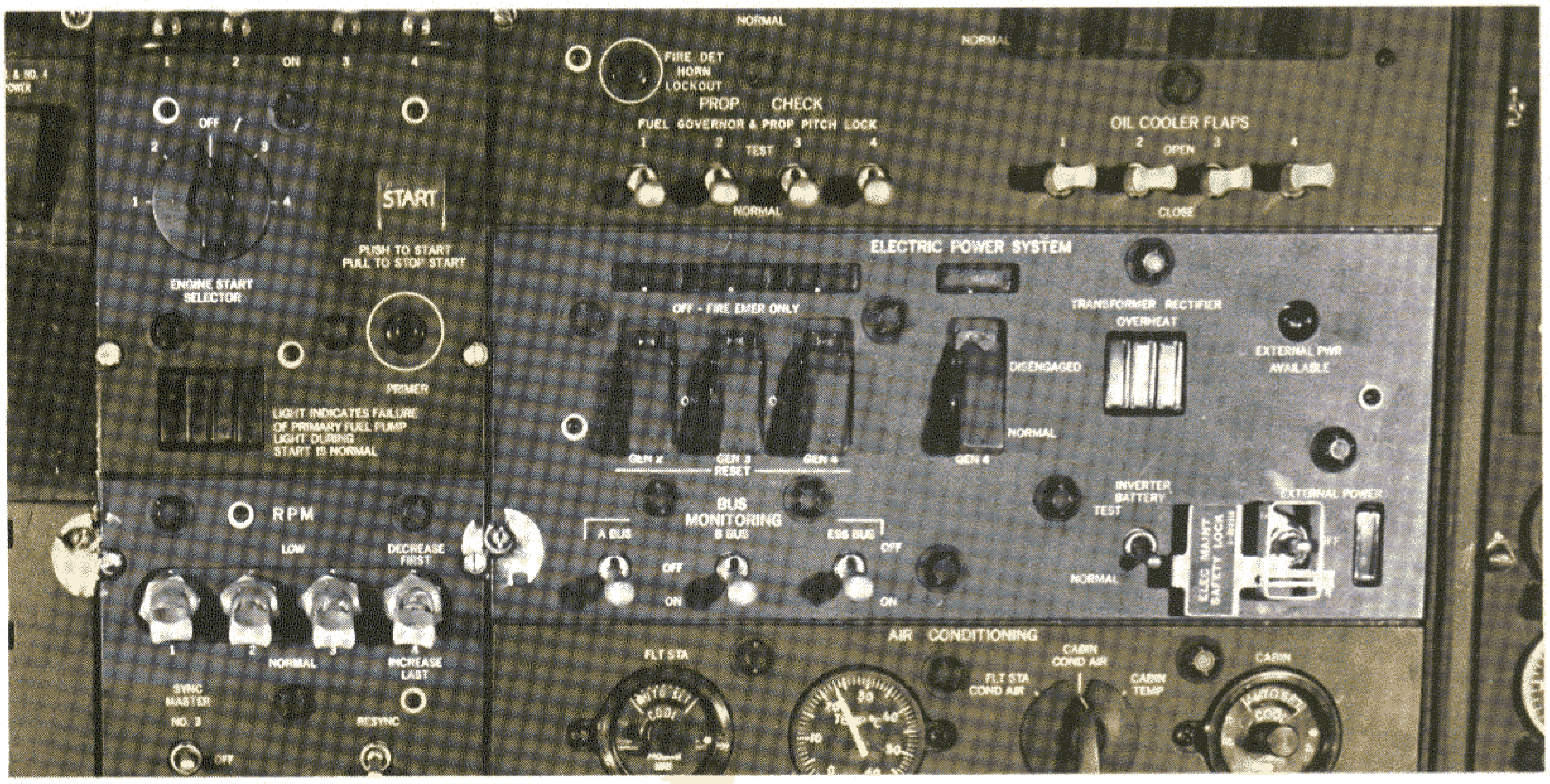
unit, it supplies flashing power to the main generator field, and is also used for a special application in the main ac bus transfer system. Since PMG output is independent of the main generator power and the aircraft battery, this is a significant and important feature, as will be shown later in this discussion.

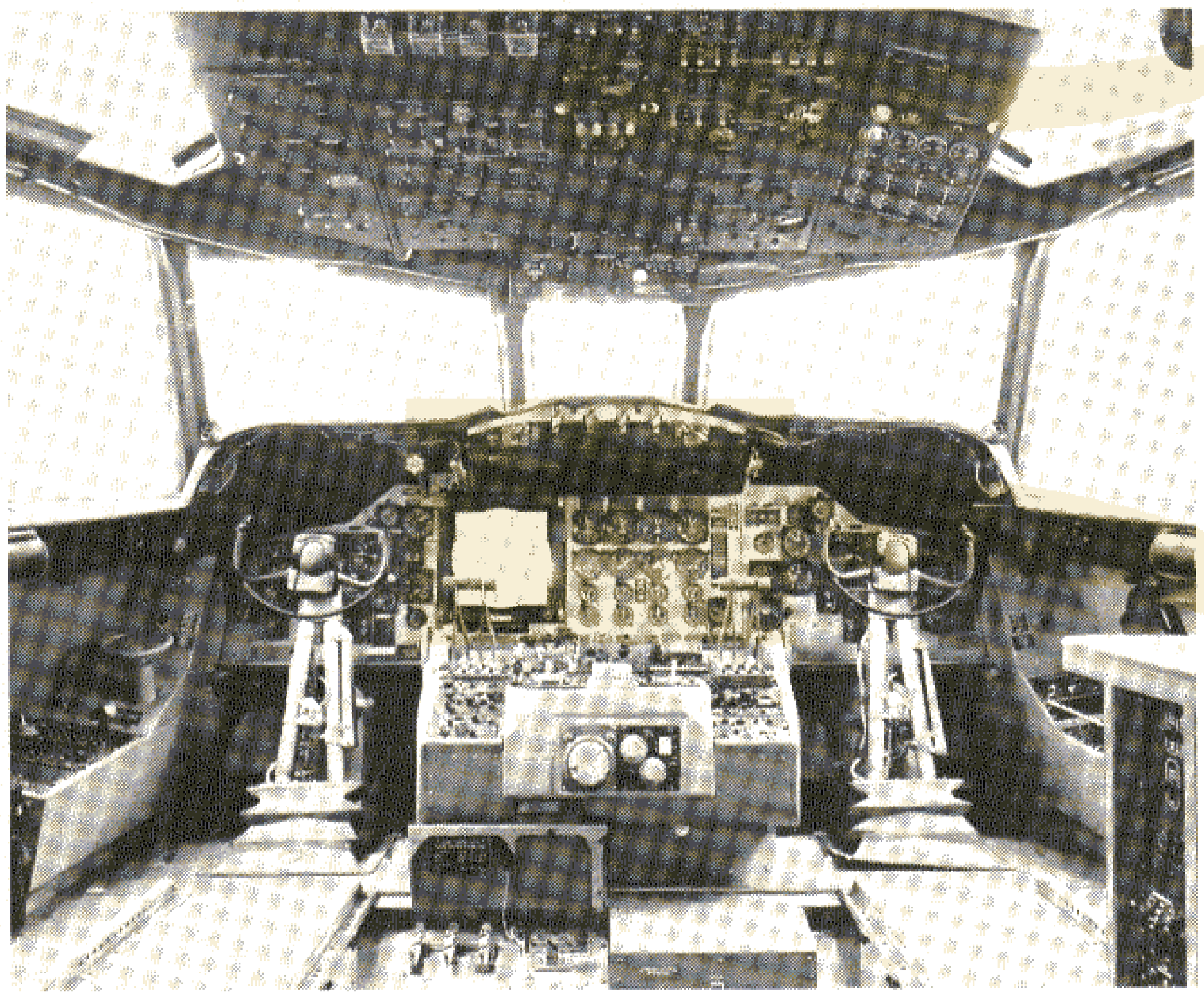
A brief review of the control and protective functions of the three generator control units is in order. As previously mentioned, these functions include the automatic operation of the main bus transfer relays which, in turn, control the distribution of all power on the aircraft with the exceptions of aircraft battery power, and the alternative "run-around" power supply sources to the Essential AC Bus (see Figure 2).

Generation System Protective Circuits Each generator control unit contains protective circuitry to sense system malfunctions and to de-energize and disconnect the generation system automatically if such malfunction occurs. Associated with the protective circuitry are three generator control switches and three yellow GEN OFF caution lights (a switch and light for each generator), which are all located on the overhead electrical control panel. In addition, an ELEC POWER master caution light is located on the center instrument panel, (see Figure 13), where it is most likely to attract the attention of the flight crew. This master light is illuminated whenever one of the GEN OFF lights is illuminated; it is also interconnected with the generator No. 4 DISENGAGE light and the transformer rectifier overheat lights. The function of the master caution light is to alert the crew that one of the electrical power caution lights on the overhead panel is illuminated. Subsequently, the master light can be extinguished by momentarily depressing the master reset switch adjacent to it. The master light is thereby disconnected from the specific circuit signalling the fault until the fault is corrected. The light will, however, be available to the remaining connected circuits.

Off-Frequency If the generator is operated at speeds which result in an output frequency either higher or lower than the specified range, it is automatically de-energized and disconnected from its load (bus) and the load is transferred to another generator if one is available. If the generator subsequently operates within the specified frequency range (as evidenced by its PMG) it will be re-energized and reconnected automatically, and operation of the generator control switch (GCS) is not required. During off-frequency operation, the pertinent GEN OFF and the ELEC POWER lights are both illuminated.

We should perhaps mention that although regarded as a fault-sensing circuit, the off-frequency network functions during normal operation as an automatic means of switching each generator on and





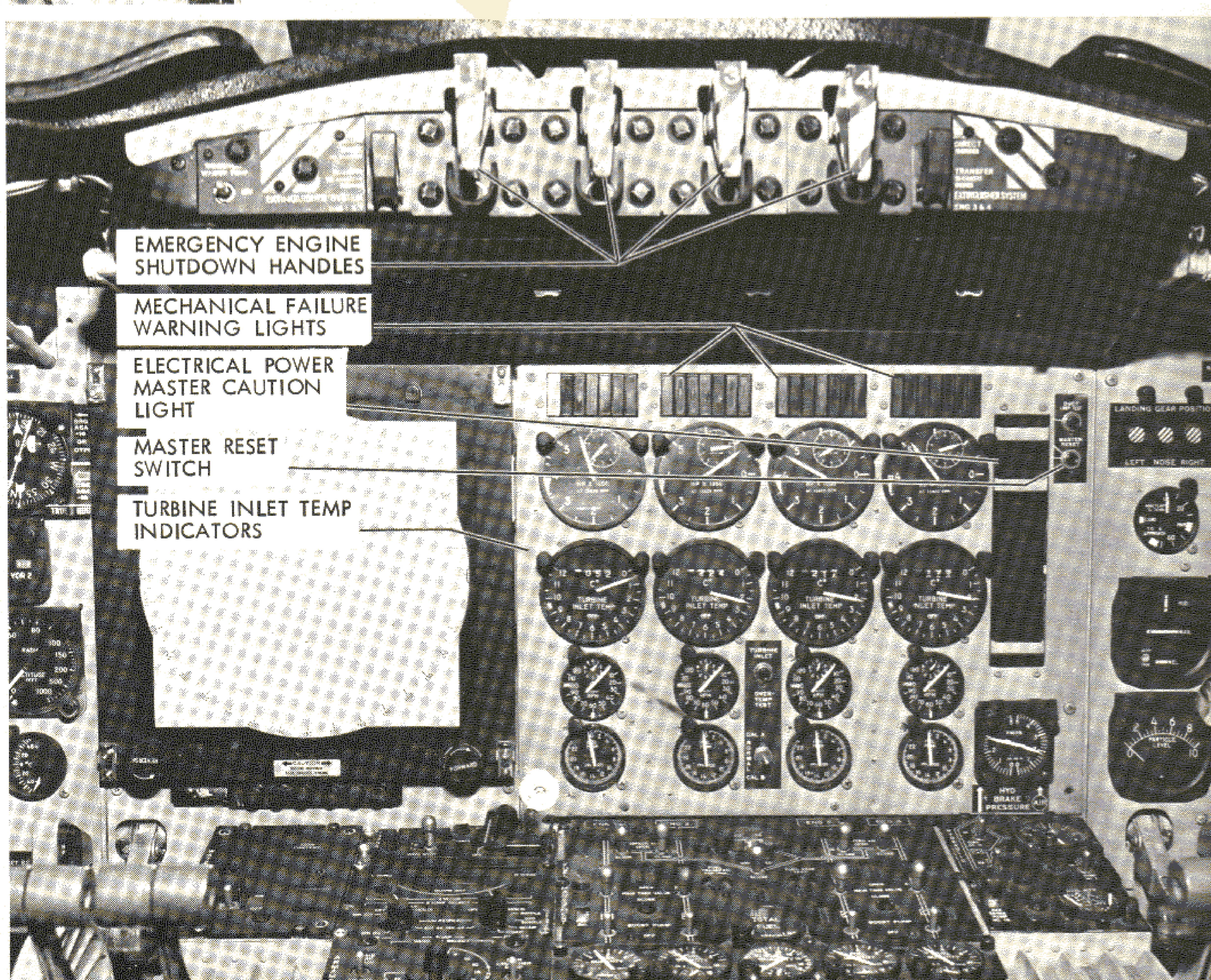


Figure 13

Flight Station Controls and Indicator Lights off. A guard on each GCS retains the switch in the ON position and the generator is automatically energized when it comes up to speed and vice versa.

Overvoltage When an overvoltage condition is sensed by the generator control unit, the generator is de-energized, is disconnected from its load, and the pertinent GEN OFF and the ELEC POWER lights are both illuminated. The load is automatically transferred to another generator if one is available. The generation system may be reset for operation by selecting the appropriate GCS to the RESET position and releasing it so that it returns to ON. If the cause of the overvoltage was temporary, the generator will be energized again, the caution lights will go out, and the generator will assume its load. If, however, the overvoltage condition still exists, the generator will trip again.

Undervoltage When an undervoltage condition is sensed by the generator control unit, a time-delay circuit allows the condition to exist for about 3 to 4 seconds to permit branch circuit protection to operate. If the condition is caused by an overload on a branch circuit, the pertinent circuit-breaker should disconnect the malfunctioning circuit, and normal generator operation will be restored automatically. If the undervoltage still exists at the end of the time delay, the generator is de-energized, is disconnected from its load, and the pertinent GEN OFF and the ELEC POWER lights are both illuminated. The load is automatically transferred to another generator if one is available. Assuming the cause of the undervoltage is rectified or isolated it is necessary to open and close the appropriate generator control (GEN CONT) circuit breaker with the generator control switch held in the RESET position in order to restore generator operation.

Feeder Fault If a fault occurs in the feeder lines between the generator and the main load center, a differential current protection system senses the fault, de-energizes the generator, disconnects it from its load, and the pertinent GEN OFF and the ELEC POWER lights are both illuminated. The load is transferred to another generator if one is available. It is impossible to reset a generator after a feeder fault without stopping the engine which is driving the generator. It will be noted in Figure 12 that the major portion of the differential protection circuit is contained in the generator control unit, but differential current-sensing transformer assemblies are located on each generator housing and at the point where the generator feeders leave each static exciter and enter the insulated main transfer relay panel, thus affording protection over the full length of the feeders, and also including the generator stator.

In Brief, the Generator Control Circuitry automatically recognizes the availability of a generator or any malfunction in the generation system. It then signals the flight crew by means of caution lights, and initiates the appropriate action. The control circuitry de-energizes a malfunctioning generator and transfers its load to another generator by controlling the operation of the main bus transfer relays. This summation is true for all malfunctions (Off-frequency, Overvoltage, Undervoltage, or Feeder Fault), and the indication to the flight crew in each instance is no different than if the GCS were simply selected OFF. However, from the previous discussion, it is apparent that the *nature* of a particular malfunction can be determined by the following action or reasoning:

1. Off-frequency is related to engine rpm and/or the state of the generator drive mechanism; the GCS is of course ineffective in correcting this condition, but generator reset is automatic if the cause of the off-frequency is corrected.
2. An overvoltage malfunction can possibly be reset by operation of the GCS alone, which should be selected to RESET and released.
3. An undervoltage malfunction requires the selection of the GCS to RESET while opening and closing the pertinent GEN CONT circuit breaker in order to reset the generator.
4. A feeder fault requires that the engine driving the generator be stopped before the resetting procedure outlined in item 3 can become effective.

It should be emphasized that if operation of the pertinent GCS alone does not reset the generator then an undervoltage or feeder fault is indicated. It may be possible to locate the malfunction, and either isolate or correct it but, in any event, it is recommended that further generator resetting action as outlined in item 3 be carried out at some time *before* shutting down the pertinent engine. The decision when such action should be undertaken—either in flight, or on the ground at the termination of the flight—should depend on the pilot's judgement based on such factors as: the number of other generators available, whether the fault has finally been isolated by circuit breaker action, and the effect of a possible power transient on the inertial navigation system.

However, if the generator cannot be reset as outlined in item 3 (even if only for a short period of time), then it must be assumed that the generator trip was caused by a feeder fault. The pertinent GCS should be selected to OFF and *no further action should be taken.* The protective circuitry, which makes it necessary to stop the pertinent engine in

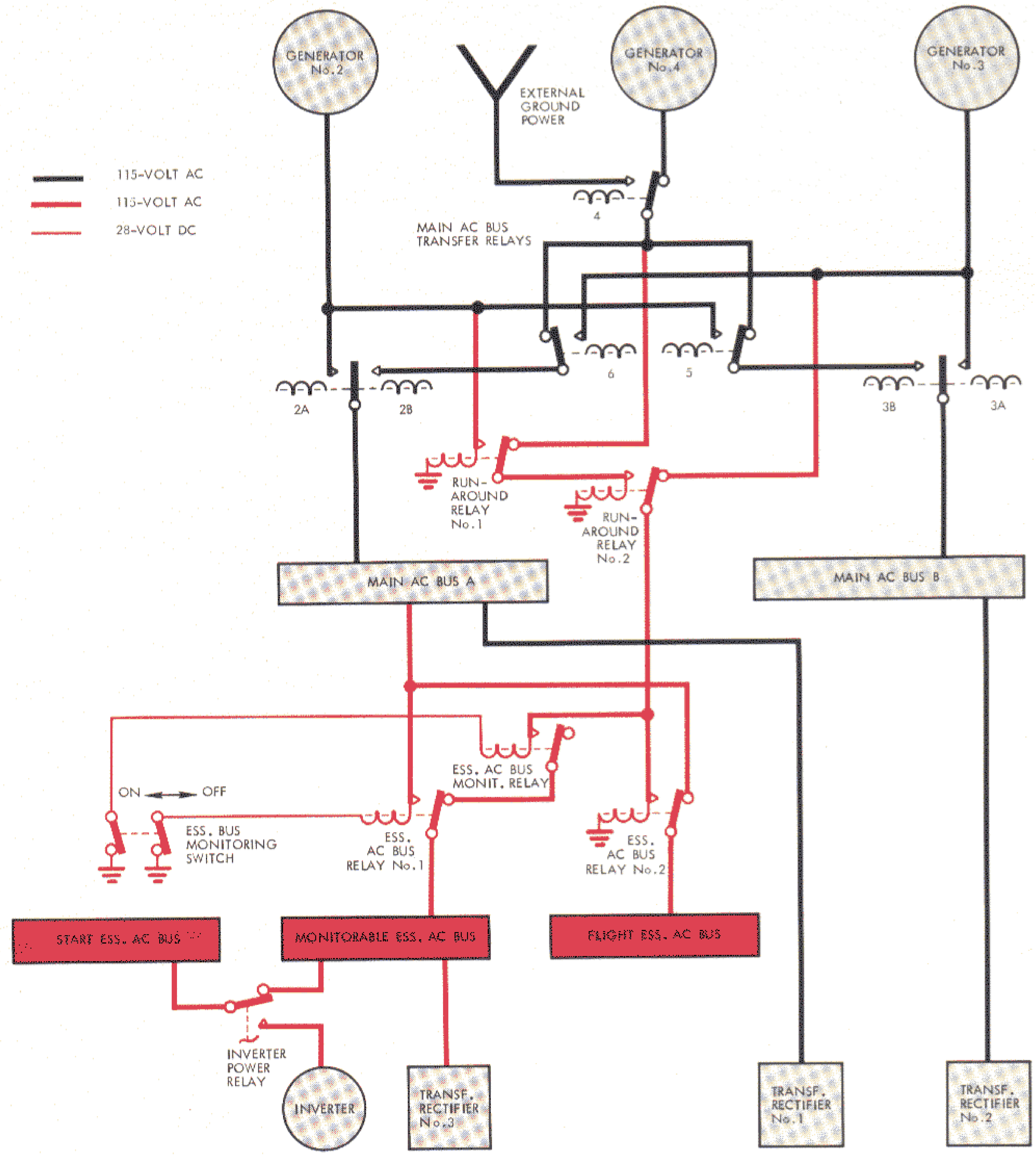


Figure 14
AC Power
System Schematic

order to reactivate a generator, is designed to ensure as far as possible that the generator is not reset in these circumstances.

We should point out that there are some excellent reasons why the item 3 procedure should be carried out before shutting down or feathering an engine. First, since stopping an engine nullifies the feeder fault lockout circuitry, then this protection is lost if an engine is feathered and unfeathered during flight (a normal procedure on some missions—particularly involving generator No. 4). Second, it follows from the first reason that the type of generator trip (undervoltage or feeder fault) can no longer be easily established without introducing the fault into the system a second time—a hazardous procedure if the cause of the generator trip was in fact a feeder fault. Thus, if the engine is stopped without attempting to reset a tripped generator, the only recourse left to the ground crew is to check out the complete generation system, before looking for more likely causes of the malfunction.

AC POWER TRANSFER AND DISTRIBUTION A simplified schematic showing the basic ac power circuit is depicted in Figure 14. It has virtually been extracted from Figure 17, which shows the same circuit in a little more detail. The 3-phase wiring in these schematics is shown by single thick lines but all the functional components such as relays are depicted. The same major ac components shown in Figures 1 and 2 are also shown in Figure 14 although it will be noted that the Essential AC Bus is shown subdivided into its three principal sub-buses: Start, Monitorable, and Flight.

Powered from phase A of the Monitorable Essential AC Bus, the Start Essential AC Bus feeds the turbine inlet temperature indicators—one per engine. The TIT indicators are probably the most important of the engine instruments and are essential during engine starting. Consequently the Start Essential AC Bus has an emergency single-phase power supply from the inverter, the power control circuit of which is described later.

The majority of the essential ac loads are carried on the Monitorable Essential AC Bus and these loads, as the name of the bus implies, can be monitored by operation of the essential bus monitoring switch. The Start Essential AC Bus is also monitored by operation of this switch but only insofar as its normal power supply is concerned.

The Flight Essential AC Bus is one of the most important buses on the aircraft and carries such loads as the pilot's pitot heater and the MM-4 attitude indicator, which could be vital to safe flight under certain circumstances.

The circuitry shown in red, including the run-around relays and the essential ac bus relays, is commonly called the run-around system, since it bypasses the main ac bus transfer system to give each segment of the Essential AC Bus a possible power source direct from any one of the generators. It is this system that is depicted by the three red lines on Figure 2. As can be seen in the Figure 14 schematic, the operation of its relays depends directly upon generator availability.

The main ac bus transfer system is shown in black and includes the transfer relays shown in Figure 14 with operating coils numbered 2A, 2B, 3A, 3B, 4, 5, and 6. These relays are controlled by a circuit which is interlocked with the three generator control units (not shown on this schematic), and each configuration of the relays follows the predetermined plan mentioned earlier and summarized in Figure 1.

The basic transfer system design and the "predetermined plan" is based on the aircraft requirements and the output available from the generators. As mentioned previously, each generator has a nominal nameplate rating of 60 kva but is capable of continuous operation at 90 kva under flight conditions.* Thus, with one generator on standby, the system capacity is actually that of two generators—totaling 120-kva nominal rating and 180-kva continuous overload rating. During design, evaluation of the potential power system capacity was based on both of these figures, but the overload capability of the generators was only considered in the design evaluation if de-icing loads (propeller and empennage de-icing) were included in the total aircraft load, or when evaluating single-generator operation. This was considered to be a reasonable practice as de-icing is required only infrequently in normal aircraft service and the loss of two out of three generators is considered to be a possible but unlikely emergency situation. The table below summarizes these design considerations and gives, in the last column, the potential growth capacity of the Orion's electric power system.

NUMBER OF GENERATORS AVAILABLE		MAXIMUM SYSTEM CAPACITY	PRESENT MAX. CONTINUOUS LOAD	FUTURE GROWTH CAPACITY
Three Gens. (#4 on Standby) or Two Gens.	Non-Icing	120 kva	54.2 kva	65.8 kva
	Icing	180	105.5	74.5
One Generator	Non-Icing	90	54.2	35.8
	Icing	90	86.4	Read Below

It will be noted from the above table that, even with the loss of one generator, the P-3 electric system has an excess capacity of 65.8 or 74.5 kva (depending upon icing conditions), which can be used for future developments. Considering the loss of two generators: for non-icing conditions, the excess capacity available for future growth is 35.8 kva—a lesser figure than the previous two but still more than ample for any requirements in the near future. However, if future requirements do exceed 35.8 kva, it will be necessary to monitor some of the non-essential loads for single-generator operation in non-icing conditions.

A similar situation already exists for single-generator operation when icing conditions are encountered. Should this unlikely emergency situation occur, an automatic non-essential load-monitoring circuit drops about 19 kva of non-essential loads (105.5 minus 86.4 kva) to keep the maximum continuous load below the maximum capacity of a single generator. The automatically monitored loads consist of the radiant floor heaters, galley equipment, and some electronic loads. It is further recommended that additional loads be manually monitored should this extreme flight condition be encountered (see the footnote on this page). In order to simplify the circuit descriptions, this non-essential load monitoring circuit has not been included in the schematics in Part One of this article.

With this background knowledge, the design and operation of the automatic transfer system, described

**The P-3A "Final Corrected Electrical Load Analysis" report gives a continuous overload rating of 80 kva (rather than 90 kva) for the installed generator. The reason for this is that the specified temperature rating of the generator feeders could be slightly exceeded at the 90-kva rating. A considerable saving in weight was achieved by using the minimum size feeders on the P-3A and they are more than adequate for the present number of electrical loads, while still leaving plenty of room for future growth. However, in the above discussion we have used the 90-kva rating from the standpoint that this is the potential rating of each generator on the P-3, which could, with little modification, be utilized in the future.*

and illustrated below, can possibly be better appreciated. The schematics are arranged in a sequence showing how the system copes with a series of malfunctions.

Transfer System Operation Figure 14 shows the generators and relays in a de-energized state, but Figure 14a, by means of light and dark lines, depicts the state of the system with all three generators energized under normal flight conditions. For reasons of clarity, the manually-operated essential bus monitoring circuit and the three transformer-rectifiers have been omitted from Figures 14a through 14e; this monitoring circuit is not used except in rare cases of emergency and is not important to the present discussion. (Incidentally this is a different monitoring circuit to the automatic monitoring circuit mentioned previously.)

In Figure 14a generator Nos. 2 and 3 are connected to their normal buses while generator No. 4 is shown energized but on standby. The Monitorable Essential AC Bus is connected to the Main AC Bus A while the Flight Essential AC Bus is connected directly to generator No. 2. It will be noted that the relay coils 2A and 3A are the only energized coils in the main transfer system under these normal flight conditions, but all of the run-around and essential bus relays are energized.

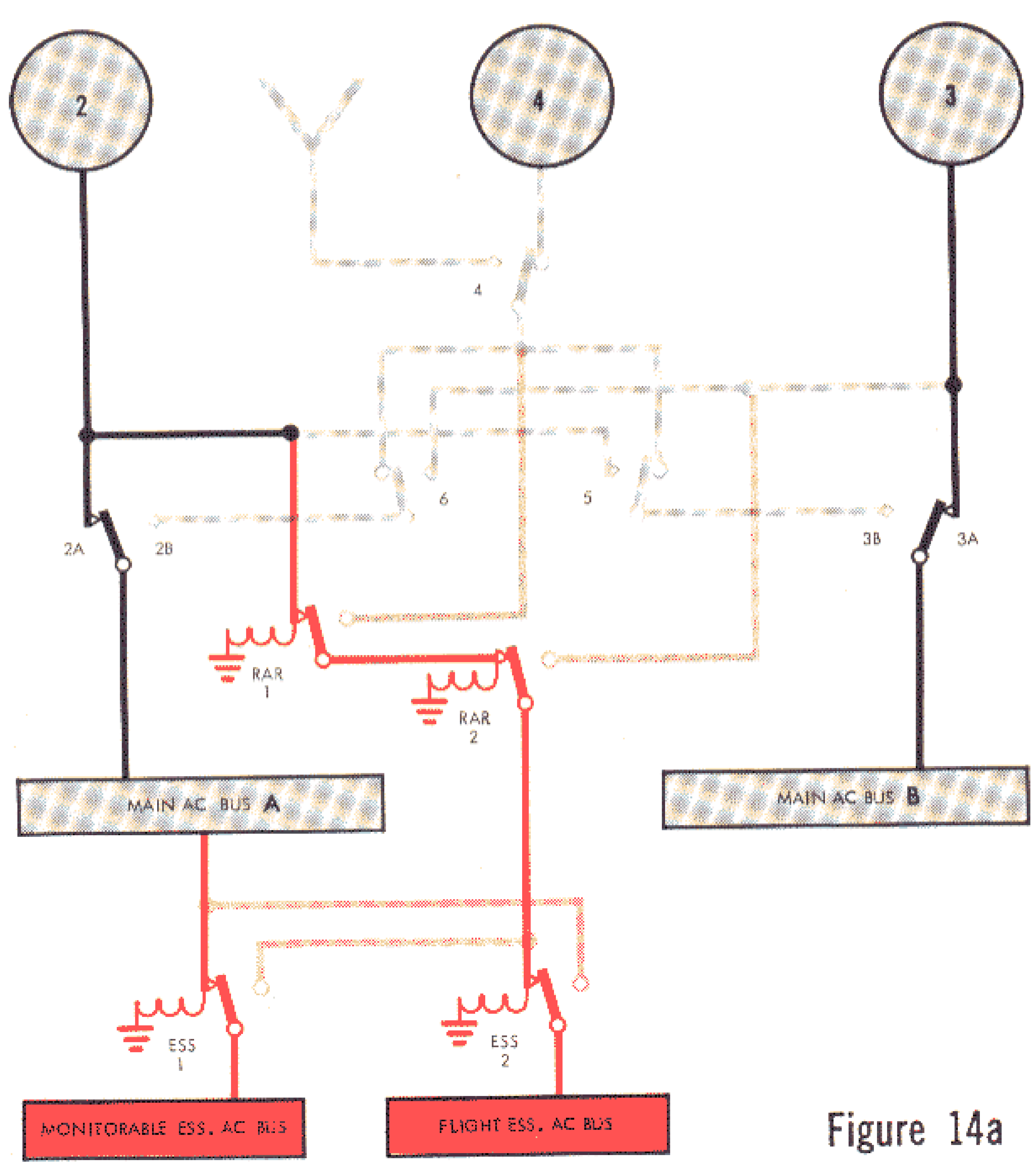


Figure 14a

Should generator No. 2 trip (see Figure 14b), the transfer system operates to disconnect generator No. 2 from the Main AC Bus A by opening relay 2A and this bus is connected to generator No. 4 through relay 2B. Run-around relay No. 1 (RAR 1) is no longer energized by generator No. 2 and the Flight Essential AC Bus is now connected directly to generator No. 4. It will be noted that on this and all subsequent essential bus transfers, the transfer depends upon relays being de-energized rather than energized, thus conforming to fail-safe concepts of design.

It will also be noted that the Monitorable Essential AC Bus remains connected to the Main AC Bus A during all main ac bus transfers. Both these buses carry inertial navigation loads which are sensitive to system power transients so that this is an important design feature. In this regard also, the high speed of operation of the main ac bus transfer relays is obviously another important consideration—the power interruption due to operation of these relays is no more than ten milliseconds.

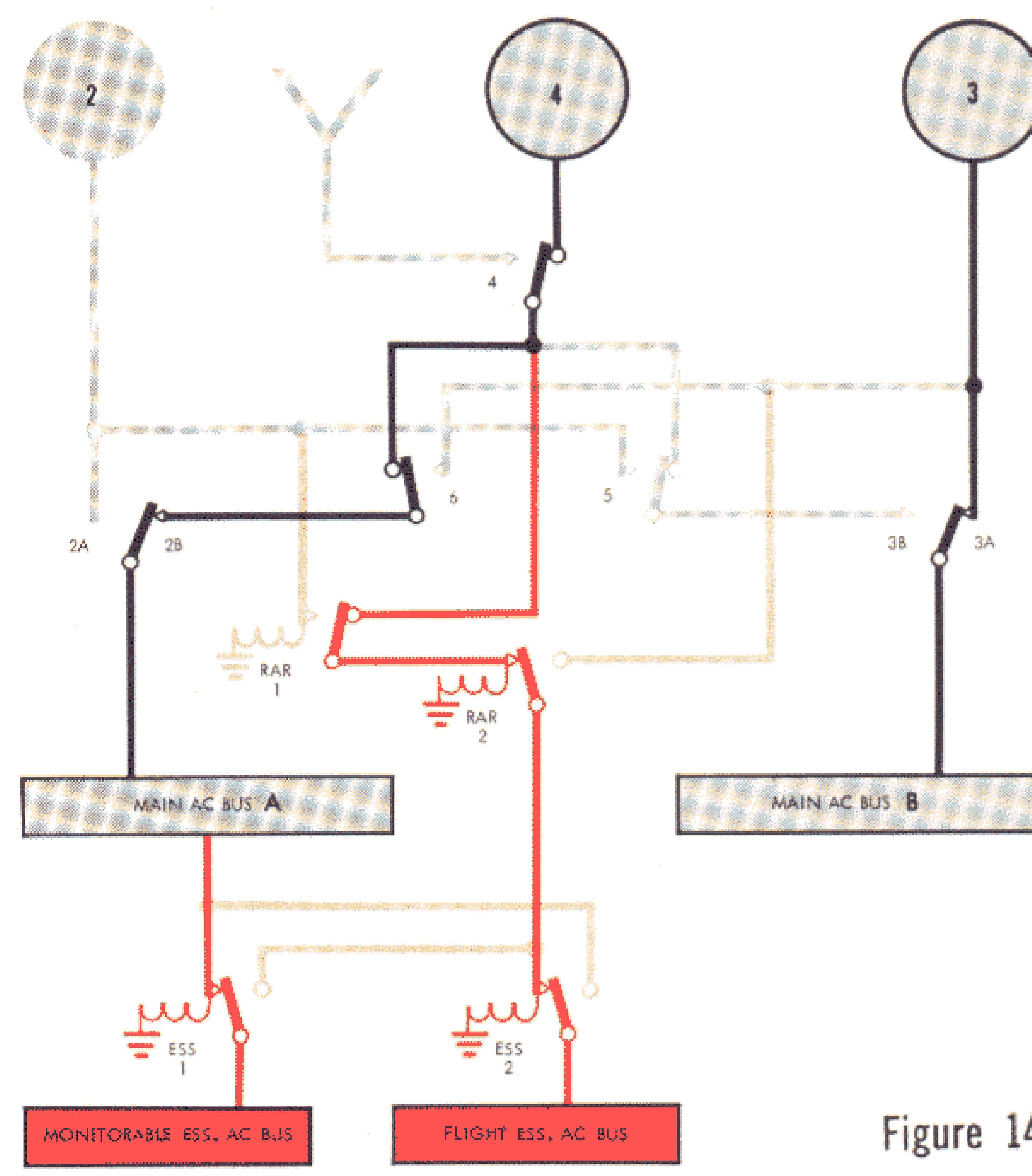


Figure 14b

Should generator No. 4 also trip (see Figure 14c), the transfer system, by closing relay 6, disconnects the Main AC Bus A from generator No. 4 and connects it to generator No. 3. Relay No. 5 also closes when generator No. 4 is de-energized but has no significance in this particular transfer operation. Run-around relay No. 2 (RAR 2) is no longer energized by generator No. 4 and the Flight Essential AC Bus is now connected directly to generator No. 3. Thus all the ac buses are now being carried by one generator but, as previously mentioned, should the airplane encounter icing conditions necessitating the use of propeller and/or empennage deicing, some of the least important loads and most of the electronics loads on the Main AC Buses will be automatically dropped. However, by checking the situation in Figure 14c with Figure 14, it will be seen that all three transformer-rectifiers are still energized and consequently the entire dc system on the aircraft is unaffected by single generator operation.

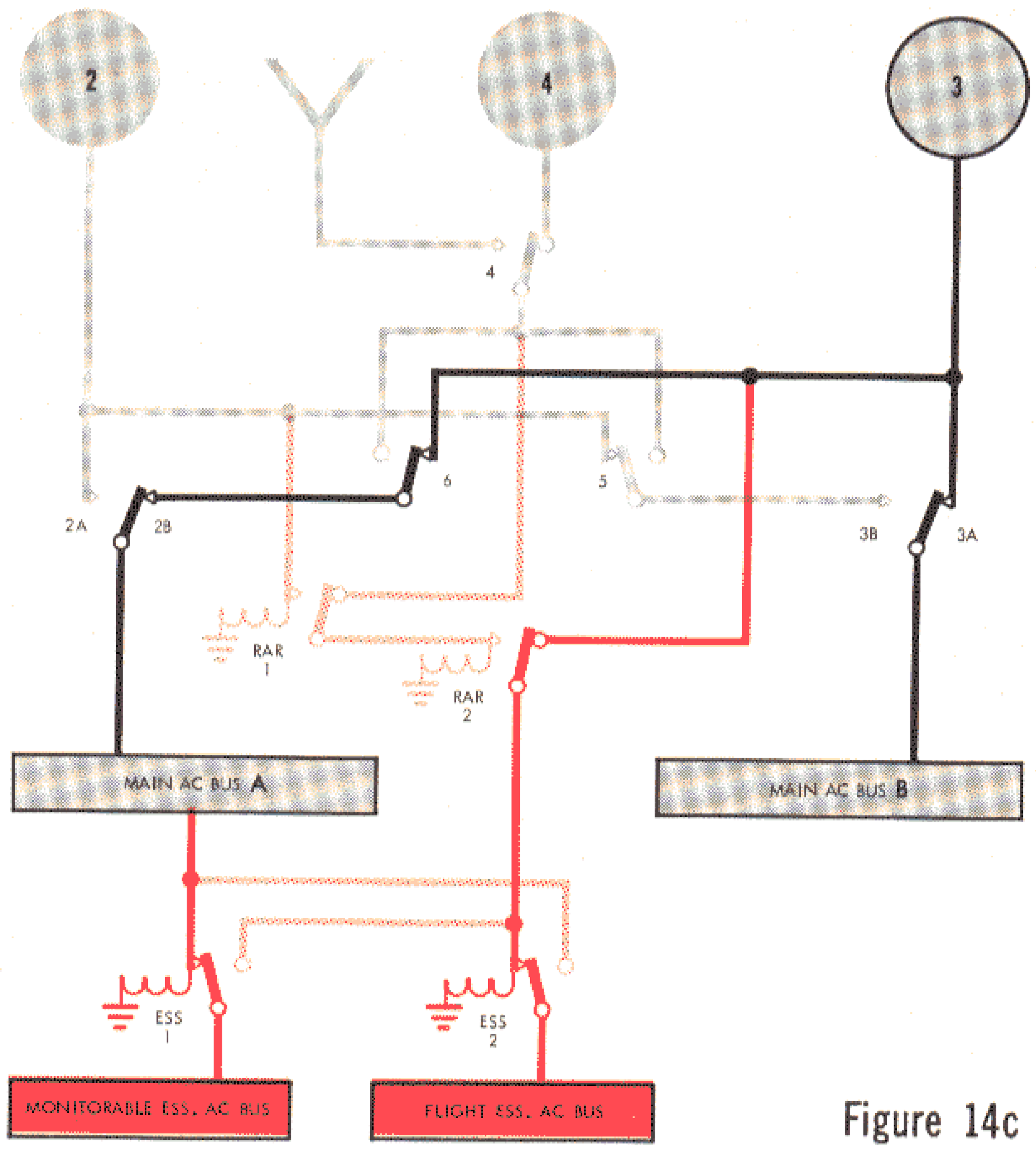


Figure 14c

In order to demonstrate the full effectiveness of the run-around transfer system, it is necessary to introduce a malfunction in the main ac bus transfer system itself. In Figure 14d we have assumed that relay 2B will not close, so that the Main AC Bus A cannot be energized. In this event the essential ac bus relay No. 1 (ESS 1) becomes de-energized, transferring the Monitorable Essential AC Bus directly to generator No. 3 through the run-around feeder system, thus bypassing the main bus transfer system.

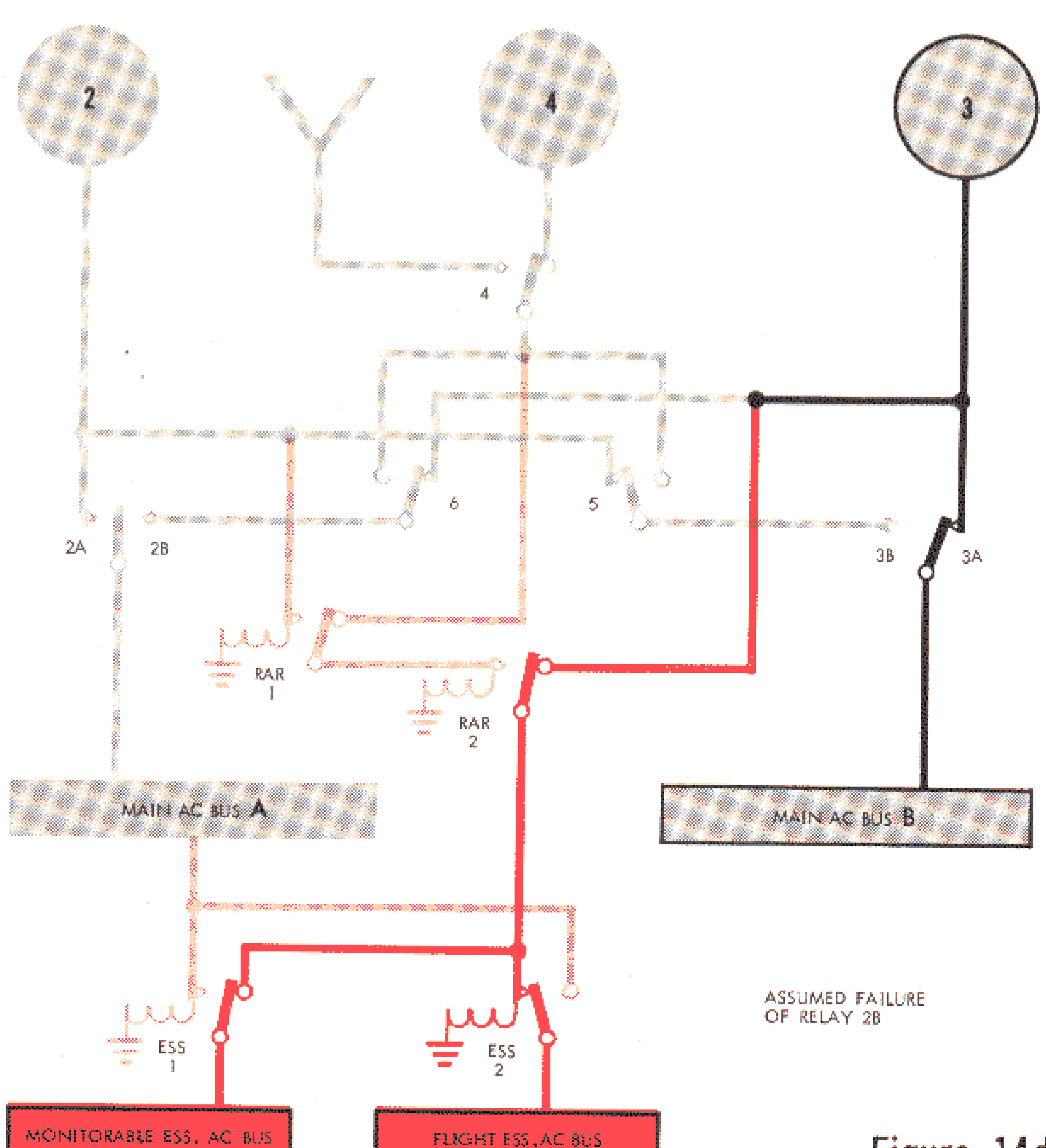


Figure 14d

We hasten to add that the series of failures such as has just been described is extremely unlikely, but it is reassuring to know just how a system will react to failures. We could invent many more series of failures to demonstrate the fail-safe capabilities of the electric power system but, before continuing with the remainder of the discussion, there is one final thought on the subject: We have previously pointed out that the Flight Essential AC Bus is one of the most important buses on the aircraft as it carries loads which could be vital to safe flight under certain circumstances. Figure 14 shows that power to this bus ultimately passes through just one relay (ESS 2). However, even if de-energized, the essential ac bus relay No. 2 would still connect the Flight Essential AC Bus to another power source. And it should also be pointed out that all the flight safety loads on the Flight Essential AC Bus have alternative power sources (not apparent on this simplified schematic) and/or have companion systems on the aircraft which could be used alternatively.

External Ground Power Transfer relay No. 4 is primarily concerned with the supply of ground power to the system. Assuming generator Nos. 2 and 3 are not available, when relay No. 4 is energized, relays 2B and 3B are also energized so that the complete power system is connected to the ground power source (see Figure 14e).

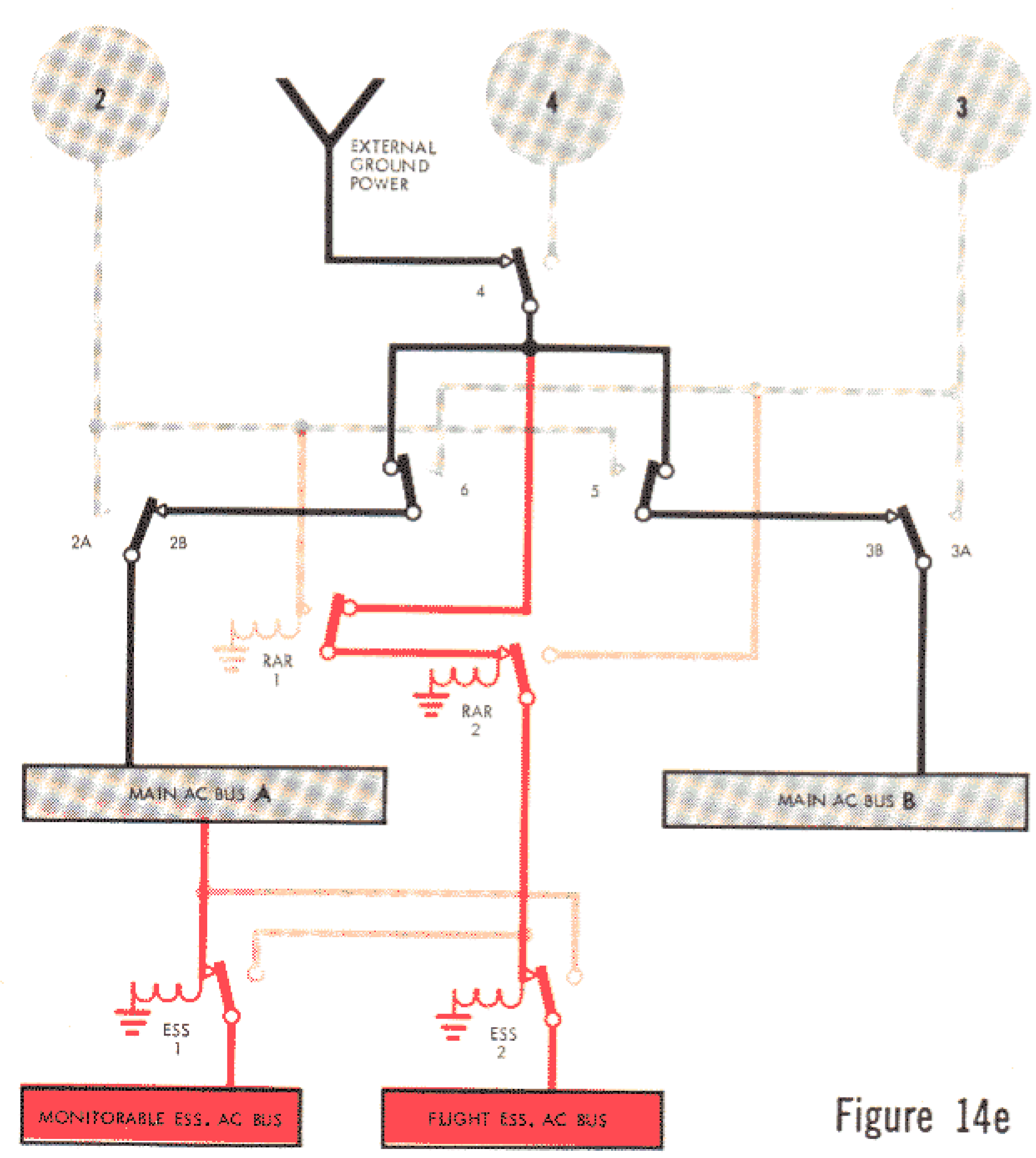


Figure 14e

Engine Low rpm Operation Assuming that ground power is not being used, when engine Nos. 2, 3, and 4 are selected to, and are operating in, LOW rpm (explained below), the main transfer relays assume the same positions shown in Figure 14e except that relay

No. 4 is de-energized. Thus the complete power system is connected to generator No. 4, and we might digress a little to further explain this feature.

For nearly all operational conditions (in NORMAL rpm), the Allison prop-jet engines maintain a relatively constant speed of 13,820 rpm.* It is this constant-speed characteristic of the engine which enables each generator to be driven directly by the engine through suitable gearing, and thus avoid the supplementary use of complicated constant-speed drive devices. For the mathematically minded: the reduction gearing (0.4316:1) to the generator drive produces a nominal generator speed of 6000 rpm. The rotating field of each generator has four pairs of magnetic poles so that each revolution of the generator produces 4 cycles (for each phase). The output frequency of the generator is thus 4 times 6000, which equals 24,000 cycles per minute or 24,000 divided by 60, which equals 400 cycles per second (cps). With this direct-drive arrangement, any slight variation in frequency due to engine rpm fluctuation is well within the airplane's electrical equipment limitations of 380 to 420 cps.

**Under static conditions on the ground there is a slight drop to 13,500 rpm with a power lever setting between Ground and Flight Idle.*

However, there is one slight complication to this otherwise simple design: For fuel economy reasons and in order to minimize engine/propeller noise while ground running, and during starting and taxiing, each engine has a LOW rpm power setting, which can only be selected while the aircraft is on the ground and which reduces the engine speed to approximately 10,000 rpm. Without some special provision all three generators would be off-frequency at this low speed setting. Consequently, the No. 4 generator is driven through a two-speed gear box which operates automatically when engine No. 4 is selected to LOW rpm and steps up the generator No. 4 drive speed from about 4,000 rpm to the required 6,000 rpm. At the same time the main transfer system also operates automatically to connect all buses to generator No. 4 when the engines are operated in LOW rpm.

The transition fom NORMAL to LOW rpm (13,500 to 10,000 rpm) is accomplished by the operation of toggle switches, which are located, one for each engine, on the overhead panel and they can be seen in Figure 13. A low rpm control circuit, which will be fully described in a future issue of the *Orion Digest,* governs the operation of the toggle switches. This circuit allows selection of an engine to

LOW rpm only if the airplane is on the ground and the respective power lever is in the Low rpm range (0° to 36° on the engine coordinator quadrant — slightly more than the Taxi or Beta range which is 0° to 34°). This control circuit also establishes a definite sequence of selection between the two idle speeds for engine Nos. 2, 3, and 4 so that load or bus transference between the generators is accomplished as smoothly as possible.

When reducing the speeds of engine Nos. 2, 3, and 4 from NORMAL to LOW the No. 4 engine has to be selected first, for the toggle switches on engine Nos. 2 and 3 are inoperative until this has been accomplished. When the No. 4 engine is selected to LOW, it decelerates and the No. 4 generator is de-energized automatically by its frequency control network. The two-speed gear box also shifts automatically so that the generator returns to normal frequency and is re-energized when the engine reaches low rpm speed. Thus generator No. 4 is then ready to assume the loads from the other generators as soon as the Nos. 2 and 3 engine speeds are reduced and their respective generators are dropped.

Conversely, when increasing the speeds of the Nos. 2, 3, and 4 engines, the No. 4 toggle switch is inoperative until engine Nos. 2 and 3 have been selected to NORMAL. Then, when the generator outputs on these engines are established at this setting, they automatically assume their normal loads from the No. 4 generator.

There are other features incorporated into this low rpm control circuit, but the above brief description of its operation suffices to point up the basic concept, which is to avoid any unnecessary time lapses during generator/bus transfers. Such time lapses could amount to several seconds if they included time for engines to accelerate or decelerate and time for the two-speed gear box to shift. Normally, the low rpm control circuit ensures that transfers are accomplished in just a few milliseconds—or almost instantaneously. However, it has also been found desirable to keep the number of such power disturbances, slight though they might be, to a minimum (see the inset on page 27).

DC POWER SUPPLY AND DISTRIBUTION The three transformer-rectifiers used to supply 28-volt dc power are identical units. Except for a cooling blower powered from the nominal 117-volt, 3-phase input leads, the operation of the unit requires no moving parts; a 3-phase power transformer steps down the input voltage and rectification is accomplished by silicon diodes. The resulting dc output is non-regulated; its magnitude is therefore slightly affected by the applied load, and the output voltage varies from 29.5 volts under zero load conditions to about 26 volts at full load. However the maximum figure is reduced in the Orion installation by ensuring that adequate dc loads (about ten percent of the nominal dc load) remain connected to be energized whenever the transformer-rectifiers are energized.

Each transformer-rectifier is provided with a loadmeter shunt in the ground return lead to permit checking the percentage of load on the unit. (The loadmeters are actually graduated from 0 to 1.0 rather than 0 to 100). The loadmeters for transformer-rectifier Nos. 1 and 2 are located on the Main DC Bus circuit-breaker panel and the loadmeter for the No. 3 unit is on one of the forward load center circuit breaker panels (see Figures 8 and 10).

Three transformer-rectifier OVERHEAT lights (one for each unit) are located on the electrical control panel, and they are designed to illuminate whenever the temperature of a transformer-rectifier exceeds a certain maximum value. Shutting off a transformer-rectifier is accomplished by pulling the appropriate XMFR RECT circuit breaker (Nos. 1, 2, or 3), located on the circuit-breaker panels of the Main AC Bus A, the Main AC Bus B, and the Monitorable Essential AC Bus respectively. As mentioned previously, the ELEC POWER master caution light on the center instrument panel would also be illuminated coincidently with any one of the transformer-rectifier overheat lights.

Returning now to the various schematics which comprise Figure 14 it can be seen, and has already been pointed out, that all three transformer-rectifiers are available as long as any one generator is supplying power. Even in the unlikely set of circumstances depicted in Figure 14d, two transformer-rectifiers are still available and have adequate capacity to supply all dc loads. Both Main AC Buses would have to be de-energized in order to reduce the number of available transformer-rectifiers to one, and this one would be transformer-rectifier No. 3 which, ultimately, would receive its power supply from any one generator via the run-around transfer system.

The basic dc power system is depicted in Figure 15. As before, this schematic expands the information given in Figure 2 but is still a slightly simplified version of the dc circuit shown on Figure 17. The principal dc buses and components are shown in color while the principal ac buses are depicted in grey to show the interconnections of the ac and dc power systems.

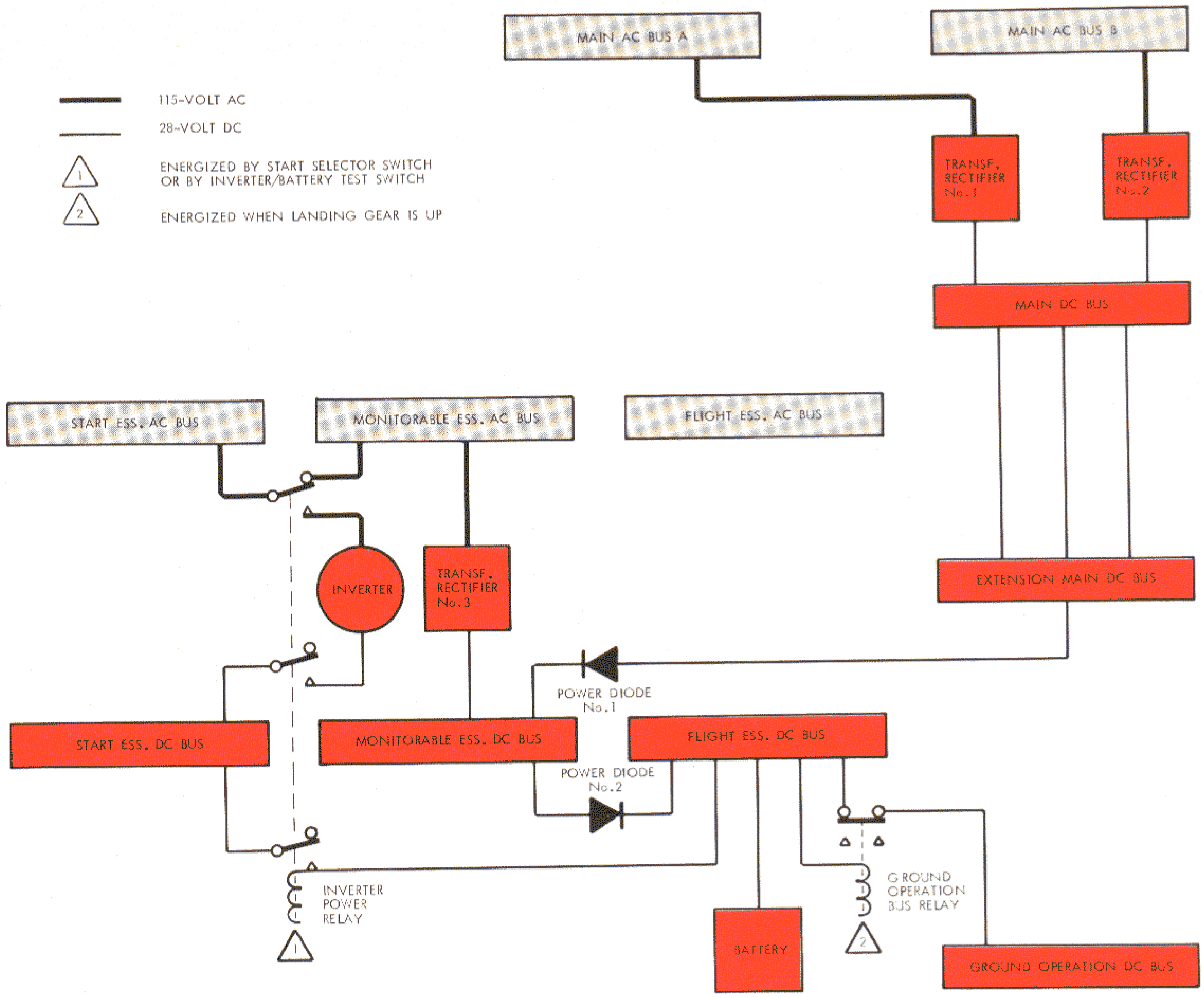


Figure 15
DC Power
System Schematic

The Main DC Bus and the Extension Main DC Bus carry most of the heavy dc loads and are powered by the transformer-rectifier Nos. 1 and 2 operating in parallel. The Main DC Bus is located in the Main Service Center, and three dc power feeders connect this bus to its extension in the flight station. The use of three feeders for this purpose is often queried and the answer to the question warrants inclusion in this discussion.

The wire gauge of each of the feeders is ample to supply the maximum load requirement of the Extension Main DC Bus (about 55 amps), and the installation of just two wires would have achieved the required safety factor of providing an alternative power supply feeder to the flight station bus. However, the use of three wires not only further improved the safety factor, it also provided a simple fail-safe circuit, should a fault develop in one of the feeders. Each of the three feeders has an 80-amp limiter at either end of the wire run. If a fault to ground occurs in any one wire, both limiters of the faulted wire open so that the fault is effectively isolated (see Figure 16). This result cannot be achieved as simply with two wires, and such items as circuit breakers and relays would have to be incorporated in the circuitry.

The Extension Main DC Bus is connected through the power diode No. 1 to the Monitorable Essential DC Bus, and this bus is also connected to its ac counterpart through transformer-rectifier No. 3. Since, under normal conditions, the Start and Flight dc sub-buses are connected to the Monitorable Essential DC Bus through the inverter power relay and through the power diode No. 2 respectively, it follows that the entire Essential DC Bus is supported by all three transformer-rectifiers.

The power diodes used in the dc system are hermetically sealed, high-voltage, silicon-rectifier cells. The No. 1 power diode prevents the transformer-rectifier No. 3 from feeding the Main DC Buses, the object being to isolate the Essential DC Bus and its primary power supply should a malfunction occur elsewhere in the dc power system. The power diode No. 1 also has a secondary function: although it allows current to flow from the Extension Main DC Bus to the Monitorable Essential DC Bus, there is actually enough of a voltage drop across the diode to ensure that, with all three transformer-rectifiers in operation, the Essential DC Bus will primarily be supplied by transformer-rectifier No. 3, with the other two transformer-rectifiers acting as standby power sources.

The battery is connected directly to the Flight Essential DC Bus. Since the Flight and Monitorable Essential DC Buses are interconnected via the power diode No. 2, the battery can consequently be charged from any of the transformer-rectifiers, but is prevented from ever supplying power to the Monitorable Essential DC Bus. Thus, the battery output is limited in order to perform the following functions:

1. Under emergency engine starting conditions (no generator power or external power sources available), the battery supplies the minimum loads required during engine starting. In these circumstances, the inverter power relay would be energized so that the Start Essential DC Bus would be connected to the Flight Essential DC Bus. Operation of the inverter power relay would also supply battery power to the inverter which, in turn, would supply 115-volt, single-phase ac to the Start Essential AC Bus, thus energizing the turbine inlet temperature (TIT) indicators.
2. It provides a reserve source of power for certain ground operations. The ground operation bus relay is de-energized (as shown in Figure 15) when the nose landing gear is down so that the Ground Operation DC Bus is connected to the Flight Essential DC Bus. Loads carried on the Ground Operation DC Bus are not required in flight and include the alternate power source for the engine oil quantity indicator, external power dc control circuits, and a dc electric-powered hydraulic pump which powers the hydraulic aircraft brakes.
3. Under extreme emergency conditions (such as the occurrence of a fire during which time the decision may be made to temporarily switch off all other electric power sources), the battery would supply the minimum dc-powered flight loads, which could possibly be essential to flight safety. These loads are of course carried on the Flight Essential DC Bus and comprise the pilot's turn and slip indicator, flight station utility lights, propeller pitchlock reset, command bell, and certain dc power control circuits. Under these same conditions the battery could also be used to supply the same loads as in item 1.

Although the battery is used for other purposes, the primary reason why a battery was incorporated in the Orion's electric power system was to provide, in conjunction with the inverter, a source of electric power to operate the essential services required during

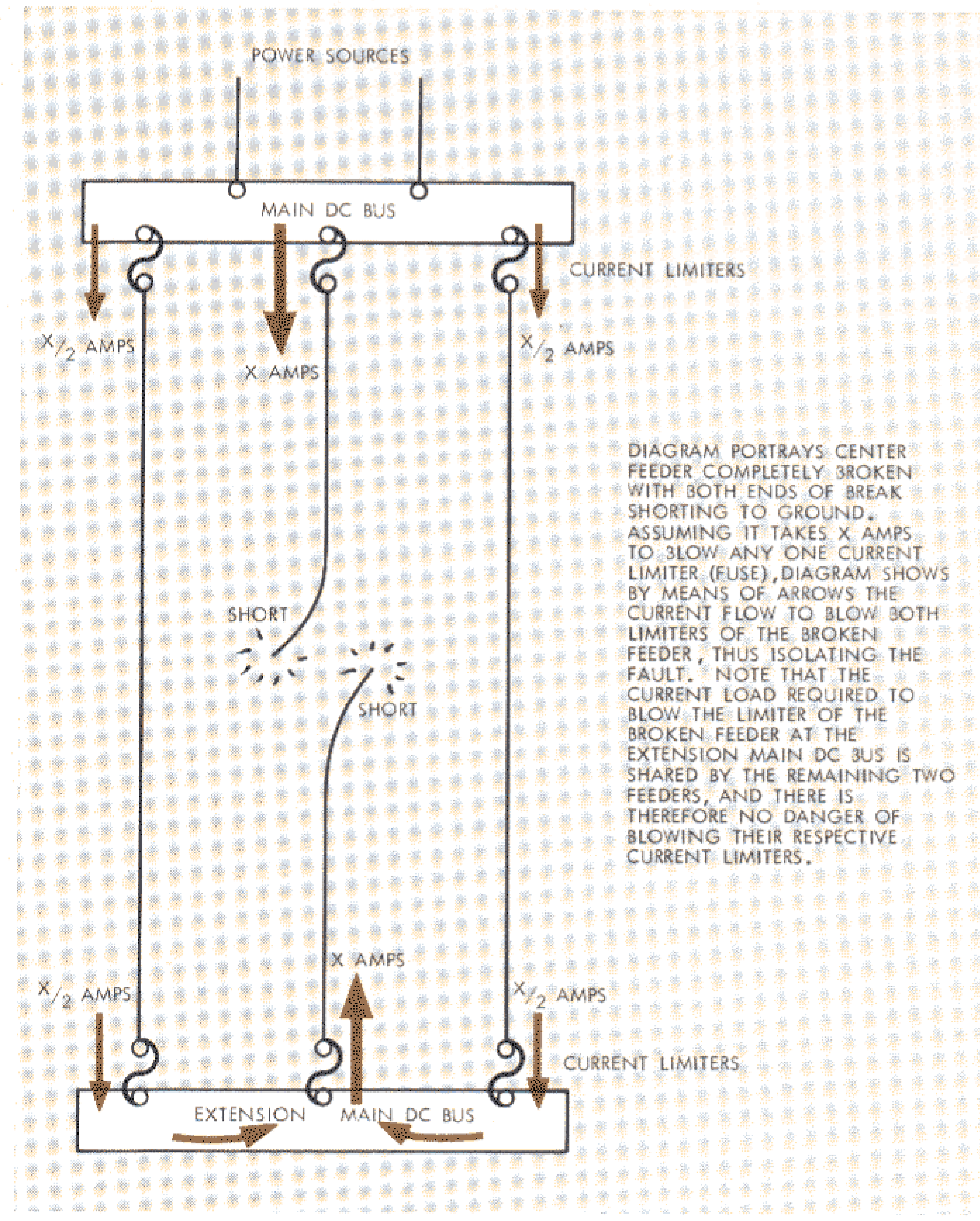


Figure 16 Fault Isolation in the Extension Main DC Bus Feeders

emergency engine starting. Consequently the battery's 11-amperehour capacity was determined by the requirements for starting the 100-voltamperes inverter. Considering all the services operated from the battery: most of them are of a momentary nature so that the average load on the battery at any time is small; at present battery loads amount to about one ampere in flight emergency (all generators and inverter off) and two amperes during ground towing (brake accumulator charged).

One component not described so far is the 100-voltamperes inverter. It is actually a standard unit with 3-phase ac output available. However, only one of the phase output leads is used, which results in derating the inverter to 60 va. The 24-volt input from the battery powers a compound-wound dc motor, which drives an alternator consisting of a 4-pole permanent magnet rotor rotating within a 3-phase stator. The motor and the alternator have a common drive shaft so that a centrifugal governor controlling the speed of the dc motor to 12,000 rpm also regulates the alternator/inverter output frequency to 400 cps. It should perhaps be noted that retraction of the OFF flags on the TIT gauges indicates that the inverter is operating, assuming that only battery power is available on the aircraft.

POWER CONTROL AND SWITCHING CIRCUITS

These circuits are shown in Figure 17, which also incorporates both the simplified ac and dc power schematics (Figures 14 and 15). The power circuitry is reproduced in black while the associated control and switching circuitry is depicted in blue. It will also be noted that all buses pertinent to the power system are shown in red, and other major components are shown in grey blocks with a minimum of internal circuitry. As an additional aid for quick trouble-shooting of the Orion's electric power system, the schematic is subdivided according to aircraft location and, further, the control switches in the "Flight Station Overhead Control Panel" subdivision are in the same relative location as seen by the crew members on the aircraft control panel (see Figure 13).

All components are labeled as they are on the aircraft or as they are found in the P-3A Electrical Wiring Data book (NAVWEPS 01-75PAA-2-13.2). And incidentally we should mention that no corrective action should be undertaken on the aircraft without first consulting the pertinent Data book. Figure 17 should only be regarded as a trouble-shooting aid with the added caution that, although correct at the time of publication, it is not subject to amendment action as is the Data book.

Unlike the previous schematics in this article, Figure 17 is complete in itself and includes all the smaller components in the power circuitry such as circuit breakers and current limiters. Also, three "electrical sub-buses" have been added. We should mention that electrical sub-buses will only be found, so named, in this article, but they actually correspond to circuit breaker panels in the main and forward load centers. For example, the Monitorable Essential DC Bus circuit breaker panel shown in Figure 10 consists almost entirely of circuit breakers attached to the Monitorable Essential DC Bus — Electrical (see Figure 17).

For each of these electrical sub-buses there is an electronic and/or armament sub-bus, which is indicated on Figure 17 but is not actually shown. The electronic sub-buses do not have easily-identifiable circuit-breaker panels on the aircraft, and the main feeder circuit breakers to them (shown on Figure

17) are the only breakers, pertinent to these buses, located on the main and forward load center circuit-breaker panels. However the electronic and armament power distribution is not relevant to the present discussion and they will be described in Part Two of this article, to be published in a future issue of the *Digest.*

Also to be included in Part Two is a schematic showing the circuits to the various electric power system indicator and warning lights. The light circuits are rather involved and are not therefore included on Figure 17, although reference is made to the lights while describing the power control and switching circuits, and brief descriptions of the operation of the lights have been given where appropriate throughout the article.

The power control and switching circuits might best be explained by assuming that the aircraft is on the ground with all engines stopped and then describing the action of the circuitry in Figure 17 as the engines are started in a normal starting sequence (see inset on this page). First, however, some explanation of the generator control switches is required:

Each generator control switch (GCS) has three positions. A switch guard holds the switch at the center ON position, and the guard has to be lifted in order to select OFF or RESET. Selection to either of the latter two positions achieves the same thing electrically, but selection to the RESET position is preferred during generator resetting operations because it is a momentary position — in other words the switch automatically returns to ON when released. It should be noted that the switch is designed to remain in the ON position at all times except for emergency or test purposes.

Shown above each GCS in Figure 17 is a section of the associated generator control unit. We could not show the complete circuitry in each generator control unit but, assuming an engine has been started and the associated generation system is functioning correctly, dc power (rectified ac) from the permanent magnet generator (PMG) in the generator passes from pin connection "a" in the generator control unit, through contacts B2, B3, A2, A1 of the GCS, and back to pin connection "X" of the generator control unit. Subsequently, PMG control power from "X" energizes the auxiliary control relay (ACR), which is the final step in energizing the generator and "signaling" the main ac bus transfer system that the generator is available for load. This circuit is broken and the generator de-energized by selecting the appropriate GCS to either OFF or RESET (see the "Generation System Protective Circuits" section for operation of the GCS)

ENGINE STARTING PROCEDURE

Some of the electronic equipment on the Orion can be sensitive to electric power disturbances, and a starting procedure was therefore established with a minimum number of generator/bus transfers. Assuming the aircraft electric power system to be operating from external ground power, the normal starting procedure is as follows:

Start No. 1 engine in NORMAL rpm. Remove ground air start source.

Start No. 4 engine in LOW rpm with bleed air from No. 1 engine. Wait for GEN NO. 4 OFF light to go out.

Switch external power OFF so that load transfers to No. 4 generator. Remove external ground power.

Start No. 3 engine in LOW rpm with bleed air from No. 1 engine.

Start No. 2 engine in LOW rpm with bleed air from No. 1 engine.

Switch No. 1 engine to LOW rpm.

The above procedure involves only one electric power transfer, and all engines are in low rpm ready for aircraft taxiing. Outlined below is the subsequent procedure prior to take-off. This is automatically established to some extent by the low rpm control circuitry, which was briefly described in the "AC Power Transfer and Distribution" section. It involves only one power transfer for each of the main ac buses and the minimum of possible power transients in the system. Before continuing we should also mention that it is a good precaution to not advance any power lever beyond the Flight Idle position until all engines are in NORMAL rpm. Advancing the No. 4 engine power lever beyond Flight Idle (out of the low rpm range), for example, will automatically select all engines to NORMAL rpm and will definitely upset the inertial navigation system.

Select No. 1 engine to NORMAL rpm. This engine of course can actually be selected at any time, as it does not affect the electric power transfer system.

Select No. 2 engine to NORMAL rpm. Wait for GEN NO. 2 OFF light to go out.

Select No. 3 engine to NORMAL rpm. Wait for GEN NO. 3 OFF light to go out.

Select No. 4 engine to NORMAL rpm.

The complete starting procedure can be summarized in an easy-to-remember sequence as follows:

1 NORMAL

4 3 2 1 LOW

1 2 3 4 NORMAL

It is assumed now that the aircraft is on the ground with all engines stopped, no external power plugged in, and all switches in their normal operating positions. These conditions are reflected in Figure 17; all relays are de-energized and, in particular, the nose uplock switch (see Figure 18) is in its normal Gear Down position so that the ground operation bus relay is de-energized, connecting the aircraft battery (the only available power source) to the Ground Operation DC Bus and enabling the few ground services on this bus, as well as those on the Flight Essential DC Bus, to be operated.

Before ac power is made available to the aircraft's electric system, a quick check of the condition of the aircraft battery can be made. By selecting the Inverter Battery Switch to TEST, a ground is provided through the switch for the inverter power relay, which is energized by the battery via the Flight Essential DC Bus. The closing of the inverter power relay starts the inverter from the battery so that a voltage check may be taken with the battery under load. About 5 seconds should elapse while holding the switch before checking the reading of the voltmeter. The voltmeter, which is located on the flight station load center circuit breaker panel, should read a minimum of 22 volts, and should normally read 23 volts or more. At the same time listen for the inverter, which should start without any sign of sluggishness.

The inverter is provided for emergency engine starting. If ac power is not available on the aircraft, selecting the engine start selector to any engine accomplishes a similar result to the inverter/battery test switch by providing a ground for the inverter power relay so that the inverter is started. The inverter then powers the TIT indicators through the Start Essential AC Bus. It will be noted that, unlike the battery test circuit, the emergency engine starting circuit passes through contacts A2 and A3 of the monitorable essential dc bus power sensing relay. Since this relay is energized whenever the Monitorable Essential DC Bus is energized, the above operation of the inverter is prevented during normal starts when another source of ac power is available.

With external power available, use of the inverter is not required. When external power is plugged in, pins E and F of the external power receptacle are connected by means of a jumper wire in the external power plug. Subsequently the phase sequence relay is energized if it senses that the sequence of the three phases (A, B, and C) is correct. Also, the External Pwr Available light on the electrical control panel is illuminated. (It should be noted that the light does not indicate that the phase sequence is correct.) Selecting the external power switch to ON should complete the circuit from the battery and Flight Essential DC Bus, through the de-energized ground operation bus relay and the Ground Operation DC Bus, through the external power switch and pins F and E of the external power receptacle, and through the closed contacts A1 and A2 of the phase sequence relay to energize the transfer relay No. 4. Not shown on Figure 17, another circuit from pin E is grounded through an amber external power indicator light adjacent to the external power receptacle.

The closing of the main contacts of relay No. 4 enables 115-volt, 3-phase ac current from the external power source to energize the complete Essential AC and DC Buses via run-around relay No. 2, the essential ac bus relay No. 2, and the essential ac bus monitoring relay — the latter being grounded through the normally ON essential bus monitoring switch.

The Monitorable Essential DC Bus — Electrical is powered from the transformer-rectifier No. 3, and it is now possible to trace a closed circuit from the BUS A CONT circuit breaker through the normally-closed contacts 5 and 6 of the A Bus Monitoring switch, through connections H and O of the generator No. 2 control unit (ACR is de-energized) to energize relay coil 2B. Thus external power is now directed through the de-energized relay No. 6 and the closed relay 2B to energize the Main AC Bus A. A similar circuit can be traced out from the BUS B CONT circuit breaker to energize relay coil 3B and energize the Main AC Bus B.

Subsequently the Main DC Bus and its extension are energized and the complete system is now powered from the external power source. It will be noted that the essential bus relay No. 1 is energized when the Main AC Bus A is energized so that the Flight Essential AC Bus is now the only bus being powered by the run-around feeder system.

Not shown on Figure 17, another set of contacts of transfer relay No. 4 close to complete a circuit to the green External Power On indicator light on the overhead electrical control panel. Also, the three GEN OFF caution lights on the electrical control panel and the ELEC POWER master caution light on the center instrument panel are illuminated as soon as the Monitorable Essential DC Bus is energized.

Involved as the above description is, the whole operation, like all the transfer operations in the power system, is accomplished almost instantaneously — in only a small fraction of a second.

Progressing with the normal engine starting procedure, the No. 1 engine (which has no generator) is started first with engine rpm at NORMAL, in order to supply bleed air for starting the other engines. The ground air source is then removed and the other engines are started in LOW rpm.

As the No. 4 engine drives the only generator capable of assuming the power system load under low rpm conditions, it is started next. The ACR (auxiliary control relay) in the generator No. 4 control unit is closed when the engine and generator come up to speed with the generation system functioning correctly. One set of contacts (Y, d) of the ACR open the circuit to the GEN NO. 4 OFF indicator light and it goes out. Selecting the External Power Switch to OFF breaks the circuit to transfer relay No. 4 and de-energizes it, so that the complete system is now transferred to generator No. 4.* Both the external power indicator light adjacent to the external power receptacle and the External Power On light on the flight station control panel go out. When the external power source is removed the External Power Available light is also extinguished.

Starting the Nos. 2 and 3 engines in LOW rpm will not affect the power distribution, as the Nos. 2 and 3 generators will be off-frequency. After starting the remaining engines, the normal procedure would be to select engine No. 1 now to LOW rpm and perform ground checks and taxi operations with all engines at this setting. However, subsequent selection of the engines to NORMAL rpm should be accomplished in an easy-to-remember 1, 2, 3, 4 sequence. Engine No. 1 can actually be selected at any time, but engines 2, 3, and 4 should be selected in that order so that the number of power transfers is kept to a minimum.

Selecting engine No. 2 to NORMAL rpm should result in the ACR in the No. 2 generator control unit and generator No. 2 becoming energized. Subsequently, the run-around relay No. 1 is also energized resulting in the run-around feeder system being taken over from generator No. 4. At the same time contacts H and O of the ACR in the No. 2 generator control unit open, de-energizing transfer relay coil 2B. ACR action also completes the circuit through contacts Y and d so that PMG control power from generator control unit connection "a" is directed through the normally-closed contacts 3 and 2 of the A-Bus Monitoring switch, and through the ACR to energize transfer relay coil 2A. Thus generator No. 2 picks up the Main AC Bus A, leaving generator No. 4 still supplying the Main AC Bus B.

Similarly, if engine No. 3 is now selected to NORMAL rpm, transfer relay coil 3B is de-energized and coil 3A is energized so that generator No. 3 takes up the Main AC Bus B, leaving generator No. 4 on standby. Action of transfer relay Nos. 2 and 3 extinguishes the respective GENERATOR OFF caution lights and, since all generators are now energized, the ELEC POWER master caution light on the center instrument panel also goes out.

If No. 4 engine is now selected to NORMAL rpm, there will be a period during which the No. 4 generator is de-energized while the two-speed gear box shifts, but the power system distribution will remain unchanged.

It should be noted that as long as generator No. 4 is energized, contacts H and O in the generator No. 4 control unit are open. However, if generator No. 4 becomes de-energized for any reason, then the ACR in generator No. 4 control unit is also de-energized. A circuit is then completed from the GEN 4 TRANSFER circuit breaker on the Monitorable Essential DC Bus — Electrical, through contacts H and O in the generator control unit and the closed contacts (U, D) on the de-energized transfer relay No. 4 to the coil of the generator No. 4 control auxiliary relay. Closing of contacts B1 and B2 of this relay completes the circuit to energize both the transfer relay Nos. 5 and 6. With generator Nos. 2 and 3 operating, this action does not affect power distribution but if, for example, generator No. 3 is now de-energized, the transfer relay No. 3 will operate so as to connect generator No. 2 to the Main AC Bus B via the already-energized transfer relay No. 5 and transfer relay No. 3B, as soon as the latter relay is energized. Thus generator No. 2 is enabled to supply both main ac buses. A similar action results if generator No. 2 is de-energized rather than generator No. 3, in which case both main ac buses would be supplied by generator No. 3.

The above description of one sequence of bus transfer operations should suffice for the reader to obtain a working knowledge of the automatic features of the Orion's electric power system. As a further aid, the series of system failures shown in Figures 14a through 14d could be followed on Figure 17 to discover how the various transfer relay positions involved in the series are actually achieved.

The Three Bus Monitoring Switches on Figure 17 would only be used in an emergency. Action of the A Bus and B Bus Monitoring switches is similar: Selection of either switch to OFF breaks the circuits

**It is important to select the External Power Switch to OFF before shutting off the external power cart or before disconnecting the external power plug. Following the correct procedure assures a clean fast transfer operation and, in particular, prevents repetitive transfers due to "rocking" the external power plug to facilitate its removal — a bad practice which is all too common.*

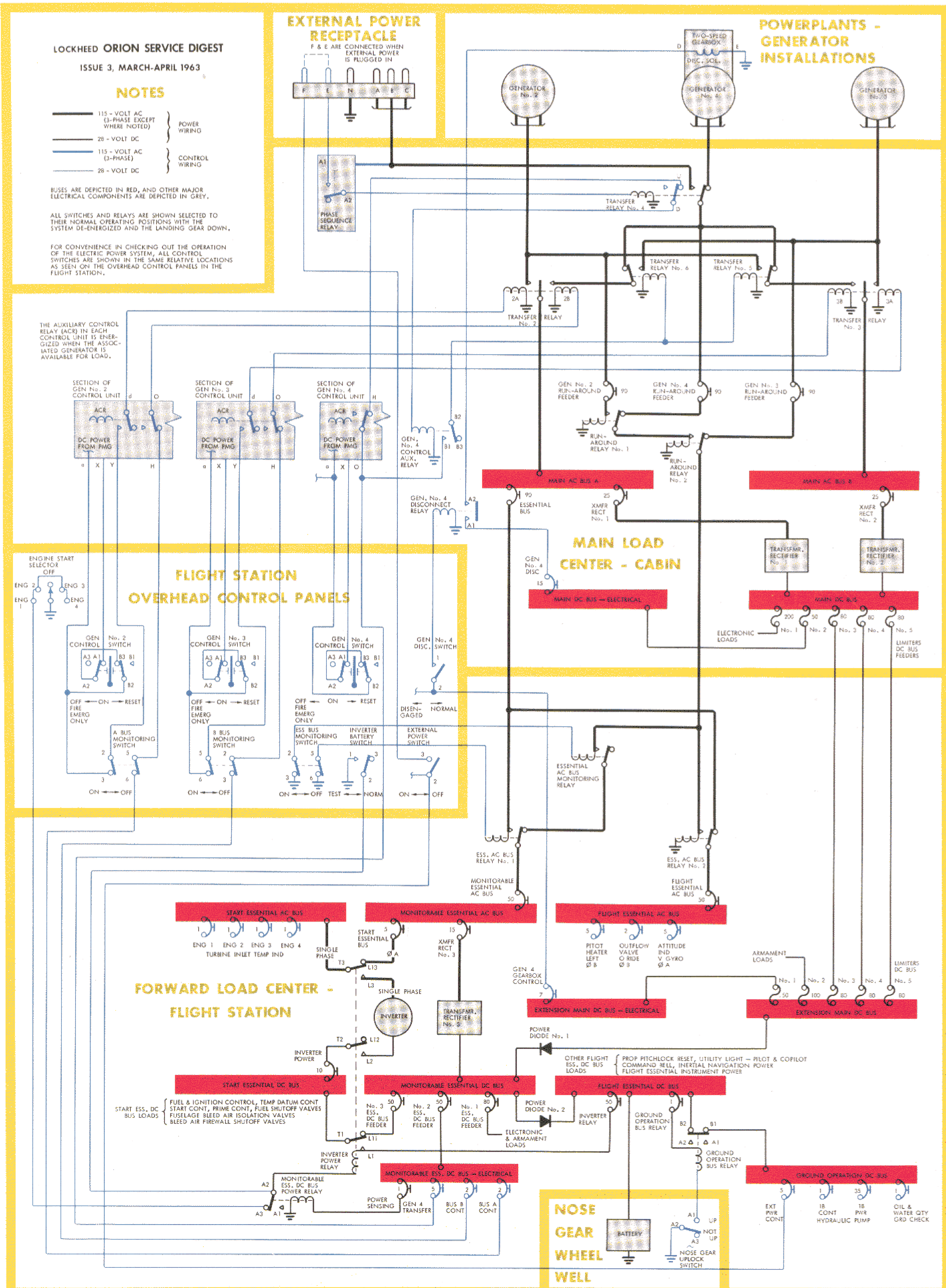


Figure 17 Orion Electric Power System with Control and Switching Circuits

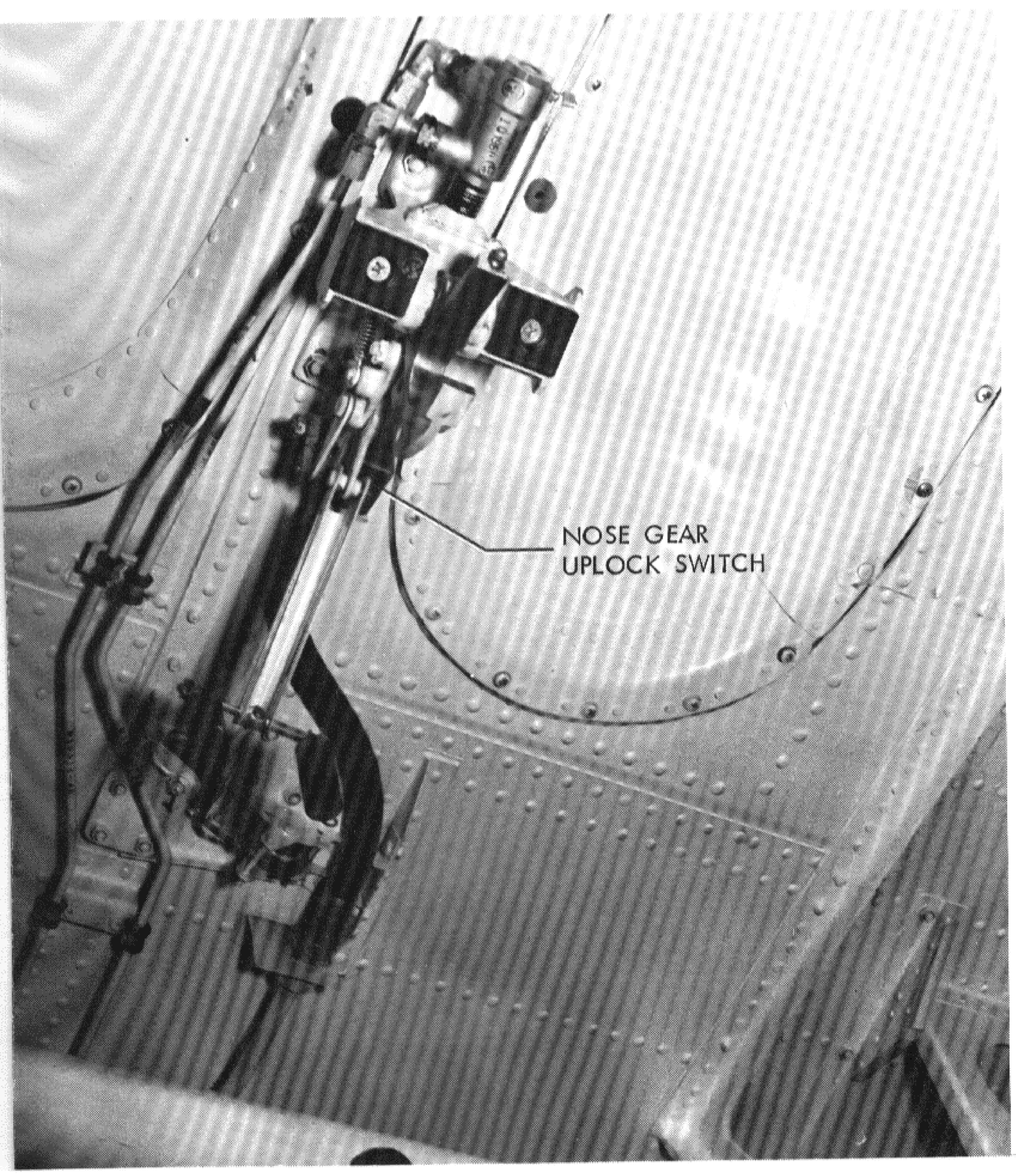


Figure 18 Nose Landing Gear Uplock Switch

to both coils of the pertinent transfer relay (No. 2 or No. 3) so that the relevant Main AC Bus is de-energized. Selecting both the A Bus and B Bus switches to OFF will stop the power supplies to the Nos. 1 and 2 transformer-rectifiers so that the Main DC Bus and its extension will also be de-energized.

Selecting the Ess Bus Monitoring switch to OFF breaks the circuit to the essential ac bus monitoring relay and the essential ac bus relay No. 1 so that the Start and Monitorable Essential AC Buses are de-energized. Although labeled Ess Bus, the use of this monitoring switch alone will not affect the Essential DC Bus. Selecting all three monitoring switches to OFF will however de-energize the Monitorable Essential DC Bus, because all three ac buses which power the transformer-rectifiers will be de-energized. In these circumstances it will be noted that the Flight Essential AC Bus would be the only remaining bus powered from a generator, assuming that one or more generators are operating. In addition, the battery-powered buses would be available.

The Generator No. 4 Disengage Switch incorporates a guard which maintains the switch in the NORMAL position, and is safetied in that position with break-away wire. Above the switch on the panel is the Generator 4 DISENGAGE light, which is illuminated if the oil temperature or oil pressure in the generator No. 4 two-speed gear box reaches unsafe limits, or if the No. 4 generator overspeeds. The ELEC POWER warning light on the center instrument panel would also be illuminated in the above circumstances. Selection of the generator No. 4 disengage switch to DISENGAGED (see Figure 17) energizes the generator No. 4 disconnect relay, which completes the circuit from the Main DC Bus to the disconnect solenoid in the two-speed gear box.

It should perhaps be mentioned that, following a disconnect, re-engagement of the two-speed gear box can only be accomplished on the ground with the No. 4 engine stopped. Further, a clean disconnect of the gear box requires that the generator be rotating during the disconnect operation. If the disconnect solenoid is energized with the engine stopped and the engine is subsequently started, the gear box can be severely damaged. It follows that if the switch guard break-away wire is ever found to be inadvertently broken, the gear box disconnect must be checked and reset, if necessary, and the wire replaced prior to starting the No. 4 engine.

Some final thoughts regarding the operation of the transfer system: It has already been pointed out that when the system is operating under normal flight conditions the only energized coils in the main ac bus transfer system are coils 2A and 3A. It can now be appreciated from Figure 17 that, since these two coils are energized from the PMGs of generator Nos. 2 and 3, then the system is actually independent of aircraft battery power for normal flight operation and emergency engine starting. However, the battery has emergency functions to fulfill and, partly to ensure that the aircraft is not operated without a battery, it will be noted that external ground power cannot be selected to supply power to the system without battery power being available on the Ground Operation DC Bus.

Related to this particular subject, it will be noted further that if the nose landing gear is being cycled on the ground, the ground operation bus relay circuit breaker on the Flight Essential DC Bus should be opened to avoid losing external ground power each time the nose gear is retracted. In its up and locked position the nose gear uplock switch disconnects the Ground Operation DC Bus from the battery so that transfer relay No. 4 is de-energized.

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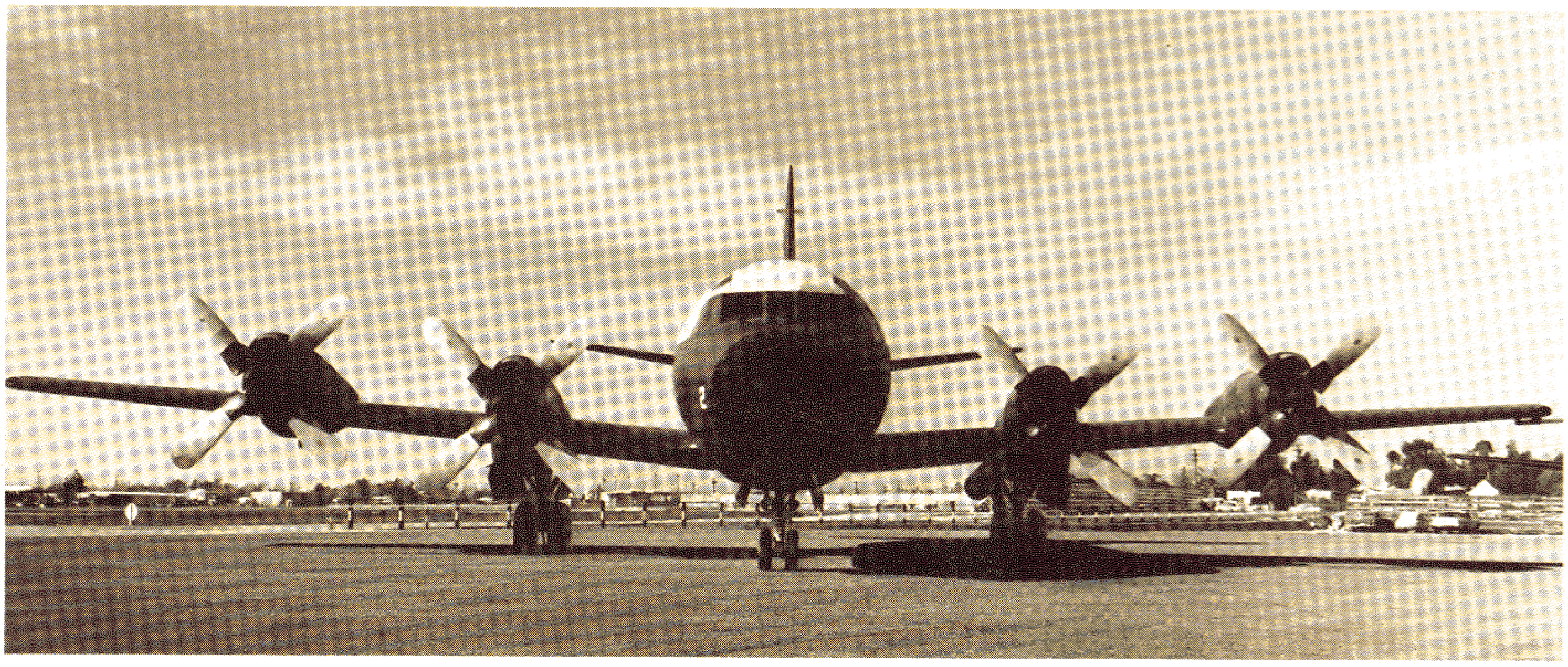

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