LOCKHEED field service digest

This publication is a digest of the most important technical information currently available and is intended to assist our customers in the service, maintenance, and operation of their Lockheed transport aircraft.

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March-April 1959

COVER PICTURE. First American built ***prop-jet*** airliner to be delivered to the Far East, Cathay Pacific Airway's ***Electras*** will enter 400-mph passenger service between Hong Kong, Bangkok, Singapore, and Manila.

EDITOR
Terence B. Donahue

LOCKHEED AIRCRAFT CORPORATION • CALIFORNIA DIVISION

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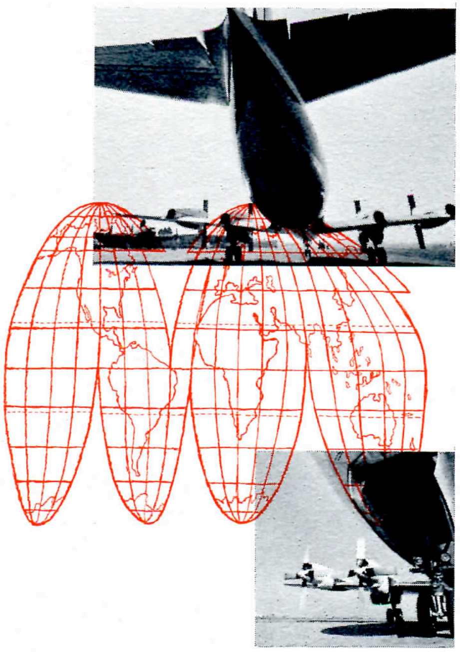


Foreword

This is the second in the Digest series of Electra introductory articles. The first article (Vol. 5, Nos. 2-3) presented a general picture of the airplane and in this and subsequent issues it is intended to describe the various aspects of the airplane in more detail. By the very nature of its interconnection with the other aircraft systems, the electric system is the next logical choice of this series. It is also a preferable choice from the viewpoint that the Electra's electric system incorporates a high proportion of significant changes and advances from past design practice.

There are many detailed variations in the electric system depending on the requirements of different airlines. We have endeavored therefore to describe a basic electric system which is generally applicable to all configurations of the Model 188 Electra. Where customer configurations differ from this basic system to any marked degree, it has been pointed out both in the text and on the illustrations.

The article is in two parts to be published in two separate issues. Part One describes the basic power system and distribution up to the load centers. In other words, the discussion begins at the power sources and generally ends at the circuit breakers of the individual circuits. Part Two will describe the generating systems and bus transfer system in more detail together with the associated control and protective functions.

The description has been presented in the form of an instructional aid, but it is hoped that those readers who are already familiar with the system will also find it useful. Finally, it should be remembered that, although applicable at the time of publication, this article should not be used as a reference source without also checking the validity of the information with the pertinent Lockheed and General Electric publications.

Acknowledgements are made to the various departments within Lockheed who reviewed these notes. The Electra Electrical Design group and the Electrical Staff and Research groups were particularly helpful and Paul de Alva, electrical design engineer, besides acting as chief consultant, contributed materially to the final presentation.

THE ELECTRA

ELECTRIC SYSTEM

INTRODUCTION

IN COMMON with most of the new turbine-powered transports the Electra utilizes 115/200-volt ac power. A small percentage of this ac supply is subsequently transformed and rectified to 28-volt dc, but this more conventional form of aircraft electric power is used on the Electra only where there are distinct advantages in doing so.

The basic ac system consists of four non-paralleled 60-kva generators supplying 400-cycle, 3-phase power through bus transfer relays to three main ac buses. It is actually a 3 generator/3 bus system and the Electra is certificated accordingly.* Each of the four generator systems contains its own protective circuitry designed to operate automatically in the event of system malfunction to ensure maximum power system reliability with a minimum of attention from flight personnel.

It is apparent from the above brief description that the Electra's electric system differs in several respects from the more conventional systems of previous airliner designs. Most significant among these differences are:

1. The utilization of high voltage alternating current.
2. The unusually high system capacity.
3. The generators are not paralleled.

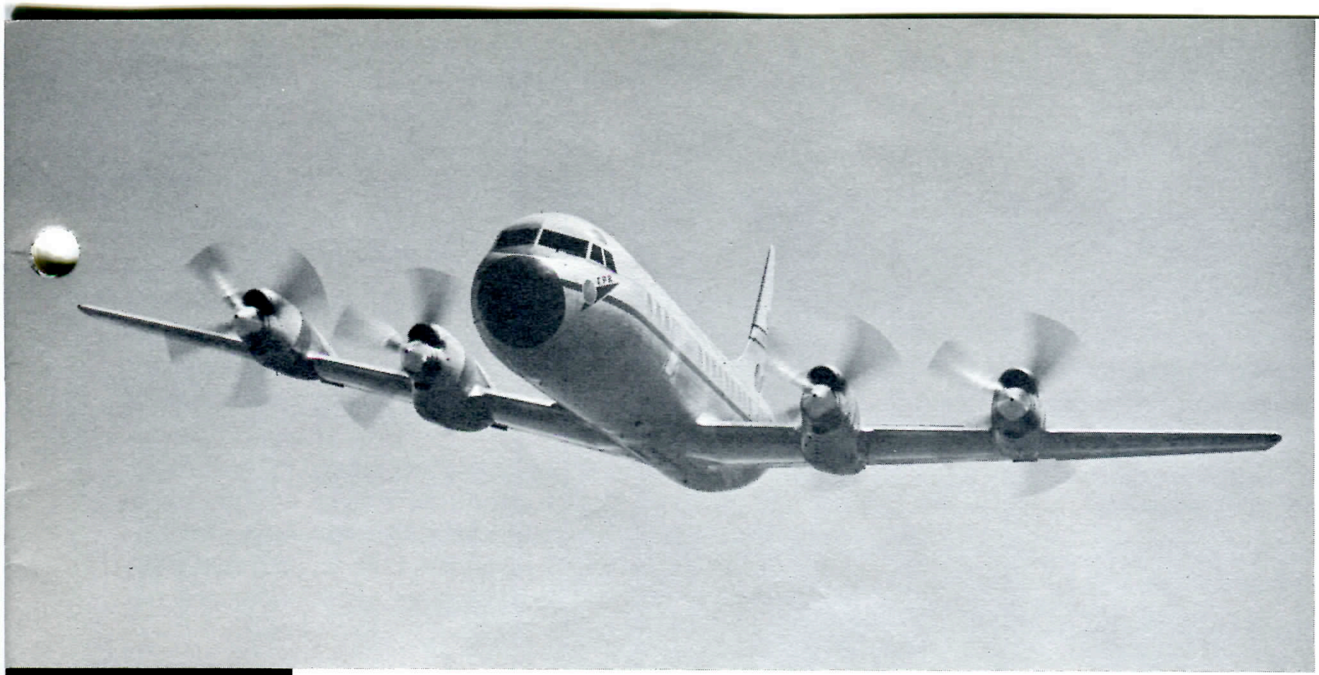
**The Electra can be dispatched with one generator inoperative; however, one of the four generators would normally be on standby.*

Before continuing, therefore, with the description of the system as it stands today, it might be interesting to review its development from the early design stages.

DESIGN DEVELOPMENT The Electra's specification called for a considerable increase in performance over contemporary airliners. In comparison with a 749 Constellation, for example, the Electra operates 30% faster, at 50% higher altitudes, carries 50% more payload, and does this with 8% less empty weight. Its mission as a short-to-medium range airliner also established the concept that it should be capable of operating from the smaller airports and be "self-contained" — using a minimum of ground support equipment.

From the outset it was obvious that considerable weight savings would have to be realized during the design of the airplane and this particularly applied to the various service systems. However, it had also been established that each of the systems such as electric, hydraulic, air conditioning, and de-icing, had to do a better job than previously, while still conforming, as far as possible, to the "self-containment" philosophy.

The total accessory power requirement to be taken from the engines in one form or another to achieve all these objectives was more than double the requirements of previous airplane designs built to a similar specification. Preliminary design studies showed that



PART ONE

the only way to meet this increased power demand efficiently was by the use of an extensive electric system, this decision being contingent upon the adoption of a high voltage system.

Electric power offered the following advantages over any other method of meeting this accessory power demand:

1. Use of a single ground power source for all ground purposes including full heating, cooling, hydraulic and control system checks — all without engines running.
2. Flexibility in permitting the location of power devices throughout the airplane closest to the point of use — and therefore providing the lightest and simplest arrangement.
3. Load transfer flexibility in the event of single or multiple engine failure and the ability to monitor selectively for non-essential functions.

The aircraft industry had generally conceded the inadequacy of the conventional 28-volt dc power supply system for the turbine powered transport. The increase in loads and feeder sizes imposed heavy weight penalties on the aircraft and the increased size of generators created additional problems in mounting them on the engine. The adoption of higher voltage electric systems offered the most logical solution. A 115/200-volt, 3-phase, 400-cycle system was finally selected for the Electra primarily because it was the only higher voltage system sufficiently developed to promise successful incorporation in the airplane development schedule. The use of alternating current also had many additional benefits.

Some of the advantages gained by utilizing a higher voltage ac power supply are:

1. Weight reduction. Generators, motors, feeders and other components are all relatively lighter than their low voltage dc counterparts. The Electra's 240-kva system (installed capacity) weighs approximately the same as a conventional 60-kva, 28-volt dc system.
2. The larger power output available allows more scope in the design of the other accessory systems while still leaving a large reserve for future development.
3. Voltage can be varied much more easily for any requirement by means of transformers.
4. Transformer rectifiers for converting ac to dc weigh much less than do inverters for converting dc to ac and are simpler in design.
5. Motors are of simple squirrel cage construction and have good torque characteristics.
6. The use of ac generators and motors eliminates commutators and the associated arcing problems, which increase with altitude.

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Much of the weight reduction afforded in the other accessory systems can be directly attributed to the concept of making the maximum use of high voltage ac electric power. The following comparison illustrates this point:

	188 Electra	749 Constellations	1049 Constellations
Air Conditioning	1800 lb	2755	2566
Hydraulic	290	589	782
Electric Power	1700	1077	1291
Total Systems Wt.	3790	4421	4639

It will be observed that the totalled figures of the accessory system weights is noticeably less for the Electra than for the 749 and 1049 Constellations. Furthermore, the total amount of accessory power to be taken from the engines in the case of the Electra (as represented by the above total systems weight figure) is more than double the total that is utilized for either of the other two aircraft. Some interesting examples of the utilization of this "extra" accessory power are:

Hydraulic — The arrangement of electrically driven hydraulic pumps in the fuselage has many inherent advantages over the conventional "engine driven pumps" system. The system is self-contained, compact, and much more flexible in operation — not being directly dependent upon the engines.

Air Conditioning — The introduction of electric radiant heating plus the use of electric duct heating and electrically driven cooling devices has resulted not only in a self-contained air conditioning system of relatively low weight; but has also increased the passenger comfort level beyond previously accepted standards.

Having discussed the reasons for, and some of the advantages of the Electra's large capacity high voltage ac system, one aspect requires some further explanation. The Electra is probably unique among the new turbine powered transports in having a non-paralleled system.

A decision was made early in the design stages to take advantage of the constant speed characteristics of the Allison prop-jet engine to avoid the use of constant speed drives. This decision predetermined the choice of a non-paralleled electric system, since it is not possible to parallel generators from different drive sources without the use of constant speed drives. Had a paralleled system been adopted for the Electra there would have been an attendant increase in the complexity and weight of the system. Furthermore, provisions for non-parallel operation would still have to be incorporated in the system design due to the questionable reliability at that time of paralleling controls.

These factors among others influenced the decision to select the non-paralleled system for the Electra which, by the use of a slightly sophisticated transfer system, provided in addition to weight economies, the very desirable advantages of simplicity and reliability.

GENERAL DESCRIPTION

High voltage ac power is used to supply all the loads having a large power demand such as the freon compressor (25 hp), heating, and lighting loads, in addition to the transformer rectifier units which supply the dc power for the airplane.

Extensive use is still made of 28-volt dc power for the many services which have been developed to a high degree through the past years and which have a small power demand. It is used primarily for control, indication, and instrument circuits, although other considerations have also influenced the extent of its use. The "self-containment" philosophy required that certain units be operable from the aircraft battery and there is also a large demand for dc power for radio.

AC POWER SYSTEM The basic simplicity in the arrangement of the main ac buses and their possible sources of supply is shown diagrammatically in Figure 1. A generator is mounted on each of the four engines and under normal conditions (shown by the black lines in Figure 1), the following applies:

The No. 1 generator supplies the Utility Bus C.

The No. 2 generator supplies the Priority Bus B.

The No. 3 generator supplies the Priority Bus A.

The No. 4 generator, again under normal conditions, operates on a standby basis, being energized, but without load.

Since the electric power system is not paralleled it may be considered essentially as three separate ac systems, each consisting of an engine driven generator with its associated control circuits, and a main bus with a selected group of loads. A fourth bus, termed the Essential AC Bus, is an additional load which is normally supplied by the No. 3 generator via the Priority Bus A. The colored lines in Figure 1 indicate the possible alternative sources of supply for the various ac buses. For the sake of clarity, the switching or transfer system is not shown in this diagram; however, each bus may only be connected to one supply source at a time. The ground power connection has also been omitted.

The Essential AC Bus feeds a selected group of services which are of primary importance to the airplane's operation and it consequently has the support of all four generators. Also, according to their relative importance, the Priority Bus A and the Priority Bus B have three generator support while the Utility Bus C has only two possible sources of supply. It should be noted that generator Nos. 1 and 4 are able to support all four buses and, in particular, either may supply the Essential AC Bus directly, thus bypassing the three main buses and the main bus transfer system.

A further refinement of the system is the use of a two speed gear box (1:1.38) on the No. 4 engine. This is used to step up the generator speed when the No. 4 engine is selected to "Low Ground Idle." All the engines have this reduced speed provision for the purpose of noise reduction on the ground and under these conditions, the No. 4 generator is able to supply all loads and the complete system is energized for ground purposes. This feature is particularly advantageous for certain airline operations which entail in-transit stops where ground power equipment may not be available or where the time factor does not warrant the use of such equipment.

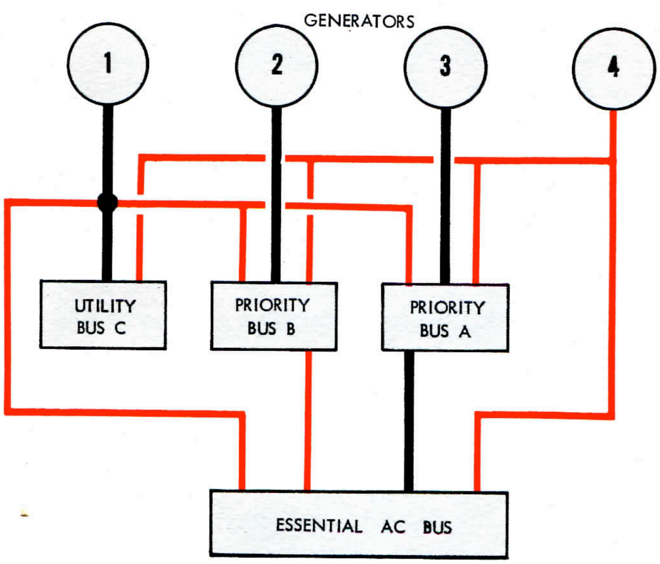

Figure 1 AC Power System

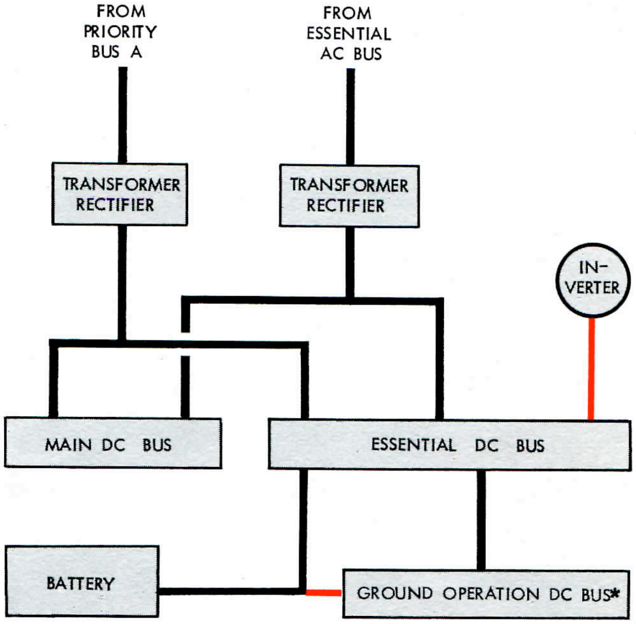

Figure 2 DC Power System

DC POWER SYSTEM The basic layout is illustrated in Figure 2. Two 150-amp transformer rectifiers obtain their input supply from the Priority Bus A and the Essential AC Bus respectively. The 28-volt dc output from each of the transformer rectifiers is then divided between the Main DC Bus and the Essential DC Bus. The dc system may be said to have 100 percent standby capacity, since either of the transformer rectifiers is independently capable of supporting the complete dc load.

Like its ac counterpart the Essential DC Bus carries loads closely associated with flight safety including the control power for the ac transfer system. All dc loads which do not come into this "flight safety" category are connected to the Main DC Bus with the exception of circuits such as cabin and service lights, refueling, door and stairway operation, dc operated hydraulic pump, etc., which may be required during ground servicing. These latter loads are connected to the Ground Operation DC Bus,* which normally receives its power supply via the Essential DC Bus.

As the black lines on Figure 2 show, the 36-ampere/hour battery would normally be connected to the Essential DC Bus and is necessary for the efficient operation of the system. Furthermore, in conjunction with the inverter, the battery supplies a limited amount of ac power for the engine starting circuits, and in the unlikely event of an extended emergency condition involving the complete loss of generated ac power, the battery and inverter are also used to supply a minimum amount of ac and dc power for the essential flight instruments.

**KLM does not have a Ground Operation DC Bus and the ground servicing loads are connected to the Essential DC Bus.*

(Continued on next page)

SYSTEM LAYOUT

The majority of the electric power system components are disposed among four principal locations which are shown in Figure 3 and are identified as follows:

1. Powerplants — generator installation.
2. Main Electrical Service Center — a compartment below the cabin floor situated immediately forward of the wing center section which accommodates the generator exciters, regulators, and control equipment as well as the main ac bus transfer and power distribution box.
3. Flight Station — which includes the forward load center (dc and flight station ac power distribution) and the electrical control panel.
4. Nose Area — which includes the nose wheel well and the external power receptacle.

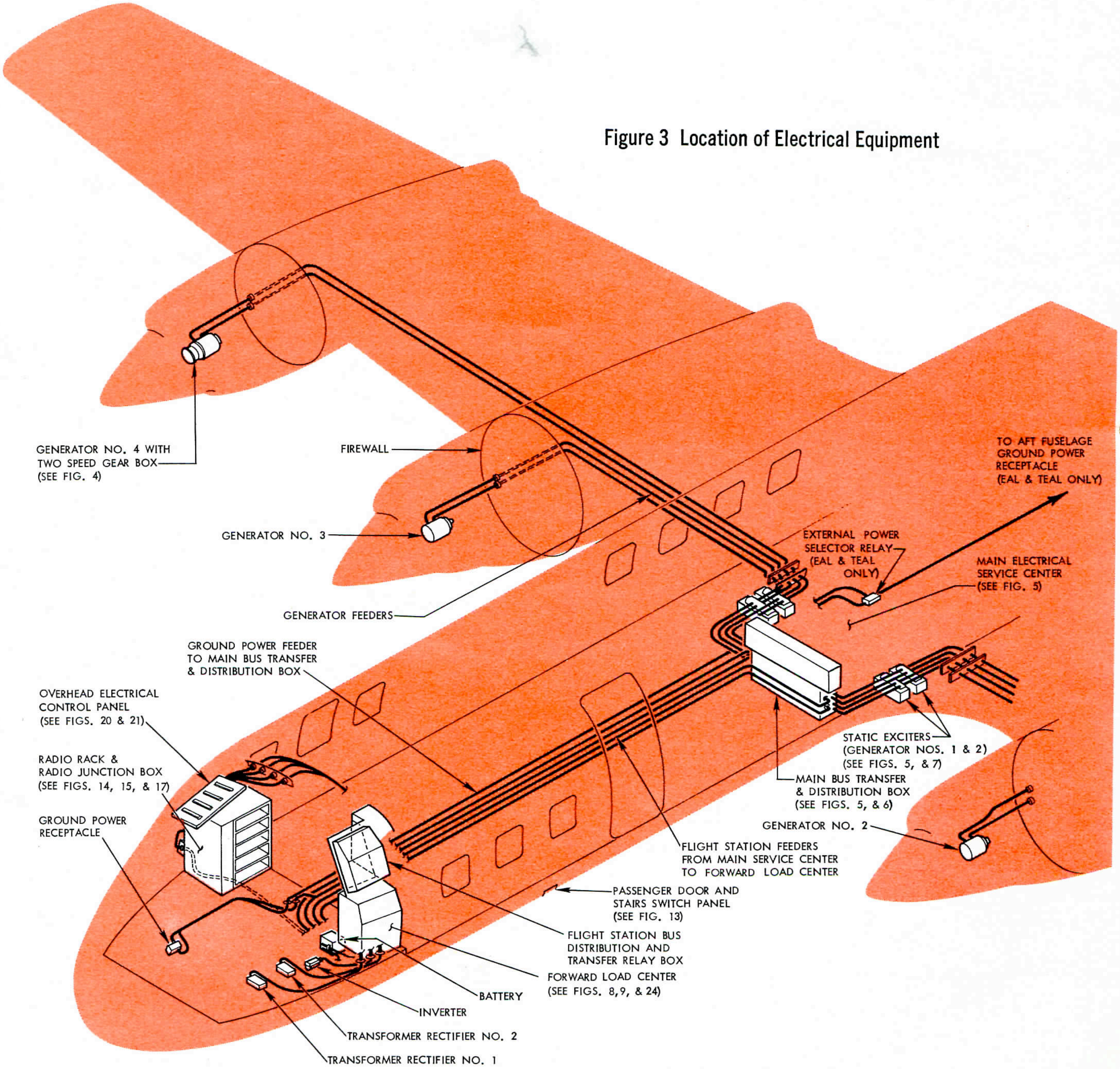

Figure 3 Location of Electrical Equipment

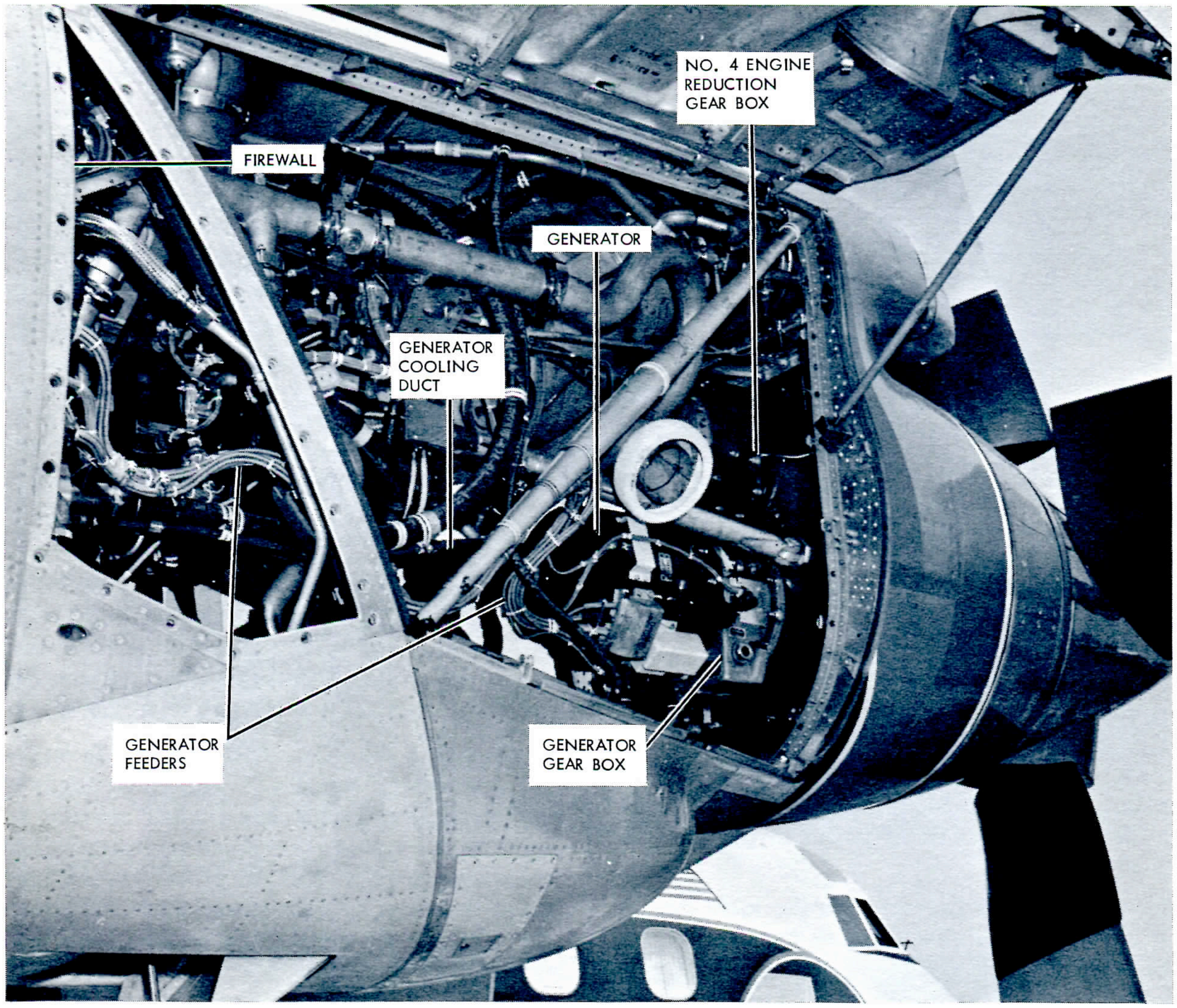

Figure 4 Generator Installation — No. 4 Engine

POWERPLANTS A 60-kva generator is mounted on the aft right hand side of each engine reduction gear box. Figure 4 shows the generator mounted on the No. 4 engine and, as previously mentioned, this particular installation differs from the other three in that a two speed gear box is interposed between the generator and the mounting pad.

Cooling air is tapped from the engine oil cooler scoop and directed to the generator through a 4-inch diameter flexible duct. A mechanically operated shut-off valve, located at the intake of each duct, is one of the items controlled by an emergency shut-down handle, one of which is provided in the flight station for each engine. To facilitate the removal of the generator, keyhole type mounting holes are provided and special ground handling equipment is available.

The generator feeders are made up of two bundles of three 6-gauge wires from each generator. Each bundle contains one wire from each phase and one of them also contains the generator neutral, a single 4-gauge wire. To minimize the possibility of crossed wires, the wiring and the terminals of the generator are color coded and this practice has been extended to cover all the 3-phase circuits on the airplane.

Wires to the generator field, the generator mechanical failure warning device, and various control circuits are, as far as possible, routed separately from the power wiring. The ground wires of these circuits and the generator neutral are all terminated on aircraft structure aft of the firewall. All other wiring between each generator and its associated components in the service center passes through the firewall at the rear of each engine installation, progresses inboard inside the wing leading edge, and enters the pressurized fuselage shell through pressure seals. Between the generators and the service center, the only break in the feeder wires is at the engine firewalls, where fireproof quick-disconnects are provided for all wires to facilitate powerplant removal.

(Continued on next page)

MAIN ELECTRICAL SERVICE CENTER The general arrangement of components in this service center can be seen in Figure 5. A large door in the lower fuselage shell provides external access to this compartment and it is also accessible through a small hatch in the center aisle of the main cabin.

The generator static exciters, voltage regulators, and control units are arranged along either side of the service center while the main transfer and distribution junction box is installed at the forward end. As Figure 5 shows, this arrangement of components is conducive to a simple and accessible layout and provides short, direct runs of the generator wiring from each wing. The generator feeders are first routed through the static exciters and then pass into the main transfer and distribution box.

The main transfer and distribution box may be considered as the nerve center of the Electra's electric system. It contains the three main ac buses and their associated circuit breaker panels (see Figure 6) as well as the generator power and bus transfer relays. It is constructed of fire-resistant laminated Fiberglas and the box itself is divided into four compartments which provide physical and electrical isolation of the different parts of the power system. All ac power sources, including ground power, are fed into this box and the transfer relays determine the distribution of power to the ac buses in the airplane.

Other components contained in the main service center include several miscellaneous relay and circuit breaker panels (see Figure 7), certain gyro-type units, and various electronic units associated with the powerplants, such as the engine torquemeters and the propeller phase synchronizer.

FLIGHT STATION The forward load center is located at the aft left hand side of the flight station and is shown in Figures 8 and 9. It consists principally of the circuit breaker panels for all the flight station ac and dc buses. These buses, together with the associated relays and other components, are housed and isolated as far as practicable in Fiberglas compartments behind the panels.

Power feeders from the main service center are routed just below the cabin floor to the forward load center and supply the flight station ac requirements, as well as the two transformer rectifiers of the dc system. The forward load center is the nerve center of the dc system and the outputs of the transformer rectifiers and the aircraft battery comprise the dc power sources.

The electrical control panel is shown in Figure 21 and is located overhead between the flight engineer's and copilot's seats. This panel contains the switches, instruments, and indicator lights that are required for the operation of the ac and dc power systems.

NOSE AREA The spaces on either side and aft of the nose wheel well directly below the flight station are outside the pressurized area and are used for the location of certain electrical components which would otherwise require special provisions for cooling, noise isolation, or ventilation. Such components as the battery, the transformer rectifiers, the inverter, and various transformers associated with the windshield heating circuits are located here as shown in

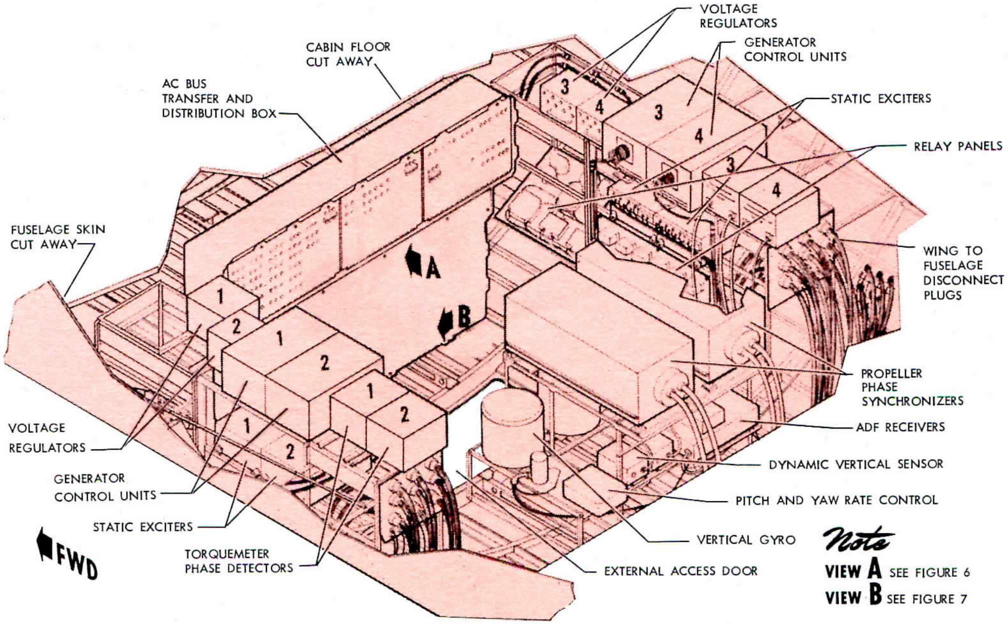

Figure 5 Main Electrical Service Center

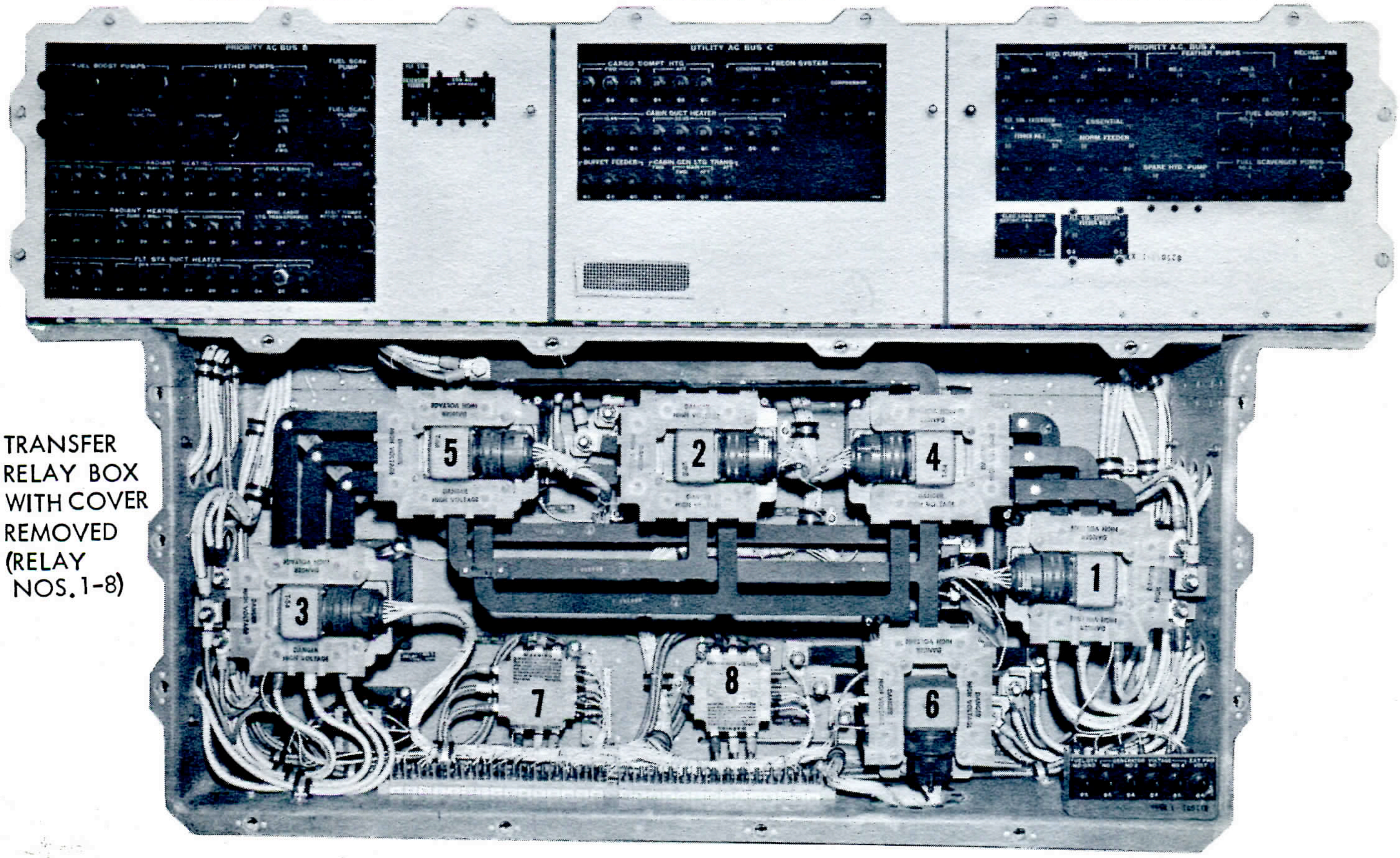

Figure 6 Main Transfer and Distribution Box

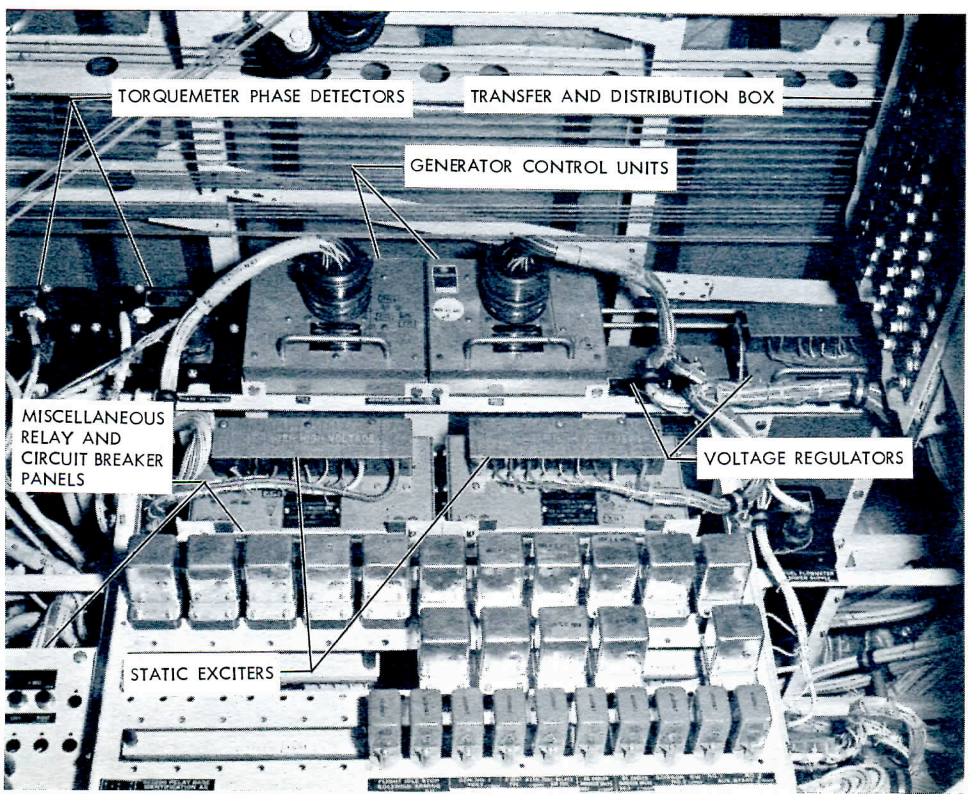

Figure 7
Main Service Center —
View Left Hand Side

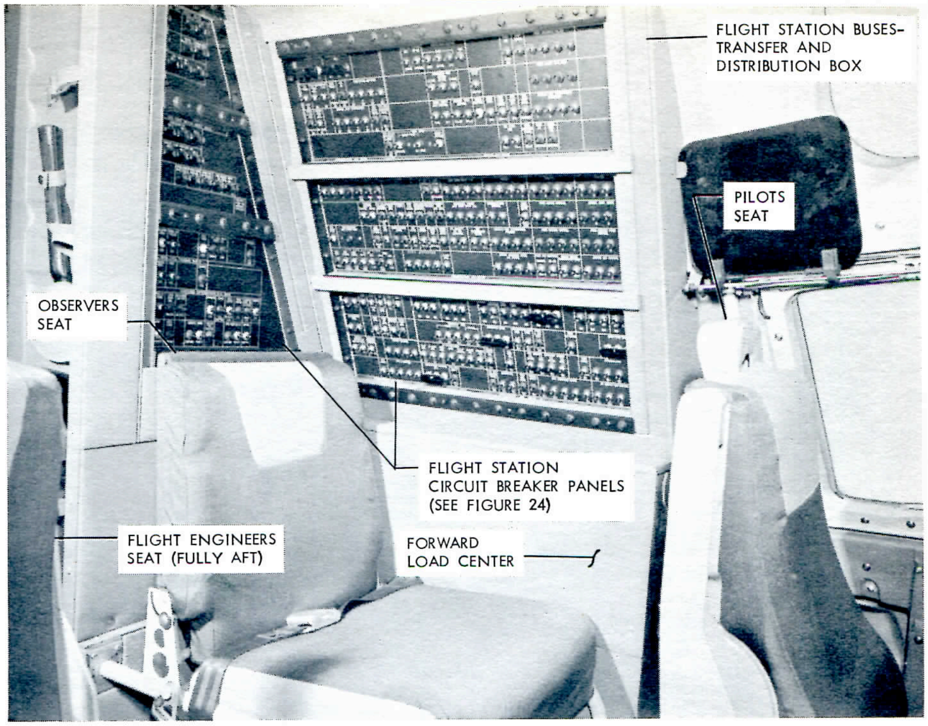

Figure 8
Forward Load Center — NAL

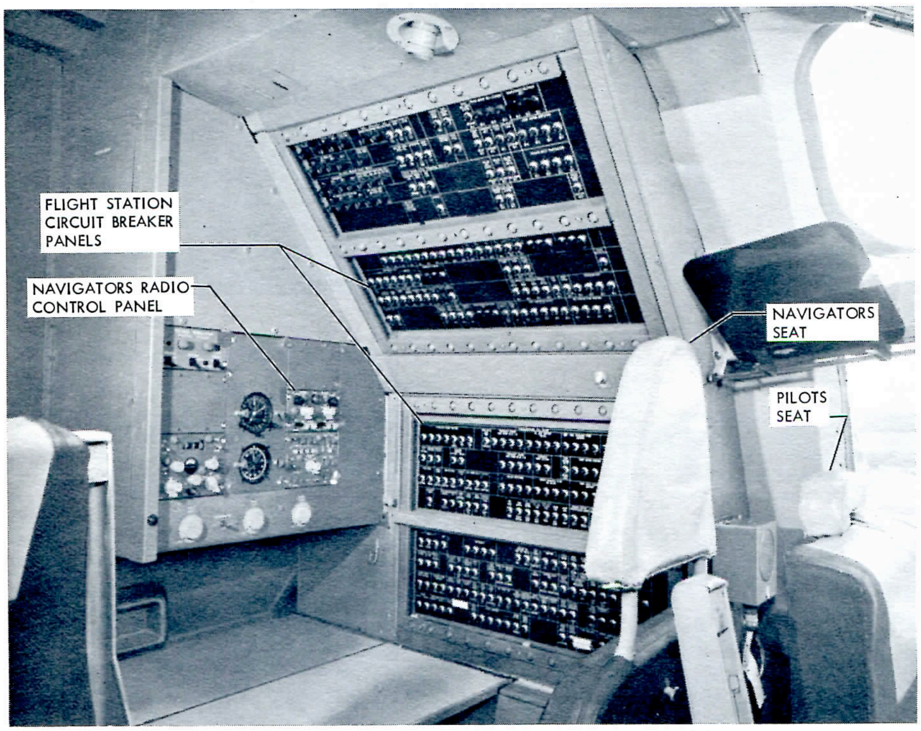

Figure 9
Forward Load Center and Navigator's Station — KLM

Figure 3. The wiring from all these items is routed through pressure seals to the forward load center.

The ground power receptacle is located on the right hand side of the nose of the airplane and has a capacity of 90-kva. Aluminum 3-phase wiring connects this receptacle directly to the distribution box in the main service center.*

Particular attention has been given to the battery installation in order to facilitate maintenance. The rack on which the battery is mounted is attached to a hoist operated by a screw jack with an integral handle, enabling the battery to be easily lowered from the fuselage. A neutralizing sump jar, with ventilation provided by tubing from flush air scoops, is installed adjacent to the battery.

The battery has a quick-disconnect plug which carries both the positive and negative leads. The negative lead is grounded to adjacent fuselage structure through the battery ammeter shunt while the positive lead is connected to the distribution system via a 100-amp current limiter, which is located just forward of the battery installation.

EAL and TEAL have an additional ground power receptacle in the rear fuselage to suit their particular operation plan.

POWER CIRCUIT DESCRIPTION

We have now discussed the basic design concepts of the ac and dc systems, and described the physical locations of the principal electric components in the airplane. This background information should now give us a better understanding of the arrangement of the power circuit and permit a more comprehensive description of the system to be made.

A complete, although still rather simplified power circuit, is depicted in Figure 12 and this discussion will, in the main, describe this schematic. It will be noted that as a further aid in creating a mental picture of the power system, this illustration has the same sub-divisions with regard to component location as the "System Layout" section. Only the generators and feeders of the four generating systems, with the associated bus transfer relays, are depicted in Figure 12. The generator/bus control circuitry has been omitted for the sake of simplicity. The generating and load transfer control systems are covered in detail in Part 2, but the following brief description is included here in order to facilitate a more detailed discussion of the rest of the system.

GENERATOR CONTROL AND PROTECTIVE CIRCUITS

Each generating system contains protective circuitry to sense system malfunctions and to de-energize and disconnect the generating system automatically when such malfunction occurs. Control switches and TRIP indicator lights for each generator are located on the electrical control panel (see Figure 21).

Overvoltage. When an overvoltage condition is sensed in the generating system, the generator will be de-energized and disconnected from its load, and its generator TRIP light will be energized. The load will be transferred to another generator or dropped if another generator is not available. For single phase overvoltage, the protection responds to the highest phase voltage. The generator system may be reset after an overvoltage by returning the applicable generator control switch to the "OFF-RESET" position, at which time the TRIP light will be extinguished. If the generator is subsequently energized and the overvoltage still exists, the system will again trip prior to reconnection of the loads.

Feeder Faults. If a fault occurs in the generator or its feeders to the bus system, a differential current system will de-energize the generator, disconnect it from its loads and operate the TRIP warning light. The load will be transferred to another generator or dropped if another generator is not available. After a feeder fault the generator system cannot be reset by means of the generator control switch. The TRIP light will remain lighted when the generator control switch is returned to the "OFF-RESET" position.

Off-Frequency Operation. If the generator is operated at speeds which would result in an output frequency higher or lower than the specified range, it will be disconnected from its load, and the load will be either transferred to another generator or dropped if another generator is not available. If the generator subsequently operates within the specified frequency range it will be reconnected automatically. Operation of the generator control switch is not required. During off-frequency operation the generator is de-energized.

Undervoltage and Bus Lockout. In the event that an undervoltage condition is sensed the following sequence of events will occur:

1. The undervoltage condition will be allowed to exist for approximately two seconds to permit branch circuit protection to operate if the condition is caused by an overload on a branch circuit.
2. If the undervoltage still exists at the end of this period, the generator will be disconnected from the bus transfer system but will remain energized. Transfer of the loads to another generator will not occur. If the disconnection results in a restoration of voltage, a fault in the bus or transfer system will have occurred, in which case the system is held in this condition with the bus remaining de-energized.
3. If disconnection of the generator from the bus and transfer system does not result in restoration of voltage, the generator is then de-energized and the transfer system is permitted to transfer the load to another generator. As in the case of a feeder fault, the generator may not be reset from this condition.

In brief, the control circuitry recognizes three possible situations — generator "OFF," generator "ON," and bus fault. A generator or feeder failure has the same final effect as a generator "OFF" condition.

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BUS TRANSFER SYSTEM This comprises the relays numbered 1 through 8 (also shown pictorially in Figure 6) and relay No. 10 which is located in the forward load center. Of these, Nos. 1 through 5 are double coil, center-off relays while Nos. 6, 7, 8 and 10 are single coil, side stable relays. To prevent any inadvertent paralleling of the generators, the transfer relays are electrically and mechanically interlocked.

The choice of generators supplying the three main ac buses is predetermined by the power system control circuitry which interconnects the coils of relay Nos. 1 through 6 with the generator control and protective circuits described above. The connection of the Essential AC Bus to one of the power sources then follows automatically and is governed by the positions of the ac relays Nos. 7, 8, and 10. The various generator/bus combinations are shown in Figure 10.

GENERATOR	1	2	3	4
NORMAL CONDITION	C	B	A E	STANDBY
ONE GENERATOR OUT	C	B	AE	—
	C	B	—	A E
	B	—	AE	C
	—	B	AE	C
TWO GENERATORS OUT	AE	B	—	—
	B	—	AE	—
	B	—	—	A E
	—	B	A E	—
	—	B	—	A E
	—	—	A E	B
THREE GENERATORS OUT	A E	—	—	—
	—	B E	—	—
	—	—	A E	—
	—	—	—	A E

Note
- A Denotes the Priority Bus A including its flight station extensions. It has 3 generator support.
- B Denotes the Priority Bus B including its flight station extension. It has 3 generator support.
- C Denotes the Utility Bus C. It has 2 generator support.
- E Denotes the Essential AC Bus. It has 4 generator support.

Figure 10 Generator/Bus Support Chart

TRANSFER SYSTEM OPERATION — Main Buses Under normal conditions the three main ac buses are connected to the generators as follows (see Figure 11):

Priority Bus A to generator No. 3 via relay 1A.
Priority Bus B to generator No. 2 via relay 3A.
Utility Bus C to generator No. 1 via relay 2B.
Generator No. 4 is energized and on standby.

Three-Generator Operation — Only three generators are required for normal operation. All electrical services are provided.

Two-Generator Operation — With any two generators operating, electric power is supplied to all loads except those served from the Utility Bus C. Power is available for all operational functions and for acceptable passenger comfort and convenience.

One-Generator Operation — With any one generator operating, power is available for all functions directly related to continuation of safe flight. This includes, under all conditions, the loads connected to the Essential AC Bus and all dc buses. If the remaining generator is on engine Nos. 1, 3, or 4, power will also be supplied to the loads on the Priority Bus A. If the remaining generator is on engine No. 2 the loads on the Priority Bus B will be supplied.

With two or more generators inoperative the loading of the remaining generators is not increased, but rather the loads are dropped by buses in order of their relative importance to the operation of the airplane. It is therefore impossible to overload the remaining generators and thus cause subsequent failure of these systems. The bus priorities are established automatically by the transfer system and no action by the flight crew is required.

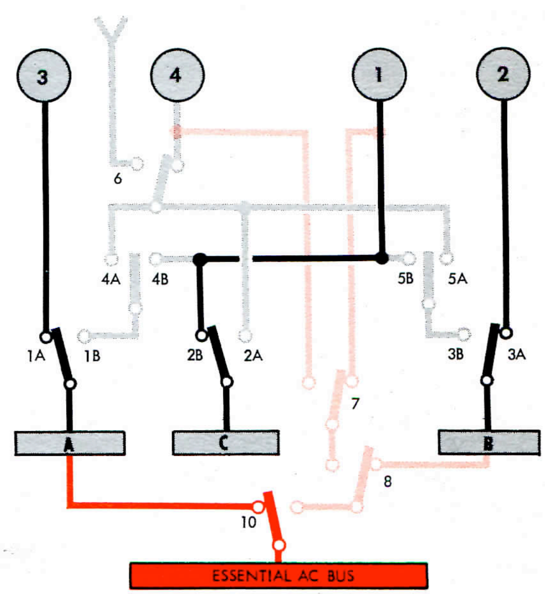

Figure 11 Bus Transfer System — Showing Normal Condition

An understanding of the operation of the transfer system is probably best achieved by describing how the system, when operating normally as above, copes with a series of generator malfunctions. It will be noted that the Essential AC Bus transfer system is shown in Figure 11 (in color) but is omitted from Figures 11a through 11d to achieve clarity. The tripping of generator No. 3, for example, would cause the transfer system to operate and transfer the Priority Bus A to generator No. 4 through relays 1B and 4A (see Figure 11a).

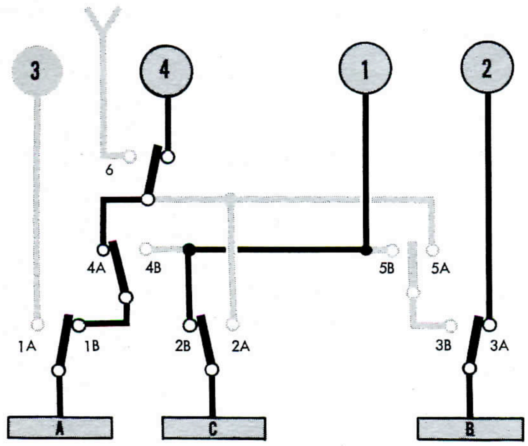

Figure 11a

Should generator No. 2 also trip, the transfer system would operate so as to disconnect generator No. 1 from Utility Bus C by opening relay 2B and would transfer this generator to the Priority Bus B through relays 5B and 3B (see Figure 11b).

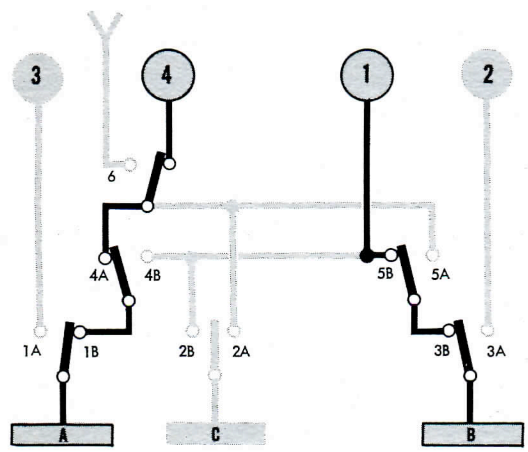

Figure 11b

Should generator No. 4 also trip, the transfer system would operate so as to disconnect generator No. 1 from the Priority Bus B by opening relay 5B and would transfer this remaining generator to the Priority Bus A through relays 4B and 1B (see Figure 11c).

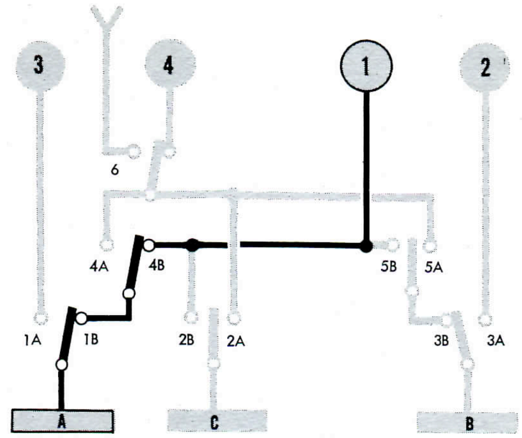

Figure 11c

Essential AC Bus. The power system has been designed with particular emphasis on preventing the occurrence of bus faults. The automatic bus lockout feature was previously described and the detail design of the system provides both mechanical and/or electrical isolation for the feeders, buses, relays, and so forth. However, should a bus fault or a transfer system malfunction occur, provisions have been made to automatically connect the Essential AC Bus (and consequently the dc system also) to power sources that bypass the main ac buses and the transfer system (see Figure 11).

Under normal conditions the Essential AC Bus is supplied from the Priority Bus A via relay No. 10. Should the Priority Bus A become de-energized, the Essential AC Bus would be transferred to the Priority Bus B. Should the Priority Bus B also become inoperative, the Essential AC Bus would then be connected directly to either of the outboard generators (Nos. 1 and 4) ahead of the transfer system.

External Ground Power. Transfer relay No. 6 is primarily concerned with the supply of external or ground power to the system. When this relay is energized the transfer control system automatically positions all the dc double coil relays (Nos. 1 through 5) to energize all three main ac buses simultaneously and consequently the complete power system, from the ground power source (see Figure 11d).

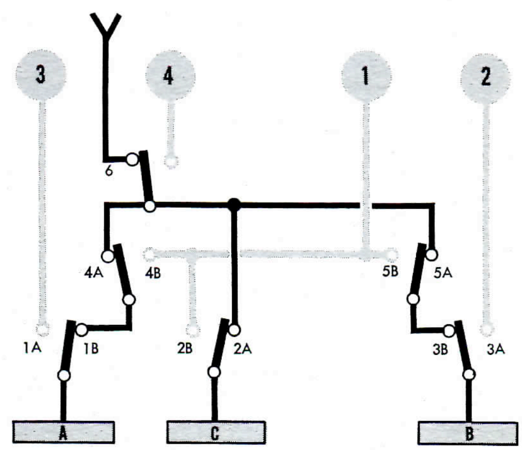

Figure 11d

GENERATOR NO. 4 GROUND POWER OPERATION The use of the two speed gear box incorporated in the No. 4 generator installation was explained in the "General Description" section. When the No. 4 generator assumes the other generator loads, the transfer system relays take up positions similar to those when the external ground power supply is connected, except that relay No. 6 will not be energized.

We might digress a little at this point in order to clarify the operation, although more complete details of the control circuitry will be given in Part 2. The transition from normal engine idle to low idle speed (13,400 to 10,000 rpm approximately) is accomplished by the operation of small toggle switches which are located, one for each engine, just forward of the pilot's power levers and they can be seen on Figure 21.* A low rpm control circuit governs the operation of the toggle switches. This allows selection of an engine to "Low Ground Idle" only if the airplane is on the ground and the respective power lever is in the Beta or Taxi range. This control circuit also establishes a definite sequence of selection between the two idle speeds for all four engines so that load transference can be accomplished as smoothly as possible.

**KLM has these switches mounted on one of the overhead control panels.*

When reducing the engine speeds from "Normal Ground Idle" to "Low Ground Idle" the No. 4 engine has to be selected first and the toggle switches on engine Nos. 1, 2, and 3 are inoperative until this has been accomplished. After the No. 4 engine has been selected to "Low Ground Idle," it decelerates and the No. 4 generator is de-energized by its frequency control network. When the engine reaches low idle speed the gear box shifts automatically, the generator returns to normal frequency, and is re-energized. The No. 4 generator is then ready to assume the loads from the other generators as soon as the Nos. 1, 2, and 3 engine speeds are reduced and their respective generators drop off the line.

Similarly, when raising the speeds of the engines, the No. 4 toggle switch is inoperative until engine Nos. 1, 2, and 3 have been selected to "Normal Ground Idle." Thus as the generator outputs on these engines are established at this setting, they automatically assume their normal loads from the No. 4 generator.

FLIGHT STATION POWER DISTRIBUTION The flight station ac requirements are supplied from the Essential AC Bus, the two flight station extensions of the Priority Bus A, and the Priority Bus B extension (see Figure 12). These buses and their respective circuit breaker panels are all located in the forward load center and are supplied by feeders from the main service center. The feeders are protected by 50-amp circuit breakers which are mounted on the transfer and distribution box in the main service center and may be listed as follows:

1. Essential-Normal AC Bus Feeder — supplies 3-phase current from the Priority Bus A to the Essential AC Bus via the transfer relay No. 10, located in the forward load center.
2. Essential-Alternate AC Bus Feeder — supplies 3-phase current from either the Priority Bus B, or generator No. 1, or generator No. 4 to the Essential AC Bus. It is connected to the other side of the transfer relay No. 10 and is routed separately from the Essential-Normal AC Bus feeder.
3. Priority Bus A Flight Station Feeder No. 1 — supplies 3-phase current from the Priority Bus A to one of two flight station extensions via the disconnect relay No. 1. This feeder also supplies the transformer rectifier No. 2 which is connected ahead of the disconnect relay so that operation of the relay will not affect the supply of primary power to the transformer rectifier.
4. Priority Bus A Flight Station Feeder No. 2 — consists of two phases (phase A and phase C) which supply the other Priority Bus A flight station extension via the disconnect relay No. 2. This feeder is routed separately from the Priority Bus A flight station feeder No. 1.
5. Priority Bus B Flight Station Feeder — consists of only one phase (phase B) which supplies the Priority Bus B flight station extension. It is routed separately from the other flight station feeders.

It will be noted that for bus transfer purposes the Priority Bus A and the Priority Bus B flight station extensions are an integral part of the main ac bus from which they originate. A non-essential load disconnect switch (Bus A & B) on the electrical control panel operates both the Priority Bus A flight station extension disconnect relays for load monitoring purposes. The Priority Bus B flight station extension is also monitored indirectly by the same switch. See the "Load Distribution and Monitoring" section.

DC POWER SYSTEM The two 150-amp transformer rectifiers are non-regulated and have independent 3-phase power inputs, each protected by a 20-amp, 3-pole circuit breaker located on the forward load center circuit breaker panel. One input originates from the Essential AC Bus. The other is taken from the Priority Bus A flight station feeder No. 1, ahead of the disconnect relay (see Figure 12).

Each transformer rectifier supplies both the Main DC Bus and the Essential DC Bus. They are normally used in parallel, and each of the four 28-volt dc power feeders is connected to the dc buses through reverse current relays and 120-amp circuit breakers which are located in the forward load center.

Switches located on the flight station electrical control panel control each transformer rectifier output by actuating the appropriate reverse current relays.* The two relays in the Main DC Bus feeders are also controlled by another switch on the electrical control panel for load monitoring purposes.

Battery Circuit. The 36-amp/hour battery is connected to the distribution system through a 100-amp current limiter and has several functions which are listed as follows:

1. It has a stabilizing influence on the dc system and, in particular, it maintains the continuity of dc control power during switching and transfer operations.
2. It provides a reserve source of power for certain ground operations.
3. In conjunction with the inverter, it supplies power to the minimum loads necessary for engine starting.
4. Under extreme emergency conditions and in conjunction with the inverter, it supplies power to the loads necessary to meet minimum flight instrument requirements.

The engine starting and flight emergency contingencies are explained in the Inverter Circuit description below but in either case the battery is connected to the Essential DC Bus via the battery relay.

For ground operations the battery is connected to the Ground Operation DC Bus via the ground operation relay and a 50-amp circuit breaker (located on the forward load center circuit breaker panel). Although the Ground Operation DC Bus is normally connected to, and could therefore receive battery power via the Essential DC Bus, this arrangement of isolating the battery and the more commonly used ground loads helps to conserve battery power.

**KLM does not have these two rectifier switches.*

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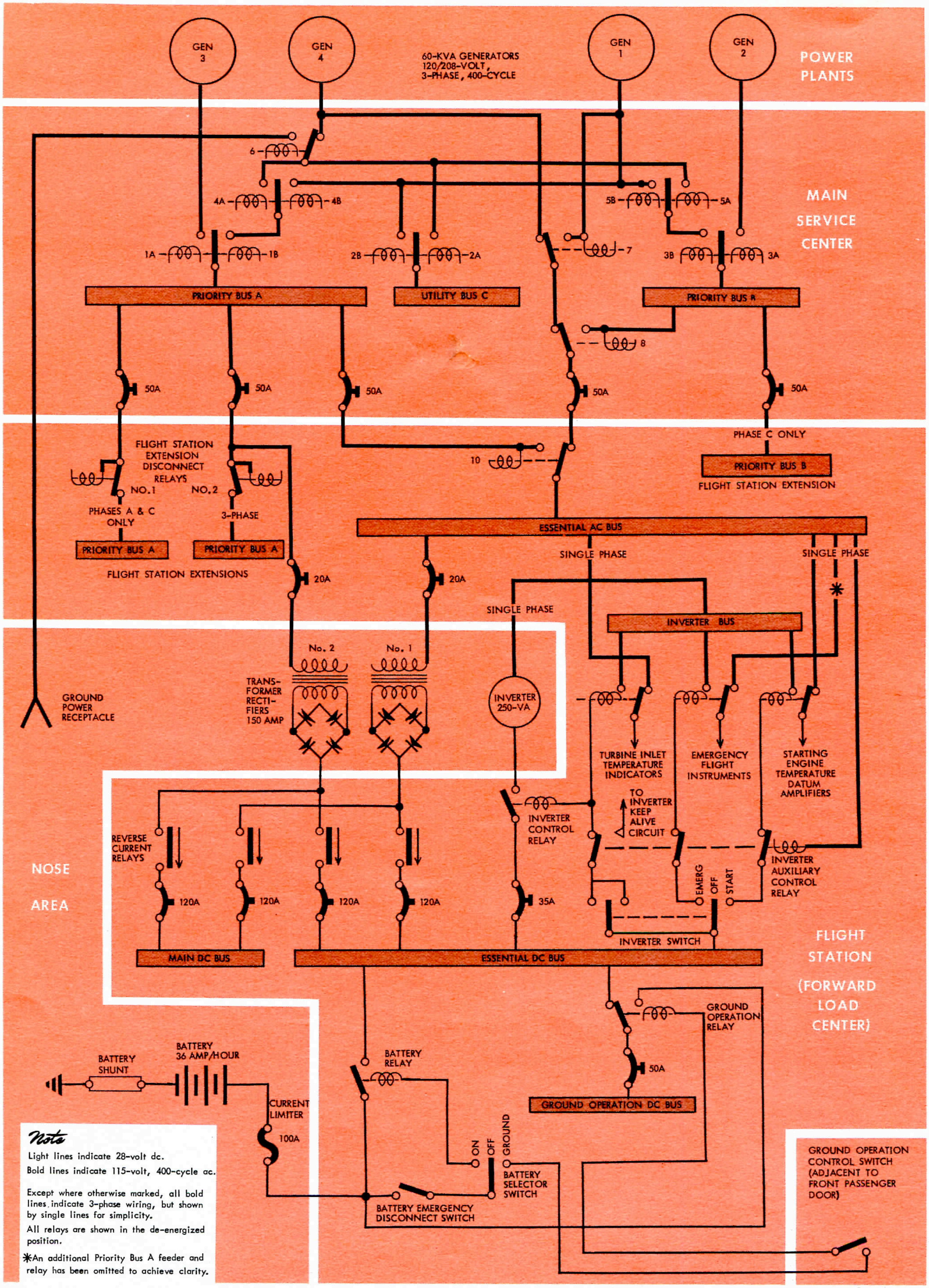


Figure 12 Electric Power System Schematic

Three switches control the relative positions of the battery and ground operation relays and consequently control the operation of the battery system:*

1. The emergency disconnect switch is normally closed. It is strategically located adjacent to the four generator control switches on the electrical control panel, and by operation of this group of five switches, all the aircraft power sources can be isolated or de-energized.
2. The battery selector switch, also located on the electrical control panel, ultimately determines the battery power distribution to either the Essential and/or the Ground Operation DC Buses.
3. The ground operation control switch is conveniently located on an external panel adjacent to the passenger entrance door. This panel also contains the door and stairway operating switches and is shown in Figure 13. When the battery selector switch is left in the "GROUND" position, the ground crew can use the ground operation control switch to energize the Ground Operation DC Bus or, alternatively, to completely disconnect the aircraft battery from the electric system.

Inverter Circuit. The 250-va inverter is connected to the Essential DC Bus and receives its power supply from the battery via a 35-amp circuit breaker and the inverter control relay. The 115-volt single phase ac output is directed to the Inverter Bus located in the forward load center.

The combination of battery and inverter provides for two previously mentioned operational conditions which are designated on the inverter switch (located on the electrical control panel) as "START" and "EMERGENCY" (see Figure 21). These conditions occur when the normal ac power supply from the Essential AC Bus is not available.

Referring to Figure 12, it will be noted that the inverter auxiliary control relay, with its three sets of contacts, is an ac relay which operates whenever the Essential AC Bus is energized. This ensures that the inverter and its associated circuits are inoperative so long as power is available from this source. The one exception to this rule is the inverter "keep alive" circuit, which pre-energizes the inverter control tube filaments whenever the inverter switch is placed in either of the closed positions. This provision allows the inverter switch to be left in the "EMERGENCY" position during normal flight operations so that the inverter circuit is ready for automatic and immediate use.

**KLM has a battery control switch only.*

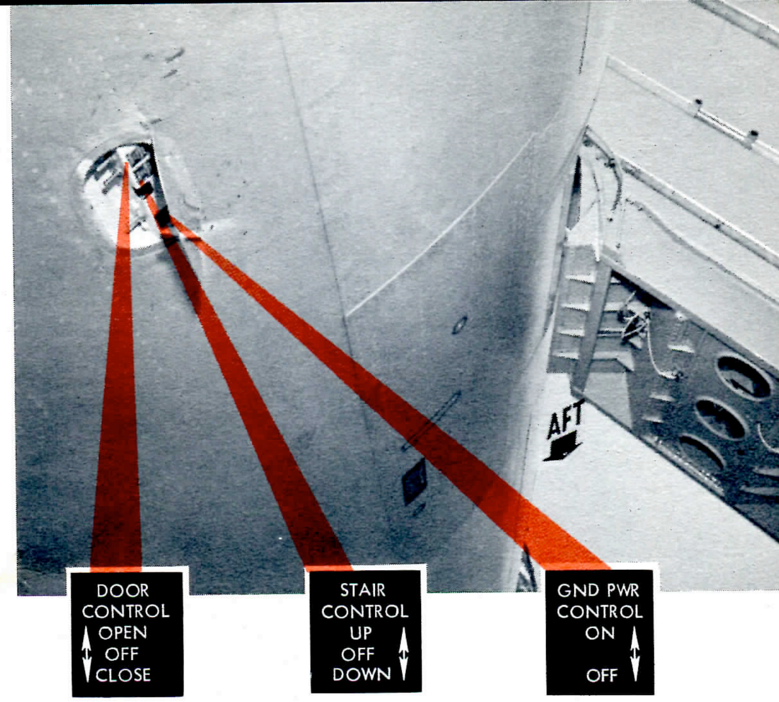


Figure 13 Passenger Door and Stairs Switch Panel

When the double pole, double throw inverter switch is placed in the "START" position, the following action is initiated, assuming that the Essential AC Bus is de-energized:

1. The inverter control relay is energized from the Essential DC Bus, thus completing the inverter power circuit and energizing the Inverter Bus.
2. The engine temperature datum amplifiers are connected to the Inverter Bus through operation of the appropriate transfer relay.*
3. The turbine inlet temperature indicators are connected to the Inverter Bus through operation of the appropriate transfer relay.

Similarly, when the inverter switch is placed in the "EMERGENCY" position, the essential flight instruments as well as the turbine inlet temperature gauges are connected to the Inverter Bus.

It will be noted that all the inverter loads are shown on Figure 12 as being normally powered from the Essential AC Bus. Some essential flight instruments have an additional supply source via one of the flight station extensions of the Priority Bus A — three power sources in all.† This aspect has been omitted from Figure 12 to achieve clarity, but can be seen more clearly on Figures 16, 18, and 19 which depict the Radio and Instrument power supplies.

**Aircraft with integral starting also have certain instruments and controls associated with the starter system connected to the Inverter Bus via this relay.*

†KLM has only one flight instrument that can be powered from the Inverter Bus — the pilot's turn and bank. It is normally powered from the Essential AC Bus.

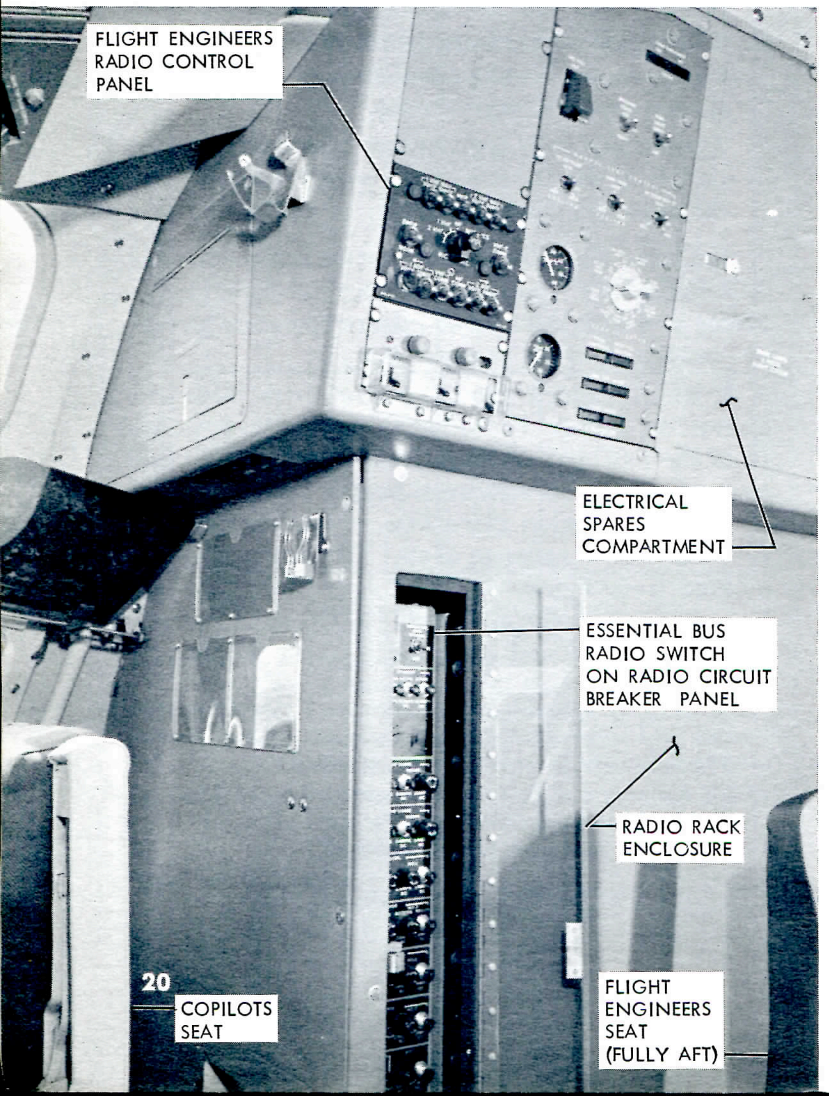
(Continued on next page)

RADIO AND INSTRUMENT POWER DISTRIBUTION

The following brief description of the electronic system power circuits is included in this article to show the interconnection of these circuits with the electric power system, and at the same time, indicate the location of the various components.

The term "electronic equipment" has rather a wide application and, in this instance, includes the radio communication equipment, the intercommunication systems, the navigational equipment, the passenger address and call systems, weather radar provisions, autopilot, and the various flight instruments. Facilities for installing all these items are provided on the Electra and different combinations of this equipment are installed to satisfy individual airline requirements.

The features of the radio and instrument power distribution which are common to all configurations are described under "General" headings and the same policy of pointing out system variations by means of footnotes has been adhered to. However, three basic power circuits exist and the "Circuit Description" section is subdivided accordingly. The principal circuit description is based on American Airline's system, which is applicable to most customer configurations except for minor details. The other two power circuits are EAL's centralized power supply system and KLM's system and these have each warranted an additional illustration and a supplementary text.



PHYSICAL DESCRIPTION—GENERAL Most of the radio equipment, including units of the automatic pilot and compass systems, are mounted in the radio rack, which is located on the aft right hand side of the flight station (see Figures 3 and 14). Attached to the forward side of the radio rack is the radio junction box which serves as a central location for the interconnection of wiring and also contains most of the electronic relays, resistors, and so forth. The inboard edge of the junction box incorporates a circuit breaker and fuse panel for the individual electronic circuits (see Figures 15 and 17), and space is allocated for spares such as fuses and light bulbs in a storage compartment above the radio rack enclosure.

The majority of the electronic system controls are located on the flight station control pedestal, and as Figure 20 shows, are accessible to both pilots and the flight engineer. Two switches located on the overhead electrical control panel monitor non-essential radio loads, and an Essential Bus radio switch is located on the radio junction box.* The left hand side of Figures 16, 18, and 19 show the components in the radio power system which are contained in the forward electrical load center and includes buses, circuit breakers and relays.

**EAL and KLM do not have an Essential Bus radio switch and KLM also has a different arrangement of radio non-essential load switching. See the respective radio power circuit schematic (Figures 18 and 19) and the appropriate supplementary description.*

Figure 14 Radio Installation and Flight Engineer's Radio Station — NAL

Radio Rack Design. There are several interesting and unusual features in the construction of the radio rack (see Figure 15). The installation has been designed so that the rack can be completely removed from the airplane, a definite advantage during some long term maintenance or overhaul tasks. The radio equipment mounts are attached directly to the rack structure, and the rack itself is attached to the floor and sidewall by means of shock mounts. As an additional safeguard a cable attaches the radio rack to the floor structure to restrain the rack should it be acted upon by abnormally high G forces. Panels and doors at the forward and inboard sides of the radio rack assembly provide access to the radio junction box and radio equipment and during flight they also provide sealing of the rack so that heat from the equipment is isolated from the aircraft's air conditioning system and can be evacuated.

The radio equipment is cooled by exhaust air from the cabin air conditioning system flowing upward through each individual piece of radio equipment according to requirements and entering three exhaust manifolds located directly over the equipment on the third and fourth shelves, and above the rack. From here the air is ducted overboard through the nose wheel well. A flow control fan and a variable control valve, both located in the nose wheel well, maintain and control this flow of cooling air through the radio rack.

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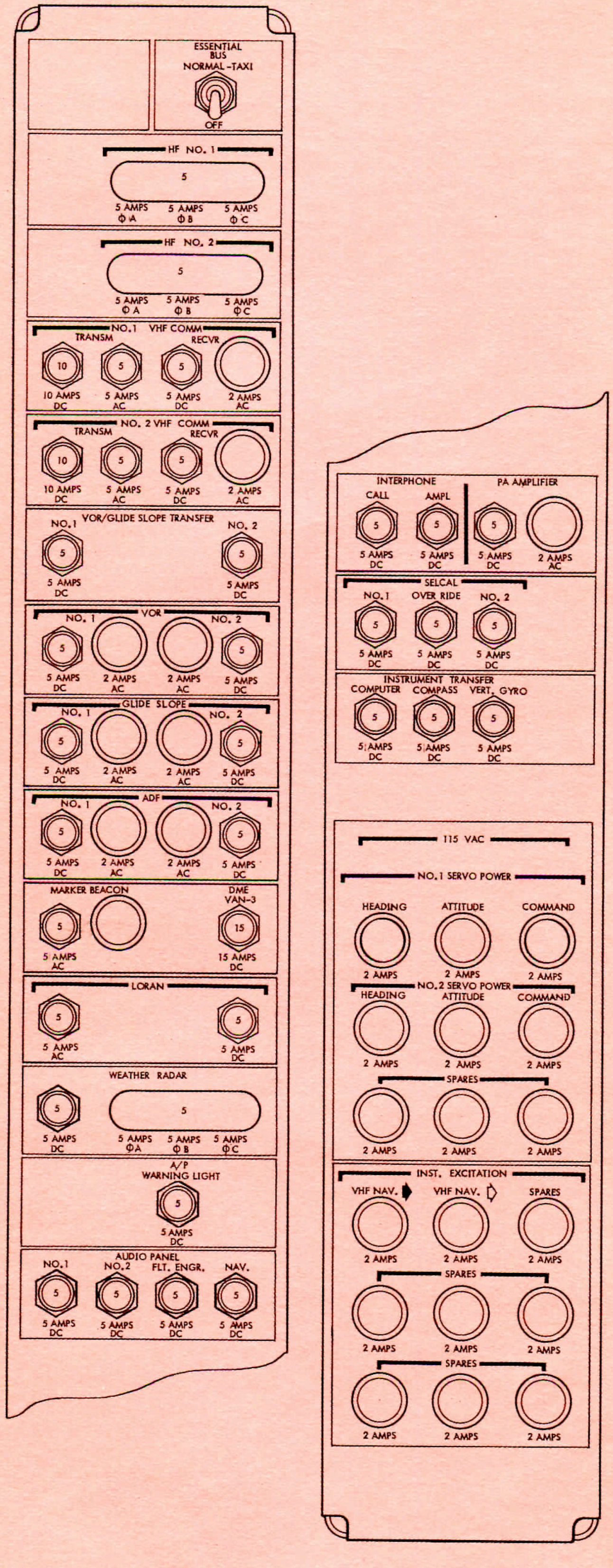


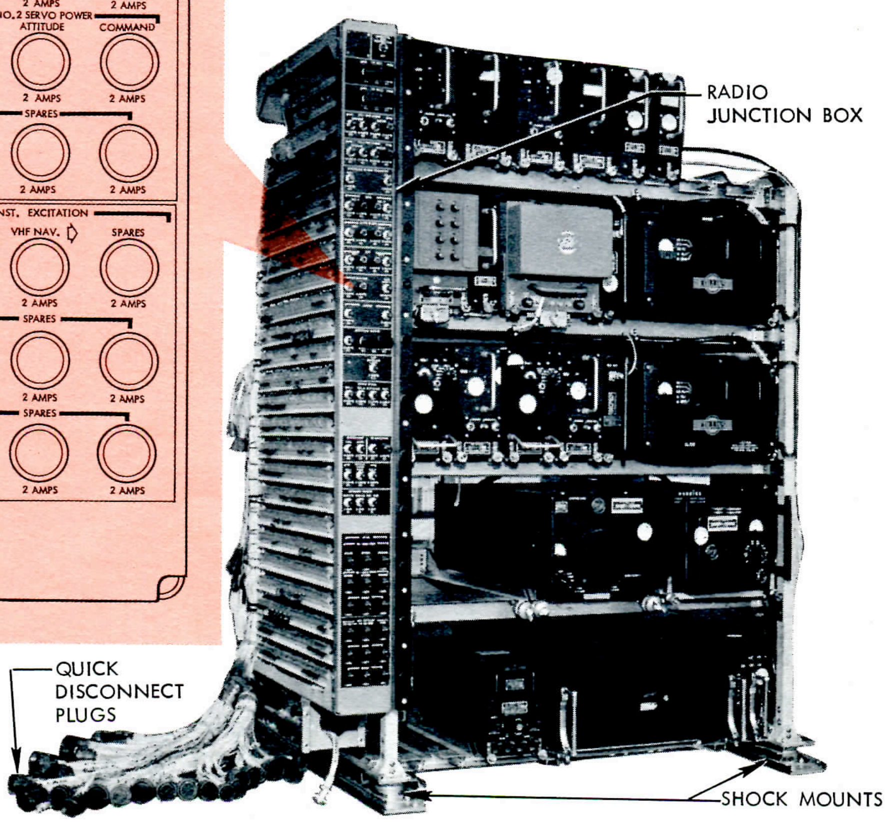


Figure 15 Radio Rack Assembly Showing Circuit Breakers —QANTAS

CIRCUIT DESCRIPTION—GENERAL Power is obtained for the electronic equipment from the flight station buses. The various circuit breakers in the forward load center through which this power is taken are listed on the left of Figures 16, 18, and 19 and can also be seen on Figure 24.

Nearly all the communications and navigational systems are actually dual installations with each of the two VHF and ADF systems also having its own antenna.* It is standard practice to number these dual installations and controls so that we have, for example, VHF-1 corresponding to the pilot's or captain's VHF, and VHF-2 corresponding to the copilot's or first officer's VHF. Dual flight instrument systems are similarly numbered. Some exceptions to the above general designation are the autopilot, distance measuring equipment (DME), weather radar, air traffic control (ATC) transponder, and marker beacon provisions, which are all single installations.†

As previously mentioned, the following circuit description is essentially applicable to American Airline's system. EAL and KLM have major differences which are enlarged upon following this description, and other configurations (including CPA, NAL, ANA, BNF, WAL, NWA, TAA, QANTAS, PSA, and TEAL) are similar to AA's system with only minor differences.

CIRCUIT DESCRIPTION—AA The radio and flight instrument loads are categorized as *essential* or *non-essential* and are shown in the upper half and the lower half respectively of Figure 16. In general, the essential loads consist of the pilot's or captain's essential radio, the pilot's instruments, and the radio/instrumentation transformer No. 1. They can all be powered from the essential buses, the instrument loads also having alternative power sources. All other radio and flight instrument loads, the radio/instrumentation transformer No. 2, and the automatic pilot come into the non- essential category and have only one power source.

The Radio Equipment is divided into three basic groups, one of which is in the essential category and two of which are in the non-essential category. They are listed (for AA) on the right of Figure 16.

1. Essential Radio Group. Equipment in this group has the Essential AC Bus and the Essential DC Bus as power sources and can be monitored by the Essential Bus radio switch on the radio circuit breaker panel. Typical loads in this group are:

VHF System No. 1	VOR System No. 1
ADF System No. 1	Glide Slope No. 1

ATC Transponder System
Radio Control Panel and Dial Lights
Crew Interphone (except pilots loudspeakers)

2. Non-essential Radio Group No. 1. Equipment in this group has the Priority Bus A (flight station extensions) and the Main DC Bus as power sources and can be monitored by the Radio Bus 1 non-essential load disconnect switch on the electrical control panel. Typical loads in this group are:

Pilots Loudspeakers	Marker Beacon System
Service Interphone	DME System
Passenger Address	Weather Radar

3. Non-essential Radio Group No. 2. Equipment in this group has the Priority Bus A (flight station extensions) and the Main DC Bus as power sources and can be monitored by the Radio Bus 2 non-essential load disconnect switch on the electrical control panel. Typical loads are:

VHF System No. 2	VOR System No. 2
ADF System No. 2	Glide Slope No. 2

Selective Calling System

The Flight Instruments including the gyro compass systems can also be divided into two basic groups:

1. Essential Flight Instruments. Included in this group are the following:

Compass System No. 1	Horizon Ampl. No. 1
Vertical Gyro No. 1	Turn and Bank No. 1

The pilot's instrument transfer relays automatically transfer the above loads (with the exception of the pilot's turn and bank, which is normally fed by the Essential AC Bus) from the Priority Bus A to the Essential AC Bus should the Priority Bus A become de-energized. The latter three instruments have an emergency source of power from the Inverter Bus via the pilot's emergency transfer relay. This is the same relay that is depicted on Figure 12, which shows the basic electric power system.

2. Non-essential Flight Instruments. Included in this group are the following loads:

Compass System No. 2	Horizon Ampl. No. 2
Vertical Gyro No. 2	Turn & Bank No. 2

Steering Computer*

These instruments have only one power source from the Priority Bus A.

**Excluding AA, most other customers have at least one HF system also.*

†Provisions are also made for installing a selective calling system (SELCAL) which is associated with various communications equipment depending upon customer requirements. EAL operates the SELCAL system in conjunction with a third VHF system (VHF-3).

**EAL and WAL install two steering computers (Nos. 1 and 2).*

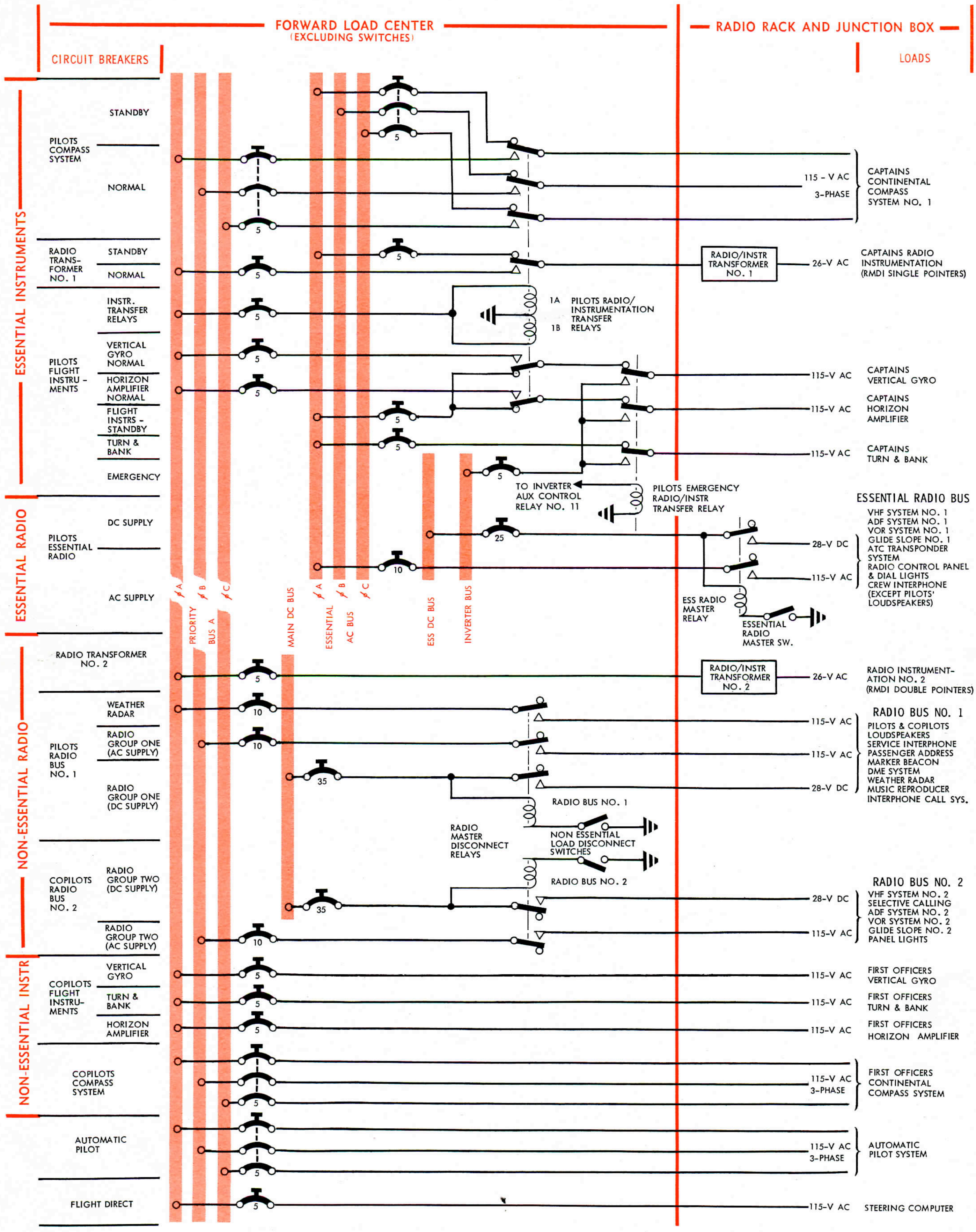


Figure 16 Radio and Instrument Power Distribution — AA

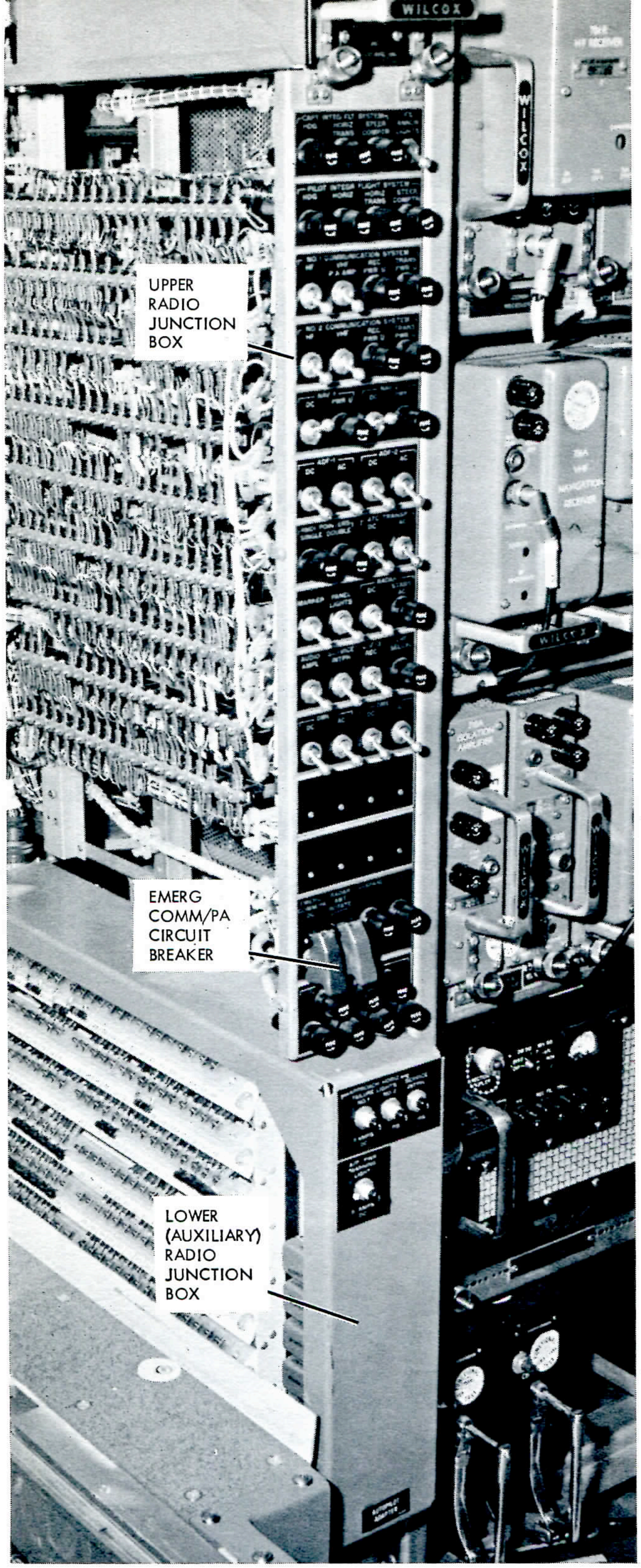


Figure 17 Radio Circuit Breaker Panel — EAL

CIRCUIT DESCRIPTION—EAL This installation is unusual in that the radio rack, complete with a junction box, electronic units, and wiring is customer furnished equipment. Lockheed furnishes the bottom shelf of the radio rack and an auxiliary junction box for the autopilot and compass components (see Figure 17). Other airline configurations use components from a variety of electronic manufacturers and most of these units contain their own integral power supply. EAL on the other hand, uses Wilcox equipment almost exclusively and the high voltage dc requirements are supplied by three voltage doubler power units (see Figure 18).

The three voltage doubler power supplies are located in the radio rack and are designated as the communications system No. 1, the communications system No. 2, and the navigation receivers (Nav. 1 and Nav. 2) power units respectively. They are identical units with dual transformer rectifiers so that each has two separate 115-volt ac inputs and two separate outputs of either 250-volts or 500-volts dc, depending upon the external connections.

Apart from a different distribution of radio loads, the other major differences between EAL's system and the previously described system concerns the essential radio. Incorporated in EAL's system is an emergency dynamotor (located in the radio rack) which supplies high voltage dc power to the most essential electronic units when the normal power source for these units is not available. Since the dynamotor is connected to the Essential DC Bus, it is therefore possible for the following radio systems to be operated for a limited time from the aircraft battery via the emergency power relay:

VHF System No. 1
Passenger Address System

Emergency dc power for these units can be monitored by the Emerg Comm/PA circuit breaker on the radio circuit breaker panel (see Figure 17) and they are normally powered from the Priority Bus A.

It will be noted also that the following units which are normally powered from the Priority Bus A have an alternate supply source from the Essential AC Bus via the pilot's transfer relays. Low voltage dc requirements for this group are obtained from the Essential DC Bus ahead of the Emerg Comm/PA circuit breaker:

HF System No. 1
ADF System No. 1 and Instrumentation
VOR System No. 1
Marker Beacon System
Glide Slope System No. 1
Interphone Call
Service Interphone
Warning Lights
Steering Computers (Nos. 1 & 2)
Horizon Amplifier No. 2

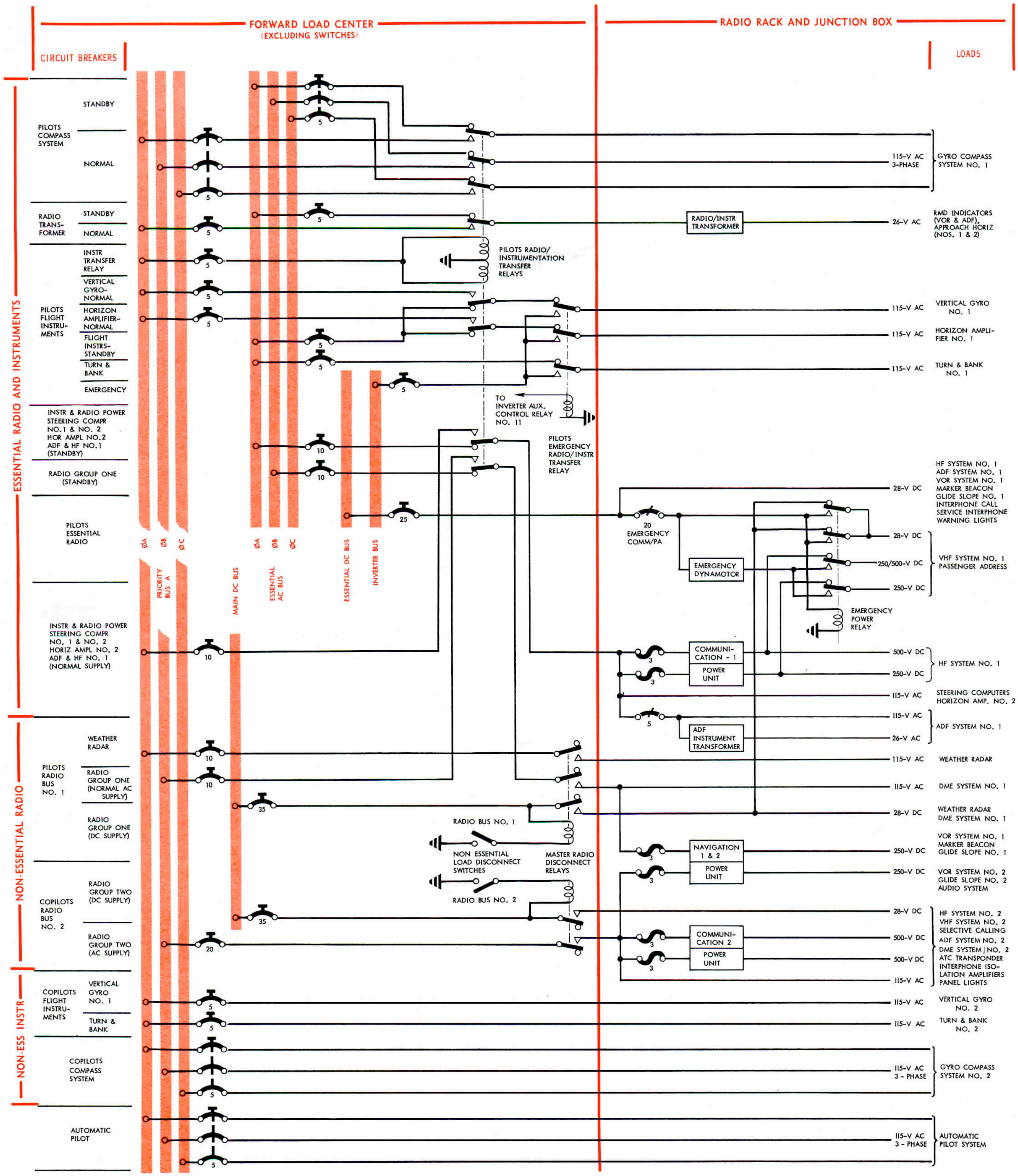


Figure 18 Radio and Instrument Power Distribution — EAL

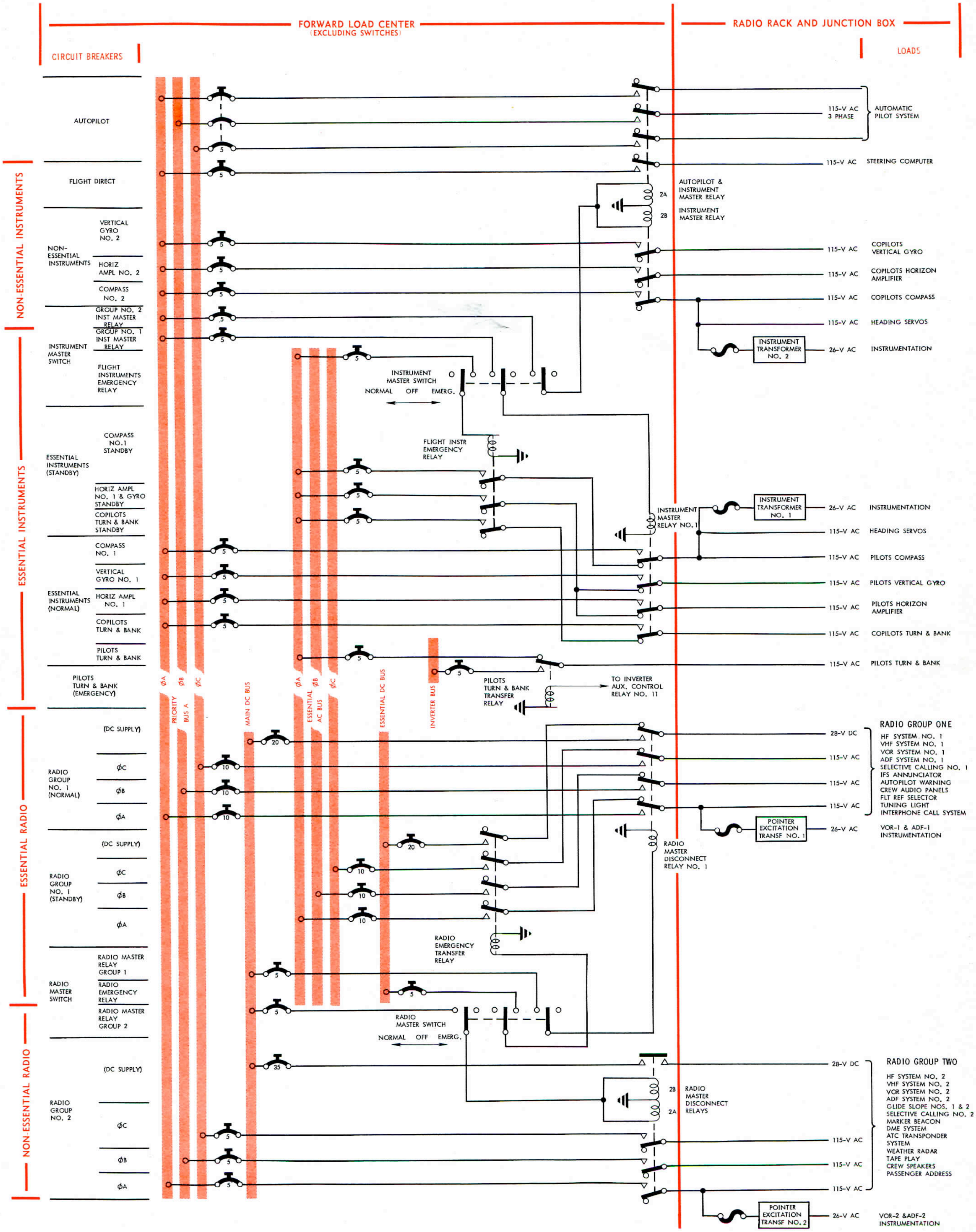


Figure 19 Radio and Instrument Power Distribution — KLM

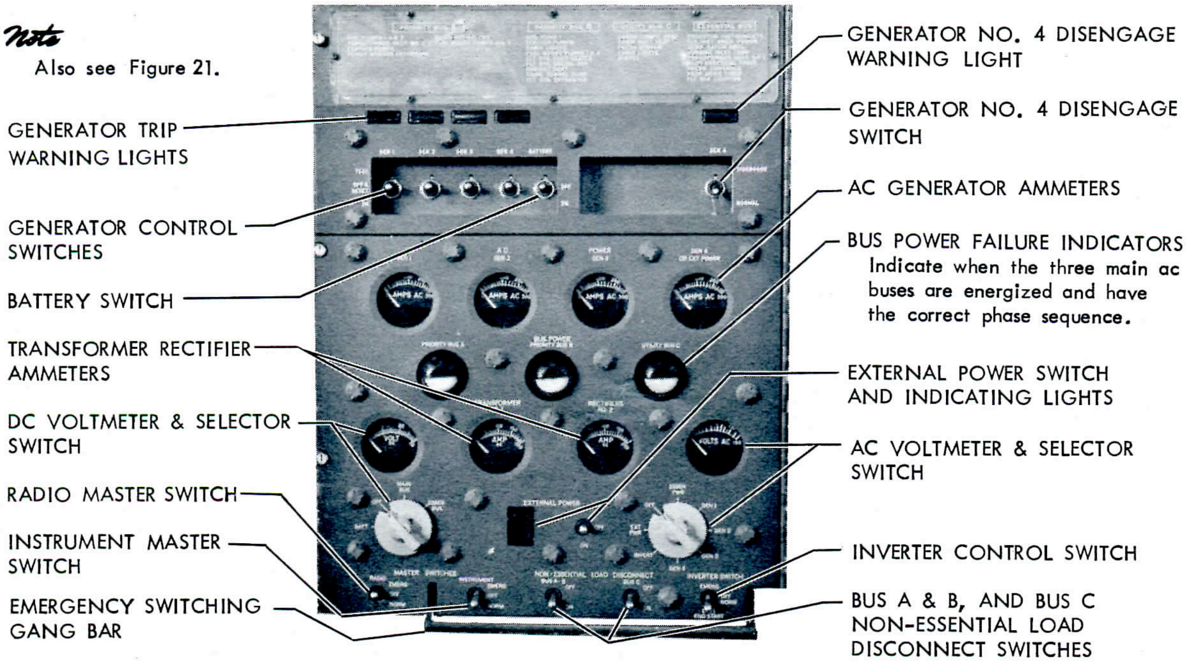


Figure 20 Overhead Electrical Control Panel — KLM

CIRCUIT DESCRIPTION—KLM The KLM radio configuration (shown in the lower half of Figure 19) differs considerably from the AA and EAL systems. The radio loads are divided into only two groups. The equipment categorized as essential is placed in Radio Group One and consists generally of the pilot's radio. All other non-essential radio loads are placed in Radio Group Two. The power supplies to the two radio groups are controlled by a three-position Radio Master Switch located on the overhead electrical control panel (see Figure 20). With this switch selected to the "NORMAL" position all the radio loads are supplied by the Priority Bus A and the Main DC Bus. With the switch selected to "EMERGENCY" the non-essential Radio Group Two is de-energized and Radio Group One is transferred to the Essential AC and DC Buses.

The KLM instrument configuration (shown in the upper half of Figure 19) is broken down similarly to the AA and EAL systems — into essential and non-essential groups. However, the power supplies to these two groups are controlled by an Instrument Master Switch (located on the electrical control panel) in a manner similar to KLM's radio system described above. Both instrument groups are normally supplied by the Priority Bus A and the pilot's instruments have an alternative supply source from the Essential AC Bus. It will be noted that the copilot's turn and bank is included in the essential group while the pilot's turn and bank is the only flight instrument with an emergency power supply from the Inverter Bus.

FLIGHT STATION CONTROLS

The principal controls and indicators for the electric and radio systems are shown in Figure 21. They are accessible and visible to all three crew members, the basic electric system controls being located on the overhead electrical control panel while the radio and autopilot controls are grouped on the center pedestal. Not shown on Figure 21 are the flight engineer's radio control panel, which is positioned above the radio rack; and the Essential Bus radio switch which is located on the radio junction box.*

OVERHEAD ELECTRICAL CONTROL PANEL The functions of most of the switches on this panel have already been explained in the "Power Circuit Description," and the "Radio and Instrument Power Distribution" sections and we have endeavored to summarize this information on Figure 21. The illustration is self-explanatory, but the following additional notes may be helpful. In many instances these notes are not applicable to KLM's system and this is so indicated. Also KLM's electrical control panel is illustrated in Figure 20.

A generator control switch is provided for each generator. With the switch in the "ON" position the generator will build up voltage and when it

**The International version (including KLM) also includes a navigator's radio control panel (see Figure 9). Also EAL and KLM do not have an Essential Bus radio switch (see the "Radio and Instrument Power Distribution" section).*

TRIPPED

GENERATOR TRIP WARNING LIGHTS
Indicates overvoltage, undervoltage or feeder fault in generating system.

DISENGAGE

GENERATOR DISENGAGE WARNING LIGHTS
Nos. 1, 2, & 3 (EAL, NWA & TEAL only) indicate generator mechanical failure.
No. 4 indicates two-speed gear box malfunction or generator overspeed.

AC BUS INDICATING LIGHTS

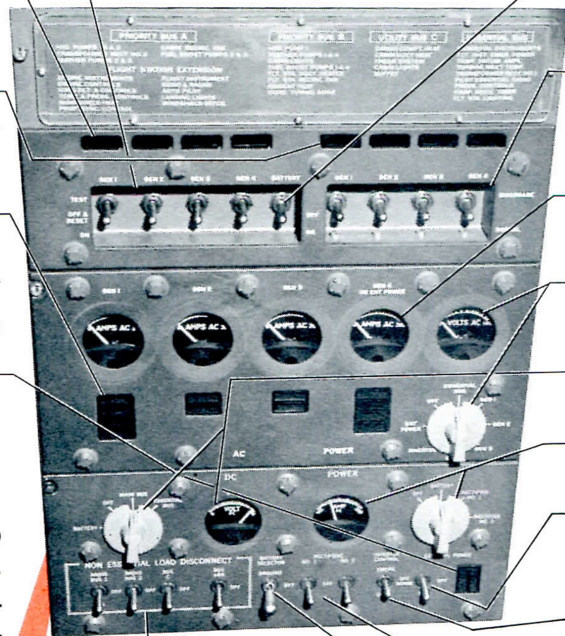
UTIL BUS C	PRIOR BUS B	PRIOR BUS A	PRIOR BUS A
PRIOR BUS B	ESSEN BUS	ESSEN BUS	PRIOR BUS B
PRIOR BUS A			UTIL BUS C
ESSEN BUS			ESSEN BUS

Lights under each ammeter indicate buses being supplied by each generator.

EXTERNAL POWER INDICATING LIGHTS
CONN - indicates that an external power cable is plugged into the ground power receptacle.
POWER - indicates that 3-phase power of the correct phase sequence is available.

CONN	POWER

GENERATOR CONTROL SWITCHES
TEST - Generator energized but not connected to system.
OFF & RESET - Generator de-energized.
ON - Generator energized and connected to system.



OVERHEAD ELECTRICAL CONTROL PANEL

BATTERY EMERGENCY DISCONNECT SWITCH
OFF - The battery is isolated from the system by opening the Battery Selector switch circuit.
ON - Battery Selector switch may be operated.

GENERATOR DISENGAGE SWITCHES
DISENGAGE - Nos. 1, 2, & 3 (EAL, NWA, & TEAL only) energizes disconnect solenoid in generator. No. 4 energizes disconnect solenoid in two speed gear box.
NORMAL - Disengage circuit de-energized.

AC GENERATOR AMMETERS
Nos. 1, 2, & 3 indicate generator current.
No. 4 indicates generator current or external ground power current when connected.

AC VOLTMETER AND SELECTOR SWITCH
Voltage outputs of the Essential AC Bus, generator Nos. 1, 2, 3, and 4, the inverter, and external ground power may be checked.

DC VOLTMETER AND SELECTOR SWITCH
Voltage outputs of the battery, the Main DC Bus, and the Essential DC Bus may be checked.

DC AMMETER AND SELECTOR SWITCH
Current outputs of the battery, and the two transformer rectifiers may be checked.

EXTERNAL POWER SWITCH
OFF - External ground power circuit de-energized.
ON - Allows external power into distribution system if voltage and phase sequence are correct and if aircraft battery is connected to the Essential DC Bus.

INVERTER CONTROL SWITCH
EMERGENCY - Supplies essential flight instruments if Essential AC Bus is de-energized.
START - Supplies starting loads if Essential AC Bus is de-energized.

TRANSFORMER RECTIFIER SWITCHES (Nos. 1 & 2)
OFF - Transformer rectifier output disconnected.
ON - Transformer rectifier output connected to dc distribution system.

BATTERY SELECTOR SWITCH
GROUND - Battery connected to Ground Operation DC Bus only
OFF - Battery is isolated from system.
ON - Battery connected to Essential DC Bus and Ground operation DC Bus if battery emergency disconnect switch is ON

INSTRUMENT PANEL WARNING LIGHTS

GEN. MECH. FAIL.
Indicates generator mechanical failure.

4 GEN. GEAR BOX
Indicates two-speed gear box malfunction or generator overspeed.

1 GEN MECH FAIL
2 GEN MECH FAIL
3 GEN MECH FAIL
4 GEN MECH FAIL
4 GEN GEAR BOX

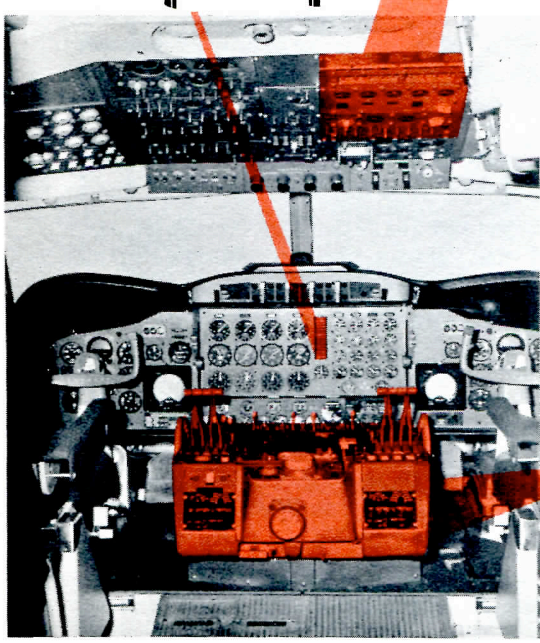
NON-ESSENTIAL LOAD DISCONNECT SWITCHES

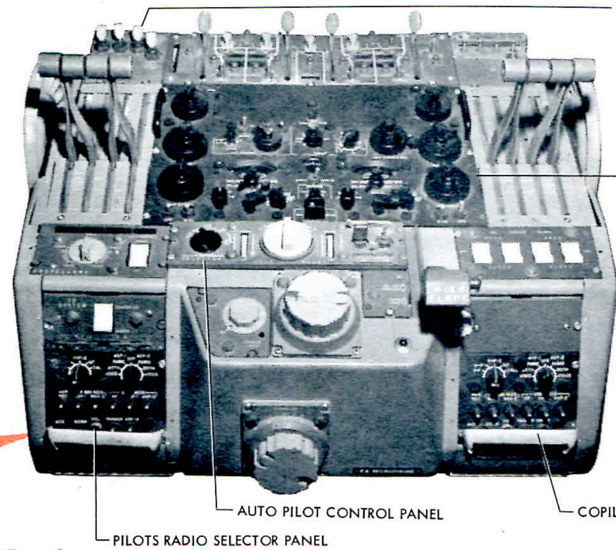
RADIO BUS 1
OFF - Radio Group 1 (Pilots Main Radio) is de-energized.
ON - Radio Group 1 is energized.

RADIO BUS 2
OFF - Radio Group 2(Copilots Radio) is de-energized.
ON Radio Group 2 is energized.

BUS C
OFF - Utility Bus C is de-energized by disconnecting it from transfer system.
ON - Utility Bus C is energized.

BUS A & B
OFF - The Priority Bus A & B flight station extensions, the Main DC Bus, and the loads on Priority Buses A & B controlled by the Main DC Bus are de-energized. This includes Radio Buses I & 2. The essential flight instruments, normally supplied by the Priority Bus A, are automatically transferred to the Essential AC Bus.
ON - The above loads are energized.





LOW GROUND IDLE SELECTOR SWITCHES

MASTER RADIO CONTROL PANEL

CENTER CONTROL PEDESTAL

AUTO PILOT CONTROL PANEL

PILOTS RADIO SELECTOR PANEL

COPILOTS RADIO SELECTOR PANEL

Note

SWITCH POSITIONS AND INDICATOR LIGHTS SHOWN IN COLOR DEPICT NORMAL STATUS WITH ALL FOUR GENERATORS ENERGIZED.

Figure 21 Flight Station Controls

is in the correct frequency range, it will be connected to the power distribution system. With the switch in the "TEST" position the generator is energized so that its output voltage may be checked, but it will not be connected to the distribution system. The center "OFF" position of the switch de-energizes the generator and any loads that may have been connected to it are automatically dropped or transferred. This same switch position is also marked "RESET" because it is necessary to return the switch to this position in order to re-connect a generator or a bus that has been automatically disconnected by protective circuitry. The generating system will of course operate automatically with the switches left in the "ON" position.

Lights above each generator control switch indicate that the generator has been "TRIPPED" because of overvoltage, sustained undervoltage (generator failure), or a feeder fault. See the "Generator Control and Protective Circuits" section. In the latter two cases it is desirable that a failed generator be left off the line for the duration of the flight and the system has therefore been designed so that the generator cannot be reset by operation of the control switch alone.

The generator No. 4 disengage warning light is illuminated when the oil temperature or oil pressure in the two speed gear box reaches unsafe limits or when the generator exceeds its speed limitations. (One possible cause of overspeed could be failure of the gear box to change gear when selecting the No. 4 engine from the low to high rpm range.) Placing the No. 4 disengage switch to the "DISENGAGE" position energizes the disconnect solenoid in the gear box to disengage both the generator and the gear box from the accessory drive gear.

The disengage switches and indicator lights shown on Figure 21 in the Nos. 1, 2, and 3 generator positions are optional.* These lights have the same function as the Nos. 1, 2, and 3 generator mechanical failure warning lights described below, and are actually contained in the same respective circuits.

Warning lights on the center instrument panel are located where they are most apt to attract attention (see Figure 21). One of them is in parallel with, and therefore has the same function as, the No. 4 generator gear box disengage light; the other four lights give early indication of a generator mechanical failure.

Voltmeters and ammeters for both the ac and dc systems are mounted on the electrical control panel, individual ammeters being provided for each generator. The ammeter in the No. 4 position also indicates external power current when power is being supplied from this source.

**They are installed on EAL, TEAL, and NWA aircraft.*

Bus indicator lights located under the four generator ammeters identify the buses being supplied by each generator.† These lights are operated by auxiliary contacts in the ac transfer relays, thus ensuring instantaneous and positive indication.

The control panel also incorporates the switches for control of the battery, inverter and the two rectifier circuits.† The operation of these has been explained previously in the "Power Circuit Description" section.

Two indicating lights and a switch on the electrical control panel and another indicator light adjacent to the ground power receptacle give a simple form of communication between flight and ground crews when plugging in ground power to the aircraft electric system. When illuminated, the "CONN" light on the control panel indicates that the external power cable is plugged into the ground power receptacle and the "POWER" light indicates that 3-phase ac power having the correct phase sequence is available from the external power supply. Assuming that both lights are illuminated, placing the external power switch in the "ON" position permits external power to be delivered into the aircraft electric distribution system. This action then illuminates the light adjacent to the ground power receptacle.

The operation of the remaining items on the electrical control panel — the non-essential load disconnect switches — is described below.

LOAD DISTRIBUTION AND MONITORING The load distribution chart (Figure 23) is typical for all customer configurations. It is arranged to show the location of the various ac and dc buses — flight station or service center. In general the distribution of the essential and non-essential loads on the various buses is self-explanatory and has already been discussed in the appropriate sections of the "Power Circuit Description" section. Some load distribution features not previously mentioned, however, concern the Priority Bus A and the Priority Bus B.

†See Figure 20 for KLM.

ENVIRONMENTAL CONDITION	PRIORITY BUS A & FLT. STA. EXTS.	PRIORITY BUS B & FLT. STA. EXT.	UTILITY BUS C
HEATING & ICING	36	54	29
COOLING	35	28	49
HEATING	35	39	31

NOTE:
The Essential AC Bus load is approximately 3 KVA under all conditions. It may be connected to either the Priority Bus A or the Priority Bus B.

Figure 22 Load Distribution Under Different Environments

(Continued on next page)

The important heavy loads such as the fuel boost pumps, the hydraulic pumps, and the propeller feathering pumps are distributed fairly evenly between these two buses. With any two generators operating, all these loads will, of course, continue to be supplied. It should be noted, however, that for one generator operation, one or more hydraulic pumps will be operative, and all the feathering pumps will still be available, even though only one of the priority buses is energized. The feathering pumps on the inoperative bus are automatically transferred by means of relays to the energized bus.

Another consideration in load distribution is to group the loads on the three main ac buses — and consequently the loads on the generators supplying these buses — so that the distribution is not adversely affected by the varying load requirements under different environmental conditions. Figure 22 illustrates to what extent this has been achieved on the Electra.

Load Monitoring. The electric system and installation has been designed so as to minimize the possibility of electrical faults occurring. Should a fault occur, however, the fault is sensed and the appropriate action taken automatically. Generators or buses are de-energized in the event of a generating system or a bus fault respectively, and branch circuit faults are cleared by tripping of the branch circuit breaker.

Although these precautionary measures have been designed into the system, it is still expedient to provide for a situation where a fault is not cleared automatically. The first indication of a fault might well be the emission of fire or smoke and in the past it has been accepted practice to cut off all electric power if the situation appeared to be sufficiently serious to warrant it. The four generator control switches and the battery disconnect switch are grouped together on the electrical control panel to facilitate this rather drastic measure being taken.

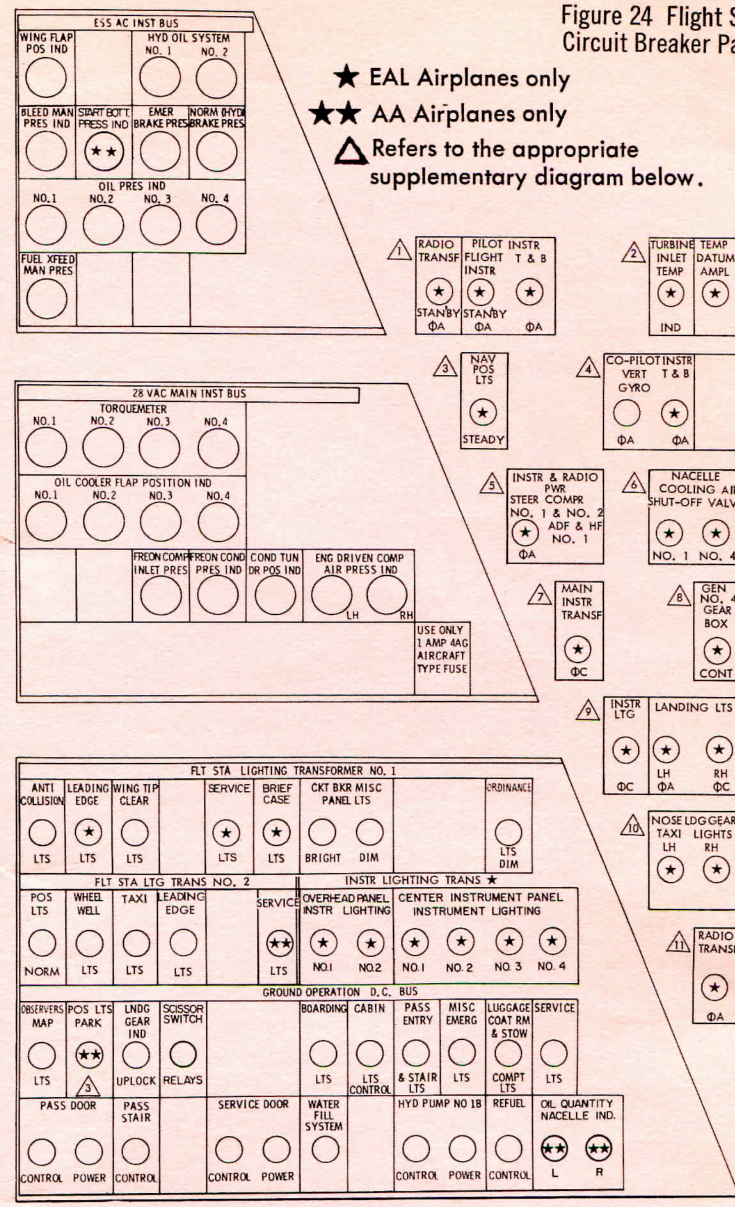


Figure 24 Flight Station Circuit Breaker Panels

However, the modern transport aircraft has become so dependent on electric power for essential functions that the complete cutting off of this power would probably only serve to further complicate an emergency. Accordingly, the Electra is also provided with the means for quick and orderly monitoring of loads in the order of their priority. The non-essential load disconnect switches on the electrical control panel (see Figures 20 and 21) are provided for this purpose. They are listed as follows:

1. The Radio Bus 1 and Radio Bus 2 disconnect switches control the radio master disconnect relays

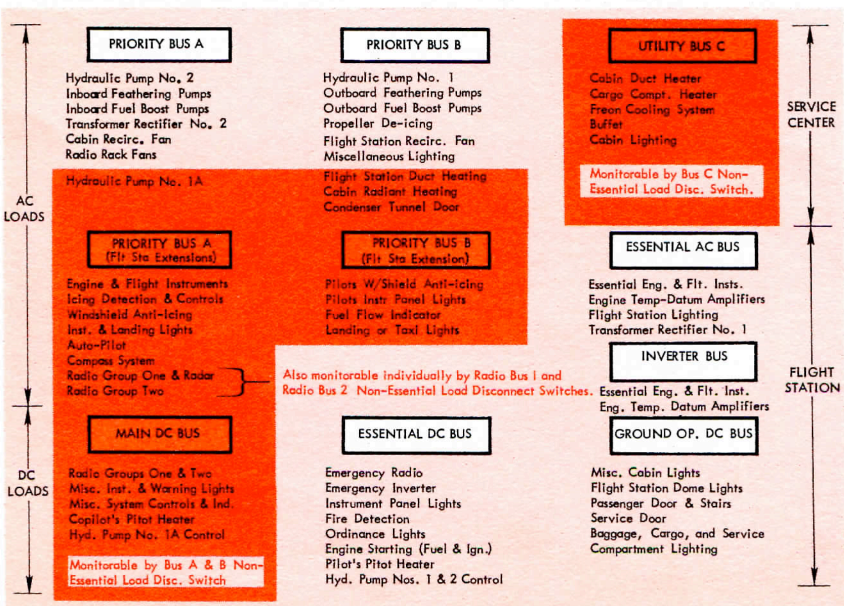
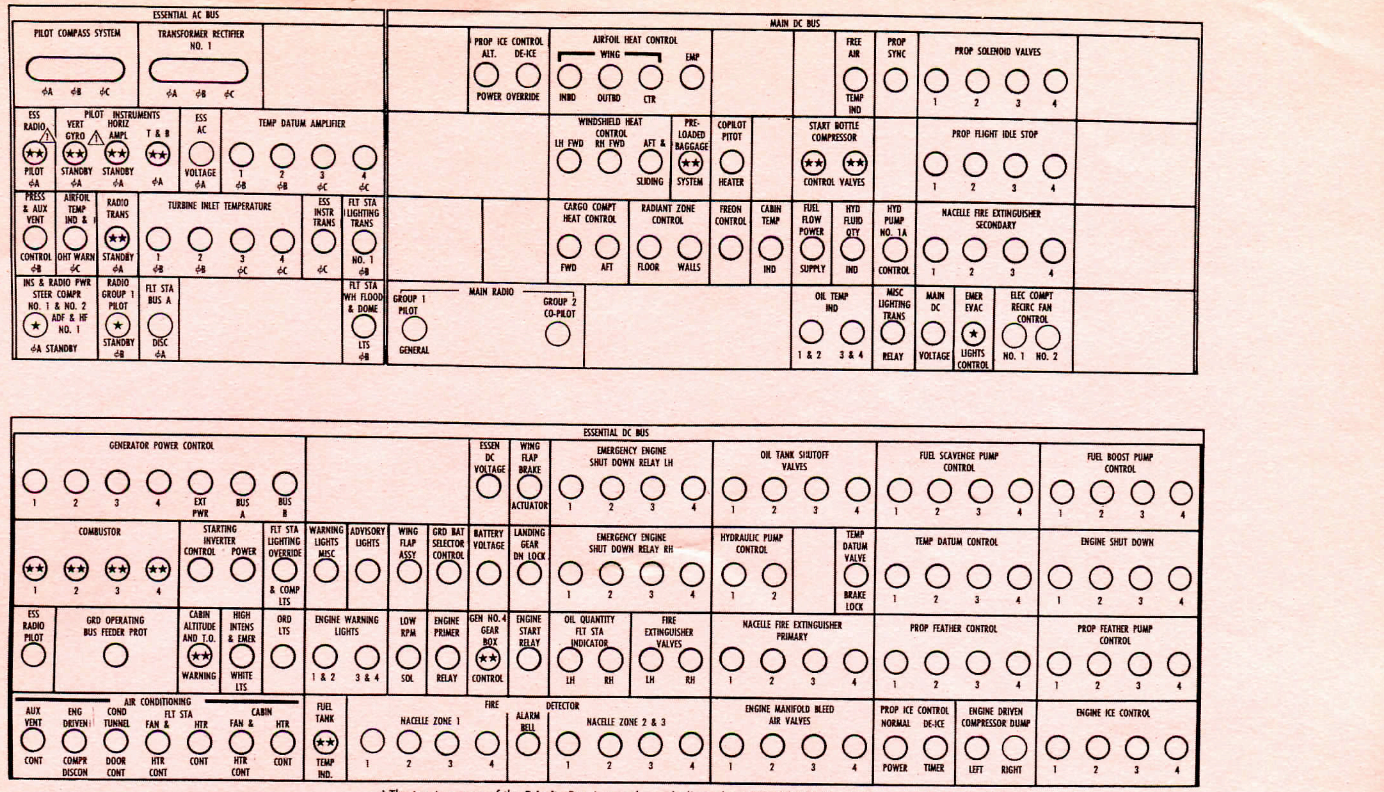
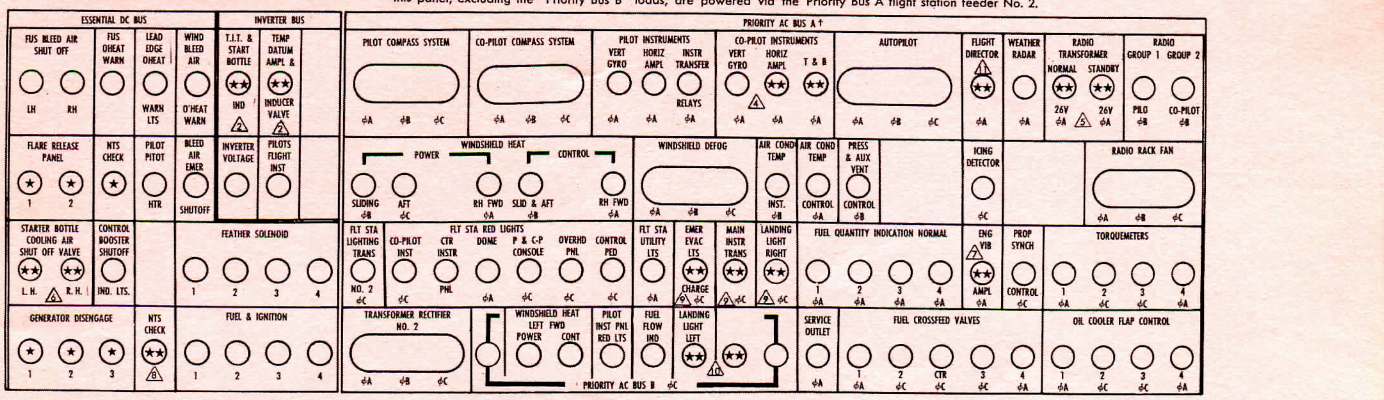


Figure 23 Load Distribution and Load Monitoring



† The top two rows of the Priority Bus A panel, excluding the "Windshield Heat—Power and Control—R.H. Forward" loads, and including the "Transformer Rectifier No. 2," are powered via the Priority Bus A flight station feeder No. 1. All other loads on this panel, excluding the "Priority Bus B" loads, are powered via the Priority Bus A flight station feeder No. 2.



shown on Figure Nos. 17 and 18.* All the radio loads (excepting the pilot's essential radio, but including the weather radar system) can be monitored by these switches.

2. The Bus C disconnect switch actually controls the 2A/2B double coil transfer relay shown on Figure 12 so as to isolate the Utility Bus C.
3. The Bus A & B disconnect switch monitors the Priority Bus A flight station extensions, the Priority Bus B flight station extension, the Main DC Bus, and most of the non-essential loads on the main ac priority buses.

The Bus A & B switch actually controls the two Priority Bus A flight station extension disconnect relays, and the two reverse current relays in the Main DC Bus feeders shown on Figure 12. It follows that all services which obtain their control power from the Main DC Bus are also automatically disconnected. Such services include the Priority Bus A and the Priority Bus B circuits shown in the color screen on Figure 22, the Priority Bus B flight station extension loads, and the non-essential radio. Thus nearly all the aircraft's non-essential services can be monitored by just two switches: the Bus C, and the Bus A & B disconnect switches. Further monitoring of the flight station loads can be accomplished by judicious use of the flight station switches and circuit breaker panels (see Figure 24).

Individual circuit protection for the main ac buses is accessible through the electrical service center hatch in the cabin floor (see Figure 6). However, it is also possible to monitor each of the priority buses as a whole by means of the generator control switches on the overhead panel. If all the control switches except the No. 2 switch are selected to "OFF" this will automatically result in the Priority Bus A being de-energized and will leave generator No. 2 supplying the Priority Bus B and the essential ac and dc loads. Similarly if the remaining generator is No. 1, 3, or 4, the Priority Bus B will be de-energized. ▲ ▲

KLM does not have these switches (see Figures 19 and 20).

LOCKHEED field service digest

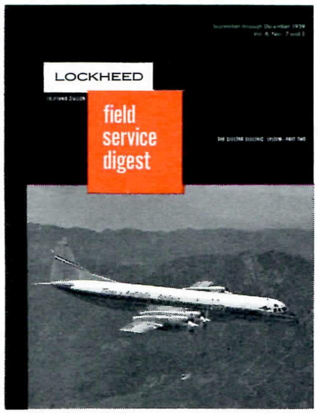
This publication is a digest of the most important technical information currently available and is intended to assist our customers in the service, maintenance, and operation of their Lockheed transport aircraft.

Contents

Vol. 6, Nos. 2 and 3
September through
December 1959

COVER PICTURE: Bearing their traditional Kangaroo emblem, Trans-Australia Airline's three sleek ***Electras*** make 400-mph hops between the major Australian cities and Tasmania.

Since introducing them into service, TAA has been regularly achieving revenue utilization averaging more than 10 hours per day.



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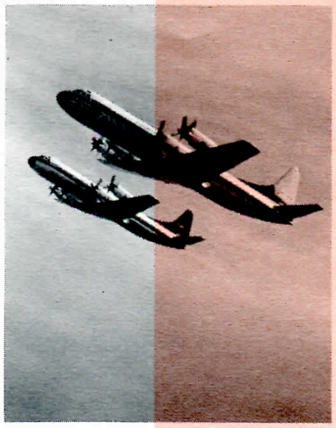

Foreword

Part One of the Electra Electric System appeared in a preceding issue of the Digest, Vol. 5, No. 5. It presented a general discussion of the Electra's electric power system in which only a cursory description was given of the generation system. It is this system, together with the bus transfer control system, which is described in this issue.

In order that this second part of the article could be presented as a complete entity it was necessary to repeat certain material from Part One. Where this has been done it has been presented briefly, and in keeping with the rest of the article, is essentially applicable to all configurations of the Model 188 Electra.

We have endeavored to describe the generation and bus transfer systems as simply as possible while still presenting an accurate and detailed working knowledge of them. By omitting all but the most pertinent information we thereby hope to achieve two objectives: to convey a general understanding of these systems to as wide a group of readers as possible; and impart a more detailed understanding of them to those readers who are directly concerned with their maintenance and operation. In the latter respect, it is believed that in the final analysis an intimate knowledge of the generation and bus transfer systems circuitry will prove to be a most important aid in trouble shooting.

This article should not be used as a reference source without also checking the validity of the information with pertinent publications which are known to be up to date. More specifically, the descriptions of the use of certain flight station controls are, in some cases, included only to facilitate the explanation of the system functions. Operation of these controls under actual service conditions should be in accordance with the operating airline's prescribed procedures and the FAA and Lockheed approved Operating Manual.

We again, as in Part One of this article, gratefully acknowledge the help extended by departments within Lockheed. Among these were the Electra Electrical Design group, the Electrical Staff and Research groups, and the Flight Test Engineering departments. In addition the General Electric Co. and the Hartman Electrical Manufacturing Co. both provided valuable assistance by their review of these notes.

THE ELECTRA ELECTRIC SYSTEM

PART TWO

INTRODUCTION

THE ADVENT of turbine powered aircraft in commercial aviation has coincided with many changes in the type of electric power generated and in the design of generation equipment. Prior to this time some models of military aircraft had already used ac systems rather than the more conventional dc system, but they had mainly used generators which incorporated rotating exciters for voltage regulation control. The Electra's ac generation system, however, utilizes static excitation with magnetic-amplifier voltage-regulation controls and protection. Also, the generator control circuits are interconnected with the load transfer system so that sensing and diagnosing a fault and then taking appropriate action is, on the Electra, largely automatic.

The automatic bus transfer program is a comparatively new concept in generation systems. However, although it achieves its primary objective of relieving somewhat the flight crews' responsibilities, it is nevertheless desirable that its operation be thoroughly understood. As mentioned in the foreword, the following description includes some of the material previously given in Part One in order to present this second part as a complete entity.

ELECTRIC POWER SYSTEM DESCRIPTION The Electra's 115/200-volt, 3-phase, ac electric power system is shown in simplified form in Figure 1. A 60-kva generator is mounted on the engine reduction gear box of each of the four prop-jet engines. Generator Nos. 1, 2, and 3 are driven directly by their respective engines, but the No. 4 generator is driven via a two speed gear box to provide power at normal frequency during engine low speed operation (Low Ground Idle).

The No. 4 generator is maintained on a standby basis during normal flight so that the Electra may be considered to have, in effect, a three generator electric system. Each generator operates independently and normally feeds one of three separate groups of loads or ac buses which are called the Priority Bus A, the Priority Bus B, and the Utility Bus C to indicate in decreasing order the importance of the loads connected to them. When a generator fails or is unavailable because of low speed, these three buses are automatically connected through transfer relays to the remaining generators in accordance with a predetermined plan. This system arrangement precludes more than one generator supplying power to any one of the main buses simultaneously, and no generator paralleling devices are necessary. The Electra's nonparalleled system also allows the constant speed characteristics of the Allison engine to be utilized to maintain each generator output frequency within the airplane's equipment limitations of 380 to 420 cycles.

The basic electric power system thus consists of the four generators, the main bus transfer relays, and the three main ac buses. In normal operation these buses carry all the loads on the airplane, including the transformer rectifiers which supply power to the dc system. A fourth ac bus, called the Essential AC Bus is also shown in Figure 1. It has a supplementary transfer system (shown in color) which is automatic in operation but which, unlike the main bus transfer system, does not require additional control circuits. The Essential AC Bus may be considered as an additional load relative to the bus or generator to which it is connected. It will be noticed that under rather exceptional circumstances it could be connected directly to either generator No. 1 or generator No. 4, thus bypassing the three main ac buses and the main bus transfer system.

A selected group of services which are of primary importance to the airplane's operation are connected to the Essential AC Bus, and it is supplied by power as long as generator power is available on the airplane. Also, according to their relative importance, the Priority Bus A and the Priority Bus B have three generator support while the Utility Bus C has two possible sources of supply. The Utility Bus C carries only what might be termed non-essential loads and is de-energized when two or more generators are inoperative.

Two 150-amp transformer rectifiers, one supplied by the Priority Bus A and the other supplied by the Essential AC Bus, provide the dc electric power requirements. The 28-volt dc output from each of the transformer rectifiers is divided between the Main DC Bus and the Essential DC Bus. In general, like its ac counterpart, the Essential DC Bus carries loads closely associated with flight safety, while loads which do not come into this category are connected to the Main DC Bus. Both the dc buses have four generator support and, in addition, the Essential DC Bus can be energized by a 36-ampere/hour battery. As this bus carries all the loads associated with the generation and bus transfer control systems, it is of particular interest in this second part of the Electra electric power system discussion.

In Figure 1 the thick bold lines (black and red) depict the positions of the transfer relays during normal operation so that the generators are shown connected to the main ac buses as follows:

Generator No. 1 to the Utility Bus C
Generator No. 2 to the Priority Bus B
Generator No. 3 to the Priority Bus A
Generator No. 4 energized and on standby

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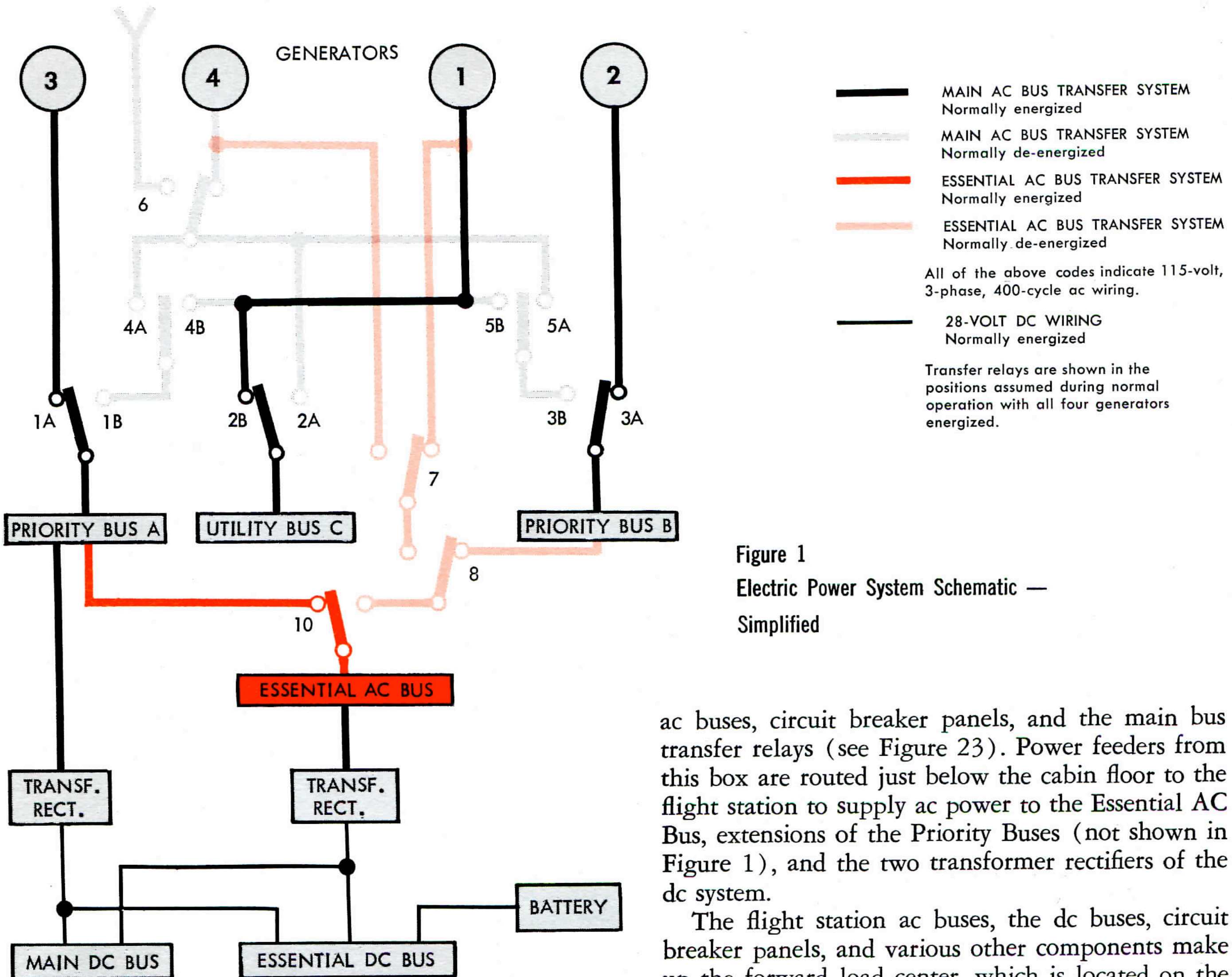


Figure 1
Electric Power System Schematic — Simplified

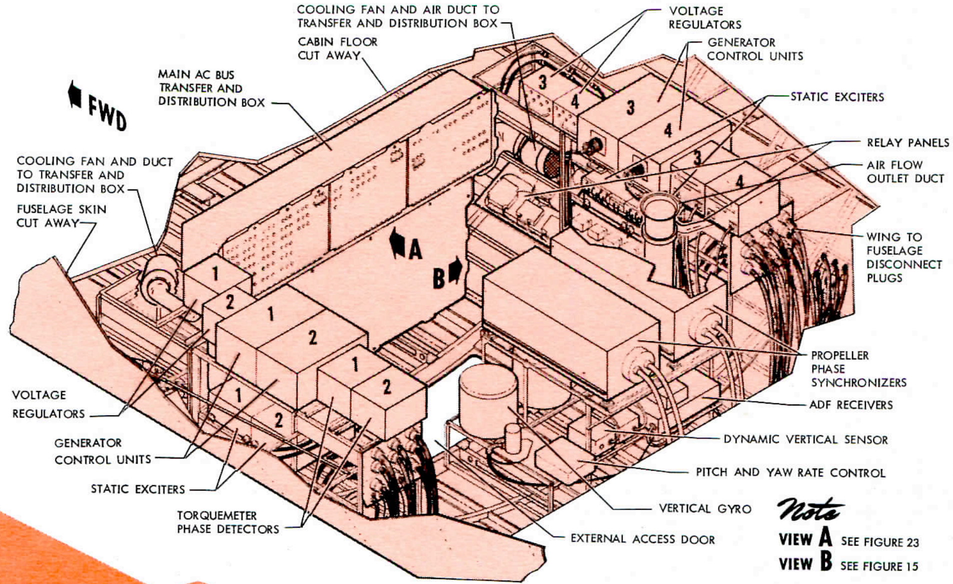
SYSTEM LAYOUT The approximate locations of the various electric system components can be seen in Figure 2. Beginning at the powerplants, Figure 6 shows the generator No. 2 installation and the generator No. 4 installation with the two speed gear box can be seen in Figure 22. The feeders from each generator, consisting of two bundles of three 6-gauge wires, and the wiring for the generator control circuits are routed first through the engine firewall where the generator neutral and various ground wires are terminated on aircraft structure. From here the generator wiring progresses inboard, inside the wing leading edge, and enters the main electrical service center through pressure seals.

The main electrical service center is accessible through a large external door and through a small hatch in the center aisle of the main cabin. It contains all the control components of the four generation systems, and a transfer and distribution box at the forward end of the compartment contains the three main ac buses, circuit breaker panels, and the main bus transfer relays (see Figure 23). Power feeders from this box are routed just below the cabin floor to the flight station to supply ac power to the Essential AC Bus, extensions of the Priority Buses (not shown in Figure 1), and the two transformer rectifiers of the dc system.

The flight station ac buses, the dc buses, circuit breaker panels, and various other components make up the forward load center, which is located on the aft left hand side of the flight station (see Figure 3). Below the flight station, the spaces on either side and aft of the nose wheel well are used for the location of items such as the transformer rectifiers, the battery, and an inverter — items which would otherwise require special provisions for cooling, noise isolation, or ventilation (see Figure 4).

Other components shown in Figure 2 are the radio rack, located opposite the forward load center, and the electrical control panel (see Figure 40), which is located overhead between the flight engineer's and copilot's seats. This panel contains the principal switches, instruments, and indicator lights required for the operation of the ac and dc electric power systems. Also shown in Figure 2, the 90-kva capacity external power receptacle is located on the right hand side of the nose of the airplane and is connected directly to the distribution box in the main electrical service center. An alternative arrangement has an additional external power receptacle in the rear fuse-

(Continued on page 8)



Main Electrical Service Center

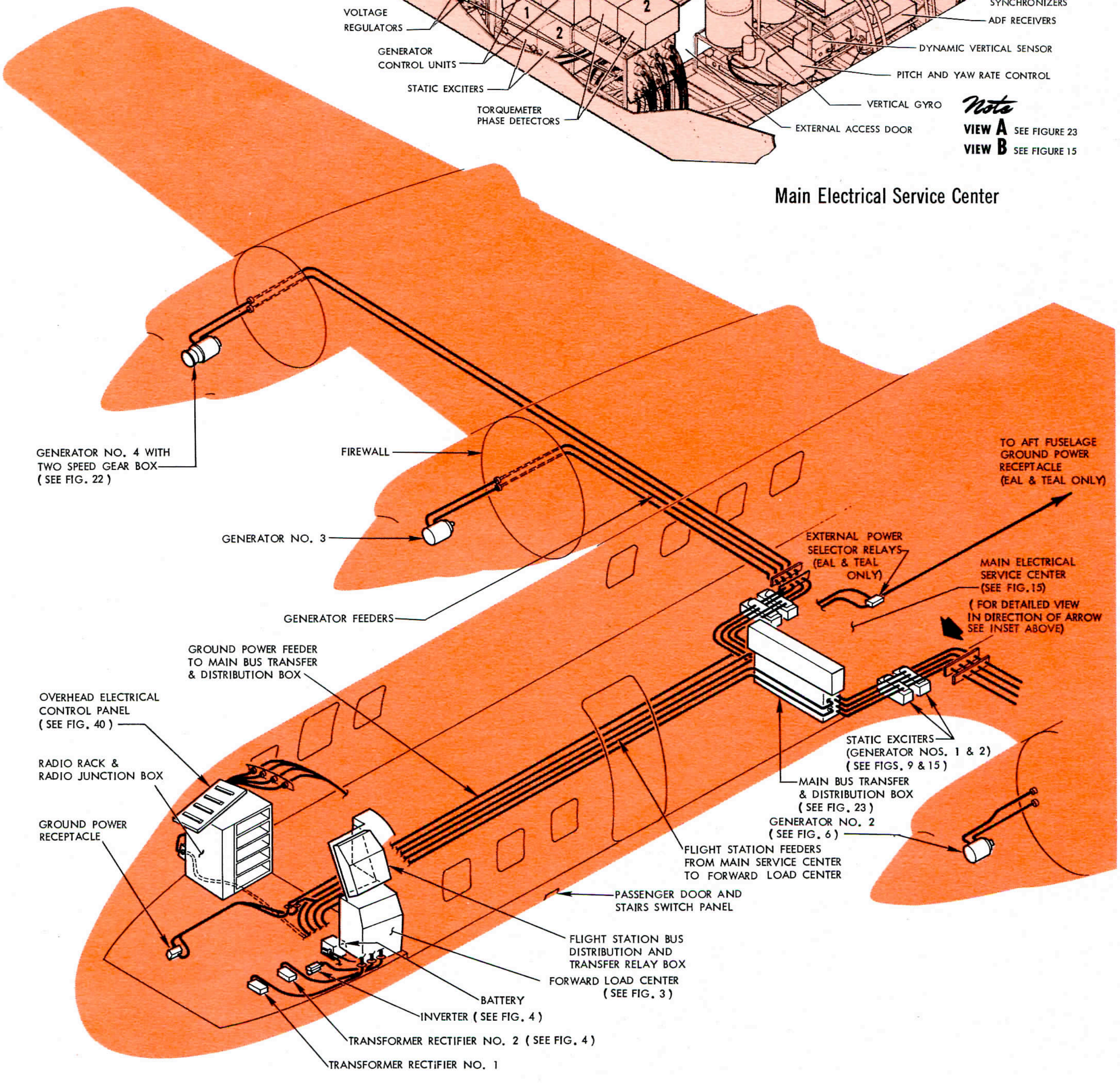


Figure 2 Location of Electrical Equipment

lage and the circuit diagrams for both these arrangements are included in this article (see Figure 41).

For the purpose of describing the generation and bus transfer systems, the Figure 1 electric power system schematic adequately shows the basic arrangement of the system. However, for those readers who may be interested, Figure 5 shows the system in greater detail. Specifically, it includes the more important switches and circuit breakers, the Priority Bus A and B flight station extension buses, and the inverter circuit. It also complements Figure 2 inasmuch as it is subdivided to show the approximate locations of electric components in the airplane.

It will be noted that Figure 5 depicts KLM's system, which is basically the same as the standard version of the electric system shown in the similar diagram (Figure 12) in Part One, but has some minor differences. By including this particular schematic, the description given in Part One is therefore made more complete. The most important differences between the two versions of the system are that the standard version has a Ground Operation DC Bus (connected to the Essential DC Bus in normal operation), and does not have the transformer rectifier transfer relay (see Figure 5), in the external power circuit.

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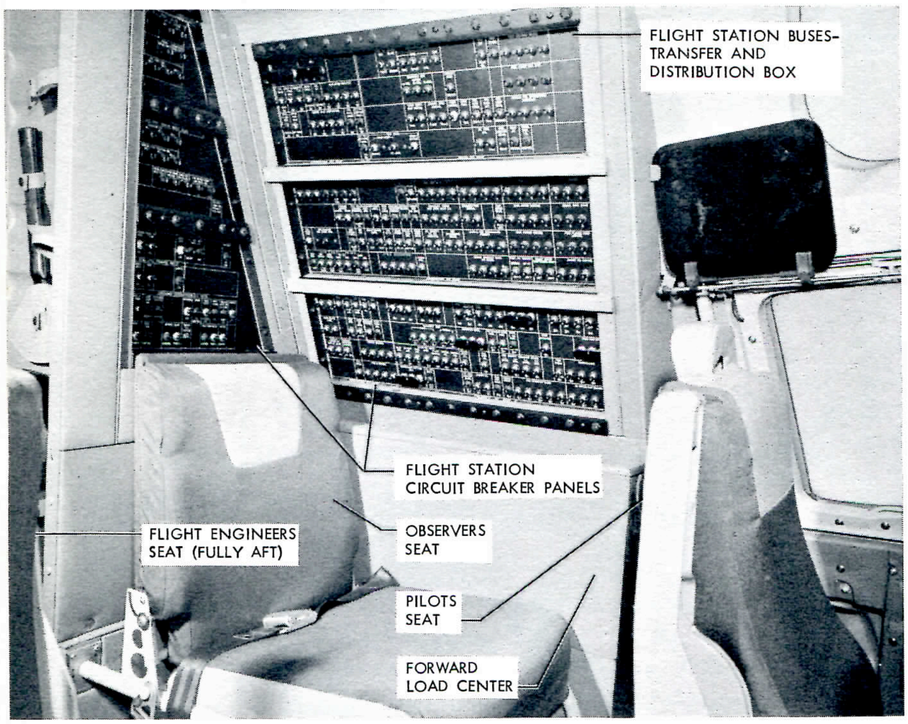


Figure 3
Forward Load Center — Domestic Airplane

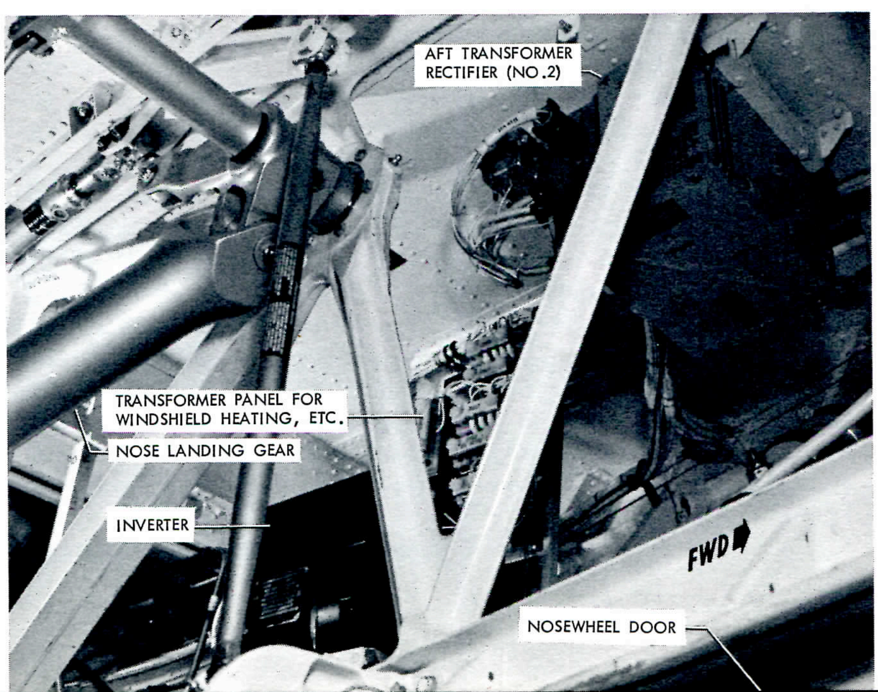


Figure 4
Transformer Rectifier and Inverter Installation in Nose Wheel Well

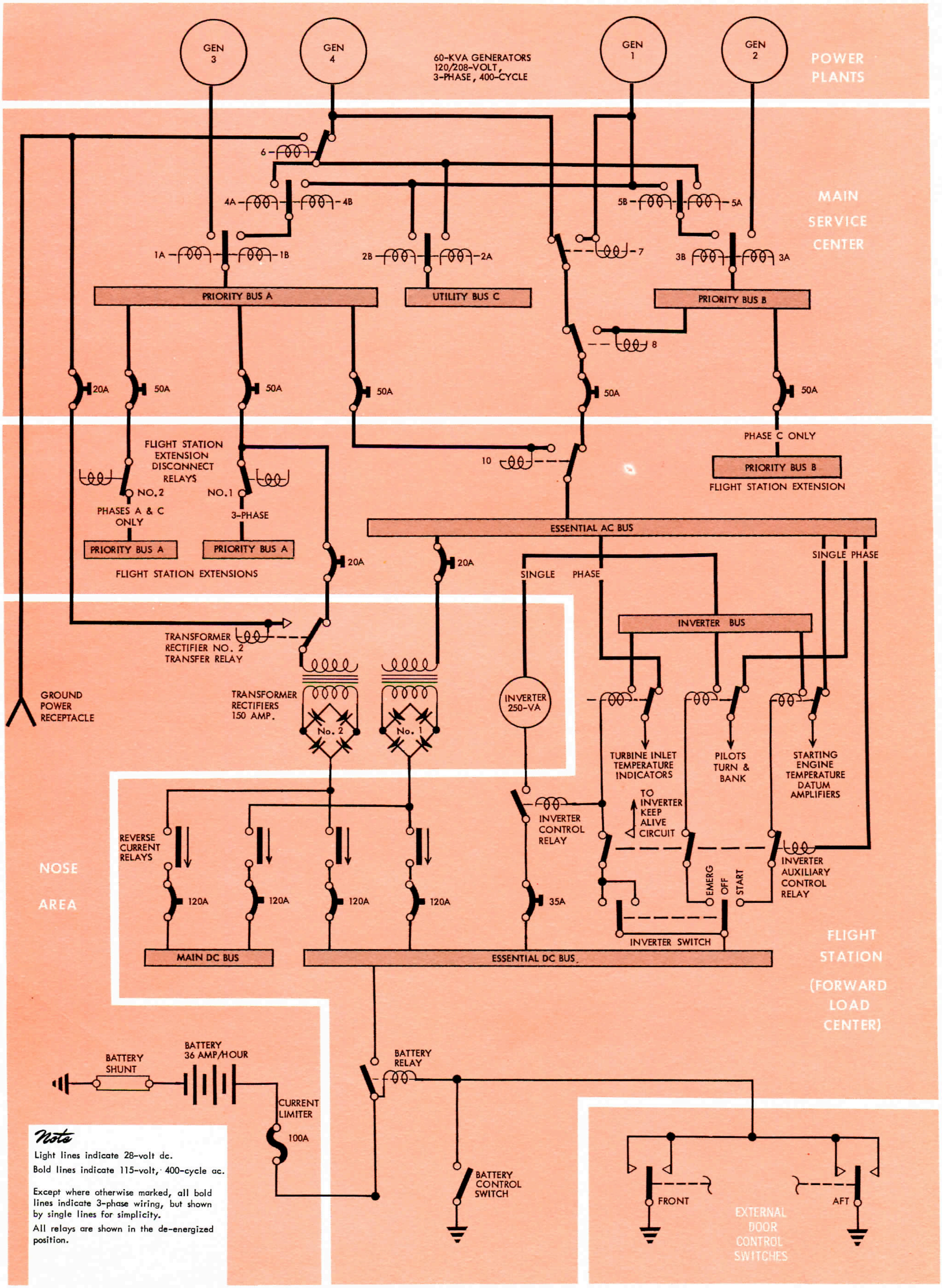


Figure 5 Electric Power System Schematic — KLM

GENERATION SYSTEM DESCRIPTION

Each generation system 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 7) and, with the exception of the generator, they are all located in the main electrical service center (see Figures 2 and 15). The two speed gear box, which is closely associated with the No. 4 generation system, is described following the explanation of the engine low rpm control circuit.

The generator's 3-phase output is fed through the static exciter, which uses both a voltage and current feed 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 supplies the generation system control and protective functions as well as the necessary signals for operation of the transfer system relays.

Also shown in Figure 7, the permanent magnet generator (PMG) is an integral part of the main generator and rotates on the same shaft. It is self-exciting and, in conjunction with a transformer rectifier, supplies flashing power to the main generator field. Having a relatively constant output, it also gives a source of control and protective power independent of the main generator power.

Feeder Faults. Each individual generation system incorporates a differential current relay feeder fault protection circuit. A 3-phase current transformer is mounted on the generator housing (see Figure 8) and a second one is attached to the transfer and distribution box, which is located in the main electrical service center (see Figure 23). By means of these transformers the current flowing in the ground leg of each phase of the generator stator windings is compared with the current flowing out of the corresponding feeder wire just ahead of the main generator relay. If the currents differ by more than a specified amount, a differential protection relay (DPR) located in the control unit de-energizes the generator.

It is noteworthy that, in addition to the differential protection system, the Electra's generation system has a high degree of inherent protection against feeder faults. Tests with the differential protection feature disconnected demonstrated that a short circuit occurring between the generator terminals and the static exciter in the main electrical service center caused collapse of the generated emf followed by collapse of the short circuit current and a subsequent undervoltage trip, except in cases where the fault was intermittent.

GENERATOR The 3-phase, Wye connected generator shown in Figure 8 was especially designed by the General Electric Company for the Electra and has the following rating: 60 kva, 120/208 volts, 380/420 cps, 5700/6300 rpm. The 3-phase output windings are mounted on the stator and an eight pole-field

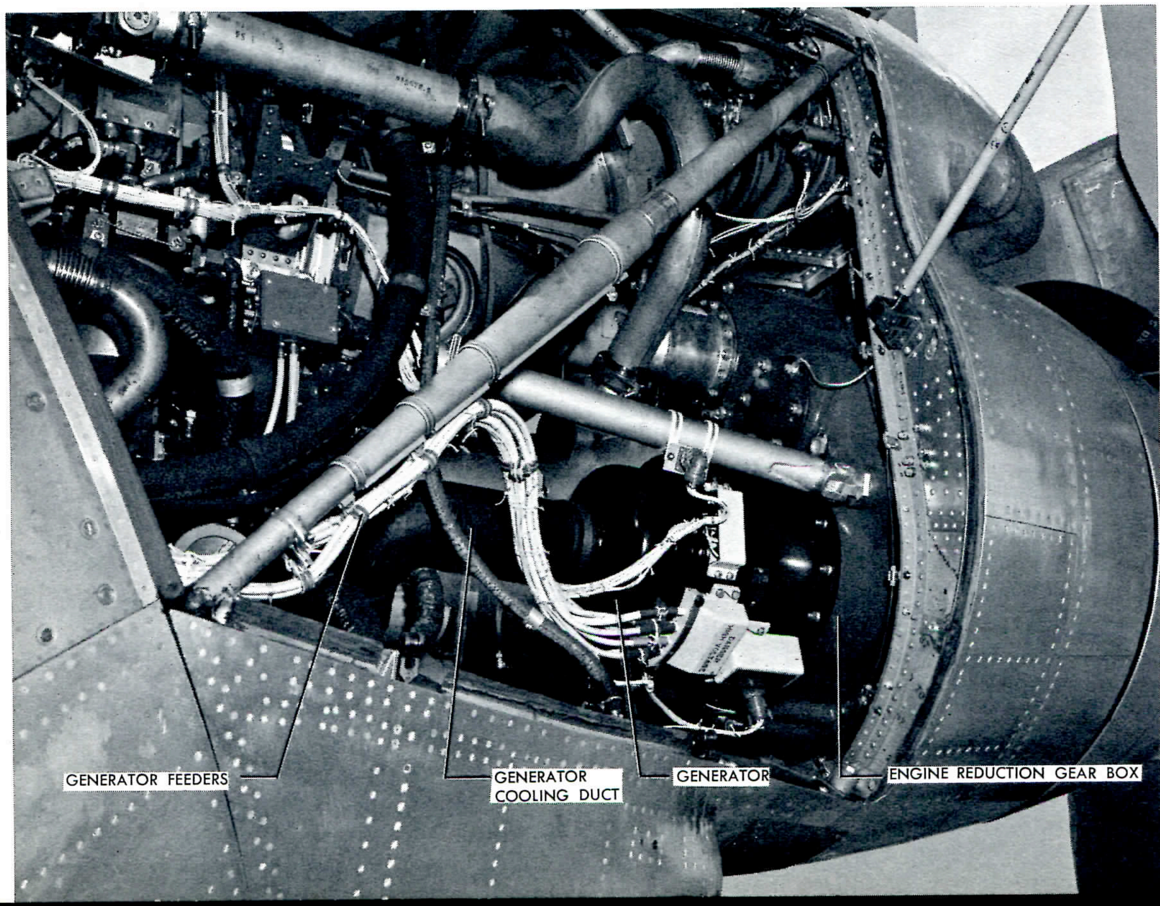


Figure 6 Generator Installation — No. 2 Engine

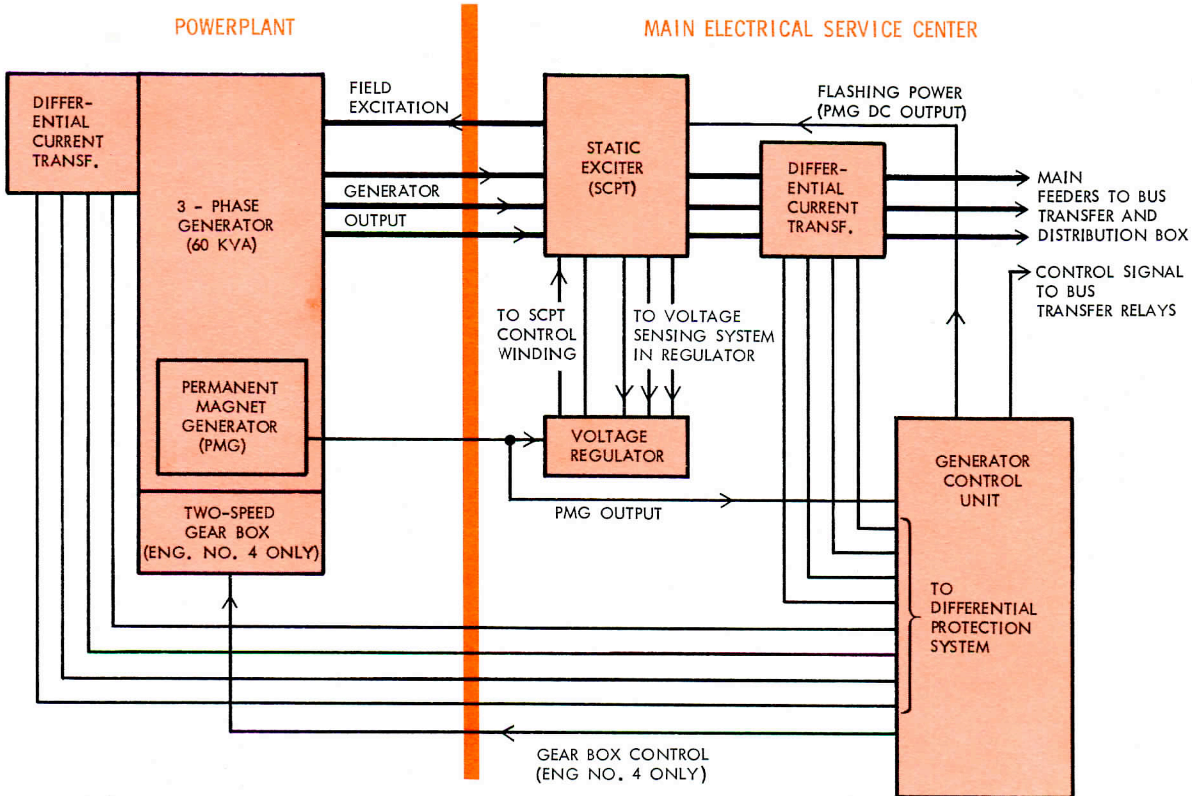


Figure 7
Generation System — Block Diagram

rotor is fed dc excitation current from the static exciter through brushes and slip rings. This can be seen schematically in Figure 16, which depicts a complete generation system.

The generator incorporates several interesting electrical and mechanical design features which offer significant advantages in the application to the Electra. The use of static excitation for example eliminates the conventional rotating exciter with its brushes and commutator so that the generator is relatively smaller and lighter, with less overhung moment, and requires less cooling.

The permanent magnet generator can be seen in Figure 8 and has a rotating magnetic field consisting of a set of equally spaced Alnico magnets cast into a solid aluminum rotor. The stator of the permanent magnet generator is pressed into the yoke and bearing support of the main generator brush rigging and gives a single phase ac output of approximately 50 volts.

Performance. During flight and under certain specified cooling conditions the generator will deliver continosly 150% (90 kva) of rated load. On the ground it will supply full load continuously without externally-supplied cooling air. The ram air cooling available in flight is adequate to satisfy the requirements at 150% rated load, but centrifugal type fans have been added to the rotor assembly to provide cooling of the generator for ground operation. Other design features include 5-per-unit single-phase short circuit capabilities and regulation to 117 volts at the bus within plus or minus 4%, under most of the specified environmental conditions and up to 200% of rated load.

A unique characteristic of this generator is that it was designed to fulfill requirements at a nominal rating of 380 cps as well as at the more standard frequency of 400 cps. This "low frequency" requirement is necessitated on the Electra because of the slight variations in engine rpm encountered while the engine is idling. The weight of the iron in the generator was increased to meet this special condition and thus obviate possible overheating at the lower engine rpm limits.

Safety Features. Two interesting features of the generator design are a bearing failure warning device and a solenoid operated disconnect mechanism.

The warning device consists of a soft copper strip which is embedded in and insulated from the main generator stator assembly. The copper strip is connected to a warning light in the flight station. Should a bearing begin to fail the increased bearing clearance allows the rotor to rub against the stator, thus smearing the copper strip across the insulation and completing the warning light circuit to ground.

The generator is driven via a stub shaft assembly which incorporates a shear section to prevent possible engine reduction gear box damage in the event of a generator seizure. In addition to this safeguard, generators are available as optional equipment with a solenoid operated disconnect mechanism in the stub shaft assembly. (The generator shown in Figure 8 does not incorporate the disconnect.) Some operators have elected to incorporate this item on their aircraft so that any one of the four generators can be individually disengaged from the engine. Switches on the flight station overhead electrical control panel operate

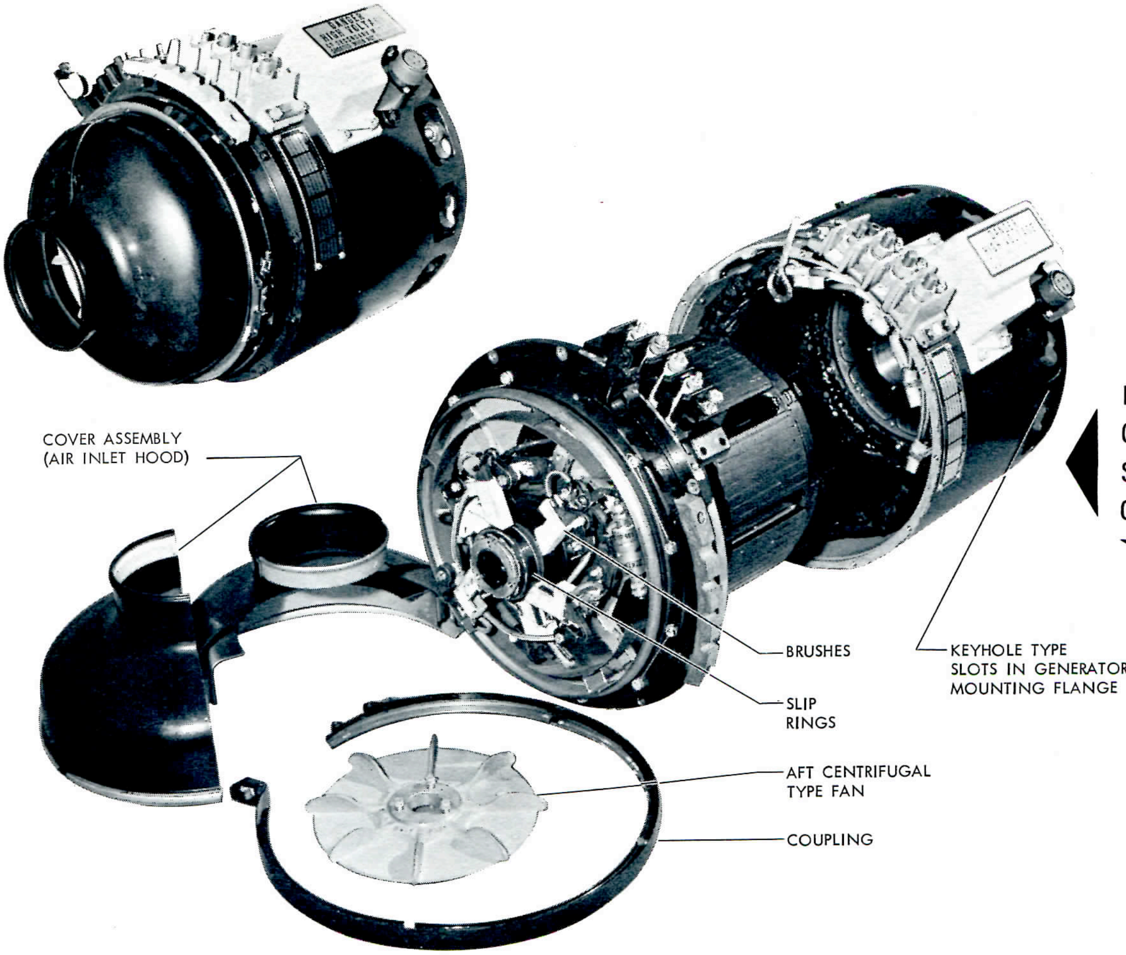
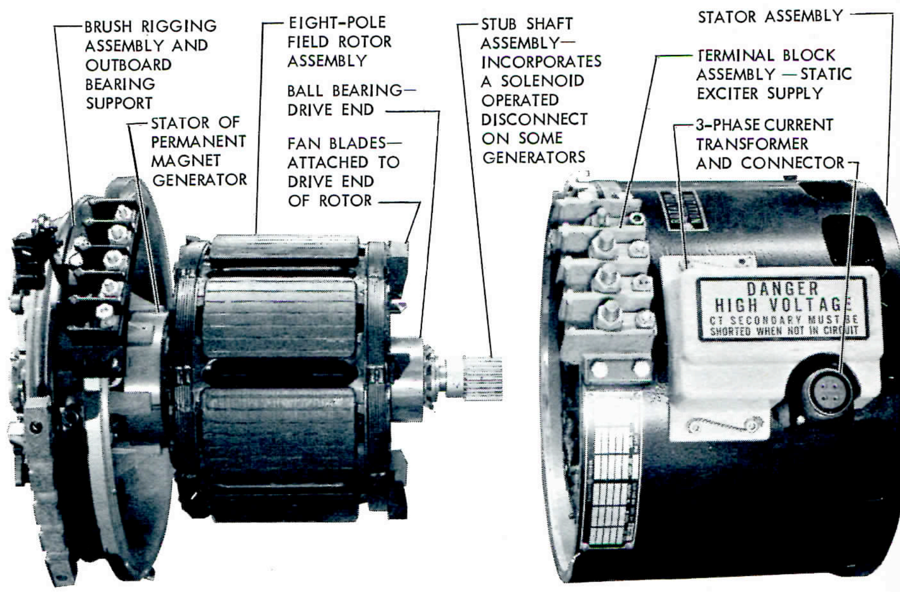


Figure 8
Generator — Showing Main Components

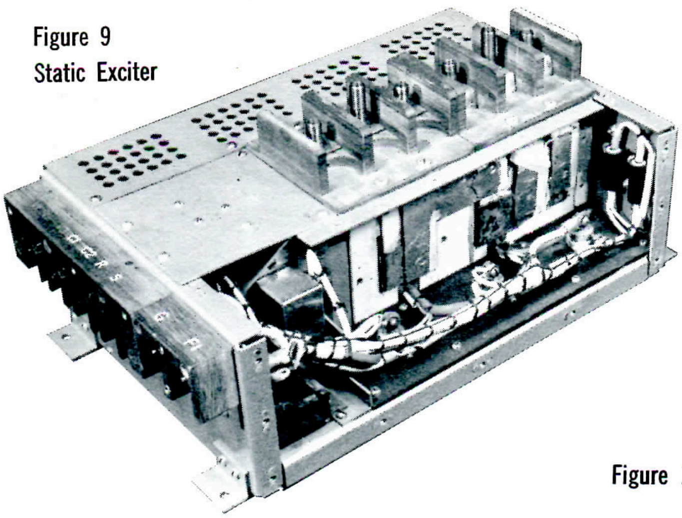
the disconnect solenoids. Also, the two-speed gear box for the No. 4 generator incorporates a disconnect mechanism which is used in lieu of the generator disconnect and is incorporated on all aircraft, regardless of whether the generator disconnect is installed.

Maintenance Aspects. Special attention has been given to the mechanical design of the generator to facilitate maintenance. Such features include: keyhole type slots, which are provided in the generator mounting flange for ease of attachment to the engine accessory drive pad; and the brush installation design, which allows for easy inspection of the brushes. Removal of the aft fan air inlet hood by means of a quick release coupling completely exposes the brushes and slip rings (see Figure 8). As previously mentioned, the absence of either a commutator or a rotating exciter on this type of generator helps to minimize maintenance and, as more efficient cooling of the generator is possible, contributes to a long overhaul life.



STATIC EXCITER The principal component in the static exciter, shown in Figure 9, is the saturable-current-potential-transformer (SCPT). It consists of three separate cores of a magnetic material, one for each phase of the generator output. Three windings — a potential winding and a current winding from each phase, and the SCPT output winding — are wound individually around each core. A fourth winding, the control winding connected to the voltage reg-

Figure 9
Static Exciter



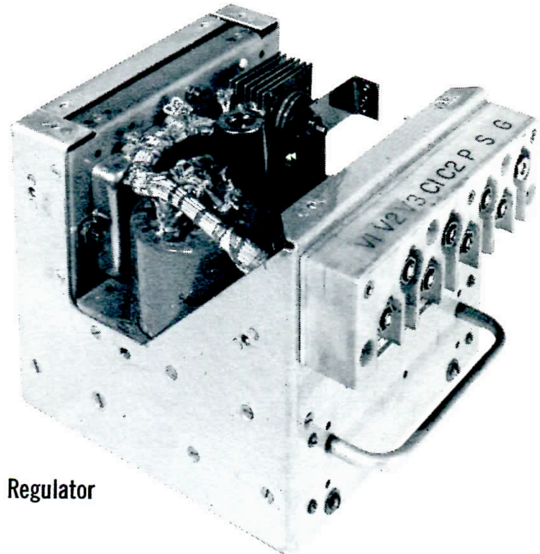


Figure 10 Voltage Regulator

ulator, is wound continuously around all three cores. The ac outputs from the transformer cores are fed to a 3-phase bridge rectifier, the dc output of which is fed back to the generator field. For illustrative purposes, only one core (representing one phase) is depicted in Figure 16 and the linear reactor which is shown in series with the potential winding provides a constant impedance to shift the phase of the voltage signal to satisfy excitation requirements. It also absorbs the line voltage when the generator is de-energized.

The voltage and current signals of the SCPT are so proportioned that over the range of normal loads the static exciter supplies generator excitation which maintains an almost constant voltage with only minor assistance from the voltage regulator. Its action may be considered essentially as that of a transformer where the current and potential coils are the primary windings and the output winding of the static exciter corresponds to the secondary windings. Referring again to Figure 16 it can be seen that an increase in load would result in a current increase in the current windings and a consequent increase in exciter output to satisfy the additional generator field requirements. Conversely, for decreases in load, exciter output also decreases.

Generator Control Relay (GCR). Incorporated in the static exciter is a generator control relay which virtually performs the role of switching the generator on and off. The operation of this relay is controlled by the appropriate generator control switch in the flight station (see Figure 40), and also by the generator control unit. When the relay is de-energized the potential windings of the SCPT are short circuited. The output of the SCPT is thus reduced to zero and the generator field excitation is effectively removed, so that the output from the generator is reduced to a residual voltage of approximately 1 volt. The GCR is further discussed in the "Generation System Operation" section.

VOLTAGE REGULATOR A signal from the voltage regulator is applied to a control winding in the SCPT to improve system accuracy and responsiveness. Its action can probably best be described by considering the following sequence of events on Figure 16 as an example:

1. Assume that the generator output voltage rises above normal.
2. The control signal from the voltage regulator then increases.
3. The SCPT saturation increases.
4. The exciter output decreases.
5. The field current decreases, returning the generator output voltage to normal.

It will be noted that no moving parts are involved in either the voltage regulator or the static exciter in the above sequence. The voltage regulator maintains a preset voltage level under all loading and environmental conditions. The regulator circuit is rather involved, so no attempt has been made to reproduce the internal circuitry in Figure 16. However, it consists essentially of a transformer rectifier circuit to provide a source of dc control power from the permanent magnet generator, a sensing circuit, a glow tube reference voltage circuit, and a single stage magnetic amplifier.

The voltage regulator uses average and highest phase sensing. A signal from each phase of the generator output is fed to a comparative network which uses the average of the three phase voltages during normal operation, but which permits highest phase take-over whenever the voltage on any one phase exceeds prescribed limits. The dc output of this sensing network is compared with the reference voltage across the glow tube. The resultant error signal is then amplified through the magnetic amplifier whose output in turn is fed to the control winding in the static exciter. A stabilizing circuit, employing exciter output and feedback, operates to improve the voltage regulator's response and stability.

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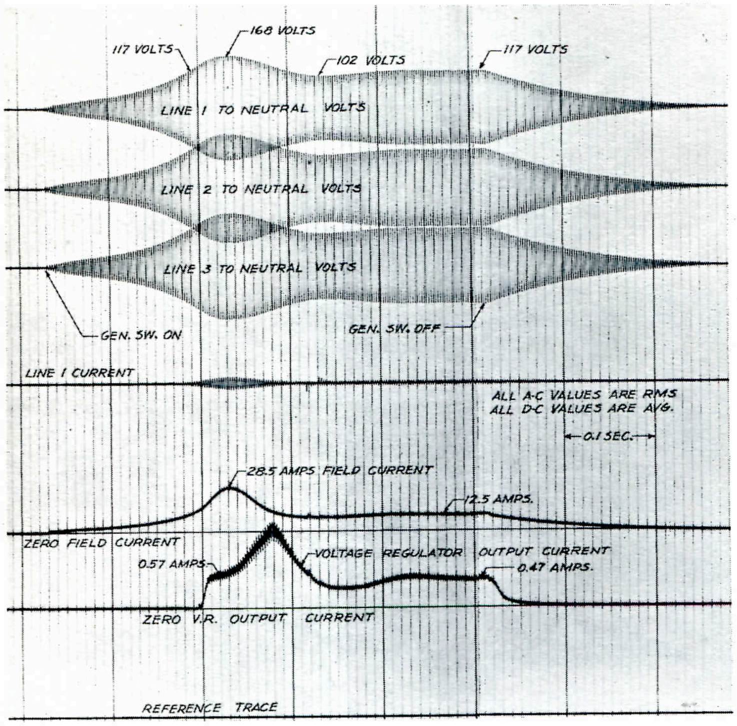


Figure 11 Oscillogram Showing Generator Buildup at 6,000 rpm with No Load — Generator Tripped Manually

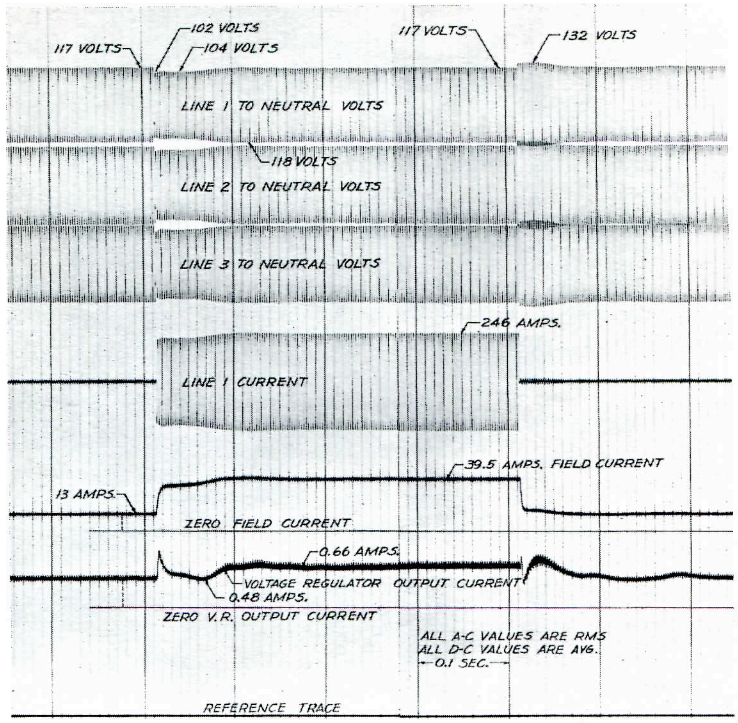


Figure 12 Oscillogram Showing Application and Removal of 150% Load at Unity Power Factor at 6,000 rpm

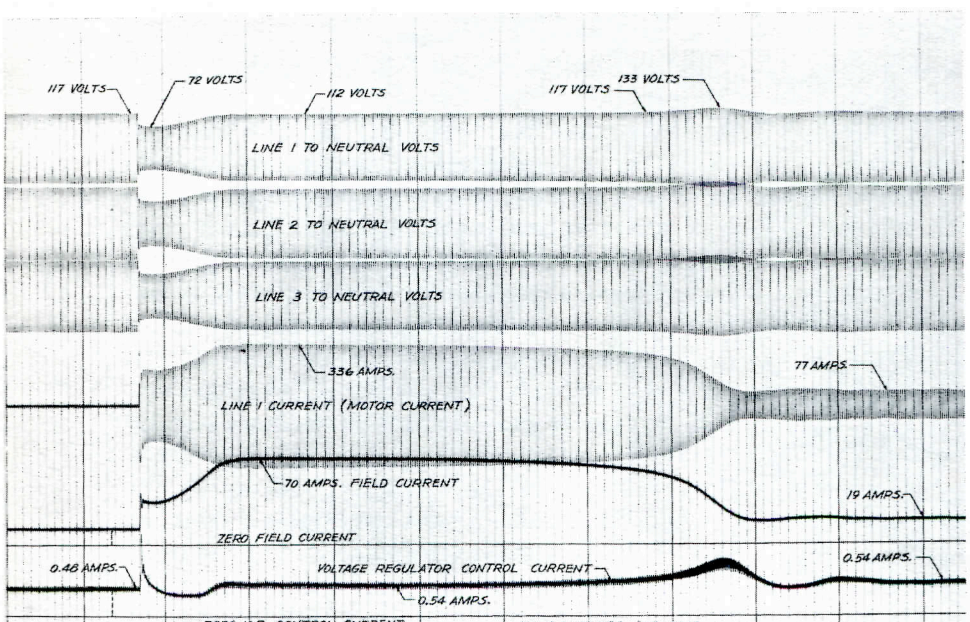
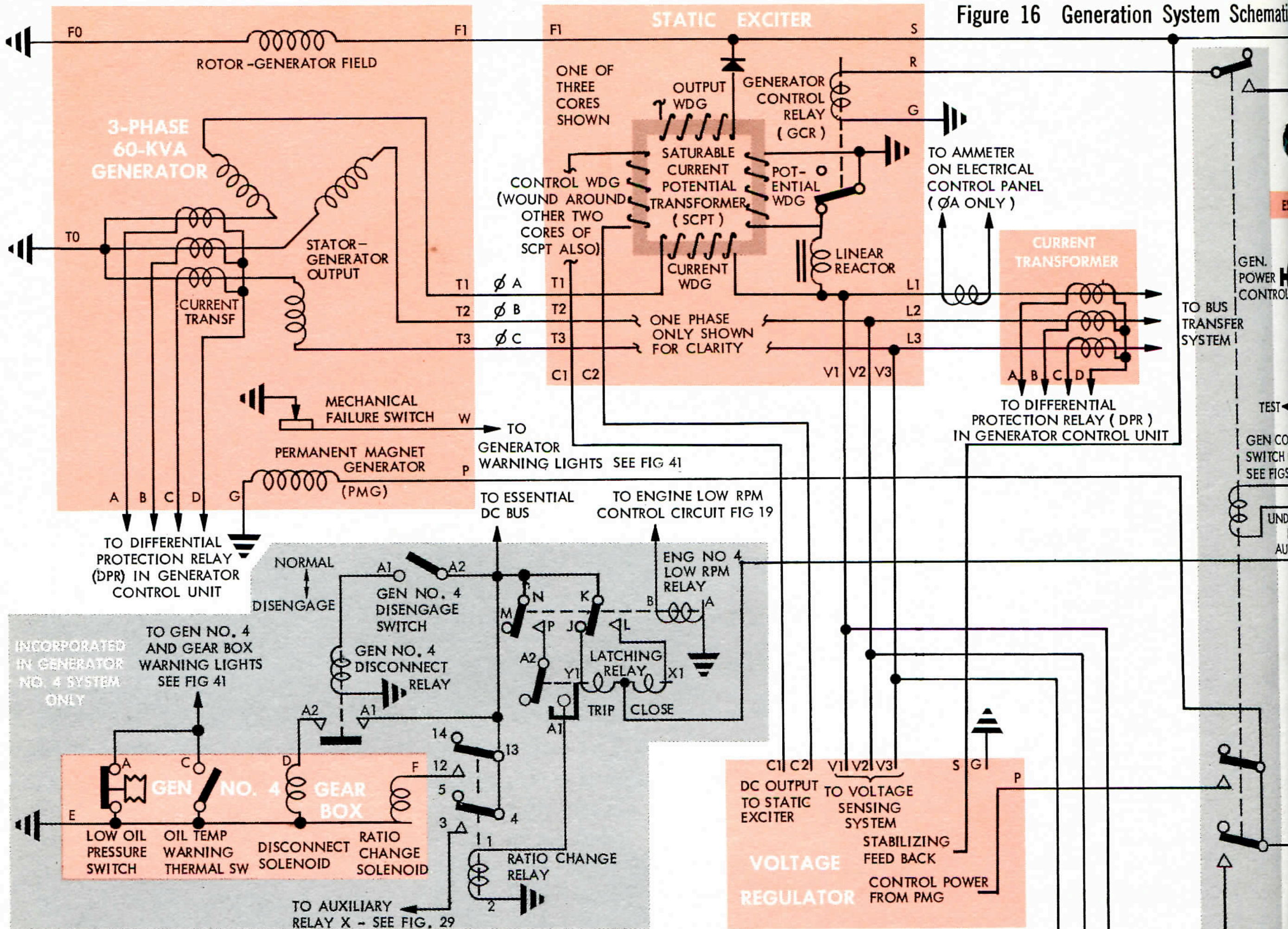


Figure 13 Oscillogram Showing Freon Compressor Motor Start with Motor Fan Loaded — No Load on System at 6,000 rpm

GENERATION SYSTEM PERFORMANCE CHARACTERISTICS Having discussed in theory the action of the static exciter and voltage regulator, it is interesting to study some actual oscillograms (Figures 11, 12, and 13), which show typical performance characteristics of the Electra's generation system. The combined action of the exciter and regulator in maintaining system voltage is particularly well demonstrated in Figure 11 depicting generator buildup.

As previously mentioned, for normal loads the static exciter will supply correct field excitation to maintain constant generator voltage with only trimming action from the voltage regulator. This design principle permits the use of a low gain, high speed regulator, which in turn results in a system that is fast in corrective action with excellent stability characteristics. Figure 12, showing the application and removal of 150% load (246 amps on each phase), demonstrates how quickly the system stabilizes even after a rather drastic load change—in less than .1 seconds in this particular example.

Figure 16 Generation System Schematic



ACR	AUXILIARY CONTROL RELAY	Energized when line voltage is above minimum value and frequency is within specified limits.
AFR	AUXILIARY FREQUENCY RELAY	Energized after TDR3 time delay when frequency is within prescribed limits.
DLR	DIFFERENTIAL PROTECTION LATCH-OUT RELAY	Energized when feeder or generator fault occurs.
DPR	DIFFERENTIAL PROTECTION RELAY	Energized when feeder or generator fault occurs.
LOR	LOCKOUT RELAY	Energized when prolonged overvoltage or generator or feeder fault occurs.
OVR	OVERVOLTAGE RELAY	Energized when prolonged overvoltage occurs.
TDR1	TIME DELAY RELAY NO. 1	Energized after line voltage has dropped below the minimum limit for a prescribed period.
TDR2	TIME DELAY RELAY NO. 2	Energized after line voltage has dropped below the minimum limit for a prescribed period.
TDR3	TIME DELAY RELAY NO. 3	Energized by UOR momentarily after frequency has been within limits for a prescribed period.
ULR	UNDERVOLTAGE LOCKOUT RELAY	Energized by TDR1.
UOR	UNDER & OVER FREQUENCY RELAY	Energized when frequency is within prescribed limits.
UVR	UNDERVOLTAGE RELAY	Energized when line voltage is above minimum limit.

Schematic is applicable to all four generation systems except that the grey color blocks indicate circuitry peculiar to No. 4 generation system.
The dark red color blocks in the generator control unit have designations (A through K) to provide a convenient reference in the text.
All switches and relays are shown positioned with the system de-energized.

STARTING AND CONTROL The permanent magnet generator (PMG) provides the primary source of control power and is independent of voltage transients due to either load or fault conditions. Since the regulation and excitation systems are also dependent on PMG voltage, the control circuit has been designed so that a loss of PMG voltage will result in the generator control relay and generator being de-energized.

Engine Starting. With the generation system functioning correctly and regardless of the position of the GCS (ON, OFF or TEST) the following occurs soon after the engine starts and the generator comes up to speed:

1. The UOR is energized by the PMG when the PMG ac output indicates an equivalent main generator frequency of approx. 360-430 cps.
2. Referring to circuit A: dc power is now made available from the PMG via the transformer rectifier, through the now closed UOR contacts (1,4), and through the AFR contacts (1,3) energizing the TDR-3 after an interval of three seconds. This delay allows sufficient time for the two speed gear box to shift (on the No. 4 engine), and the engine speed to stabilize before the generator is energized.
   TDR-3 contacts (7,5) close, energizing AFR coil.
   AFR locks itself in through its own contacts (1,4).
   AFR contacts (1,3) open, de-energizing TDR-3.
3. AFR contacts (5,8) close, completing PMG field flashing and GCR circuits, if the GCS is in the ON or TEST positions.

Flashing Power. To energize the generator the GCS must be selected to ON or TEST (if the switch was not closed before starting the engine). This enables PMG dc power to go through the closed DPR contacts, the GCS, the LOR contacts (1,3), and the now closed AFR contacts (5,8) to:

1. Energize the GCR and thus remove the shorting contacts across the SCPT potential windings.
2. Flash the main generator field via ACR contacts (14,13).

Generator output should now build up, with the field current being supplied from the static exciter. Rectifier REC 27 prevents the field current from being fed back to the control unit circuitry.

Removal of Flashing Power. When the generator output attains a predetermined level (approx. 105 volts) the following occurs:

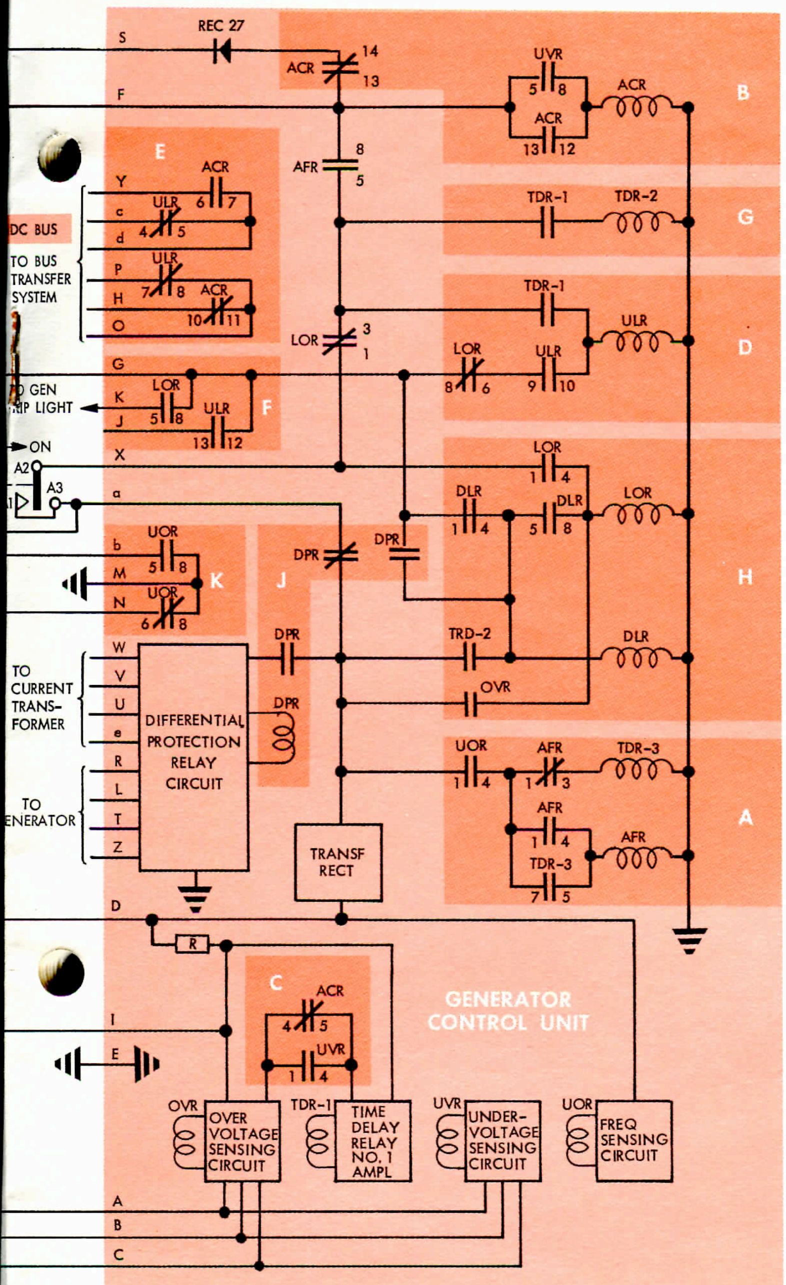
1. Undervoltage sensing circuit energizes UVR coil.
2. Referring to circuit B: PMG dc power is supplied through now closed UVR contacts (5,8) to energize ACR coil.
   ACR locks itself in through its own contacts (13,12).
   ACR contacts (14,13) open and remove flashing power.

With the generator energized, the combined action of the static exciter and regulator stabilizes the output at 117 volts ($\pm$ 4%), while frequency, directly related to engine rpm, is held to approx. 400 cps.

The Auxiliary Control Relay (ACR) has other useful functions connected with the bus transfer and the undervoltage protective systems.

The energizing of the ACR (initiated by the UVR) also closes ACR contacts (6,7) and opens ACR contacts (10,11) in the transfer system (Circuit E). This action, in effect, signals the bus transfer system that the generator is energized, is functioning correctly, and is available for connection of loads. This status of the generation system is checked when the GCS is selected to the TEST position. Selecting the GCS to the ON position completes the operation and connects the generator to load according to the requirements of the bus transfer system.

The undervoltage protection circuit incorporates a time delay relay (TDR-1) which introduces a 3-second interval before removing load from the generator following an undervoltage condition of the system. Referring to circuit C; when UVR contacts (1,4) are closed (generator



has normal voltage output and the UVR coil is energized), a bias current is introduced in the TDR-1 magnetic amplifier rendering the TDR-1 relay inoperative. Conversely, an undervoltage condition will open UVR contacts (1,4) and energize the TDR-1. Since an undervoltage condition also exists when the generator voltage is building up (as distinct from an undervoltage condition initiated by a malfunction), the normally closed ACR contacts (4,5) prevent the TDR-1 from "timing out" before the system can build up to normal voltage.

PROTECTIVE CIRCUITS It is assumed that with the GCS selected to ON, the system is operating normally and the generator is connected to load.

Undervoltage Protection. An undervoltage condition may be caused by a generation system malfunction, a bus fault, or a fault in one of the utilization circuits. The undervoltage protection circuitry, upon sensing an undervoltage condition, distinguishes between these types of faults and either isolates the fault or de-energizes the generator. This is accomplished as follows:

1. UVR is de-energized when voltage drops below approx. 105 volts on any one or more of the three phases.
2. Referring to Circuit C: UVR contacts (1,4) open. ACR contacts (4,5) are already open because ACR is energized.
3. TDR-1 is energized after the specified time delay of three seconds. (This allows sufficient time for circuit breakers to clear possible overloads in the utilization circuits causing the undervoltage).
4. Referring to circuit D: TDR-1 contacts close, energizing ULR coil. ULR contacts (9,10) close, enabling dc power from the Essential DC Bus (battery) to lock in the ULR relay.
5. ULR contacts (4,5 and 7,8) in circuit E open, removing all loads from the generator, and preventing bus transfer.
6. ULR contacts (13,12) in circuit F also close but are not used.
7. The TDR-1 contacts in circuit G also close, making PMG dc power available to energize the TDR-2 coil after a specified delay (approx. one second). This allows time for the generator voltage to re-establish itself, if possible, following disconnection from loads.

If the generator voltage *does* return to normal after removal of load (indicating a bus fault) the following occurs:

1. UVR is re-energized.
2. UVR contacts (1,4) in circuit C close (ACR contacts already open), de-energizing TDR-1 coil and opening TDR-1 contacts in circuit G.

The generation system is now operating at normal voltage free of load. The ULR in circuit D is still energized and locked in by its own contacts (9,10) from the Essential DC Bus power supply. This ensures that the generator and its loads are separated and that they are both isolated from the aircraft system until the trouble is located and corrected. It will be noted that the system can be reset by opening and closing the appropriate Generator Power Control circuit breaker on the Essential DC Bus, breaking the electric latch on the ULR.*

If generator voltage does *not* return to normal after load removal (indicating a generator or feeder fault), the following occurs:

1. TDR-1 remains energized.
2. TDR-1 contacts in circuit G stay closed, energizing TDR-2 coil after a 1-second delay.
3. Referring to circuit H: TDR-2 contacts close, energizing DLR coil. DLR contacts (1,4) close, locking in DLR from the Essential DC Bus. DLR contacts (5,8) close, energizing LOR coil.
   LOR contacts (1,4) close, locking in LOR from the PMG dc supply. LOR is also locked in by DLR contacts (1,4) and (5,8) from the Essential DC Bus.
4. LOR contacts (1,3) open, de-energizing the GCR, shorting out the SCPT potential windings and thus de-energizing the generator.
5. LOR contacts in circuit F close, energizing the generator TRIP light.
6. LOR contacts (8,6) in circuit D open, breaking the lock on the ULR.
7. ACR coil in circuit B is de-energized when LOR contacts (1,3) open.
8. Referring to circuit E: ULR contacts (4,5) and (7,8) close.
   ACR contacts (6,7) open, and ACR contacts (10,11) close, permitting bus transfer if another generator is available.

The trouble should be remedied before using the generator again. It will be noted that to reset the system the GCS has to be selected to OFF-RESET and the Generator Power Control circuit breaker opened and closed, as LOR and DLR are locked in by both PMG and battery power.*

Overvoltage Protection. If the OVR circuitry detects an overvoltage condition on one or all three phases, the OVR is energized after a certain time delay. This time varies according to the amount of the overvoltage — the higher the voltage, the shorter the time delay. Subsequently, the following action is initiated:

1. Referring to circuit H: OVR contacts close, energizing LOR coil. LOR contacts (1,4) lock in LOR from the PMG dc supply via GCS.
2. LOR contacts (1,3) open, de-energizing the GCR, shorting out the SCPT potential windings and thus de-energizing the generator.
3. LOR contacts in circuit F close, energizing the generator TRIP light.
4. ACR coil in circuit B is de-energized.
5. In circuit E, ACR contacts (6,7) open, and ACR contacts (10,11) close, permitting bus transfer if another generator is available.

When the trouble is remedied the system may be reset by placing the GCS to the OFF-RESET position and returning it to the ON position.*

Differential Current Protection. A generator feeder fault initiates the following sequence of events:

1. Referring to circuit J: DPR is energized.
   The normally closed DPR contacts open, de-energizing the GCR, shorting the SCPT potential windings, and de-energizing the generator. One set of normally open DPR contacts close, holding in the DPR from the PMG dc supply. (The differential current that initially actuates the DPR is lost when the generator is de-energized.)
   A second set of normally open DPR contacts also close, energizing the DLR and the LOR (Circuit H) from the Essential DC Bus.
2. LOR contacts (1,3) open, also breaking the GCR circuit. It will be noted that the DPR is held in by PMG power, which is taken ahead of the GCS. This positively ensures that the faulted generation system cannot be re-energized. In fact it is necessary to stop the engine, and therefore PMG output, in order to de-energize the DPR.
3. LOR contacts in circuit F close, energizing the generator TRIP light.
4. ACR coil in circuit B is de-energized.
5. In circuit E, ACR contacts (6,7) open, and ACR contacts (10,11) close, permitting bus transfer if another generator is available.

Under/Over Frequency Protection. Provided that the generator frequency is between approx. 360 and 430 cps, the UOR will be energized. Should the generator speed be outside these limits, the following will take place:

1. In circuit A, UOR contacts (1,4) open, de-energizing AFR coil.
2. AFR contacts (5,8) open, de-energizing the GCR, shorting out the SCPT potential windings and de-energizing the generator.
3. ACR coil in circuit B is de-energized.
4. In circuit E, ACR contacts (6,7) open, and ACR contacts (10,11) close, permitting bus transfer if another generator is available.

**Operation of these controls under actual service conditions should be in accordance with the operating airline's prescribed procedures and the FAA and Lockheed approved Operating Manual.*

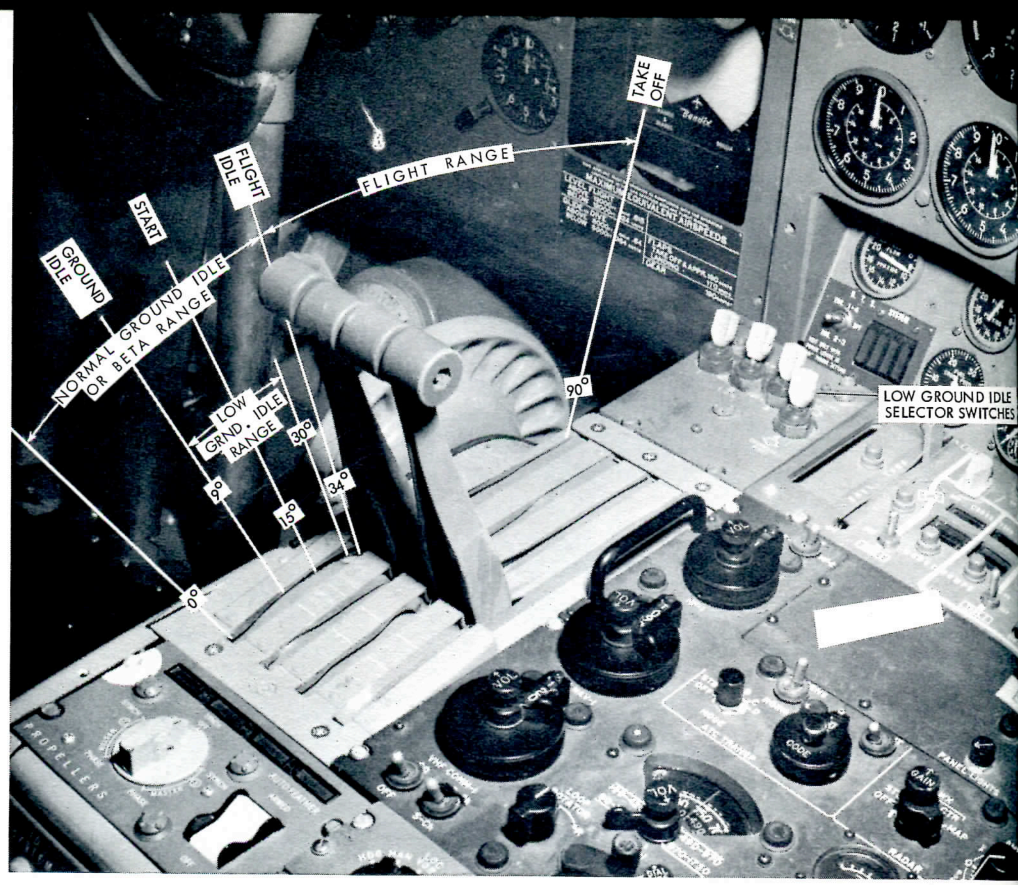


Figure 17
Engine Power Levers and
Low RPM Switches

ENGINE LOW RPM AND GENERATOR NO. 4 GEAR BOX CONTROL CIRCUITS

Normally, and for all flight conditions, the prop-jet engines maintain a relatively constant speed of 13,820 rpm, except for a slight drop to 13,400 rpm at the Normal Ground Idle position. In order to minimize airport noise during engine starting and taxiing, and for fuel economy reasons, each engine has a Low Ground Idle setting which reduces the engine speed to approximately 10,000 rpm. Since the generators would be off frequency at this low rpm setting the No. 4 generator is provided with a two speed gear box enabling this generator to operate in the normal frequency range and carry the entire ac and dc load under these ground conditions.

ENGINE LOW RPM CONTROL CIRCUIT Each engine incorporates a low rpm solenoid which, when energized, resets the engine fuel governor to achieve the Low Ground Idle selection. Four low rpm selector (toggle) switches control the operation of the low rpm solenoids, subject to certain operating conditions (see Figure 17).

One function of the low rpm control circuit is to establish a definite sequence of selection between the two idle speeds for all four engines. This provision is necessary in order to minimize electric power interruptions which might otherwise occur while loads are being transferred between generators. It would be undesirable, for example, to select engine Nos. 1, 2, and 3 to Low Ground Idle until the No. 4 engine and generator had first been established at that speed, ready to assume the loads of the other generators as they dropped off the line.

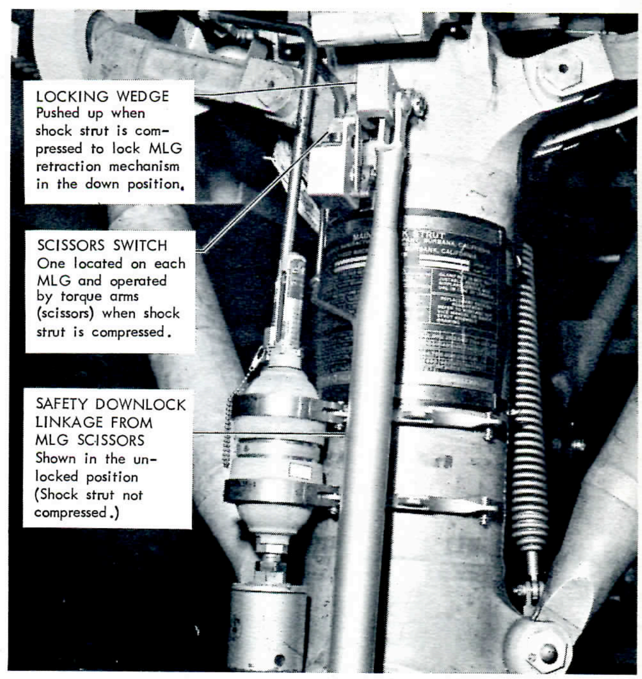


Figure 18 Main Landing Gear Scissors Switch

Selection of an engine to Low Ground Idle by operation of the toggle switch is only possible if all the following conditions are satisfied (see Figure 19):

1. The airplane is on the ground. That is, operation of the main landing gear scissors switches (see Figure 18), has energized the scissors switch relay No. 2 and, in turn, the low rpm solenoid disarming relay.
2. The respective power lever is in the Low Ground Idle range (9° to 30° on the engine coordinator quadrant).

3. The engines are selected in the correct sequence. That is, engine No. 4 before engine Nos. 1, 2, and 3.

Selection of the engines from Low to Normal Ground Idle is contingent upon breaking the circuit to the respective low rpm solenoids. This can be accomplished in any one of the following ways:

1. By operation of the appropriate toggle switch in the correct sequence. That is, engine Nos. 1, 2, and 3 before engine No. 4.
2. By advancing or retarding the appropriate power lever out of the Low Ground Idle range.
3. By the low rpm solenoid disarming relay becoming de-energized and thus de-energizing all four low rpm solenoids.

It will be noted on Figure 19 that the low rpm relay is de-energized when the No. 4 engine attains a speed in excess of 13,000 rpm. Thus, should the No. 4 engine be selected to Normal Ground Idle when any one or more of the Nos. 1, 2, and 3 engines are still in Low Ground Idle, the circuits to the low rpm solenoids of these latter engines would be broken when the low rpm interlock relay becomes de-energized, and they would automatically accelerate to the Normal Ground Idle condition. It should be emphasized that this method should not be used as a normal operational procedure as it involves a more than momentary loss of electric power. The provision is only included in the low rpm circuitry to prevent the more extended loss of electric power that would occur if the No. 4 engine were selected to Normal Ground Idle with the other three engines remaining in Low Ground Idle.

The engine low rpm relays are also interconnected with other circuits. To obtain efficient operation of the air cycle machines under Low Ground Idle conditions, the engine Nos. 2 and 3 low rpm relays are connected with the control circuit for the respective cabin supercharger (also known as engine driven compressor or EDC). Of particular interest in this discussion, however, the No. 4 engine low rpm relay incorporates contacts which are interconnected with the generator No. 4 two-speed gear box control circuit.

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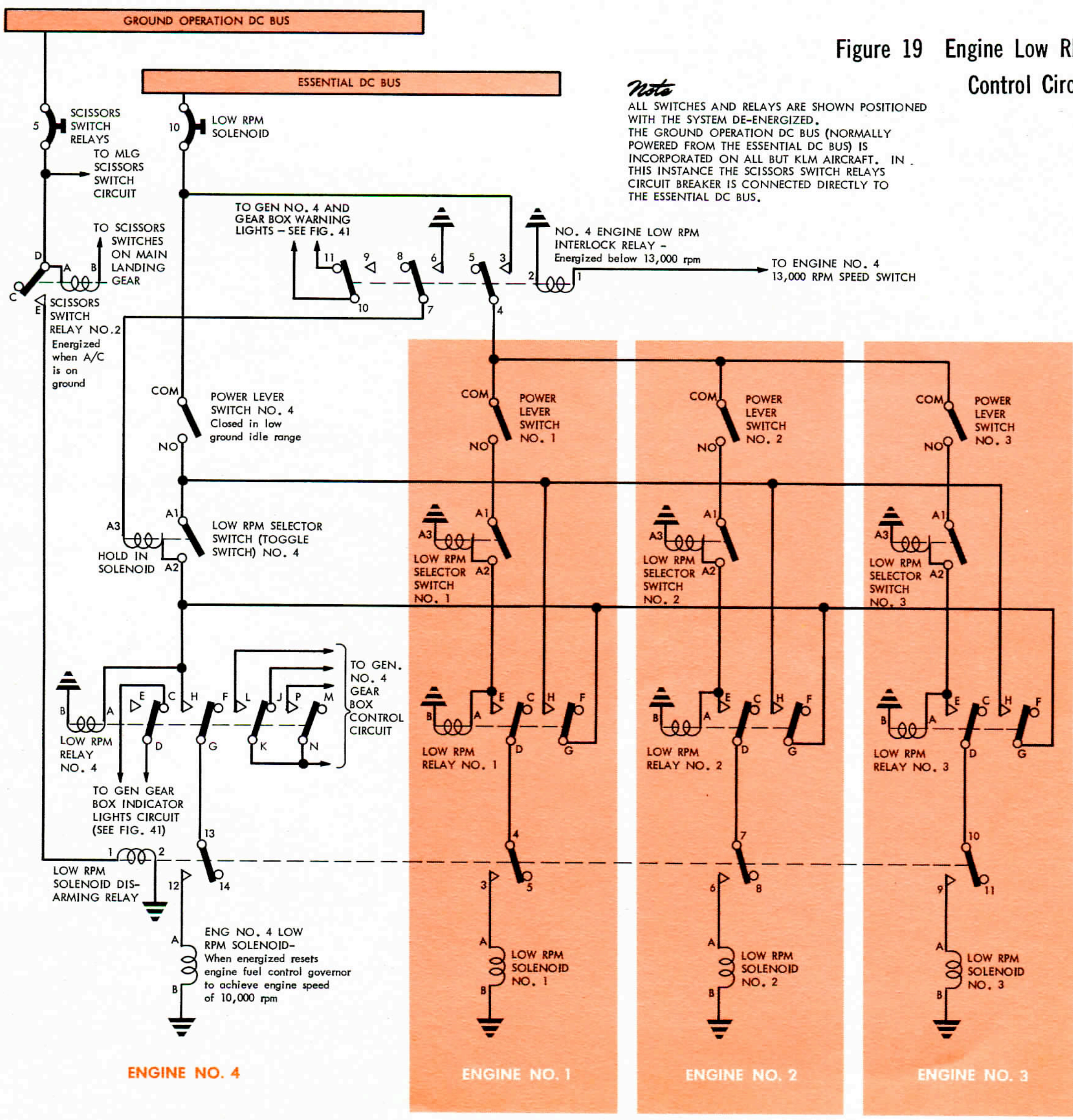


Figure 19 Engine Low RPM Control Circuit

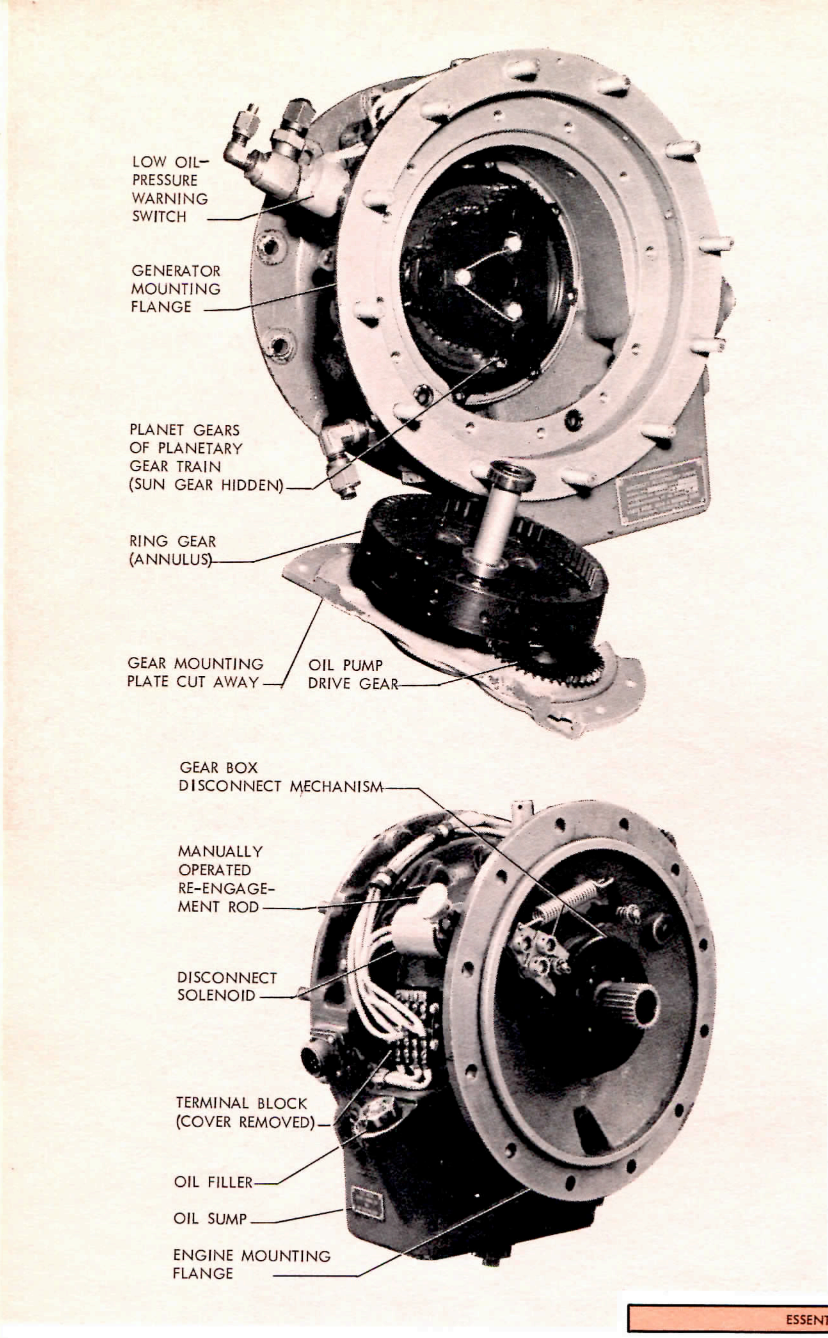


Figure 20
Generator No. 4 Gear Box

GENERATOR NO. 4 GEAR BOX DESCRIPTION Referring to Figures 20 and 22, the gear box utilizes a planetary gear train which, for most operational conditions, is locked to give a 1:1 ratio (direct drive). In order to drive the generator at normal speed when the engine is selected to Low Ground Idle, a friction clutch is engaged to lock the sun gear of the planetary gear train, thus imparting a speed increase of 1.38 times the gear box input drive to the generator.

An integral 60 to 80-psi lubrication and hydraulic system is incorporated in the gear box. A solenoid operated valve controls a hydraulic piston to operate the friction clutch — the ratio change or gear shift being accomplished automatically in something less than three seconds. To protect the gear box, a low oil pressure switch and a high oil temperature warning thermal switch are provided and these, as well as a generator overspeed circuit, are connected to two warning lights (see Figures 40 and 41). One light is located on the main instrument panel in the flight station while the other is located just above the No. 4 generator gear box disconnect switch on the overhead electrical control panel.

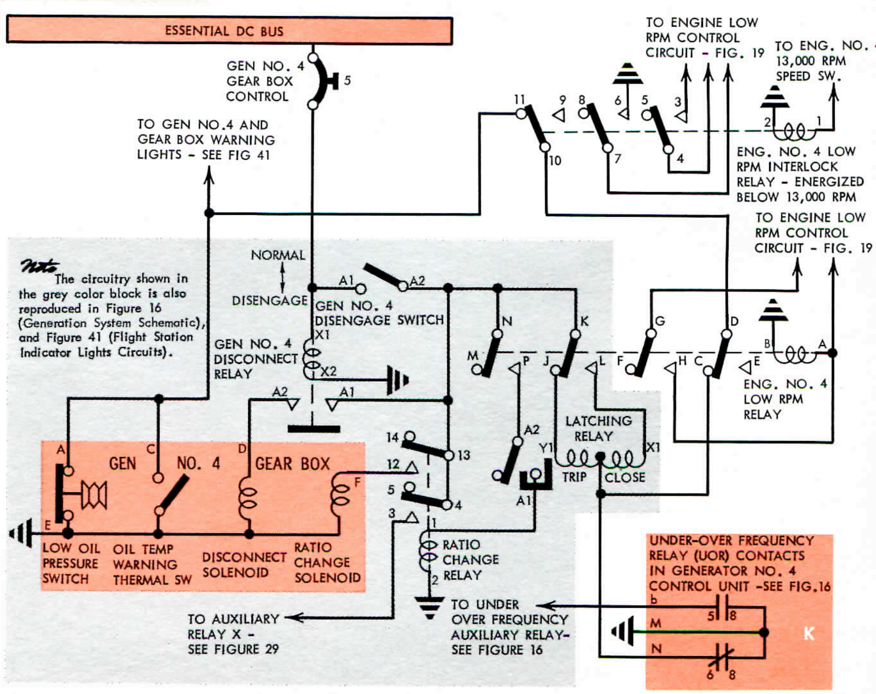


Figure 21
Gear Box Control Circuit

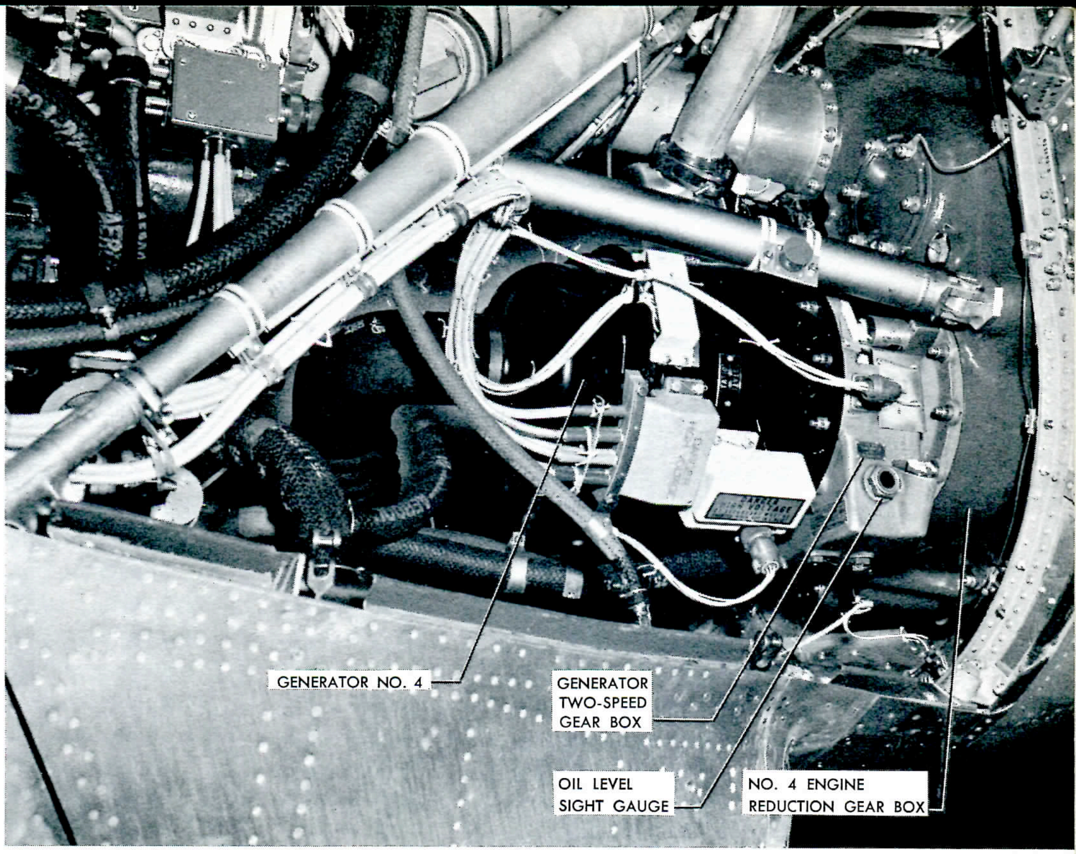


Figure 22
Generator and Gear Box Installation — No. 4 Engine

GENERATOR NO. 4 GEAR BOX OPERATION As previously noted, the circuitry shown in the grey shaded blocks in Figure 16 is peculiar to the engine No. 4 generation system. For convenience this same circuitry has been reproduced in Figure 21 and also included in Figure 41, which shows the appropriate indicator light circuits. In the following description reference can be made to any one of these schematics as well as to Figure 19 in order to follow the operation of the generator gear box.

With the airplane on the ground and the No. 4 engine at Normal Ground Idle, the following action is initiated when the No. 4 engine low rpm selector switch is depressed:

1. The No. 4 engine low rpm relay is energized, completing the circuit to the low rpm solenoid. Thus the fuel flow to the No. 4 engine is reduced so that the engine speed begins to fall from approximately 13,400 rpm to 10,000 rpm.
2. When the engine speed drops to 13,000 rpm the low rpm interlock relay is energized, closing the circuit to the hold-in solenoid of the low rpm selector switch.
3. Further reduction in engine speed de-energizes the under/over frequency relay (UOR), which is normally energized between approximately 360 and 430 cycles.
4. UOR contacts (5,8) in circuit K on Figure 16 open, de-energizing the under/over frequency auxiliary relay and de-energizing the generator.
5. UOR contacts (6,8) in circuit K close, completing the latching relay "close" coil circuit from the Essential DC Bus, and through contacts (K,L), of the low rpm relay to ground.
6. Latching relay contacts (A1,A2) close and are mechanically latched, energizing the ratio change relay coil.
7. Ratio change relay contacts (12,13) close, energizing the gear box ratio change solenoid to shift the gearing into the higher ratio.
8. Ratio change relay contacts (3,4) also close to energize the auxiliary X relay in the bus transfer control circuit. The function of this relay is explained in the "Bus Transfer Control Circuit" section.

When the No. 4 engine reaches low idle speed (approximately 10,000 rpm) and the gear box has shifted, the generator will return to normal speed and frequency. Thus the UOR is again energized, the under/over frequency auxiliary relay is subsequently energized returning the generator control circuits to normal status, and the latching relay, although de-energized, remains mechanically latched. The No. 4 generator will now be energized again and available to accept the loads from the other three generators when the Nos. 1, 2, and 3 engines are selected to Low Ground Idle.

The reverse procedure is again subject to the previously explained operational conditions. When the No. 4 engine low rpm relay is de-energized by operation of the power lever or the low rpm toggle switch, the engine and generator speed is increased, the UOR is de-energized, the generator is de-energized, the latching relay is tripped by the then energized "trip" coil, and the ratio change solenoid circuit is broken. *(Continued on next page)*

LOAD TRANSFER AND DISTRIBUTION

The ac distribution system consists of buses, transfer relays, wiring between these components, and circuit protection. As mentioned previously, the majority of these items are contained in the transfer and distribution box, which is located in the main electrical service center (see Figures 2 and 23). The lower half of this box contains the principal bus transfer relays, which are of unusual interest and play a unique role in the Electra's electric system.

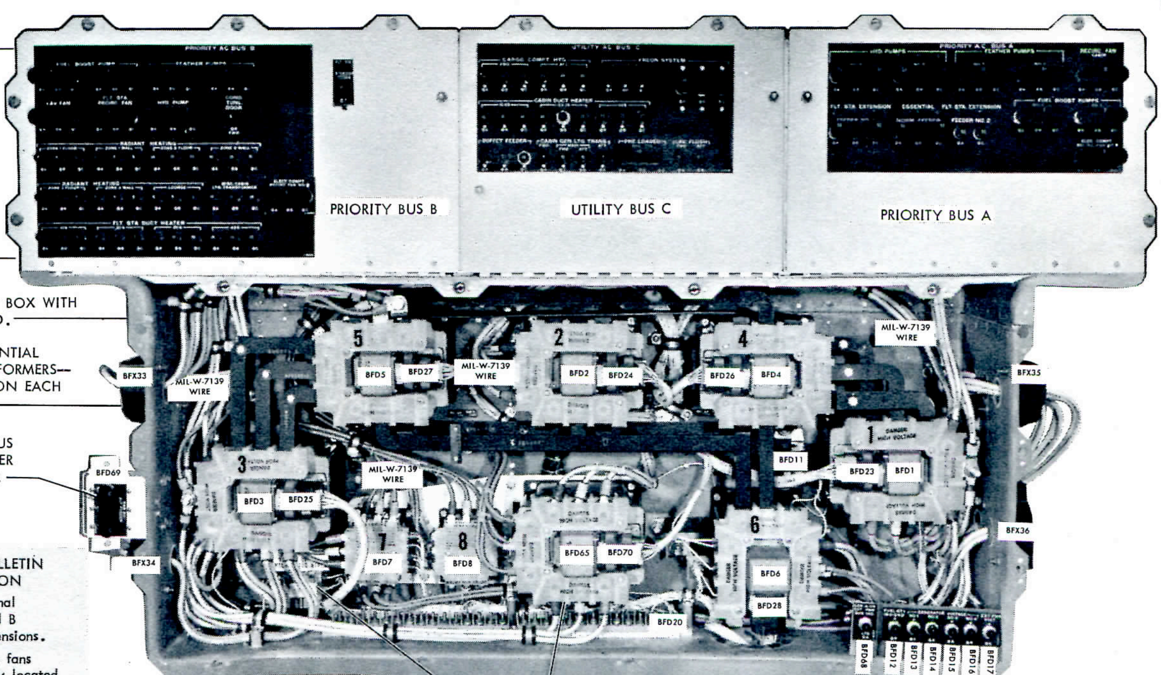
TRANSFER RELAYS DESCRIPTION In the introductory section in Part One of this article (*Digest* Vol. 5, No. 5) we discussed the development of the electric power system from the early design stages and discussed the reasons for, and some of the advantages derived from, the final configuration of the four-generator/three-bus nonparalleled system. The ultimate success of this system depended to a large extent upon evolving an efficient transfer and distribution system and, in particular, the development of suitable bus transfer relays. Three power system characteristics which specifically influenced the design of these relays were:

1. The use of 3-phase ac generators of unusually large capacity.
2. The automatic features of the system—requiring reliable and well coordinated indication in the flight station, of the status of the system.
3. The desirability of keeping the operation of this power system essentially independent of aircraft battery power.

Two basic types of relays, each rated at 250 amperes, were developed by the Hartman Electrical Manufacturing Company specifically for the Electra's main bus transfer system. One is a 3-pole, side stable, normally closed configuration operated by a single coil system. The other is a 3-pole, double throw, center-off arrangement with a set of coils for each closed position.

Based on the above characteristics of the Electra's somewhat unique electric system and the resulting design requirements, several unusual features were incorporated in the relays. Looking at the double throw type relay shown in Figure 24 these include:

1. Absolute phase isolation throughout the design of the relay. Some specific examples are the ceramic arc chutes completely surrounding the contacts and externally, the heavy terminal shield which separates and covers the terminal lugs and bus ends.
2. Positive mechanical interlocking to prevent simultaneous closure of both sets of contacts.
3. Twelve sets of auxiliary contacts closely coordinated with the operation of the main contacts to



NO.	SERVICE BULLETIN DESCRIPTION
285	Introduces additional Priority Bus A and B Flight station extensions.
287	Introduces cooling fans that are externally located rather than inside the box. See Figure 2.
403	Changes and relocates prop. de-icing relay. Relocates cooling fans within the box if S/B 287 is not incorporated.
408	Relocates Essential AC Bus Alternate Feeder and circuit breaker. Introduces fire resistant feeder wires to spec. MIL-W-7139. Applies fire resistant coating to box.

Note

Numbers (1 thru8) identify bus transfer relays. Identification tags refer to cartouche numbers used on equipment, and circuit diagrams. Refer to the pertinent Electrical Data Book.
Transfer and distribution box shown incorporates Service Bulletin Nos. 285, 287, 403, and 408 (see list on left)

Figure 23 Main Bus Transfer and Distribution Box

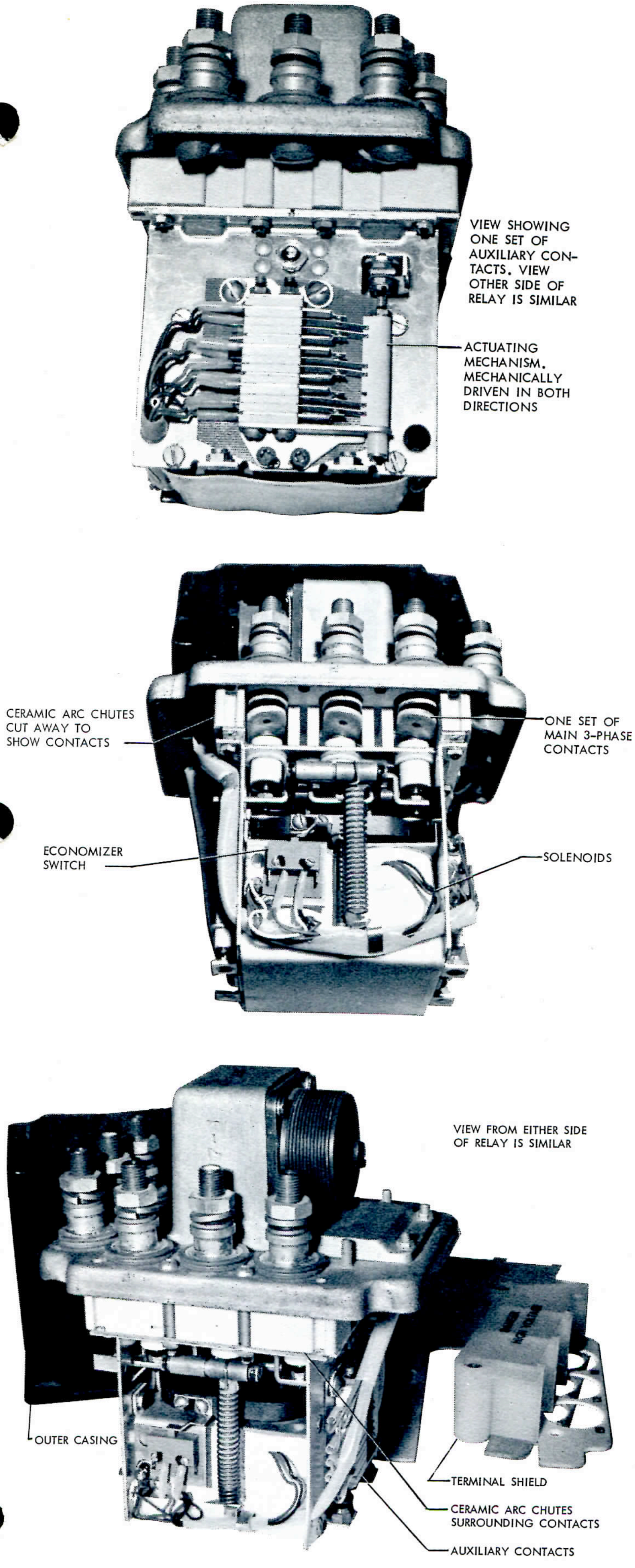


Figure 24 Bus Transfer Relay — Double Throw Type

ensure true indication of the open, closed, and intermediate positions of the main contacts. In order to meet this rather stringent requirement the auxiliary contacts are mechanically actuated in each direction rather than relying on springs for return operation.

4. Operation of the relay from a relatively low power source. This requirement was necessary so that the relay could in certain instances be operated from the dc ouput of a permanent magnet generator, thus conforming to the design philosophy of a self-contained generation system. The solenoid portions of the relay were provided with unusually efficient magnet circuits, which besides meeting the low power consumption requirements, also gave the very high contact pressure needed to provide good contact with low millivolt drop across the contacts.

The final result of applying the above design requirements is a series of relays which weigh less than 10 lb each, require less than 60-watts of control or actuation power, and are capable of handling the full 90-kva overload rating of the General Electric 400-cycle generators at 115/200 volts.

BUS TRANSFER CONTROL CIRCUIT Part One of this article described how the bus transfer relays operated according to a schedule based on the number of generators available and the bus or load priorities (see Figure 25). The bus transfer control system, shown schematically in Figure 29, establishes this schedule. The control is obtained principally from ACR (auxiliary control relay) and ULR (undervoltage lockout relay) contacts in each of the four generator control units, which are shown in color block E on Figure 16. Figures 26 and 27 reproduce this portion of Figure 16 and both poles of the generator control switch to illustrate how the bus transfer control system is built up from each generation system. *(Continued on next page)*

GENERATOR	1	2	3	4
NORMAL CONDITION	C	B	AE	STANDBY
ONE GENERATOR OUT	C	B	AE	—
	C	B	—	AE
	B	—	AE	C
	—	B	AE	C
TWO GENERATORS OUT	AE	B	—	—
	B	—	AE	—
	B	—	—	AE
	—	B	AE	—
	—	B	—	AE
	—	—	AE	B
THREE GENERATORS OUT	AE	—	—	—
	—	BE	—	—
	—	—	AE	—
	—	—	—	AE

Note

A.
Denotes the Priority Bus A including its flight station extensions. It has 3 generator support.

B.
Denotes the Priority Bus B including its flight station extension. It has 3 generator support

C.
Denotes the Utility Bus C. It has 2 generator support.

E.
Denotes the essential AC Bus. It has 4 generator support.

Figure 25 Generator/Bus Support Chart

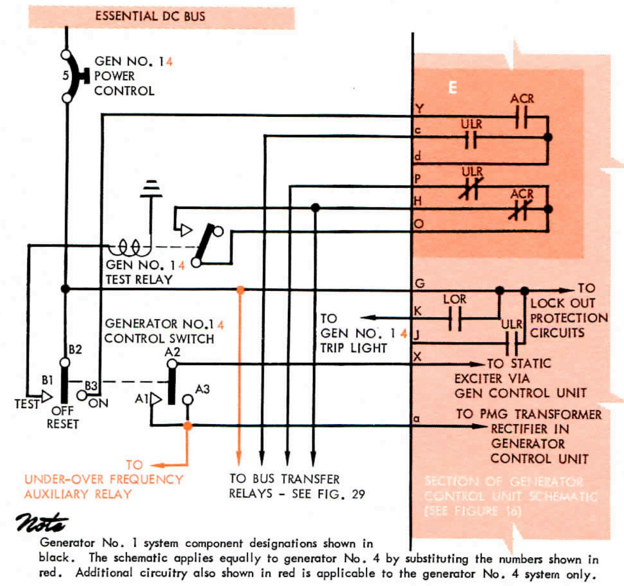


Figure 26 Bus Transfer Circuit — Typical for Generator Nos. 1 and 4

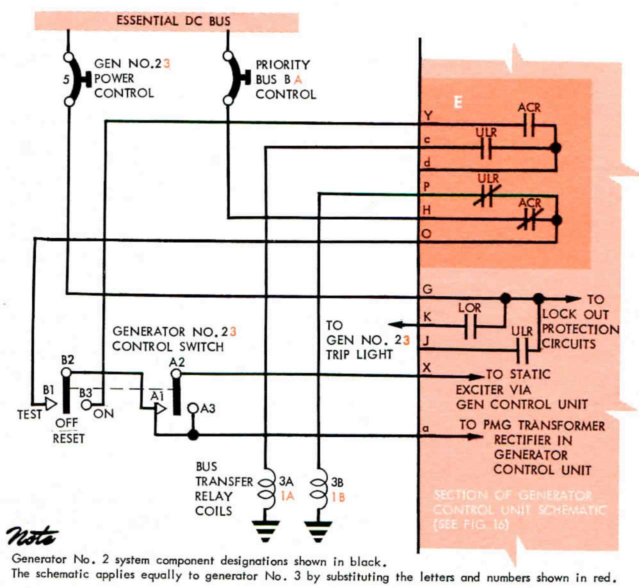


Figure 27 Bus Transfer Circuit — Typical for Generator Nos. 2 and 3

Figure 29 combines all four such generation circuits in a simpler form and, with the addition of the external power transfer control circuits, the whole comprises the bus transfer control system. It should be noted that relay X is concerned with the generator No. 4 gear box and external power operations, while, the receptacle selector relays (RSR-A and RSR-B) are incorporated in the circuitry when dual external power receptacles are fitted.

In the "Generation System Operation" section it was pointed out that, among other things, when a generator is able to supply power, its normally open ACR contact (6,7) closes, its normally closed ACR contact (10,11) opens, and the ULR contacts (4,5) and (7,8) stay closed. The appropriate part of Figure 16 has been reproduced below (Figure 28a) to show this condition. Similarly, Figures 28b and 28c below show the positions of the contacts for the two undervoltage conditions also explained in the "Generation System Operation" section.

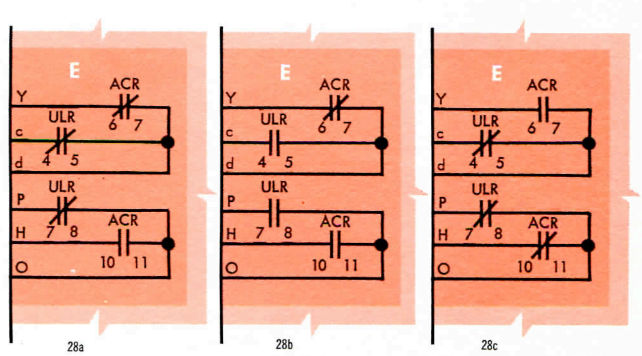
For the normal operation of the system, all four generators would be energized and the generator control switches would be selected to "ON." All the ACR and ULR contacts in Figure 29 would assume positions conforming to Figure 28a so that relay coils 1A, 2B, and 3A would be energized as shown by the bold lines in Figure 29. Thus under normal conditions the three main ac buses are connected to the generators as follows:

Priority Bus A to generator No. 3 via relay 1A
Priority Bus B to generator No. 2 via relay 3A
Utility Bus C to generator No. 1 via relay 2B

It will be noted that generator No. 4 is on standby because various transfer and auxiliary relay contacts (normally-open contacts 1B, 3B, 5B and X) are interposed in the control circuit. These prevent any of the transfer relay coils being energized via the generator No. 4 control switch.

All the built-in operating sequences of the automatic transfer system can be investigated by correlating Figures 28, and 29. For example, with the system operating normally as above, the tripping of generator No. 3 would cause the ACR and ULR contacts in this generation system to assume positions as shown in Figure 28c. Coil 1B would be energized and coil 1A would be de-energized. Subsequently coil 4A would also be energized from the Essential DC Bus via the generator No. 4 control switch, the applicable ACR and ULR contacts in the No. 4 generation system, and the now closed 1B contacts. Thus the Priority Bus A would be transferred to generator No. 4.

For normal operation the aircraft battery is connected to the Essential DC Bus and is available as a source of control power for the bus transfer system. However, as mentioned in the "Transfer Relays Description" section, the system has been designed so that it is not reliant on the battery. The power for operating relay coils 1A and 3A comes directly from the

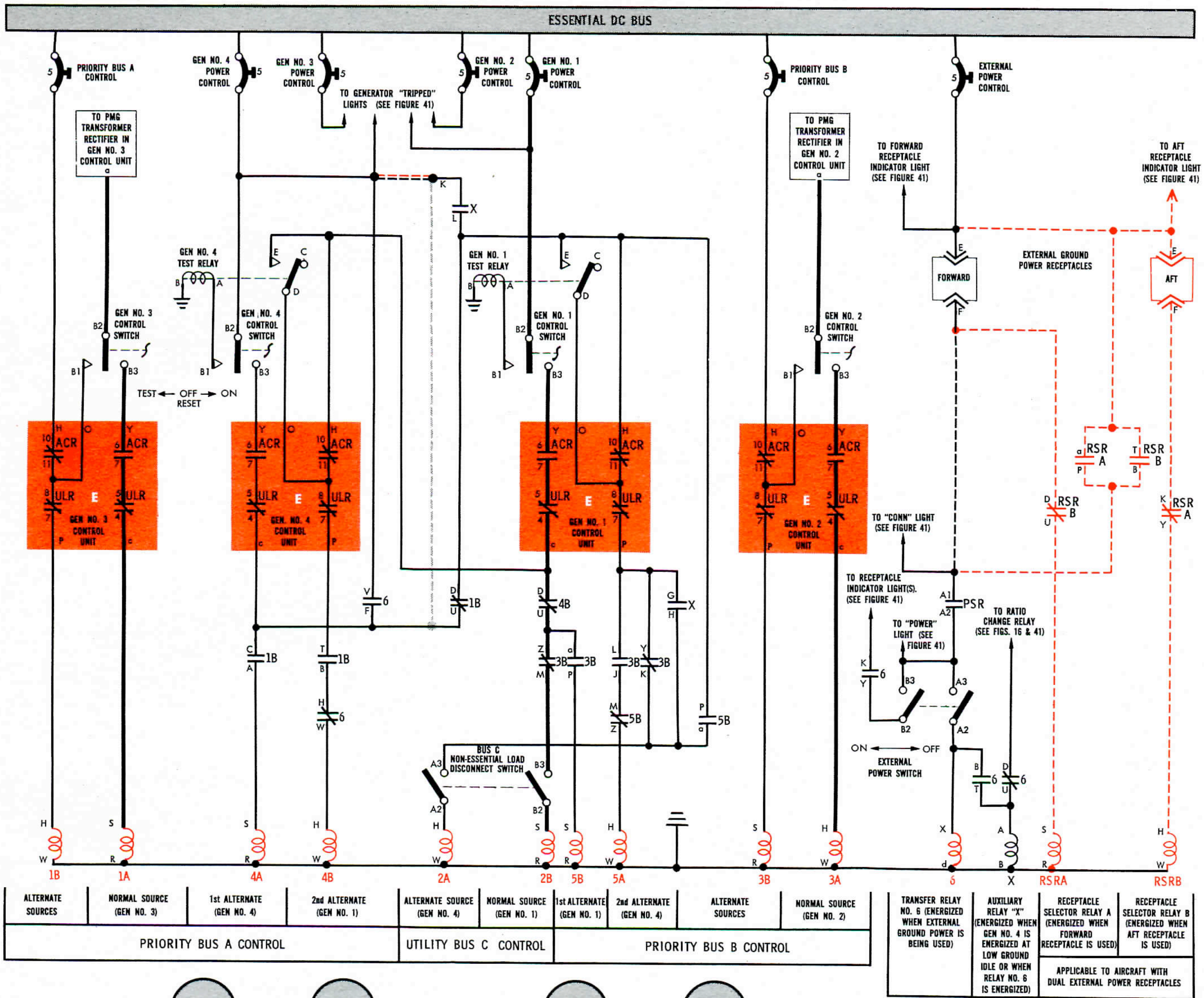


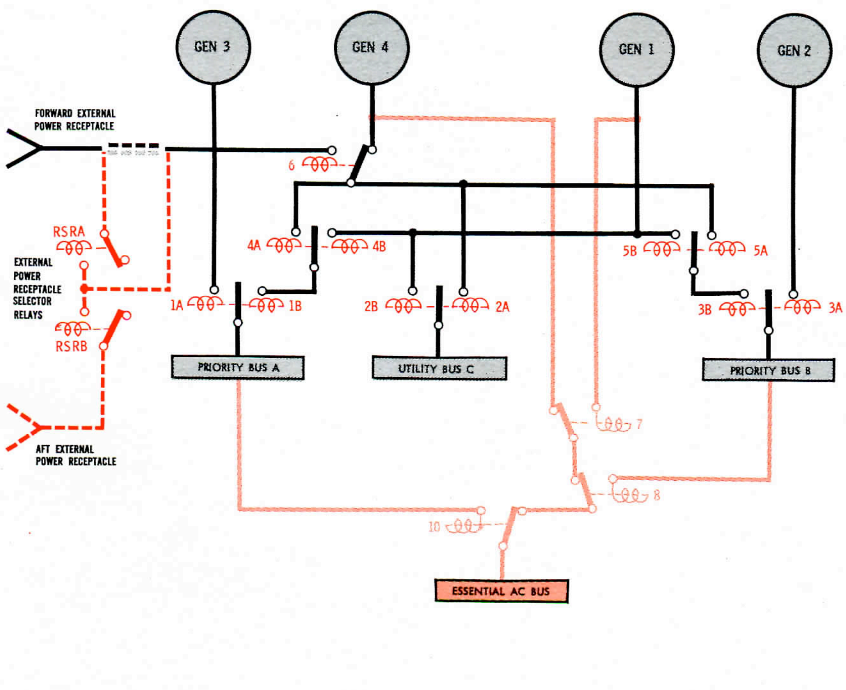
28a Generator Energized and Available for Connection to Load

28b Undervoltage Due to Bus Fault

28c Undervoltage Due to Generator or Feeder Fault — Generator De-energized

Figure 28 Transfer Control Relay Contacts (ACR and ULR) in Generator Control Unit





Note

ACR AUXILIARY CONTROL RELAY
ULR UNDERVOLTAGE LOCKOUT RELAY
X AUXILIARY RELAY "X"
PSR PHASE SEQUENCE RELAY
RSR EXTERNAL POWER RECEPTACLE SELECTOR RELAY

1. All switches and relays are shown positioned with the system de-energized.
2. Transfer relay coils are shown in red to facilitate correlating the diagrams. The legend beneath these coils in the upper diagram indicates the circumstances under which they would be energized.
3. The light red color blocks show the auxiliary control relay (ACR) and undervoltage lockout relay (ULR) contacts in each generator control unit.
4. The circuitry in light red (———) on the lower diagram shows the Essential AC Bus transfer system and is included for reference purposes only.
5. The upper diagram is applicable to all configurations of the Electra Electric System with the following reservations:
   - A. The circuitry for the dual external power receptacle configuration (EAL and TEAL) is shown by solid black lines (———) and dotted red lines (– – – –). Also see Figure 41.
   - B. The circuitry for the single external power receptacle configuration (see Note 5C for KLM) is shown by solid black lines (———) and dotted black lines (– – – –). Also see Figure 41.
   - C. KLM has a single external power receptacle configuration which includes a transformer rectifier transfer relay (see Figs. 5 and 43). Refer to the inset on the right for KLM's External Power Control circuit. The rest of this schematic is applicable to KLM's system by following the solid black lines (———) and the dotted grey lines (┄┄┄).
   - D. The bold black lines (━━━) indicate the closed circuits to the transfer relay coils 1A, 2B, and 3A. This is the condition of the circuitry when the system is operating normally with generators 1, 2, and 3 energized. Note that with generator 4 also energized, and on standby the ACR and ULR contacts in each generator control unit assume positions as shown in Figure 28a.

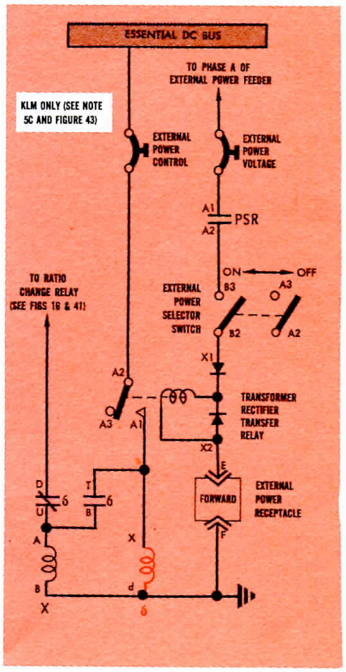


Figure 29 Bus Transfer Control System Schematic

PMG's of generator Nos. 3, and 2 respectively. Thus, for starting purposes, either of these generators can be energized first without the aid of the battery and, subsequently, the Essential DC Bus is energized (via either of the priority buses and the transformer rectifiers) to supply control power for the remainder of the bus transfer system.

It is also apparent from Figure 29 that in order to supply external ground power to the system with all engines stopped (generators de-energized), the aircraft battery is required to operate the pertinent control relays. This fact is not significant in regard to normal flight operation and servicing. However, during certain overhaul periods, it is common practice to remove the aircraft battery at a time when frequent use of external power may be required. Lockheed designed ground power equipment is available for this contingency, mainly consisting of a battery eliminator (operated from the external power supply) which connects to the aircraft battery power plug, and substitutes for the battery. At the same time the two transformer rectifiers can be rendered inoperative, thus greatly reducing the ground operating time on these components and improving the service life.

TRANSFER SYSTEM PERFORMANCE CHARACTERISTICS
Some oscillograms taken during the testing of a mockup of the Electra system by the Lockheed Electrical Research group are of particular interest since they actually demonstrate how quickly the system reacts and stabilizes during various load transfer operations. Oscillograms are shown in Figures 31, 33, 36 and 38 while Figures 30, 32, 34, 35, 37, and 39 show the positions of the relays in the transfer system before and after each transfer operation. All the above illustrations are arranged by Figure No. in a sequence of events beginning with the electric power system operating from external ground power and then being transferred to generator No. 4, with engine No. 4 at Low Ground Idle (Figure 31).

Then, with engines Nos. 1, 2, and 3 selected to Normal Ground Idle, the generator control switches of these engines are selected to "ON" so that these generators pick up their normal buses from generator No. 4. Figure 33 shows the resultant transfer action after closing the generator No. 3 control switch.

Engine No. 4 is now selected to Normal Ground Idle also, with generator No. 4 still energized but on standby. The GCS No. 3 is then selected to "OFF" (Figure 36), causing the Priority Bus A to transfer from generator No. 3 to generator No. 4.

Finally, Figure 38 shows the transfer of the Priority Bus A to generator No. 1 by shutting down engine No. 4 — resulting in an under-frequency signal in the No. 4 generation system. *(Continued on page 30)*

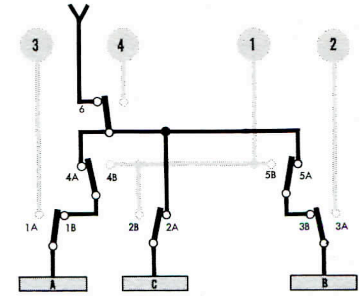


Figure 30

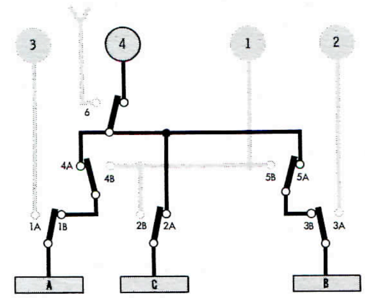


Figure 32

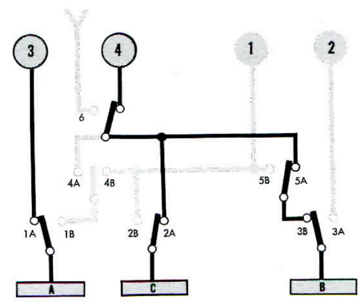


Figure 34

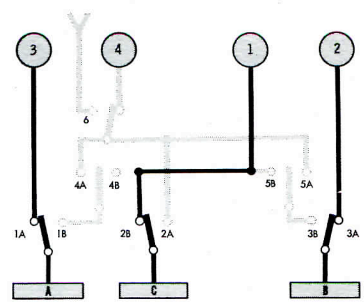


Figure 35

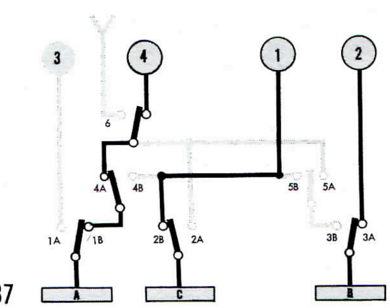


Figure 37

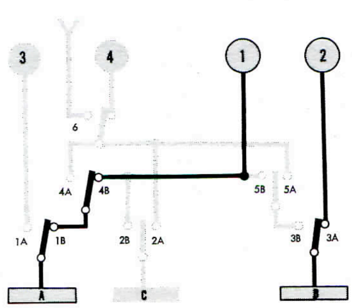
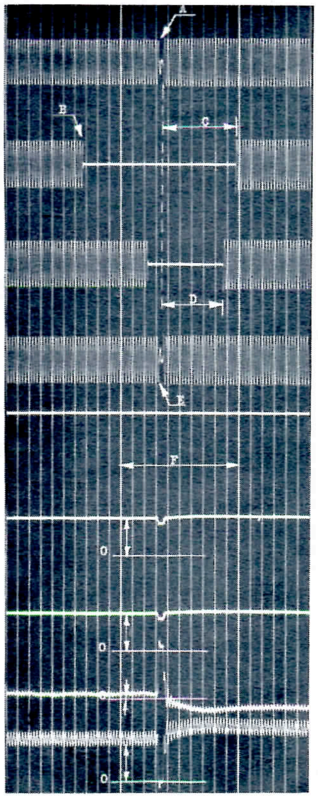


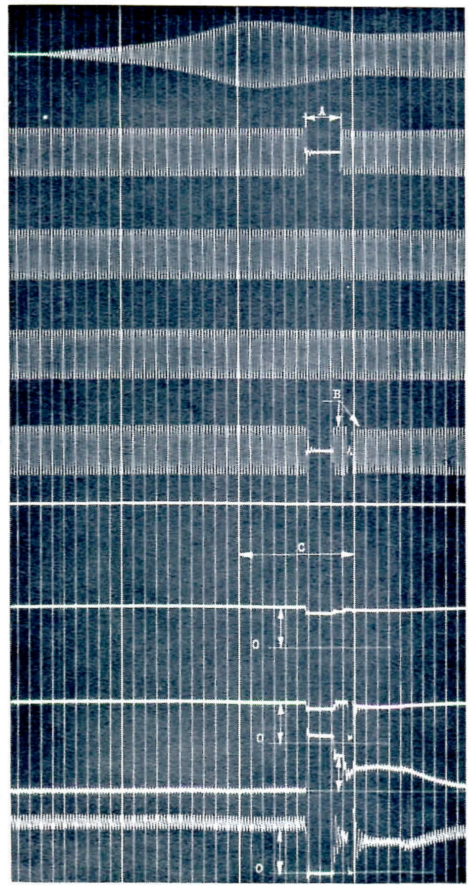
Figure 39

Note (Figures 31, 33, 36, 38, 42)
All ac values are rms. All dc values are average.
Refer to Figure 5 for clarification of the references to the dc system functions.
Note that both transformer rectifiers were used during these tests, but only one (T/R No. 1) was instrumented.
The terms "pick-up" and "drop-out" are used in the explanatory notes to the oscillograms. Their use in this context is defined as follows:
PICK-UP — time taken for a relay to complete its energized function.
DROP-OUT — time taken for a relay to recede from its energized position.



A. Relay No. 6 contact transfer time on drop-out: 0.005 sec.
B. Relay No. 5A opened momentarily. Caused by the auxiliary relay "X" (see Figure 29) being momentarily de-energized.
C. Pick-up time of auxiliary relay "X" and relay No. 5A: 0.060 sec.
D. Pick-up time of auxiliary relay "X" and relay No. 2A: 0.050 sec.
E. Relay No. 10 did not drop-out. Essential AC Bus is de-energized only while the Priority Bus A is being transferred.
F. Timing lines at 0.100 sec.

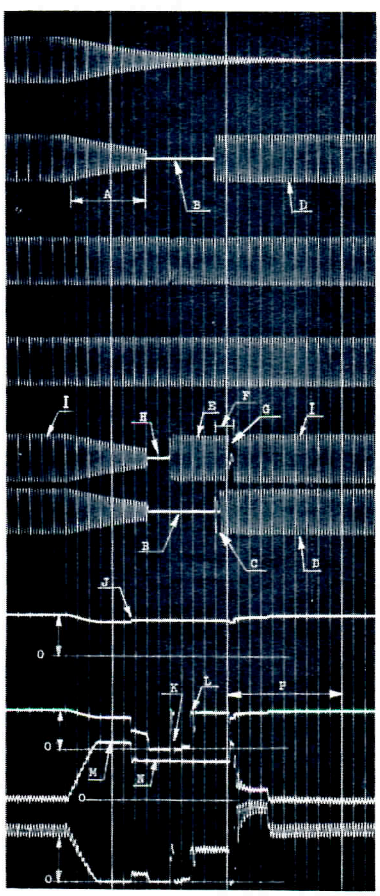
Figure 31
Oscillogram Showing Transfer of Main AC Buses from External Power to Generator No. 4 at Low Ground Idle



A. Relay No. 1 contact transfer time from 1B to 1A: 0.030 sec.
B. Priority Bus A de-energized a sufficient time to cause a typical transfer of the Essential AC Bus to the Priority Bus B and back to the Priority Bus A. See Figure 36 for a fuller description of this occurrence.
C. Timing lines at 0.100 sec.

Figure 33
Oscillogram Showing Transfer of Priority Bus A from Generator No. 4 at Low Ground Idle to Generator No. 3 at Normal Ground Idle

Figure 36
Oscillogram Showing Transfer at Normal RPM of Priority Bus A from Generator No. 3 to Generator No. 4



A. Drop-out time of relay No. 1A: 0.065 sec.
B. Priority Bus A de-energized for 0.060 sec.
C. Relay No. 10 contact bounce.
D. Priority Bus A transferred from Generator No. 3 to Generator No. 4
E. Essential AC Bus momentarily transferred to the Priority Bus B. Caused by relay No. 10 becoming momentarily de-energized.
F. Relay No. 10 pick-up time.
G. Relay No. 10 transfer time of contacts.
H. Relay No. 10 drop-out time.
I. Essential AC Bus connected to Priority Bus A.
J. Essential DC Bus supplied by battery only.
K. Main DC Bus reverse current relays opened.
L. Main DC Bus reverse current relays reclosed.
M. Battery carrying all the dc load.
N. Battery carrying only the Essential DC Bus load.
P. Timing lines at 0.100 sec.

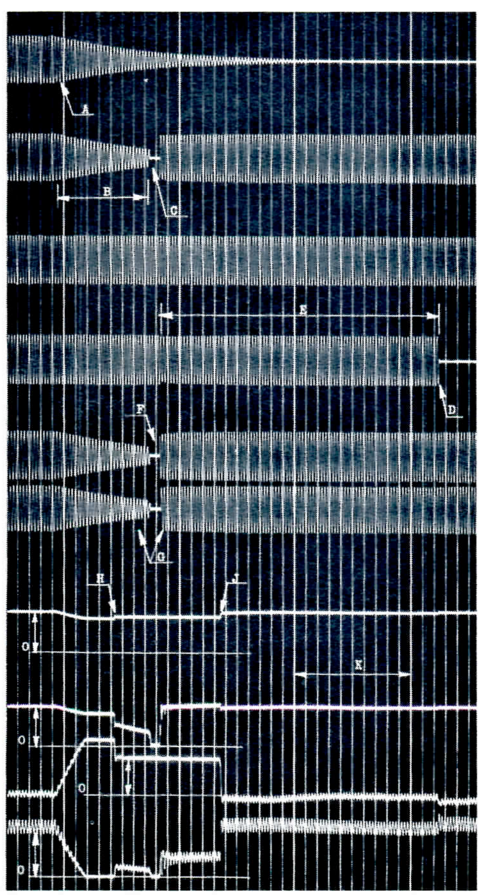


Figure 38
Oscillogram Showing Transfer at Normal RPM of Priority Bus A from Generator No. 4 to Generator No. 1

A. Generator No. 4 de-energized by the UOR (under-over frequency relay) on under frequency.
B. Relay No. 4A drop-out time: 0.080 sec.
C. Relay No. 4 contact transfer time from 4A to 4B: 0.010 sec.
D. Utility Bus C is de-energized when Generator No. 1 is transferred to the Priority Bus A.
E. Priority Bus A and Utility Bus C connected together to Generator No. 1 for 0.240 sec.
F. Essential AC Bus did not transfer momentarily to Priority Bus B (See Figs. 33 and 36) because the Priority Bus A transfer time is less than the relay No. 10 drop-out time.
G. Priority Bus A transferred from Generator No. 4 to Generator No. 1.
H. Essential DC Bus supplied by battery only.
J. Transformer rectifiers returned to the Essential DC Bus.
K. Timing lines at 0.100 sec.

GENERATOR CONTROL SWITCHES
TEST - Generator energized but not connected to system.
OFF & RESET - Generator de-energized.
ON - Generator energized and connected to system.

TRIPPED

GENERATOR TRIP WARNING LIGHTS
Indicates overvoltage, undervoltage or feeder fault in generating system.

DISENGAGE

GENERATOR DISENGAGE WARNING LIGHTS
NOS. 1, 2, & 3 (EAL, NWA, TEAL, QANTAS, CAPITAL) indicate generator mechanical failure. No. 4 indicates two-speed gear box malfunction or generator overspeed.

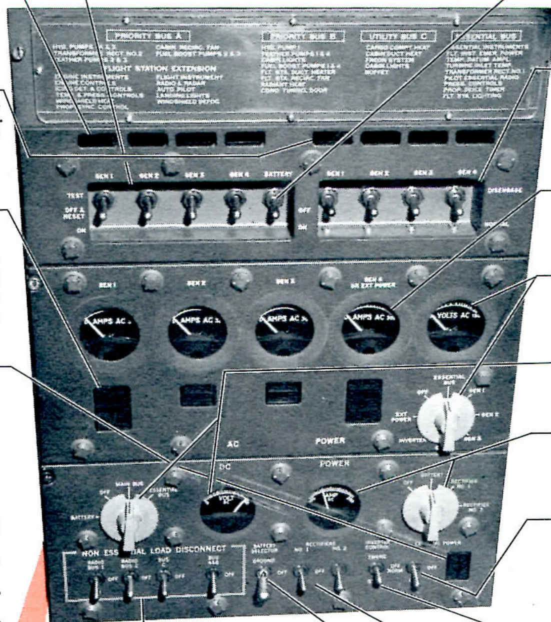
AC BUS INDICATING LIGHTS

UTIL BUS C	PRIOR BUS B	PRIOR BUS A	PRIOR BUS A
PRIOR BUS B	ESSEN BUS	ESSEN BUS	PRIOR BUS B
PRIOR BUS A			UTIL BUS C
ESSEN BUS			ESSEN BUS

Lights under each ammeter indicate buses being supplied by each generator.

EXTERNAL POWER INDICATING LIGHTS
CONN - indicates that an external power cable is plugged into the ground power receptacle.
POWER - indicates that 3-phase power of the correct phase sequence is available.

CONN | POWER



OVERHEAD ELECTRICAL CONTROL PANEL

BATTERY EMERGENCY DISCONNECT SWITCH
OFF - The battery is isolated from the system by opening the Battery Selector switch circuit.
ON - Battery Selector switch may be operated.

GENERATOR DISENGAGE SWITCHES
DISENGAGE - Nos. 1, 2, & 3 (EAL, NWA, TEAL, QANTAS, CAPITAL) energizes disconnect solenoid in generator. No. 4 energizes disconnect solenoid in two-speed gear box.
NORMAL

AC GENERATOR AMMETERS
Nos. 1, 2, & 3 indicate generator current.
No. 4 indicates generator current or external ground power current when connected.

AC VOLTMETER AND SELECTOR SWITCH
Voltage outputs of the Essential AC Bus, generator Nos. 1, 2, 3, and 4, the inverter, and external ground power may be checked.

DC VOLTMETER AND SELECTOR SWITCH
Voltage outputs of the battery, the Main DC Bus, and the Essential DC Bus may be checked.

DC AMMETER AND SELECTOR SWITCH
Current outputs of the battery, and the two transformer rectifiers may be checked.

EXTERNAL POWER SWITCH
OFF - External ground power circuit de-energized.
ON - Allows external power into distribution system if voltage and phase sequence are correct and if aircraft battery is connected to the Essential DC Bus.

INVERTER CONTROL SWITCH
EMERGENCY - Supplies essential flight instruments if Essential AC Bus is de-energized.
START - Supplies starting loads if Essential AC Bus is de-energized.

TRANSFORMER RECTIFIER SWITCHES (Nos. 1 & 2)
OFF - Transformer rectifier output disconnected.
ON - Transformer rectifier output connected to dc distribution system.

BATTERY SELECTOR SWITCH
GROUND - Battery connected to Ground Operation DC Bus only
OFF - Battery is isolated from system.
ON - Battery connected to Essential DC Bus and Ground operation DC Bus if battery emergency disconnect switch is ON

INSTRUMENT PANEL WARNING LIGHTS

GEN. MECH. FAIL. indicates generator mechanical failure

4 GEN. GEAR BOX Indicates two-speed gear box malfunction or generator overspeed.

1 GEN MECH FAIL
2 GEN MECH FAIL
3 GEN MECH FAIL
4 GEN MECH FAIL
4 GEN GEAR BOX

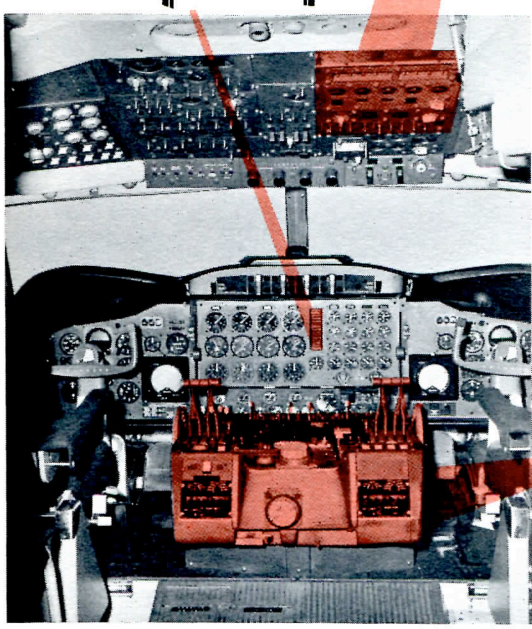
NON-ESSENTIAL LOAD DISCONNECT SWITCHES

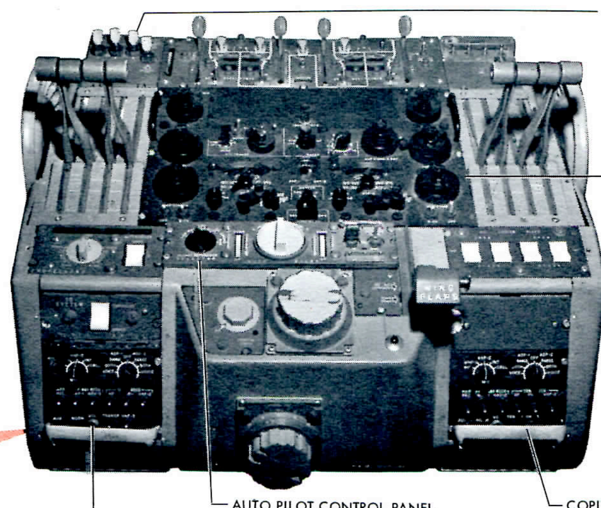
RADIO BUS 1
OFF - Radio Group 1 (Pilots Main Radio) is de-energized.
ON - Radio Group 1 is energized.

RADIO BUS 2
OFF - Radio Group 2(Copilots Radio) is de-energized.
ON Radio Group 2 is energized.

BUS C
OFF - Utility Bus C is de-energized by disconnecting it from transfer system.
ON - Utility Bus C is energized.

BUS A & B
OFF - The Priority Bus A & B flight station extensions, the Main DC Bus, and the loads on Priority Buses A & B controlled by the Main DC Bus are de-energized. This includes Radio Buses I & 2. The essential flight instruments, normally supplied by the Priority Bus A, are automatically transferred to the Essential AC Bus.
ON - The above loads are energized.





LOW GROUND IDLE SELECTOR SWITCHES

MASTER RADIO CONTROL PANEL

CENTER CONTROL PEDESTAL

AUTO PILOT CONTROL PANEL

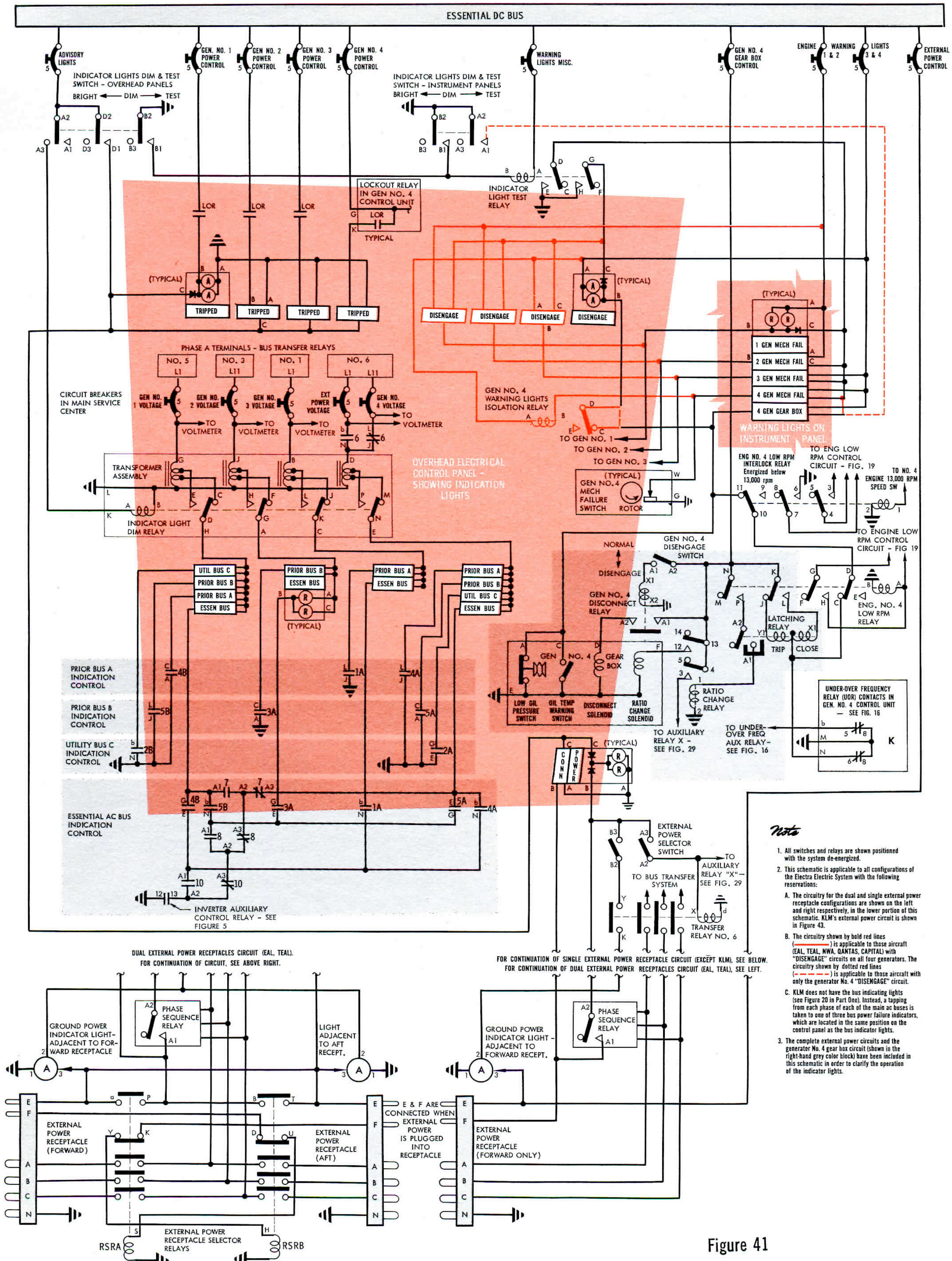
PILOTS RADIO SELECTOR PANEL

COPILOTS RADIO SELECTOR PANEL

Note SWITCH POSITIONS AND INDICATOR LIGHTS SHOWN IN COLOR DEPICT NORMAL STATUS WITH ALL FOUR GENERATORS ENERGIZED.

SEE FIGURE 20 (PART ONE) FOR KLM'S OVERHEAD ELECTRICAL CONTROL PANEL

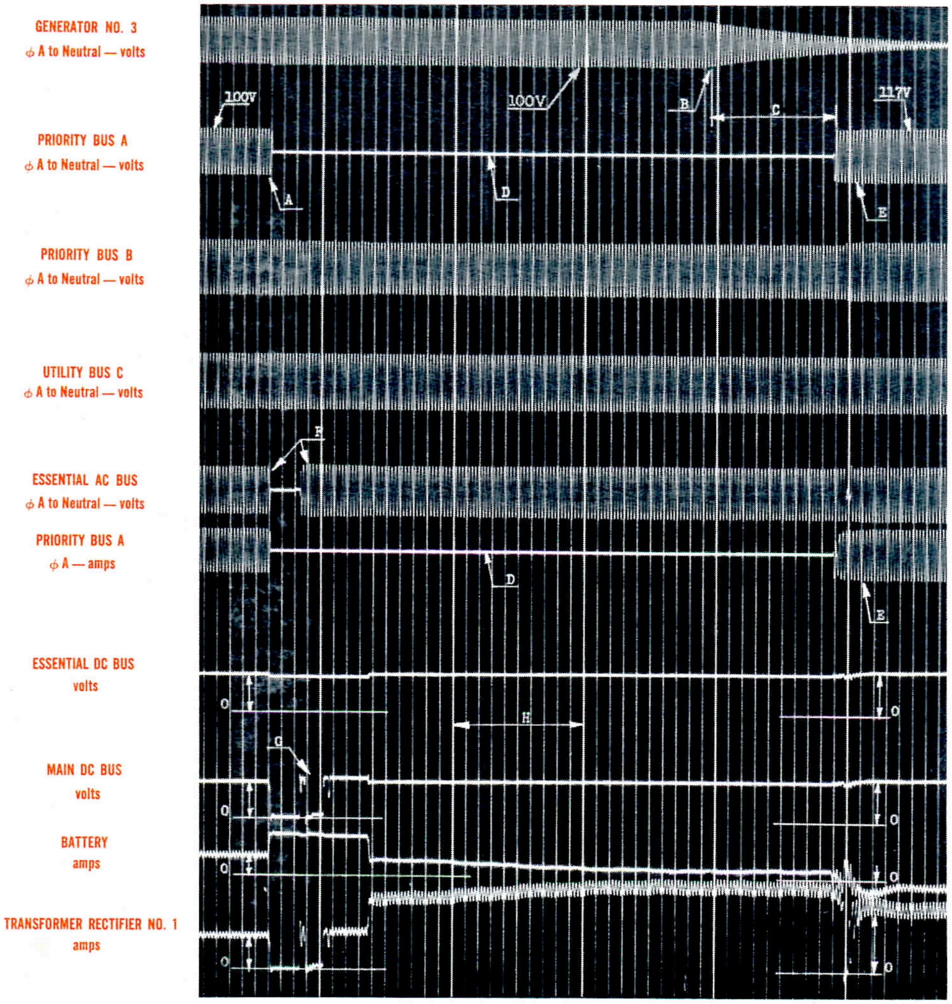
Figure 40 Flight Station Controls and Indicator Lights



Note

1. All switches and relays are shown positioned with the system de-energized.
2. This schematic is applicable to all configurations of the Electra Electric System with the following reservations:
   A. The circuitry for the dual and single external power receptacle configurations are shown on the left and right respectively, in the lower portion of this schematic. KLM's external power circuit is shown in Figure 43.
   B. The circuitry shown by bold red lines (————) is applicable to those aircraft (EAL, TEAL, NWA, QANTAS, CAPITAL) with "DISENGAGE" circuits on all four generators. The circuitry shown by dotted red lines (– – – – –) is applicable to those aircraft with only the generator No. 4 "DISENGAGE" circuit.
   C. KLM does not have the bus indicating lights (see Figure 20 in Part One). Instead, a tapping from each phase of each of the main ac buses is taken to one of three bus power failure indicators, which are located in the same position on the control panel as the bus indicator lights.
3. The complete external power circuits and the generator No. 4 gear box circuit (shown in the right-hand grey color block) have been included in this schematic in order to clarify the operation of the indicator lights.

Figure 41
Flight Station Indicator Light Circuits with External Power and Gear Box Control Circuits



Note

The note at the top of page 27 is also applicable to this Figure. Refer to the "Undervoltage Protection" section on pages 16 and 17, and Figures 16, 28, and 29. Note that this section of oscillogram is taken just prior to the TDR-1 (time delay relay No. 1) being energized, which occurs approximately three seconds following the undervoltage signal.

A. Relay No. 1A opened. Initiated by the ULR (undervoltage lockout relay) being energized (see circuits D and E on Figure 16).
B. Generator No. 3 tripped on undervoltage and initiated Priority Bus A transfer. Note that Generator No. 3 voltage did not return to normal following disconnection from load, thus indicating a generator or feeder fault.
C. Pick-up time of relay Nos. 1B and 4A: 0.090 sec.
D. Priority Bus A de-energized for 0.43 sec.
E. Priority Bus A transferred from Generator No. 3 to Generator No. 4.
F. Typical transfer of the Essential AC Bus to the Priority Bus B and back to the Priority Bus A. See Figure 36 for a fuller description of this occurrence.
G. Typical transient of Main DC Bus (see Figure 36).
H. Timing lines at 0.100 sec.

Figure 42
Oscillogram Showing Transfer of Priority Bus A from Generator No. 3 to Generator No. 4 — Caused by Undervoltage Trip of Generator No. 3

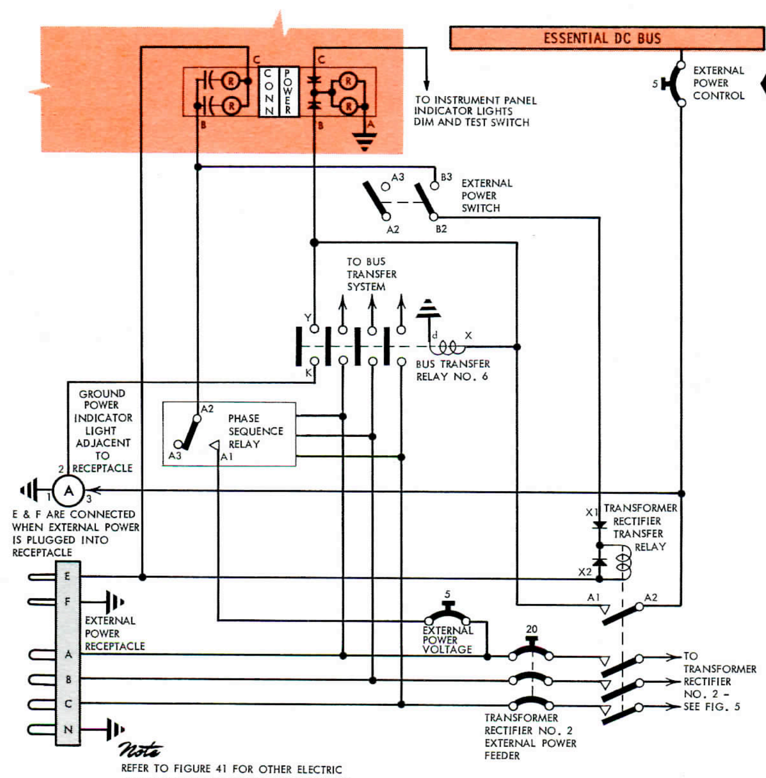


Figure 43
External Power and Indicator Lights Circuit—KLM

The capability of the system to take corrective action automatically against certain simulated system malfunctions is demonstrated in Figure 42. It will be noted that this portion of the original oscillogram shows a simulated undervoltage fault and is taken just prior to the TDR-1 being energized following the 3-second time delay (see page 17).

FLIGHT STATION CONTROLS AND INDICATOR LIGHT CIRCUITS

The principal controls and indicators for the Electra's electric power system are shown in Figure 40. This illustration has been repeated from Part One and therefore shows some control switches that have not been discussed in this second part of the article. Reference should be made to Part One for a description of the operation of these switches, although in most cases, the short explanatory notes on the illustration will be found to be adequate.

We are more concerned in Part Two with the con-

REVISIONS AND ERRATA FOR PART ONE OF THE ELECTRA ELECTRIC SYSTEM

Page 11, Figure 6—Revise title to read: "Figure 6 Main Transfer and Distribution Box. (See Figure 23 in Part Two for the latest configuration)."

Page 17, left column — Item 5 should read: ". . . consists of only one phase (phase C) which supplies . . ."

Page 18, Figure 12—Revise title to read: "Figure 12 Electric Power System Schematic (See Figure 5 in Part Two for KLM's system)."

Page 18, Figure 12 — The identification numbers (1 and 2) to the flight station extension disconnect relays are transposed. Also, there should be no connection between the coils to these two relays and the flight station feeders. See Figure 5 in Part Two for the correct arrangement.

Page 20, right column—In the paragraph beginning "The majority of . . ." the reference to Figure 20 should be changed to Figure 21.

Page 28, Figure 21—After the Note in red, just above the figure title, add a new item: "For KLM's Electrical Control Panel, see Figure 20 in Part One."

Pages 28 and 29 — The references to EAL, NWA and TEAL should also include QANTAS AND CAPITAL. References appear twice on Figure 21 and once in the footnote under the left column on page 29.

Page 30, Figure 24—Revise title to read: "Figure 24 Flight Station Circuit Breaker Panels—AA and EAL."

Page 31, top of left column—The reference to Figure Nos. 17 and 18 should be changed to Figure Nos. 16 and 18 respectively.

Page 31, top of right column — The reference to Figure 22 should be changed to Figure 23.

ILLUSTRATION INDEX — THE ELECTRA ELECTRIC SYSTEM

Note: Illustrations show typical configuration except as noted below.

trols directly associated with the generation and bus transfer systems. The generator control and disengage switches have already been described, but this article would not be complete without including the indicator light circuit diagrams, a knowledge of which is also important in system trouble shooting. Figure 41 superimposes these circuits on a color silhouette of the overhead electrical control panel shown in Figure 40 so that the indicator lights may be more easily distinguished. The associated center instrument panel lights are also depicted in both illustrations.

A portion of the generator disengage lights circuit on Figure 41 is shown in color so that this schematic can be applied to aircraft that have either one or four disengage lights and switches. In order to further clarify the indicator light circuitry, the generator No. 4 gear box control circuit (see Figure 21) has been included, as well as two versions of the external power circuits (single and dual power receptacles). Due to lack of space on Figure 41, a third version of the external power and indicator lights circuit (KLM's) is shown in Figure 43.

This concludes our two-part discussion of the Electra electric system. By confining the commentary to the power system, it is hoped that the general reader has gained a firm background upon which to base his knowledge of the total electric system and the various functional systems which depend on it for power. For the electrical specialist, it is intended that the emphasis given the generation and bus transfer systems will give him a more intimate knowledge of their operation as well as provide a convenient reference source for trouble shooting.

Future Digest articles dealing with the various Electra functional systems will also include such additional circuit information as will facilitate a better understanding of system operation. ▲ ▲