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ORION

THE NC-12A MOBILE ELECTRIC POWER PLANT

editor ROY BLAY

assistant editors DON WADSWORTH : WAYNE CRADDUCK

art VIRGINIA ROBINS

FRONT AND BACK COVERS Detachment Alfa of Patrol Squadron Thirty has the responsibility of training flight crews for the P-3A operating squadrons of the Atlantic Fleet.

In the spring of 1962, VP-8 and VP-44, the first two operational Orion squadrons, were busy transitioning to the new ASW aircraft. At this early stage of the Orion's induction, Navy personnel were receiving most of their training from factory schools and other sources, but it was expected that VP-30, based at Jacksonville, Florida with the assignment of training crews for other Navy aircraft, would eventually take over the Orion flight crew training program as well.

Accordingly, Detachment Alfa was formed at U.S. Naval Air Station, Patuxent River, Maryland, where most of the P-3A activities on the Atlantic seaboard are centered. A nucleus of Patrol Squadron Thirty personnel was assigned to this training detachment together with personnel from other Atlantic Fleet patrol squadrons, including many from VP-8 and VP-44. Thus established, Detachment Alfa began an intensive training program aimed at producing a highly skilled instruction staff.

Until their first P-3A arrived in late November 1962, Detachment Alfa gained experience and proficiency by operating aircraft borrowed from VP-8. Exercises were scheduled with fleet submarines so that pilots and aircrewmen could gain firsthand experience in applying the techniques and procedures they would soon be teaching. On 14 January 1963, the first class of trainees checked aboard. Eleven weeks later they graduated and went to their respective squadrons as the first in the flow from a new pipeline of trained P-3A flight crews.

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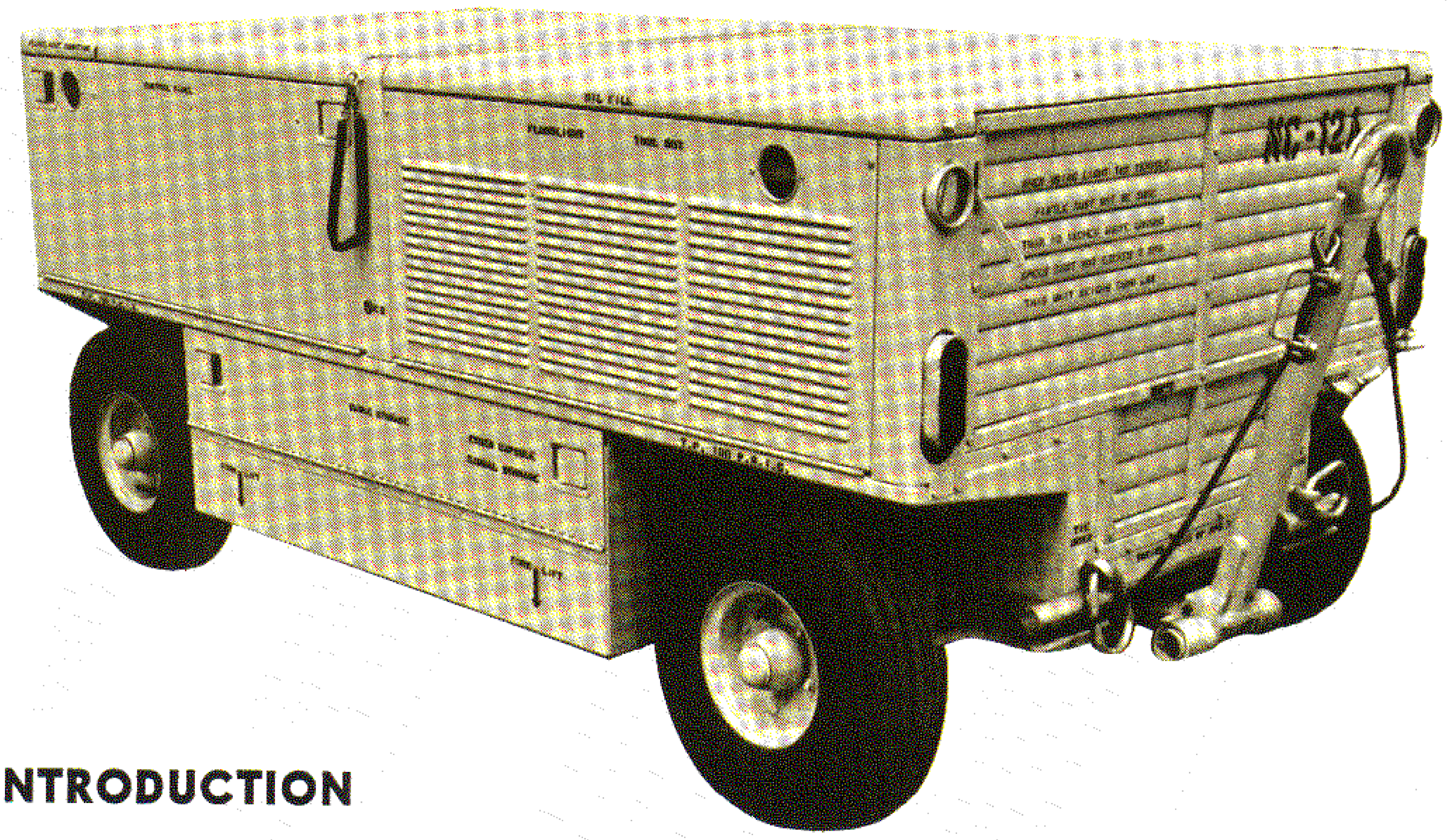
NC-12A MOBILE ELECTRIC POWER PLANT



INTRODUCTION

THE 115/200-V, 400-cps, 3-phase electrical system has become the standard primary power source for new aircraft, and these electrical systems are using substantially more power than previous designs. The P-3 Orion, for instance, could require more than 50 kva if much of its equipment were energized simultaneously during ground check out work. The designers provide the aircraft with generation systems that are closely regulated and constantly monitored, so that the electrical components that use the power are well protected from variations in voltage and frequency that can cause erratic operation or damage. This is extremely important with ac systems, for much of today's equipment is quite sensitive to faulty power, and in some cases permanent damage can result from a few seconds operating time if bus voltage or frequency deviates more than a few percent from normal.

Providing such large quantities of high-quality power at the point it is needed on the flight line requires a powerful mobile unit that responds precisely to load variations and, like the aircraft generation systems, the ideal ground power source will continuously evaluate its own product and refuse to support a bus rather than to supply power that would be detrimental to the aircraft. The Navy's new power plant — the NC-12A — has all these characteristics, and it also furnishes an ample source of 28-volt dc power. The NC-12A was built by American Astro Systems, Inc. of El Monte, California; designed to meet Navy and Lockheed specifications by American Astro's engineers in collaboration with Lockheed electrical design experts. Lockheed-California Company is the prime contractor for the unit.

The ground power plant is an indispensable and complex item of support equipment for the Orion, and as such it warrants the same high order of care and prudent use as the aircraft. Our product support organization regards these diesel powered generating systems as an extension of our airplane, and we hope that this article of general and specific information will promote efficient use of this important "accessory."

The NC-12A is the second of two models designed to fulfill the Navy requirement. Only 16 units of the first model, the NC-12, were produced, and although there are similarities between the 12 and 12A, they are so different in detail that we found it impractical, indeed, impossible, to discuss both machines in a single article and do justice to either. At the time of this writing American Astro has produced 84 of the NC-12A models — more than 5 times as many as the NC-12 total — and since all Orion bases have the A model, this article is devoted exclusively to it. The official Navy document, the Instruction and Parts-Breakdown Manual, for each model is available at every using activity; NAVWEPS 19-45B-9 for the NC-12; NAVWEPS 19-45-283 for the NC-12A.

GENERAL DESCRIPTION

CHASSIS The unit is mounted on a compact 4-wheel trailer; 45″ high, 60″ wide, 105″ long. The rear wheels have mechanical brakes which can be engaged manually by pulling the brake handle at the front of the trailer. The brake system is interconnected with the towing tongue. The tongue has heavy counter-balance springs which tend to keep it erect against the front of the unit, in which position interconnecting linkage sets the brakes automatically. To release the brakes, it is necessary to hold the tongue down in towing position and manually release the hand brake.

The trailer is divided into two compartments. The front compartment contains the diesel power plant, the rear compartment contains the generating systems and the fuel tank. The top cover is hinged at the center, providing a separate access door for each compartment. The engine cover opens at the front and has counter-balance springs, the aft cover opens at the rear and has a prop bar for normal access, or it can be laid forward over the engine cover for more complete access.

The trailer sides have many large piano-hinged access doors, but the front and rear walls are permanently mounted grills for the two engine cooling radiators. Controls and indicators for the engine and for the generation systems are arranged at the forward and aft ends (respectively) of a control panel accessible through a door on the aft-right side of the power unit. The electrical control panel can be unlatched and swung forward for access to many of the electrical components, including the voltage regulators and the generation systems protective package.

There is a low-slung compartment on the left side for the engine starting batteries, a slightly larger one on the right side for stowing the three 25-foot-long aircraft connector cables; two ac cables and one dc cable. A full length pan covers the bottom, so that when the power plant is operating with the top and side access panels closed, the cabinet serves as a duct between the front and aft radiators, and a single belt-driven fan at the front of the power plant is enabled to draw air in through the rear radiator and exhaust it forward through the front radiator. Engine intake air is also drawn through the rear radiator, and it is exhausted through dual exhausts, one on each side of the front radiator. Thus, the combined air flow provides ample ventilation for the heat producing electrical components in the aft compartment.

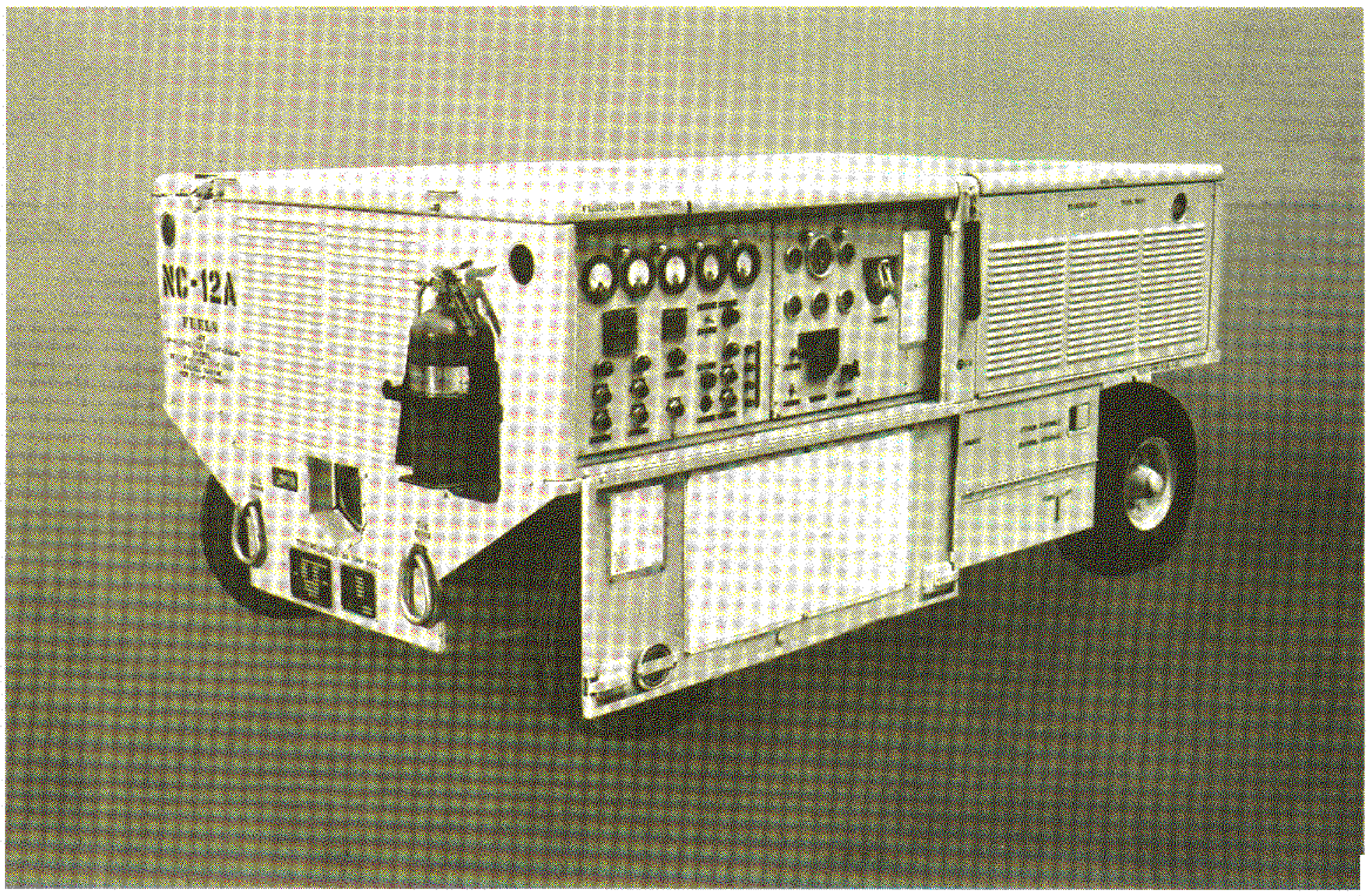


Figure 1
NC-12A
Right Side View
with Control
Panel Access Open

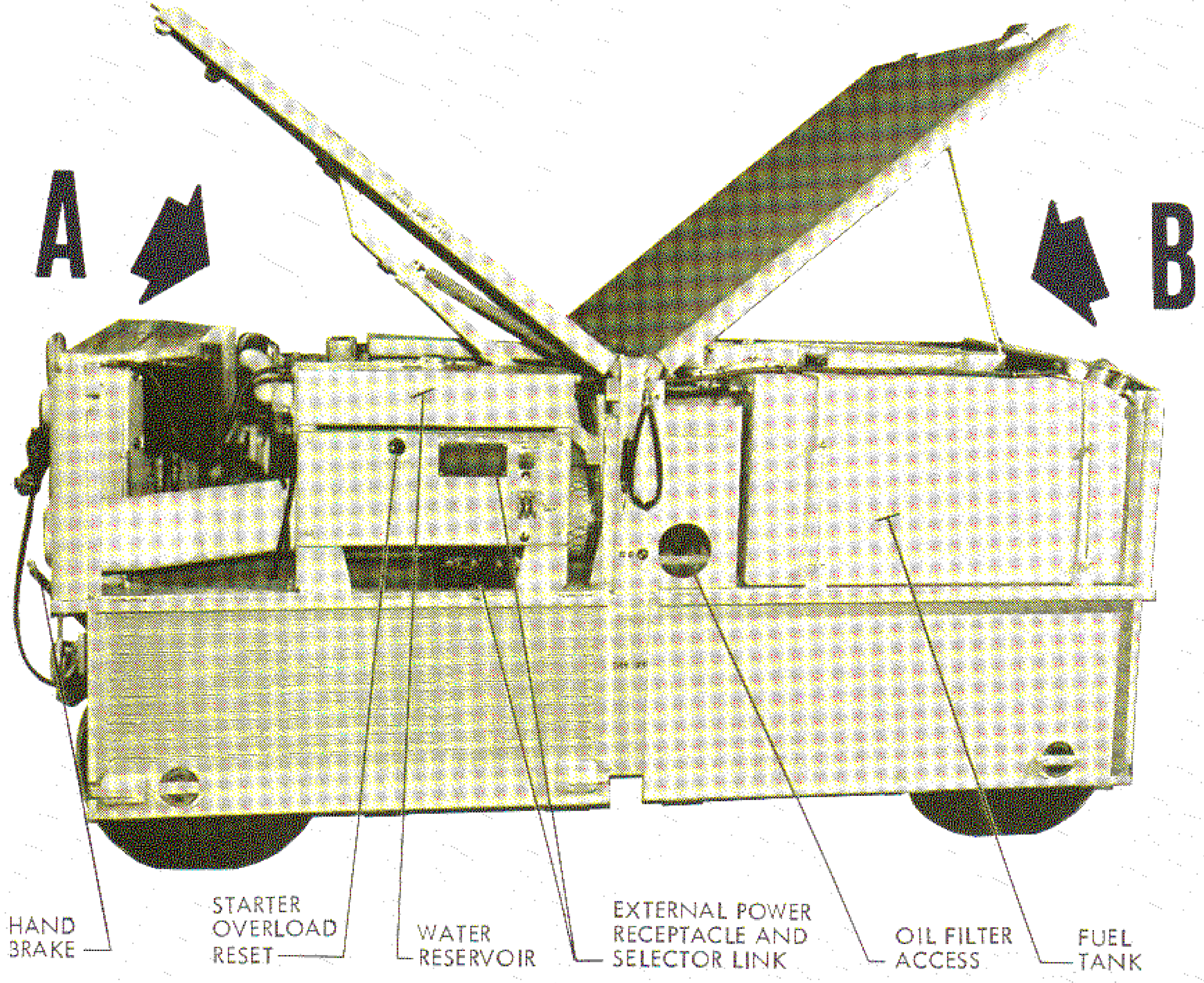
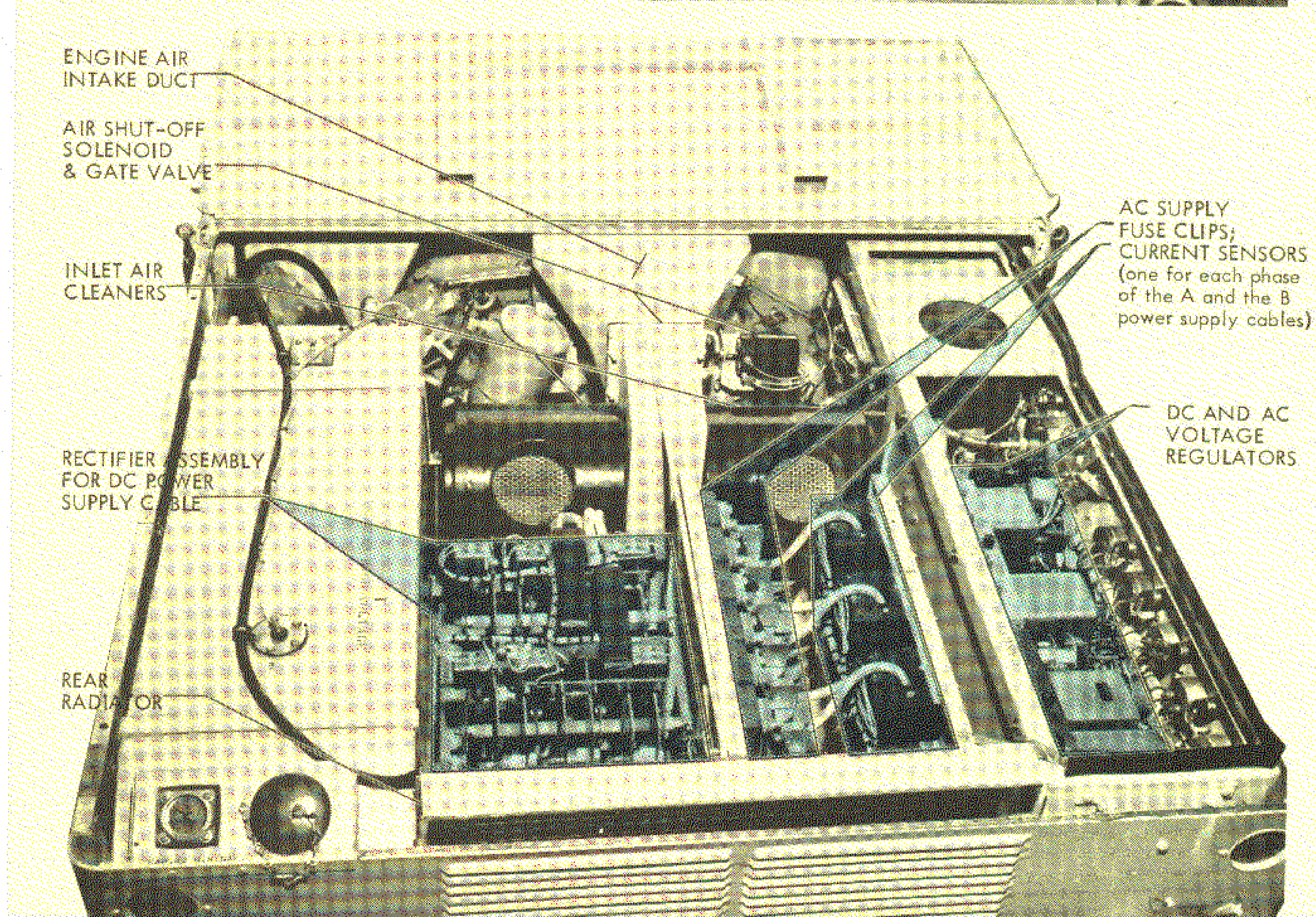


Figure 2
General Views Through Left Side and Cover Access Doors

VIEW A

VIEW B



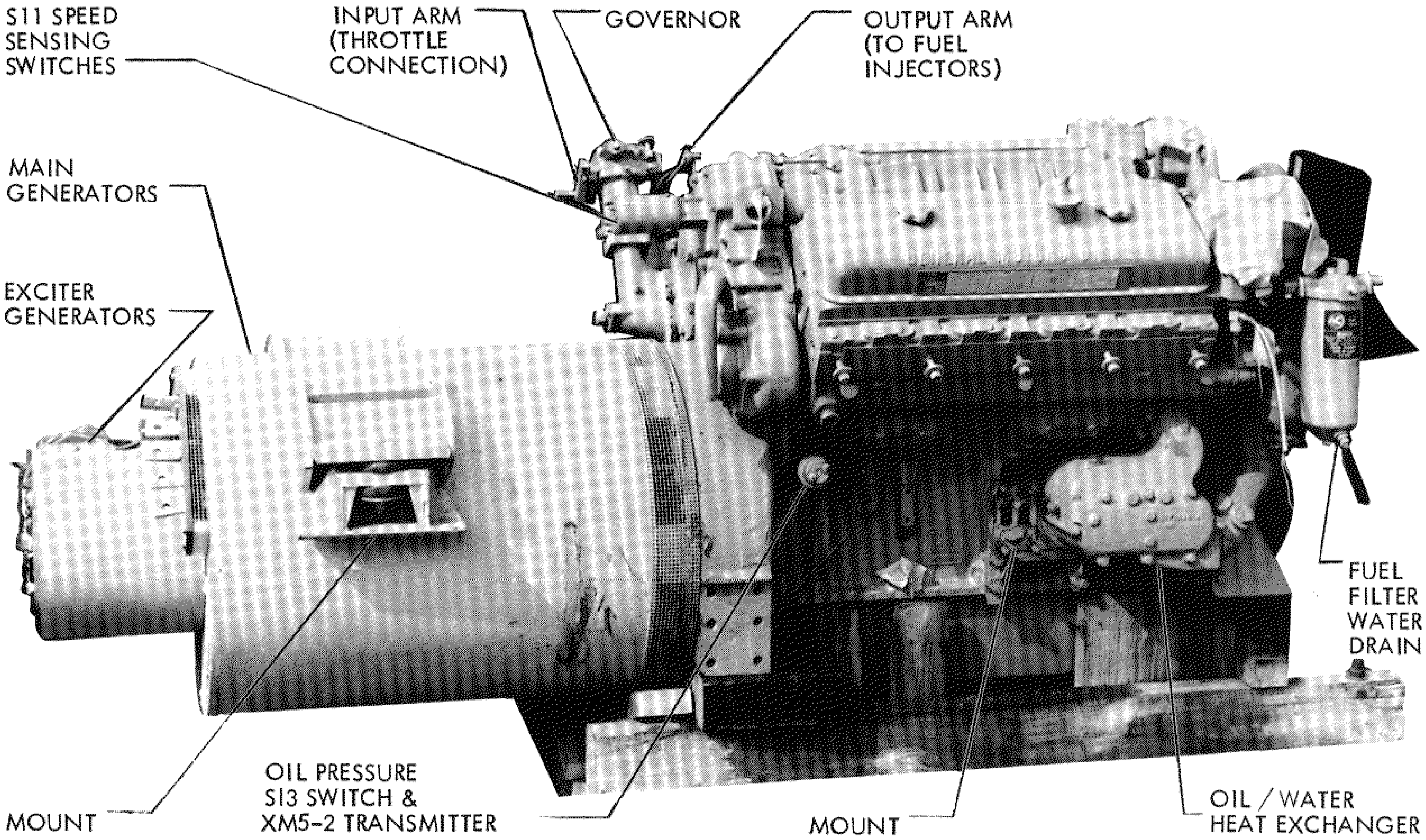


Figure 3 Engine/Generators Assembly Before Installation

THE ENGINE is a V-8 diesel of the General Motors V-71 Series. The Navy uses many engines of this series, and parts and service for it are available from existing Navy organizations. It is a blown, 2-stroke-cycle engine. Each cylinder has four exhaust valves which open when the piston is about midway in its power stroke. As the piston descends further, slots in the cylinder walls are uncovered and air is blown into the cylinder from a pressurized chamber between the cylinder banks, sweeping out the exhaust gases through the open valves. The exhaust valves close, and at the end of the compression stroke (17 to 1 compression ratio) the heat of compression will ignite atomized fuel which is pumped in at extremely high pressure by the piston in the fuel injector nozzle. The injector pistons are actuated by lobes on the left and right exhaust valve cam shafts through conventional roller-type cam followers, push rods, and overhead rocker arms. Each injector has an internal fuel metering device. The amount of fuel injected during a stroke of the injector piston is variable from zero (fuel cut-off) to full-fuel by positioning a control rod which adjusts a rack within the injector body. The four injector control rods for each cylinder bank are pinned to individual cranks on a torque tube that extends the length of the head inside the valve cover, and the left and right torque tubes are interconnected at the forward end of the engine. From this point a master control linkage runs aft to the output arm of the governor (see Figure 4). There are no sensing and/or servo variables in this purely mechanical fuel control; any excursion of the governor output arm readjusts the eight injectors instantly and identically.

The governor is a hydro-mechanical device with an integral oil pump that furnishes control pressure from a supply of engine oil tapped off the engine's forced lubrication system. There is a control known as a throttle, but it has no direct effect on the engine air or fuel supply, nor does it act directly to alter power output. The throttle has four detented positions — STOP, START, IDLE, and RUN — and its mechanical action is limited to positioning a bell-crank input arm on the governor.

In the first two throttle positions, STOP and START, the governor is requested to maintain zero rpm, and the fuel injectors are held by spring load in the fuel cut-off position.

In the last two positions, IDLE and RUN, the governor is directed to maintain a steady engine speed of about 1000 and 1846 rpm, respectively. The governor senses the existing engine speed, and if rpm deviates, the governor—through its hydraulic actuator, its output bell-crank, and the mechanical linkage — readjusts the eight fuel injectors as necessary to recover the selected engine speed.

The governor is extremely quick in its responses and, in combination with the two-stroke-cycle engine, a change in load is answered by a change in power almost instantly. The engine is rated at 215 bhp at operating speed, and even under high load it produces surprisingly little vibration. Note that the number of power impulses received by the crankshaft at RUN speed, 1846 rpm, is equal to that of a four-stroke-cycle engine running at 3692 rpm.

The engine's liquid cooling system is thermostatically controlled, and it is used also to cool the engine oil by means of the oil-to-water heat exchanger shown in Figure 3. As the thermostat valve passes progressively more water to be cooled in the radiators, the changing balance in water pressure on either side of the thermostat valve (at the front of the right cylinder head) is used as hydraulic pressure to open the front radiator louvers, promoting the cooling air flow. There is a manual control lever which may be used to open the louvers prematurely, but the manual control will not override the automatic control to close the louvers.

A thermal switch senses the temperature of water before it is cooled in the radiator, and if water temperature reaches 205° F, the switch opens and (as explained later) shuts down the engine automatically. Thereafter, the switch prevents operation of the starter until the water cools. (An oil pressure sensing switch in this circuit performs the automatic shutdown when oil pressure drops below 5 psi, but this switch does not prevent starter operation.)

The centrifugal water pump is mounted at the forward end of the right cylinder bank, and is driven by that bank's camshaft drive. The pump output is forced through the oil cooler, into the block and both heads for upper cylinder cooling, and returned to the pump inlet. If the water is cold, it repeats the cycle; if warm, a part of the flow is diverted into the top of the front radiator, circulates down and out the bottom to, and through, the rear radiator before returning to the water pump inlet. The system is replenished from a small reserve tank at the left of the engine compartment. The water should be held to a fairly exact level, 1 to 2 inches below the reservoir filler.

The gear type fuel pump is located at, and driven from, the front end of the engine blower shaft between the cylinder banks. It draws fuel from the tank through a strainer and propels it under pressure through a filter to a fuel supply gallery for each cylinder bank, providing an oversupply of fuel to the four injectors in each head. The fuel flow not used by the injectors passes into a return fuel gallery in each head, carrying some of the heat away from the injectors, and is returned to the fuel tank.

The diesel engine will assimilate any of the fuels placarded at the filler well without mechanical readjustment but, oddly enough, jet fuels seem better suited than diesel for this installation, due to the generally low power demand made on the engine.

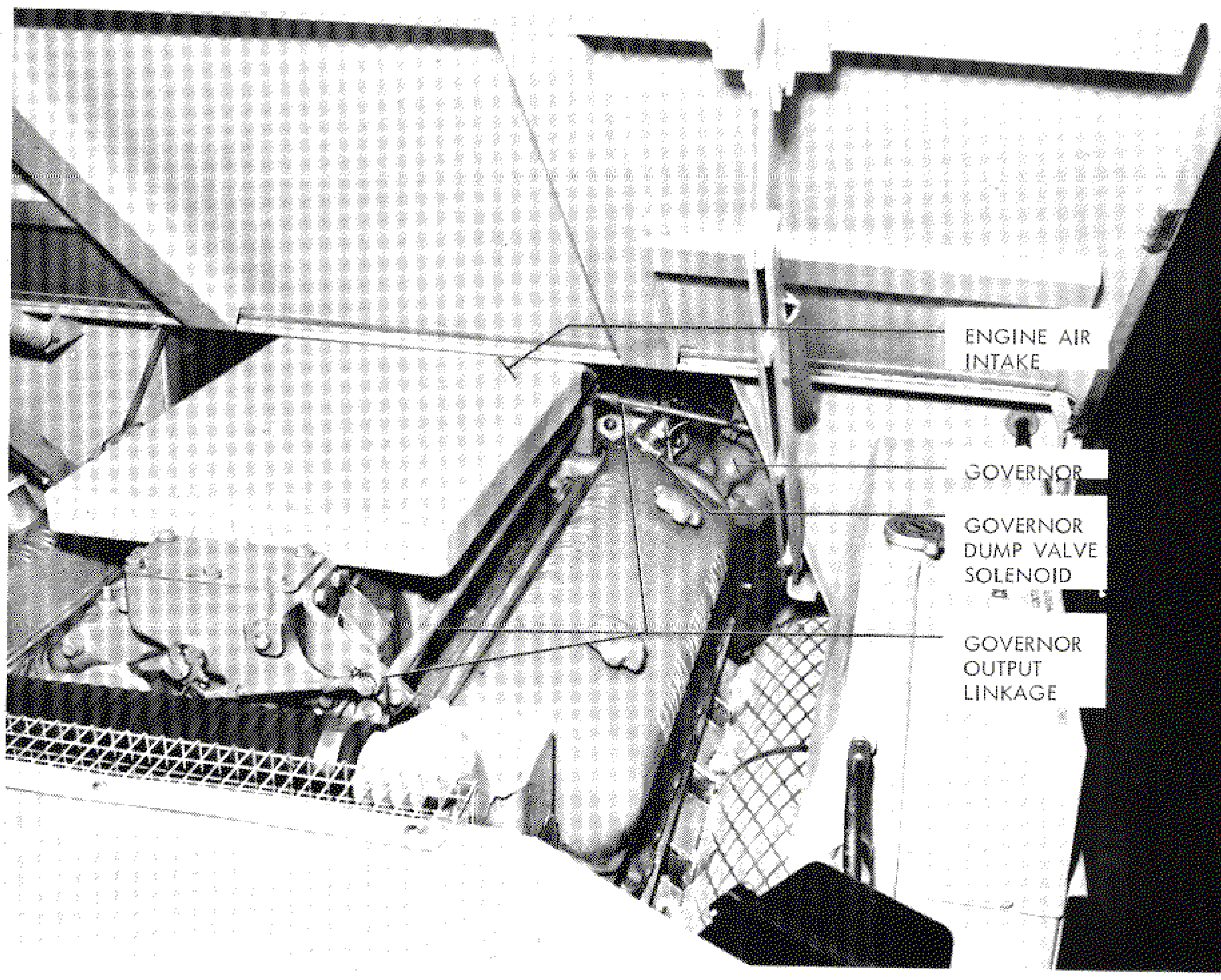
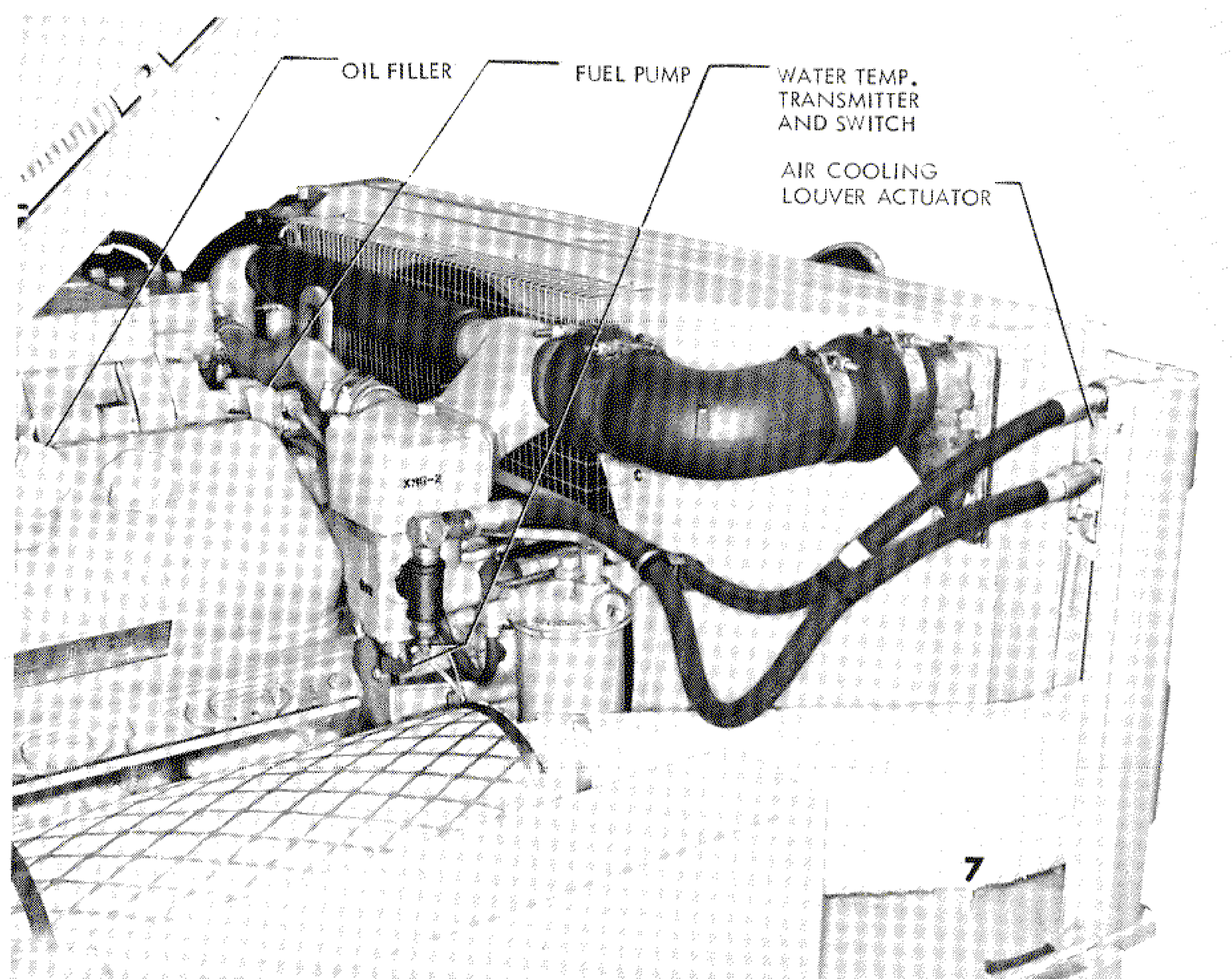


Figure 4A Engine Installation — View Looking Aft over Left Cylinder Bank

Figure 4B Engine Installation — View with Right Front Access Door Open



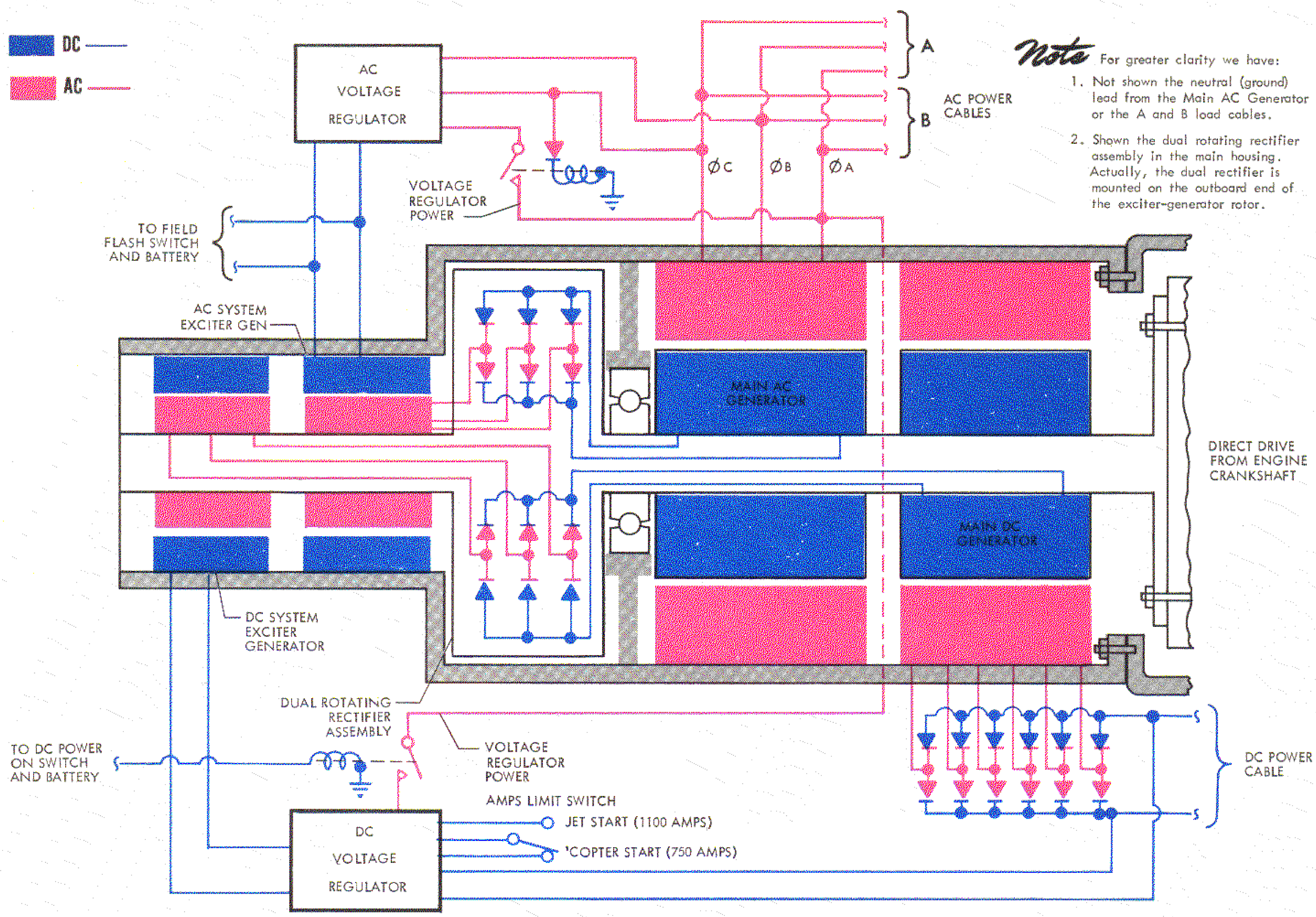


Figure 5 Simplified Schematic of NC-12A Dual Brushless Generator Installation

If an extensive, uninterrupted run is planned, the tank should best be filled or nearly full before start. Fuel consumption rate depends on the exact power load, of course, but even under a continuous medium-high load a tank of fuel will last about 6 hours. To minimize water condensation, it is good practice to keep the fuel tank full when the unit is idle.

The fuel filter which can be seen in Figure 3, and the fuel strainer, which is on the opposite side of the engine, both serve as water traps. The petcocks on the bottom of their cases should be opened daily — preferably before the first start is made — to remove water accumulations.

Usually, crankcase oil is MIL-L-2104A, but for sub-zero operation MIL-L-10295 is to be used. If MIL-F-16884C Diesel Marine fuel must be used, MIL-L-9000E lubricating oil should be used in the crankcase.

As a rule, diesel engines are difficult to start during cold weather, and if possible the unit should be sheltered during idle periods in winter. However, the NC-12A has special provisions for cold weather starting, utilizing ether from small cartridges, one of which is shown in Figure 13. The screw-cap chamber, which can be seen at the right side of the engine control panel in Figure 6, is connected to the engine air intake duct by a small copper tube. Before a cold-weather start is made, an ether cartridge is dropped into the chamber, the cap is applied, and the bail on the cap is swung 180 degrees. This punctures the cartridge, and ether is injected into the engine air intake duct. (An additional cartridge is injected for each 10 degrees below 40° F.) The start is then made with the throttle in RUN position, and with a fresh cartridge loaded in the chamber. This lowers the ignition point of the fuel-air mixture, and the engine should start and become self-sustaining, but if it shows a tendency to die, the new cartridge can be injected. The throttle should be returned to IDLE *immediately* when it becomes apparent that the engine is self sustaining, for the warm up should always be made at about 1000 rpm. This procedure is placarded on the engine control panel adjacent to the injector chamber.

THE ELECTRICAL POWER GENERATING UNIT is designed specifically for use with the GM diesel engine. It is actually four generators in a single housing, mounted on a single shaft. The large housing shown in Figure 3 contains a main generator for ac and a main generator for dc power supply. The small extension off the main housing contains an exciter generator for each of the main generators. The generator shaft is coupled directly to the engine fly wheel, so the complications and power losses generally associated with gear boxes and clutches are completely eliminated.

Of course, there are separate ac and dc voltage regulation systems which sense the output voltage available to the aircraft and maintain close-tolerance output by varying input to the exciter-generators.

The items which are traditionally most troublesome on generation systems—brushes, commutators, and slip-rings — are not used on the NC-12A. This deletion was made possible by providing exciter-generators of conventional design (stationary field windings, rotating output windings) and main generators which are the reverse of the exciter (rotating field windings, stationary output windings). Thus, in each generation system: 1) The voltage regulator controls the exciter-generator field through stationary connections. 2) The exciter-generator output — which is 3-phase ac — is then full-wave rectified by a rectifier assembly that is mounted on (and rotates with) the generator shaft. 3) Since the main generators are of the rotating field design, the rectified output of the exciter-generators can be connected directly to the main generator rotors, and the main generator output is then taken off the stator windings through fixed connectors.

The main ac generator is wye wound with the center tap (neutral) grounded, providing what is known as a 4-wire system with a 115-v potential between any phase lead and ground; 200-v potential between any two phase leads. The main ac generator is rated to produce 125 kva* constantly, and this is made available to two separately controlled extension cables (rated at 75 kva each), — a more-than-adequate ground power supply for two Orions.

The other main generator is known as the dc generator, but in actuality it produces 6-phase ac current which is full-wave rectified by 12 large diodes mounted on heat-dissipating plates (which can be seen in Figure 2) at the left of the generator compartment. This arrangement produces dc power without commutators and brushes, and yields, at the rectifier output, a very high-frequency "ripple" (4800 impulses per second) which is easily filtered to provide a "smooth" dc voltage at the single extension cable.

Fully stated, the generator is said to be rated at "125-kva at .75 power factor." This indicates that, given sufficient motive power and a pure resistance load, the generator could supply 125 kw. Aircraft buses will almost invariably be carrying some resistive and some reactive circuits. Reactive circuits introduce a power factor into the generator load, requiring some special provisions in the design of the generator. The NC-12A ac generator designers allowed for a load circuit varying from a power factor of 1.0 (pure resistance) to .75 (a more than normal amount of reactance). When the generator is loaded by a bus exhibiting the lower power factor, it will safely supply 93.75 kw (.75 x 125), and the NC-12A engine will be almost at top power for continuous operation.

The power capability of the dc generation system is given, in terms of the generator's ac output, as 25 kva and, in terms of the usable dc output, as 750 amps at 28 volts. The dc rating requires some interpretation, for the dc regulator has an integral 2-range current limiting circuit which reduces output voltage when the system is supplying a heavy load, such as the high amperage required by aircraft engine starters. The range selector has two positions closely identified with the intent of the circuit: JET START (950 to 1100 amps); 'COPTER START (650 to 750 amps). In these limiting ranges, the circuit will automatically diminish voltage in the dc power cable as amperage increases. Voltage can, and will, be depressed practically to zero if necessary to prevent amperage from exceeding the upper range limits. Note that the selector must be in JET START position to obtain the full rated output, 750 amps at 28 volts, for if the selector is in 'COPTER START, voltage will be far depressed at 750 amps.

The available engine power limits the amount of ac and dc power which can be obtained simultaneously. For this reason there is also a collective rating for the NC-12A, expressed as "87.5-kva (at .75 power factor) and 750 amps dc." In practice, of course, it is entirely proper to draw more from one generation system if the other is lightly loaded.

It is possible to use the ac generator separately, but it is *not* possible to energize the dc generator unless the ac generator is energized. None of the generators retain residual magnetism, and they do not produce power automatically when driven at operating speed. The generators are energized in sequence, as follows:

1. DC power from the unit's battery circuit is used to flash the field of the ac exciter-generator.
2. The output of the exciter-generator automatically energizes the main ac generator. The ac voltage regulator is energized from the main output, and control of the ac exciter generator shifts from the flash control to voltage regulator control. Thus an ac generation cycle is established that will continue so long as the main ac output is satisfactory in respect to voltage and frequency.
3. If dc power is needed, actuating the DC Load ON switch will energize the dc voltage regulator with power taken off Phase A of the main ac generator; the dc exciter generator is energized, and a self-controlling cycle is established similar to the ac cycle. However, this cycle is not self powered, as the ac control is, for the dc voltage regulator must receive a continuous supply of ac power from the main ac generator.

FUNCTIONAL SEQUENCE — ENGINE START THROUGH POWER "ON"

Figure 8 shows a much simplified mechanical/electrical schematic intended for purposes of familiarization only. The mechanical components are crude, showing the scheme rather than accurate mechanical detail, and we have omitted many electrical components and circuits in the interests of simplification. A complete circuit diagram mounted inside the NC-12A control panel access door is arranged ideally for trouble shooting, with terminal numbers identified and each symbol labelled with the code number that is placarded adjacent to the actual component on the NC-12A. We have used this mode of identification on the simplified schematic also, for example, "K116 Master Relay".

In the following text we have listed major steps of the normal procedure for putting the NC-12A into use, starting with no circuits energized — as shown on the schematic — and as the various circuits are energized, each component in each circuit is briefly discussed as to purpose.

Of course engine oil, fuel, and water levels should always be checked before starting.

— SELECT START POWER SOURCE. The "Power Selector Link" (upper left on the Figure 8 schematic) is on the left side of the NC-12A, just above the battery compartment. The link is a slotted terminal-jumper bar secured by large wing nuts, and normally it is in LOCAL BATT position. If the batteries are low, however, and external power must be used to start, the jumper bar must be connected to the EXT PWR terminal. This disconnects the batteries, and they can be removed for charging. If an extended run is planned and the batteries are not too low, they may be reconnected and recharged from their normal source by transferring the selector back to LOCAL BATT position after the engine is started. Note, however, that *the terminal studs will be "hot" and the jumper must be handled with the respect due such high amperage connectors.* The studs are in an insulated box, but if a tool provides a short to the frame, the operator's hands may be injured or components in the battery charging circuit may be damaged.

Incidentally, the circuits powered by the battery and/or the belt driven generator are essential to operation of the NC-12A. If all power to these circuits is lost after the start is made, engine fuel will be cut off and all aircraft feeder cables will be de-energized.

The control panel illumination lights can be turned on before the start if it is necessary, and a flood light (provided as loose equipment with each power unit) can be plugged into a receptacle on the face of the panel for area illumination. It is poor practice, however, to waste battery power with the flood light before engine start.

— SELECT "START" AT THE THROTTLE CONTROL KNOB. The position designated START on the throttle-position quadrant is understandably misleading to the uninitiated. A normal engine start *cannot* be made with the knob at this position, for the governor input arm will not be moved far enough to clear its fuel cut-off range, and no fuel will be injected. It is best, however, to consciously select this position before each start is made, for at this position the fuel and water gauges can be checked.

When the throttle is moved from STOP to START, the only significant effect on the controls is to close the two-pole throttle switch, S6.

The circuit through one pole is relatively simple, furnishing power to three engine instruments — fuel quantity, oil pressure, and water temperature — and to the power and control circuits of the low fuel level warning horn. If the fuel level is ¼ tank or less at this time, a float operated switch will close, and the klaxon will give audible warning that the unit will probably not run for much more than an

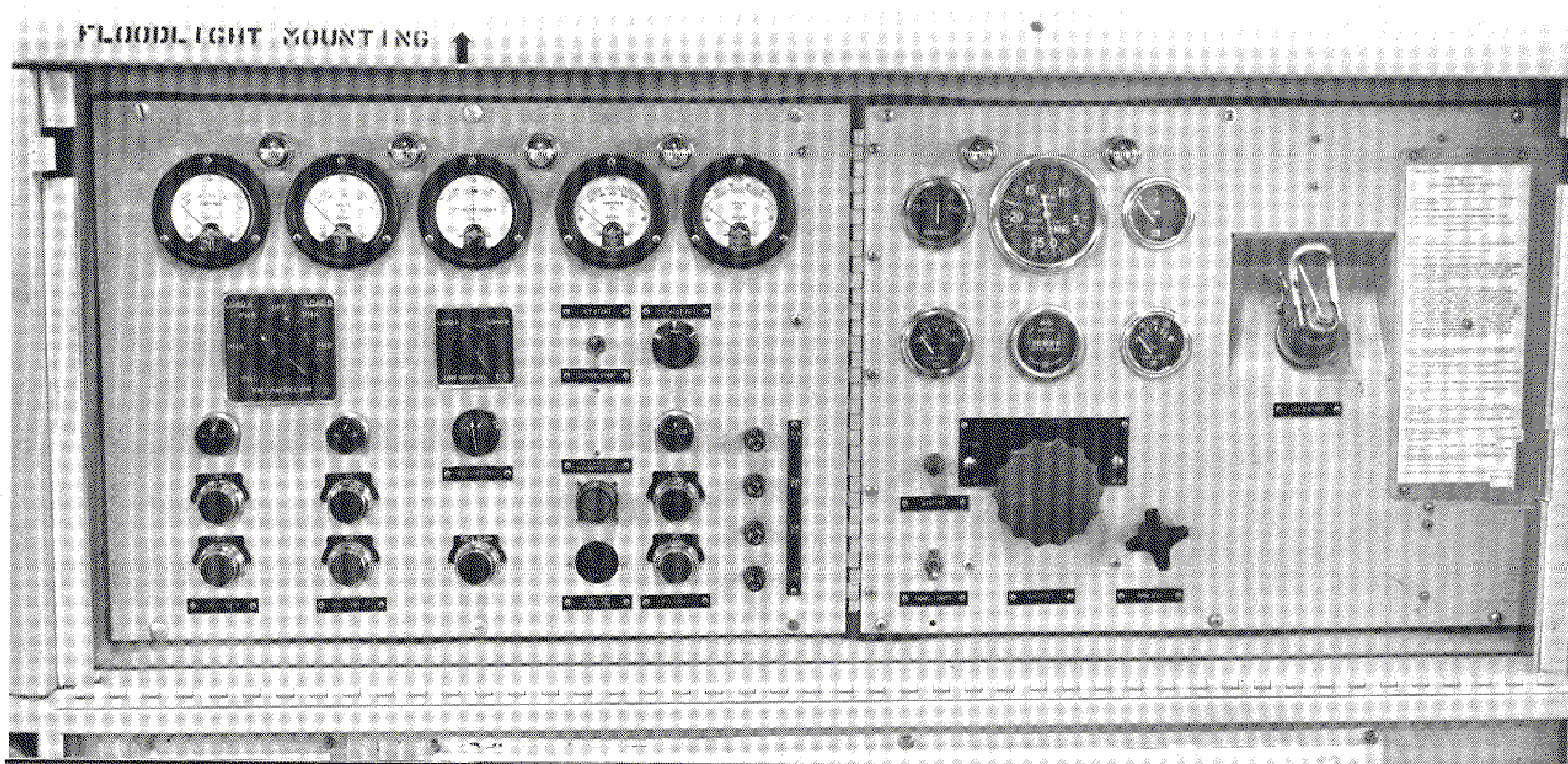


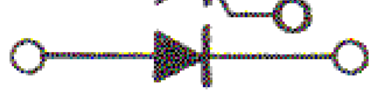
Figure 6
Control Panels.
Electrical control
(left) panel is hinged;
swings forward
for access.

hour. If this occurs while the unit is in use, the irritating sound is quite distinct from the exhaust roar, and there is no lockout for the horn; the only remedy is to turn the throttle control knob to STOP and service the tank. This design ensures that someone will take remedial action promptly (or that every one working in the area will get a tin ear) before power is inadvertently lost on the airplanes concerned.

The circuit through the other pole of the S6 throttle switch routes power to the S13 oil pressure sensing switch (open at this time), one pole of the starter button switch (open at this time), pin N of the protective package, and through one of the closed contacts of the Field Flash button switch to pin G of the protective package.

The Figure 7 schematic shows only a minimum of the protective package circuitry — and only at the "business" end of the package — that must be thoroughly understood to appreciate its action in the present context and also in connection with other important functions discussed later.

Four parallel-connected silicon controlled rectifiers (SCR's) are the heart of this unit. These are a relatively new development in electrical hardware, and are additionally mysterious when found in a dc circuit where there is obviously nothing to rectify.

The electrical diagram symbol for the SCR () is the same as the diode symbol () except for the added connection for the control circuit, which is known as the "gate" terminal. The SCR has the characteristics of a diode, in that it is a solid-state semi-conductor that presents a nearly insurmountable resistance to current flow of "reverse" polarity. Unlike the diode, however, the SCR blocks current flow of forward polarity (in the direction indicated by the symbolic arrow) until a "trigger" voltage is applied to the gate terminal*, at which time the SCR "fires," that is, it is transformed almost instantly into a true diode. Once fired, the SCR continues to conduct — even though the trigger voltage is removed — so long as voltage of the correct polarity is available to the main terminals. When the main terminal voltage is removed, the SCR regains its original characteristics, blocking current flow in either direction.

**Actually, this blocking of correct-polarity current is limited, and can be overcome if the voltage is elevated to a specific "break over" point. At this point the blocking resistance drops to an insignificant level, and the SCR becomes a near-perfect conductor of "forward" polarity current until the current is interrupted. This feature of the SCR's is not exploited on the NC-12A, but readers may encounter the SCR in use on other equipment to which this characteristic is as important as the gate control explained here.*

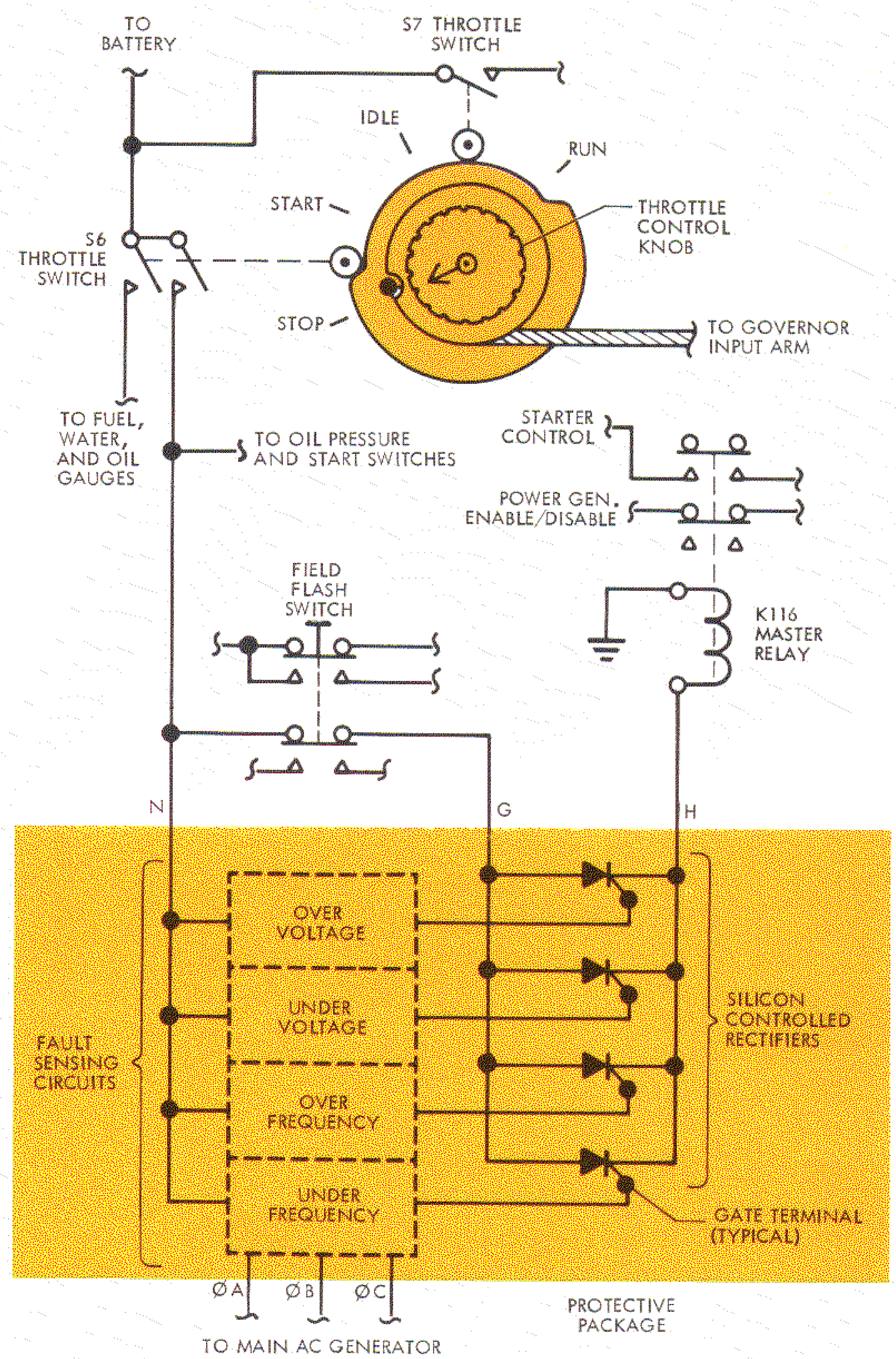


Figure 7 Abbreviated Control Schematic (excerpted from Figure 8 Master Schematic)

Thus, in this application, each SCR performs exactly the same function as a self-holding relay — such as the K107 relay on the schematic —and, just as with the holding relay, the circuit will hold itself closed until it is interrupted at a remote point.

In the protective package, the control (trigger) signal for each SCR originates in one of the fault sensing circuits indicated by blocks on the schematic. The output of the main ac generator is "sampled" by these circuits, and if a fault is sensed, dc current from pin N will be shunted to trigger the appropriate SCR, the SCR will fire (close and hold closed), and a continuous voltage will be transferred from pin G to pin H and thence to the coil of the K116 Master Relay. Thus the purpose of the protective package is to energize the master relay when the ac generator produces an unacceptable power supply (less than 85 to 95 volts, more than 126 volts; less than 375 to 380 cps, more than 415 to 425 cps).

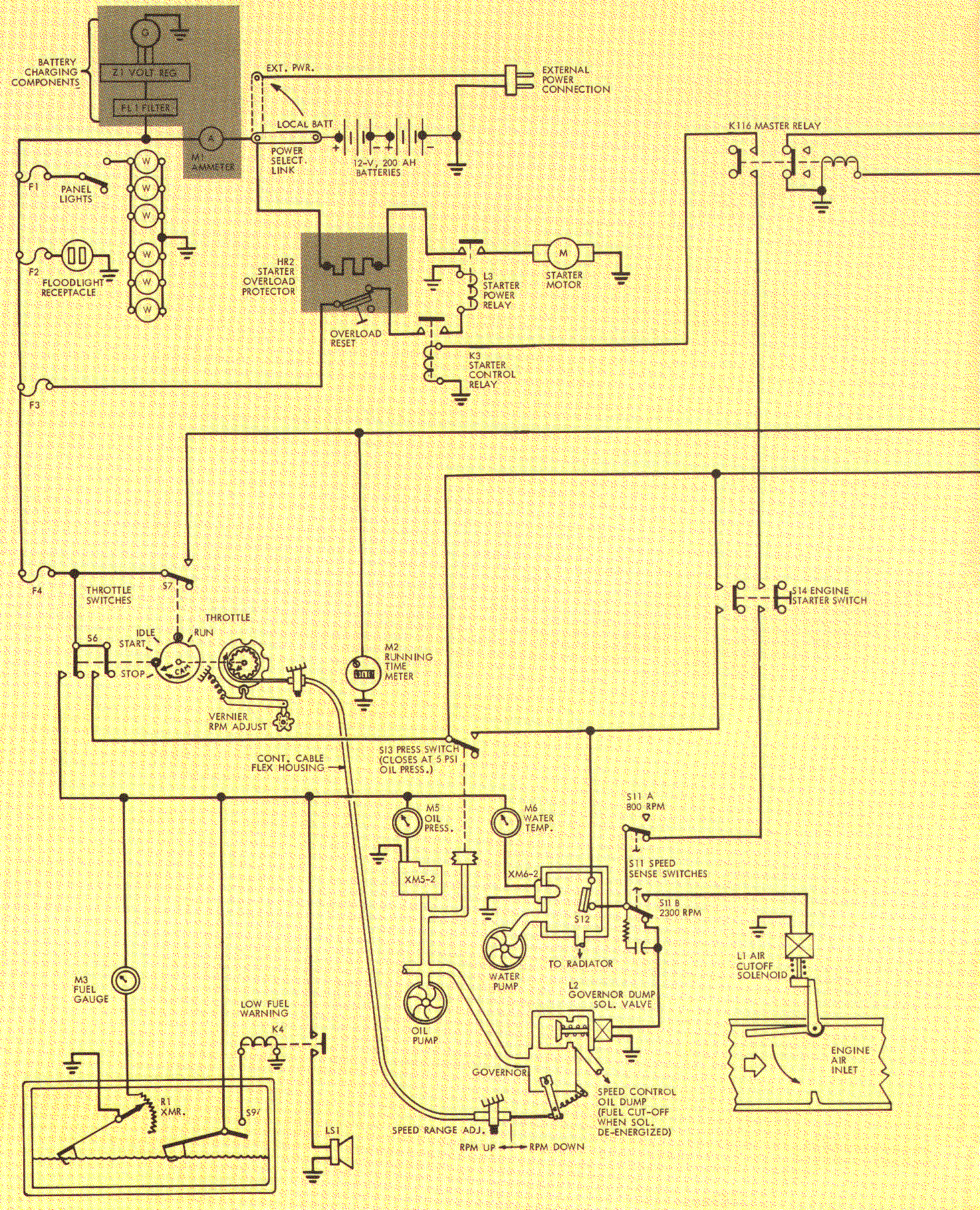
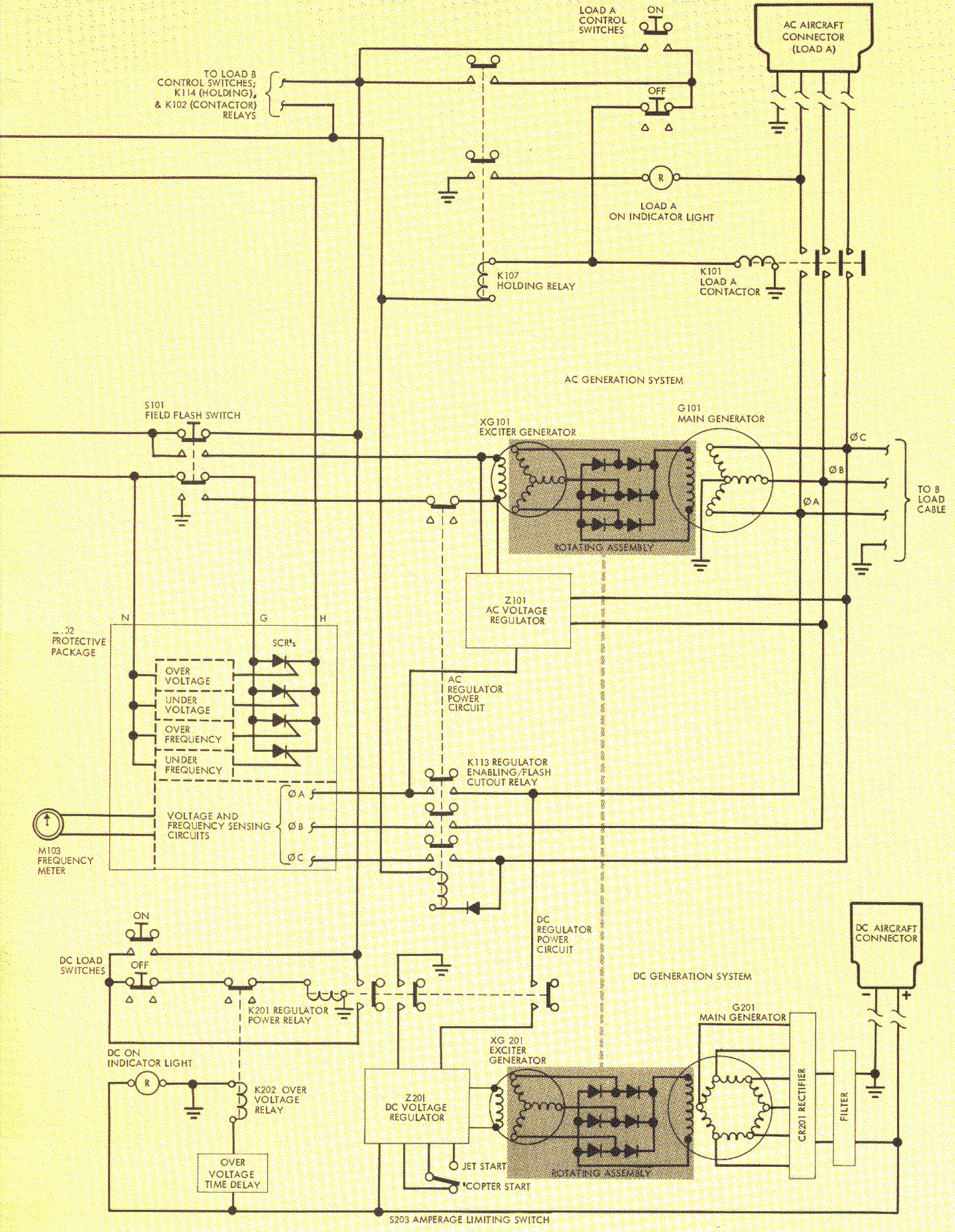


Figure 8 Master Schematic. Additional ac generation system



controls and indicators, not shown here, can be seen in Figure 10.

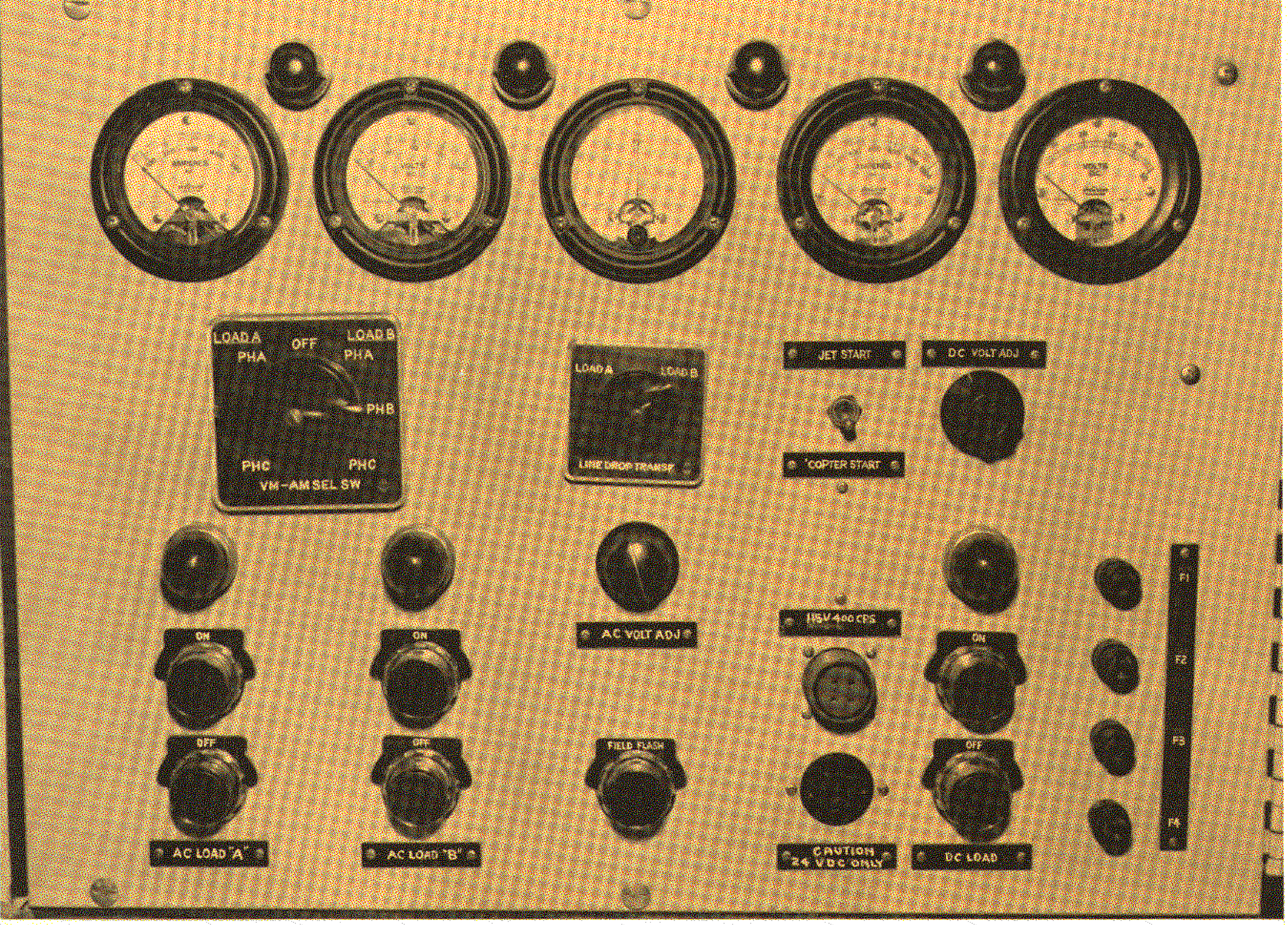


Figure 9
Controls and Indicators for AC and DC Systems

Since we are tracing the circuits from the S6 throttle switch before the unit is started, there is obviously no ac voltage, and the under voltage SCR will fire* and complete a circuit from pin G to pin H, energizing the coil of the two-pole master relay, K116. This has no immediate effect, for there is no potential at any of the K116 contacts at this time, but the stage is now set to initiate the engine start.

— SELECT "IDLE" AT THE THROTTLE CONTROL KNOB. This has no electrical effect, but through a cable control the throttle pulls the governor input arm out of the fuel cutoff range into the fuel metering range.

— PRESS START BUTTON. This is a two-pole switch that energizes a loop circuit from, and back to, the start switch through a series of automatic protective devices, all of which must be correctly positioned before start. The loop begins at the starter button contact that was energized when the S6 throttle switch closed, passes through S12 water temperature sensing switch (that will be closed unless water temperature is 205° F or more) and two engine-speed sensing switches. Since engine speed is zero, the two switches will be positioned as shown; the "2300 rpm switch" shunting power to the governor dump solenoid valve; the "800 rpm switch" completing the loop to the start button. The circuit continues through the second pole of the start button, the now-closed contacts of the K116 master relay, and the circuit is completed through the K3 (start control) relay coil. The closed K3 contacts energize the L3 (starter power) relay coil, and the closing of the L3 contacts energizes the start motor.

Thus, it can be seen that a number of conditions (and a number of components) must be correct before the start motor can be energized. To recap: The throttle must not be in the STOP position; the start button must be depressed; the water temperature must be less than 205° F; engine speed must be less than 800 rpm; the protective package must be signalling an ac power fault, holding closed the normally-open pole of the K116 master relay. The last item ensures that the protective package is in place, and a most important fault sensing circuit is operating properly. Without this inter-lock provided by the K116 relay, it would be possible to start and run the unit with the protective package completely disconnected and/or inoperative.

As the engine begins to turn, oil pressure will build up to more than 5 psi, closing the pressure sensing switch and furnishing a bypass circuit around the first contact of the start button so that the gov-

**It would seem logical that the under-frequency SCR would also fire at this time, but in fact it does not. The frequency sensing segment of the protective package utilizes a resonant ac circuit, and it cannot produce trigger voltage before ac power is available.*

ernor dump solenoid valve will remain energized via the S11B (2300 rpm) switch when the start button is released. After the diesel begins to fire, it will accelerate rapidly to about 1000 rpm (normal idle speed), the S11A (800 rpm) switch will open, and the starter control and power relays, K3 and L3, will both open.

Thus the start motor is protected from over-speed automatically, and there is no necessity for the operator to try to judge when the diesel has gained sufficient speed to continue acceleration without the starter. Indeed, in view of the high cost in battery charge when a start aborts due to premature cut-out of start power, it is good technique for the operator to hold the start button in until the engine reaches idle speed, relying on the automatic speed switch rather than trying to judge when to cut out the start motor. If the engine should die, however, DO NOT RE-ENERGIZE THE STARTER UNTIL THE ENGINE AND THE STARTER STOP TURNING, for severe damage can result.

If the diesel does not "catch" and accelerate as it should, protracted cranking could damage the start motor if it were not for a final protective device which limits the cranking time to a safe period. This device (HR2) transforms a fraction of the starter power into heat, and in about 30 seconds accumulated heat will trip (open) the thermal switch in the starter control circuit, de-energizing the starter power relay. If the HR2 thermal switch trips, the operator can reset it manually after a one minute cooling period has elapsed — a period he might best devote to investigating why the diesel failed to start the first time. Figure 2 shows the location of the reset button access hole.

Allow the engine to run at idle for 3 to 5 minutes if it was cold at start; 1 minute if the water temperature is up.

— SELECT "RUN" AT THROTTLE CONTROL. This moves the governor input arm, selecting approximately the engine speed needed (1846 rpm) to produce the nominal ac frequency (400 cps). There is no ac output to measure as yet, of course, but the mechanically driven tachometer is prominently marked at 1846, and this position is further identified as "400 cps." The tachometer will probably not be perfectly accurate but it will be close enough for the purposes of this preliminary setting if the meter needle is set carefully on the 1846 mark by adjusting engine speed with the small "Vernier" throttle knob.

When the main throttle control was set to RUN position, the throttle cam will have closed the S7 throttle switch. The engine run-time clock will start immediately if the S7 switch functions properly, and the operator can — and should — check this quickly by observing the run indicator on the clock face. This is a small window, in the upper left quadrant of the indicator, fitted with a cross bar that revolves slowly as the clock runs. He should also check that the engine oil pressure indicator is well above the danger area (0 to 20 psi).

Power from the S7 switch continues past the clock and through a pole of the Field Flash switch, but has no immediate effect. The other pole of the Field Flash switch is conducting power from the S6 throttle switch at this time, maintaining the "undervoltage" signal from the protective package.

— PRESS THE FIELD FLASH BUTTON. When depressed, this two-pole switch shunts dc power from the S7 switch through the field of the ac exciter generator and also provides a ground for the flash circuit. A second and equally important function results from depressing the Flash switch. Power is removed from all four SCR's (disabling the power-fault signal from the protective package); the K116 relay is de-energized, and it resumes the normal position shown in the schematic.

The flashed exciter generator field will produce ac power, which is rectified and impressed on the field windings of the main ac generator. Almost immediately after the Flash button is pushed, the main ac generator output will be at, or nearly at, its normal value. A tap off the Phase C output lead provides power which is rectified and impressed on the control coil of a four-pole relay (K113), known as the Voltage Regulator Enabling/Flash Cutout relay. Note that ground for this circuit is provided by one pole of the de-energized K116 master relay. The K113 enabling relay will actuate when Phase C voltage reaches about 120 volts, shunting all three phases of the ac generator output to the protective package sensing circuit. If the protective package finds voltage and frequency to be within tolerance, the "trigger" voltage disappears from the gate terminal of the under voltage SCR. A tap off the Phase A lead, adjacent to the protective package, provides power to the ac voltage regulator, which commences controlling the exciter generator field. Simultaneously a fourth pole of the K113 enabling relay opens the flash circuit.

The frequency meter will be energized from the frequency sensing circuit in the protective package, and the operator can now verify the accuracy of the tachometer before releasing the Flash button. If the frequency is out of tolerance (400 cps, plus or minus 20) it should be adjusted with the Vernier throttle, for when the Flash button is released, the protective package is again made fully operative and faulty output will promptly de-energize the ac generation system. The ac voltmeter is also operative while the Flash button is depressed, and the operator can check and adjust voltage if he wishes, but it is not likely that the voltage will be out of tolerance unless there is a serious maladjustment or malfunction. At this time, of course, the voltmeter offers the only sure evidence that the ac generation system is functioning, for there is no amperage at this time, and the frequency meter is a null-type gauge that reads approximately 400 cps when it is not energized.

Note that there is a 7-position selector switch on the control panel labelled VM-AM SEL SW (see Figures 9 and 10) which allows the operator to read amps in each phase *of each cable*; voltage in each phase *at the generator*. However, neither voltage nor amperage will register if the selector switch is in OFF position, and an operator sometimes thinks the ac generation system is inoperative when, in fact, he has neglected to select a phase position at the VM-AM selector.

The primary function of the K116 master relay can now be seen. If, at any time after the Flash button is released, the protective package senses a fault in the ac power supply, it will actuate the master relay almost immediately. This breaks the circuit which has kept the enabling relay actuated, the ac voltage regulator is disabled, all field excitation power is lost, and generator output drops to zero.

The drop-out time for frequency faults is 1 to 2 seconds. Drop-out time for voltage faults varies with the type and severity of the fault. When heavy loads are removed or applied, generator voltage will inevitably surge up or drop off until the voltage regulator can re-adjust its excitation output. The protective package will accommodate these very brief peaks, but will not tolerate them if they are sustained. Note that a short circuit within the aircraft can result in a depression of generator voltage. Since aircraft circuit-breakers also have some tolerance for brief surges, it is problematical whether the circuit-breaker will open the shorted circuit, or the protective package under-voltage drop-out will operate first.

— POWER THE DESIRED EXTENSION CABLE. The load ON and OFF circuits are quite simple, and are identical for the A and B cables. The two circuits are in parallel, Figure 8 shows the A load control and indicating circuits.

When the A cable ON switch is depressed, the K107 self-holding relay is energized, locking in the K101 relay, which transfers the 3 phase ac power to the aircraft connector plug. Note, however, that K107 relay depends upon the normally closed contacts of the master relay for a ground connection. If the protective package sensing elements detect a fault in the ac generator output and actuates the K116 master relay, the A cable holding and contactor relays (and the B cable relays as well) will open and de-energize the cables. An indicator light located adjacent to the load switch will glow when the respective connector cable is energized.

The dc generation system can be energized at any time after the ac system is energized, but it is *not* energized automatically. Pressing the DC Load ON switch closes the three contactor poles of relay K201. One pole serves to "hold" closed the K201 relay, one pole shunts power from the main ac generator to the dc voltage regulator, and the other pole provides ac ground for the regulator. As voltage from the main dc generator builds up (actually generated as 6-phase ac power, rectified to 28-V dc) it is impressed automatically on the dc extension cable, and the red indicator light adjacent to the DC load ON switch will illuminate.

Although the protective package and the master relay are not directly involved in the main dc power production, note that the dc voltage regulator is dependent on the main ac generator for its power supply, so it is not possible to use the dc generator unless the ac generation system is energized and its output is within the tolerance range allowed by the protective package.

As mentioned previously, the dc voltage regulator has an amperage limiting feature that automatically diminishes voltage in two selectable load ranges. In flight line use, aircraft engine starters are the most common loads that are severe enough to activate the current limiting circuit, causing line voltage to drop. The two limiting ranges, JET START and 'COPTER START, are keyed to the requirements of the different size starters. Without the current limiting feature, when the aircraft starter button is pushed the inrush current could reach a level that would be damaging to the starter. A power source design which limits the inrush current in this way is said to provide "soft starting" which substantially reduces the incidence of starter failures.

The current limiting feature also protects the generator against overload. Note that the dc power supply incorporates no fuse, circuit breaker, or other device to mechanically open the supply circuit.

The aircraft is protected from dc over-voltage by a time-delay relay (K202) which works through the K201 relay to deprive the dc voltage regulator of its ac power supply. A 7-volt increase — to 35 volts — in the main dc output will initiate the time-delay cycle, and the over-voltage relay will operate and de-energize the generation system if the dc output, continues at this unacceptably high level for 2 to 5 seconds. If voltages in excess of 35 are sensed, the time delay is progressively shortened.

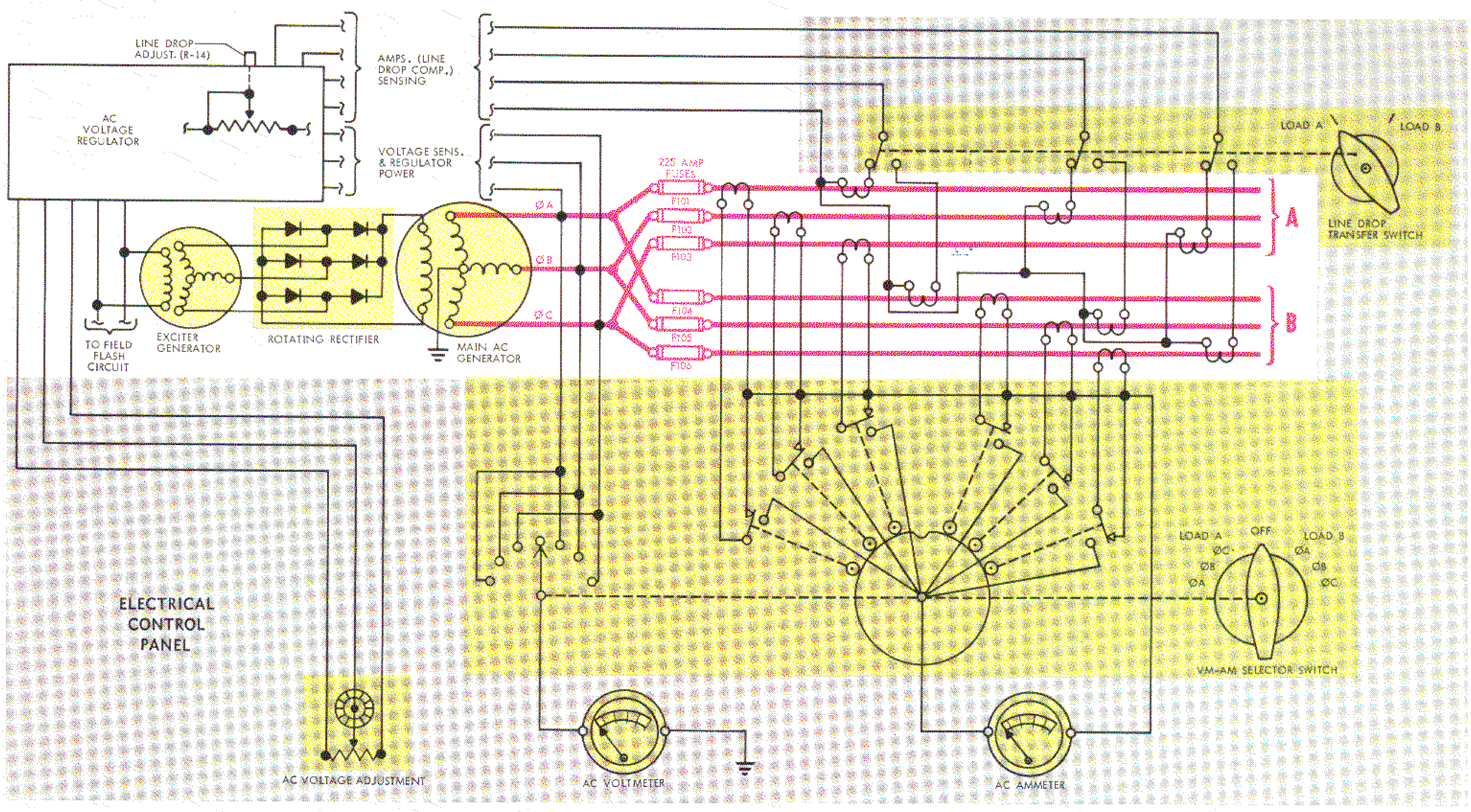


Figure 10 Schematic of AC System Selectors and Indicators

LINE DROP COMPENSATION

The amount of voltage lost between generator and bus is constant *only* if the load and the cable dimensions are constant. Since loads vary considerably, there can be a variation in bus voltage that would be significant to sensitive ac components, even though the power unit voltage regulator holds the generator output voltage to a constant value. For this reason, the NC-12A regulators have automatic compensation features that take load (amperage) variations into account and varies voltage *at the generator* to prevent variation *at the airplane bus.*

Since there are two cables connected to a single generator in the ac system, the operator must choose which cable load is to be compensated. For example, if both connectors are to be used, and it is thought preferable to maintain the closest tolerance on airplane "A", the operator should select LOAD A at the Line Drop Transf. selector (see Figure 9) and set the voltage at 115 with the A cable energized, but carrying no load. Thereafter, current flow in the A cable will create a proportional signal in current transformers which sense current flow through the three phase wires of the cable, and this signal will induce the voltage regulator to increase generator voltage as necessary to compensate for the loss in the A cable. Thus, the voltage read at the control panel will appear to be slightly too high while the cable selected as "master" is carrying an appreciable load, and, unfortunately, the other cable's voltage is "slaved" to this. However, the effect on the slaved airplane bus voltage will be almost imperceptible unless there is a great difference between the amount of current being fed to the two airplanes.

If two Orions, parked abreast, are to be powered from a single power plant, it will be necessary to add an extension to at least one cable, but note that the compensation system was designed for symmetrical cables, and is adjusted at the factory to allow for the voltage drop characteristic to the 25-foot lengths provided. The compensating system can be re-adjusted to allow for a longer cable, but if asymmetrical cables are employed, the discrepancy in bus voltage will be aggravated. Therefore, if the power unit is customarily used to power two large wing-span aircraft it will be most logical to add equal extensions to both ac cables, and recalibrate the ac voltage regulator to allow for the additional resistance. This is done quite easily by applying an extremely accurate voltmeter to a moderately loaded bus (50 to 100 amps as read on the NC-12A ammeter) supported by one of the extended cables, and turning the compensator adjustment shown in Figure 11 until the *bus voltage* reads 115. The manual ac voltage adjustment knob on the face of the control panel should be set at mid-range before re-adjusting the compensator. After the adjustment is made, substitute the other cable and check that its resistance characteristics are similar. For best accuracy, all the electrical components should be at normal operating temperature, for resistance values throughout the unit will be abnormally low if components are abnormally cool.

A check of the voltage compensation system should also be made if a replacement cable is installed, and in view of the fact that resistance values tend to increase with age, it will be best to check the system at least once a year even if no components are replaced.

The machine has demonstrated an amazing ability to maintain steady voltage and frequency at the aircraft bus under varying load conditions, provided that the line drop compensator has been recently adjusted under representative conditions. If an extremely high order of accuracy is required for test purposes, a machine that is in good condition and that has been recently adjusted as described above can be depended upon to maintain frequency and voltage at the bus — under the most severe load changes — within 1% of the nominal value, that is, 396 to 404 cps; 113.8 to 116.2 volts.

The dc generation system has a similar circuit to offset voltage loss in transmission, but it is simpler because of the single cable. Except for load and voltage values, the procedure for adjusting the compensator is the same as for the ac system. The potentiometer adjustment is identified R316 Line Drop Comp. Set (see Figure 11) on the dc regulator.

GENERAL SERVICE INFORMATION

ENGINE CLEAN-OUT The NC-12A promises to have a lengthy useful life, for it has more than enough power for the sizeable demands of two Orions, and it is not likely that new aircraft designs will over-tax the machine. Indeed, in use with the Orion the machine ordinarily uses such a small fraction of the engine's horsepower that it is necessary to periodically take the reserve horses out for exercise. If the diesel is used at low power, especially at IDLE speed, for protracted periods, carbon sludge accumulates in the cylinders and in the exhausts and eventually serious trouble may result.* When heavy sludge deposits are seen in the exhaust stacks, the portended trouble can be avoided by a short run at high power. At high power, the various engine components will soon reach the operating temperatures for which they were designed and the carbon deposits will burn out, and/or be loosened enough to blow out the exhaust stacks.*

It would certainly *not* be advisable to utilize aircraft components just to exercise a diesel engine, nor is a flight line the ideal place to spread burning specks of carbon. We suggest that the machine be removed from the flight line, and that one or more load banks be used to obtain the high power setting. It is not necessary to load the machine 100% for clean-out purposes, but a load well above 50% should be imposed, so it will be preferable to connect at least two cables to load banks in order to obtain a high engine load while allowing a safety margin for the cables.

Of course, ac and dc load banks could be used in combination, and the load could be applied in an infinite combination of ways. It seems likely, however, that ac load banks only will be used, and resistance loads will be applied. If the load is to be measured with the NC-12A ammeter, note that the ammeter will measure the amperage in only one phase of one cable at a time. With such a set-up, if only one cable can be used do not exceed 200 amps. This allows some safety margin for the cable, but represents only a moderate load on the diesel power plant.

If two load banks of 45 or more kw rating are available, an optimum clean-out load can be imposed. Assuming that purely resistive loads are applied equally to both cables, the ammeter will read 125 amps on each phase of the "A" cable and the "B" cable when the engine is operating nearly at top power.

The engine cooling system is more than ample for normal operation when it is new, and the occasional high-power run will test that it has not deteriorated. It is good procedure in normal operation, and especially important after a high power run, to allow the engine to operate a few minutes at IDLE before shutting down. This will allow the cooling system to stabilize temperatures within the engine, and ensure against boiling after shutdown.

**Service experience to date shows that the activities using MIL-J-5624 (jet) fuels have less sludging problems than those using diesel fuels.*

**At this writing, more detailed procedures are being worked out for conducting the engine clean-out without igniting hazardous and damaging stack fires. Consult the latest official instructions before attempting the clean-out operation.*

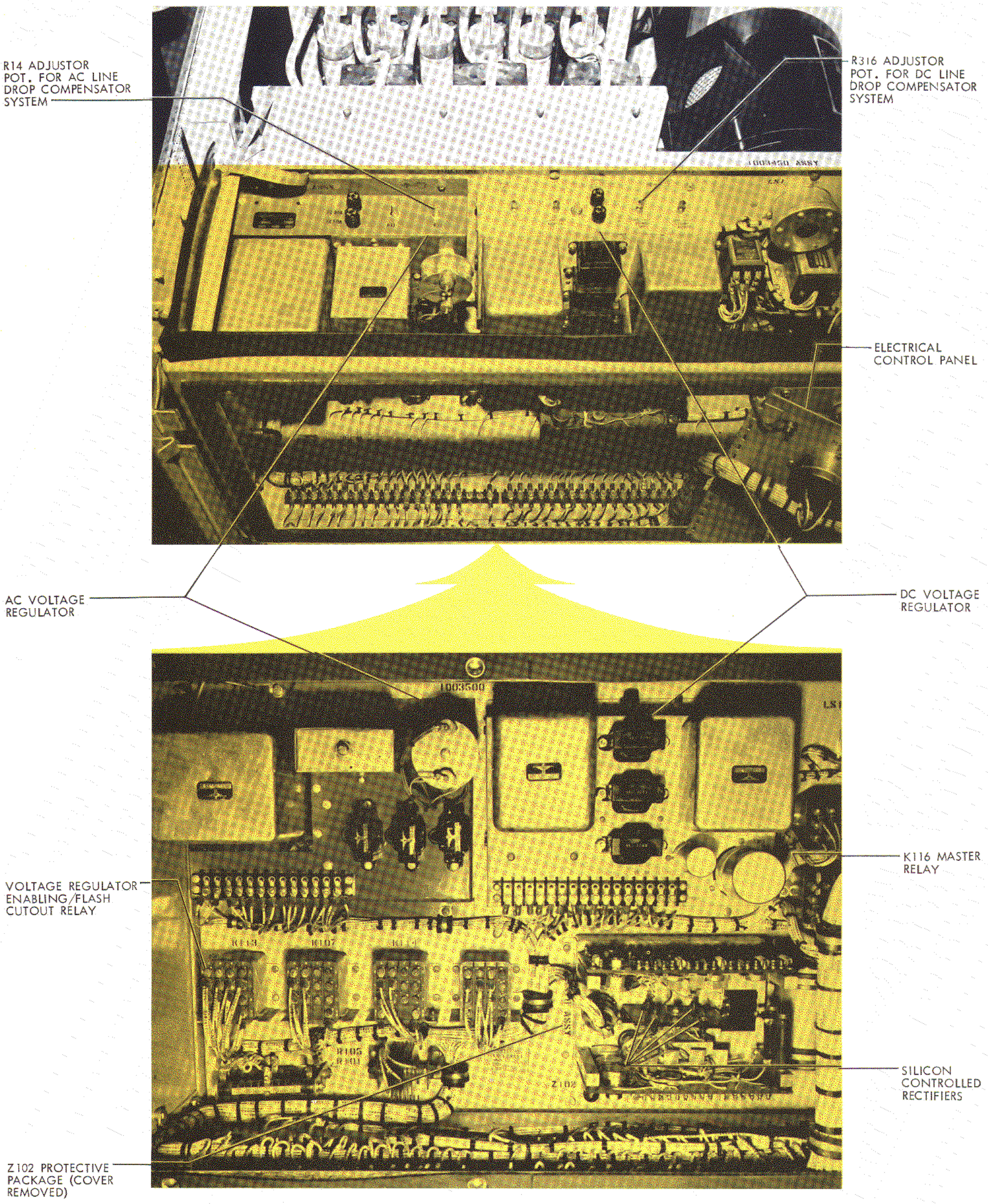


Figure 11 Views Looking Down and Inboard at Components Behind the Electrical Control Panel

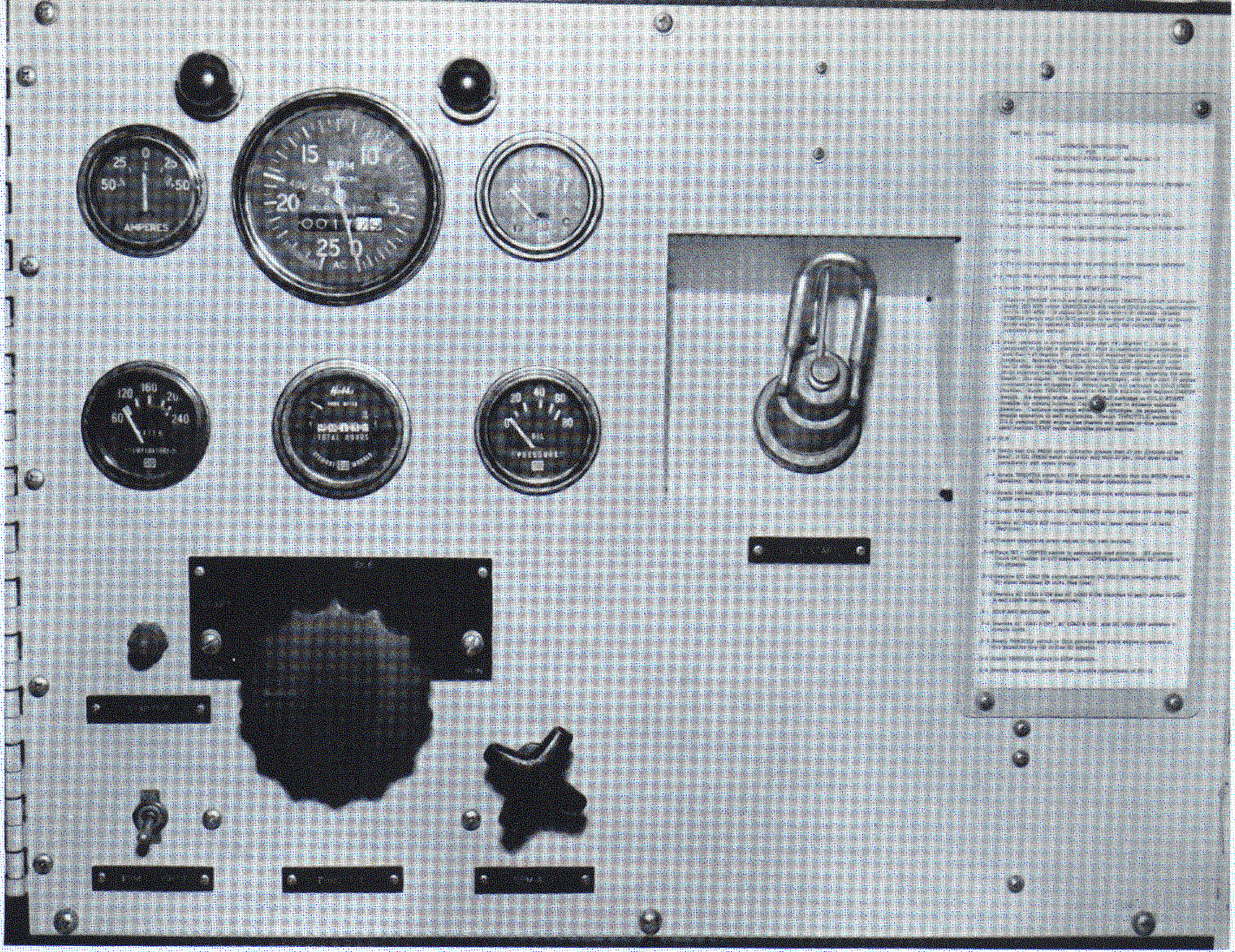


Figure 12 Engine Controls and Indicators

TIPS ON COLD ENGINE STARTS In preparing this article, we asked Mr. Werner Schwenzfeier, a GM Diesel expert who has started the NC-12A repeatedly in sub-zero temperature, to comment on the problem of cold weather starting. He stated that the procedure described in the Engine discussion (and outlined on the engine control panel placard) is correct in its essentials, but cautioned against unnecessarily abusing the engine with too much ether and over-acceleration of a cold, dry engine. When injecting ether into the inlet air duct before start, he believes the rule — one cartridge per each 10°F below 40 — should be followed, but that 4 cartridges are the most that should be used, regardless of the temperature. After the engine begins to fire — however erratically — more cartridges can be injected as necessary to achieve steady operation. (Expended cartridges should be removed promptly to avoid sticking.)

Further, Mr. Schwenzfeier points out that although every ether-enriched start of a V-71 engine should be made with the fuel control at "full-fuel" position, the combination of throttle and governor used in the NC-12A installation will provide full-fuel just as quickly and effectively with the throttle selected to IDLE as it will at RUN position. Therefore, if IDLE throttle is used for the cold start, the combustion mixture will be correct and the engine will automatically be spared a full-power acceleration to top speed.

TROUBLE SHOOTING In view of the many automatic protective devices on the unit, it is to be expected that it will occasionally be necessary to locate the cause of a partial or total shutdown. It is beyond the scope of this article to define specific trouble shooting procedures, but the following paragraphs describe some logical approaches if there are no obvious visual clues:

Over-voltage is the only type of dc power fault for which automatic protection is afforded. If dc power is lost during use, the cause most probably originated in dc over-voltage unless ac voltage is lost also. A possible exception would be the case in which someone inadvertently pushed the Field Flash button. This would have the effect of simultaneously de-energizing all three connector cables, but the ac voltage at the power unit would return to normal when the button was released.

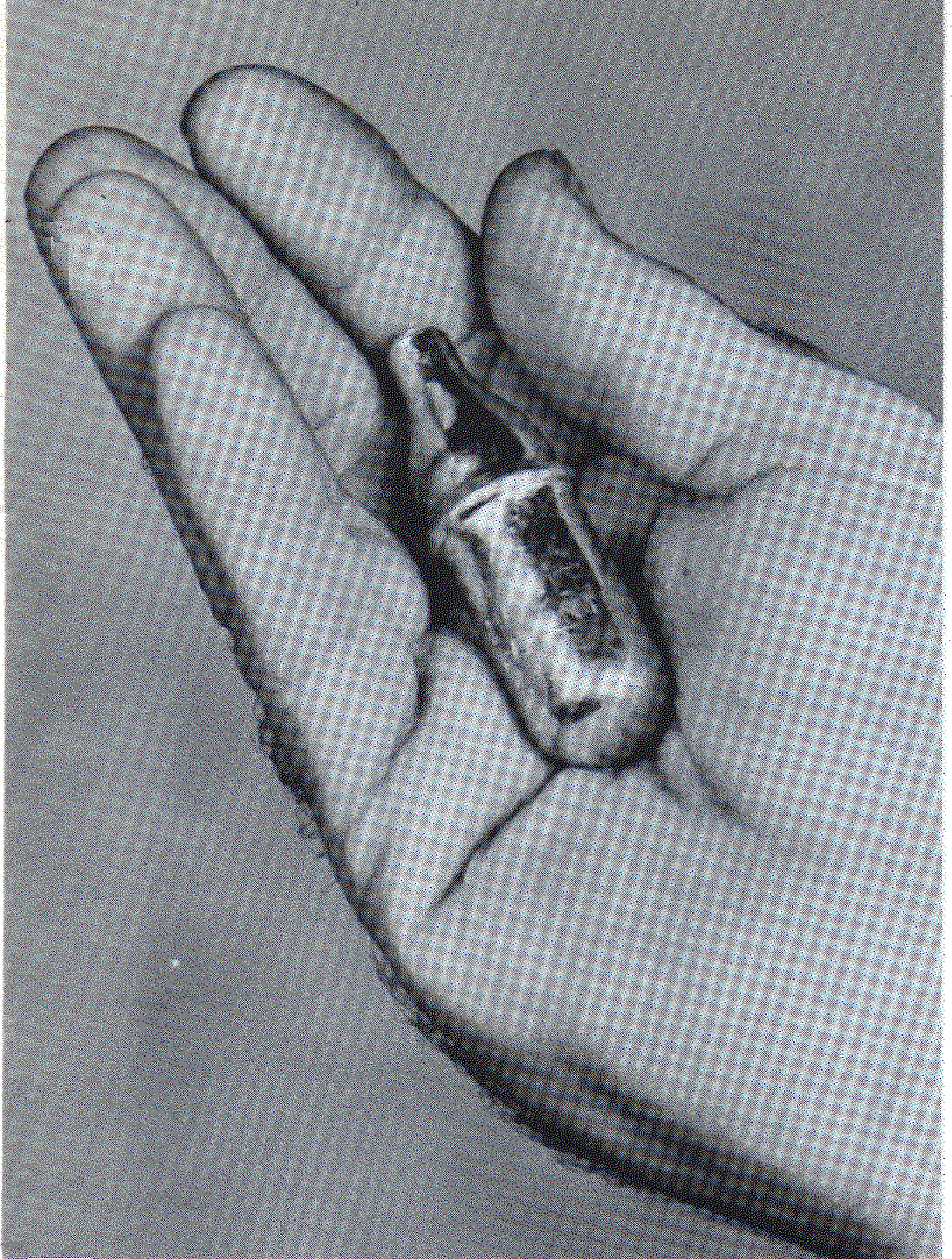


Figure 13 Ether Cartridge, Cold-Weather Starting Aid for NC-12A

A fault in ac voltage or frequency will completely de-energize the ac and dc generation systems. If this occurs, the operator should be particularly cautious. A short circuit in the aircraft may have induced an undervoltage shutdown, and if so, the fault must still exist. The safest and easiest course will be to remove the external power connectors from the aircraft and investigate the power unit separately. Then, if there are no apparent engine difficulties, the Field Flash button can be pushed (and held down, if necessary) to investigate the ac voltage and frequency. If the voltage cycles repeatedly while the button is held down, building up to 80 or 90 volts before dropping back, a failure of the ac voltage regulator is indicated.

If voltage and frequency appear normal while the Field Flash button is held down, but voltage drops to zero when the button is released, the protective package is probably at fault.

If all results are normal when the Field Flash button is operated, and (assuming that the cables are disconnected from the aircraft) if the cables draw no amperage when power is applied to them, the trouble must have originated in a circuit fault in the aircraft, or in a momentary fault which occurs when the generators are loaded, most probably of a mechanical nature. We suggest that it would be wisest to investigate the aircraft concerned and eliminate the possibility of short circuits before re-energizing aircraft buses.

Should the engine die while under load, the ordinary causes (water, oil, and fuel supplies) can be quickly checked, but we wish to point out one important item that should always be checked before attempting to restart the engine:

The engine speed will normally never exceed about 2000 rpm, but if it does overspeed, a final and supremely important protective device is operated by the 2300 rpm switch shown in the Figure 8 schematic. At 2300 rpm this switch will transfer from its normal position, initiating the engine shutdown by dumping governor oil pressure just as is done in the normal shutdown when the throttle is moved below the IDLE position. When the switch transfers, it also momentarily energizes a solenoid which allows a gate valve in the engine air intake duct to close, and the engine is starved of air. This is necessary because the governor/fuel injection system has already demonstrated its inability to control speed by controlling fuel and cannot be depended upon to shut down the engine. The only sure way to prevent the engine from running to destruction is to starve it of oxygen. The engine air intake valve is in prominent view (see Figure 2) and can be manually opened and the solenoid reset quite easily, but if the engine has shutdown and this valve is found to be closed *do not defeat this safety device and start the engine until the cause of the overspeed is found and rectified.* A closed air intake valve must be considered as a warning that the engine speed cannot be controlled.

Shut-down by air starvation is to be regarded as an automatic, last-ditch emergency function, and it is not good practice to artificially induce such a shutdown just to demonstrate the function. The blower, which is downstream of the gate valve, has oil seals which are primarily designed to seal engine oil pressure against normal positive blower pressure. When the gate valve closes with the engine running at high speed, the blower will induce negative pressure, and there is some chance that the seals will be weakened or damaged.

Recently, Lockheed Product Support Organization obtained a new NC-12A, and field service personnel experimented with it to learn its intricacies. When it arrived, the machine was "pickled"—just as it comes from the factory—and in putting it into operation we encountered two temporary difficulties which may be peculiar to this particular machine, but it seems reasonable that one or both may be common to other power plants, and other operators may benefit from our experience.

The initial start and warm up was normal and uneventful, but after a few minutes at RUN speed, and under load, the engine died momentarily, and the cycle repeated at random intervals. The engine never labored—it died cleanly and recovered cleanly, giving classic symptoms of water or air in the fuel or in the governing oil pressure. Surprisingly, the trouble stemmed from the cooling system.

In the initial filling of a totally empty cooling system, it is not possible to provide enough water for continuous running, due to the fact that the thermostat valves will be closed and little or no water will reach the radiators. When the thermostat valves open, the reserve supply will drain into the system, but this is not sufficient to prevent the water pump from cavitating, causing momentary interruptions in the coolant flow. On our experimental machine, the coolant temperature sensing switch, reacting to a reduced flow of hot water followed by a sharp return to normal flow and temperature, opened and closed accordingly and governor control pressure was first dumped, then re-established before the engine could die completely. When engine power cycles, the power generators may be de-energized by the protective package because of the drop in ac frequency, and once the engine is relieved of its load it may run quite normally.

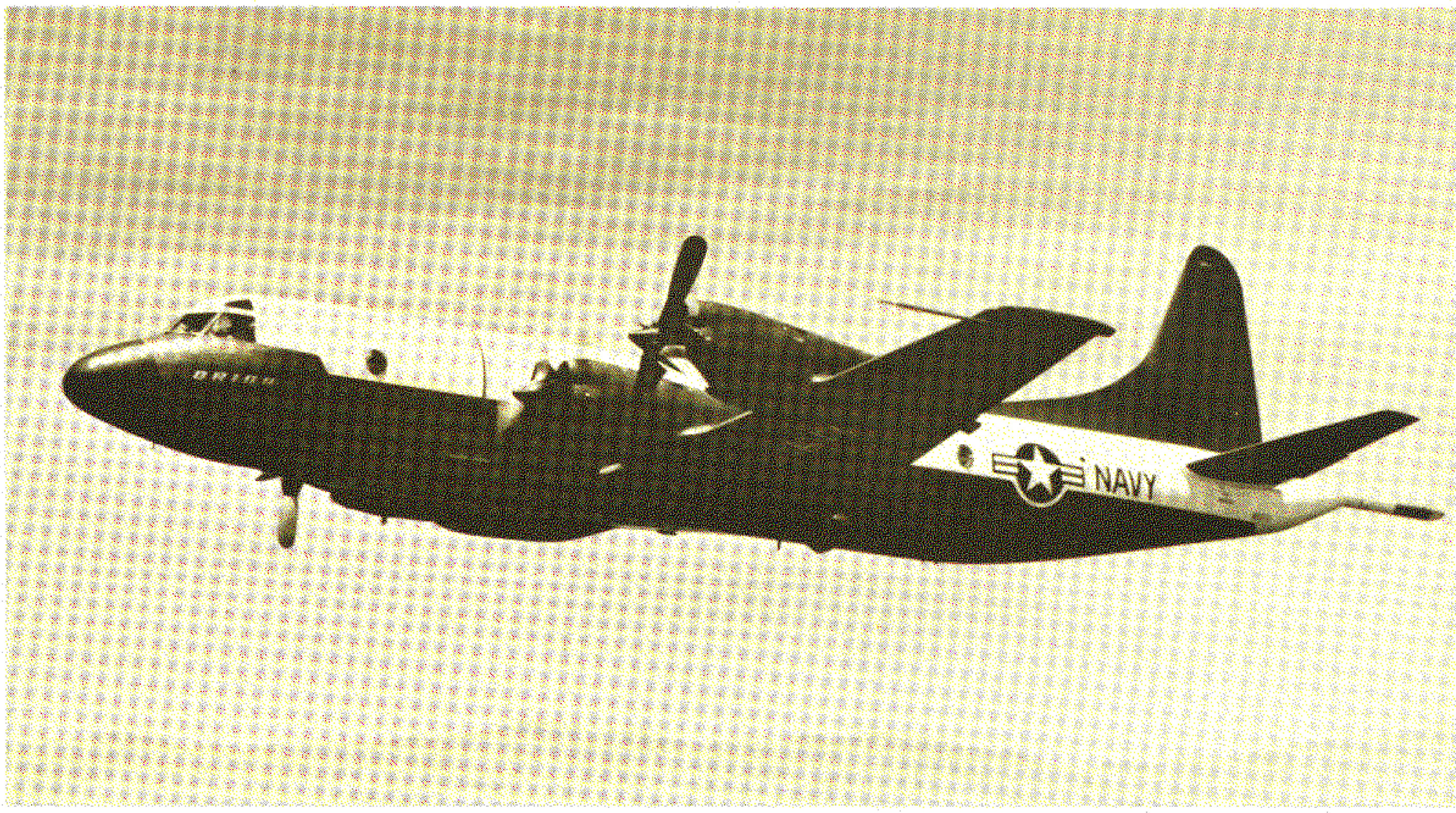
Such troubles will be infrequent, of course, for there is seldom any reason to drain and refill the radiator.

A word of caution: DO NOT OVERFLOW THE TANK. Electrical components, including the HR2 starter protector, are mounted below the reserve water tank, and sloppy over-filling can cause as much trouble as under-filling.

The second trouble we encountered with our experimental unit appeared to be a serious malfunction at first, for the dc generation system initially refused to build up normal voltage, but in fact this was due to a natural trait of the dc voltage regulator, interacting with the ac generating system.

It is, surprisingly, characteristic of this voltage regulator that a reduction in its ac power supply voltage below 115 actually promotes the initial build-up of excitation power; a slight elevation above 115 will slow the initial build-up; an appreciable elevation may totally block it. This phenomenon has no significance normally, and even if a machine does evidence trouble as described above, the cure is so elementally simple that it will present no difficulty, provided, of course, that the operator knows the nature of the dc regulator beforehand. We suggest that, *if the dc generator voltage does not build up promptly when the DC Load ON button is pushed, the operator should first reduce ac voltage,* (turn the AC Volt Adj. knob to the left) *then return it immediately to its original setting.*

Note that voltage at the ac generator can be elevated appreciably by the automatic line-drop compensating feature, and it is a normal—even desirable—inter-action that temporarily blocks out the dc generation system while the ac system is heavily loaded. After the dc regulator completes its initial build-up of excitation output, it loses its sensitivity to power supply voltage, and subsequent variations of voltage at the ac generator will not adversely affect the dc system. ▲ ▲



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Patuxent River NAS, Maryland	F. Hampton, Resident Rep.	P.O. Box 218, NATC Patuxent River, Maryland	Volunteer 3-3111 Ext. 645 or 251
Patuxent River NAS, Maryland	T. Snelling, Resident Rep.	P.O. Box 218, NATC Patuxent River, Maryland	Volunteer 3-3111 Ext. 645 or 251
Norfolk NAS, Virginia	A. Barber, Resident Rep.	P.O. Box 8127, Ocean View Station Norfolk 3, Virginia	622-8211 Ext. 2685
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