

THE INSTALLATION AND CALIBRATION OF
A DYNAMOMETER TEST CELL

by

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A THESIS

submitted to

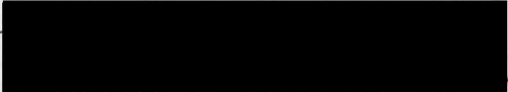
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THE INSTALLATION AND CALIBRATION OF A DYNAMOMETER TEST CELL

I. INTRODUCTION

The project consisted of adapting, installing, and calibrating a test cell built by the Packard Motor Car Company to fit the requirements of the Oregon State College aeronautical laboratory. The equipment consisted of most of the necessary parts used by the Packard Company in their test cells. These test cells were used to run-in and test Rolls-Royce, Model V-1650-3&7 aircraft engines, manufactured by the Packard Company during World War II.

The installation embodied many changes due to the many differences in the type of location and requirements as compared to those of the Packard Company.

The foundations for the dynamometer base and engine bed plates were the first concern. By referring to the Packard blueprints, the relative position of each plate and the size and thickness of the base or foundations were determined. Working with these requirements in mind, the dynamometer was mounted on a base constructed upon the existing building floor, and the engine bed plates were mounted upon a base constructed below the floor level. To accommodate the bed plates, a section of the existing floor was removed.

Adaptation of the exhaust system was undertaken next. Since the requirements of our installation include primarily engine test methods, the exhaust system was completely changed. To facilitate exhaust removal, to cut down engine back pressures, and as an aid in simulating altitude conditions, the exhaust system was converted

to an induction-type system.

The air-intake system, as received, did not have any provision for throttling the amount of air entering the engine carburetor. Since this is necessary for altitude simulation, a butterfly valve was constructed and mounted in the duct leading to the carburetor.

In the fuel system used by Packard, fuels of three separate octane ratings were used for engine run-in. Since the use of different types of fuel is unnecessary in the installation as required at Oregon State College, the system was changed so that one fuel only could be used. The Packard Company used two complete oil systems; one for engine operation, and one for flushing the engine with clean oil upon completing a run-in. In our case, the requirements for the oil system are: A means of measuring consumption, a means of cooling, and a filter to remove dirt from the oil. The oil system was constructed to meet these requirements.

The engine coolant system, as used by Packard, consisted of a glycol solution for cooling the engine, which was in turn cooled by water through a heat exchanger. Because of the cost and amount of equipment available, it was decided that water would be a more satisfactory and cheaper method of cooling. Therefore, water is piped directly to the engine coolant pump.

Wiring systems of the unit were changed to fit the electric power sources available. Three electrical systems were required; 110-volt A-C, 230-volt D-C, and 24-volt D-C. 110-volt power was obtained from the existing supply. 230-volt power was obtained by installing a motor-generator set. 24-volt power was obtained through

use of batteries and the engine generator.

II. DYNAMOMETER

The power absorption unit of the test cell is a Midwest Dynamatic Eddy Current Dynamometer in which all of the energy generated is absorbed as heat and removed by running water through channels in the stator. This unit will absorb 2000 horsepower at a rotor speed of 2000 RPM. Used in conjunction with the dynamometer is a Kron weigh scale for determining the torque being absorbed by the dynamometer. By use of a dynamatic stator-mounted exciter, excitation for the dynamometer field is obtained from the engine being tested. The power thus used will register properly on the scale; therefore the exciter becomes a minor power absorption unit.

The dynamometer and weigh scales are mounted on a single base. The installation involves locating this base at a proper level and in a secure manner. The dynamometer and torque-scale base are mounted upon a seven-inch concrete bed which was built on the existing floor of the building. The base is held to the floor and concrete bed by means of one-inch machine bolts; eight in number. These bolts are secured in the building floor with Leadite.

The dynamometer exciter is a separately excited generator and uses a 250-volt, four ampere, direct current supply for excitation. To obtain this amount of direct current, it was necessary to install a motor-generator set with a capacity of 250 volts and six amperes. The controls for the motor-generator set are located in the control

room.

The Kron weigh scale is coupled directly to the dynamometer stator. The stator is made so that the lever arm used will be 31.5 inches in length. Figure 1 shows the torque scale and dynamometer.

III. ENGINE MOUNTING SYSTEM

The engine mounting system is composed of two bed plates, two cross members, and an engine mount. The engine mount is bolted to the cross members which are supported by the bed plates. The mounting system is constructed in such a manner that adjustment for engine and dynamometer shaft alignment may be made in any direction. Axial adjustment may be made by using tracks in the bed plates, horizontal and right-angle adjustment by tracks in the cross members, and vertical adjustment by using the slotted holes through which the engine-mount bolts run.

The installation of the engine-mounting system consisted of constructing a six-inch concrete base upon which the engine bed plates were mounted. To obtain the proper elevation relative to the dynamometer base, the engine bed plates were sunk three inches into the existing building floor. The bed plates are secured in place with sixteen, one-inch bolts; each bed plate requiring eight bolts. After installing the bed plates, the cross members and engine mount were placed in position. Figures 2 and 3 show the engine mounted in position.

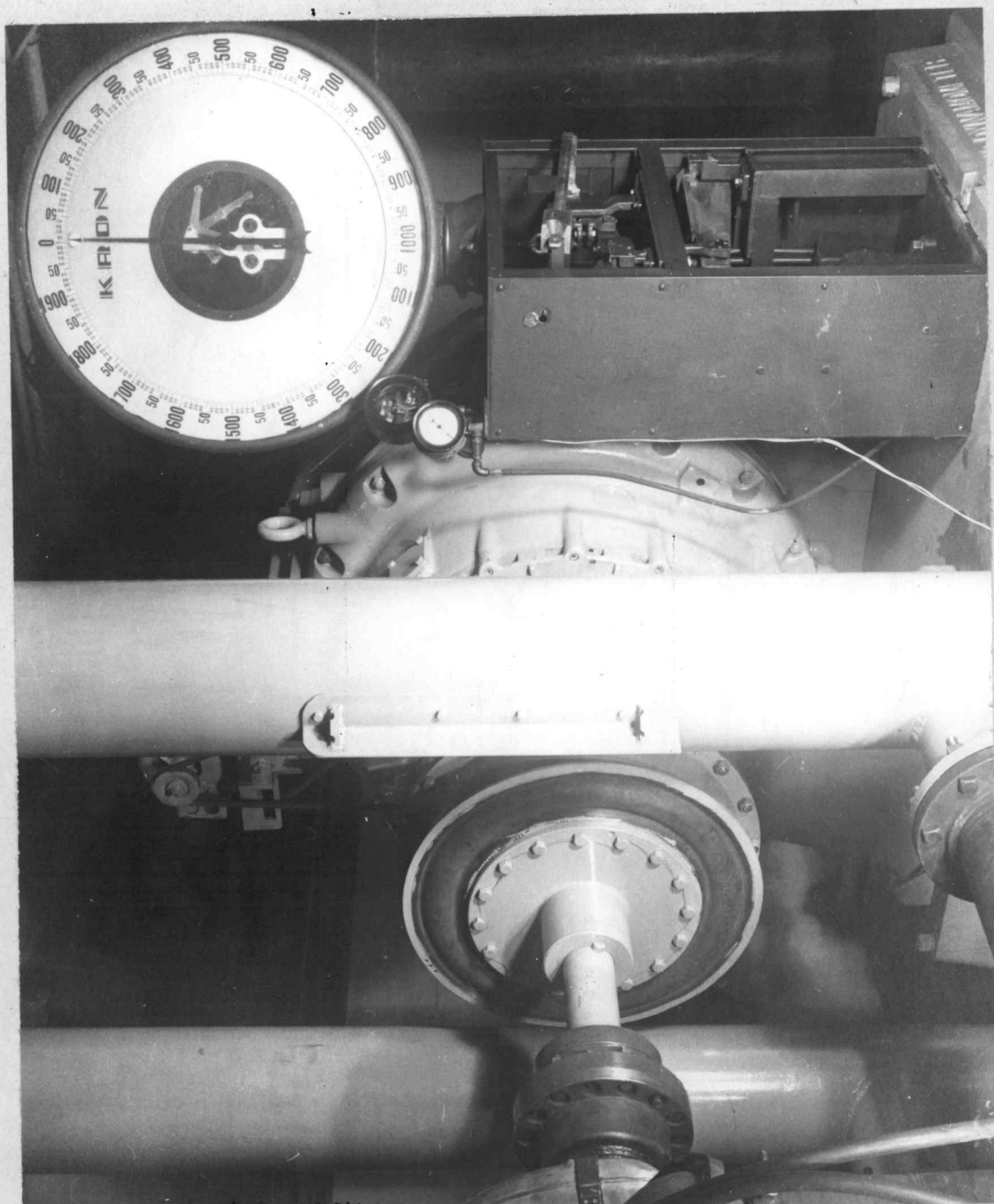
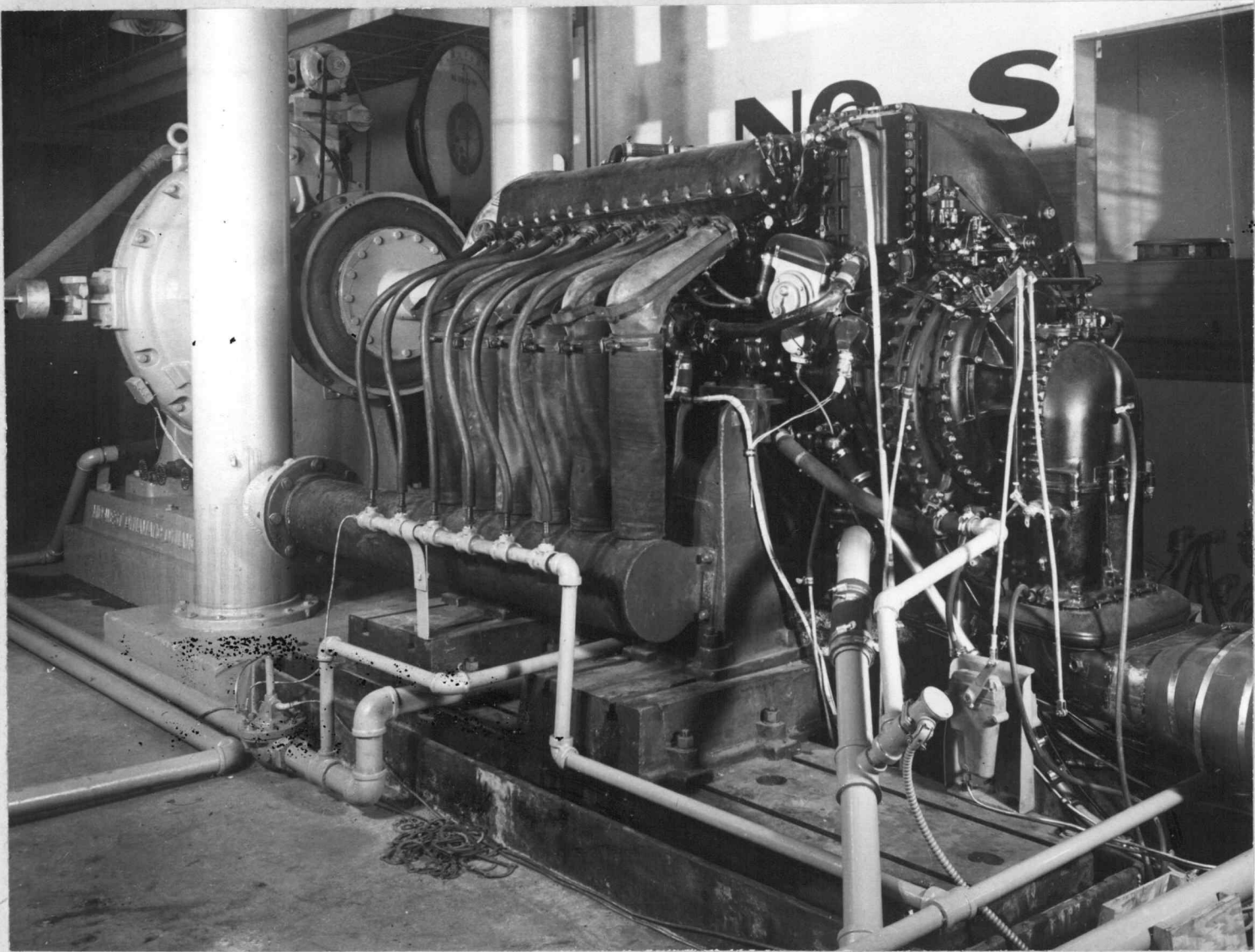


Figure 1. Photograph of Dynamometer and Torque Scale.

Figure 2. Photograph of Left Side of Engine.



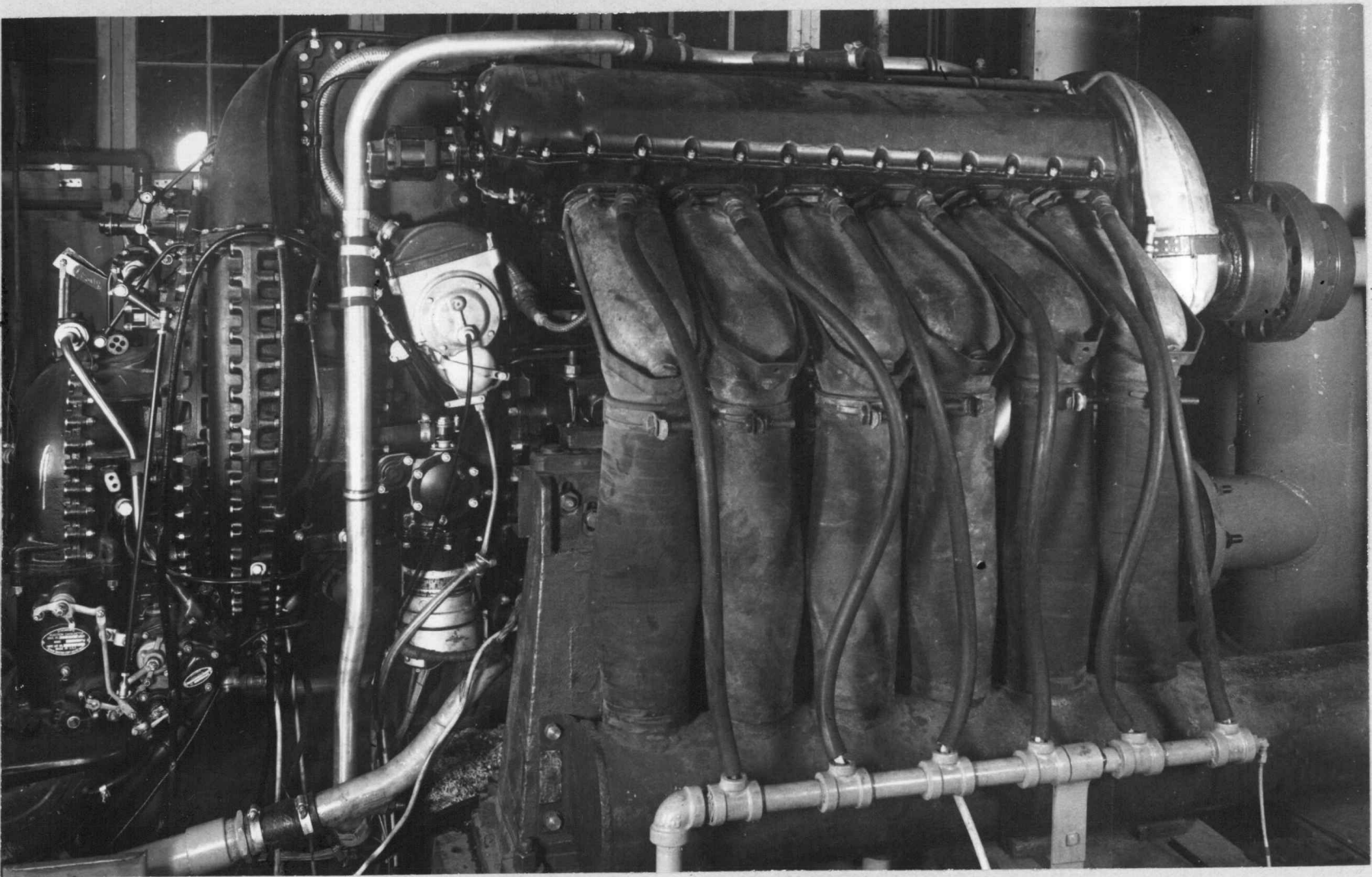


Figure 3. Photograph of Right Side of Engine.

IV. ENGINE EXHAUST SYSTEM

The exhaust system consists of an individual water-cooled stack for each cylinder, two collector pipes, a main duct leading out of the building, and an electrically-driven fan.

The water-cooled stacks are coupled directly to the engine exhaust ports and flexible connectors join the stacks to the collector pipes mounted on each side of the engine. The collector pipes are joined to the main duct leading out of the building. An electrically-driven fan is located in the main duct. The fan causes a low-pressure area by blowing air past a modified venturi; thus drawing the exhaust gases through the system. The exhaust system is diagramed in Figure 4.

V. AIR INTAKE SYSTEM

The air intake system is composed of an air-surge tank, an air-metering bottle, a seven-inch flow nozzle, a screened entry box, and a duct leading to the carburetor and containing a butterfly valve.

The air is inducted into the entry box and then through the flow nozzle, where the amount of airflow can be measured. The air then goes through the metering bottle, the surge tank, and into the carburetor.

The purpose of the butterfly valve in the air intake is to throttle the amount of air entering the engine in order to simulate altitude conditions. The control for the butterfly valve is a

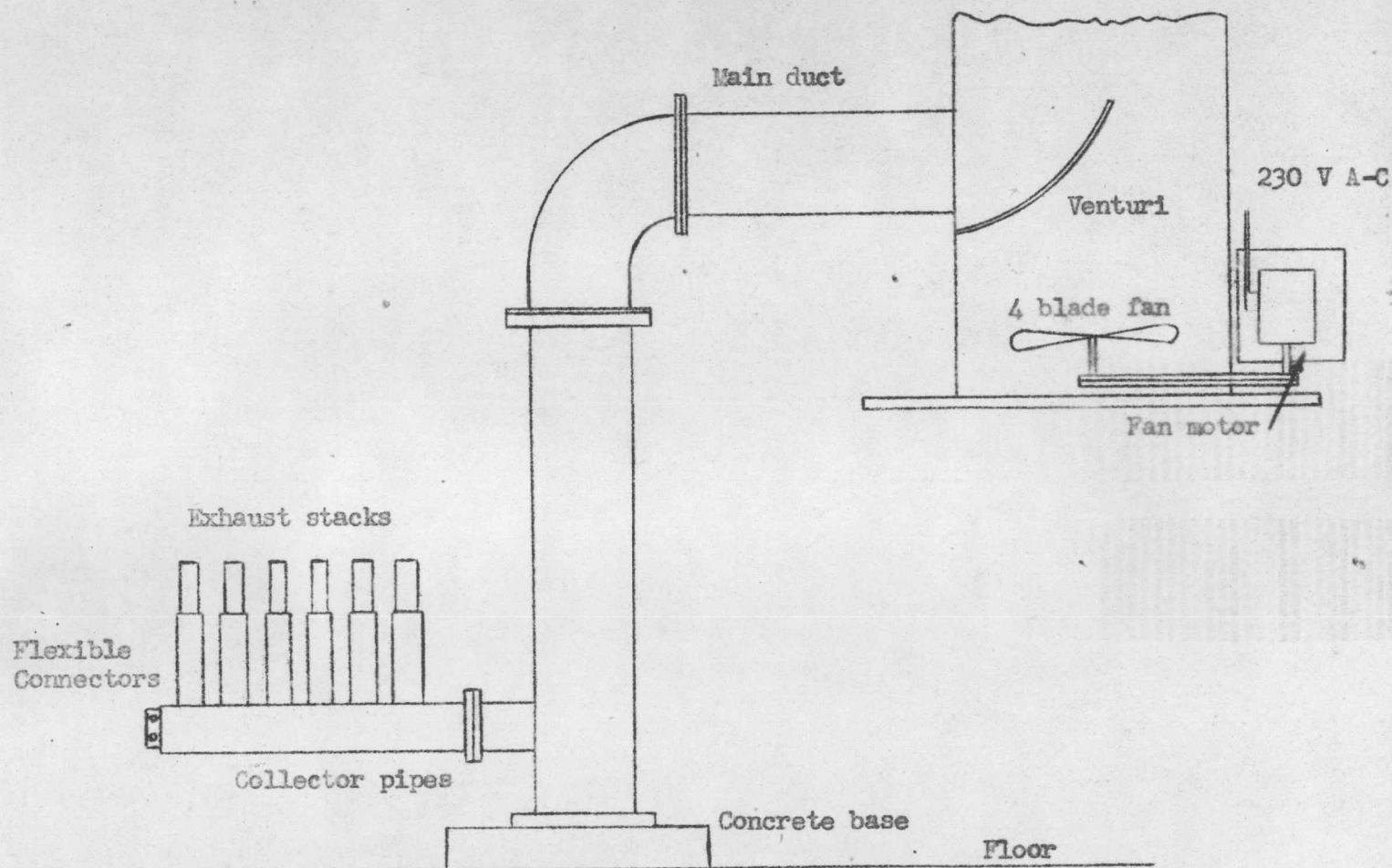


Figure 4. Schematic Diagram of Exhaust System.

Sperry Hydraulic type, the master control being located on the control panel.

Figure 5 is a diagram of the air-intake system.

VI. FUEL SYSTEM

At the time of this writing, the fuel system is composed of an 80-gallon supply tank, a fuel booster pump, a fuel shut-off valve, a fuel strainer, a 50-pound capacity fuel weigh tank, a Toledo Electric Eye weigh scale, and two rotameters that are connected in parallel.

The fuel is pumped by the booster pump from the supply tank to the weigh tank. The shut-off valve and strainer are located between the supply and weigh tanks. From the weigh tank fuel flows through the rotameters to the engine-driven pump, and then to the carburetor. The two rotameters are connected in parallel so that either the high or low-range instrument can be used.

The fuel rotameters, shown in Figure 21, are located in the control room. The fuel lines are of three-quarter inch aluminum aircraft tubing, with three-quarter inch aromatic hose used for flexible connectors. A schematic diagram of the fuel system is shown in Figure 6.

The supply tank and weigh scale are installed in the southwest corner of the engine room, as shown in Figure 7.

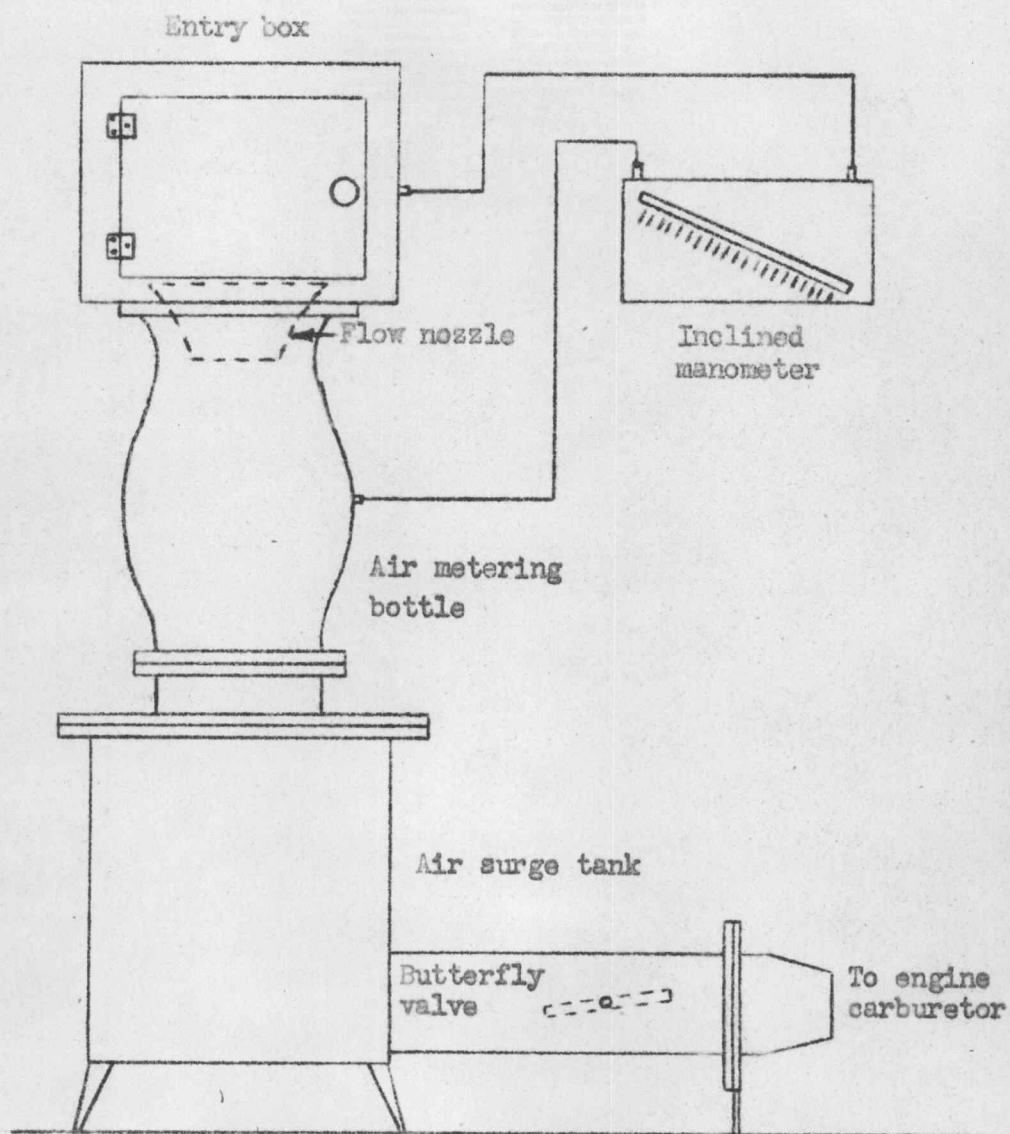


Figure 5. Schematic Diagram of Air Intake System.

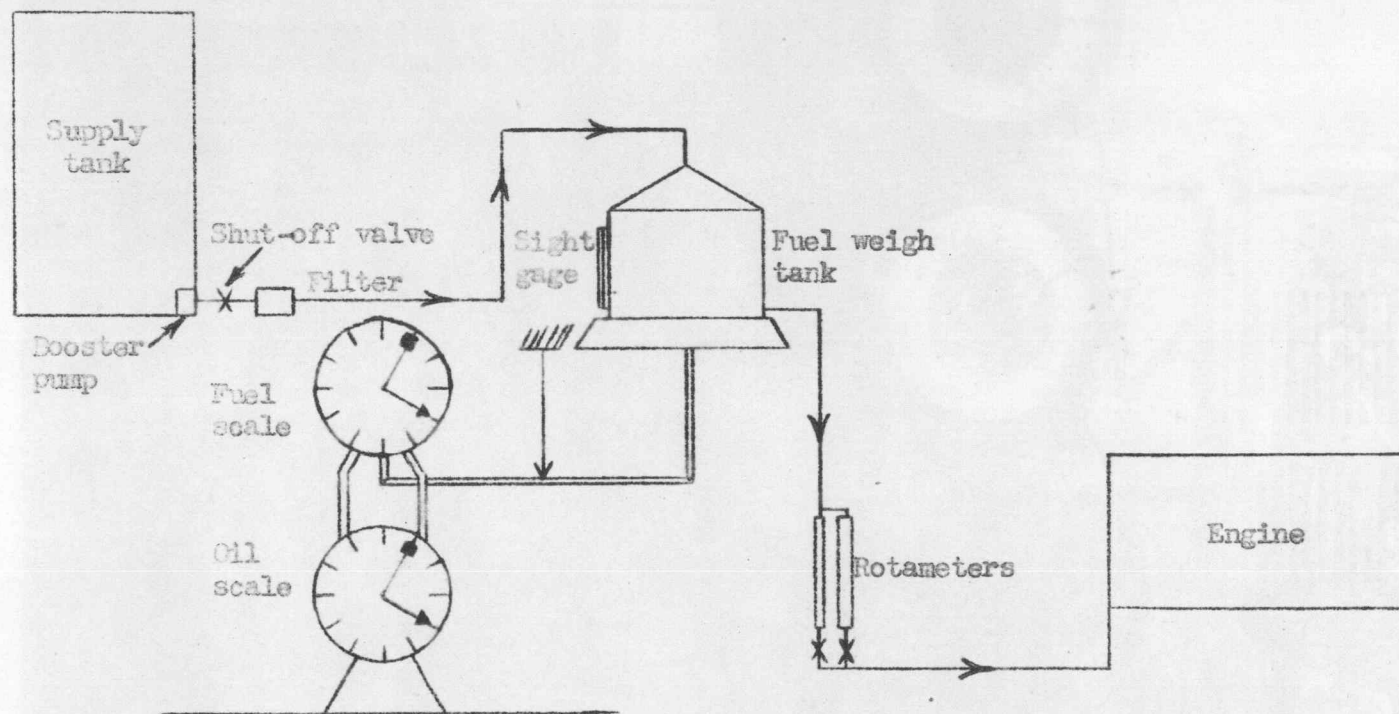


Figure 6. Schematic Diagram of Fuel System.

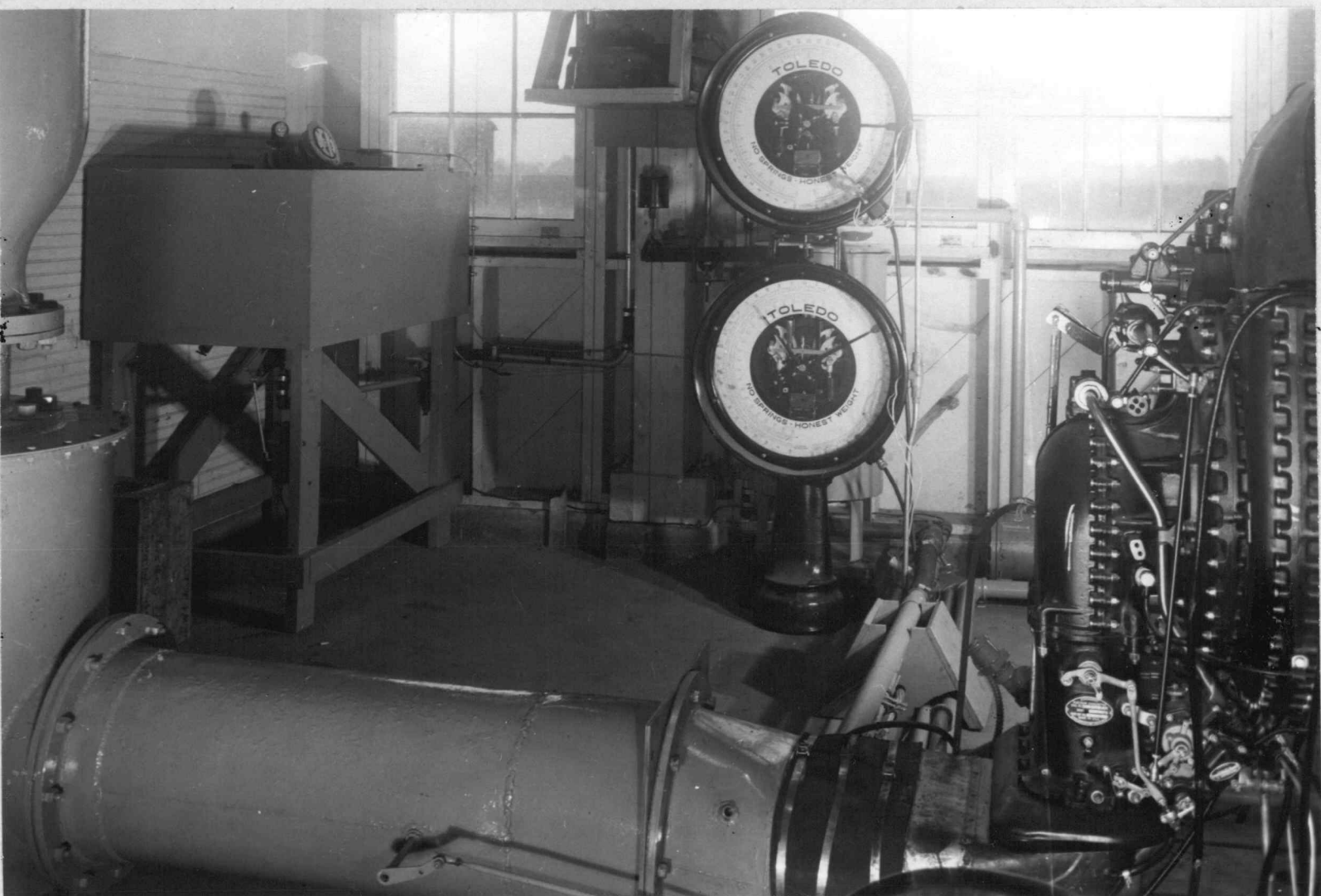


Figure 7. Photograph of Fuel Weigh Tank and Scales.

VII. OIL SYSTEM

The oil system is composed of a 40-gallon supply tank mounted on the oil weigh scale, and which also serves as the oil weigh tank, a cuno oil filter, and an oil cooler.

The oil passes from the supply tank to the engine-driven pump, and from the engine scavenge oil pump through the cuno oil filter, the oil cooler, and back to the supply tank.

The oil weigh scale and supply tank are installed in the same place as the fuel weigh scale since the fuel weigh scale is mounted on top of the oil weigh scale.

Oil is piped from the supply tank to the engine-driven pump by a two-inch line. A one and one-half inch line returns oil from the engine, through the filter and heat exchanger, to the supply tank. Figure 8 shows a diagram of the oil system. Figure 9 is a photograph of the oil cooler, filter, and oil cooling water valve.

Operating in conjunction with the oil system are pressure switches that ground the engine magnetos in case the oil pressure drops too low.

VIII. COOLANT SYSTEM

Water is used for cooling the dynamometer, the engine, the oil heat exchanger, and the exhaust stacks. Air-operated valves are used for regulating the flow of water through each division of the system.

A one-inch line supplies water to the oil cooler, a two-inch

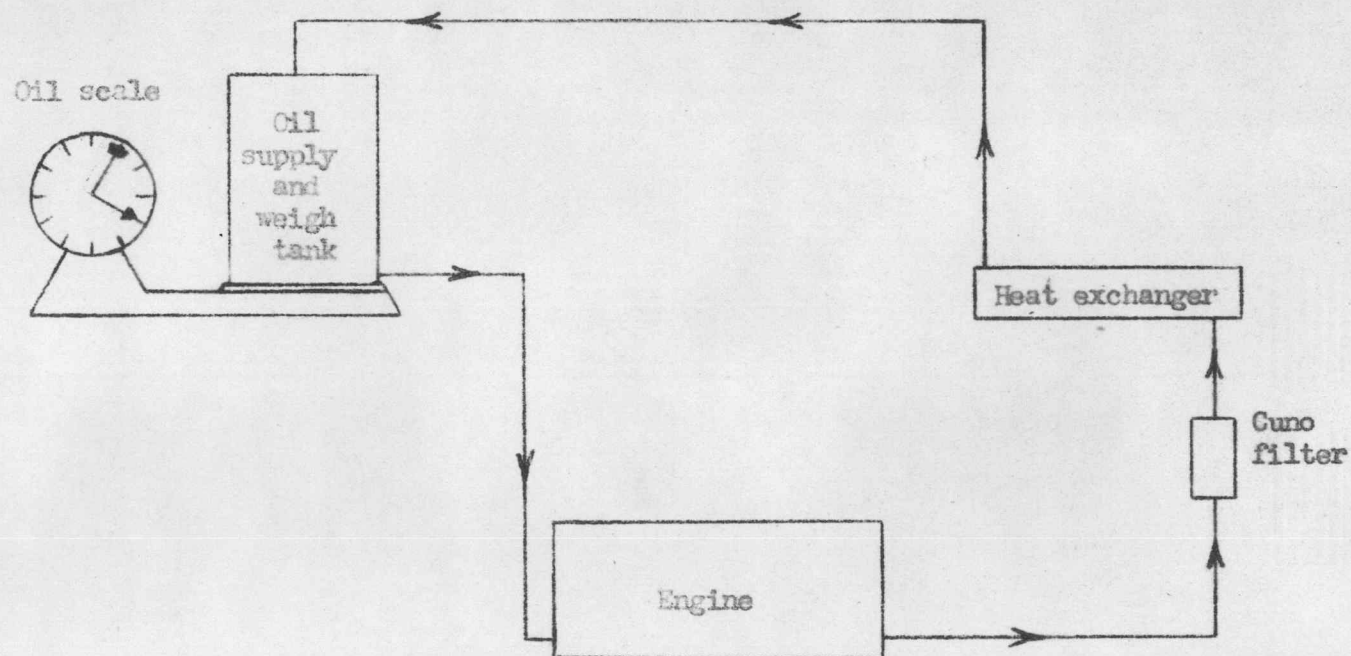


Figure 8. Schematic Diagram of Oil System.

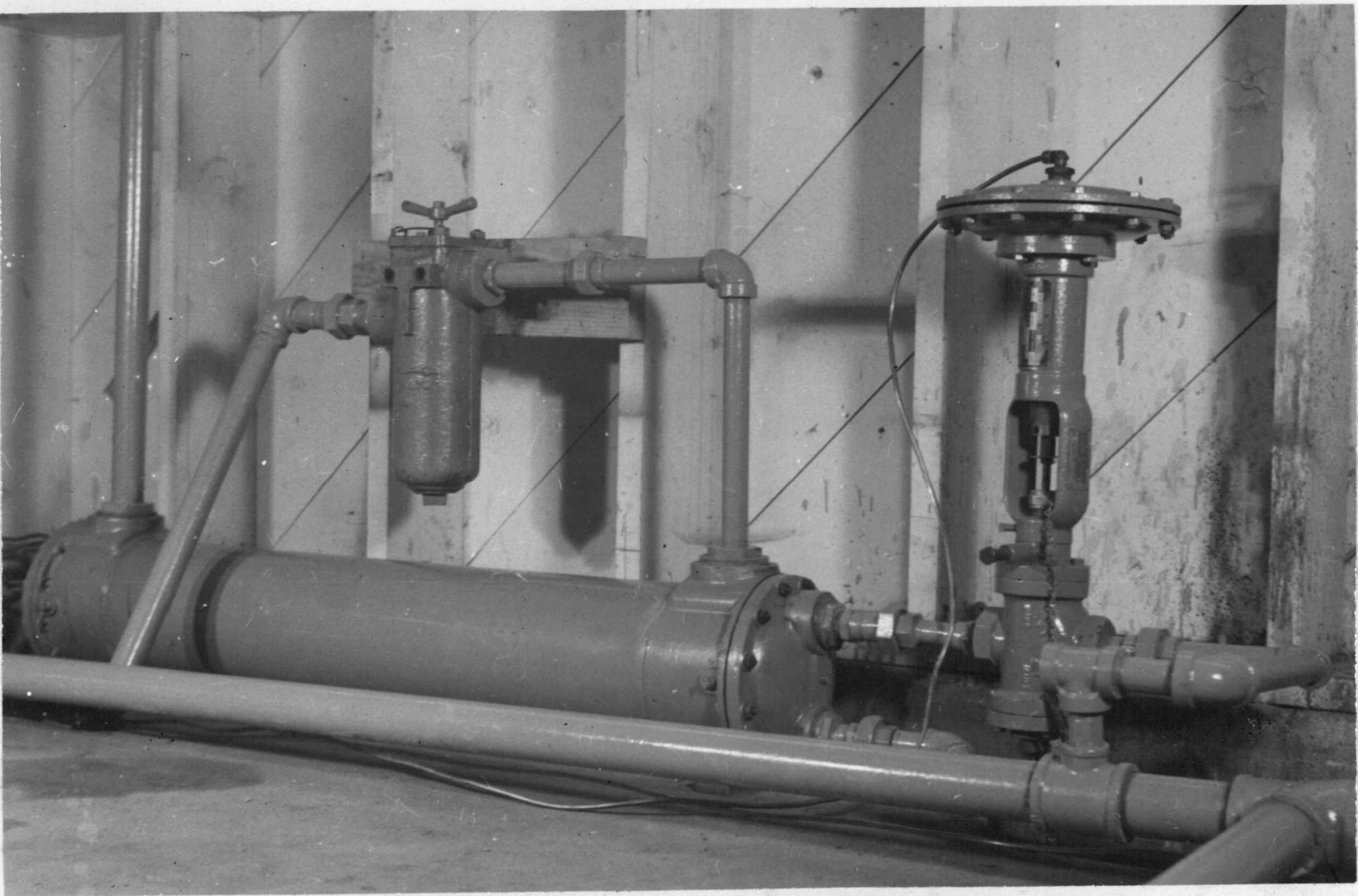


Figure 9. Photograph of Oil Filter, Oil Cooler,
and Oil Cooling Water Valve.

line to the engine, and another two-inch line to the dynamometer.

Figure 10 is a diagram of the coolant system.

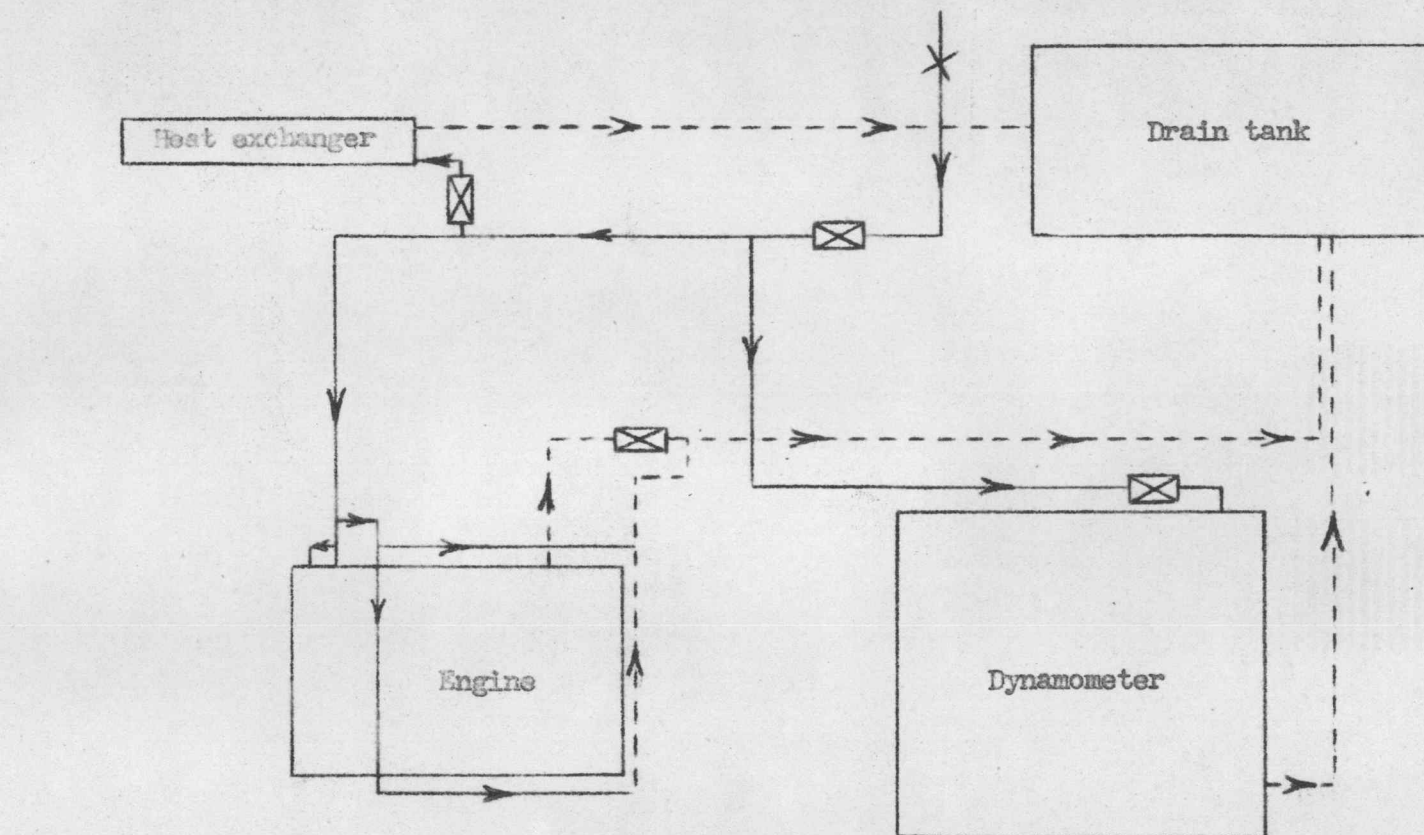
Incorporated in the coolant system are three safety switches. A Warwick Coolant Level Electrode is mounted in the engine coolant inlet line. This grounds the engine magnetos and shuts off dynamometer excitation in case the engine coolant stops flowing. A pressure switch which grounds the engine magnetos and shuts off dynamometer excitation in case of water pressure failure is attached to the dynamometer water inlet line. A temperature switch located in the dynamometer water outlet line grounds the engine magnetos and shuts off dynamometer excitation in case of too high temperature.

IX. WIRING AND ELECTRIC SYSTEMS

The test unit uses three separate electrical systems; 110-volt alternating current, 230-volt direct current, and 24-volt direct current. The test unit, as received, included only the wiring in the instrument and control panel which, in itself was not complete. This made it necessary to rewire most of the instrument and control panel system, and all of the engine, dynamometer, and weigh scale systems.

The 110-volt system is required in the instrument and control panel only for operation of A-C instruments. The power source is a wall plug in the instrument and control room.

The 230-volt system is required for power to the dynamometer, the dynamometer controls, and the dynamometer exciting generator. A motor-generator set, located in the engine room, is used to supply



- Water out
- Water in
- ⊠ — Remote control valve
- ✕ — Manual control valve

Figure 10. Schematic Water Piping Diagram.

power.

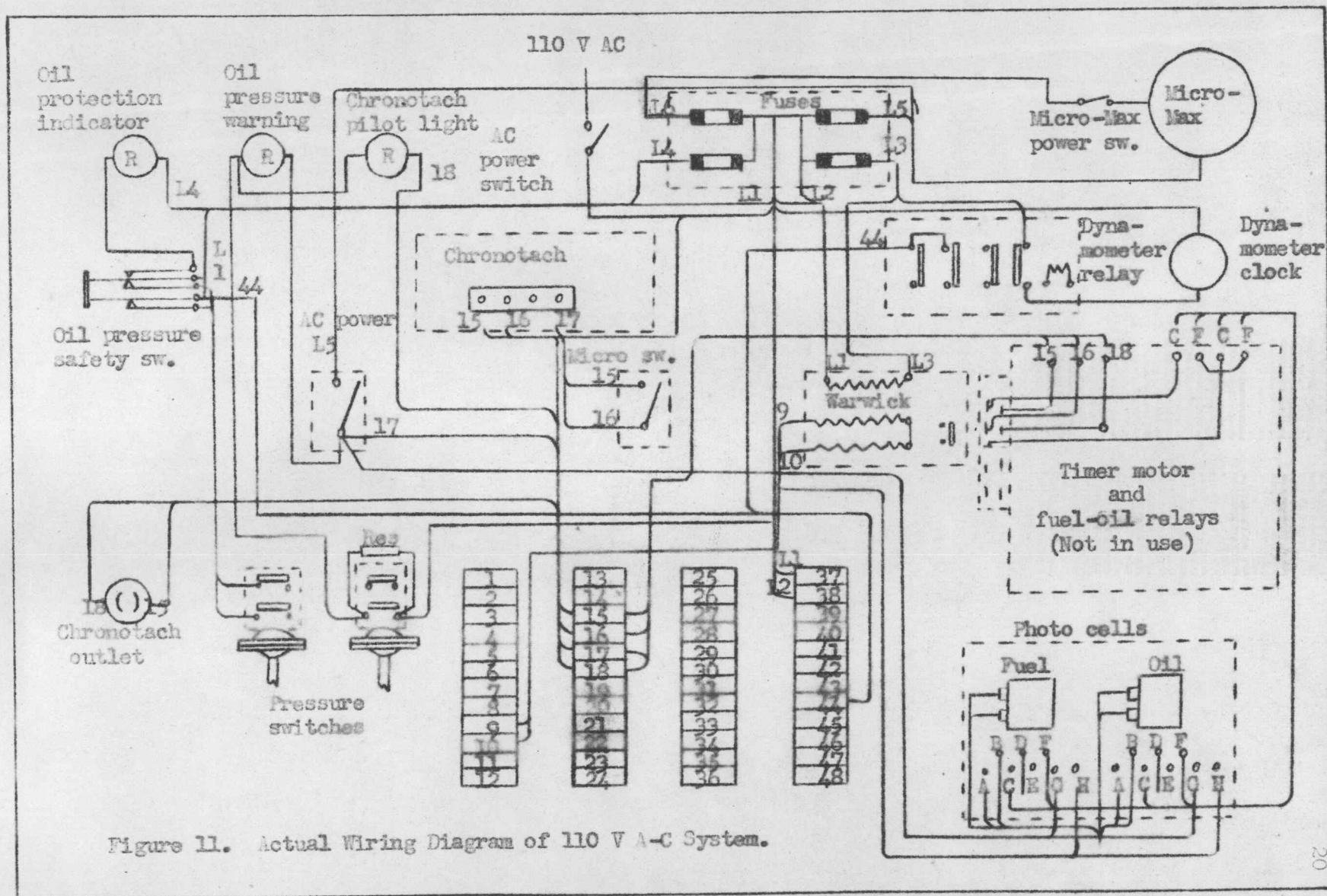
The 24-volt system is required by the engine being tested. The Packard Company used a transformer and rectifier to obtain 24-volt power, but this was not included in the equipment received. The batteries and engine generator supply 24-volt power for the system as it is used now. This system is identical to that used in aircraft.

For convenience in trouble-shooting or changing of equipment, an accessory board is located in the engine room. The generator-control panel is mounted on this board and all wiring to the engine room passes through it. Cannon plugs are used as connectors at the accessory board for all wiring except that which goes to the dynamometer, in which case a terminal strip is used. All wires to the instrument panel are connected to the different instruments through a terminal strip. Each connection on the terminal strip is numbered for convenience in trouble-shooting, maintenance, and as an aid in the identification of different wires.

Figures 11, 12, 13, 14, 15, 16, and 17 show the different wiring diagrams. Figure 18 is a photograph of the accessory board.

X. INSTRUMENTS AND CONTROLS

All instruments and controls, except for weigh scales, torque scale, and dynamometer water-pressure gage, are located in the control room. The reason for this is primarily that of safety, but it is also an aid in taking readings and performing tests.



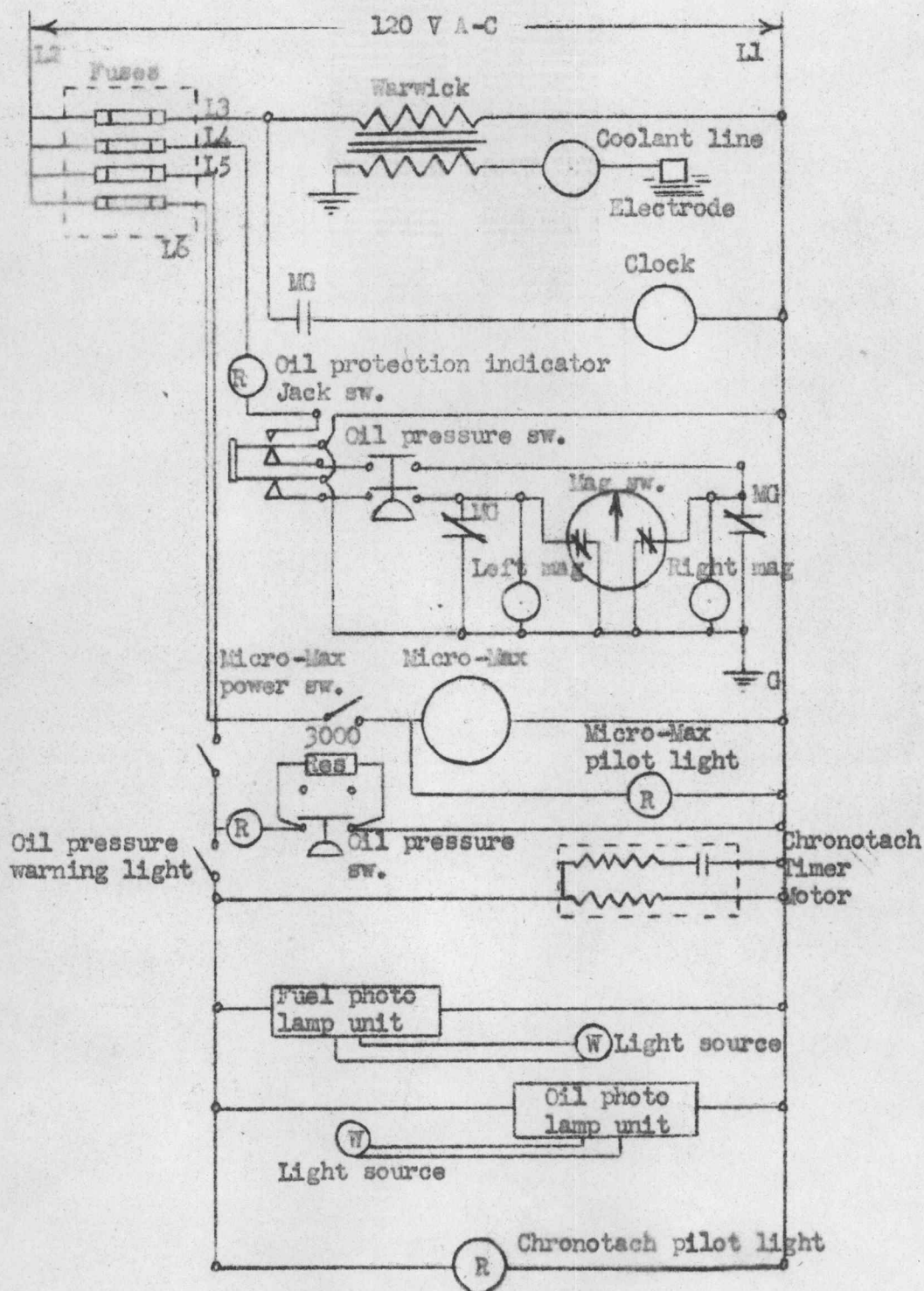


Figure 12. Schematic Wiring Diagram of 110 V A-C System.

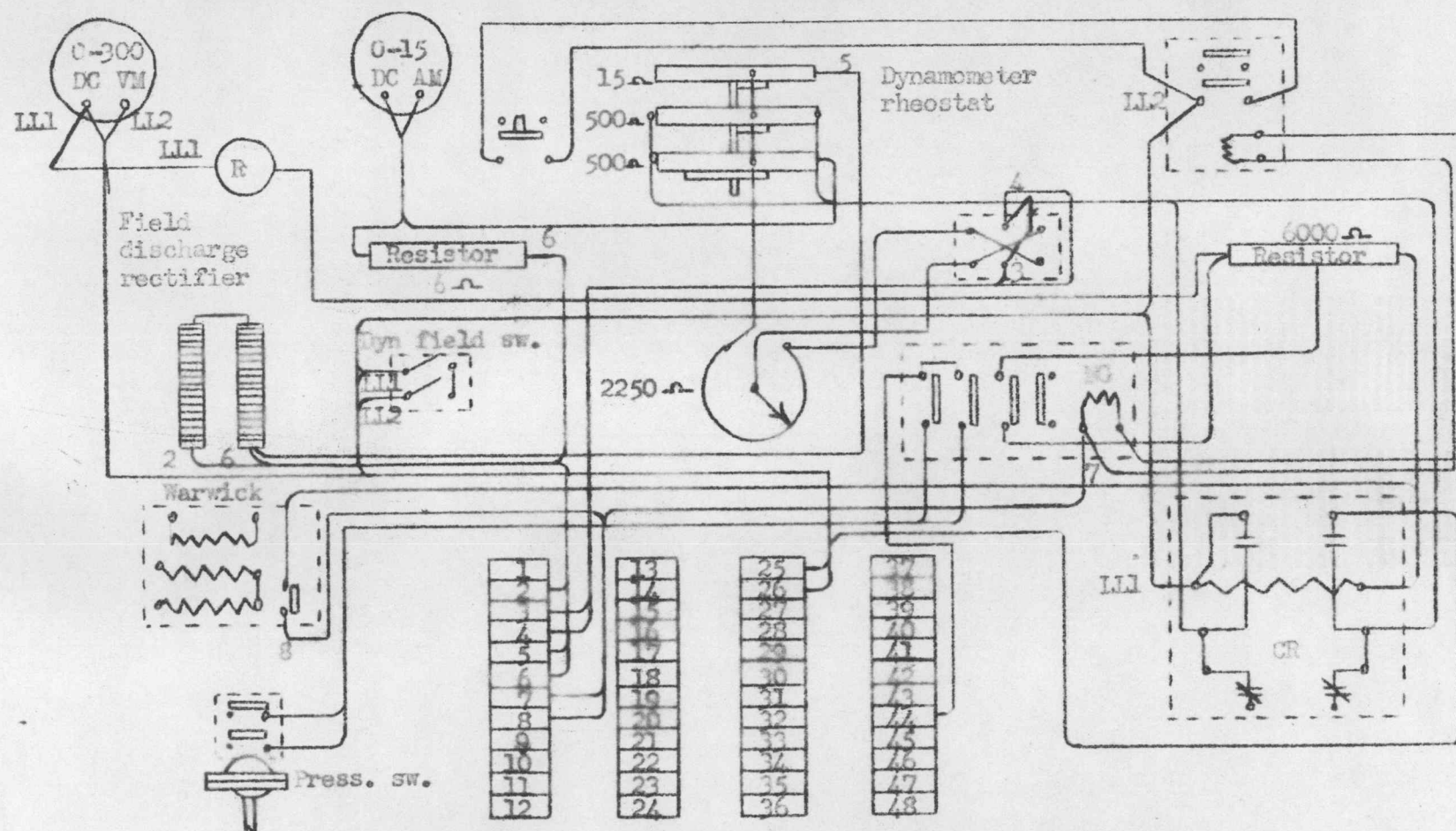


Figure 13. Actual Wiring Diagram of 230 V D-C System.

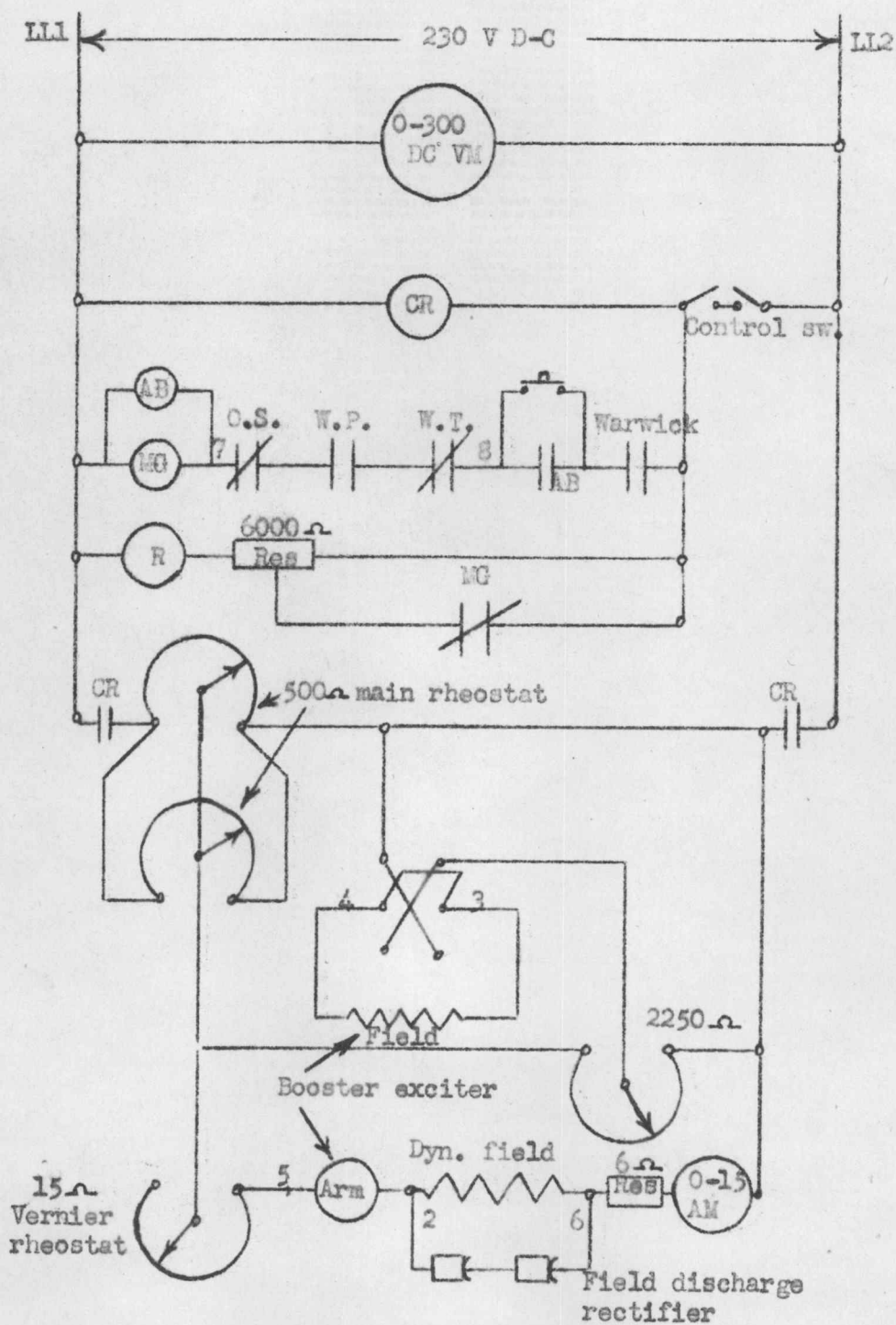
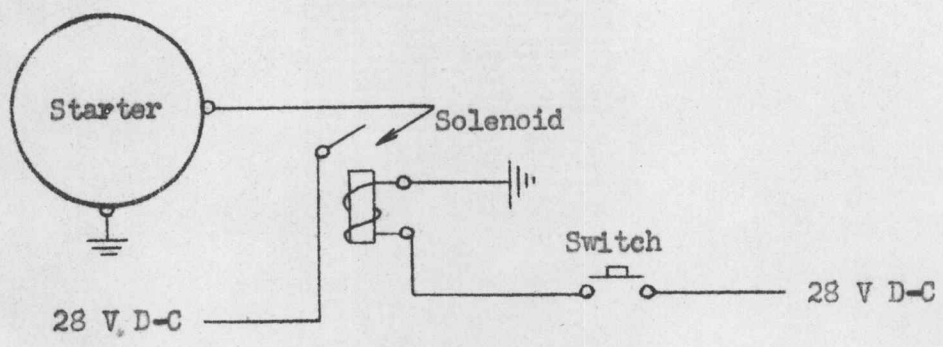
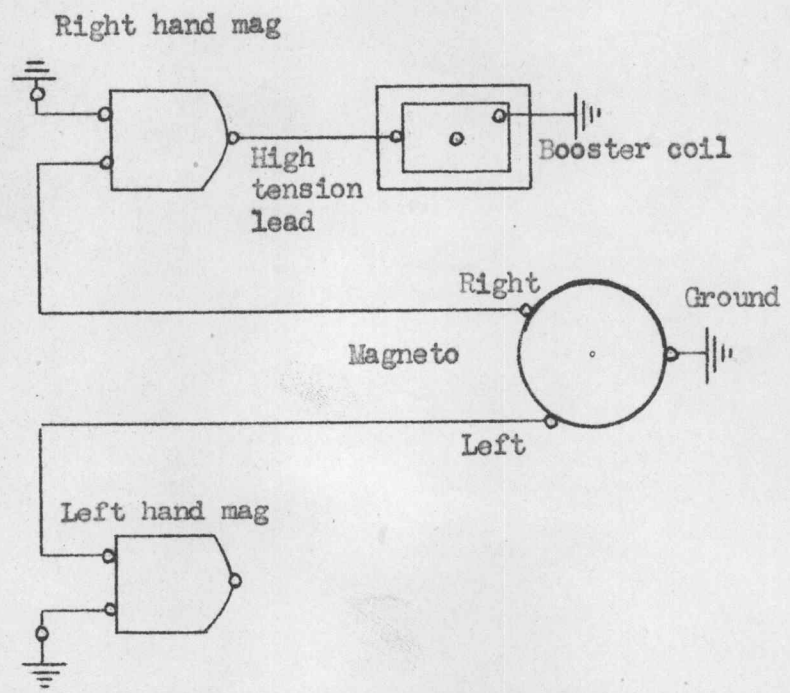


Figure 14. Schematic Wiring Diagram of 230 V D-C System.



Starter Circuit.



Magneto and Booster Coil Circuit.

Figure 15.

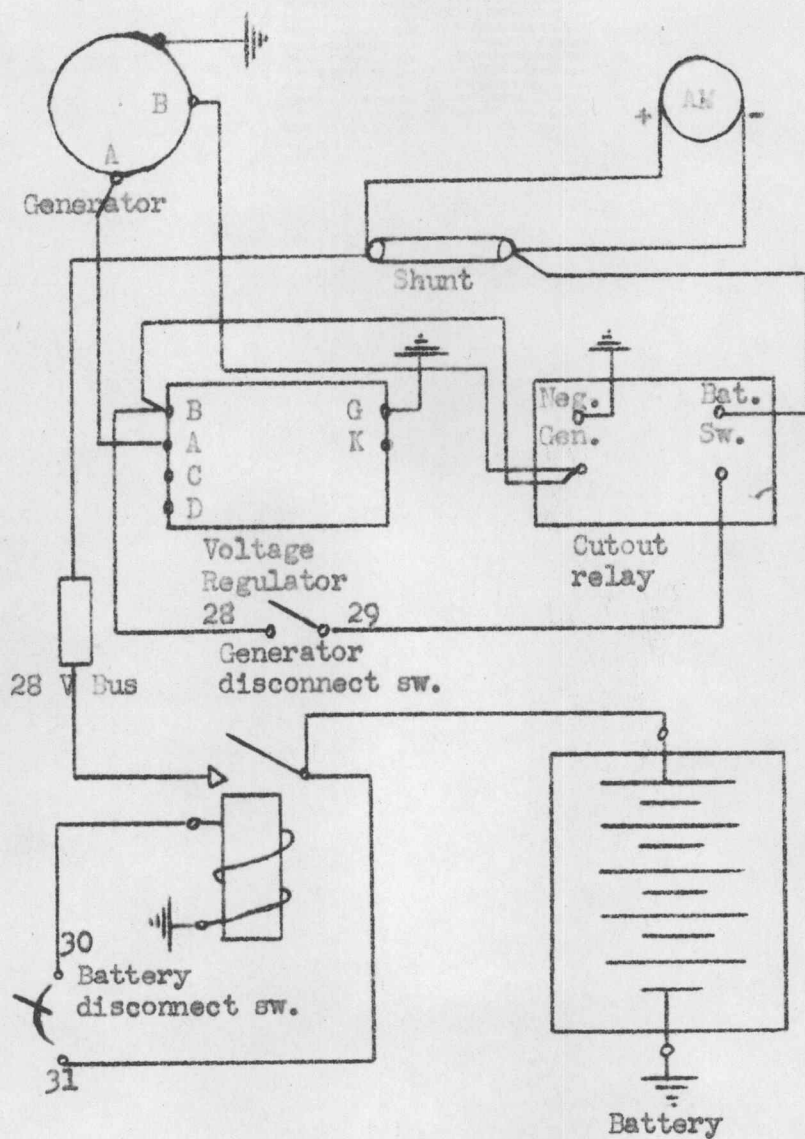
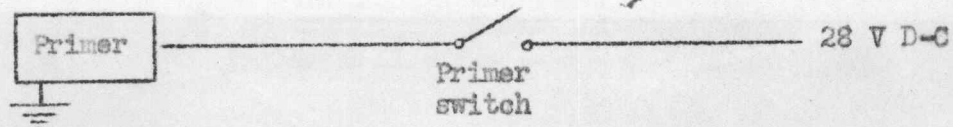
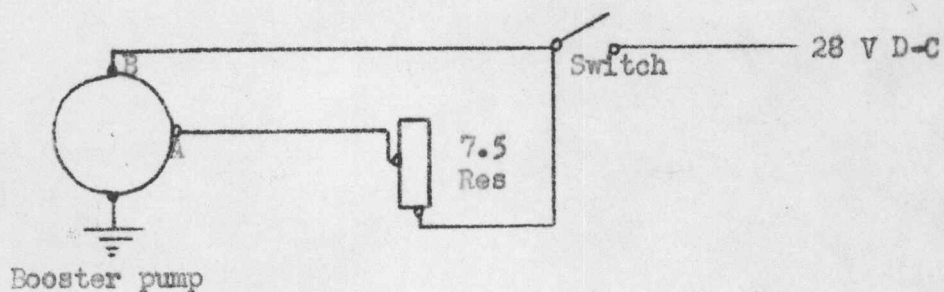


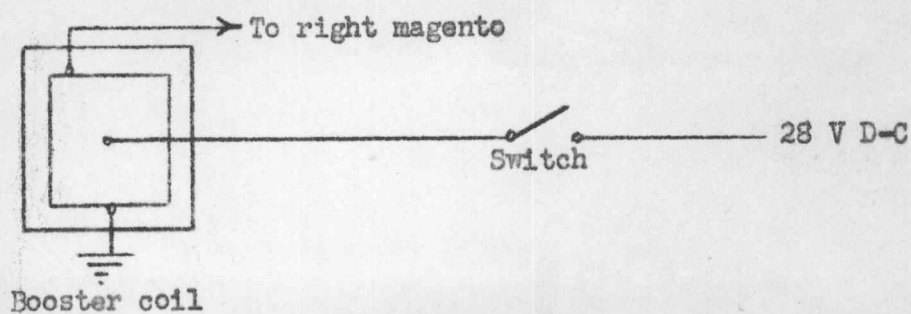
Figure 16. Battery and Generator Circuit.



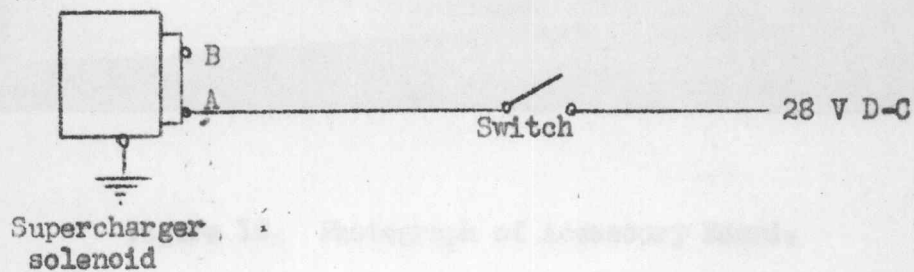
Primer Circuit.



Booster Pump Circuit.



Booster Coil Circuit.



Supercharger Solenoid Circuit.

Figure 17.

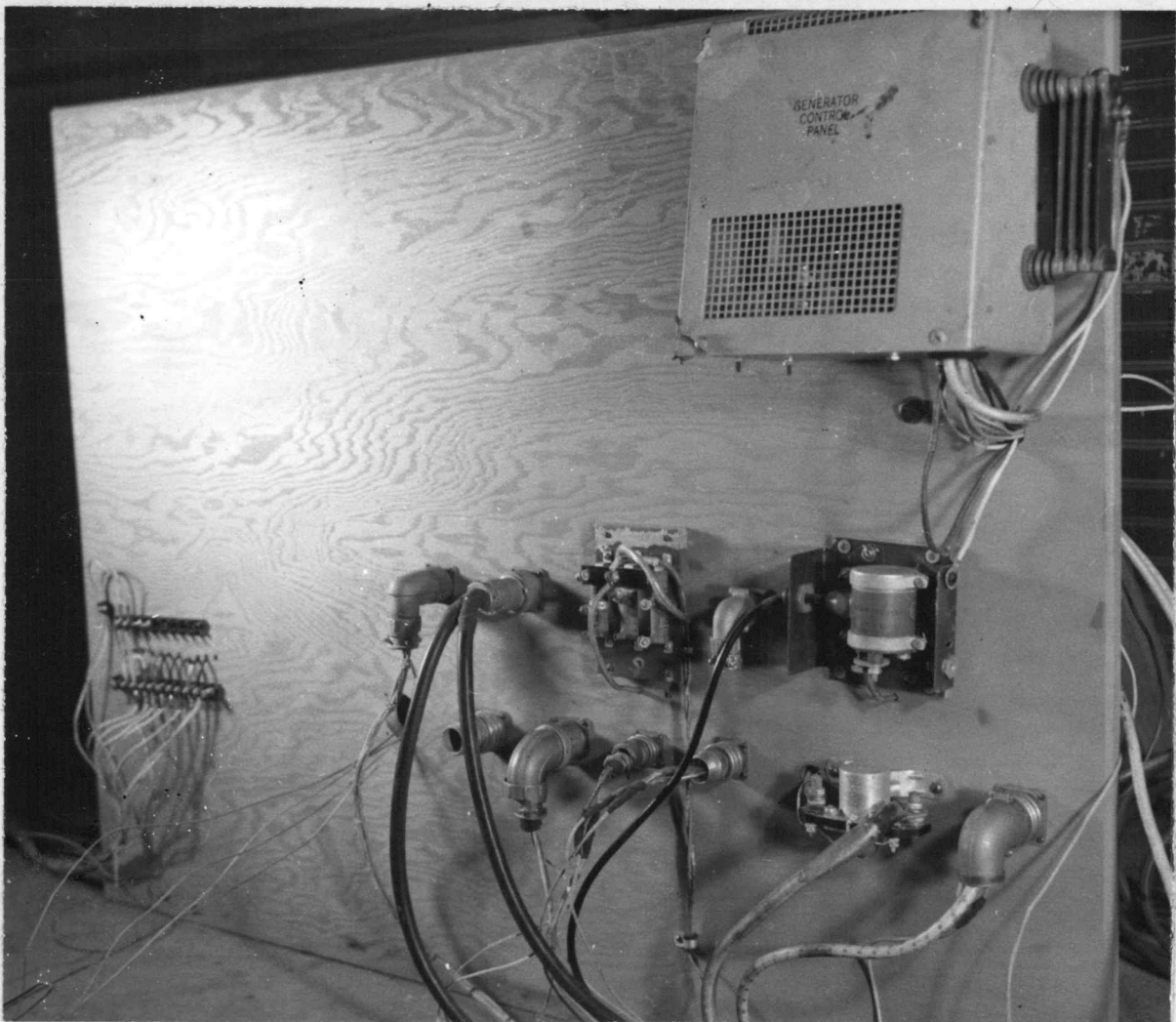


Figure 18. Photograph of Accessory Board.

Figures 19, 20, and 21 show the control and instrument room.

A. Instruments.

1. Pressure measuring instruments

(a) Bourdon-type gages

- (1) Auxiliary oil pressure, psi
- (2) Scavenge oil pressure, psi
- (3) Main oil pressure, psi
- (4) Fuel pump inlet pressure, psi
- (5) Fuel nozzle pressure, psi
- (6) Supercharger coolant-out pressure, psi
- (7) Supercharger gear changer pressure, psi
- (8) Dynamometer water pressure, psi
- (9) Coolant-out pressure, psi
- (10) Coolant-in pressure, psi

(b) Manometers

- (1) Airflow, inches of water (inclined manometer)
- (2) Manifold pressure, inches of mercury
- (3) Air stack pressure, inches of mercury
- (4) Carburetor pressure drop, inches of mercury
- (5) Exhaust back pressure, inches of mercury
- (6) Carburetor inlet pressure, inches of water
- (7) Crankcase pressure differential, inches of water

2. Temperature measuring instruments

(a) Gas bulb, Bourdon-type gages

- (1) Intake manifold temperature, degrees F
- (2) Engine coolant outlet temperature, degrees F
- (3) Oil inlet temperature, degrees F
- (4) Oil outlet temperature, degrees F

(b) Thermocouples

- (1) Dynamometer coolant inlet temperature
- (2) Dynamometer coolant outlet temperature
- (3) Dynamometer shell temperature front
- (4) Dynamometer shell temperature rear
- (5) Exhaust manifold temperature
- (6) Engine coolant inlet temperature
- (7) Fuel temperature
- (8) Orifice air temperature
- (9) Carburetor air temperature

Iron-Constantine thermocouples are used in conjunction with a Leeds-Northrop, self-balancing type galvanometer. This instrument gives temperature readings in degrees Fahrenheit. A selector switch is used to obtain the connection with each thermocouple.

3. Fuel consumption measuring devices

- ### (a) Rotameters, pounds/hour. (Two instruments are used; one giving high readings and the other low-range readings).

- (b) Fuel weigh scale, pounds. (A Toledo Electric Eye scale is used. The electric eye is used in conjunction with the chronotach timer and revolution counters, starting at zero and stopping them after 50 pounds of fuel has been used by the engine).

4. Oil consumption measuring devices

- (a) Oil weigh scale, pounds. (Operation is the same as the fuel weigh scale).

5. Tachometers

- (a) Dynamometer tachometer, RPM
- (b) Chronotachometer, RPM, minutes, and revolutions

6. Electrical measuring devices

- (a) Dynamometer ammeter, amps D-C
- (b) Dynamometer voltmeter, volts D-C
- (c) Engine-generator ammeter, amps D-C
- (d) Engine-generator voltmeter, volts D-C

7. Miscellaneous instruments

- (a) Dynamometer clock, dynamometer running time, hours
- (b) Fuel-air ratio indicator, pounds of fuel/pounds of air

B. Controls.

1. Engine controls

- (a) Mixture control
- (b) Throttle
- (c) Magneto switch
- (d) Starter switch
- (e) Primer switch
- (f) Supercharger solenoid switch
- (g) Ignition booster switch

The mixture control and throttle are operated by means of Sperry Hydraulic Type control switches, as listed above. These are standard aircraft type switches.

2. Dynamometer controls

- (a) Dynamometer field switch
- (b) Dynamometer rheostats
- (c) Dynamometer relay control button

3. Coolant controls

- (a) Main gate valve (manual)
- (b) Coolant to dynamometer, engine, exhaust coolers,
and oil cooler
- (c) Engine coolant control
- (d) Dynamometer coolant control
- (e) Oil cooler control

All coolant-control valves except the main gate valve are air-operated Fisher valves. The air-control valves are located on the control panel.

4. Exhaust control

- (a) Exhaust fan motor control

5. Fuel controls

- (a) Booster pump switch
- (b) Fuel shut-off valve

The fuel shut-off valve is operated from the control panel by a Sperry Hydraulic Control.

6. Air intake controls

- (a) Air intake butterfly control. This is of the Sperry Hydraulic type and is located on the instrument panel.

XI. CALIBRATION

The calibration of each measuring instrument was checked before installation. The weigh scales were checked using weights of known values. The weights were loaded directly on the scale platforms. The torque scale was checked by loading known weights on the opposite side of the dynamometer stator from the scale. All Bourdon-type pressure gages were checked using a dead-weight tester and a hydraulic tester. Gas bulb type thermometers and thermocouples were checked using a standard mercury in glass thermometer. The

Figure 19. Photograph of Overall Instrument and Control Panel.

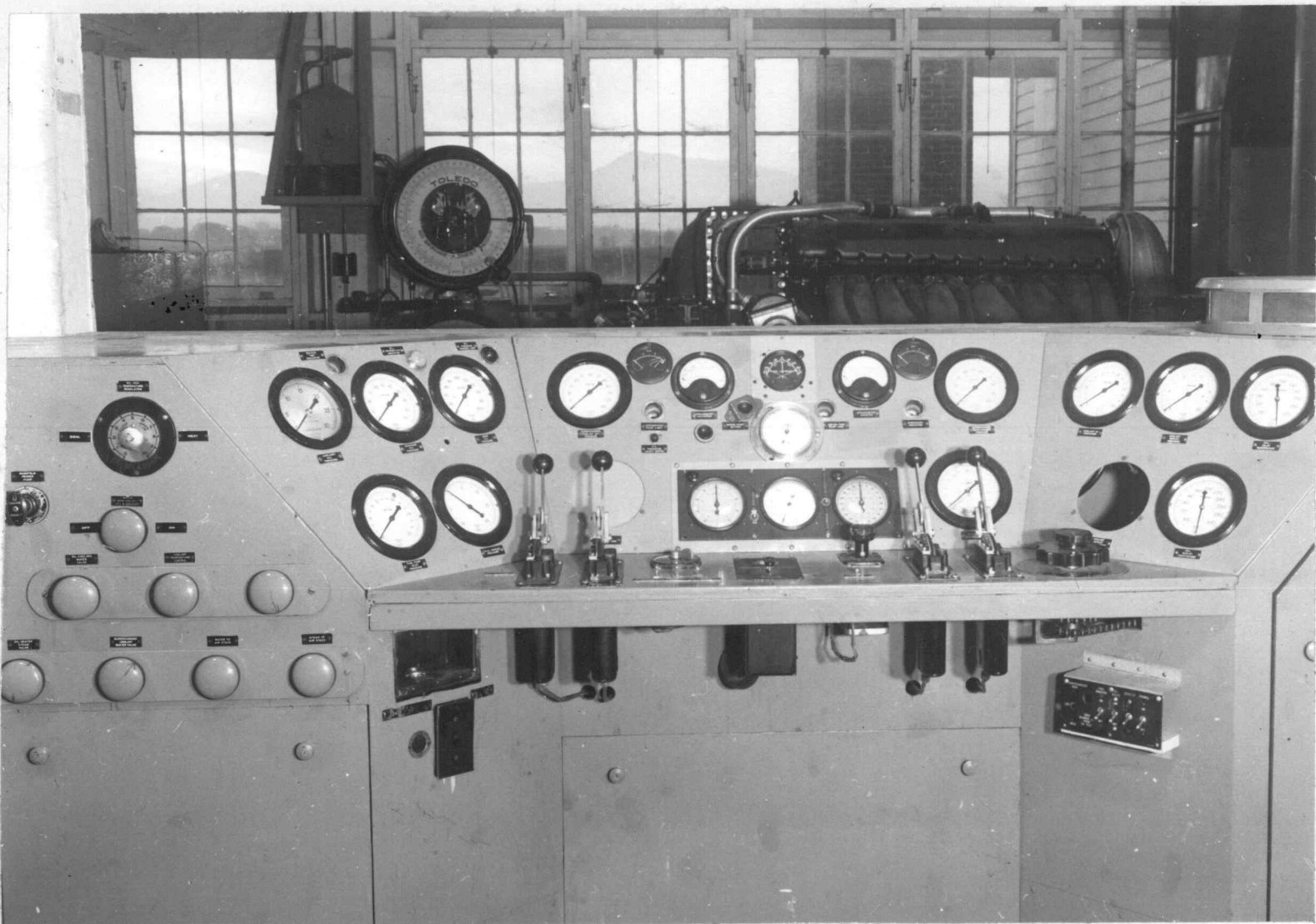
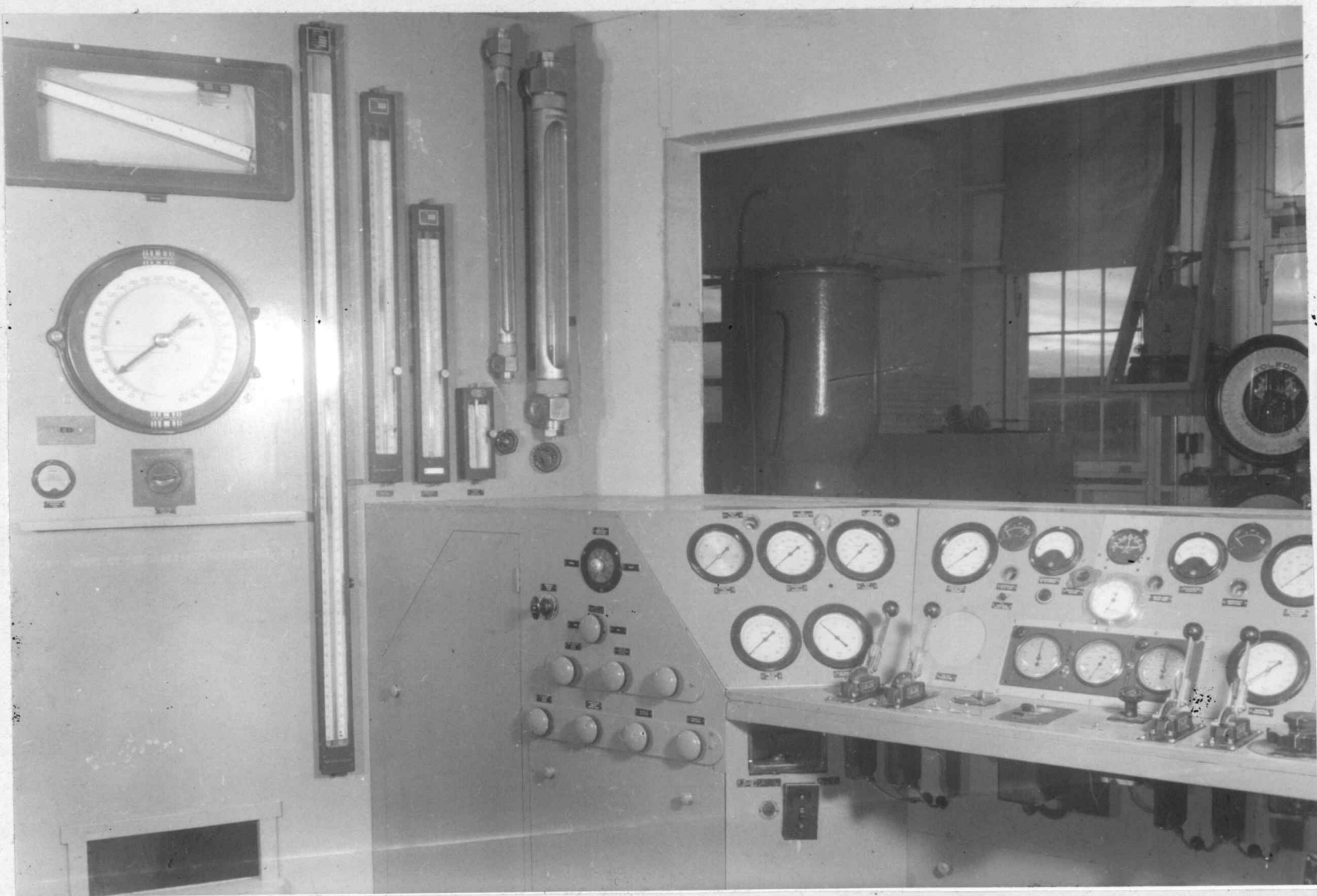


Figure 20. Photograph of Manometer Board and Control Panel.



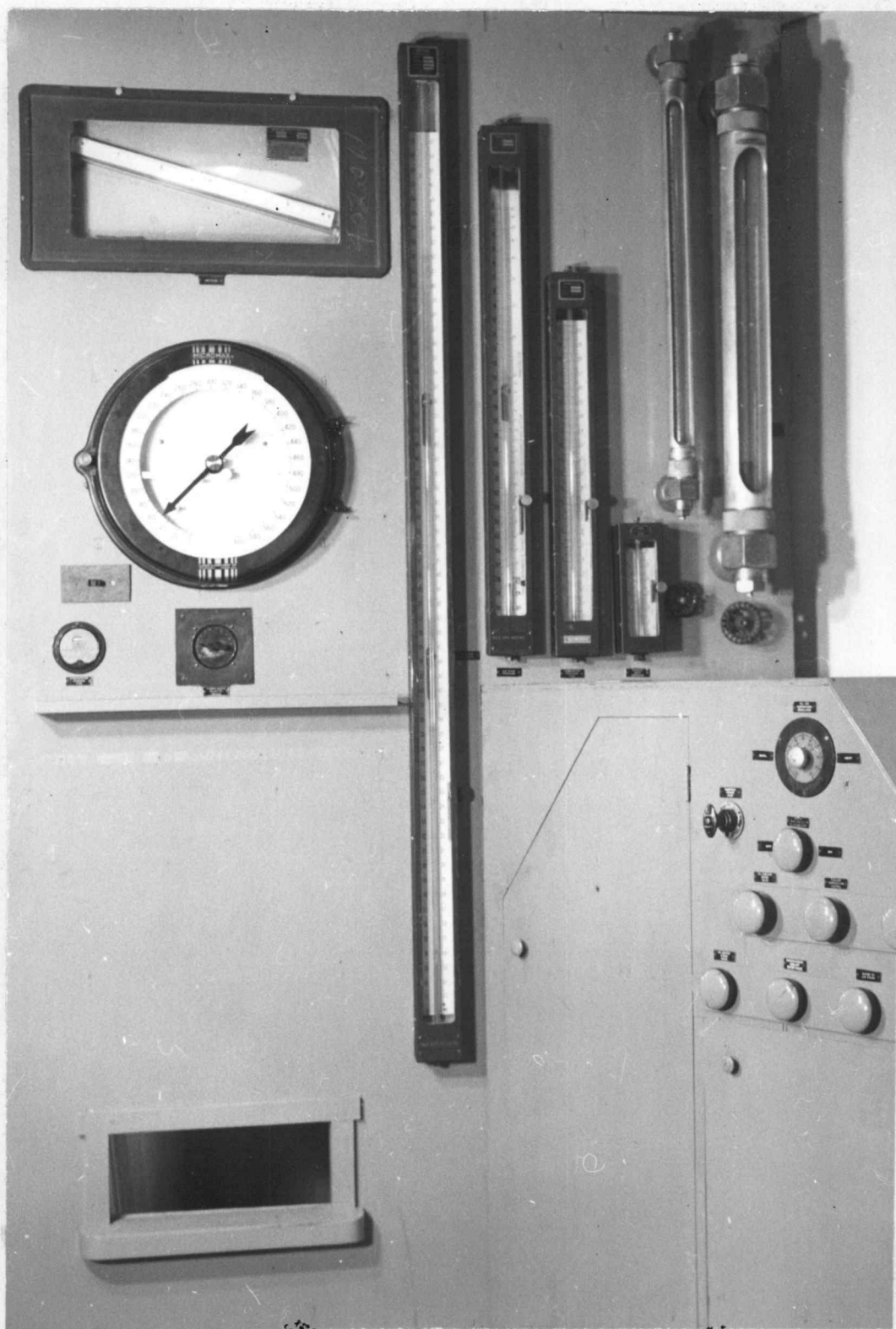


Figure 21. Photograph of Manometer Board.

tachometers were checked with the aid of a C-1 Army test unit. The readings of the tachometers being tested were adjusted to read the same as the tachometer of the test unit, which had been previously calibrated. In every case the instrument being tested was adjusted to read within approximately two percent of the reading given by the primary instrument.

The dynamometer and torque scale, as installed in the test setup, uses a 31.5 inch lever arm. This results in the horsepower formula:

$$\text{BHP} = \frac{2\pi \times \text{RPM of dynamometer} \times \text{torque scale reading in pounds}}{\text{X length of torque arm in feet} \times 33,000},$$

or,

$$\text{BHP} = \frac{2\pi N_D Q}{33,000},$$

where,

$$\pi = 3.1416$$

$$N_D = \text{dynamometer RPM} = 0.479 \times \text{engine RPM of V-1650}$$

$$Q = \text{torque in ft-lb.}$$

For a 31.5 inch lever arm:

$$\text{BHP} = \frac{N_D \times \text{scale reading}}{2000},$$

or,

if N_E = engine RPM of V-1650 engine,

$$\text{BHP} = \frac{N_E \times \text{scale reading}}{4175}.$$

XIII. TEST-STAND OPERATING PROCEDURES

A. Prior to starting.

1. See that air compressor is running, and that air pressure is at least 50 psig.
2. Turn to "full on" position the valve marked "Water to dynamometer, engine, oil cooler, and exhaust stacks."
3. Turn A-C power switch "on".
4. Turn instrument power switch "on".
5. Turn battery disconnect switch "on."
6. Turn oil pressure safety switch "on".
7. Place air-intake butterfly valve control at "full open" position.
8. Check fuel supply and make certain that fuel weigh tank is full. (Use sight gage located on weigh tank).
9. Check oil supply by observing sight gage on tank. The tank should be at least half-full.
10. Set all manometers to the correct zero point.
11. Zero airflow draft gage.
12. Standardize micro-max temperature indicating instrument.
13. Zero chronotach timer and revolution counter.
14. Open small rotameter valve and close large one.

B. Engine starting.

1. Mixture control in "idle cut-off".
2. Throttle "cracked".
3. Supercharger in low blower. (Supercharger solenoid switch "off").
4. Fuel shut-off valve open.
5. Turn exhaust fan switch "on".
6. Fuel booster pump on. Fuel pressure should be held between the limits of eight and 12 psi during starting. This is to aid in starting since the engine fuel pump is not in operation until the engine starts.
7. Prime engine using electric primer switch for not over two seconds. Overpriming should be avoided as it is detrimental to the engine, as well as dangerous to laboratory personnel.
8. Turn ignition switch to "both".
9. Turn ignition booster switch "on".
10. Engage starter by pushing engine start button.
11. When engine fires, move mixture control immediately to the "auto-rich" or "run" position.
12. Check main oil pressure; minimum is 50 psi in 30 seconds. If this value is not reached in 30 seconds the engine should be stopped immediately.
13. Warm up engine at 1200 RPM in "auto-lean" position of the mixture control.

14. After engine is warm, check the following items at 2300 RPM:

- (a) Main oil pressure-----70-80 psi
- (b) Oil-out temperature-----160-180 degrees F
- (c) Coolant-out temperature-----165-190 degrees F
- (d) Fuel nozzle pressure-----16-18 psi
- (e) Generator output-----28.5 volts, 100 amps
- (f) Magnetos: Right-----100 RPM, max drop
Left-----130 RPM, max drop
- (g) Supercharger-----50 RPM drop in high blower

Do not leave in high blower over 20 seconds.

C. Dynamometer starting procedure.

1. Be sure that water is flowing through dynamometer.
2. See that dynamometer field switch is "off".
3. Bring engine up to desired speed.
4. Turn excitation on and increase to desired load.
5. Although cooling, theoretically, could be allowed to rise to 180 to 200 degrees Fahrenheit, the fact is that whenever water is heated in long passages to 150 or 160 degrees Fahrenheit, "steam pockets" are apt to form wherever the velocity of the water is not high near the hot surface of the metal. Therefore, the recommended maximum temperature is 140 degrees Fahrenheit, although 160 degrees Fahrenheit is permissible.

D. Shut-down or stopping procedure.

1. Reduce engine speed and dynamometer excitation simultaneously.
2. Mixture control in "auto-lean" position.
3. When idle speed is reached, turn dynamometer field switch to "off" position. (Allow water to run).
4. Move throttle forward, and between 1100 and 1200 RPM move mixture control to "idle cut-off" position. As engine stops firing, move throttle full forward slowly.
5. Shut off water to engine and oil cooler.
6. Close fuel shut-off valve.
7. Turn "off" exhaust fan.
8. Shut off dynamometer water and main water control valves.
9. Turn off all other valves.
10. Turn off all switches.

XIII. SUGGESTIONS AND CONCLUSIONS

To improve the accuracy in the test setup and to make possible a greater range in the tests that can be performed, it is suggested that the changes listed below be made:

A. Find a means of cooling the intake air. This could be done by installing a refrigeration unit in the air intake. By cooling the air during altitude simulation, the conditions would be

much nearer to an actual altitude condition.

B. Add a heating unit to the air intake. This would enable the operator to determine the effect of high temperature on engine performance, and would also make detonation testing simpler.

C. By modifying the present engine mount and adding a blower unit, air-cooled engines could be tested.

D. Add a means of weighing the amount of coolant used by the engine. This could be done either by use of an automatic weighing, such as that used in the fuel system, or by installing a rotameter in the coolant line of the engine.

In conclusion it should be brought to attention that a test unit, such as the one installed, is of great value as an aid to familiarization with the following:

A. Aircraft engine test methods

B. Production-type test methods

C. Methods of instrumentation and construction of a test unit

Furthermore, the installation can be utilized, with few changes, for almost any engine research problems that may arise.