# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## TECHNICAL NOTE

## No. 952

A UNIT LABORATORY ENGINE OIL SYSTEM PROVIDING FOR A

REMOTE INDICATION OF OIL FLOW AND OIL CONSUMPTION

TOGETHER WITH BLOW-BY MEASUREMENT

By William K. Koffel and Arnold E. Biermann

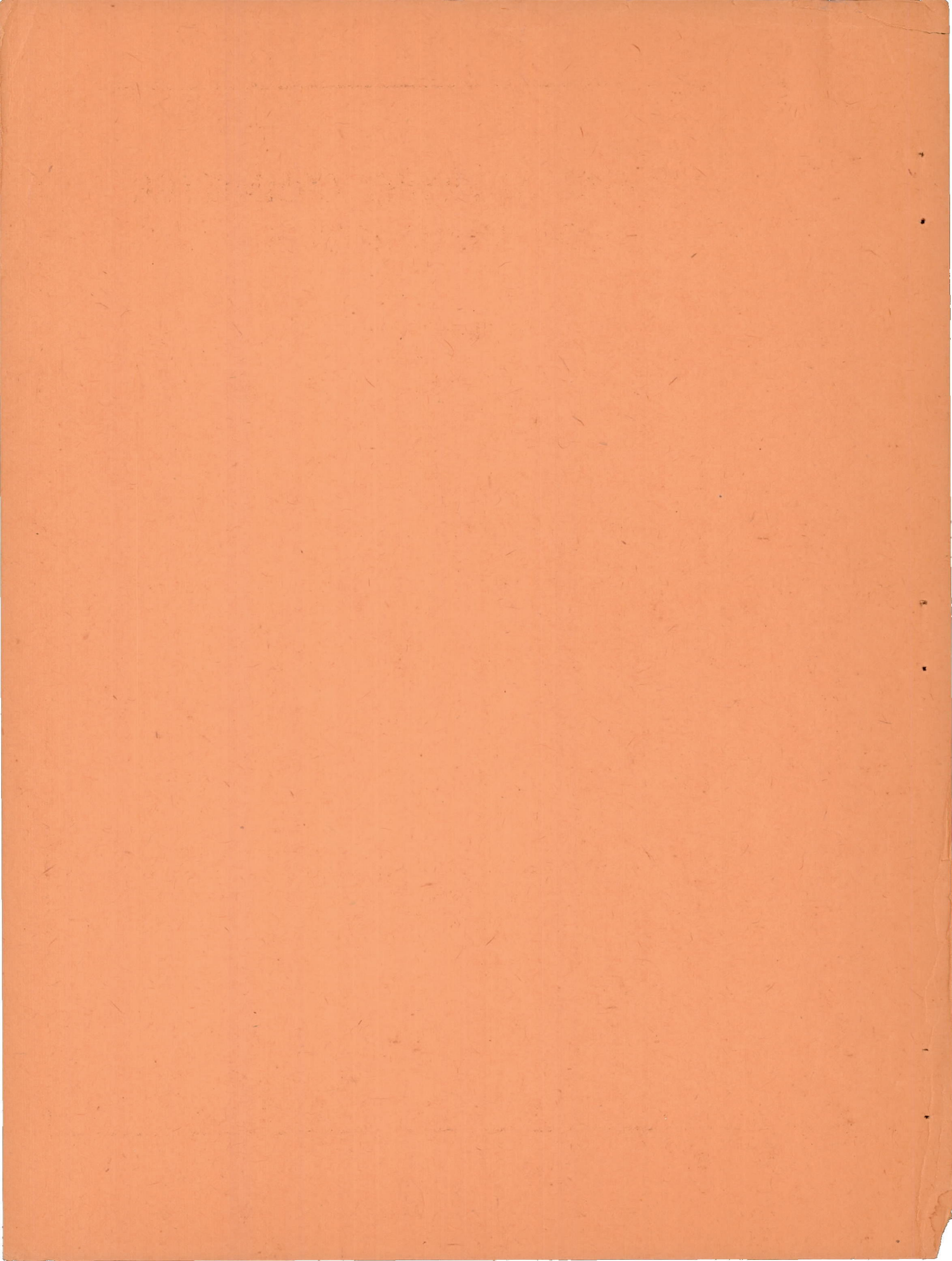Aircraft Engine Research Laboratory
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SUMMARY

A unit oil system and oil-weighing device designed for labora-
tory engine tests to permit the remote measurement of oil-flow rate
and oil consumption is described. The system regulates the oil
pressure and temperature and is closed to make possible the accurate
measurement of blow-by gas. The oil is weighed by a self-contained
diaphragm and pilot-valve assembly, which uses compressed air as
the transmitting medium. Several of these unit systems have given
satisfactory service for more than a year.

INTRODUCTION

A unit oil system and oil-weighing device for laboratory test
engines was developed during 1942 and 1943 by the Fuels and Lubri-
cants division of the NACA. The object of this development was to
provide an accurate semiportable laboratory oil system of the closed
type for the measurement of blow-by gas and the elimination of fumes.
A remote means of indicating oil flow and oil consumption was pro-
vided in order that the oil system might be placed below the test
engine to permit the use of a gravity oil return, which would obviate
the need for a scavenge pump with its consequent foaming.

SINGLE-CYLINDER-ENGINE OIL SYSTEM

A single-cylinder-engine oil system with connections to the
test engine and closed piping circuit for blow-by measurement is
shown schematically in figure 1. The main components of the oil
system are oil-weighing tank and weighing-diaphragm assembly, oil
pump, oil-temperature-regulator system, and oil strainer. Oil
flows by gravity, or is pumped from the engine sump to the top of

the oil-weighing tank from which it flows by gravity, to the lower
compartment. It is then pumped by a gear pump through the oil
heater-cooler system, which regulates the oil temperature, and
then back to the engine through a combined oil strainer and mani-
fold, which supplies lubricant to the various engine bearings and
spray jets. It will be noted that, although all the oil passes
through the oil heater, the flow divides on its way to the
temperature-regulating valve, some going through the oil cooler
and the rest flowing directly to the temperature-regulating valve.

The heating elements of the oil heater have a low-wattage
dissipation per unit surface area to avoid local overheating with
consequent deterioration of the oil. A thermoswitch at the outlet
of the oil heater turns off the heater when the temperature of the
oil reaches the desired value.

For automatic temperature control, valves 1 and 3 (fig. 1) are
closed and valves 2 and 4 are opened; this operation passes both
hot and cold oil through the thermostatic mixing valve and over its
active control element. The automatic temperature setting is
adjusted by turning the stem of the thermostatic mixing valve
(fig. 2). Manual temperature control is obtained by closing
valves 2 and 4 and setting valves 1 and 3 in such a way that the
desired temperature is maintained by mixing the hot and the cold
oil.

Oil pressure to the engine is regulated by a pressure-relief
valve that discharges into the top of the lower compartment of the
oil-weighing tank. The safety pressure-relief valve, shown in
figure 1, is set at approximately 40 pounds per square inch to
avoid excessive pressures in the oil cooler caused by the forcing
of cold oil through the cooler or the accidental closing of the
temperature-regulating valves.

The warm-up bypass valve near the test engine (fig. 1) is
opened before starting the engine in order that the oil can flow
back to the oil-weighing tank and pass through the heater again;
thus the oil warm-up time is reduced. This valve is closed before
the engine is started to bring the engine oil pressure and flow to
normal. The engine warm-up time is greatly reduced by the circula-
tion of hot oil through the crankcase.

The entire oil system is closed in order that blow-by gases
can be led from the sealed crankcase through a blow-by tube to a
blow-by meter. When a scavenge pump is used on the engine, the
pressure-equalizer tube (fig. 1) should be of such a size as to
eliminate surging of the weighing manometer. On engines such as

the Cooperative Universal type equipped with a cylinder of about
200-cubic-inch displacement it has been found that this tube must
be at least 1 inch in diameter.  In some instances it has been
found necessary to provide a surge tank in the crankcase blow-by
system to prevent fluctuations in the blow-by manometer.  The
surge tank in this case would be inserted in series with the blow-by
tube shown in figure 1.  This surge tank is most likely to be nec-
essary on single-cylinder engines made by modifying a multicylinder
engine crankcase.

Figures 2 and 3 demonstrate the compact arrangement of the
single-cylinder-engine oil system and its oil-weighing tank.  The
unit system is mounted on an angle-iron base and may be placed
beside an engine on the bedplate, if the engine has its own sump
pump, or under the floor away from the test setup.  This unit oil
system is adaptable to various laboratory tests because it has its
own oil pump and means of pressure and temperature control and
because the weighing tank serves as the oil reservoir.  A flexible
power cable is connected to any convenient outlet to supply power
for the oil pump and the oil heater.  Cooling water can be supplied
to the oil cooler through a hose or a pipe.  The temperature of the
water leaving the oil cooler is regulated by a thermostatic water
regulator (not shown in figs. 2 and 3), which minimizes the amount
of cooling water required.

The four temperature-regulating valves and the thermostatic
mixing valve are arranged in one vertical plane in order that
manual-control shafts for conveniently operating these valves can
be most readily extended to the control bench if the unit is
located under the floor.  The pump and the heater are remotely
controlled by a seven-wire cable that connects into the side of
the motor starter box.  This cable leads to two start-and-stop
switches mounted on the control panel.  The switches are so wired
that the oil heater cannot be turned on unless the oil-pump-motor
current is on.  A green pilot light indicates that the pump-motor
current is on and a red pilot light indicates that the heater
current is on.

The unit oil system described can be used, with slight modifi-
cation, on engines that have their own pressure and scavenge pumps.
In such cases a bypass valve must be installed around the relief
valve used for setting the engine-oil pressure.  The bypass valve
is closed to circulate warm-up oil in the lines to and from the
engine and is opened as much as necessary to lower the oil-in
pressure to the engine pump before the engine is started.

OIL-WEIGHING-TANK ASSEMBLY

Operation. - The oil-weighing tank (fig. 4) is divided into
two compartments connected to each other by an overflow pipe and
a dump valve that is normally held open by a spring and closed by
air pressure.  Oil returning from the engine flows into the upper
compartment and through the dump valve into the lower compartment.

The oil pressure in the lower compartment is balanced by the
air pressure acting on the oil-weighing-diaphragm assembly (fig. 5)
bolted to the side of the lower compartment near the bottom.  The
air pressure is proportional to the oil pressure at the weighing
diaphragm and, because the lower compartment has a constant cross
section, the air pressure is also proportional to the weight of
oil above the diaphragm if the oil level is below the bottom of
the upper tank compartment.

When the dump valve is closed by turning the three-way air
cock (fig. 1), oil continues to flow from the engine into the upper
compartment where it is stored; meanwhile, the pump removes oil at
a steady rate from the reserve oil in the lower compartment.  As
oil is removed by the pump, the pressure at the weighing-diaphragm
assembly drops.  The corresponding drop in the balancing air pres-
sure is observed on the weighing manometer in the control room.
The manometer is timed as it drops a certain distance and its rate
of descent is calculated in inches per minute.  The corresponding
oil-flow rate, in pounds of oil per minute, can be read from a
calibration curve.

After the manometer descent has been timed, the three-way cock
is returned to its original position and the dump valve releases
the trapped oil to the lower compartment.  The overflow pipe in the
upper compartment is of such length that the oil in the upper com-
partment will overflow before the pump removes all the oil from the
lower compartment.  The engine will thus have an uninterrupted
supply of oil in case the operator forgets to open the dump valve.
The oil that flows through the dump valve or the overflow pipe is
conducted by a cone to the walls of the lower compartment along
which it flows to the main body of the oil in the compartment.  In
this way the escape of gases entrained in the oil is promoted and
splashing of the incoming oil, which would cause the indicating
manometer to bounce, is prevented.  The pressures in the lower and
the upper compartments are equalized by a tube extending from the
apex of the cone through the overflow pipe to the top of the upper
compartment (fig. 4).

A study of figures 1 and 4 shows that any oil flowing into the
lower compartment from the engine oil-pressure-relief valve will

not affect the determination of the rate of oil flow to the engine.
Similarly, if the total oil flow to the engine is divided and each
flow rate is desired, the flows not being measured are returned to
the lower compartment and will not affect the measurement of the
flow rate being determined.

Oil consumption is obtained from the drop of the weighing-
manometer column over a period of time. Initial and final manometer
readings are taken at the same oil-flow conditions, and the amount
of oil consumed is read from a calibration curve.

Design of tank. - The oil-weighing tank and the oil system
described have been used on multicylinder engines with changes in
the size of the component parts. For best results, the weighing
tank should be designed for particular oil requirements of an engine.
Several factors must be considered in designing a tank: oil-flow
rate, maximum manometer-dropping rate that can be observed with
sufficient accuracy, required accuracy of oil-consumption determi-
nations, and reserve capacity of the tank between additions of oil.
The tank should be so designed that, when the oil flow is measured,
the indicating manometer should drop about 20 inches of water during
the readings; the time required for such a descent should be about
40 seconds or longer. A smaller manometer drop or a more rapid
rate of descent will cause inaccuracy.

Oil-weighing-diaphragm assembly. - The oil-weighing diaphragm
and its pilot valve are part of a self-contained assembly (fig. 5)
that is bolted to the side of the lower compartment of the oil-
weighing tank. The oil pressure exerts an upward force on the
diaphragm that is balanced by compressed air throttled by the
poppet valve into the space above the diaphragm. As the oil pres-
sure decreases, the diaphragm moves down, owing to an excess of
air pressure, and opens the exhaust port formed by the lower tip
of the pilot-valve stem and the conical seat in the end of the
valve-adjusting screw. The excess air is then led back through
drilled passages in the center stud of the diaphragm to a rubber
tube exhausting to the atmosphere. Air pressure is thus reduced
until the diaphragm moves back to its equilibrium position and both
valve ports are closed. An increase in oil pressure opens the
upper valve port and raises the pressure required without opening
the lower port; therefore, the pressure above the diaphragm is
always directly proportional to the oil pressure acting on the
diaphragm. When the system is flushed and refilled with oil, it
is necessary to bleed the air from the under side of the diaphragm,
which is readily accomplished through the bleed plug shown in
figure 5.

The poppet valve shown in figure 5 is closed by gravity and by a small unbalanced air pressure acting on its upper end. Inasmuch as the diameter of the valve port is 1/8 inch and the maximum differential pressure acting on it is about 1.5 pounds per square inch, the unbalanced force on the valve stem has a negligible effect upon the sensitivity of the diaphragm. The slight taper of the upper valve face permits smooth descent of the manometer with no surging or hunting and, at the same time, allows the valve stem to adjust itself to a slightly eccentric diaphragm. The diaphragm fabric is cemented to the metal diaphragm disk. (See fig. 5.)

Another satisfactory weighing-diaphragm assembly is shown in figure 6. This diaphragm has an effective area of about 10 square inches and uses a balanced-pressure piston-ported spool valve. In operation, compressed air enters the upper port and is throttled into the central chamber, which is connected by drilled passages to the space above the diaphragm and to the space above the piston-spool valve. The operation of this weighing diaphragm is essentially the same as the weighing diaphragm shown in figure 5. The pilot valve shown in figure 6 has a flexible wire connecting it to its diaphragm in order to minimize side thrust caused by an eccentricity of the diaphragm.

Either type of pilot valve is initially adjusted to bring the diaphragm to its equilibrium position when the center of the diaphragm is in the same plane as its outside edge. This adjustment is made by turning the adjusting screw in the center stud shown in figure 5 or by changing the length of the connecting wire between the valve and the diaphragm shown in figure 6. The compressed-air supply should be filtered and regulated to a pressure of about 1 pound per square inch in excess of that necessary for the maximum manometer pressure.

Design of weighing-diaphragm assembly. - Diaphragm sensitivity increases as the square of the effective diameter and directly as the flexibility of the diaphragm fabric; therefore, a large effective area and a flexible fabric for accurate oil-consumption measurements are desirable. Nothing is gained by increasing the sensitivity of the diaphragm beyond the point where the percentage error in the readings of the air-pressure manometer will mask the improved diaphragm performance. The effective diaphragm area is assumed to be the area of a disk, the diameter of which is equal to the mean diameter of the flexible annular portion of the fabric. The flexible part of the diaphragms used in the apparatus described is about 3/4 inch wide and the material is oil-resistant impregnated fabric having a thickness of 1/32 inch.

Both the diaphragm assembly using the poppet valve (fig. 5) and the diaphragm assembly using the balanced-pressure piston-ported spool valve (fig. 6) have been satisfactory but, for small effective areas, the spool valve allows a more compact design because it does not need the special bleed tube to the atmosphere. The poppet valve is simpler to make and does not require the lapped surfaces that are necessary in the spool valve.

An application. - In certain tests it may be desirable to watch the oil consumption. Inasmuch as this type of oil-weighing device uses air as the transmitting medium, a pressure-against-time, strip-chart recorder can be used in parallel with the manometer. The change in oil consumption can thus be watched and its value computed from the slope of the curve. Oil-consumption readings are usually taken every 5 minutes for a 1/2-hour period when determining specific oil consumption.

## CALIBRATION OF THE WEIGHING DEVICE

The weighing device was calibrated using a setup similar to that shown in figure 1, in which the test engine was replaced by a globe valve to vary the oil flow and a three-way plug valve to direct oil into a weighing pail or to return it to the upper compartment of the weighing tank. A stop watch was started as the manometer column passed the 18-inch mark and was stopped when the column passed the 3-inch mark. This 15-inch drop was chosen because oil would then be falling through an onobstructed part of the lower compartment and some oil would still remain above the weighing diaphragm at all times. The manometer was read to within ±0.05 inch of water for both oil-flow rate and oil-consumption determinations. The hand timing was probably accurate within ±0.2 second, and the oil was weighed to ±0.5 ounce; all measurements were accurate to about 1 percent.

During the calibration of the oil-weighing device, oil consumption was simulated by pumping about 9.5 pounds of oil from the lower compartment, through the globe and the plug valves, and into a weighing pail. The drop in air pressure at the indicating manometer represented the pounds of oil removed. Both the initial and the final manometer readings were taken with the dump valve open and the oil flowing through the entire system just as though oil were being supplied to a running engine.

Figure 7 shows the relationship between the weighing manometer-dropping rate in inches of water per minute and the rate of oil flow in pounds per minute.

The pounds of oil per inch of water is plotted against the oil flow in pounds per minute in figure 8. The oil-flow rate has a slight influence on the oil-consumption factor. This effect, however, is very small for the usual variations in the rate of oil flow to an engine.
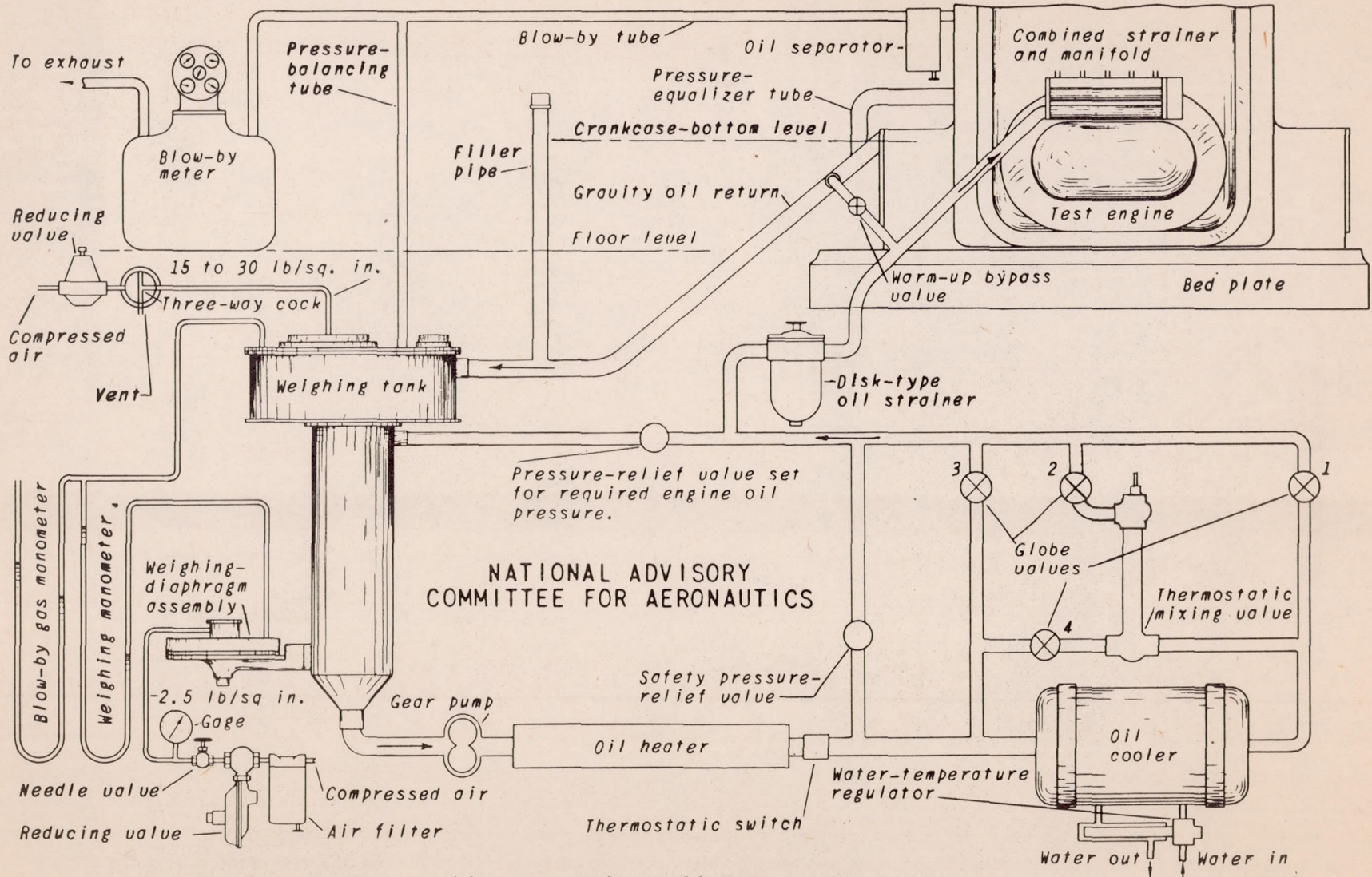
## SUMMARIZATION OF DESIGN FEATURES

In the unit laboratory oil system providing for a remote indication of oil flow and oil consumption, together with blow-by measurement, the following features have been obtained:

1. A separate motor-driven pump is used to circulate the oil through the engine or the oil system before the engine is started.

2. Automatic oil pressure and temperature regulation are provided.

3. The oil temperature and pressure regulating apparatus and the oil-weighing device are incorporated in a semiportable unit with remote control.

4. The oil system is closed in order that accurate blow-by measurements can be made.

5. The oil-weight reading is remotely indicated and depends only upon weight of the oil. No effects of temperature upon the calibration of either oil-flow or oil-consumption rates were found within the limits of experimental accuracy when the temperature was varied from 165° F to 205° F.

6. The system is able to reproduce results within ±2.5 percent for both oil-flow and oil-consumption determinations.

7. The weighing device maintains its calibration over long periods of time without attention. Experience has indicated a good stability of calibration; the device, however, requires a new calibration if the diaphragm assembly is taken apart.

8. The manometer gives a steady indication of oil weight and drops smoothly during flow-rate determinations. No trouble has been experienced with hunting at the low air pressures supplied to the pilot valve. Variations in supply air pressure of $\pm 0.5$ pound per square inch had no effect on the manometer reading.
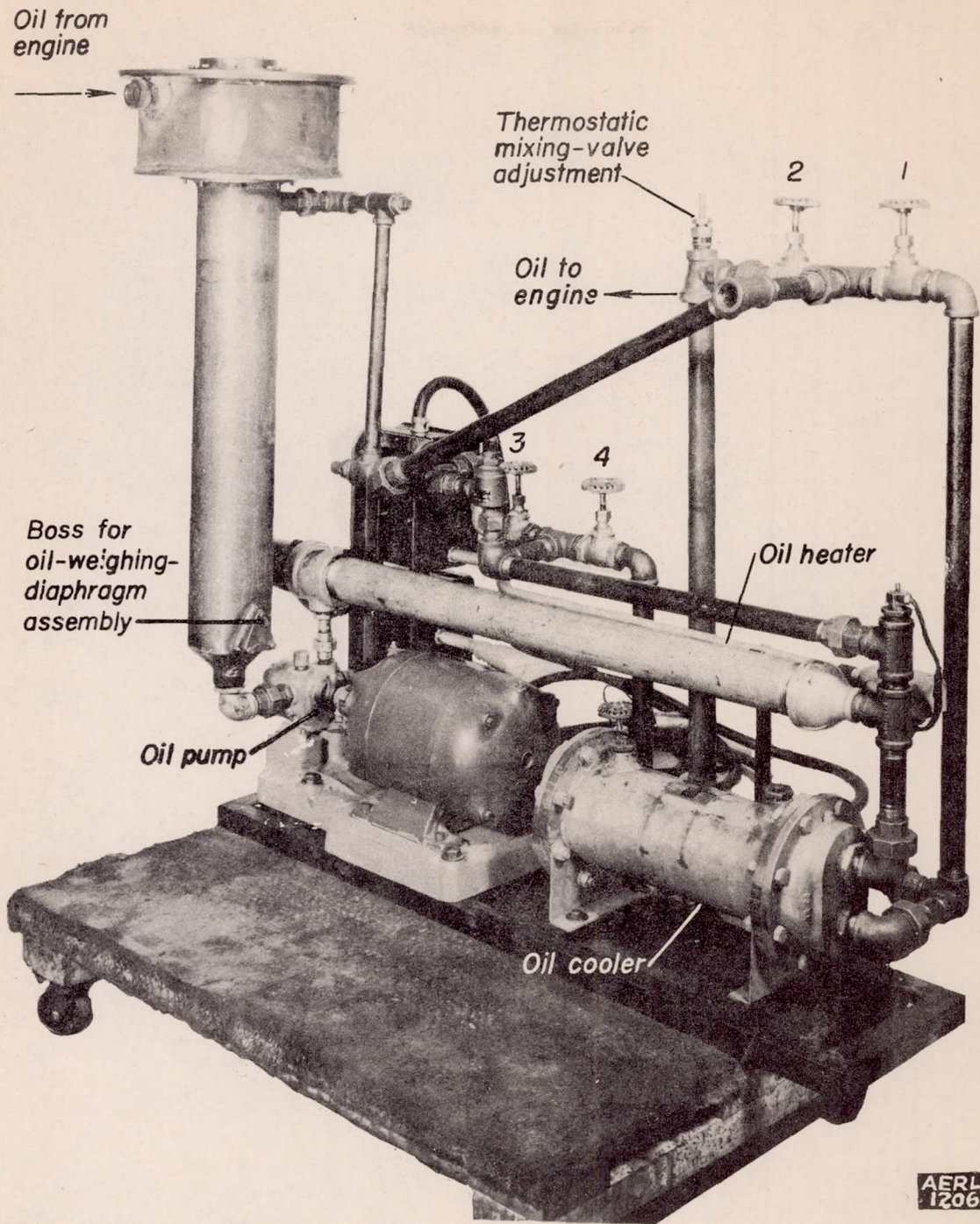
Aircraft Engine Research Laboratory,
 National Advisory Committee for Aeronautics,
  Cleveland, Ohio, August 5, 1944.

Figure 1. - Closed single-cylinder-engine oil system for measurement of blow-by gas, oil flow, and oil consumption.

Fig. 1
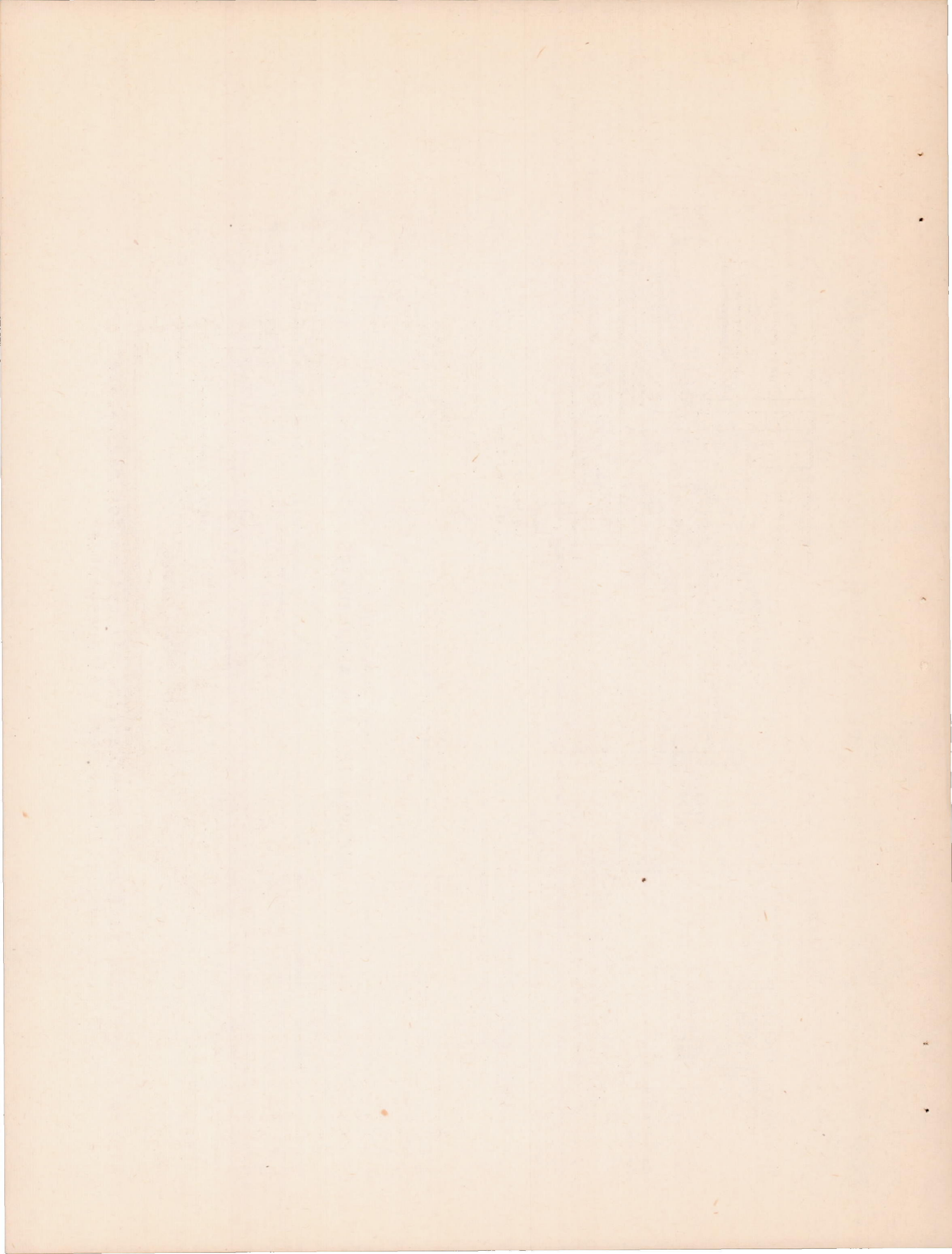
Figure 2. – Rear view of unit single-cylinder-engine oil system.
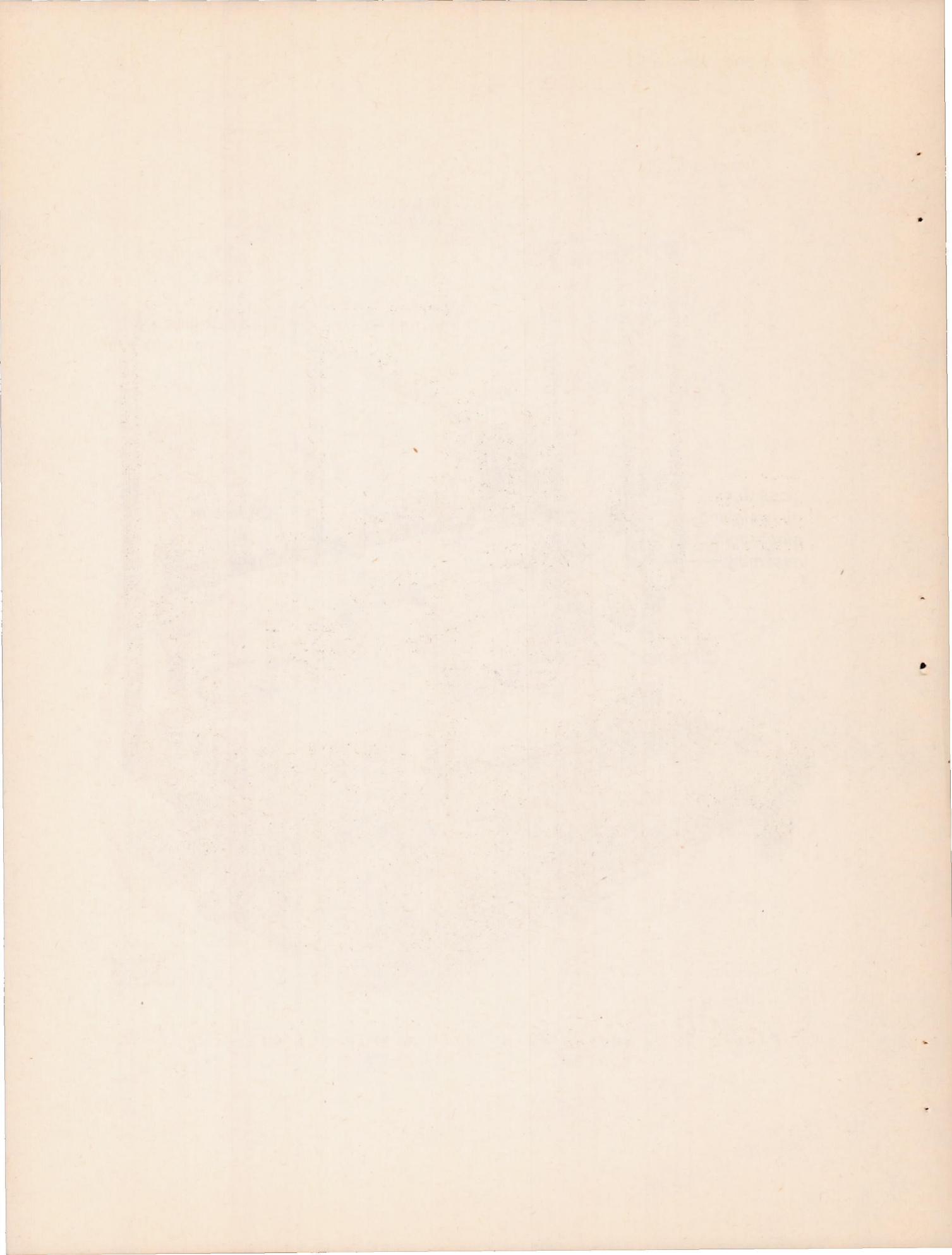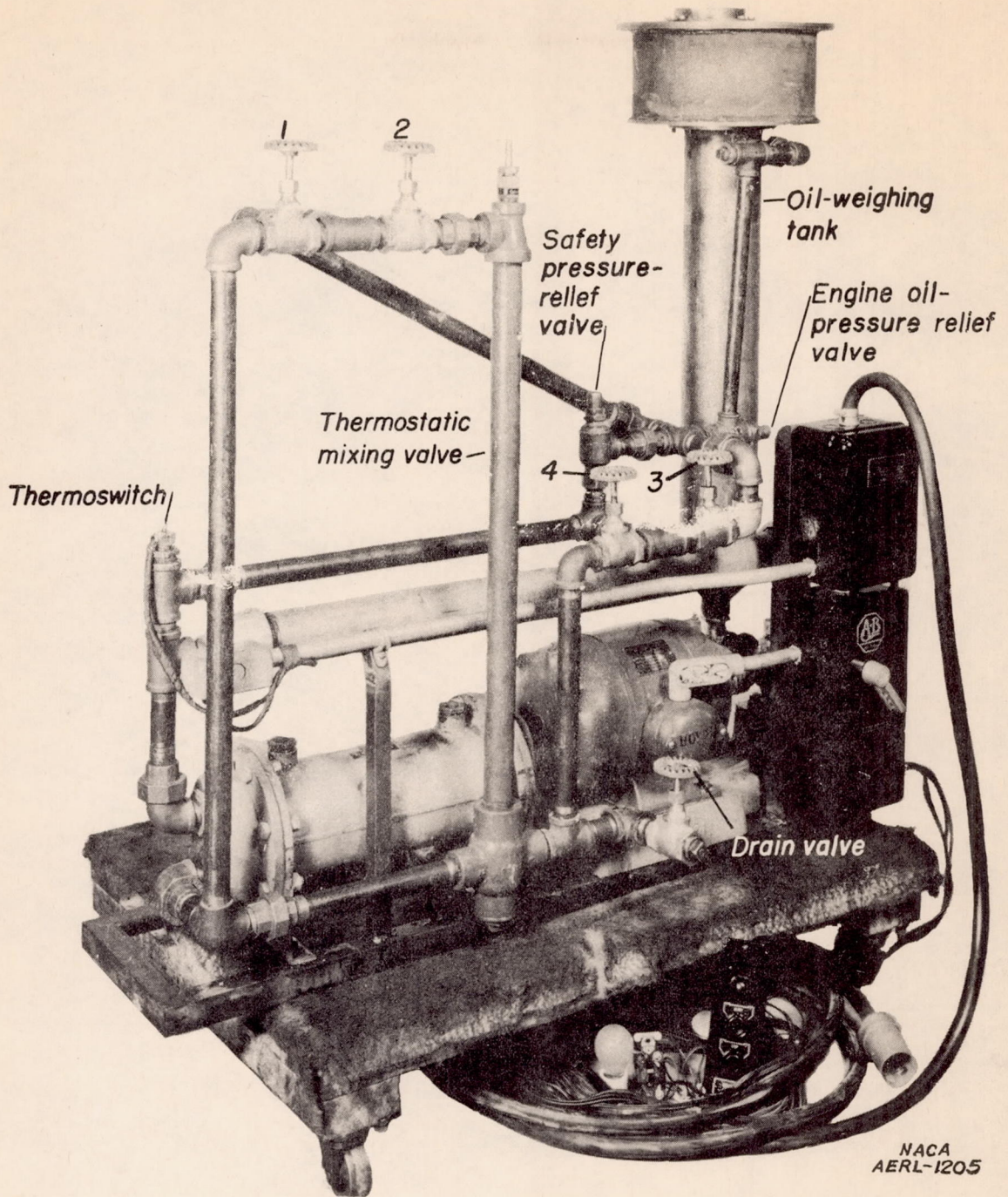
Figure 3. — Front view of unit single-cylinder-engine oil system.
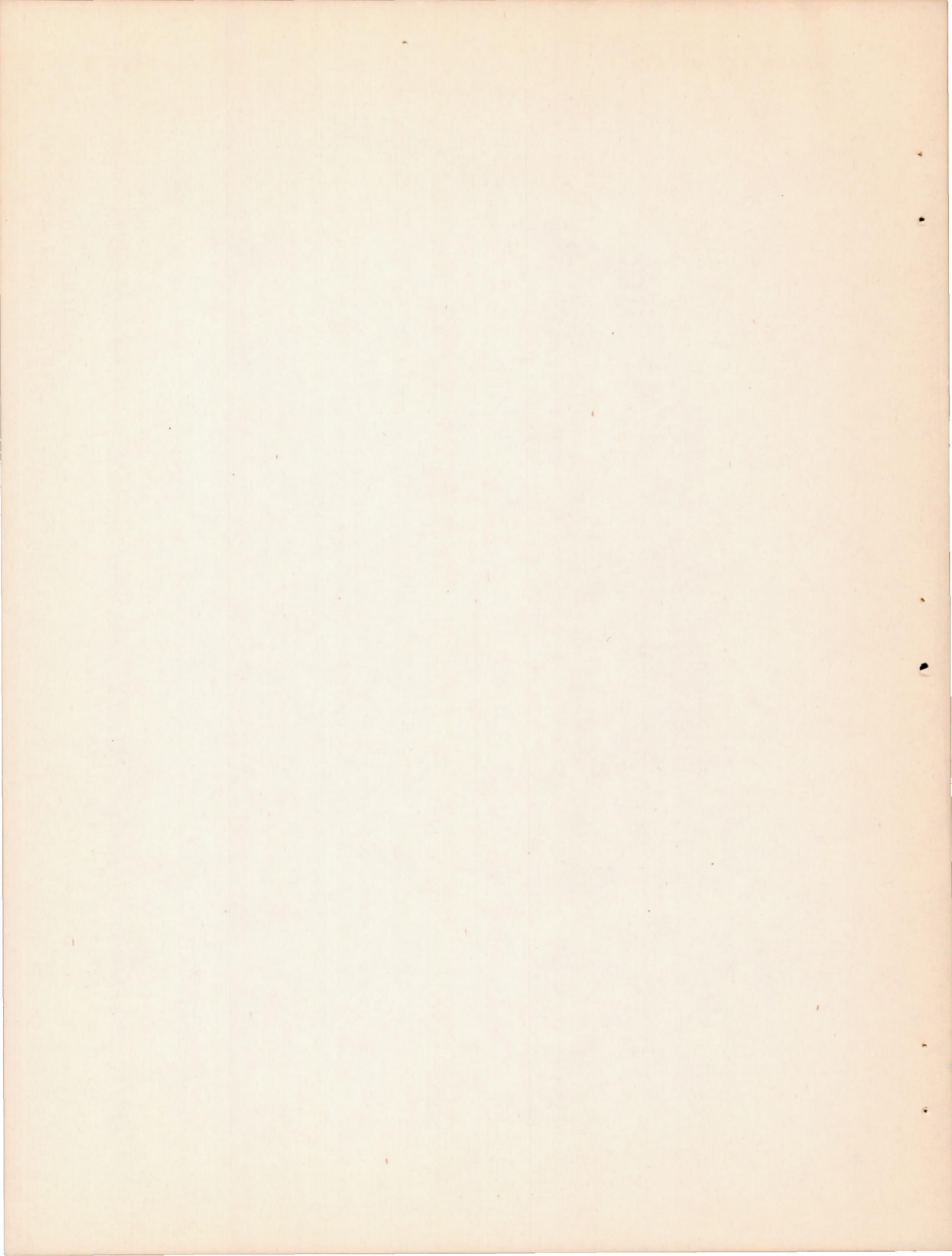
Figure 4. – Cross section of single-cylinder-engine oil-weighing tank.
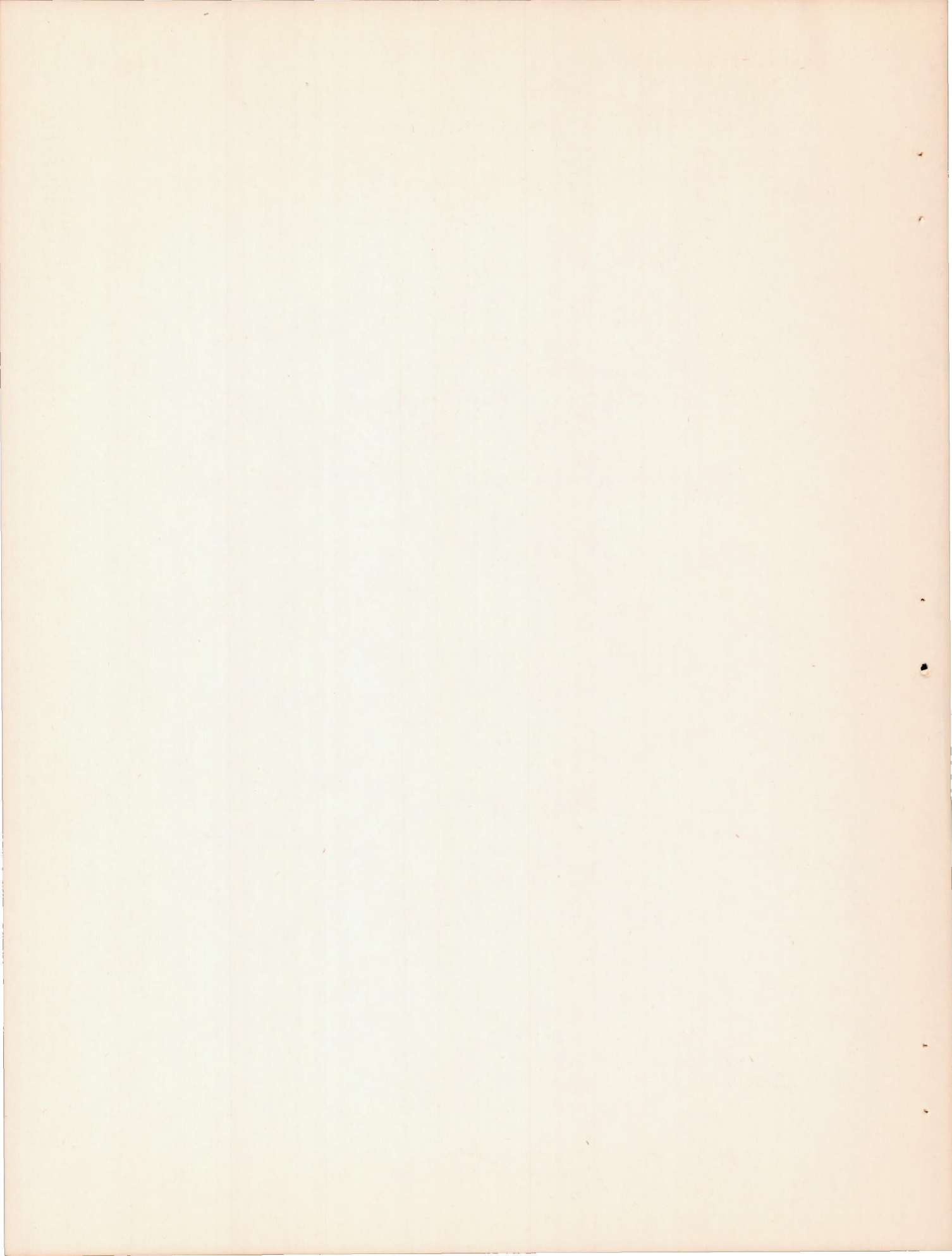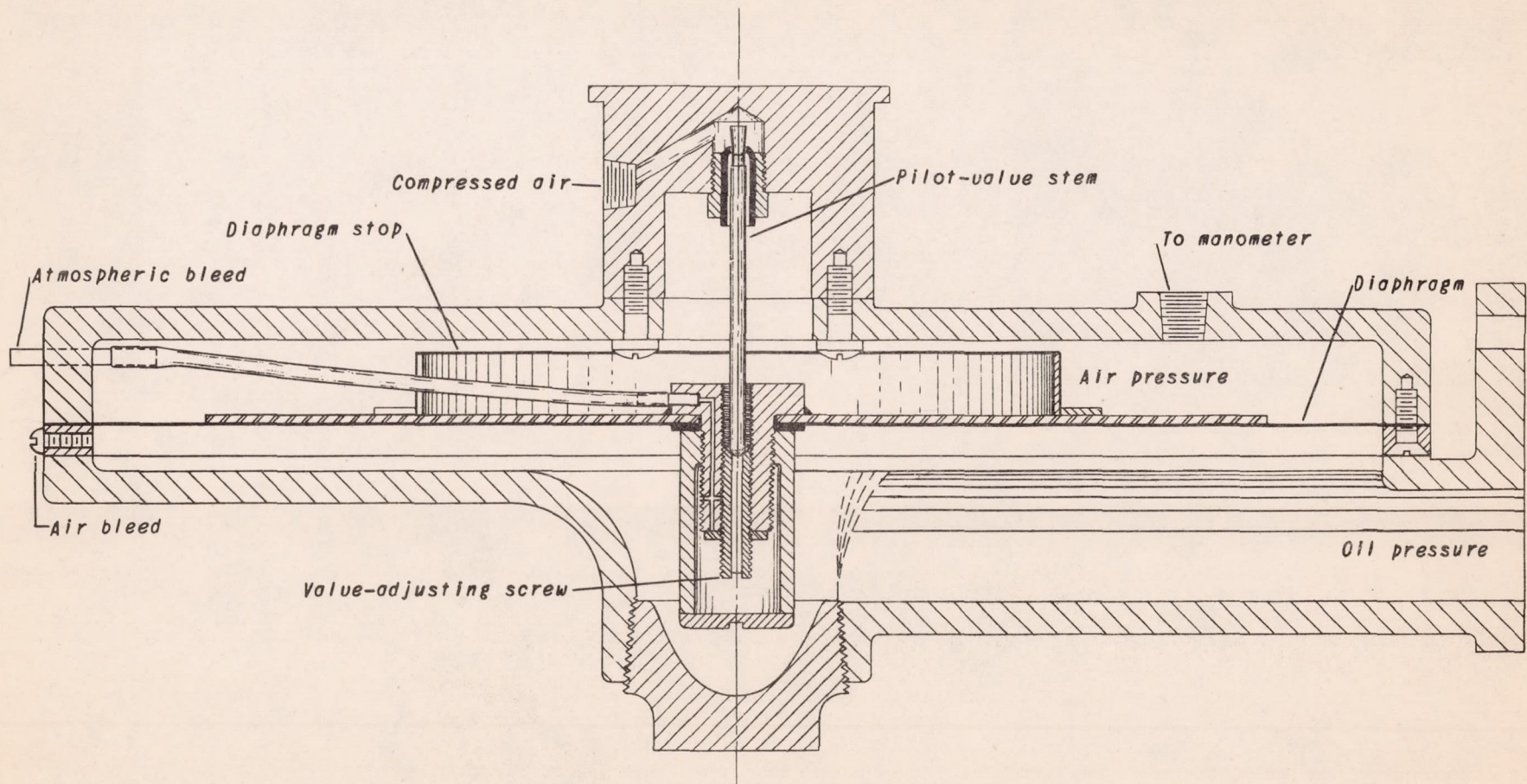
Figure 5. — Weighing-diaphragm assembly, poppet-valve type. Effective area, approximately 65 square inches.
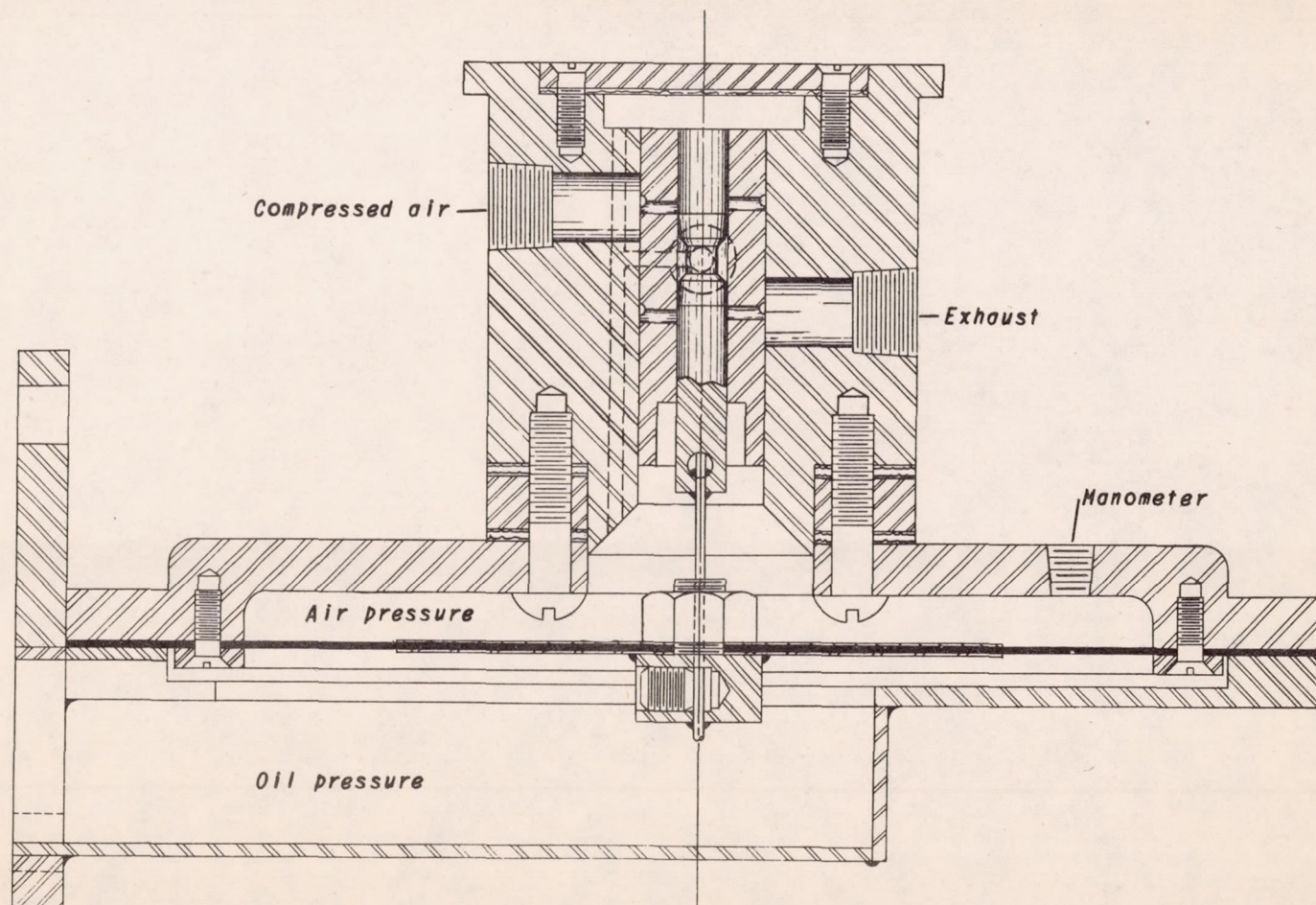
Fig. 5

Compressed air

Exhaust

Manometer

Air pressure

Oil pressure

Figure 6. - Weighing-diaphragm assembly, balanced-pressure piston-ported spool-valve type.  Effective area, approximately 10 square inches.
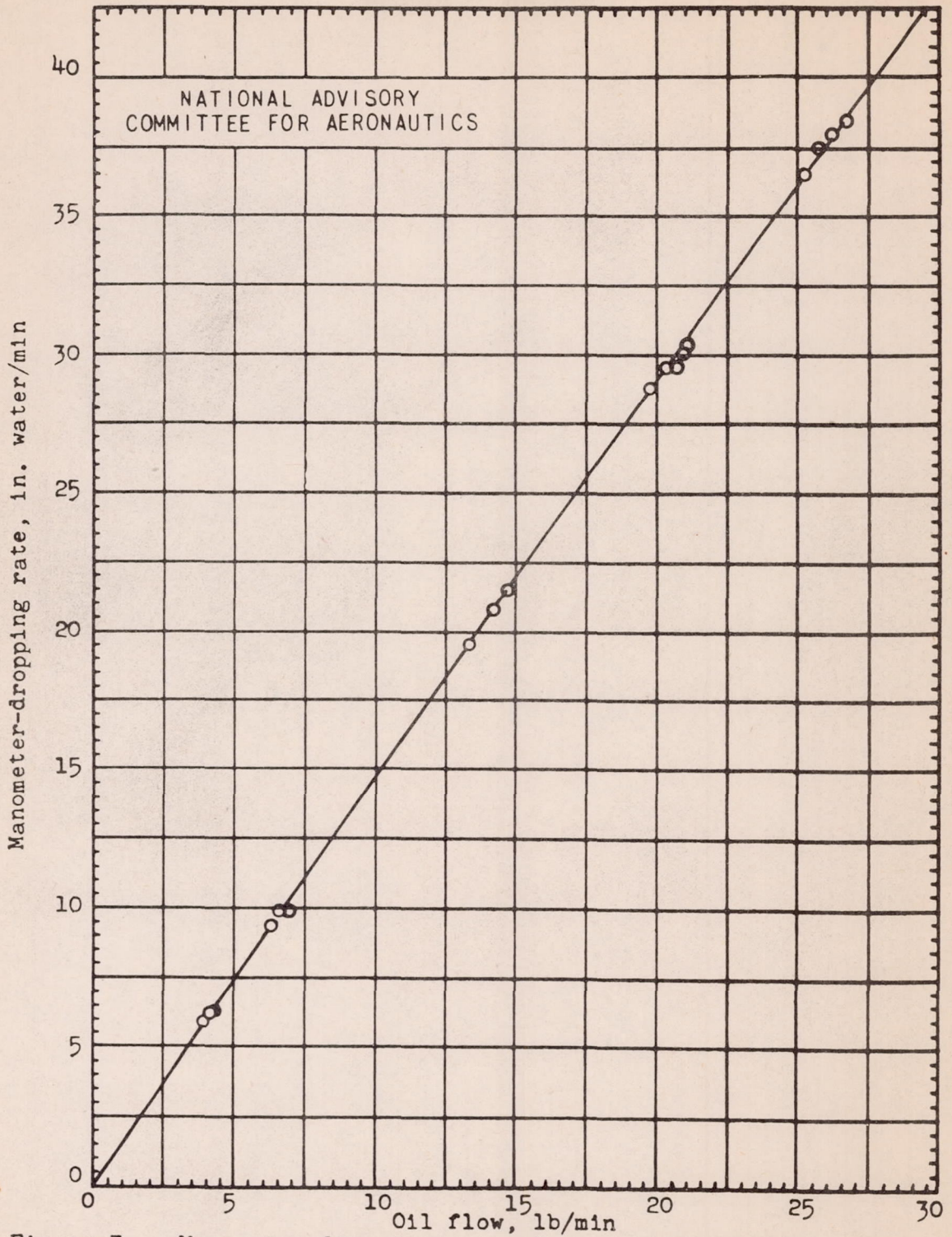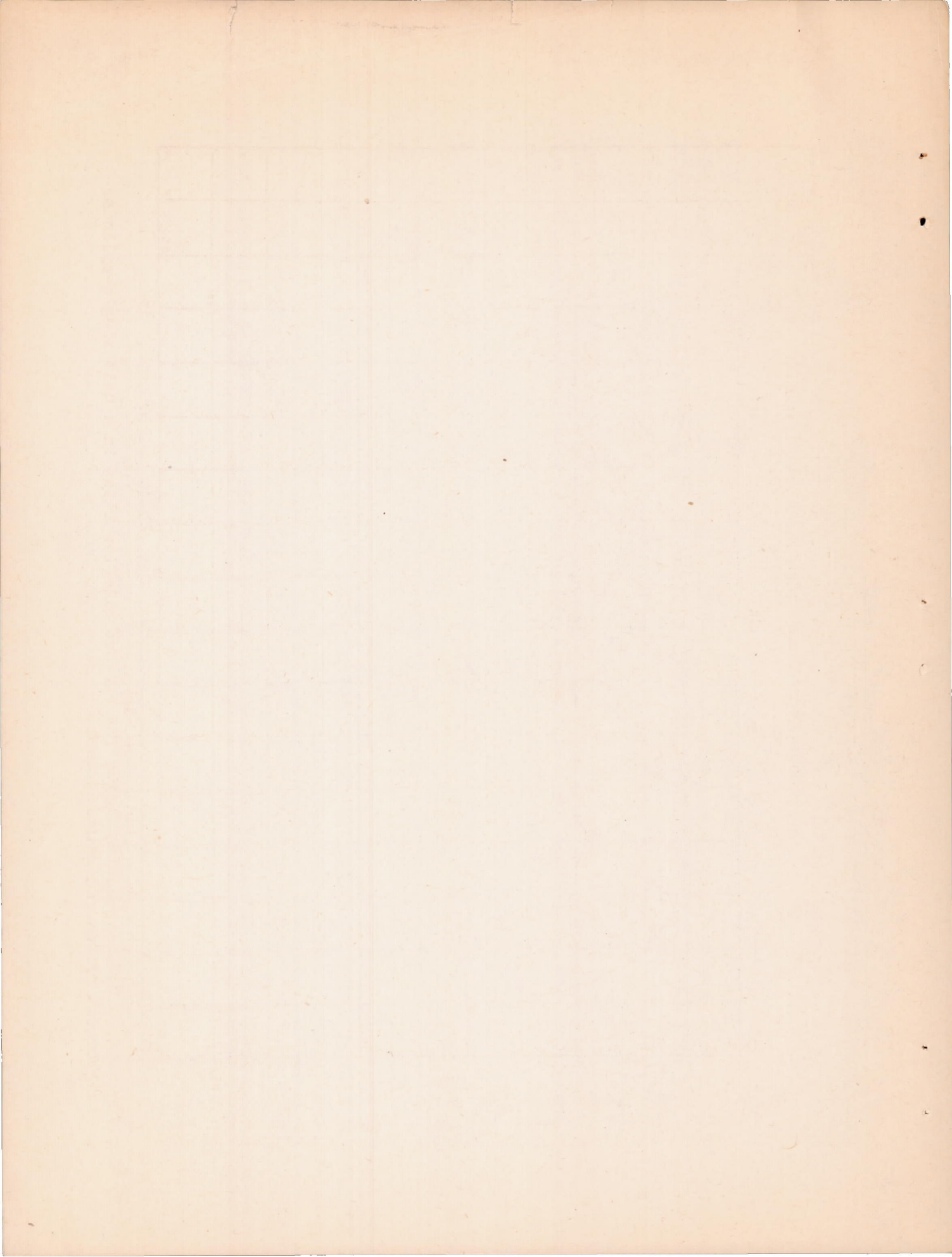
Fig. 6

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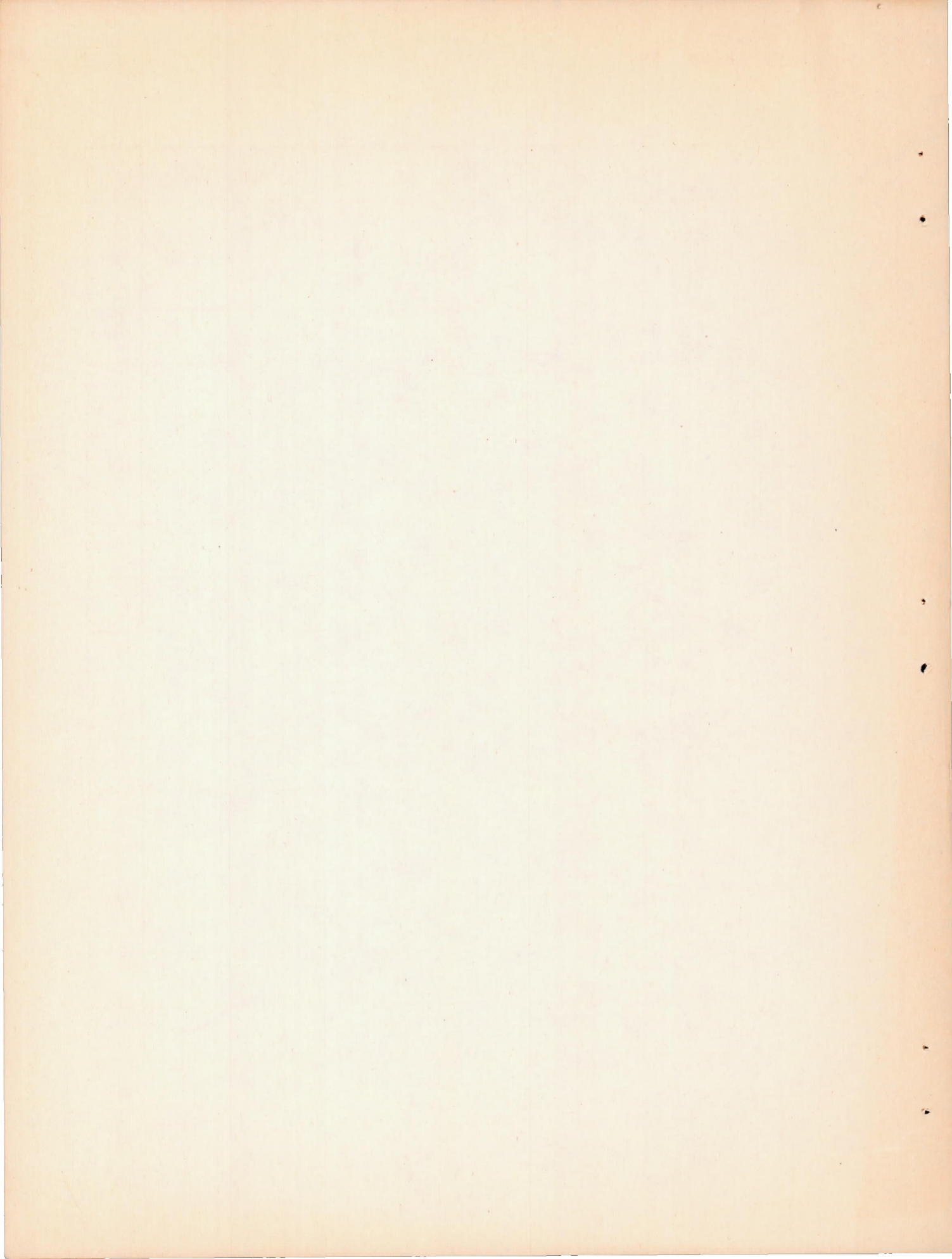
Figure 7. - Manometer-dropping rates for various oil-flow rates in a unit single-cylinder-engine oil system and weighing tank.
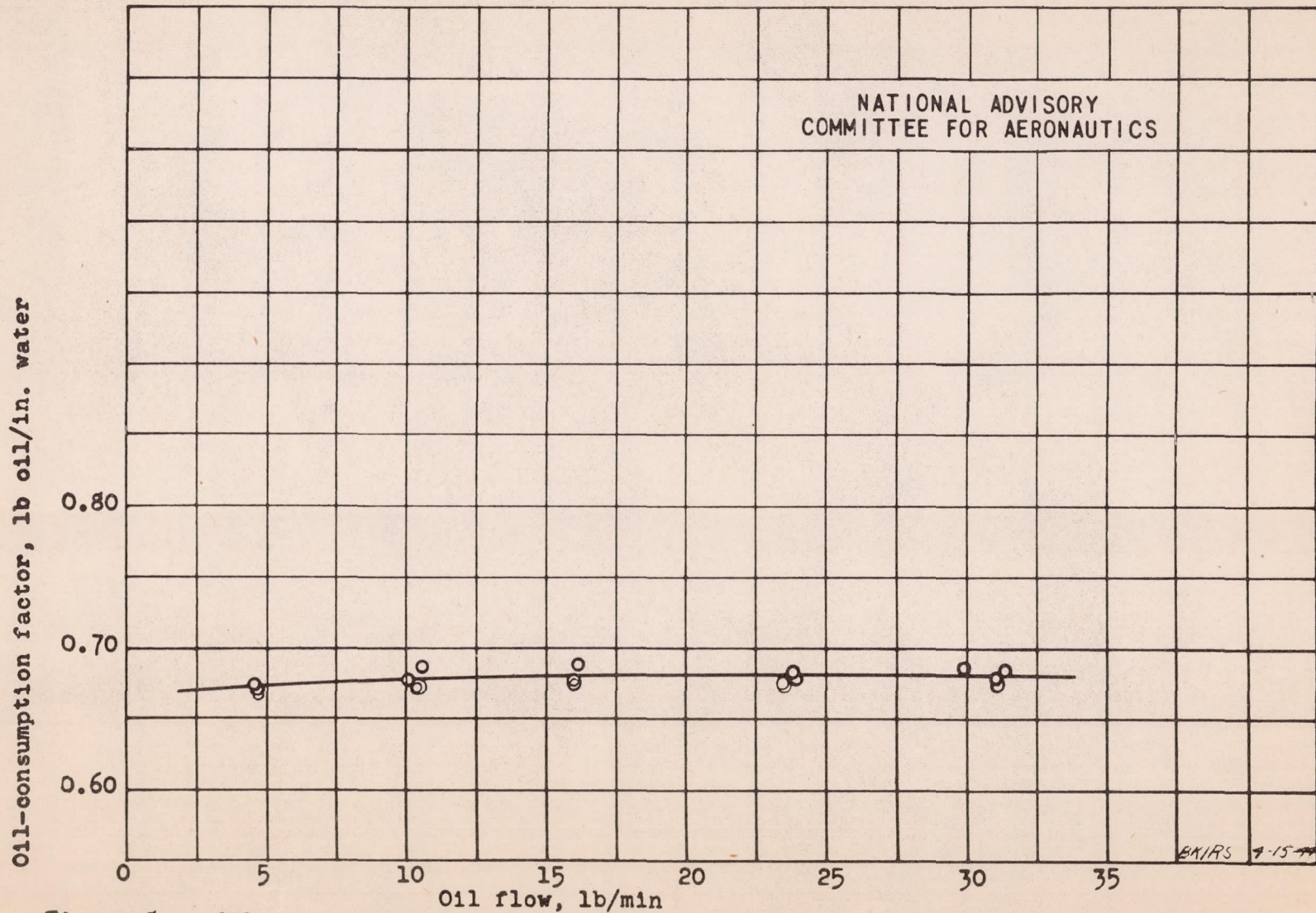
Figure 8. – Oil-consumption factor for various oil-flow rates in a unit single-cylinder-engine oil system and weighing tank.

Fig. 8