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BREAKING AIRCRAFT-ENGINE OIL FOAMS BY USE OF ELECTRICALLY CHARGED CONDENSER PLATES

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ADVANCE RESTRICTED REPORT

BREAKING AIRCRAFT-ENGINE OIL FOAMS BY USE OF ELECTRICALLY CHARGED CONDENSER PLATES

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SUMMARY

Object.- To determine the effectiveness of a charged condenser for breaking oil foams and to obtain data on which to base the design of such a device for mounting at the oil-tank inlet of an airplane.

Scope.- The use of a charged condenser with its associated brush discharge for breaking oil foams was studied. In this device the oil foam is made to pass between the condenser plates, where it is broken.

The influence of condenser-plate area and arrangement, condenser-plate design, condenser-plate voltage, and oil temperature on the action of an electrical foam breaker was investigated by means of a convenient laboratory apparatus. Tests were carried out with two oils, an SAE 40 Diesel oil containing additives and grade 1120 aviation oil without additives. Data are presented covering the effect of water in the oil on the foam-breaking effectiveness of the charged condenser. In addition tests were made with gasoline-oil mixtures containing up to 50 percent of gasoline by volume at temperatures from 170° F to 200° F to determine whether gasoline-air mixtures above the oil are ignited by the discharge across the condenser plates. Possible sources of the required high voltage for operating the foam breaker, safety measures that should be taken in their application, and design recommendations for a foam breaker are discussed.

Summary of results.- Foam-breaking tests with condensers charged to potential differences from 12,500 to 19,000 volts on foams produced from an SAE 40 Diesel lubricating oil at temperatures from 120° F to 180° F and grade 1120 aviation oil at temperatures from 150° F to 180° F have shown:

1. For a given condenser the foam-breaking rate increased with applied voltage and oil temperature. Oil additives, however, may modify the tendency of foams to break more readily at high foam temperatures.

2. The foam-breaking effectiveness of the condenser was increased when the oil recovered by the foam-breaking process was drained from the foam that remained to be broken.

3. Foam breaking was most rapid near the edges of the condenser plate.

4. Water concentrations in the oil of less than 6 percent by volume did not influence the foam-breaking rate.

Ignition of gasoline-oil mixtures containing up to 50 percent of gasoline by volume from 170° F to 200° F by the discharge across the condenser plates did not occur.

Conclusions.- The foam-breaking tests and the experience with the operation of the laboratory form of the proposed foam breaker indicate that oil-foam breakers that employ charged condenser plates are suitable as a means of eliminating oil foaming. This apparatus should be considered in those installations in which the oil foaming cannot be eliminated through other changes in the mechanics of the oil system or through the possible use of defoaming additives.

INTRODUCTION

Unpublished reports from several sources concerning lubrication and oil-pumping difficulties that occur in aircraft engines during flight as a result of oil foaming prompted the study and development of a method of controlling oil foaming by charged condenser plates placed at the oil-tank inlet. This work was conducted at the Aircraft Engine Research Laboratory of the NACA from February to June 1943.

Loss of oil from the engine to the air and reduced oil delivery to the engine are the two difficulties associated with oil foaming during flight. Loss of oil occurs when the volume of foam produced exceeds the available capacity of the oil tank, the engine crankcase, and the oil-tank vent line connecting the two. The excess foam is lost to the air with the engine blow-by through the crankcase breather. This loss of oil is sometimes sufficient to reduce the flight range of the airplane below the limit imposed by the fuel supply and may occur at any flight altitude.

The delivery from the pressure pump supplying the engine with oil falls off with increased oil-entrained air at the pump inlet. This subject was discussed in detail in a report delivered by Dolza at an SAE meeting on June 8, 1942. The work of Pigott (reference 1) closely paralleled the work of Dolza. These workers have pointed out that the presence of the air in the oil reduces the suction developed at the pump inlet; and at high altitudes, where the atmospheric pressure is low, the difference between the pressure at the oil tank and the pump inlet is insufficient to supply the oil to the pump at the rate required for satisfactory engine lubrication. As a result, flight is restricted to altitudes appreciably lower than those which the airplane could otherwise attain.

The presence of oil foam in the tank can contribute to the aeration of the oil flowing to the oil pressure pump in the following ways:

1. The air in the foam can be reincorporated into the main body of the oil by splashing of the oil in the tank during airplane maneuvers.

2. When the oil supply is low, the oil that forms the foam may represent an appreciable part of the total oil supply. The clear oil that remains for circulation therefore spends less time for each passage through the oil system in the oil tank where it can lose the air entrained in it. The oil flowing to the pressure pump has more entrained air than it would have if the oil in the foam were available for circulation. This condition is particularly true of oil systems employing a hopper-type oil tank that provides for the rapid circulation of a portion of the oil in the tank.

The dispersion of crankcase gas in oil, from which foam is produced when the gas bubbles attempt to pass through the oil surface to the adjacent atmosphere in the oil tank, is formed by the mixing action of the scavenge pump on a combined charge of oil and crankcase gas drawn from the crankcase oil sump. The capacity of the scavenge pump drawing oil from the engine exceeds the capacity of the pressure pump delivering oil to the engine. This excess pump capacity is provided to insure that oil does not accumulate in the engine crankcase. As a result, the extra capacity of the scavenge pump is satisfied by crankcase gases drawn in with the scavenged oil.

Whether the dispersion of gas in the oil formed by the scavenge pump will result in foam upon discharge into the oil tank depends on the presence of foaming agents in the oil, which are as yet unidentified. These foaming agents may be present in new oil, or they may be formed or introduced in use. The amount of foam formed per gallon of oil-gas mixture of given proportions can be somewhat reduced by providing means of coalescing the gas bubbles and separating them from the oil before the mixture joins the main body of oil in the tank. Some methods of this type are considered in references 1 and 2. A thorough discussion of the status of the oil-foaming problem was made in 1942 by W. J. McCann. (See reference 3.)

Three general methods of controlling oil foaming can be used:

1. An antifoam additive can be used in the oil.

2. Oil-system pumps, piping, and related accessories can be modified to minimize the aeration of oil and thereby reduce consequent foaming.

3. Foam can be permitted to form and then be broken before it can adversely affect the engine lubrication system.

The method of controlling oil foaming considered in this paper comes under the third category and involves the separation of the foam from the oil as it enters the oil tank and the breaking of this foam in an electric field and the associated brush discharge between charged electrical conductors through which the foam is made to flow. In the form of the device recommended in this report, the electrical conductors are modified condenser plates, one of which is in direct contact with the foam and the other which is separated from the foam by a solid dielectric.

The purpose of the research was to establish the value of using strong electric fields between charged condenser plates for breaking oil foams and to determine the importance of various design factors and oil properties that are likely to influence the effectiveness of a foam breaker. The data obtained must not be considered to represent an accurate evaluation of the effect of design factors and oil properties on the foam-breaking rate because simple laboratory apparatus was used to obtain the data and in some cases complete control over the variables was not possible.

A laboratory form of a proposed foam breaker designed to be mounted at the mouth of the oil-tank inlet is described herein and a drawing of a similar foam breaker considered suitable for an oil system circulating up to 15 gallons of oil per minute, corresponding to the oil-circulation rate of a 1000-horsepower, air-cooled engine, is included.

APPARATUS

The principal element of the foam-breaking device described in this report is a pair of condenser plates charged to a potential difference of about 15,000 volts alternating current. The foam to be broken was made to pass between the condenser plates, where the combined effect of the electrostatic field and the brush discharge between the plates broke the foam. One condenser plate is in contact with the oil foam and will hereinafter be called the "wet" plate; the other plate is separated from the foam by a solid dielectric and will be designated the "dry" plate. In the particular apparatus used in obtaining data, the plates were separated by a 0.20-inch free gap and a 3.5-millimeter thickness of glass, against which one of the plates was mounted. The action of the electrostatic field on foam bubbles is illustrated in figure 1. A single soap bubble was placed between two condenser plates, which were spaced $1\frac{1}{2}$ inches and charged to a potential difference of 5000 volts. Figure 1(a) illustrates the normal shape of the bubble without the applied voltage. Figure 1(b) shows the bubble distorted to the breaking point in the electrostatic field.

The apparatus used to produce the foam and to investigate the effect of the several primary variables involved in this method of foam breaking is illustrated in figure 2. Foam was formed by cycling the oil from the sump (3-quart capacity) through the motor-driven gear pump, into the foam tube, and by gravity back to the sump. The oil entered the foam tube through a set of holes 0.035 inch in diameter drilled in a tube, which was completely immersed in the oil; the top of the oil-injection tube can be seen in figure 3. The rate of foam production was increased by passing the oil and air into the foam tube through these holes.

The capacity of the pumping system was varied by the bypass valve, which was set to make the pump delivery exceed the rate at which oil flowed from the foam tube to the sump. In this way a mixed charge of air and oil was drawn into the pump. Injection of this charge into the foam tube produced the foam shown in figures 4 and 5.

The foam tube was made from a 28-inch length of 100-millimeter outer diameter and 93-millimeter inner diameter glass tubing. The 1-inch-diameter side arms placed 16 inches up from the lower end served as mountings for glass-rod supports for the wet condenser plate that was fixed inside the tube. A heating coil covering the lower 6 inches of the foam tube was used with the oil-immersion heater at the pump inlet to maintain the oil at the test temperature.

A second tube similar in design to the foam tube without the condenser was employed to store oil at the test temperature for use in displacing the test foam through the condenser. (See figs. 2 and 4.)

The dry plate of the condenser (figs. 2 and 5) was made by wrapping a wire-screen band, 4 inches wide, completely around the outside of the foam tube. The wet plate was made either of thin metal foil or of screen supported on the cylindrical surface of a metal tube $3\frac{1}{4}$ inches in diameter and 4 inches long (fig. 6(a)). Slots were cut in the metal tube to provide for the passage of oil through the screen to the inside of the tube (fig. 6(b)). One end of the tube was closed by a flat metal plate into which a glass tube was inserted. This glass tube conducted the oil that passed through the screen to the oil in the lower regions of the foam tube. A glass cover was placed over the open end of the metal tube to prevent foam that passed unbroken through the condenser from spilling into the metal tube. Rubber spacers inserted between the wet plate and the inside wall of the foam tube maintained a uniform annular passage 0.20 inch wide through which the foam was passed during a test. The 3.5-millimeter thickness of glass between the plates, which was provided by the wall of the foam tube, was important in maintaining a uniform electrical brush discharge across the gap. Without the glass or an equivalent dielectric material, undesirable arcing between the plates tends to occur. The foam-breaking action of the condenser is lost when arcing occurs.

The voltages used for these tests were obtained with a neon-sign transformer, the output voltage of which was controlled by varying the voltage impressed on the primary by a second variable-output step-down transformer.

TEST PROGRAM AND TEST PROCEDURE

Tests were run to determine the effect of the following factors on the foam-breaking rate:

1. Condenser-plate area and arrangement
2. Condenser wet-plate design
3. Condenser-plate voltage
4. Oil temperature
5. Water in the oil

An SAE 40 Diesel lubricating oil that contained additives and foamed readily was used for most of the tests. Grade 1120 aviation oil without additives, which foamed moderately, was used to indicate the effectiveness of charged condenser plates on the breaking of a typical aviation oil foam. Tests were included to determine whether the brush discharge between the charged condenser plates would ignite a gasoline-air mixture.

When the oil was brought to test temperature, a portion of the oil was stored in the heated storage tube and the rest was cycled as previously described to produce the test foam in the foam tube. The rate of oil circulation was about 4 gallons per minute. The pump bypass valve (fig. 2) was so adjusted that air drawn in with the oil was the proper amount to give the maximum rate of foam production in the foam tube. No attempt was made to measure the circulated air.

When sufficient foam for the test was produced, the cycling of oil was stopped and the sump was filled with oil from the storage tube. The pump bypass valve was then set from previous calibration to give the desired nominal pumping rate of the sump oil into the foam tube. This oil, without air, acted as a liquid piston in the foam tube and raised the foam between the charged condenser plates. The flow rate of the foam into the space between the condenser plates, in cubic inches per second, was determined by timing the rise of the line of separation between the foam and the clear oil in the foam tube of known diameter.

At the start of its upward displacement the column of foam was made to extend to either the upper or the lower edge of the wet plate, depending on the test to be run. The test procedure chosen depended on the amount of stable foam that could be made at the test temperature from the test oil. In order to compare an oil that foamed readily with one that foamed moderately, similar tests were run with the foam of both oils reaching the lower edge of the condenser before the test. When the foam reached the lower edge of the condenser at the beginning of the test, the percentage of the condenser covered by the foam when 50 cubic inches of foam were displaced between the plates was determined. If the foam reached the top of the condenser plate before the test, the height above the condenser reached by the foam was recorded when 72 cubic inches of foam were displaced through the condenser. The ratio of this height to that through which the line of separation between oil and foam moved to displace the 72 cubic inches of foam gave the proportion of foam that passed unbroken through the condenser. The percentage of foam broken was obtained by subtracting this value from unity and multiplying by 100.

RESULTS AND DISCUSSION

Condenser-Plate Area and Arrangement

Effect of condenser-plate area.- Three dry condenser plates of 1-, 2-, and 4-inch width were successively used with a 4-inch-wide wet plate made of 120-mesh screen. The top edge of each dry plate was fixed at the same level as the top edge of the wet condenser plate. Diesel lubricating oil was used for these tests. The initial foam column before the voltage was applied reached the top edge of the condenser plates for each test of this series. The applied voltage was 19,000. The oil temperature was 160° F, corresponding to a viscosity of 43 centistokes, or 197 Saybolt Universal seconds.

The results obtained from these tests are shown in figure 7. At a foam-displacement rate of 8 cubic inches per second, the amounts of foam broken by the 2-inch and the 4-inch plates were, respectively, 1.15 and 1.44 times that broken by the 1-inch plate. At a foam-displacement rate of 16 cubic inches per second, the amounts of foam broken by the 2-inch and the 4-inch plates were, respectively, 1.29 and 1.74 times that broken by the 1-inch plate.

The fact that the variation in the percentage of foam broken at a given rate of foam displacement is approximately linear with respect to the condenser-plate area but is not proportional indicates that the electric field at the edges of the condenser was more effective in breaking foam than the space between the edges. This point was verified by experiments described in the following paragraphs.

Effect of condenser-plate arrangement.- In order to evaluate the effect of condenser-plate arrangement, three tests were made using, successively, one 2-inch-wide dry plate and two 1-inch-wide dry plates which were so mounted that the bottom edge of the higher plate was separated from the top edge of the lower plate by a distance of 1/4 inch in one test and 1 inch in the other test. The top edge of the higher dry plate was at the same level as the top edge of the 4-inch-wide wet plate. Diesel lubricating oil was used at 160° F with a condenser voltage of 19,000. The initial foam column extended to the top edge of the condenser plates.

The results obtained are plotted in figure 8. Two 1-inch-wide dry plates were more effective than one 2-inch-wide dry plate and the gain obtained with the two plates increased with the distance between them. At a rate of foam displacement of 10 cubic inches per second, the percentage of foam broken by the 2-inch plate was 60; for the two 1-inch plates 1/4 inch apart, 71; and for the two 1-inch plates 1 inch apart, 86.

The gain obtained by using two separated 1-inch plates was believed to be principally due to doubling the length of the condenser-plate edge provided by the two separated plates. When the spacing between the plates was 1/4 inch, the adjacent edges of the plates were so close that their electrical fields apparently overlapped and the effect was not that of two separate edges. A large part of the improvement obtained with the 1-inch spacing, however, was probably also due to the improved drainage of the oil recovered from the foam through the wet-plate screen. The oil recovered between the condenser plates by breaking the foam tended to wet the oncoming foam and made it difficult to break unless proper drainage for the recovered oil was provided. In the case of the 1-inch-spaced dry plates, the oil recovered from the foam broken in the field of the lower plate was allowed more time to drain before the foam moved through the field of the second plate and the foam was therefore more easily broken. The curve for a 3-inch-wide dry plate, for which the drainage time was the same as that for two 1-inch-wide dry plates spaced 1 inch, indicates by comparison with the curve for the two 1-inch-spaced dry plates the gain in foam-breaking effectiveness obtained by providing the additional condenser-plate edge.

The most effective condenser dry plate, therefore, would be one that will give the maximum edge effect. Dry plates made of wires would probably provide the greatest length of condenser edge for a fixed over-all condenser area.

Wet-Plate Design

The greater the thickness of the oil film making up the foam, the more difficult it was to break the foam. As foam breaking proceeded between the condenser plates, the oil recovered from the broken foam drained down and wetted the oncoming foam. This effect can be observed near the top of the foam column at the edge of the condenser plate in figure 5. A collar of solid oil tops the foam column. At the middle of this collar the oil can be seen flowing downward over the oncoming oil foam.

The necessity of providing for drainage of the oil recovered from the foam was demonstrated with the wet plate illustrated in figure 6. The oil recovered from the broken foam drained through the screen to the inside of the steel tube and joined the main body of clear oil via the glass tube. Foam did not rise in the glass tube during the foam-breaking tests because the lower end of the tube was always sealed by the layer of clear oil. Foam did not move through the screen unless an appreciable pressure drop existed across the screen to force the foam through it. (See fig. 9.)

For the test to determine the effect of oil drainage on foam breaking, cylindrical wet plates 4 inches long of 80-mesh screen, 120-mesh screen, and solid copper foil were used. The dry plate was cylindrical and was made of 120-mesh screen 4 inches in diameter and 4 inches long. Diesel lubricating oil at 160° F was used in all tests. The condenser voltage was 19,000. The initial column of foam extended to the top of the condenser.

The data obtained are plotted in figure 10. At a foam-displacement rate of 12 cubic inches per second, the amount of foam broken using wet plates of 120-mesh and 80-mesh screen were 110 percent and 126 percent, respectively, of the value obtained with the solid copper-foil wet plate that provided no drainage for the recovered oil.

Some of the improvement in foam-breaking effectiveness with the coarser-screen wet plate might have been due to an edge effect similar to the effect observed for the dry plate. A small discontinuity in the metal of the wet plate will produce the same edge effect as a much larger discontinuity in the dry plate because the wet plate is in contact with the foam and the dry plate is separated from the foam by a dielectric. The edge effect produced by wet-plate discontinuities therefore increases with the coarseness of the mesh. The edge effect is attributed to the relatively high discharge current density between the condenser plates at the edge or the discontinuity in the condenser. The closer the edge or discontinuity is approached, the greater the current density will be.

More effective drainage of the recovered oil would have been realized if the wet plate had been in a horizontal plane instead of in a vertical plane because an appreciable amount of recovered oil ran down the column of foam. The tests conducted, therefore, did not evaluate the entire effect of the drainage of recovered oil.

The recommended form of the wet plate provides for the drainage of the oil recovered from the foam. With wet plates of the type discussed in this report, drainage is most readily accomplished when the wet plate is horizontal. Any form of the electrical foam breaker should provide for the separation of clear oil from the foam in the mixture of foam and oil flowing to the foam breaker in such a way that the foam to be broken contains as little oil as possible.

It has not been determined how coarse the screen mesh may safely be without permitting an undue amount of foam to pass unbroken through the screen with the oil. Observations made during these tests showed 80-mesh screen to be satisfactory for oils having a viscosity less than 67 centistokes, or 320 Saybolt Universal seconds, corresponding to grade 1120 aviation oil at temperatures above 160° F.

Condenser Voltage

Tests to evaluate the effect of condenser voltage were made with both Diesel lubricating oil and grade 1120 aviation oil. Voltages of 12,500, 14,600, 16,800, and 19,000 were used. The initial foam column extended to the lower edge of the condenser plates.

The data obtained for the Diesel lubricating oil at 160° F and 180° F are shown in figure 11 and those for the grade 1120 aviation oil at 160° F and 180° F are shown in figure 12. These data show that the gain in rate of foam displacement, when a constant percentage of the condenser plate was covered, decreased for each additional step of approximately 2200 volts for both oils in almost every case. For instance, for both oils at 160° F and 180° F, the following table gives the rate of displacement at the various test condenser voltages when 70 percent of the condenser was covered:

TABLE 1. - VARIATION IN RATE OF FOAM DISPLACEMENT WITH CONDENSER VOLTAGE FOR 70 PERCENT OF PLATE COVERED

Voltage	Rate of foam displacement (cu in./sec)				Gain in rate of foam displacement for each 2200-volt step (cu in./sec)			
	Diesel lubricating oil		Grade 1120 aviation oil		Diesel lubricating oil		Grade 1120 aviation oil	
	160° F	180° F	160° F	180° F	160° F	180° F	160° F	180° F
12,500	1.8	2.4	1.0	1.8	------	------	------	------
14,600	4.9	4.8	2.6	7.9	3.1	2.4	1.6	6.1
16,800	7.8	7.1	5.0	10.5	2.9	2.3	2.4	2.6
19,000	9.2	7.8	6.5	12.2	1.4	.7	1.5	1.7

Between 16,800 and 19,000 volts the gain obtained by raising the voltage dropped rapidly for both oils at 180° F. It is probable that increasing the voltage beyond 24,000 would not be justified by the small increase in allowable rate of foam displacement obtained for these oils at 180° F with the apparatus.

The analyses of the data indicate that an optimum condenser-plate potential difference exists for a condenser of given design for each oil beyond which the gain in foam-breaking effectiveness obtained by increasing the voltage does not compensate for the increased care required in the construction of the condenser for use at the voltages above the optimum. For a condenser employing a 0.20-inch free gap and a thickness of dielectric equivalent to a 3.5-millimeter thickness of pyrex glass, a satisfactory voltage for most oils would be about 20,000.

A comparison of data for the Diesel lubricating oil at 160° F with data for grade 1120 aviation oil at 180° F (table 1), the temperatures at which the oils had approximately the same viscosity, shows that the Diesel lubricating oil, which formed the more stable foam, was more difficult to break.

Oil Temperature

Tests to evaluate the effect of oil temperature were carried out with the same apparatus and the same procedure as the tests described in the preceding section.

The data obtained for the Diesel lubricating oil at temperatures varying from 120° F to 180° F with a constant voltage of 19,000 are shown in figure 13. The same data for the grade 1120 aviation oil for temperatures from 150° F to 180° F are plotted in figure 14. For the Diesel oil, the rate of foam displacement at an oil temperature of 160° F was 2.3 times as great as the foam displacement at 120° F for 70 percent of the plate covered. For the aviation oil, a change in temperature from 150° F to 180° F multiplied the rate of foam displacement for 70 percent of plate covered by a factor of 2.2.

It will be noted that breaking of the Diesel oil foam was not accomplished by this electrical means as readily at 180° F as it was at 160° F. This effect was noted in similar data obtained at other condenser voltages not included in the report. It is believed that certain of the additives in this oil acquire oil-film protective qualities at elevated temperatures that offset the general tendency of the films to rupture more easily at the higher temperatures.

For the grade 1120 aviation oil, the effect of oil temperature on foam-breaking rate is considered to be one of viscosity and possibly surface tension rather than temperature. The lower the oil viscosity, the thinner the oil film in the foam and the more readily is it broken. When drainage through the wet plate was provided, the rate at which the oil recovered from the foam moved through the wet-plate screen increased with temperature.

The analyses of these results indicate that the foam-breaking rate obtained with the electrical foam breaker increased with foam temperature. Oil additives that become surface active at the higher temperatures and promote foam stability may modify this trend.

Water in Oil

The effect of water in the oil on the foam-breaking rate obtained with the electrical foam breaker was determined with Diesel lubricating oil at 160° F. The Diesel lubricating oil was chosen for these tests because water solutions of the detergents present in the oil were better conductors of electricity than water-in-oil emulsions which would have been obtained with grade 1120 aviation oil. The tests with Diesel lubricating oil then represented the case where conductance was the greater. The results obtained are summarized in table 2 and show that the quantities of water in the Diesel oil up to approximately 6 percent by volume had little effect on the foam-breaking efficiency of the condenser. A considerable reduction in the foam-breaking efficiency of the condenser occurred when the water in the oil was increased to 8.78 percent by volume. Tests were made at 19,000 volts with a nominal foam-displacement rate of 16 cubic inches per second. A dry plate of 4-inch width and a wet plate of 120-mesh screen were used.

TABLE 2. - EFFECT OF WATER IN DIESEL LUBRICATING OIL ON CONDENSER FOAM-BREAKING EFFICIENCY

Percentage water in oil	Percentage of foam broken	Foam-displacement rate (cu in./sec)
0.00	71	15.32
1.76	72	16.00
4.04	79	16.35
5.98	71	16.35
8.78	33	16.75

It is unlikely that the amount of water in oil in an airplane-engine crankcase would be above 6 percent for any appreciable length of time in view of the fact that the oil temperature in the crankcase is around 220° F and the atmospheric pressure above 20,000-feet altitude is less than one-half that at sea level. Quantities of water in excess of 1 or 2 percent of the oil would boil out under these conditions. Foams formed from a sample grade 1120 aviation oil that had been drained from an engine after 200 hours of flight service were observed to break under the action of the foam breaker as readily as new-oil foams. The concentration of water in the used service oil together with other oil contaminants coming from the engine, the fuel, and the oxidation products of the oil was insufficient to affect the foam-breaking effectiveness of the charged condenser plates or to alter appreciably the power required for operation of the foam breaker.

DESIGN OF THE ELECTRICAL FOAM BREAKER

A laboratory form of an electrical foam breaker suitable for installation in an aircraft oil tank is illustrated by a diagram in figure 15 and by photographs in figure 16. A wet plate of 80-mesh screen was used, which provided for the separation of clear oil from foam in the incoming aerated oil. The mixture of foam and oil entering the tank (fig. 15) passed up through the center tube and over the conical portion of the screen. Clear oil moved through the 80-mesh screen and ran down the outside of the screen and center tube to the main body of oil in the tank. The foam stayed on the inside of the screen and flowed over the top of the inverted cone. As it passed over the horizontal lip of the cone, the foam was broken within the electrical field of the condenser made up of a wet plate, which is the horizontal lip of the cone, and a dry plate, which is located on the flat surface of the glass cover over the cone. Some of the oil recovered from the foam broken on the cone lip drained through the lip screen and flowed down along the outside of the cone to the oil tank. The recovered oil that did not have a chance to drain through the screen flowed around the very fine foam bubbles that were normally the last to be broken by the electric field. If these foam bubbles were so small that they were submerged by the recovered oil, then the electric field did not break them. This foam plus the oil flowed over the rim of the cone lip and plated out to a thin layer on the cylindrical rim of the cone. The fine bubbles were thus uncovered and subjected to the electric field of the condenser formed by the cylindrical rim as a wet plate and a wire-mesh band around the cylindrical sides of the cone cover as the dry plate.

The foam that separates from the clear oil is shown in figure 16(a). The foam is seen pouring down the cylindrical glass form used to support the rim of the cone screen that constitutes the wet plate. When the voltage was applied, in this case 13,900 volts, the foam was broken and the clear recovered oil was observed to pour from the cylindrical rim of the wet plate, as shown in figure 16(b). The quantity of oil that was recovered from the foam was appreciable. Some foam was formed by the falling streams of recovered oil splashing in the main body of the oil.

In an actual installation, a funnel-shaped duct should be provided for conducting the recovered oil down to the oil surface to prevent splashing.

A proposed form of the foam breaker that is suitable for mounting on the inlet line of an aircraft oil tank is illustrated in figure 17. Its action is identical with the laboratory form previously discussed, but its form differs from it in the greater amount of screen area provided for separating the clear oil from the foam. Based on the experience obtained with the laboratory foam breaker, a potential difference of 18,000 volts is recommended for a condenser of the dimensions shown in the drawing. The specific voltage to be used for a foam breaker of given design will depend on the maximum flight altitude at which the airplane will fly. The voltage at which undesirable arcing will occur across the condenser plates is less at altitude, where the atmospheric pressure is low, than that at sea level. The voltage chosen must be below this critical value. This foam breaker was designed for grade 1120 aviation oil 165° F or hotter circulating at rates up to 15 gallons per minute.

The device does not increase the oil-flow resistance because the clearances provided for the foam passages are available to the oil if it is too viscous at reduced temperatures to move rapidly through the screen. For the same reason no oil-flow difficulties can result from nonhorizontal flight.

The most suitable materials for the dry-plate support have not been determined. Pyrex glass appears to serve quite well, but undoubtedly there are suitable plastic materials which would be less fragile than glass.

The type of electric current available on the airplane will determine the method that can be used for obtaining the voltage required for the foam breaker. If only direct current is available, a form of large spark coil with a current interrupter in the primary of the coil would serve. If alternating current is available, a low-capacity high-voltage transformer is all that would be required. The voltage supplied to the spark plugs would probably be satisfactory. A second magneto may be required to supply current to the foam breaker. The high-voltage source should be mounted on the outside of the oil tank just above the foam breaker in order that high-voltage lines only several inches long can be used. If a second magneto is used for producing the high voltage, it should be electrically driven at the oil tank.

The power consumed by the laboratory model of the foam breaker, which is comparable in design and capacity with the proposed airplane installation, was less than 60 watts.

SAFETY CONSIDERATIONS

The following test was made to determine whether the type of discharge that occurs between the condenser plates is capable of igniting an explosive mixture of gasoline vapor and air that may be present in the oil tank if gasoline dilution is practiced. Oil-gasoline mixtures containing 5 to 50 percent of AN-F-28, Amendment-1, aviation gasoline leaded with 4.5 ml TEL per gallon were heated to a temperature from 170° F to 200° F. Air was bubbled through the mixture and the air-fuel mixture passed between two condenser plates across which a strong brush discharge was maintained. In no case did ignition occur. The airplane oil-tank atmosphere is composed of crankcase gas pumped with the oil to the tank. The oxygen concentration of this gas is normally between 10 and 16 percent. The ignition tests with pure air containing 20 percent of oxygen therefore represented the worst possible condition.

Positive assurance that ignition cannot be caused by the foam breaker can be provided by bleeding exhaust gas into the oil sump at about the rate of 5 gallons per minute. The gas circulated with the oil is then essentially oxygen-free and ignition cannot possibly occur.

The primary circuit of the spark coil or transformer should be protected with a fuse. If arcing between the condenser plates should occur, the fuse would cut off the applied voltage.

Deposits of carbon from used engine oil on the surfaces of the insulators may conceivably make it difficult to maintain the required high electrical potentials across the condenser plates because of electrical leakage through the carbon. If this electrical leakage does occur, more care in the design of the insulators and the plate mountings will be necessary than is indicated in the foam-breaker design given in this report. Provision should be made in the installation design for permitting easy access to the condenser plates for inspection and cleaning. The wet-plate screen will act as a filter and some oil-borne solids will undoubtedly be deposited there.

SUMMARY OF RESULTS

The data on oil-foam breaking with charged condenser plates, one of which is in contact with the foam and the other which is separated from the foam by a material of high dielectric strength have shown:

1. Oil foams broke most readily in the space between the condensers in the region of the condenser-plate edges.

2. Drainage of the oil recovered from the foam away from the foam that remained to be broken improved the effectiveness of the foam breaker.

3. The foam-breaking rate increased with applied voltage below the voltage at which arcing between the condenser plates occurred.

4. The rate of foam breaking generally increased with temperature. Oil components or additives that become foam stabilizers at the higher temperatures may modify this tendency.

5. Water in the oil in quantities less than 6 percent by volume did not influence the rate of foam breaking.

6. The electrical brush discharge between the condenser plates did not ignite gasoline-air mixtures.

DESIGN RECOMMENDATIONS FOR AIRCRAFT-OIL-SYSTEM FOAM BREAKER

1. At least one condenser plate should be separated from the foam by a solid material of good dielectric properties that does not permit arcing between condenser plates at altitudes where the atmospheric pressure is low.

2. One or both condenser plates should be provided with holes or channels to permit the drainage of oil recovered from the broken foam away from the oncoming foam.

3. In order to provide as great a length of condenser edge as possible for a condenser plate of given over-all size, the dry condenser plate should be formed from narrow metallic tape or wire suitably supported on solid material of high dielectric strength.

4. Provision should be made for separating the foam from the oil in the air-oil mixture entering the oil tank before the foam is introduced between the condenser plates. The use of a wire screen for this purpose appears to be satisfactory.

5. The applied condenser voltage should not exceed the voltage at which arcing between the plates occurs at the maximum flight altitude.

6. A modified form of foam breaker consisting of a grid of modified condenser plates whose adjacent elements are oppositely charged to a suitable difference of potential could be installed

above the oil level in the oil tank to break the foam that reaches it. Alternate condenser plates should be insulated from contact with the foam according to recommendation 1.

CONCLUSIONS

The foam-breaking tests and the experience with the operation of the laboratory form of the proposed foam breaker indicate that oil-foam breakers that employ charged condenser plates are suitable as a means of eliminating oil foaming. This apparatus should be considered in those installations in which the oil foaming cannot be eliminated through other changes in the mechanics of the oil system or through the possible use of defoaming additives.

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National Advisory Committee for Aeronautics,
Cleveland, Ohio.

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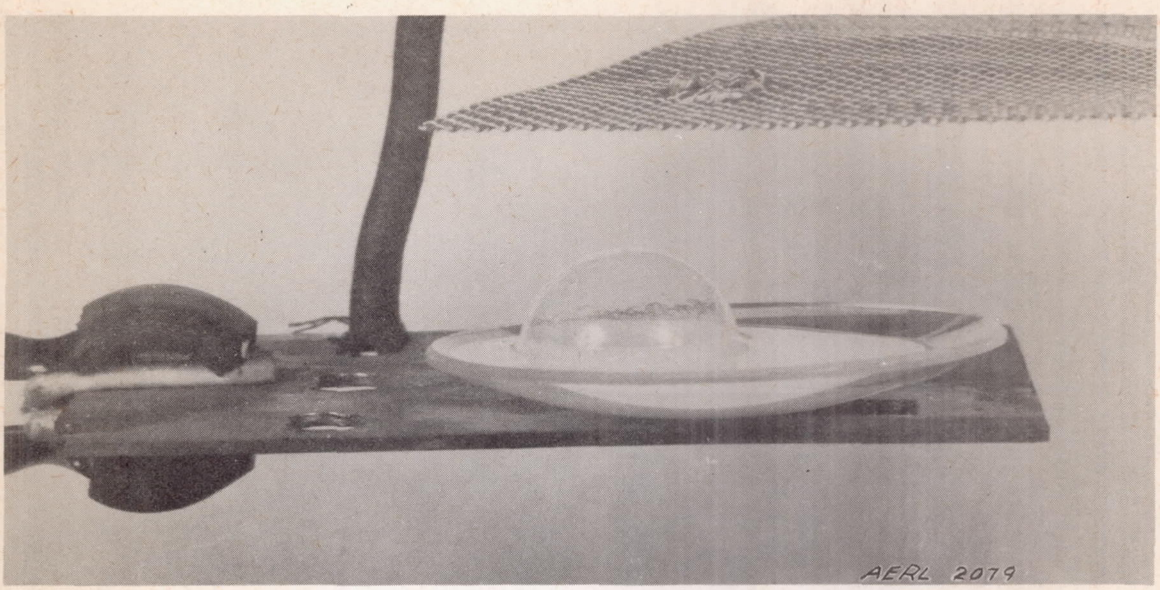
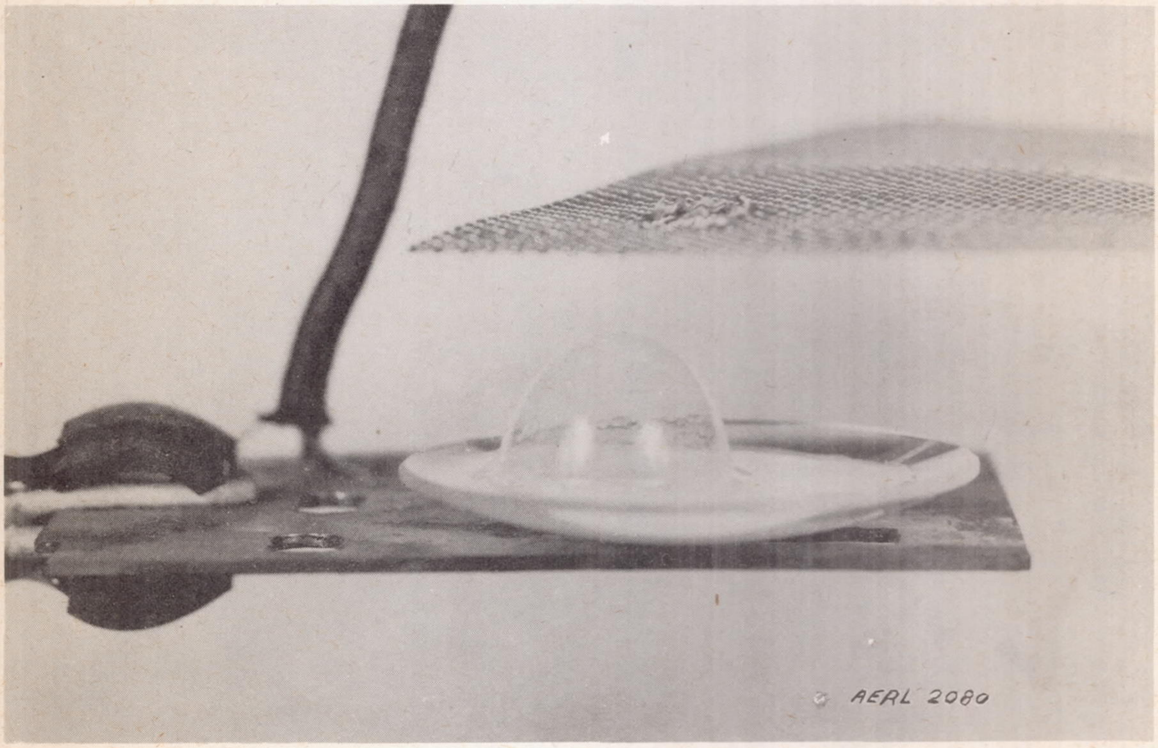
2. Sulzman, E. C.: Aircraft Engine Installation. Aero. Eng. Rev., vol. 1, no. 6, Sept. 1942, pp. 5-11.

3. McCann, W. J.: Foaming and Aeration in Aircraft Engine Oil Systems. NACA RB, July 1942.



(a) No voltage



(b) Voltage applied

Figure 1. - Behavior of soap bubble in electric field.

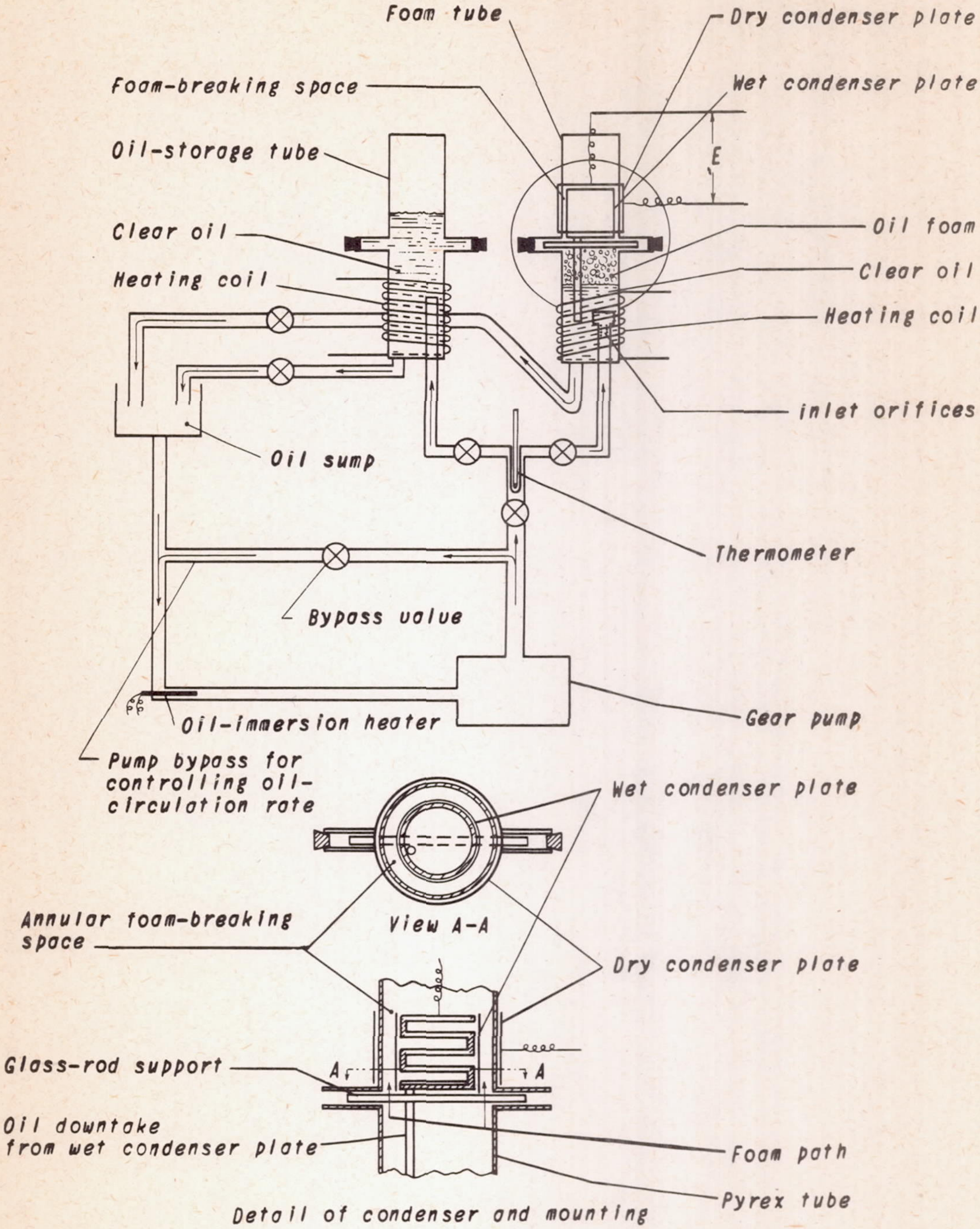


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Figure 2. - Laboratory apparatus for producing foam and measuring foam-breaking rate.

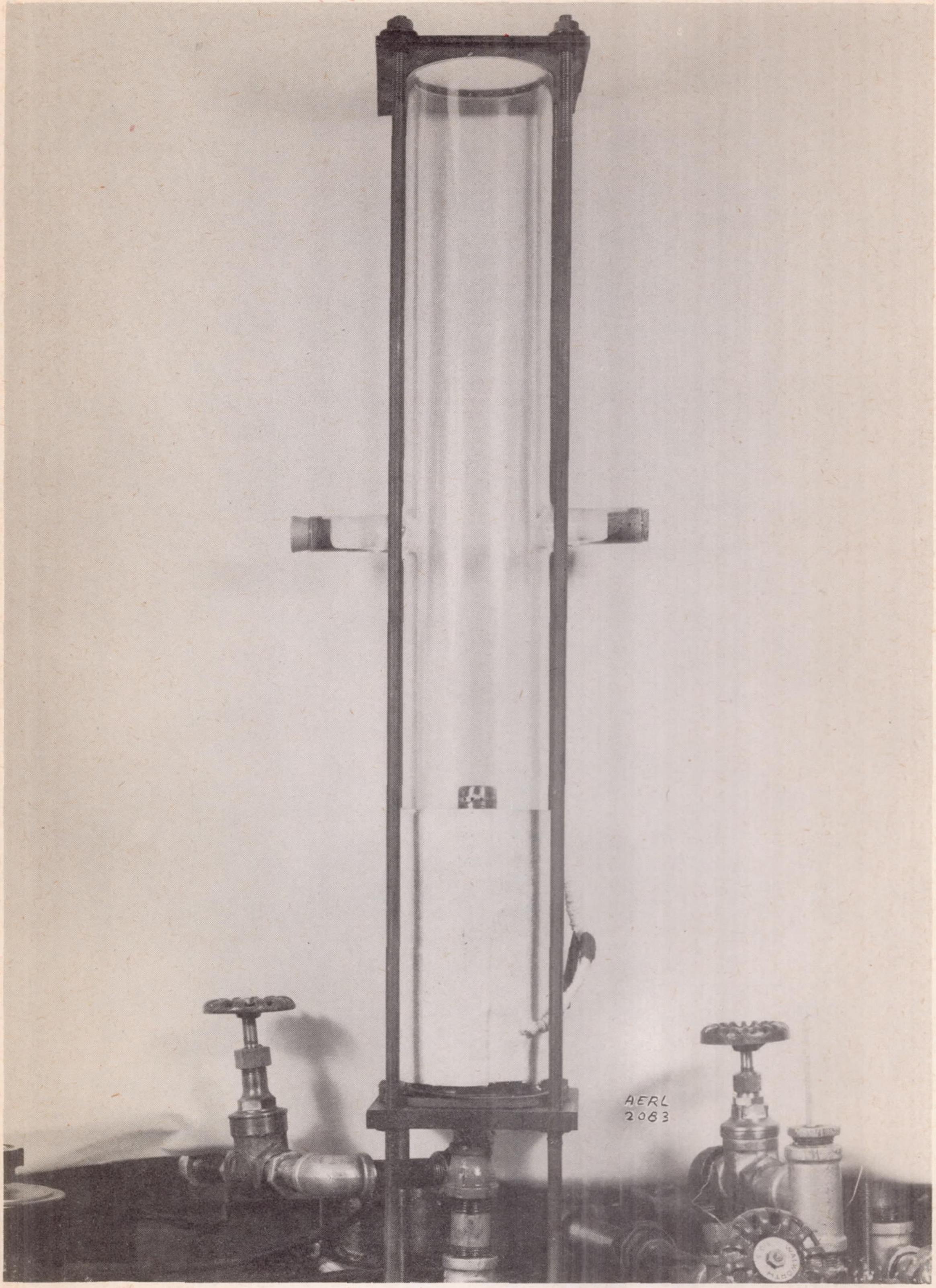


Figure 3. - View of empty foam tube without condenser.

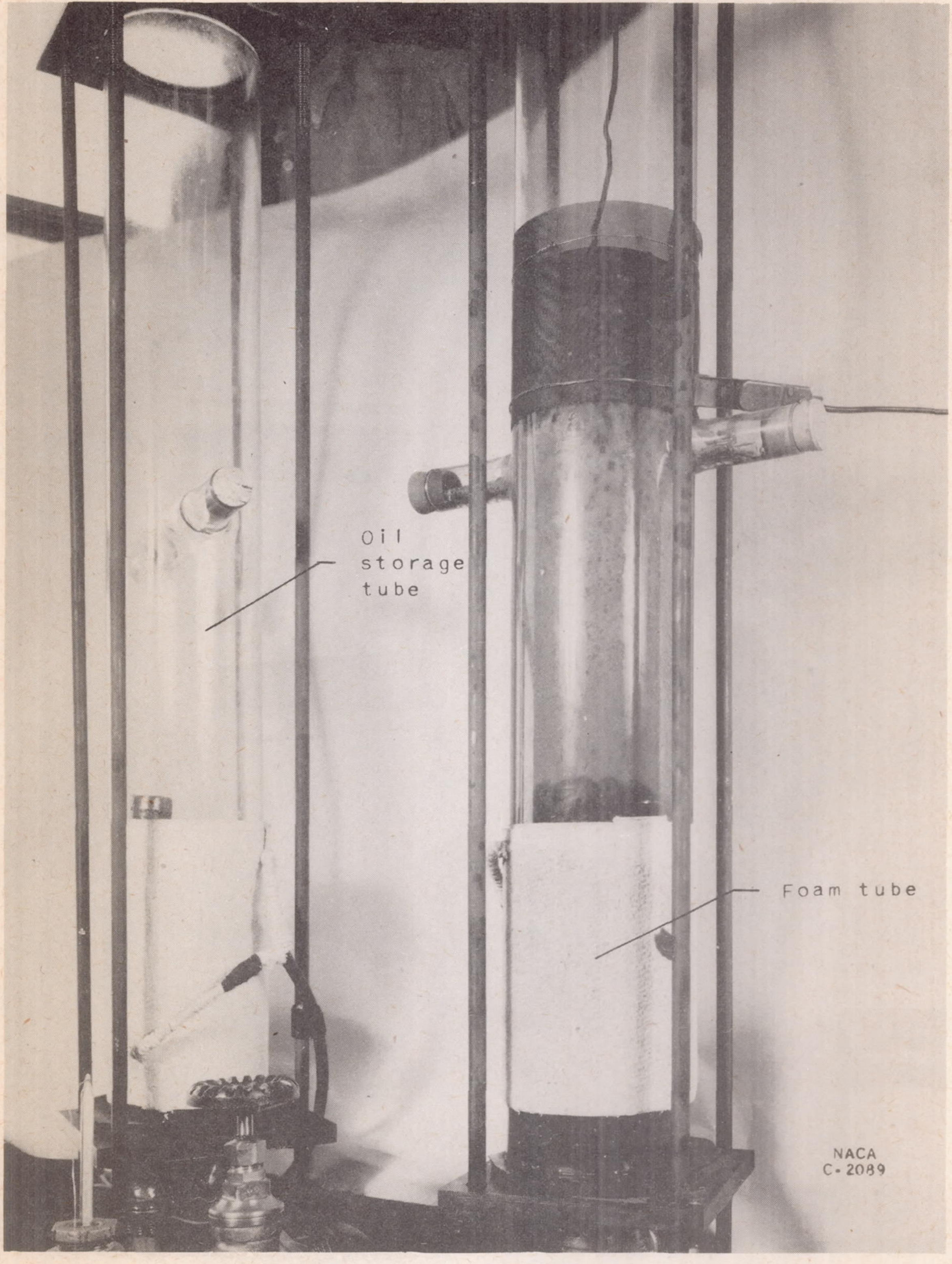


Figure 4. - Foam tube and oil-storage tube.

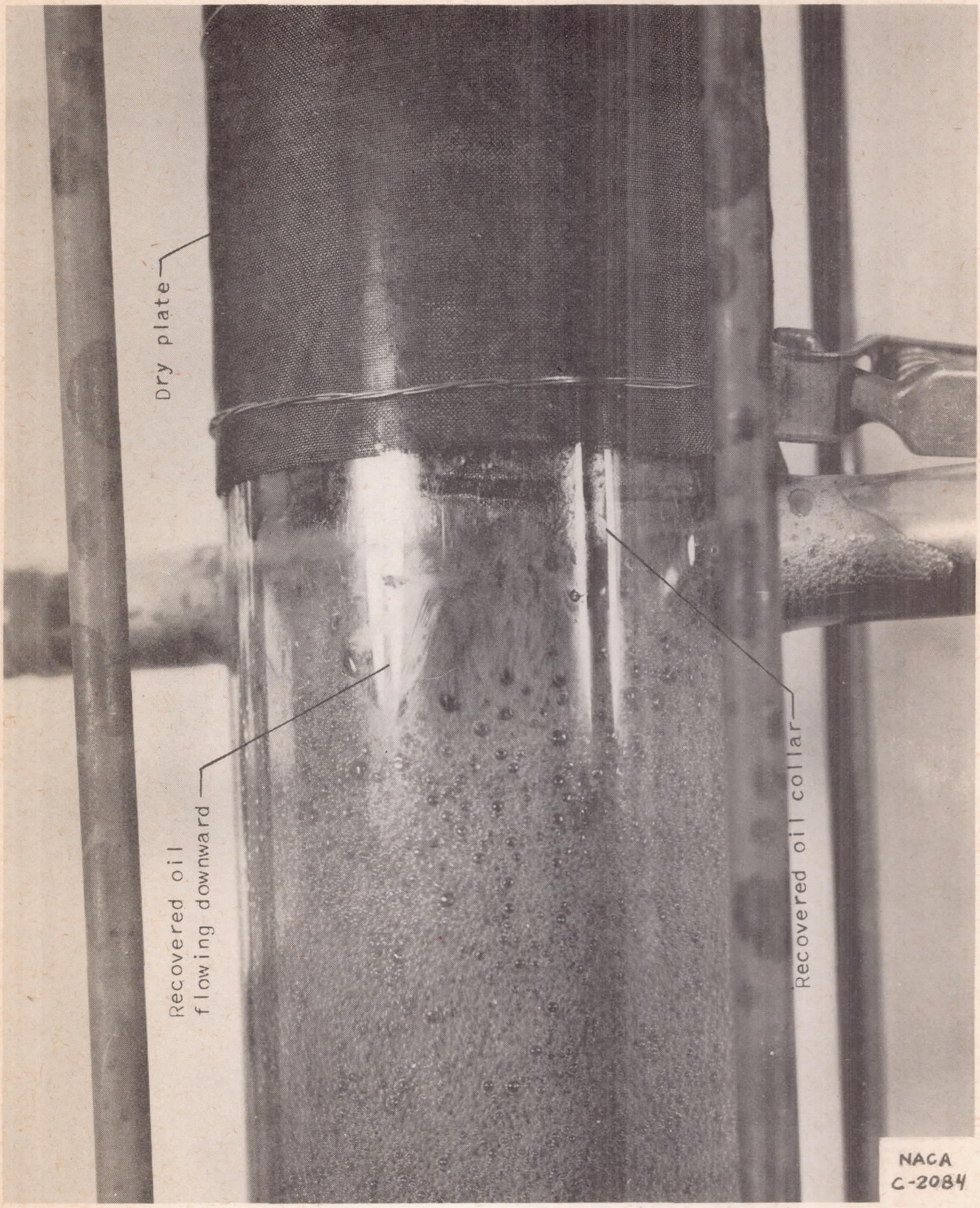
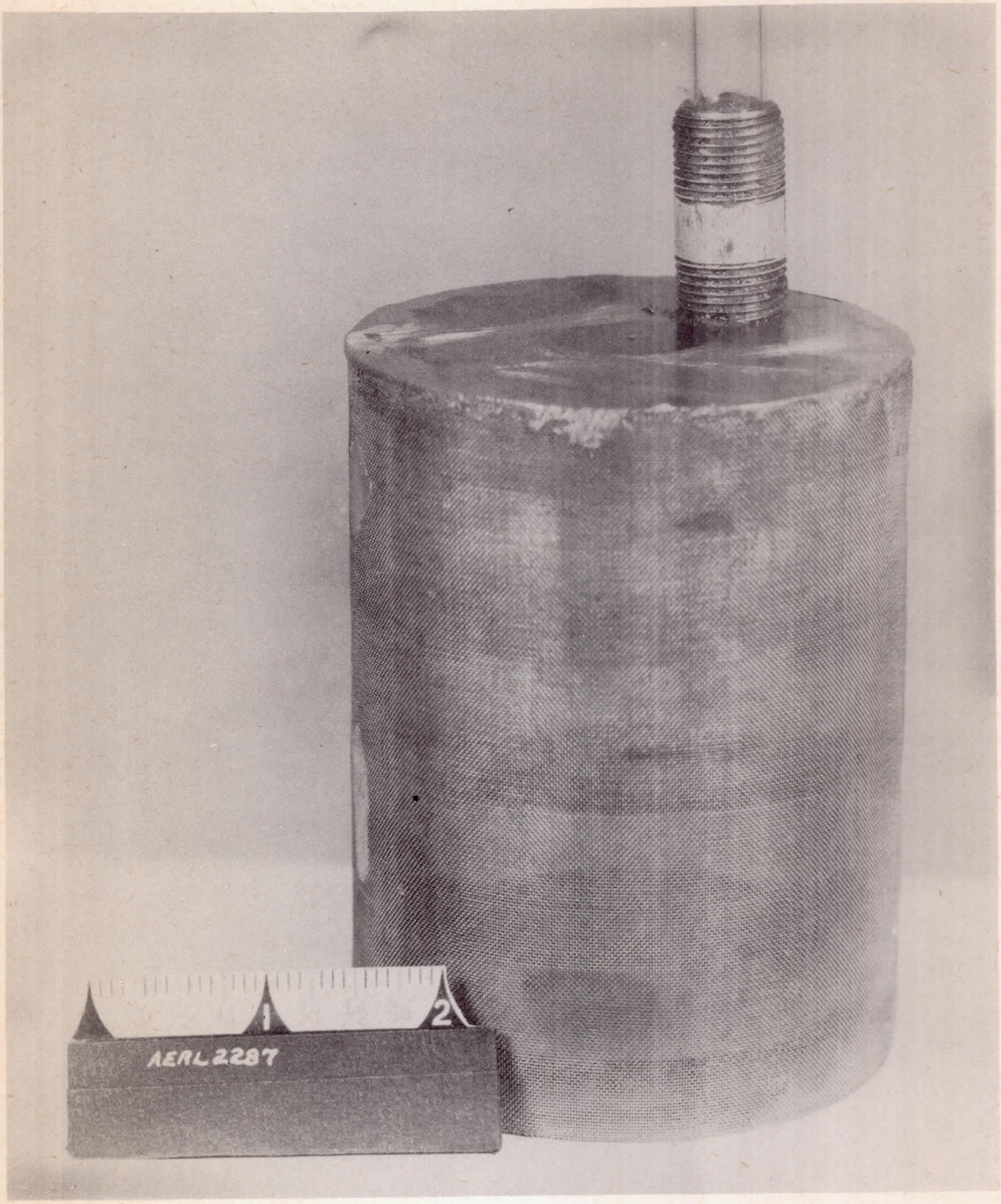
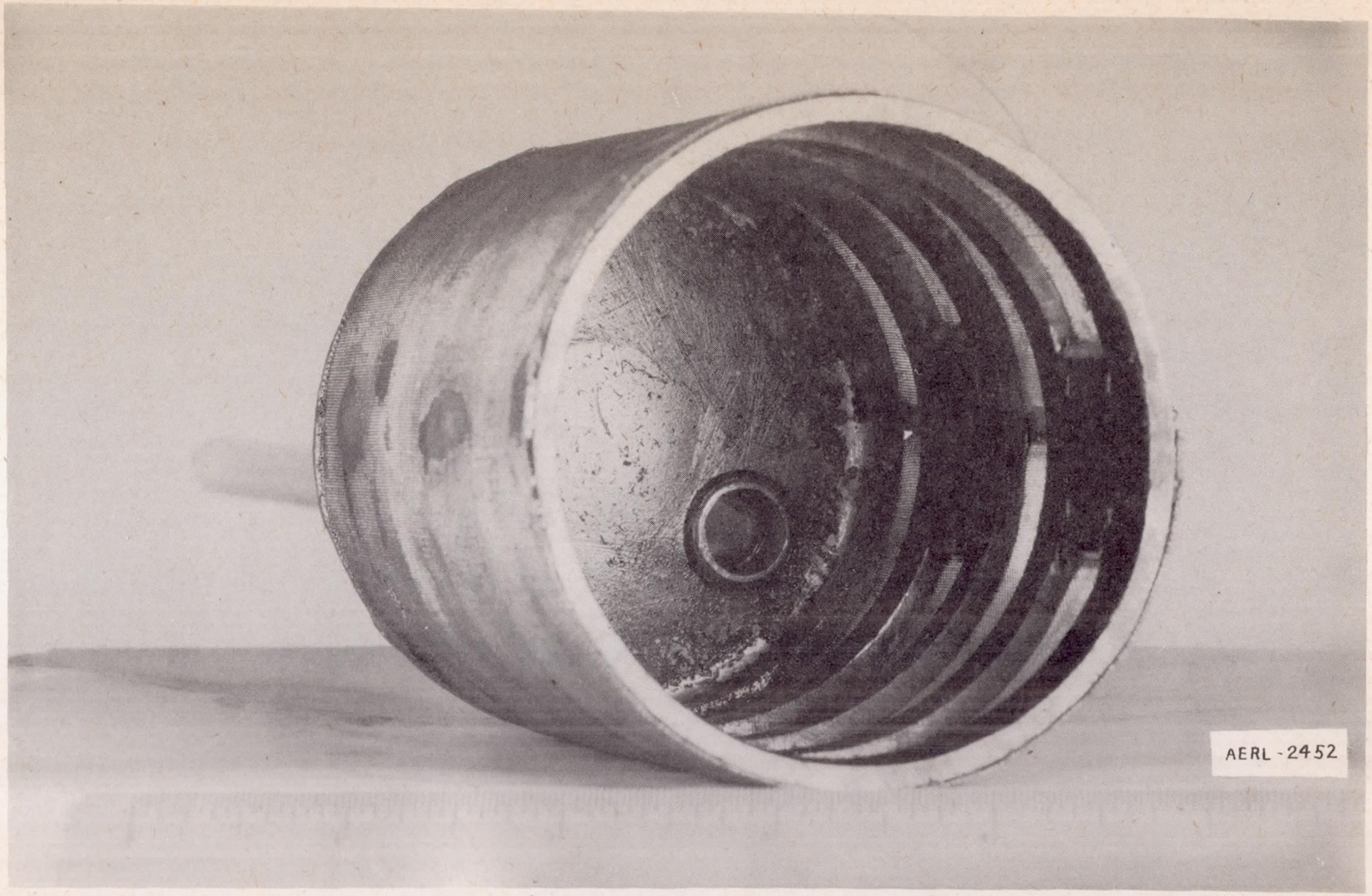


Figure 5. - Foam entering condenser gap. The thin top collar of solid oil has been recovered from foam already broken. Oil at middle of column has started to flow down the tube.



(a) Wet plate.

Figure 6. - Construction of wet plate.



(b) Wet plate showing cutaway plate support.

Figure 6. - Concluded. Construction of wet plate.

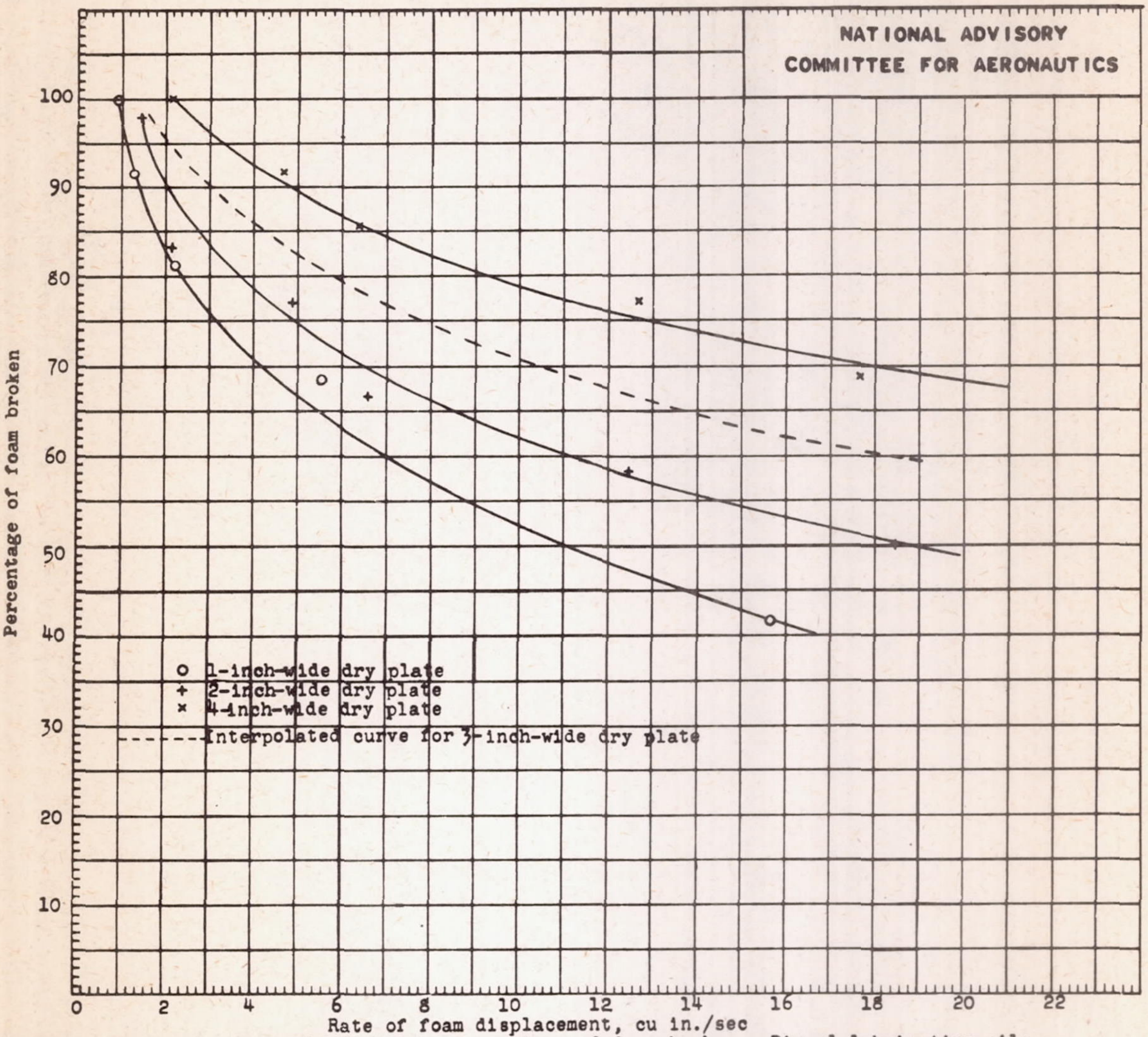


Figure 7. - Effect of dry plate area on percentage of foam broken. Diesel lubricating oil; temperature, 160° F; viscosity, 43 centistokes, 197 Saybolt Universal seconds; wet plate, 120-mesh screen; condenser potential difference, 19,000 volts; total foam displaced, 72 cubic inches.

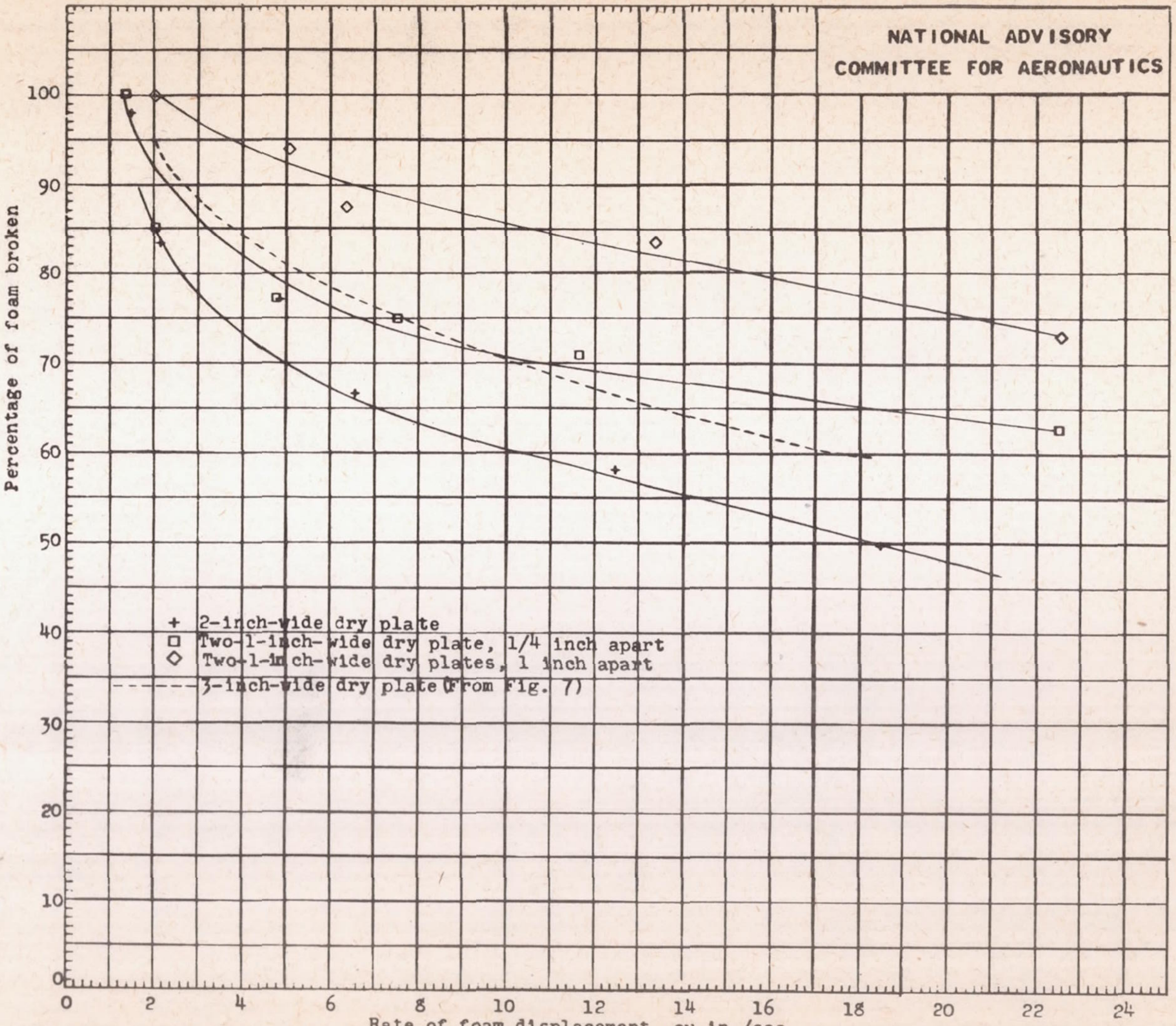


Figure 8. - Effect of dry-plate arrangement on percentage of foam broken. Diesel lubricating oil; temperature, 160° F; viscosity, 43 centistokes, 192 Saybolt Universal seconds; wet plate, 120-mesh screen; condenser potential difference, 19,000 volts; total foam displaced, 72 cubic inches.

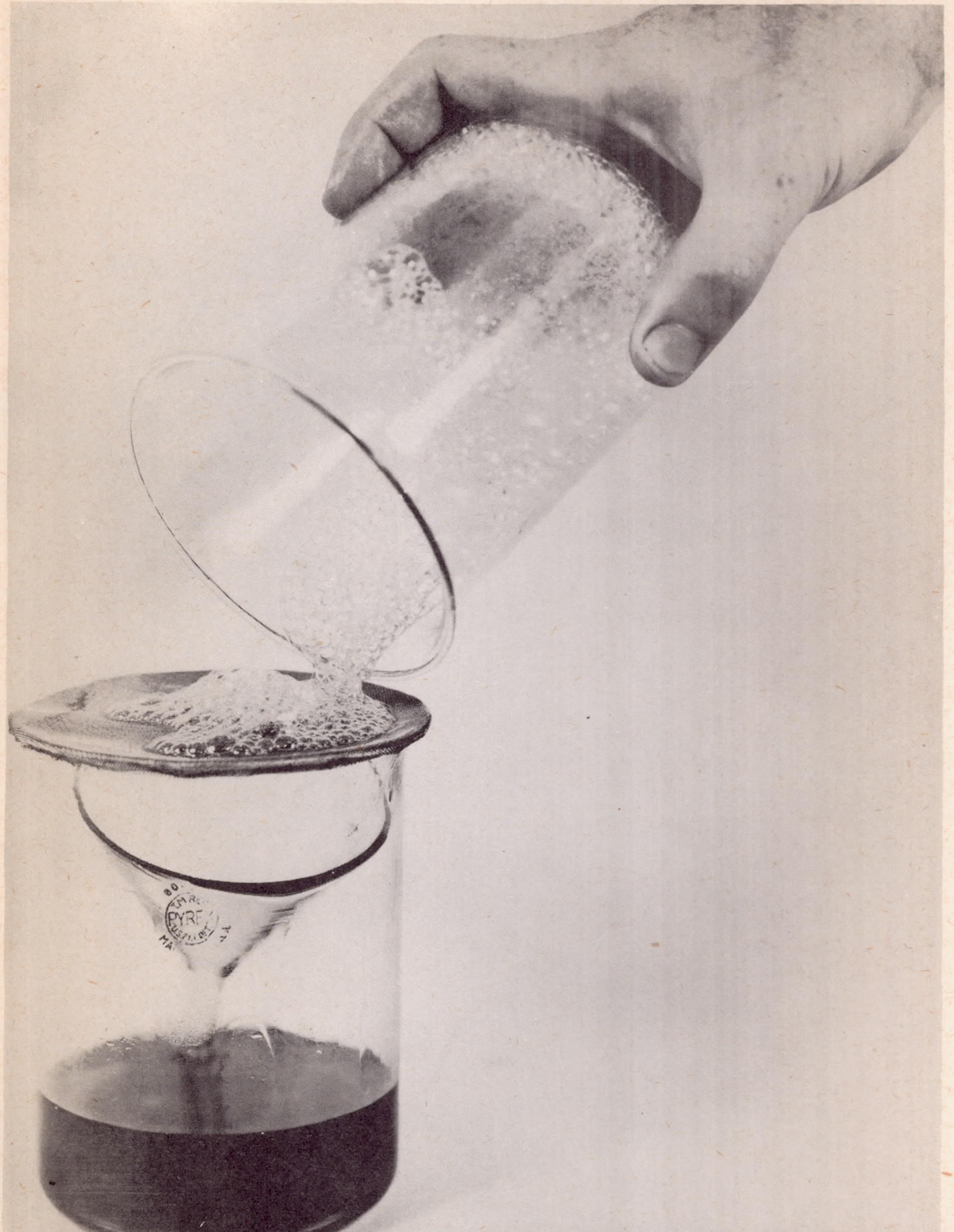


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Figure 9. - Separation of clear oil from foam by a screen.

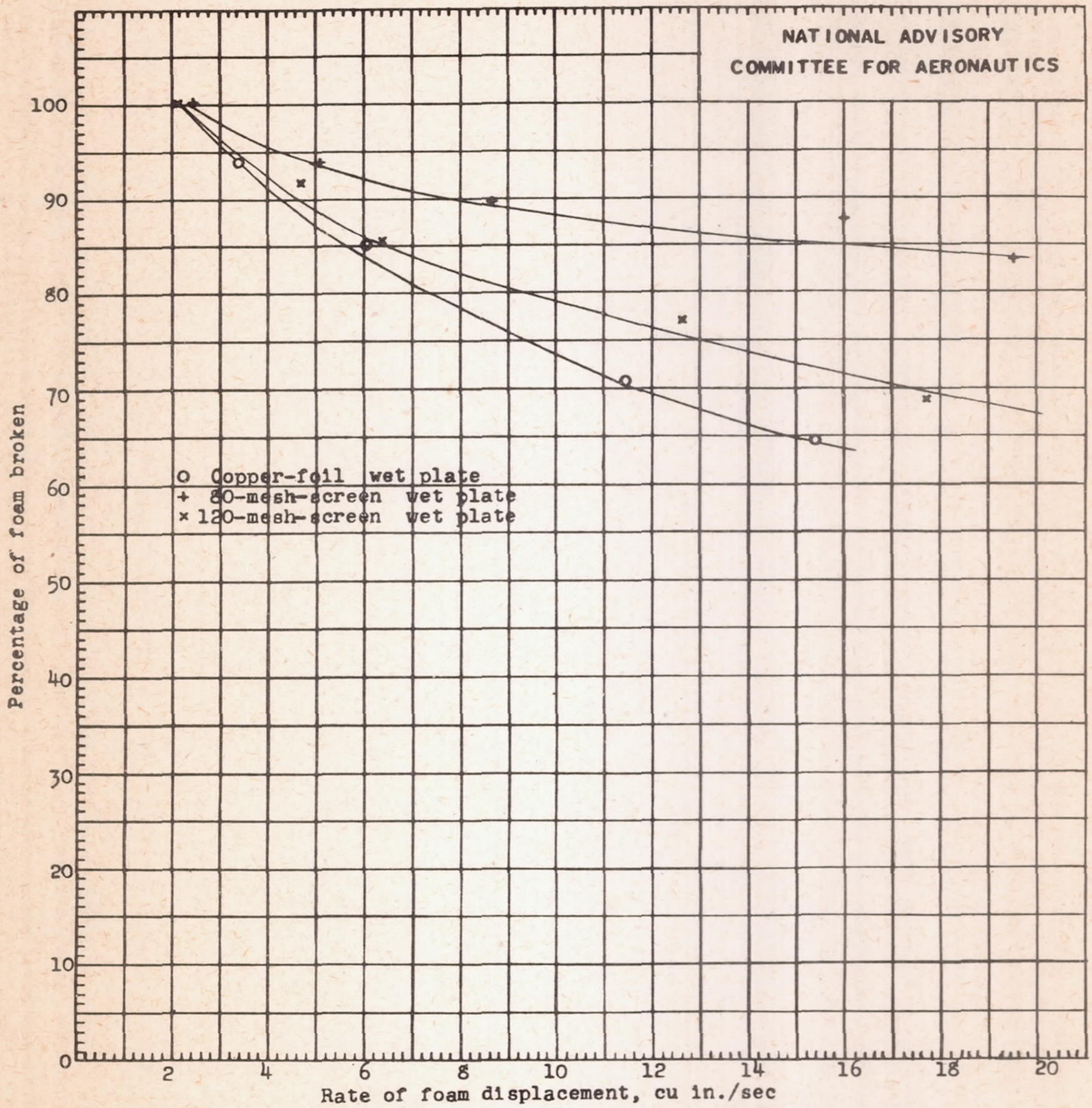
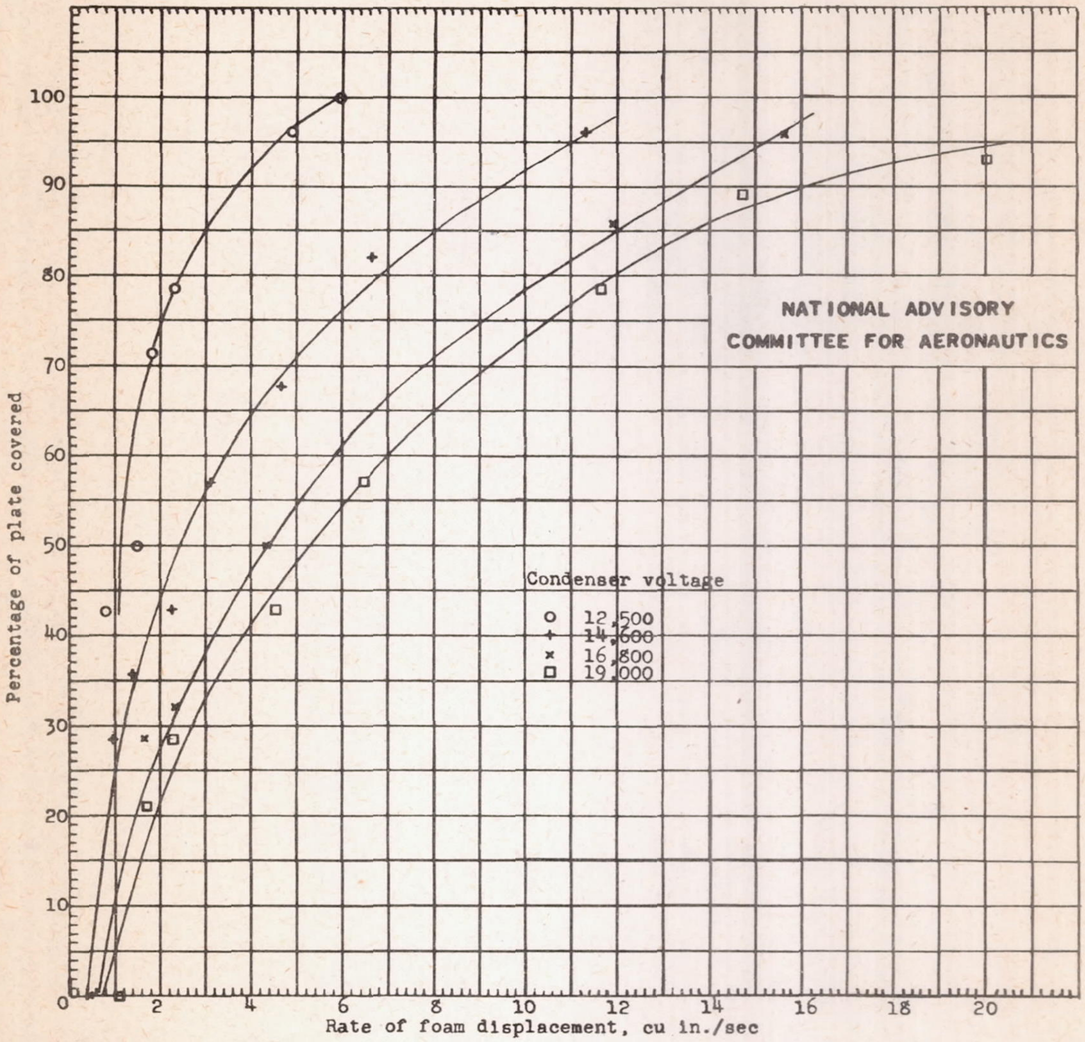
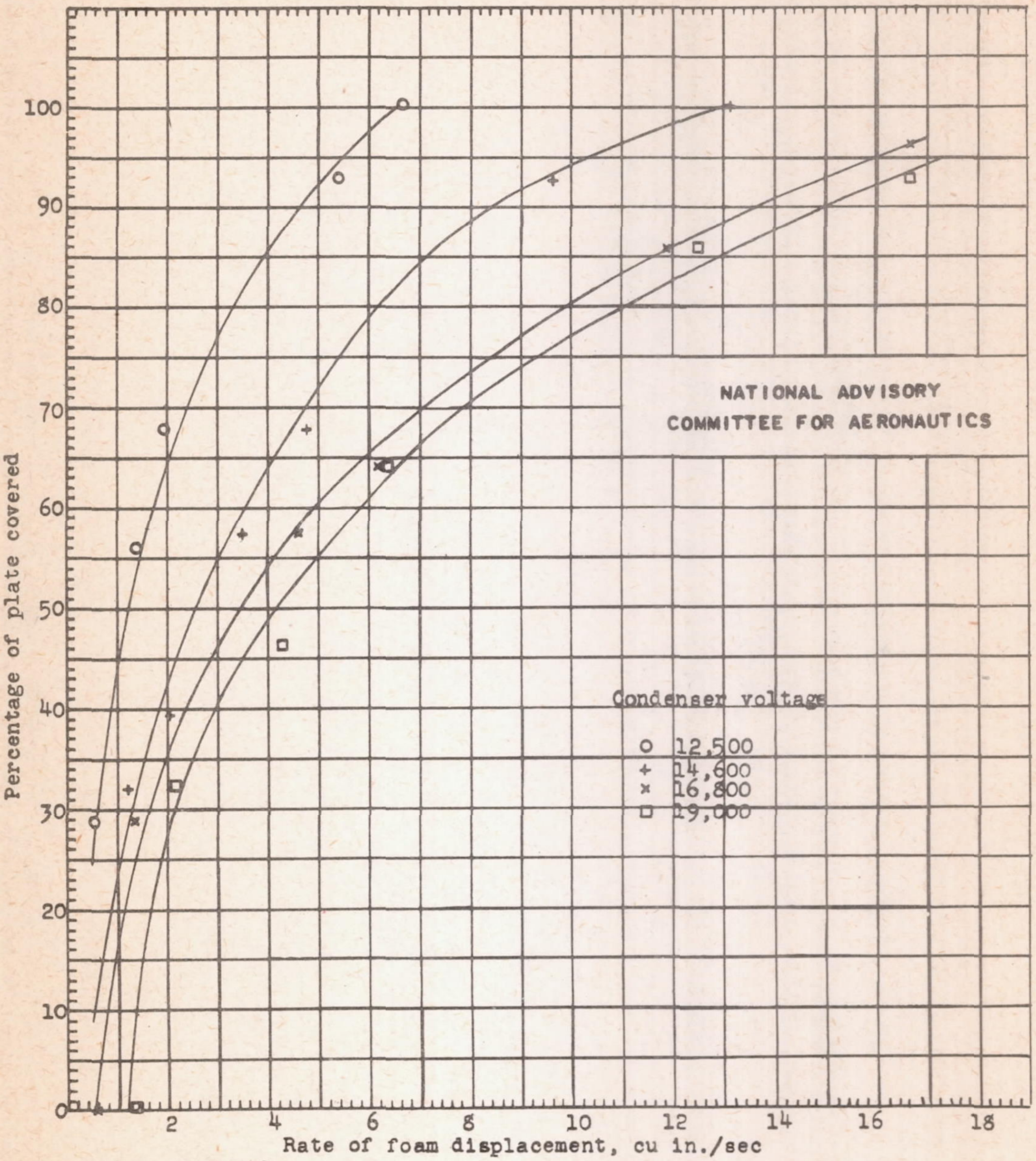


Figure 10. - Effect of oil drainage through wet plate on foam breaking. Diesel lubricating oil; viscosity, 43 centistokes, 197 Saybolt Universal seconds; oil temperature, 160° F; dry plate, 4-inch band, 120-mesh screen; condenser potential difference, 19,000 volts; total foam displaced, 72 cubic inches.



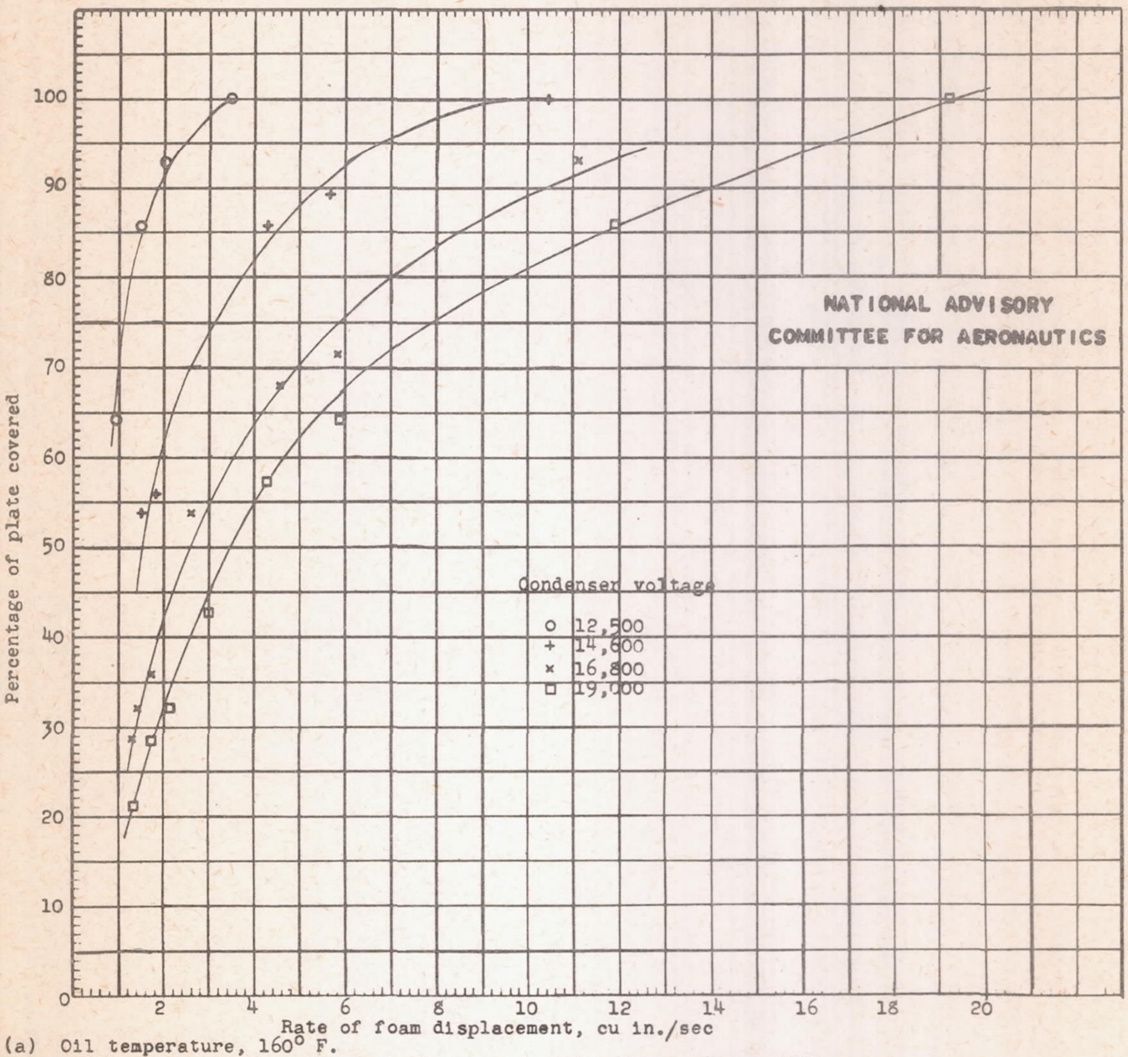
(a) Oil temperature, 160° F.

Figure 11. - Effect of condenser voltage on foam breaking. Diesel lubricating oil; viscosity, 43 centistokes, 197 Saybolt Universal seconds; dry plate, 4 inches wide; wet plate, 120-mesh screen; total foam displaced, 50 cubic inches.

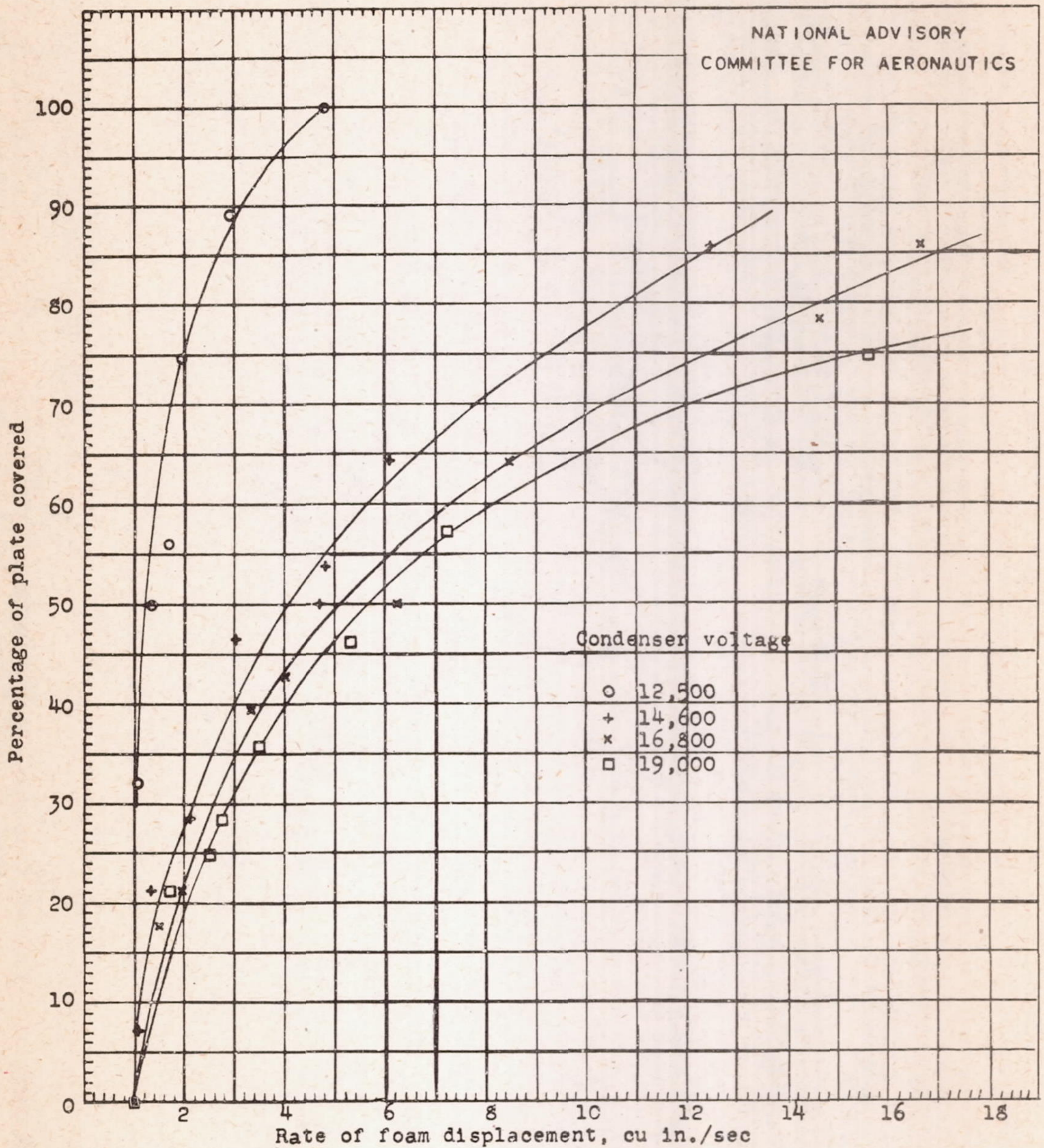


(b) Oil temperature, 180° F.

Figure 11. - Concluded. Effect of condenser voltage on foam breaking. Diesel lubricating oil; viscosity, 27 centistokes, 125 Saybolt Universal seconds; dry plate, 4 inches wide; wet plate, 120-mesh screen; total foam displaced, 50 cubic inches.



(a) Oil temperature, 160° F.
Figure 12. - Effect of condenser voltage on foam breaking. Grade 1120 aviation oil; dry plate, 4 inches wide; wet plate, 120-mesh screen; total foam displaced, 50 cubic inches.



(b) Oil temperature, 180° F.

Figure 12. - Concluded. Effect of condenser voltage on foam breaking. Grade 1120 aviation oil; dry plate, 4 inches wide; wet plate, 120-mesh screen; total foam displaced, 50 cubic inches.

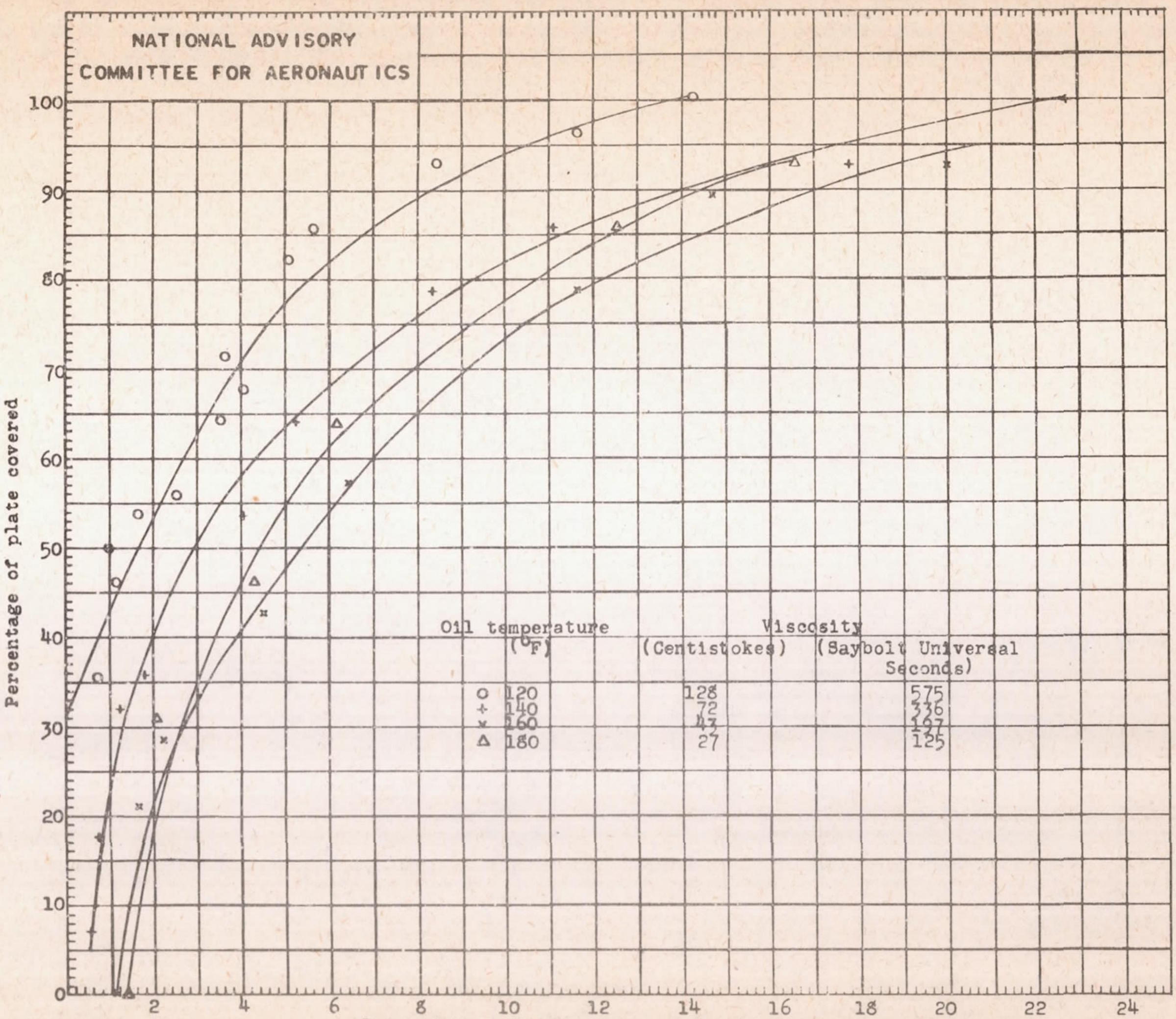


Figure 13. - Effect of oil temperature on foam breaking. Diesel lubricating oil; dry plate, 4 inches wide; wet plate, 120-mesh screen; condenser potential difference, 19,000 volts; total foam displaced, 50 cubic inches.

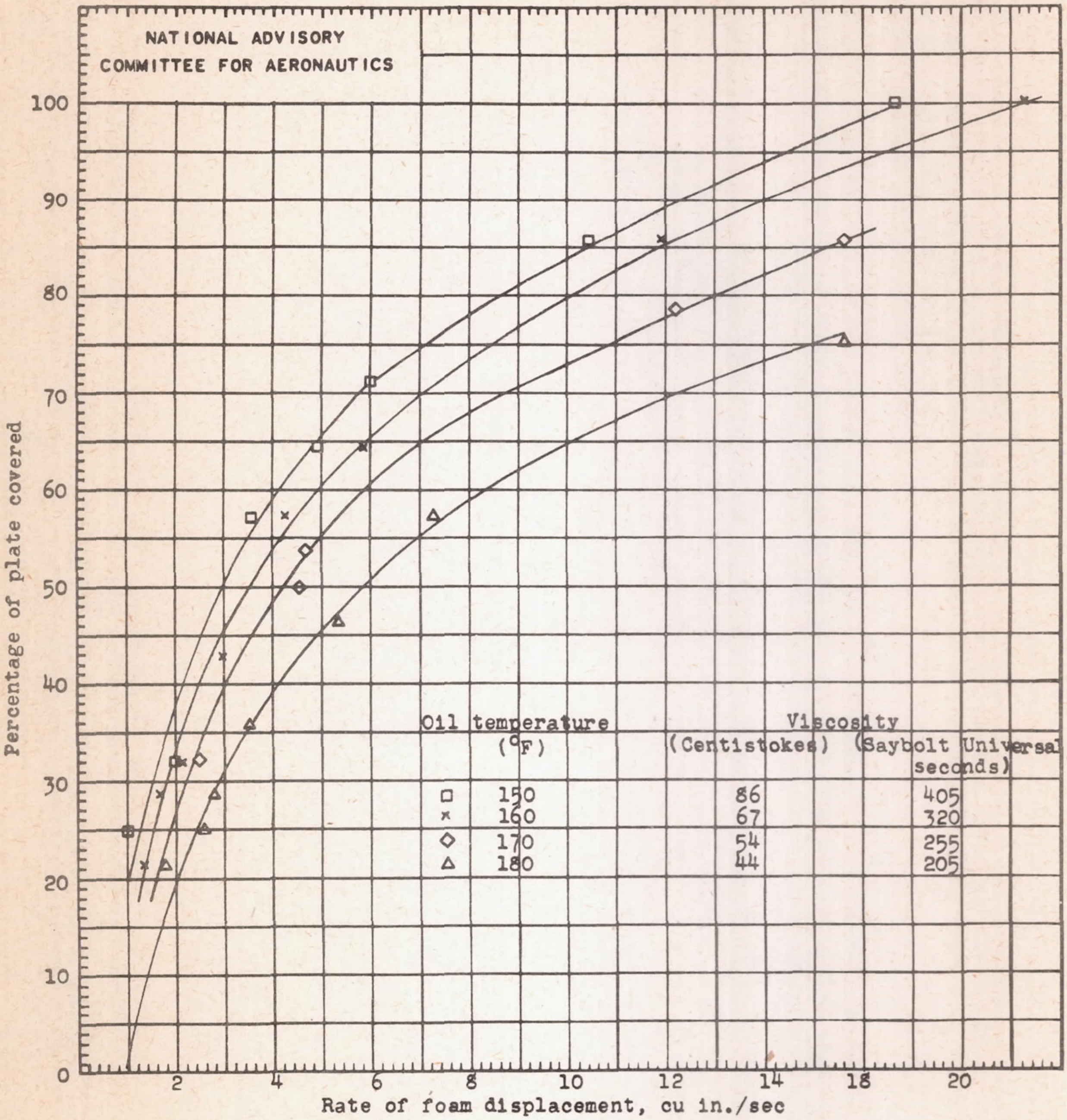


Figure 14. - Effect of oil temperature on foam breaking. Grade 1120 aviation oil; dry plate, 4 inches wide; wet plate, 120-mesh screen; condenser potential difference, 19,000 volts; total foam displaced, 50 cubic inches.

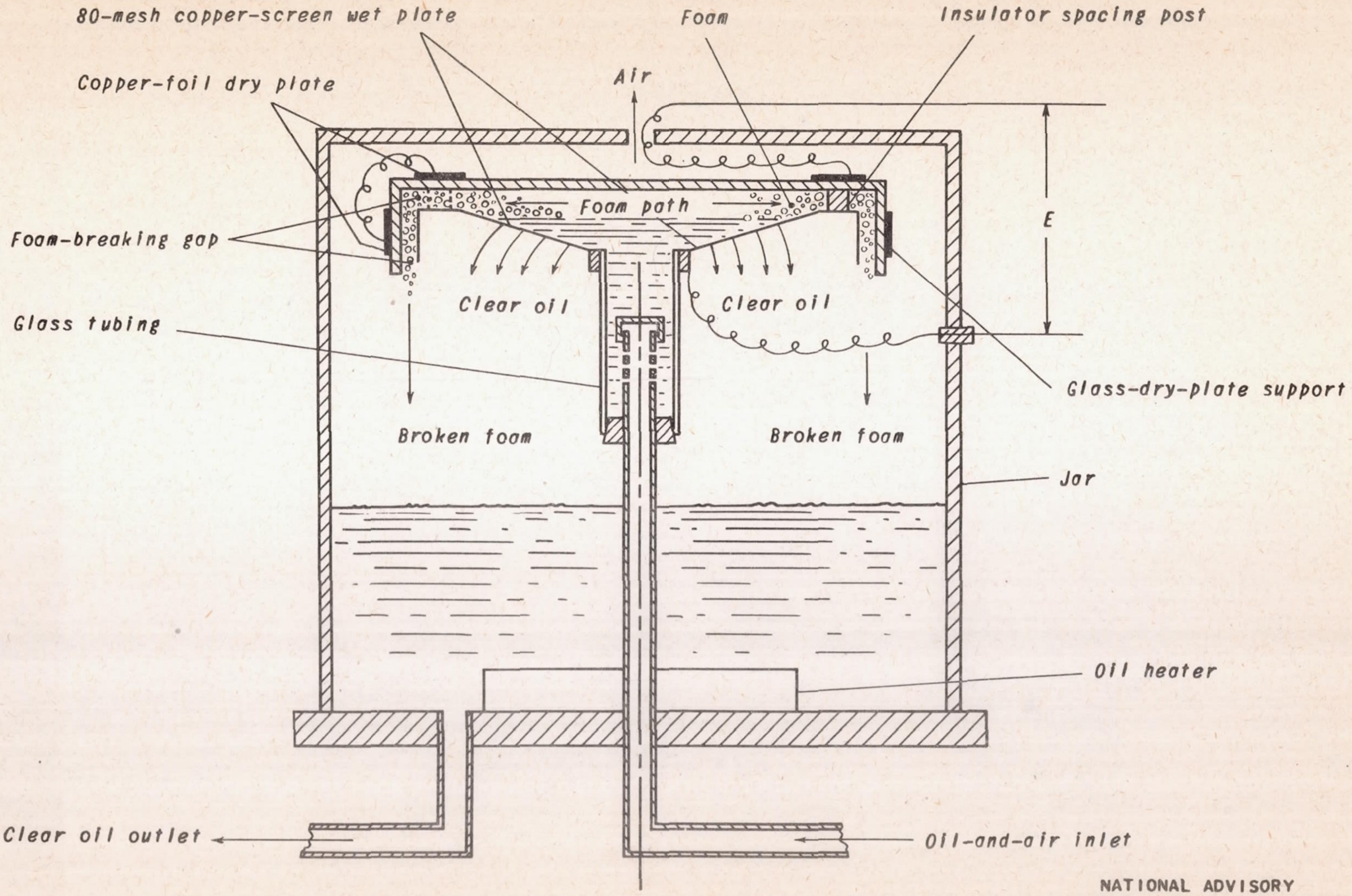


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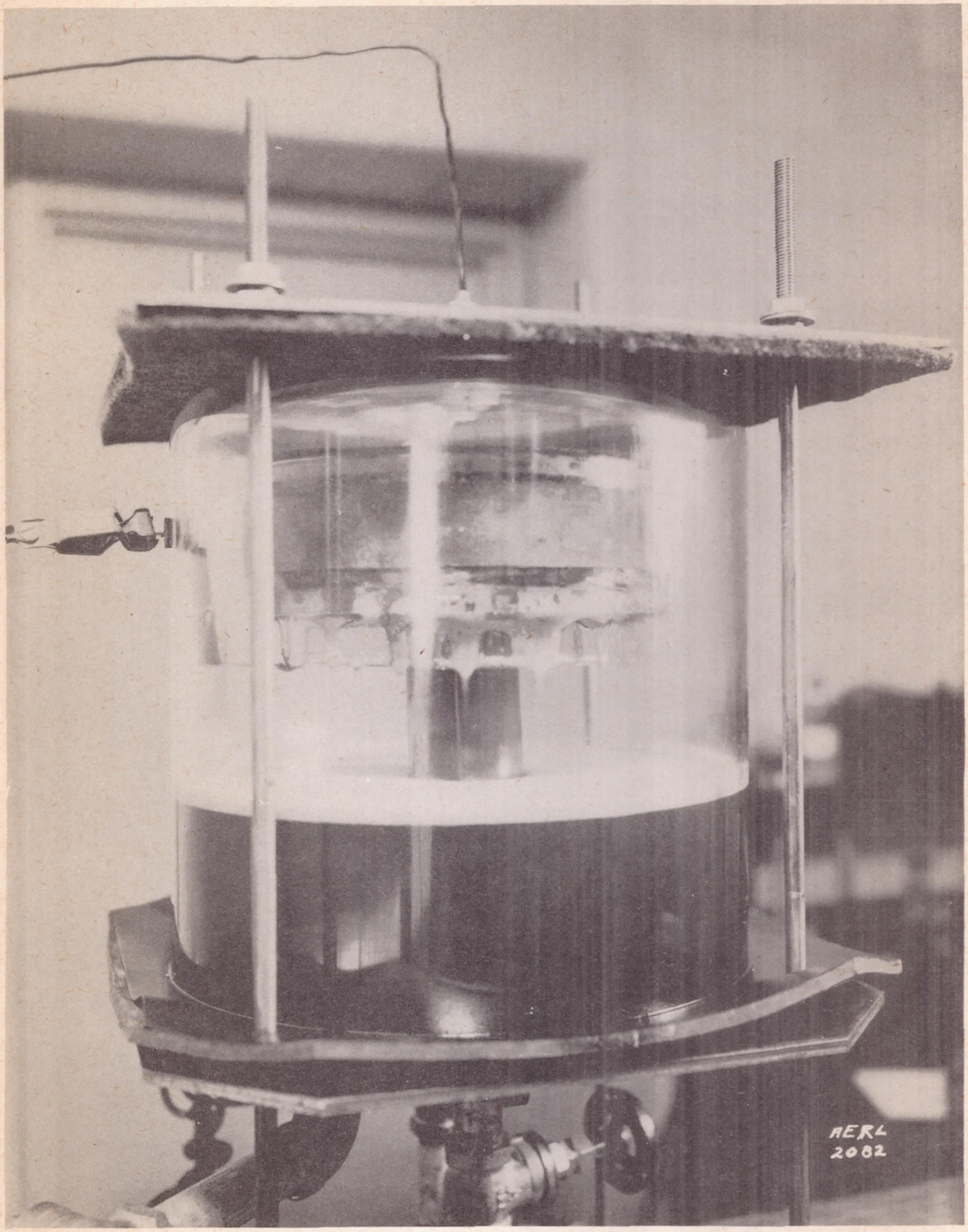
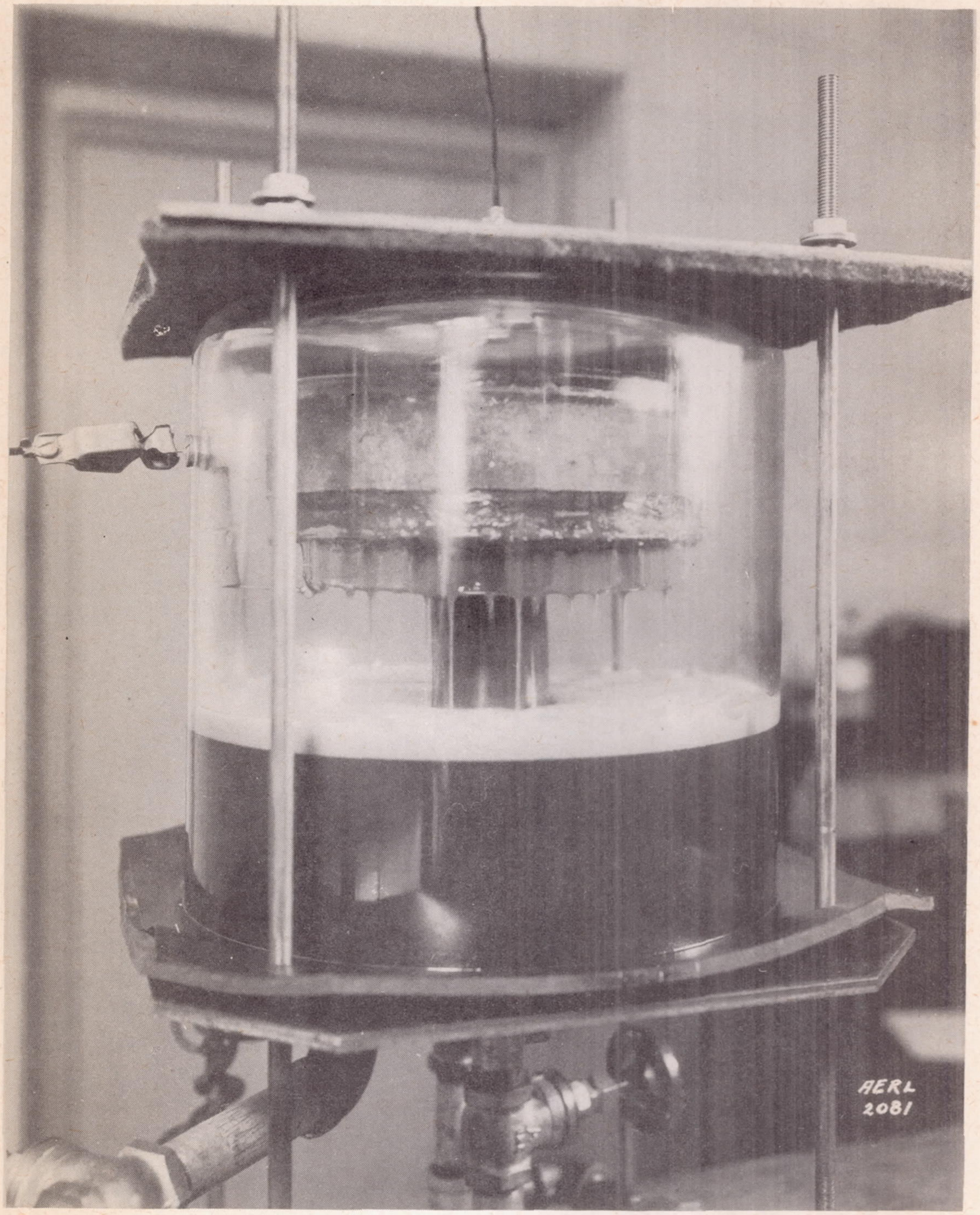
Figure 15. - Sketch of laboratory form of oil-tank foam breaker.



(a) No voltage.

Figure 16. - Laboratory oil-tank foam breaker.



(b) Voltage applied.

Figure 16. - Concluded. Laboratory oil-tank foam breaker.

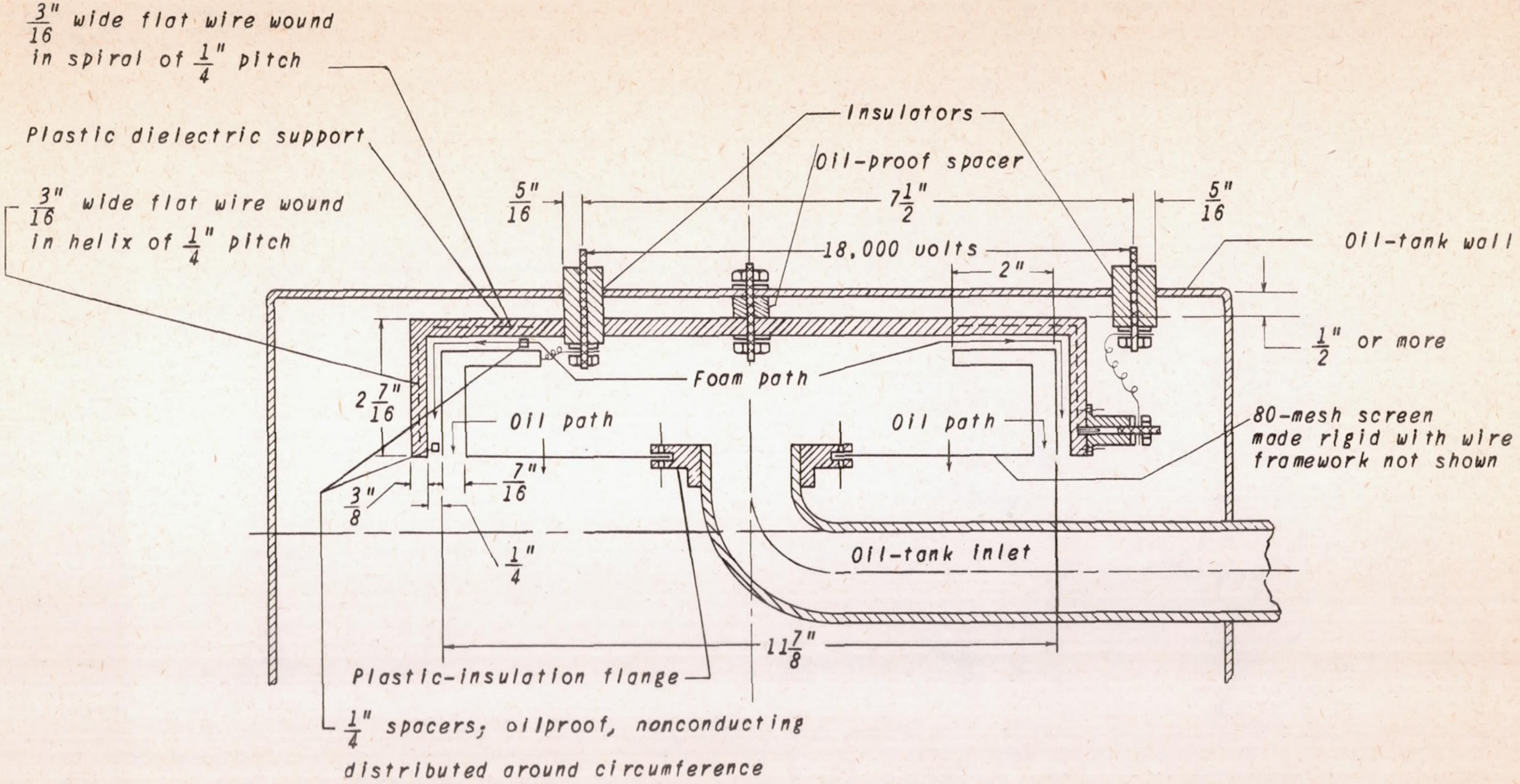


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Figure 17. - Oil-tank foam breaker.