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LABORATORY INVESTIGATION OF ICING IN THE CARBURETOR AND SUPERCHARGER INLET ELBOW OF AN AIRCRAFT ENGINE

I - DESCRIPTION OF SETUP AND TESTING TECHNIQUE

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WASHINGTON

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NACA AIRCRAFT ENGINE RESEARCH LABORATORY

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

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SUMMARY

The laboratory research apparatus and testing technique developed and used at the NACA Cleveland laboratory to investigate the icing and de-icing of the carburetor and supercharger inlet of typical aircraft-engine induction systems under conditions closely simulating flight through a wide range of engine icing conditions is described. The apparatus permits the installation of the carburetor and the accessory housing including the inlet elbow and the supercharger assembly, which is driven by an electric dynamometer. A representative setup is shown.

The technique involved in the determination of the limiting-icing curves and temperature requirements for the removal of ice are presented, together with representative results of icing and de-icing tests.

Descriptions are presented of the systems used for controlling carburetor-deck pressure, air temperature and humidity, the rate and temperature of simulated rain, the fuel temperature, the air dilution and exhausting of the combustible mixture, the carburetor throttle angle, and fuel-air ratio.

Experience in the use of the equipment has indicated that the use of a rotating supercharger impeller adds to the validity of the results because considerable turbulence and recirculation of fuel induced by impeller rotation are responsible for much of the refrigeration icing.

INTRODUCTION

Investigations of icing in aircraft-engine carburetor-induction systems have been conducted by Pratt & Whitney at the York Corporation (PWA-342, Jan.-Oct. 1941). Research was also undertaken at the National Bureau of Standards under the direction of the NACA and the results of these investigations are reported in references 1 to 4. In 1944 the project at the National Bureau of Standards was transferred to the NACA Cleveland laboratory where more adequate engine test facilities are available. The setup described herein incorporates apparatus with more accurate and sensitive controls than had been previously available and makes it possible to investigate induction-system icing at low temperatures and humidities.

A general program outlining a series of fundamental aircraft induction-system icing investigations was jointly prepared by the Army Air Forces, the National Bureau of Standards, and the NACA Subcommittee on Induction System De-Icing Problems. As part of the program requested by the Air Technical Service Command, Army Air Forces, apparatus was designed to investigate carburetor ice formation and elimination. The present report includes a description of the laboratory setup and testing technique developed at the NACA Cleveland laboratory. Succeeding reports will present correlations between arbitrary classifications of induction-system icing, the seriousness of icing in a full-scale engine on a test stand, and an attempt to correlate the laboratory tests with flight results.

DESCRIPTION OF APPARATUS

A general view of the test apparatus used for the laboratory investigations of induction-system icing is shown in figure 1. The test equipment consists of the following: (1) a dynamometer to drive the supercharger; (2) twin ducts to provide air having controlled pressure, temperature, and moisture content for icing and de-icing the induction system; (3) a fuel-air mixture, dilution, and exhaust system; (4) a controlled-temperature fuel system; (5) a controlled-temperature water-injection system for simulating water ingestion into the carburetor during flight through rain; and (6) the carburetor and accessory housing assembly being tested.

Dynamometer Drive System

A 200-horsepower dynamometer is used as a variable-speed motor to drive the supercharger. The speed-control rheostats are motor-operated and remotely controlled from the control panel shown in figure 2. The dynamometer may be operated at speeds up to 3600 rpm and has a speed regulation of 8 percent from no load to full load. Under the conditions of operation for which it was used, the dynamometer speed regulation was about ±1 percent. Dynamometer torque measurements are possible but were not an essential part of this investigation.

Icing- and De-Icing-Air Supply

Pressure regulation. - The air supply used for icing and de-icing the induction system enters through a 6-inch duct. This supply is available either as refrigerated air at temperatures as low as -100° F (with correspondingly low dew point) and at pressures up to 6 pounds per square inch, or at approximately 80° F and pressures from 5 to 30 pounds per square inch. A 6-inch diaphragm valve, manually controlled or by an automatic pressure regulator, maintains a constant pressure to within ±0.1 inch of mercury at a point just above the carburetor deck. A 2-inch bypass around this valve, which contains a self-operated pressure-regulating valve for smaller air flows, is not used during these tests. Although carburetor-deck pressure will vary in flight during icing conditions, pressure regulation is used because the refrigerated-air supply is simultaneously used for other research in the laboratory and the supply pressure varies inversely with the quantity used in such a way as to affect the air-flow measurements. When the carburetor-deck pressure is maintained at a pressure altitude of 2000 feet, any normal fluctuation in supply pressure could be taken care of by the pressure regulator; any observed variation in air-flow rate can therefore be attributed to the formation or removal of ice in the induction system. When an air flow as high as 11,000 pounds per hour is used for icing, it is necessary to maintain a pressure altitude of approximately 6000 feet because of the limited capacity of the refrigerated-air supply duct.

Temperature regulation. - Downstream of the pressure regulator, the 6-inch duct enlarges to 8 inches and branches off into an icing-air duct used for icing the induction system and a de-icing-air duct for de-icing it. Each branch contains a group of manually controlled electric heaters comprising five 20-kilowatt elements, a bypass around the heaters, mixing dampers downstream of the heaters and in the bypass, and a thin-plate orifice for measuring air flow well downstream of the mixing dampers. Temperature regulators with thermal elements located 5 diameters downstream of the orifice plates in each duct control the setting of the opposed-action mixing dampers through air-driven power cylinders, thus allowing the proper proportioning of cold air and reheated air to provide air of the desired temperature. Temperature control can be maintained to within ±1.5° F for the rapidly varying air-flow rates that occur under severe icing conditions or under rapid de-icing conditions and to within ±0.5° F for slower variations.

The dry-bulb temperature is measured at a point just above the carburetor deck by a shielded thermocouple. No dynamic temperature correction to the air-temperature reading was considered necessary for a maximum velocity of 60 miles per hour in the duct.

Humidity regulation. - Humidity regulation of the air used for icing and de-icing the induction system is accomplished by injecting steam into each air duct, as shown in figure 3. Two points of steam injection are shown for each duct, one in the elbow downstream of each orifice and the other just above the electric heaters. The position above the electric heaters is the most satisfactory point because the steam is injected into the reheated air before it is blended with the icing air and does not condense even after mixing with icing air to obtain humidities of 100 percent at temperatures as low as -20° F. The possibility of icing the orifice with this system of humidification and thus obtaining false air-flow readings was considered. Tests with this apparatus have shown, however, that for temperatures below freezing, no orifice differential pressure reductions are noted providing that neither water nor fuel was injected into the induction system. The steam piping is so arranged that manual control of injection into either duct can be maintained by means of needle valves, using either manual or automatic control of injection into the other duct. Automatic humidity control is accomplished by means of an air-operated wet-bulb temperature regulator, which acts to position either one or both of two diaphragm-operated valves in the steam line. A 1/8-inch needle valve F and a 1-inch V-port valve G (fig. 3) are so arranged that either one may be placed under automatic control while the other is being operated manually or both may be operated manually or automatically. During icing conditions, which result in slow air-flow-rate variations, automatic control of humidity is quite satisfactory but under extreme conditions of icing and during de-icing runs the air-flow-rate variations are so rapid that manual control of humidity is required. In either event, it is possible to maintain the wet-bulb temperature to ±1.5° F.

Continuously wetted wick-covered thermocouples were installed in the de-icing- and icing-air ducts to measure wet-bulb temperatures above freezing (fig. 4). For temperatures below freezing, wet bulbs were found to be unsatisfactory and an automatic dew-point indicator was developed. A small sample of air is drawn through the instrument from the duct just above the carburetor deck by means of a vacuum pump. A correction is made to the dew-point reading for the pressure drop between the duct and the instrument. The useful range of the dew-point indicator extends from about -40° to 80° F. This instrument has an accuracy of ±1° F and the rate of response is such that a shift in dew point from -30° to 60° F can be measured in 45 seconds with proportionately less time for smaller shifts.

Alternate duct system. - The de-icing- and icing-air ducts join above the carburetor deck. Both are equipped with a shut-off valve upstream of the junction and a 4-inch bleed line just upstream of the shut-off valve. The bleed lines are connected through shut-off valves and pressure-regulating valves to an altitude exhaust system capable of maintaining pressures as low as 3.5 inches of mercury absolute. The shut-off valves are operated by compressed-air actuating cylinders controlled by a solenoid-operated valve. During icing previous to a de-icing test, the de-icing-air duct is shut off but is allowed to bleed air through the altitude exhaust system at a rate approximating that required at the time de-icing is started. The temperature and humidity of the de-icing air are maintained at the required values, whereas the flow rate is maintained by an automatic pressure regulator operating a control valve in the exhaust system. When de-icing air is required, energizing the solenoid valve allows the compressed-air cylinders to operate the shut-off valves so that the icing-air duct is shut off from the induction system and allowed to bleed to the exhaust system and at the same time the de-icing-air valve is opened and its bleed duct is closed, thus admitting de-icing air to the induction system at the desired temperature and humidity. The double bleed system employed reduces to a minimum any pressure pulsation that would occur when changing from icing to de-icing air and eliminates thermal lag due to the heat capacity of the ducts.

The ducts are insulated with 4 inches of canvas-covered hair felt up to a point near the junction of the de-icing- and icing-air ducts.

The alternate duct system just outlined resembles a conventional aircraft alternate de-icing-air system in that the heated de-icing air is immediately available. In an aircraft system, however, the pressure of the de-icing air is lower than that of the icing air owing to the engine-cooling pressure drop and the poor flow conditions. The results obtained for de-icing time as a function of temperature using the laboratory duct system are therefore not directly applicable to any particular aircraft but do serve as a basis for determining the heat requirements for de-icing the same induction system in any aircraft regardless of the type of alternate de-icing-air intake system used.

Fuel-Air Mixture Dilution and Exhaust System

The unburned fuel-air mixture is ducted from the outlet of the supercharger through the roof of the building. A butterfly valve mounted in this duct near the supercharger exit is remotely controlled by means of a hydraulically actuated follow-up mechanism and serves to control the supercharger outlet or manifold pressure. A shroud around the outlet of the mixture exhaust duct is so arranged as to allow air from the engine cooling-air system of the laboratory to enter peripherally at a pressure from 40 to 50 inches of water and dilute the fuel-air mixture to about one-half its original value. The diluted mixture then passes upward to the atmosphere through a 16-inch pipe 30 feet long. The stack has an open truncated cone-shaped section so attached at the bottom that a flow of air is also induced through the stack from the roof of the building by the high velocity of the dilution air and the mixture. Such an arrangement removes any combustible mixture that may tend to settle on the roof of the building near the exhaust stack.

Fuel System

The fuel system used is shown in figure 5. Two grades of fuel, AN-F-22 and 28-R, are furnished at a pressure of about 35 pounds per square inch from the main laboratory system and either grade can be used for tests. After being filtered, the fuel passes through one of two constant-head float-type flowmeters. Valves permit a choice of either flowmeter for use in measuring fuel consumption, depending on the flow rate employed.

Fuel cooling system. - The fuel then passes through an ammonia cooler F, which is capable of reducing the fuel temperature to -20° F. The amount of cooling is controlled by an air-operated thermostat G, which controls a valve in the ammonia suction line. A bypass H in the fuel line is placed around the cooler and a remotely controlled three-way motor-operated valve I proportions the amount of fuel passing through the cooler and also the amount being bypassed. Fuel temperatures can be maintained to within ±1° F with this system.

Fuel piping system. - A pressure-reducing valve K is placed downstream of the proportioning valve I and is adjusted to maintain the required fuel pressure at the inlet to the carburetor. Three solenoid-operated valves M and N controlled by a single three-position switch are placed in the line in such a way that: (1) fuel can entirely bypass the carburetor and be returned to a storage tank R outside the building, (2) or, fuel can be piped to the carburetor and metered by it then pass through a dummy injector Q (a fuel-injection unit placed in the line to simulate the pressure drop in the actual engine fuel-injection unit), and finally pass to the storage tank, (3) or, fuel can enter the carburetor, be metered there, and be injected into the induction system.

By use of the system outlined here, the carburetor and the fuel can be quickly brought to a desired temperature and the fuel-flow rate so set by means of the carburetor mixture control that the required fuel-air ratio can be established before any fuel is injected into the induction system.

Water-Injection System

The system shown in figure 6 is used to regulate the water injected into the induction system through atomizing nozzles at a point above the carburetor deck to simulate flight through rain. The water enters from the mains through a filter and passes through a pressure-regulating valve set to reduce the water pressure to a value below the lowest normal pressure fluctuation in the line. The water flow is measured by means of one of two constant-head float-type flowmeters. Needle valves in the flowmeter lines permit choice of either meter depending on the range of flows to be measured and also permit control of the water-flow rate. The water then passes through a small cooler mounted near the injection point and containing refrigerated ethylene glycol as coolant, after which solenoid-operated valves allow the water to be injected or pass to a drain. The temperature of the ethylene glycol is maintained by passing it through a cooler similar to that employed for cooling the fuel. An air-operated thermostat regulates the ethylene-glycol temperature by controlling a valve in the ammonia suction line of the cooler. A positive displacement pump is employed for circulating the ethylene glycol through the cooler and heat exchanger. With this system it is possible to maintain the water temperature to within ±1° F at temperatures as low as 34° F.

Installation of Supercharger-Carburetor Combination

The installation of a typical supercharger-carburetor combination is shown in figure 7. The accessory housing is bolted to an angle plate fastened to the test bed and a direct drive is provided to the dynamometer. A transparent plastic inlet duct above the carburetor is positioned by special short dowels and cables are fastened to the removable metal duct at one end and to toggle clamps rigidly mounted on the test bed at the other end. The entire assembly is held together by tightening the cables and may be quickly taken apart for examination of ice formations by operating the toggle clamps to loosen the cables. A metal camera stand is rigidly mounted on the floor which can be quickly swung over the supercharger inlet or carburetor for photographing ice formations. The stand also serves as a mounting for two receiving units of the hydraulic follow-up type. These receiving units serve to regulate the carburetor throttle and mixture settings through "quick-disconnect" links. The hydraulic receivers are remotely actuated from the control panel in the adjoining control room. Observation of the test unit from the control room is possible through double glass windows.

A selsyn-type throttle-position indicator is attached to the throttle shaft not only to indicate throttle opening for a given power condition but also to detect creeping of the carburetor throttle and to indicate throttle movement when an automatic manifold-pressure regulator is used. A throttle lock is also utilized to prevent throttle creepage and consequent change in air-flow rate when constant throttle setting is necessary.

Oil is supplied to the assembly by a system comprising a pump, a cooler, a heater, and controls to regulate supply pressure and temperature. The scavenge pump incorporated in the accessory housing is used to return the oil to the supply pump suction.

During operation, the test-room temperature rises to above 100° F but heat transfer to the carburetor and the inlet elbow from the test room (and from the supercharger and hot engine oil) will not greatly differ from that in an actual engine installation in flight.

METHODS AND TESTS

Establishing test conditions. - In icing tests, the dampers must be adjusted immediately upstream of the junction of the icing- and de-icing-air ducts in order that only icing air flows to the carburetor. The entire bleed system is closed to prevent air flowing through the de-icing duct.

Conditions are established by first setting the carburetor-deck pressure. This pressure, corresponding to a desired altitude simulation, is obtained by adjustment of the automatic control on the 6-inch valve in the main refrigerated-air supply. With the throttles in a wide-open position, the engine speed is then adjusted to the desired value. Air flow and manifold pressure are set by simultaneous adjustment of the throttles and manifold-pressure control valve. When the air flow is adjusted prior to fuel injection, it is always necessary to set a value of orifice differential pressure slightly less than the desired final value because after fuel is injected the density of the air entering the supercharger, which is operating at constant speed, is increased by the cooling effect of the fuel evaporation and consequently a greater weight of air will then flow through the system.

The desired dry-bulb carburetor-air temperature is obtained by setting the automatic temperature regulator to the required temperature. Condensate from the steam system is removed by bleeding the system prior to the injection of steam. (See fig. 3.) Steam is then injected into the air stream at either of the two steam injection points in sufficient quantity to obtain the desired humidity and is automatically or manually regulated.

Before the test run, fuel is metered through the carburetor but bypassed around the injection nozzle to the storage tanks. (See fig. 5.) By this arrangement the fuel temperature, as well as the correct rate of flow corresponding to the desired fuel-air ratio, can be established.

The carburetor is equipped with a special mixture-control disk and is calibrated before use and, although approximate settings of fuel flow can be obtained by setting the mixture control in the regular automatic-lean, automatic-rich, or full-rich positions, a more accurate flow rate can be obtained by further adjustment using the special mixture-control disk.

The correct temperature and flow rate of free water is established prior to injection by bypassing the water-injection nozzle to the drain. (See fig. 6.)

Icing tests. - With the test setup operating at established and stable conditions, the fuel and water (if both are being used) are switched from "bypass" to "inject." As previously explained, this injection of fuel causes a slight increase in the air-flow rate; however, this increase takes place in a few seconds. Immediately after the air-flow rate becomes stable, the clock on the control panel is started and readings are recorded.

The following data are recorded during each run:

Fuel flow
Wet-bulb temperature
Dry-bulb temperature
Manifold temperature
Fuel temperature
Water temperature (if used)
Dew point (if dew-point indicator is used)
Throttle angle
Orifice static pressure
Orifice differential pressure
Compensated metering-suction differential of carburetor
Carburetor-deck pressure
Carburetor pressure drop
Manifold pressure
Engine speed
Time

A complete record of these data is made not only immediately after the test begins but also after 1 minute and every 3 minutes thereafter for the duration of the test. For special tests of longer than 15-minute duration, readings are taken after longer intervals depending upon the icing conditions.

During a test run, the nature and location of icing can be conveniently observed through the transparent plastic duct above the carburetor and through two small observation windows located on either side of the inlet elbow between the carburetor and the impeller. By observation through these windows just after the fuel flow is cut off at the termination of a test run, the surfaces subject to icing may be easily viewed.

In order to obtain photographs of icing after a test run, the entire system can be quickly shut down. The duct above the carburetor is removed in order that the carburetor can also be removed and turned upside down, providing an excellent view of the throttles. By this procedure the inside of the inlet elbow is also exposed for photographing. Complete shutdown and disassembly for this purpose can be accomplished in approximately 30 to 45 seconds. Typical icing photographs taken by this method are reproduced in figure 8.

Heated-air de-icing tests. - Before a de-icing test, the damper valves just upstream of the junction of the icing- and de-icing-air ducts are adjusted to provide icing air to the carburetor but the bleed system is opened to the altitude-exhaust system. With the damper valves in this position, the bleed from the de-icing-air duct is open whereas that from the icing-air duct is closed.

The procedure for icing the test unit prior to the de-icing run is the same as that previously described. Icing is allowed to progress until the air-flow rate is reduced to an arbitrarily chosen value of 2000 pounds per hour. During the icing period, approximately 2000 pounds per hour of air is allowed to bleed through the de-icing-air duct at the chosen de-icing dry-bulb and wet-bulb temperature.

When sufficient icing takes places to reduce the air-flow rate to the desired value, a switch is operated that permits de-icing air to flow through the carburetor. By this procedure, the bleed from the de-icing-air duct is closed and that from the icing-air duct is opened. At the same time, the clock is started and readings of orifice differential in the de-icing-air duct and fuel flow are recorded. These readings are taken every 0.2 minute through 2 minutes, and every 0.5 minute thereafter for a total of 5 minutes or until air-flow recovery is achieved.

Special tests. - Variations of the previously described techniques are necessary in running special tests, which include those using water or alcohol-water injection with the fuel, special throttle plates or special ice indicators, alcohol anti-icing and de-icing tests, new methods of fuel injection to minimize icing, the use of a manifold-pressure regulator, and studies of fuel distribution due to icing.

ICING TEST RESULTS

The results of the icing tests are classified into three groups. If during a 15-minute test no ice is visible in the induction system, the result is classified as no visible icing; if icing is visible but the original air-flow rate does not drop as much as 2 percent, the result is classified as visible icing; but if the icing is of such a nature as to cause a reduction in original air-flow rate of 2 percent or more, the result is classified as serious icing. In flight, icing of the induction system may manifest itself as a drop in manifold pressure with subsequent loss in power or as a leaning out or enrichment of the fuel-air ratio with subsequent rough operation and loss in power.

The results of a single typical icing test series are presented in figure 9 as limiting curves for the regions of visible icing and serious icing. In figure 9(a), the regions have been defined by the carburetor-air temperature and its relative humidity and the water-injection rate. Such a plot is useful for spot-checking data during the running of tests and for flight use. When the dry-bulb temperature of the air and its wet-bulb temperature or dew point are known, a point may be immediately plotted by reference to a set of psychrometric tables, such as reference 5. For interpretation and analysis, however, a more useful way of plotting the limits of the regions of visible icing and serious icing is shown in figure 9(b). Here the regions have been defined by the actual heat content of the carburetor air (including that due to the free water carried in) and the moisture content of the air. A more accurate view of the mechanism of induction system icing can be obtained by considering that the amount of icing obtained will be dependent on the heat content of the air and the amount of water available for freezing. Furthermore, plotting the data as shown in figure 9(b) permits more accurate fairing of the limits of icing.

Computation of the heat content of air-water vapor and air-water mixtures and of the air-water-vapor content at any pressure or temperature can be made from relations given in thermodynamic textbooks.

The results of a typical de-icing test series are shown in figure 10. Figure 10(a) shows the time to recover 95 percent of the original air-flow rate as a function of the de-icing-air dry-bulb temperature for three different relative humidities. These same data plotted as recovery time as a function of the wet-bulb temperature of the de-icing air (fig. 10(b)) produce a single curve.

CONCLUDING REMARKS

The testing techniques and the control systems are considered to be adequate for a laboratory investigation of the icing and de-icing of reciprocating-engine induction systems. The fact that a rotating supercharger impeller is used adds to the validity of the results in that observations have shown that considerable turbulence and recirculation of fuel is induced by impeller rotation, which is responsible for much of the refrigeration icing.

Experience has shown that certain improvements in the setup and in testing technique are desirable. The most important consideration is that a knowledge of the range of air temperatures and moisture content encountered in flight would reduce the required range of laboratory icing investigations. Furthermore, the proper simulation of rain and impact icing conditions requires additional research on the type and location of water-spray nozzles. It is desirable to record continuously the air-flow rates during icing and de-icing and also the fuel-flow rates during those processes because of the extremely rapid changes that occur. It is recommended that the carburetor be calibrated before use, in which event it is easier to record the compensated metering-suction differential than the actual fuel flow.

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REFERENCES

1. Kimball, Leo B.: Icing Tests of Aircraft-Engine Induction Systems. NACA ARR, Jan. 1943.

2. Essex, Henry A., and Galvin, Herman B.: A Laboratory Investigation of Icing and Heated-Air De-Icing of a Chandler-Evans 1900 CPB-3 Carburetor Mounted on a Pratt & Whitney R-1830-C4 Intermediate Rear Engine Section. NACA ARR No. E4J03, 1944.

3. Galvin, Herman B., and Essex, Henry A.: Fluid De-Icing Tests on a Chandler-Evans 1900 CPB-3 Carburetor Mounted on a Pratt & Whitney R-1830-C4 Intermediate Rear Engine Section. NACA ARR No. E4J06, 1944.

4. Galvin, Herman B., and Essex, Henry A.: A Laboratory Investigation of the Icing Characteristics of the Bendix-Stromberg Carburetor Model PD-12F5 with the Pratt & Whitney R-1803-C4 Intermediate Rear Engine Section. NACA ARR No. E4J18, 1944.

5. Anon.: Heating Ventilating Air Conditioning Guide 1944. Vol. 22. Am. Soc. Heating and Ventilating Engineers (New York), 22d ed., 1944, pp. 10-17.

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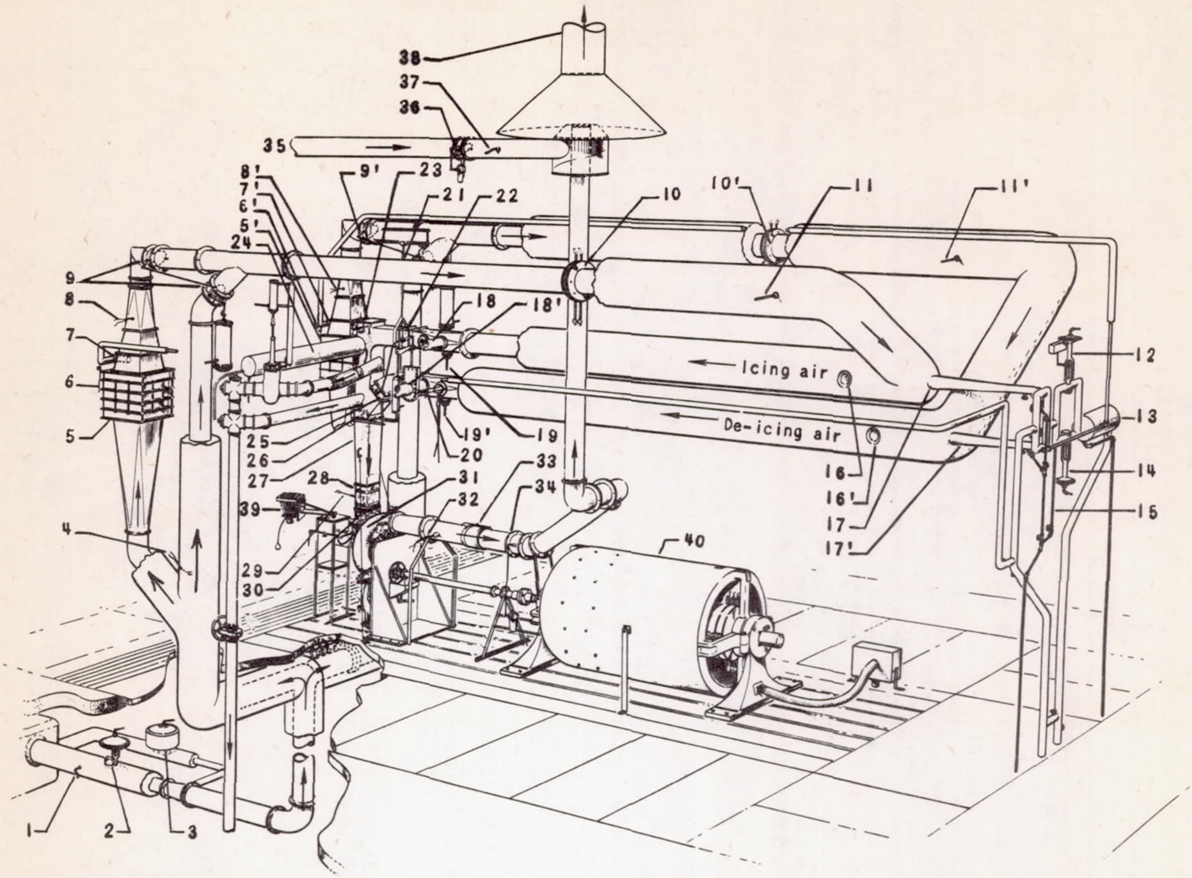

1	Air supply pressure tap
2	6-in. automatic pressure-control valve
3	2-in. automatic pressure-control valve
4	Air-supply temperature
5	Heaters, icing duct
5'	Heaters, de-icing duct
6	Steam bleed, icing duct
6'	Steam bleed, de-icing duct
7	Steam injection, icing duct
7'	Steam injection, de-icing duct
8	Heater air temperature, icing duct
8'	Heater air temperature, de-icing duct
9	Air-temperature control dampers, icing duct
9'	Air-temperature control dampers, de-icing duct
10	Orifice, icing duct
10'	Orifice, de-icing duct
11	Air-temperature control element, icing duct
11'	Air-temperature control element, de-icing duct
12	1/8-in. steam valve
13	Water separator
14	1-in. steam valve
15	Steam bleeds
16	Observation window, icing duct
16'	Observation window, de-icing duct
17	Steam injection, alternate, icing duct
17'	Steam injection, alternate, de-icing duct
18	Air bleed, icing duct
18'	Air bleed, de-icing duct
19	Water drain, icing duct
19'	Water drain, de-icing duct
20	Wet-bulb and dry-bulb temperature unit
21	Flexible duct support
22	Icing air damper
23	Water-injection nozzles
24	Water cooler
25	De-icing air damper
26	Alternate water-injection nozzle
27	Removable duct
28	Transparent removable duct
29	Deck temperature
30	Carburetor
31	Accessory housing assembly
32	Manifold temperature
33	Static electricity jumper
34	Manifold-pressure control damper
35	Dilution air supply
36	Dilution air control damper
37	Diluting air pressure tap
38	Exhaust stack and air dilution ejector
39	Camera
40	Dynamometer

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Figure 1. - General view of apparatus for induction-system icing tests.

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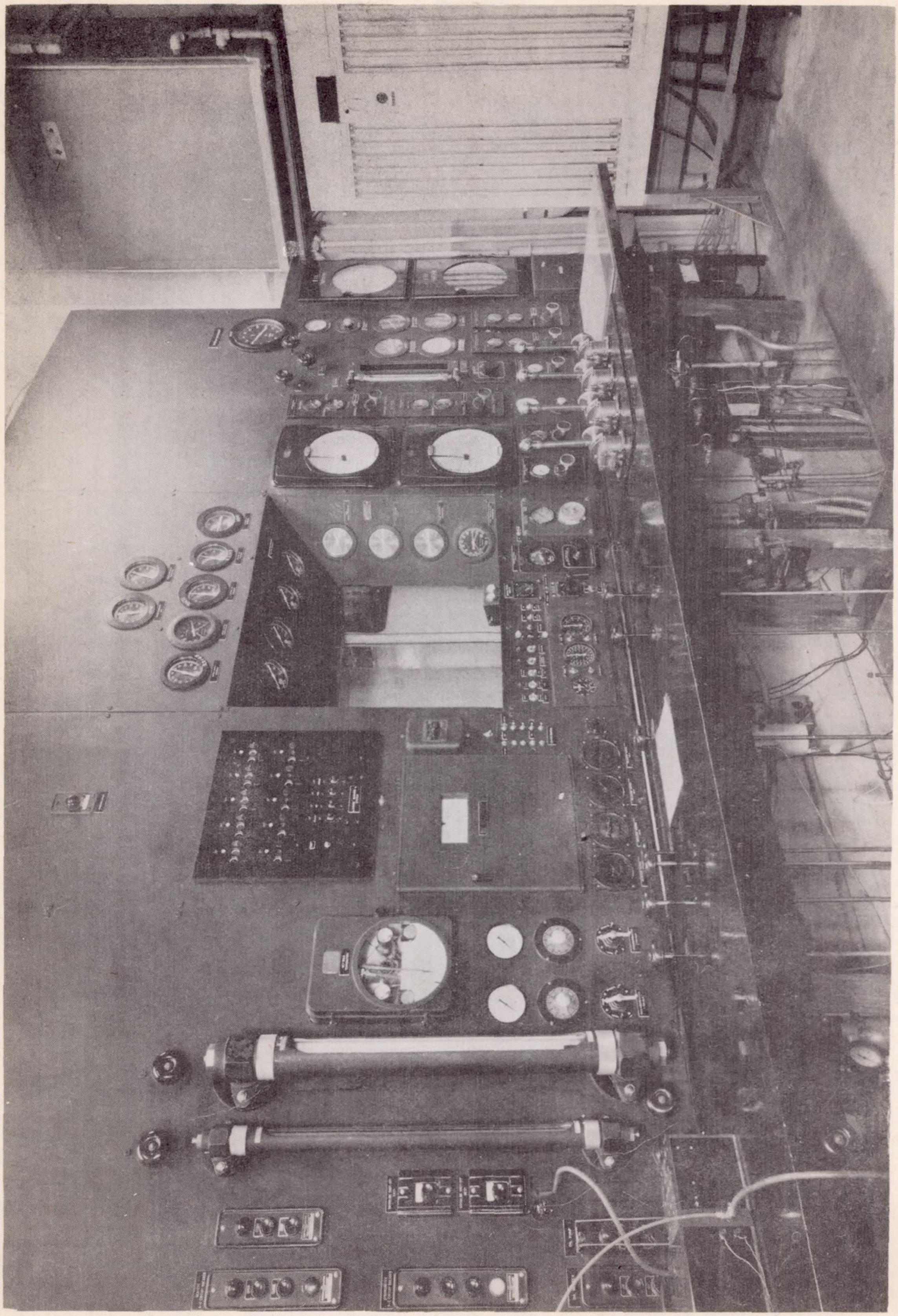

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Figure 2. - Control panel for induction-system icing-test apparatus.

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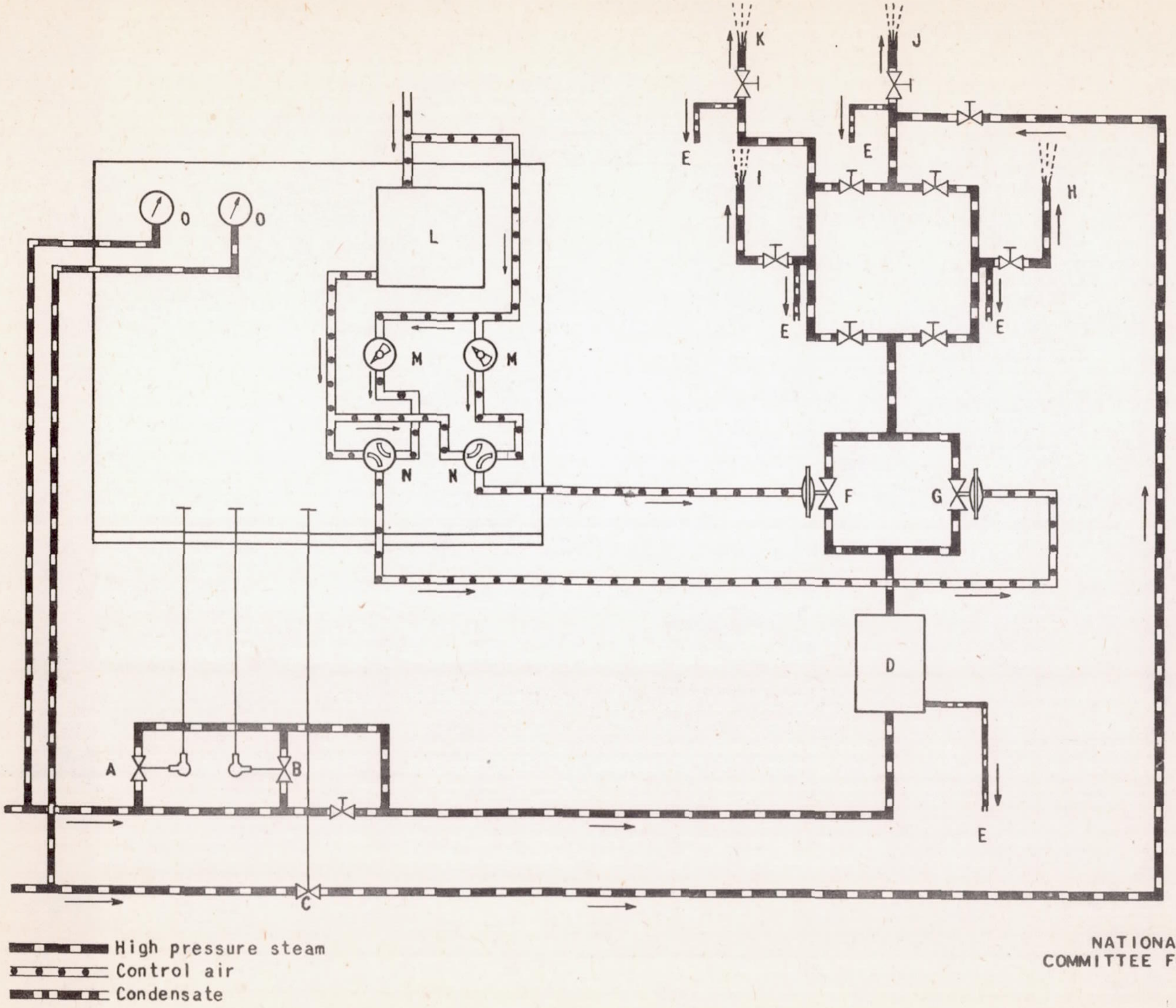

A 1/8-in. needle valve, manual
B 1/4-in. needle valve, manual
C 1/2-in. needle valve, manual
D Water separator
E Steam bleeds
F 1/8-in. needle valve, automatic
G 1-in. v-port valve, automatic
H Steam injection nozzles icing duct
I Steam injection nozzle de-icing duct
J Alternate steam injection nozzle icing duct
K Alternate steam injection nozzle de-icing duct
L Automatic humidity controller
M Gradual switches
N Positive transfer switches
O Pressure gages

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Figure 3. - Humidification system for induction-system icing tests.

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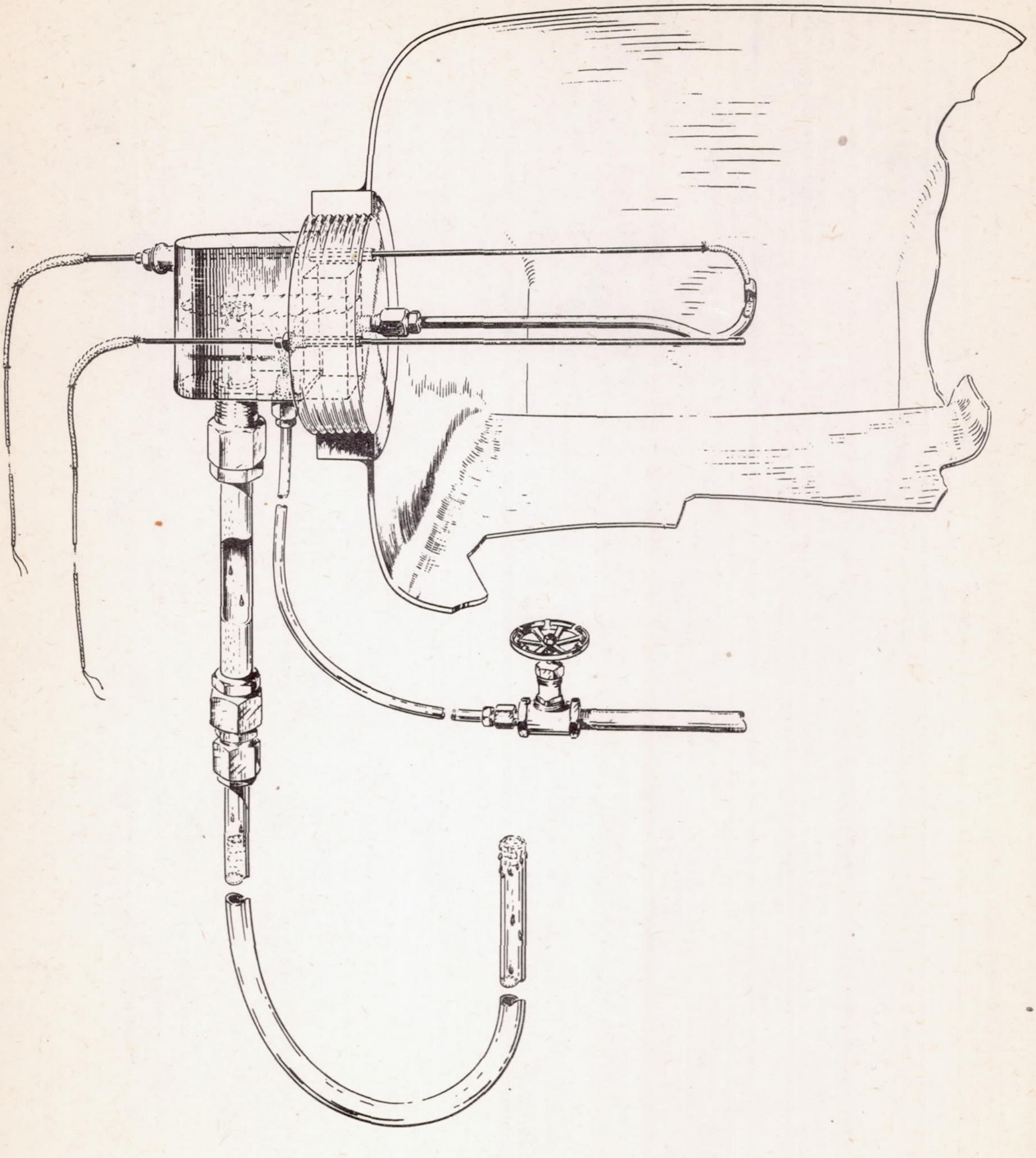

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Figure 4. - Sketch of apparatus containing a continuously wetted wick-covered thermocouple for measuring wet-bulb temperatures above freezing and a shielded thermocouple for measuring dry-bulb temperature.

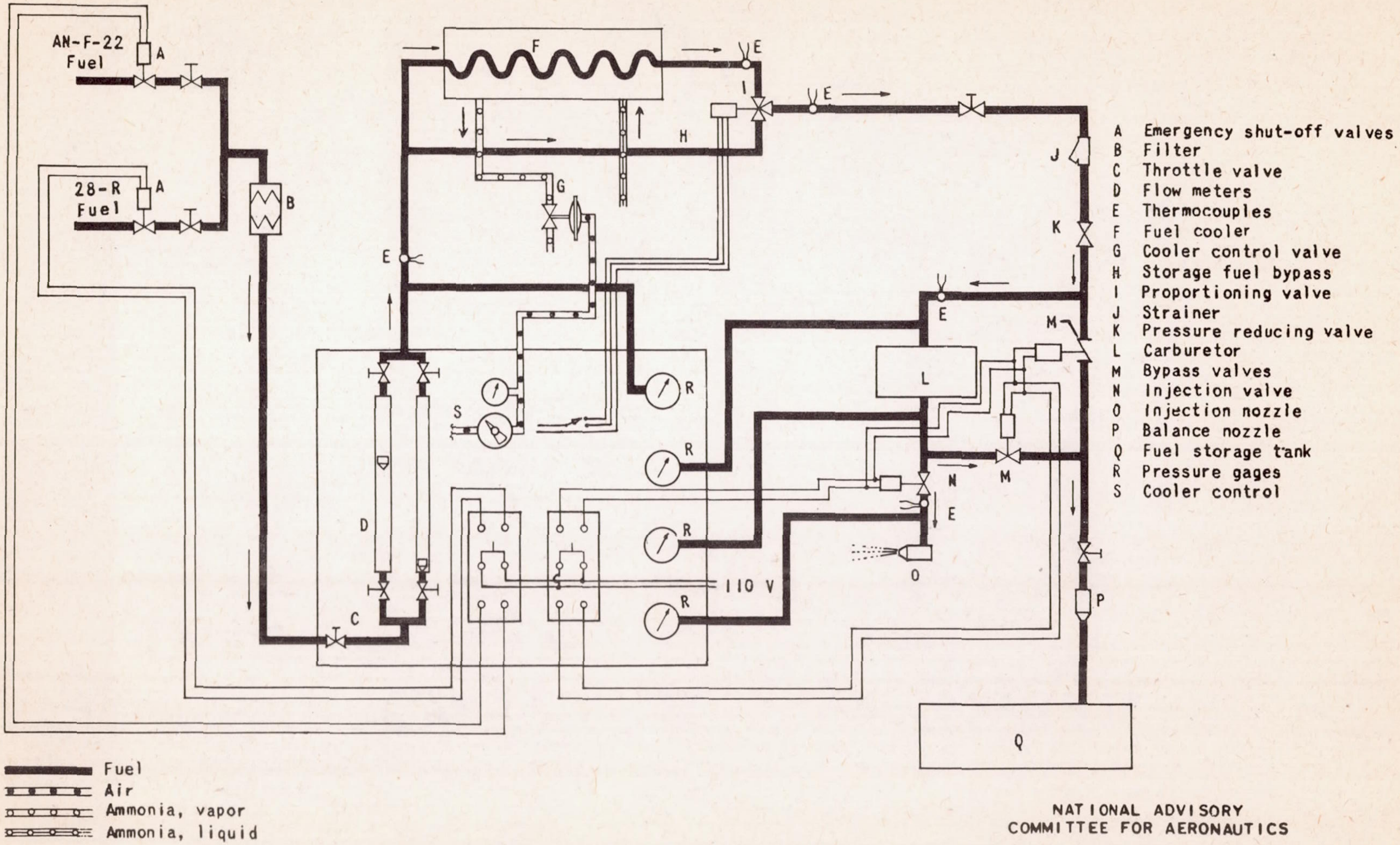

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Figure 5. - Fuel system for induction-system icing tests.

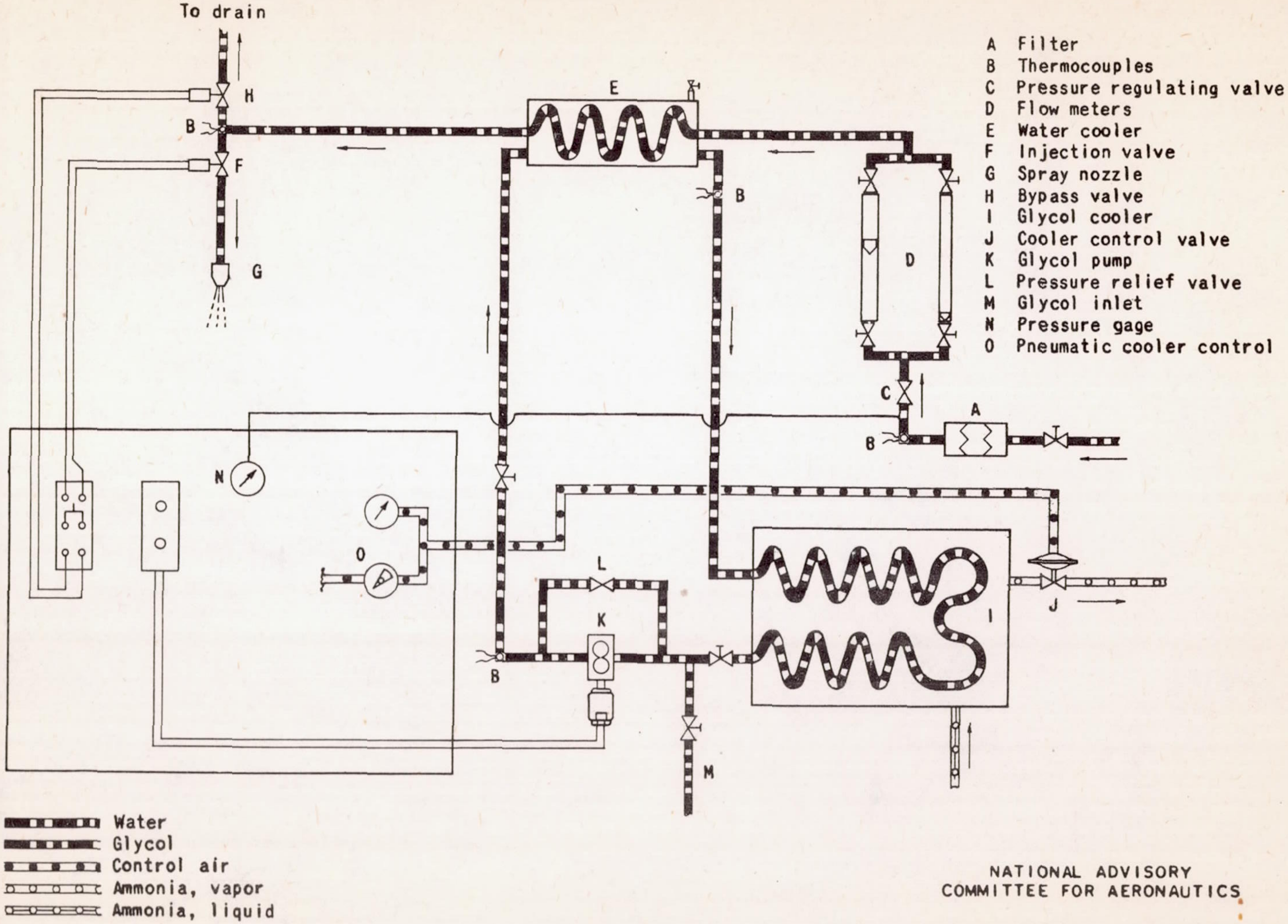

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Figure 6. - Water system for induction-system icing tests.

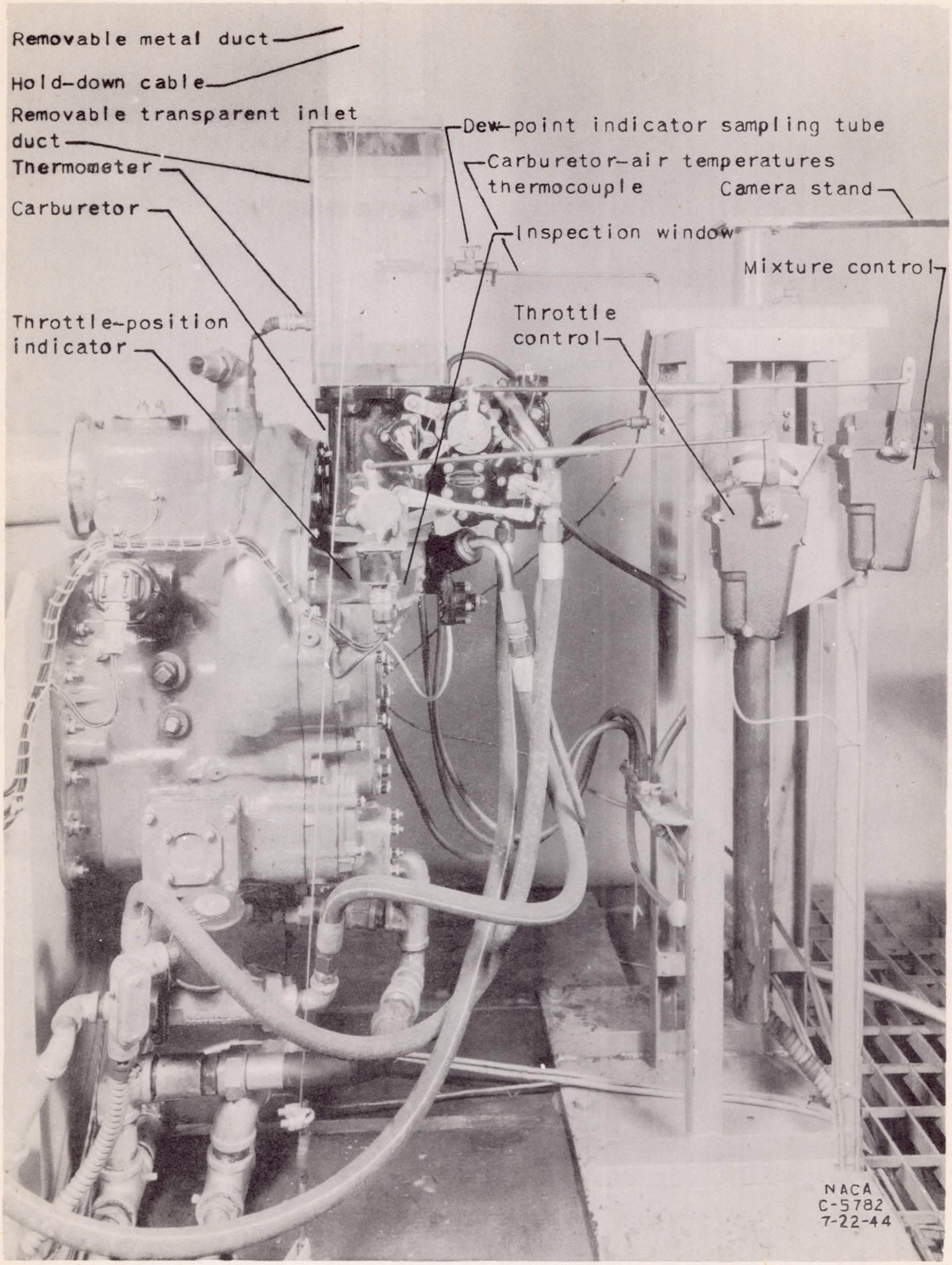
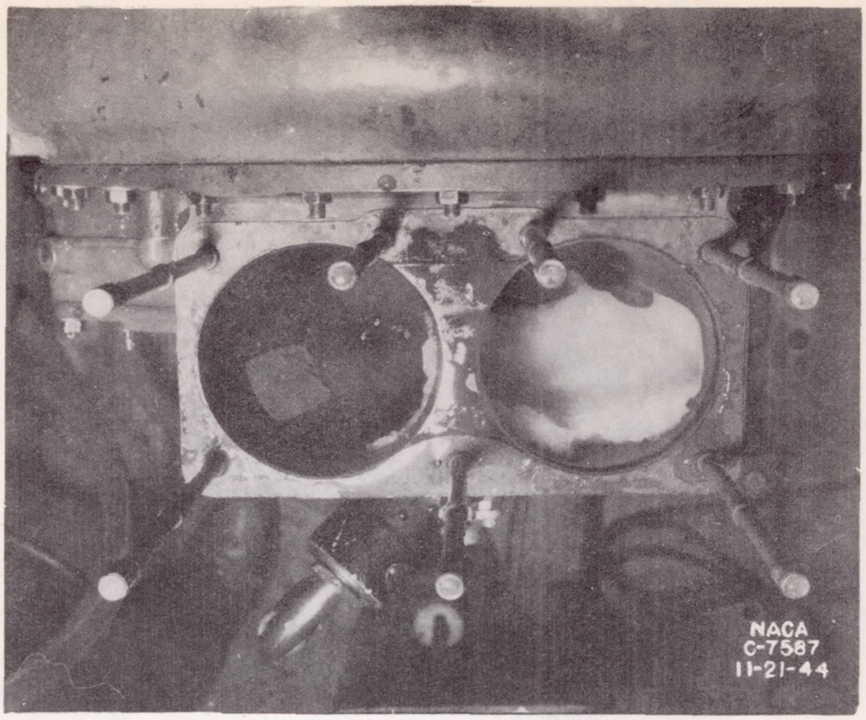
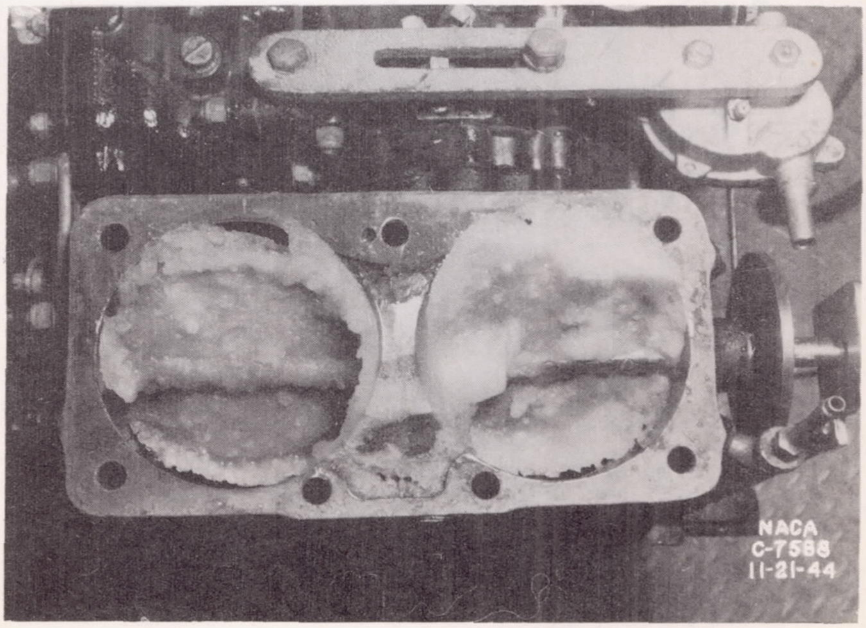


Figure 7. - Accessory housing assembly with carburetor installed for induction-system icing tests.

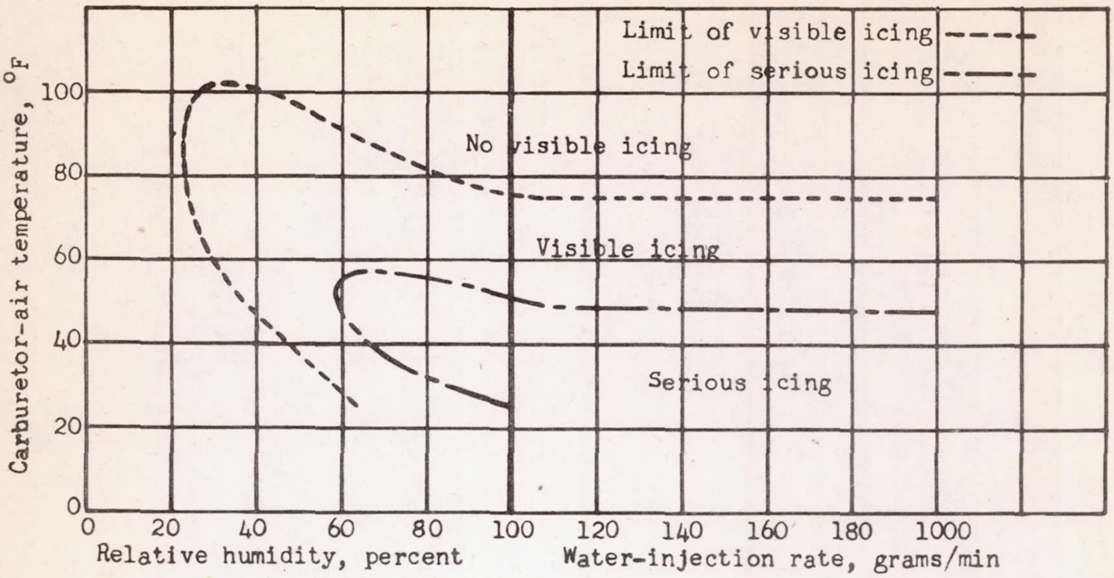


(a) Ice in supercharger inlet elbow.

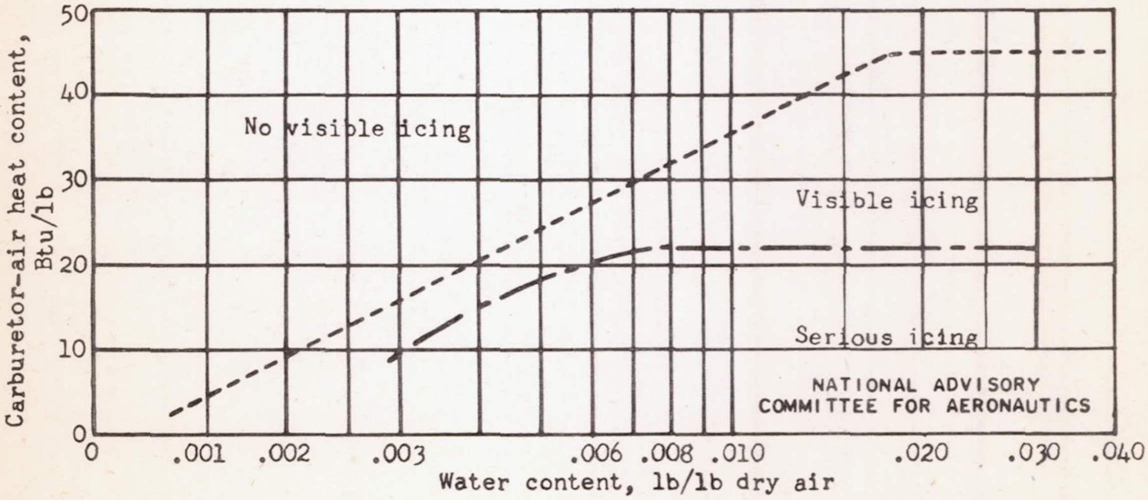


(b) Ice on throttles viewed from under side of carburetor.

Figure 8. - Typical induction-system icing.

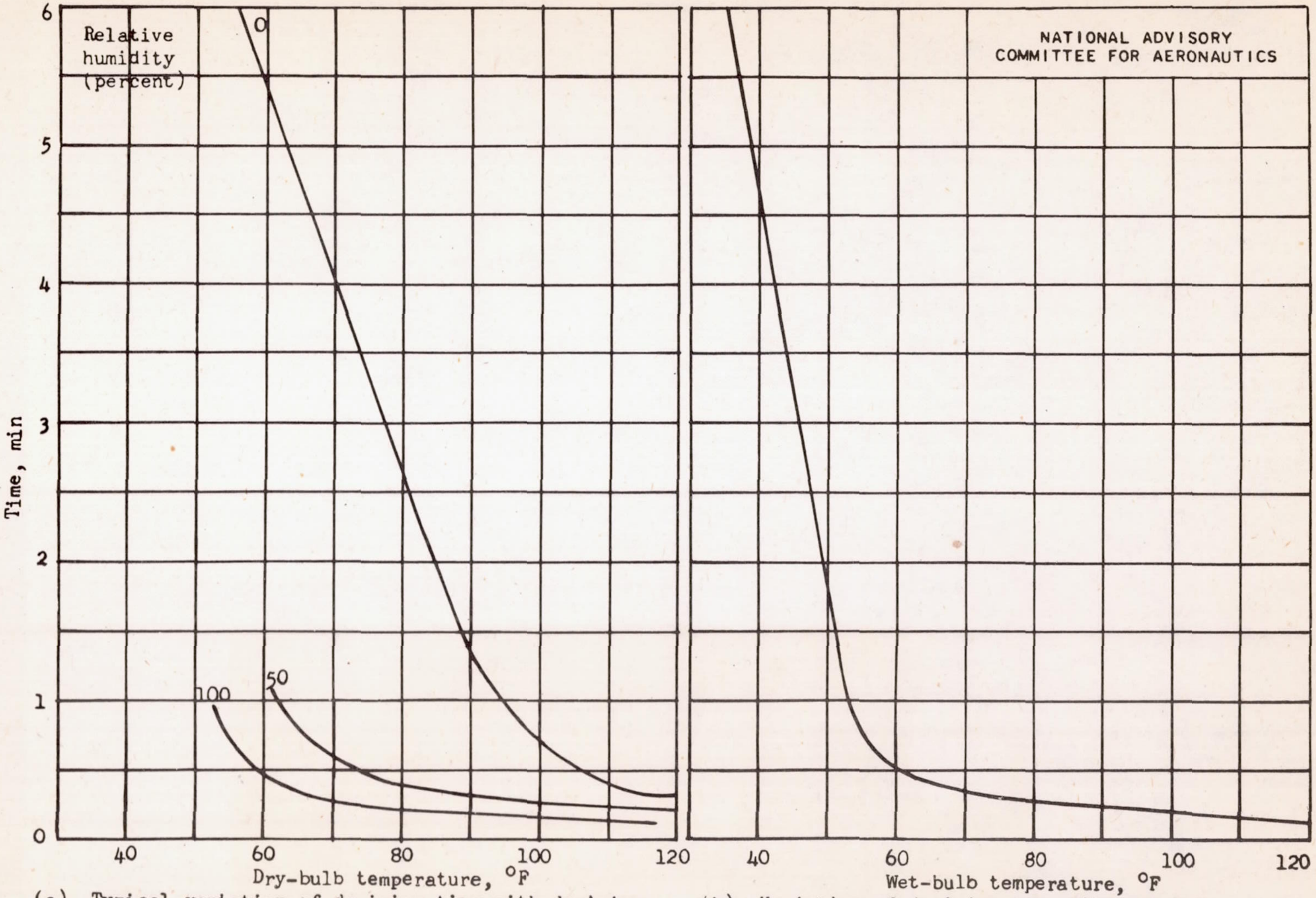


(a) Typical variation of limiting-icing conditions with carburetor-air temperature and relative humidity and rate of water injection.



(b) Typical variation of limiting-icing conditions with heat content and water content of air.

Figure 9. - Typical limiting-icing curves.



(a) Typical variation of de-icing time with de-icing-air dry-bulb temperature.

(b) Variation of de-icing time with wet-bulb temperature.

Figure 10. - Typical de-icing curves showing time for recovery of 95 percent of original air flow.