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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

By Henry A. Essex and Herman B. Galvin

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

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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

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SUMMARY

Tests were made on a Chandler-Evans 1900 CPB-3 carburetor mounted on a Pratt & Whitney R-1830-C4 intermediate rear engine section to find the limiting conditions for (1) no icing, (2) icing that would not affect engine operation, termed "visible icing," and (3) icing that would affect engine operation. The criterion of icing affecting engine operation was chosen as a drop in air-flow rate of 50 pounds per hour. The limits of air temperature and moisture content for such icing, as well as for visible icing, have been established at simulated cruising and rated powers for carburetor-air temperatures from 20° F to 80° F and for moisture contents from approximately 25 percent relative humidity to free-water injection simulating a very heavy rainfall.

The optimum temperatures for removal of ice formed at two different temperatures were determined for both cruising and rated powers over a range of de-icing air temperatures from 55° F to 134° F and a range of air-moisture contents from about 20 percent relative humidity to a rate of free-water injection of 250 grams per minute.

Results of these tests showed that no visible icing occurred above 80° F and no icing affecting engine operation, above 70° F for any moisture content investigated. At rated-power conditions, no icing sufficient to affect engine operation within a period of 5 minutes occurred at relative humidities below 100 percent at any temperature tested. At cruising conditions, icing affecting engine operation occurred within 15 minutes at relative humidities as low as 60 percent and within 3 hours at a relative humidity as low as 38 percent.

The time required to remove ice from an induction system partly choked with ice formations was dependent on the wet-bulb temperature of the heated air and decreased only a slight amount as the heated-air wet-bulb temperature increased above 90° F. This relation was valid for all conditions of icing and engine operation investigated. Restoration of normal fuel-air ratio occurred almost simultaneously with the recovery of initial air-flow rate.

INTRODUCTION

The NACA is carrying out a research program on aircraft-engine induction systems to determine the atmospheric conditions under which ice forms in the induction systems, the severity of the icing encountered, and means of reducing and eliminating such icing. The results of previous work in this program are described in references 1 and 2.

This report is the first in a series of three covering the results of an investigation of the icing and de-icing characteristics of a Pratt & Whitney R-1830 engine induction system. The research was carried out at the National Bureau of Standards under the joint sponsorship of the Army, the Navy, and the NACA between April and September 1943.

The present report deals with the determination of the limiting icing conditions and with research on heated-air de-icing for the induction system, which includes a Chandler-Evans 1900 CPB-3 carburetor mounted on an R-1830-C4 intermediate rear engine section. In both parts of this research, pressure altitudes obtained during the tests varied from 750 to 2700 feet. Tests were performed at both simulated cruising and simulated rated-power conditions of engine operation.

The second report of the series (reference 3) covers the results of a program to determine the most effective rate and method of injection of de-icing fluid to remove a heavy ice formation from the induction system. The third report (reference 4) covers work on the determination of the icing characteristics of the induction system with a Bendix-Stromberg PD-12F5 carburetor.

Three types of icing commonly encountered in carburetors are "throttling icing" caused by the pseudoadiabatic expansion of the carburetor air in the metering venturis and past the throttle edges, "fuel-evaporation icing" caused by cooling resulting from the vaporization of the fuel, and "impact icing" caused by free water striking the induction-system surfaces and freezing there when the intake-air temperature is below 32° F.

The purpose of the tests of limiting icing conditions was to determine the values of carburetor-air temperature and moisture content of the intake air at which no icing, either of the throttling or the fuel-evaporation type, occurred. Heated-air de-icing tests were made to determine the wet-bulb temperature of carburetor air required to remove ice from the induction system after it had been partly blocked with ice formed under severe icing conditions.

Acknowledgement is made to the manufacturers whose products were used in these tests for their cooperation in supplying parts and service.

APPARATUS

The altitude laboratory of the National Bureau of Standards in which these tests were performed is described in reference 1. A standard Chandler-Evans 1900 CPB-3 carburetor mounted on a Pratt & Whitney R-1830-C4 intermediate rear engine section constituted the induction system tested. Electrically driven constant-displacement exhausters were used instead of the supercharger impeller to induce air flow.

Fuel metering in this carburetor was controlled by the differential pressure between two rows of impact tubes and a set of orifices at the maximum thickness of two streamlined bars running across the carburetor and thereby giving a venturi effect. The fuel was injected from a horizontal fuel nozzle bar located at the bottom of the carburetor directly below the throttles. The air flow was controlled by twin butterfly throttles, which turned in opposite directions and closed off the air when their leading edges met in the center of the carburetor.

The apparatus used to determine the limiting icing conditions (fig. 1) is the same as that described in reference 1 with the exception of the air-intake duct, which was especially designed to fit the induction system used in these tests.

The apparatus used in the heated-air de-icing tests is shown in figure 2. An air-intake duct equipped with an internal flapper valve that could be operated to admit either hot or cold air into the carburetor was substituted for the intake duct used in the tests for the determination of the limiting icing conditions. A bypass was placed in the heated-air duct upstream of the entrance of the air-intake duct and connected to the inlet of an auxiliary blower. Heated air could bypass or be drawn through the intake duct as desired by proper manipulation of the flapper valve and the three slide valves; the first slide valve was mounted in the bypass piping, the second just ahead of the intake-duct entrance in the heated-air duct, and the third in the cold-air duct. Use of these valves insured that no leakage occurred between the cold-air and the hot-air systems.

Heated-air temperatures were controlled by an automatic temperature regulator, which operated opposed-action butterfly valves. These valves proportioned the amounts of hot and cold air before they were mixed in a plenum chamber at the outlet of the heating unit.

The humidity of the heated air was controlled by injecting steam into the plenum chamber of the air heater. The locations of this steam-injection point for the control of humidity and the water-injection point for the control of free-moisture content are shown in figure 2.

Wet-bulb and dry-bulb thermometers located at the carburetor-air temperature stations shown in figures 1 and 2 were used to measure the humidity and temperature of the carburetor air.

An unleaded fuel of 73-octane rating was used in all the tests. The distillation curve of this fuel obtained from tests run at the National Bureau of Standards is plotted in figure 3 together with the distillation curve of 28-R fuel (AN-F-28, Amendment-2, grade 100/130), which is representative of fuels in current use by the military services.

METHODS AND TESTS

Two engine power conditions were simulated in each part of the test program. An air-flow rate of 4000 pounds per hour with a fuel-air ratio of 0.070 has been designated simulated cruising power, and an air-flow rate of 7000 pounds per hour with a fuel-air ratio of 0.100, simulated rated power. The desired air-flow rate was obtained by positioning the throttle and operating a variable bleed in the exhaust line to give the carburetor pressure drops required (as determined from air-box calibration data furnished by the manufacturer) for the chosen air-flow rate. The carburetor mixture control was manually adjusted to give the desired initial fuel-air ratios but during the tests the carburetor automatically metered the fuel for air-flow changes.

In neither the limiting-icing-condition tests nor the heated-air de-icing tests was any attempt made to vary the pressure altitude at the carburetor from sea-level conditions, but pressure drop in the ducting gave pressure altitudes ranging from about 750 to about 2700 feet.

Throughout all series of tests, the fuel temperature was maintained approximately between 45° F and 55° F and the water temperature, between 35° F and 40° F. This seemingly wide range of temperatures represents only a small variation of heat input and would therefore have little measureable effect on the test results.

The rate of water injection used to simulate rain collected in the induction system by an airplane in flight was estimated by assuming that the rate of water injection of an airplane is proportional to the frontal area of the air scoop, the speed of the airplane, and the rain density in the air. It is estimated that an airplane with an air-scoop area of 48 square inches flying at a speed of 160 miles per hour through air with a rain density of 2 grams per cubic meter (moderately heavy rain) would collect rain at the rate of about 250 grams per minute. It is recognized that slipstream effects, splashing, and peculiarities of scoop design may cause variation in water-collection rates in particular airplane installations.

Limiting-Icing-Condition Tests

In the tests of limiting icing conditions, the air flow, the fuel-air ratio, the carburetor-air temperature, the humidity, and the rate of free-water injection were established at the desired values for each test. After these conditions were set, the fuel and the water flows were suspended until it was ascertained that no ice was present anywhere in the induction system, at which time the flows were again turned on and the timing was started. Thereafter, at regular intervals, measurements were taken of air flow, fuel flow, air pressure within the duct, carburetor pressure drop, and carburetor-metering-suction differential pressure.

At the end of the test period the exhausters were shut off and the ice formation was examined either through the observation windows or by dismantling the induction system. In many cases, the ice formations were photographed to permit further analyses of the icing characteristics of the induction system.

In the determination of the limiting conditions of visible icing and icing affecting engine operation, three series of tests were run. The ranges of conditions were as follows:

Series (a)	Length of run (min)	Initial air flow (lb/hr)	Initial fuel-air ratio	Carburetor-air temperature (°F)
I	15	4000	0.070	20-80
II	30-180	4000	.070	40-70
III	5	7000	.101	35-70

Series (a)	Carburetor-air moisture content		
	Relative humidity (percent)	Water in excess of saturation (grams/min)	Total initial (lb/lb of air)
I	12-100	0-2500	0.00092-0.0919
II	37-89	----------	.0031-.0099
III	61-100	0-1500	.0043-.0422

[a]Series I and II, cruising power; series III, rated power.

Heated-Air De-Icing Tests

The heated-air de-icing tests were made by icing the induction system until the air flow was greatly reduced by a large ice formation. At the same value of reduced air flow in every test, the air valves were manipulated to quickly transfer heated air of controlled temperature and humidity to replace the cold icing air previously being supplied to the carburetor. At the change-over and thereafter at 0.1-minute intervals observations of air flow and fuel flow were recorded.

While the icing air and the free water were being supplied to the carburetor through the cold-air duct, the heated air was bypassed through the auxiliary blower at approximately the air-flow rate at which change-over would be made and its temperature and humidity were set to the values desired for de-icing. When the time for change-over approached, the free water used for icing was cut off or reduced to one-half as in the runs of one series in which it was desired to observe the effect of free water on de-icing by heated air.

The chosen value of air flow at the change-over point was 2500 pounds per hour because it was observed that a very severe but reproducible ice formation resulted from permitting the icing to proceed to this point. When the icing was permitted to proceed further, the air flow frequently continued to fall so rapidly within the short interval required for change-over that no recovery was possible by means of heated air. Because the test condition used represented such severe icing, it was expected that, in actual flight, corrective measures would be applied long before the air flow dropped to 2500 pounds per hour. The ranges of conditions under which the heated-air de-icing tests were made are given in the following table:

Series (a)	Initial icing conditions				De-icing conditions			
	Air flow (lb/hr)	Fuel-air ratio	Carburetor-air temperature (°F)	Water injection (grams/min)	Water injection (grams/min)	Air temperatures		Heat content (Btu/lb)
						Dry bulb (°F)	Wet bulb (°F)	
A	4000	0.070	40	500	0	60-134	56-114	23.8-101.8
B	7000	.100	40	500	0	72-128	67-99	31.5-66.3
C	4000	.070	40	500	250	65-90	65-90	31.4-57.1
D	4000	.070	25	250	0	69-119	56-101	23.8-73.2
E	7000	.100	25	400	0	71-100	54-88	22.6-53.0

[a] Series A, C, and D, cruising power; series B and E, rated power.

In addition to the tests made, an attempt was made to de-ice the induction system with air of constant relative humidity over a range of dry-bulb temperatures; no means were available, however, for automatically maintaining both wet-bulb and dry-bulb temperatures and the proposed tests were therefore abandoned.

RESULTS AND DISCUSSION

Limiting-Icing-Condition Tests

Classification of ice occurrences. - In the determination of the limiting icing conditions, it was found necessary to classify the ice formations according to effect because, within the range of temperatures and moisture contents investigated, ice of the throttling, the fuel-evaporation, and the impact types occurred. The term "no visible icing" is self explanatory. The ice formations classified as visible icing were those not sufficiently large to cause a drop in air-flow rate of 50 pounds per hour within the test period. Such an ice formation is shown in figure 4. When the original air flow was reduced by 50 pounds per hour or more within the period of the test, it was assumed that the ice formation would affect engine operation because, although the resulting power loss in an engine might be negligible, an ice formation large enough to produce such a drop might affect mixture distribution and cause uneven firing in some of the cylinders. Icing that affected engine operation may be seen in figures 5, 6, and 7.

Location of ice formations. - Most of the ice formations resulting from fuel evaporation accumulated on the turning vanes or on the boss that enclosed the impeller-shaft bearing. (See figs. 5, 6, and 7.) In many of the runs, however, ice formed on the fuel nozzle bar and on the under side of the dual throttles. These formations were caused by a combination of fuel-evaporation and throttling cooling.

Pseudoadiabatic expansion of the air stream through the metering venturis and the throttle openings condensed water from the air stream and slightly cooled adjacent metal parts. The water froze on the throttle plates and on the other metal parts that had been further cooled by evaporating fuel lifted up under the throttles by the turbulence in their wake (fig. 5(b)).

Effect of icing on fuel-air ratio. - In all the tests in which ice formed below the impact tubes and the streamlined venturi bars, the fuel-air ratio did not vary from the carburetor calibration curve (fig. 8) by more than 2.5 percent. When the icing was allowed to reduce the air flow to the idling range, however, the variation became as much as 10 percent leaner than the calibration-curve values (fig. 9). This wider variation was not believed to have been caused by the icing but by instrumental errors that increased at low air and fuel flows. When impact ice formed on the impact tubes and on the venturi bars, however, the metering suction differential was disturbed, thereby causing the fuel-air ratios to become as high as 0.130 (fig. 10).

Limiting icing conditions. - Table I presents the results of all the tests of limiting icing conditions. These results are shown in figures 11 and 12, together with curves of relative humidity and rate of water injection in excess of saturation. The red bands straddling the curves of limiting icing conditions designate the possible variation.

The limits of visible icing at cruising conditions are shown by the upper dashed curve in figure 11. The maximum temperature at which icing was observed over the range of water contents tested was 80° F. Directly beneath the limit of visible icing lies the limit of icing affecting engine operation within 3 hours. This region extended to 70° F and to relative humidities as low as 38 percent. Many of the 3-hour runs were characterized by ice accretions that built up until they restricted the air flow and then broke away as the bond of ice to the engine or the carburetor parts was loosened by melting. The air flow in such cases increased almost to its original value and then began to drop; after several such cycles, the trend was unmistakably downward.

The region of icing affecting engine operation within 15 minutes lies below the lowest limiting-conditions curve in figure 11. The highest temperature reached by the limiting-conditions curve of icing affecting engine operation was 65° F. This region extended to relative humidities as low as 60 percent.

In the tests performed at simulated rated-power conditions, it was observed from the plot of the data (fig. 12) that, within the range of experimental error, no icing affecting engine operation occurred at relative humidities below 100 percent. The maximum temperature at which icing affected engine operation within 5 minutes was about 70° F.

Heated-Air De-Icing Tests

The results of the heated-air de-icing tests are presented in table II and in figures 13 to 16. Typical icing curves showing the reduction in air flow and the variation of fuel-air ratio with time during the icing process are shown with the curves of de-icing time history in figures 17 to 20.

Criterion and measure of de-icing effectiveness. - The criterion of de-icing effectiveness was chosen as the time required to attain 95 percent of the maximum air flow recovered. The maximum recovered air flow was taken as the air flow after de-icing was completed. In some of the runs, ice remaining in the induction system prevented full recovery of air flow within the arbitrary 5-minute test period and these runs have therefore been disregarded.

The temperature most significant in considering the de-icing effectiveness of air is the wet-bulb temperature because the heat transfer to the ice takes place through a water interface. The time required to recover 95 percent of the maximum recovered air flow with heated air of varying temperature and relative humidity has therefore been plotted against the wet-bulb temperature of the air.

Variation of de-icing time with wet-bulb temperature. - All the results of the tests in which no free water was injected (series A, D, E, and B in figs. 13, 14, 15, and 16, respectively) indicate a rapid decrease in time required for de-icing as the wet-bulb temperature was increased to values between 70° F and 90° F and only a slight decrease in de-icing time for higher wet-bulb temperatures.

The results of injecting 250 grams of water per minute during de-icing to simulate free-water injection through leaky alternate hot-air intakes on airplanes (series C tests) have been plotted with those of the series A tests in figure 13. Except for the injection of free water, these two series of tests were made under similar test conditions. For air, the wet-bulb temperature is a function of the enthalpy (heat content in Btu/lb) and the injection of 250 grams of water per minute increased the enthalpy of the de-icing air by only 1.4 Btu per pound. This increase in enthalpy is equivalent to a wet-bulb temperature rise amounting to only 2° F for a wet-bulb temperature of 65° F and to only 1° F for a wet-bulb temperature of 90° F. Thus the results indicate that the injection of small amounts of free water during the de-icing process does not affect the recovery time within the limits of observational error. The values of enthalpy used in this report were taken from reference 5.

Effect of character and location of the ice on de-icing time. - Results of the de-icing tests performed with an initial air-flow rate of 4000 pounds per hour have been plotted in figures 13 and 14. These curves are dissimilar because the icing conditions of series A (fig. 13) produced an evaporation-ice formation that almost completely filled the air passage below the carburetor, whereas the low-temperature runs of series D (fig. 14) produced an impact-icing condition that coated the upper surfaces of the carburetor with a thin film of ice. The difference in the shapes of the curves in figures 15 and 16, which show the results of the de-icing tests at an initial air-flow rate of 7000 pounds per hour, is attributable to a similar difference in the locations and types of ice formation.

Effect of air-flow rate on de-icing time. - From a comparison of the results obtained from removing the impact ice formed at two different air-flow rates in series D and E (figs. 14 and 15, respectively), it is noted that the curves are similar in shape and magnitude of values. The similarity probably results from the rapid melting and blowing away of the small impact-ice formations covering the throttle openings, which permitted the air-flow rate to recover to the normal value determined by the throttle setting; thus, for this type of ice formation, de-icing time was not affected by throttle opening.

The results given by the tests of series A and B (figs. 13 and 16, respectively) show curves of similar shape. Comparison of the values of points on the curves shows that it required a longer time to restore an air flow of 7000 pounds per hour than to restore one of 4000 pounds per hour at the same wet-bulb temperature. The difference between the recovery times is believed to be due to the fact that the ice formed in the series A and B tests was of the evaporation type and almost completely filled the air passage. In such an event, the amount of air flow restored would depend on the quantity of ice melted out; hence, for equal wet-bulb temperatures, the time for restoration of the air-flow rate of 7000 pounds per hour would be greater than the time required to restore the smaller air-flow rate.

Recovery of fuel-air ratio. - The time required for recovery of the initial fuel-air ratio (as measured) somewhat lagged the air-flow recovery in the various tests. It is believed that these lags were caused by slow response of the rotameters used for measuring the fuel flow and that actually little or no difference existed between the air-flow-rate and the fuel-air-ratio recovery times.

The fuel-air ratio at the time of 95 percent maximum air-flow-rate recovery was generally richer than the fuel-air ratio at the start of each test (see table II) and deviated from the initial value by as much as 10 percent in many cases. The deviations might have occurred for one or more of the following reasons:

1. Errors and lag were inherent in the carburetor-temperature compensator.

2. Water might have entered the carburetor temperature-compensating unit during the icing portion of the tests and prevented full temperature compensation when the de-icing air was turned on.

3. Differences in calibration errors between the orifices measuring cold-air and hot-air flow could cause differences in the computed fuel-air ratios.

4. Changes in air-flow distribution due to the use of alternate duct systems might have influenced carburetor metering.

Basis for rating aircraft induction-air heaters. - Aircraft induction-air heaters have generally been rated on the basis of rise in dry-bulb temperature; the nature of the results of all the de-icing tests indicates, however, that the wet-bulb temperature of the heated air governs de-icing effectiveness. The wet-bulb temperature rise may be determined without the use of actual wet-bulb thermometers by first computing the Btu rise (enthalpy increase) of the heater. For any given condition of air entering the heater, the inlet enthalpy can then be determined by reference to a psychrometric table or chart and the enthalpy of the air leaving the heater will be the sum of the inlet-air enthalpy and the enthalpy increase supplied by the heater. Further reference to psychrometric data will yield the outlet wet-bulb temperature as a function of enthalpy.

SUMMARY OF RESULTS

The following results are strictly applicable only to the Chandler-Evans carburetor, model 1900 CPB-3, mounted on a Pratt & Whitney R-1830-C4 intermediate rear engine section operated under the test conditions of this program:

1. The maximum upper limit of carburetor-air temperature at which visible icing was observed was 80° F at any moisture content investigated for operation at 15 minutes at simulated cruising conditions.

2. The upper carburetor-air temperature for icing affecting engine operation was 70° F within 3 hours of operation at simulated cruising-power conditions or within 5 minutes at simulated rated power.

3. The lower limit of relative humidity for icing affecting engine operation over the range of temperatures investigated was about 60 percent for the 15-minute runs at cruising conditions and about 38 percent for the 3-hour runs at cruising conditions.

4. Icing affecting engine operation within 5 minutes of operation at simulated rated-power conditions occurred only for air temperatures below 70° F and only for air moisture contents equivalent to or above saturation.

5. Protuberances such as the fuel nozzle bar in the carburetor and the turning vanes at the entrance to the supercharger section were lodging places for most of the ice formations.

6. The time necessary to restore the air flow by means of heated air after the induction system had been partly blocked with ice decreased with increased wet-bulb temperature of the heated air.

7. The injection of free water at rates up to 250 grams per minute during de-icing had no effect on the time for restoration of 95 percent of the maximum recovered air flow at simulated cruising conditions when the ice formed at a carburetor-air temperature of 40° F.

8. The optimum wet-bulb temperature for restoring air flow was found to be between 70° F and 90° F for all conditions of icing investigated.

9. The fuel-air ratio remained within 10 percent of the calibrated value under all icing conditions except impact-icing conditions and was restored by the application of heated air as rapidly as the air flow within the limits of observational error.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

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TABLE I - RESULTS OF LIMITING-ICING-CONDITION TESTS OF CHANDLER-EVANS 1900 CPB-3 CARBURETOR MOUNTED ON A PRATT & WHITNEY R-1830-C4 INTERMEDIATE REAR ENGINE SECTION

Run	Carburetor air					Enthalpy (Btu/lb)	Air flow		Initial fuel-air ratio	Effect (a)	Length of run (min)	Remarks
	Dry-bulb temperature (°F)	Wet-bulb temperature (°F)	Moisture content		Absolute moisture content (lb/lb of dry air)		Initial (lb/hr)	Minimum (lb/hr)				
			Relative humidity (percent)	Free water (grams/min)								
Series I (cruising power) - Initial condition: air flow, 4000 lb/hr; fuel-air ratio, 0.070												
1	20	17	56	-------	0.0013	6.1	4200	4140	0.064	1	15	Thin scum of ice on all interior surfaces of air passage; throttles frosted
2	25	21	50	-------	.0014	7.4	4000	4000	.069	2	15	Thin coating of ice on rear of air passage, turning vanes coated, lump on right side of vanes
3	25	25	100	-------	.0028	8.9	4000	3880	.070	1	15	Thin layer of ice in rear of air passage
4	25	20	38	-------	.0012	7.1	4000	4000	.069	2	15	Slight visible icing on throttle and on air-passage window
5	25	22.5	70	-------	.0020	8.9	4000	4000	.069	2	15	Slight icing on turning vanes; throttles frosted
6	32	29.5	74	-------	.0029	10.7	4040	4040	.069	2	15	Ice on throttles and on fuel nozzle bar; rime on turning vanes
7	32	32	100	-------	.0037	11.7	4040	3920	.068	1	15	Ice formed on throttles, fuel nozzle bar, and in air passage
8	35	35	100	-------	.0043	13.0	4020	3920	.070	1	15	Ice on turning vanes; prominent formation on bottom of throttle plates
9	40	34	53	-------	.0027	12.6	4000	4000	.070	2	15	Throttles frosted; ice on under sides of throttles and fuel nozzle bar; formation on turning vanes
10	40	37.5	80	-------	.0041	14.0	4000	3900	.070	1	15	Ice on turning vanes; slight icing between throttles and on fuel nozzle bar
11	50	43.5	60	-------	.0046	16.9	3970	3920	.070	1	15	Slight icing in upper rear of air passage and on fuel nozzle bar; ice on top three turning vanes
12	50	35	12	-------	.00092	13.0	3960	3920	.071	2	15	Slight frost at top of adapter; ice on right-hand turning vanes
13	30	27	68	-------	.0023	9.7	4020	4020	.070	2	15	Throttles frosted; ice on under sides of throttles, on nozzle bar, turning vanes, and sides of air passage
14	35	32.3	75	-------	.0032	11.9	4020	3900	.070	1	15	Throttles frosted; ice on under sides of throttles, on nozzle bar, and turning vanes
15	40	36	68	-------	.0036	13.4	4000	3900	.070	1	15	Throttles frosted; ice on under sides of throttles, on nozzle bar, and turning vanes
16	50	44.5	65	-------	.0050	17.4	4020	3940	.070	1	15	Throttles frosted; ice on turning vanes
17	60	51.5	56	-------	.0062	21.1	3980	3940	.071	2	15	Slight ice on turning vanes and on top of fuel nozzle bar
19	60	54.5	70	-------	.0079	22.9	3970	3940	.071	2	15	Ice on turning vanes; slight formation on fuel nozzle bar
20	60	57	84	-------	.0093	24.4	3970	3940	.071	2	15	Ice at rear of air passage and on turning vanes
21	30	28	78	-------	.0028	10.1	4060	3920	.069	1	15	Ice on turning vanes, fuel nozzle bar, and on under sides of throttles
22	60	60	100	-------	.0111	26.4	3980	3940	.070	2	15	Heavy ice formation on three top turning vanes
23	60	60	---------	50	.0127	26.7	3980	3910	.074	1	15	
24	60	60	---------	75	.0135	26.8	4000	3920	.070	1	15	Lump of ice in center of air passage
25	60	60	---------	125	.0151	27.1	4000	3910	.070	1	15	Large chunk of ice in center of air passage; ice on turning vanes
26	55	52	82	-------	.0076	21.4	4000	3960	.070	2	15	Ice on turning vanes
27	53	49	75	-------	.0065	19.7	4000	3980	.071	2	15	Ice on upper turning vanes; prominent formation at top rear of air passage
28	53	51	88	-------	.0075	20.8	4000	3900	.070	1	15	Heavy formation on turning vanes
31	20	20	100	-------	.0021	7.1	4020	3950	.071	1	15	Ice formed on lower turning vanes and on under side of carburetor
32	20	19	85	-------	.0019	6.7	4020	3950	.070	1	15	Formations on bottom of carburetor, on air-passage walls, and on turning vanes

[a]1, icing affecting engine operation; 2, visible icing; 3, no visible icing

TABLE I - RESULTS OF LIMITING-ICING-CONDITION TESTS OF CHANDLER-EVANS 1900 CPB-3 CARBURETOR MOUNTED ON A PRATT & WHITNEY R-1830-C4 INTERMEDIATE REAR ENGINE SECTION - Continued

Run	Carburetor air: Dry-bulb temperature (°F)	Carburetor air: Wet-bulb temperature (°F)	Carburetor air: Moisture content: Relative humidity (percent)	Carburetor air: Moisture content: Free water (grams/min)	Carburetor air: Absolute moisture content (lb/lb of dry air)	Enthalpy (Btu/lb)	Air flow: Initial (lb/hr)	Air flow: Minimum (lb/hr)	Initial fuel-air ratio	Effect (a)	Length of run (min)	Remarks
Series I (cruising power) - Initial condition: air flow, 4000 lb/hr; fuel-air ratio, 0.070 - Continued												
33	25	23	75	-------	0.0021	8.2	4000	3920	0.071	1	15	Ice on under side of carburetor, air-passage walls, and turning vanes
34	45	41.5	75	-------	.0048	15.9	3980	3930	.070	1	15	Ice on turning vanes; slight formation on under side of throttles
35	45	42.5	82	-------	.0052	16.4	3980	3860	.070	1	15	Throttles frosted; slight formation on under side of throttles
36	45	42	79	-------	.0050	16.1	3980	3910	.070	1	15	Ice on turning vanes and walls of air passage
38	55	53	88	-------	.0081	22.0	3980	3920	.071	1	15	Heavy ice formation on turning vanes and on air-passage walls
39	50	45	68	-------	.0052	17.6	4020	3920	.070	1	15	Slight formation on under side of throttles and on nozzle bar; ice on turning vanes
40	45	41	71	-------	.0045	15.7	4020	3910	.070	1	15	Throttles frosted; ice on air-passage walls and turning vanes
41	45	39	58	-------	.0037	14.7	4000	3980	.070	2	15	Ice on turning vanes and air-passage walls; throttles frosted
42	45	40	65	-------	.0041	15.2	4040	3960	.069	1	15	Ice on turning vanes; heavy formation on under sides of throttles
43	52	48	75	-------	.0062	19.2	3990	3960	.070	2	15	Turning vanes coated with ice
44	58	56	89	-------	.0092	23.8	3980	3950	.070	2	15	Heavy ice formation on upper turning vanes especially on left side
45	58	57	94	-------	.0097	24.4	3980	3950	.070	2	15	Space between several of the turning vanes almost filled with ice; ice on air-passage walls
46	58	58	100	-------	.0103	25.1	3980	3950	.071	2	15	Turning vanes encrusted with ice; ice on air-passage walls
47	63	63	---------	250	.0206	29.9	4000	3940	.070	1	15	Unstable ice formation mainly on second turning vane
48	63	63	---------	500	.0288	31.3	4000	3960	.071	2	15	Unstable ice formation on top turning vanes
49	60	60	---------	750	.0359	30.6	4000	3970	.070	2	15	Glazed ice on turning vanes
50	57	57	---------	500	.0265	27.2	3980	3890	.071	1	15	Lumps of ice jammed against turning vanes
51	58	58	---------	750	.0352	29.3	3980	3950	.071	2	15	Large lump of ice in center of air passage
52	55	55	---------	1000	.0423	28.7	4000	3910	.070	1	15	Solid lump of ice in front of upper turning vanes
53	58	58	---------	1250	.0520	32.1	3960	3950	.071	2	15	Slight icing on vanes
54	55	55	---------	1500	.0588	31.5	4000	3900	.069	1	15	Large chunk of ice in center of air passage in front of top turning vanes
55	58	58	---------	1750	.0689	34.9	3950	3890	.071	1	15	Chunk of ice in center of air passage
56	55	55	---------	2000	.0754	34.2	4000	3860	.070	1	15	Heavy ice formation in front of turning vanes
57	58	58	---------	2250	.0850	37.6	3990	3950	.070	2	15	Slight icing of turning vanes; lump in center of air passage
58	35	30	54	-------	.0025	10.9	4000	4000	.071	2	15	Coating of ice on turning vanes and air-passage walls; throttles frosted
59	55	55	---------	2500	.0919	37.0	4000	3910	.068	1	15	Large chunk of ice in front of turning vanes
60	40	40	---------	500	.0217	18.0	4000	1000	.070	1	5.4	Glazed formation in space in front of turning vanes choking off air passage
61	60	48	40	-------	.0044	19.2	4020	4020	.071	2	15	Ice on turning vanes; thin coating on throttles and air-passage walls
63	70	53	30	-------	.0047	22.0	4000	3960	.072	2	20	Slight icing of turning vanes and light coating on unjacketed part of air passage
64	75	55.5	26	-------	.0050	23.5	4000	3980	.071	2	15	Ice on air-passage walls and a few knobs on turning vanes
65	78	57	25	-------	.0052	24.4	4050	4050	.070	3	15	Thin layer of ice on unjacketed portion of air passage
66	78	60	34	-------	.0070	26.4	4050	4050	.069	2	15	No visible icing
67	80	67	51	-------	.0112	31.5	4040	4040	.070	2	15	Small ice lumps on turning vanes
68	80	69	58	-------	.0130	33.4	4060	4060	.068	3	15	No visible icing
69	78	75	87	-------	.0181	38.5	4090	4090	.069	3	15	No visible icing
70	75	75	100	-------	.0187	38.5	4000	4000	.070	3	15	No visible icing
71	71.5	71.5	100	-------	.0166	35.3	4040	4040	.070	3	15	No visible icing
72	70	70	100	-------	.0157	34.0	3990	3960	.070	2	15	Slim sliver of ice at bottom edge of adapter
73	70	70	---------	125	.0199	34.7	3990	3990	.070	3	15	No visible icing
74	67	67	---------	250	.0224	32.9	4020	4020	.071	3	15	No visible icing
75	65	65	100	-------	.0132	30.0	4010	4010	.070	2	15	Slight ice on turning vanes
76	65	65	---------	500	.0297	32.8	4010	4010	.070	2	15	Light formation on turning vanes
77	65	61	80	-------	.0106	27.1	4010	3950	.070	1	15	Incrustation of ice on turning vanes and on rear wall of air passage
78	63	61	89	-------	.0111	26.9	4020	4020	.070	2	15	Ice on turning vanes and on upper air-passage walls
94	65	65	---------	750	.0379	34.1	4020	4010	.070	3	15	No visible icing
95	62	62	---------	1000	.0448	33.3	4020	4020	.070	3	15	No visible icing
96	60	60	---------	1500	.0603	34.6	4030	4030	.069	2	15	Ice in center of air passage and on turning vanes

[a]1, icing affecting engine operation; 2, visible icing; 3, no visible icing.

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TABLE I - RESULTS OF LIMITING-ICING-CONDITION TESTS OF CHANDLER-EVANS 1900 CPB-3 CARBURETOR MOUNTED ON

A PRATT & WHITNEY R-1830-C4 INTERMEDIATE REAR ENGINE SECTION - Concluded

Run	Carburetor air					Enthalpy (Btu/lb)	Air flow		Initial fuel-air ratio	Effect (a)	Length of run (min)	Remarks
	Dry-bulb temperature (°F)	Wet-bulb temperature (°F)	Moisture content		Absolute moisture content (lb/lb of dry air)		Initial (lb/hr)	Minimum (lb/hr)				
			Relative humidity (percent)	Free water (grams/min)								
Series II (cruising power) - Initial conditions: air flow, 4000 lb/hr; fuel-air ratio, 0.070												
79	50	43	56	-------	0.0043	16.6	4060	3870	0.069	1	80	Ice on turning vanes and on upper rear walls of air passage
80	60	58	89	-------	.0099	25.1	3970	3840	.072	1	90	Ice on turning vanes and in rear of air passage
81	55	47.5	57	-------	.0053	18.9	4020	3950	.069	1	30	Ice coated all turning vanes
82	58	48	47	-------	.0048	19.2	3980	3870	.071	1	90	
83	40	35	61	-------	.0031	13.0	4020	3860	.070	1	40	Ice on turning vanes and on top sides of throttles
84	50	42	50	-------	.0038	16.1	3980	3730	.071	1	30	Ice-coated turning-vane area and upper walls of air passage
139	55	47.5	57	-------	.0053	18.9	4000	3370	.071	1	180	Turning-vane area almost closed by ice formation; thin layer on air-passage walls
140	60	50	49	-------	.0054	20.3	3980	3500	.070	1	180	Ice built up slowly on turning vanes
141	65	52	40	-------	.0053	21.4	4090	3980	.068	1	180	Ice on turning vanes
142	70	55	37	-------	.0058	23.2	4080	4030	.069	1	180	Lumps of ice formed on turning vanes
143	60	48	40	-------	.0044	19.2	4060	3980	.070	1	180	Ice formations in and around turning vanes
144	70	60	56	-------	.0088	26.4	4020	3990	.070	2	120	
Series III (rated power) - Initial conditions: air flow, 7000 lb/hr; fuel-air ratio, 0.101												
104	55	48	61	-------	0.0055	19.2	7110	7070	0.102	2	5	Ice-covered observation window
105	50	46.5	78	-------	.0059	18.4	7060	7060	.103	2	5	Observation window frosted on inside
106	45	43	86	-------	.0054	16.6	7090	7050	.103	2	5	Slight icing on turning vanes; frost on bottom of air passage
107	45	45	100	-------	.0063	17.6	7110	7070	.103	2	5	Ice on air-passage walls and on turning vanes
108	45	45	---------	50	.0073	17.8	7090	6960	.102	1	5	
113	55	55	100	-------	.0092	23.2	6960	6930	.099	2	5	Film of ice on observation window
114	55	55	---------	50	.0102	23.4	6920	6830	.100	1	5	Ice on turning vanes
115	60	60	100	-------	.0110	26.4	6910	6860	.100	1	5	Ice on turning vanes
116	60	60	---------	50	.0120	26.6	6920	6830	.100	1	5	Ice on turning vanes
118	40	40	100	-------	.0052	15.2	6780	6780	.100	2	5	Ice on rear wall of air passage and on turning vanes
119	40	40	---------	50	.0062	15.4	6910	6810	.100	1	5	Ice obscured window
120	65	65	100	-------	.0132	30.0	6960	6890	.100	1	5	Thin layer of ice on turning vanes
121	65	59	71	-------	.0093	25.7	6980	6980	.101	3	5	No visible icing
122	70	70	100	-------	.0157	34.0	6970	6940	.101	3	5	No visible icing
123	60	60	---------	125	.0134	26.8	7000	6670	.099	1	5	Ice on turning vanes
124	65	65	---------	125	.0156	30.4	6970	6860	.100	1	5	Ice-blocked turning vanes
125	67	67	---------	50	.0152	31.7	6950	6890	.101	1	5	Lump of ice formed in center of air passage
126	70	70	---------	50	.0167	34.2	6900	6900	.100	3	5	No visible icing
127	67	67	---------	250	.0190	32.3	6910	6760	.100	1	5	Chunks of ice in front of turning vanes
128	70	70	---------	375	.0227	35.2	7050	7050	.101	3	5	No visible icing
129	35	35	100	-------	.0043	13.0	6890	6890	.099	2	5	Ice-coated air-passage walls and turning vanes
130	35	35	---------	50	.0052	13.2	7030	6800	.100	1	5	Ice on air-passage walls and turning vanes
131	67	67	---------	500	.0237	33.1	6980	6910	.101	1	5	Lumps of ice in front of turning vanes
132	70	70	---------	625	.0276	36.0	6960	6960	.102	3	5	No visible icing
135	67	67	---------	750	.0285	33.9	6940	6910	.101	2	5	Ice between turning vanes
136	67	67	---------	1000	.0334	34.7	6890	6870	.101	2	5	Ice chunks in front of turning vanes
137	65	65	---------	1250	.0371	34.0	6920	6540	.101	1	5	Ice between turning vanes
139	65	65	---------	1500	.0422	34.8	6850	6850	.101	3	5	No visible icing

[a]1, icing affecting engine operation; 2, visible icing; 3, no visible icing.

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TABLE II. - RESULTS OF HEATED-AIR DE-ICING TESTS ON A CHANDLER-EVANS 1900 CPB-3 CARBURETOR MOUNTED ON A PRATT & WHITNEY R-1830-C4 REAR ENGINE SECTION

Run	Initial air flow (lb/hr)	De-icing air at carburetor: Wet-bulb temperature (°F)	De-icing air at carburetor: Dry-bulb temperature (°F)	De-icing air at carburetor: Relative humidity (percent)	De-icing air at carburetor: Heat content (Btu/lb)	95-percent air-flow recovery (lb/hr)	Time for 95-percent air-flow recovery (min)	Fuel-air ratio at 95-percent recovery	Maximum air-flow recovery (lb/hr)
Series A (cruising power) - Initial icing conditions: air flow at 40° F, 4000 lb/hr; fuel-air ratio, 0.070; water injection, 500 g/min									
8	4000	60	60	100	26.4	----------	----------	----------	----------
9	4000	79	84	81	42.5	3410	0.9	0.081	3590
10	4020	93	94	96	60.0	3450	.3	.073	3630
11	4050	66	66	100	30.7	3510	1.45	.0725	3690
12	4000	98	111	63	67.9	3410	.2	.068	3590
13	4000	114	114	100	101.8	3420	.1	.066	3600
14	4000	106	134	40	83.0	3360	.2	.075	3540
15	4000	58	64	71	25.1	----------	----------	----------	2670
16	4020	60	69	60	26.4	----------	----------	----------	3250
17	4020	61	75	46	27.1	3330	7.7	.074	3510
18	4000	64	80	42	29.2	3370	2.9	.075	3550
19	4000	72	94	35	35.7	3330	2.3	.077	3510
20	4000	75	120	12	38.5	3320	.8	.077	3490
22	4000	83	90	75	46.9	3430	.4	.072	3610
23	4000	65	94	20	30.0	3390	1.25	.077	3570
24	4020	72	80	69	35.7	3460	1.5	.076	3640
25	4000	56	64	62	23.8	----------	----------	----------	----------
26	4020	68	93	27	32.3	3410	1.3	.075	3590
27	4020	69	70	95	33.1	3480	1.1	.073	3660
28	4000	66	68	90	30.7	3440	2.7	.072	3620
29	4000	76	80	84	39.4	3450	.5	.072	3630
30	4000	86	86	100	50.5	3460	.3	.071	3640
31	4000	82	90	72	45.7	3430	.45	.0735	3610
48	4030	66	72	74	30.7	3420	.5	.067	3600
49	4000	77	77	100	40.4	3400	.4	.075	3580
50	4000	94	96	93	61.5	3380	.5	.076	3560
51	4000	100	100	100	71.4	3360	.2	.078	3540
Series B (rated power) - Initial icing conditions: air flow at 40° F, 7000 lb/hr; fuel-air ratio, 0.100; water injection, 500 g/min									
32	7060	70	72	91	34.0	----------	----------	----------	4360
33	7060	78	86	71	41.4	6470	2.0	0.106	6810
34	7020	84	95	64	48.1	6440	1.0	.108	6780
35	7030	89	112	41	54.4	6400	.8	.105	6740
36	6970	91	122	31	57.1	6400	.65	.109	6740
37	6930	95	117	45	63.1	6290	.6	.106	6620
38	6940	97	128	33	66.3	6340	.8	.109	6670
39	6990	79	94	52	42.5	6430	2.3	.107	6770
41	7060	75	97	36	38.5	6410	1.9	.108	6750
42	7030	85	96	64	49.2	6400	.7	.105	6740
43	7000	71	76	79	34.8	6370	5.8	.104	6710
44	7030	73	84	60	36.6	6340	3.6	.106	6670
45	7030	67	80	52	31.5	6240	7.4	.105	6570
46	7030	88	104	54	53.0	6390	.5	.104	6730
47	7000	96	104	75	64.6	6410	.7	.109	6750
Series C (cruising power) - Initial icing conditions: air flow at 40° F, 4000 lb/hr; fuel-air ratio, 0.070; water injection, 500 g/min (During this series of runs, 250 g/min of water were injected during the de-icing process.)									
52	4050	74	74	100	38.9	3490	0.2	0.076	3670
53	4030	65	65	100	31.4	3360	2.8	.076	3540
54	4030	84	84	100	49.5	3430	.5	.074	3610
55	4030	78	78	100	42.8	3450	.75	.071	3630
57	4030	90	90	100	57.1	3330	.2	.077	3510
58	4020	76	76	100	40.8	3430	.4	.075	3610
Series D (cruising power) - Initial icing conditions: air flow at 25° F, 4000 lb/hr; fuel-air ratio, 0.070; water injection, 250 g/min									
59	3980	68	69	95	32.3	3360	0.6	0.074	3540
60	4010	61	70	61	27.1	3370	1.1	.072	3550
61	3980	66	76	60	30.7	3330	1.1	.080	3510
62	3990	56	75	29	23.8	3310	2.5	.077	3480
63	4010	73	82	66	36.6	3380	.5	.067	3560
64	3980	75	86	61	38.5	3340	.6	.071	3520
65	3980	84	86	92	48.1	3360	.4	.076	3540
66	4010	84	92	72	48.1	3410	.3	.070	3590
67	4030	89	108	48	54.4	3360	.3	.078	3540
68	3990	91	111	47	57.1	3320	.2	.067	3490
69	4010	101	119	54	73.2	3270	.2	.066	3440
Series E (rated power) - Initial icing conditions: air flow at 25° F, 7000 lb/hr; fuel-air ratio, 0.100; water injection, 400 g/min									
70	6940	58	79	27	25.1	6350	0.9	0.139	6680
71	6970	74	77	87	37.5	6130	.7	.097	6450
72	6880	72	94	35	35.7	6040	.8	.109	6360
73	6920	66	80	49	30.7	5980	.7	.109	6290
74	6940	69	74	78	33.1	6060	1.2	.109	6380
75	6980	64	81	40	29.2	5960	1.1	.095	6270
76	6940	54	71	32	22.6	5840	1.5	.105	6150
77	6920	63	78	44	28.5	6010	.9	.102	6330
78	6880	60	78	35	26.4	5670	1.7	.103	5970
79	6940	60	80	31	26.4	5930	.95	.1045	6240
80	6980	75	86	61	38.5	6130	.5	.099	6450
81	6980	80	100	43	43.5	6090	.5	.109	6410
82	6970	84	90	78	48.1	6080	.3	.094	6400
83	6950	88	100	63	53.0	6160	.3	.099	6480

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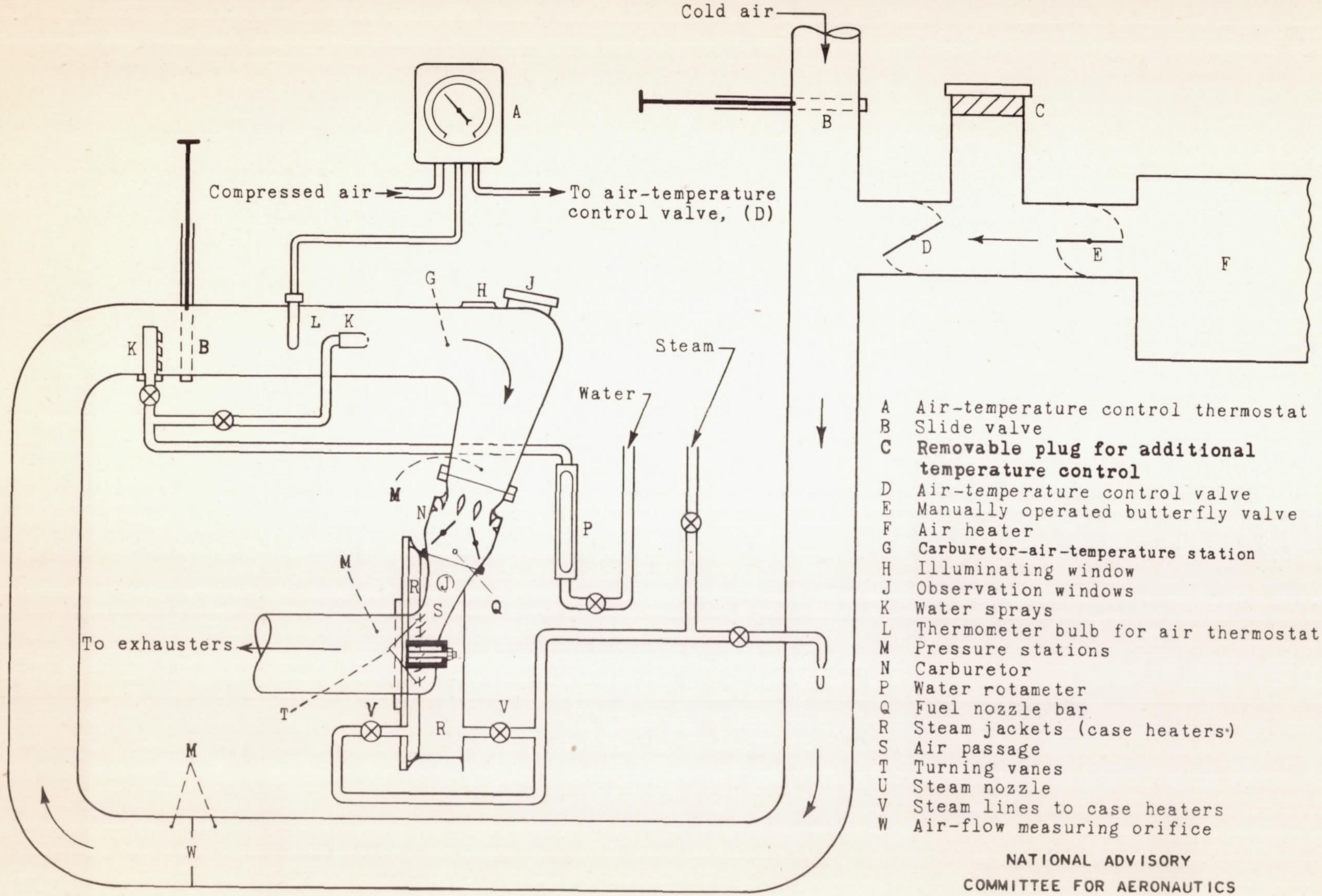

A Air-temperature control thermostat
B Slide valve
C **Removable plug for additional temperature control**
D Air-temperature control valve
E Manually operated butterfly valve
F Air heater
G **Carburetor-air-temperature station**
H Illuminating window
J Observation windows
K Water sprays
L Thermometer bulb for air thermostat
M Pressure stations
N Carburetor
P Water rotameter
Q Fuel nozzle bar
R Steam jackets (case heaters)
S Air passage
T Turning vanes
U Steam nozzle
V Steam lines to case heaters
W Air-flow measuring orifice

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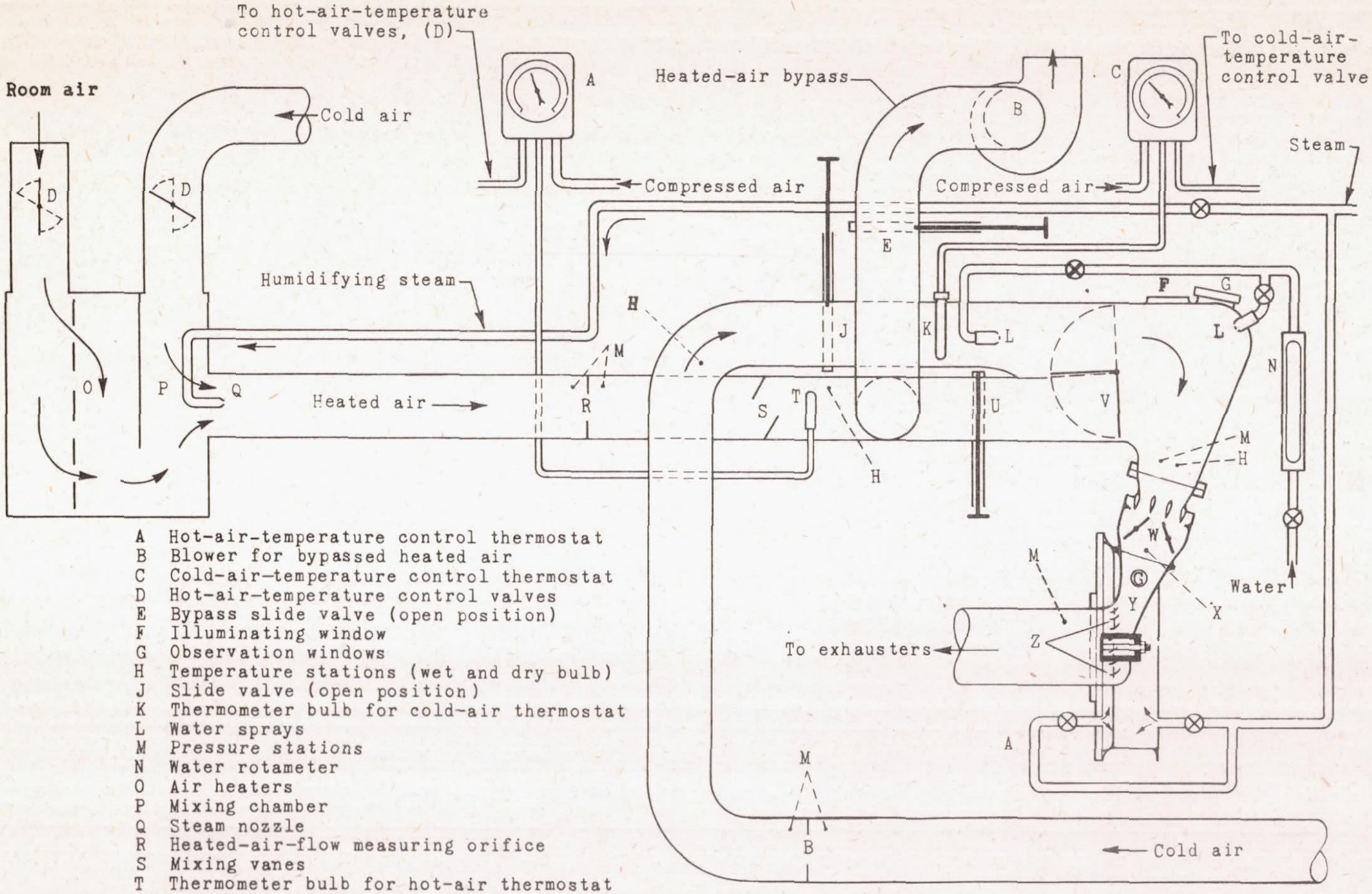
Figure 1 . - Schematic diagram of induction-system-icing test apparatus.



A Hot-air-temperature control thermostat
B Blower for bypassed heated air
C Cold-air-temperature control thermostat
D Hot-air-temperature control valves
E Bypass slide valve (open position)
F Illuminating window
G Observation windows
H Temperature stations (wet and dry bulb)
J Slide valve (open position)
K Thermometer bulb for cold-air thermostat
L Water sprays
M Pressure stations
N Water rotameter
O Air heaters
P Mixing chamber
Q Steam nozzle
R Heated-air-flow measuring orifice
S Mixing vanes
T Thermometer bulb for hot-air thermostat
U Slide valve (closed position)
V Flapper valve (cold-air position)
W Carburetor
X Fuel nozzle bar
Y Air passage
Z Turning vanes
A Steam lines to case heaters
B Cold-air-flow measuring orifice
H Carburetor air-temperature station

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Figure 2. - Schematic diagram of induction-system heated-air de-icing test apparatus, shown in position for initial icing.

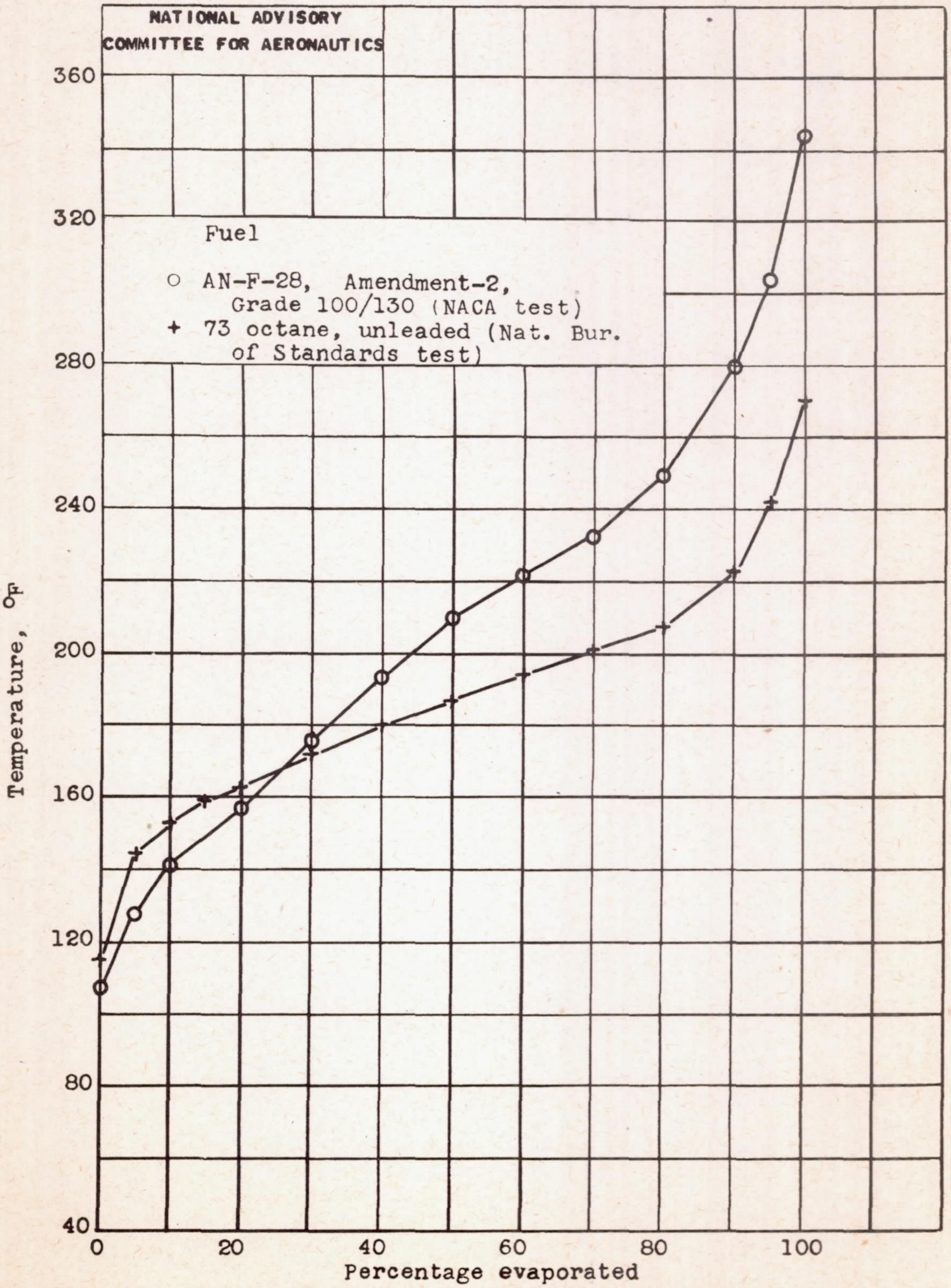


Figure 3. - Comparison of A.S.T.M. fuel-distillation curve for the fuel used in the icing tests with that of an AN-F-28 fuel.

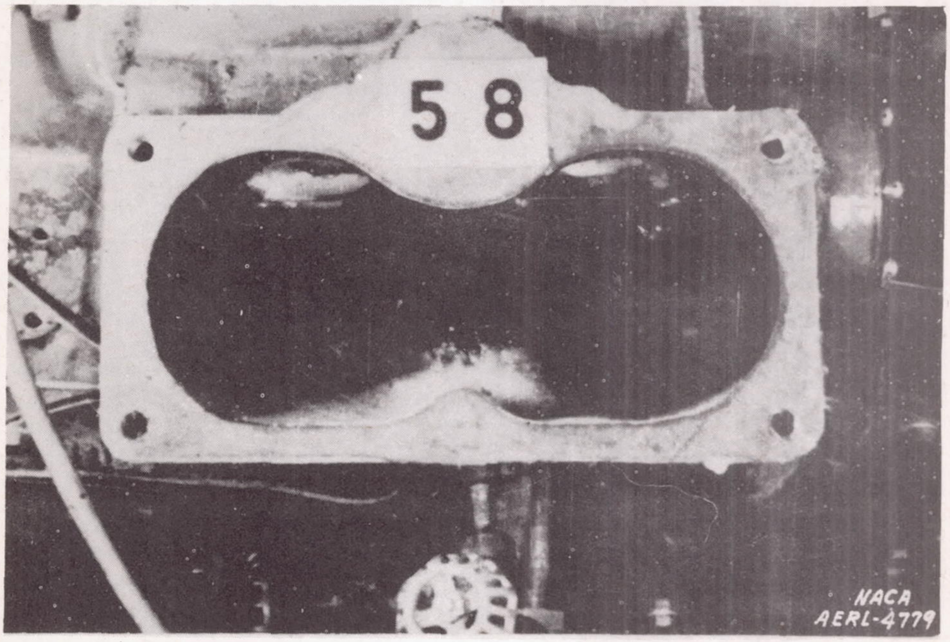
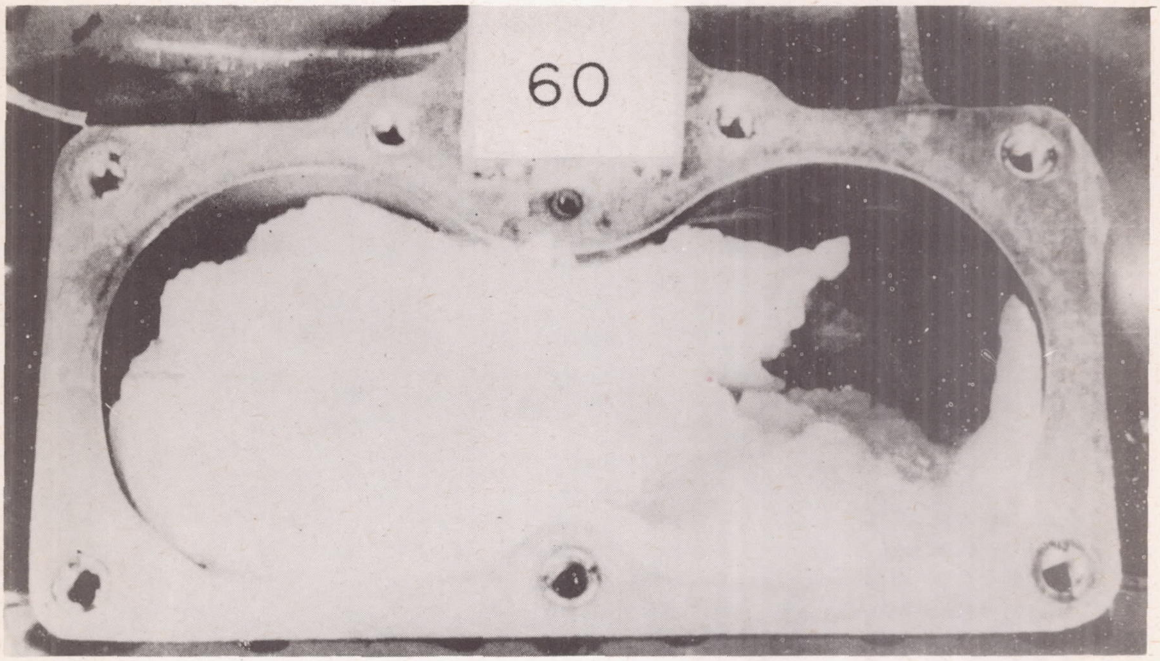
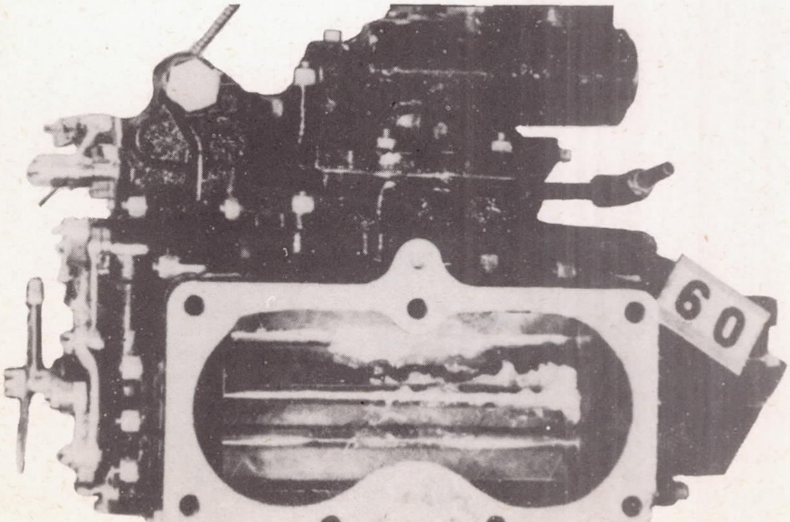


Figure 4. - Visible icing in engine-air passage not affecting engine operation. Carburetor-air temperature, 35° F; relative humidity, 54 percent; initial air-flow rate, 4000 pounds per hour; initial fuel-air ratio, 0.071



(a) Ice in engine-air passage.



(b) Bottom view of carburetor.

Figure 5. - Icing affecting engine operation. Carburetor-air temperature, 40° F; water-injection rate, 500 grams per minute; initial air-flow rate, 4000 pounds per hour; initial fuel-air ratio, 0.070.

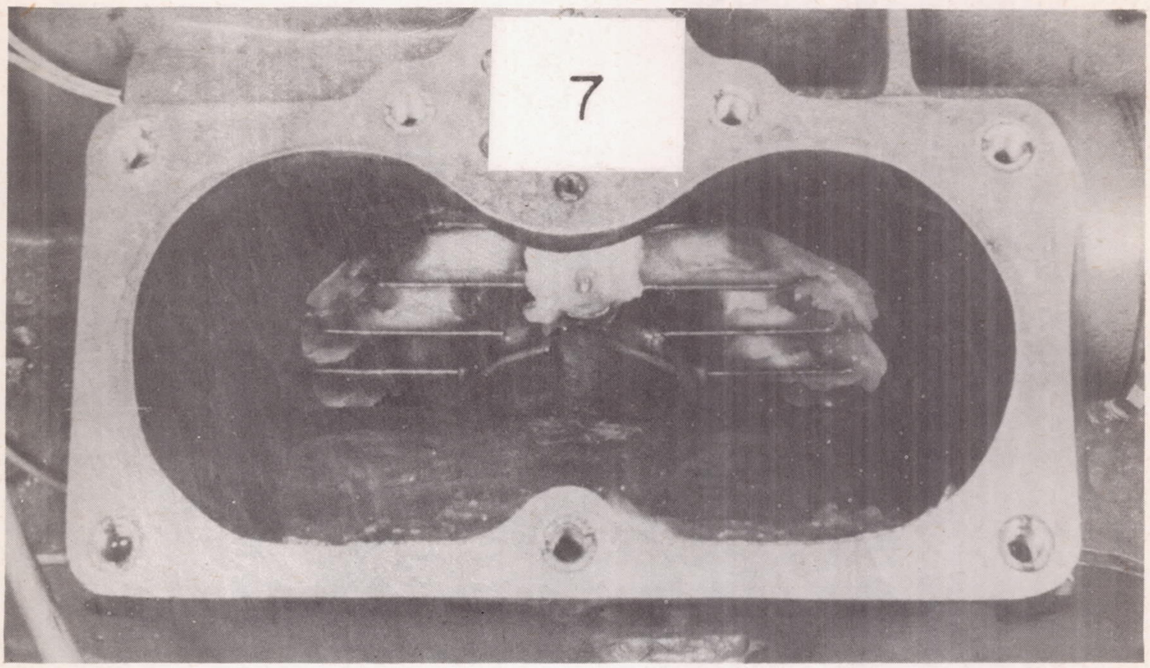


Figure 6. - Turning-vane ice affecting engine operation. Carburetor-air temperature, 32° F; relative humidity, 100 percent; initial air-flow rate, 4040 pounds per hour; initial fuel-air ratio, 0.068.

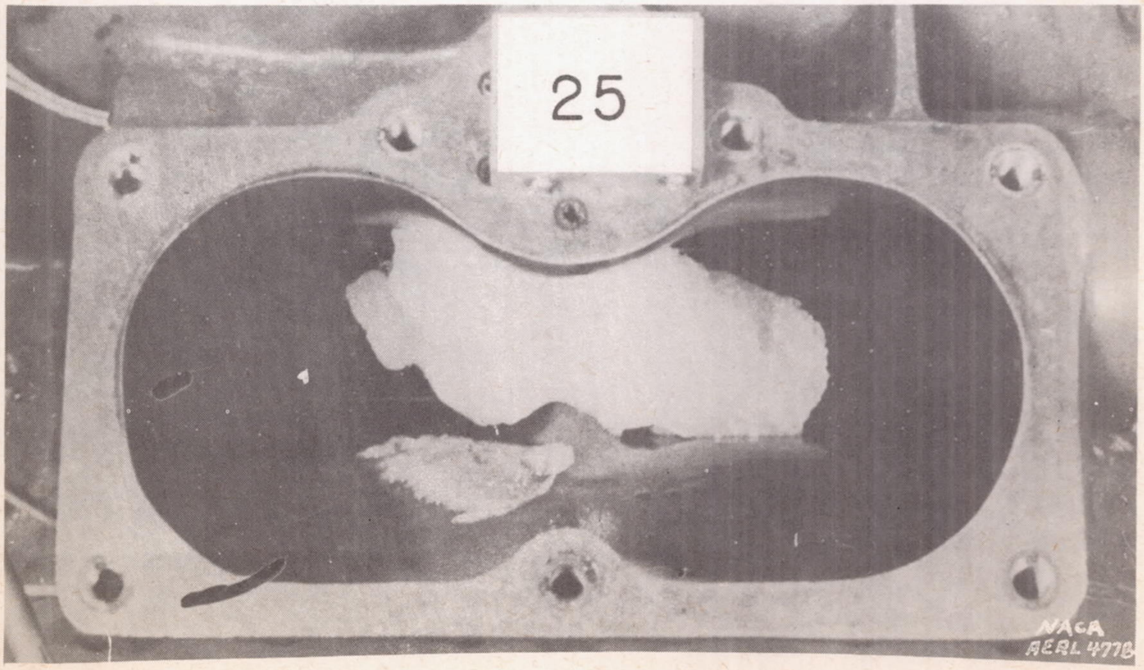


Figure 7. - Ice lump lodged in air passage affecting engine operation. Carburetor-air temperature, 60° F; water-injection rate, 125 grams per minute; initial air-flow rate, 4000 pounds per hour; initial fuel-air ratio, 0.070.

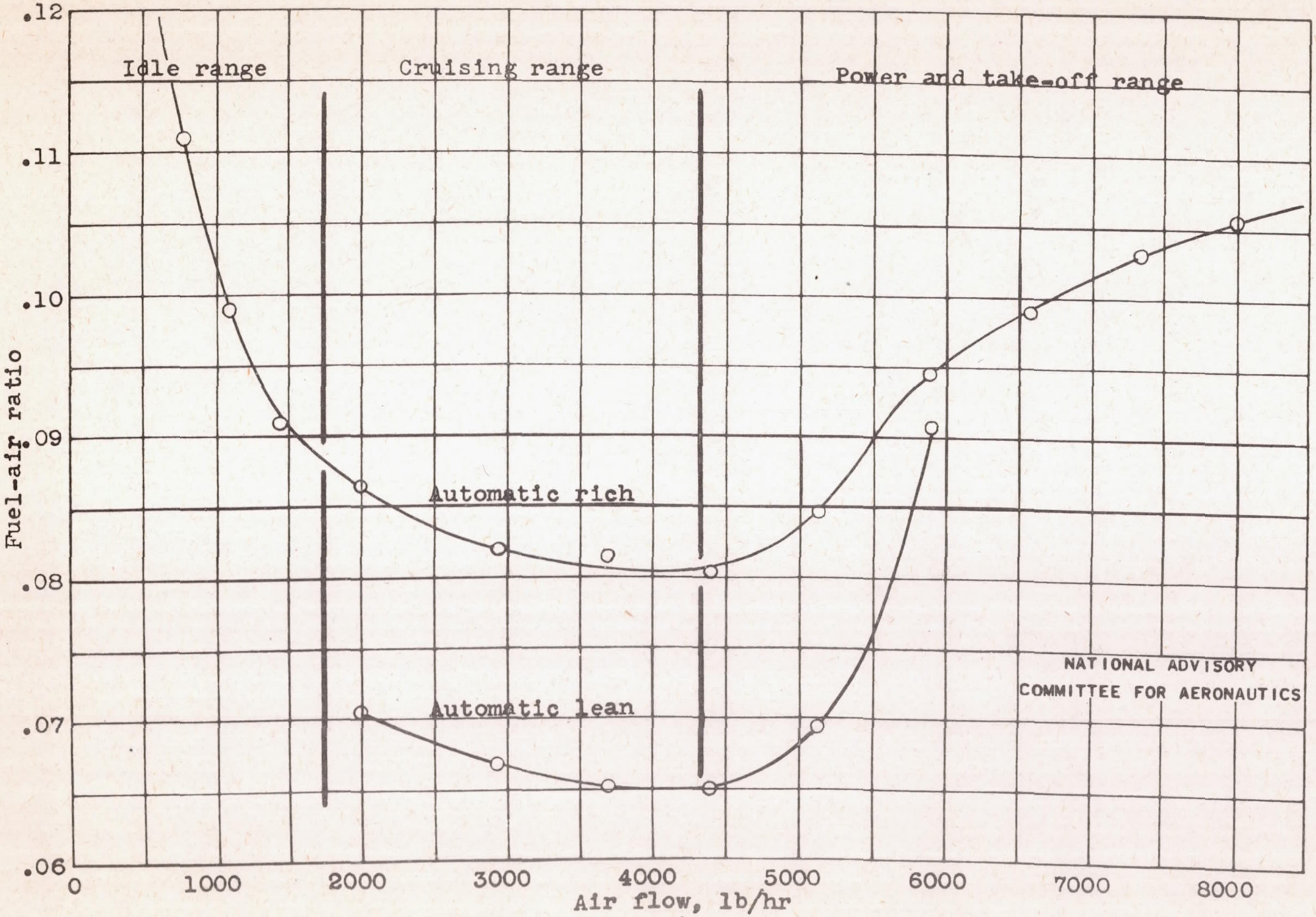


Figure 8. - Carburetor-metering characteristics. Chandler-Evans carburetor, model 1900 CPB-3, serial no. 1306.

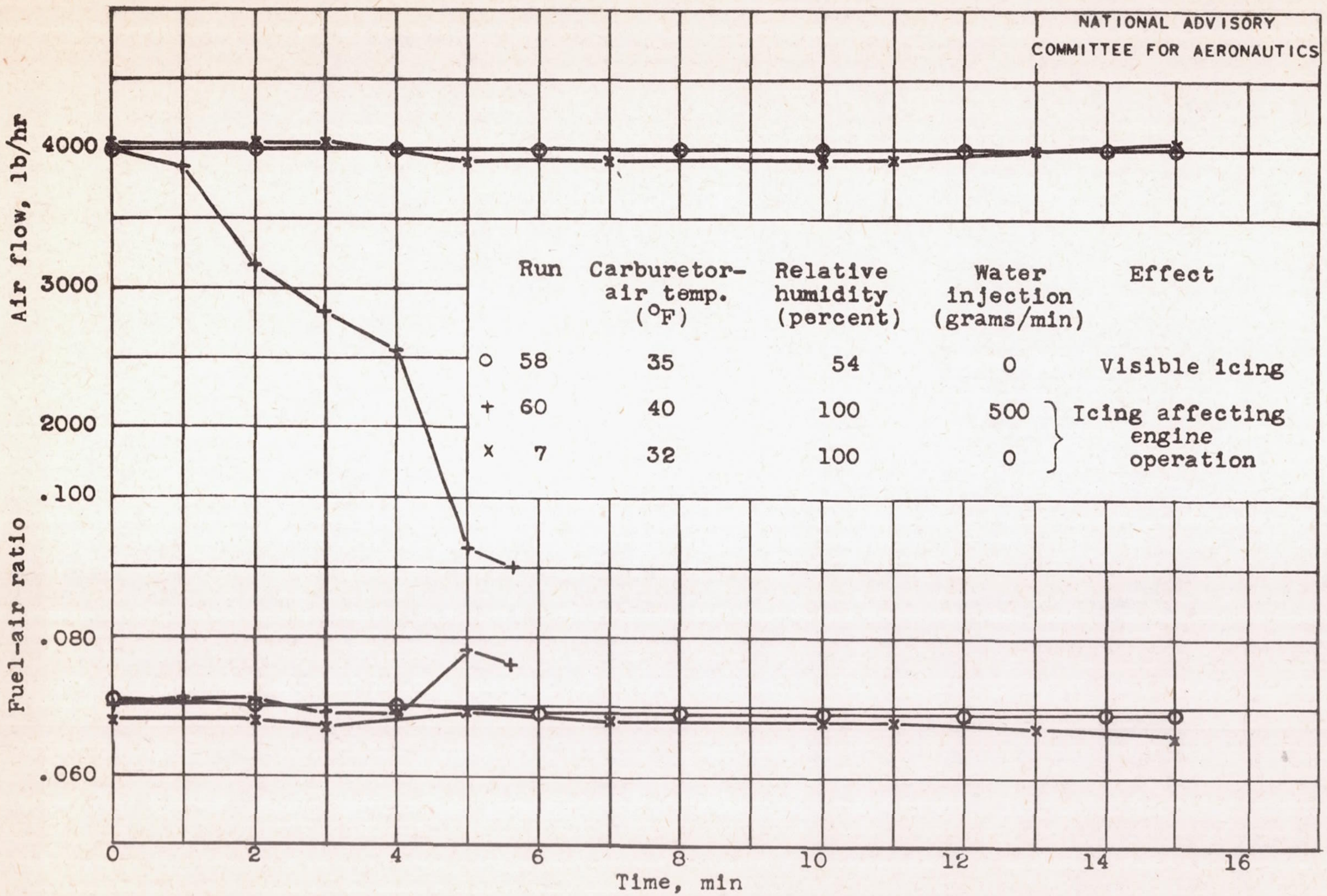


Figure 9. - Effect of icing on air flow and carburetor metering at simulated cruising power. Series I tests.

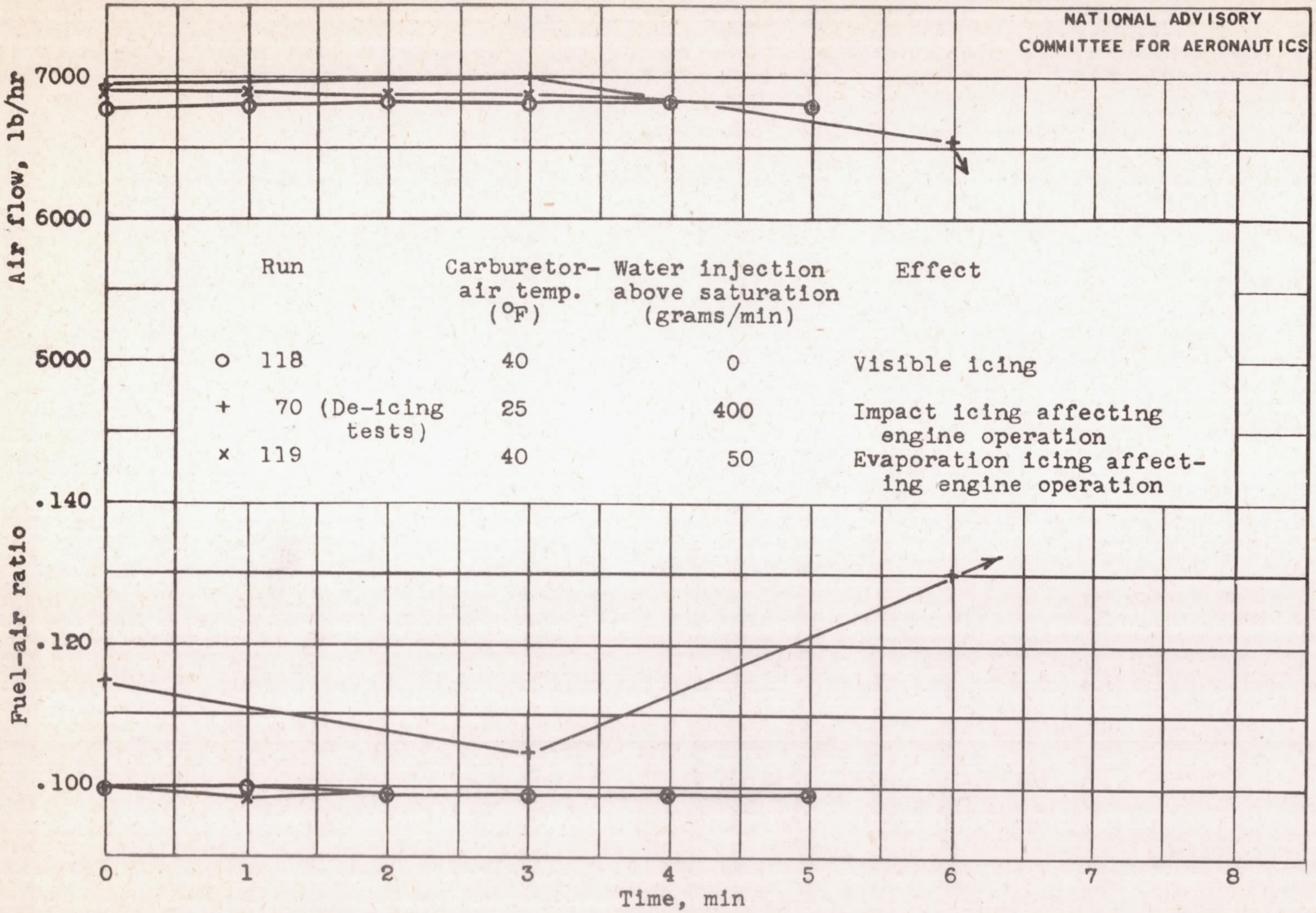


Figure 10. - Effect of icing on air flow and carburetor metering at simulated rated power. Series III tests and run 70 of heated-air de-icing tests.

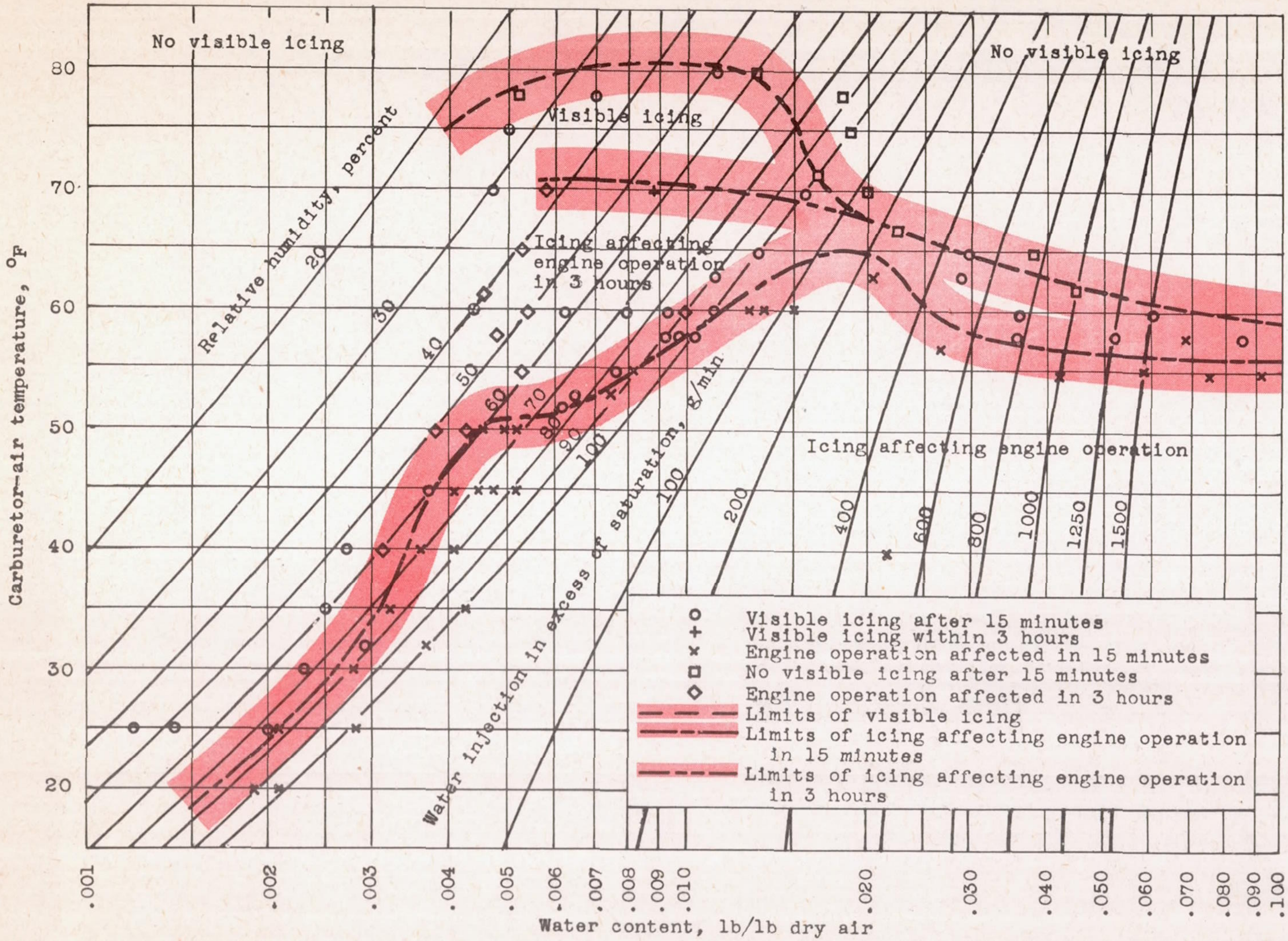


Figure 11. - Limiting icing conditions at simulated cruising power. Chandler-Evans carburetor, model 1900 CPB-3; Pratt and Whitney R-1830-C4 intermediate rear engine section; initial air-flow rate, 4000 pounds per hour; initial fuel-air ratio, 0.070; series I and II. The width of the red band designates the possible variation in the limiting conditions.

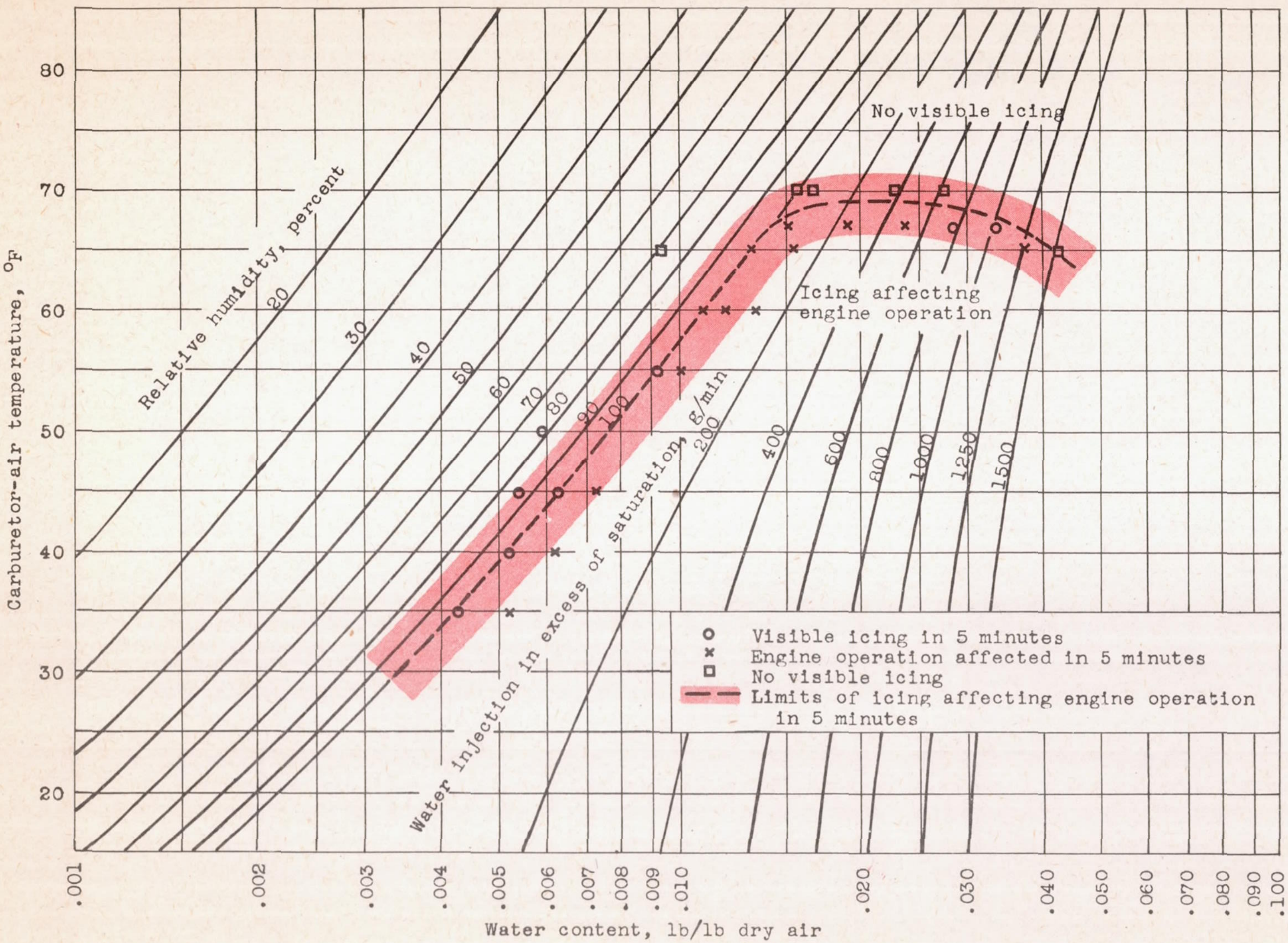


Figure 12. - Limiting icing conditions at simulated rated power. Chandler-Evans carburetor, model 1900 CPB-3; Pratt and Whitney R-1830-C4 intermediate rear engine section; initial air-flow rate, 7000 pounds per hour; initial fuel-air ratio, 0.100; series III. The width of the red band designates the possible variation in the limiting conditions.

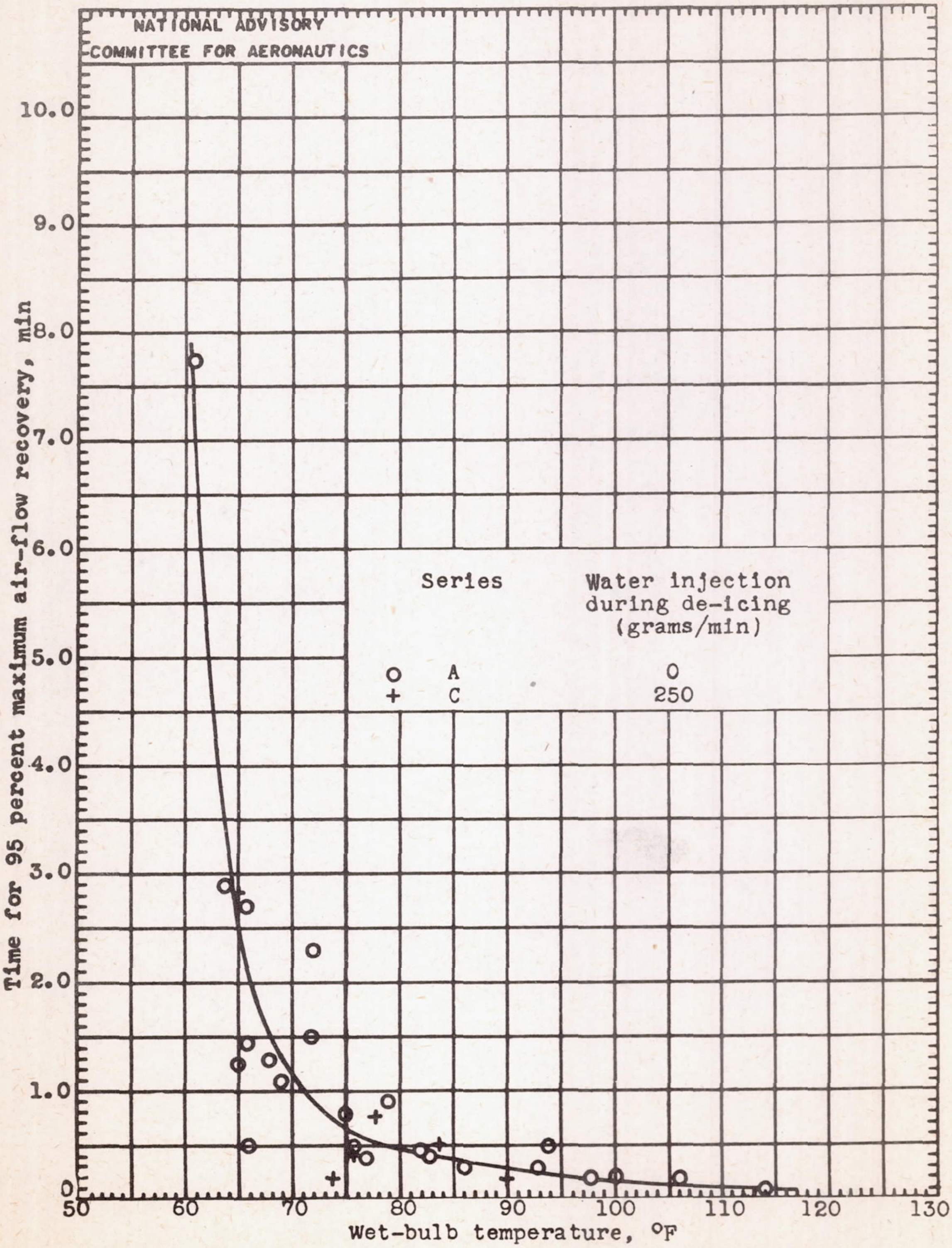


Figure 13. - Effect of wet-bulb temperature on air-flow-recovery time, series A and C, simulated cruising power. Initial conditions: air-flow rate, 4000 pounds per hour; carburetor-air temperature, 40° F; fuel-air ratio, 0.070; water-injection rate during icing, 500 grams per minute.

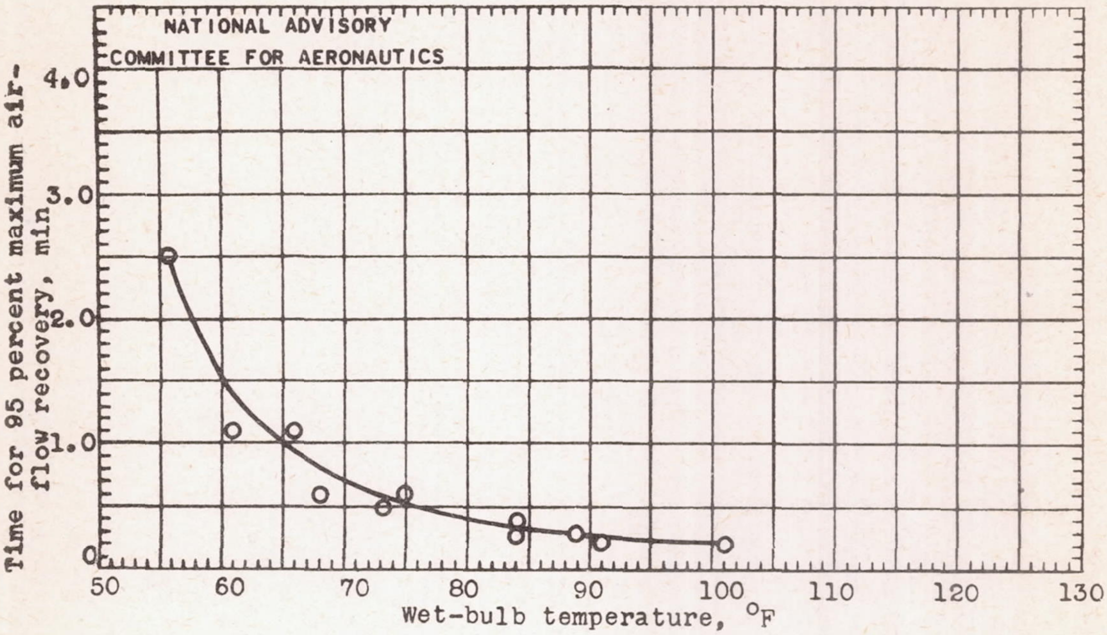


Figure 14. - Effect of wet-bulb temperature on air-flow-recovery time, series D, simulated cruising power. Initial conditions: air-flow rate, 4000 pounds per hour; carburetor-air temperature, 25° F; fuel-air ratio, 0.070; water-injection rate, 250 grams per minute during icing only.

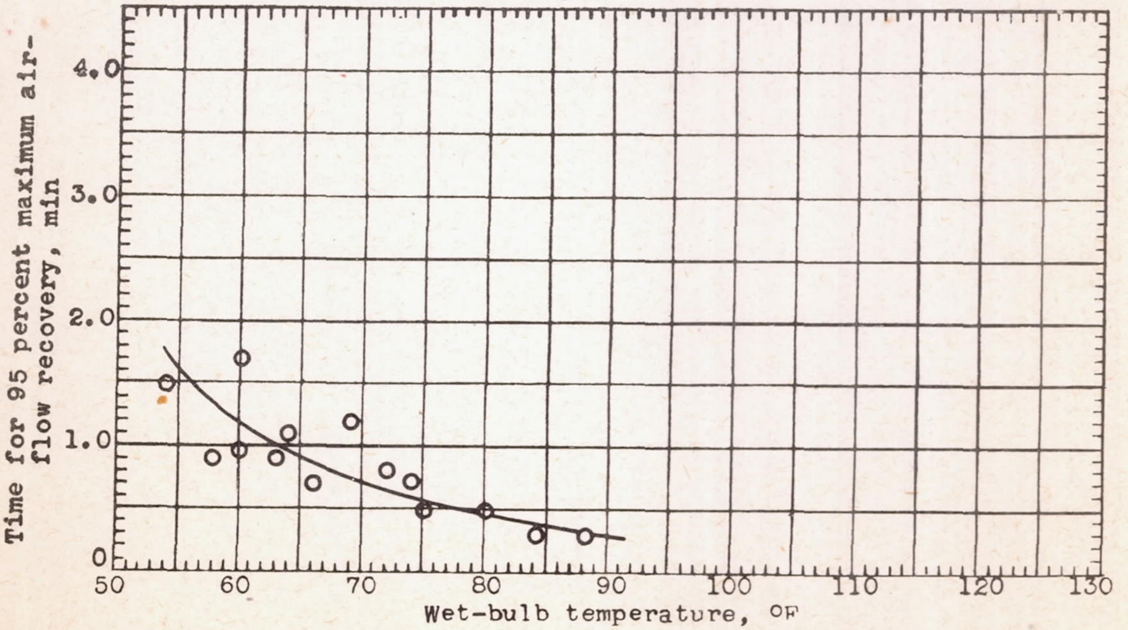


Figure 15. - Effect of wet-bulb temperature on air-flow-recovery time, series E, simulated rated power. Initial conditions: air-flow rate, 7000 pounds per hour; carburetor-air temperature, 25° F; fuel-air ratio, 0.100; water-injection rate, 400 grams per minute during icing only.

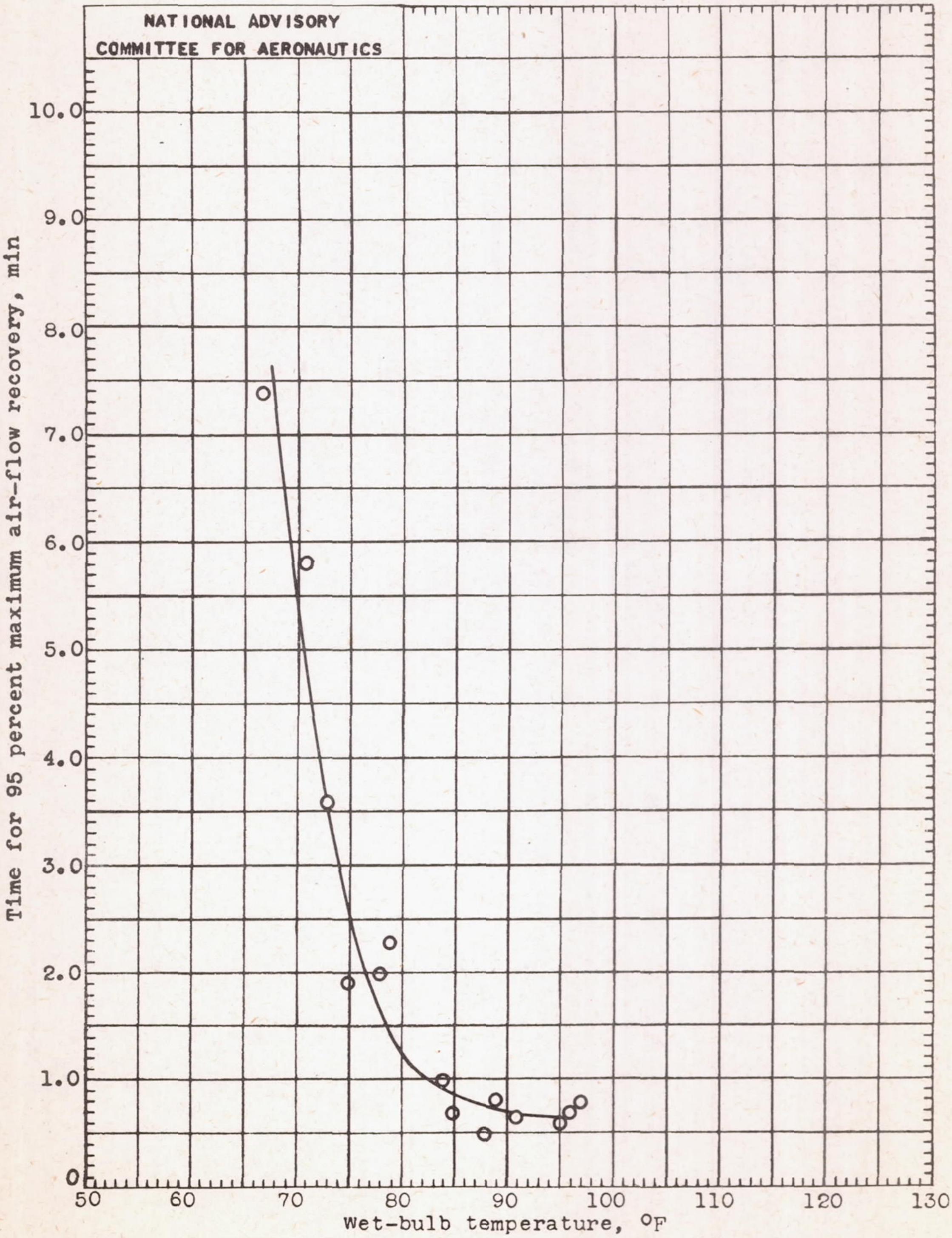


Figure 16. - Effect of wet-bulb temperature on air-flow-recovery time, series B, simulated rated power. Initial conditions: air-flow rate, 7000 pounds per hour; carburetor-air temperature, 40° F; fuel-air ratio, 0.100; water-injection rate, 500 grams per minute during icing only.

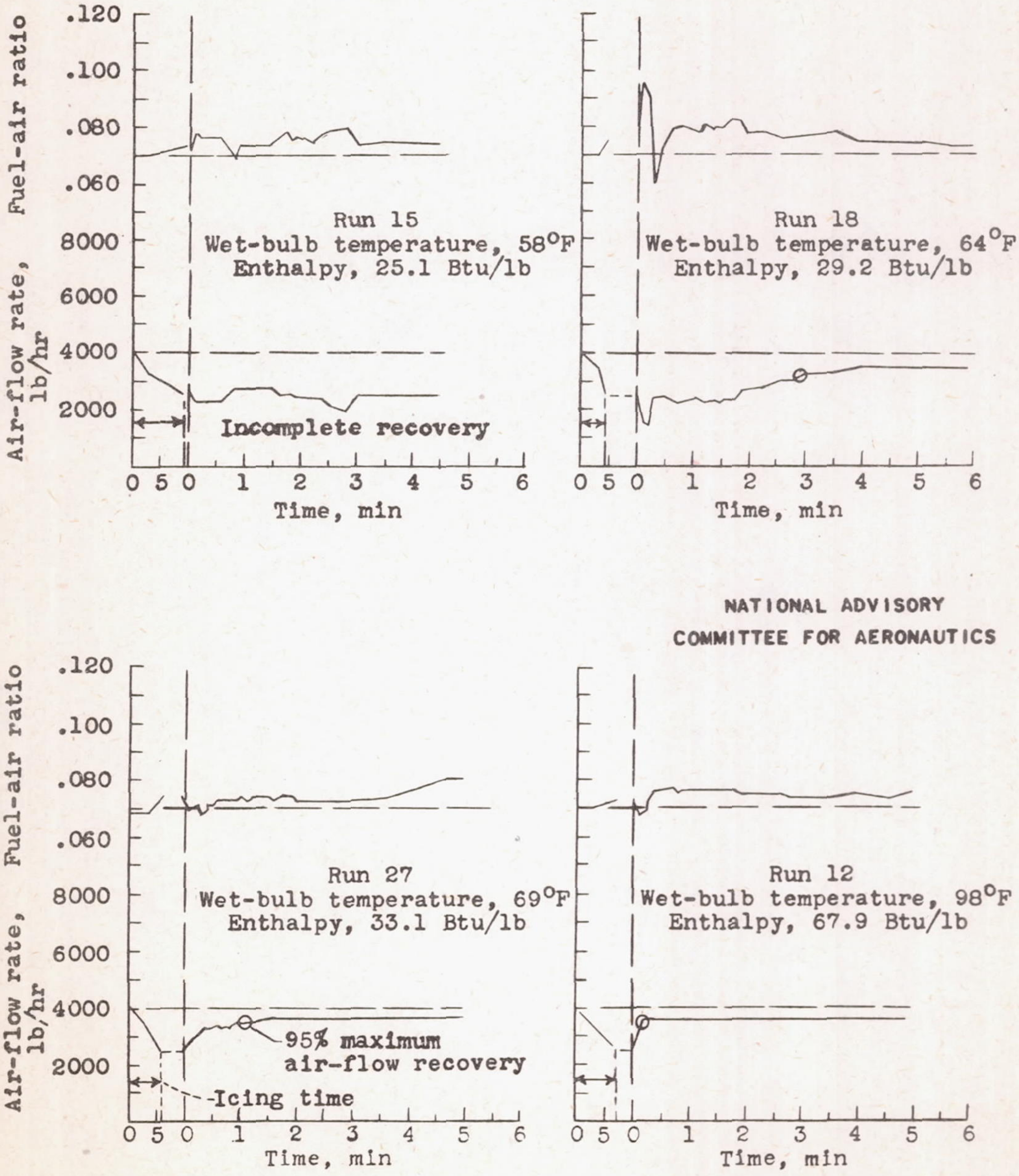


Figure 17. - Time history of de-icing by means of heated air, simulated cruising power, series A. Initial conditions: air-flow rate, 4000 pounds per hour; fuel-air ratio, 0.070; carburetor-air temperature, 40° F; water-injection rate, 500 grams per minute during icing only.

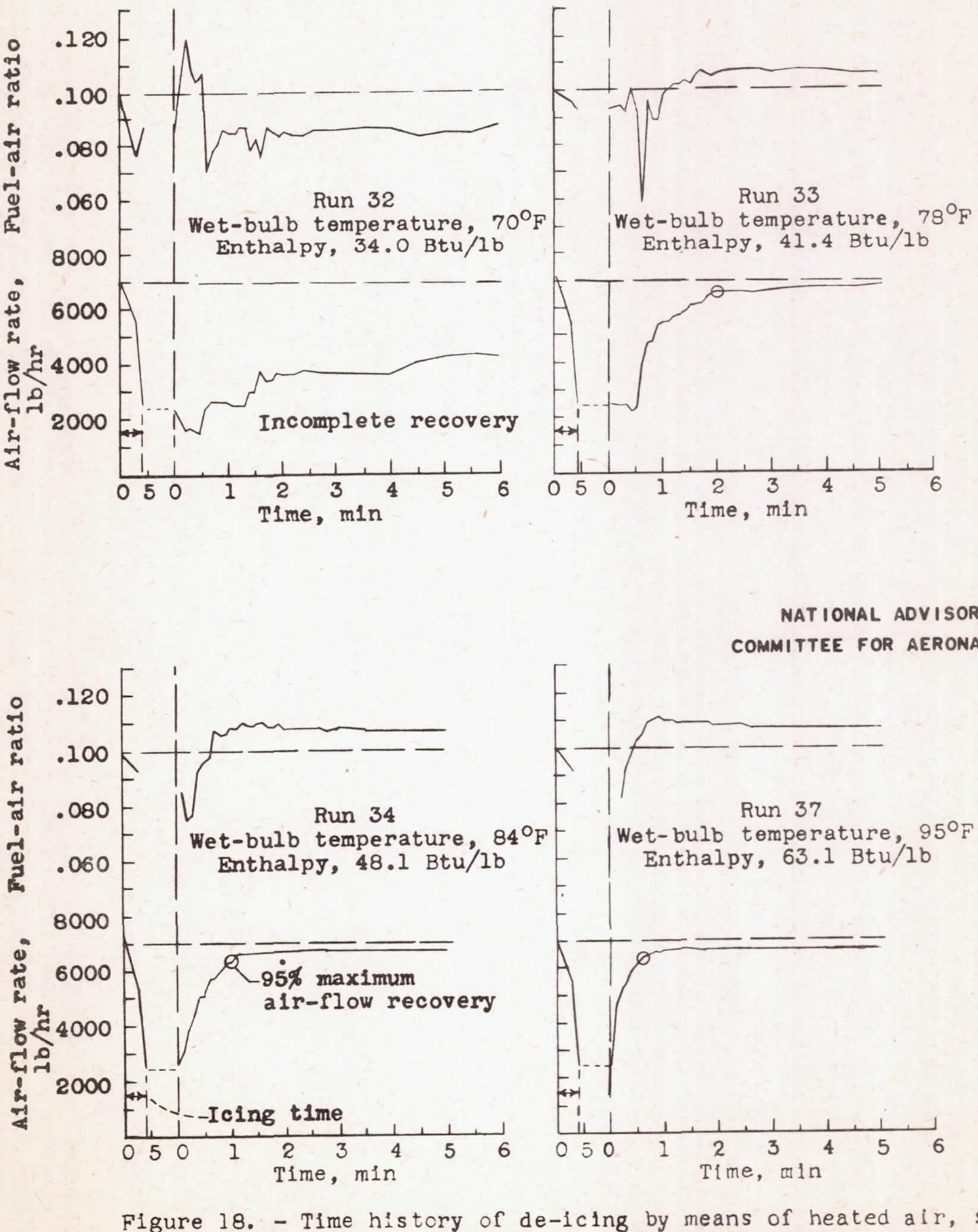


Figure 18. - Time history of de-icing by means of heated air, simulated rated power, series B. Initial conditions: air-flow rate, 7000 pounds per hour; fuel-air ratio, 0.100; carburetor-air temperature, 40° F; water-injection rate, 500 grams per minute during icing only.

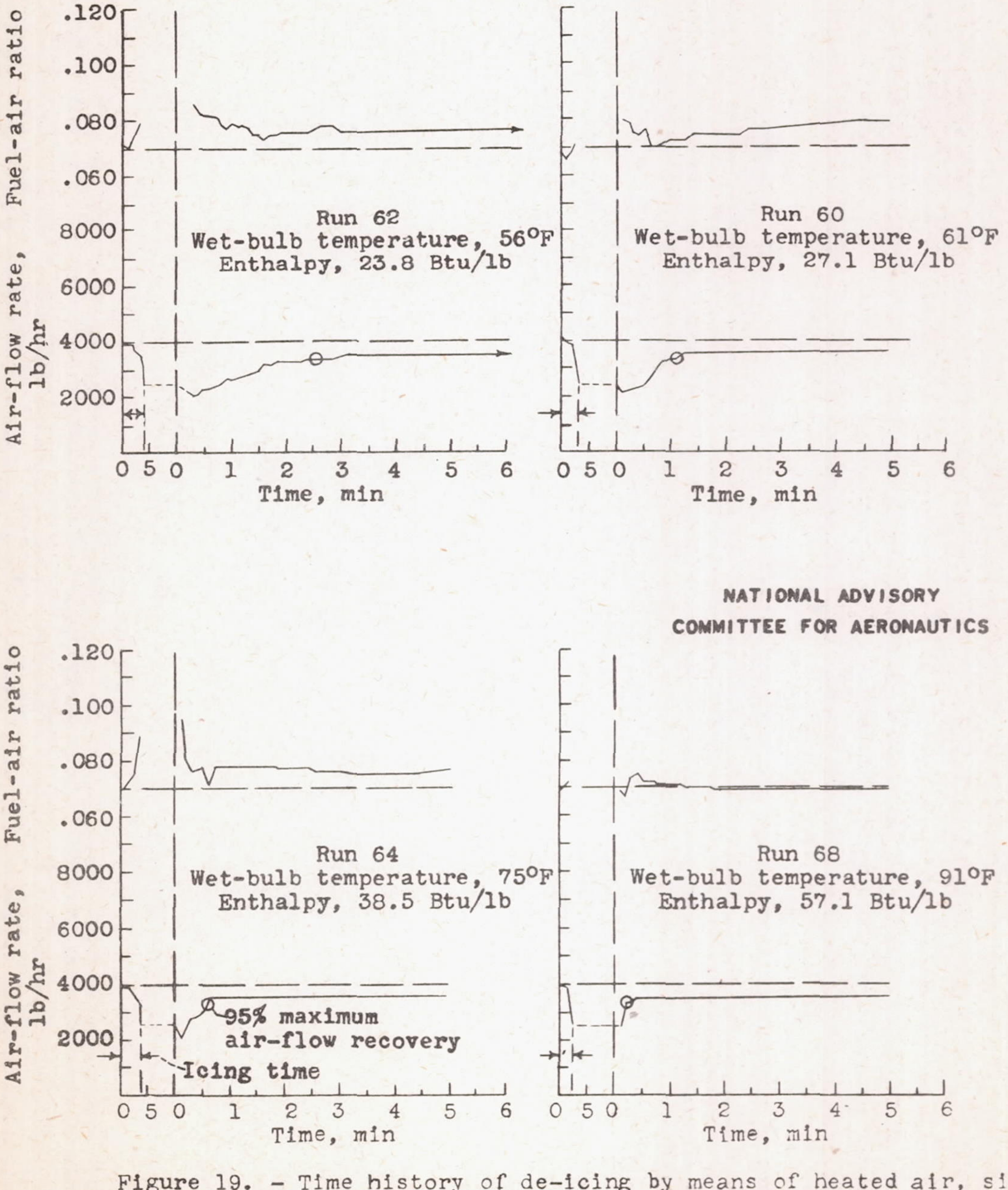


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Figure 19. - Time history of de-icing by means of heated air, simulated cruising power, series D. Initial conditions: air-flow rate, 4000 pounds per hour; fuel-air ratio, 0.070; carburetor-air temperature, 25° F; water-injection rate, 250 grams per minute during icing only.

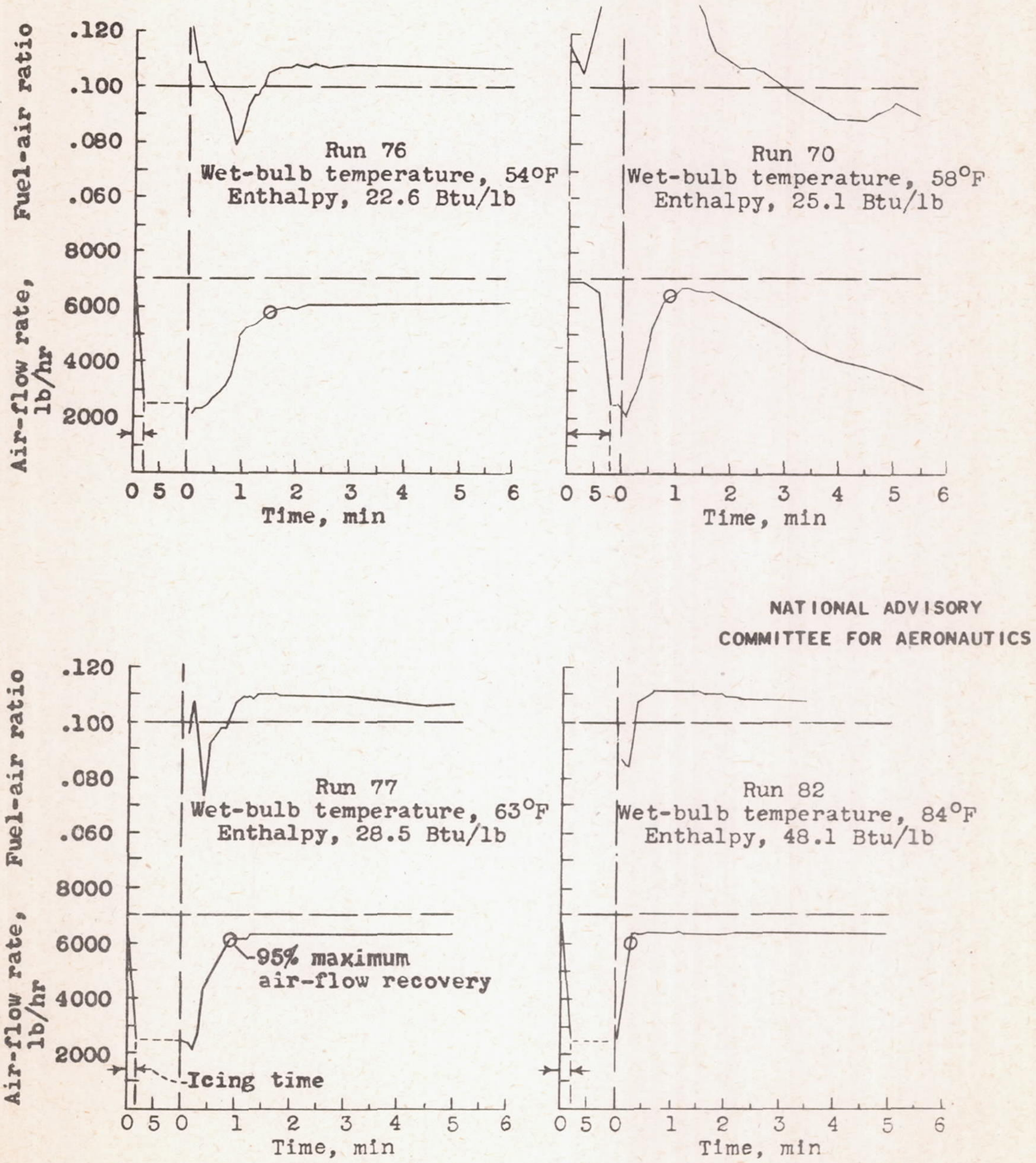

Figure 20. - Time history of de-icing by means of heated air, simulated rated power, series E. Initial conditions: air-flow rate, 7000 pounds per hour; fuel-air ratio, 0.100; carburetor-air temperature, 25° F; water-injection rate, 400 grams per minute during icing only.