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

III - HEATED AIR AS A MEANS OF DE-ICING THE CARBURETOR AND SUPERCHARGER INLET ELBOW

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NACA

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NACA AIRCRAFT ENGINE RESEARCH LABORATORY

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

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

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SUMMARY

A twin-barrel injection carburetor and a supercharger inlet elbow, forming part of the induction system of an aircraft engine, were used in a laboratory investigation to establish quantitatively the relation between wet- and dry-bulb temperatures of the de-icing air and the time required to recover a given air-flow loss due to icing. Tests were run at one severe icing condition during simulated operation at normal rated power and at two severe icing conditions at 60-percent normal rated power. The air-flow recovery times were determined for dry and humidified de-icing air at various temperatures from 45° to 120° F.

The time required to restore 95 percent of the maximum possible air flow after the initial air flow had been reduced by icing to approximately 2000 pounds per hour was found to correlate with wet-bulb temperature of the de-icing air and to decrease only slightly as the heated-air wet-bulb temperature was increased above 80° F. Under impact icing conditions, the metering characteristics of the carburetor were seriously affected, resulting in very irregular values of fuel-air ratio during the de-icing period. Under the same initial conditions of carburetor-air temperature and humidity, the ice formed at 60-percent power conditions required more time to remove under the same de-icing conditions than that formed at normal rated power conditions.

INTRODUCTION

At the request of the Air Technical Service Command, Army Air Forces, an investigation of the icing characteristics and elimination of ice formation in the induction system of a fighter airplane was conducted during the fall of 1944 at the NACA Cleveland laboratory. The series of tests reported herein was made on a carburetor mounted on an engine-stage supercharger assembly and covers that part of the investigation concerning the determination of the relation between the wet- and dry-bulb temperature of the de-icing air and the time required for removing ice from the system.

The results of a previous investigation of induction-system de-icing by heated air show that the time required to recover a given air-flow loss due to icing is dependent on the wet-bulb temperature of the de-icing air (reference 1).

The induction system for this airplane, which has no direct provision for heating the carburetor air, incorporates an alternate air intake to prevent free water from entering the system and offers several indirect methods of controlling carburetor-air temperature. A manually controlled valve allows the direct ram air to be shut off and air from the main wheel wells to be drawn through the induction system. Some temperature rise always occurs through the turbosupercharger and by regulating the intercooler flaps the net temperature rise can be controlled. Added heat may also be obtained by increasing the power output of the engine.

Tests were performed at simulated normal rated and cruising engine power conditions at carburetor-air temperatures of 25° F for both powers and at 35° F for only the cruise power. These test conditions were selected because the determination of icing characteristics reported in reference 2 shows that at below-freezing air temperatures serious icing can occur on the air metering parts on top of the carburetor at any power condition; whereas, at inlet-air temperatures above freezing, the icing is more serious below the throttles at the low power conditions.

APPARATUS

The induction system de-icing installation for these tests, which consists of a twin-barrel injection-type carburetor mounted on an engine-stage supercharger assembly, is shown schematically in figure 1 and is described in reference 3.

The icing and de-icing air ducts leading to the carburetor are equipped with tight shut-off valves connected by a linkage that provides for simultaneous opening of one valve and closing of the other, giving a rapid means of changing from icing to de-icing conditions. Air bleed lines from each duct, which are equipped with valves, permit continuous flow of de-icing or icing air supply when not flowing through the carburetor. Simultaneous operation of the four duct and bleed valves is accomplished by the use of a single solenoid-operated valve to control the air supply to the two valve-actuating cylinders.

PROCEDURE

The range of conditions under which the de-icing tests were conducted is as follows:

Normal rated power (percent)	Initial icing conditions				De-icing-air temperatures	
	Air flow (lb/hr)	Fuel-air ratio	Carburetor-air temperature (°F)	Water injection (grams/min)	Dry bulb (°F)	Wet bulb (°F)
60	4620	0.080	35	250	50-120	35-120
60	4620	.080	25	250	70-120	59-120
100	7700	.095	25	250	45-110	45-110

A water injection of 250 grams per minute at the carburetor corresponds to a free-water content within the duct of 8.6 and 5.2 grams per cubic meter for 60-percent normal rated power and rated power, respectively. These values were used to correlate the de-icing results with the determination of icing characteristics reported in reference 3 and were selected without knowledge of the actual values obtainable at the carburetor in the airplane. Controlled humidification of the air, icing and de-icing, was accomplished by injecting steam into the air ducts at a point a sufficient distance from the carburetor to insure complete mixing of the air and steam. The carburetor-deck pressure was maintained equivalent to an altitude of approximately 2000 feet.

When icing of the induction system had caused the air flow to drop to approximately 2000 pounds per hour, the valves were shifted to allow the de-icing air to flow through the carburetor. Both air supplies were bypassed at the rate of approximately 2000 pounds per hour when not being drawn through the induction system to prevent surging during and after the shifting of the valves and to allow constant moisture content and temperature to be maintained. An icing-air flow of 2000 pounds per hour was chosen as the value at which to begin de-icing because the rate of increase of air flow from that point allowed sufficient time for recording the de-icing data. The de-icing-air flow and the fuel flow were simultaneously recorded every 0.1 minute for 1 minute, every 0.2 minute for 2 minutes, and every 0.5 minute thereafter up to 5 minutes. Because the air flow varied during de-icing, the amount of steam injected into the air stream was adjusted to maintain a constant wet-bulb temperature. If the air flow showed no signs of recovery during the arbitrary 5-minute test period, the test was discontinued.

The incoming de-icing-air temperature was approximately -60° F before it was heated and humidified. When no steam was added to the de-icing air, the relative humidity was assumed to be 0 percent at the temperature of the tests. No tests were made with free water injected during the de-icing runs because the tests reported in reference 1 indicated that this amount of free water has no effect on the de-icing time within the limits of observational error.

RESULTS AND DISCUSSION

The data obtained from the de-icing tests with the laboratory setup of the induction system are summarized in table I, which includes the initial icing conditions, the de-icing conditions, and the recovery data.

Criterion of de-icing effectiveness. - For a supercharger operating at constant speed with constant inlet pressure, an increase in air temperature decreases the mass air-flow rate through the induction system. Thus, with the de-icing air, the maximum possible air-flow rate recovered was less than the initial icing air-flow rate. The variation of air flow with temperature was experimentally determined. Figure 2 shows the change in mass air flow with dry-bulb temperature, maintaining constant carburetor-deck pressure, engine speed, and throttle setting. The time taken to recover 95 percent of the maximum possible warm-air flow was taken as the criterion of effectiveness of the de-icing, because above 95 percent the slope of the recovery curve becomes quite flat, as shown by figure 3. In all the tests conducted on de-icing, the de-icing was found to be a combination of thermal and mechanical processes. The ice surface next to the metal parts was melted and then whole sections of ice were swept into the supercharger impeller by the air stream, usually resulting in a rather irregular recovery of air flow. In all cases, the fuel-air ratio was in the operable range at the time of recovery but, in several tests where the recovery was extremely rapid, the lag of the fuel rotameter float was appreciable, indicating a leaner mixture than was actually being metered by the carburetor.

The maximum allowable de-icing time of one engine of a two-engined aircraft cannot be estimated because it is governed by such factors as the absolute altitude, the power reserve of the other engine, and whether engine stoppage or excessive roughness occurs. As shown in table I, when the heat content above 0° F of the combustion air is over 40 Btu per pound, the de-icing or recovery time is 0.6 minute or less.

Results of 60-percent rated power tests. - The results of tests at initial carburetor-air temperatures of 35° and 25° F indicate that the wet-bulb temperature is the most significant factor in determining the de-icing time for similar icing conditions. Figure 4(a) shows that after icing at an initial air temperature of 35° F, the de-icing time varies with dry-bulb temperature and relative humidity. When the same data are plotted against wet-bulb temperature (fig. 4(b)), the curve obtained corresponds closely to the curve for saturated de-icing air in figure 4(a). The results of the tests at an initial air temperature of 25° F are presented in figure 5. As for the tests at an initial air temperature of 35° F (fig. 4(b)), a single curve represents the relation of de-icing time and wet-bulb temperature (fig. 5(b)). When the wet-bulb temperature of the de-icing air is increased above 80° F, no appreciable reduction in de-icing time occurs.

Results of normal rated power tests. - The de-icing time for simulated normal rated power tests with an initial carburetor-air temperature of 25° F is also dependent on the wet-bulb temperature because all the experimental points, regardless of relative humidity, lie close to a single curve in figure 6(b). The minimum de-icing time is again obtained at a wet-bulb temperature of approximately 80° F. The experimentally determined 100-percent relative humidity curve of de-icing time as a function of dry-bulb temperature along with constant relative-humidity lines that were calculated from the 100-percent relative humidity curve are shown in figure 6(a).

Effect of icing conditions on de-icing time. - The heat requirements for de-icing during the tests at simulated 60-percent normal rated power, with an initial carburetor-air temperature of 35° F, were less than those at 25° F with the same simulated power (fig. 7). These reduced heat requirements are due to the lower engine and carburetor-metal temperature at 25° F and the difference in type of ice produced at the two icing conditions. The icing conditions at 35° F produced a soft, spongy, fuel-evaporation type of icing in the inlet elbow and on the under surfaces of the throttle plates. This type of ice contained a large percentage of fuel and was poorly bonded to the metal surfaces. Hard tightly adhering impact ice was formed on the upper surfaces of the throttle plates during the icing conditions at 25° F. The impact ice, being well bonded to the metal surfaces, was more difficult to remove than the spongy fuel-evaporation ice.

Effect of engine power conditions on de-icing time. - For similar icing conditions, the de-icing time was greater for the 60-percent rated power runs than for the normal rated power runs at wet-bulb temperatures less than 70° F (fig. 8). At normal rated power the throttle was open about 20° more than at cruise conditions and the impact icing on the throttle plates had relatively little effect, the ice in the inlet elbow being mainly responsible for the decrease in air flow. For tests at simulated cruising power under these same icing conditions, the impact ice that formed on the upper surfaces of the throttle plates was mainly responsible for reducing the air flow. The heat input and air velocity for the de-icing process are less at 60-percent normal rated power conditions and therefore, the de-icing time for the same wet-bulb temperatures was longer for cruising power conditions than for normal rated power conditions. The comparison of tests at simulated normal rated power and those at 60-percent normal rated power therefore indicates that the position of the throttle may determine which type of ice most affects the air-flow recovery time.

Correlation between air-flow recovery and fuel-air ratio. - Typical changes in fuel-air ratio with increased air flow during the de-icing process are shown in figure 9(a). At the beginning of the de-icing period (air-flow rates, 1500 to 2500 lb/hr), the curves show quite a wide range of fuel-air ratios but at an air-flow rate of approximately 3200 pounds per hour, the curves converge to nearly the original fuel-air ratio of 0.080.

The flow-limit curves for the twin-barrel injection carburetor superimposed upon a band that has within its boundaries 85 percent of the points of the experimental data under icing conditions in which the air-metering parts of the carburetor remain ice free are shown in figure 9(b). The flow-limit curves, as obtained from the Air Technical Service Command, Army Air Forces, showed the fuel-air ratio limits for a mixture-control setting of automatic rich. The fuel-air ratio for the initial air flow used in these tests was 0.080, which is higher than that provided by the carburetor at automatic rich. When the mixture control is manually set to obtain an initial fuel-air ratio of 0.080, an effect equivalent to using larger fuel jets in the carburetor resulted without changing the metering characteristics. It was thus possible to raise the limit curves for automatic rich to encompass the initial fuel-air ratio and air-flow conditions.

From these two sets of curves (fig. 9(b)), it can be seen that, as the air flow approaches complete recovery, the carburetor meters more nearly within the normal-flow limit range. The overly rich mixture at the beginning of the de-icing period was due in part to lag in the temperature compensator. Thus, when heated air was suddenly turned on for de-icing, the carburetor continued to meter for a short time as though the denser icing air was still flowing and, hence, gave a richer mixture. Compensator lag is undoubtedly present whenever the air temperature is suddenly increased but the effects are most noticeable for icing at air temperatures above 32° F; because at carburetor-air temperatures below 32° F, the icing of the air-metering parts produces erratic metering that outweighs the lag. The compensator is expected to more closely follow the slower temperature rise available in the airplane. Some doubt exists as to whether the temperature compensators are affected similarly in the airplane and in the laboratory setup because comparative temperature surveys were not made. It is believed, however, that this error would be small and nearly constant.

The calculated fuel-air ratio during the first part of the recovery was subject to error due to inertia of the rotameter float and to the displacement of fluid by the float. Consideration of these errors indicates that, because the error was large only during the first few seconds of the de-icing period, a correction was not warranted for the data of figure 9. The flow rate corrected for the displacement error is the indicated flow rate plus the fluid displaced by the moving float in unit time. In run 7 at normal rated power (table I), the possible error in flow reading was approximately 63.5 percent in the first 0.10 minute that the fuel resumed flow. The error was reduced to approximately 14 percent in the next 0.10 minute.

The values of fuel-air ratio during the first part of the de-icing period were influenced by the inaccuracy in obtaining correct air-flow readings at the lower air-flow rates when using a fixed orifice for the entire range. This effect arises because for a given error in differential pressure reading across the orifice, the air-flow rate determination is more in error at the lower rates. A similar inaccuracy is to be expected in the metering characteristcs of the carburetor at very low air-flow rates.

The deviations from the allowable flow limits of the carburetor as the air flow approached complete recovery are due to variations in the initial fuel-air ratio settings.

Under icing conditions at carburetor-air temperatures below 32° F, especially at simulated normal rated power conditions, the metering characteristics of the carburetor were seriously affected and the fuel-air ratios were very erratic for approximately the first 80 percent of the recovery. Ice that formed on the impact tubes, the boost venturi, or the nozzle tended to change the metering characteristics of the carburetor and random removal of these deposits accounted for some of the apparent erratic changes in fuel-air ratios. In several instances, the fuel nozzle and metering sections were so blocked by ice that the fuel flow completely ceased. Variations in fuel-air ratio from 0 to 0.600 were observed during the first part of the de-icing period of some runs.

SUMMARY OF RESULTS

From tests of a twin-barrel injection carburetor and engine-stage supercharger assembly, the following results were obtained:

1. De-icing time was a function of the nature of the ice formation and of the wet-bulb temperature of the de-icing air.

2. De-icing time decreased very rapidly with increase in wet-bulb temperature to 80° F, above which the time required to de-ice was not materially reduced as the wet-bulb temperature increased.

3. Under the same initial conditions of carburetor-air temperature and humidity, the ice formation produced at simulated 60-percent normal rated power conditions generally required more time to remove under the same de-icing conditions than that formed under simulated normal rated power conditions.

4. Lag in the temperature compensator invariably resulted in overly rich fuel-air mixtures at the beginning of de-icing periods following icing at carburetor-air temperatures above 32° F.

5. Ice that formed on the carburetor-air-metering parts at carburetor-air temperatures below 32° F caused more erratic fluctuations of fuel-air ratio during de-icing and required more time to de-ice at a given wet-bulb temperature than fuel-evaporation ice that formed below the throttles.

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Cleveland, Ohio.

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TABLE I

RESULTS OF HEATED-AIR DE-ICING TESTS OF A TWIN-BARREL INJECTION CARBURETOR AND ENGINE-STAGE SUPERCHARGER ASSEMBLY

CARBURETOR MOUNTED ON ALLISON V-1710-89 ACCESSORY HOUSING ASSEMBLY

[60 percent normal rated power - Initial icing conditions: air flow at 35° F, 4620 lb/hr; fuel-air ratio, 0.080; relative humidity, 100 percent; water injection, 250 grams/min]

Run	Initial air flow (lb/hr)	De-icing air at carburetor				Maximum air flow recovered (lb/hr)	95 percent maximum possible recovery		
		Wet-bulb temperature (°F)	Dry-bulb temperature (°F)	Relative humidity (percent)	Heat content from 0° F (Btu/lb)		Air flow (lb/hr)	Recovery time (min)	Fuel-air ratio at recovery
1	4675	32	50	0	12.0	4540	4360	5.7	0.078
2	4635	37.5	60	0	14.45	4500	4280	5.4	.078
3	4645	42	50	52	16.6	4055	--------	--------	--------
4	4665	43	70	0	16.8	4500	4260	4.0	.079
5	4660	47	80	0	19.1	4455	4210	3.0	.080
6	4625	50	60	50	20.8	4520	4270	1.4	.079
7	4635	50	60	50	20.9	4480	4280	1.2	.081
8	4640	50	50	100	20.8	4575	4310	.8	.079
9	4660	51.5	90	0	21.6	4450	4170	1.3	.081
10	4645	55	100	0	24.0	4440	4110	.7	.083
11	4650	58	70	50	26.0	4455	4250	.5	.079
12	4640	58	70	50	26.0	4515	4240	.75	.079
13	4630	59	110	0	26.5	4435	4050	.35	.080
14	4620	60	60	100	27.3	4470	4240	.43	.079
15	4620	62.5	120	0	29.0	4225	4000	.4	.082
16	4640	66	80	49	31.7	4420	4190	.4	.076
17	4650	69	69	100	34.4	4380	4210	.8	.081
18	4670	75	90	51	40.0	4310	4180	.6	.080
19	4655	75	90	51	40.0	4430	4160	.3	.078
20	4650	83	100	51	49.2	4485	4110	.2	.073
21	4640	83	100	51	49.2	4360	4100	.3	.078
22	4655	83	83	100	49.2	4470	4120	.12	--------
23	4670	86	88	92	52.9	4340	4100	.1	--------
24	4640	92	110	51	61.2	4300	4060	.3	.081
25	4650	100	120	51.5	75.3	4210	4020	.2	.074
26	4610	100	100	100	75.3	4270	3980	.2	.078
27	4670	100	100	100	75.3	4385	4030	.2	.080
28	4645	110	110	100	97.5	4195	3950	.15	.074
29	4620	120	120	100	126.4	4090	3870	.1	.073

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TABLE I - Continued

RESULTS OF HEATED-AIR DE-ICING TESTS OF A TWIN-BARREL INJECTION CARBURETOR AND ENGINE-STAGE SUPERCHARGER ASSEMBLY - Continued.

[60-percent normal rated power - Initial icing conditions: air flow at 25° F, 4620 lb/hr; fuel-air ratio, 0.080; relative humidity, 100 percent; water injection, 250 grams/min]

Run	Initial air flow (lb/hr)	De-icing air at carburetor				Maximum air flow recovered (lb/hr)	95 percent maximum possible recovery		
		Wet-bulb temperature (°F)	Dry-bulb temperature (°F)	Relative humidity (percent)	Heat content from 0° F (Btu/lb)		Air flow (lb/hr)	Recovery time (min)	Fuel-air ratio at recovery
30	4620	51	60	55	21.4	4070	--------	--------	--------
31	4630	59	70	54	26.5	4405	4200	6.3	0.083
32	4635	67	80	52	32.6	4570	4160	1.4	.079
33	4640	69	80	59	34.4	4550	4160	.45	.075
34	4625	70	70	100	35.4	4415	4240	.4	.078
35	4640	70	70	100	35.4	4485	4250	.6	.080
36	4650	70	70	100	35.4	4630	4260	.5	.077
37	4615	70	70	100	35.4	4345	4230	1.3	.081
38	4635	75	90	51	40.0	4470	4110	.6	.080
39	4590	80	80	100	45.5	4325	4150	.4	.080
40	4630	80	80	100	45.5	4640	4180	.3	.079
41	4610	82	100	48	47.9	4345	4050	.4	.082
42	4635	90	90	100	58.6	4300	4120	.3	.076
43	4635	90	90	100	58.6	5010	4120	.2	.068
44	4610	92	110	52	61.2	4235	4000	.2	.083
45	4600	100	120	51	75.3	4150	3950	.2	.079
46	4635	100	100	100	75.3	4655	4060	.2	.086
47	4600	100	100	100	75.3	4255	4030	.1	.057
48	4620	110	110	100	97.5	4170	3980	.2	.076
49	4625	120	120	100	126.4	4390	3920	.3	.084

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TABLE I - Concluded

RESULTS OF HEATED-AIR DE-ICING TESTS OF A TWIN-BARREL INJECTION CARBURETOR AND ENGINE-STAGE SUPERCHARGER ASSEMBLY - Concluded.

[Normal rated power - Initial icing conditions: air flow at 25° F, 7700 lb/hr; fuel-air ratio, 0.095; relative humidity, 100 percent; water injection, 250 grams/min]

Run	Initial air flow (lb/hr)	De-icing air at carburetor				Maximum air flow recovered (lb/hr)	95 percent maximum possible recovery		
		Wet-bulb temperature (°F)	Dry-bulb temperature (°F)	Relative humidity (percent)	Heat content from 0° F (Btu/lb)		Air flow (lb/hr)	Recovery time (min)	Fuel-air ratio at recovery
1	7660	40	40	100	15.6	5280	--------	--------	--------
2	7690	43	43	100	17.1	7010	--------	--------	--------
3	7700	45	45	100	18.1	7500	7320	8.9	0.090
4	7700	50	50	100	20.8	7565	7265	2.16	.091
5	7740	55	55	100	23.9	7480	7240	1.75	.090
6	7760	60	64	80	27.4	7950	7170	.58	.088
7	7730	60	60	100	27.4	7560	7190	1.16	.092
8	7725	65	65	100	31.0	7440	7130	.8	.090
9	7740	70	80	61.5	35.3	7390	6990	.6	.089
10	7700	70	70	100	35.3	7500	7060	.54	.089
11	7720	75	80	79.5	40.0	7335	6970	.4	.085
12	7725	75	75	100	40.0	7280	7030	.6	.090
13	7700	80	90	65	45.5	7185	6840	.38	.078
14	7770	80	80	100	45.5	7250	7015	.55	.091
15	7750	85	85	100	51.5	7240	6945	.4	.088
16	7730	90	90	100	58.6	7325	6880	.24	.081
17	7720	95	95	100	66.0	7400	6810	.25	.079
18	7745	100	100	100	75.3	7320	6785	.2	.074
19	7720	105	105	100	85.6	7255	6710	.27	.078
20	7750	110	110	100	97.5	7815	6685	.2	.076

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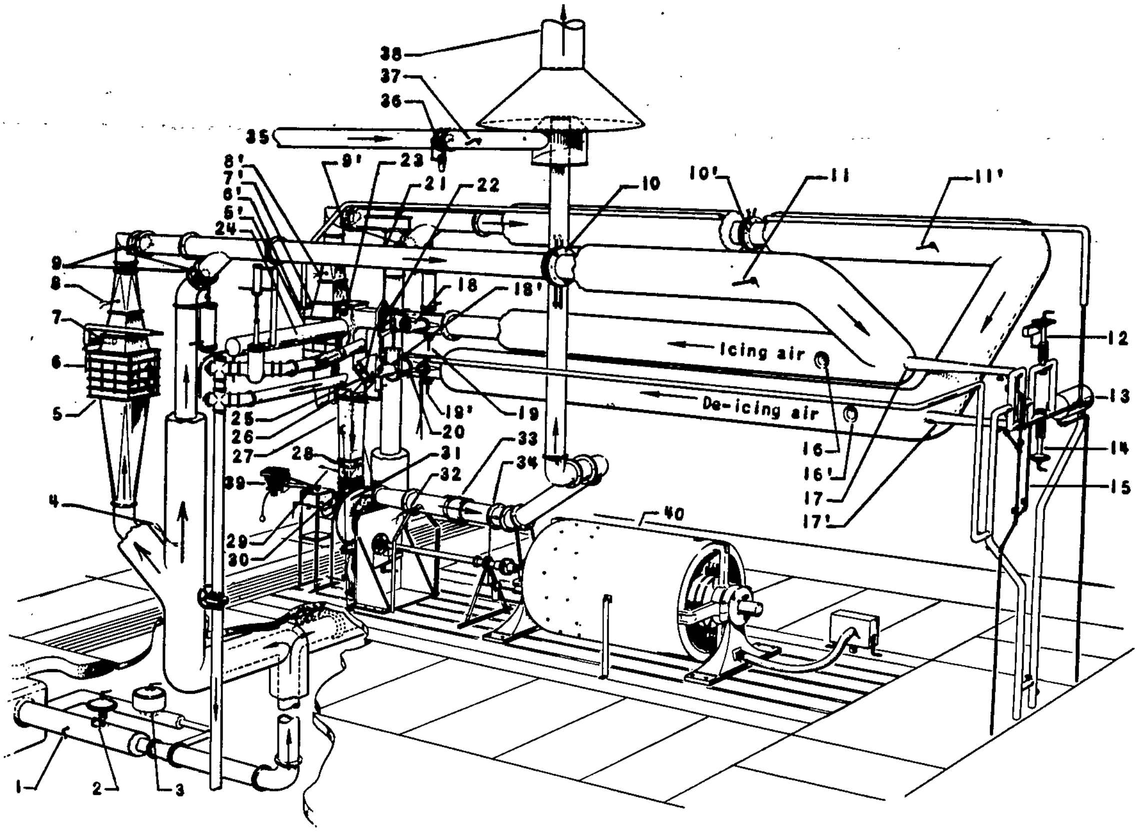

1	Air supply pressure tap
2	6-in. automatic pressure-control valve
3	2-in. automatic pressure-control valve
4	Air-supply temperature
5	Heaters, icing duct
5'	Heaters, de-icing duct
6	Steam bleed, icing duct
6'	Steam bleed, de-icing duct
7	Steam injection, icing duct
7'	Steam injection, de-icing duct
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. - Induction system de-icing installation.

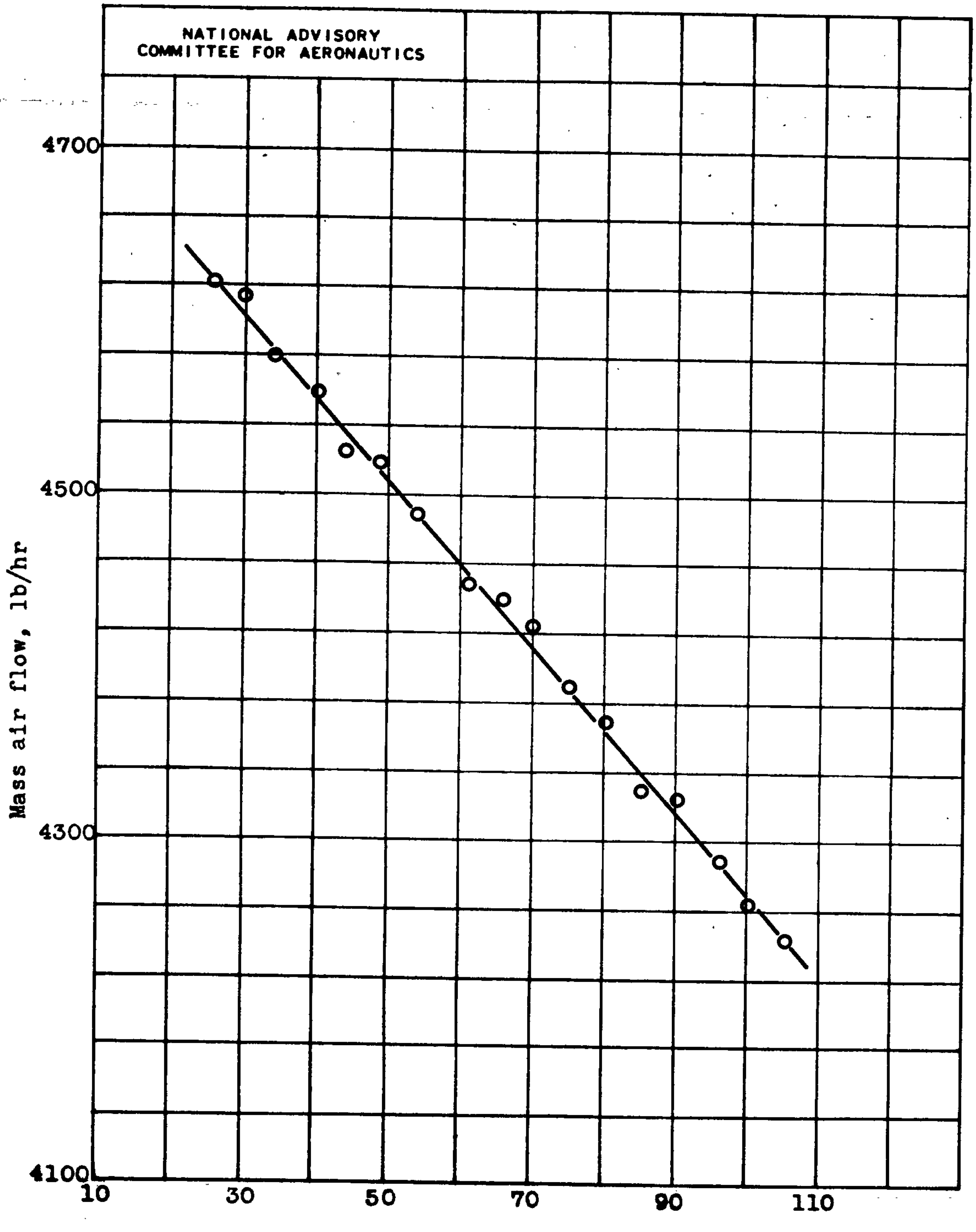


Figure 2. - Effect of carburetor-air temperature on mass air flow. Carburetor-deck pressure, 28.86 inches mercury absolute; engine speed, 2200 rpm; throttle setting, constant.

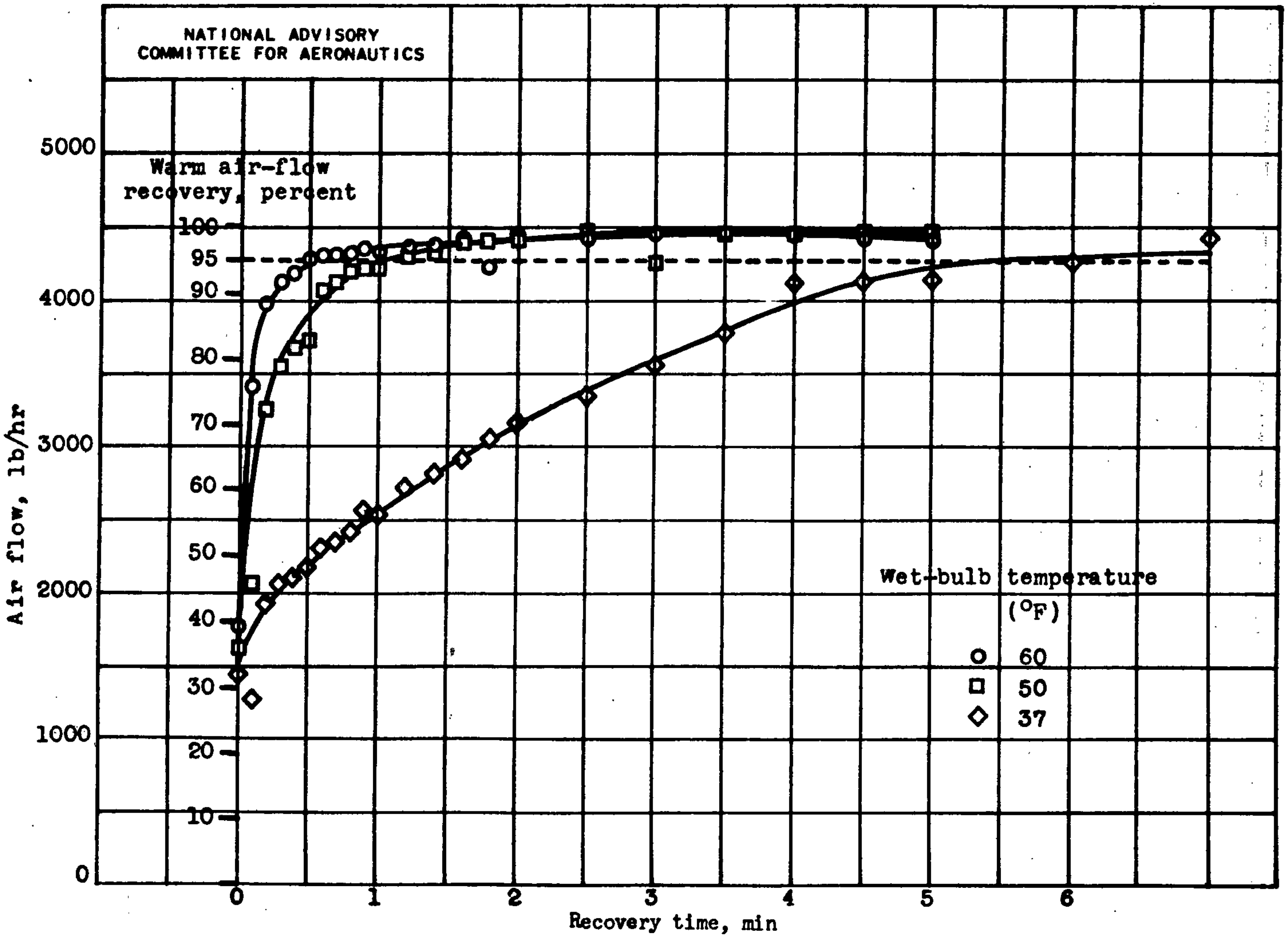
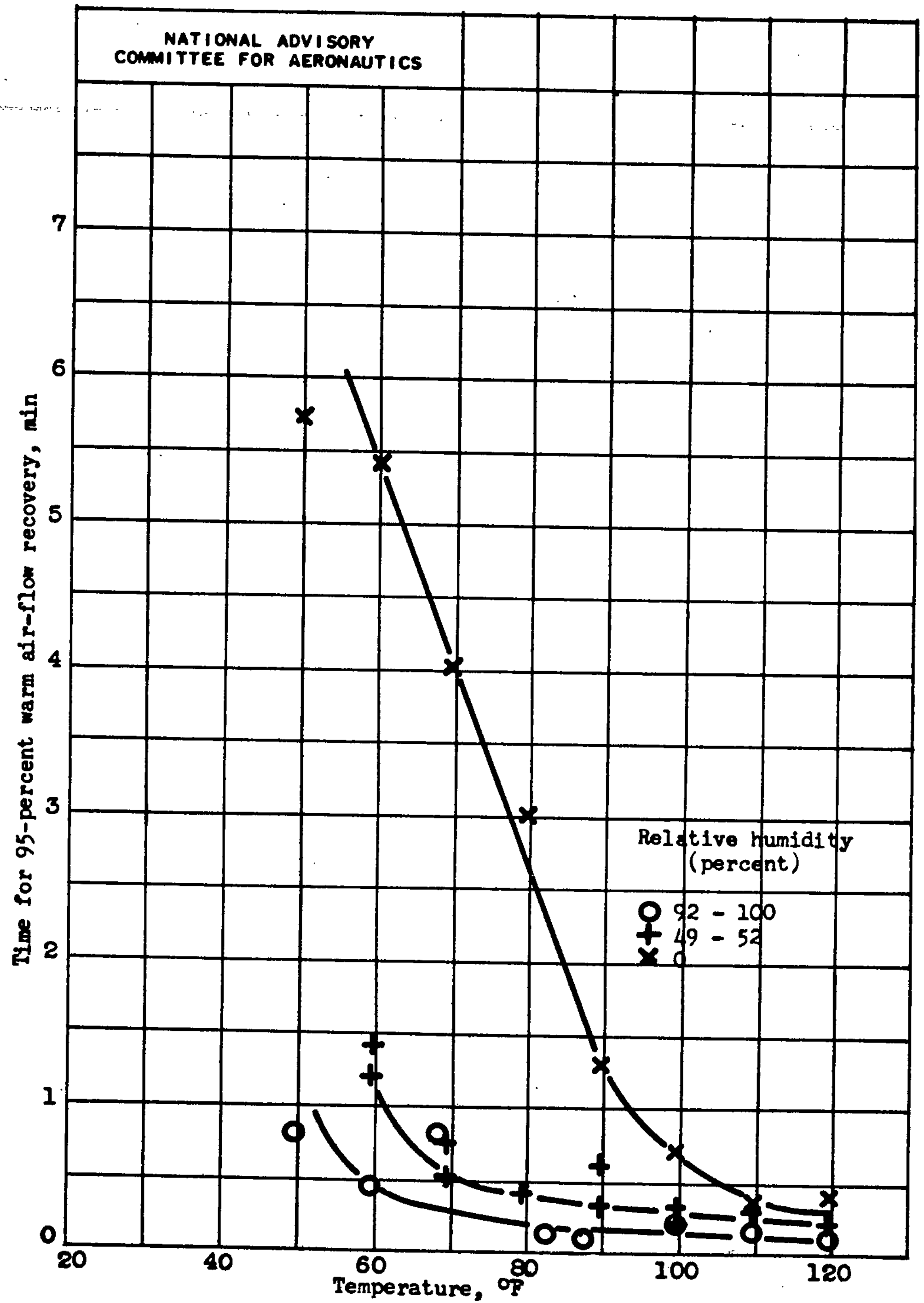
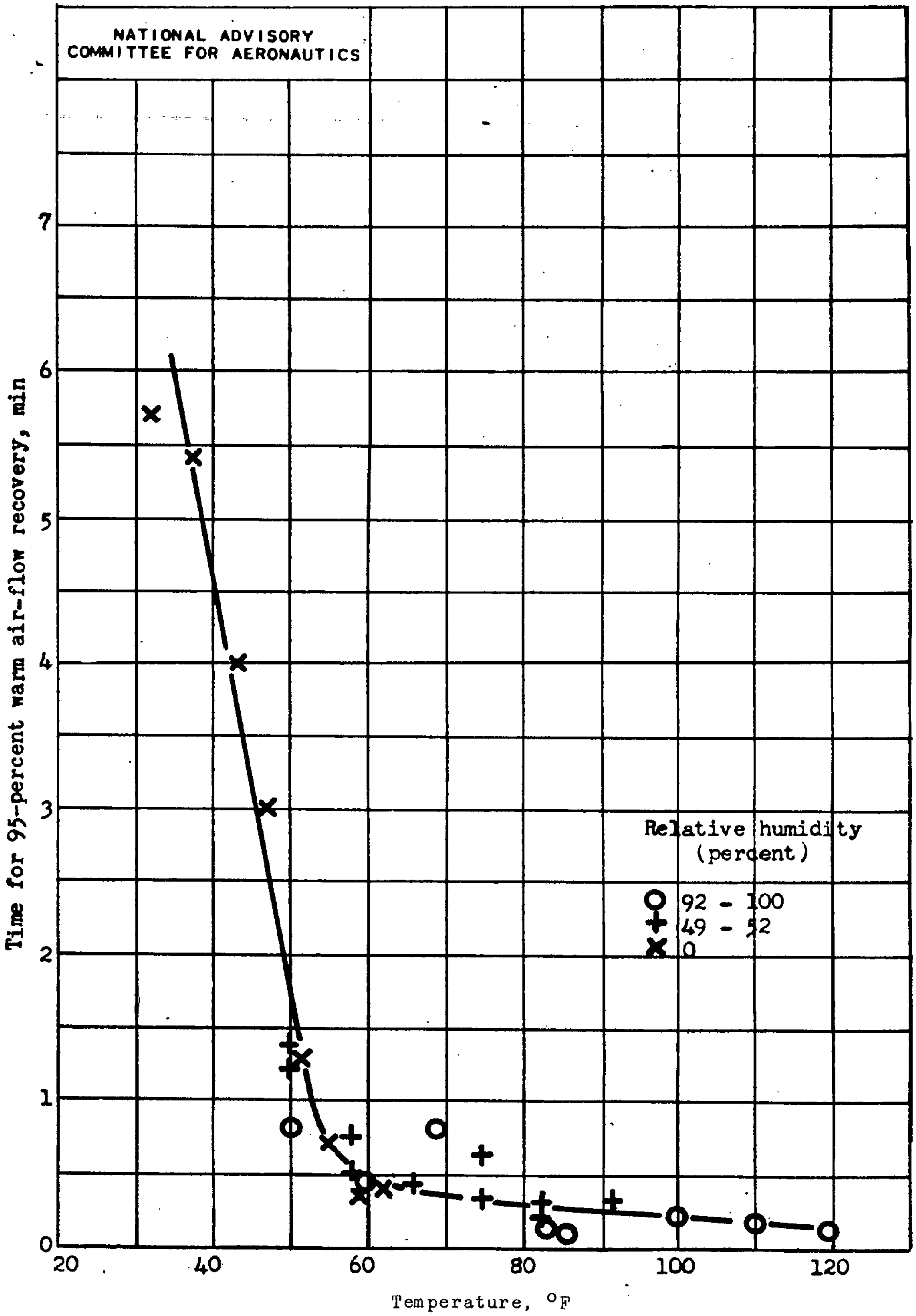


Figure 3. - Typical time history of heated-air de-icing for simulated 60-percent normal rated power at 60° F dry-bulb temperature. Initial icing conditions: air flow, 4620 pounds per hour; dry-bulb temperature, 35° F; relative humidity, 100 percent.



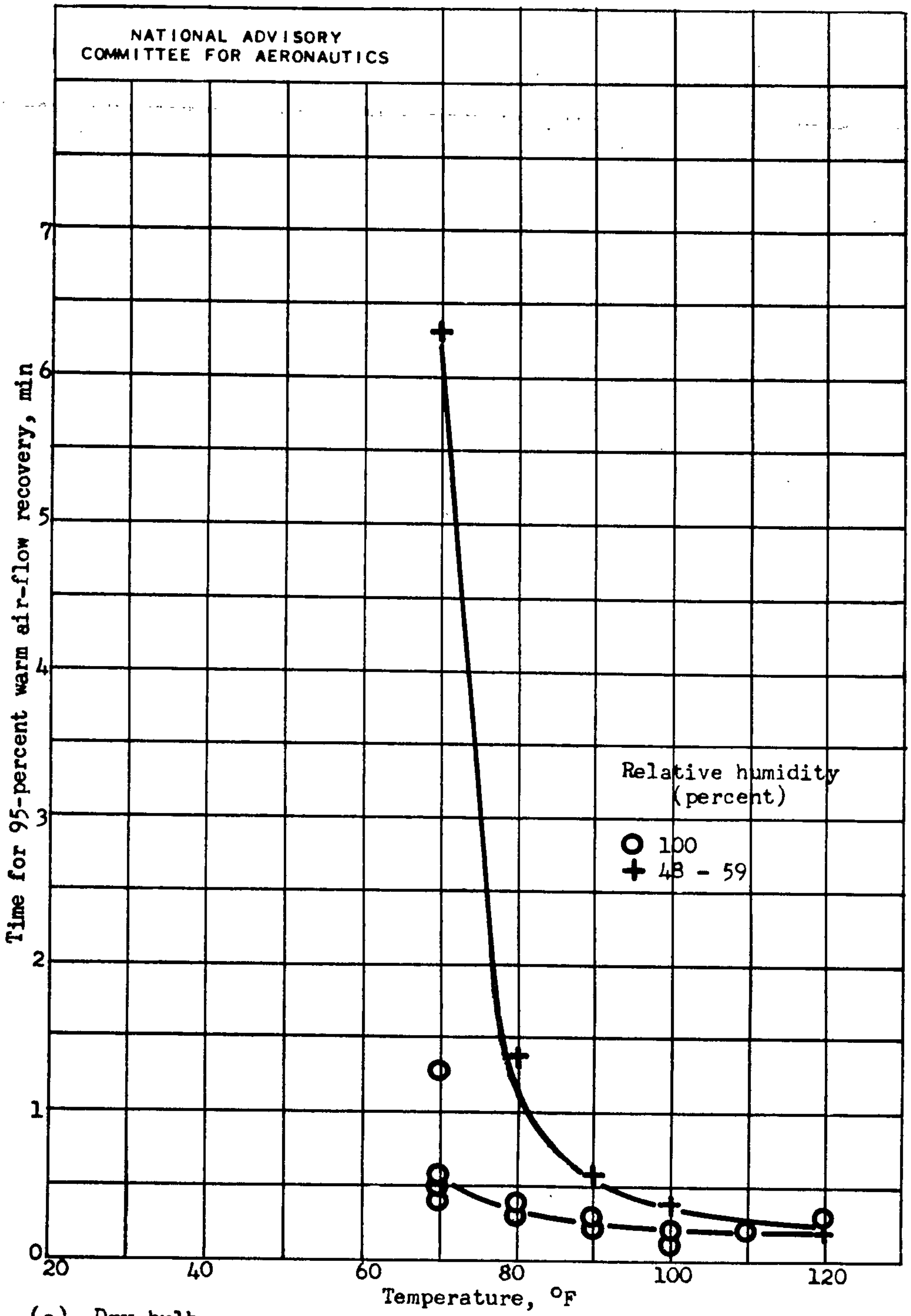
(a) Dry bulb.

Figure 4. - Effect of de-icing-air temperature on air-flow recovery time at simulated 60-percent normal rated power. Initial conditions: air flow, 4620 pounds per hour; carburetor-air temperature, 35° F; fuel-air ratio, 0.080. De-icing started after air flow dropped due to icing to approximately 2000 pounds per hour.



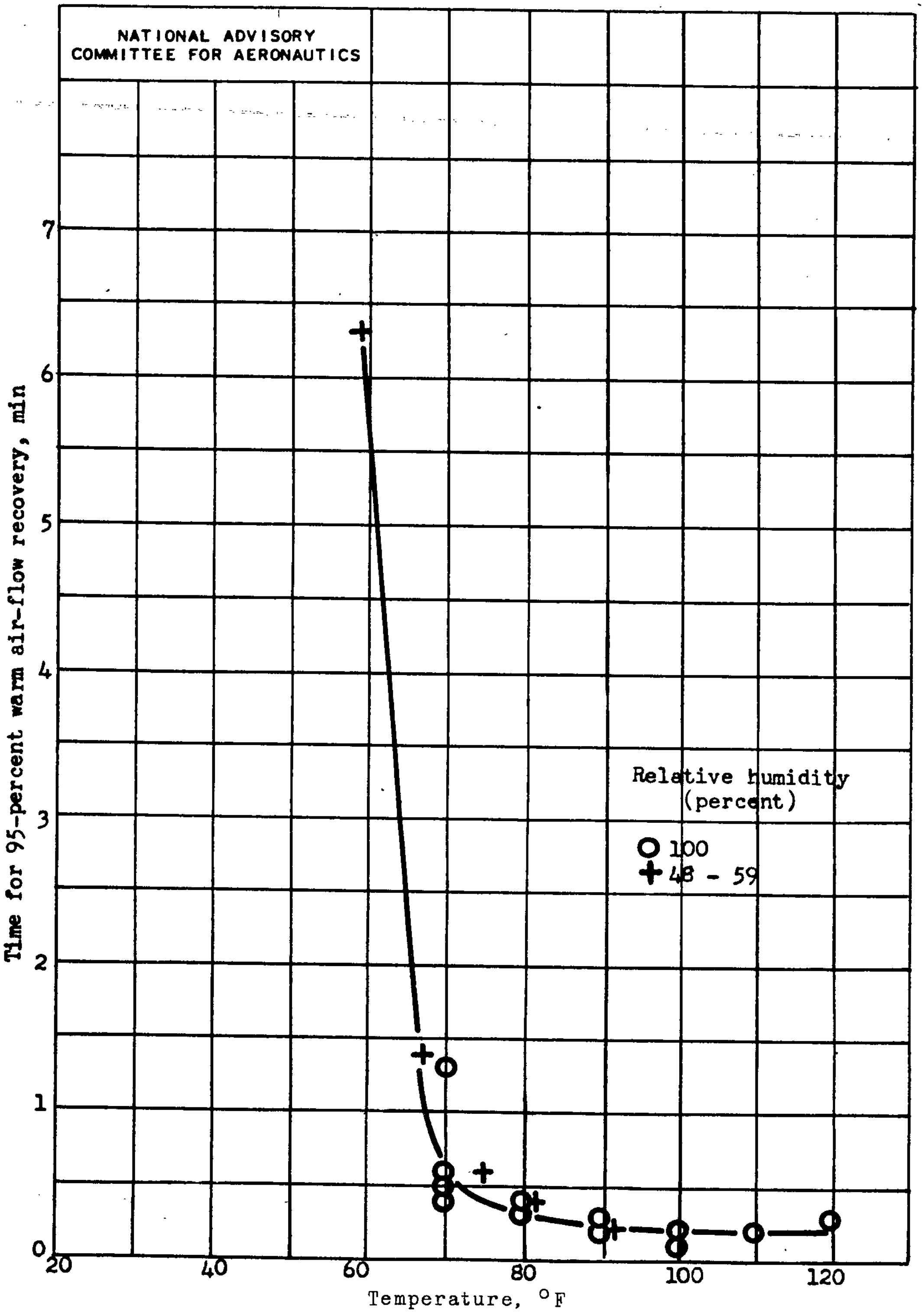
(b) Wet bulb.

Figure 4. - Concluded. Effect of de-icing-air temperature on air-flow recovery time at simulated 60-percent normal rated power. Initial conditions: air flow, 4620 pounds per hour; carburetor-air temperature, 35° F; fuel-air ratio, 0.080. De-icing started after air flow dropped due to icing to approximately 2000 pounds per hour.



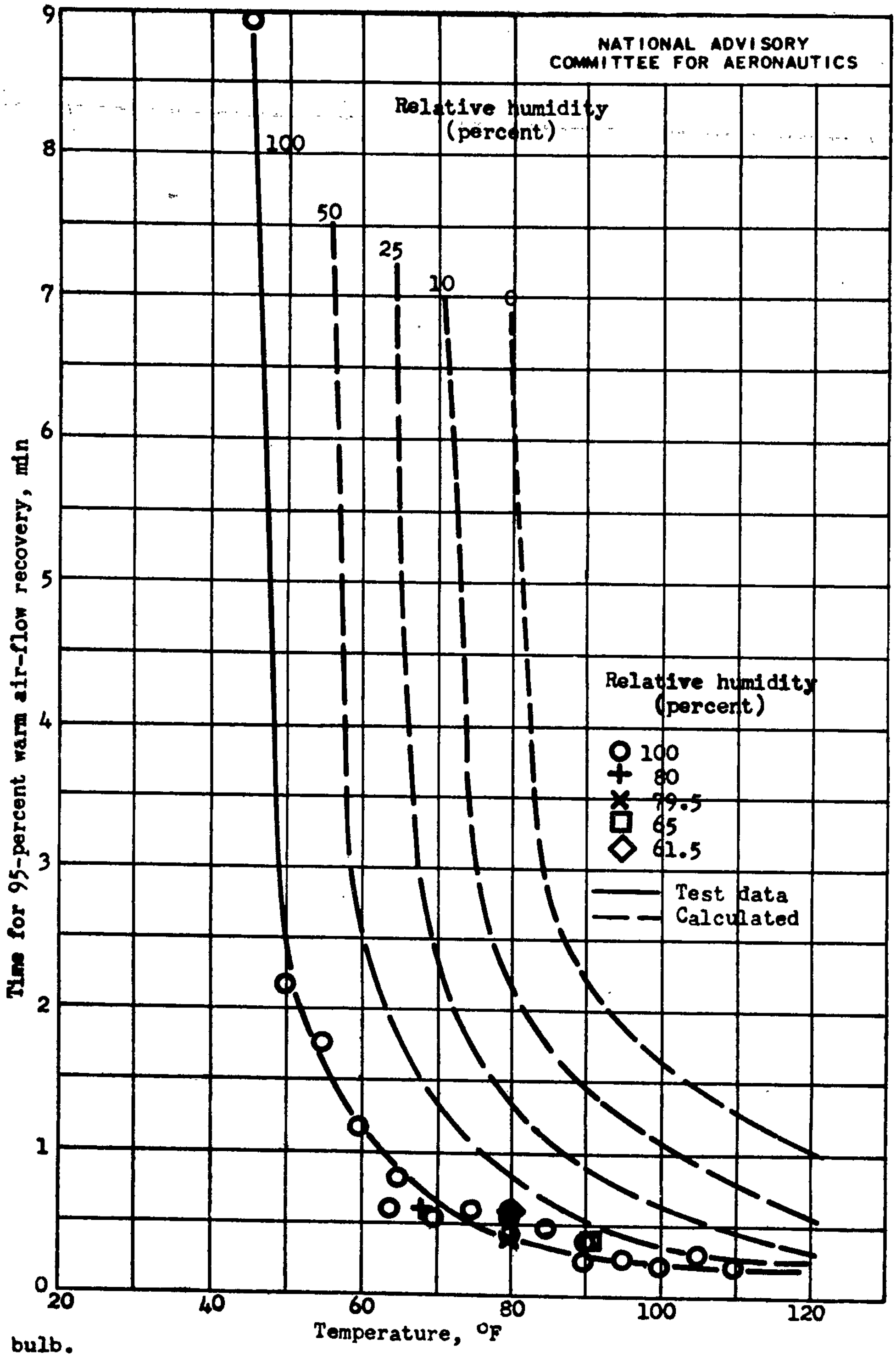
(a) Dry bulb.

Figure 5. - Effect of de-icing-air temperature on air-flow recovery time at simulated 60-percent normal rated power. Initial conditions: air flow, 4620 pounds per hour; carburetor-air temperature, 25° F; fuel-air ratio, 0.080. De-icing started after air flow dropped due to icing to approximately 2000 pounds per hour.



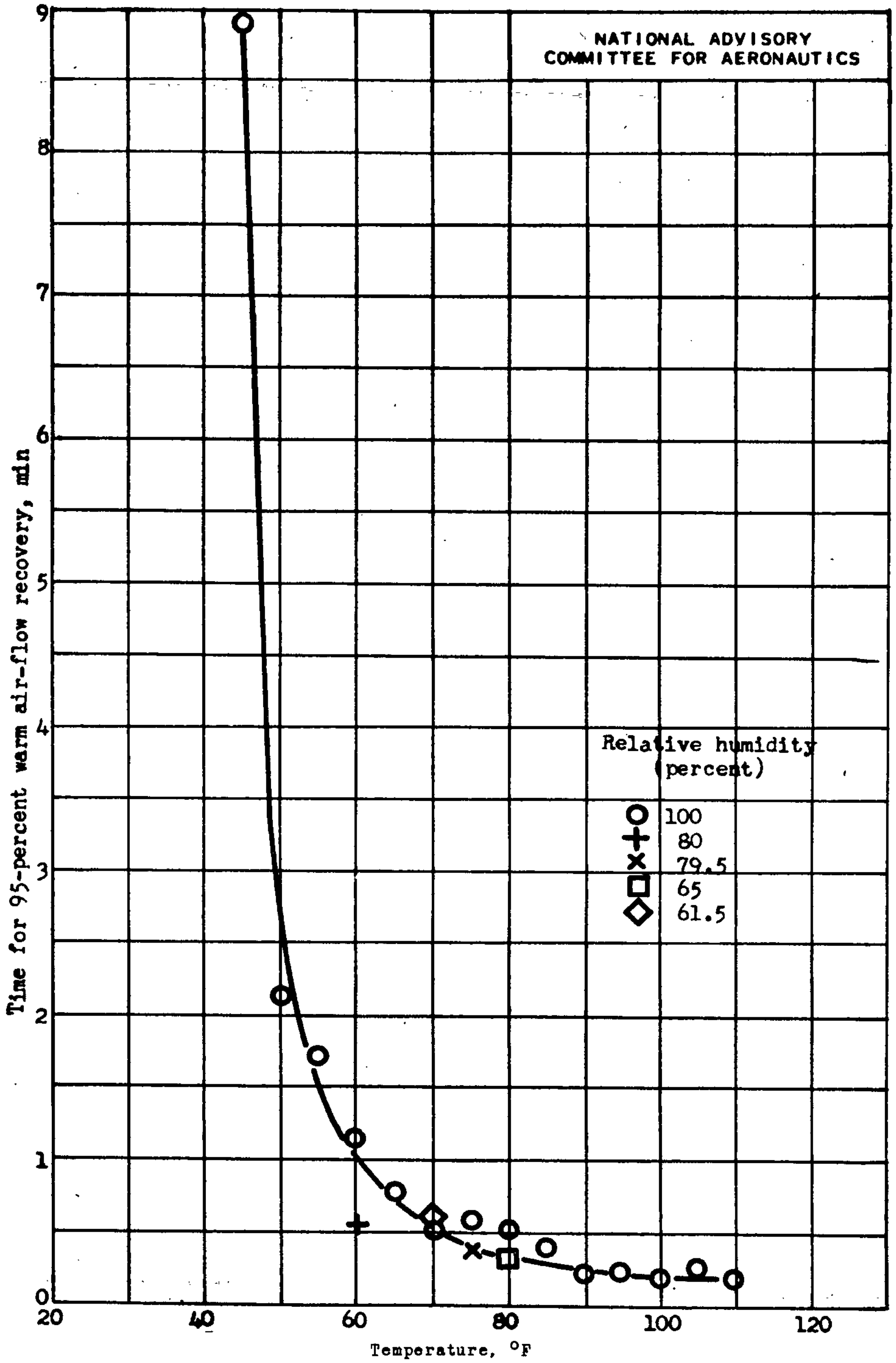
(b) Wet bulb.

Figure 5. - Concluded. Effect of de-icing-air temperature on air-flow recovery time at simulated 60-percent normal rated power. Initial conditions: air flow, 4620 pounds per hour; carburetor-air temperature, 25° F; fuel-air ratio, 0.080. De-icing started after air flow dropped due to icing to approximately 2000 pounds per hour.



(a) Dry bulb.

Figure 6. - Effect of de-icing-air temperature on air-flow recovery time at simulated normal rated power. Initial conditions: air-flow, 7700 pounds per hour; carburetor-air temperature, 25° F; fuel-air ratio, 0.095. De-icing started after air flow dropped due to icing to approximately 2000 pounds per hour.



(b) Wet bulb.

Figure 6. - Concluded. Effect of de-icing-air temperature on air-flow recovery time at simulated normal rated power. Initial conditions: air-flow, 7700 pounds per hour; carburetor-air temperature, 25° F; fuel-air ratio, 0.095. De-icing started after air flow dropped due to icing to approximately 2000 pounds per hour.

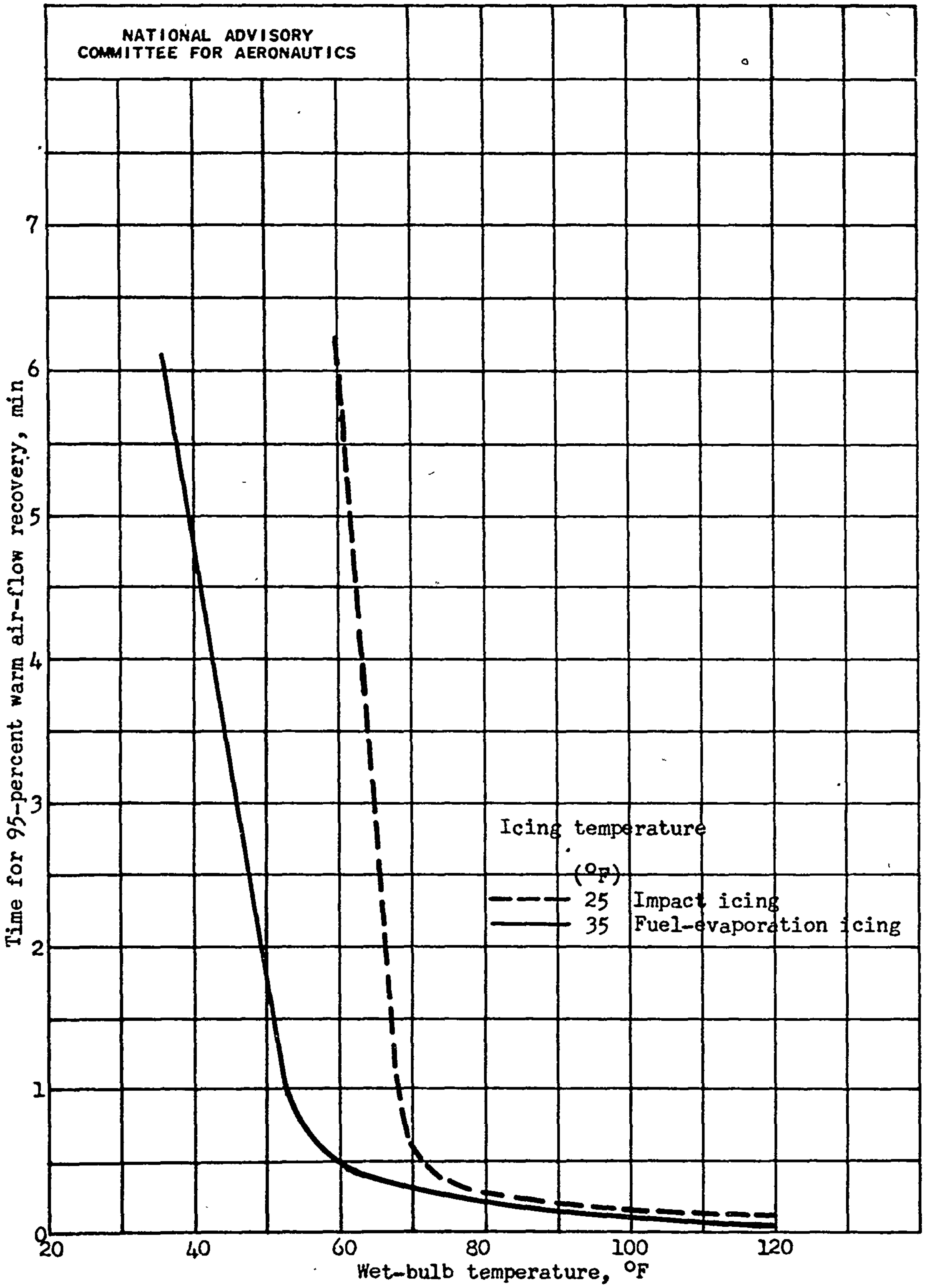


Figure 7. - Effect of icing conditions on recovery time at 60-percent normal rated power. Initial conditions: air flow, 4620 pounds per hour; fuel-air ratio, 0.080. De-icing started after air flow had dropped due to icing to approximately 2000 pounds per hour.

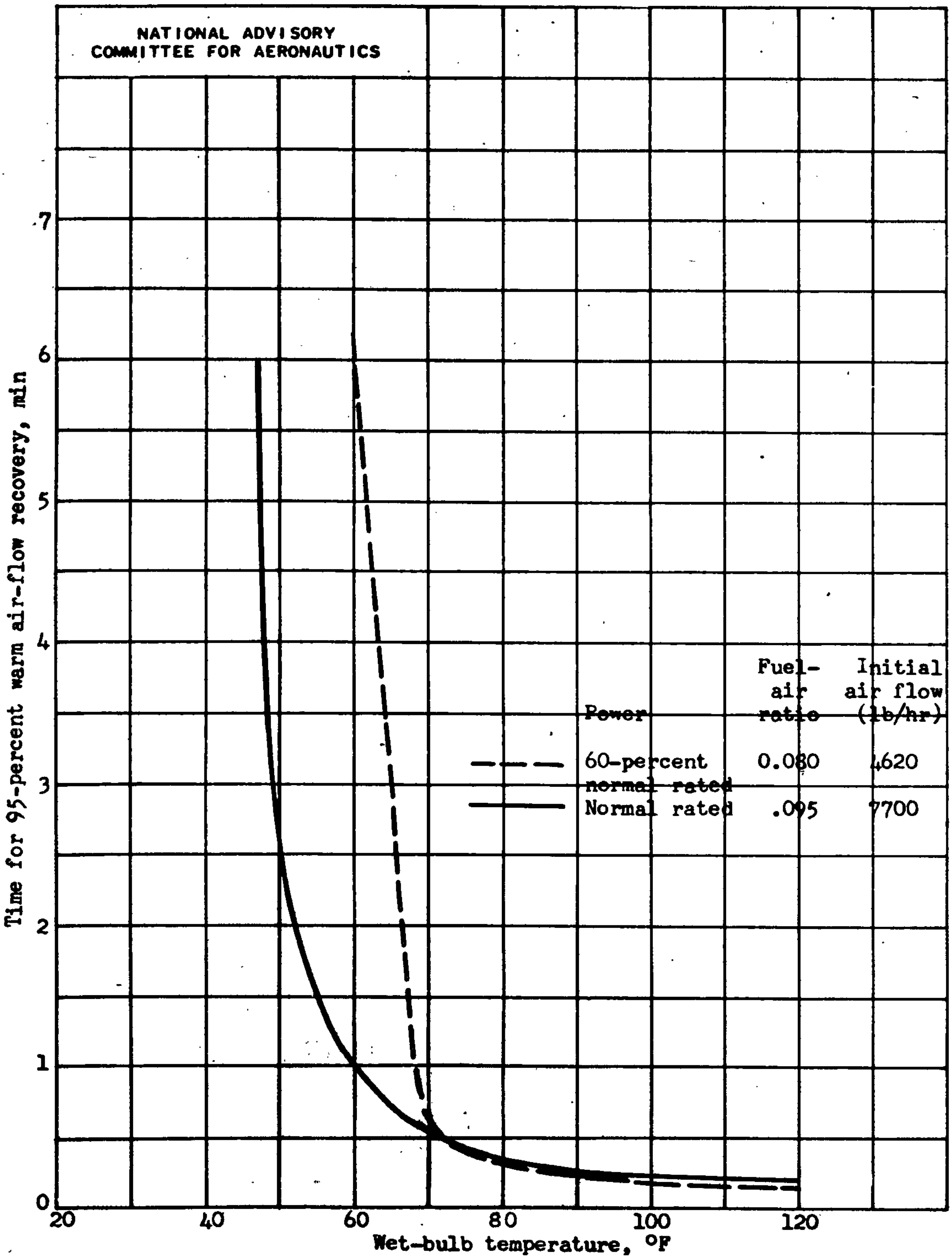
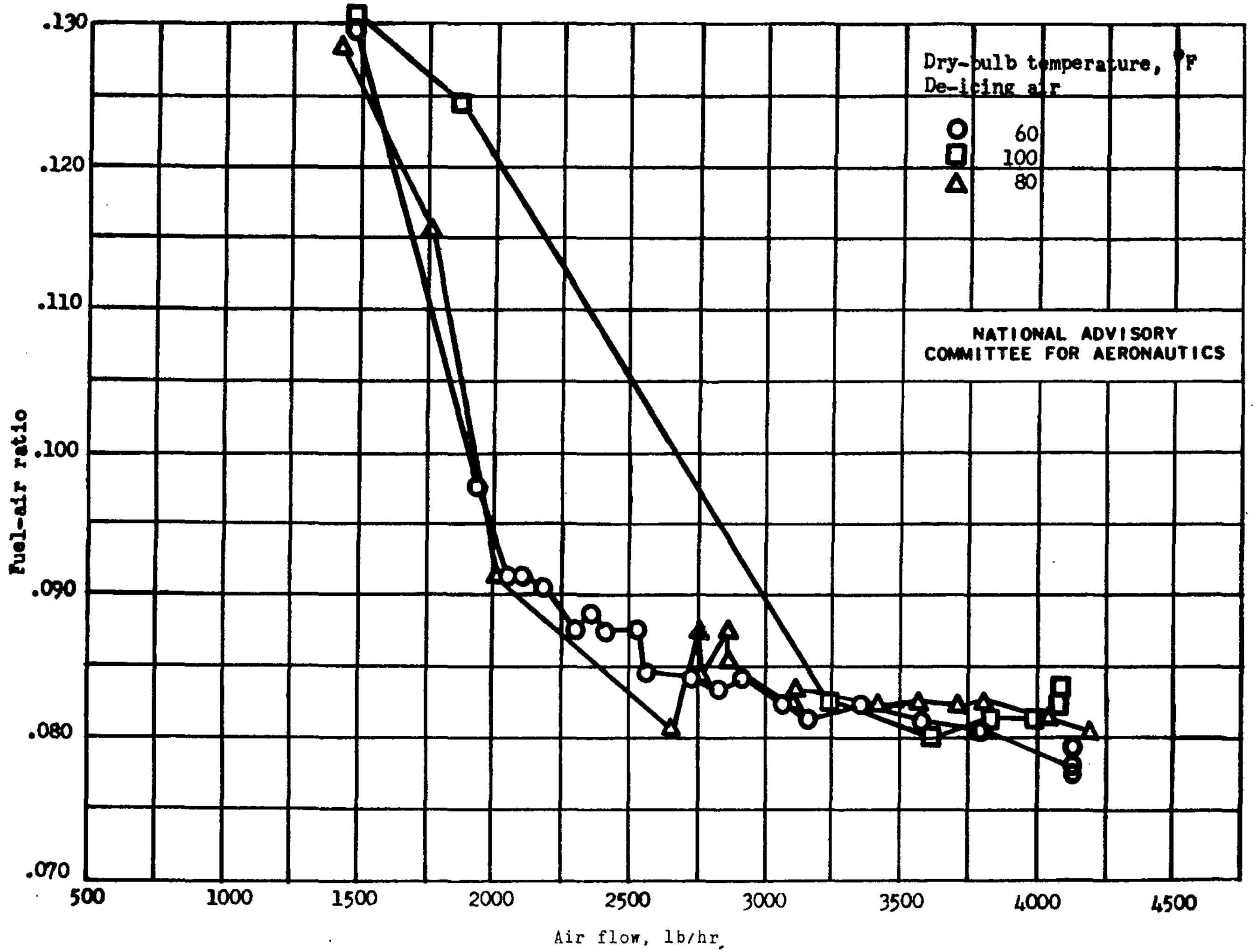
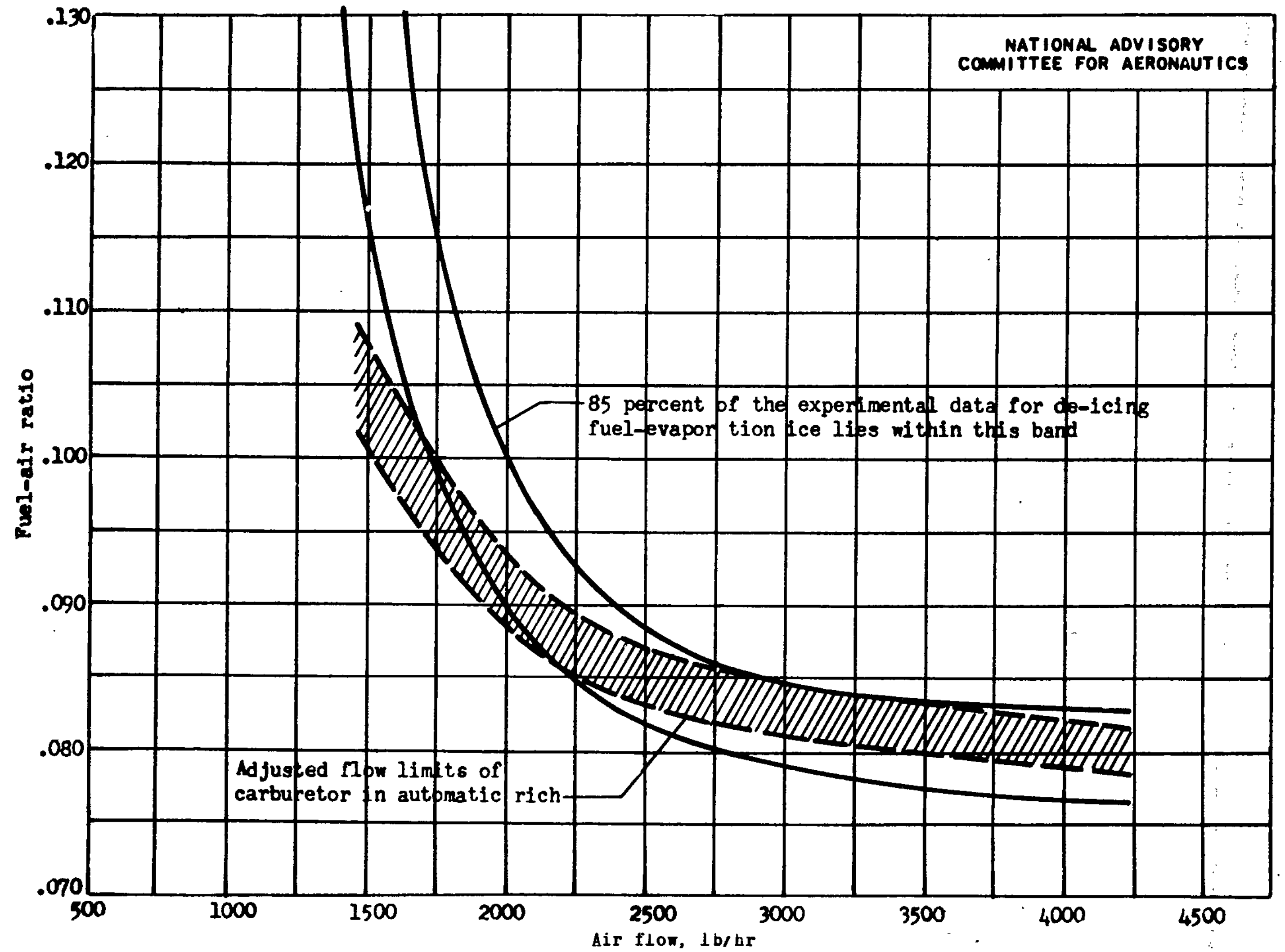


Figure 8. - Effect of power conditions on recovery time at icing temperature of 25° F. De-icing started after air flow dropped due to icing to approximately 2000 pounds per hour.



(a) Typical runs showing carburetor metering characteristics during de-icing of fuel-evaporation ice

Figure 9. - Comparison of observed metering characteristics of twin-barrel injection carburetor during de-icing period with allowable flow limits. Initial conditions: simulated 60-percent normal rated power; air flow, 4620 pounds per hour; carburetor-air temperature, 35° F; fuel-air ratio, 0.080. De-icing started after air flow dropped due to icing to approximately 2000 pounds per hour.



(b) Summation of test data superimposed upon adjusted flow limits of carburetor.

Figure 9. - Concluded. Comparison of observed metering characteristics of twin-barrel injection carburetor during de-icing period with allowable flow limits. Initial conditions: simulated 60-percent normal rated power, air flow, 4620 pounds per hour; carburetor-air temperature, 35° F; fuel-air ratio, 0.080. De-icing started after air flow dropped due to icing to approximately 2000 pounds per hour.