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A LABORATORY INVESTIGATION OF THE ICING CHARACTERISTICS OF THE BENDIX-STROMBERG CARBURETOR MODEL PD-12F5 WITH THE PRATT & WHITNEY R-1830-C4 INTERMEDIATE REAR ENGINE SECTION

By Herman B. Galvin and Henry A. Essex

Aircraft Engine Research Laboratory
Cleveland, Ohio

WASHINGTON

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ADVANCE RESTRICTED REPORT

A LABORATORY INVESTIGATION OF THE ICING CHARACTERISTICS OF THE BENDIX-STROMBERG CARBURETOR MODEL PD-12F5 WITH THE PRATT & WHITNEY R-1830-C4 INTERMEDIATE REAR ENGINE SECTION

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SUMMARY

Icing tests were made on a Bendix-Stromberg PD-12F5 carburetor mounted on a Pratt & Whitney R-1830-C4 intermediate rear engine section. Limiting-icing conditions were established for simulated cruising power and for simulated rated power over a range of carburetor-air temperatures from 20° F to 95° F, relative humidities from 19 to 100 percent, and rates of water injection simulating ingested rain from 0 to 1500 grams per minute.

The criterion of icing affecting engine operation was chosen as a drop in air flow of 50 pounds per hour. For tests made at simulated cruising power, the maximum temperature at which icing affecting engine operation occurred was 66° F and the minimum relative humidity was 44 percent. The maximum temperature and the minimum relative humidity for which visible icing would occur are estimated to be 102° F and 21 percent, respectively. Much of the ice forming at relative humidities below 100 percent occurred on the throttle plates. The formations were particularly unstable in localities where the heat transfer from the outer carburetor walls was good. When water in excess of saturation was injected upstream of the carburetor, the resulting ice formations occurred on the X-bar extending across the barrels of the carburetor and on the turning vanes at the entrance to the supercharger impeller.

The results of the simulated rated-power runs indicated that icing affecting engine operation occurred at a maximum temperature of 73° F and only at moisture contents in excess of saturation. The maximum temperature at which icing was observed was 75° F.

Recommendations have been made for alleviating the seriousness of icing in induction systems.

INTRODUCTION

This report is the third in a series of three covering the results of a laboratory investigation of the icing and de-icing characteristics of a Pratt & Whitney R-1830-C4 engine induction system. The research reported herein was carried out by the NACA at the National Bureau of Standards in December 1943 and January 1944.

The first report (reference 1) deals with the determination of limiting icing conditions and research on heated-air de-icing for the induction system, which included a Chandler-Evans 1900 CPB-3 carburetor mounted on an R-1830-C4 intermediate rear engine section. The second report (reference 2) covers 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 present report presents the results of research to determine the icing characteristics of the induction system including the 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 through the throttle openings, "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.

Only throttling icing and fuel-evaporation icing were produced during this series of tests. The limits of carburetor-air temperature and moisture content for the formation of these types of ice were determined for simulated cruising and rated-power conditions of engine operation over a range of carburetor-air temperatures from 20° F to 95° F, relative humidities from 19 to 100 percent, and rates of water injection from 0 to 1500 grams per minute simulating flight through rain. Pressure altitudes obtained during the tests varied from 750 to 2700 feet.

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

DESCRIPTION OF APPARATUS

The apparatus used in the icing tests of the Bendix-Stromberg carburetor was the same as that used in previous icing tests and is described in reference 1. A schematic diagram of the test setup with the Bendix-Stromberg carburetor in place is shown in figure 1.

Some features in the configuration of the Bendix-Stromberg PD-12F5 carburetor that affect the icing characteristics of this carburetor-engine combination are as follows: The carburetor has two venturi-shaped barrels, each with a butterfly throttle at the bottom. The throttles are mounted on a common shaft. Metering control is obtained from pressure differentials developed between a small boost venturi and a set of impact tubes above each barrel. Fuel is injected into the air stream from several orifices in a nozzle protruding downward from the center of the bottom of the carburetor body. Two arms extend radially from the base of the fuel nozzle across the exits of each carburetor barrel in such a way that they form an X across the engine-air passage.

A special nonleaded fuel with a 73-octane rating was used in these tests. Figure 3 of reference 1 shows the volatility curve for this grade of fuel as compared with that of 28-R fuel (AN-F-28, Amendment-2, grade 100/130), which is representative of fuels in current use by the military services. The 73-octane fuel is more volatile than standard aviation fuels and hence may tend to aggravate the icing characteristics of the induction system.

TEST PROCEDURE

The procedure used in this research was similar to that used in the icing investigation reported in reference 1. The desired air flow 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. The desired conditions of temperature and humidity were then established. The mixture control of the carburetor was set at automatic lean for the simulated cruising tests and at automatic rich for the simulated rated-power tests. After the mixture control had been set, the fuel was turned on long enough to check the fuel-air ratio against the carburetor calibration curve (fig. 2), then turned off, and the induction system examined for ice formations. When it had been determined that no ice was present in the induction system, the fuel and the free water were simultaneously turned on and the timing was started.

Readings of air flow, fuel flow, duct pressure, compensated carburetor metering-suction differential pressure, and carburetor pressure drop were taken at 3-minute intervals for a period of 15 minutes during the cruising runs and at 1-minute intervals for a period of 5 minutes during the rated-power runs. The ranges of conditions used in these tests are shown in the following table:

Series	Power condition	Initial air flow (lb/hr)	Mixture setting	Temperature range (°F)	Range of moisture content		Length of run (min)
					Relative humidity (percent)	Water in excess of saturation[a] (grams/min)	
A	Cruising	4000	Automatic lean	20-95	19-100	0-1500	15
B	Rated	7000	Automatic rich	26-76	92-100	0-1000	5

[a]Free water was injected in excess of saturation to simulate flight in rainfall and should not be confused with free-water injection to increase engine power.

RESULTS AND DISCUSSION

Classification and nature of ice formations. - The test results obtained were classified in three categories: no visible icing, visible icing, and icing affecting engine operation. When no ice was visible anywhere in the induction system after the period of the test, the run was classified as having no visible icing. If ice was seen but if the formation caused a drop in air flow of less than 50 pounds per hour, the icing was called visible icing. An ice formation large enough to cause a drop in air flow of 50 pounds per hour or more was designated icing affecting engine operation.

Classification of the icing according to its effect does not take into consideration the type, the size, or the location of the ice formation. The small mass of ice protruding from the edge of the throttle plates (see fig. 3) after run 12 of series A (cruising power) reduced the air flow by 200 pounds per hour. The much larger ice formation (see fig. 4) caused by fuel evaporation in run 71 of series A had no effect on air flow. A formation like that shown in figure 4 may have some effect on engine operation by disturbing the mixture distribution but, because variations in mixture distribution could not be measured in any way, icing has been classified only with respect to the effect on mass air flow.

Limiting icing conditions at simulated cruising power. - The results of the tests made at simulated cruising-power conditions are shown in table 1 and are plotted in figures 5 and 6. The lines representing the limit of icing affecting engine operation and the limit of visible icing have been faired in on figure 5, then transformed to coordinates of air temperature and water content, and drawn on figure 6 where they are shown with red bands designating the estimated variation in the limits. This procedure was adopted in determining the limits of the regions of visible icing and icing affecting engine operation because, when the data were plotted with enthalpy and water content as the coordinates (fig. 5), it was believed that greater accuracy in fairing the limits could be obtained.

The results shown in figure 5 indicate that, as the moisture content of the air increased, the heat content (enthalpy) of the air at which icing affecting engine operation occurred increased to a value of about 23 Btu per pound of air, where it remained constant until the water content of the air reached saturation. The icing that took place at conditions in the area enclosed beneath this portion of the curve and the line of 100-percent relative humidity occurred chiefly on the throttles. A typical example of this type of icing, which probably formed when the water vapor in the air stream condensed as the air expanded pseudoadiabatically through the boost venturi and the venturi section of the carburetor, is shown in figure 3. The condensate froze when it struck the throttles and the other metal surfaces of the lower section of the carburetor that had been cooled by the backflow of evaporating fuel and by the adiabatic expansion of the air through the throttles. The location of the auxiliary venturi in relation to the throttle plate is believed to be responsible for the amount of condensate striking it and hence aggravated icing of the throttles.

When the moisture content was increased above 0.009 pound per pound of dry air, the upper limit of enthalpy for icing affecting engine operation increased to about 29 Btu per pound of air and then more slowly to about 35 Btu per pound of air as the water content increased to about 0.060 pound per pound of air. The predominating ice formations occurred on the turning vanes and the X-bar below the carburetor. This icing was probably caused by the refrigerating effect of evaporating fuel. Ice formations of the type that occurred at high rates of free-water injection are shown in figure 7.

The limit of visible icing as shown in figure 5 increased to higher enthalpy values with increasing water content and reached a maximum value of about 53 Btu per pound of air at a water content of 0.040 pound per pound of dry air.

Reference to figure 6 shows that the upper limit of carburetor-air temperature for which icing affecting engine operation occurred increased from about 25° F at a relative humidity of 90 percent to about 66° F at a relative humidity of about 44 percent. As the relative humidity increased to about 100 percent, the temperature limit dropped to about 56° F and then increased to about 65° F as free water was injected into the duct above the carburetor to simulate flight through rain.

Figure 6 also shows that the upper temperature limit of visible icing increased from a temperature of 25° F at a relative humidity of about 44 percent and reached a maximum value of about 102° F at a relative humidity of about 30 percent. As the relative humidity was increased to 100 percent, the upper temperature limit of visible icing fell to about 86° F and then decreased slowly as free water was injected.

It was noted during the simulated cruising-power runs that ice would form on the tops of the throttle plates and then, as the test proceeded, gradually melt away from the areas closest to the outer throttle-shaft bearings. This phenomenon was probably caused by heat conduction from the outside of the carburetor along the throttle shaft.

Limiting icing conditions at simulated rated power. - The results of the tests made at simulated rated power are shown in table 2 and are plotted in figure 8. For this condition of engine operation, icing affecting engine operation occurred at carburetor-air temperatures up to about 73° F but only for moisture contents in excess of saturation.

The maximum temperature at which visible icing occurred was 75° F. It should be noted that this temperature is only 2° F higher than that at which icing affecting engine operation could occur. Tests to determine the complete limits of visible icing were not made because the required conditions of carburetor-air temperature and humidity could not be obtained with the apparatus available.

Effect of throttle setting on limiting icing conditions. - Figure 9 shows the limits of icing affecting engine operation for both simulated cruising-power and rated-power conditions. The chief difference between these limits is that, for the rated-power tests, no icing affecting engine operation could be produced below saturation at any carburetor-air temperature investigated. One explanation for the nonoccurrence of such ice lies in the fact that, during the rated-power runs, the throttles were almost completely open, which eliminated the attendant adiabatic expansion together with the subsequent cooling of the metal carburetor parts below the throttles. Furthermore, the backflow of evaporating fuel caused by a stalled condition of the downstream side of the throttles was greatly reduced. Any condensate formed as a result of pseudoadiabatic expansion through the boost and the barrel venturis would therefore not freeze.

It can be seen that the maximum temperature at which icing affecting engine operation occurred is about 8° F higher for the rated-power runs than for the cruising-power runs. No explanation for this occurrence can be given at present.

Effect of icing on fuel-air ratio. - In most of the icing tests, the fuel-air ratio varied by not more than 3 percent from the values given in the carburetor calibration curve (fig. 2); however, several tests were made in which a variation of 4 percent occurred.

SUMMARY OF RESULTS

The following results obtained from these tests are applicable only to the Bendix-Stromberg PD-12F5 carburetor mounted on a Pratt & Whitney R-1830-C4 intermediate rear engine section over the range of variables tested and are believed to be conservative because the criterion of icing affecting engine operation was chosen as a reduction in air flow of only 50 pounds per hour:

1. The upper limit of carburetor-air temperature for icing affecting engine operation within 15 minutes at simulated cruising power was about 66° F.

2. For the range of temperatures investigated, the lower limit of relative humidity for icing affecting engine operation within 15 minutes at simulated cruising power was found to be about 44 percent.

3. For cruising-power conditions, the upper temperature limit of visible icing was estimated to occur at 102° F; the lower limit of relative humidity occurred at about 21 percent.

4. For 5 minutes of operation at simulated rated power, icing affecting engine operation occurred at a maximum carburetor-air temperature of 73° F and only at moisture contents in excess of saturation.

5. The maximum temperature at which icing was observed during simulated rated-power operation was 75° F.

6. The fuel-air ratio generally varied by not more than 3 percent from the values given by the carburetor calibration curve during all the icing tests.

7. Icing that took place during the simulated cruising-power tests at relative humidities below 100 percent usually formed on the

throttle plates. These formations were found to be unstable in locations where heat transfer from the outer carburetor walls was good.

8. For moisture contents in excess of saturation, icing occurred on the carburetor X-bar and on the turning vanes in the supercharger-impeller entrance.

RECOMMENDATIONS

From the results of these tests and those of references 1, 2, and 3, certain characteristics common to all the induction systems tested have been shown to be contributing factors to the icing problem. Some recommendations to alleviate the seriousness of the problem are as follows:

1. The injection of free water into the carburetor-air passage to simulate flight through rain has been shown to affect the icing characteristics of induction systems adversely. Carburetor ramming-air intakes and internal air passages should be so designed as to exclude any rain from entering with the induction air.

2. Some configurations of auxiliary venturi, throttle plate, and fuel nozzle have been shown to lead to serious icing. The fuel nozzle should be redesigned, or moved as far downstream from the throttle plate as possible, to prevent the cooling of the plate by evaporating fuel eddying back in its wake. In the event that turning vanes are present in the supercharger-impeller entrance, fuel should be injected downstream of such vanes and the spray so directed that any possibility of splash or backflow would be eliminated. In this connection, a throttling device may be located elsewhere in the induction system than in the carburetor body.

3. The presence in the induction system of obstructions such as X-bars, turning vanes, and thermometer bulbs increases the icing hazard by permitting the accumulation of ice on them and, in some cases, by increasing the turbulence of the evaporating fuel-air mixture and allowing it to strike the metal surfaces in the system and cool them below the freezing point. An ideal induction system should have no obstructions or protuberances and should have an expanding section below the point of fuel injection to allow any ice formed to pass through freely and also to decrease turbulence.

4. Application of heat to the carburetor body and throttles would prevent much of the icing occurring on these parts.

5. In flight, the engine should be operated with as large a throttle opening as possible whenever a choice exists as to means of obtaining the required power.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, November 20, 1944.

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

TABLE 1. - RESULTS OF LIMITING-ICING-CONDITION TESTS OF BENDIX-STROMBERG PD-12F5 CARBURETOR WITH PRATT & WHITNEY R-1830-C4 INTERMEDIATE REAR ENGINE SECTION AT SIMULATED CRUISING POWER

[Series A; length of run, 15 min]

Run	Carburetor air					Enthalpy (Btu/lb)	Air flow		Fuel-air ratio		Effect[a]
	Dry-bulb temperature (°F)	Wet-bulb temperature (°F)	Moisture content		Absolute moisture content (lb/lb of dry air)		Initial (lb/hr)	Minimum (lb/hr)	Initial	Final	
			Relative humidity (percent)	Water in excess of saturation (grams/min)							
3	25	20	38	0	0.00105	7.09	4030	4030	0.068	0.066	3
4	25	25	100	0	.00272	8.91	3990	3860	.067	.068	1
5	20	16	42	0	.00090	5.72	4000	4000	.064	.066	2
7	35	28	37	0	.00160	10.08	3990	3990	.069	.066	2
10	40	32	38	0	.00202	11.73	4000	3980	.069	.067	3
11	40	36	68	0	.00358	13.41	3980	3860	.069	.067	1
12	40	38	84	0	.00438	14.29	4030	3830	-------	.066	1
13	40	35	61	0	.00316	12.98	3980	3980	.067	.064	2
14	35	32	73	0	.00315	11.73	4020	3950	.065	.063	1
15	45	33	20	0	.00129	12.14	3980	3980	.068	.068	3
16	45	36	39	0	.00250	13.41	4010	4010	.068	.066	2
17	45	39	58	0	.00369	14.74	4010	4010	.068	.066	2
18	45	41	71	0	.00452	15.66	3980	3980	.068	.066	2
19	45	41	71	0	.00452	15.66	3960	3840	.069	.067	1
20	45	40	65	0	.00412	15.19	3960	3890	.069	.068	1
21	50	44	62	0	.00474	17.11	4010	3920	.069	.068	1
23	50	39	33	0	.00255	14.74	4010	4010	.068	.067	3
24	55	43	34	0	.00317	16.62	3990	3990	.068	.067	2
25	55	49	65	0	.00603	19.70	3990	3940	.068	.067	1
26	55	48	60	0	.00552	19.16	3990	3920	.069	.068	1
27	55	47	55	0	.00503	18.64	3970	3900	.068	.068	1
28	55	45	44	0	.00408	17.61	4010	3990	.068	.067	2

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

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TABLE 1. - RESULTS OF LIMITING-ICING-CONDITION TESTS OF BENDIX-STROMBERG PD-12F5 CARBURETOR WITH PRATT & WHITNEY R-1830-C4 INTERMEDIATE REAR ENGINE SECTION AT SIMULATED CRUISING POWER - Continued

Run	Carburetor air					Enthalpy (Btu/lb)	Air flow		Fuel-air ratio		Effect[a]
	Dry-bulb temperature (°F)	Wet-bulb temperature (°F)	Moisture content		Absolute moisture content (lb/lb of dry air)		Initial (lb/hr)	Minimum (lb/hr)	Initial	Final	
			Relative humidity (percent)	Water in excess of saturation (grams/min)							
29	60	51	53	0	0.00591	20.80	3990	3940	0.069	0.068	1
30	60	50	49	0	.00549	20.25	3990	3900	.070	.068	1
31	60	49	44	0	.00490	19.70	4010	3970	.069	.067	2
32	60	47	35	0	.00385	18.64	3990	3990	.070	.068	2
33	65	48	25	0	.00326	19.16	3970	3970	.069	.067	2
34	65	53	44	0	.00585	21.95	3990	3930	.068	.067	1
35	65	52	40	0	.00530	21.38	3990	3990	.065	.067	2
36	70	57	44	0	.00699	24.40	4000	3980	.069	.067	2
37	67	59	62	0	.00888	25.70	4010	3970	.069	.068	2
38	68	57	51	0	.00746	24.40	4030	3980	.067	.067	1
40	68	62	72	0	.01057	27.76	4030	4010	.068	.067	2
41	65	61	80	0	.01062	27.06	4040	4020	.068	.066	2
42	62	58	79	0	.00940	25.05	4030	4010	.068	.067	2
43	60	55	73	0	.00814	23.15	4030	4030	.068	.067	2
44	57	52	72	0	.00712	21.38	3970	3910	.068	.067	1
45	55	52	82	0	.00759	21.38	3960	3870	.068	.068	1
46	58	56	89	0	.00920	23.77	3990	3990	.068	.067	2
47	57	57	100	0	.00989	24.40	4020	4000	.068	.066	2
48	54	54	100	0	.00886	22.55	4030	4010	.069	.068	2
49	50	50	100	0	.00763	20.25	4010	3890	.068	.067	1
50	60	54	68	0	.00757	22.55	3990	3940	.068	.066	1
51	50	50	100	50	.00929	20.53	3990	3840	.068	.067	1
52	53	53	100	20	.00925	22.06	3980	3900	.068	.068	1

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

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TABLE 1. - RESULTS OF LIMITING-ICING-CONDITION TESTS OF BENDIX-STROMBERG PD-12F5 CARBURETOR WITH PRATT & WHITNEY R-1830-C4 INTERMEDIATE REAR ENGINE SECTION AT SIMULATED CRUISING POWER - Continued

Run	Carburetor air					Enthalpy (Btu/lb)	Air flow		Fuel-air ratio		Effect[a]
	Dry-bulb temperature (°F)	Wet-bulb temperature (°F)	Moisture content		Absolute moisture content (lb/lb of dry air)		Initial (lb/hr)	Minimum (lb/hr)	Initial	Final	
			Relative humidity (percent)	Water in excess of saturation (grams/min)							
53	56	56	100	20	0.01026	23.88	3990	3920	0.069	0.068	1
54	60	60	100	50	.01268	26.65	4010	3730	.070	.069	1
55	62	62	100	20	.01252	27.87	3990	3820	.070	.070	1
56	65	65	100	30	.01420	30.13	3990	3950	.070	.068	2
57	67	67	100	20	.01483	31.62	3990	3970	.069	.069	2
58	65	65	100	100	.01649	30.51	4020	3990	.069	.068	2
59	67	67	100	200	.02080	32.62	3990	3950	--------	.065	2
60	67	67	100	100	.01747	32.06	4010	4010	.069	.068	2
61	68	68	100	80	.01732	32.75	4010	3970	.066	.065	2
62	67	67	100	150	.01912	32.34	4010	3970	.066	.064	2
63	65	65	100	300	.02315	31.63	3990	3950	.070	.068	2
64	66	66	100	400	.02695	32.96	3990	3970	.069	.068	2
66	68	68	100	250	.02289	33.69	4030	4000	.069	.068	2
68	70	70	100	200	.02240	35.07	3980	3960	.066	.064	2
69	70	70	100	300	.02562	35.63	4020	3980	.065	.064	2
70	69	69	100	400	.02843	35.34	4000	3960	--------	.064	2
71	66	66	100	500	.03027	33.52	3990	3990	.069	.068	2
72	29	26	67	0	.00223	9.29	3990	3990	--------	.067	2
74	68	68	100	600	.03458	35.65	3990	3940	.068	.068	1
75	69	69	100	550	.03339	36.18	4000	4000	.068	.067	2
76	68	68	100	700	.03784	36.20	4000	4000	.068	.067	2
77	65	65	100	800	.03979	34.43	3980	3950	.067	.067	2
78	62	62	100	800	.03838	32.22	3990	3940	.068	.067	1

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

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TABLE 1. - RESULTS OF LIMITING-ICING-CONDITION TESTS OF BENDIX-STROMBERG PD-12F5 CARBURETOR WITH PRATT & WHITNEY R-1830-C4 INTERMEDIATE REAR ENGINE SECTION AT SIMULATED CRUISING POWER - Continued

Run	Carburetor air					Enthalpy (Btu/lb)	Air flow		Fuel-air ratio		Effect[a]
	Dry-bulb temperature (°F)	Wet-bulb temperature (°F)	Moisture content		Absolute moisture content (lb/lb of dry air)		Initial (lb/hr)	Minimum (lb/hr)	Initial	Final	
			Relative humidity (percent)	Water in excess of saturation (grams/min)							
79	60	60	100	900	0.04103	31.41	3970	3870	0.068	0.068	1
80	63	63	100	900	.04209	33.49	4000	3960	.068	.067	2
81	67	67	100	150	.01915	32.35	3990	3990	.069	.067	2
82	66	66	100	600	.03358	34.07	3990	3970	.068	.067	2
83	63	63	100	700	.03545	32.37	4000	3940	.068	.068	1
84	63	63	100	550	.03039	31.52	4020	4000	.069	.068	2
85	63	63	100	100	.01560	29.04	4000	3930	.069	.068	1
86	63	63	100	250	.02056	29.87	4000	3910	.068	.067	1
87	63	63	100	400	.02552	30.70	4000	3820	.068	.068	1
88	61	61	100	1000	.04461	32.63	3990	1400	.068	------	1
89	63	63	100	1000	.04539	34.04	4000	3820	.064	.067	1
90	65	65	100	1000	.04637	35.53	3990	3950	.070	.069	2
91	65	65	100	1250	.05440	36.89	4010	3950	.069	.068	1
92	67	67	100	1250	.05540	38.44	4010	3970	.069	.068	2
93	65	65	100	1500	.06270	38.27	4010	3970	------	.068	2
94	63	63	100	1500	.06194	36.82	4000	3960	.069	.068	2
95	61	61	100	1500	.06090	35.38	4010	3970	.068	.068	2
96	58	58	100	1500	.06016	33.43	3980	3860	.068	.068	1
97	40	40	100	0	.00519	15.19	4000	3830	.070	.067	1
98	40	40	100	250	.01346	16.59	3980	2000	.070	.081	1
99	40	40	100	500	.02173	17.97	4000	2000	.071	.084	1
100	31	28	69	0	.00250	10.08	4030	4030	------	.066	2
101	75	53	19	0	.00358	21.95	3980	3980	.069	.067	3

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

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TABLE 1. - RESULTS OF LIMITING-ICING-CONDITION TESTS OF BENDIX-STROMBERG PD-12F5 CARBURETOR WITH PRATT & WHITNEY R-1830-C4 INTERMEDIATE REAR ENGINE SECTION AT SIMULATED CRUISING POWER - Concluded

Run	Carburetor air					Enthalpy (Btu/lb)	Air flow		Fuel-air ratio		Effect[a]
	Dry-bulb temperature (°F)	Wet-bulb temperature (°F)	Moisture content		Absolute moisture content (lb/lb of dry air)		Initial (lb/hr)	Minimum (lb/hr)	Initial	Final	
			Relative humidity (percent)	Water in excess of saturation (grams/min)							
102	75	74	96	0	0.01798	37.51	3980	3980	0.068	0.065	2
103	75	60	41	0	.00765	26.37	4000	3980	.068	.066	2
104	78	63	43	0	.00890	28.48	3990	3990	.067	.066	2
105	83	65	37.5	0	.00912	29.96	3980	3960	.067	.066	2
106	86	66	34	0	.00913	30.73	3970	3970	.067	.065	2
107	90	67	29	0	.00892	31.51	3950	3950	.068	.067	2
108	88	73	49	0	.01430	36.60	4000	4000	.067	.065	2
109	82	80	92	0	.02147	43.51	4030	4030	.067	.065	2
110	88	84	85	0	.02459	43.05	4000	4000	.066	.064	3
111	85	85	100	0	.02629	49.24	3970	3970	.066	.064	2
112	87	87	100	0	.02810	51.74	3980	3980	.067	.064	3
113	23	22	87	0	.00218	7.80	4030	4010	-------	.065	2
114	86	86	100	200	.03381	51.58	3990	3990	.067	.065	2
115	87	87	100	300	.03810	53.42	3970	3970	.066	.066	3
116	86	86	100	500	.04385	53.27	3970	3970	.067	.065	3
117	84	84	100	600	.04528	51.39	4000	4000	.066	.066	3
118	82	82	100	550	.04193	48.77	4010	4010	.066	.066	2
119	83	83	100	400	.03782	49.10	4000	4000	.068	.066	2
120	83	83	100	800	.05092	51.31	4020	4020	.066	.066	2
121	85	85	100	900	.05593	54.22	4020	3990	.068	.056	3
122	95	85	66.5	0	.02377	49.24	3980	3980	.066	.064	3
123	90	80	65	0	.02005	43.51	4020	3980	.067	.065	2

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

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TABLE 2. - RESULTS OF LIMITING-ICING-CONDITION TESTS OF BENDIX-STROMBERG FD-12F5 CARBURETOR WITH PRATT & WHITNEY R-1830-C4 INTERMEDIATE REAR ENGINE SECTION AT SIMULATED RATED POWER

[Series B; length of run, 5 min]

Run	Carburetor air					Enthalpy (Btu/lb)	Air flow		Fuel-air ratio		Effect[a]
	Dry-bulb temperature (°F)	Wet-bulb temperature (°F)	Moisture content		Absolute moisture content (lb/lb of dry air)		Initial (lb/hr)	Minimum (lb/hr)	Initial	Final	
			Relative humidity (percent)	Water in excess of saturation (grams/min)							
200	39	38	92	0	0.00460	14.29	7000	7000	0.096	0.097	2
201	50	50	100	0	.00763	20.25	7000	6960	.095	.096	2
202	45	45	100	20	.00669	17.67	7000	6890	.097	.098	1
203	33	33	100	20	.00431	12.20	6920	6690	.101	.100	1
204	55	55	100	20	.00957	23.21	6920	5830	.097	.095	1
205	65	65	100	20	.01353	30.02	6990	5960	.106	.094	1
206	61	61	100	0	.01144	27.06	7020	7000	.099	.098	2
207	70	70	100	0	.01574	33.96	7000	6970	.098	.099	2
208	72	72	100	20	.01726	35.76	6990	6900	.096	.099	1
209	75	75	100	20	.01911	38.52	6990	6980	.097	.099	2
210	73	73	100	100	.01937	36.92	7000	6810	.097	.098	1
211	76	76	100	200	.02319	40.06	6950	6950	.097	.099	3
212	72	72	100	350	.02352	36.81	6980	6620	.097	.097	1
213	74	74	100	500	.02754	39.10	7000	6980	.096	.098	3
214	71	71	100	600	.02768	36.74	6980	6640	.096	.097	1
215	72	72	100	100	.01877	36.02	7010	6780	.096	.097	1
216	74	74	100	750	.03226	39.89	7000	6980	.097	.098	2
217	72	72	100	850	.03300	38.41	6980	6850	.097	.098	1
218	74	74	100	1000	.03702	40.69	6990	6960	.097	.099	3
219	72	72	100	1000	.03581	38.88	7000	6840	.097	.098	1
220	28	28	100	0	.00313	10.08	7010	7000	.097	.097	2

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

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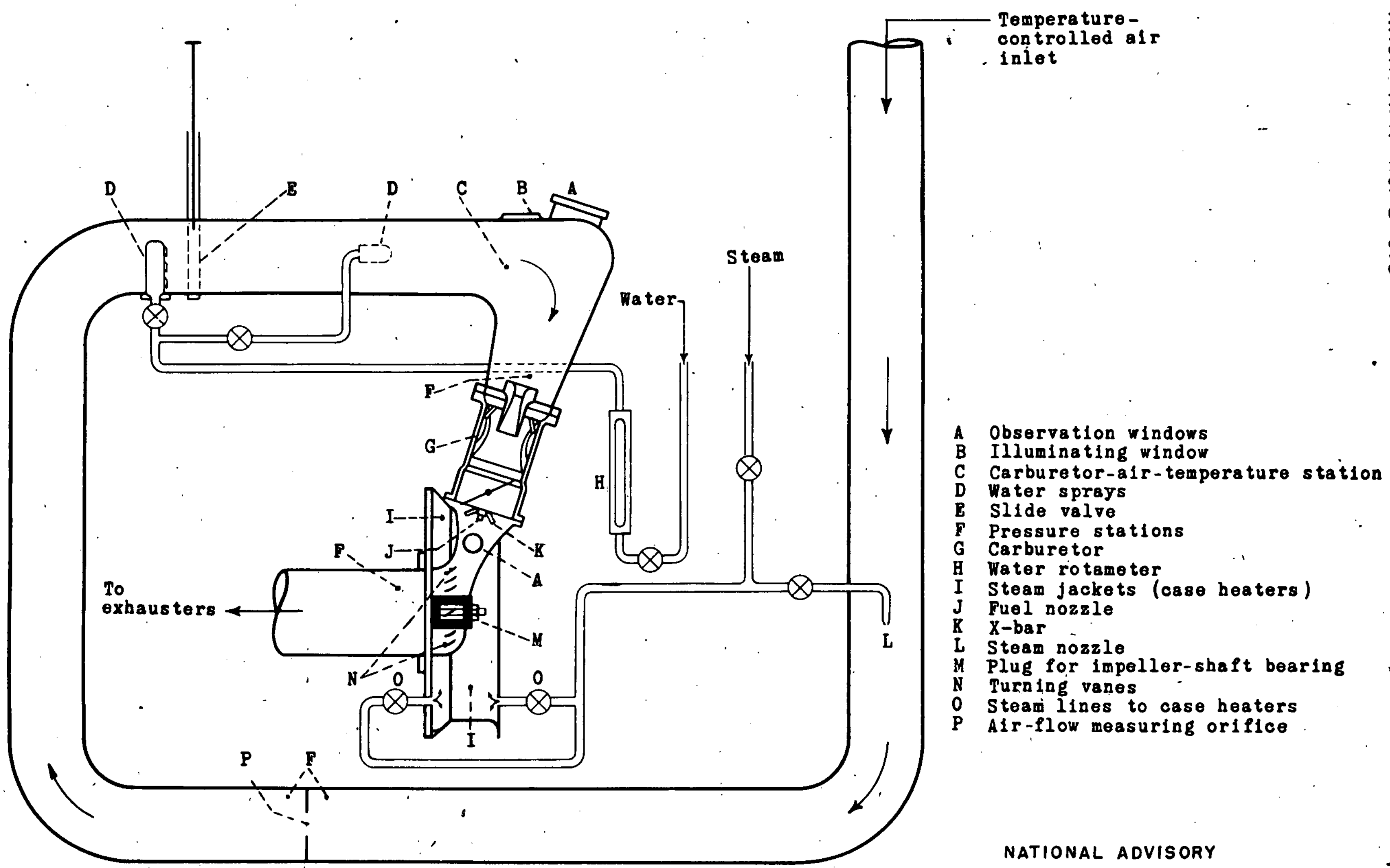


Figure 1. - Schematic diagram of test apparatus.

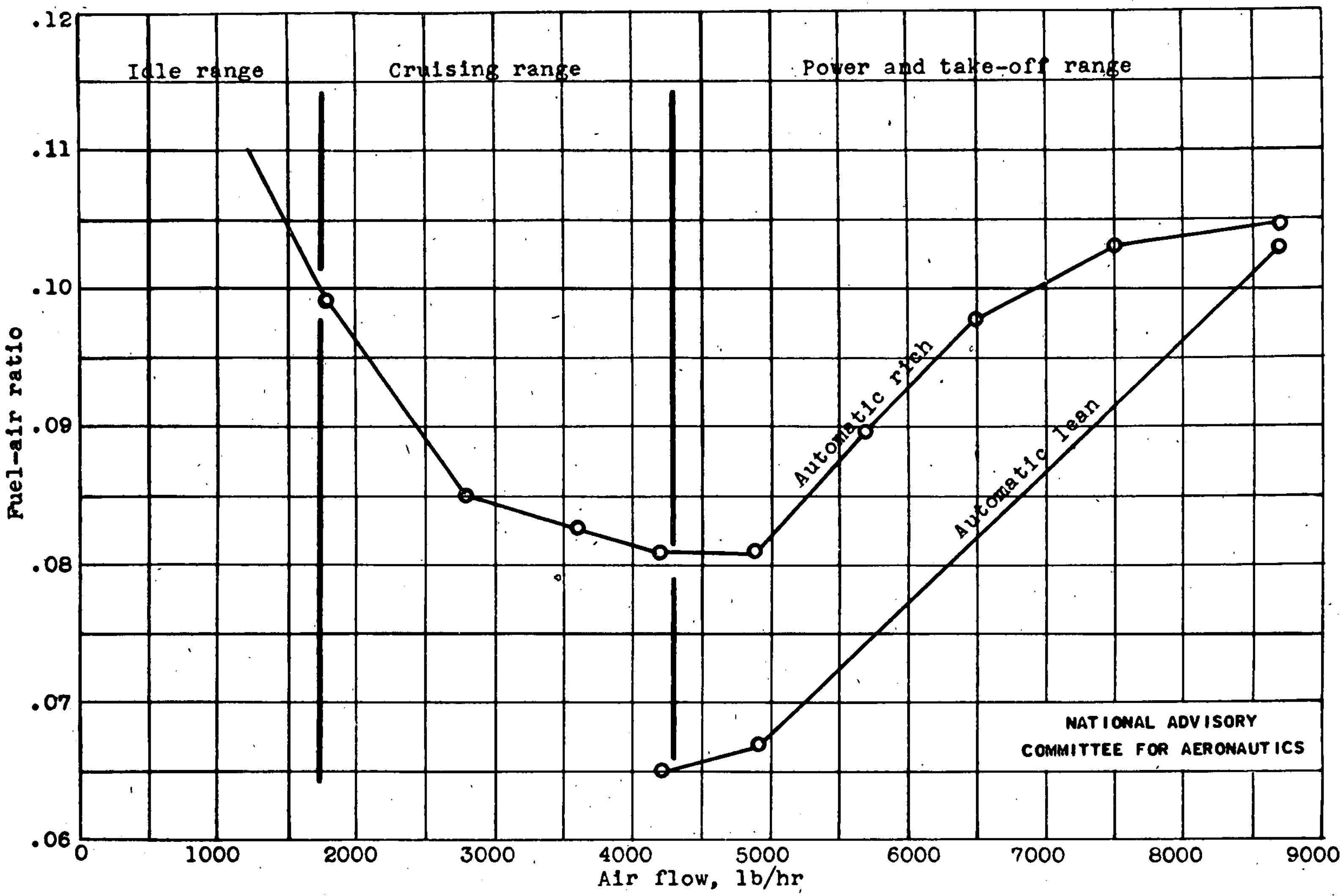


Figure 2. - Carburetor-metering characteristics. Bendix-Stromberg carburetor, model PD-12F5 Ser. No. 326684. Data from manufacturer's tests.

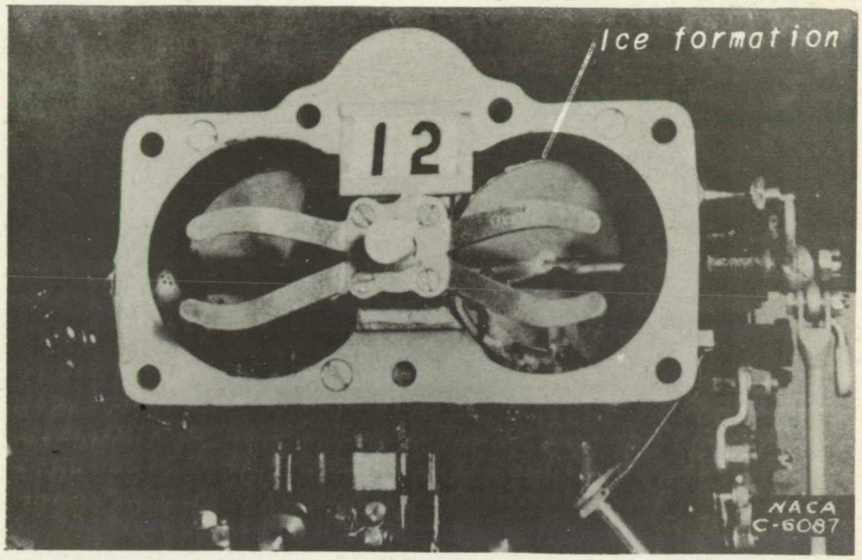


Figure 3. - Icing affecting engine operation at cruising power. Run 12; bottom view of Bendix-Stromberg PD-12F5 carburetor; carburetor-air temperature, 40° F; relative humidity, 84 percent; initial air flow, 4030 pounds per hour.

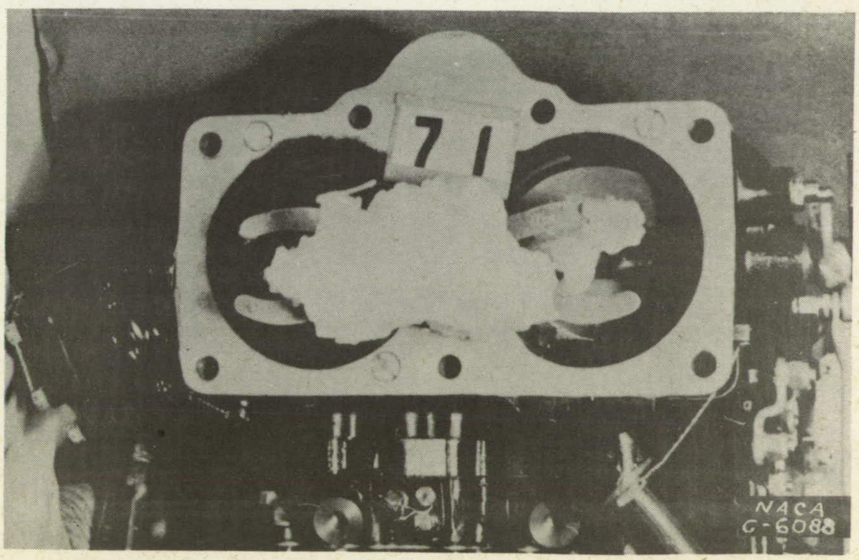


Figure 4. - Visible icing at cruising power. Run 71, bottom view of Bendix-Stromberg PD-12F5 carburetor; carburetor-air temperature, 66° F; water-injection rate, 500 grams per minute; initial air flow, 3990 pounds per hour.

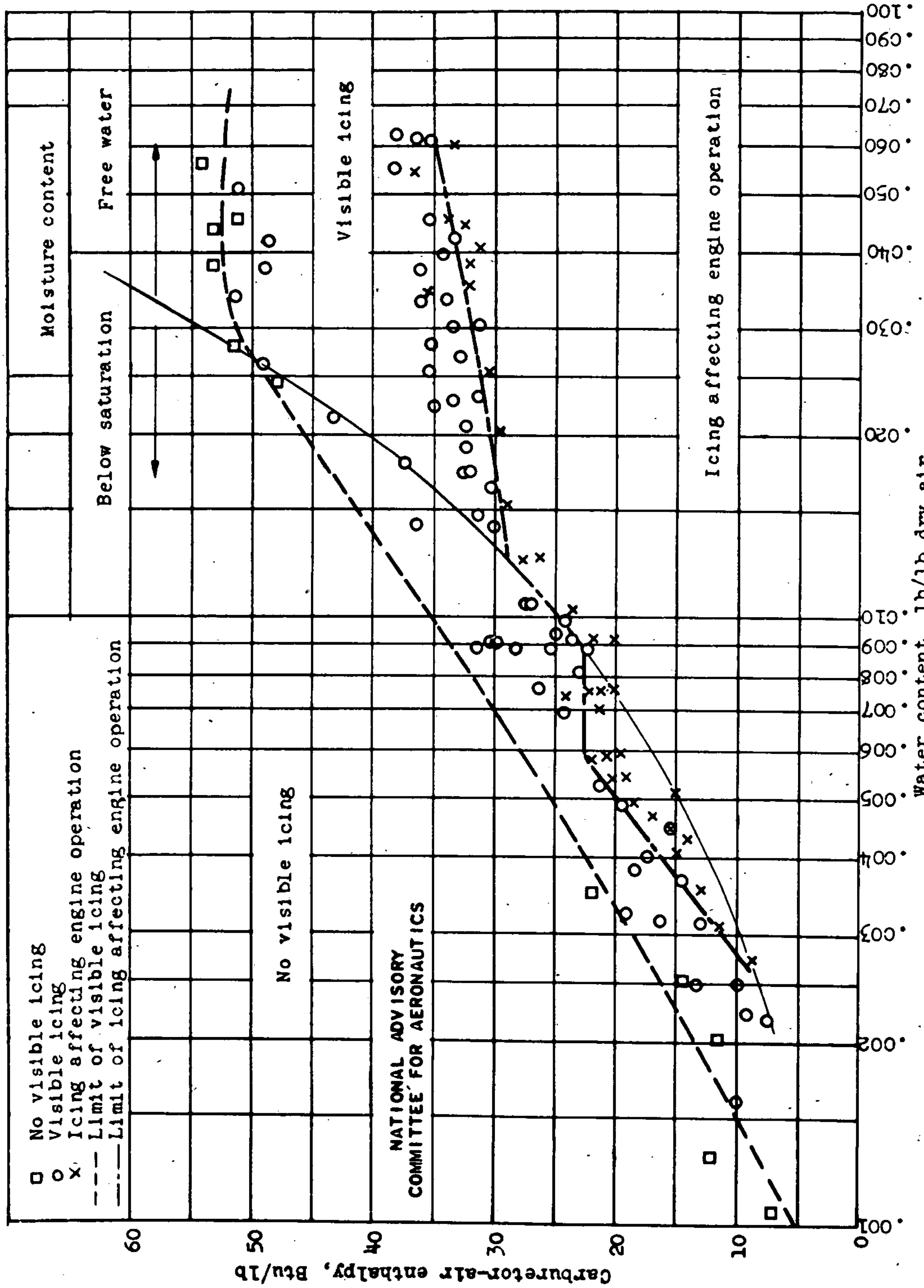


Figure 5. - Limiting icing conditions of enthalpy and moisture content at simulated cruising power. Bendix-Stromberg carburetor, model PD-12F5, with Pratt & Whitney R-1830-C4 intermediate rear engine section; initial air flow, 4000 pounds per hour; initial fuel-air ratio, 0.068; series A.

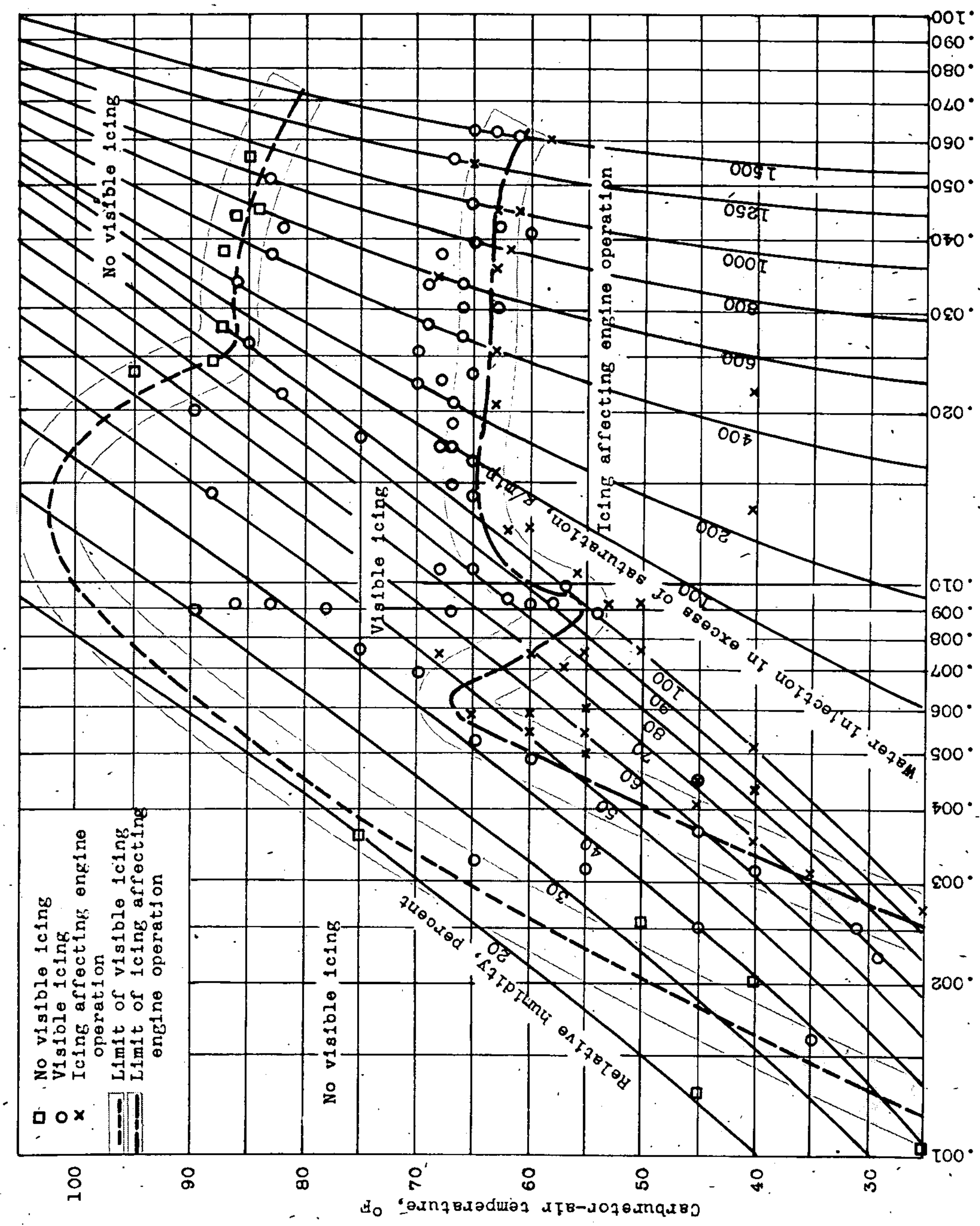
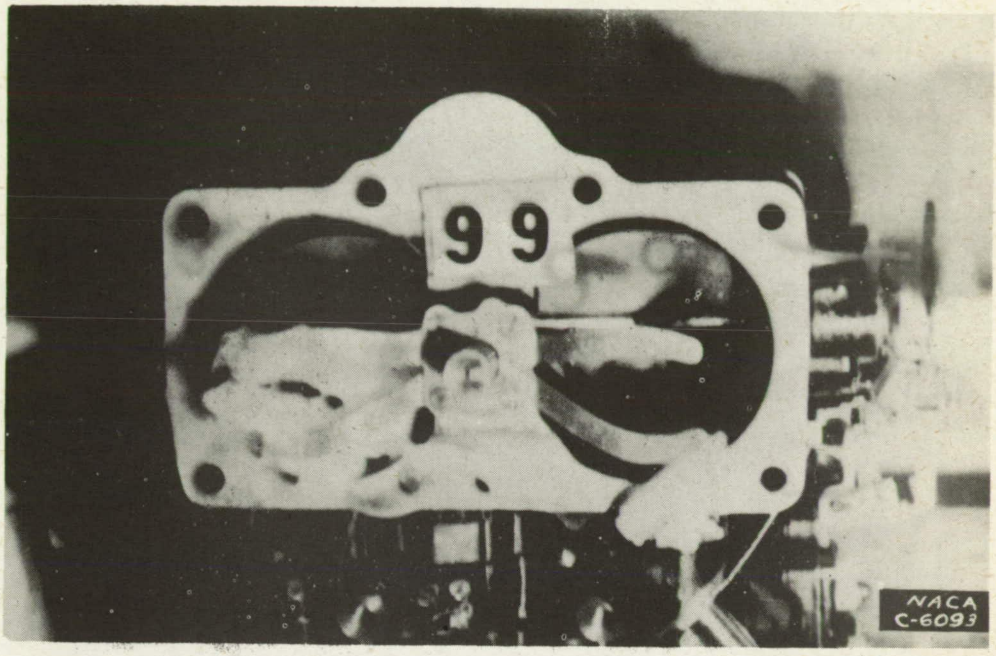
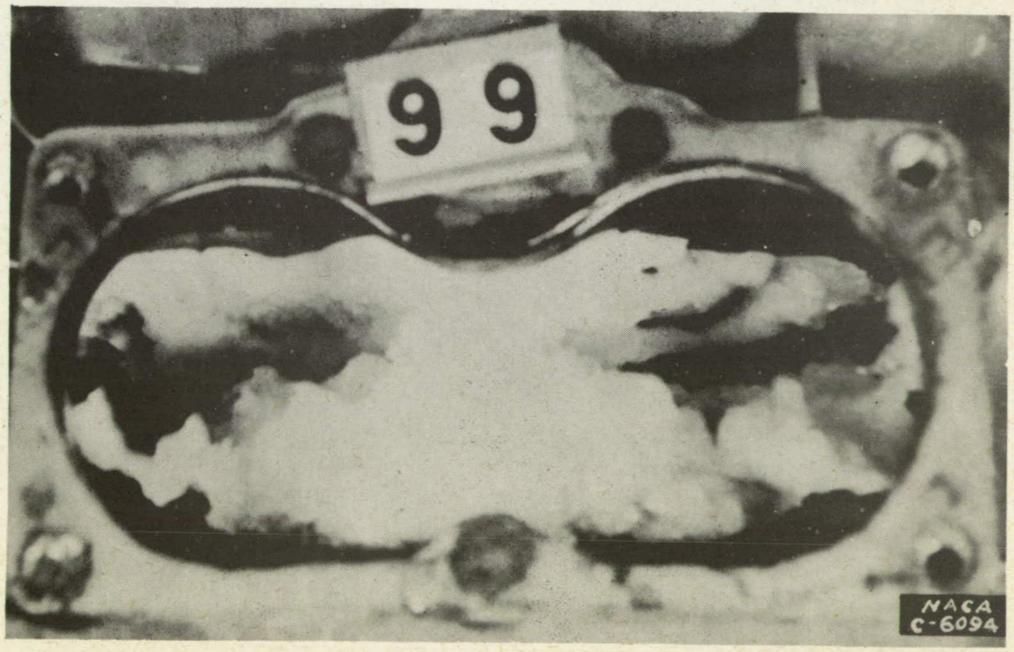


Figure 6.- Limiting icing conditions at simulated cruising power. Bendix-Stromberg carburetor, model PD-12F5, with Pratt and Whitney R-1830-C4 intermediate rear engine section, series A. Initial conditions: air flow, 4000 pounds per hour; fuel-air ratio, 0.068. Red bands designate the estimated variation in limiting conditions.



(a) Bottom view of carburetor showing ice formations on X-bar.



(b) Ice formations in engine air passage.

Figure 7. - Evaporation icing affecting engine operation at cruising power. Run 99; Bendix-Stromberg PD-12F5 carburetor; carburetor-air temperature 40° F; water-injection rate, 500 grams per minute; initial air flow, 4000 pounds per hour.

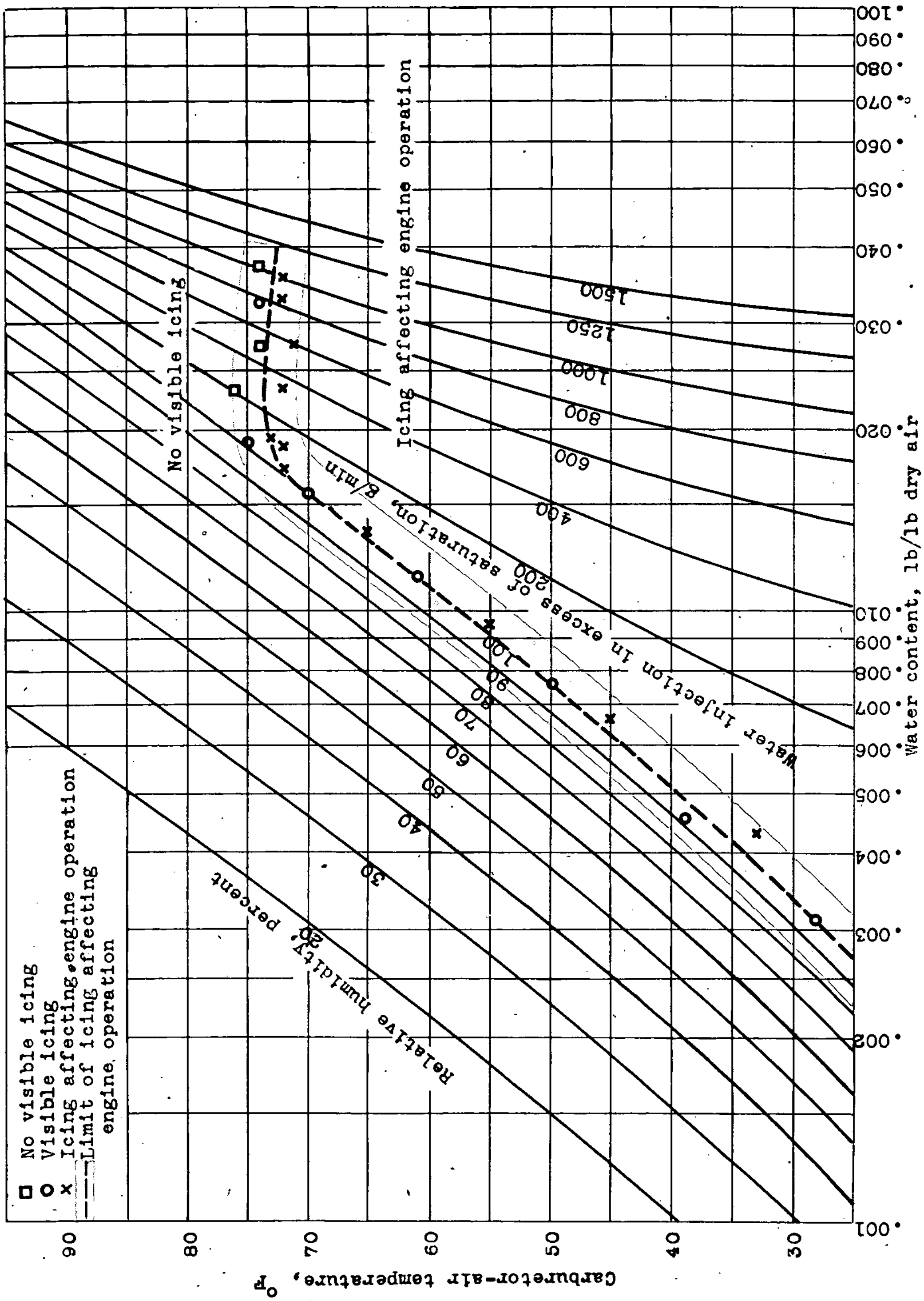


Figure 8.- Limiting icing conditions at simulated rated power. Bendix-Stromberg carburetor, model PD-12F5, with Pratt and Whitney R-1830-C4 intermediate rear engine section, series B. Initial conditions: air flow, 7000 pounds per hour; fuel-air ratio, 0.100. A red band designates the estimated variation in limiting conditions.

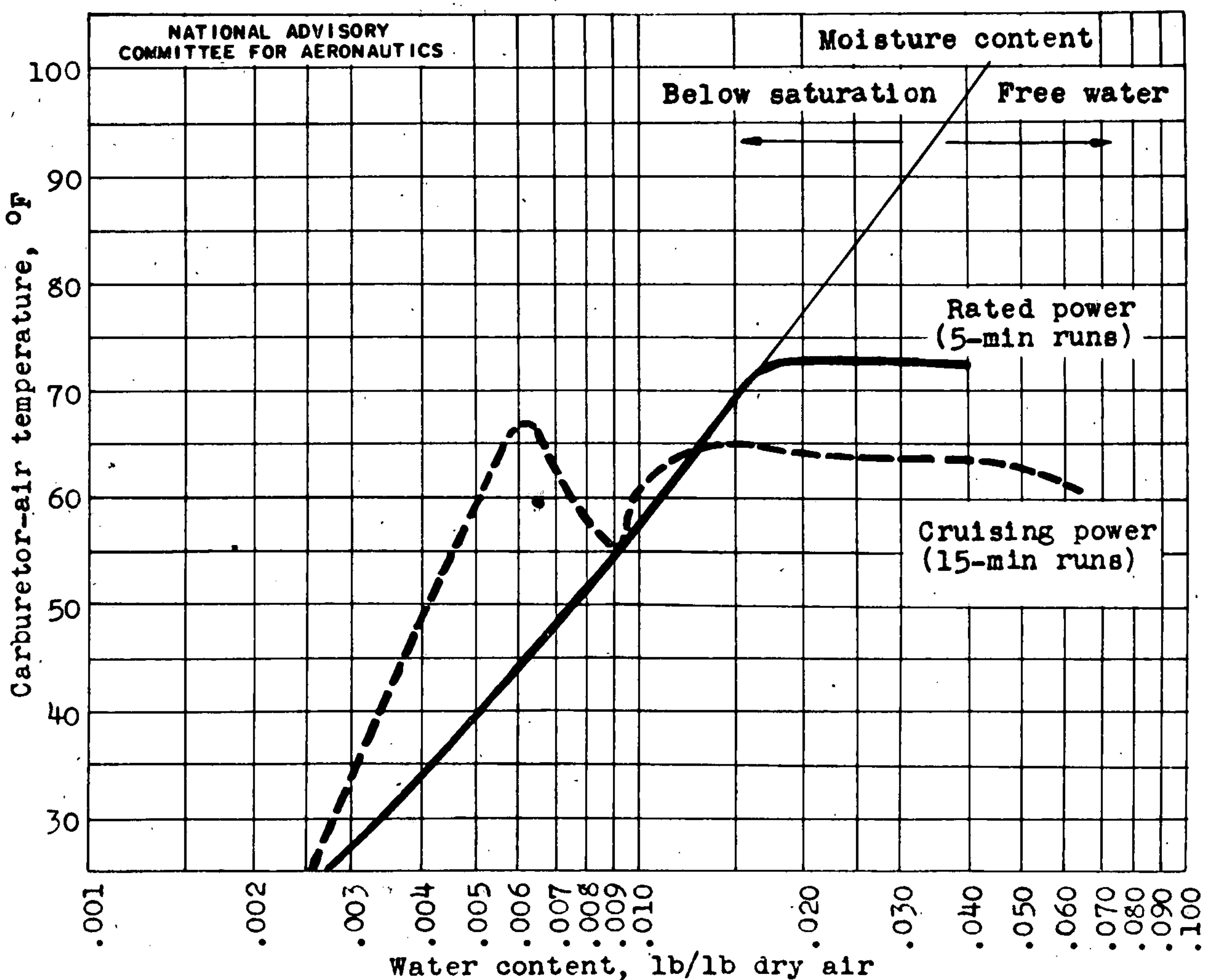


Figure 9. - Comparison of limits of icing affecting engine operation for simulated cruising and rated powers. Bendix-Stromberg carburetor, model PD-12F5, with Pratt & Whitney R-1830-C4 intermediate rear engine section.