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

V - EFFECT OF INJECTION OF WATER-FUEL MIXTURES AND WATER-ETHANOL - FUEL MIXTURES ON THE ICING CHARACTERISTICS

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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

V - EFFECT OF INJECTION OF WATER-FUEL MIXTURES AND WATER-ETHANOL — FUEL MIXTURES ON THE ICING CHARACTERISTICS

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SUMMARY

Tests were conducted to determine the effects of internal coolants injected with the fuel on the icing characteristics of a twin-barrel injection carburetor mounted on an engine-stage supercharger assembly. Tests were made at air-flow conditions that simulated war emergency power.

The results show that for a range of water-fuel ratios from 0 to 0.82, carburetor-air (dry-bulb) temperatures from -20° to 60° F, and carburetor-air relative humidities from 50 to 100 percent, serious icing of the supercharger inlet elbow and of the throttle plates occurred at carburetor-air temperatures below 40° F; for a range of water-ethanol — fuel ratios from 0.20 to 0.80, no serious icing occurred down to -20° F and negligible icing was observed.

INTRODUCTION

At the request of the Air Technical Service Command, Army Air Forces, an investigation has been made of ice formation and elimination in the induction system of an aircraft engine used in a lighter airplane. One phase of this investigation was the study of the effects of internal coolants, consisting of water and water-ethanol mixtures, on induction-system icing.

With low outside-air temperature and high relative humidities, the injection of water-fuel mixtures at some point below the carburetor in the induction system was expected to introduce an icing hazard; whereas the injection of a mixture of water and ethanol, having a depressed freezing point, was expected to minimize the possibility of serious icing.

The purpose of tests made from August to November of 1944 at the NACA Cleveland laboratory was to determine the effect of varying water-fuel and water-ethanol – fuel ratios on the severity or rate of icing of the induction system at various carburetor-air temperatures and relative humidities at war emergency power rating. A supercharger assembly with a carburetor was used to study the icing effects of the two internal coolants as an extension of the investigation reported in reference 1.

APPARATUS

The apparatus for the internal-coolant injection was essentially the same as that described in reference 2 with a few alterations to facilitate water and water-ethanol injection. The conventional fuel-injection nozzle was replaced by a larger injection nozzle capable of discharging the increased amount of liquid. The design of the larger nozzle is essentially the same as the conventional type, except that the size of the nozzle opening and the pintle are larger to accommodate the higher flow rates required with internal-coolant injection.

The water for the water-fuel injection tests was metered directly from the city water supply. For the water-ethanol – fuel injection tests, a large tank was added to retain the water-ethanol solution, an air-pressurizing system was connected to the tank to provide sufficient pressure to inject the solution, and a rotary pump was installed for filling the tank with water-ethanol solution and for continuously circulating the liquid in the tank.

Fuel was metered by the metering section of the carburetor and the coolant-fuel ratio was held constant throughout each run by a needle valve, which permitted the coolant to flow into the fuel line at a point 3 feet from the injection nozzle.

TESTS

The water-ethanol solution used consisted of a mixture by volume of 50 percent water and 50 percent ethanol (ethyl alcohol denatured with 5 percent methyl alcohol).

The procedure and equipment used in these tests are described in detail in reference 2. In addition, internal-coolant flows and temperatures were recorded at frequent intervals. Conditions were established and stabilized at the beginning of each run before the injection of the internal-coolant and fuel mixtures.

The following conditions were held constant during each run:

Engine speed, rpm	3000
Internal-coolant temperature, °F	40
Carburetor top-deck pressure, inches of mercury absolute . . .	23

An air flow of approximately 10,700 pounds per hour and a fuel-air ratio of 0.08 were established at the beginning of each run.

The following table presents the range of variables used in test operation:

Coolant	Carburetor-air temperature (°F)	Relative humidity (percent)	Coolant ratio
Water-fuel	0-60	59-100	0-0.81
Water-ethanol - fuel	-20-60	58-100	0.20-0.80

RESULTS AND DISCUSSION

Observation through windows in the supercharger inlet elbow and through the transparent section above the carburetor showed that all the ice formed in the inlet elbow. Ice formations were first observed on the center rib below the carburetor. During runs at very severe icing conditions, ice would continue to form around the impeller entrance, the injection nozzle, and in the inlet elbow below the nozzle. Sometimes ice formed on the rotating hub of the impeller. Because these runs were made at full throttle, no throttle icing was encountered and, as no free water in excess of saturation was injected above the carburetor, no impact icing occurred.

Results of icing tests with water-fuel injection and with water-ethanol - fuel injection are presented in tables I and II, respectively. The criterion of serious icing has been chosen as a 2-percent reduction in air flow (reference 1). When water-fuel injection was used, serious icing was encountered at carburetor-air (dry-bulb) temperatures below 40° F and at all relative humidities investigated in these tests. When water-ethanol - fuel injection was used, no serious icing was encountered at any of the conditions of these tests, which covered a range of dry-bulb temperatures between 60° and -20° F.

The reduction of air flow resulting from icing when water injection was used has been plotted as a function of time in figures 1, 2, and 3. The fluctuation in air flow during the icing process was caused by the forming and breaking away of the ice deposits, which may be due to the weakening bond between the ice and metal parts as the ice formation became thicker and the transfer of heat from the outside thereby increased. Because of this periodic forming and breaking off of ice, the initial rate of decrease in air flow is a good indication of the severity of icing conditions.

A thorough analysis of the thermodynamic process that takes place in an induction system supercharger inlet elbow requires a complete knowledge of the fractions of water, ethanol, and fuel vaporizing, the temperatures existing at all parts, the amount of heat transfer from the outside, and the quantity of water impinging on those surfaces subjected to freezing temperatures. If it is assumed that 100 percent of the fuel evaporates, calculations show that the resulting cooling is sufficient to freeze all the water to ice when water is injected with the fuel at a ratio of 0.6 without any additional cooling from the carburetor air, which agrees with the test results inasmuch as serious icing occurred at carburetor-air temperatures up to 40° F. When a water-ethanol mixture having a freezing point of -30° F is injected with the fuel as an internal engine coolant, temperatures existing in the supercharger inlet elbow are above that required to freeze the mixture. Small deposits of ice and frost that were observed during runs of water-ethanol injection probably resulted from condensation of moisture from the saturated carburetor air when it was cooled upon entering the inlet elbow and not from the freezing of the water-ethanol mixture.

SUMMARY OF RESULTS

The following results were obtained from tests to determine the effect of internal-coolant injection with fuel on the icing characteristics of an aircraft engine and are applicable only to the induction system tested.

1. Serious icing occurred at carburetor-air temperatures below 40° F when only water was injected with the fuel.

2. The results of tests using water-ethanol — fuel injection indicated that very little visible icing and no icing of a serious nature occurred at carburetor-air temperatures as low as -20° F and at relative humidities as low as 58 percent.

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Cleveland, Ohio.

REFERENCES

1. Essex, Henry A., Keith, Wayne C., and Mulholland, Donald R.: Laboratory Investigation of Icing in the Carburetor and Supercharger Inlet Elbow of an Aircraft Engine. II - Determination of the Limiting-Icing Conditions. NACA MR No. E5L18a, 1945.

2. Mulholland, Donald R., Rollin, Vern G., and Galvin, Herman B.: Laboratory Investigation of Icing in the Carburetor and Supercharger Inlet Elbow of an Aircraft Engine. I - Description of Setup and Testing Technique. NACA MR No. E5L13, 1945.

TABLE I. - SUMMARY OF INDUCTION-SYSTEM ICING TESTS

AND RESULTS WITH WATER-FUEL MIXTURES

[Fuel-air ratio, 0.08; water-fuel temperature, 40° F; carburetor top-deck pressure, 23.0 in. Hg absolute; engine speed, 3000 rpm]

Initial air flow (lb/hr)	Water-fuel ratio	Carburetor-air temperature (°F)	Relative humidity (percent)	Results
10,575	0.30	60	100	No visible icing
11,030	.59	60	100	Do.
10,680	(a)	40	100	Visible icing
10,575	0.31	40	100	Do.
10,765	.41	40	100	Serious icing
10,720	.57	40	100	Visible icing
11,230	.59	40	100	Do.
11,125	.79	40	100	Do.
10,660	(a)	30	100	Visible icing
10,630	0.30	30	100	Serious icing
11,230	.31	30	100	Do.
10,650	.44	30	100	Do.
11,180	.57	30	100	Do.
10,660	.60	30	100	Do.
11,230	.81	30	100	Do.
11,190	(a)	20	100	Visible icing
11,380	0.20	20	100	Serious icing
11,245	.33	20	100	Do.
11,070	.40	20	100	Do.
10,800	.61	20	100	Do.
11,040	.62	20	100	Do.
10,680	.67	20	100	Do.
10,720	.79	20	100	Do.
11,475	(a)	0	100	Visible icing
11,425	0.20	0	100	Serious icing
10,690	.31	0	100	Do.
10,740	.60	0	100	Do.
10,720	.81	0	100	Do.
10,735	(a)	40	60	No visible icing
10,450	0.31	40	59	Serious icing
11,210	.60	40	60	Visible icing
11,165	.82	40	59	Do.
11,170	0.31	40	50	Visible icing
10,450	.31	40	59	Serious icing
10,410	.31	40	79	Visible icing
10,575	.31	40	100	Do.

[a]No water injection.

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TABLE II. - SUMMARY OF INDUCTION-SYSTEM ICING TESTS

AND RESULTS WITH WATER-ETHANOL — FUEL MIXTURES

[Fuel-air ratio, 0.08; water-ethanol — fuel temperatures, 40° F; carburetor top-deck pressure, 23.0 in. Hg absolute; engine speed, 3000 rpm]

Initial air flow (lb/hr)	Water-ethanol — fuel ratio	Carburetor-air temperature (°F)	Relative humidity (percent)	Results
10,680	0.30	60	100	Visible icing
10,675	.80	60	100	Do.
10,670	0.29	40	100	Visible icing
10,670	.59	40	100	Do.
10,590	.80	40	100	Do.
10,555	0.30	35	100	Visible icing
10,730	.59	35	100	Do.
10,750	.80	35	100	No visible icing
10,780	0.30	30	100	No visible icing
10,770	.60	30	100	Do.
10,740	.80	30	100	Do.
10,515	0.20	0	100	Visible icing
10,535	.39	0	100	Do.
10,540	.58	0	100	Do.
10,555	.78	0	100	Do.
10,720	0.30	-20	100	Visible icing
10,685	.60	-20	100	Do.
10,685	.79	-20	100	Do.
10,765	0.20	40	58	No visible icing
10,765	.30	40	58	Do.
10,750	.40	40	58	Do.
10,785	.59	40	58	Do.
10,790	.80	40	58	Do.

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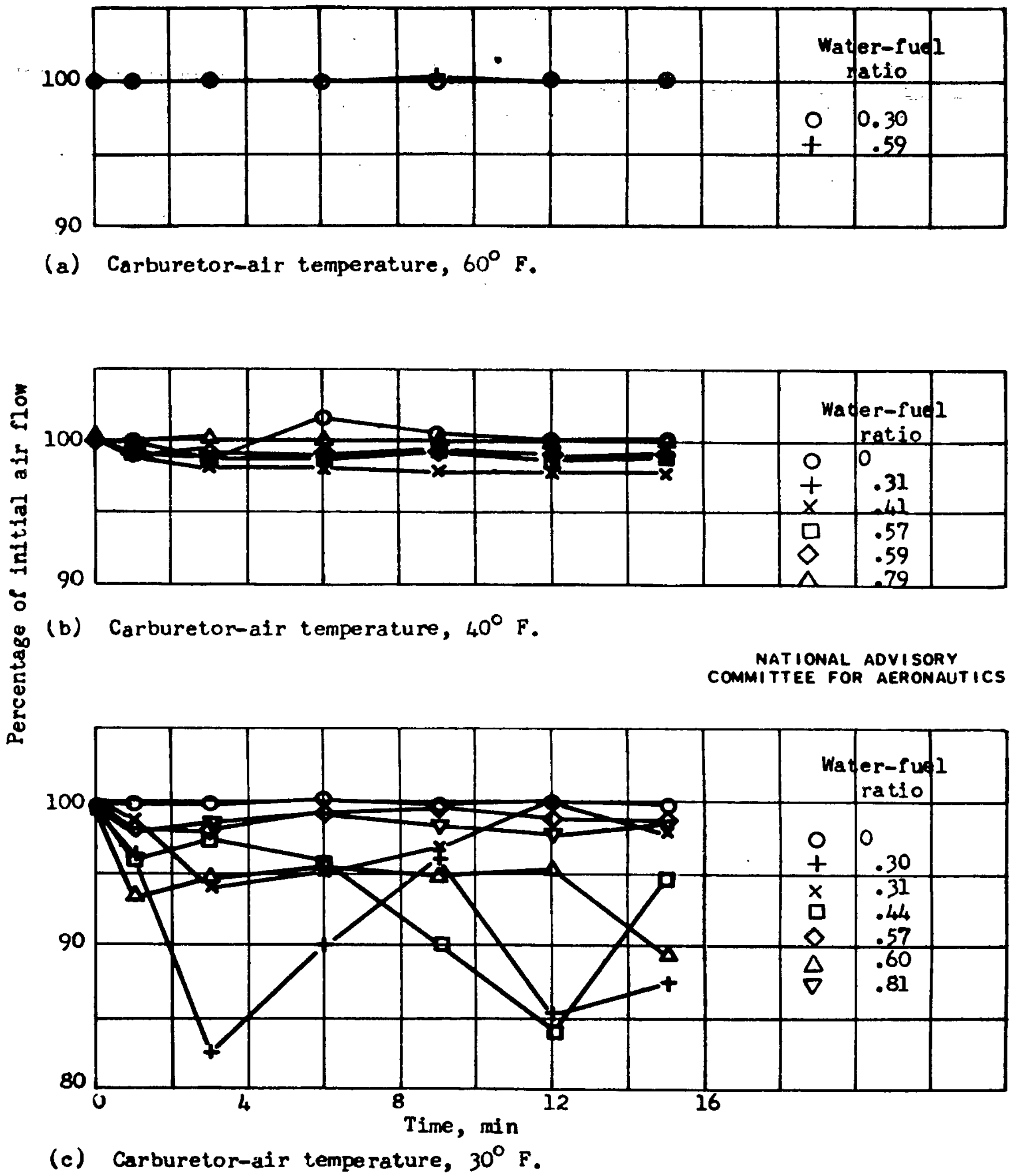
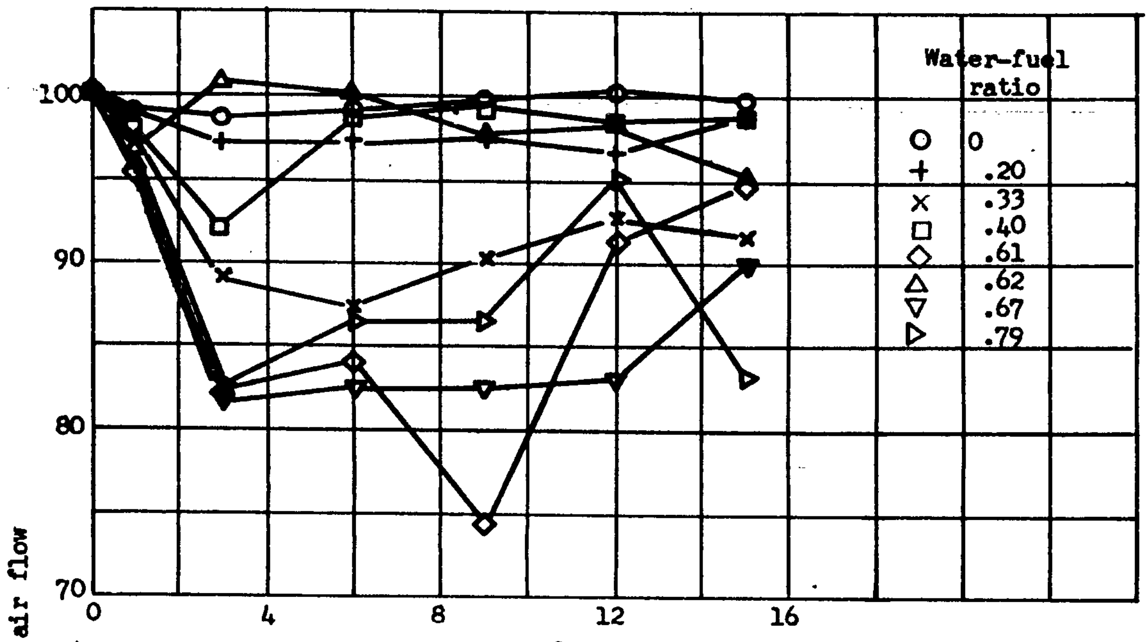


Figure 1. - Effect of varying water-fuel ratio on air flow at 100-percent relative humidity. Fuel-air ratio, 0.08; carburetor top-deck pressure, 23.0 inches mercury absolute; initial air flow, 10,700 pounds per hour; engine speed, 3000 rpm.



(d) Carburetor-air temperature, 20° F.

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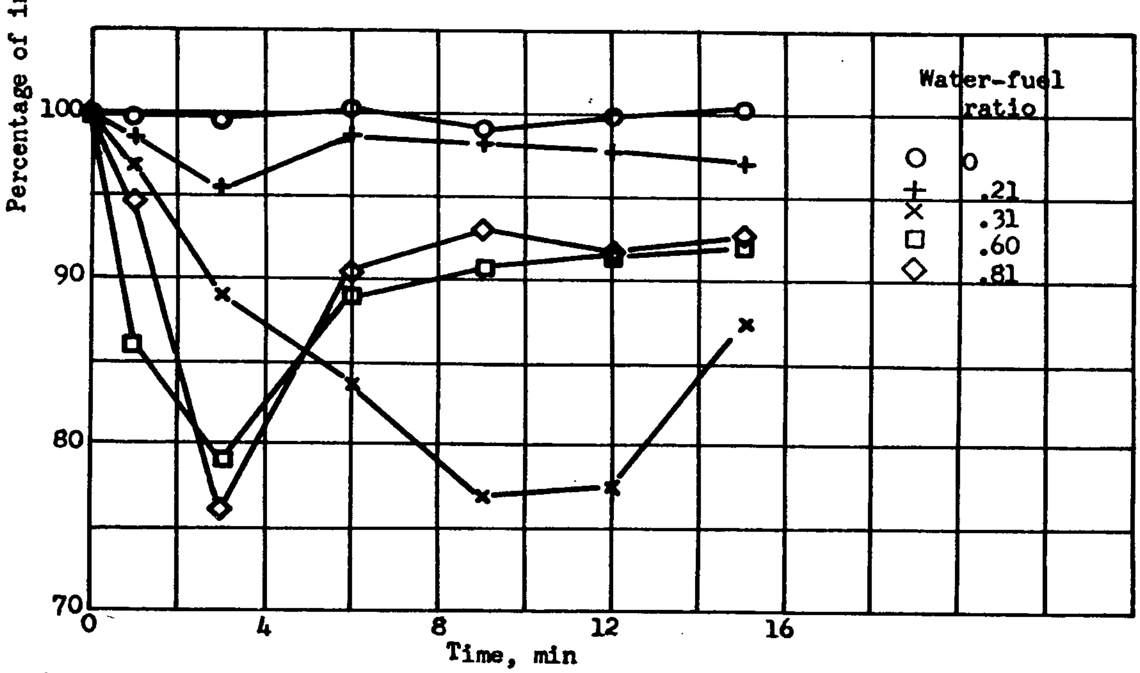

(e) Carburetor-air temperature, 0° F.

Figure 1. - Concluded. Effect of varying water-fuel ratio on air flow at 100-percent relative humidity. Fuel-air ratio, 0.08; carburetor top-deck pressure, 23.0 inches mercury absolute; initial air flow, 10,700 pounds per hour; engine speed, 3000 rpm.

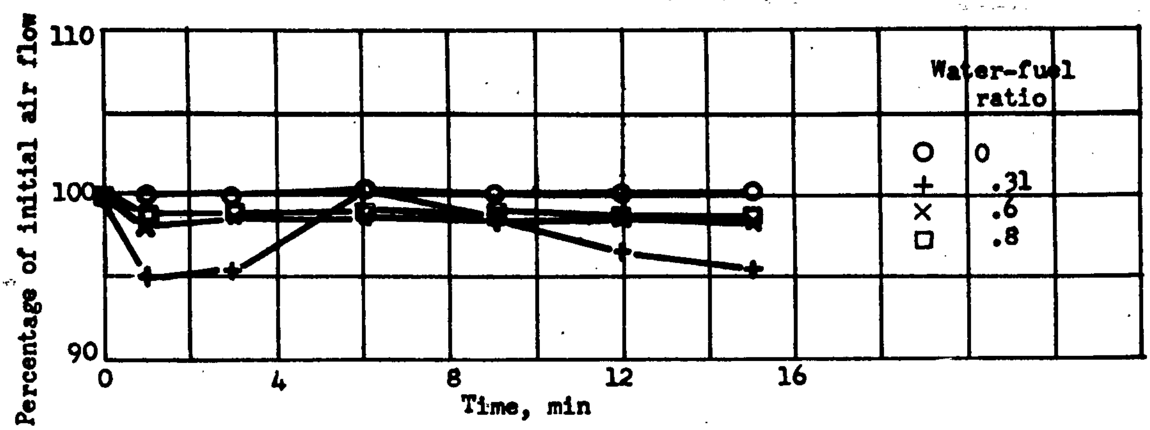

Figure 2. - Effect of varying water-fuel ratio on air flow at 60-percent relative humidity. Carburetor-air temperature, 40° F; fuel-air ratio, 0.08; carburetor top-deck pressure, 23.0 inches mercury absolute; initial air flow, 10,700 pounds per hour; engine speed, 3000 rpm.

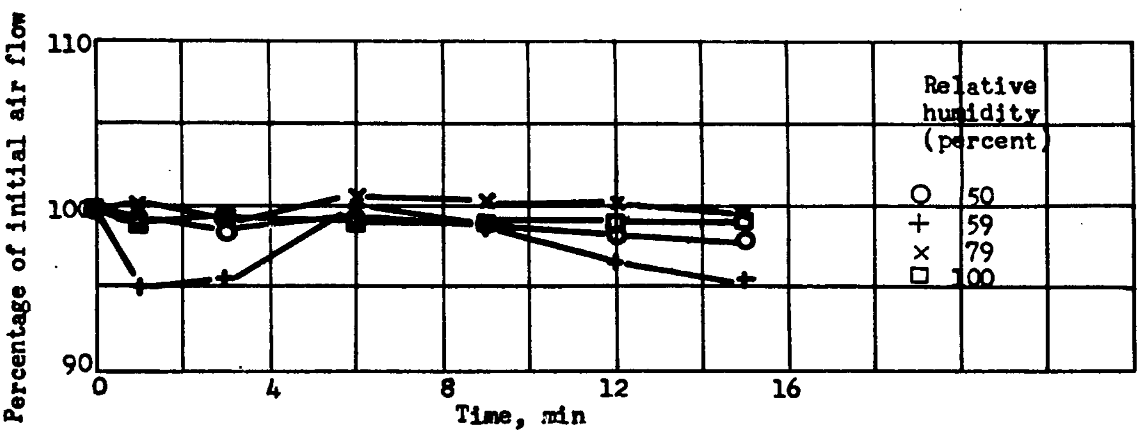

Figure 3. - Effect of varying relative humidity on air flow. Water-fuel ratio, 0.31; carburetor-air temperature, 40° F; fuel-air ratio, 0.08; carburetor top-deck pressure, 23.0 inches mercury absolute; initial air flow, 10,700 pounds per hour; engine speed, 3000 rpm.