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RESEARCH MEMORANDUM

INLET ICING AND EFFECTIVENESS OF HOT-GAS BLEEDBACK FOR ICE PROTECTION OF TURBOJET ENGINE

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NATIONAL ADVISORY COMMITTEE
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November 26, 1948

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RESEARCH MEMORANDUM

INLET ICING AND EFFECTIVENESS OF HOT-GAS BLEEDBACK FOR ICE PROTECTION OF TURBOJET ENGINE

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SUMMARY

An investigation of icing and ice protection at the inlet of a turbojet engine has been conducted in the NACA Cleveland altitude wind tunnel. A method of ice protection was studied whereby hot gas was bled from the turbine inlet and injected into the air stream ahead of the compressor inlet. Icing conditions were simulated by spraying water into the air stream ahead of the engine nacelle. The investigation was conducted at simulated altitudes of 5000 and 20,000 feet with ambient-air temperatures from 0° to 35° F.

Formation of ice at the compressor inlet reduced the net thrust, increased the specific fuel consumption based on net thrust, and within a short period of time rendered the engine inoperative because of excessively high turbine temperatures. The hot-gas bleedback system removed ice that had formed and prevented further ice formation at the compressor inlet at ambient-air temperatures from 25° to 30° F. At an ambient-air temperature of 0° F, ice formation was prevented at 11,000 rpm, but ice formed very slowly at 10,000 rpm with the bleedback system in operation. At an engine speed of 12,000 rpm with 4.0 percent of the gas flow bled to the inlet, the net thrust was decreased 18.8 percent and the specific fuel consumption based on net thrust was increased 21.3 percent.

INTRODUCTION

Ice formation at the compressor inlet of a turbojet engine in flight will result in a reduction in thrust. Serious icing will render the engine inoperative as a result of excessively high exhaust-gas temperatures. Flight in icing weather without equipment to protect the engine inlet from ice is therefore extremely hazardous, particularly with engines that have axial-flow compressors.

As part of a general program being conducted at the NACA Cleveland laboratory on ice protection at the inlet of turbojet engines, an investigation was conducted in the altitude wind tunnel from April to July, 1947 with a turbojet engine having an axial-flow compressor. A method of ice protection was studied in which hot gas was bled from the turbine inlet and injected into the air stream ahead of the compressor inlet in order to heat the inlet air above the freezing temperature. This method of ice protection will be referred to as "hot-gas bleedback". Gas was bled from the turbine inlet because the gas at this station has the highest temperature and pressure in the engine. Because of the high temperature of the gas, a relatively small quantity is needed to heat the inlet air above the freezing temperature. The gas can be discharged into the air stream at very high velocity because of its high pressure, thus affording good penetration.

The investigation was conducted at two simulated altitudes and over a range of ambient-air temperatures. Objectives of the program were: (1) to study the characteristics of compressor-inlet icing and the effect of icing on engine performance; (2) to study ice prevention and de-icing at the compressor inlet by means of hot gas injected into the air stream; and (3) to determine the effect of hot-gas bleedback on engine performance.

INSTALLATION AND INSTRUMENTATION

An early experimental Westinghouse 24C turbojet engine was mounted in a wing nacelle installed in the test section of the altitude wind tunnel. The engine has an 11-stage axial-flow compressor, a double-annulus combustion chamber, and a two-stage turbine. The rated thrust of the engine is approximately 3000 pounds at static sea-level conditions and an engine speed of 12,500 rpm. The corresponding air flow is about 58.5 pounds per second. No screens were installed in the induction system of this engine.

The engine installation with the hot-gas bleedback system installed is shown in figure 1. A plan drawing of the engine and the hot-gas bleedback system is presented in figure 2. Hot gas was bled from two diametrically opposite points at the turbine inlet. The gas was carried to the top of the engine through two 3-inch-diameter ducts and forward in a single 4-inch-diameter duct. At the front of the engine, the hot gas was directed into two 3-inch-diameter ducts on either side of the inlet duct and was discharged into a manifold formed by the cowl-inlet lip. Holes were located around the inner circumference of the cowl-inlet lip, through which the gas was injected into the air stream normal to the direction of air flow. A butterfly valve that regulated the flow of hot gas was located in the 4-inch-diameter duct at the rear of the engine. A survey rake was installed at the forward end of this duct to obtain measurements of temperature and pressure, which were used to calculate the mass flow that was bled to the inlet. Two thermocouples and two static-pressure orifices were installed within the hot-gas manifold. All hot-gas ducts were insulated by several layers of asbestos tape.

The following four configurations of hole arrangements in the hot-gas manifold at the cowl inlet were investigated (fig. 3(a)):

Configuration	Number of holes	Hole diameter (in.)	Total hole area (sq in.)	Maximum bleedback (percent)
1	76	11/32	7.05	4.8
2	19	1/2	3.74	3.5
3	15 4	1/2 7/8	5.35	4.0
4	9 3	5/8 7/8	4.57	4.7

In configuration 4, provision was made to prevent ice formation on the starting-motor housing by internal heating of the housing dome. A hemispherical cap was installed over the dome, as shown in figure 3(b). Hot gas was bled into the cap through a streamlined strut, passed between the cap and the dome, and discharged into the air stream.

Temperature distributions across the inlet duct with hot-gas bleedback were obtained with a thermocouple survey rake that extended radially to the center of the duct (fig. 2) and was mounted in a plane $31\frac{1}{4}$ inches downstream of the plane at which the hot gas was injected. Similar rakes were mounted at the compressor inlet. For configuration 4, an additional thermocouple rake was installed at the $31\frac{1}{4}$-inch station in order to obtain a temperature survey across the full diameter of the duct. Ambient-air temperature was measured with two thermocouples located immediately upstream of the water spray.

A strut on which five air-atomizing spray nozzles were mounted (fig. 4) was installed 7 feet ahead of the cowl inlet and 12 feet ahead of the compressor inlet in the tunnel test section. In order to permit better control of inlet icing conditions, a movable spray-nozzle assembly was used for configuration 4, with which the spray nozzles could be located at distances from 1 to 7 feet ahead of the cowl inlet. A periscope that extended from the wall of the tunnel test section could be raised above or lowered in front of the engine inlet from outside of the test section (fig. 4). A floodlight and a 16-millimeter motion-picture camera were installed inside the fairing at the lower end of the periscope in order to photograph the inlet of the engine under icing conditions.

PROCEDURE

The investigation was conducted at an airspeed of 140 miles per hour and pressure altitudes of 5000 and 20,000 feet, with ambient-air temperatures from 0° to 35° F at each altitude. The engine was operated below the rated engine speed of 12,500 rpm in order to allow for the rise in exhaust-gas temperature that occurred when ice formed or when the bleedback system was operated. The highest engine speed at which hot-gas bleedback was used was 12,000 rpm, at which speed the turbine-outlet temperature without bleedback was 80° F below the limiting value. The highest engine speed at which inlet icing was investigated was 11,000 rpm, at which speed the turbine-outlet temperature without bleedback and without ice on the inlet was 200° F below the limiting value.

The liquid-water concentrations and droplet sizes (approximately 55 microns) used in the icing conditions for this investigation were larger than those normally encountered in the atmosphere. The ice-protection results based on severe icing conditions are therefore considered to be conservative. De-icing results obtained subsequent to icing would not be affected. Some of the water froze before reaching the compressor inlet at all spray-nozzle positions. This effect was minimized by heating the water to a temperature of at least 100° F.

For the phase of the investigation in which the penetration of the hot gas at the compressor inlet and the effect of hot-gas bleedback on performance was determined, no water was injected into the air stream. Engine performance data and temperature profiles in the inlet duct and at the compressor inlet were obtained with various amounts of hot-gas bleedback at several engine speeds. Thrust was calculated from measurements obtained with a survey rake mounted at the exhaust nozzle.

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Three procedures were used in the study of ice prevention and de-icing. In the procedure for ice prevention, hot gas was bled into the inlet before the water spray was turned on. The effectiveness of the hot gas for preventing ice formation at the compressor inlet was thus determined. In the first procedure for de-icing, the inlet was iced until the turbine-outlet temperature was within 50° to 100° F of the limiting value; hot gas was then bled into the inlet while water was still being sprayed into the air stream. This procedure determined the effectiveness of the hot gas for de-icing the inlet and preventing further icing. De-icing was continued until all ice had been removed. In the second procedure for de-icing, the inlet was iced until the turbine-outlet temperature was within 50° F of the limiting value; then the water spray was shut off and hot gas was bled to the inlet. This method determined the time required to de-ice the inlet and the manner in which it de-iced. During this part of the investigation, the characteristics of inlet icing were studied and the effect of inlet icing on performance was determined.

RESULTS AND DISCUSSION

Characteristics of Inlet Icing

The first indication of inlet icing was a rise in turbine-outlet temperature, which usually occurred approximately 2 to 4 minutes after the water spray was turned on. When the water spray was left on and no effort was made to prevent ice formation on the compressor-inlet guide vanes, excessively high turbine-outlet temperatures occurred at all engine speeds and rendered the engine inoperative within 1 to 2 minutes after the initial indication of icing. A photograph of the compressor inlet partly iced is shown in figure 5(a) for an engine speed of 10,000 rpm and a turbine-outlet temperature of 1150° F, which is approximately 100° F above the normal operating temperature. The photograph shows ice formation on the compressor-inlet guide vanes and a heavy ice formation on the dome of the starting-motor housing. An ice formation at the compressor inlet that rendered the engine inoperative is evident in figure 5(b), which shows that the air passage near the roots of the compressor-inlet guide vanes was almost completely blocked, a large percentage of the air passage near the tips of the guide vanes was blocked, and a very heavy coat of ice had formed on the dome of the starting-motor housing.

On several occasions, the inlet was deliberately iced until the turbine-outlet temperatures reached the limiting value. The engine was then stopped and a visual inspection was made of the inlet ice formations. The first- and second-stage rotor blades had a smooth coating of ice about $\frac{1}{8}$ inch thick that extended rearward and covered approximately 75 percent of the blade chord. The first- and second-stage stator blades had similar ice formations. In each case the formation was greatest at the blade roots and little or no ice existed at the blade tips. On one occasion, ice formations extended about 6 inches ahead of the leading edge of the inlet guide vanes although air passages still existed between adjacent ice formations.

Considerable reductions in net thrust resulted from ice formations at the compressor inlet. The percentage decrease in net thrust is presented in figure 6 as a function of the percentage decrease in air flow for several engine speeds at altitudes of 5000 and 20,000 feet, an airspeed of 140 miles per hour, and an ambient-air temperature of about 30° F. Icing of the compressor-inlet guide vanes throttled the inlet air and produced the same effect on engine performance that would be encountered in operation at ram-pressure ratios below 1.0. In addition to inlet throttling, the ice that formed on the first few stages of the compressor blades changed the compressor efficiency, which further affected the engine performance. When the air flow had been decreased by approximately 28 percent, the engine could no longer be operated at any speed without exceeding the turbine-outlet temperature limits. A 26-percent decrease in air flow was accompanied by a 30.2-percent decrease in net thrust.

As the inlet became iced, the specific fuel consumption based on net thrust increased very rapidly, as shown in figure 7. When the air flow was decreased 26 percent, the specific fuel consumption increased 48.0 percent. The increase in specific fuel consumption was large because as the inlet became iced the net thrust was reduced, while the engine fuel flow was increased in order to maintain constant engine speed.

Characteristics of Hot-Gas Bleedback

Effectiveness for ice protection. - Temperature profiles in the inlet duct and at the compressor inlet were obtained for the four bleedback configurations to determine the penetration of the hot gas into the air stream. A large number of small holes were used in configuration 1 in order to obtain a homogeneous mixture of hot gas around the circumference of the compressor inlet. The hole arrangement was progressively modified for the other three configurations so that a more uniform radial temperature distribution could be obtained. For all the temperature profiles shown, the bleedback valve was wide open.

The temperature profiles across the inlet duct and the compressor inlet for configuration 1 are shown in figure 8 for engine speeds of 8000 and 10,000 rpm. The hot gas penetrated 6 inches into the air stream (fig. 8(a)). The temperature was excessively high near the outer wall of the inlet duct and the temperature at the center portion of the duct was approximately the same as ambient-air temperature. The engine could not be operated at an engine speed of 12,000 rpm with the bleedback valve wide open without exceeding the turbine-outlet temperature limits.

Inasmuch as inadequate penetration was obtained with the first configuration, the holes in the manifold were modified. Experiments have shown that the depth of penetration of a jet is approximately proportional to the orifice diameter and the square of the ratio of jet velocity to stream velocity. The diameter of the holes for configuration 2 was therefore increased from $\frac{11}{32}$ to $\frac{1}{2}$ inch and the number of holes was reduced from 76 to 19, with a corresponding reduction in area from 7.05 to 3.74 square inches. This reduction in hole area decreased the gas flow that was bled to the inlet. The compressor-inlet temperature was thereby reduced, with a resulting increase in compressor Mach number and a corresponding rise in compressor-outlet and turbine-inlet pressures. The higher pressures obtained in the hot-gas manifold therefore increased the jet velocity.

Temperature profiles obtained with configuration 2 at engine speeds of 8000, 10,000, and 12,000 rpm are presented in figure 9. The temperature in the inlet duct (fig. 9(a)) was approximately constant for a distance of 4 inches from the outer wall and decreased to approximately ambient-air temperature at a distance of $7\frac{1}{2}$ inches from the outer wall. All the air entering the compressor inlet was above the ambient-air temperature (fig. 9(b)). A photograph of the compressor inlet, which was obtained after approximately 10 minutes of de-icing at an engine speed of 10,000 rpm and with the water spray off (fig. 10(a)), shows that large formations of ice remained on the starting-motor housing and compressor-inlet guide vanes. After 20 minutes of de-icing (fig. 10(b)), very little ice had been removed from the starting-motor housing because of inadequate penetration of the hot gas.

In order to improve the penetration, four of the 19 holes in the hot-gas manifold were enlarged from $\frac{1}{2}$- to $\frac{7}{8}$-inch diameter for configuration 3, with a corresponding increase in area from 3.74 to 5.35 square inches. Temperature profiles obtained with configuration 3 for engine speeds of 6000, 9000, and 11,000 rpm are presented in figure 11. The temperature in the inlet duct, measured directly downstream of one of the large holes (fig. 11(a)), was approximately constant for a distance of $5\frac{1}{2}$ inches from the outer wall and gradually decreased to approximately 28° F above ambient-air temperature at the duct center line for engine speeds of 9000 and 11,000 rpm. At the compressor-inlet annulus, the temperature was only about 15° F lower at the inner wall than at the outer wall (fig. 11(b)).

For configuration 4, the dome of the starting-motor housing was internally heated with hot gas (fig. 3(b)) and 12 holes were drilled 30° apart in the hot-gas manifold; three of these holes, 120° apart, were $\frac{7}{8}$ inch in diameter and the other nine holes were $\frac{5}{8}$ inch in diameter. Temperature profiles across the diameter of the inlet duct and at the compressor inlet for engine speeds of 8000, 10,000, and 11,000 rpm are shown in figure 12. The temperature across the inlet duct (fig. 12(a)) was considerably above the ambient-air temperature and was lowest at the duct center line. The temperature profile was uniform across the compressor-inlet annulus (fig. 12(b)) except near the inner wall, where the temperature was highest because of the hot gas discharged from the cap of the starting-motor housing.

Hot-gas bleedback with configuration 4 was effective not only in preventing ice formation at the compressor inlet but also in de-icing the inlet under continued icing conditions. At an ambient-air temperature between 25° and 30° F, the inlet was iced at several different engine speeds until the turbine-outlet temperature was approximately 1200° F. Hot gas was then bled to the inlet with the water spray remaining on. At engine speeds from 10,000 to 11,000 rpm, approximately 5 minutes were required to clear the inlet of ice and further ice formation was prevented. For the same conditions with the spray water off, the inlet was completely de-iced in 2 minutes. After the inlet was iced at an ambient-air temperature of about 0° F, approximately 10 minutes were required to remove the ice from the starting-motor housing and the inlet guide vanes with the water spray off. An additional 15 minutes were required to remove pieces of ice that had broken off the starting-motor housing and the inlet-duct wall. No de-icing was attempted at an ambient-air temperature of 0° F with the water spray on.

In order to determine ice-prevention characteristics with configuration 4, the water-spray and hot-gas-bleedback systems were operated simultaneously. During such operation for 30 minutes at an ambient-air temperature of 0° F and an engine speed of 11,000 rpm, no ice formed at the compressor inlet. At the same ambient-air temperature and an engine speed of 10,000 rpm, the turbine-outlet temperature rose from 1030° to 1100° F in 15 minutes because a small amount of ice had formed on the compressor-inlet guide vanes. No ice formed on the starting-motor housing.

Effect on engine performance. - Bleeding hot gas to the inlet of the engine resulted in a reduction of net thrust. The net thrust is presented in figure 13 as a function of the percentage of gas flow bled to the inlet for several engine speeds at an altitude of 20,000 feet and an airspeed of 140 miles per hour. For each engine speed, the net thrust decreased as the percentage of bleedback increased. The data in figure 13 are cross-plotted in figure 14 to show the relation between net thrust and engine speed for various amounts of bleedback. At an engine speed of 12,000 rpm, the net thrust was reduced from 1160 pounds to 950 pounds by bleeding 4.0 percent of the gas flow to the inlet. The percentage decrease in net thrust is presented as a function of the percentage of gas flow bled to the inlet in figure 15 for the same data. The loss in net thrust varied linearly with the gas flow bled to the inlet. With 4.0-percent bleedback, the net thrust decreased 7.4 percent at an engine speed of 8000 rpm and 18.8 percent at 12,000 rpm. Approximately three-fourths of the decrease in net thrust was due to the increased compressor-inlet temperature resulting from bleedback. The remainder of the thrust decrease was attributed to lower mass flow out of the tail pipe than through the compressor and to the decreased jet velocity. The decreased jet velocity resulted from a lower mass flow through the turbine than through the compressor, which required that an increased amount of energy be absorbed per pound of gas to drive the turbine.

The relation between fuel consumption and the percentage of gas flow bled to the inlet is shown in figure 16. At engine speeds below 12,000 rpm, the fuel consumption increased slightly as the percentage of gas flow bled to the inlet was raised, whereas at 12,000 rpm the fuel consumption decreased slightly as the bleedback increased. A cross plot of these data is presented in figure 17 to show the relation between fuel consumption and engine speed for various amounts of bleedback. These data indicate that at an engine speed of approximately 11,650 rpm, changing the amount of bleedback would have no effect on the fuel consumption. The reduction in fuel consumption at high engine speeds as the bleedback increased was a function of the engine characteristics. Because the slope of the fuel-consumption curve increases with engine speed, the reduction in fuel consumption resulting from the decreased air density with bleedback was greater than the increase in fuel consumption resulting from bleeding gas from the turbine inlet.

Variations in specific fuel consumption based on net thrust with percentage of gas flow bled to the inlet are shown in figure 18. The specific fuel consumption increased at all engine speeds as hot gas was bled to the inlet. A cross plot of the data shown in figure 18 is presented in figure 19 to show the relation between specific fuel consumption and engine speed for various amounts of bleedback. At an engine speed of 12,000 rpm, the specific fuel consumption was increased from 1.14 to 1.38 when 4.0 percent of the total gas flow was bled to the inlet. The relation between the percentage increase in specific fuel consumption based on net thrust and the percentage of gas flow bled to the inlet is shown in figure 20. The percentage increase in specific fuel consumption varied linearly with the percentage of bleedback. With 4.0 percent of the gas flow bled to the inlet, the specific fuel consumption increased 15.8 percent at 8000 rpm, 24.2 percent at 10,000 rpm, and 21.3 percent at 12,000 rpm.

Effects of Ice on Engine Operation

During the process of de-icing, pieces of ice broke off the cowl lip, the duct wall, and the starter housing. Large pieces of ice lodged against the compressor-inlet guide vanes and small pieces shattered upon impact with the guide vanes and passed through the engine. The ice passing through the engine caused momentary reductions in engine speed of 300 to 1000 rpm and on several occasions combustion blow-out occurred during de-icing at an engine speed of 10,000 rpm.

An inspection of the engine after several hours of operation in icing conditions revealed that the trailing edges of the compressor-inlet guide vanes were damaged and one of the first-stage rotor blades was slightly bent. Operation was continued after the rotor blade and the inlet guide vanes were replaced.

SUMMARY OF RESULTS

The following results were obtained from a wind-tunnel investigation of a hot-gas bleedback system for protecting the inlet of a turbojet engine from ice:

1. With icing conditions at ambient-air temperatures between 25° and 30° F and engine speeds from 10,000 to 11,000 rpm, the hot-gas bleedback system de-iced the compressor inlet in about 5 minutes and prevented further ice formation. At an ambient-air temperature of 0° F and an engine speed of 11,000 rpm, ice formation at the compressor inlet was prevented. At 10,000 rpm and the same ambient-air temperature, ice formed very slowly on the compressor-inlet guide vanes with the bleedback system in operation.

2. Bleeding hot gas to the engine inlet resulted in reductions in net thrust and increases in specific fuel consumption based on net thrust. With 4.0-percent bleedback at an engine speed of 12,000 rpm, the net thrust was decreased 18.8 percent and the specific fuel consumption was increased 21.3 percent.

3. Without hot-gas bleedback, formation of ice on the compressor inlet reduced the net thrust, increased the specific fuel consumption based on net thrust, and within a short period of time rendered the engine inoperative as a result of excessively high turbine-outlet temperatures. When the formation of ice had reduced the air flow 26 percent at a given engine speed, the net thrust was decreased 30.2 percent and the specific fuel consumption based on net thrust was increased 48.0 percent.

4. Ice shattering against the compressor-inlet guide vanes and passing through the engine damaged the inlet guide vanes, slightly bent a first-stage rotor blade, and on several occasions caused combustion blow-out.

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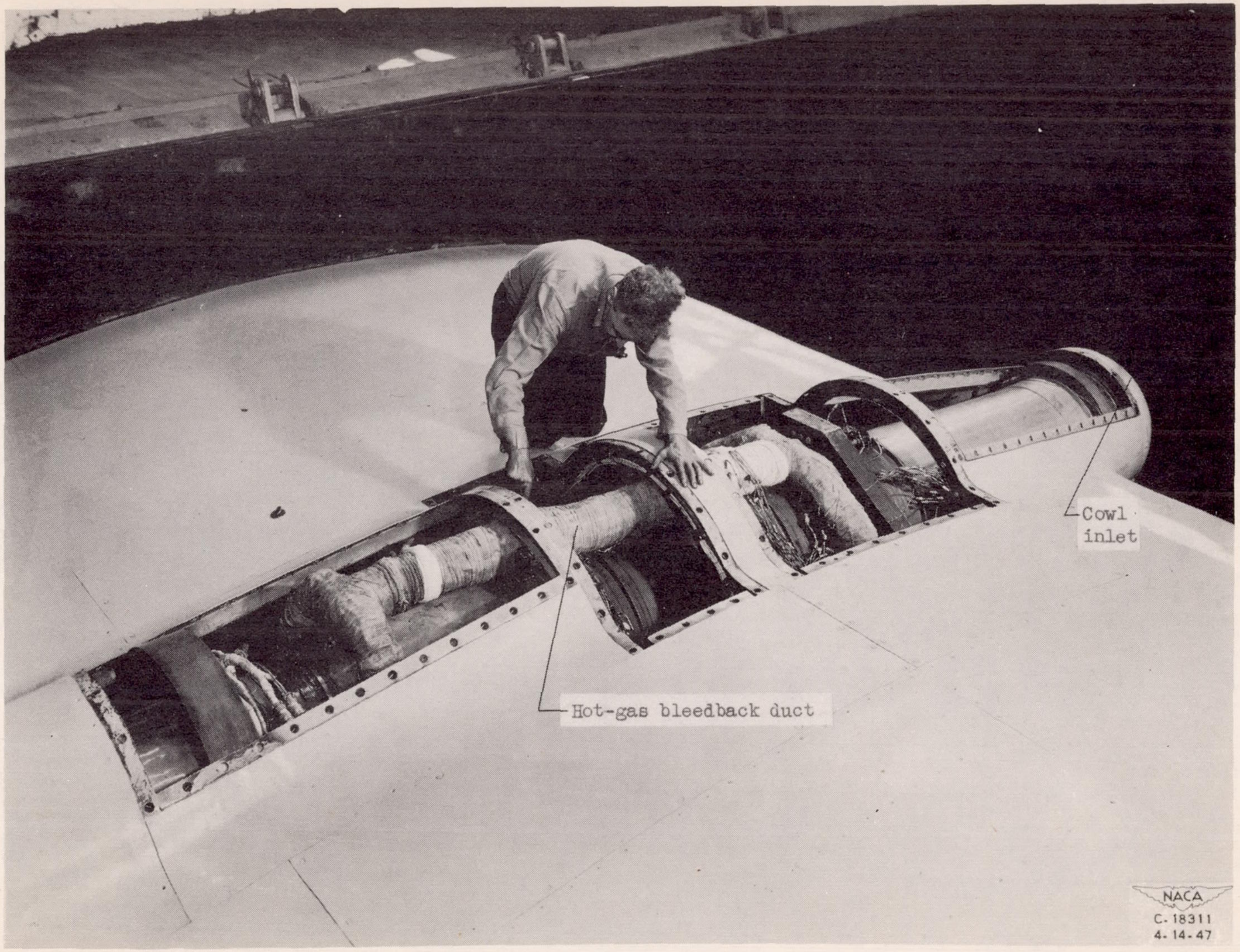

Figure 1. - Engine installation with hot-gas bleedback system installed.

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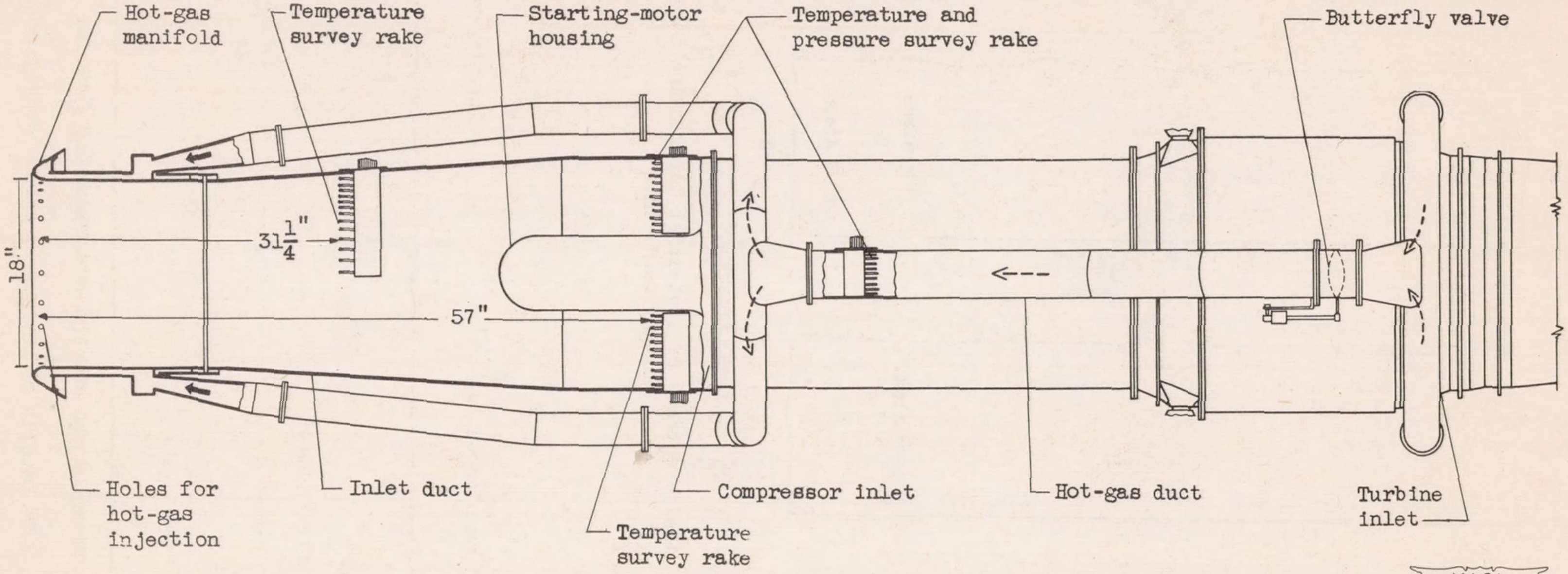
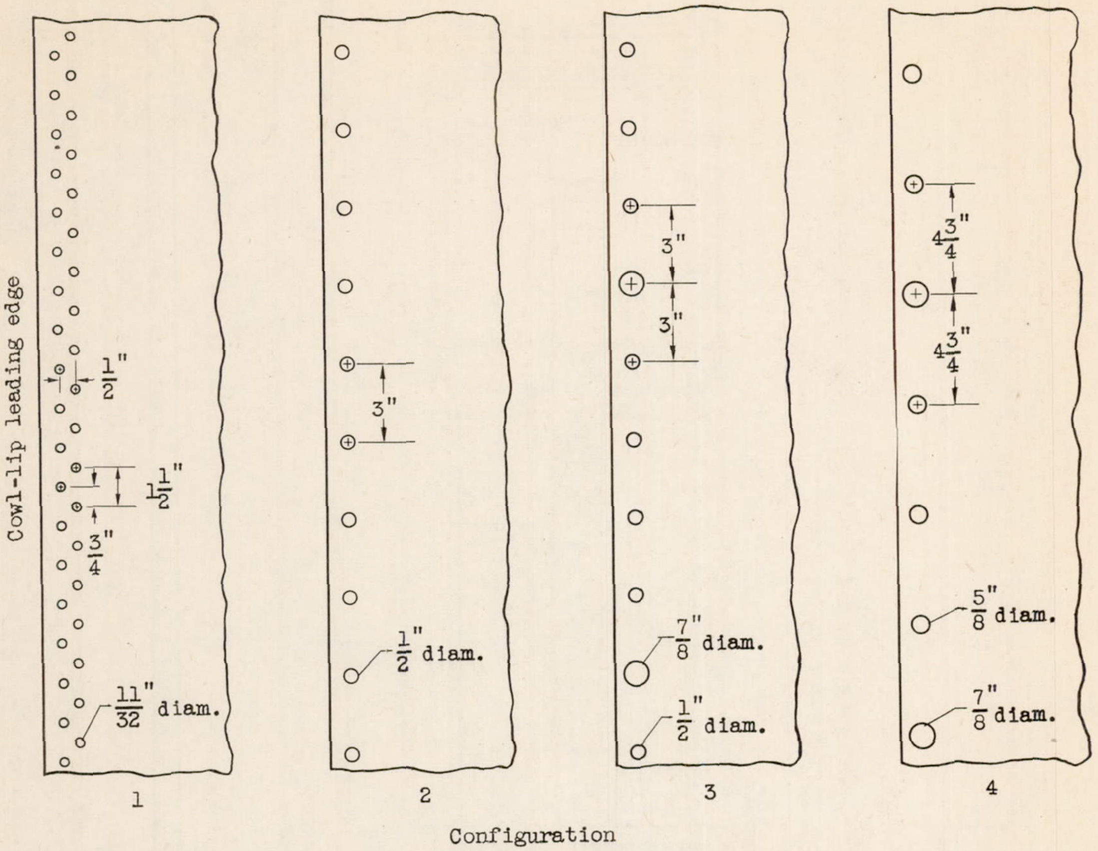
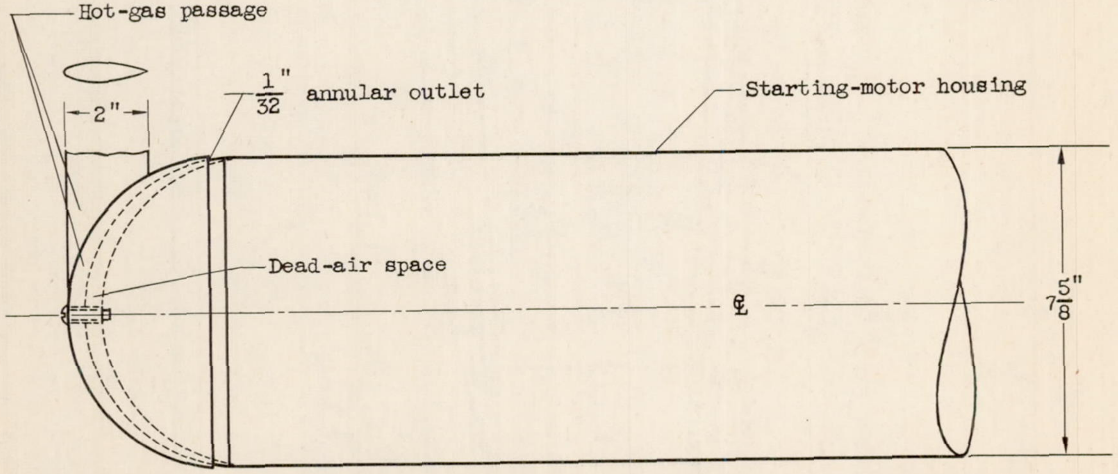


Figure 2. - Plan drawing of hot-gas bleedback system and instrumentation installed on engine.



(a) Developed view of inside surface of cowl-inlet lip showing hole arrangements in hot-gas manifold.



(b) Installation of heated cap on starting-motor-housing dome for configuration 4.

Figure 3. - Details of hot-gas bleedback configurations.

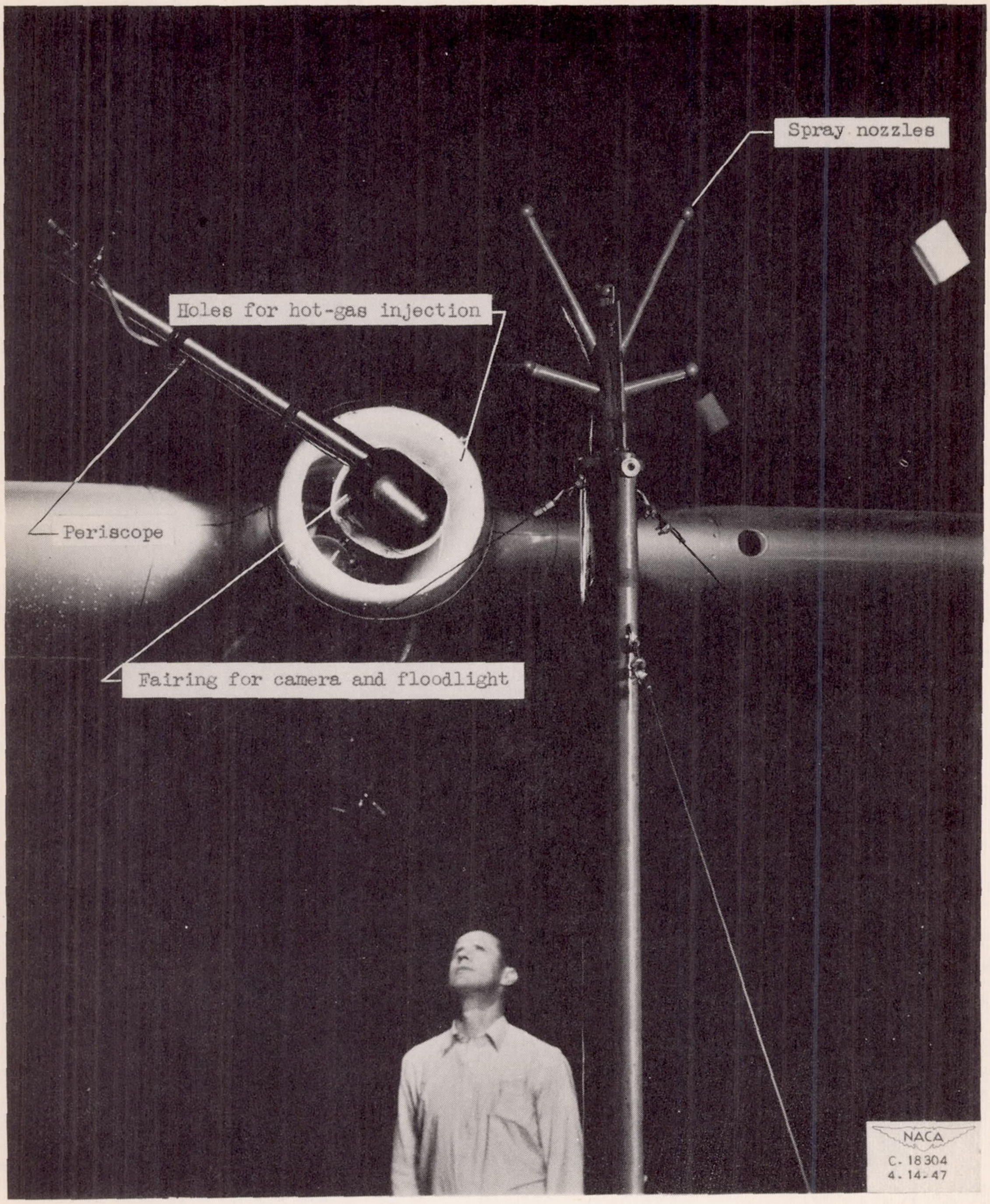
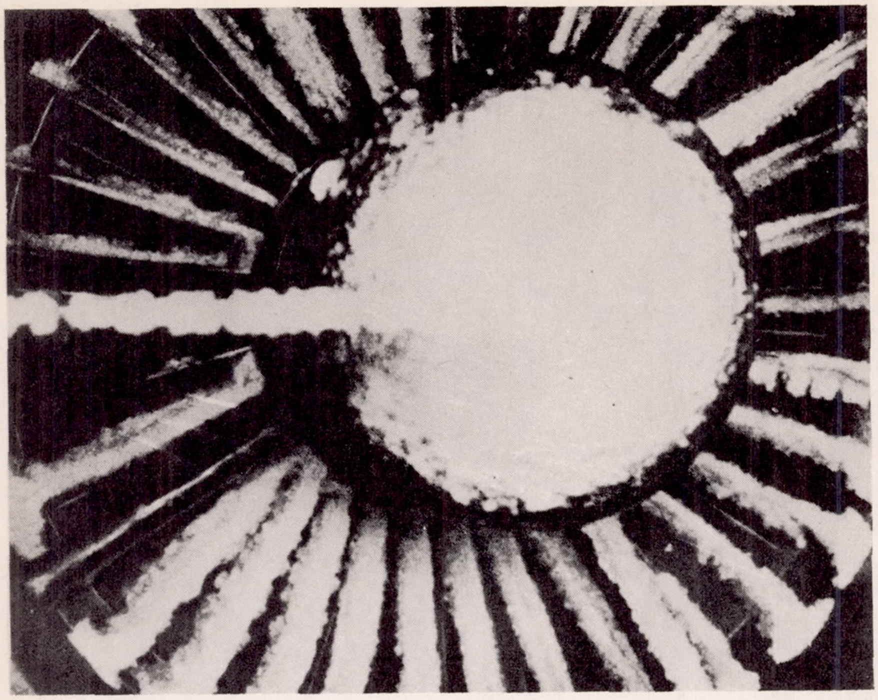
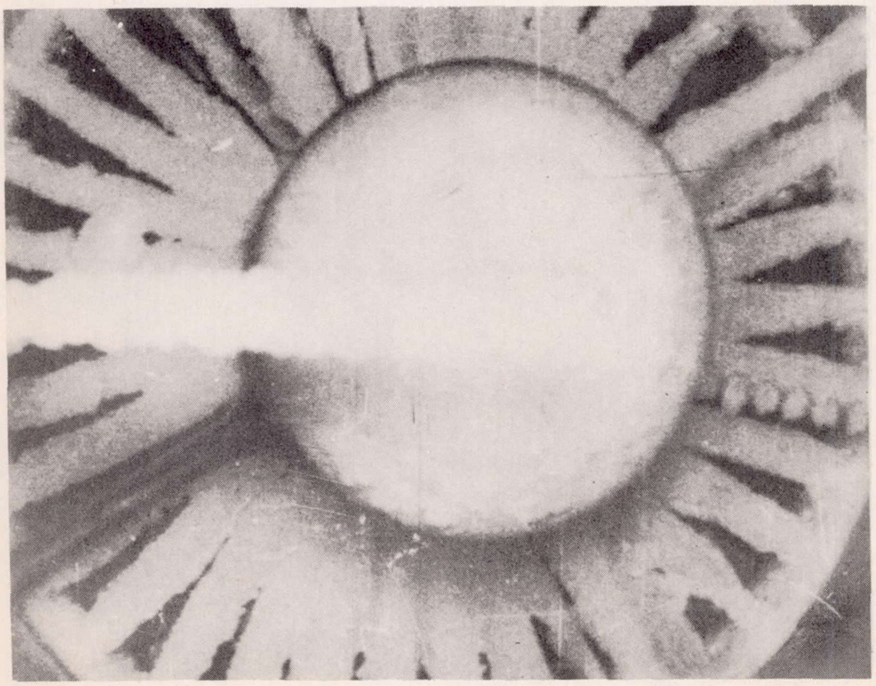


Figure 4. - Front view of engine installation showing water-spray nozzles and periscope.



(a) Turbine-outlet temperature, 1150° F (approximately 100° F above normal); engine speed, 10,000 rpm.



(b) Engine inoperative at any engine speed owing to excessive turbine-outlet temperature.

Figure 5. - Compressor inlet iced with hot-gas bleedback system inoperative. Altitude, 20,000 feet; airspeed, 140 miles per hour; ambient-air temperature, 30° F.

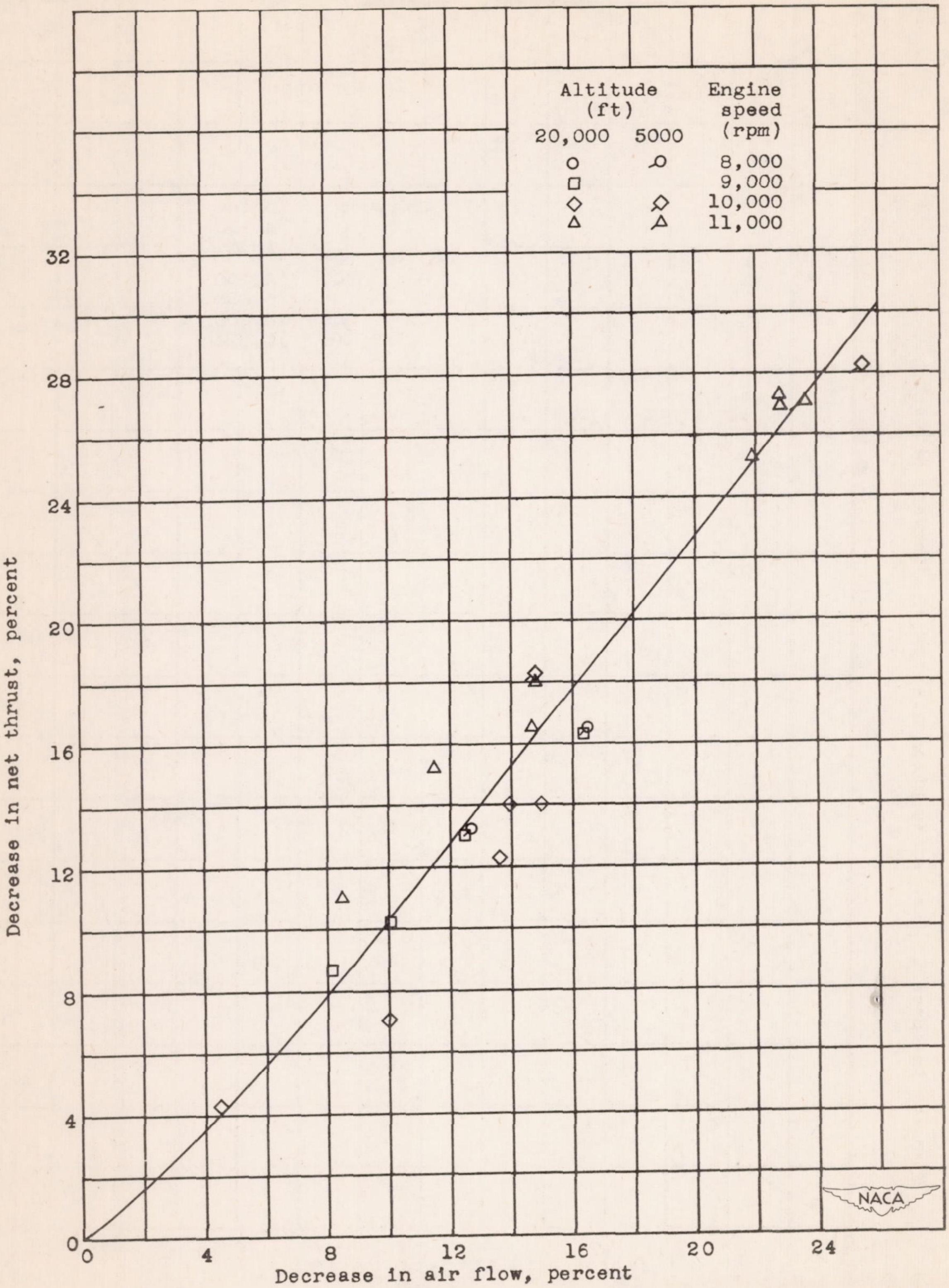


Figure 6. - Effect of inlet icing on net thrust without hot-gas bleedback for various engine speeds at altitudes of 5000 and 20,000 feet. Airspeed, 140 miles per hour; ambient-air temperature, 30° F.

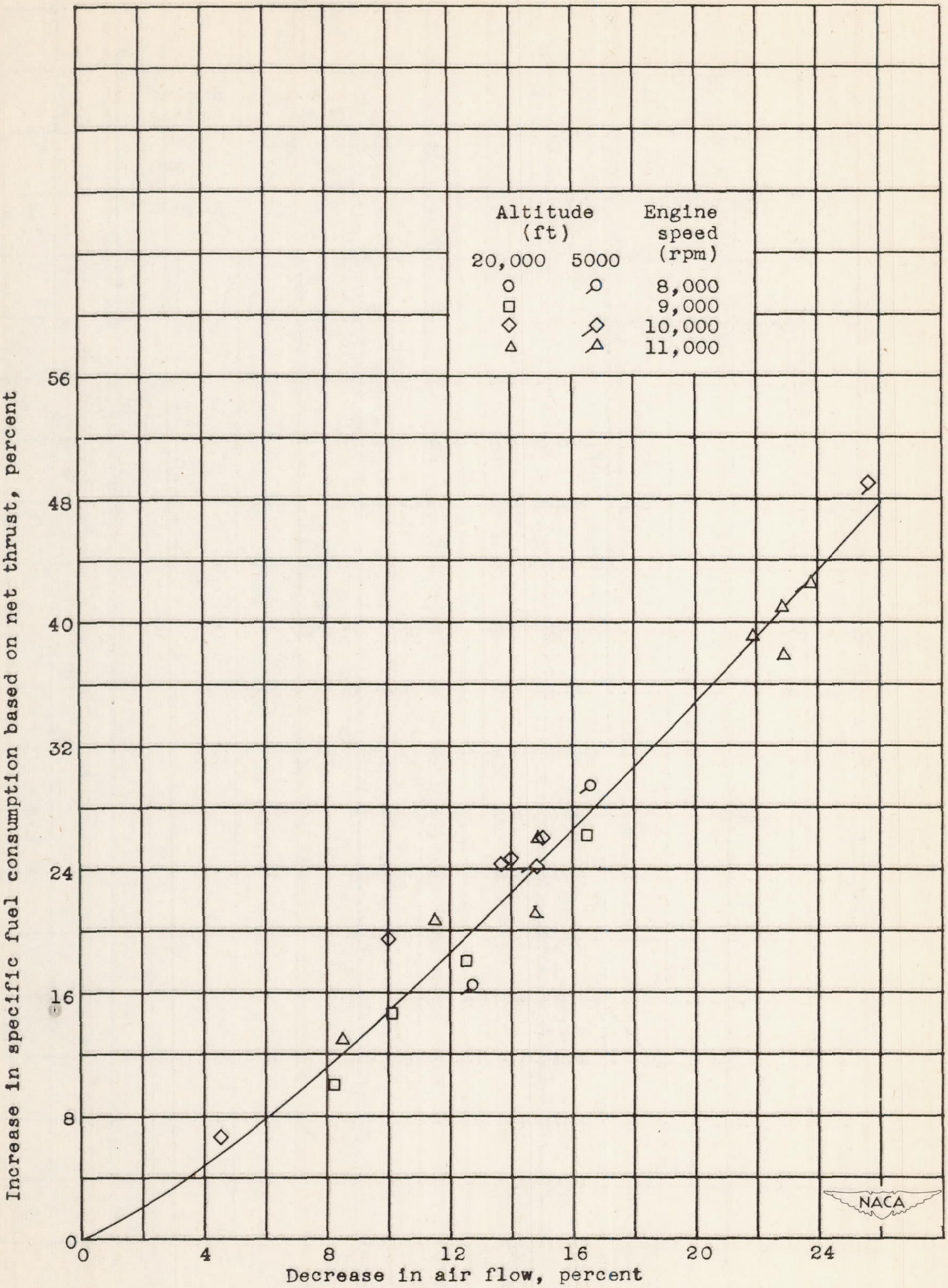
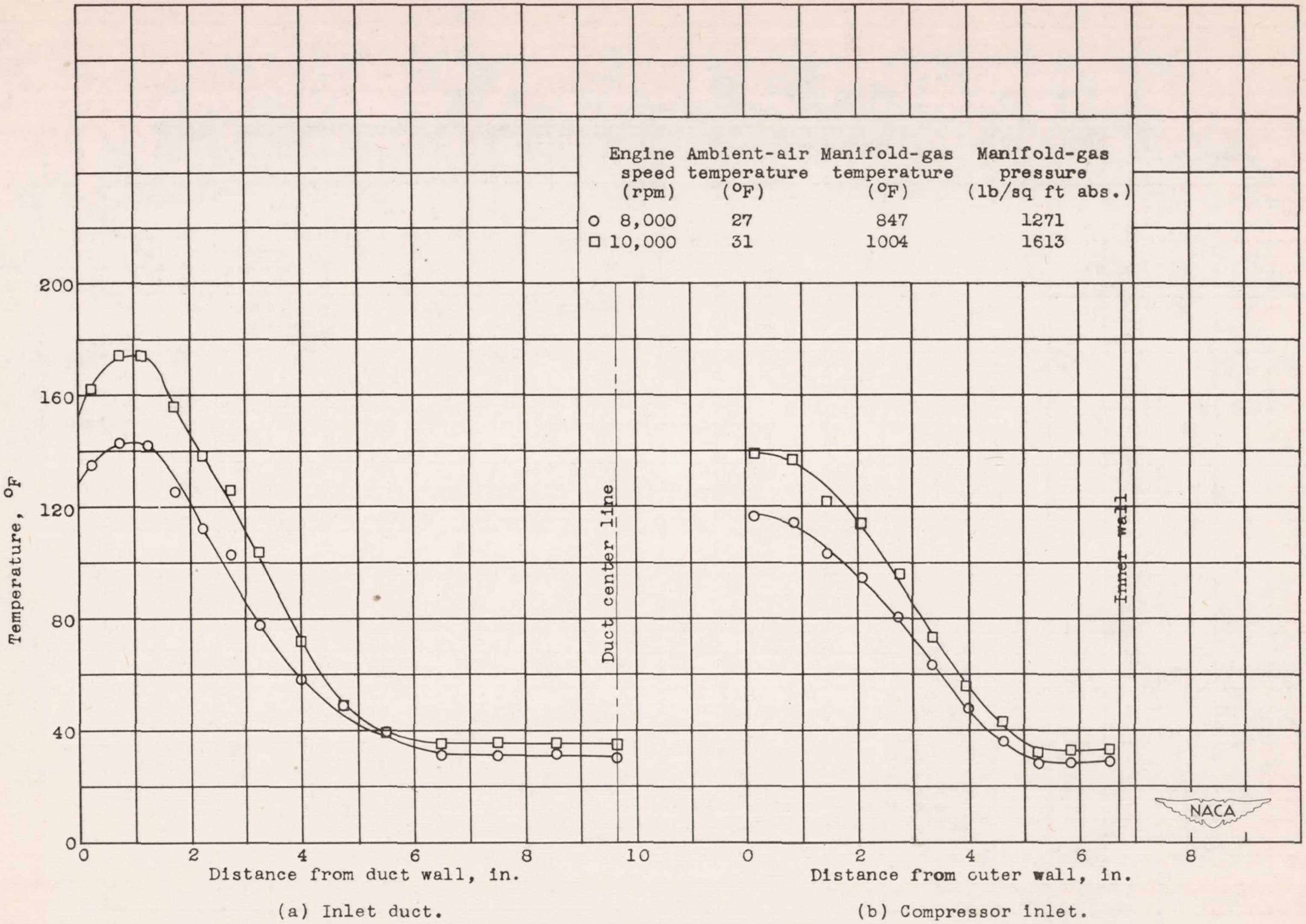


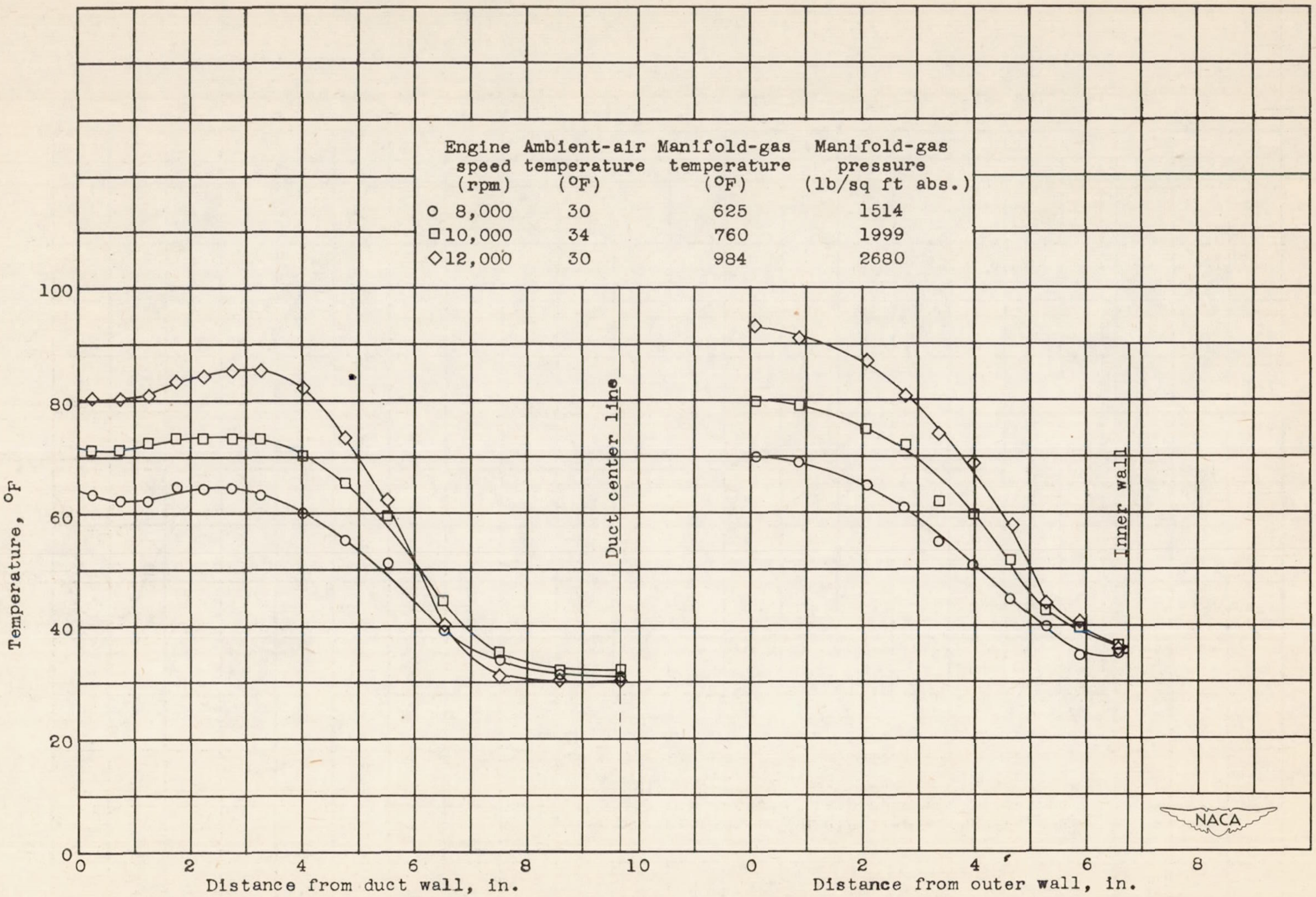
Figure 7. - Effect of inlet icing on specific fuel consumption based on net thrust without hot-gas bleedback for various engine speeds at altitudes of 5000 and 20,000 feet. Airspeed, 140 miles per hour; ambient-air temperature, 30° F.



(a) Inlet duct.

(b) Compressor inlet.

Figure 8. - Temperature profiles across inlet duct and compressor inlet with configuration 1. Altitude, 20,000 feet; airspeed, 140 miles per hour.

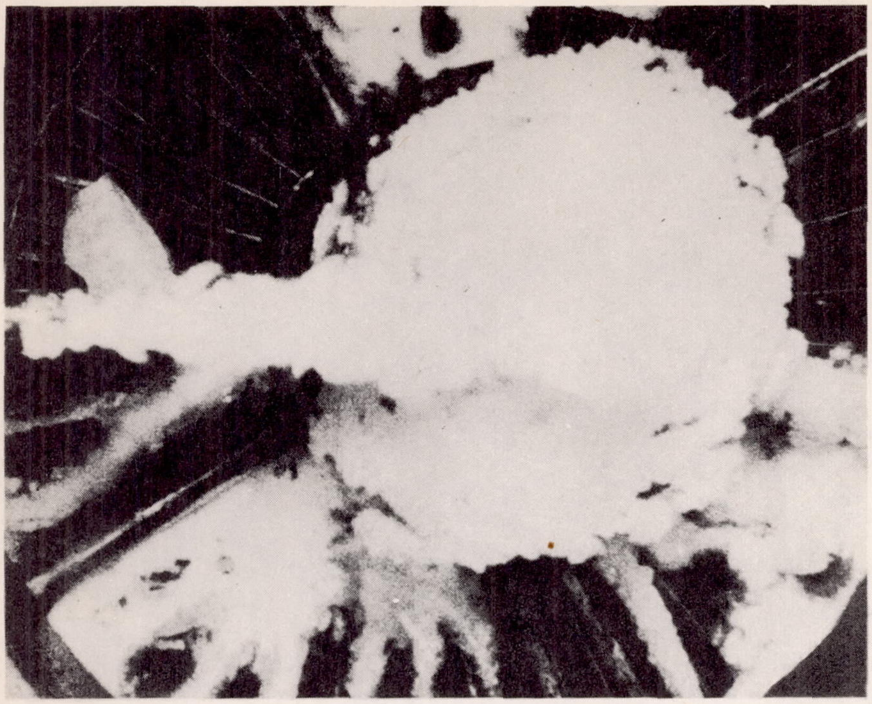


Engine speed (rpm)	Ambient-air temperature (°F)	Manifold-gas temperature (°F)	Manifold-gas pressure (lb/sq ft abs.)
○ 8,000	30	625	1514
□ 10,000	34	760	1999
◇ 12,000	30	984	2680

(a) Inlet duct.

(b) Compressor inlet.

Figure 9. - Temperature profiles across inlet duct and compressor inlet with configuration 2. Altitude, 20,000 feet; airspeed, 140 miles per hour.



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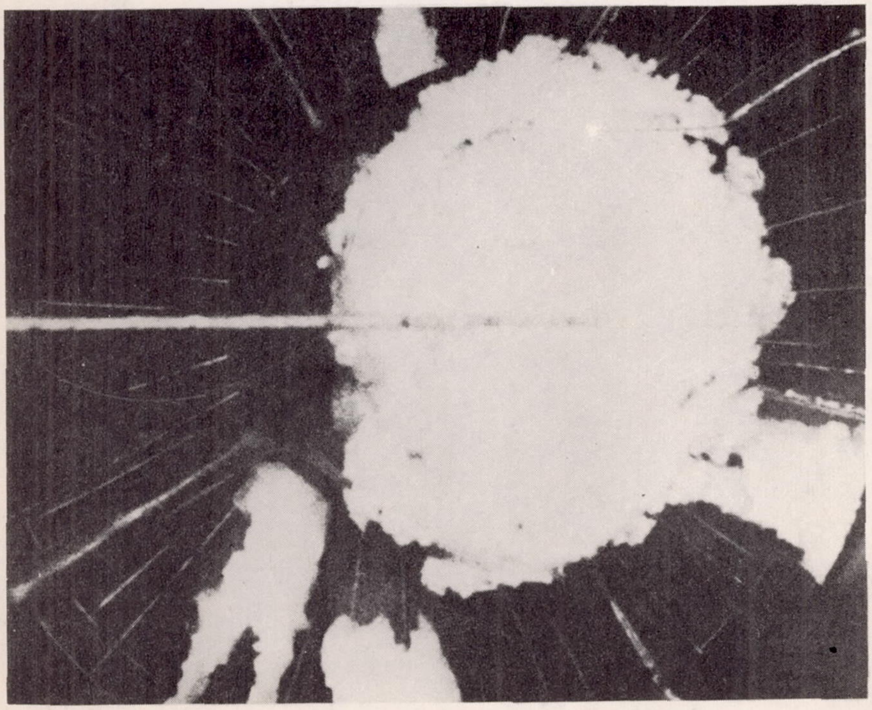
(a) After 10 minutes de-icing.



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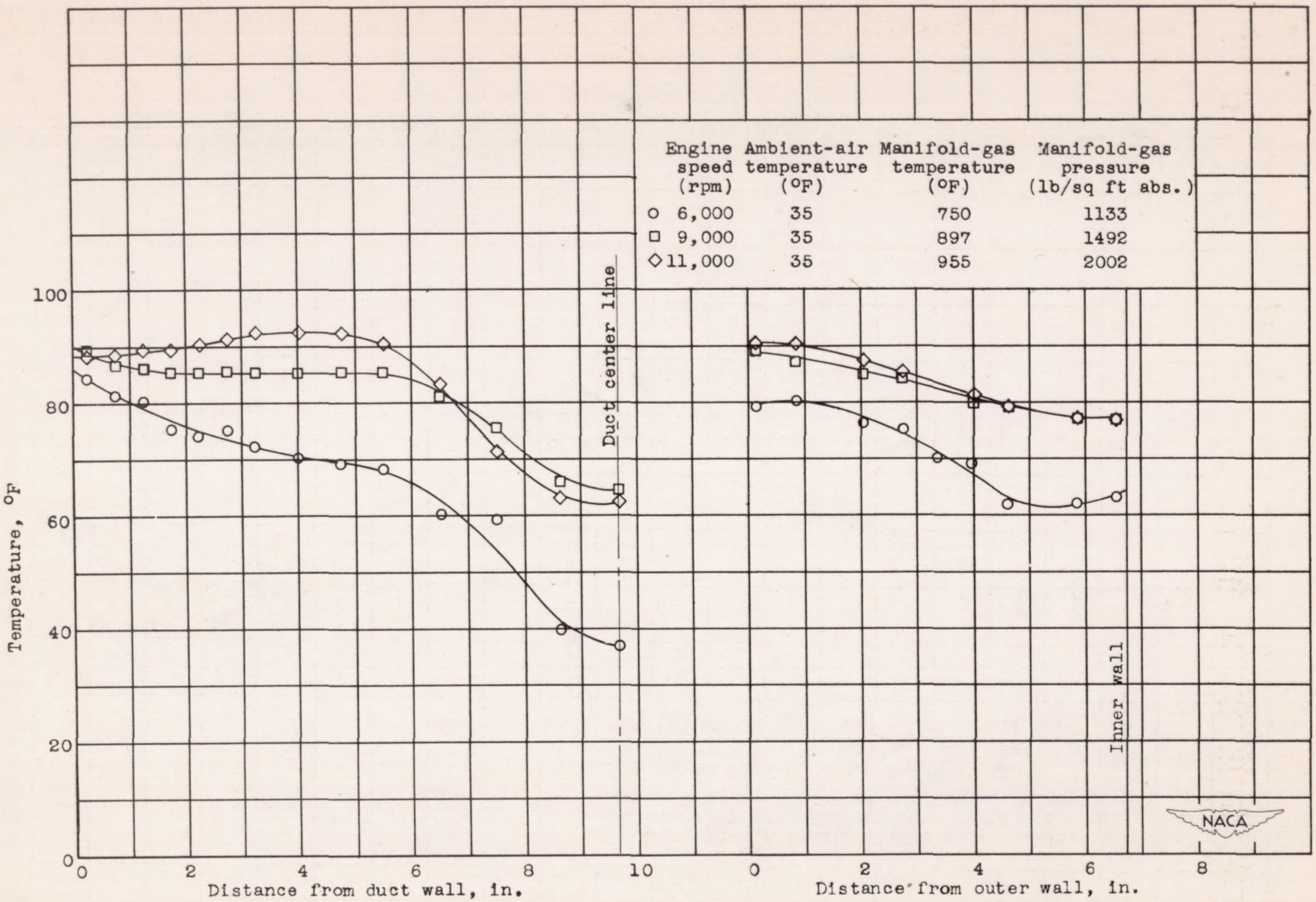
(b) After 20 minutes de-icing.

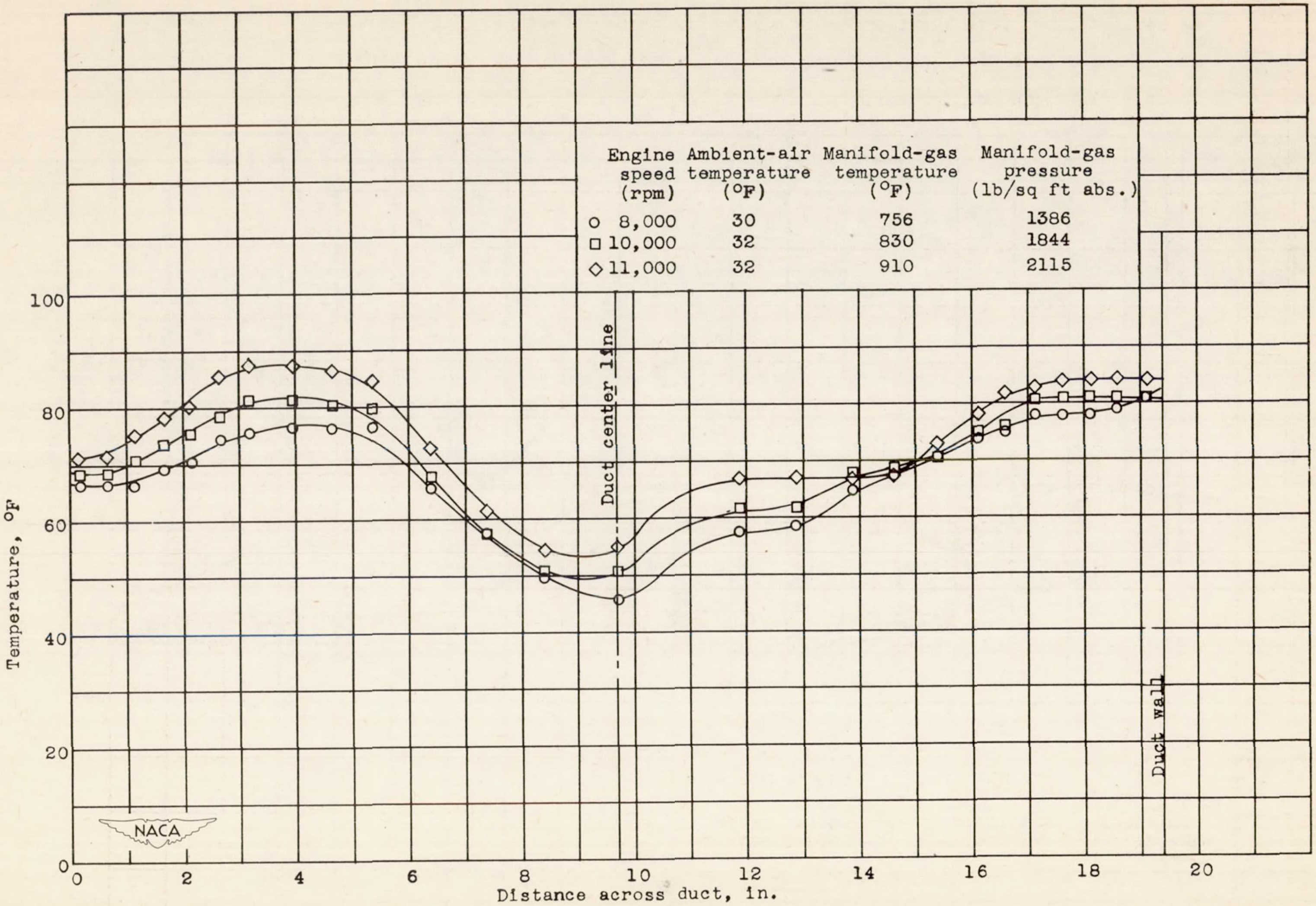
Figure 10. - Compressor inlet during de-icing with configuration 2. Altitude, 5000 feet; airspeed, 140 miles per hour; ambient-air temperature, 30° F; engine speed, 10,000 rpm; water spray off.



(a) Inlet duct.

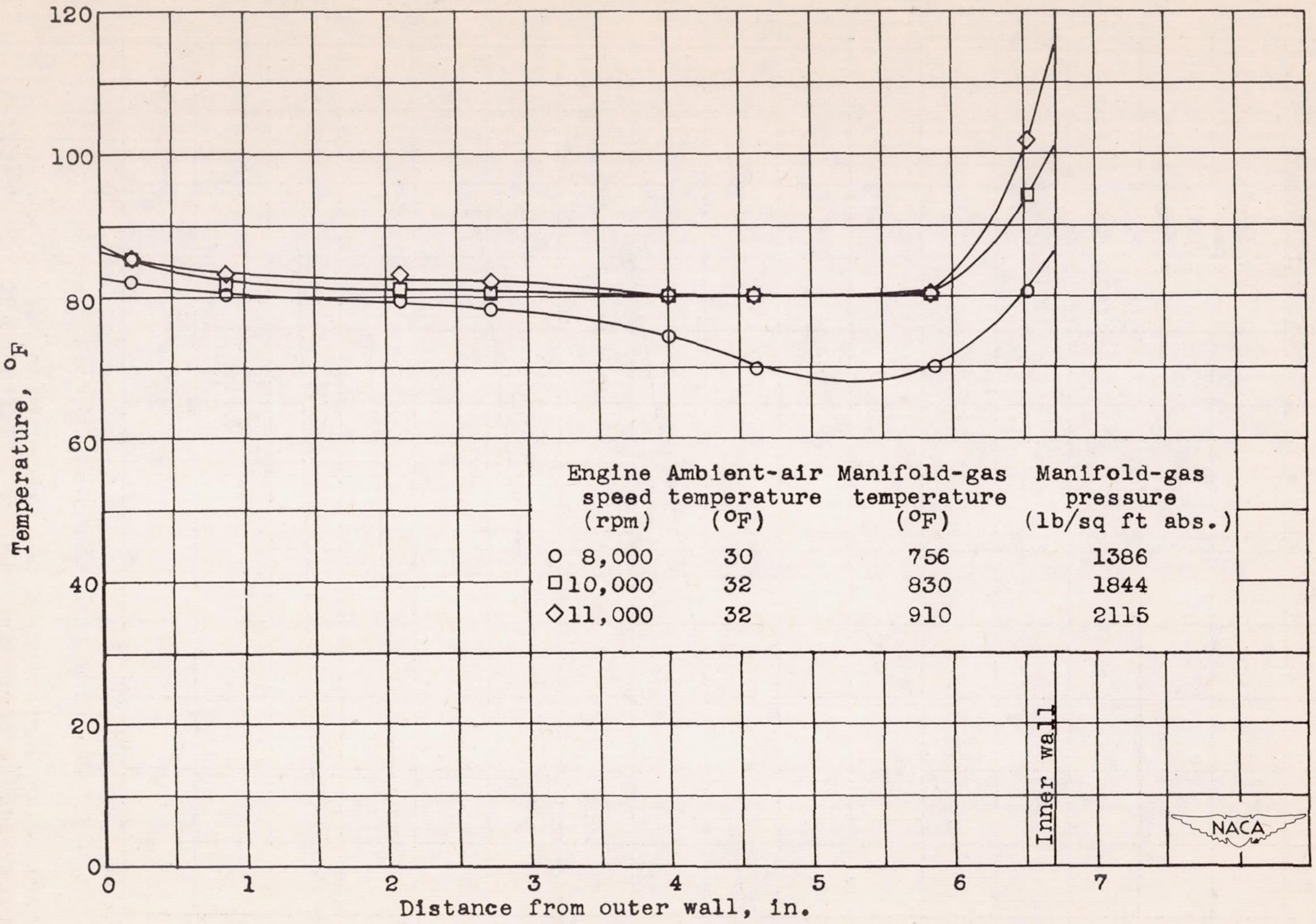
(b) Compressor inlet.

Figure 11. - Temperature profiles across inlet duct and compressor inlet with configuration 3. Altitude, 20,000 feet; airspeed, 140 miles per hour.



(a) Inlet duct.

Figure 12. - Temperature profiles across inlet duct and compressor inlet with configuration 4. Altitude, 20,000 feet; airspeed, 140 miles per hour.



(b) Compressor inlet.

Figure 12. - Concluded. Temperature profiles across inlet duct and compressor inlet with configuration 4. Altitude, 20,000 feet; airspeed, 140 miles per hour.

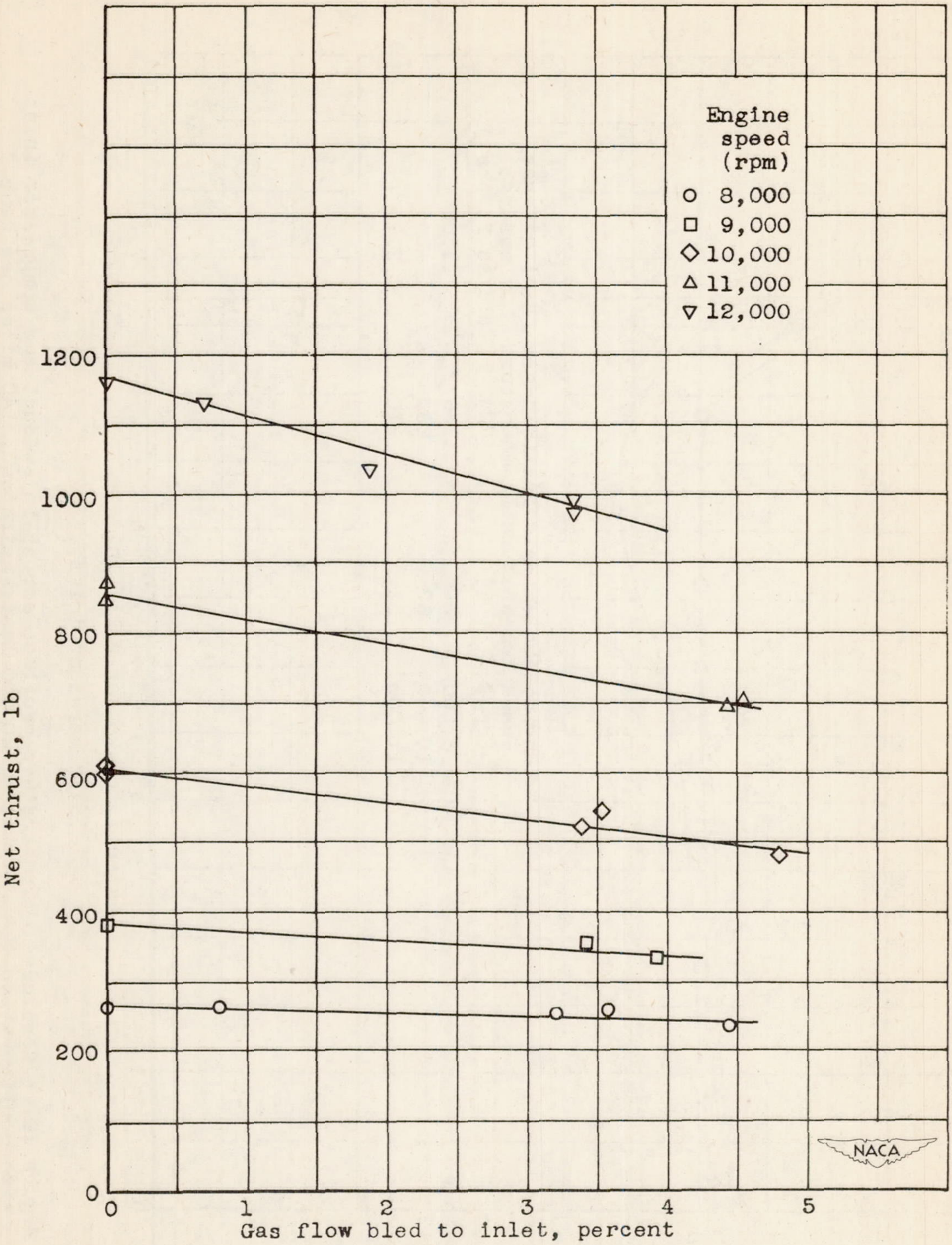


Figure 13. - Variation of net thrust with percentage gas flow bled to compressor inlet. Altitude, 20,000 feet; airspeed, 140 miles per hour; ambient-air temperature, 30° F.

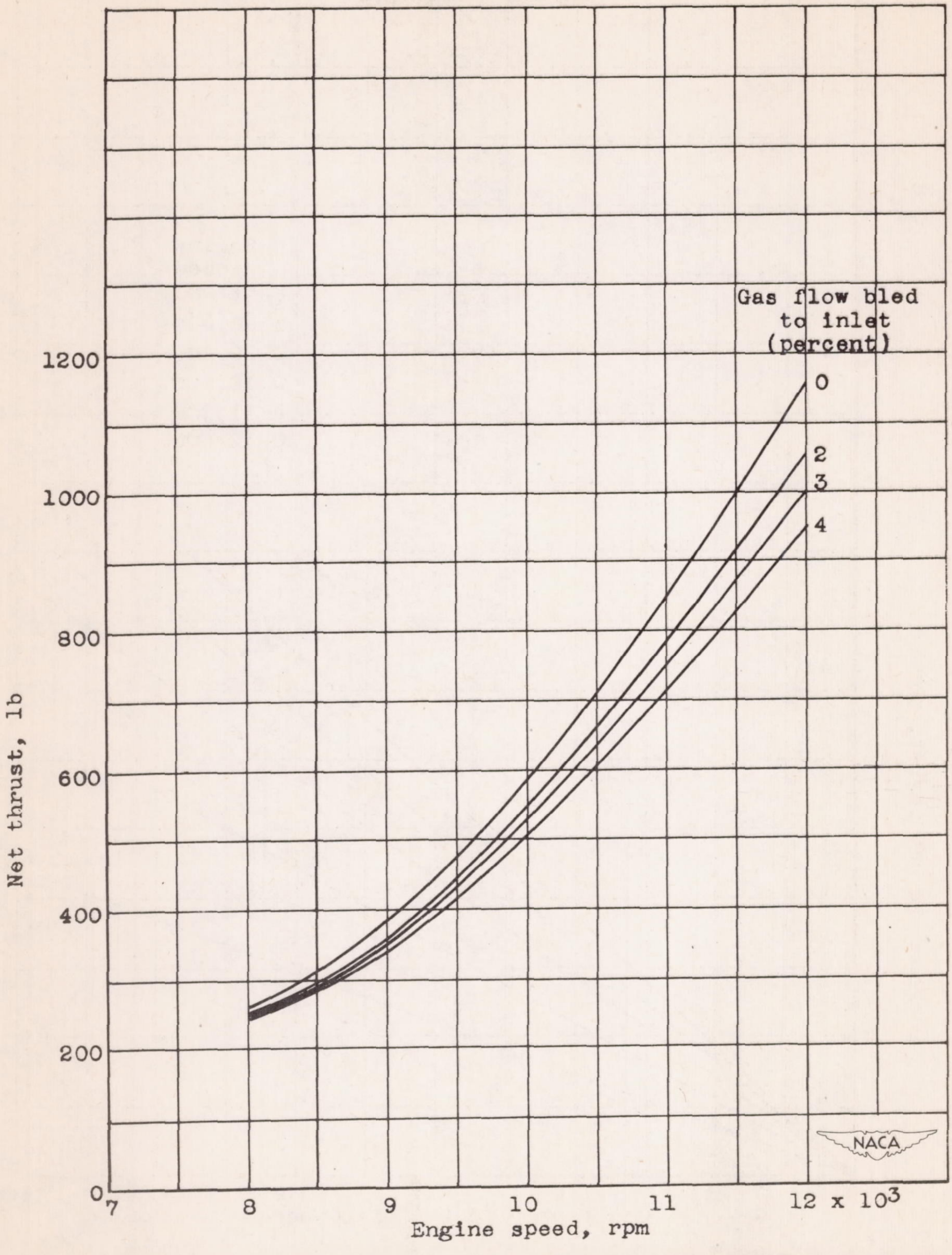


Figure 14. - Relation between net thrust and engine speed for various amounts of hot gas bled to compressor inlet. Altitude, 20,000 feet; airspeed, 140 miles per hour; ambient-air temperature, 30° F.

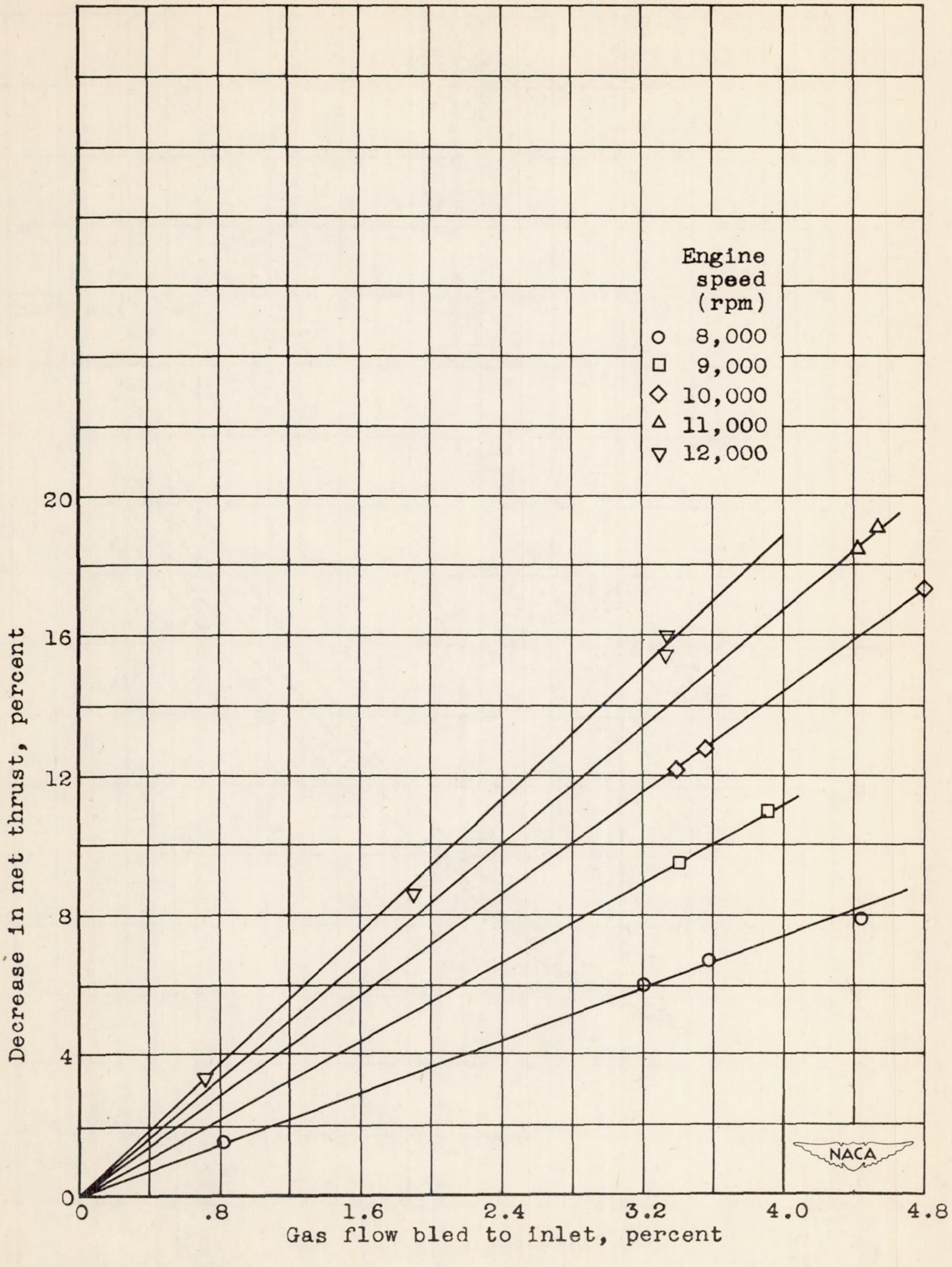


Figure 15. - Variation of percentage decrease in net thrust with percentage gas flow bled to compressor inlet. Altitude, 20,000 feet; airspeed, 140 miles per hour; ambient-air temperature, 30° F.

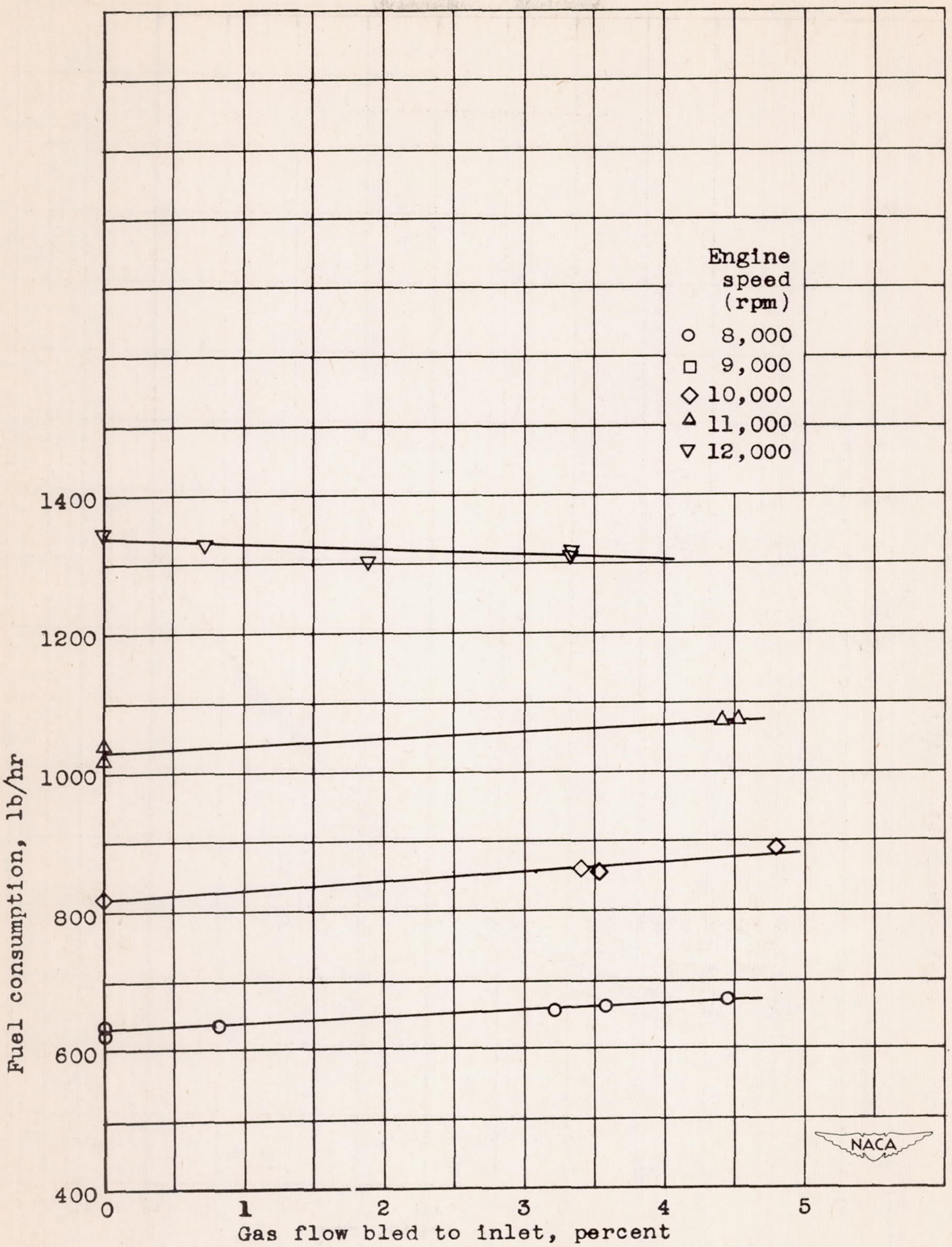


Figure 16. - Variation of fuel consumption with percentage gas flow bled to compressor inlet. Altitude, 20,000 feet; airspeed, 140 miles per hour; ambient-air temperature, 30° F.

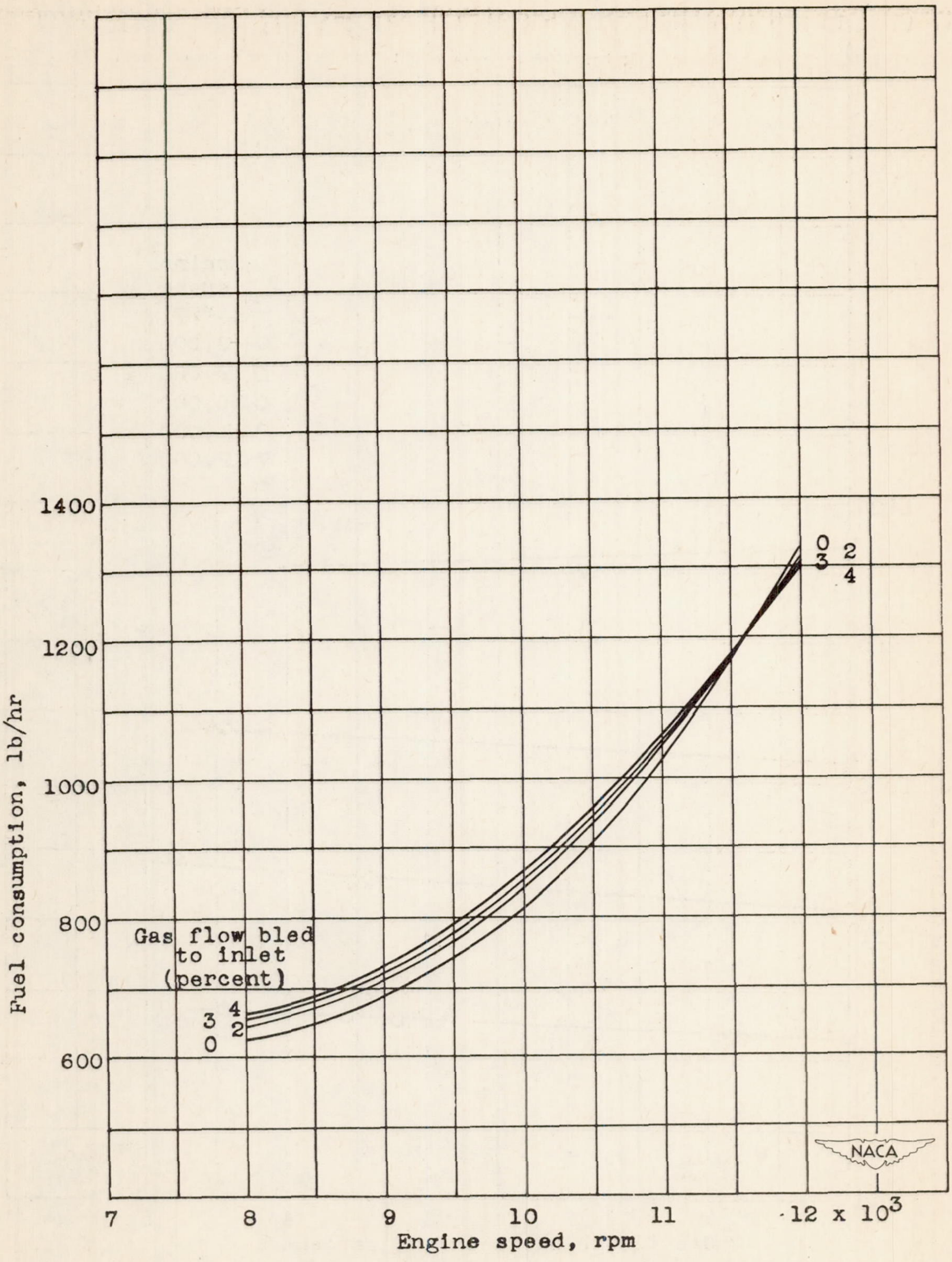


Figure 17. - Relation between fuel consumption and engine speed for various amounts of hot gas bled to compressor inlet. Altitude, 20,000 feet; airspeed, 140 miles per hour; ambient-air temperature, 30° F.

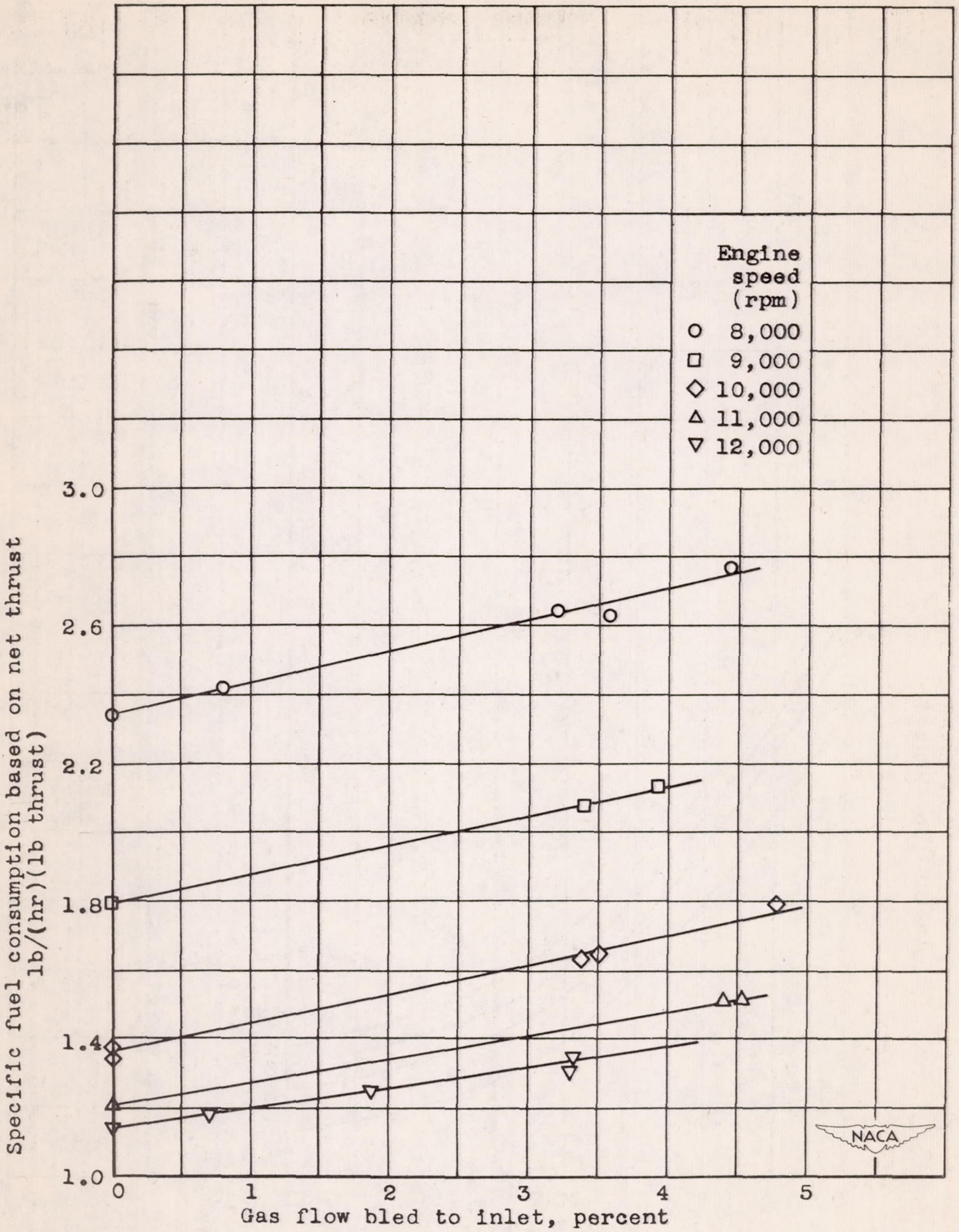


Figure 18. - Variation of specific fuel consumption based on net thrust with percentage gas flow bled to compressor inlet. Altitude, 20,000 feet; airspeed, 140 miles per hour; ambient-air temperature, 30° F.

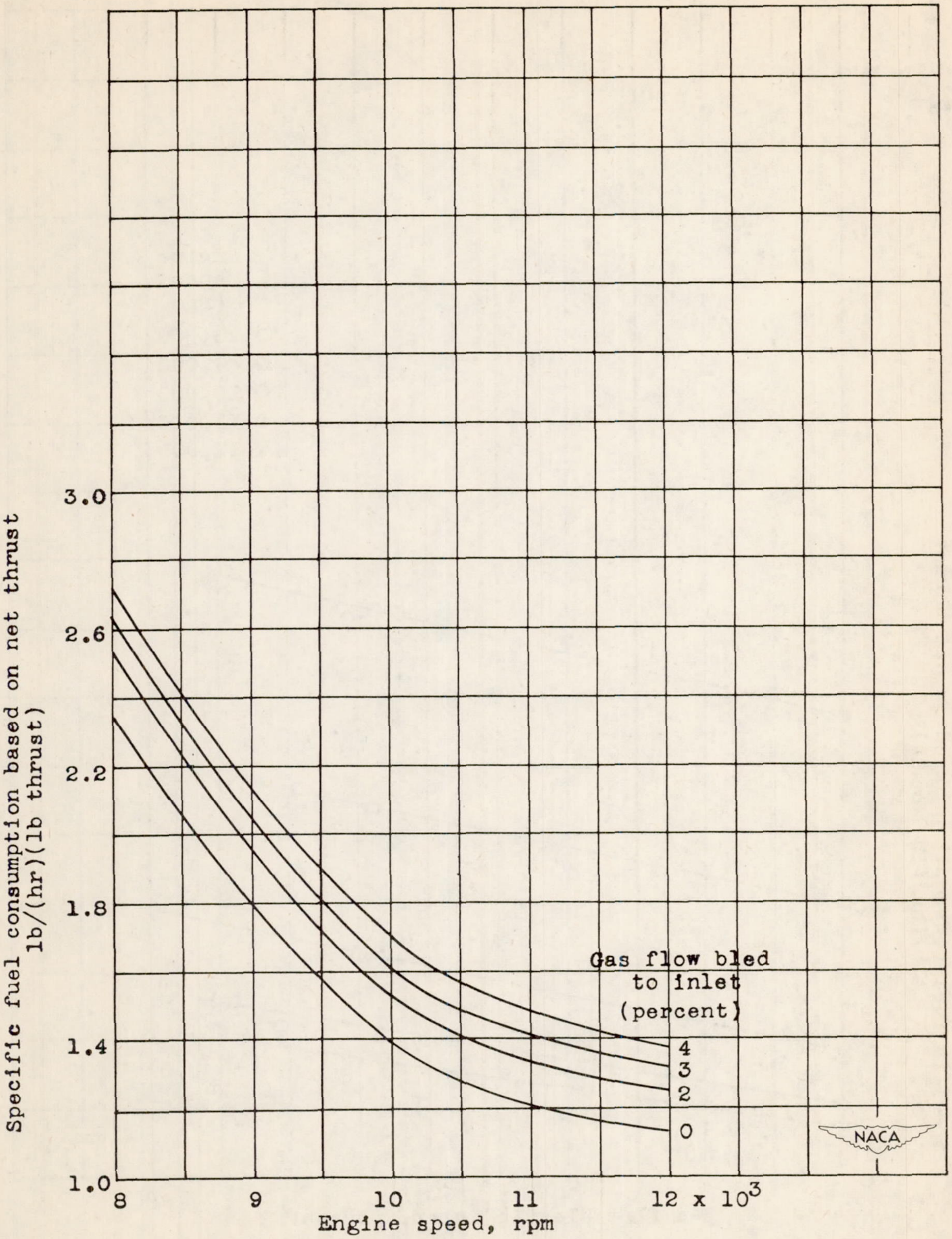


Figure 19. - Relation between specific fuel consumption based on net thrust and engine speed for various amounts of hot gas bled to compressor inlet. Altitude, 20,000 feet; airspeed, 140 miles per hour; ambient-air temperature, 30° F.

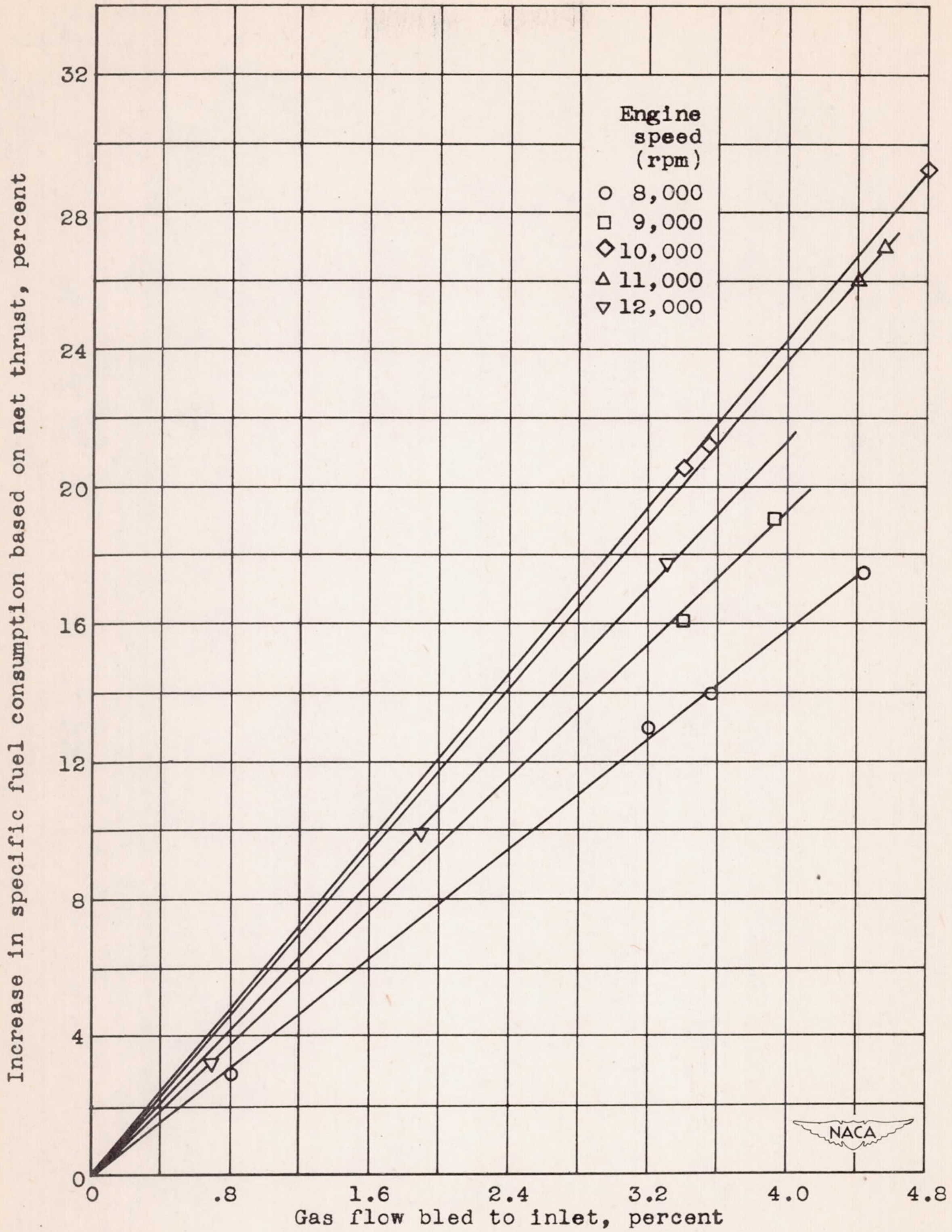


Figure 20. - Variation of percentage increase in specific fuel consumption based on net thrust with percentage gas flow bled to compressor inlet. Altitude, 20,000 feet; airspeed, 140 miles per hour; ambient-air temperature, 30° F.