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RESEARCH MEMORANDUM

EFFECTS OF INLET ICING ON PERFORMANCE OF AXIAL-FLOW TURBOJET ENGINE IN NATURAL ICING CONDITIONS

By Loren W. Acker and Kenneth S. Kleinknecht

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY

A flight investigation was conducted at the NACA Lewis laboratory to study the effect of inlet icing on the performance of an axial-flow turbojet engine. The range of meteorological conditions encountered included liquid-water contents from 0.1 to 0.9 gram per cubic meter, average water-droplet sizes from 10 to 27 microns, and ambient-air temperatures from 13° to 26° F. Stratus, or layer, clouds were the only type of cloud structure encountered.

The greatest effect of inlet icing on engine performance occurred at a liquid-water content of 0.9 gram per cubic meter, when the jet thrust was reduced 26 percent and the tail-pipe temperature was increased 160° F. The greatest rate of deterioration in engine performance occurred within the initial few minutes of flight in an icing condition. During prolonged flights in an icing condition, inlet icing was characterized by a cyclic growth and shedding of ice accretions. Ice accretions on the compressor-inlet guide vanes accounted for approximately one-half of the total reduction in engine performance caused by inlet icing. Large ice formations on several occasions broke away from the surfaces of the air inlet and were swept through the engine, but did not cause any structural damage to the compressor blades.

INTRODUCTION

The formation of ice on the inlets of axial-flow turbojet engines has long been recognized as a hazard that may produce serious reductions in engine performance. A particularly critical component of the engine inlet in this respect is the guide vanes. The guide vanes collect ice readily because of their thin profile and because their large camber and close spacing present a large exposed frontal area. In order to protect the turbojet engine against the icing hazard in flight, consideration must also be given to the remaining components of the engine inlet: the front-main-bearing support struts, the dome-shaped accessory housing, and the leading-edge region of the engine cowling. In addition, unpublished data indicate that the passage of extraneous pieces of ice through a turbojet engine may cause structural damage to the compressor blades.

A preliminary investigation of the effect of icing on the performance of an axial-flow turbojet engine conducted in a wind tunnel under severe icing conditions (reference 1) indicated that excessive tail-pipe temperature occurred after a few minutes of operation.

A flight investigation to determine the effect of natural icing on the performance of an axial-flow turbojet engine was initiated at the NACA Lewis laboratory in January 1948. Because of the relatively late start, little data were obtained during this first winter. These data are presented in references 2 and 3. During the winter of 1948-49, a more extensive program was conducted, and performance data and inlet photographs from these investigations are presented herein. As a part of the present investigation, heat was applied to all of the components of the engine inlet except the guide vanes in order to isolate the effect of icing at the guide vanes on engine performance.

APPARATUS AND INSTRUMENTATION

Two turbojet engines with 10- and 11-stage axial-flow compressors, respectively, were used in the investigation. The engines were otherwise similar, both having an annular combustion chamber and a two-stage turbine. The engine change was made when the combustion chamber failed in the 10-stage-compressor engine.

The engine was mounted on a strut under the wing and between the right inboard nacelle and the fuselage of a four-engine bomber-type airplane (fig. 1). The engine installation is shown in detail in figure 2.

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The turbojet engine was provided with electrical anti-icing boots on the inlet lip, the starter-housing dome, and the four front-bearing support struts. These boots were capable of producing heat intensities of 8 to 10 watts per square inch. Power for the anti-icing boots was furnished by a 110-volt alternating-current auxiliary power plant.

In order to allow for a reasonable rise in tail-pipe temperature as the engine inlet collected ice, a tail pipe of approximately 7 percent greater area than the standard tail pipe was used for this investigation.

Instrumentation on the turbojet engine consisted of pressure tubes and thermocouples at the compressor outlet for determining combined compressor and cowling-inlet efficiency, and a pressure-and-temperature survey rake at the tail-pipe outlet for determining jet thrust and air flow.

Ambient-air temperature measurements were made by means of a resistance-type bulb thermometer mounted under the fuselage of the airplane. This temperature bulb was shielded to eliminate radiation effects and direct impact of water droplets.

Values of liquid-water content and average droplet diameter were calculated by the rotating-multicylinder method (reference 4). The cylinders were $\frac{1}{8}$, $\frac{1}{2}$, $1\frac{1}{4}$, and 3 inches in diameter.

Photographs of the engine inlet were obtained in flight with an aerial camera body (fig. 3) fitted with a special lens and shutter assembly and an electronic flash unit. The camera was mounted on a movable tripod, which was anchored to the side of the airplane fuselage approximately 3 feet ahead of the turbojet-engine inlet. One leg of the tripod was a hydraulic cylinder and was used to lower the camera below the engine inlet after a photograph was obtained (fig. 3).

PROCEDURE

Data on meteorological conditions and the effect of icing on engine performance obtained during this investigation are presented in the form of time-history charts for each flight. Photographs of the engine inlet, taken periodically during the icing encounters, are also included. The meteorological and engine-performance data are summarized in table I.

The meteorological variables measured included liquid-water content, average droplet diameter, and ambient-air temperature. All data were taken at pressure altitudes from 2800 to 9300 feet, and the engine-thrust data were corrected to a pressure altitude of 6000 feet in order that a better comparison of the results from the various flights could be made. The total flight time in natural icing conditions during this investigation was approximately 8 hours. Data for only 5 hours are shown, however, because of repetition of light icing conditions at liquid-water contents of 0.1 to 0.2 gram per cubic meter.

The flights were made in stratus and stratocumulus clouds because of their frequent occurrence in the Great Lakes region of the United States, where the investigation was conducted. The data do not include icing conditions in the cumulus-type clouds where higher liquid-water contents are known to exist over relatively short horizontal distances. Durations of the icing encounters ranged from 35 to 100 minutes. In order to realize flight durations in icing conditions of this severity, the airplane was maneuvered through the icing clouds in various directions.

Turbojet-engine performance parameters measured during the flights included rotational speed, jet thrust, tail-pipe temperature, weight rate of air flow, and combined efficiency of the compressor and the inlet cowling. Data on the combined efficiency were not obtained for all flights.

The turbojet engine was operated at rotational speeds of 100- and 92-percent rated speed, which correspond to take-off and cruising flight conditions, respectively. One flight was made with the engine operating continuously at each of these two engine speeds and the remaining flights were made at alternating engine speeds. During the alternate-speed flights, meteorological and engine-performance data were obtained at intervals of approximately 5 minutes. The engine inlet was photographed during the changes in engine speed.

RESULTS AND DISCUSSION

During flights 1 and 2, heat was applied to all of the inlet components except the guide vanes in order to isolate the effect of guide-vane icing on the engine performance. The heat intensity applied to the cowling lip, the starter dome, and the front-bearing support struts was of the order of 8 to 10 watts per square inch.

Flight 1 was made in a relatively light icing condition; the liquid-water content varied from approximately 0.1 to 0.2 gram per cubic meter at an ambient-air temperature of 13° to 16° F, with an average water-droplet size of 12 to 27 microns. The resulting ice accretions on the inlet guide vanes caused maximum reductions of approximately 7 and 6 percent in jet thrust and 5 and 4 percent in the engine air flow during a 50-minute operation at 100- and 92-percent rated engine speed, respectively, (fig. 4). The effect of inlet icing on tail-pipe temperature was negligible for both engine speeds.

A photograph of the engine inlet, taken approximately 25 minutes after encountering icing during flight 1, is shown in figure 5. A very light ice formation is shown on the guide vanes and no ice is visible on the first stages of the compressor stator blades. Other parts of the engine inlet contained practically no ice because of the electric heating applied to these components.

During the first part of flight 2, heat was again applied to all of the components of the engine inlet except the guide vanes; whereas in the last part of the flight, no heat was employed. The purpose of this flight was to evaluate further the loss in performance due to inlet-guide-vane icing in comparison with the performance loss incurred by icing of the entire inlet under similar icing conditions. During flight 2, the range of meteorological conditions encountered were: liquid-water content from 0.1 to 0.5 gram per cubic meter; average droplet size from 11 to 20 microns, and ambient-air temperature from 22° to 26° F.

The data obtained from flight 2 are shown in figure 6. In the first part of the flight, during which icing protection was provided for all of the inlet components except the inlet guide vanes, maximum losses of 8 percent in jet thrust, 6 and 4 percent in air flow, and a 4- and 6-percent decrease in compressor efficiency occurred during 45 minutes of operation at 100- and 92-percent rated speed, respectively, because of the restriction imposed by ice on the guide vanes. Increase in engine tail-pipe temperature due to the ice formations was negligible during this period at both engine speeds.

In the second part of flight 2, when no icing protection was provided for the engine air inlet, a maximum reduction of 13 and 16 percent in jet thrust, 9 and 10 percent in air flow, and 8 and 6 percent in combined compressor and inlet efficiency occurred during 40 minutes of operation at 100- and 92-percent rated engine speed, respectively. Accompanying this loss in engine performance was a maximum tail-pipe-temperature rise of 50° F for both engine speeds.

Comparison of the results of the two phases of flight 2 (fig. 6) revealed that ice accretions on the compressor-inlet guide vanes accounted for about one-half the total reduction in engine performance caused by ice on the air inlet. The range of icing conditions remained sufficiently alike throughout the flight to validate this comparison.

The series of photographs taken during the two parts of flight 2 are shown in figures 7 and 8, respectively. The time intervals at which the photographs were taken are indicated for convenience in figure 6. Photographs from the first part of the flight (fig. 7) show the progress of the guide-vane ice formations from 11 to 35 minutes after the icing condition was encountered.

Photographs taken during the second part of the flight (fig. 8) show the progress of the ice formations on the entire engine inlet, when no heating was applied to any of the components. The guide-vane ice formations were similar to those of the first part of the flight. These formations, which appeared to be clear ice built-up, became unstable and broke off in a continuing cycle. This cycle of forming and shedding occurred several times during both parts of flight 2, and was characteristic of all flights in the investigation. After 15 minutes of the second part of the flight had elapsed, however, the formations on the inlet lip and the starter dome became large and the guide-vane formations appeared to stabilize. A large quantity of the water droplets was probably separated out of the air stream by the large crater-like formations on the inlet lip and the starter dome and collected on these formations ahead of the guide vanes.

During flights 3 to 5, in contrast to flights 1 and 2, ice was permitted to form on all components of the turbojet-engine air inlet. Flight 3 was made with the engine operating at 92-percent rated speed, flight 4 at 100-percent rated speed, and flight 5 alternately at both speeds. During flight 3, the engine was operated for about 75 minutes. The liquid-water content varied from approximately 0.4 to 0.9 gram per cubic meter, which was the highest value of liquid-water content reached during the entire investigation. Water-droplet diameters ranged from 12 to 14 microns and the ambient-air temperature from 17° to 22° F. The resulting ice formations on the engine inlet caused a maximum reduction of 26 percent in thrust and a maximum increase of 160° F in tail-pipe temperature after 70 minutes of operation in the icing condition, as shown in figure 9. Photographs of these ice formations are shown in figure 10. During that part of the flight indicated by the dashed sections of the curves in figure 9, the icing was too intermittent and light to permit reliable measurements.

The reduction in engine thrust and the increase in tail-pipe temperature that occurred during flight 3 are understandable from examination of the large ice accretions on the front-bearing support struts and the large loose pieces lodged on the inlet guide vanes, as shown in figure 10(a). Ice formations can be observed on the first-stage stator blades of the compressor. Further penetration of ice formations in the compressor are not detectable. Soon after the photograph in figure 10(a) was taken, the large ice formations shown began to break up and pass through the engine. A photograph taken 6 minutes later (fig. 10(b)) shows that a large portion of the ice formation had disappeared. The result was an increase in engine thrust and a decrease in tail-pipe temperature of approximately 50° F (fig. 9).

In flight 4, the turbojet engine was operated at rated speed for 35 minutes in an icing condition in which the liquid-water content varied from 0.4 to 0.6 gram per cubic meter, with water-droplet sizes of 11 to 16 microns and an ambient-air temperature of about 25° F. After 22 minutes of operation in this icing condition, the engine thrust was reduced approximately 18 percent, the air flow was decreased by 12 percent, and the tail-pipe temperature was increased 20° F (fig. 11). Within $3\frac{1}{2}$ minutes after entering the icing condition, the engine thrust was reduced 14 percent and the rate of air flow was reduced 9 percent. This rapid rate of reduction in engine performance during the first few minutes of exposure to the icing clouds was attributed to the fact that during this initial period no shedding occurred as in flight 2, which caused a steady growth of the ice formation. Following the initial $3\frac{1}{2}$-minute period, the process of shedding and rebuilding began and effectively reduced the rate of growth of the ice. The rate of deterioration of engine performance was consequently reduced.

The ice formations on the engine inlet after 22 minutes of operation in the icing condition of flight 4 is shown in figure 12. The first-stage stator blades of the compressor had a light formation of ice and one second-stage stator blade evidently had an ice accretion at the blade root. Further penetration of ice formations into the compressor is not visible.

During flight 5, the engine was operated at 100- and 92-percent rated speed for 70 minutes in an icing condition in which the liquid-water content varied from 0.1 to 0.5 gram per cubic meter, with water-droplet sizes of 10 to 18 microns and an ambient-air temperature of 20° to 24° F. Operation in this icing condition resulted in a maximum reduction of 12 and 9 percent in engine thrust, 7 and 5 percent in air flow, 9 and 5 percent in compressor efficiency, and tail-pipe temperature was increased a maximum of 40° and 10° F at 100- and 92-percent rated speed, respectively, (fig. 13). Within the first minute in the icing encounter, the engine thrust at rated speed was reduced approximately 10 percent and the tail-pipe temperature increased 40° F. The initial losses were equivalent to the maximum losses reached during the entire 70-minute flight, thus illustrating again that the steady growth of the ice formation during the first few minutes of exposure to icing caused the greatest rate of reduction in engine performance. A photograph taken after approximately 23 minutes of operation in this icing condition (fig. 14) shows the typical ice formations obtained during the encounter.

After approximately 30 minutes of operation in the icing encounter of flight 5, the engine instantly swallowed about two-thirds of the inlet-lip ice formation and almost all the formations on the other inlet components. A sudden but momentary drop of approximately 1000 rpm in engine speed occurred. The quantity of ice that passed through the engine is indicated by a comparison of the two inlet photographs in figure 15, which were taken 1 minute before and 1 minute after the incident. Immediately after the ice formations passed into the engine, the jet thrust and the air flow partly recovered and the tail-pipe temperature was decreased 35° F. A close inspection of the engine after the flight revealed no damage to the compressor or stator blades. On several other occasions, large quantities of ice were observed to pass into the engine with approximately the same results.

Because of the type of airplane employed, flight speeds were limited to the range of 165 to 205 miles per hour. At these speeds and with the range of engine power investigated, the inlet velocity ratio of the engine was of the order of 1.5, with the result that the liquid-water content and water-droplet sizes of the air passing into the inlet closely approximated free-stream conditions. At the considerably higher flight speeds associated with the operation of turbojet-powered aircraft, however, the inlet velocity ratio would be reduced to approximately 0.6 and thus effectively increase the liquid-water content in the engine inlet above that of free stream.

SUMMARY OF RESULTS

The following results were obtained with an axial-flow turbojet engine operating in natural icing conditions for the following range of meteorological conditions encountered during the flight investigation: liquid-water content, 0.1 to 0.9 gram per cubic meter; water-droplet size, 10 to 27 microns.

1. The ice accretions that collected on the several components of the air inlet of the turbojet engine with no anti-icing at the inlet resulted in reductions of engine thrust ranging from 9 to 26 percent and increases in tail-pipe temperature of from 0° to 160° F. The effects of ice accretions on engine air flow and on the combined efficiency of the compressor and inlet diffuser were of approximately the same order of magnitude as the thrust losses. The greatest effect of icing on engine performance occurred at a liquid-water content of 0.9 gram per cubic meter.

2. The investigation showed that the greatest rate of deterioration in engine performance caused by inlet icing occurred in the first few minutes of flight in an icing condition, the thrust of the engine being reduced as much as 14 percent within $3\frac{1}{2}$ minutes of operation in icing conditions.

3. The accretions of ice on the engine inlet, particularly on the guide vanes and support struts, followed a continuous cycle of building up and shedding.

4. During several of the flights, light ice accretions were observed on blades of the first and second stators of the compressor.

5. The data indicated that ice accretions on the inlet guide vanes accounted for approximately one-half of the total reduction in engine performance caused by ice formations on the air-inlet surfaces.

6. During several flights, unusually large ice formations on the several components of the engine inlet broke away almost instantaneously and were swept through the engine. On one occasion, passage of the ice through the compressor resulted in a momentary decrease in engine speed of approximately 1000 rpm. Subsequent examination of the engine revealed no evidence of damage to the compressor stator or rotor blades. Further operational experience is considered necessary to fully evaluate the importance of this aspect of the engine icing problem.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

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2. Acker, Loren W.: Preliminary Results of Natural Icing of an Axial-Flow Turbojet Engine. NACA RM E8C18, 1948.

3. Acher, Loren W.: Natural Icing of an Axial-Flow Turbojet Engine in Flight for a Single Icing Condition. NACA RM E8F01a, 1948.

4. Anon.: The Multicylinder Method. The Mount Washington Monthly Res. Bull., vol. II, no. 6, June 1946.

TABLE I - EFFECT OF ICING ON PERFORMANCE OF AXIAL-FLOW TURBOJET ENGINE

Flight	Liquid-water content (g/cu m)	Average droplet size (microns)	Ambient-air temperature (°F)	Duration of icing encounter (min)	Engine speed (percent max.)	Thrust loss (percent max.)	Air-flow loss (percent max.)	Combined compressor and inlet efficiency loss (percent)	Tail-pipe temperature rise (°F)
[a]1	0.1 - 0.2	12 - 27	13 - 16	50	92	6	4	-	0
					100	7	5	-	0
[a]2	.3 - .5	11 - 17	22 - 25	45	92	8	4	6	0
					100	8	6	4	0
2	.1 - .5	11 - 20	22 - 26	50	92	16	10	8	50
					100	13	9	6	50
[b]3	.4 - .9	12 - 14	17 - 22	76	92	26	-	-	160
4	.4 - .6	11 - 16	25	35	100	18	12	-	40
5	.1 - .5	10 - 18	20 - 24	70	92	9	5	5	10
					100	12	7	9	40

[a]8 to 10 watts/sq. in. anti-icing current provided on inlet lip, starter dome, and front-bearing support struts.

[b]Flight made with engine having 10-stage axial-flow compressor.

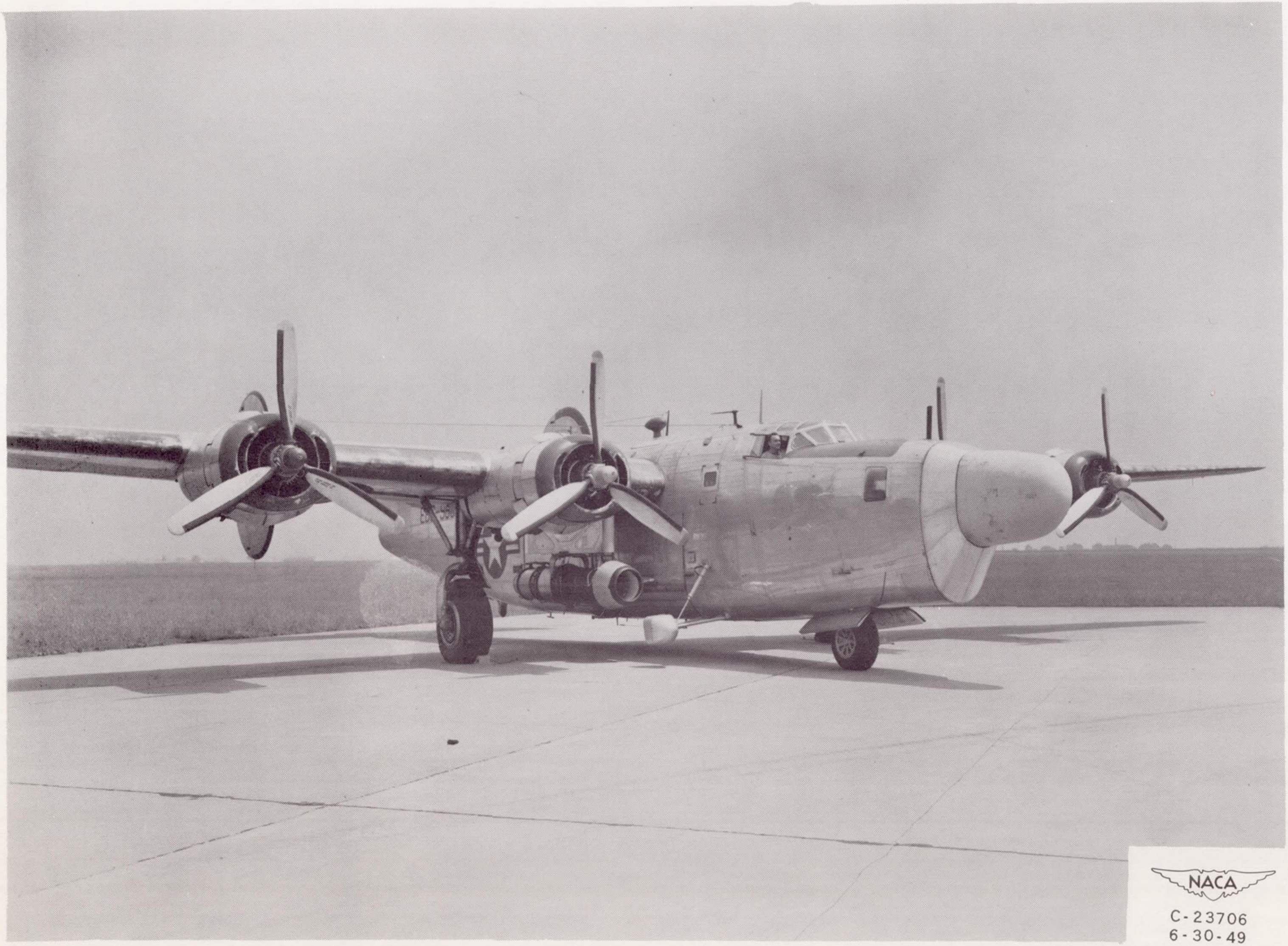

Figure 1. - Flight installation for investigation of icing of axial-flow turbojet engine.

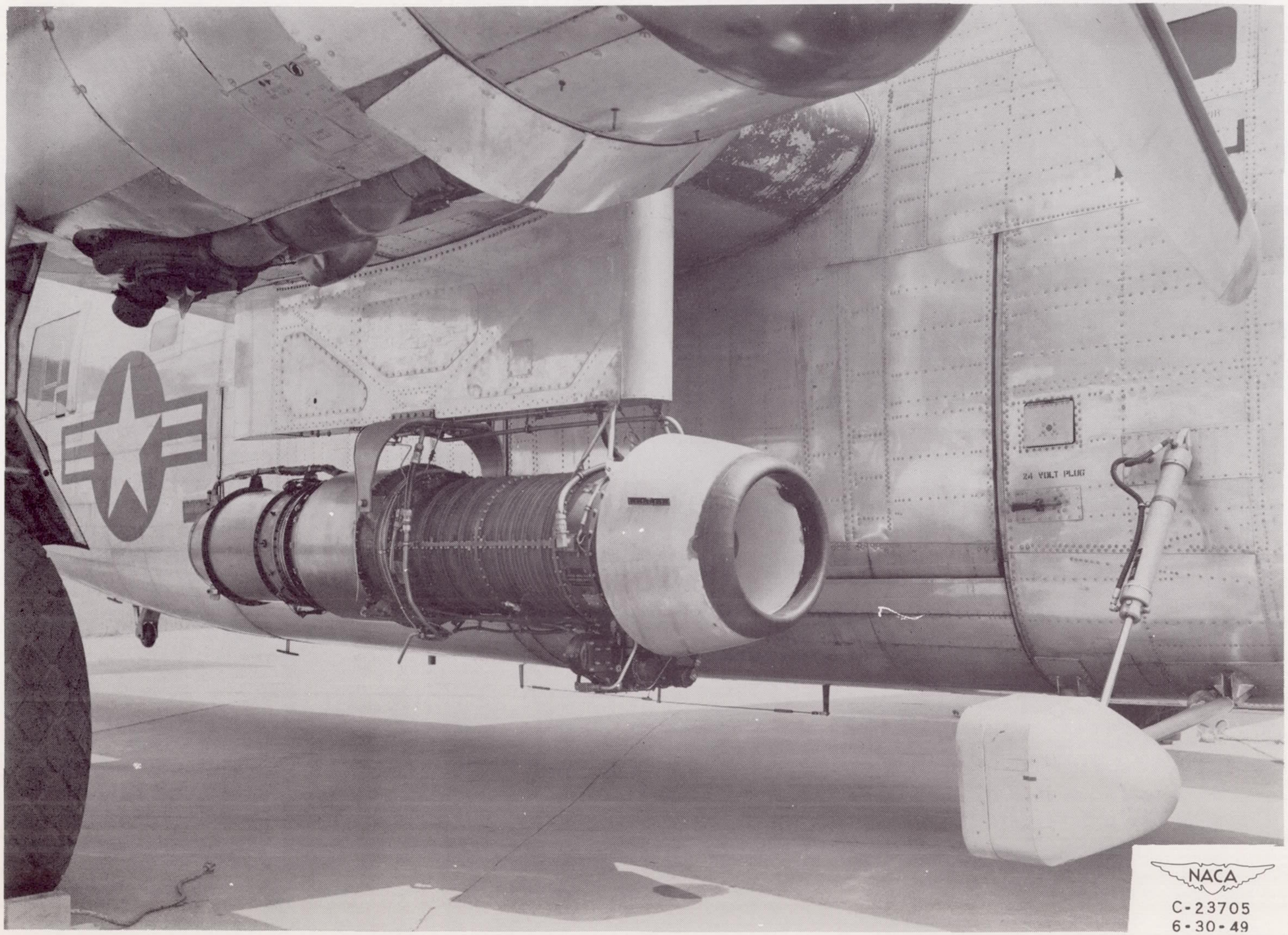

Figure 2. - Close-up view of turbojet engine and camera housing.

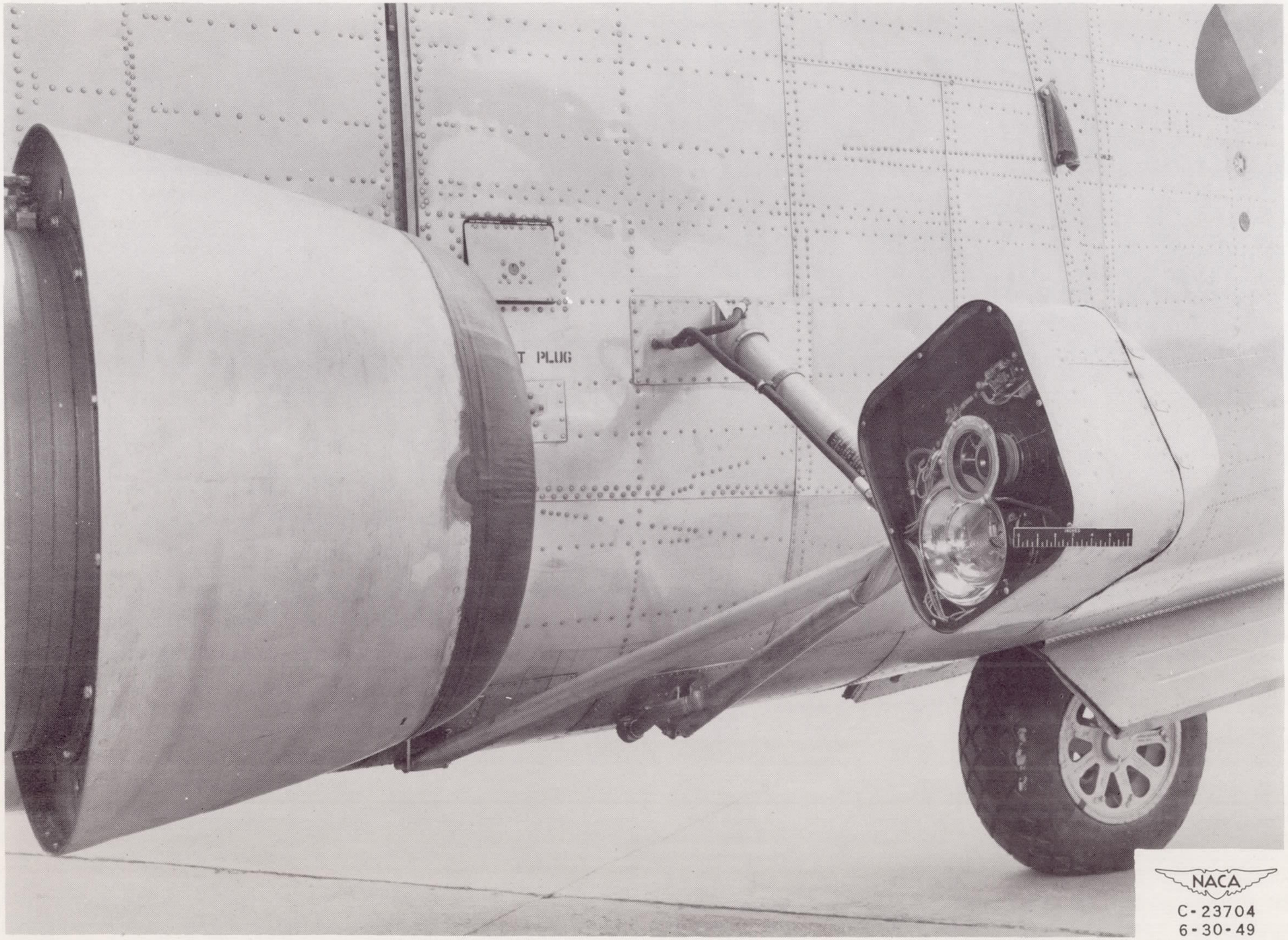

Figure 3. - Camera and mounting used for photographing turbojet-engine inlet in flight.

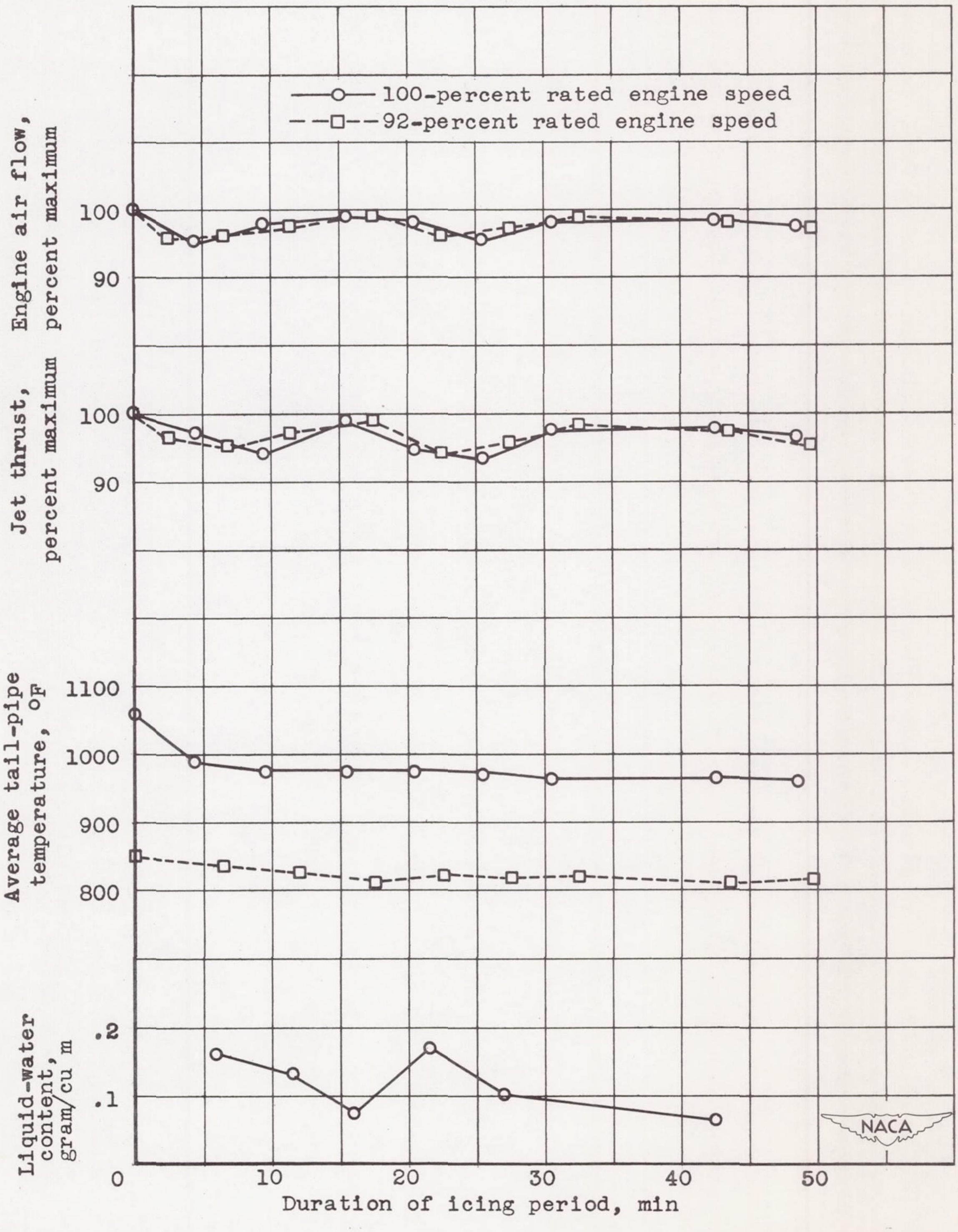

Figure 4. - Time history of flight data obtained in icing condition during flight 1. Ambient-air temperature, 13° to 16° F; droplet size, 12 to 27 microns; indicated airspeed, 185 to 205 miles per hour; pressure altitude, 3400 to 9300 feet.

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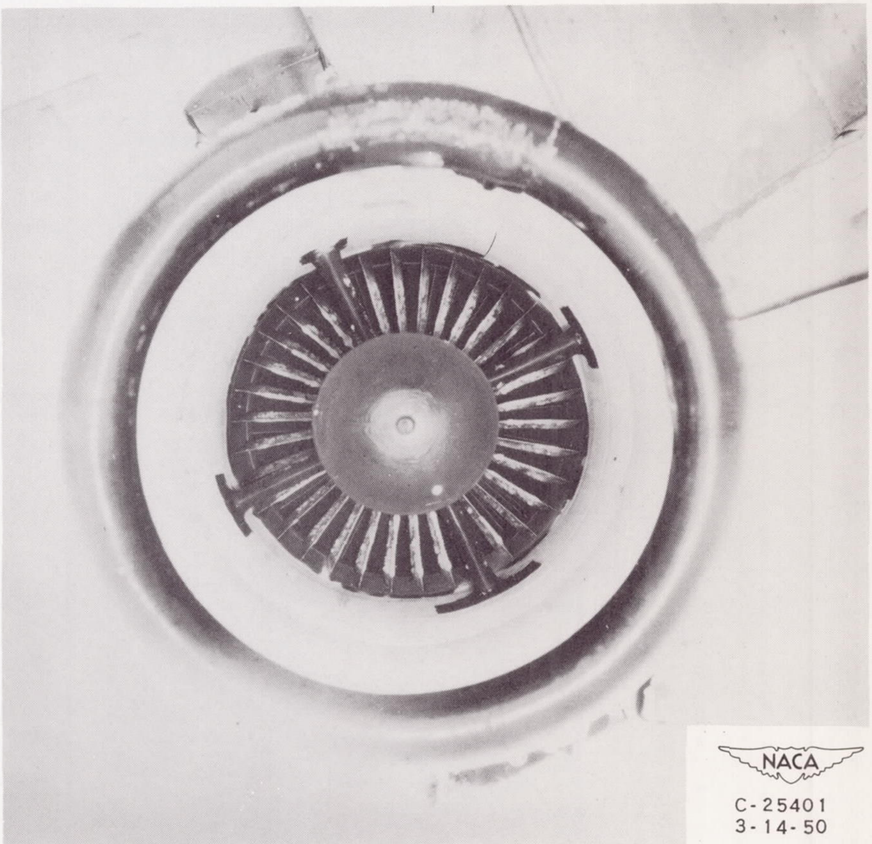

Figure 5. - Ice formation on compressor-inlet guide vanes during flight 1. Time in icing, 25 minutes; liquid-water content, 0.1 to 0.2 gram per cubic meter; droplet size, 12 to 7 microns; ambient-air temperature, 13° to 16° F; loss in thrust, 6 percent.

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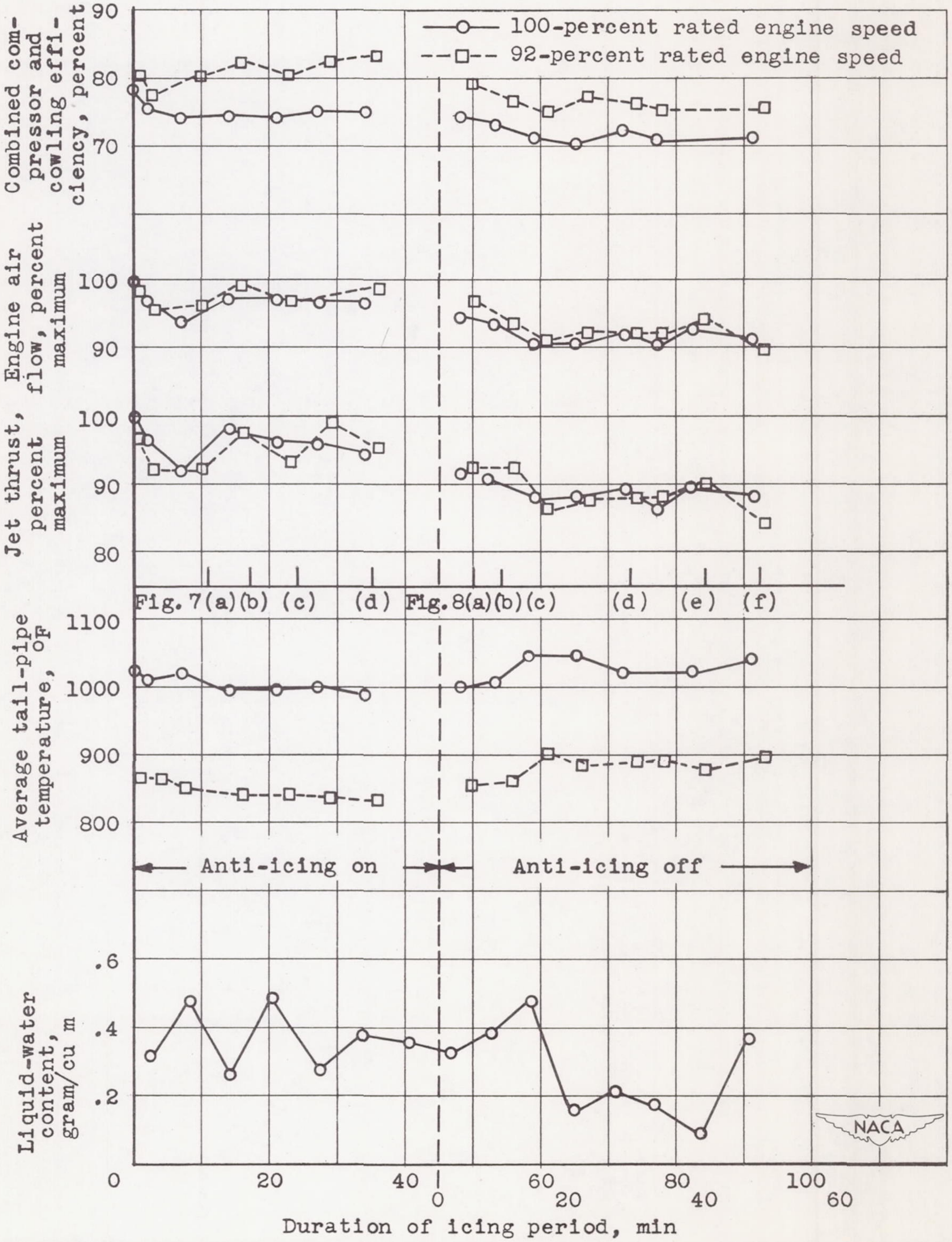

Figure 6. - Time history of flight data obtained in icing condition during flight 2. Ambient-air temperature, 22° to 26° F; droplet size, 11 to 20 microns; indicated airspeed, 170 to 180 miles per hour; pressure altitude, 5000 to 6400 feet.

(a) Elapsed time in icing conditions, 11 minutes.

Figure 7. - Ice formation on compressor-inlet guide vanes during flight 2, with anti-icing. Liquid-water content, 0.3 to 0.5 gram per cubic meter; droplet size, 11 to 17 microns; ambient-air temperature, 22° to 25° F; thrust loss, 8 percent.

(b) Elapsed time in icing conditions, 17 minutes.

Figure 7. - Continued. Ice formation on compressor-inlet guide vanes during flight 2, with anti-icing. Liquid-water content, 0.3 to 0.5 gram per cubic meter; droplet size, 11 to 17 microns; ambient-air temperature, 22° to 25° F; thrust loss, 8 percent.

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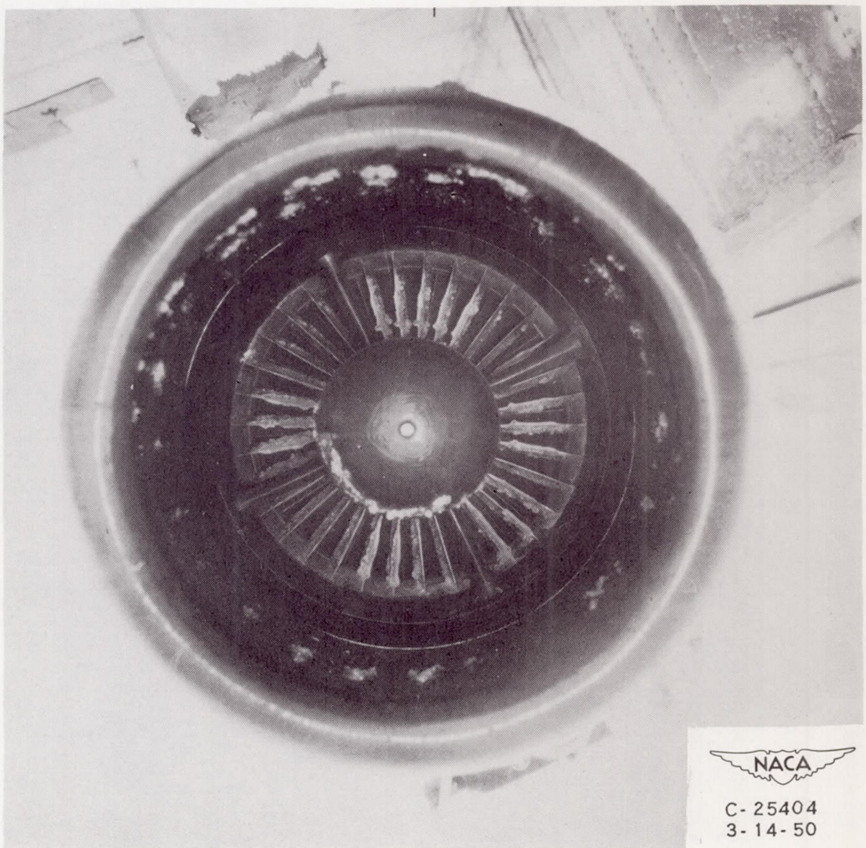

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(c) Elapsed time in icing conditions, 24 minutes.

Figure 7. - Continued. Ice formation on compressor-inlet guide vanes during flight 2, with anti-icing. Liquid-water content, 0.3 to 0.5 gram per cubic meter; droplet size, 11 to 17 microns; ambient-air temperature, 22° to 25° F; thrust loss, 8 percent.

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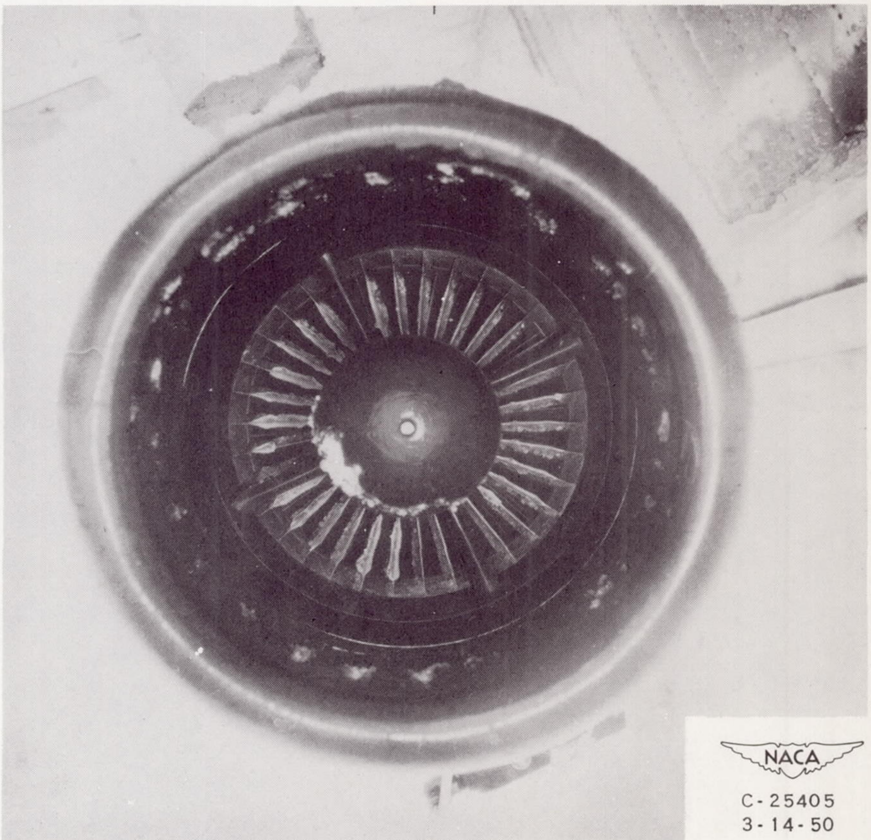
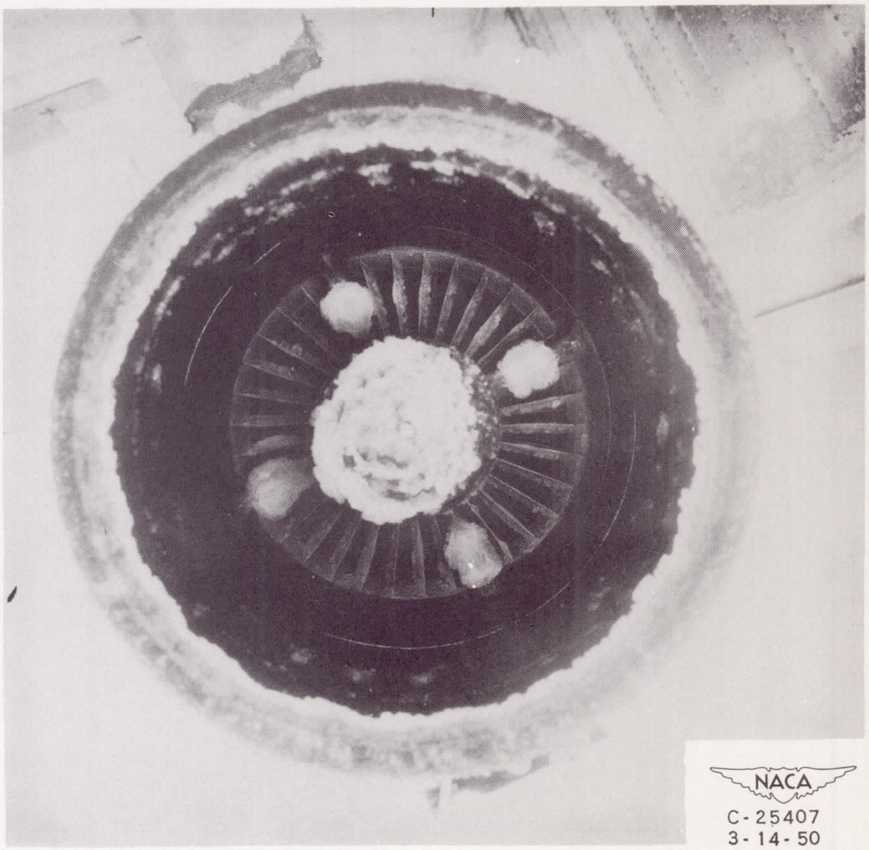


(d) Elapsed time in icing conditions, 35 minutes.

Figure 7. - Concluded. Ice formation on compressor-inlet guide vanes during flight 2, with anti-icing. Liquid-water content, 0.3 to 0.5 gram per cubic meter; droplet size, 11 to 17 microns; ambient-air temperature, 22° to 25° F; thrust loss, 8 percent.

(a) Elapsed time in icing conditions, 5 minutes.

Figure 8. - Ice formation on turbojet-engine inlet during flight 2, without anti-icing. Liquid-water content, 0.1 to 0.5 gram per cubic meter; droplet size, 11 to 20 microns; ambient-air temperature, 22° to 26° F; thrust loss, 13 to 16 percent.



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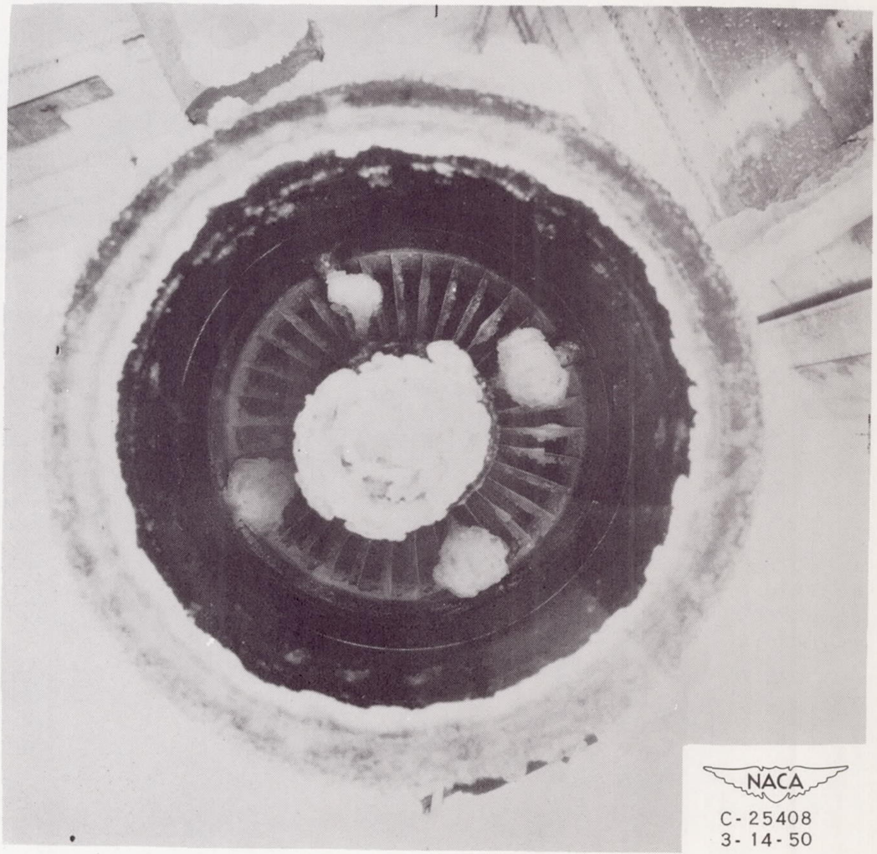
(b) Elapsed time in icing conditions, 9 minutes.

Figure 8. - Continued. Ice formation on turbojet-engine inlet during flight 2, without anti-icing. Liquid-water content, 0.1 to 0.5 gram per cubic meter; droplet size, 11 to 20 microns; ambient-air temperature, 22° to 26° F; thrust loss, 13 to 16 percent.



(c) Elapsed time in icing conditions, 15 minutes.

Figure 8. - Continued. Ice formation on turbojet-engine inlet during flight 2, without anti-icing. Liquid-water content, 0.1 to 0.5 gram per cubic meter; droplet size, 11 to 20 microns; ambient-air temperature, 22° to 26° F; thrust loss, 13 to 16 percent.

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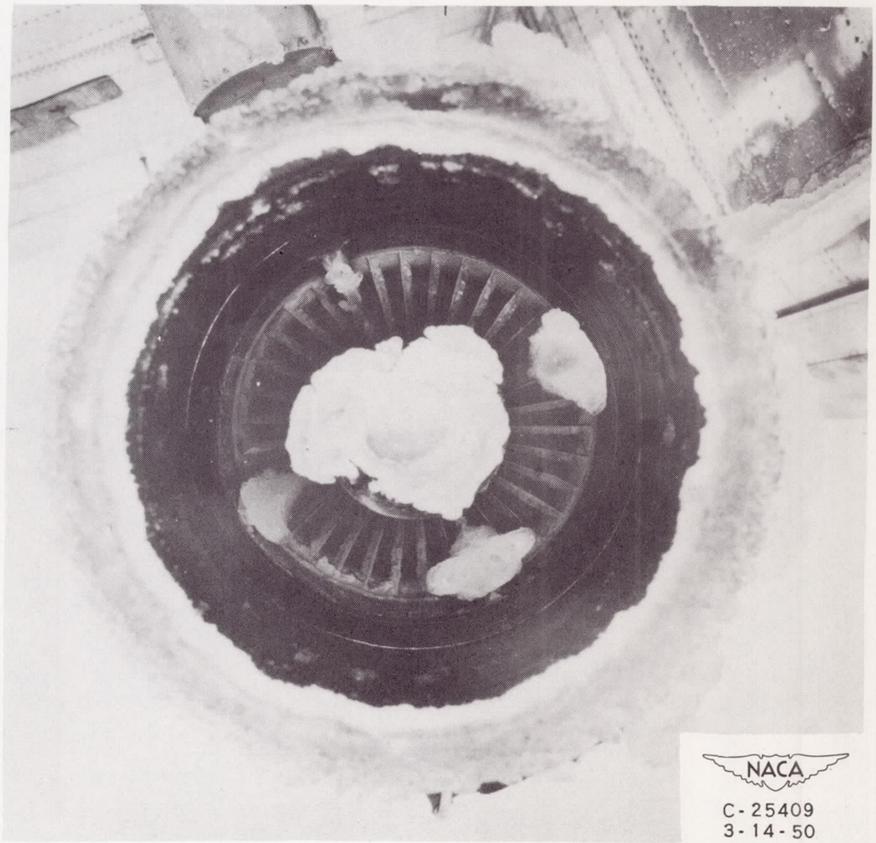
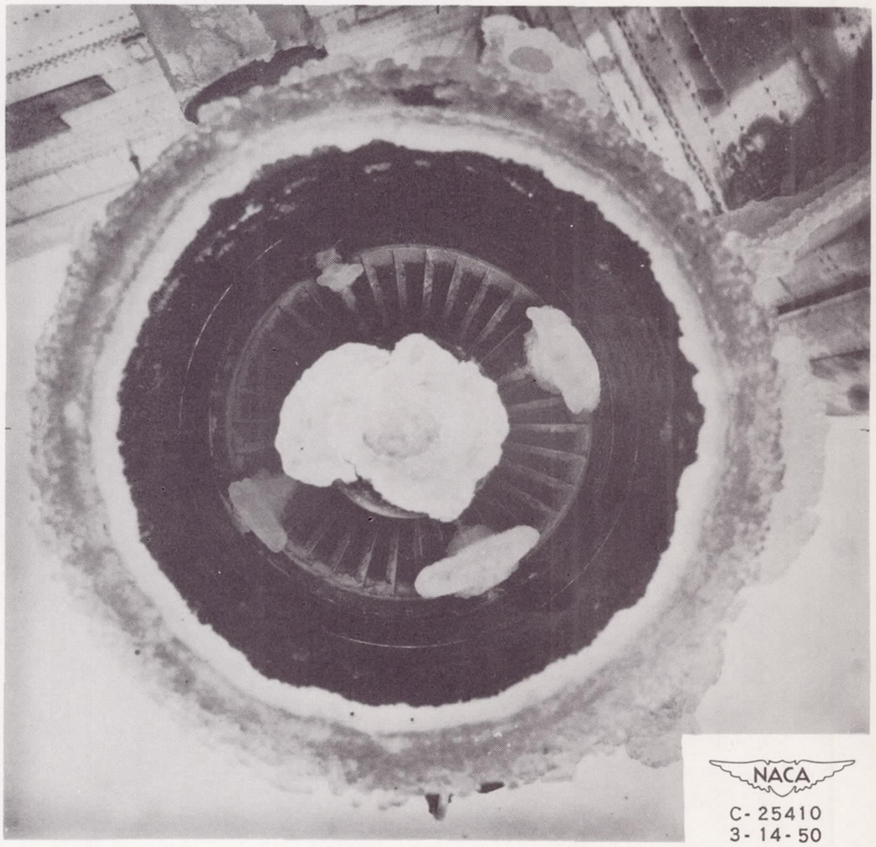


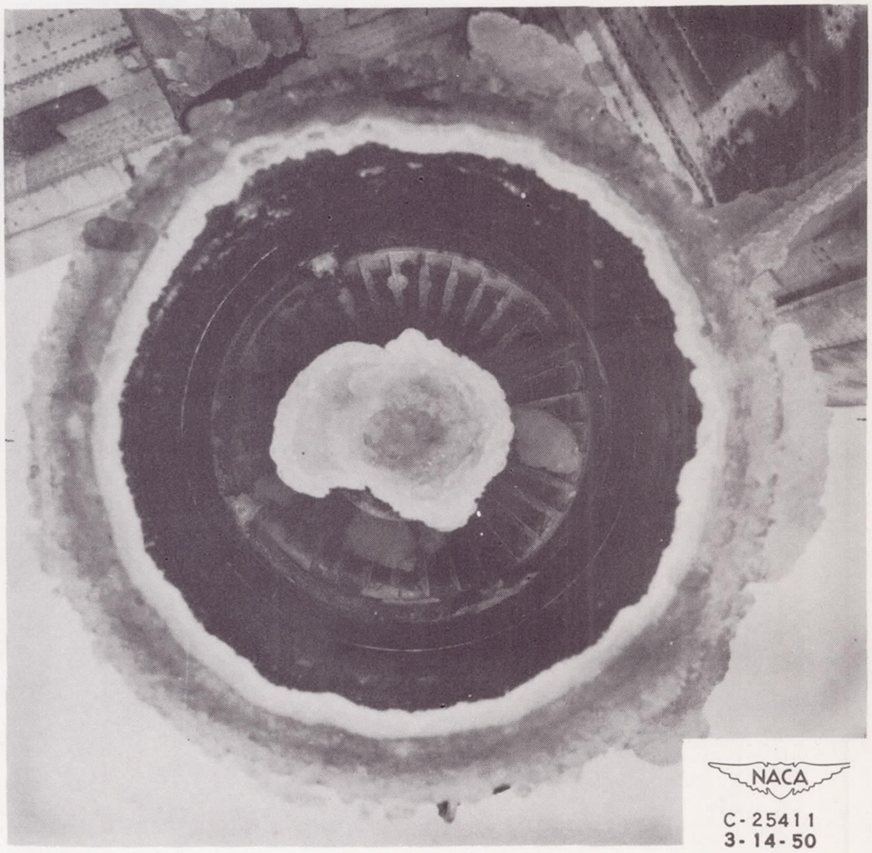
(d) Elapsed time in icing conditions, 28 minutes.

Figure 8. - Continued. Ice formation on turbojet-engine inlet during flight 2, without anti-icing. Liquid-water content, 0.1 to 0.5 gram per cubic meter; droplet size, 11 to 20 microns; ambient-air temperature, 22° to 26° F; thrust loss, 13 to 16 percent.



(e) Elapsed time in icing conditions, 39 minutes.

Figure 8. - Continued. Ice formation on turbojet-engine inlet during flight 2, without anti-icing. Liquid-water content, 0.1 to 0.5 gram per cubic meter; droplet size, 11 to 20 microns; ambient-air temperature, 22° to 26° F; thrust loss, 13 to 16 percent.



(f) Elapsed time in icing conditions, 47 minutes.

Figure 8. - Concluded. Ice formation on turbojet-engine inlet during flight 2, without anti-icing. Liquid-water content, 0.1 to 0.5 gram per cubic meter; droplet size, 11 to 20 microns; ambient-air temperature, 22° to 26° F; thrust loss, 13 to 16 percent.

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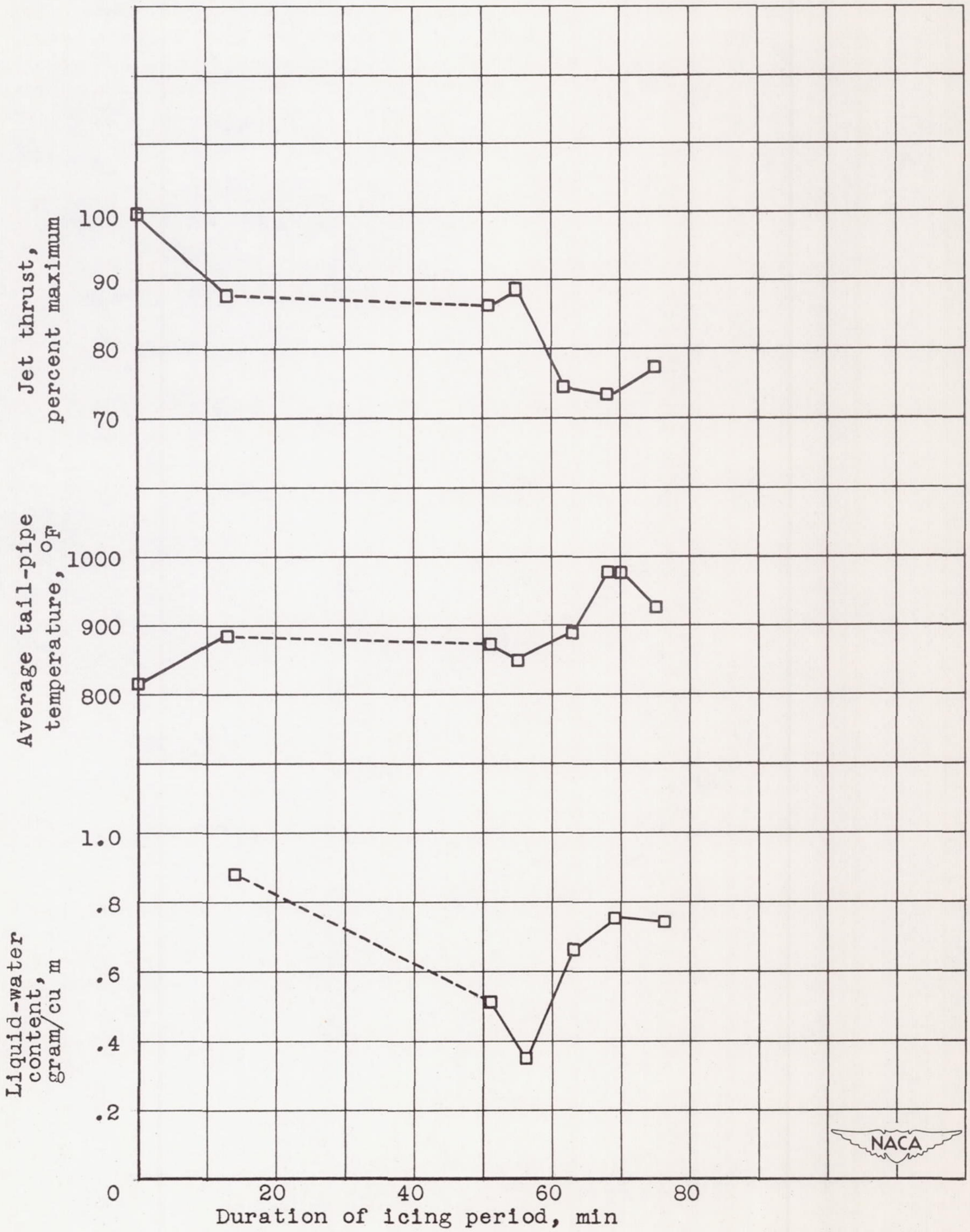

Figure 9. - Time history of flight data obtained in icing condition during flight 3 at 92-percent rated engine speed. Ambient-air temperature, 17° to 22° F; droplet size, 12 to 14 microns; indicated airspeed, 173 to 185 miles per hour; pressure altitude, 4600 to 5900 feet.

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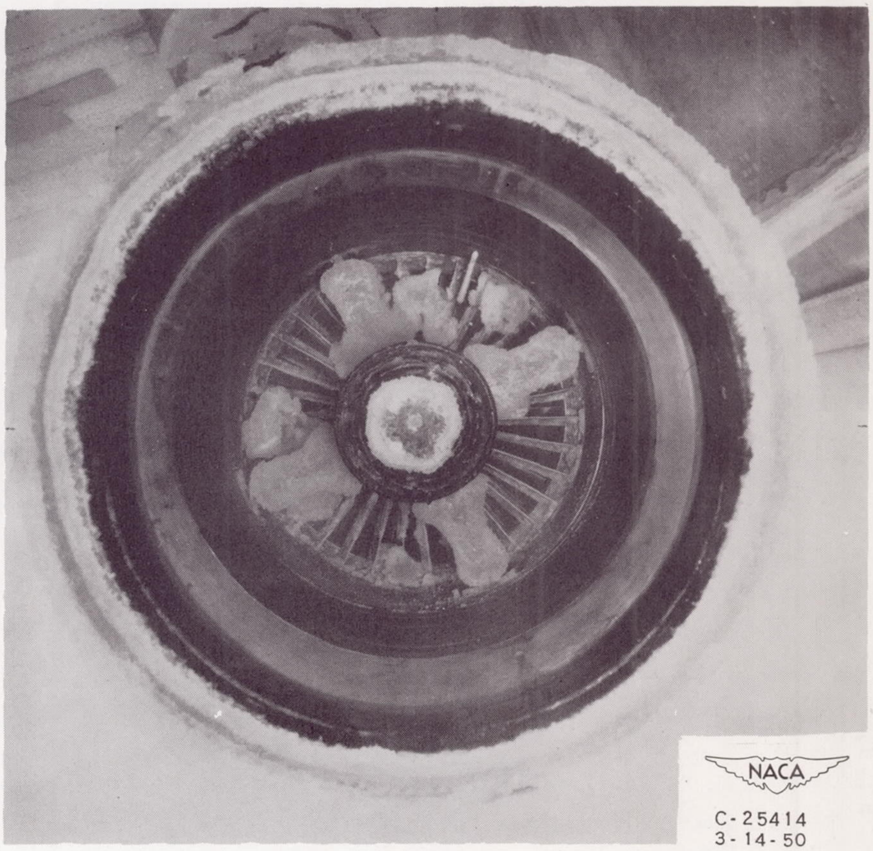

(a) Elapsed time in icing conditions, 70 minutes.

Figure 10. - Ice formation on turbojet-engine inlet during flight 3 at 92-percent rated speed. Liquid-water content, 0.4 to 0.9 gram per cubic meter; droplet size, 12 to 14 microns; ambient-air temperature, 17° to 22° F; thrust loss, 26 percent.

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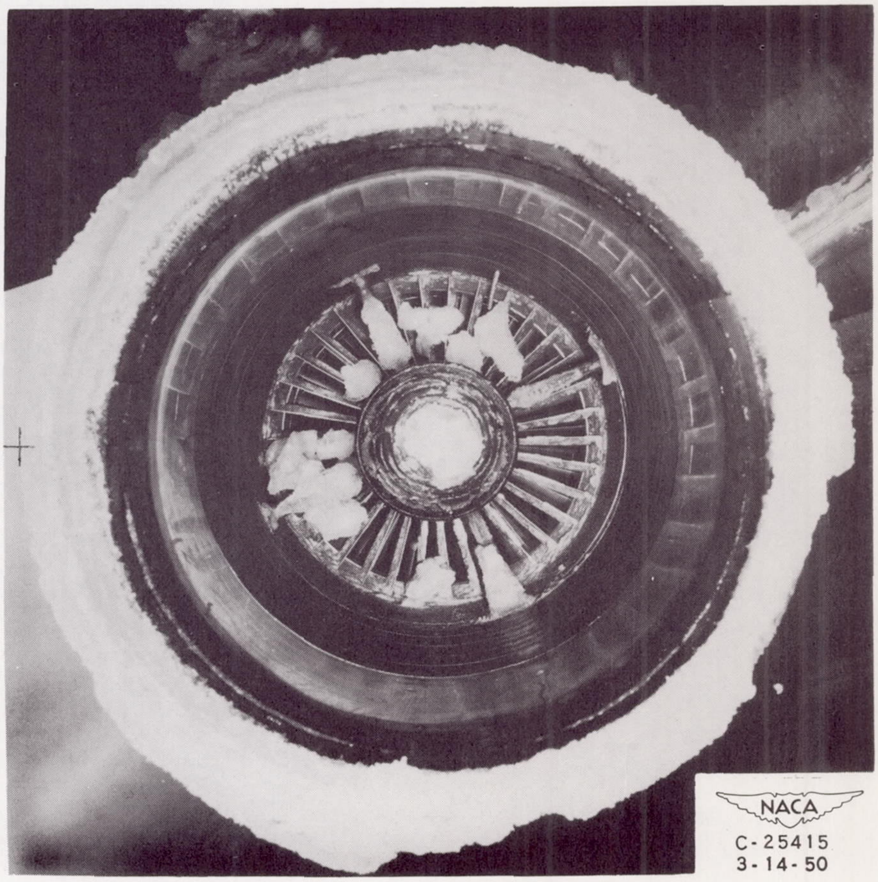

(b) Elapsed time in icing conditions, 76 minutes.

Figure 10. - Concluded. Ice formation on turbojet-engine inlet during flight 3 at 92-percent rated engine speed. Liquid-water content, 0.4 to 0.9 gram per cubic meter; droplet size, 12 to 14 microns; ambient-air temperature, 17° to 22° F; thrust loss, 26 percent.

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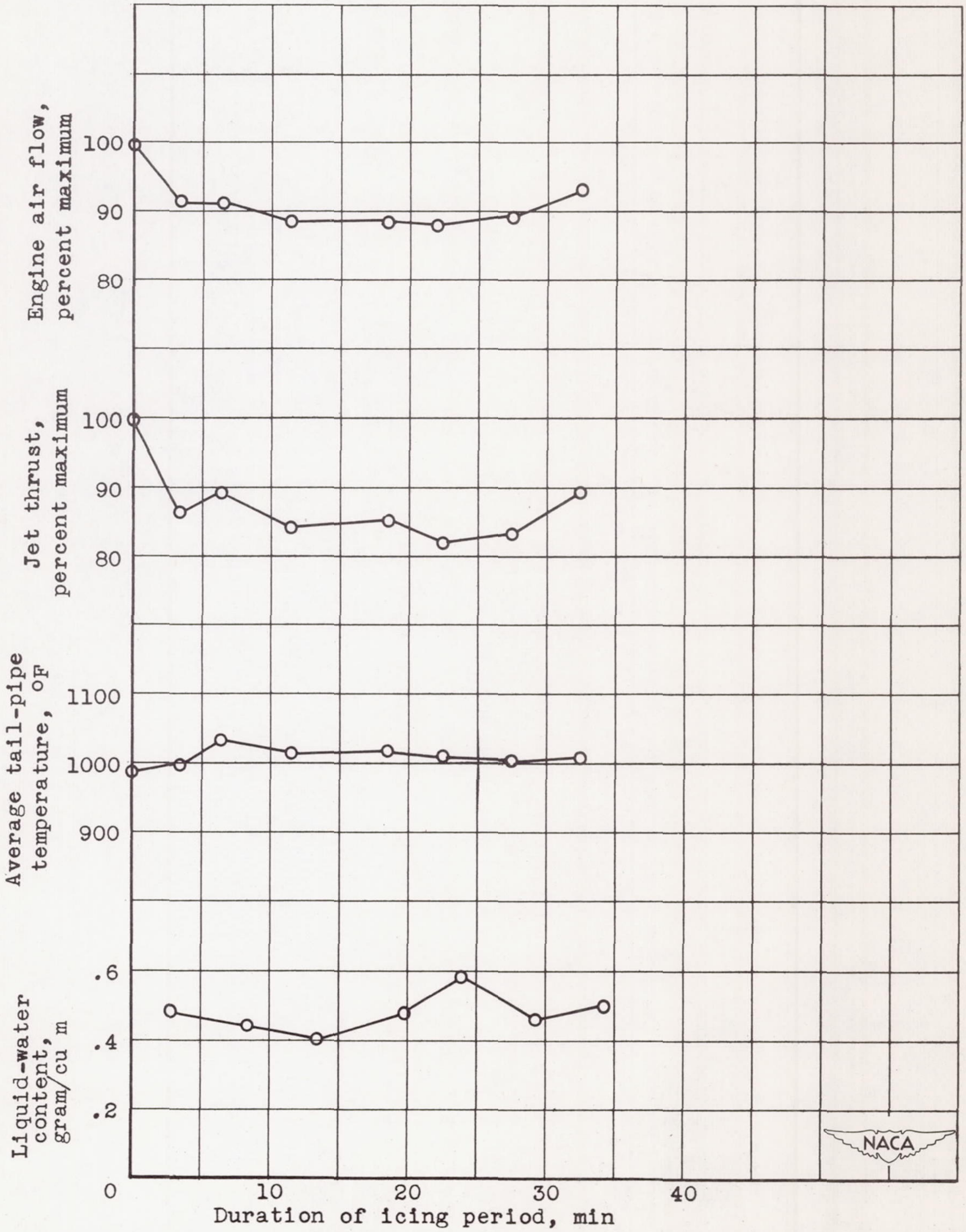

Figure 11. - Time history of flight data obtained in icing condition during flight 4 at rated engine speed. Ambient-air temperature, 25° F; droplet size, 12 to 16 microns; indicated airspeed, 165 to 180 miles per hour; pressure altitude, 2800 to 5000 feet.

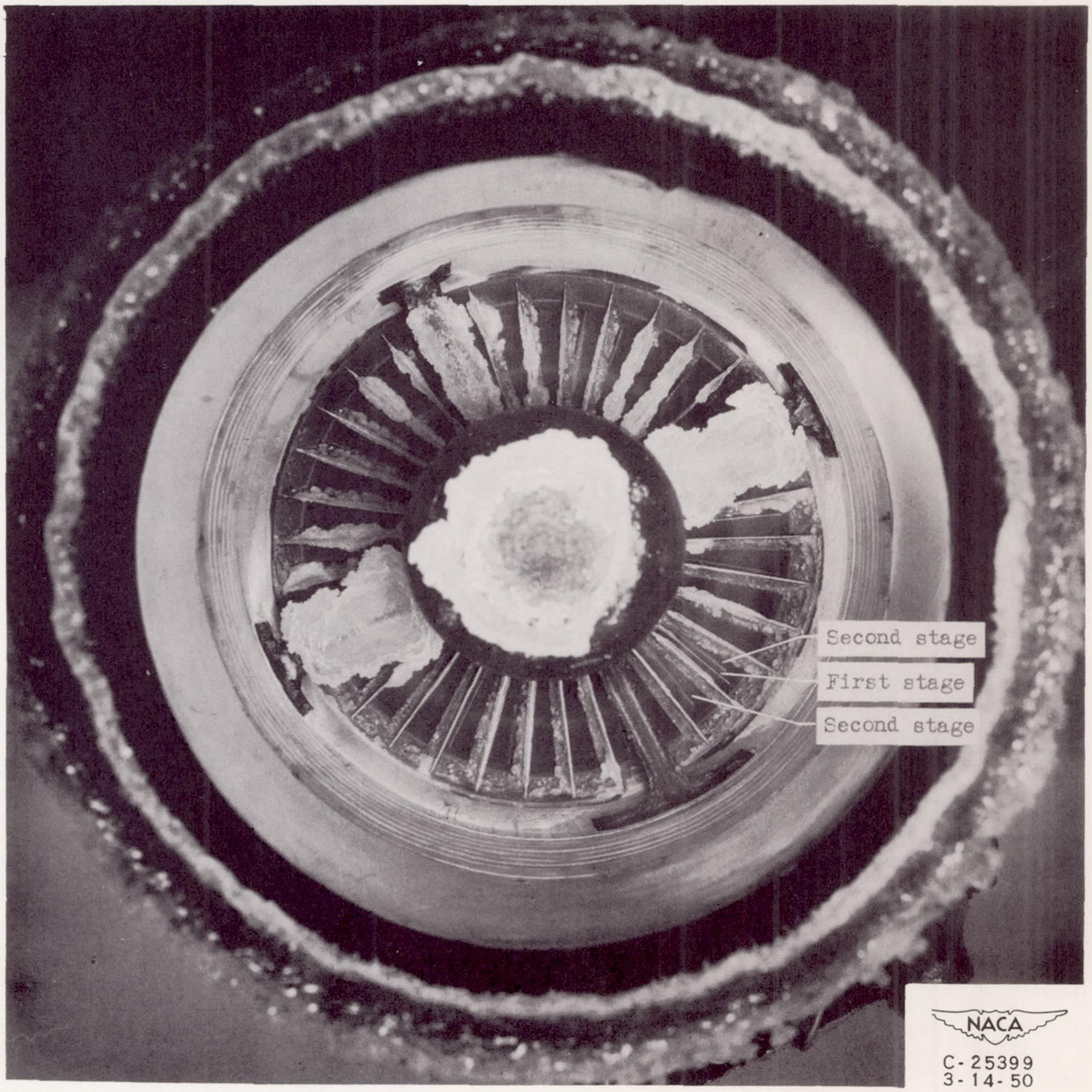

Figure 12. - Ice formations on turbojet-engine inlet at rated speed during flight 4. Time in icing, 22 minutes; liquid-water content, 0.4 to 0.6 gram per cubic meter; drop size, 11 to 16 microns; ambient-air temperature, 25° F; loss in thrust, 18 percent.

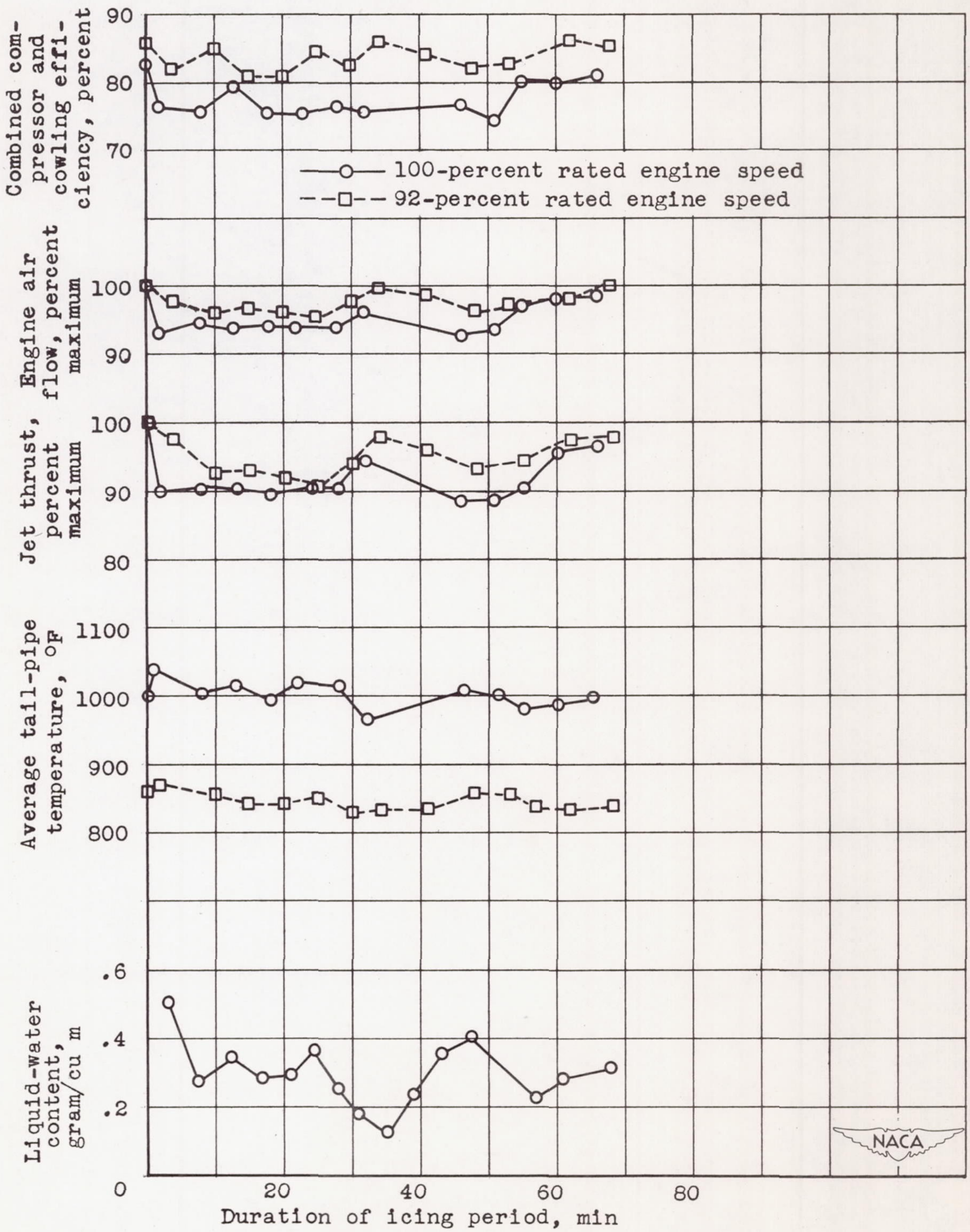

Figure 13. - Time history of flight data obtained in icing condition during flight 5. Ambient-air temperature, 20° to 24° F; droplet size, 10 to 18 microns; indicated airspeed, 175 to 180 miles per hour; pressure altitude, 4200 to 4500 feet.

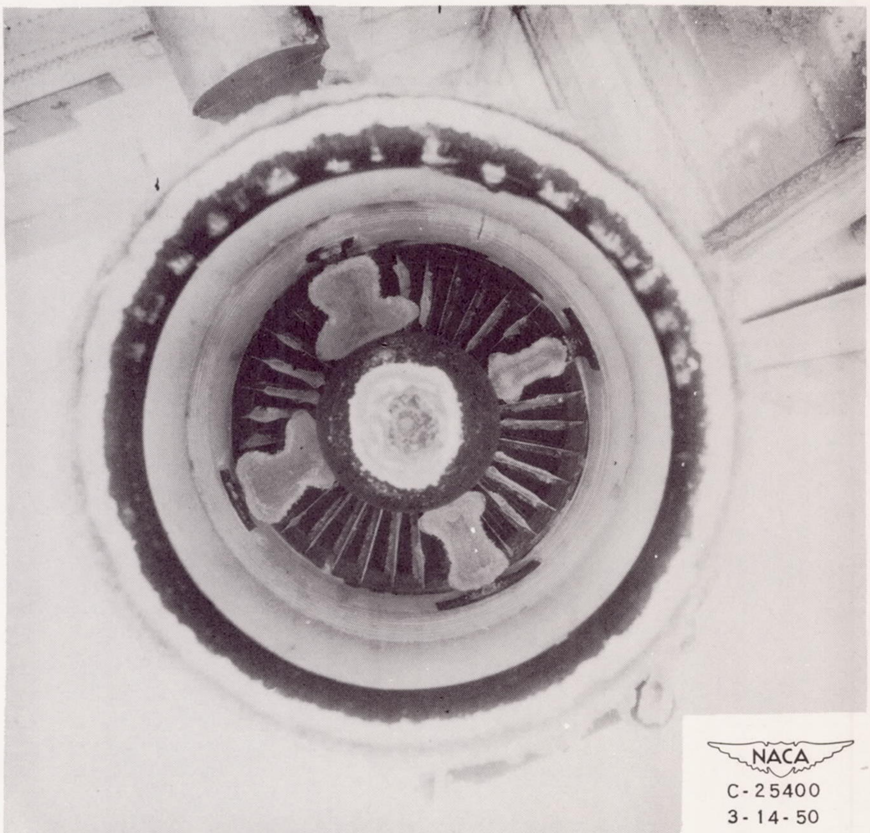

Figure 14. - Ice formation on turbojet-engine inlet during flight 5. Time in icing, 23 minutes; liquid-water content, 0.1 to 0.5 gram per cubic meter; droplet size, 10 to 8 microns; ambient-air temperature, 20° to 24° F; thrust loss, 9 to 12 percent.

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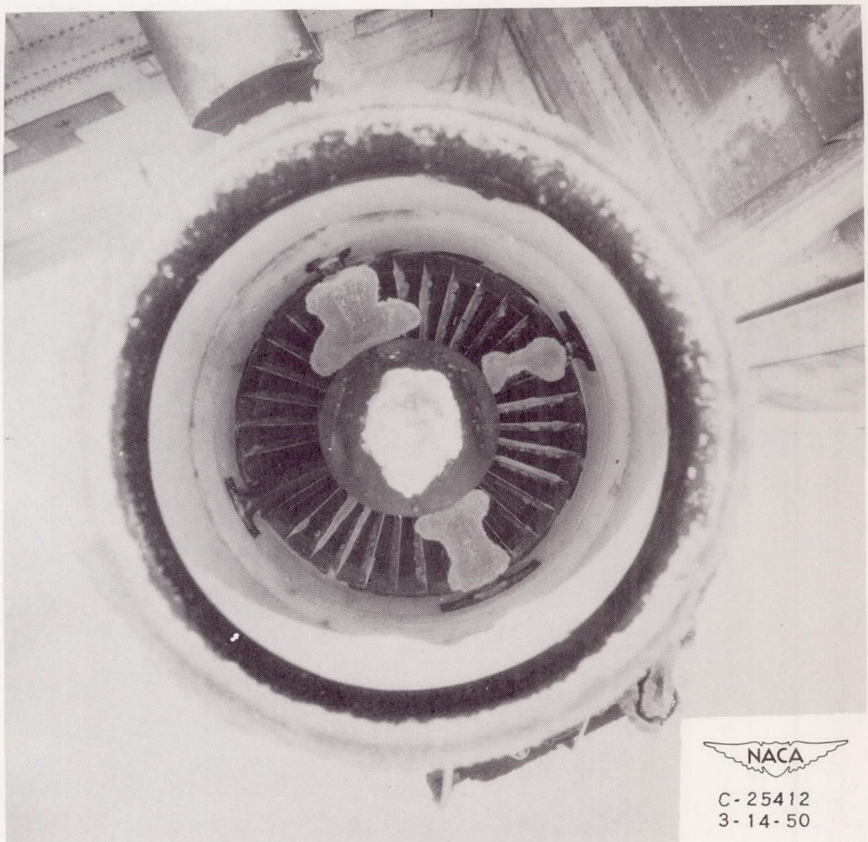

(a) 1 minute before ice formations passed into engine.

Figure 15. - Ice formations on turbojet-engine inlet after approximately 30 minutes of operation in icing condition of flight 5.

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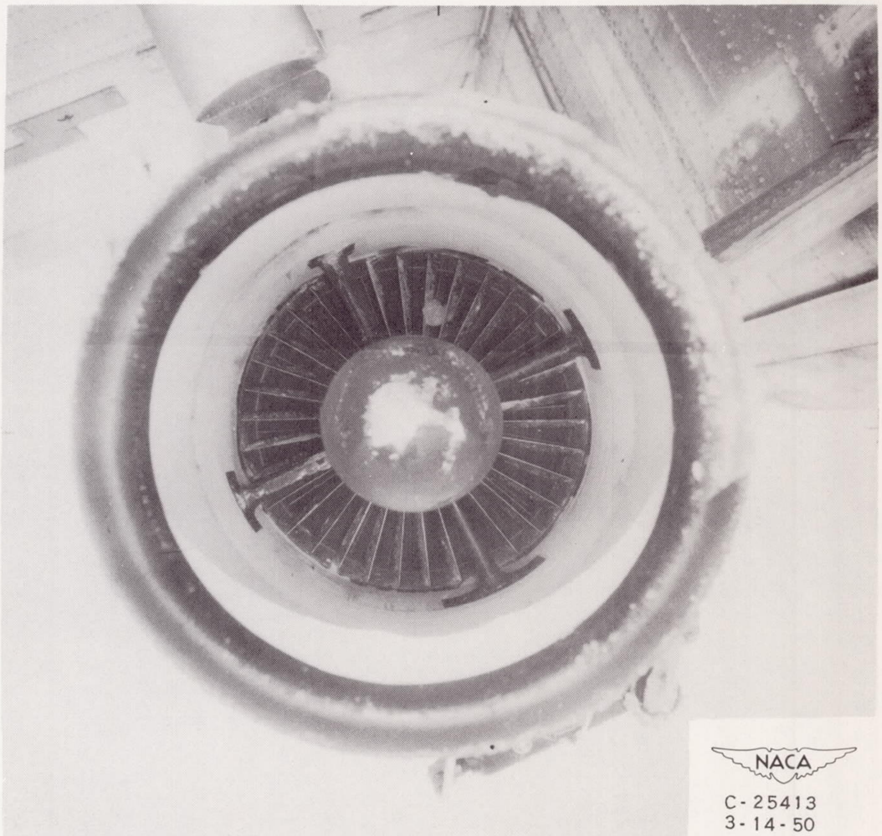

(b) 1 minute after ice formations passed into engine.

Figure 15. - Concluded. Ice formations on turbojet-engine inlet after approximately 30 minutes of operation in icing condition of flight 5.

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