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RESEARCH MEMORANDUM

INVESTIGATION OF THE AERODYNAMIC AND ICING CHARACTERISTICS OF A RECESSED FUEL CELL VENT ASSEMBLY

II - RAMP FLOOR VENT-TUBE MOUNTING

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation has been conducted in the NACA Cleveland icing research tunnel to determine aerodynamic and icing characteristics of a ramp-type recessed fuel cell vent assembly with the vents located on the floor of the ramp. Vent-tube static-pressure differentials and pressure surveys over the vent ramp were obtained as a function of angle of attack and tunnel-air velocity. Icing experiments were made at medium and high angles of attack and at tunnel-air velocities of 220 and 370 feet per second to determine the vent-tube pressure and air-flow losses.

The results of the aerodynamic investigation show that because the vent tubes are not located in the area of maximum pressure, the vent-tube static pressures are submarginal for a tunnel-air velocity of 220 feet per second and angles of attack up to 12°. The vent tubes remained ice-free under severe icing and freezing-rain conditions for icing periods up to 60 minutes. Severe and rapid losses in pressure and moderate losses in air flow through the vent tubes were observed during the icing period. These losses were due to icing of the ramp and rear wall of the vent and the wing surface.

INTRODUCTION

An investigation to determine the pressure and icing characteristics of a recessed fuel cell vent installation has been conducted in the icing research tunnel of the NACA Cleveland laboratory as part of a general study of aircraft icing.

The recessed fuel vent installation, located on the lower surface of the outer wing panel, was designed as a modification of the configuration described in reference 1. The vent tubes in the configuration for this investigation, however, were located on the floor of the ramp rather than on the rear slope. The recessed vents are intended to replace fuselage and nacelle flush-type vents, which are believed to constitute a serious fire hazard. Because the location of the recessed vents are in an area susceptible to icing, particularly during low-speed cruise, climb, and letdown flight conditions, it was necessary to determine whether ice formations on the vent could sufficiently reduce the vent air flow or fuel-cell internal pressure to cause collapse or failure of the fuel cells.

APPARATUS AND INSTRUMENTATION

An NACA 65,2-216 airfoil section of 8-foot chord was used as a wing model for the vent installation (fig. 1). The wing model was equipped with an external electric heater over the leading-edge region back to 20-percent of chord. Details of the vent are shown in figure 1(b).

The vent assembly was so installed that the rear edge of the recess was located at 67 percent of chord on the lower surface of the airfoil section. Three tubes $1\frac{1}{4}$ inches in diameter (tubes 1, 2, and 4; fig. 1(b)) and one tube 1 inch in diameter (tube 3) were mounted flush on the bottom of the recess with the tube openings normal to the wing surface, and each tube extended to a common outlet on the upper surface of the airfoil. Valves were placed in the vent lines to control air flow and the flow of air was measured by means of a calibrated orifice installed in each vent tube. In addition to the orifice pressure measurements, one static pressure was measured on the upstream side of each tube 1 inch inside the opening, and ramp surface static-pressure measurements were made at nine locations on the center line of the ramp, as shown in figure 2.

Simulated freezing-rain and icing conditions were provided by air-atomizing water-spray nozzles located upstream of the airfoil section.

EXPERIMENTAL TECHNIQUES AND PROCEDURE

Aerodynamic. - Aerodynamic experiments similar to those in reference 1 were conducted without air flow and with an air flow of 0.6 pound per minute through the large vent tubes. The vent pressure characteristics were determined as a function of tunnel-air velocities of 220 and 350 feet per second and at angles of attack ranging from 0° to 12°.

Icing. - The icing characteristics of the vent installation were determined for angles of attack of 7° and 14° and at tunnel-air velocities of 370 and 220 feet per second, respectively. The icing conditions ranged from a liquid-water concentration of 1.0 to 1.5 grams per cubic meter for ambient-air temperatures from 0° to 23° F. The droplet size for these experiments was 15 microns, based on volume maximum. The icing investigation was conducted at high angles of attack in order to expose the vent openings and the vent ramp to the maximum direct water impingement.

The vent installation was also investigated for a freezing-rain condition, at an ambient-air temperature of 23° F, in which the liquid-water concentration was approximately 1.8 grams per cubic meter and the droplet size was larger than 20 microns.

RESULTS AND DISCUSSION

During the aerodynamic investigations, the tunnel blocking effect by the wing at high angles of attack affected the reading of the static tube used to obtain tunnel static pressure. The data presented herein are not corrected for tunnel wall effects and blocking.

A minimum positive pressure differential of 2 inches of water between the interior of the fuel cell and the fuel-cell compartment has been recommended by the Douglas Aircraft Company for satisfactory operation of the fuel cell. This criterion has been used to evaluate the merits of the vent system under investigation. A reduction of this pressure differential might lead to collapse of the fuel cells under certain operating conditions.

Aerodynamic. - The variation of pressure distribution over the vent surface and the rear vent wall is presented in figure 3 for various angles of attack. The pressures are presented in terms of the pressure coefficient $\frac{p-p_0}{q_0}$, where p is the surface static pressure, p_0 is the free-stream static pressure, and q_0 is the free-stream velocity pressure. All local static pressures at the upstream end of the vent ramp are negative. At the bottom of the ramp, the surface pressures are positive at angles of attack greater than 4°. 923

The pressures obtained at the openings of the vent tubes for angles of attack ranging from 0° to 12° are shown in figure 4 for the condition of no vent air flow. The vent-tube pressure is shown as a static-pressure differential (p_s-p_0), where p_s is the static pressure measured 1 inch inside the tube opening. The vent-tube pressure increased rapidly with increasing angles of attack. For the high tunnel-air velocity, the pressure differential reaches a maximum at an angle of attack of 9°, and this peak illustrates the effect of tunnel blocking by the wing at high angles of attack. The low velocity curve shows this tendency to peak at approximately 12°.

The marginal vent pressure condition of 2 inches of water positive pressure is not attained for the range of angles of attack investigated at a tunnel-air velocity of 220 feet per second. This marginal vent pressure is attained at an angle of attack of approximately 6.5° for a tunnel-air velocity of 350 feet per second. On the basis of these observations, the vent installation is submarginal in its aerodynamic characteristics at air velocities below 220 feet per second for angles of attack up to 14°.

<u>Icing.</u> - In general, the icing investigation of the recessed vent installation showed that the vent lines remained free of ice formations, although the air flow and the static pressure in the vent line were reduced. On an over-all basis, the vent surfaces were coated with a light ice formation. The vent ramp was severely iced only at the upstream end. Considerable ice formations accreted to the rear slope of the vent installation and for long icing periods very light frost formations were observed in the vent tubes.

Photographs of typical formations of ice on the vent and wing surfaces are shown in figure 5. The icing condition for this part of the investigation was as follows: tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; and liquid-water content, 1.5 grams per cubic meter. At the end of 30 minutes (fig. 5(a)), only a light ice formation was observed on the vent ramp and no ice or frost was observed in the vent tubes. At the rear of the vent installation, a ridge of ice approximately 3/4-inch thick was built up near the wing surface. These formations of ice, particularly at the rear edge of the vent recess, increased in size and extent as the icing period was increased (fig. 5(b)).

The growth of ice at the rear of the vent installation occasionally protruded into the air stream to such an extent that a scoop effect was obtained, as shown in figure 5(b). The ice formation shown in figure 5(b) increased the pressure in the bottom vent tube.

For the icing conditions investigated, the static pressure in the vent tubes and the air flow through the vent tubes were reduced with progressive icing. These losses were caused by rough ice formations on the wing surface upstream of the vent ramp, light ice formations on the vent ramp, and frost formations inside the vent tubes. The fact that the upstream orifice static pressure and the vent-tube static pressure gave identical readings under all icing conditions indicates that the vent-tube static-pressure openings did not ice. The variation of vent-tube static pressure and air flow with time for the icing conditions shown in figure 5 is presented in figures 6 and 7, respectively.

The vent-tube pressure is plotted as a pressure differential (p_s-p_0). In general, the pressure differential decreased rapidly with time during the icing period. Figure 6 shows that the desired 2-inch pressure differential between the vent-tube pressure and the ambient static pressure is submarginal for a non-icing condition. The increase in pressure differential in vent tube 4 near the end of the icing period is accounted for by the scooping effect of the ice formations as described in the discussion of figure 5(b). After the tunnel shutdown at the end of 30 minutes, some ice formations were blown off the wing surface when the tunnel was restarted. The reduction of the wing ice formations account for the increase in vent-tube pressure differentials shown to occur at point A in figure 6.

A typical reduction of vent air flow with time during an icing period is shown in figure 7. From an original value of 0.605 pound per minute, the air flow through a vent tube decreased with time, as shown in figure 7. The icing conditions were the same as for figure 5. The partial removal of wing surface ice formations (point A) had the effect of increasing the air flow through the vent tubes by reducing the roughness upstream of the vent openings and by reducing the turbulent condition of the air flow over the wing surface.

Icing experiments were also conducted at an angle of attack of 7° and tunnel-air velocities of 220 and 370 feet per second at ambient-air temperatures of 20° and 0° F, respectively. The icing characteristics of the vent installation and the pressure losses for these experiments were similar to, but less severe than, those described for an angle of attack of 14°.

During the simulated freezing-rain experiment (fig. 8) the ice formations on the wing were observed to build up normal to the surface rather than facing into the air stream. The ice formation just aft of the wing de-icer accummulated to a maximum thickness of 2.5 inches. The results of the simulated freezing-rain experiment were similar to the icing experiments in that the vent pressure and air flow through the vent tubes decreased rapidly with time.

CONCLUDING REMARK

The characteristics of several modifications of ramp-type recessed fuel cell vent assemblies, in which the vent tubes are mounted on either the floor or the rear wall of the ramp, are being investigated in the NACA Cleveland icing research tunnel.

SUMMARY OF RESULTS

The following results were obtained from an aerodynamic and icing investigation of a recessed fuel-cell vent installation with vent tubes mounted at the vent ramp floor:

1. The results of the aerodynamic investigation show that the pressures at the vent-tube openings are submarginal. A vent-tube pressure differential of less than 2 inches of water at the tube opening was attained at angles of attack up to 12° and a tunnel-air velocity of 220 feet per second.

2. The recessed fuel-cell vent tubes remained ice-free for angles of attack up to 14° under severe icing and simulated freezing-rain conditions of 30- to 60-minute duration.

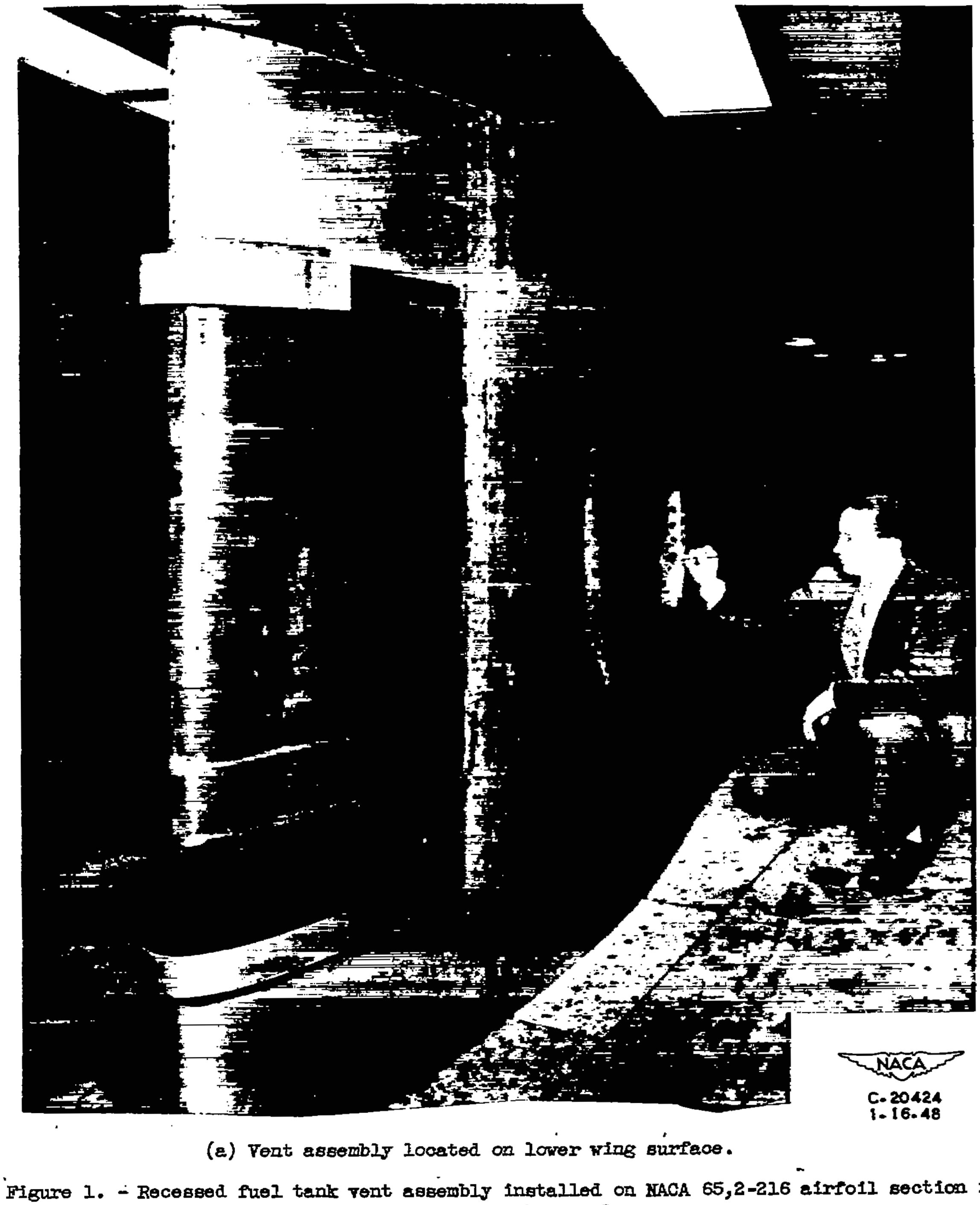
3. Severe and rapid losses in the vent-tube static pressure were recorded under icing conditions at angles of attack of 7° to 14°. A change in tunnel-air velocity from 220 to 370 feet per second at an angle of attack of 7° did not appreciably change the icing characteristics of the vent installation.

4. The vent-tube air flow was decreased by the general icing characteristics of the vent installation and the ice formations on the wing surface.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, February 5, 1948.

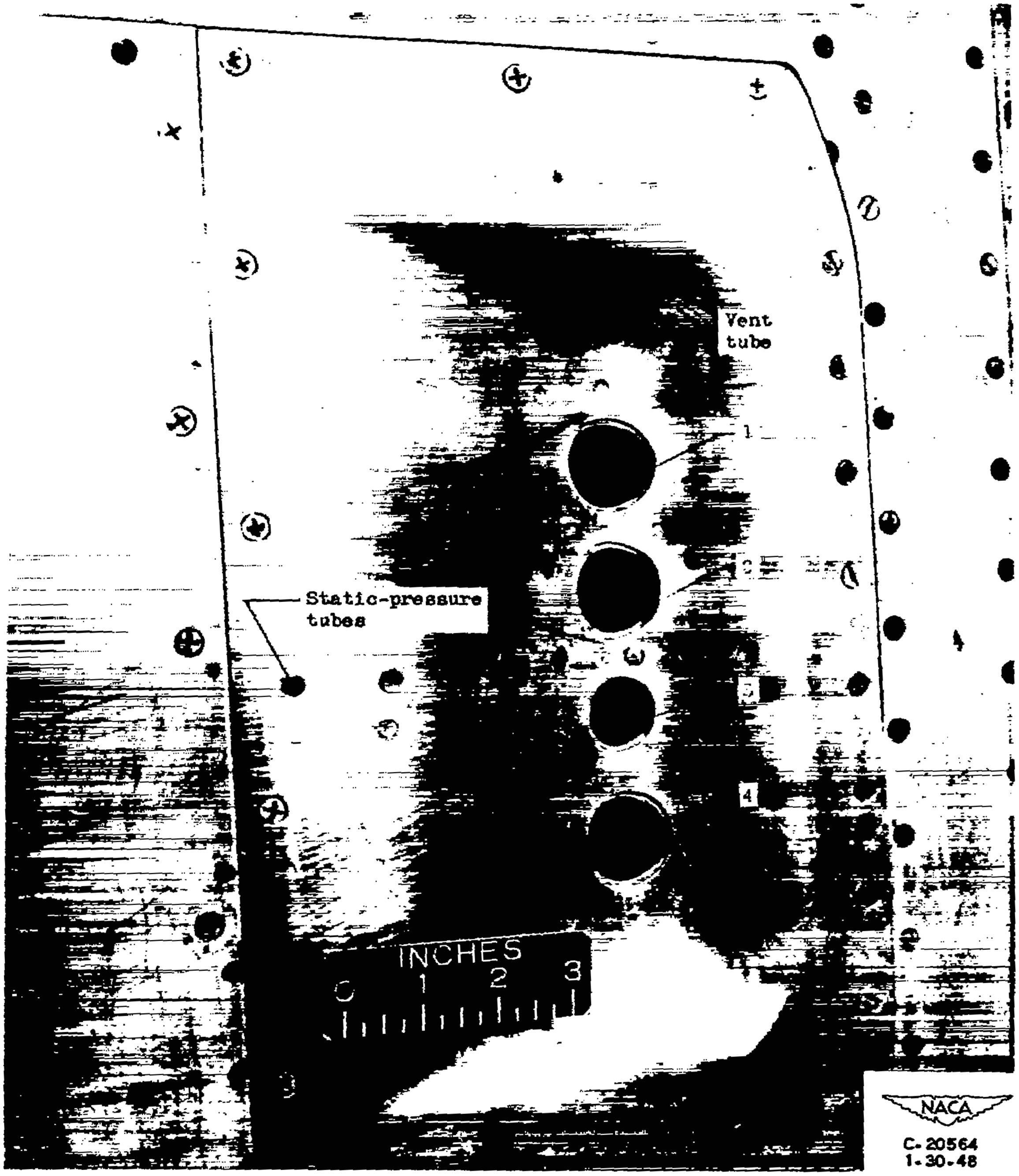
REFERENCE

1. Ruggeri, Robert S.: Investigation of the Aerodynamic and Icing Characteristics of a Recessed Fuel Cell Vent Assembly. I - Rear Wall Vent-Tube Mounting. NACA RM No. E8A27b, 1948.



(a) Vent assembly located on lower wing surface.

Figure 1. - Recessed fuel tank vent assembly installed on NACA 65,2-216 airfoil section in icing research tunnel.



(b) Close-up view of vent installation.

Figure 1. - Concluded. Recessed fuel tank vent assembly installed on NACA 65,2-216 airfoil section in icing research tunnel.

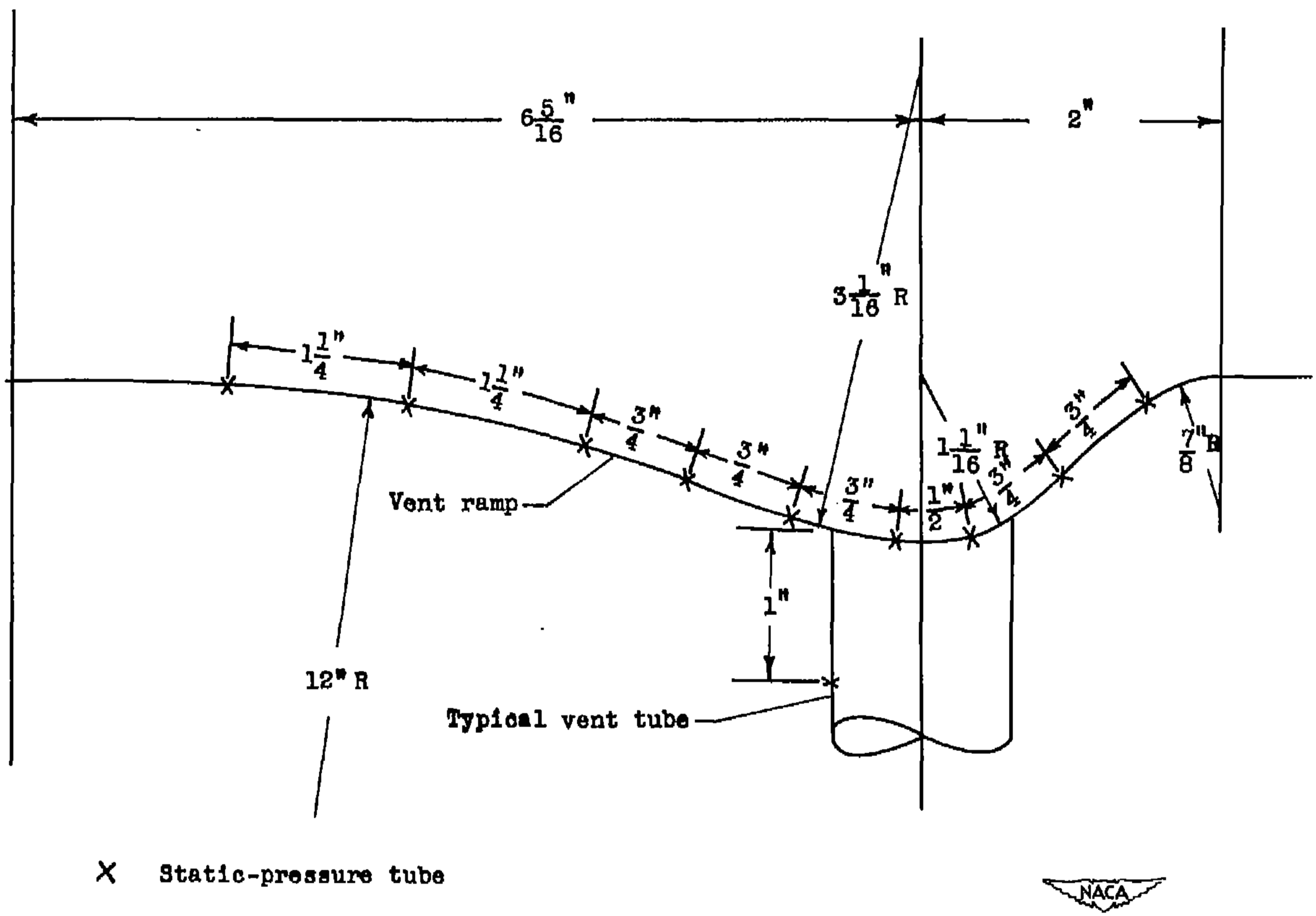


Figure 2. - Schematic diagram of fuel-tank vent assembly showing locations of static-pressure tubes.

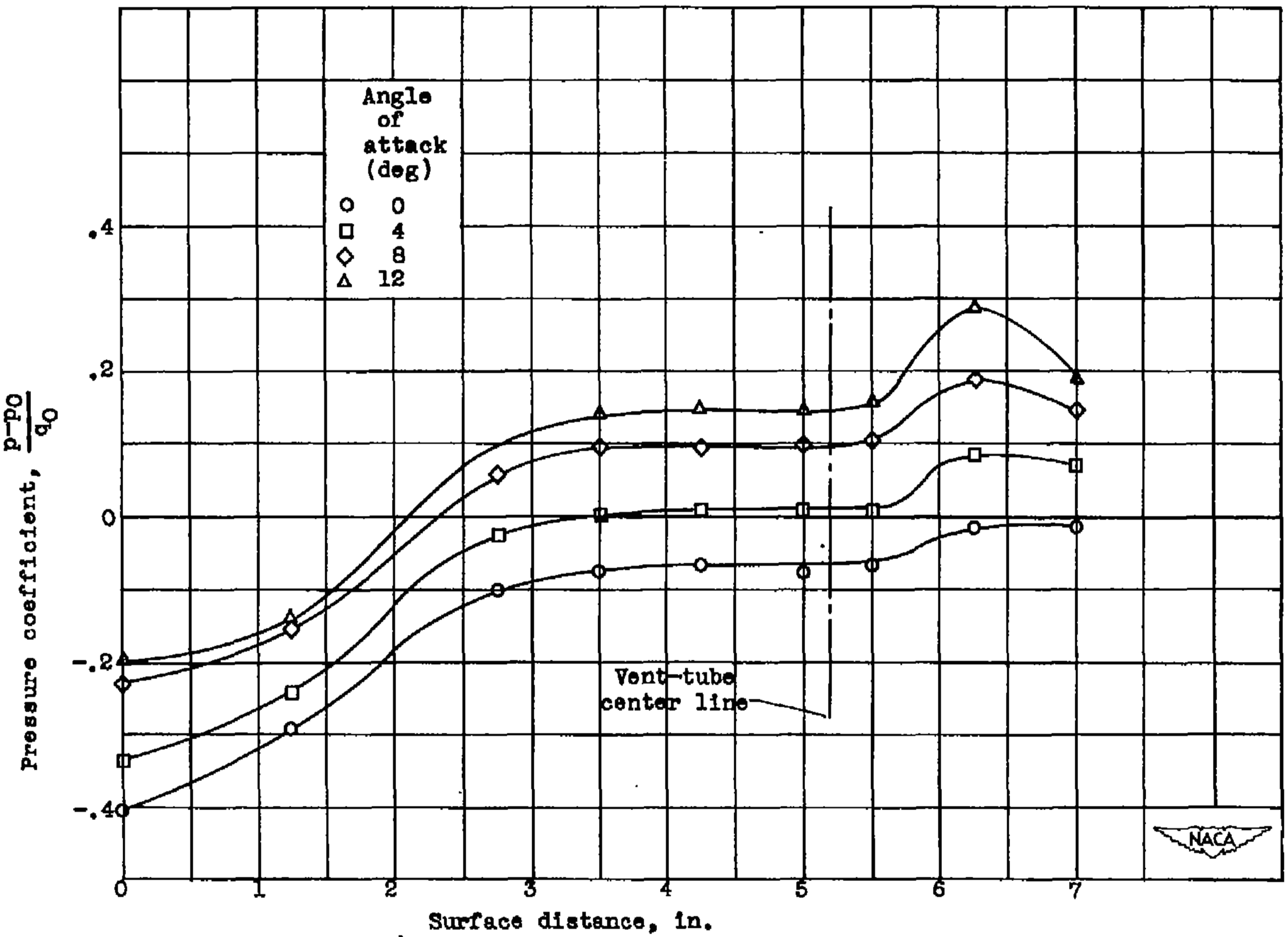


Figure 3. - Effect of angle of attack on pressure distribution over fuel vent ramp surface. No vent air flow; tunnel velocity, 220 feet per second.

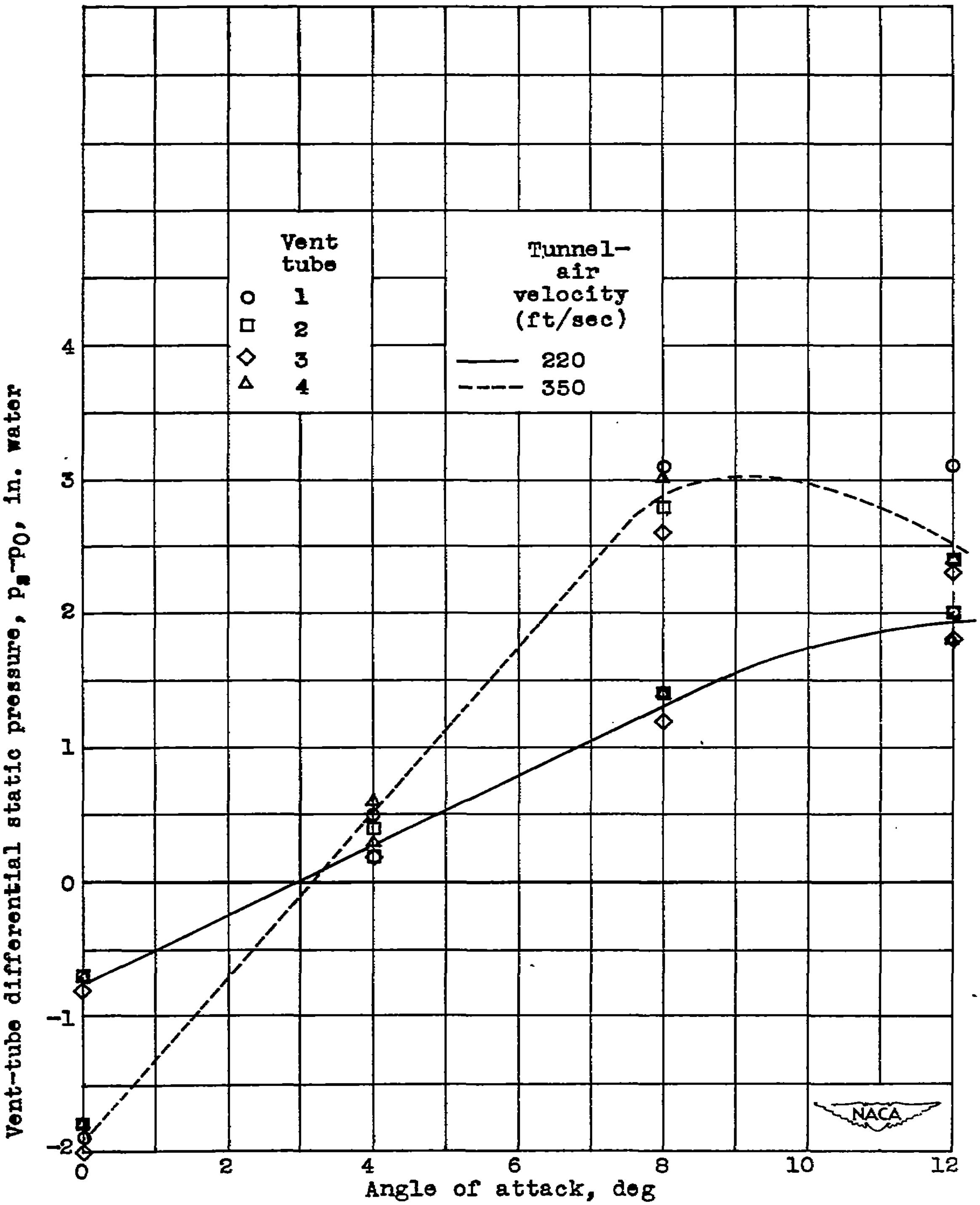
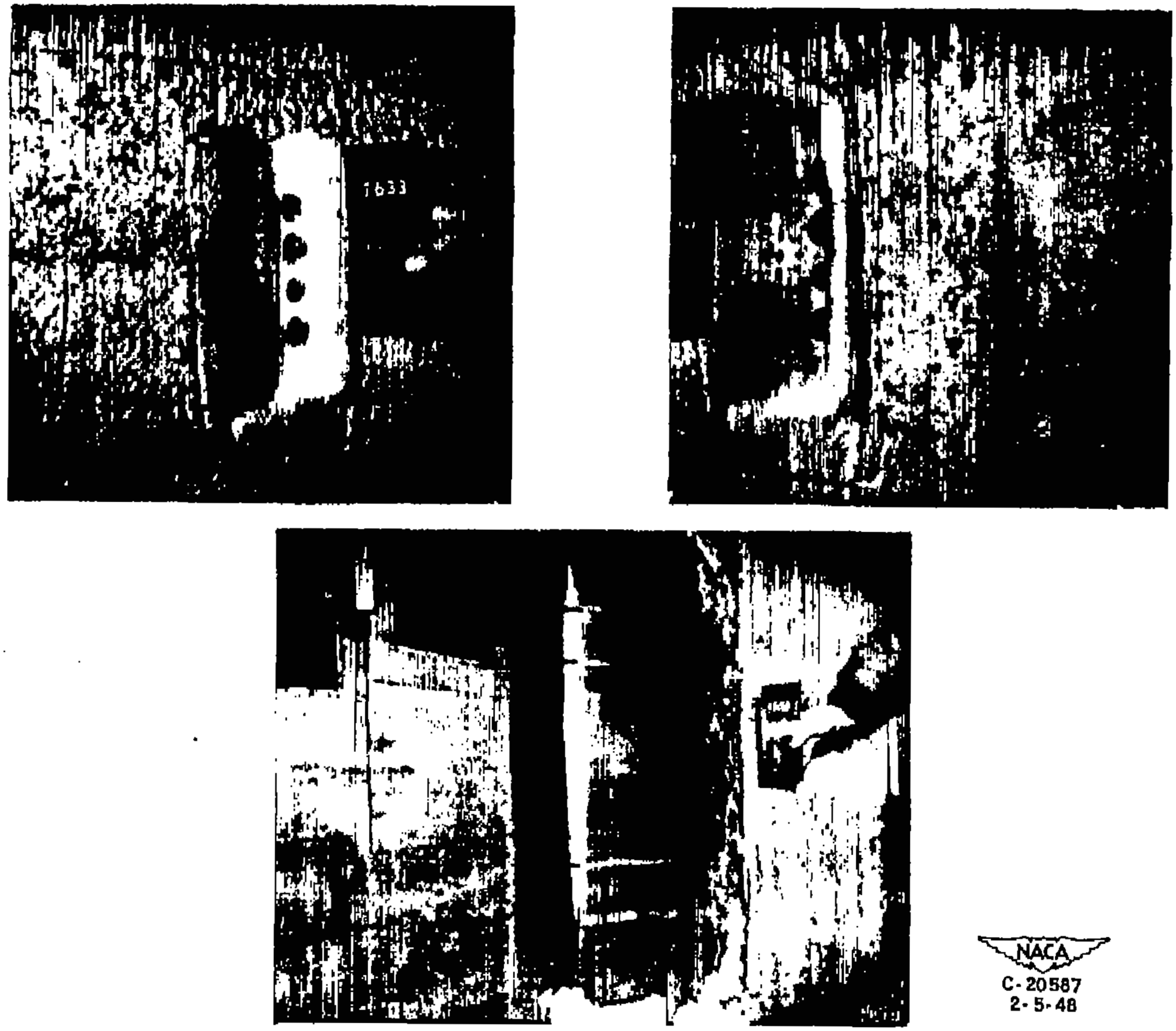


Figure 4. - Variation of vent-tube differential static pressure with angle of attack. No vent air flow.



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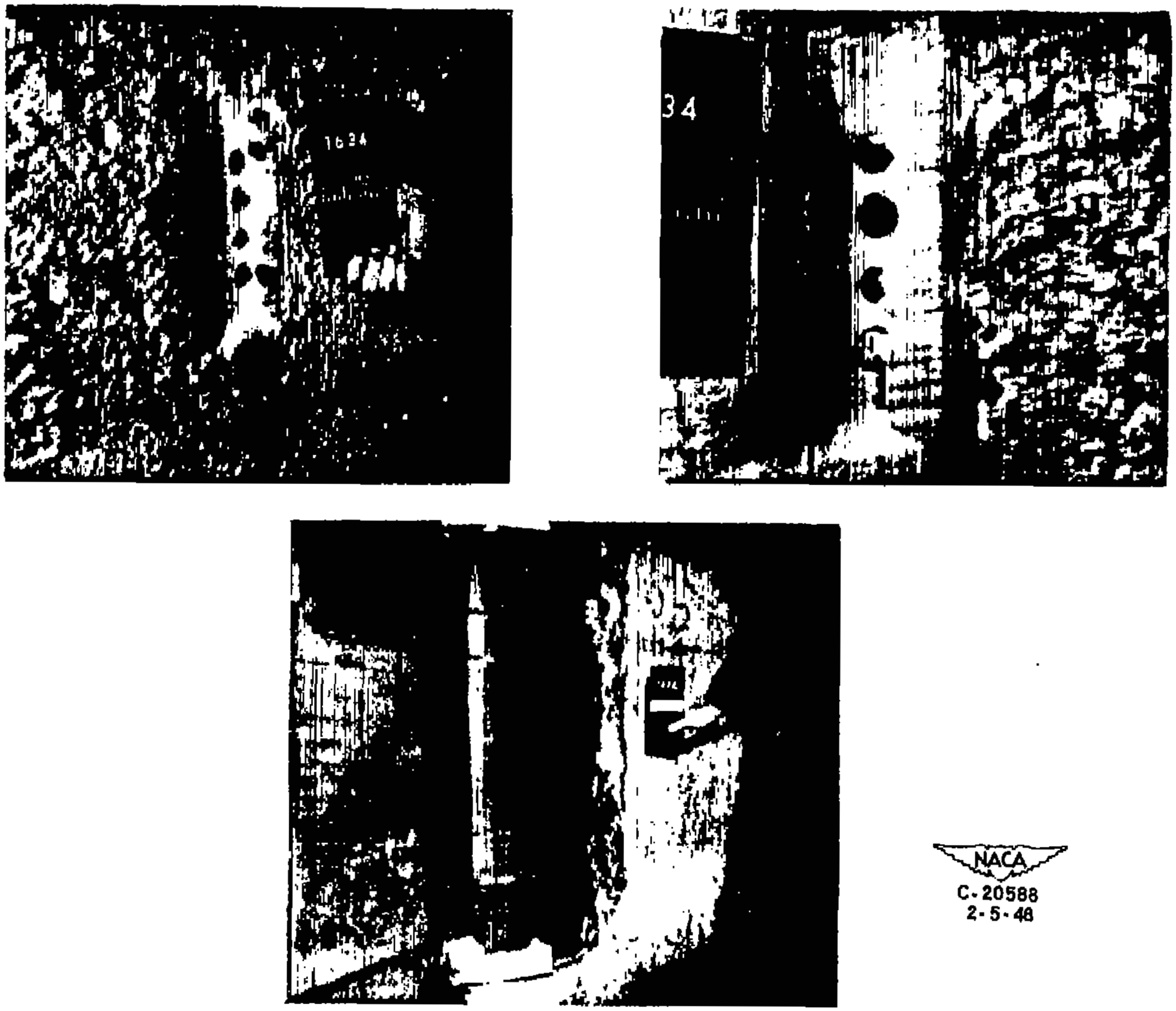
(a) Icing period, 30 minutes.

Figure 5. - Photographs of ice formations on fuel cell vent and wing surface. Tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; liquid-water content, 1.5 grams per cubic meter; droplet size, 15 microns.



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(b) Icing period, 60 minutes.

Figure 5. - Concluded. Photographs of ice formations on fuel cell vent and wing surface. Tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; liquid-water content, 1.5 grams per cubic meter; droplet size, 15 microns.

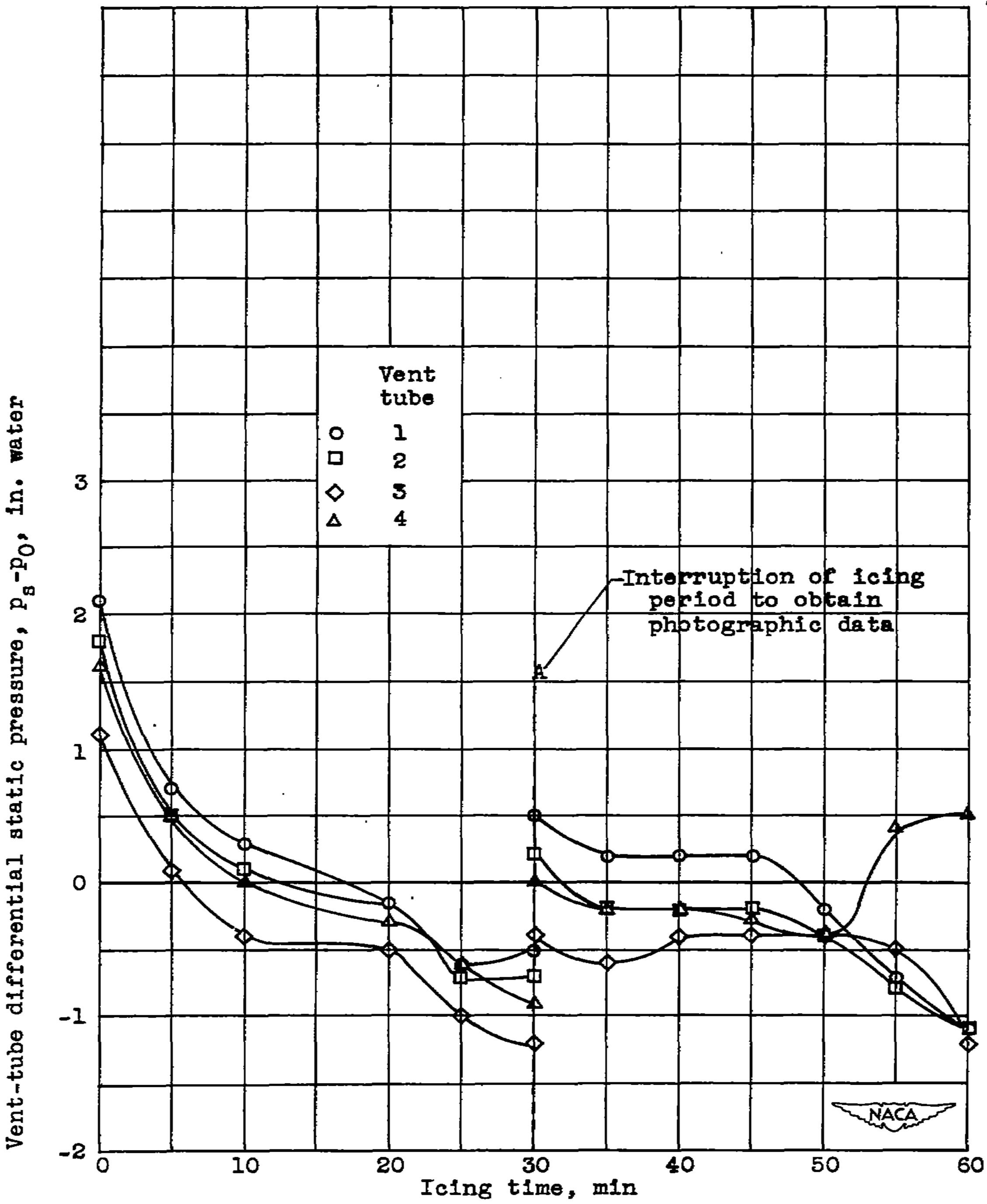

Figure 6. - Variation of vent-tube differential static pressure with icing time for 60-minute icing period. Tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; liquid-water content, 1.5 grams per cubic meter; droplet size, 15 microns.

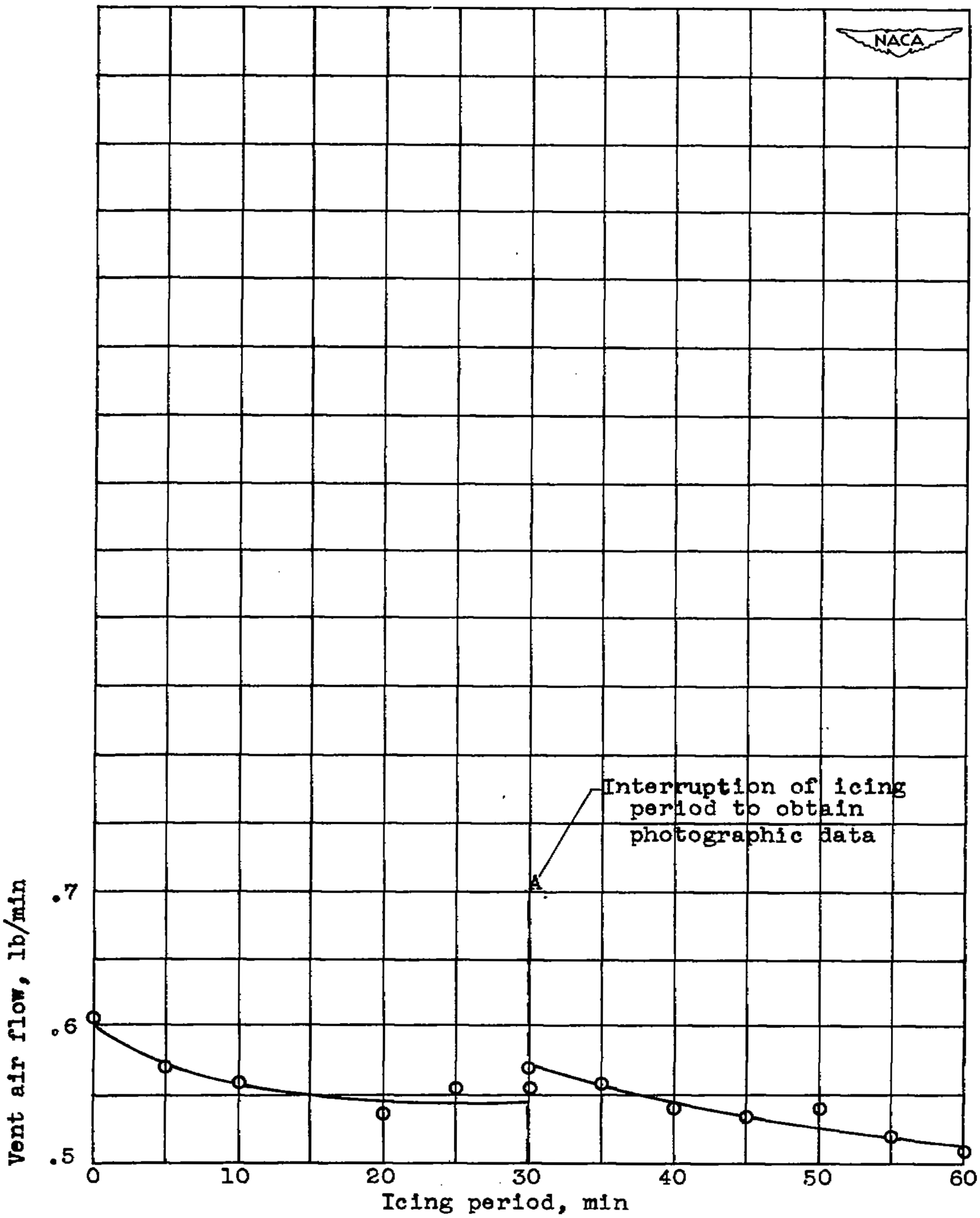

Figure 7. - Variation of typical vent air flow (vent tube 1) with icing time for 60-minute icing period. Tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; liquid-water content, 1.5 grams per cubic meter; droplet size, 15 microns.

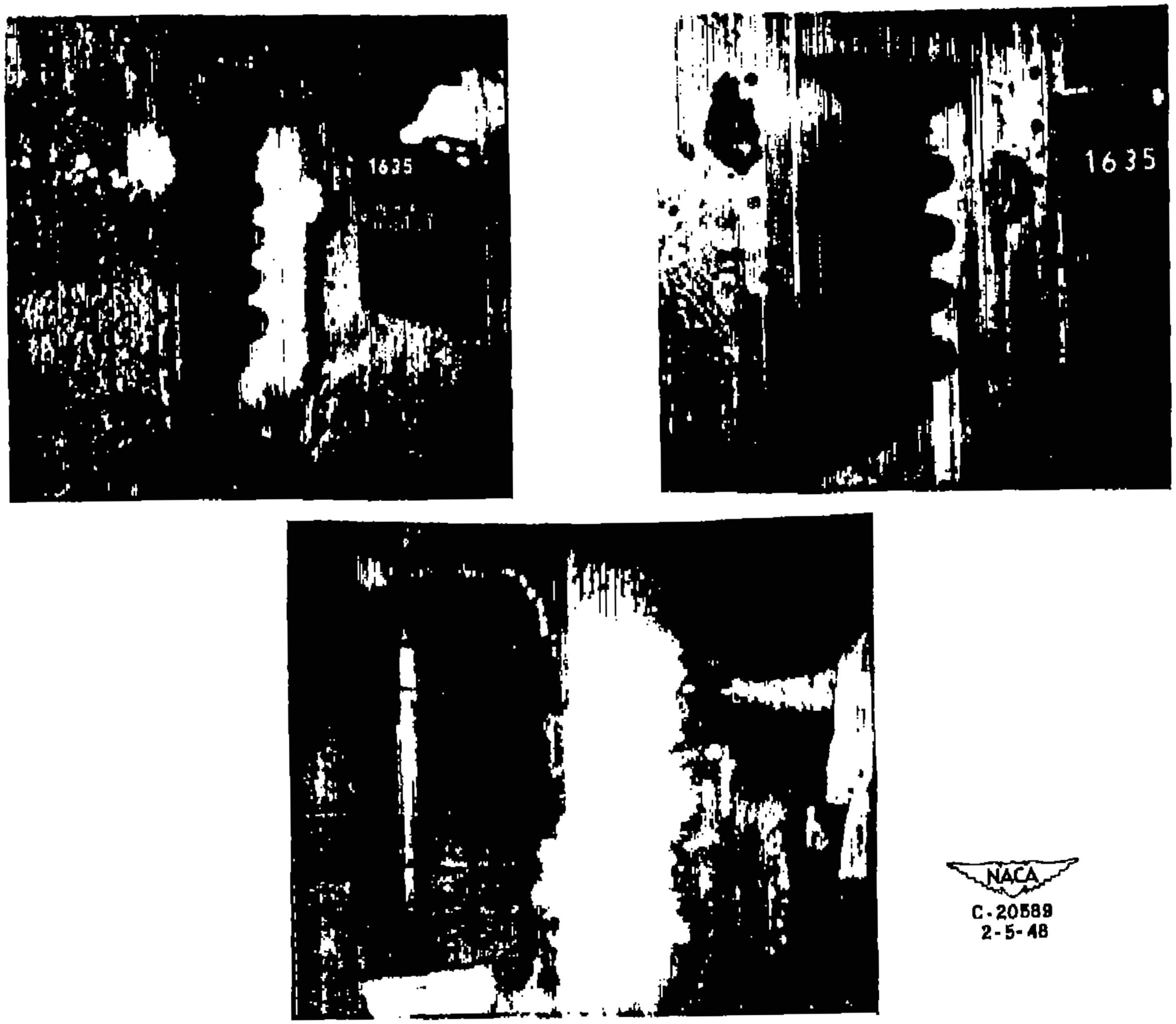

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Figure 8. - Photographs of ice formations on fuel cell vent and wing surface after 35-minute freezing-rain condition. Tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; liquid-water content, approximately 1.8 grams per cubic meter; droplet size, larger than 20 microns.