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ICING TUNNEL TESTS OF A
COMPOSITE POROUS LEADING EDGE
FOR USE WITH A
LIQUID ANTI-ICE SYSTEM

KU-FRL-464-3

by

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for

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INTRODUCTION

Liquid ice protection systems which distribute a glycol-water solution onto leading edge surfaces through a porous skin have been shown to be very effective. Numerous airplanes in Europe already employ such systems as standard equipment. Tests recently conducted in the NASA Lewis Icing Research Tunnel confirmed the efficacy of a liquid system on general aviation airfoils and generated some data on required flow rates (Ref. 1).

All liquid ice protection systems currently in use, as well as the one described in Reference 1, use a sintered stainless steel mesh as the porous skin through which the glycol is distributed. While the stainless steel is strong, rigid, and smooth, and functions very satisfactorily, it is relatively heavy, accounting for approximately 50% of the total weight of the hardware of such a system. The desire to reduce this weight, coupled with the advent of airplanes almost totally constructed of composite materials, has stimulated investigation of alternate porous leading edge materials, particularly composites.

This report presents the results of a test of a composite porous leading edge panel in the Lewis Icing Research Tunnel and compares those results with the performance of the previously tested stainless steel leading edge with the same geometry.

SYMBOLS

c_ℓ	section lift coefficient
LWC	liquid water content, g/m^3
T	total temperature
V	free stream equivalent airspeed
WS	wing station, in
α	angle of attack

TUNNEL DESCRIPTION AND TEST CONDITIONS

The NASA Lewis Icing Research Tunnel (IRT) is a closed-cycle, refrigerated tunnel with a rectangular test section 1.83 m (6 ft.) high by 2.74 m (9 ft.) wide by 6.1 m (20 ft.) long (Figure 1). Maximum tunnel airspeed is 134 m/sec (300 mph). A natural icing cloud is simulated by injecting a water spray upstream of the test section.

The area of interest on the test model is confined to that region in the center of the test section where the icing cloud is most uniform, covering a cross-sectional area of .9 m (3 ft.) high by 1.5 m (5 ft.) wide. The liquid water content (LWC) of the cloud can be varied from about .5 to over 2 g/m^3 with volume median droplet diameters in the range of 10 to 20 microns. The tunnel airflow temperature can be varied from -28.9°C (- 0°F) to ambient.

For this series of tests, two test section equivalent airspeeds were chosen, namely 49.2 m/sec (96 knots) and 90.3 m/sec (175 knots). These speeds correspond to the best rate of climb speed and the cruise speed of a typical high performance, single-engine airplane and duplicate the speeds used in Reference 1.

Since the LWC and water drop size ranges of the IRT icing cloud depended upon tunnel airspeed, operating envelopes for LWC and drop size were plotted for the given airspeeds of interest, 49.2 m/sec and 90.3 m/sec (Figure 2). From these two tunnel operating envelopes the extreme values and several midpoint values of LWC and drop size were chosen as the icing cloud test conditions (Figure 2). The LWC and drop size varied then from .65 to 2.4 g/m^3 and 11 to 20 microns, respectively. Figures 3 and 4 illustrate where the tunnel icing cloud test conditions are located on the continuous maximum and intermittent maximum icing condition curves specified in FAR Part 25 (Ref. 2).

The type of ice (i.e., glaze or rime) that formed on the airfoil depended primarily on the tunnel total air temperature. To produce glaze ice, the tunnel total air temperature was set at -3.9°C (25°F); and to produce rime ice, it was set at -15°C (5°F). The ambient or outside air temperature (OAT) corresponds to the static air temperature in the tunnel test section. For the two airspeeds chosen, namely 49.2 m/sec and 90.3 m/sec, the OAT's for glaze ice were -5.1°C and -7.8°C, respectively; and the OAT's for rime ice were -16.2°C and -18°C, respectively. The true airspeeds were 43.7 m/sec and 85.3 m/sec at T = 5°F and 44.7 m/sec and 86.9 m/sec at T = 25°F.

MODEL DESCRIPTION

The wing section tested was taken from an actual single-engine, light airplane. The original wing tapered from a NACA 64_2A215 airfoil at the root (WS 0) to a NACA 64_1A412 airfoil at the tip (WS 216). The wing incorporated a modification proposed by Raymond Hicks (Refs. 3, 4) of NASA Ames Research Center. This modification, which adds thickness to the forward 30 percent of the upper surface, increases $c_{\ell_{max}}$, reduces C_d at high C_ℓ, and improves stall characteristics. A typical "Hicks" modification is shown in Figure 5.

The wing section tested was fastened securely to the turntable on the floor of the tunnel, using the spar fittings that are used to attach the wing to the fuselage of the airplane. A clearance of one-half inch was allowed between the outboard end of the wing segment and the ceiling of the six-foot high test section of the tunnel. The centerline of the tunnel was at WS 58 of the original wing. Table 1 gives the airfoil coordinates at WS 58, where the wing chord is 63.25 inches. The chord tapers 1.1 inches per foot of span, and the wing is twisted 0.167 degrees per foot of span (washout). Figure 6 shows the wing section with composite leading edge installed in the NASA Lewis Icing Research Tunnel.

ICE PROTECTION SYSTEM DESCRIPTION

The system tested consists of porous composite panels attached to the leading edge of the wing, and a pump that distributes a glycol based fluid from a tank to the panels through plastic tubing.

The fluid exudes from the porous panels onto the surface of the wing, providing either an anti-icing capability by dissoving the supercooled water droplets and preventing the formation of ice, or a deicing capability by chemically breaking the bond of established ice. A significant feature of the system is that protection is obtained aft of the panels by the flow of the fluid along the chord to the trailing edge, thus preventing the formation of ice anywhere aft of the active leading edge.

The porous leading edge panel used in this test was attached to the original wing leading edge, as shown in the cross-sectional drawing in Figure 7. The width of the porous region is 8.7 cm. The panel is divided spanwise into three separate porous sections. Referring to the vertical position of the wing in the tunnel, the upper and lower sections are 20.3 cm long and the middle section is 30.4 cm long. The maximum thickness of the panel is 3.2 mm. The flow rate into each section was controlled independently by three variable positive displacement pumps.

The fluid reservoir behind the porous leading edge skin consists of a composite backing panel and a thin polyvinylfluoride sheet that separates the fluid from the porous leading edge. The purpose of the polyvinyl fluoride sheet, whose porosity is much lower than that of the composite skin, is to distribute the glycol evenly over the entire active portion of the panel, regardless of the chordwise pressure distribution changes that occur as angle of attack changes. Pressure tests showed that the net porosity of the leading edge panel was much higher than that of the original stainless steel panel.

This resulted in uneven distribution of glycol. This is discussed more fully in the following section.

The fluid used in this test is composed of 80% monoethylene glycol and 20% deionized water.

The edges of the active portion of the panel must be placed such that extreme positions of the stagnation points for which icing protection is required are no closer to the edge than approximately 1 cm. This ensures that the fluid will always be distributed on both the upper and lower surface of the wing. Figure 7 shows the location of the stagnation points on the leading edge for each angle of attack used in this test.

The composite skin consists of two outer layers of Kevlar and a middle layer of fiberglass in a resin matrix. The composite panel was designed and manufactured by Fiber Materials, Inc., of Biddeford Maine.

The weight of the composite panel was 390 grams, about one-third that of the previously tested stainless steel panel of the same dimensions.

TEST RESULTS

Normal operation of the glycol-exuding porous leading edge system is in the anti-ice mode; that is, the glycol flow rate is sufficient to prevent any ice from forming on the wing. This is possible as long as the glycol-water solution on the surface maintains a freezing temperature below the ambient air temperature. The solution freezing temperature increases as the ratio of the water catch rate to the glycol flow rate increases. A series of runs was conducted in the Lewis IRT to determine the minimum glycol flow rate at which anti-icing could be maintained.

The method of determining the glycol flow rate corresponding with the anti-ice threshold was as follows. At a given flight condition, the flow rate was set to be well above the anti-ice threshold. The flow rate was then reduced in steps, allowing about 30 seconds for the system to stabilize at each point, until small flecks of ice began to appear on the leading edge in the vicinity of the stagnation point. At the anti-ice threshold, the small ice flecks, ranging up to about 3 mm in diameter, would form and then be swept downstream in less than one minute. A glycol flow rate lower than the threshold value would cause the ice flecks to persist, gradually growing into larger patches before being shed from the wing.

To obtain the minimum anti-ice glycol flow rates, all three sections were used simultaneously during each run to establish the independent flow rate values from each section. During the first day the center section was inoperative due to a leak in the tube fitting. Flow rates are presented in terms of specific flow rate: milliliters of glycol per square centimeter of active panel per minute.

Figures 8 through 11 present results of the anti-icing tests for four different icing conditions. The anti-ice threshold is defined in terms of glycol specific fluid flow as a function of liquid water content (LWC). In examining the data, several conclusions may be readily drawn.

It is clear that anti-ice performance was achieved at all conditions tested using the composite leading edge panel. Although angle of attack had relatively little effect on the anti-ice flow rate, there was a wide variation in the performance between the three separate panels. There was also a considerable amount of scatter in the definition of the anti-icing threshold flow rate for a given condition.

More important, however, is the comparison between anti-ice flow rates for the composite panel and the previously tested stainless steel TKS panel. It is obvious that much higher total flow rates were required for the composite panel than for the stainless steel panel.

The porosity of the composite panel is believed to be the cause of this discrepancy. Bench tests as well as pressure measurements of the glycol during test runs showed that the composite panel was much more porous than the stainless steel panel. Thus the back pressure in the reservoir of the composite panel was relatively low. Therefore, the stagnation pressure on the outer surface of the leading edge was able to inhibit glycol flow at the stagnation point, forcing more glycol out near the edges of the porous panel. This process could be observed clearly by eye in the IRT. Since the need for anti-ice protection is greatest at the stagnation point, much more total fluid was required to achieve that critical protection at the stagnation point.

The problem of non-uniform distribution of fluid through the porous leading edge can probably be solved by merely decreasing the porosity of the composite porous panel system. Construction of such a panel and further testing to verify this has been proposed.

CONCLUSIONS

Tests of a composite porous leading edge panel in the NASA Lewis IRT have led to the following conclusions:

1. Anti-ice protection of a composite leading edge was possible for all simulated flight conditions tested.
2. Glycol flow rates required to achieve anti-ice protection were generally much higher than those required for a previously tested stainless steel TKS panel (Ref. 1).
3. The low reservoir pressures of the glycol during test runs indicated that more uniform distribution of glycol, and therefore lower glycol flow rates, can probably be achieved by decreasing the porosity of the panel.
4. Significant weight savings can be achieved in fluid ice protection systems if composite porous leading edge panels can be used. Composite panels weigh about one-third the weight of comparable stainless steel panels.
5. The resistance of composite panels to abrasion and erosion must yet be determined before they can be incorporated in production systems.

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2. Federal Aviation Regulations, Part 25, Appendix C - Airworthiness Standards: Transport Category Airplanes, Department of Transportation, Federal Aviation Administration, Washington, D.C., June 1974.

3. Hicks, R. M., and Schairer, E. T., "Effects of Upper Surface Modification on the Aerodynamic Characteristics of the NACA 63_2-215 Airfoil Section," NASA TM 78503, January 1979.

4. Szelazek, C. A., and Hicks, R. M., "Upper-Surface Modifications for $C_{\ell_{max}}$ Improvement of Selected NACA 6-Series Airfoils," NASA TM 78603, August 1979.

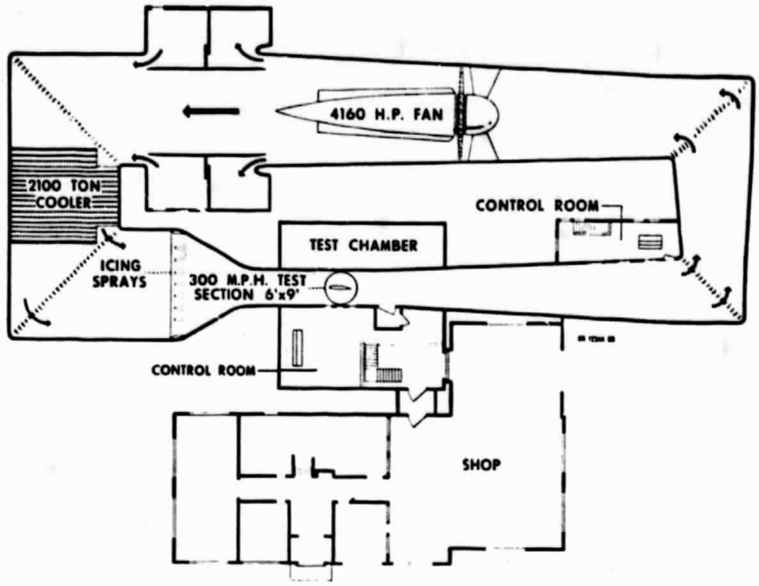

Figure 1. - NASA Lewis Icing Research Tunnel.

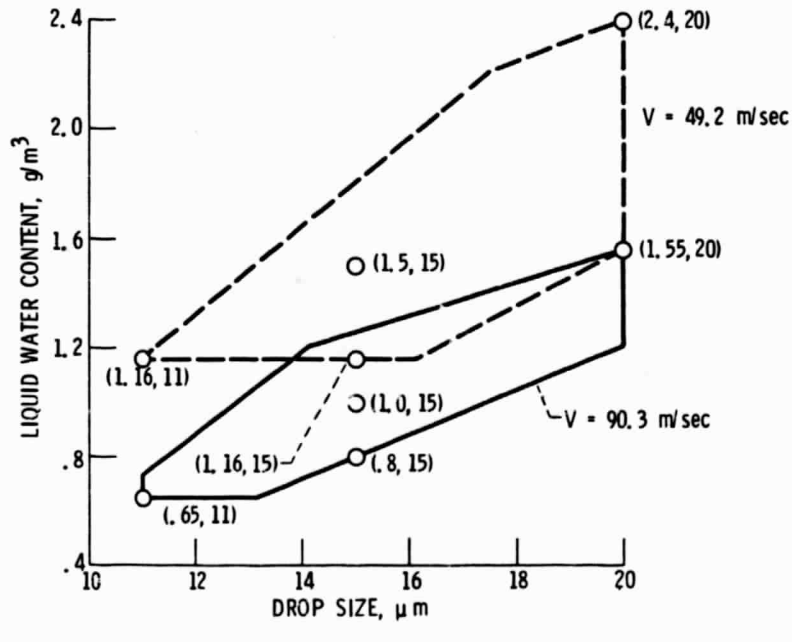

Figure 2. - IRT Operating Envelopes and Test Points.

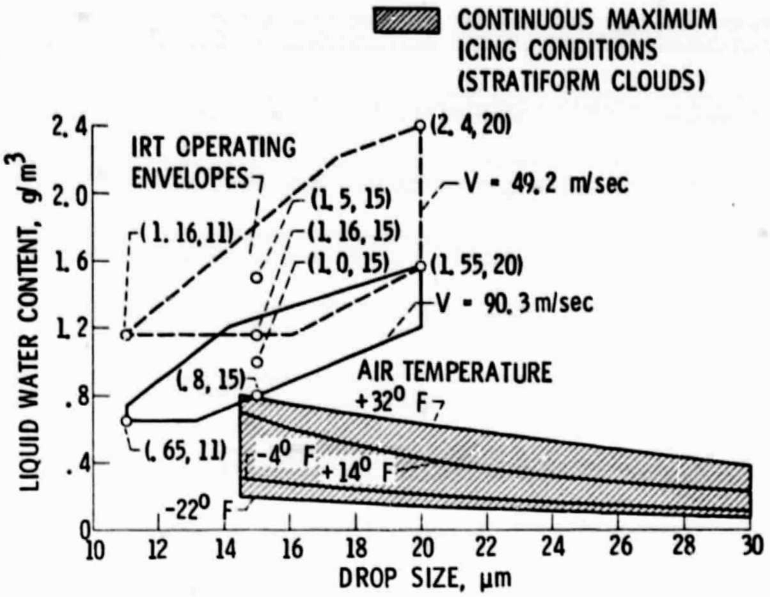

Figure 3. - Continuous Maximum Icing Conditions (ref. 1) and IRT operating envelopes.

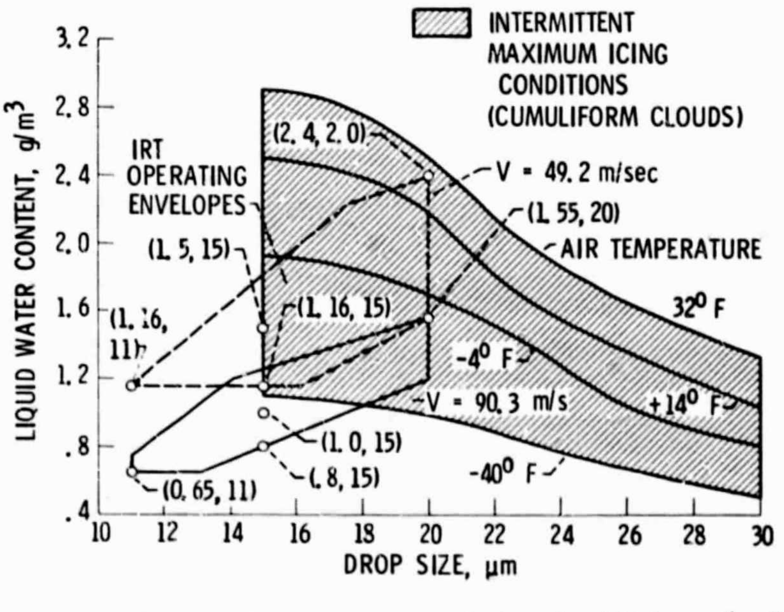

Figure 4. - Intermittent Maximum Icing Conditions (ref. 1) and IRT operating envelopes.

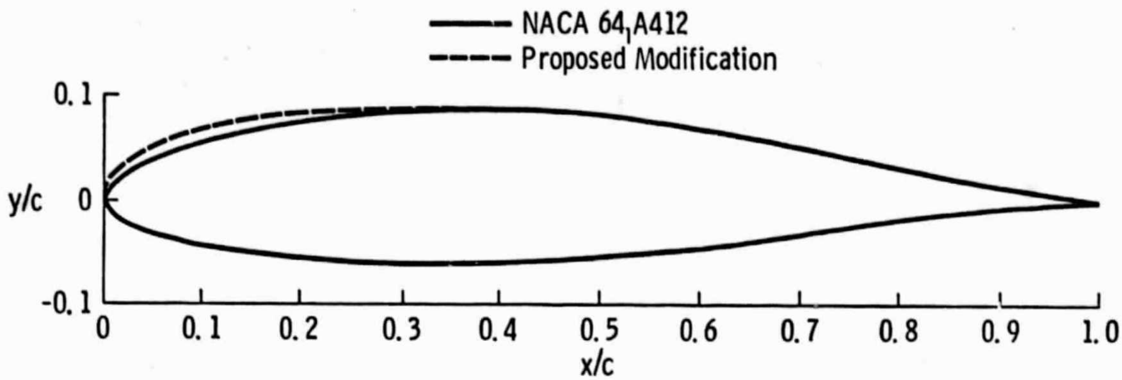

Figure 5. - Hicks Modification on a NACA 64_1A412 Airfoil.

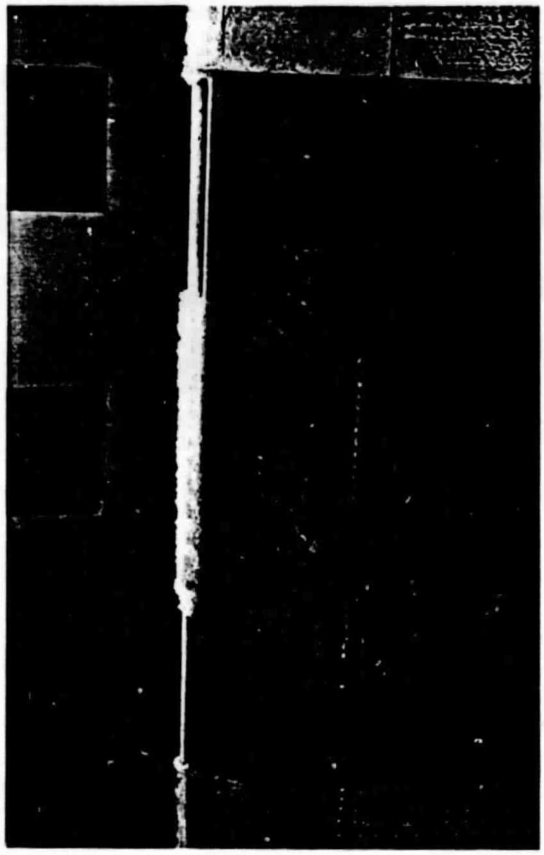

Figure 6. - Wing with Composite Porous Leading Edge
Installed in the NASA Lewis IRT.

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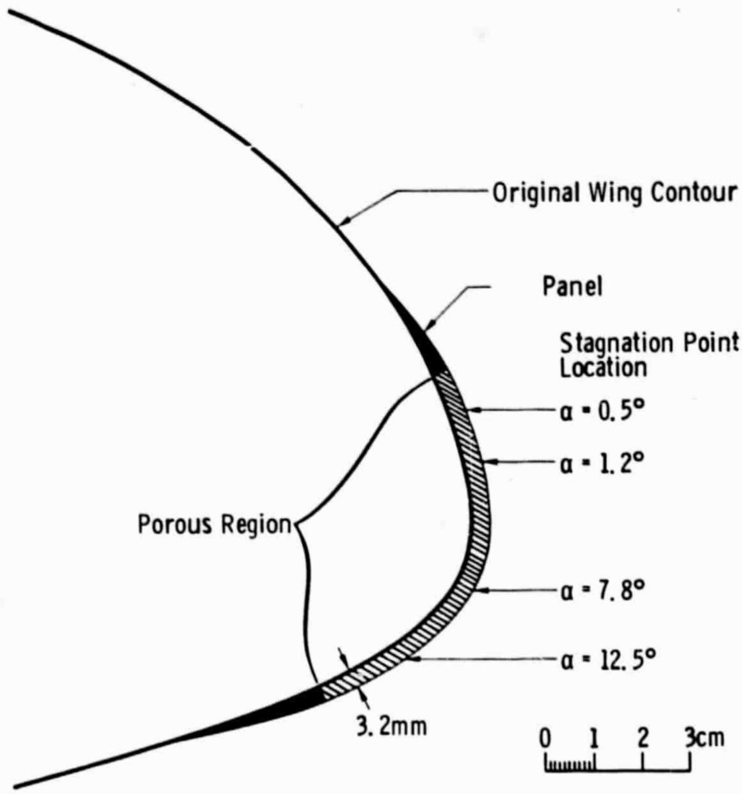
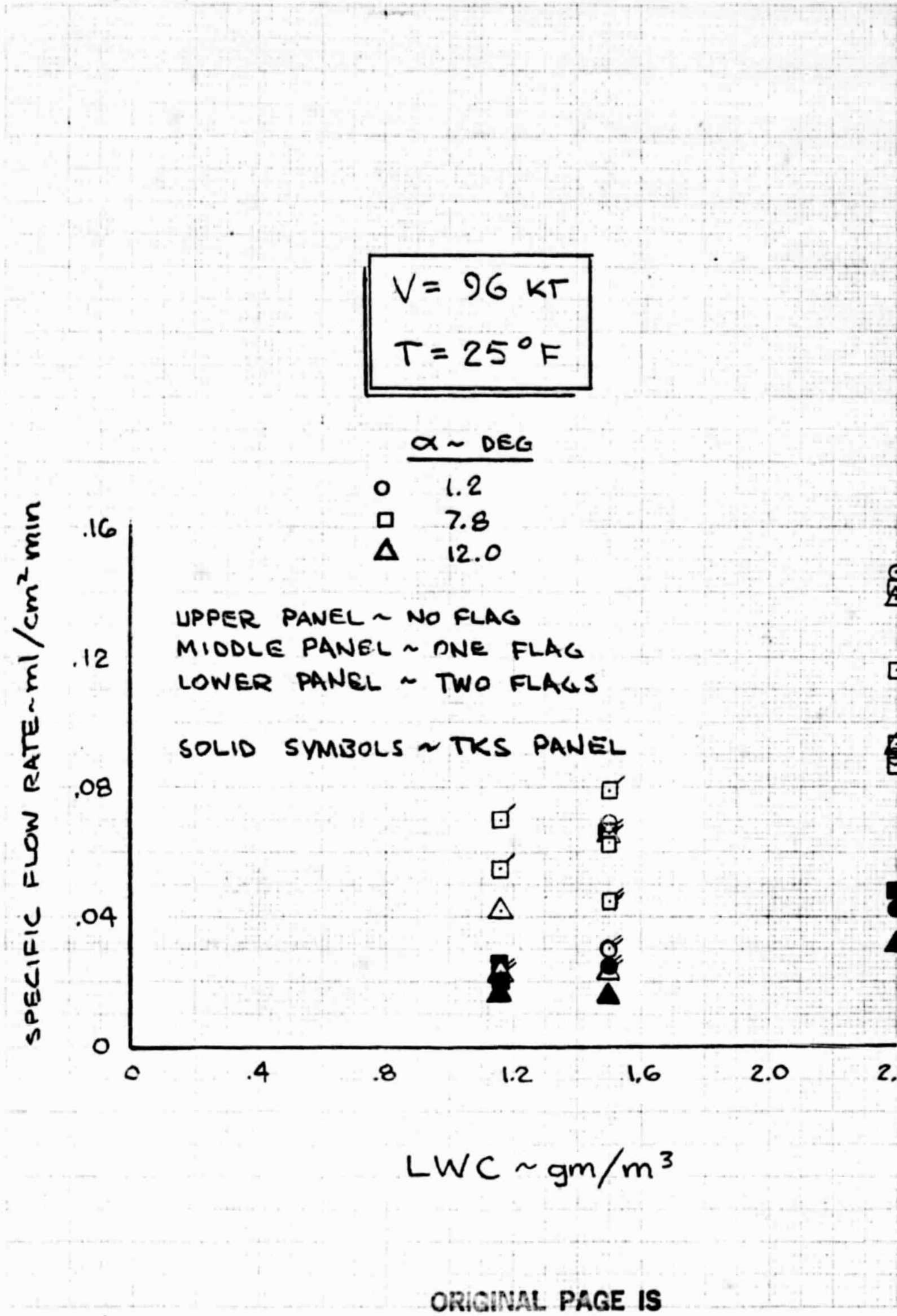


Figure 7. - Cross Section of the T.K.S. Porous Panel Installed on the Test Wing at WS 58.



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CALC			REVISED	DATE	Figure 8. - Anti-ice Thresholds of a Composite Porous Panel at V = 96 kt, T = 25°F.	
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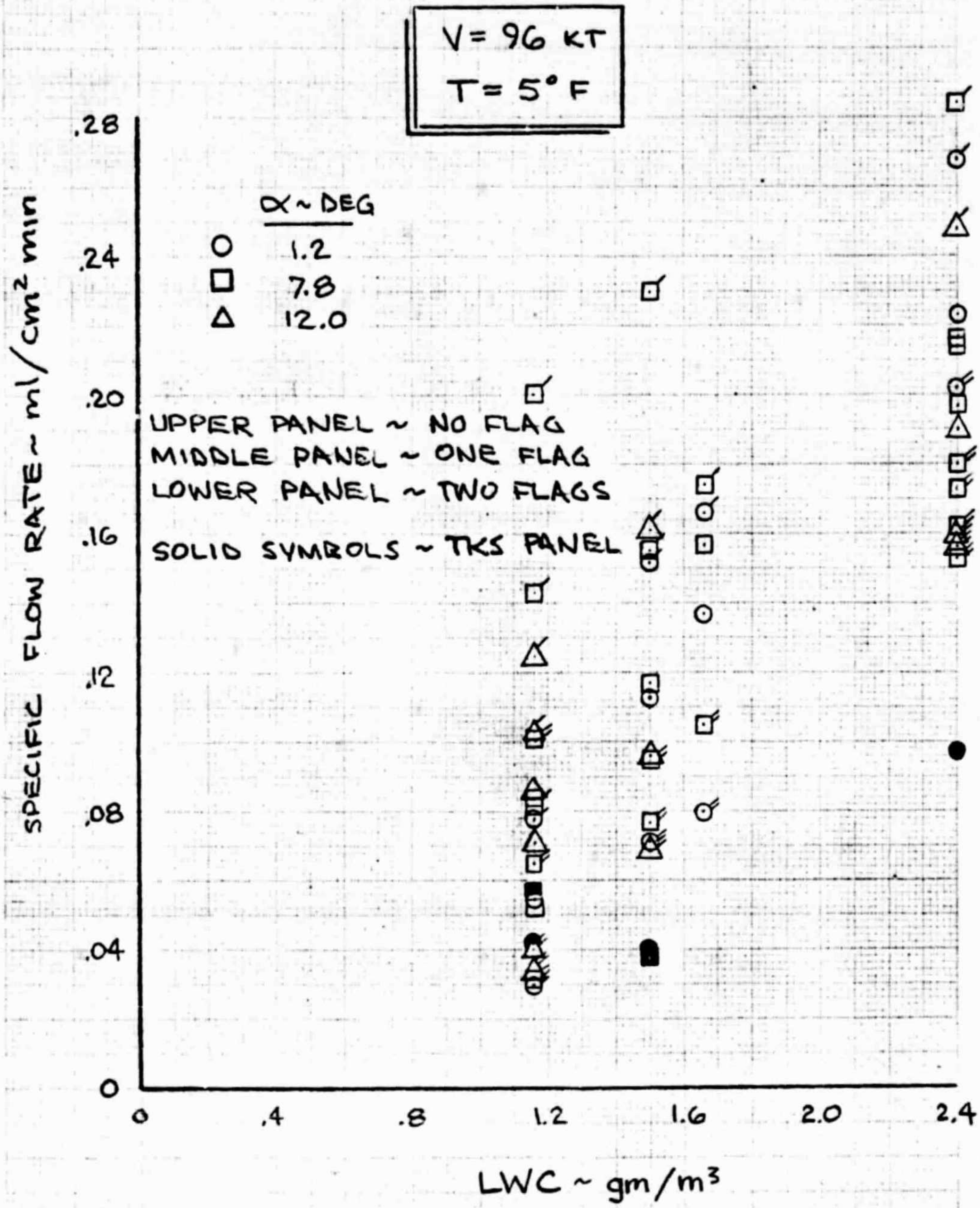

CALC			REVISED	DATE	Figure 9. - Anti-ice Thresholds of a Composite Porous Panel at V = 96 kt, T = 5°F.	
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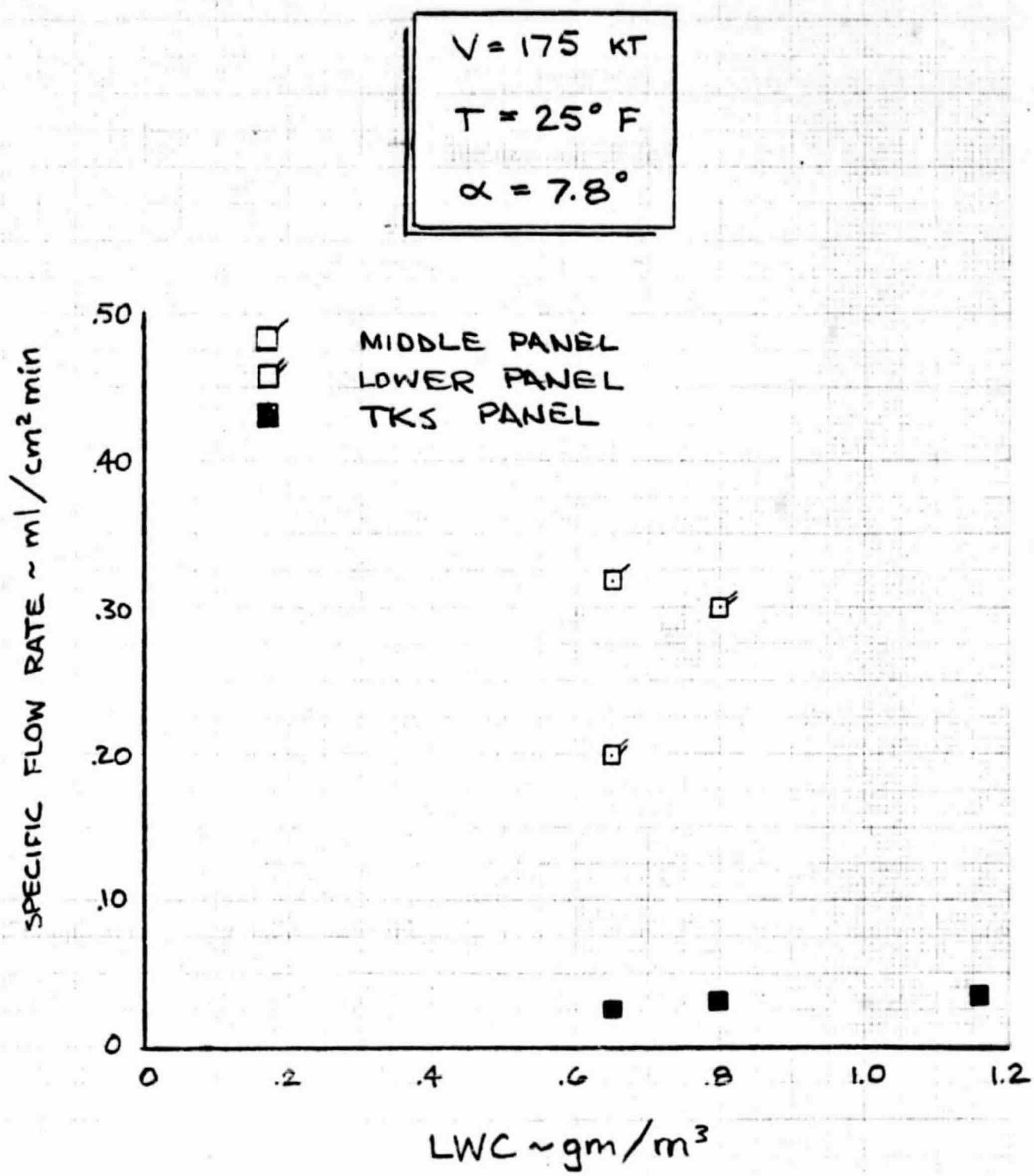

CALC			REVISED	DATE	Figure 10. - Anti-ice Thresholds of a Composite Porous Panel at V = 175 kt, T = 25°F, α = 7.8°.
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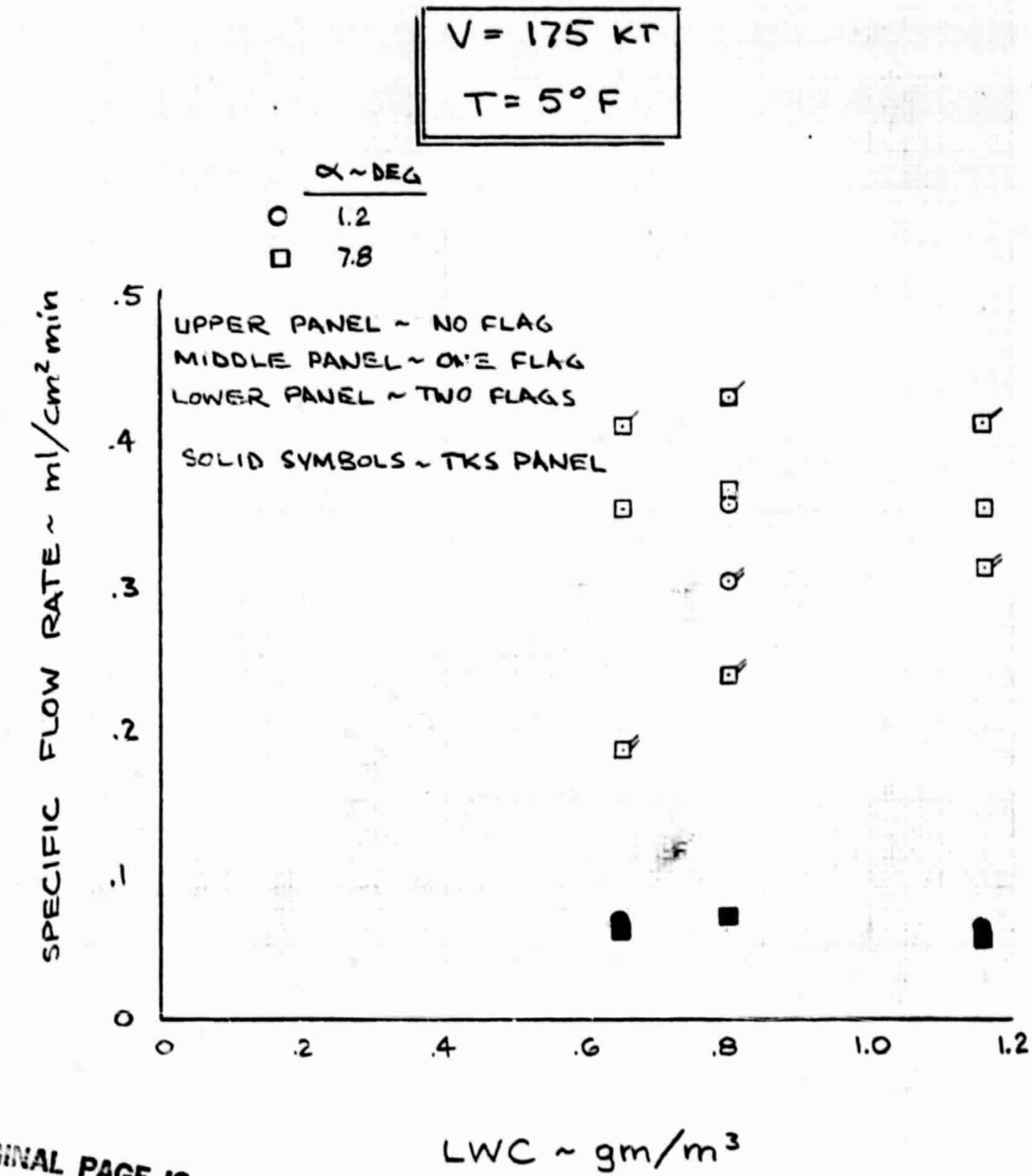

CALC			REVISED	DATE	Figure 11. - Anti-ice Thresholds of a Composite Porous Panel at V = 175 kt, T = 5°F.
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