Engineering Notes

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Thermodynamic Performance of an Airplane Wing Leading Edge Anti-Icing System

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Nomenclature

d = distance along surface measured from lower wing surface at spar 1, ft
P_c = local surface pressure coefficient
T_A = ambient temperature °R
T_S = surface temperature R

Introduction

STANDARD thermodynamic anti icing performance procedures are used to analyze the thermal capabilities of the wing leading edge anti icing system on a business jet airplane

Dry air flight tests were performed to gather chordwise and spanwise surface temperature distribution and hot bleed air flow data for a wide range of aircraft operating conditions These data are used to formulate an effective thermodynamic efficiency for the hot air channel in the wing leading edge This efficiency, combined with the analytical procedure, allows the prediction of chordwise and spanwise surface temperature variations for any known aircraft flight and icing conditions Required wing surface pressure coefficients are obtained from computer codes for potential flow and verified with wind tunnel test data

Evaluation of the procedure is performed by comparing calculated and measured surface temperatures for a variety of conditions This comparison indicates that although accuracy is excellent, the method does tend to be somewhat con servative, i e , calculated temperatures tend to be somewhat cooler than measured

Measured Anti-Icing Performance

Flight tests were conducted on an instrumented jet airplane Test data were obtained at a variety of aircraft altitude and airspeed conditions Hot air flow rate to the leading edge, air flow temperature aircraft airspeed and altitude, ambient temperature, and wing leading edge surface temperatures were recorded for each test condition Thermocouples bonded to the external leading edge surface were used to obtain the temperature data From three to ten thermocouples were bonded to the leading edge at six different spanwise locations The instrumented stations are shown in Fig 1 Chordwise location of the thermocouples for a typical station is shown in Fig 2

Test data were recorded for a variety of flight conditions as shown in Table 1 Data were recorded for dry ar as well as natural icing conditions

Data Analysis

A detailed thermodynamic basis for the data reduction and analysis is presented in Ref 2 The model used in this analysis is reported in Ref 1 and is a modification of that developed for engine nacelle inlet lip anti icing analysis reported in Ref 2 The main modification requires a change to substitute the span of the heated portion of the wing leading edge for the circumference of the nacelle inlet lip Dry air flight test data is used to determine an effective anti icing efficiency of the hot air flow channel in the wing leading edge This is a measure of the effectiveness of the hot air in heating the external surface Channel efficiencies are computed for each set of flight test data. These are related to changes in aircraft altitude and airspeed, ambient temperature, and engine power setting (as it affects bleed air flow rate to the wing leading edge and the bleed air temperature) Although it would appear that changes in the internal bleed flow conditions or external flight conditions would result in radically different channel ef ficiencies, this is not the case For a given type of internal bleed flow distribution system, the surface temperature, which is used to determine the channel efficiency, is directly related to the ambient conditions and quantity of heat, whether provided by virtue of higher bleed mass flow or bleed air temperature Thus the calculated efficiency for the range of conditions tested is nominally independent of variations in these parameters Hence, in order to use a larger data base for

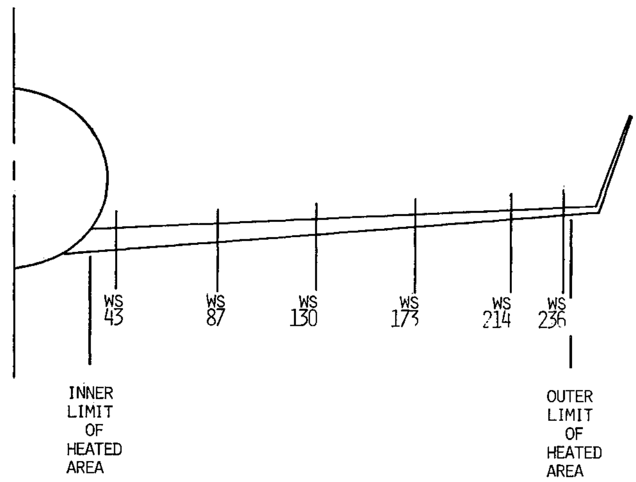

Fig 1 **Instrumented wing stations.**

Table 1 **Flight test conditions**

Condition	Range
Altitude 1000 ft	1 45
Ambient temperature F	– 80 65
Airspeed knots	165 349
Bleed flow lb/min per wing	9 9 13 7
Bleed temperature °F	359 464
Droplet diameter, μm	5 29
Liquid water content, gm/m^3	02 0 35

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improved accuracy of the channel efficiency, the individual test efficiencies for a number of flight test conditions are averaged Thus there will be an average efficiency for each instrumented position on the wing leading edge

Local surface pressure coefficients are required in order to calculate the local surface velocity and local Reynolds number The local Reynolds number is needed to determine the local heat transfer coefficient Local surface pressure coefficients are derived from potential flow computer codes for a Mach number of 0 35 The Karman Tsien pressure correction formula is used to adjust these data for any variaton in aircraft Mach number Local surface tem peratures, required for calculating the channel efficiency, were measured during the test flights

Utilizing the calculated pressure data and measured surface temperatures the average channel efficiencies are computed Icing analysis is performed by using the computed channel efficiency to predict spanwise and chordwise surface tem perature distributions for any aircraft flight and icing con dition Surface pressure data and the local average channel efficiencies are used, along with the required aircraft con

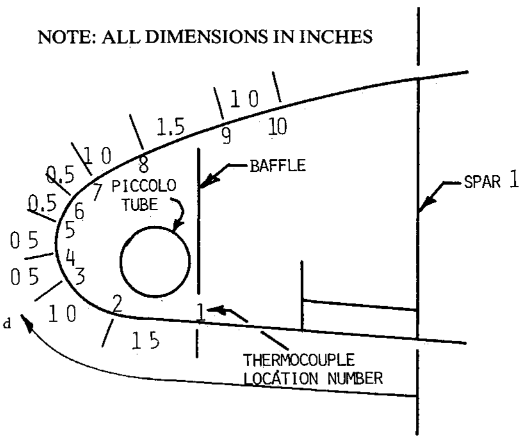

Fig 2 Typical instrumentation points on wing leading edge

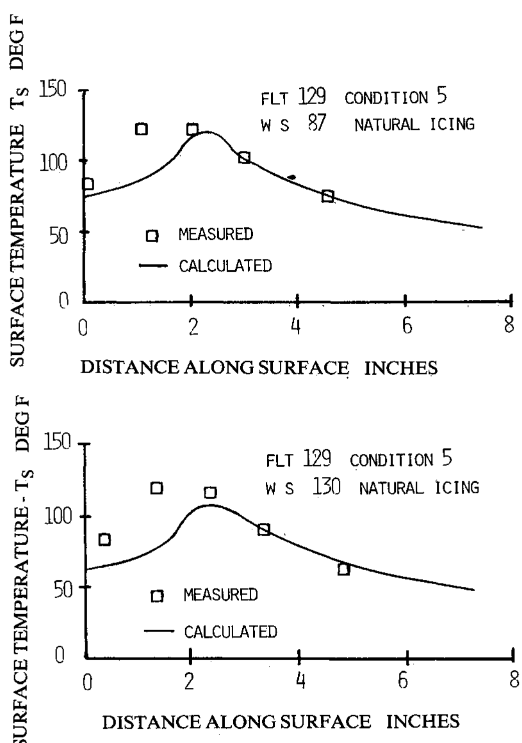

Fig 3 Comparison of calculated and measured surface temperature, Flight 129, Condition 5

ditions and bleed air conditions, to compute local wing surface temperature

Discussion of Results

The test of the validity of such a procedure as that proposed is to calculate wing leading edge surface temperatures based on known test conditions and compare them with the corresponding measured values. This was done for all of the test data available A typical example of the results for natural icing conditions is shown in Fig 3 It is seen that predicted surface temperatures are generally within ±10 °F of the measured values It is apparent that the method is, in general, very conservative in that it tends to predict surface temperatures that are colder than those measured

A comparison of calculated and measured values of T_S/T_A for natural icing conditions for all six instrumented wing stations and for each thermocouple location indicated that there appears to be a consistent ±5% scatter and that the method tends to be quite conservative by 5 10% of T_S/T_A

Conclusions

The formulation of an accurate method for calculating chordwise and spanwise surface temperature distribution for the heated portion of a wing leading edge has been ac complished It provides for the effects of droplet size and liquid water content and requires only information about aircraft, atmospheric, and hot bleed air conditions

For icing conditions, the accuracy of the method is ±10% or less when compared to measured data and tends to be conservative Thus the leading edge anti icing system should maintain more of the leading edge clear of ice than indicated by the calculated surface temperature profiles

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References

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Application of Panel Methods in External Store Load Calculations

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Nomenclature

Kl	= wing leading edge definition parameter
M_∞	= freestream Mach number
u v w	= perturbation velocity components, Fig 1
V_∞	= freestream velocity

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