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A FEW MEASUREMENTS OF THE TEMPERATURES ON UNHEATED SURFACES EXPOSED TO AIRPLANE ICING

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SUMMARY

Six observations are reported on the heating of surfaces during ice formation. In each case good agreement with the predictions of Messinger[1] are found.

INTRODUCTION

During a visit to the summit of Mt. Washington, the authors performed a few experiments in which the temperatures of unheated surfaces exposed to icing were measured. The experiments were performed, for the most part, in a small 6-inch diameter wind tunnel designed, built, and operated by the Navy personnel at Mt. Washington. More experiments were carried on than are reported here, but only in a few cases were we able to get reliable simultaneous meteorological data. In all icing runs, temperature increases were noted in the icing area except in very light icing.

THE EXPERIMENTAL APPARATUS

The measurements were made on a 15/16-inch diameter by 6 inches long cylinder of wood. A single iron-constantan thermocouple was imbedded

in the surface. The wires ran approximately 1/8 inch from the junction in the axial direction, then through holes in the surface to a hollow core, and thence to a Brown self-balancing potentiometer. The accuracy of reading was determined to be 1°F at 32°F by comparison with a Weather Bureau calibrated thermometer. The wooden cylinder was inserted radially into the 6-inch diameter wind tunnel.

The tunnel was powered by an air ejector installed downstream of the test section. Since the air was taken from an air compressor with a very small receiver, there was considerable variation in pressure and the air velocity in the tunnel did not remain steady.

The results are presented in Table I. A typical calculation is given for run 15.

Run 15.

Liquid water content	0.26 grams/meter^3
Drop size	10.6 microns in diameter
Drop size distribution	"A"
Barometric pressure	798 millibar
Velocity head in tunnel	13 inches alcohol (S.G.= 0.827)
Air velocity	231 ft/sec.
Drop Reynolds modulus	45
Scale modulus	21.8
K	2.06
ϕ	981
β_o (from Langmuir-Blodgett, Ref.2)	0.565
E_M (from Langmuir-Blodgett)	0.405
θ_M (from Langmuir-Blodgett)	54°
Rate of water catch at stagnation point	7.6 lbs/(hr)(ft)^2

Unit thermal conductance at stagnation point (Ref. 3)	56.9 BTU/(hr)(ft)^2(°F)
"b" (Messinger, Ref. 1)	0.134
Predicted surface temperature	22°F
Measured surface tamperature	20°F

Note: The ice accretion appeared as shown in Fig. 1. The water drops were concentrated near the tunnel centerline due to tunnel inlet effects.

In addition to the tests described above, an attempt was made to measure the temperature of the interface during icing as a function of time, other conditions being fixed. The basic apparatus used consisted of a 1-inch diameter glass cylinder with a fine wire resistance thermometer attached along the stagnation line as in Fig. 2.

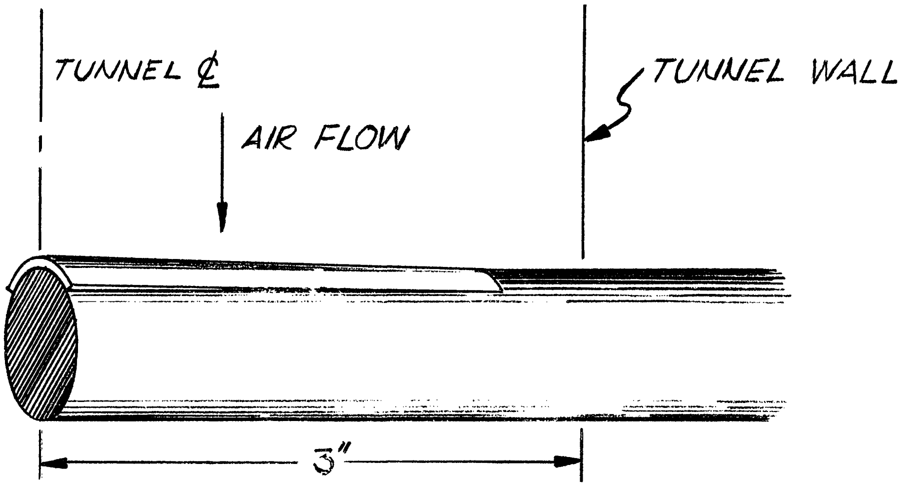

Fig. 1 Typical ice formation on 1-inch diameter cylinder in Navy 6-inch icing tunnel; 140 mph, 10.6 μ drop size, 0.26 g/m^3.

Suitable bridge and amplifier circuits were devised for measuring the temperature effects on the resistance wire. This arrangement had a temperature sensitivity of about 0.1°F and because of the small mass and proper location of the sensing element, the temperature of the interface could be followed closely.

Unfortunately, the natural icing conditions were quite erratic and unreliable during the visit to Mt. Washington, and no adequate test could be given this latter apparatus. Several runs were made, however,

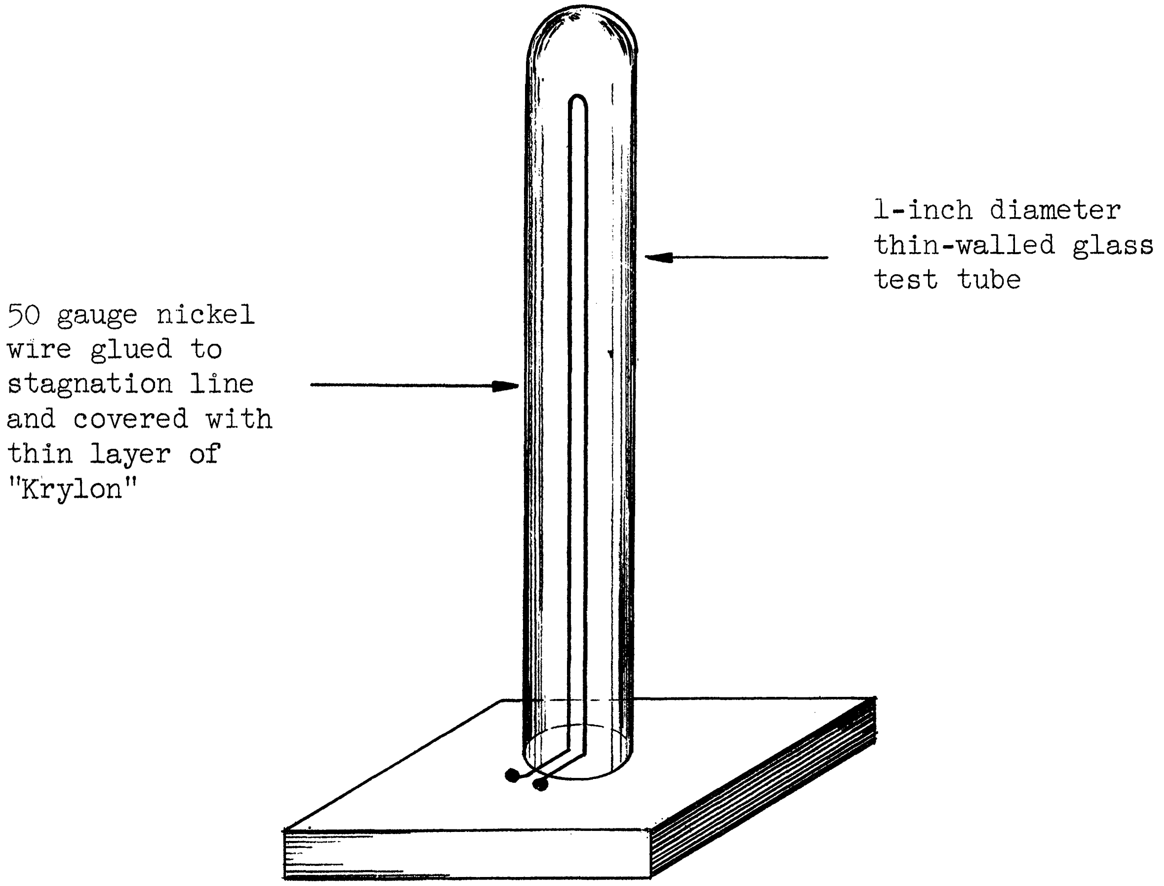

Fig. 2. Second aparatus

and in a qualitative way, the results are in agreement with what was expected. Additional runs will be made in order to provide a better evaluation of the equipment. The experiments emphasized the desirability of using a recording instrument rather than an indicating instrument for the temperature measurement. The change of temperature is quite rapid on exposure to icing, and it is difficult to take good data from an indicating instrument.

CONCLUSIONS

More careful experiments are needed, but these data do show that the effects of heat of fusion as described by Messinger are operative even through an ice layer 0.19 inch thick.

TABLE I

Run No.	Exposure time, sec.	γ °F meas.	U ft/sec. meas.	h $\frac{\text{Btu}}{(\text{Hr})(\text{ft})^2(°\text{F})}$ comp.	R_u comp.	ψ comp.	E_M comp.
14	97	12	231	56.9	45	21.8	0.405
15	95	12	231	56.9	45	21.8	0.405
16	159	12	217	55.2	42	21.8	0.405
17	211	12	231		45	21.8	0.405
18	389	12	222		43	21.8	0.405
19	320	12	203	51.4	39.5	21.8	0.40

Run No.	β_o comp.	R_W $\frac{\text{lb}}{(\text{hr})(\text{ft})^2}$ comp.	b comp.	t_s comp.	t_s meas.	W* comp.	W* meas.	θ_M comp.	θ_M meas.	δ in. comp.	δ in. meas.
14	0.565	7.6	0.134	22	20						
15	0.565	7.6	0.134	22	21.5	1.27	0.915				
16	0.565	7.14	0.129	21.8	18	2.00	1.06	54	70	0.080	0.0625
17	0.565	0	0	12	12	2.84	1.47	54	56	0.107	0.109
18	0.565	0	0	12	12.5					0.197	0.187
19	0.560	2.94	0.0574	16.7	20	3.80	2.29				

See following page for explanation of symbols.

Υ = total temperature of stream

U = tunnel air speed

h = unit thermal conductance at cylinder stagnation point

R_u= droplet Reynolds modulus

ψ = scale modulus

E_M= percentage catch

β_o= "concentration" at stagnation point

R_W= rate of water catch at stagnation point

b = $R_W C_p/h$, dimensionless (C_p = i for water)

t_s= surface temperature °F

W = weight of ice collected, grams

θ_M= angle from stagnation point to farthest impingement

ζ = ice thickness at stagnation point

* The centrifuging effect of the bellmouth served to cause an ice formation such as shown in Fig. 1.

Runs 14, 15, 16 had thermocouple at stagnation point

Run 17 had thermocouple at 56° from stagnation

Run 18 had thermocouple at 180° from stagnation

Run 19 had thermocouple at 30° from stagnation

REFERENCES

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3. Giedt, W. H., "Effect of Turbulence Level of Incident Air Stream on Local Heat Transfer and Skin Friction on a Cylinder" Jour. Aero. Sci., Nov. 1951, p. 725.