The Blasius solution provides another boundary condition at $\xi = 1$.

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Ablation Surface Cross-Hatching on Cones in Hypersonic Flow

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Introduction

THE investigation reported herein was directed toward understanding and suppressing crosshatched patterns on ablating surfaces. A number of prior programs have been reported in Refs. 1–5. The objective of this particular study was to perform wind-tunnel experiments to assist in determining the source and mechanism of crosshatched patterns on ablating surfaces. Specifically, tests were made to satisfy the following objectives: 1) provide crosshatched patterns at higher edge Mach numbers and smaller cone angles than heretofore realized in ground-based tests and 2) determine the effect of nose bluntness on cross-hatching. Additional objectives beyond the scope of this Note will be found in the final contract report.[6] This work extends an earlier in-house effort (Ref. 5) to a more realistic simulation of the re-entry vehicle flight regime and geometry. The previous tests were all conducted at Mach 6 on sharp-nosed models, mostly camphor and Korotherm. As reported in Ref. 5, cross-hatching was obtained at lower surface pressures than anticipated. This made feasible the present tests at smaller cone angles and higher Mach numbers, and resulted in cross-hatching at an edge Mach number of 6.2, an appreciable increase over previous wind-tunnel data.

Description of Wind-Tunnel Ablation Tests

The tests were conducted in the Douglas Aerophysics Lab. 2-ft hypersonic wind tunnel at Mach numbers of 6, 8, and 10, on 6°, 10°, and 15° conical models. Schlieren, 35-mm still, and motion pictures were taken during each test. Models were weighed and measured before and after each run to determine the amount of material lost resulting from ablation. Rubber molds and epoxy casts were made of the post-test models for a more permanent record of the ablated surface patterns.

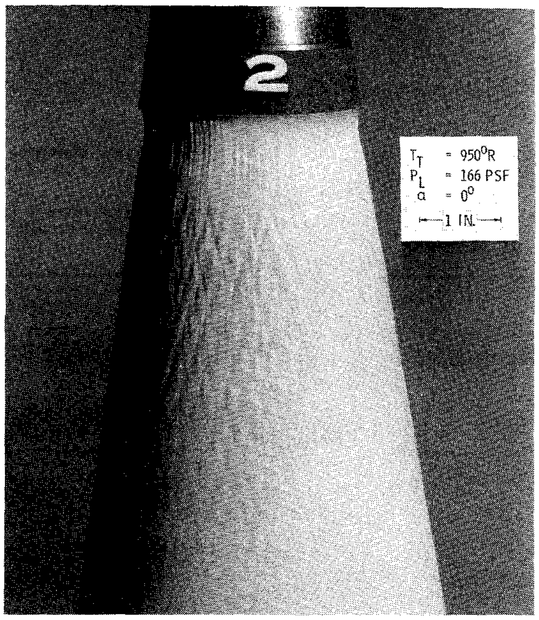

Fig. 1 10° camphor cone after 43 sec at $M_\infty = 6$.

Camphor and special Korotherm were chosen as the ablative materials, based upon the various materials tried in previous tests. Camphor worked well, even at the severe environment of Mach 10. For details on special fabricating techniques, etc., see Refs. 5 and 6. Clear camphor over black Noryl‡ cores gave good visual ablation surface pattern detail during testing, but only for a small area where the lighting was perfect. Consequently, $\frac{1}{4}$% of titanium dioxide was added to the powdered camphor before isostatic pressing to give a white or translucent ablation surface.

Korotherm was used primarily because of its previous performance at Mach 6. In its subliming mode it produced a wind-tunnel crosshatched pattern more similar to that of phenolic, fused-silica-fiber in flight than did camphor (Fig. 13 of Ref. 5). Unfortunately, no cross-hatching was obtained on Korotherm during the present tests, except for occasional local areas that ablated as a liquid. The crosshatched pattern in these areas was wiped out by surface tension and solidification of the liquid layer at the end of the

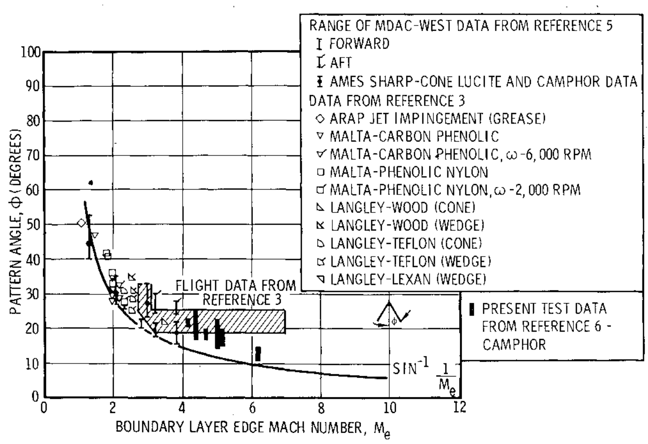

Fig. 2 Surface pattern angle as a function of local Mach number.

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‡ Modified phenylene oxide thermoplastic resin.

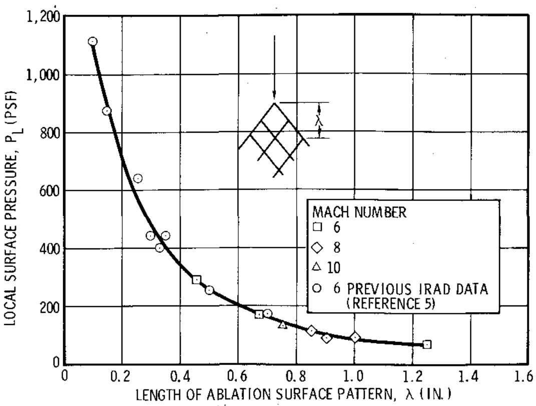

Fig. 3 Variation of camphor ablation surface pattern length with local surface pressure.

run, but was visible in the photographs and movies taken during the tests. The following results and conclusions are all based on the camphor data.

Results and Discussion

A 10° camphor cone after 43 sec at Mach 6 is shown in Fig. 1. This figure also shows the typical model construction with the sharp steel nose separated from the ablative material by a ceramic insulating spacer.

Pattern angle and size

One of the important objectives of these tests was to determine whether the pattern angle continues to lie close to the Mach angle as Mach number increases. Figure 2 shows the range of pattern angles obtained as a function of edge Mach number together with previous data. Figure 2 shows that the pattern angle continues to lie just above the edge Mach angle as Mach number increases.

Figure 3 shows the variation of the streamwise length of the ablation patterns with local surface pressure. Data from the previous in-house work at Mach 6 are included. It should be noted that the addition of higher Mach numbers and smaller cone angles did not invalidate the previous correlation, but merely extended it to higher pattern lengths and lower pressures. It can be shown that these data are consistent with the pattern angle vs Mach angle correlation of Fig. 2 and with the Probstein-Gold idea[7] that cross-hatching occurs because of a resonance between boundary-layer disturbance and a suitable inelastic deformable surface.

Effect of nosetip bluntness

To check the effect of nosetip blunting on cross-hatching, the 10° cone was tested with various radius nosetips. Figure 4 shows the pattern angles plotted vs their local edge Mach number. Data for the sharp nose as well as bluntness ratios of 0.05 and 0.15 are included. Even this moderate bluntness can reduce edge Mach number by nearly half and consequently has a marked influence on the pattern angle correlation. These data, which are plotted at the correct local edge Mach number, fit the sharp cone pattern angle versus edge Mach number correlation. If uncorrected, the 0.15 bluntness data would violate the correlation. There is no indication of a limiting minimum angle above Mach 3 as suggested by the flight data of Ref. 3 which are indicated in Fig. 3. It is believed that nose bluntness effects, such as those shown in Fig. 4, may resolve this discrepancy between flight and ground test data.

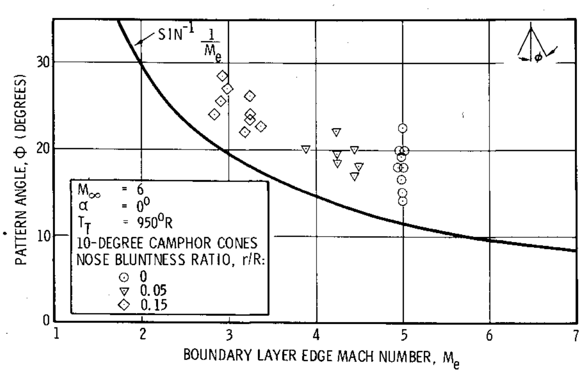

Fig. 4 Effect of nosetip bluntness on surface pattern angle.

Summary and Conclusions

Hypersonic wind-tunnel tests of conical camphor models extended the cross-hatching angle vs edge Mach number correlation, showed nosetip bluntness effects compatible with this correlation, and extended the curve showing pattern wavelength varying inversely with local pressure.

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Quasi-Static Thermal Stresses due to a Moving Heat Source in a Circular Disk

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Nomenclature

a = radius of disk or cylinder
E = Young's modulus
h = heat-transfer coefficient
k = thermal conductivity
r_o = radial coordinate of heat source
T = temperature
Q_o = intensity of heat source
α = thermal expansion coefficient
β = h/k
κ = thermal diffusivity
λ_m = eigenvalues
ν = Poisson's ratio
ξ = phase angle
ϕ = stress function
ω = angular velocity
∇^2 = Laplacian operator

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