This limiting point agrees well with the values from the distortion-free probes. The larger probes, however, show decreasing values in the constant-displacement regions. It is interesting to note that if the maximum values of Δ/D are plotted instead of the constant-displacement values, the agreement with the smaller diameter data is good.

Included on this figure for comparison is the level of Δ/D obtained by previous investigations[1,2] in incompressible flow. The displacement level obtained in this study is more than double that obtained previously in incompressible flow.

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Further Experimental Studies of Cross-Hatching

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A CONCLUSIVE theoretical explanation of the phenomenon of cross-hatching is still outstanding,[1–3] and consequently, additional experimental observations are of interest.

This Note describes the effect of nose blunting, exposure time and initial temperature of axisymmetric bodies on the main characteristics of the ablation surface pattern. The study was made in the same facility, under similar stagnation conditions, as in Ref. 4. Cones of 10–62° total vertex angle were tested at zero angle of attack. The ablation materials were wax and camphor, which liquefied and sublimed respectively under the present test conditions.

1. Effect of Nose Blunting

Figure 1 shows the cant angle ϕ of crosshatched patterns observed on self-blunting cones, consisting entirely of ablation material, vs Mach number M_e, where M_e is calculated for sharp nose cones. These results are compared with those previously obtained on sharp nose models which followed the Mach angle trend, shown by the solid curve. Present data agree with free-flight results[5] and thus prove that the apparent "freezing" of ϕ for Mach numbers M_e larger than 3 is due to nose blunting, i.e. improper use of M_e instead of the actual local Mach number on the blunt nose cones.

2. Effect of Exposure Time

There was for each test conditions an optimum wind-tunnel running time t after which a well contrasted pattern was observable. A typical run time on a 26° total angle cone was 15 sec $\pm$ 2 sec. The pattern is nonexistent or too weak for a run time less than 13 sec and disorganized for times larger than 17 sec.

Figure 2 shows this time t as a function of the static pressure p_e, for a nearly constant temperature ratio $(T_r - T_W)/T_W = 0.0989 - 0.1278$. The recovery temperature T_r was calculated by assuming

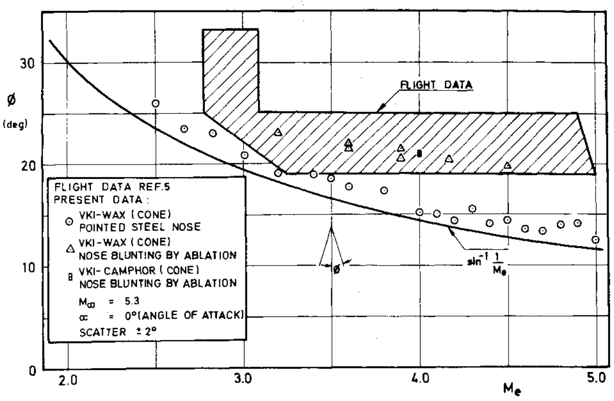

Fig. 1 Influence of the Mach number M_e on the cant angle $\phi - M_e$ calculated for unblunted cones.

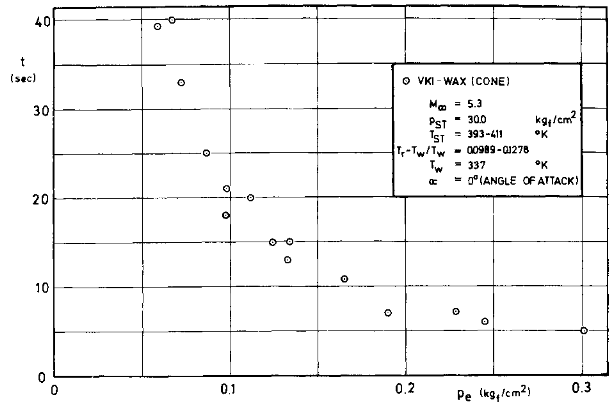

Fig. 2 Run time required for a developed cross-hatched pattern as a function of the local static pressure p_e.

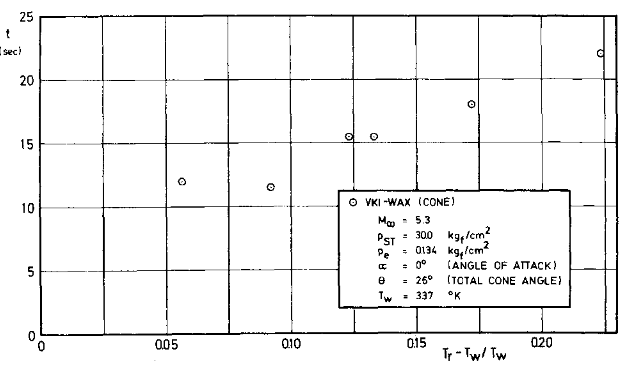

Fig. 3 Run time required for a developed cross-hatched pattern as a function of the driving temperature ratio $(T_r - T_W)/T_W$.

a turbulent recovery factor of 0.895. $T_W = 337°K$ is the temperature at which wax liquefies, independent of p_e. Figure 3 shows t as a function of the driving temperature ratio $(T_r - T_W)/T_W$ for a constant static pressure p_e. As may be seen, the run time t is in inverse proportion to the static pressure p_e and increases nearly linearly with the temperature ratio.

3. Expansion Corner

The influence of an expansion wave on the development of cross-hatching has been examined by testing double cone models as sketched in Fig. 4. The result is compared with that on a single cone.

The run was stopped after 15 sec, when a developed pattern appeared on the fore-cone. As may be seen, the pattern on the after-cone has not yet appeared. This is a striking result of the influence of run time. Indeed, the static pressure was lower on the

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after-cone, because of the expansion corner, resulting in a longer required run time for the pattern development, according to Fig. 2.

This is further demonstrated by Fig. 5 which shows the result obtained by testing the same double cone model for 25 sec, i.e. the optimum time required based on the after-cone static pressure, according to Fig. 2. In this case, a disintegrated pattern appeared on the fore-cone whilst the after-part is covered with cross-hatching. However, this pattern is less clear than on a single cone of 18°, which is shown for comparison. The reason is that the boundary-layer flow is highly perturbed by the surface irregularities on the fore-cone when the pattern starts to develop on the after-body.

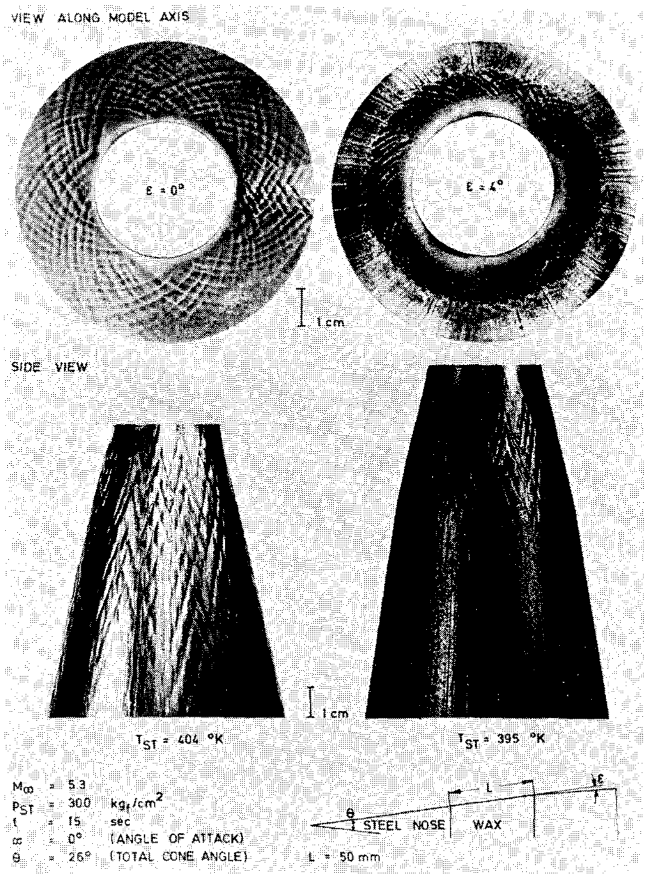

Fig. 4 Influence of an expansion wave on the cross-hatching formation.

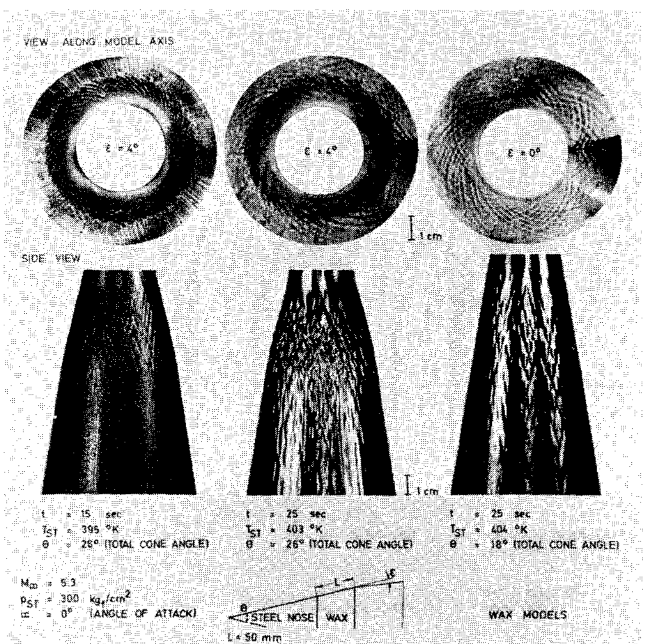

Fig. 5 Influence of run time on the cross-hatching formation (expansion wave models).

4. Effect of the Initial Temperature of the Ablation Material

In Fig. 6 are shown two initially identical cones that were tested under the same stagnation conditions, but at different initial temperatures. The higher temperature model was preheated in the region between 50 mm from the steel nose down to the base, at a temperature close to liquefaction. As may be seen, the streamwise spacing λ is considerably larger on the preheated wax model, λ being the streamwise length of a cell of the diamond shaped pattern. A result which tends to indicate that viscosity and resistivity of the material (wax) play an important role in the cross-hatching development. This may support the theory of Probstein and Gold,[1] who assume that cross-hatching is the result of a differential deformation of the surface of a viscous, inelastic, solid material.

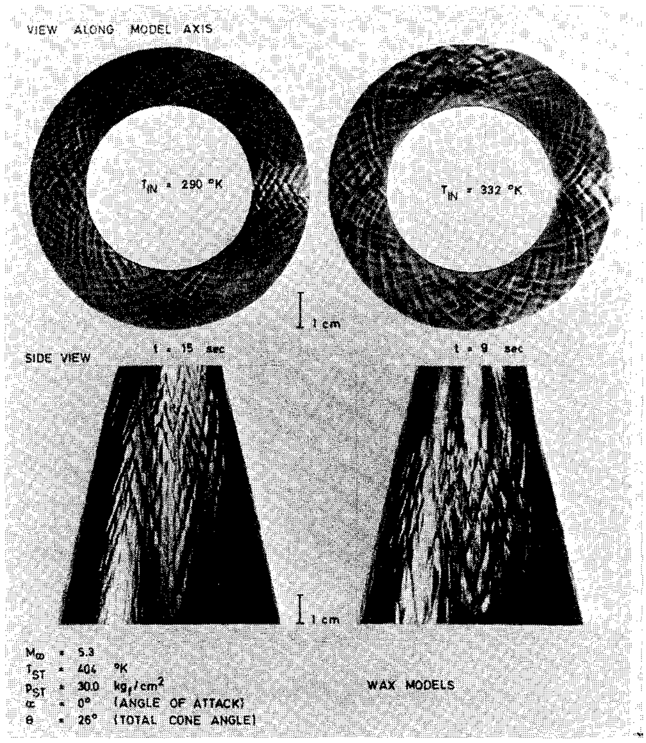

Fig. 6 Influence of the initial ablation material temperature on the streamwise spacing λ.

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