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Axial Compression Corner Flow with Shock Impingement

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Introduction

SEVERAL corner flow studies have been conducted by many researchers, both theoretically and experimentally, from simple, sharp leading-edge flat plates intersecting at right angles to more complex compression corners formed by unsymmetrical wedges intersecting at various angles.[1] Most of the studies focused on characterizing the flow structure with little, if any, effort on determining aerodynamic heating. Therefore, very little heat transfer data is available on axial corner flow. For corner flows with shock impingement, a situation that would exist in the engine inlet of a hypersonic vehicle, no experimental heat transfer data have been reported in the literature. This Note presents a portion of such experimental results, which are the first of their kind, from a 90-deg axial compression corner with external oblique shock impingement. A more detailed presentation of this study is given in Ref. 2.

Experimental Program

A sketch of the model with pertinent dimensions and coordinate system is shown in Fig. 1. The model consists of a forebody, cowl, and strut. The forebody has a 10-deg wedge section for the forward half of its total length of 18 in. The cowl has a 10-deg wedge angle and a length of 9 in. The strut has a 5-deg half-angle with 4.4 in. and 2.8 in. of height at the leading and trailing edges, respectively. The model was tested in the NASA Langley 20-in. Mach 6 wind tunnel[3] at a stagnation temperature of 420°F and a freestream unit Reynolds number of 3.35×10^6/ft with and without boundary-layer trips.

The surface heat transfer distribution was obtained using the phase-change paint technique described by Jones and Hunt.[4] The painted model was injected into the test stream and subjected to aerodynamic heating until the paint melted. A 35-mm color camera recorded the progression of the paint melt line at a rate of 30 frames/s. The local heat transfer coefficient h at the melt line was calculated from the analytical solution to the transient, one-dimensional heat conduction equation for a semi-infinite slab given in Ref. 3. The error in the calculated h using the phase-change paint method can be as large as 30%.[4,5] However, even with this degree of error, this technique is still quite useful to obtain the heating pattern, determine salient heating features such as localized "hot spots," and provide at least a correct order of magnitude estimate of the quantitative value of the heat transfer.

Surface oil-flow patterns were obtained using a mixture of titanium dioxide and silicon oil distributed over the model surface in a random dot pattern. Oil-flow development in the compression corner was captured using a 35-mm camera operating at 30 frames/s.

Results and Discussion

The heating rate contours computed from the phase-change paint experiments for the sharp-strut model without boundary-layer trips are shown in Fig. 2. The normalizing value of h_{ref} corresponds to the undisturbed laminar heat level at a distance of 4.4 in. along the 10-deg cowl from its leading edge, which is also the height of the cowl at the leading edge. Two distinct peak heating areas are shown on the cowl surface near the corner and downstream of the shock impingement region. The

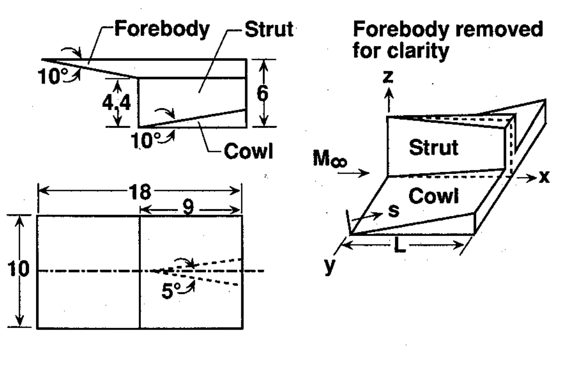

Fig. 1 Corner flow model configuration.

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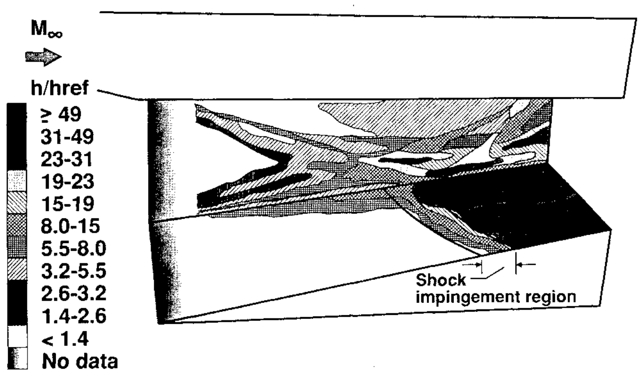

Fig. 2 Heat transfer distribution in the cowl-strut corner (no boundary-layer trips).

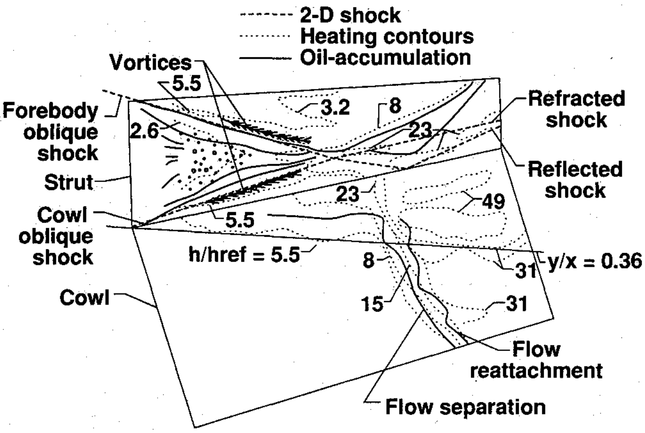

Fig. 3 Two-dimensional shock location and oil-flow lines shown with heating contours (no boundary-layer trips).

peak heating is approximately 50 times the undisturbed laminar reference heating level and on the order of 1.5 times that of the surrounding area downstream of the shock impingement. The h/h_{ref} value of the surrounding area is from 31 to 49. The heating in the vicinity of the corner, upstream of the shock impingement region, is much lower than the peak heating but higher than the heating in the undisturbed regions. The contours on the strut show a lower heat transfer coefficient in the triangular region formed by the strut leading edge and the crossing pattern of the forebody and cowl shock waves. Downstream of the shock interference region, the heating pattern on the strut is extremely complex due to highly three-dimensional flow interactions.

Figure 3 shows the opened-out cowl and strut surface of the model with the same heating contours of Fig. 2. The prominent oil accumulation lines are superimposed on both surfaces for direct comparison with heating contours. On the cowl surface, oil accumulation lines indicating flow separation and reattachment correspond to the region of high heating gradients indicated by the closely spaced heating contour lines. This region is created by the forebody shock impingement on the cowl. The arbitrarily chosen $y/x = 0.36$ line bounds the corner heating contours upstream of the forebody-cowl shock impingement location and the two peak heating regions downstream of the forebody-cowl shock impingement location. On the strut surface, the feather-shaped oil accumulation lines coincide with the two-dimensional inviscid shock lines from the forebody and cowl that are projected on the strut surface. Separated flow in the triangular region, upstream of this forebody-cowl shock crossing pattern, is indicated by the oil-flow pattern. Also, the highest heating rates ($h/h_{ref} = 23$) on the strut surface occurred in the region between the refracted and reflected shock waves.

Similar results (not presented) were obtained with flow trips that produced turbulent level heating ahead of the shock impingement region. Generally, the features of the tripped case were similar to the untripped case, except that the flow separation did not occur on the strut surface upstream of the shock interaction region for the tripped boundary-layer case. Also, the same two peak heating regions occurred on the cowl, and the heating level was about the same as that for the untripped case, indicating that the shock interference heating was independent of the upstream boundary-layer conditions for the present investigation.

Conclusions

The aerodynamic heating in an axial compression corner with an external oblique shock impingement is characterized qualitatively. The local peak heating occurred on the cowl near the corner downstream of the forebody-cowl shock impingement location and was about 50 times the reference undisturbed laminar heating. The peak heating was on the order of 1.5 times that of the surrounding value downstream of the shock impingement. There was no significant difference in the magnitude and location of the peak heating between the untripped and tripped cases.

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Effects of Space Radiation on High-Temperature Superconducting Thin Films of $YBa_2Cu_3O_{7-x}$

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Introduction

HIGH-TEMPERATURE superconducting materials are expected to offer significant improvements in the performance of spacecraft components. Specifically, low surface

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