Flap Turbulent Heating Characteristics Obtained from a Hypersonic Shock Tunnel

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Theme

FLAPS are used as aerodynamic control surfaces for re-entry vehicles. At low altitudes, the boundary layer is turbulent over most of the vehicle and may produce severe surface heating rates and gradients to a highly deflected flap. This paper presents turbulent heating, skin friction, and pressure data on flaps from a test program conducted at Cornell Aeronautical Laboratory (CAL). Also presented are flap heating correlations, and data comparison with published data.

Content

Testing—The test was performed in the 96-in. CAL Hypersonic Shock Tunnel. The test model was a sharp nosed, 36-in. long 8.5° half-angle cone, with a spherical aft closure dome and four trailing flaps (Fig. 1). A flat area forward of the flap provides a transition from the conical surface to the planar flap. Flap deflections were varied from 10° to 30°, as referenced to body centerline. The test model was extensively instrumented with heat transfer, pressure, and skin-friction gages (Fig. 1). Test conditions were: $M_\infty = 7.8 - 13.3$ and $Re_\infty = 3.3 \times 10^6 - 70.3 \times 10^6$.

Test Data—Centerline heating rate distributions on the deflected flap showed a common characteristic of peak heating near midchord, where flow impingement occurred. Local heating increased with flap deflection, and the peak heating point tended to move forward on the deflected flap. For all test conditions, flap length was sufficient to ensure that the impingement process is completed on the flap. Flap-to-cone heating ratio h_F/h_c increased with decreasing Reynolds number, and exhibited a clear peak heating point near midchord and a fall-off near the flap lateral edge for higher flap deflection angles. Also, flap heating rates were more sensitive to freestream Mach number than to the freestream Reynolds number. Heating at the forward portion of the flat did not seem to depend on flap deflection angle. At the aft end of the forward flat, heating decreased further with increasing deflection angle, indicating flow separation. Axial heating decay in the flat region was more pronounced in the lower Reynolds number runs. Spanwise flap heating distributions showed a significantly increasing heating rate spanwise outward only near the hingeline. Pressure distributions near the flap hingeline showed higher pressure at flap outer edge than at the centerline. This can be attributed to less flow expansion occurring at the flap outer edge due to the shorter flat length.

Skin-friction gages were most useful in detecting separated flow, because output from these gages changes sign when reverse flow occurs. The degree of flow separation at the forward region of the flap was analyzed. At higher Reynolds numbers, higher flap angles were required to separate the flow. The centerline pressure distribution data trend was the same as observed on heating and skin-friction data. There were indications that pressures on the aft end of the flat were influenced by the flap for higher flap deflections. Near the flap hingeline strong pressure gradients occurred, while near the flap aft edge the pressures stabilize to near inviscid values. As in the discussion of the flap heating and skin-friction data, several data trends indicate definite flow separation in the hingeline vicinity.

Data Correlations—local flap heating rate data were normalized to aft cone heating. The data were found to be directly proportional to M_∞ for the low Reynolds number (3×10^6) data, except for the 10° data. A similar correlation was made with $Re_\infty^{0.1}$. A linear dependency of h_F/h_c on $M_\infty/Re_\infty^{0.1}$ was obtained for the range of M_∞ and Re_∞ used in the test. Figure 2 shows a typical correlation obtained on T20 location. The second correlation for flap heating was established between flap heating and pressure. The purpose

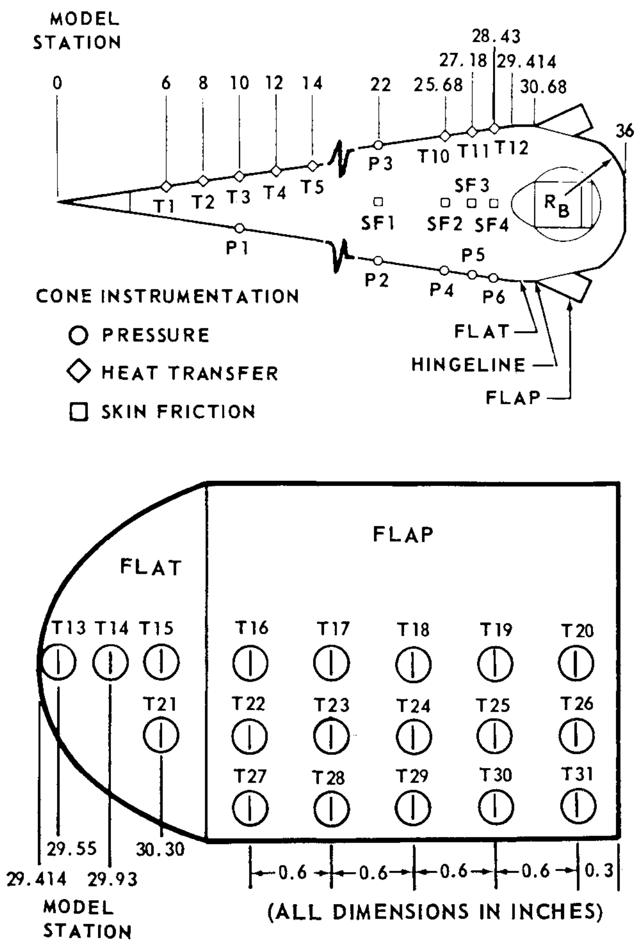

Fig. 1 Test model and flap-heat-transfer instrumentation.

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Index categories: Boundary Layers and Convective Heat Transfer—Turbulent; Re-entry Vehicle Testing.

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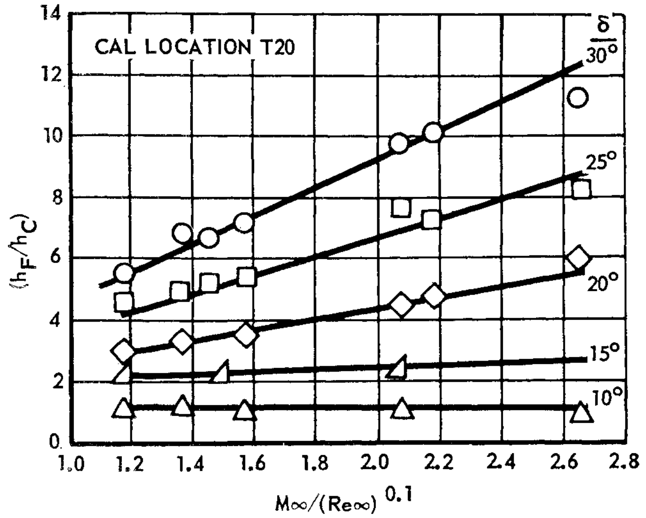

Fig. 2 Flap heating correlation.

of this correlation was to obtain further insight into separated-reattached flow characteristics over the flaps. In the reattachment region, an exponent of 0.8 correlated data well for the expression $h_F/h_c = (p_F/p_c)^n$. In Ref. (1) it was pointed out that for attached and reattached turbulent flows, the pressure exponent in the above expression is 0.72 ~ 0.81. The data trend showed that in the flap-induced separation region (near hingeline), the pressure exponent (n) would be greater than 0.8 if the above pressure interaction theory is applied.

Data trends observed for flap heating distribution was further examined with the aid of skin-friction data. Except in the forward region of the flap, where flow separation occurred, a simple correlation between heating and skin-friction data was seen. In the separated flow region, where reverse flow was evident, skin-friction data exhibited an erratic pattern and lower values if compared with attached flow data. Skin-friction data at the forward location showed considerable data scatter, indicative of reverse flow. Data at the aft portion of flap showed a more consistent data trend.

Figure 3 shows our data comparison with Ref. (2) data. Both data show an essentially linear dependency of h_{max}/h_c on flap deflection angle. Another data comparison between Ref. (2) and our data is also shown in Fig. 3. Even though there is a slight difference in slope between Nestler's and ours, it is seen that a successful collapsing of Mach number effect on h_{max}/h_c has been achieved for our data. Here again, our data seems to have extended the Nestler correlation to higher Mach number regions. These results indicate that this correlation can be used for estimating maximum impingement heating rates on a deflected surface for supersonic turbulent flow. Our data correlation results showed a somewhat weaker dependency compared to Bushnell's data of Ref. (3). Reference (4) peak Stanton number was approximately proportional to $(Re_\infty)^{-0.2}$. Some of the wedge peak heating data of Ref. (5) shows $h_{max} \propto (Re_\infty)^{-0.35}$. Our data showed a relationship of $h_{max} \propto (Re_\infty)^{-0.3}$.

Conclusions—Satisfactory design correlation of turbulent heat flux data on flaps in supersonic local flow has been achieved using Re_∞, M_∞, and flap deflection as correlating parameters. Extension of existing data correlation methods published in Ref. (2–5) to the higher Re_∞ and M_∞ regions also has been successful.

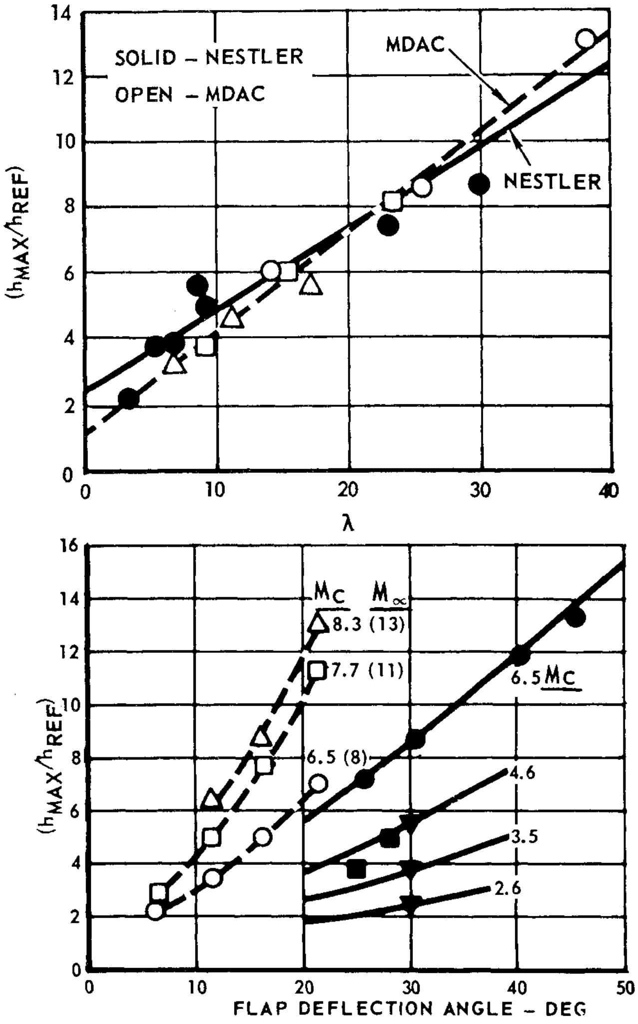

Fig. 3 Maximum flap heating correlations.

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