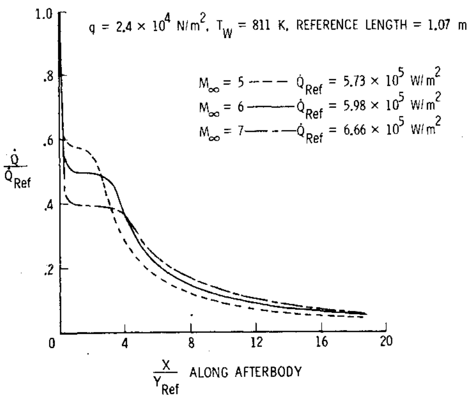

Fig. 2 Heating rate distributions for Mach 5, 6, and 7 flight.

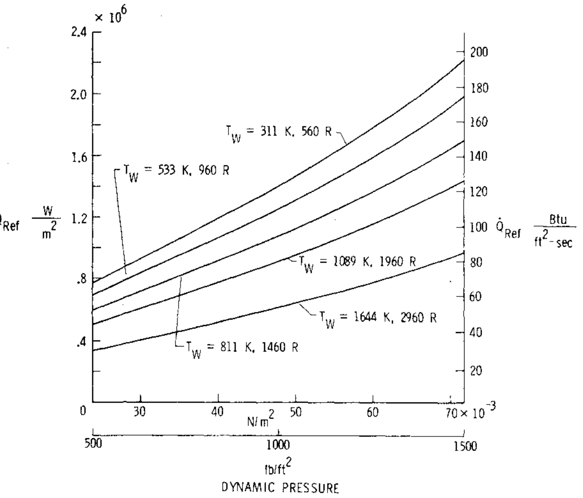

Fig. 3 Initial heating-level variation due to changes in dynamic pressure, $M_\infty = 6$.

wall temperature, and reference length. The results also showed that variations in wall temperature and reference length shifted the distributions by less than 5% for a fixed flight Mach number. Therefore, $\dot{Q}_{ref}$ appears to be a good normalizing factor for this study. The absolute effects of changing the dynamic pressure, wall temperature, and reference length can now be examined.

The effect on the afterbody nozzle wall initial heating level of varying the reference length from 0.76 m to 1.52 m for a Mach 6 flight condition [$q = 2.4 \times 10^4$ N/m^2 (500 lb/ft^2)] was examined. For a given wall temperature, a 12% variation in $\dot{Q}_{ref}$ over the stated reference length range was obtained. This variation could be approximated by a one-sixth power law.

Figure 3 presents the variation in $\dot{Q}_{ref}$ due to changes in the dynamic pressure for Mach 6 flight where a reference length of 1.07 m has been assumed. Curves are shown for five wall temperatures that span the range of possible wall values. The actual wall temperature will be a function of the thermal protection system selected for the vehicle and may well be a function of location along the afterbody as well. The tripling of the initial heating level shows that, as would be expected, dynamic pressure is the major parameter affecting the nozzle heating rate. [This variation (Fig. 3) could be approximated by a 0.98 power law.]

Conclusions

A study has been conducted to estimate the heating levels on the external nozzle of a scramjet/airframe-integrated research aircraft. A parametric examination of the effects of Mach number, reference length, and wall temperature showed that the heating-rate distributions are independent of reference length and wall temperature. The initial heating rates obtained for a Mach 6 flight case are in the 3-8 × 10^5 W/m^2 (30-70 Btu/ft^2-sec) range.

Underlying the entire study is the question of nozzle boundary-layer formation and growth and what corresponding reference length should be used in the computation. Our results have shown that reference length is not the dominant factor setting the heating levels and we have tried to bound the actual length. Further work will be required to obtain a better understanding of the combustor exit boundary layer before more detailed calculations of the rates can be obtained.

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Errata

Remarks on Thin Airfoil Theory

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It has been brought to my attention by N. H. Kemp that there were sign errors in some of the equations in the above Engineering Note. The corrections are as follows:

$$J_{n+1} + J_{n-1} = 2\cos\phi J_n + (2/n)\,[1-(-1)^n] \tag{11}$$

$$J_1 = -\int_0^\pi \cot\left(\frac{\theta+\phi}{2}\right)d\theta = -2\log\cot(\phi/2) \tag{15}$$

$$A = \frac{4}{\sin 2\phi} - 2\frac{\log\cot(\phi/2)}{\sin\phi} \tag{16}$$

In Eqs. (17), (19), and (20) the right-hand sides should be multiplied by (−1) so that the final result, Eq. (20), reads

$$\int_0^\pi \frac{\sin n\theta\, d\theta}{(\cos\theta - \cos\phi)} = \frac{4\sin n\phi}{\sin 2\phi} - 2\frac{\sin n\phi}{\sin\phi}\log\cot\frac{\phi}{2} - [1-(-1)^n]\frac{1}{n\cos\phi} \tag{20}$$

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