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Reply by Author to D. K. Edwards

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THE author gratefully acknowledges Dr. Edwards' correction of the shape factor curves in Ref. 1 and the comments on the utility of approximating a metal oxide laden exhaust plume as a conical surface. His enlargement of the concept to introduce an "effective shape factor" should prove useful to thermal designers who must protect spacecraft surfaces from rocket plume radiation.

The analysis of Ref. 1 represented a first, and apparently unsteady, step in attempting to reduce an extremely difficult problem to a level which could be treated by hardware oriented thermal designers. Subsequent studies of the "metal oxide plume problem" are reported in Ref. 2–4, in which the integro-differential equation of radiative transfer is solved by the diffusion-iteration approximation. These studies together with a vastly different problem reported in Ref. 5 support the following conclusions: 1) the emittance from an isothermal, isotropically scattering dispersion is not diffuse (Ref. 2), 2) directional emittance, uniform over a "surface," is analytically equivalent to a surface of nonuniform radiostiy when computing the radiant flux at a remote location (Ref. 5, 2–4), and 3) the value $\omega = 1$ is the best approximation for an isotropically scattering conical plume with an albedo approaching unity and an exit optical-scattering depth of about 3 (Ref. 4).

The author agrees that the reference radiosity J_0 should be a measured quantity rather than computed. However, if J_0 is measured at the exit plane of a rocket nozzle (a common location), the assumption $\omega = 1$ is conservative insofar as the axial decay is more rapid. The exit-plane radiosity is enhanced by radiation from heteropolar gas products that cool rapidly downstream of the exit plane, and the "searchlight" effect of the combustion chamber and nozzle enclosure irradiating particles immediately downstream of the exit plane. Both of these effects become less pronounced several exit diameters downstream of the exit plane. A third influence, that of anisotropic scattering, on the magnitude of ω cannot be assessed properly at this time. The results of an exploratory study of the searchlight effect together with anisotropic scattering are reported by Stockham and Love.[6] However, their cylindrical geometry with constant density is a model of the plume in the vicinity of the exit plane only and does not provide any insight to the magnitude of ω.

Dr. Edwards' product $Q_a\tau$ is an apparent emittance at the exit plane. In Ref. 4 it is identified as the normal emissivity (emittance) at the cone surface. An order of magnitude uncertainty in the imaginary part of the refraction index for fused Al_2O_3 indicates that $0.02 \leq Q_a\tau \leq 0.20$ where $\tau = 3$. This observation, together with the uncertain influence of gaseous radiation and searchlight effect provides additional support for obtaining J_0 from measurements rather than computations.

Finally, the expression for directional emittance, $\epsilon/\epsilon_{\text{normal}} = 0.50\ (1 + \cos\theta)$, appears to be a reasonable fit for Chandrasekhar's H-function for semi-infinite plane dispersions, but the emittance from a conical geometry has a more complicated directional character. Emittance curves for a conical geometry are presented in Ref. 4 and these show both polar and azimuthal dependence on angle. In the plane containing the conical axis, the emittance resembles $\epsilon/\epsilon_{\text{normal}} \approx 1 + \sin\theta$ while in a plane normal to the axis $\epsilon/\epsilon_{\text{normal}} \approx \cos\theta$. However, in view of 1) the equivalence between nondiffuse local emittance and a nonuniform radiosity distribution, and 2) the rapid axial decay of gaseous radiation and the searchlight effect, it appears that Edwards' Figs. 8 and 9 are most useful for thermal design. It should be observed that the combination $\omega = 1$ and $\epsilon = 0.50\ (1 + \cos\theta)$ is roughly equivalent to the choice $\omega = 2$.

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Comments on "A Reattachment Criterion for Turbulent Supersonic Separated Flows"

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BATHAM[1] has shown that his reattachment criterion correlates certain experimental data with an empirical constant K. This correlation should be interpreted as one possible correlation in a region of possible solutions. It has been shown[2] that the turbulent pressure coefficient at reattachment depends upon both Reynolds number (initial boundary layer) and Mach number for free reattachments.

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