Application to Asteroid Belt Mission

The spacecraft configuration evaluated was one developed under JPL contract,[6] and was based on use of a Mercury Electron Bombardment Ion propulsion system, Fig. 2. The study trajectory was a 1190-day mission through the asteroid belt (Fig. 3) chosen to gather data in this region of the solar system. Due to the large variation in impact velocity and flux throughout the mission, area losses were calculated for small segments of the mission and summed to obtain total area loss. Assuming that the power loss will be 50% of the area loss, the percent power loss was computed for the spacecraft with various substrate thicknesses, Fig. 4. The model of Ref. 7 was applied to estimate the extent of the meteoroid stream hazard. It was found that the number of active zones encountered was very sensitive to departure date. An Oct. 1, 1975 launch would result in one encounter and a Nov. 1, 1975 launch date in no encounters. An intermediate departure date of Oct. 22, 1975 would result in four encounters. The Oct. 1, 1975 launch trajectory would pass through the stream of the comet Schaumasse in fall 1977, with a predicted power less of 2.5%.

Conclusions

1) Providing the meteoroid environment models used define the true upper limit of the sporadic meteoroid population, the solar panel power loss during the 1190-day study mission because of sporadic cometary and asteroidal particles would have an absolute upper limit of 8% based on a 100% fracture zone reflection, and a best estimate upper limit of 4% based on a 50% reflection factor. 2) The addition of a substrate should significantly reduce the above power loss values (Fig. 4), with 0.002-in. thick Kapton or equivalent being helpful, and 0.008-in. providing the maximum benefit. 3) Hypervelocity impact testing of solar cells is recommended for the determination of the effective reflection factor associated with a given solar panel design. The 10^{-6} g glass particles fired by the electrothermal hypervelocity impact guns closely approximate the meteoroid particles predicted to be the main source of solar panel degradation. These test facilities are therefore a logical choice for determination of reflection factors. 4) The power loss values previously noted can be significantly increased if the solar panels are exposed to a cometary stream or streams. Therefore, launch dates should be selected which avoid encounters with the known active shower zones.

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Chemical Nonequilibrium Boundary-Layer Effects on a Simulated Space Shuttle Configuration during Re-Entry

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FUTURE space shuttle missions dictate lifting entry into the Earth's atmosphere under conditions which place stringent requirements on the vehicle's thermal protection system (TPS). General surveys of the severe heating environment during space shuttle re-entry and the current thinking toward solution of these problems have been given in recent articles by Faget[1] and Lecat.[2] The shuttle vehicle will re-enter at higher altitudes and lower velocities than did previous vehicles, which means that chemical nonequilibrium phenomena in the shock layer will become of increasing importance. Because currently proposed shuttle vehicles are long ($\sim$100 ft), nonequilibrium relaxation effects must be considered in estimates of nonequilibrium heating rates to be encountered under high altitude re-entry conditions. The present Note reports an investigation into chemical nonequilibrium boundary-layer effects on a simulated space shuttle configuration (a 20° half-angle sphere-cone having a nose radius of 1.0 ft) at zero angle of attack under altitude-velocity conditions of 200,000 ft and 16,000 fps in the Earth's atmosphere. Since a metallic reradiation heat shield will probably be used for the shuttle TPS, a constant wall temperature of 2000°R is assumed. Total body length is taken to be 100.0 ft. Although the sphere-cone geometry at zero angle of attack is not an accurate representation of current shuttle concepts, the results reported herein should be representative of the nonequilibrium effects to be expected.

Analysis

The present investigation makes use of the chemical nonequilibrium laminar boundary-layer analysis reported by Adams et al.[3] in conjunction with an inviscid streamline absorption technique similar to that used by Kaplan.[4] The following assumptions and guidelines are followed in the boundary-layer analysis: 1) The boundary layer is laminar. 2) The basic gas model is a multicomponent mixture of chemically reacting perfect gases made up of N, O, N_2, O_2, NO, NO^+, and e^-. The gas is in vibrational equilibrium but in chemical nonequilibrium as controlled by the 11-chemical-reaction model used by Blottner[5] with the reaction rates of Bortner.[6] 3) Multicomponent diffusion between species is allowed throughout the viscous region. For the ionized species, ambipolar diffusion is employed; thermal diffusion is neglected for all species. Enthalpies, specific heats, and binary diffusion coefficients for the individual species are taken from Blottner,[5] whereas viscosity and thermal conductivity for the mixture are obtained from Wilke's formula using individual species properties from Blottner.[5] 4) Effects of wall surface conditions are considered by examining both noncatalytic and fully catalytic walls following Lenard.[7] 5) Radiative phenomena in the boundary layer (emission and absorption) are not

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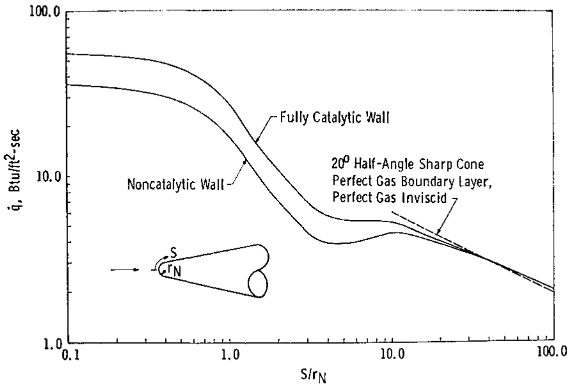

Fig. 1 Surface heat-transfer distribution.

considered. 6) No-slip wall boundary conditions are used for velocity and temperature. 7) Numerical solution of the governing nonequilibrium boundary-layer equations is by an implicit finite-difference technique following Blottner.[5] 8) Boundary-layer outer edge conditions are obtained from an inviscid streamline absorption technique following Kaplan.[4] The equilibrium air blunt body and method of characteristics program developed by Lomax and Inouye[8] is used to define the inviscid pressure distribution and bow shock shape. Selected inviscid streamlines are then traced through a prescribed pressure distribution using the chemical nonequilibrium streamtube integration technique of Lomax and Bailey.[9] The location where a given inviscid streamline crosses the bow shock is determined by a mass flux balance on the boundary layer; in crossing the bow shock at a given location, chemically frozen, real-gas, Rankine-Hugoniot relations are used. Iteration is applied until convergence of the mass flux in the boundary layer with the mass flux used in the inviscid streamtube analysis is attained; typically two to three iterations are required.

Results

Eggers and Wong[10] pointed out the desirability of a noncatalytic wall for reduction of nonequilibrium heating during entry of lifting vehicles. As shown in Fig. 1, a noncatalytic wall will reduce the wall heat transfer rate by $\sim$35% relative to the fully catalytic wall condition in the nose region ($s/r_N <$ 4) of the present body. For $s/r_N \geq 40$, $\dot{q}$'s for both cases approach the sharp-cone values based on a perfect gas laminar boundary-layer analysis using perfect gas inviscid outer edge conditions following Adams.[11] As shown by the solid curves

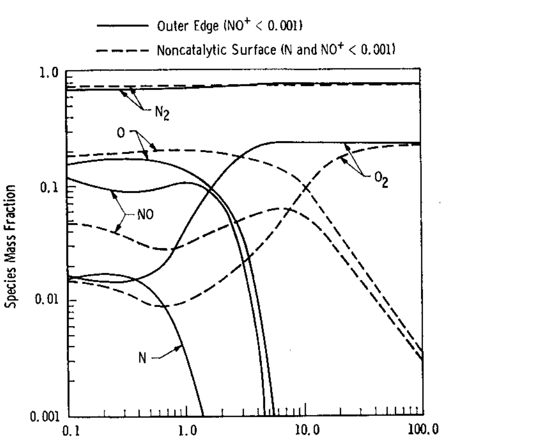

Fig. 2 Species distribution as determined from converged streamline absorption analysis.

in Fig. 2, the boundary layer has completely swallowed all of the inviscid outer edge dissociated species, due to nose bluntness, by $s/r_N \approx 5$. Downstream of this point the gas mixture is undissociated air at the outer edge of the boundary layer. However, note that sharp conical behavior is not attained until approximately $s/r_N \approx 40$, so that the distance $5 < s/r_N <$ 40 can be regarded as a nonequilibrium relaxation region where the boundary layer recovers from its upstream history of a dissociated, reacting flow through chemical recombination within the boundary layer. This relaxation region can be clearly seen in terms of the various species mass fractions along the noncatalytic surface as shown by the dashed curves in Fig. 2. At $s/r_N = 5$ the oxygen atom mass fraction at the noncatalytic wall is 0.15, whereas along the outer edge of the boundary layer at the same body location the oxygen atom mass fraction is only 0.002. Further note, from Fig. 2, that a surface distance of approximately 50 nose radii is required to relax the noncatalytic wall value of the oxygen atom mass fraction below 0.01.

Conclusions

Although a noncatalytic wall is certainly effective in reducing surface heat transfer in the nose region, downstream the noncatalytic wall will lose its effectiveness due to the swallowing process of the nose bluntness effects by the boundary layer. Chemical nonequilibrium (recombination in the boundary layer) is of importance in determining the relaxation distance required to attain sharp cone behavior through the swallowing process. For a noncatalytic wall this relaxation distance may occupy a significant portion of the total body length. Hence, consideration of chemical nonequilibrium effects on the boundary layer should be included in design of a space shuttle TPS utilizing coated metals and alloys which inhibit surface recombination of dissociated species.

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