Only very narrow ranges of acceleration are feasible for solar probe missions with HEV > 0 at launch into heliocentric orbit. There are increases in payload ratios obtainable by using these trajectories as compared to the HEV = 0 cases. However, the tradeoff in total mass injected initially into orbit about the sun for the additional burnout velocity required may not make the HEV > 0 cases desirable for solar probe missions.

Conclusions

Relatively simple low-thrust, constant-acceleration trajectories are useful for solar probe missions for only a very limited range of accelerations. The major limiting factor is the terminal configuration angle ϕ. All trajectories studied met the success criteria for total time and velocity to be gained.

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Surface Roughness Effects on Radiant Heat Transfer

R. G. Hering* and T. F. Smith†
University of Illinois at Urbana-Champaign, Urbana, Ill.

THE apparent thermal radiation properties of a one-dimensionally rough surface with V-shaped roughness elements of identical included angle were recently reported.[1] In this Note the rough-surface properties are employed to examine the influence of surface roughness on the radiant energy transfer rate of an isolated plane surface with specified uniform temperature when the surface is fully illuminated by a uniform collimated solar flux. Surface roughness effects on equilibrium temperature were explored in a recent study.[2]

The radiant heat-transfer rate per unit area from the isolated rough surface q with apparent emittance ϵ_H and direction-dependent, apparent solar absorptance $\alpha_a^*(\theta')$ in the solar field of solar constant S is determined by the difference between the emission rate and the rate of absorption of incident energy. For a surface at temperature T, the radiant heat-transfer rate per unit black surface emissive power is

$$q/\sigma T^4 = \epsilon_H - \alpha_a^*(\theta')S^* \cos\theta' \qquad (1)$$

where σ and θ' denote the Stefan-Boltzmann constant and the direction of incident flux relative to the normal of the mean surface plane, respectively, and $S^*(= S/\sigma T^4)$ is a dimensionless energy ratio characterizing the relative magnitude of solar flux to surface emission rate. For a smooth

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* Professor, Department of Mechanical Engineering. Member AIAA.

† Research Assistant, Department of Mechanical Engineering.

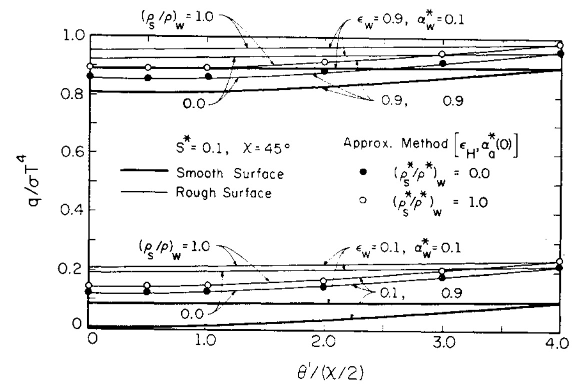

Fig. 1 **Surface roughness effects on radiant heat transfer ($S^* = 0.1$).**

surface of identical material, the apparent properties are replaced with wall emittance ϵ_w and wall absorptance for solar energy α_w^* both of which are taken direction independent.

The apparent properties depend on groove wall properties (ϵ_w, α_w^*), roughness element included angle (χ), and parameters which characterize interreflection phenomena within surface asperities. The latter are the wall specularity for emission $(\rho_s/\rho)_w$ and the wall specularity for solar energy $(\rho_s^*/\rho^*)_w$, where ρ_s (or ρ_s^*) and ρ (or ρ^*) denote the specular component of wall reflectance and total reflectance, respectively. As $(\rho_s/\rho)_w$ [or $(\rho_s^*/\rho^*)_w$] varies from zero to unity, the groove walls change from diffusely reflecting to specularly reflecting. Typical apparent property results are presented in Ref. 1.

Typical dimensionless heat-transfer results for $\chi = 45°$ are presented for wall property values of 0.1 and 0.9 and the extreme values of the specularity parameters in Figs. 1, 2, and 3 for S^* values of 0.1, 1.0, and 10, respectively. The smooth- and rough-surface heat fluxes are influenced in a similar manner by wall properties, energy ratio S^*, and di-

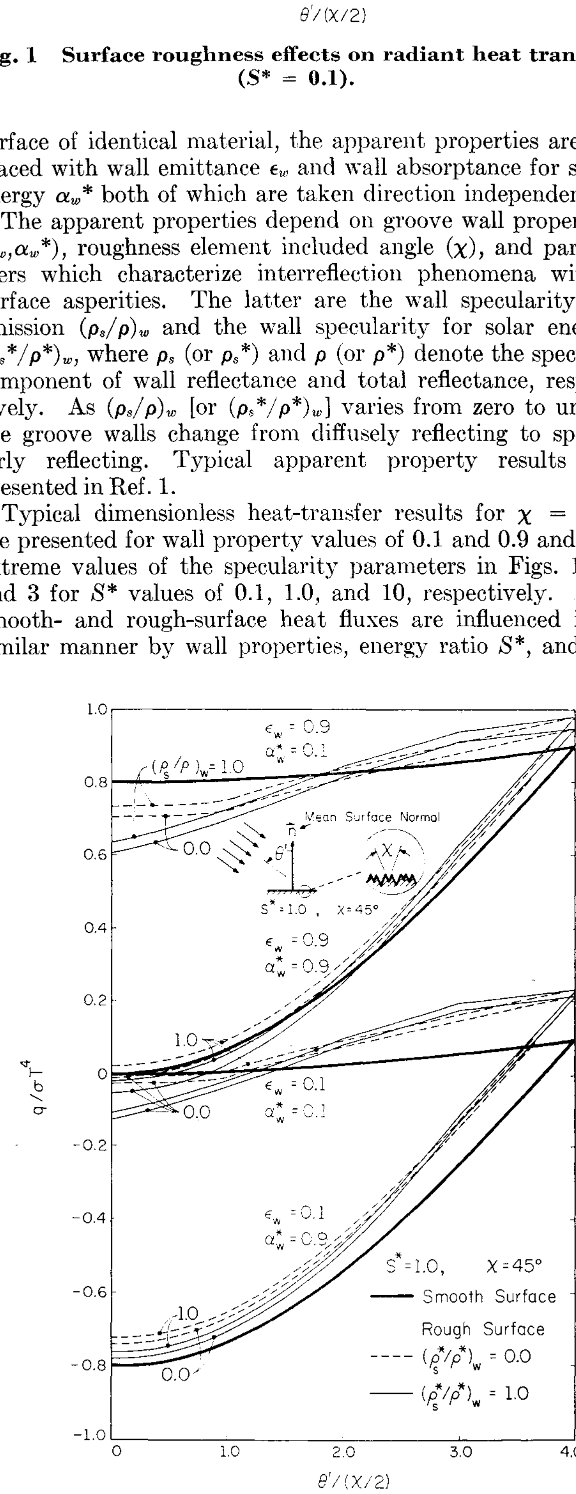

Fig. 2 **Surface roughness effects on radiant heat transfer ($S^* = 1.0$).**

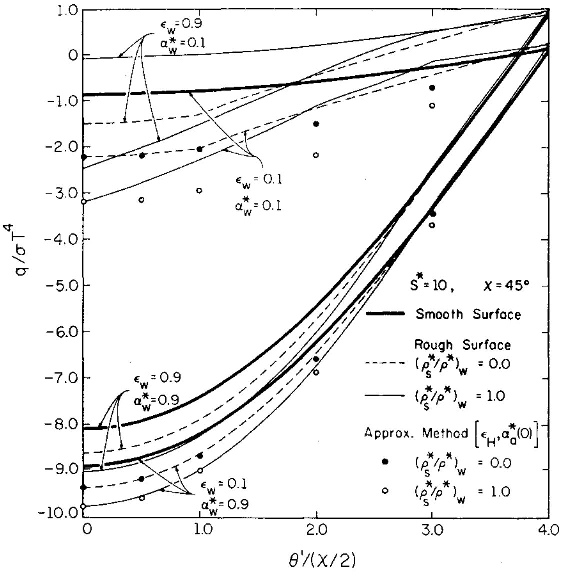

Fig. 3 Surface roughness effects on radiant heat transfer ($S^* = 10$).

rection of incident energy, although in the latter instance, the smooth surface flux generally exhibits a weaker directional dependence. For the emission-dominated situation illustrated in Fig. 1, radiant fluxes are positive and less than unity with the level of flux determined by wall emittance. The influence of the specularity parameter for solar energy $[(\rho_s^*/\rho^*)_w]$ is imperceptible in the figure. As interreflections within surface asperities vary from diffuse to specular, the rough surface flux increases by less than 4% for the high-emittance surface and 15% for the low-emittance surface. Heat transfer from the rough surface exceeds that from the smooth surface of identical material at all directions of incidence with the discrepancy at normal incidence less than 10% for the low-emittance surface and as large as a factor of 15 for the low-emittance, high-absorptance surface. The large discrepancies for the latter surface are attributed to the small smooth surface flux values and the large increase in apparent emittance caused by roughness on surfaces of low emittance. In the solar-flux-dominated situation shown in Fig. 3, the radiant flux varies from a large negative value at normal incidence to values lying between zero and unity at grazing incidence. Now the flux level is dictated by solar absorptance except at and near grazing incidence when the flux is governed by apparent emittance. The influence of wall specularity for emitted energy is imperceptible and as surface asperities vary from diffusely to specularly reflecting, the rough surface heat-transfer rate to the surface at normal incidence increases by less than 5% for the high-absorptance surface to a value 70% larger for the high-emittance, low-absorptance surface. At normal incidence, radiant flux to the rough surface exceeds that to the smooth surface by about 10% for the high-absorptance surface but this discrepancy increases to a factor of almost 25 for the high-emittance, low-absorptance surface for reasons similar to those cited earlier. For the situation in Fig. 2, where emission and solar flux are equally important ($S^* = 1.0$), the extent of the variation in flux with direction of incidence is intermediate to those already discussed. Except at large angles of incidence, the dominant wall property value now is the ratio of solar absorptance to emittance (α_w^*/ϵ_w). Both specularity parameters are important, although the S^* affects normal-incidence, rough-surface heat flux results for small and large values of α_w^*/ϵ_w by a factor of two to three times more than the 5% influence of $(\rho_s/\rho)_w$. Again, large discrepancies between smooth- and rough-surface heat transfer exists when small flux values are encountered.

At grazing incidence, rough-surface fluxes are determined by apparent emittance. Employing this apparent property with apparent solar absorptance at normal incidence yields the rough-surface results at normal incidence. Since measurements of these two properties are not uncommon, one may ask how accurately these two property values will predict heat flux rates for all directions of incidence. Calculations were performed and the results are shown in Figs. 1 and 3. It is apparent that in the emission-dominated situation, the approximation is excellent. Results derived on the same basis for $S^* = 10$ show good agreement for the high-solar-absorptance surface, but those for the low-absorptance surface depart significantly from the rough-surface results at intermediate directions of incidence particularly for surface asperities that are specularly reflecting. In the latter instance, the results are sometimes in poorer agreement with the rough-surface results than are the smooth-surface values. The large discrepancies at low α_w^* and large S^* are attributed to the strong dependence of the apparent directional absorptance on direction of incident energy for the surfaces considered here. The use of the aforementioned technique at $S^* = 1.0$ shows the same trends but to a lesser degree than those discussed for the emission-dominated and solar-flux-dominated situations.

In conclusion, it has been demonstrated that surface roughness can significantly influence radiant heat-transfer rates. When roughness is neglected and fluxes are evaluated using material property values, the discrepancy between values so calculated and those which fully account for roughness can be orders of magnitude when the dimensionless fluxes are less than unity. For dimensionless flux values greater in absolute value than unity, the difference exceeds 10%. Surface-roughness effects are particularly important for low-emittance surfaces when emission is dominant, low-solar-absorptance materials when incident flux is dominant, and for materials with α_w^*/ϵ_w near unity in situations where emission rate and incident flux are comparable. The use of apparent emittance and normal solar absorptance for all directions of incident energy yields results in excellent agreement with rough-surface fluxes except for materials of low α_w^* in solar-flux-dominated situations at intermediate directions of incidence.

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Exothermic Bimetallic Ignition System

P. N. Laufman*

Lockheed Propulsion Company, Redlands, Calif.

SOLID-PROPELLANT rocket-motor ignition systems are becoming more complex as the associated missile systems become more sophisticated. The acceptable bands of ignition transients (Fig. 1) become narrower and ignition spikes must

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* Engineering Supervisor, Lockheed Propulsion Company. Associate Fellow AIAA.