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Transient Ablation of Teflon Hemispheres

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Introduction

FOR high-speed entry of space vehicles into atmospheric environments, ablation is a practical method for alleviating severe aerodynamic heating. Several studies[1-3] have been undertaken on steady or quasi-steady ablation. However, ablation is a very complicated phenomenon in which a nonequilibrium chemical process is associated with an aerodynamic process that involves changes in body shape with time. Therefore, it seems realistic to consider that ablation is an unsteady phenomenon. In the design of an ablative heat-shield system, since the ultimate purpose of the heat shield is to keep the internal temperature of the space vehicle at a safe level during entry, the transient heat conduction characteristics of the ablator may be critical in the selection of the material and its thickness.

Kindler[4] studied Teflon ablation in arc-heated airflow. He measured the internal temperature and recession depth along the centerline during ablation. However, the measurements are not sufficient to explain completely the thermal behavior of the heat-shield material. This Note presents an experimental study of transient ablation of Teflon, with particular emphasis on the change in body shape, the instantaneous internal temperature distribution, and the effect of thermal expansion on ablation rate.

Experiment

The experiment was performed in a high-enthalpy hypersonic wind tunnel of the blow-down type.[3] The freestream conditions were: Mach number $M_\infty = 5.74$, stagnation temperature $T_{st} = 1020°C$, and stagnation pressure $P_{st} = 1$ atm.

Hemisphere-cylinder Teflon models were made by compressing Teflon powder containing a temperature sensor under high temperature. The diameter of the cylinder was 20 mm. The temperature sensor was a chromel-alumel thermocouple, each element being 0.1 mm in diameter. Since it was difficult to install several sensors in a model, either one thermocouple or several were buried in each model. The whole temperature distribution was obtained by superposition of the temperature histories in each experiment. Soft x-ray photography was used to check the state of the buried thermocouples and the position of their junction.

Since the ablation phenomenon is essentially transient with the change in body shape, continuous data on the change in shape are required. In this experiment, the origin of the time axis is when the valve of the wind tunnel opens. We considered two methods for measuring the ablation rate (recession velocity): 1) after the wind-tunnel valve closes, the ablation rate is measured; and 2) instantaneous shapes of an ablating model are measured by photographs taken every few seconds. The apparent ablation rate measured from the photographs is corrected by subtracting the effect of thermal expansion. In the first method, even though the valve is closed, the heat transfer to the model is not cut off instantaneously and completely. Furthermore, the model shortening measured after the test is completed, i.e., when the model cools to its initial temperature, is not exact. Some

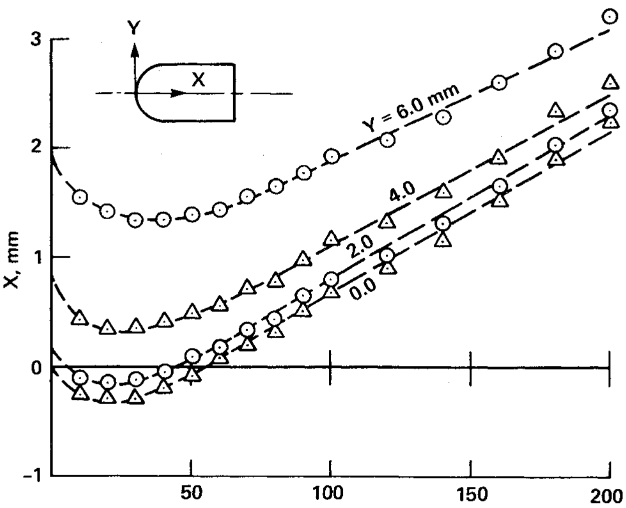

Fig. 1 Recession depth history.

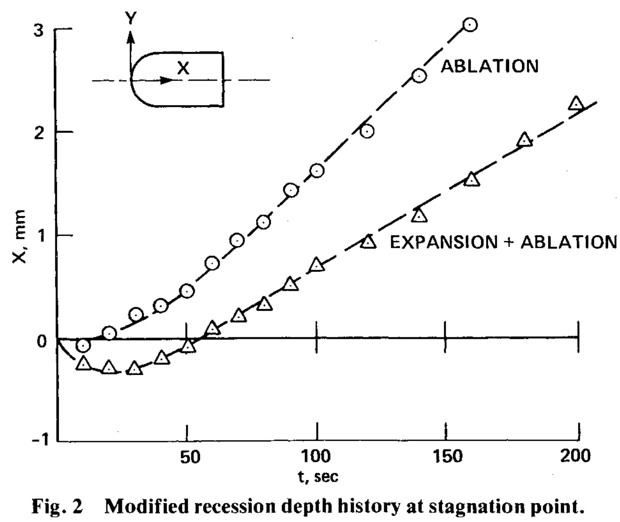

Fig. 2 Modified recession depth history at stagnation point.

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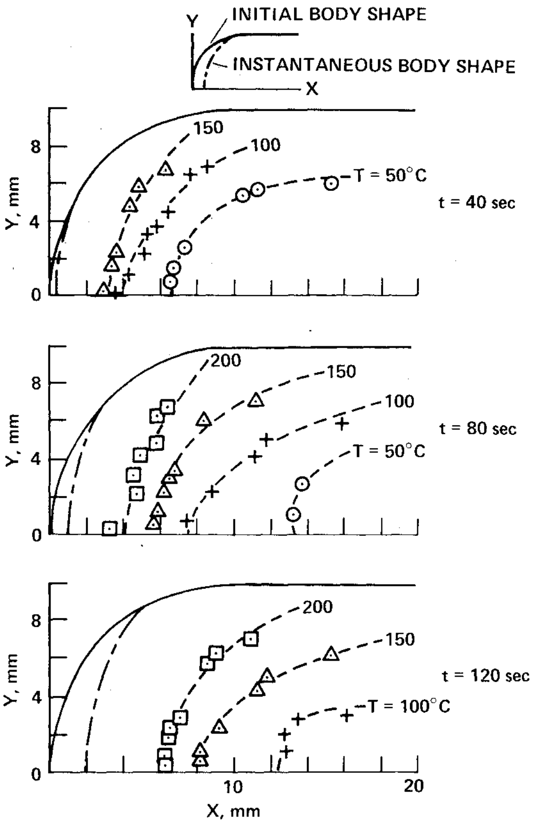

Fig. 3 Instantaneous internal temperature distribution.

thermal expansion remains as a permanent deformation due to the physical nature of Teflon. Therefore, the second method was adopted in this experiment. The effect of the thermal expansion was estimated by the following method: Before the wind tunnel is turned on, several axial positions are marked along the model. Displacements of the marks were measured from the photographs, and the value of the thermal expansion was evaluated approximately by extrapolating these data.

Results and Discussion

Figure 1 shows typical recession depth results. Since the nose is initially spherical, the initial x coordinate of the model is positive at any y coordinate except at the stagnation point ($y=0$). (Figure 1 indicates only an apparent value.) When the model at room temperature is suddenly exposed to a uniform high-enthalpy stream, large heat transfer takes place because of the large temperature difference. However, this heat is absorbed by the thermal capacity of the model itself and the surface temperature increases only slightly. Even though ablation occurs, the recesssion depth does not seem to be considerable at first. Therefore, the model length first increases because of thermal expansion.

Figure 2 shows the modified recession depth at the stagnation point compared with raw data. The figure shows that the recession rate attains steady-state conditions after 100 sec. The recession rate with consideration of thermal expansion, however, differs significantly from one which does not consider it. Previous experiments of steady ablation have neglected the effect of thermal expansion and, consequently, have underestimated the ablation rate.

The main purpose of the present experiment was to determine the transient ablation from the point of view of the instantaneous internal temperature distribution. Figure 3 shows the instantaneous isothermal lines at intervals of 50°C; the internal temperature increases with time and the local thermal expansion cannot be neglected. The internal temperature distribution changes abruptly in a very thin layer, i.e., gel layer,[5] near the body surface. The thickness of this layer is of the same order as that of the thermocouple junction, so that the measurements in the surface region are not reliable. Furthermore, the diffusion of heat inside the ablator in the direction parallel to the surface tangent cannot be neglected.

Conclusions

It takes more than 60 sec for recession to exceed the thermal expansion at stagnation point, and the effect of the thermal expansion on recession velocity cannot be neglected. Note that the heat flow inside the heat-shield material in the direction parallel to the surface tangent cannot be neglected. Therefore, a one-dimensional analysis is not valid.

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Intermittent Transition Flow in a Boundary Layer

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Introduction

DHAWAN and Narasimha[1] developed a method of calculating the properties of a boundary layer undergoing transition by preserving the essential intermittency of the flow. Narasimha[2] modified Emmons'[3] original formulation to obtain an intermittency function described by

$$\gamma = 1 - e^{-A\xi^2} \tag{1}$$

where $\xi = (x - x_t)/\lambda$, x_t is the transition point, and A and λ are empirical constants. Using the data of Schubauer and Klebanoff,[4] A was evaluated as 0.412; λ is a fit factor defined as

$$\lambda = (x)_{\gamma=0.75} - (x)_{\gamma=0.25} \tag{2}$$

By comparison with other data Eq. (1) was shown to be a good approximation to a "universal" intermittency function for boundary-layer transition. Some ambiguity did appear near $\gamma = 0$ which was attributed mainly to the influence of pressure gradients. In order to generalize this approach, a

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