An estimate of the effective resistivity can be made using the data in Figs. 1 and 2. Such an estimate will necessarily be crude since, as pointed out earlier, it is not clear how much of the applied voltage actually drops over the Z-93. Future work, now underway, will attempt to quantify this. At this point we will assume that all of the voltage drops and simply apply Ohms law to the two curves. Ignoring a strong voltage dependence noted in the electron collection data and using 40 V, the maximum potential permitted on SSF by the plasma contactor specification, we find that the effective resistivity is approximately 160,000 $\Omega\text{-m}^2$ for electron collection and about 450,000 $\Omega\text{-m}^2$ for ion collection.

Conclusions

The ability of Z-93 thermal control paint to conduct current from a simulated space plasma was measured directly in a space simulation chamber. For ions the collected current was found to be reduced by about a factor of three from that of metal. For electrons, currents were observed to be a factor of 50 smaller than metal at low voltages. The actual effect on Space Station Freedom cannot be determined without sophisticated modeling, which will proceed as part of the plasma contactor program, but from these results it is unlikely that surfaces coated with Z-93 will make any significant contribution to plasma contactor currents.

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Ronald K. Clark
Associate Editor

Interaction of Rocket Plumes with the Outer Hypersonic Flowfield During the Re-Entry Maneuver

Alexander Karl* and Claus Weiland†
Messerschmitt-Bölkow-Blohm GmbH, Munich, Germany

Introduction

MODERN reusable spacecraft like the European HERMES or the German two-stage concept SÄNGER have a reaction control system (RCS) for attitude control in orbit. Such a system also has to control the attitude during the initial part of the re-entry trajectory until the vehicle can use its aerodynamic systems. The Space Shuttle can aerodynamically control the movement around the yaw axis for the first time at a height of 50 km. The same maneuver for HERMES is possible with the aerodynamic systems at a height of 70 km due to the winglets. Above this height, the RCS has to control the motion. Therefore, it is necessary to have knowledge about the interaction of a rocket plume from an RCS thruster and the hypersonic flowfield around the vehicle.[1] In this Note, a numerical approach to this problem is presented. A simple two-dimensional configuration and the Euler equations are used for the first approximation. The greatest problems for the numerical integration arise through the large pressure and density gradients between the rocket plume and the undisturbed flowfield. Therefore, in this Note, a simple method is presented to improve the treatment of the resulting jet expansion. Several parametric studies are carried out. The thrust of the RCS thruster (velocity, density, and pressure at the exit) and the angle of attack of the body are changed. The medium is treated as a perfect gas. In the following sections, the method of solution, the special treatment of the expansion, and some results will be discussed.

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*Scientist.
†Head of Fluid Dynamics Branch, MBB Space Group.

Method of Solution

The two-dimensional, time-dependent conservative Euler equations of a compressible fluid are solved by a finite volume relaxation method.[2-4] The flow variables are defined at the cell centers and the coordinates at cell vertices. The inviscid fluxes are linearized with respect to the density, velocities, and the total enthalpy to obtain matrices that are easier to compute and better suited for hypersonic flows than in a case of a linearization with regard to the conservative variables. The steady-state operator is discretized to second-order accuracy. The discretization of the Euler terms is based on a symmetric total variation diminishing (TVD) scheme using a four-argument minmod limiter to avoid numerical oscillations near extremas.[5] In every time step, the resulting pentadiagonal coefficient matrix is iteratively inverted by a symmetric point Gauss-Seidel relaxation. In the iteration from time level n to level $n + 1$, the boundary conditions are treated explicitly. As a consequence, the solution vector has all its components at the same order of accuracy only when the iterations have converged.

The initial calculations have shown that there are some problems with the treatment of the expansion of the rocket plume. Therefore, different methods are considered to improve the performance of the numerical code in this region. Finally, the best choice was the treatment of the expansion with the analytical solution of Prandtl-Meyer. This method is presented in the next section.

Treatment of the Expansion with the Prandtl-Meyer Solution

Figure 1 shows a sketch of the region of the flowfield with the end of the RCS thruster and the expansion. For the special treatment, first the average of the pressures in cells one, two, and three are calculated. This pressure is considered as the pressure after the expansion of the rocket plume. With this pressure p_2 and all of the flow variables (M_1, p_1, ρ_1, κ) inside of the nozzle, the Mach number

$$M_2 = \sqrt{\frac{2}{\kappa - 1}\left[\left(1 + \frac{\kappa - 1}{2}M_1^2\right)\left(\frac{p_2}{p_1}\right)^{(1-\kappa)/\kappa} - 1\right]} \tag{1}$$

and the density

$$\rho_2 = \rho_1\left[\frac{1 + (1 - 1/\kappa)M_1^2}{1 + (1 - 1/\kappa)M_2^2}\right]^{1/(\kappa - 1)} \tag{2}$$

after the expansion can be calculated. For this calculation, an isentropic behavior of the flow is assumed, and κ is the ratio of specific heats. With the Mach numbers M_1 and M_2 and the isentropic Prandtl-Meyer theory, the flow angle after the expansion

$$\theta = \nu(M_2) - \nu(M_1) \tag{3}$$

with

$$\nu(M) = \sqrt{\frac{\kappa+1}{\kappa-1}}\left[\arctan\sqrt{\frac{\kappa-1}{\kappa+1}(M^2-1)}\right] - \arctan\sqrt{M^2-1} \tag{4}$$

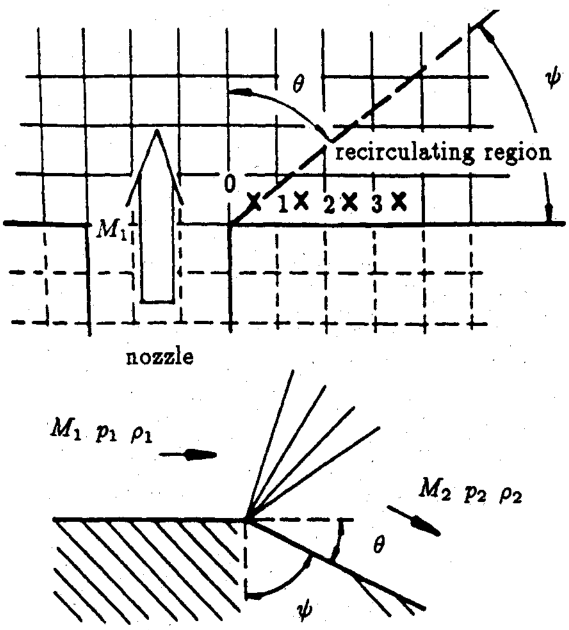

Fig. 1 Prandtl-Meyer expansion and special treatment of the expansion region.

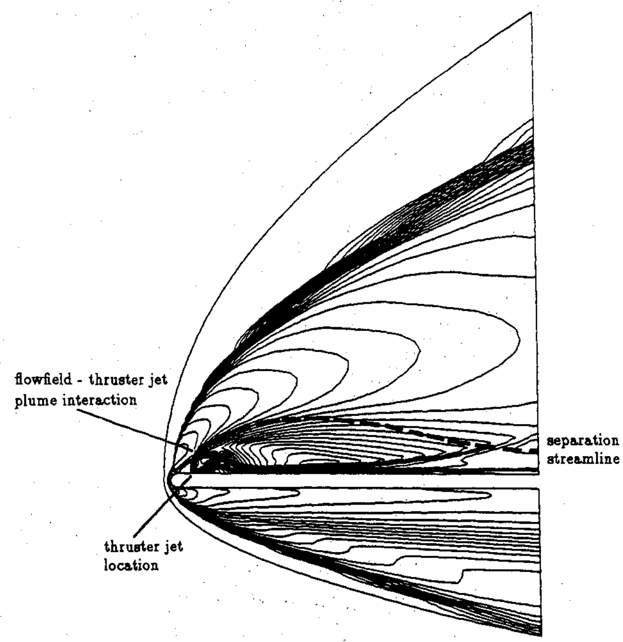

Fig. 2 Lines of constant Mach number.

can be calculated. The Cartesian velocity components u, v can be calculated with the Mach number M_2 and the flow angle θ. Now all of the conservative flow variables behind the expansion (ρ_2, $\rho_2 u$, $\rho_2 v$, e) are known or can be calculated. These values are input as the flow variables for cell number zero. The procedure is repeated every time step, and so the result is a centered expansion wave. Through repetition of this procedure at every time step, the interaction of the recirculating region and the outer flowfield is assured. With the modified program, several calculations are made with various parameters. Some results are presented in the next section.

Results

The flowfield around a plate with a blunt nose is calculated. The jet is located at the upper side of the plate shortly after the nose. All calculations are made with a 40 × 269 grid. The grid is clustered around the location of the rocket plume because of the large gradients in the flowfield. In the following, the results for special parameters of the RCS thruster are 1) exit velocity v_e is 1950 m/s, 2) exit density ρ_e is 2.56×10^{-3} kg/m^3, and 3) exit pressure p_e is 8.7 $mbar$. This exit velocity of the RCS thruster corresponds to 75% of the maximum exit velocity $v_{e,0}$ for which calculations have been performed. The parameters of the undisturbed flowfield are 1) height H is 70 km, 2) Mach number M_∞ is 8, 3) density $\rho\infty$ is 8.74×10^{-5} kg/m^3, and 4) pressure p_∞ is 0.0552 $mbar$.

Figure 2 shows the lines of constant Mach number. Clearly, the strong effect of the thruster jet on the bow shock of the body can be seen. The shock is strongly displaced at the upper side of the body. The visible dashed line in Fig. 2 is a so-called separation streamline or contact line. This streamline is the boundary between two regions. The inner region contains only material from the RCS thruster. In contrast, the outer region contains material from the undisturbed flow. With this line it is possible to define a distance of penetration for the rocket plume, e.g., the maximum distance between the separation streamline and the body. Figure 3 shows the lines of constant density in a blow up of the forward part of the body. Clearly visible is the interaction of the bow shock of the body and the shock in front of the thruster jet. Figure 4 shows the drag coefficient for a variation of the exit velocity of the RCS thruster. The lift and drag coefficients are calculated in the usual manner. The reference area is the tail surface of the body. The drag coefficient remains constant until the shock in front of the thruster reaches the cylinder part in front of the body. At this point, the drag coefficient has a sharp raise. The

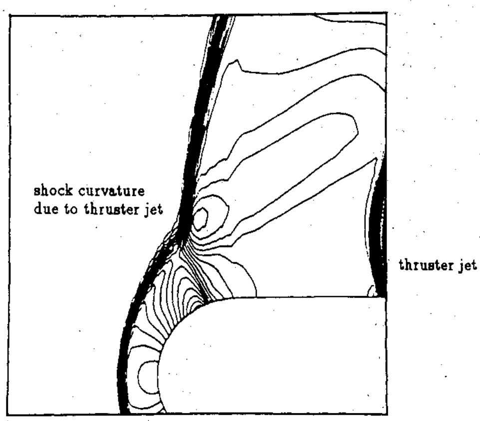

Fig. 3 Blow up of the lines of constant density.

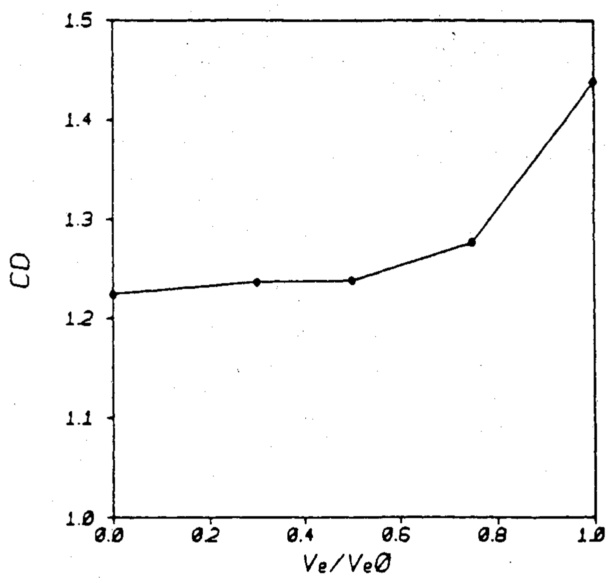

Fig. 4 Drag coefficient for a variation of the exit velocity of the RCS thruster. The freestream Mach number is 8 and the height is 70 km. The exit velocity of the RCS thruster v_{e0} is 2600 m/s.