Skin Friction Reduction by Injection Through Combinations of Slots and Porous Sections

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Theme

FLUID injection for thermal protection and skin friction reduction on flight vehicles has received considerably study. Energy conservation has now elevated the importance of skin friction reduction. The information available for supersonic speeds[1-3] is limited, but it indicates drag reductions large enough to be interesting from a systems viewpoint. The competing configurations are the porous wall and the tangential slot, but there have been few studies when a direct comparison of the two schemes was made at the same nominal conditions. Further, combinations of the two schemes might be expected to be beneficial as a result of synergistic interactions. This report presents the results of a comparative study of slot injection, porous wall injection through a short strip and combinations of the two at freestream conditions of Mach 2.9, stagnation pressure of 6.9 N/m^2 (100 psia) and total temperature of 290K. A "flat plate," solid wall configuration was also studied as a reference point. The principal data obtained were: 1) schlieren photographs; 2) wall pressure; 3) Mach number profiles; and 4) wall shear measured with a floating element balance. Wall shear was also inferred from Preston Tube measurements.

Contents

These experiments were performed in a 23-cm × 23-cm wind tunnel with interchangeable nozzles, and the model was a modified version of one of these nozzles. The streamline normally produced at the axis of a two-dimensional, symmetric supersonic nozzle is replaced by a solid surface. Just beyond the last expansion wave in the nozzle, the surface steps down (0.64 cm) to form the slot for the slot injection cases (see Fig. 1a). The slot lip is 0.041-cm thick.

The porous injection box measures 5.08 cm in the streamwise direction and spans the tunnel. There is a solid section 0.64 cm long at the upstream and downstream edges; the middle 3.81-cm length is porous, sintered stainless steel (65-μ mean porosity). For the porous-wall-only tests, the box was arranged as in Fig. 1b. For the combined slot/porous wall tests, the two boxes were arranged as in Fig. 1c.

The final section of the nozzle was instrumented with static pressure taps (0.787-mm diam) and thermocouples in both the streamwise and spanwise directions. A "flate plate" configuration was obtained by raising the instrumented section upward 0.64 cm from that shown in Fig. 1a.

The skin friction balance used in these experiments is described in detail in Ref. 4. The floating head of the balance was made oblong in the lateral or spanwise direction to minimize the pressure gradient effects. The area of the floating element was 3.200 cm^2, and the surface of the test section wall and floating head were flush to within ±0.0025 cm for all tests.

Three sets of probes were used to measure pressures in the flow to deduce Mach number distributions and surface shear via the Preston Tube technique. The cone-static probe used a 10° cone with base diameter of 0.157 cm; four 0.033 cm ports were drilled at 90° intervals around the circumference. One pitot probe was used in conjunction with the cone-static probe at the outer edge of the boundary layer to obtain the local freestream Mach number. The probe tip was made by flattening 0.318-cm o.d. tubing to a rectangular cross section. The second type of pitot probe was simply twelve 0.071-cm o.d., 0.041-cm i.d. tubes mounted on a thin rake, equally spaced at intervals of 0.127 cm up from the wall. Two sizes of Preston tubes (0.073-and 0.241-cm o.d. both with i.d./o.d. = 0.6) were used. They were chosen to correspond to cases near the minimum and maximum size suggested in Ref. 5 based upon the "flat plate" boundary layer.

Wall shear data were obtained directly with the floating element balance and indirectly via Preston Tube measurements. All the data were taken at an axial distance of 12.7 cm from the end of the slot ($X/a = 20$). The presentation of the slot/porous wall combination data required the choice of a new coordinate system. Indeed, it was decided to present the data for the two separate configurations on this new type of plot also for purposes of direct comparison. In Fig. 2, the horizontal axis of the graph has been selected to reflect the actual total mass flow injected, nondimensionalized by the mass flow through a unit area of the freestream. This has been done so that systems decisions for a practical scheme are more

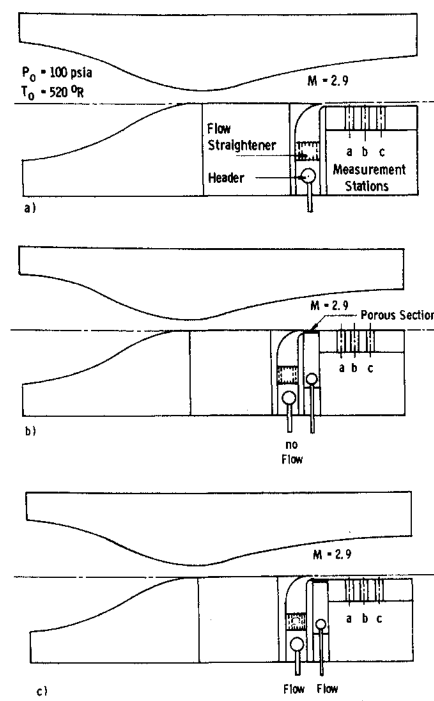

Fig. 1 Model configuration: a) slot-only tests; b) porous wall section tests; c) slot/porous section combination tests.

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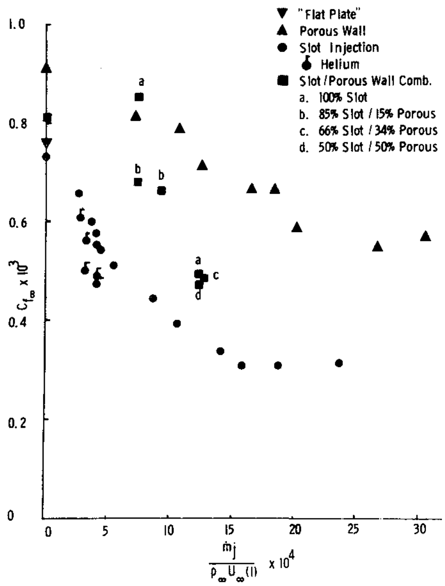

Fig. 2 Skin friction balance data.

easily reached. The vertical axis is simply a skin friction coefficient based upon edge conditions ahead of injection.

A very sharp reduction in wall shear is obviously produced with increasing injection rate down to a minimum in each case. Clearly, the tangential slot provides the greatest reduction in wall shear per unit rate of injection. Helium proved to be a more effective injectant than air for the slot configuration.

The porous wall schemes apparently suffer from a roughness-induced initial rise in shear at low injection rates. There does seem to be a potential for gain by combining slot and porous injection if the roughness-induced initial rise can be reduced. This assessment is based upon a consideration of the points labeled "a, c, and d" clustered in the middle of Fig. 2. Point "a" corresponds to the slot/porous wall configuration (Fig. 1c), but with all the injection through the slot. The resulting skin friction is higher than that for the slot-only configuration at the same injection rate as a result of the roughness of the porous wall insert. Point "d" corresponds to the same injection rate but with 50% through the porous wall section. The skin friction is reduced. Thus, if the roughness induced rise in skin friction could be eliminated or minimized, the combination scheme might produce results below the slot-only results.

To avoid confusion on the plots, the Preston Tube results are presented separately for the slot-only and porous-wall-only cases in Figs. 3a and 3b. Also included for comparison is a fairing of the balance data. First, the Preston tube is clearly capable of providing very useful information for mass injection flows. This is especially true if one were to recast the results as C_f/C_{f_0}, since the shape of the curves is very well predicted. Second, the larger Preston Tube consistently gave the best quantitative results.

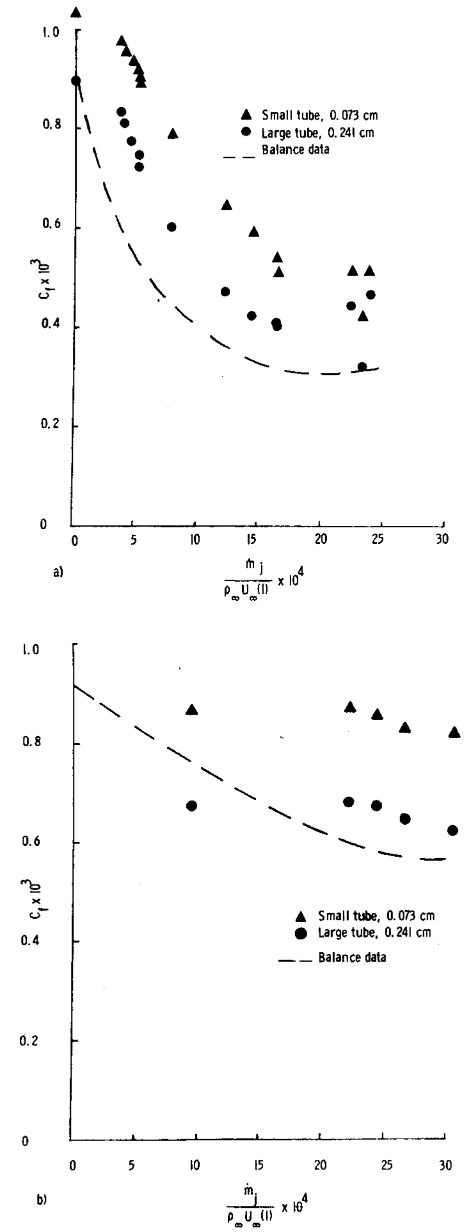

Fig. 3 Preston tube data: a) slot only; b) porous wall.

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