Effects of External Burning on Spike-Induced Separated Flow

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Abstract

WIND-tunnel measurements of the effects of burning hydrogen in a region of spike-induced separated flow are presented and analyzed. External burning is shown to eliminate the reattachment shock wave that is necessary to maintain ordinary spike-induced flow separation. This results in an additional 40-50% drag reduction beyond that achievable with the minimum drag, nonburning spike. The injectant flow rate needed to achieve a given drag reduction for a particular nose/spike geometry is shown to scale with the freestream mass flow in the enclosing streamtube.

Contents

During the mid-1960s, Maurer and Brungs, in West Germany, investigated the effects of external burning on the drag of a hemispherical nose[1] with a flow separation spike or an aerospike to create the flame-holding region of separated flow. The present tests are the first experiments with an external burning aerospike since the early work of Maurer and Brungs. The objective of these experiments was generally to improve our understanding of the external burning aerospike and to gain some insight into scaling techniques.

Overall force and moment data were obtained, via an internal strain gage balance, on a hemisphere-cylinder model of 20.574 cm base diameter and blunt ogive-cylinder models of 20.574 and 10.287 cm base diameters (Fig. 1). In addition, top and bottom centerline pressures were obtained on a 20.574 cm blunt ogive-cylinder model. For all external burning tests it was necessary to use a flame holder, or disk, on the spike tip to sustain combustion at supersonic speeds.[2]

Flowfield photographs reveal that external burning eliminates the reattachment shock wave that sustains ordinary spike-induced flow separation by providing the adverse pressure gradient needed to create reversed flow (Fig. 2).‡ This is in complete agreement with the results of Maurer and Brungs. Further evidence of the elimination of the reattachment shock is present in the pressure distribution data on the blunt ogive-cylinder model (Fig. 3). Not only does external burning eliminate the high pressures associated with the reattachment shock, but the forward nose pressures continue to decrease as the hydrogen flow rate decreases. Likewise, elongating the spike for the minimum flow rate caused a further decrease in nose pressures. Though hydrogen injection alone, without burning, tends to reduce the shock-induced pressure peak, it does not eliminate it as burning does. Thus, burning is necessary to achieve the maximum drag reduction.

How combustion eliminates the reattachment shock wave is not well understood. It is believed that burning greatly reduces the pressure rise needed to sustain the separated region by decreasing the total pressure in the shear layer at the edge of the separated region. This is accomplished through a reduction in the Mach number and the density of the shear layer via heat addition. Furthermore, combustion in the recirculation region (the experiments show that the flow recirculation persists even with combustion) will increase the volume of the flow locally, reducing the need for additional flow to be turned back into the recirculation region. All of these effects evidently combine, allowing the separated region to be maintained without reattachment shock waves.

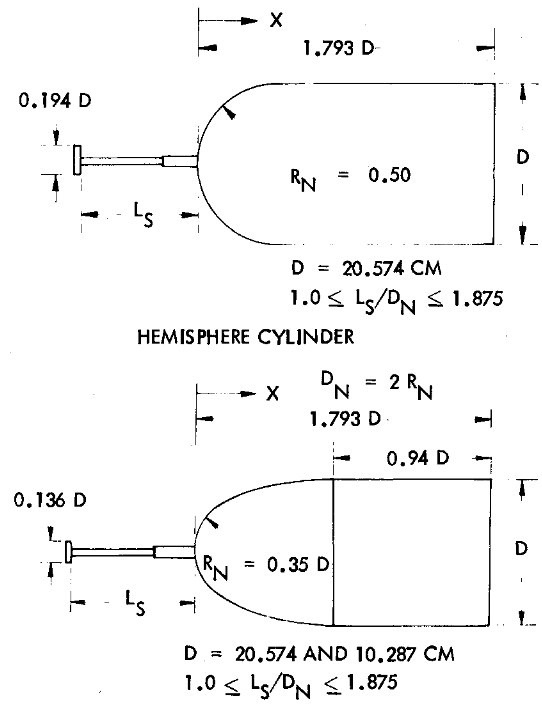

Fig. 1 Model configurations.

The zero angle-of-attack axial force measurements for the blunt ogive nose show that external burning causes C_A to decrease monotonically as the nondimensional hydrogen flow rate decreases for the shorter spike lengths (Fig. 4). For the longer spikes ($L_S/D_N = 1.625$ and 1.875) a distinct minimum is evident in the C_A curves. Furthermore, the longer spikes show reduced C_A overall. The axial force minimum that occurs for certain spike lengths seems to be associated with a focusing of the external burning region on the nosetip.[2]

To make these data truly useful, one must be able to scale the drag level with some nondimensional, external burning flow rate. For the aerospike the effects of external burning have been successfuly scaled by dividing the hydrogen mass flow rate by the mass rate of freestream flow in the cylinder that encloses the hemispherical nosetip $\dot{m}_{H_2}/\dot{m}_\infty$, as illustrated in the inset sketch of Fig. 4. When one scales the axial forces of the 20.574 and 10.287 cm blunt ogive noses (which have Reynolds numbers at 3.66 and 1.83 × 10^6,

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‡For these schlieren photographs a horizontal knife edge was used; thus, shock waves are dark above and light below the model.

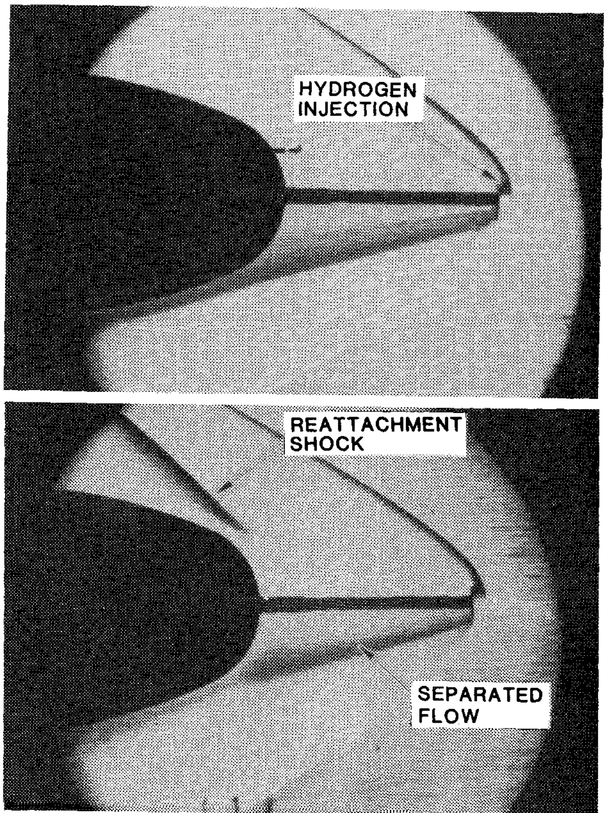

Fig. 2 Schlieren photographs showing that burning eliminates the reattachment shock wave; $M = 2.2$, $\alpha = 0$.

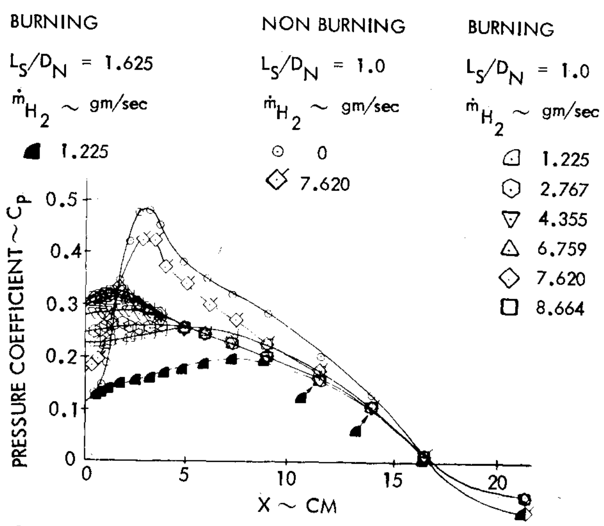

Fig. 3 Effects of injection with and without burning on the pressures over the blunt ogive nose; $M = 2.2$, $\alpha = 0$.

respectively, based on the diameter of the spherical nosetip) with a 1.5-caliber aerospike, the curves line up (Fig. 4), indicating that this is a valid scaling technique. Likewise, the Maurer-Brungs axial force data for a 4.0 cm diam hemisphere and the present data for a 20.574 cm diam hemisphere agree well for identical nondimensional injection rates, considering the differences in drag caused by the disk (Fig. 5).§ Surprisingly, the Reynolds number based on the nose diameter for the Maurer-Brungs test and the present hemisphere model are nearly identical (5.3×10^6 vs 5.23×10^6, respectively). Though these results do not conclusively verify the scaling technique, they strongly support its veracity.

§The disk tip results in reduced axial force overall. The reduced force on the blunt nose due to the disk increasing the separated region more than offsets the drag of the disk.

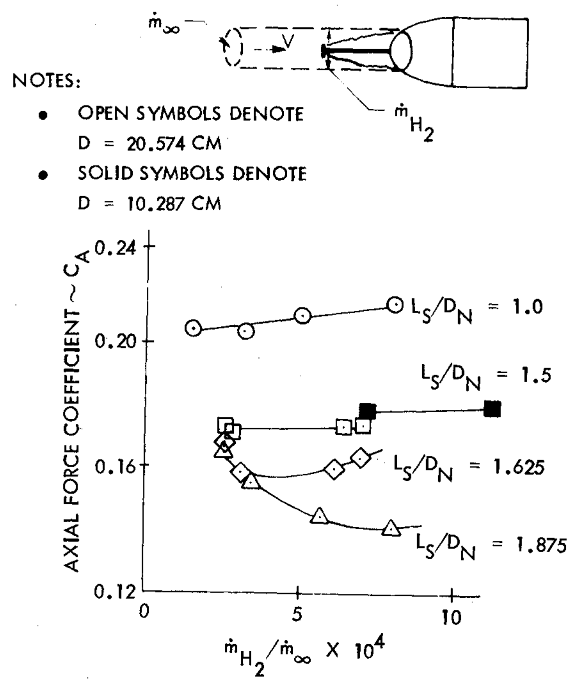

Fig. 4 Effects of spike length and flow rate with burning on the axial force of the blunt ogive nose and aerospike; $M = 2.2$, $\alpha = 0$.

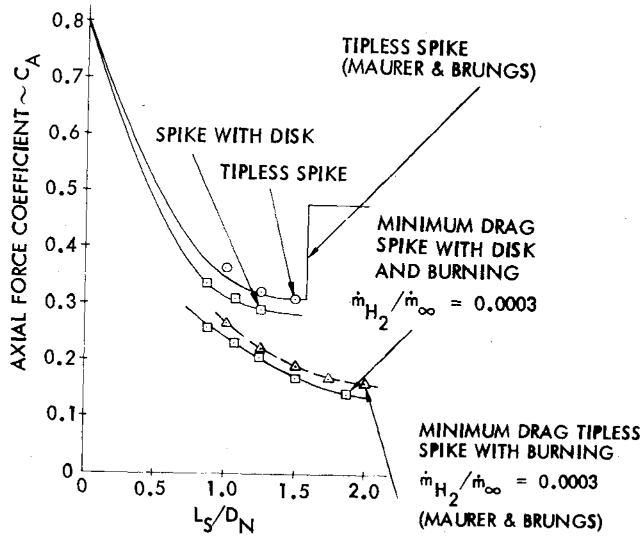

Fig. 5 Effect of spike length and external burning on the axial force of the hemisphere nose and aerospike; $M = 2.2$, $\alpha = 0$.

Conclusions

Wind-tunnel measurements of the effects of external burning in a region of spike-induced separated flow have shown that external burning significantly reduces drag below that achievable with an ordinary aerospike. There is evidence that the injectant flow rate needed to achieve a given drag reduction for a particular propellant and nose/spike geometry scales with the freestream mass flow within the streamtube that encloses the hemispherical nosetip.

References

[1]Maurer, F. and Brungs, W., "Influencing the Drag and the Bow Wave by a Heat Addition in the Stagnation Point Domain of Blunt Bodies in Supersonic Flow," presented to the VI International Congress of Flight Sciences (ICAS), Munich, Germany, Sept. 9-13, 1968.

[2]Reding, J.P. and Jecmen, D.M., "Effects of External Burning on Spike-Induced Separated Flow," AIAA Paper 82-1360, Aug. 1982.

[3]"Lockheed Supersonic Wind Tunnel Technical Description," Lockheed Aircraft Corp., Report No. C-1-II.