Mixing Enhancement in Supersonic Combustion Ramjets

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Supersonic Combustion Ramjets

Figure 1 Schematic of Boeing X-43A taken from [1]

A supersonic combustion ramjet (scramjet) is the preferred air-breathing propulsion concept for hypersonic flight vehicles with Mach numbers in the range of 5-12. A typical example of such a vehicle is illustrated above. The scramjet technology presents a myriad of fluid dynamical challenges, such as

- Hypersonic boundary layer stability/transition
- Supersonic combustion unstart, i.e. the breakdown of supersonic combustion
- Mixing enhancement in high-speed mixing layers

Mixing Enhancement in Scramjets

Fast mixing and fast combustion are of importance for the efficiency and the success of the scramjet technology. A faster mixing translates into a reduced combustor length and hence into a reduced skin friction drag, a reduced vehicle weight and thereupon an increased efficiency.

It is known that the shear-layer growth rate reduces drastically with increasing convective Mach numbers M_c [2]. Additionally, reacting shear-layers present reduced growth rates compared to their non-reacting counterparts [3]. Hence, the mixing in reacting high-speed shear-layers, as present between fuel and oxidizer streams in scramjet combustors, is inherently slow. In order to enhance mixing efficiency, shock/shear-layer interaction presents a viable option.

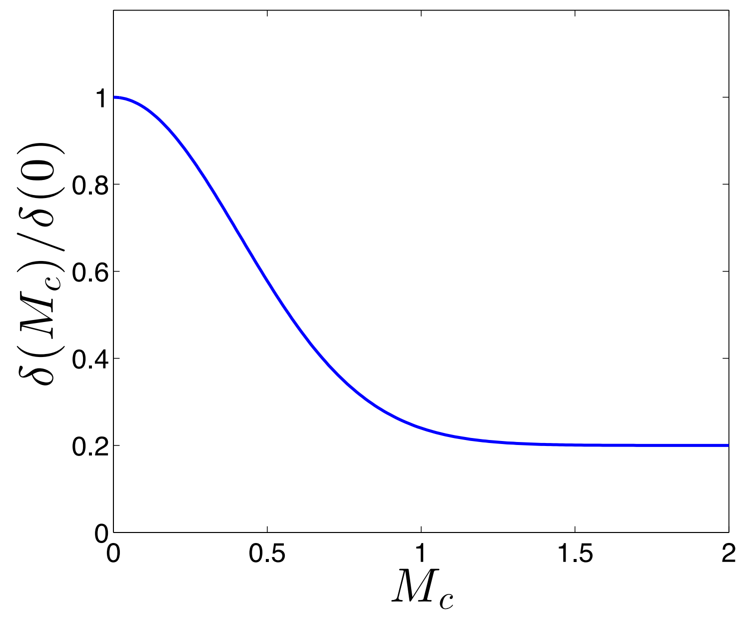

Figure 2 Experimental fit of the turbulent shear-layer thickness $\delta(M_c)$ compared to its incompressible counterpart $\delta(M_c\!=\!0)$ showing the compressibility effect on shear-layer growth rates, taken from [4].

Shock/Shear-Layer Interaction (SSLI)

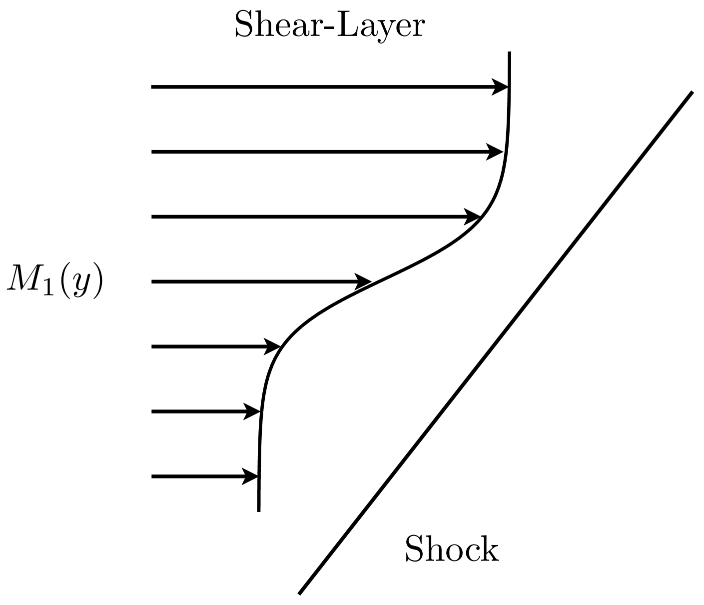

Figure 3 Schematic of the analyzed shock/shear-layer interaction problem.

During the passage of a straight oblique shock wave through a Mach number or density non-uniformity, i.e., a shear-layer, the straight shock is bent. Vorticity is produced due to the interaction of this curved shock with the incoming flow. This increase in post-shock vorticity acts as a mixing enhancement mechanism.

For several applications in supersonic combustion the heat release associated with the shock cannot be neglected and the thermodynamic state across the shock may change from vibrationally frozen to vibrationally excited. Hence the assumption of constant specific heat capacity ratios and adiabatic conditions across the shock may be too restrictive. In particular, we analyze the effect of heat release and high-temperature gas effects in shock/shear-layer interaction. We include these effects in an analytical approach to compute the shock-angle variation across the shear-layer and the resulting vorticity production.

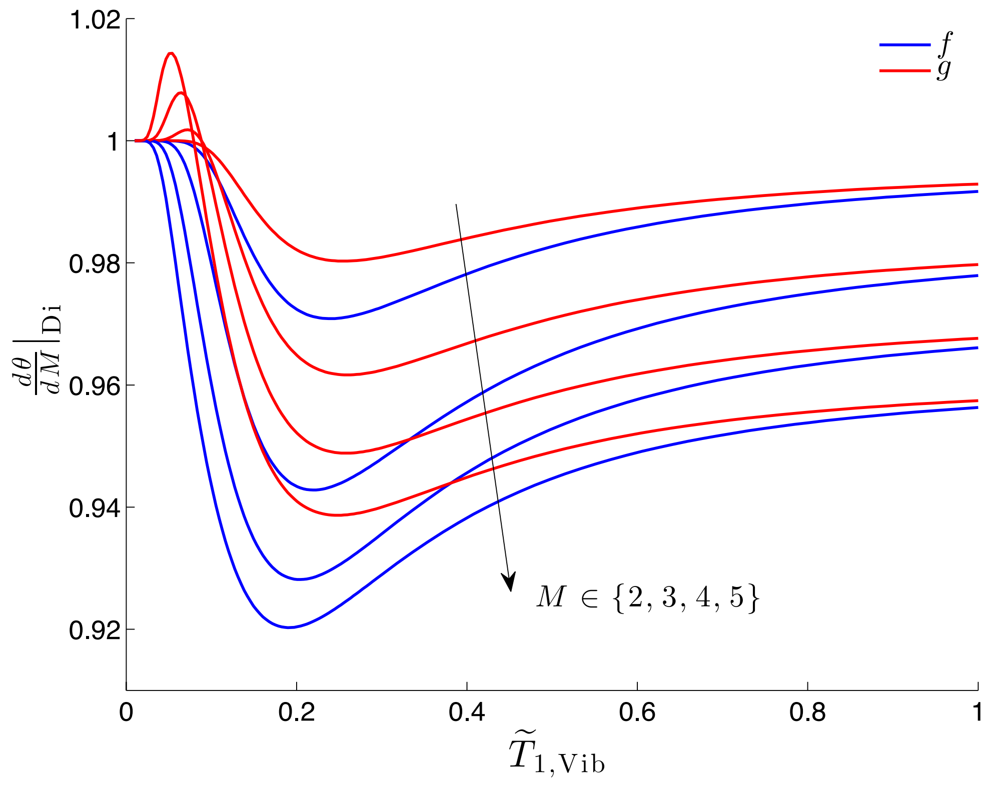

Figure 4 Effect of vibrational activation on the shock-angle variation across the shear layer for two different constraints regarding the jump of the heat capacity ratio across the curved shock (f and g).

References

[1] de.wikipedia.org/wiki/Boeing_X-43
[2] Papamoschou, D. *et al.* (1988). J. Fluid Mech., **197**
[3] Mahle, I. *et al.* (2007). J. Fluid Mech. **593**
[4] Dimotakis, P. E. (1991), GALCIT Report FM 91-2

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