Investigation of hypersonic shock-wave/boundary-layer interactions

R.O. Bura, Y.F. Yao, N.D. Sandham, G.T. Roberts
Aerodynamics and Flight Mechanics Research Group, School of Engineering Sciences,
Aerospace Engineering, University of Southampton, Hants SO17 1BJ, United Kingdom.

Shock-wave/boundary-layer interactions (SBLIs) are of special importance in hypersonic flows. The generation of shock waves by various surfaces of a vehicle or engine and the impingement of those shocks on other surfaces can greatly amplify the local heat transfer, particularly if the SBLIs result in boundary-layer separation and subsequent re-attachment.

Numerical simulations of 2-D hypersonic laminar shock-wave/boundary-layer interactions (SBLIs), by solving the Navier-Stokes (NS) equations using a compressible flow simulation code, have been carried out. The configuration considered is an isothermal flat plate with a laminar boundary layer interacting with an impinging shock, the latter being produced by a wedge mounted above the plate with incidence angles (θ) with respect to the free-stream flow as shown in Fig. 1.

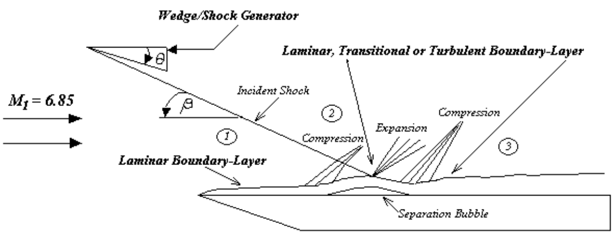

Figure 1. Schematic of flow configuration.

Figure 2. Schlieren image of interactions with 15.57^o shock angle.

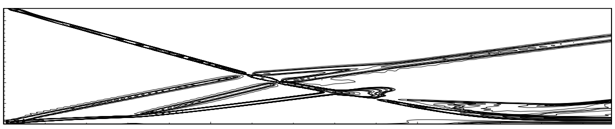

Figure 3. Numerical image of interactions with 15.57^o shock angle.

This paper will be an update on that presented at ISSW23 (Bura et al. 2001), which presented numerical simulation results of SBLIs in freestream Mach number of 6.85 and unit Reynolds number of 2.45×10^6 m^{-1} ($Re \simeq 2.5 \times 10^5$), and the updated paper will include further results of this case. In addition, a comprehensive investigation will be performed to verify whether numerical solutions are able to confirm the local properties of the free interaction region at the separation point for various Mach numbers and shock strengths (see Table 1). For hypersonic cases ($M_1 = 6.85$ and 7.73), the effect of various Reynolds numbers will also be investigated.

Table 1. Parameters used in the simulations.

M_1	Re	Shock angle, β
2.00	2.96×10^5	$31.67^o, 32.58^o, 34.05^o, 35.50^0$
4.50	2.51×10^5	$14.4^o, 16.5^o, 18.5^o$
6.85	2.51×10^5	$10.43^o, 12.00^o, 13.72^o, 15.57^0$
6.85	7.79×10^5	$13.72^o, 15.57^0$
7.73	4.56×10^5	$8.07^o, 9.48^o, 11.08^o$
7.73	8.44×10^5	11.08^o

Experimental results will be used for comparison with 2-D numerical results at $M_1 = 6.85$ and 7.73. The comparisons at $M_1 = 7.73$ will be with surface pressure and heat-fluxes (obtained from (Kaufman and Johnson 1974)). The comparisons at $M_1 = 6.85$, however, will be limited to measured separation bubble lengths (obtained via oil flow). Fig. 2 and Fig. 3 show comparison of density gradient obtained from simulations with experiment (obtained from Southampton University Light Piston Isentropic Compression hypersonic wind tunnel).

Numerical simulations of 3-D laminar hypersonic SBLI with leading edge perturbations are about to be performed and the results will be presented. It is hoped that the paper will contain some assessment of the stability of the flowfield to such perturbations.

References

Bura RO, Roberts GT, Sandham ND and Yao YF (2001) Simulation of Hypersonic Shock-wave/Boundary-Layer Interactions. Proceedings of 23rd International Symposium on Shock-waves (ISSW23), July 21-27 2001, Forth Worth, Texas, USA, pp.1371-1377.

Kaufman II LG and Johnson CB (1974) Weak Incident Shock Interactions with Mach 8 Laminar Boundary-Layers. NASA TN D-7835