Accelerating Two-Dimensional Supersonic Wedge Flow

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Abstract

An experimental and numerical investigation was performed to study the effects of accelerating a wedge with an attached shock wave. In particular, the experiment aimed to capture possible curvature of shock waves, which could validate CFD (Computational Fluid Dynamics) results, so that dynamic flow fields could be studied in greater detail. A test rig was designed to rapidly pitch a wedge about a fixed pivot inside a supersonic wind tunnel. A shadowgraph flow visualisation setup was used to capture high speed footage of the shock waves during the motion. Digital image processing techniques were then used to extract the shape of the shock waves, as well as the motion of the wedge. It was found that the experimental setup was unable to provide sufficient resolution of the shock shape to make significant conclusions about the dynamic effects (shock curvature) caused by the rotation. However, the shock wave angles did deviate from the angles predicted for a stationary wedge, beyond the bounds of uncertainty. These deviations could not be correlated clearly with rotational derivatives. However, independent CFD results showed that the shock wave curvature was actually significant on this scale and must be partly responsible for these deviations. Fitting the CFD results to the experiment indicated that there was noise in the experimental results. Possible sources of noise were identified, including vibration of the wedge mounts during rapid actuation.

In addition to a commercial Finite Volume (FV) CFD code used in this study, a new Unsteady Method of Characteristics (MoC) code was developed, based on the modified tetrahedral network by Sauerwein [1]. It is capable of simulating arbitrary motions of an attached shock domain with a flat line surface. Specific modifications to the previous method included a factorisation of the dicretised compatibility equations, which resulted in faster and more robust convergence; a more natural parameterisation of shock point properties which improved the convergence rates and robustness of the shock point solutions; and development of an attached shock tip boundary for the purposes of this study. These codes were

applied to match the Experimental rotations and used for a parametric study of transverse accelerations of attached shock domains. They showed strong agreement in all aspects, on the scale of the dynamic flow features (primarily shock wave curvature) being studied. Additionally, the MoC code was shown to provide smoother results, with less computational effort - largely due to the advantages of a shock fitting approach for this shock bound problem.

Application of these codes to rotating experimental rotation profiles showed how shock waves curve as they lag the motion of the wedge surface. For these relatively slow rotating cases, the angular velocity was the most significant cause of shock curvature, due to the rapid change in surface angle with respect to the upstream flow. It was demonstrated that the shock curvature causes pressure and other flow property gradients to propagate into the bound shock domain, due to its varying tangential angle of incidence with respect to the upstream flow. In the linearly accelerating parametric study, extreme transverse accelerations were applied to an attached shock, oblique wedge domain - producing significant shock wave curvature and pressure gradients in the domain. This curvature was caused by compression and expansion waves generated by the accelerating wedge surface which interact with the incident shock wave to strengthen or weaken it. Once again, the curvature presents as a lagging of the shock wave as it follows the accelerated motion of the wedge. Varying the acceleration resulted in proportionally increased shock curvature. Whereas the curvature was relatively insensitive to varying Mach numbers. Additionally, the relative velocity of the wedge with respect to the upstream flow was shown to produce an initial deviation of the shock angle compared to the static angle for a stationary wedge - which then curved in the opposite direction under the influence of the surface pressure waves.

These numerical results have some significance since they were verified by independent numerical methods. However, it is crucial that a new experiment be designed to provide direct validation for future work - which may also involve curved or three-dimensional geometries.