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Effect of acceleration into a non-uniform flow field

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Abstract

This work details the development of a technique for prescribing arbitrary flight to a projectile in a non-inertial reference frame; where the reference frame accelerates relative to an inertial one. That is, the fluid is held stationary, and the projectile accelerates through it. This allows a shift in focus from the flow fields induced by rectilinear accelerated motion, to those developed by non-rectilinear flight too. This is of interest as a plethora of studies already exist for straight line flight, yet few if any, consider the implications surrounding complex manoeuvres. The value in the developed technique is its ability to prescribe any trajectory, to eliminate the need to incorporate source terms as conservation is automatic, and that it maintains the computational efficiency associated with modelling in a inertial reference frame. Numerical verification demonstrated equivalent contour plots of air density and surface pressures to those resolved by the validated source term approach. In addition, the technique was validated for rectilinear and non-rectilinear flight. The rectilinear validation used data collected for a sphere decelerating under its drag in a ballistic range experiment conducted by Saito et al. The non-rectilinear case used data generated by a NACA 0012 aerofoil oscillating unsteadily in an experiment conducted by Landon. A study into the flow field evolution as a body undergoes acceleration into disturbed air was performed and compared to results obtained from acceleration into a uniform and undisturbed flow field, and dramatic disparities were illuminated. The investigation considered an axisymmetric sphere decelerating from Mach 1.25 to Mach 0.65 before re-accelerating to Mach 1.25. The sudden deceleration from a supersonic initial velocity resulted in all the flow structures surrounding the sphere to propagate ahead of it. They were then encountered during the re-acceleration. This explains how the disturbed flow field was generated. The sphere experienced three acceleration magnitudes: 347 g's, 694 g's and 1735 g's. A NACA0012, diamond, and supercritical aerofoil were also investigated. They were only accelerated at 347 g's but were considered at angles of attack equal to 0, 5, and 10 degrees. Lastly, the dynamic behaviour of the bow, cylinder, and tail shocks of a cone-cylinder-flare travelling at Mach 1.25, which was prescribed an elliptical flight path was analysed. A second run was performed. This time non-rectilinear acceleration, from Mach 0.5 to Mach 1.3, was experienced by the projectile during its elliptical manoeuvre and the vortex street in its wake was shown to curve towards the turn centre of

the path. The same flight path was prescribed to a diamond aerofoil for comparison. The primary reason for discrepancies in the flow fields generated by acceleration into a disturbed and undisturbed air is the former still interacts with fluid representing flow features characteristic of its initial supersonic flight, even though the projectile's Mach number is subsonic. Acceleration into disturbed air results in complex flow field interactions. These interactions prove to be far more intricate than those caused by acceleration into undisturbed air. This is illustrated when inspecting flow field contour plots, as well as by the significant aerodynamic lift and drag discrepancies that manifest.