Aerodynamics in Arbitrarily Accelerating Frames: Application to High-*g* Turns

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Abstract: Fifth-generation missiles accelerate up to 100 *g* in turns, and higher accelerations are expected as agility increases. We have developed the theory of aerodynamics for arbitrary accelerations, and have validated modelling in a Computational Fluid Dynamics code. In this paper we will show fin disruption by strake vortices.

1. Introduction

Computational Fluid Dynamics has been shown to provide well-validated models of aerodynamic loads and flow fields under conditions of constant velocity or constant angular velocity, or for displacements of control surfaces, for aeroelastic applications, and for some store release cases. However, as air vehicles and missiles become more manoeuverable, the question arises of how aerodynamic loads change when acceleration of significant magnitude is applied. Among the motivating applications is the effect of the displacement of vortices in turns, since the disruption of expected loads on fins may have serious consequences for the trajectory.

2. Theory and implementation

The transformation of the Navier-Stokes equations between an inertial frame and an arbitrarily accelerating frame has been formulated by Löfgren [[1]] and Forsberg [[2]]. Since the presence of significant source terms leads to unstable behaviour and long convergence times in numerical codes, the absolute, or inertial, frame formulation ahs been implemented in the code EURANUS [[3]]. The code uses a Finite Volume, structured mesh multi-grid solver with Total Variation Diminishing flux-splitting, and implicit solution with dual time-stepping for time-accurate application. Validation of this model has been demonstrated for rotating plates and oscillating airfoils [[4]][[5]].

3. Results

In a previous paper [[5]] we have shown example cases for a hemisphere-cylinder with thin strakes in the x-configuration extending the length of the cylinder. Viscosity is neglected. For a typical speed of v = 600 ms^{-1} at angle of attack α = 15º, a contrast was found between the case in which pitch rate q = 0 s^{-1}, and that in which q = -5 s^{-1}, the latter corresponding to a turn at 300 *g*. A vortex originates on the upper strake and propagates backwards to the base. Changes of pressure in the aft region of the missile were of the order of 10^{4} Pa due to the shifting of the vortex towards the centre of the turn.

In the current work we add simple fins in the x-configuration to the model. Pressures in the region where the upper fin is to be placed are about 80 000 Pa, and pressures in the region where the lower fin is to be placed are of the order of 140 000 Pa. We again measure the normal force and pitching moment in the cases q = 0 s^{-1} and q = -5 s^{-1}. We obtain the load change due to the disruption of aerodynamics at the fins due to the shift in the position of the vortex generated by the upper strake.

The work includes assessment of the cases in terms of dimensionless constants derived from the Navier-Stokes equations for accelerating terms, and a conclusion as to whether these constitute a good guide to the significance of the non-linear effects modeled.

4. References

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