ADVANCED CFD-BASED COUPLED COMPUTATIONAL APPROACH FOR PREDICTION OF COMPLEX FLIGHT BEHAVIORS

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Improved computer technology and state-of-the-art numerical procedures now enable solutions to complex, three-dimensional problems associated with projectile and missile aerodynamics. Detailed understanding of controlled flight behaviors is critical for enhanced vehicle maneuverability of these munitions. Advanced computational techniques are being developed to understand flight behaviors of both unguided and guided projectiles. One such technique couples computational fluid dynamics (CFD) and rigid body dynamics (RBD) for simultaneous prediction of unsteady aerodynamics and flight dynamics in an integrated manner. The coupled approach is to capture static and dynamic aerodynamic behavior over short time durations with different motions. Performing coupled simulations in this manner allows for screening of situations where conventional aerodynamic models based on static wind tunnel or CFD techniques break down. These instances are encountered more often as wider classes of munitions (small-medium-large caliber) feature control inputs and the associated flow complexity such as interactions, unsteadiness, and high angle of attack. Thus, a major benefit of these coupled simulations is to mitigate risk of unanticipated flight behaviors during unguided and especially guided free-flight experiments. Also, in the traditional uncoupled approach, efforts are being directed at developing alternate CFD procedures such as angle of attack and Mach sweeps are for rapid generation of aerodynamics for both simple and complex configurations at all speeds from subsonic to supersonic. In the present work, research has been focused on the development and application of advanced alternate CFD technique as well as CFD-based coupled techniques for accurate prediction of projectile aerodynamics and flight dynamics.

The advanced CFD capability used here solves the unsteady Navier-Stokes equations, incorporates unsteady boundary conditions and a special coupling procedure. This research is a big step forward in that it allows “virtual fly-out” of projectiles on the supercomputers, and it predicts the actual fight paths of a projectile (flight dynamics) and all the associated unsteady free-flight aerodynamics in an integrated manner. In the coupled CFD/RBD procedure, the forces and moments are computed every CFD time step and transferred to a six degrees of freedom (6-DOF) module that computes the body’s response to the forces and moments. The response is converted into translational and rotational accelerations that are integrated to obtain translational and rotational velocities and integrated once more to obtain linear position and angular orientation. This method automatically takes into flow interactions (e.g. canard-fin vortex interactions on a canard-controlled projectile) during the flight. It also yields a wealth of data unavailable in experimental methods, but it does involve highly computer intensive calculations requiring large computational resources. Flow fields, pressure distributions, forces and moments on various surfaces, and the complete twelve-state RBD history are available from the coupled solutions. The aerodynamic coefficients are then determined using regression and parameter estimation techniques.

Current research efforts are focused on integrating flight control system (FCS) into the coupled CFD/RBD method for simulations of guided control maneuvers. The resulting coupled CFD/RBD/FCS technique can be used for open and closed loop control maneuvers where canards or fins are deflected in a desired fashion based on the control algorithm to provide control authority needed. The canard/fin deflections output of the flight control element is used to move the grid (locations and velocities) for the next CFD time step computation. CFD computes the aerodynamic forces/moments that dictates the projectile flight motion and subsequent controlled deflections subject to the control algorithm.

Numerical simulations of the virtual fly-outs have been carried out at DOD Defense Supercomputing Resource Centers using 352 processors on a Cray XC-40. Numerical simulations have been performed using an advanced scalable unstructured flow solver and a time-accurate Navier-Stokes computational technique that includes grid motion capabilities. Dual time-stepping was used to achieve the desired time-accuracy for time-accurate CFD computations of unsteady flow fields. In addition, the projectile in the coupled CFD/RBD simulation actually moved along with its grid as it flew downrange. In the present study, our application of interest is a fin-controlled projectile (see Figure 1). Projectile control is provided using a small aft portion of the fins. The coupled CFD/RBD capability has been exercised here on this fin-controlled projectile and has been demonstrated using a roll and pitch maneuvers. Unstructured grids are generated about each fin separately (Figure 1). The fin grids are then overset with the background projectile mesh to a Chimera overlapped mesh for the fin-controlled projectile. The advantage is that the individual grids are generated only once and the Chimera procedure is then applied repeatedly as required during the canard motion without the need to generate the meshes at each time step. Initially, computed results have been obtained for this projectile at a supersonic speed, M = 2.0 and angle of attack, α = 0° for the fin-controlled projectile with no fin control. Computed pitch angle and hence, the angle of attack increases to α greater than 40°. The orientation of the projectile of course changes from one instant in time to another as the projectile flies down range. Computed results have also been obtained for a controlled maneuver using coupled CFD/RBD/FCS with initial pitch rate of 3 rad/s and same initial velocity, M=2. Rear fins were deflected to provide the control authority needed to bring the pitch rate to zero. Coupled results clearly show the desired outcome in the pitch rate history (see Figure 3) and the associated control deflections reaching a maximum of 10° needed in the maneuver (Figure 4). Details of these coupled computations without and with control maneuvers on the aerodynamics and flight dynamics of the fin-controlled projectile will be included in the full paper. The present work represents a significant advance in the state-of-the-art CFD-based multidisciplinary time-dependent predictive capability critically required for the development of future advanced maneuvering munitions.

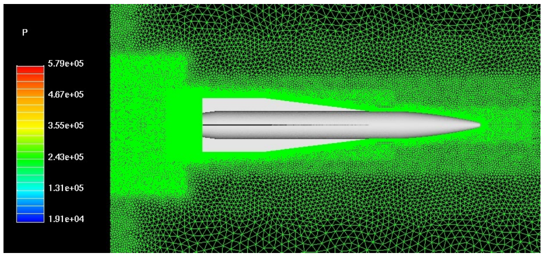

Figure 1. Computational mesh near the finned projectile geometry.

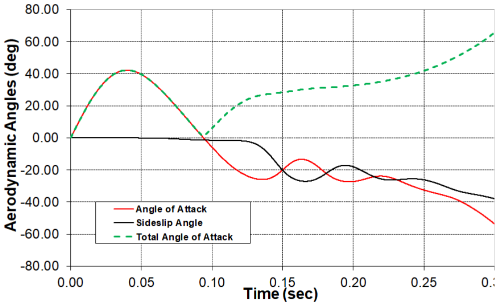

Figure 2. Pitch angle as a function of time.

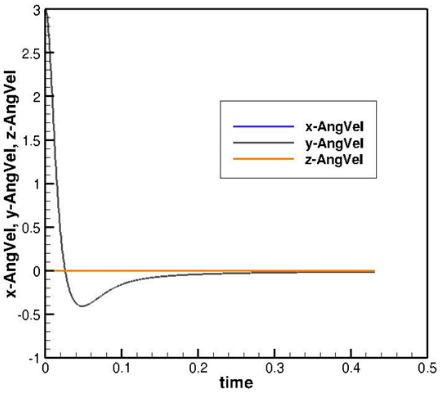

Figure 3. Angular rates as a function of time.

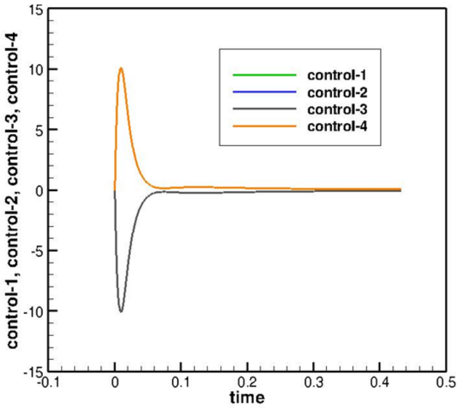

Figure 4. Control fin deflections as a function of time.