Development and Application of Multidisciplinary Coupled Computational Techniques for Projectile Aerodynamics

J. Sahu*, M. Costello**, and C. Montalvo**
Corresponding author: jubaraj.sahu.civ@mail.mil

* U.S. Army Research Laboratory, APG, MD, USA
** Georgia Institute of Technology, Atlanta, GA, USA.

Abstract: The As part a DOD challenge project, time-accurate multidisciplinary coupled computational fluid dynamics (CFD)/rigid body dynamics (RBD)/flight control system (FCS) methods are being developed and applied to a canard-controlled projectile. The effect of canard roll control maneuver on the unsteady aerodynamics and flight dynamics will be determined and presented.

Keywords: Computational Fluid Dynamics, Coupled Methods, Multidisciplinary Application, Projectile Control.

1 Coupling Procedure

The advanced CFD capability used here solves the unsteady Navier-Stokes equations, incorporates unsteady boundary conditions and a special coupling procedure. The present 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 and all the associated unsteady free-flight aerodynamics using coupled CFD/RBD/FCS techniques 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 which 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. Ongoing research and coupling of FCS with CFD/RBD procedure now is beginning to extend the capability of the coupled technique further for simulation of control maneuvers. The added element of this coupling is the flight control system or the guidance, navigation, and control aspect. An interface was created and developed for easy transfer of both the RBD state variables and the flight control system variables of interest between the CFD flow solver and RBD/FCS code. The aerodynamic forces and moments are computed at every time step in CFD part and transferred to the RBD/FCS code which does both RBD and FCS simulations. The FCS simulation provides as output the flight control variables based on a given FCS design and control laws. The output of RBD state and the control variables are transferred to the CFD flow solver which then computes the aerodynamic forces and moments subject to these RBD state and control variables.

2 Results

Numerical simulations of the virtual fly-outs have been carried out at ARL Defense Supercomputing Resource Center using 128 processors on a Linux Cluster as part of Grand Challenge Project. 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/FCS simulation actually moved along with its grid as it flew downrange. In the present study, our application of interest is a canard-controlled projectile (see Figure 1). Projectile control is provided using canards. The control maneuver is achieved by two canards located in the nose section of the projectile. The coupled CFD/RBD/FCS capability has been exercised here on this canard-controlled projectile and has been demonstrated using a roll control example. Unstructured grids are generated about each canard separately (Figure 2). The two canard grids are then overset with the background projectile mesh to a Chimera overlapped mesh for the canard-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. Computed results have been obtained at an initial transonic speed, M = 0.8 and angle of attack, $\alpha = 0°$ for the canard-controlled projectile. The orientation of the projectile of course changes from one instant in time to another as the projectile flies down range. Aerodynamic forces and moments vary accordingly in the coupled CFD/RBD/FCS flight simulations as shown in Figures 3 and 4.

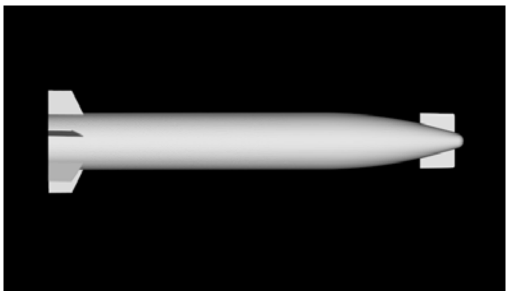

Figure 1. Canard-controlled finned projectile geometry.

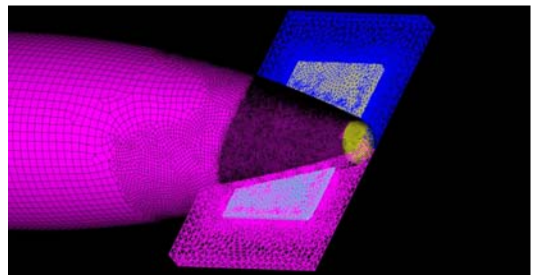

Figure 2. Unstructured Chimera mesh in the nose region of the projectile.

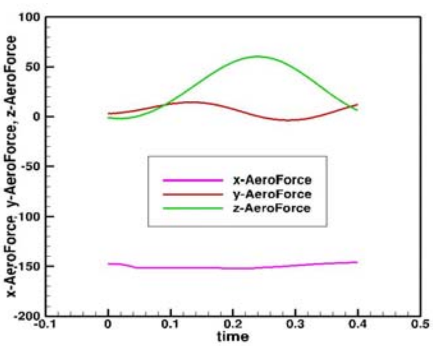

Figure 3. Aerodynamic forces as a function of time.

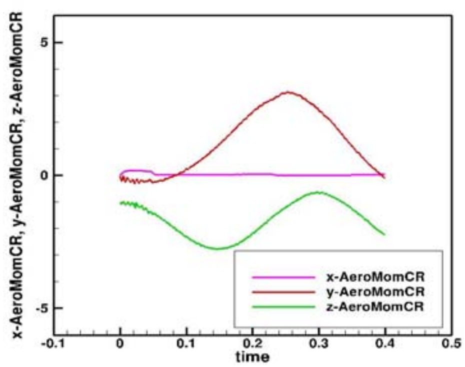

Figure 4. Aerodynamic moments as a function of time.

3 Conclusion and Future Work

Details of these coupled computations showing the effect of canard control maneuver on the unsteady aerodynamics and flight dynamics of the canard-controlled projectile will be included in the full paper. The present work represents a significant advance in the state-of-the-art multidisciplinary time-dependent predictive capability critically required for the development of future advanced maneuvering munitions.