First Viscous CFD Analysis of Grid Fins Gives Better Prediction of Missile Trajectory

A viscous computational fluid dynamics (CFD) analysis of a missile with grid fins has provided new information that can be used to predict missile trajectories more accurately. Prior to the development of this model, grid fins were studied by means of wind tunnel tests and inviscid CFD analysis, but neither provided certain critical aerodynamic parameters needed to infer the fins' effect on the missile's trajectory. The U.S. Army Research Lab's viscous CFD analysis method has created a visual representation of airflow around the missile and through the fins. This method also provides numerical parameters such as axial forces and drag coefficients that are needed to accurately predict the trajectory. One challenge in developing a viscous CFD model for this purpose was creating an analysis mesh of the grid fin geometry. By choosing a solver that supports unstructured meshes, Army engineers were able to create a mesh containing more than three million cells in about two weeks. The results of the viscous CFD analysis correlated very closely with wind tunnel tests. In the future, this model will be used to assist in other missile designs.

A grid fin is a lifting and control surface that differs from a typical solid fin. The grid fin uses a honeycomb design that allows air to pass through the fin rather than bypass around it. Typically it has an outer frame supporting an inner grid of small intersecting planar surfaces. Grid fins have been employed on some Soviet air-to-air missiles but have not been used on any missile systems in the West. Interest in grid fins has increased in recent years because of certain advantages they offer over conventional planar controls. One advantage is the ability to maintain lift at higher angles of attack since grid fins do not have the same stall characteristics as planar fins. Another is their very small hinge moment, which can reduce the size of control actuator systems. A third advantage is that grid fin curvature has little effect on performance, so that folding the fins down onto the missile body is a storage design advantage. "These features allow grid fins to perform well at high angles of attack and high Mach numbers, making them well-suited for use on highly maneuverable munitions," explains James DeSpirito, aerospace engineer at U.S. Army Research Laboratory, Aberdeen Proving Ground, Maryland.

The aerodynamic performance of grid fins has been investigated since the mid-80s. The Defence Evaluation and Research Agency (DERA) in the United Kingdom has performed wind tunnel tests on grid fins and compared their aerodynamic characteristics to conventional planar fins. In addition, aeroballistic range flight tests have been conducted at the U.S. Air Force Research Laboratory

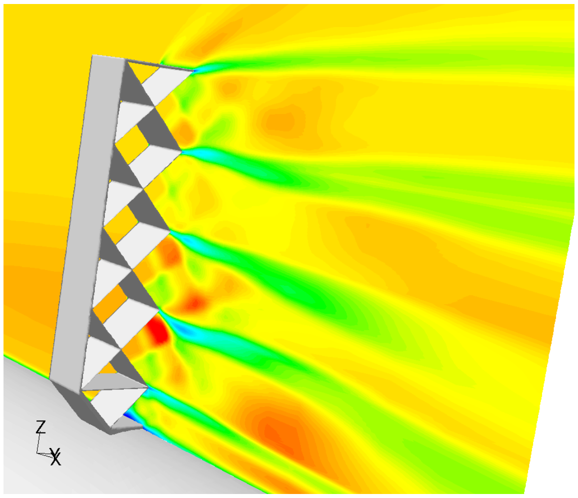

Figure 1: Mach number contours on symmetry plane through top fin

Aeroballistic Research Facility (ARF) at Eglin AFB, Florida. Although these studies proved useful in helping understand the aerodynamic characteristics of grid fins for preliminary design purposes, certain critical information was lacking. For example, it was not possible to visualize the flow field around the fins. "With testing, we can get basic forces, but can't see how the forces interact with the fins," says DeSpirito. "We know that at a certain angle of attack there are two big vortices coming off the back of missile, but we also want to know how they interact with the fins. They only way to understand this interaction is to visualize the flow field with CFD."

Developing a viscous CFD model

To obtain this information, DeSpirito decided to develop a viscous CFD model. "A viscous solution would permit the determination of the percentage of forces due to viscous and pressure effects," he explains. The CFD program he chose to use was FLUENT from Fluent Incorporated, Lebanon, New Hampshire. One reason he chose this software was because it supports the use of an unstructured mesh. "Because the scales of an analysis mesh vary greatly between the missile and the grid fins, manually creating of the grid could take a prohibitive amount of time," says DeSpirito. "Because of the automated tools in Fluent's preprocessor, GAMBIT, it was possible to carry out this task for the complex geometry with a minimum of effort."

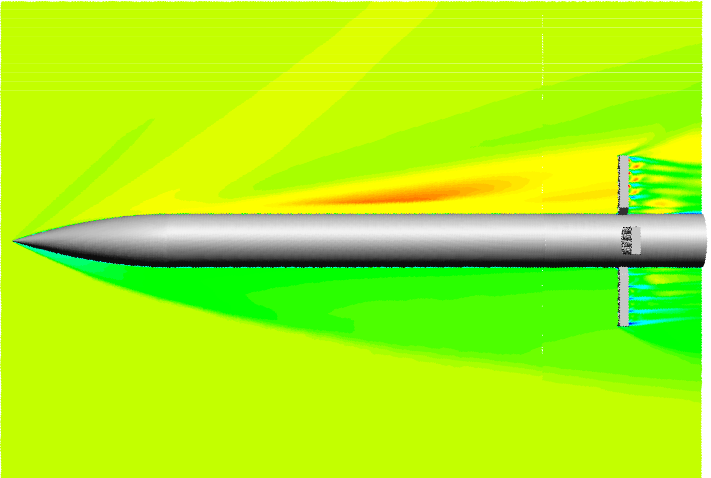

Figure 2: Mach number on symmetry plane for grid fin case α **= 20°**

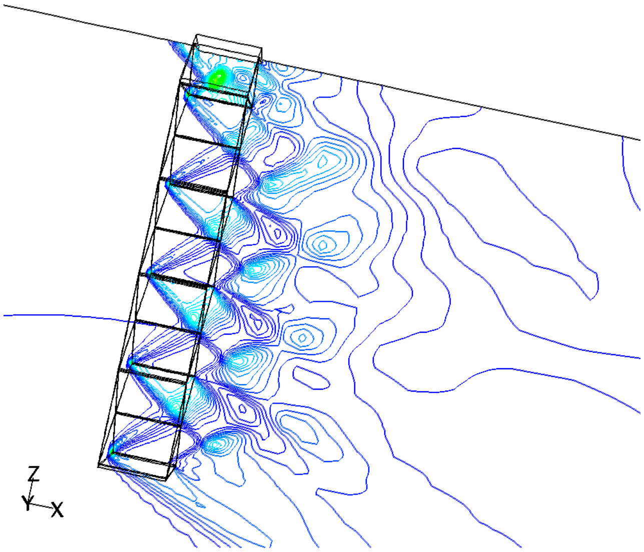

Figure 3: Pressure coefficient contours on symmetry plane through bottom fin (Fin 2)

DeSpirito began by using GAMBIT to create the geometry of a 13-caliber, four-finned, generic missile shape. "Normally a geometry is built from the bottom up, creating first lines and then surfaces," says DeSpirito. "With GAMBIT, a solid modeler, it was also possible to work from the top down. This method proved to be easier, especially for modeling the honeycomb frame. I modeled it the way it would be machined, subtracting cubes from a rectangular slab." Creating the geometry of the fins took about half a day.

Once the geometry was built, DeSpirito began creating the analysis mesh. "GAMBIT turned out to be very helpful here, not only because it supports unstructured meshes," DeSpirito continues. "It also has special tools that address difficult meshing situations." One of these involved the fact that DeSpirito needed two different scales of mesh in this problem, a high-density mesh for the fin region and a lower density mesh for the rest of the missile. Joining these mesh regions would have taken a prohibitively long time to do manually. Instead DeSpirito used a GAMBIT capability to build a nonconformal interface, one where two adjacent (and different) mesh regions can be joined. The FLUENT solver allows flow variables to be passed across this kind of interface, despite the fact that the meshes on either side are different.

DeSpirito used the implicit, compressible (coupled) solver to calculate the three-dimensional flow field. The calculations were made at Mach numbers of 2, 2.5, and 3 and at several angles of attack. The analyses were run on a six-processor SGI

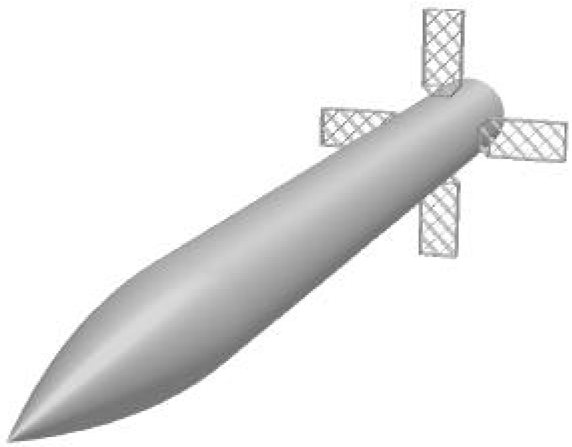

Figure 4: Geometry for grid fin case (B1AL2R)

Onyx 2 computer with R12000 processors. The grid fin calculations took about 5 minutes per iteration. The solution converged in about 1500 iterations.

Comparison with test results

The analysis provided results that had not been available previously, such as the axial force and drag coefficient on the missile. It also provided a visual image of the flow field, which has the potential to be very helpful in understanding issues such as the effect of missile aerodynamics on the fins or the impact of the shock waves coming off the fins. "CFD lets us gain insight into what the flow is doing," says DeSpirito. "We can see the interaction of recirculation regions and shock waves. These are things we weren't aware of before and they have improved our understanding of how the fins work."

The simulation results were validated by comparing the computed aerodynamic coefficients for the grid fins against detailed wind tunnel measurement data. The validation process also included calculating the flow field for the missile body alone and the missile body with conventional planar fins and comparing these results against wind tunnel data. "We saw very good agreement with the measured data for all the configurations we investigated," says DeSpirito. For the grid fin case, the aerodynamic coefficients were within 6.5 % of the wind tunnel data. The normal force coefficient on the individual grid fins was within 11 % of the test data. The simulations were also successful in calculating the flow structure around the fin in the separated-flow region at higher angles of attack. This was evident in the successful calculation of the nonlinear behavior for that fin, which showed negative normal forces at higher angles of attack.

The work that DeSpirito did indicates that viscous CFD analysis offers an accurate method for calculating the flow field and aerodynamic coefficients for missiles with grid fins. It gives designers more information than experimental or other numerical simulation methods, providing a tool that can help them optimize the use of grid fins. According to DeSpirito, this work has spurred new interest in grid fins, and the CFD method is currently being used in the design of a new air-to-air missile.

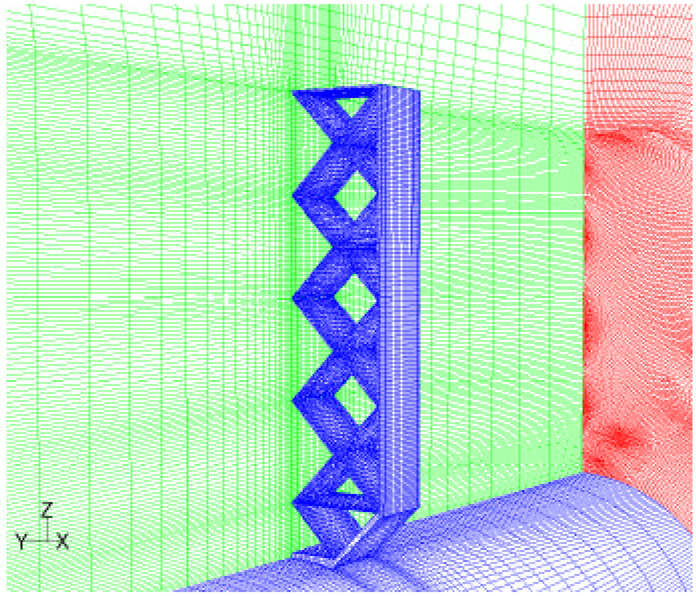

Figure 5: Unstructured mesh in tail region of grid fin case