Effects of the Litening Pod and ATFLIR on F-18C Hornet Weapons Release

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In December 1998, during routine bombing practice at Fallon, NV, an F-18C released a Mark 82 bomb which impacted the Targeting Forward Looking Infrared Pod (TFLIR) attached to the aircraft fuselage. Subsequent studies by Midshipman W. H. Godiksen, USN, revealed that the likely cause was a shock wave that developed from the trailing edge of the targeting pod, which hit the tail fins of the weapon leading to the adverse change in trajectory. Our study compared the developed pitch and yawing moments from the ATFLIR and the geometrically different and physically larger Litening external targeting pod. Both the CFD simulations and limited wind tunnel testing show that the Litening pod, as compared with the ATFLIR, has an overall reduction in pitch and yaw moments on a Mark 82 bomb. The consistent trends between the CFD simulations and wind tunnel testing suggest that flight testing of the Mark 82 adjacent to the Litening pod is appropriate.

Nomenclature

ATFLIR	= Advanced Targeting Forward Looking Infrared Pod
CFD	= Computational Fluid Dynamics
DCLM	= Incremental Pitching Moment Coefficient Difference (ATFLIR – Litening Pod). Positive Nose Up.
DCLN	= Incremental Yawing Moment Coefficient Difference (ATFLIR – Litening Pod). Positive Nose Right.
MK-82	= Mark 82 500lb bomb
TFLIR	= Targeting Forward Looking Infrared Pod

I. Introduction

In order to establish safe flight conditions for the release of bombs or other stores from attack aircraft, the Navy conducts flight tests at various aircraft attitudes, Mach numbers, and store configurations and determines the initial path taken by the falling store. This determination of path is generally made using a series of high speed photographs, known as photogrammetrics, or the analysis of data taken from an accelerometer located on the store itself, known as telemetry. Though very accurate, many such flight tests are necessary in order to approve a range of acceptable flight conditions, and these are costly in both time and money. In the absence of pre-flight analysis, the most benign flight condition is chosen as the starting point of the flight test, typically fully sub-sonic. The release envelope is gradually expanded through subsequent releases by increasing the Mach number and altitude. Many such flights are required to reach the boundary of the aircraft flight envelope.

The number and duration of flights required can be significantly reduced by predicting trajectories before flights are begun. This pre-flight flow analysis is accomplished in both the wind tunnel and through computational fluid dynamics (CFD). Prior to any flight testing, predicted trajectories are obtained using one or both of these methods, and these results are used to determine which configurations require flight tests and to what extent. For instance, a clearance to Mach 0.95 may require a build-up approach beginning at a benign flight condition such as Mach 0.85 and progressing up to Mach 0.95 at steps of 0.05 Mach. Extensive wind tunnel and CFD analysis could permit fewer

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steps in the build-up to the endpoint if CFD and wind tunnel analysis shows the endpoint to be safe, and interim flight test steps match predictions.

A. Background

The inspiration for this research began with routine bombing practice conducted in Fallon, Nevada in December of 1998. The pilot was flying an F-18C aircraft with a Targeting Forward-Looking Infrared Pod (TFLIR) mounted on the side of the plane's fuselage and a Mark-82 (MK-82) bomb hanging from the inboard wing pylon adjacent to the targeting pod. Figure 1 shows an F-18C aircraft with a TFLIR attached to the fuselage and a fuel tank attached to the inboard pylon.

Figure 1. TFLIR on F-18C.

When the pilot dropped the MK-82 from his aircraft, the nose of the bomb yawed away from the fuselage which caused the bomb's tail fins to impact the TFLIR. This result was unexpected as this flight condition had been cleared for safe release in the aircraft's tactical manual. An investigation soon revealed that the TFLIR had been considered a part of the aircraft and that its effect on store separation had been assumed to be negligible. As a result, neither wind tunnel nor flight testing had been done to determine what effect it might have. After this incident, the Navy decided to begin a flight test program in order to establish safe release parameters. Analysis by then Midshipman Godiksen[1] showed that CFD could be useful in predicting stores release behavior on the F-18C equipped with the TFLIR Pod.

At this same time the Navy introduced the Advanced Targeting Forward Looking Infrared Pod (ATFLIR), which is geometrically similar to the TFLIR but significantly more capable. A picture of the ATFLIR pod mounted on an F-18C can be seen in Figure 2. The main difference in shape between these two pods is the fairing on the leading edge of the ATFLIR, which is not present on the TFLIR. In most other aspects, these pods look essentially identical. There are subtle differences in the geometry of the trailing end of the pods which were initially not thought to be significant compared to the larger differences in their front-end geometries. This assumption was shown to be wrong.

Figure 2. ATFLIR on F-18C.

This pod was examined in the flight test program in the same manner as the TFLIR. It was expected that the ATFLIR would have nearly the same effect on the aircraft's flow field as the TFLIR due to their geometric similarity. However, flight test results soon proved otherwise. At speeds just under the speed of sound, between Mach 0.90 and 0.95, the flight test results showed significant differences in the trajectories of bombs dropped next to the TFLIR versus those beside the ATFLIR. Although the cause of this variance was not understood, time and schedule constraints precluded further research. The flight test program concluded by restricting the release of certain stores in proximity to either targeting pod to a subset of the full combat aircraft flight envelope.

While these test flights were successful in establishing safe store release conditions for these pods, they did not produce a full understanding of the effect of the (A)TFLIR pod on the F-18C flow field. Furthermore, the full operating envelope of the combat aircraft was restricted. Analysis of this release condition is challenging. The geometric differences between the two pods are subtle and the flow field at the Mach number of interest is fully transonic with a number of shocks forming and moving as the store is released. O'Brien, Snyder and Hallberg[2] have recently completed a CFD study of the effect of different tail geometries on the ATFLIR stores separation characteristics.

In this study we compare the stores separation characteristics of a MK-82 for the ATFLIR and for the Litening pod, which, as shown in Figure 3, is geometrically different and physically larger that the ATFLIR. Comparison will be made on the pitch and yaw moments developed on the MK-82 by these different external targeting pods.

Figure 3. Litening Pod on F-18C.

II. Computational Method

In order to save time and money, computational fluid dynamics software was used to predict the moment coefficient on the store. The software used was the TETRUSS suite. The NASA Tetrahedral Unstructured Software System (TETRUSS) was developed during the 1990's to help provide a rapid aerodynamic analysis and design capability to aerodynamicists. The system is composed of several different integrated software pieces.

A. Grid Generation

The grid generation was done through a program named GridTool. This program changes the Computer Aided Design (CAD) into a grid representation, which can be used by the rest of the programs. The process of geometry and grid parameter preparation with GridTool constitutes 50 – 90 percent of the total grid-generation time. It also provides the input file for VGRID, which is the next software package in the process. VGRID is a program for automatic generation of tetrahedral unstructured grids suitable for computing Euler and Navier-Stokes flow solutions. The process is based on an Advancing front and an Advancing layer method. Both of these techniques are based on a marching process in which tetrahedral cells form on top of each other. The surface grid can be seen in Figure 4.

B. Flow Solver

As described in Walsh and Cenko,[3] USM3Dns[4,5] is a tetrahedral cell-centered, finite volume Euler and Navier-Stokes (N-S) flow solver. Inviscid flux quantities are computed across each cell face using Roe's[6] flux-difference splitting (FDS). Spatial discrimination is accomplished by a novel reconstruction process,[7] which is based on an analytical formulation for computing solution gradients within tetrahedral cells. The solution is advanced to a steady state condition by an implicit backward-Euler time-stepping scheme.[8] Flow turbulence effects are modeled by the Spalart-Allmaras (S-A) one-equation model,[9] which is coupled with a wall function to reduce the number of cells in the sub layer region of the boundary layer.

The USM3Dns code is designed for the easy addition/modification of boundary conditions (B.C.). It supports the standard B.C.'s of flow tangency or no-slip on solid surfaces, characteristic inflow/outflow for subsonic boundaries, and free stream inflow and extrapolation outflow for supersonic flow. Some additional special boundary conditions are available as well.

The version of the program that was used included parallel processing. The tetrahedral grid was divided into a certain number of pieces and communication between these partitions is accomplished through Message Passing Interface. This speeds up the solution method by allowing an individual processor to solve the flow field in a limited number of the tetrahedrals.

The grid for the Litening Pod configuration was divided into approximately 7.6 million tetrahedrons while the grid for the ATFLIR configuration was divided into approximately 12.7 million tetrahedrons, each of varying size and generated from the surface grid as shown in Figure 4. This three dimensional grid was solved using multiple Pentium processors. The solution for the Litening Pod would take approximately 50 hours to converge on 14 processors, for a total time of 700 processor hours per solution. This was repeated for 10 Mach numbers for a total of 7,000 processor hours. The solution for the ATFLIR would take approximately 5.5 hours to converge on 25 processors, for a total time of 137.5 processor hours per solution. This was repeated for 10 Mach numbers for a total of 1,375 processor hours.

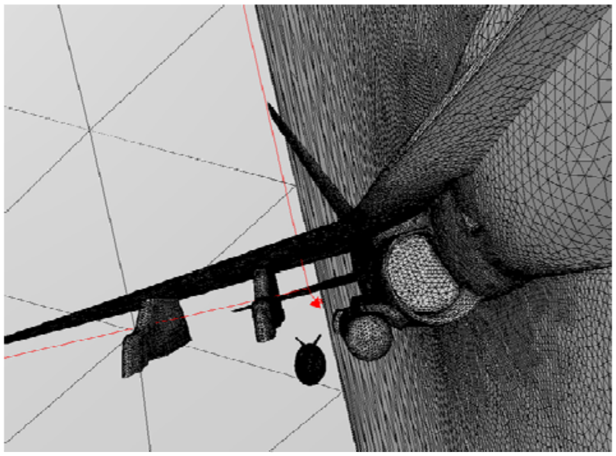


Figure 4. Grid of Varying Resolution.

C. Geometry Differences

As the suspected cause of the adverse stores separation characteristics is shockwaves emanating from the trailing edge of each targeting pod, the relative distance along the body axis from the trailing edge of the pod to the location of the store is the most important factor for predicting shockwave interaction with the store. Figure 5 shows this relative distance for the Litening Pod and for the ATFLIR. The Litening Pod is physically much larger than the ATFLIR, thus its trailing edge is much closer to the store along the body axis. The result is that the shockwave has a smaller effect from the Litening Pod than from the ATFLIR.

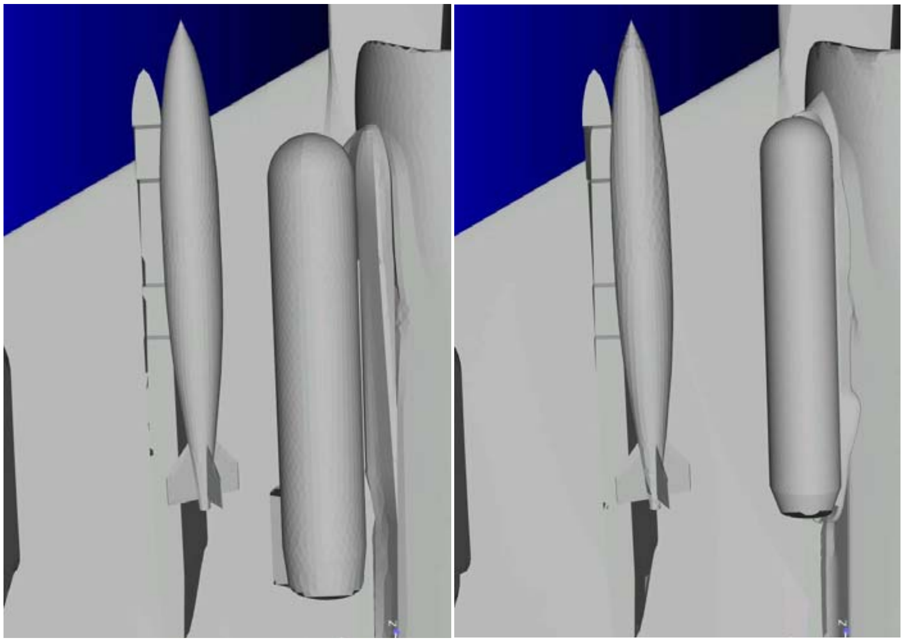


Figure 5. Relative Distance Between Litening Pod (left) or ATFLIR (right) and MK-82 Store.

Previous studies by midshipmen have shown that the primary problem in the store separation characteristics stems from the blunt aft section of the pod. This part of the pod caused a shockwave to hit the tail of the store, which causes the detrimental yawing moment and the collision. A view from underneath the aircraft can be seen in Figure 6. In this view it is clear that the shockwave from the nose of the ATFLIR strikes the store in the middle of its body, whereas the shockwave from the aft of the pod strikes close to the fins of the MK-82. This design element, which was previously thought to be inconsequential, has been shown to have a large effect on the store separation properties.[1] Adverse pitching and yawing moments are produced when there is an unequal pressure distribution at a significant distance from the center of gravity of the store. The trailing edge shockwave is known to produce such unequal pressure distributions near the trailing edge of the store.

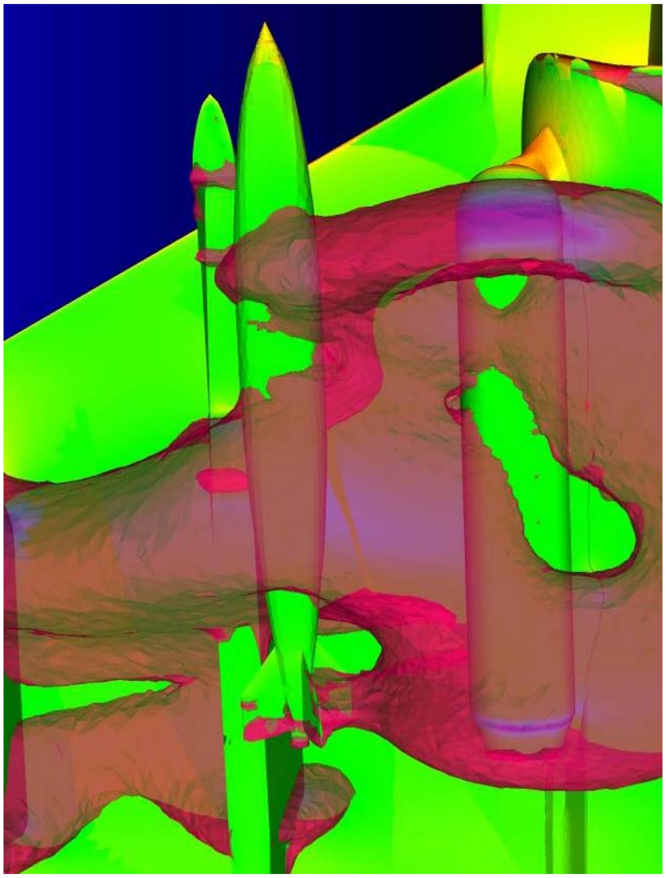


Figure 6. Developed Shockwaves from ATFLIR

III. Simulation Results

The Mach sweep for all versions was conducted and the yawing and pitching moment were analyzed. It was found that there was a 0.4 to 0.7 improvement in the pitching moment from the Litening Pod compared with the ATFLIR, whereas the wind tunnel testing predicted an improvement of 1.2 throughout the transonic range (see Figure 7). Throughout the entire Mach range analyzed, there also was an improvement of the incremental yawing moment by a reduction of 0.4 from the Litening Pod to the ATFLIR. As shown in Figure 8, corresponding wind tunnel testing predicted a 0.4 to 0.8 reduction over the same range.

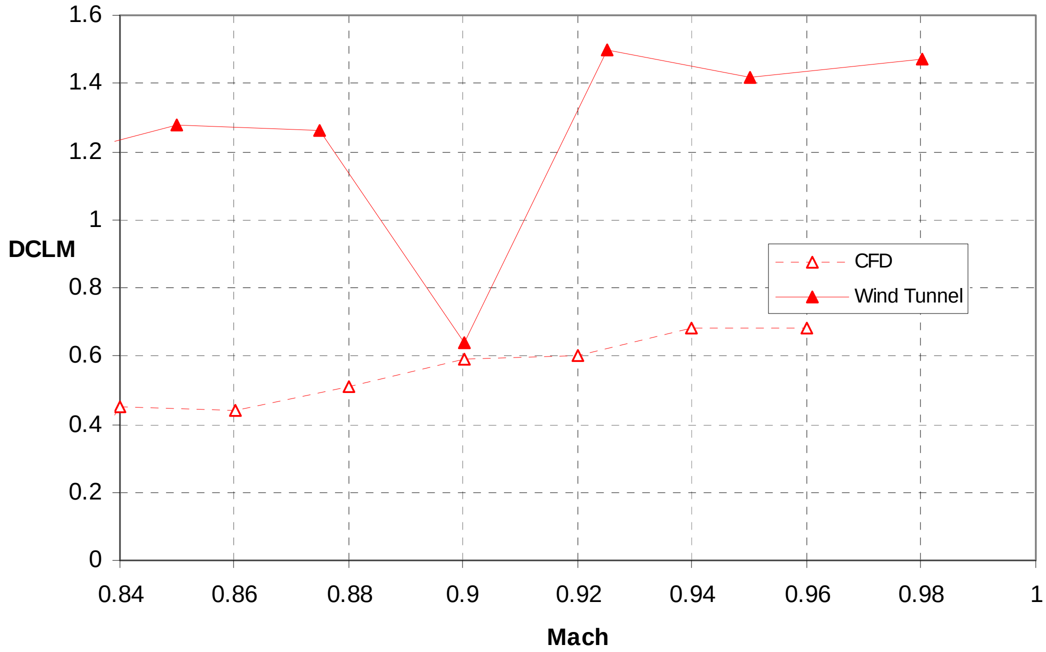


Figure 7. Incremental Pitching Moment Coefficient Difference (ATFLIR – Litening Pod), Positive Nose Up (DCLM) vs. Mach Number.

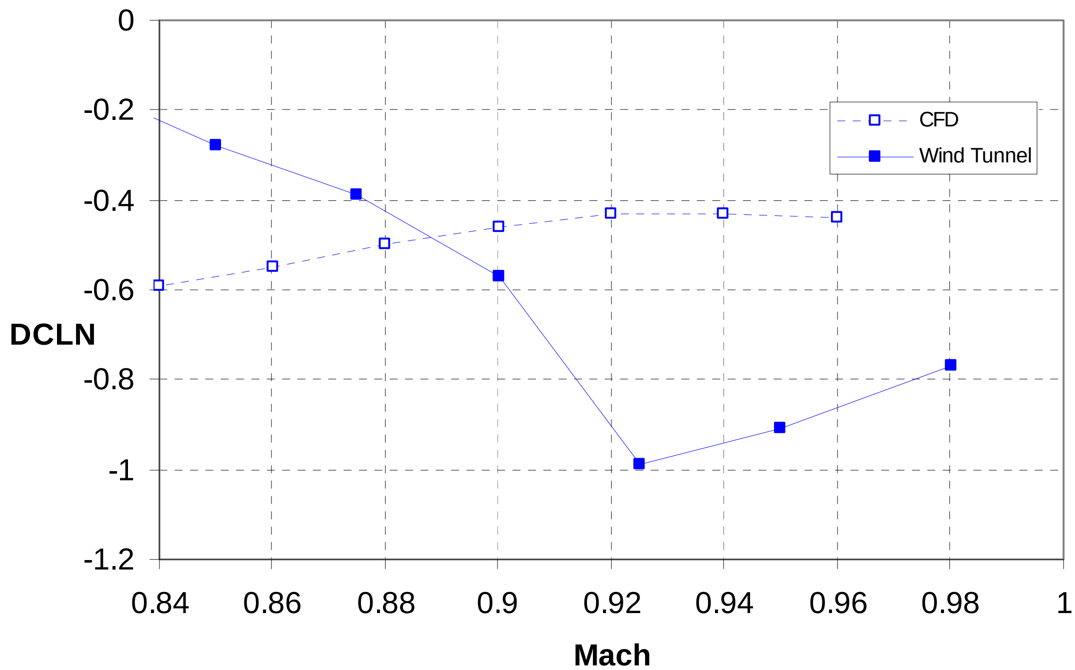
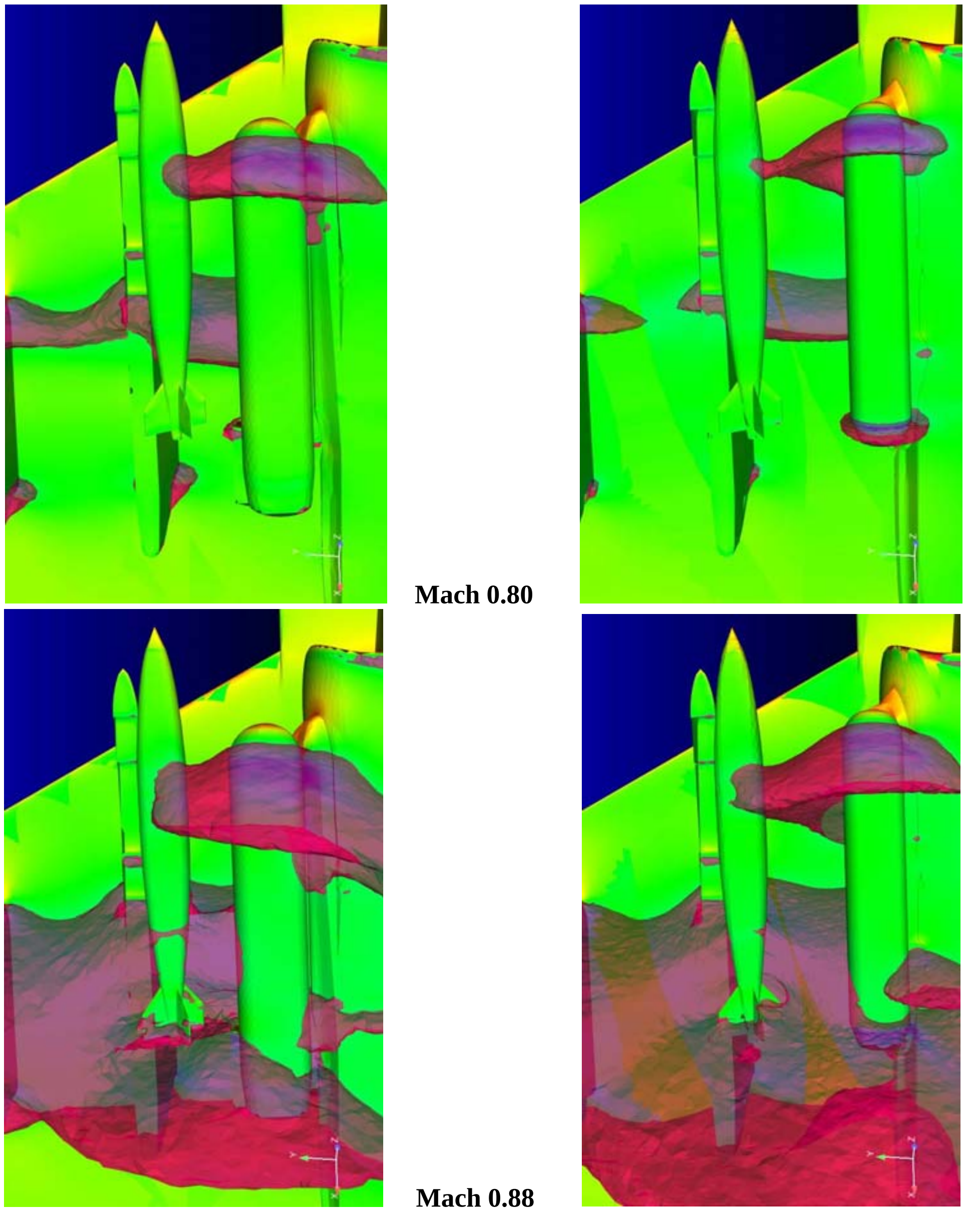


Figure 8. Incremental Yawing Moment Coefficient Difference (ATFLIR – Litening Pod), Positive Nose Right (DCLN) vs. Mach Number.

Figure 9 compares the shockwave interference with the store with the Litening Pod configuration on the left and the ATFLIR configuration on the right. The shockwave emanating from front end of either pod interacts with the store at the approximate location of it center of gravity, thus creating little or no moment on the store. However, the shockwave from the trailing edge intersects the store close to the tail of the MK-82. These cause a large moment on the store and cause it to rotate, possibly into the aircraft. From Figure 9 it is easy to see that the shockwave interaction on the store from the Litening Pod is significantly less than that of the ATFLIR throughout the transonic region. However, the shockwave on the Litening Pod created from the notch on the side of the pod could pose serious problems for longer stores.



Mach 0.80

Mach 0.88

Figure 9. Comparison of Propagating Shockwaves from Litening Pod (left) and ATFLIR (right).

IV. Conclusions

CFD analysis confirms wind tunnel data that the Litening Pod has significantly better store separation characteristics, with regards to yawing and pitching moments, than the ATFLIR. Flow visualization, made possible with CFD, helps explain the mechanism whereby a released store interacts adversely with a shock wave generated by the aft end of the external targeting pod. Although CFD does not exactly match the wind tunnel test data, the trends do show general correlation. Some of the error could possibly be attributed to comparison of wind tunnel results from two different wind tunnels that are different in size. Also, the aircraft models used in the wind tunnels were also of different size. Because the wind tunnel models were of different size, the aft end of the models had to be modified in order to affix the balance. Finally, the Litening Pod grid simulation was only run using the first order differencing as second order differencing resulted in a numerically unstable computation.

Acknowledgments

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References

[1]Godiksen, W.H., "Effect of Targeting Pod Addition on F-18C Store Separation Characteristics," *AIAA Atmospheric Flight Mechanics Conference*, August 2008.

[2] O'Brien, C.W., Snyder, M.R. and Hallberg, E.N., "Effect of Targeting Pod Modification on F-18C Hornet Weapons Release," *ITEA Stores Separation Conference,* April 2010.

[3]Walsh, J. and Cenko, A., "USM3D Prediction of Mk-83 Trajectories from the CF-18 Aircraft," *AIAA 2001-2431,* 2001.

[4]Frink, N., "Upwind scheme for solving the Euler equations on unstructured tetrahedral meshes," *AIAA Journal*, Vol. 30, No. 1, 1992, pp 70-77.

[5]Frink, N., "Tetrahedral unstructured Navier-Stokes method for turbulent flows," *AIAA Journal*, Vol. 36, No. 11, 1998, pp 1975-1982.

[6]Roe, P., "Characteristic based schemes for the Euler equations," *Annual Review of Fluid Mechanics*, Vol. 18, 1986, pp 337-365.

[7]Frink, N., "Recent progress toward a three-dimensional unstructured Navier-Stokes flow solver," *AIAA Paper 94-0061*, 1994.

[8]Anderson, W. and Bonhaus, D., "An implicit upwind algorithm for computing turbulent flows on unstructured grids," *Computers Fluids*, Vol. 23, No. 1, 1994, pp 1-21.

[9]Spalart, P. and Allmaras, S., "A one-equation turbulence model for aerodynamic flows," *AIAA Paper 92-0439*, 1992.