ICAS 2006
25TH INTERNATIONAL CONGRESS OF THE AERONAUTICAL SCIENCES

IHAAA Applications to Store Separations

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Keywords: *F-18, Store Separation, CFD, HPC*

ABSTRACT

Prior to the implementation of the Institute for High Performance Computing (HPC) Applications to Air Armament (IHAAA) the Naval Air Systems Command (NAVAIR) had two choices for clearing new aircraft/store configurations. These were wind tunnel testing or the build up approach (also called hit-or-miss). Wind tunnel testing required at least six months of lead-time and a minimum of $500K. The build up approach consisted of increasing the release airspeed until the store came uncomfortably close to hitting the aircraft/adjacent stores. However, for quick turn-around, it was the only choice. This approach was not only very costly, but in some cases might have required a flight clearance recommendation that was too conservative. The IHAAA has provided the Navy with another tool that is both cost effective and capable of providing flight clearance recommendations in a timely fashion .

NOMENCLATURE

BL: Aircraft Buttline, positive outboard, in.
Cl: Rolling moment coefficient, positive rt wing down
C_m: Pitching moment coefficient, positive up
C_N: Normal Force coefficient, positive up
C_n: Yawing moment coefficient, positive nose right
C_Y: Side force coefficient, right
KCAS Knots Calibrated Airspeed
M: Mach number
P: Store roll rate, positive rt wing down
Q: Store pitch rate, positive nose up
R: Store yaw rate, positive nose right
Z: Store C.G. location, positive down, ft.
α: Angle of attack, deg.
ϕ: PHI Store roll angle, positive rt wing down, deg.
ψ: PSI Store yaw angle, positive nose right, deg.
θ: THE Store pitch angle, positive nose up, deg.

1 INTRODUCTION

The NAVAIR Store Separation Branch is responsible for authorizing and certifying the safe release of weapon systems from all Naval aircraft. Typically this process begins with either detailed sub-scale wind tunnel data or an experience-based database developed from a similar weapon system. When no wind tunnel data were available, a validation phase consisting mainly of an extensive flight test program was required. This required flight test data to be taken at increasing Mach numbers until the store came close to, or actually hit, the aircraft. Although, this approach has proved successful in the past, there are risks to both material assets and personnel. These risks can be minimized by using state-of-the-art CFD analysis methods. In addition, the utilization of these methods in coordination with wind tunnel and flight testing methods can greatly reduce development/validation time, costs and supply valuable insight to flow mechanism that can further enhance weapon performance.

The difficulty in using any method to predict the carriage and subsequent release of a weapon is not only in accurately simulating the complex component interactions, but also in providing this information quickly enough to authorize the clearance of the weapon. To combat this situation, the U.S. Navy independently developed an Integrated Test and Evaluation (T&E) approach to store separation which includes wind tunnel testing, analysis methods, and ultimately flight testing [1]. The interaction between all three competencies is essential for a timely completion of this process. In an attempt to further minimize the time and cost of the above flight certification process, Naval aircraft programs [2,3,4] have introduced advanced CFD methods to support and supplement wind tunnel testing. CFD methods have also provided a limited database for older aircraft, where no sub-scale models are available [5].

The Air Force, Army, and Navy have long-term, proven CFD modeling and simulation experience and software development expertise that has supported advanced weapon development and integration. Each uses unique CFD codes to augment traditional sources of engineering data such as flight and wind tunnel testing. In the past year, the three services, under the auspices of the High Performance Computing (HPC) center have combined their efforts to establish an Institute for HPC Applications to Air Armament (IHAAA).

2 IHAAA

Two of the three services top priorities are to more rapidly meet wartime warfighter requests and to reduce development effort risks. The IHAAA holds the promise of meeting both of these shortfalls. IHAAA will enable delivery of increased flight envelopes with decreased flight test resulting in rapid delivery of war-winning capability during the next Operation ENDURING FREEDOM or IRAQI FREEDOM. Developmental efforts will also benefit as HPC-based simulations developed by the IHAAA mitigate developmental risk by subjecting designs to the severity of the flight environment (in an HPC model) early enough in the acquisition cycle to positively influence the design. The AMRAAM, JDAM, and JSOW programs all experienced schedule-expanding and cost-multiplying fin failures during flight test that could have been predicted if the goals of the IHAAA were realized and applied in the concept and design phases.

The mission of the IHAAA is to provide our nation's warfighters with enhanced combat capability through application of HPC techniques for air armament design, integration, and evaluation. The vision is to be a sustainable enterprise ensuring HPC technology transition and application to provide quick reaction to warfighter needs and reduce acquisition cost, schedule, and risk. The strategic goals of the Institute are: to establish a customer-oriented enterprise integrating laboratory, development, test and sustainment organizations; to guarantee technology transfer; to broaden applicability of HPC tools; and to build acquisition community confidence in HPC capability. A key Institute strategy is to become the research-to-customer bridge by pulling relevant technology from researchers and integrating it into the air armament acquisition process. During the first year, the IHAAA institute decided to concentrate the three services efforts in the areas of store separation, unsteady flow, and aircraft/store geometry library.

The store separation team picked two areas of air armament where conventional, wind tunnel based techniques have not always provided a good prediction of flight test results. These were in the areas of weapons bay flowfields, and moving control surfaces.

3 F/A-18C/Litening Pod

In support of Northrop Grumman's efforts to market the Litening Pod to the Australian and Canadian governments for use on their F/A-18 aircraft, Northrop Grumman contracted NAVAIR to support flight certification of the Litening Pod and associated pylon mounting system on Station 4. The flight certification should permit operation of the Litening Pod mounted on the pylon and operation of the pylon mounted without the pod. Northrop Grumman desired to obtain a flight certification to operate the pod on the station without restriction to the flight envelope and maneuver capability of the F/A-18 A/B/C/D aircraft using F/A-18 OFP load 17C.

NAVAIR agreed to provide pre flight analysis and flight test support of five stores on station three with Litening Pod on station four: GBU-38, GBU-12, MK-84, Dual AIM-120 and FPU-8 external fuel tank. The purpose of the flight test program was to clear these stores to their TACMAN limits. The results for the F-18C/GBU-38 and F-18C/GBU-12 were reported previously [6].

3.1 CFD tools

NAVAIR uses several CFD tools to provide pre flight trajectory predictions. In the past, NAVAIR has used Splitflow [2], USM3D [3], Overflow [5] and TranAir [7]. Recently, NAVAIR has obtained the BEGGAR and Cobalt codes. These were the primary tools that were used for this IHAAA project.

3.1.1 Description of the Cobalt Code

Cobalt is a cell-centered, finite volume CFD code. Its foundation is based on Godunov's first-order accurate, exact Riemann solver. Second-order spatial accuracy is obtained through a Least Squares Reconstruction. For parallel processing, grids are decomposed into zones using ParMetis. Since unstructured grids can be split into essentially equal zones, it achieves nearly perfect load balancing -> run on *n* processors, get a speed-up of *n*. *Cobalt* contains several turbulence models including Spalart-Allmaras, Menter's SST, Wilcox's 1998 *k-w* and Detached Eddy Simulation (DES) for Spalart and Menter's Models. For time accurate simulations, second-order temporal accuracy coupled with Newton sub-iterations still allow large time steps to be taken. New capabilities include rigid-body motion and equilibrium air physics.

Cobalt outputs directly to several leading post-processing formats. Since the resulting output files are in the post-processor's native format, reading in results will require less time and less memory. In addition, time-dependent files can be written to allow for easy visualization of unsteady data.

3.1.2 Description of the BEGGAR Code

The philosophy behind Beggar is to use a Chimera, or overlapped, grid system so that the components of a problem may be gridded independently of each other and then assembled to form the complete system of computational grids. By automating the Chimera assembly process and incorporating an algorithm to solve the rigid-body equations of motion, the code has become a user-friendly platform ideal for store separation calculations. To further increase the applicability of the code, a coarse-grain parallelization of the code has been implemented that significantly reduces the amount of wall clock time needed for complex problems. Recently, (6+) DOF has been successfully implemented into the Beggar code to allow the simulation of stores with moving components such as rotating fins.

Beggar is capable of numerically approximating the solution to either the three-dimensional curvilinear form of the Reynolds Averaged Navier-Stokes (RANS) equations, the thin-layer Navier-Stokes equations, or the Euler equations. Additionally, separate sets of equations may be solved in different blocks of the grid system. For example, a grid of a wing section may be evaluated based on the RANS equations while an outer Cartesian grid representing the free-stream may use the Euler equations to model the pertinent physics. The set of governing equations is discretized using a finite-volume formulation. The linear system of equations is solved with a symmetric Gauss-Seidel relaxation scheme, while Newton’s Method is used to advance the solution in time as well as synchronize the solution at the block boundaries. Upwinding is accomplished through either Steger-Warming flux vector splitting or Roe flux vector differencing of the inviscid flux vectors. The viscous flux vectors are discretized using central differencing. Available turbulence models include the Baldwin-Lomax algebraic model, the Baldwin-Barth one-equation model, the Spallart-Almaras one-equation model and the 2-equation K-ε with wall functions. For the Litening pod analyses only inviscid solutions were used.

3.2 F/A-18C/MK-84 Litening Pod

Flight test data existed [8] for the MK-84 store located on the F-18C station 3 with an ATFLIR located on station 4. Extensive wind tunnel and flight test data for the GBU-31 (MK-84 JDAM) on station 3 with an AIM-7 on station 4 were also available.

Preliminary Euler CFD calculations [9] indicated that the Litening pod would have similar aerodynamic effects to the ATFLIR. It was decided that an incremental CFD approach would be used for this configuration. The wind tunnel data for the GBU-31 next to the AIM-7 would be corrected by the Cobalt predicted increments in aerodynamic coefficients for the effects of Litening Pod relative to the ATFLIR. The MK-84/Litening Pod Cobalt solution at M = 0.95 is shown in Figure 1.

GBU-31 on station 3 with ATFLIR on station 4 increments were computed to the basic GBU-31 wind tunnel test data using the Cobalt unstructured code. The ATFLIR predicted increments were then used with the GBU-31 grid data adjacent to the AIM-7 to predict the GBU-31 trajectory with ATFLIR on station 4. As may be seen in Figure 2, an excellent match with flight test was achieved using this approach. Since no wind tunnel test data were available for the MK-84 on station 3, an approach[10] using MK-84 freestream data combined with corrected GBU-31 grid data was used. The MK-84 trajectory predicted using this approach was again an excellent match with the flight test data, Figure 3. note that these predictions were done well after the flight tests were completed.

The final step was to use the CFD predicted Litening Pod induced increments (- 1. in C_m and 1 in C_n) and the GBU-31 clean grid data to predict the MK-84 trajectory next to the Litening pod. In this case, the prediction was done prior to the flight test. An excellent match with the flight test at M = 0.90 was obtained, Figure 4.

The agreement with the flight test data was equally good at M = 0.93, 570 KCAS, Figure 5. The agreement between the predicted and actual miss distances is shown in Figure 6.

On the basis of these results, the MK-84 was cleared to it's end point with the Litening pod on station 4.

3.3 F/A-18C/MK-82 Litening Pod

For the MK-82 and GBU-38 stores a similar procedure was followed. Extensive wind tunnel and flight test data were available for the GBU-38 with adjacent ATFLIR. An excellent match with flight test results was achieved [11] using this wind tunnel data. The Cobalt code predicted store carriage loads were compared to the wind tunnel data in Figure 7.

As may be seen in Figure 7, there was an excellent match in the predicted yawing moment for the GBU-38 store with adjacent ATFLIR to wind tunnel data. The magnitude of the pitching moment was overpredicted, but the trends were in good agreement with the test data. The predicted pitching and yawing moments for the MK-82/Litening pod are very similar to the GBU-38 values. When the GBU-38 grid data were combined with the MK-82 freestream data, no significant differences were seen in the GBU-38 or MK-82 trajectories adjacent to the Litening pod. This approach had been validated by the excellent match between pre-flight predictions and flight test data for the MK-84/Litening pod flight test program, Figure 8. To provide an estimate of the worst conditions, the Mk-82 trajectories were run with a yawing moment increment of 1.0. As may be seen in Figure 9, this substantially changes the trajectory.

However, the predicted miss distance for this case is little different to that for the GBU-38 flight test results presented previously [6], Figure 10. Since the miss distance prediction was still greater than ten inches, it was felt that flight test for this case was not warranted.

On the basis of these predictions, the MK-82 store was cleared to it's TACMAN limits without any flight testing. This was the first time that the Navy has cleared a store to it's end point without any flight testing required.

F/A-18C/FPU-8 Litening Pod

The BEGGAR code was used to clear the 330 gallon tank adjacent to the litening pod. CFD predictions were compared to flight test data for the FPU-8 trajectory next to ATFLIR, Figure 11. Based on these results, the flight clearance was issued to the end point. Excellent match with the pre flight predicted miss distance was demonstrated, Figure 12.

4. CONCLUSIONS

Have we finally replaced the need for the wind tunnel in store separation? Not quite yet!

The examples shown in the paper, and which probably represent the limit of CFD's applicability, had several characteristics that made the approach possible. The hierarchy of store separation difficulty, in decreasing order, can be described as follows:

1) New store on new aircraft
2) Existing store on new aircraft
3) New store on existing aircraft
4) Existing store on existing aircraft (new configuration)
5) Existing store on modified aircraft (previously cleared configuration)

All the examples shown fall in the last category. The reason that CFD was a practical alternative was that there existed substantial wind tunnel and flight test data for both the F/A-18C/D aircraft and the stores that were tested. Since the aircraft modification only affected one station, it was reasonable to calculate the incremental effects using CFD. For cases where large amounts of test data are required, the wind tunnel has no match at the present time.

Even when these conditions are met, the need for wind tunnel testing has not been eliminated. The Dual AIM-120, and all stress mounted on the CVER, were not considered to be capable for flight clearance without wind tunnel testing.

5. ACKNOLEDGEMENTS

The authors wish to express their appreciation to the HPCMPO office, without whose funding support this work would not have been possible.

6. REFERENCES

[1] Cenko, A., et al “Integrated T&E Approach to Store Separation – Dim Past, Exciting Future,” ICAS 96-3.3.2, Sept. 1996.

[2] Sisco, B., and Cenko, A., "SPLITFLOW Prediction of MK-83 Trajectories from the CF-18 Aircraft," AIAA Paper 2001-2430, June, 2001.

[3] Walsh, J., and Cenko, A., "USM3D Prediction of MK-83 Trajectories from the CF-18 Aircraft," AIAA Paper 2001-2430, June, 2001.

[4] Cenko, A., Niehwoner, R., and Ryckebusch, C.,“ “Evaluation of the Capabilities of CFD to Predict Store Trajectories from Attack Aircraft,” ICAS 2002 paper 2.6.1.

[5] Ray, E. S.,”CFD Method for Separation of SLAM-ER from S-3B and P-3C,” AIAA paper 2002.

[6] Cenko, A., “One CFD Calculation to End Point Flight Testing **(***Has CFD Finally Replaced the Wind Tunnel***?)**, AIAC paper 2005-003, August 2005.

[7] Madson, M. et al “TranAir Computations of the flow about a Generic Wing/Pylon/Finned-Store Configuration,” AIAA paper 94-0155, Jan. 1994.

[8] Carron, T. J., “Advanced Targeting Forward Looking Infrared (ATFLIR) Phases I and II Adjacent Stores Separation Testing on F/A-18A/B/C/D Aircraft,” NAVAIR Report #NAWCADPAX/RTR-2000/125, Oct 2003.

[9] Stadhopolis, N., “MK-84 Store Separation Characteristics Comparison Between Litening and Nighthawk Pods,” BAES Report MAU-261-239, July 2004.

[10] Davids, S., and Cenko, A., “Grid Based Approach to Store Separation,” AIAA Paper 2001-2418, June 2001.

[11] Cenko, A.T., et al **“**Use of Statistical Tools to Improve Modeling and Simulation of Store Separation,” Aeronautical Journal, Sept. 2005.

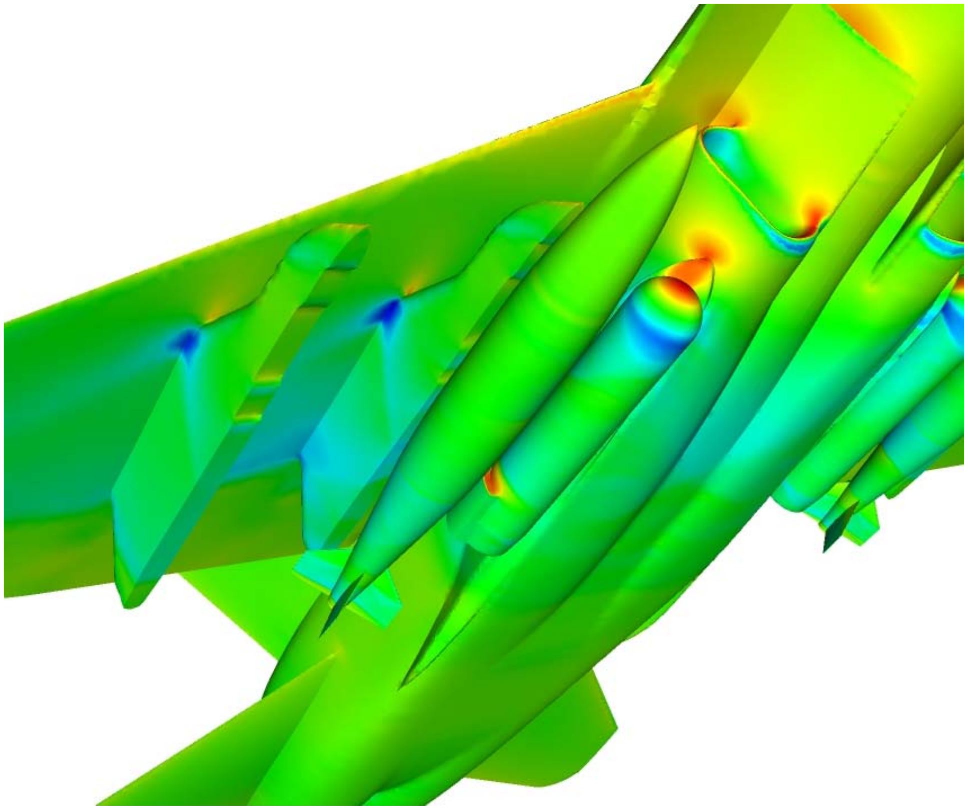

Figure 1 COBALT Solution of F-18C/MK-84 Litening pod Station 4

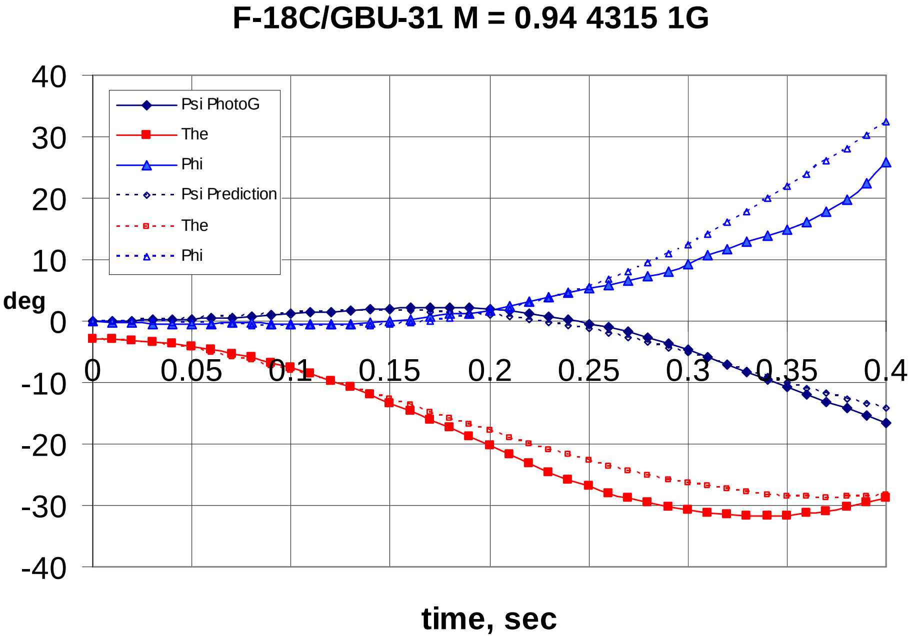

Figure 2 GBU-31 Trajectory next to ATFLIR

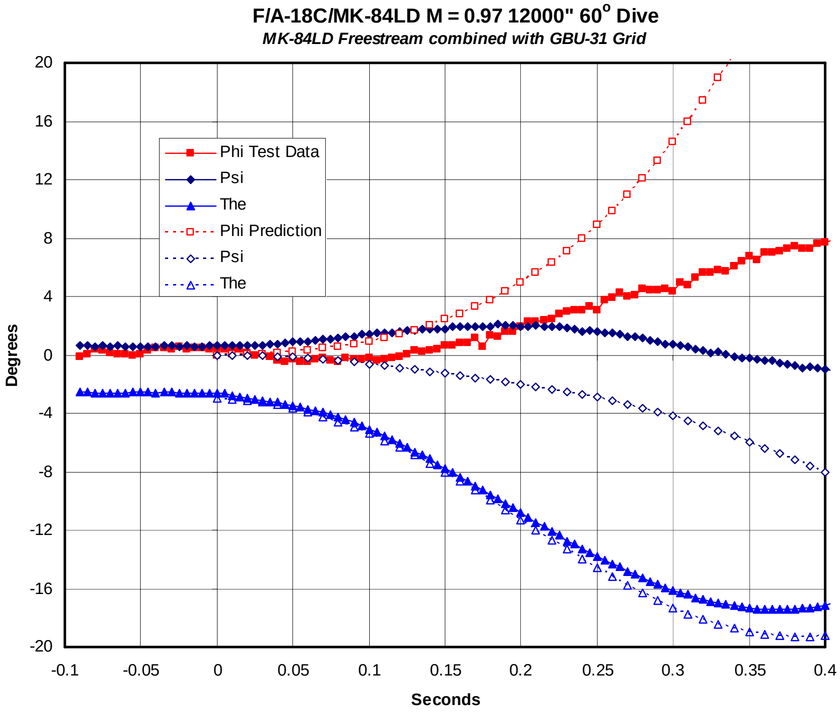

Figure 3 MK-84 Trajectory next to ATFLIR

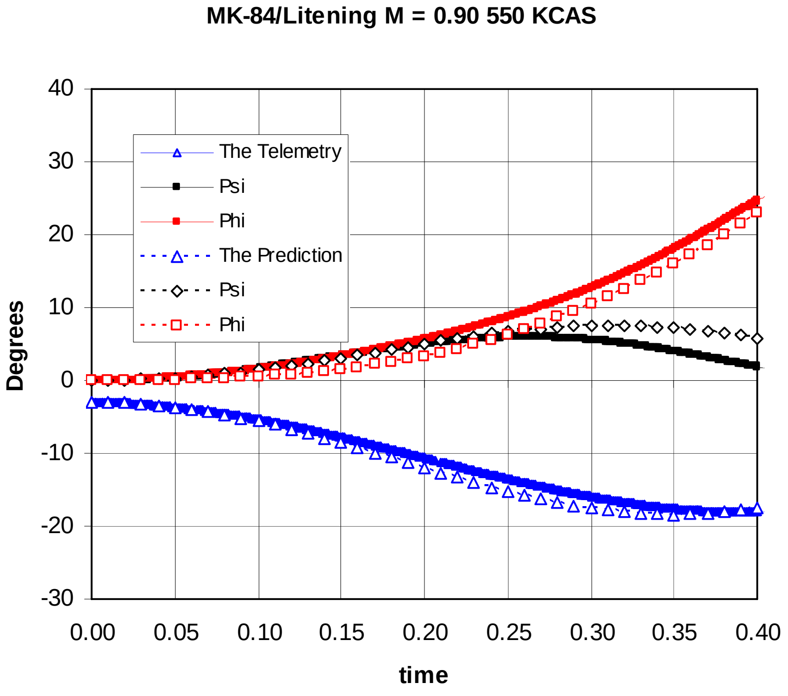

Figure 4 MK-84 Trajectory next to Litening Pod at M = 0.90

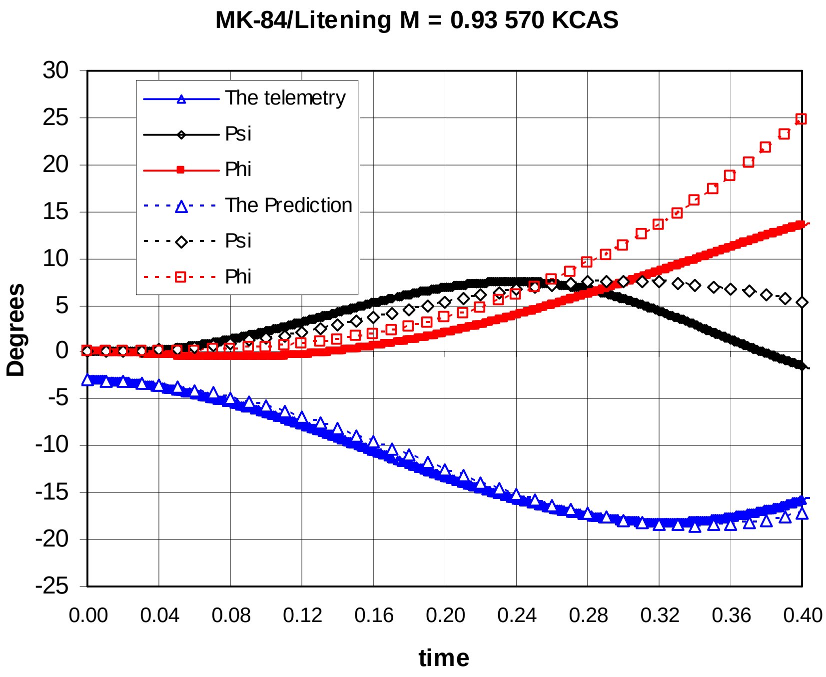

Figure 5 MK-84 Trajectory next to Litening Pod at M = 0.93

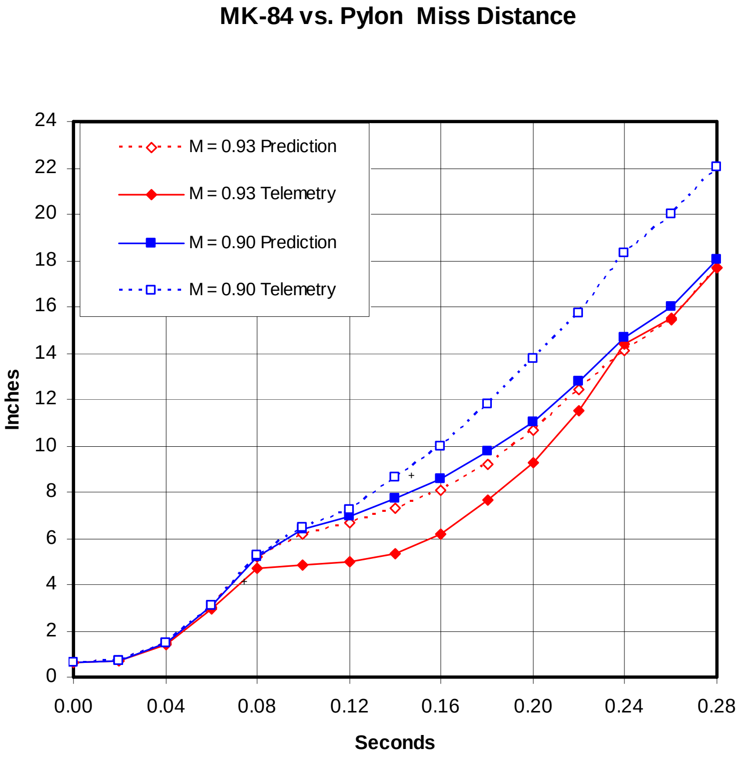

Figure 6 MK-84 Miss Distance

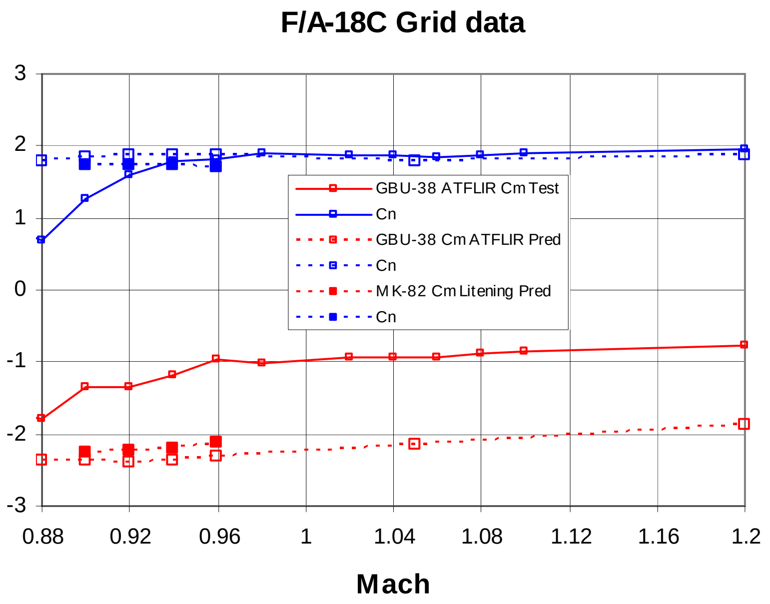

Figure 7 GBu-38 and MK-82 C_m and C_n Mach Variation

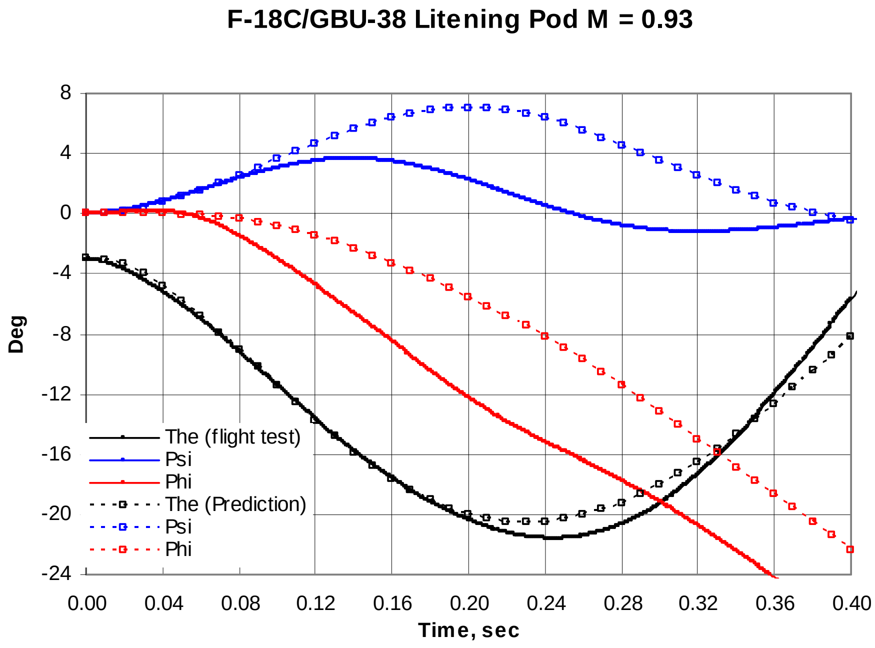

Figure 8 GBU-38 Trajectory Comparison

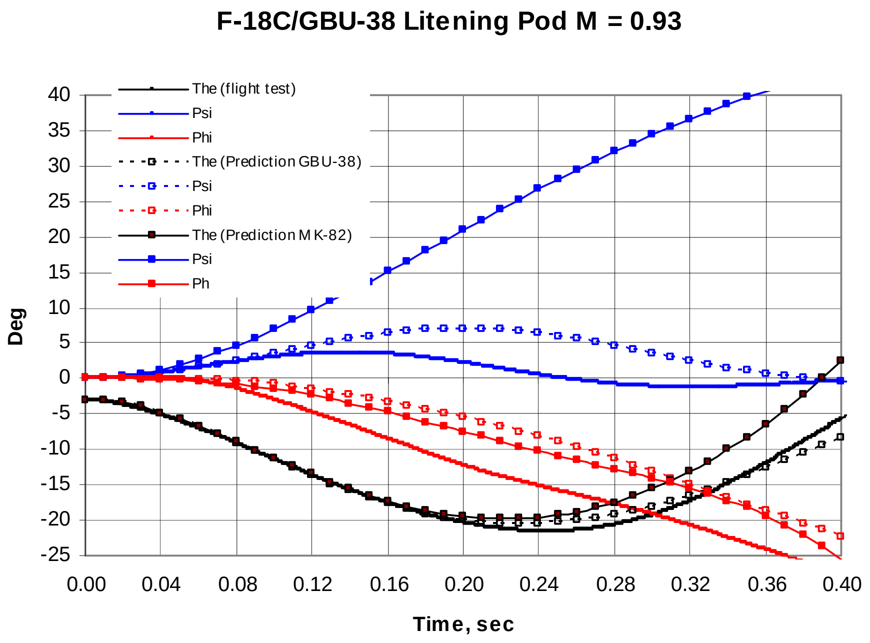

Figure 9 MK-82 Worst case trajectory Prediction

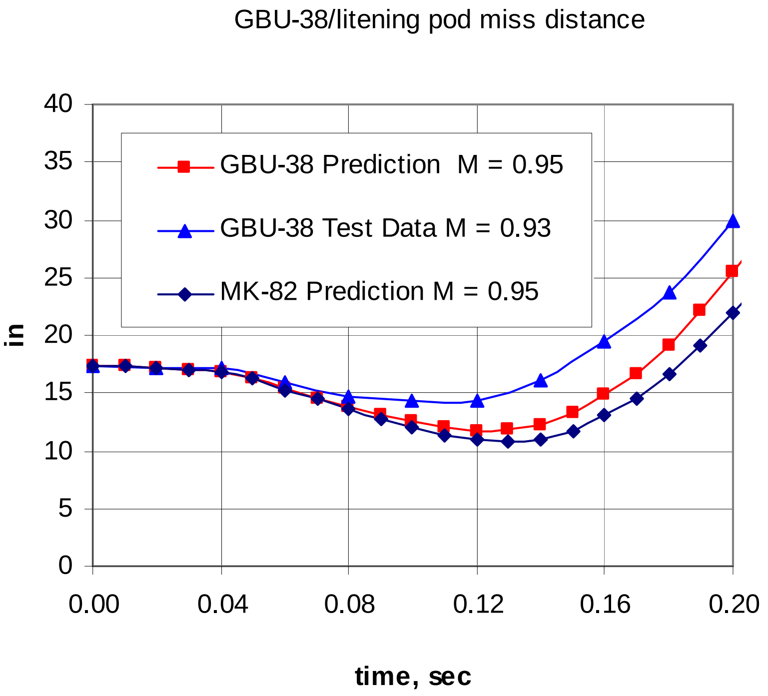

Figure 10 MK-82 Miss Distance Comparison

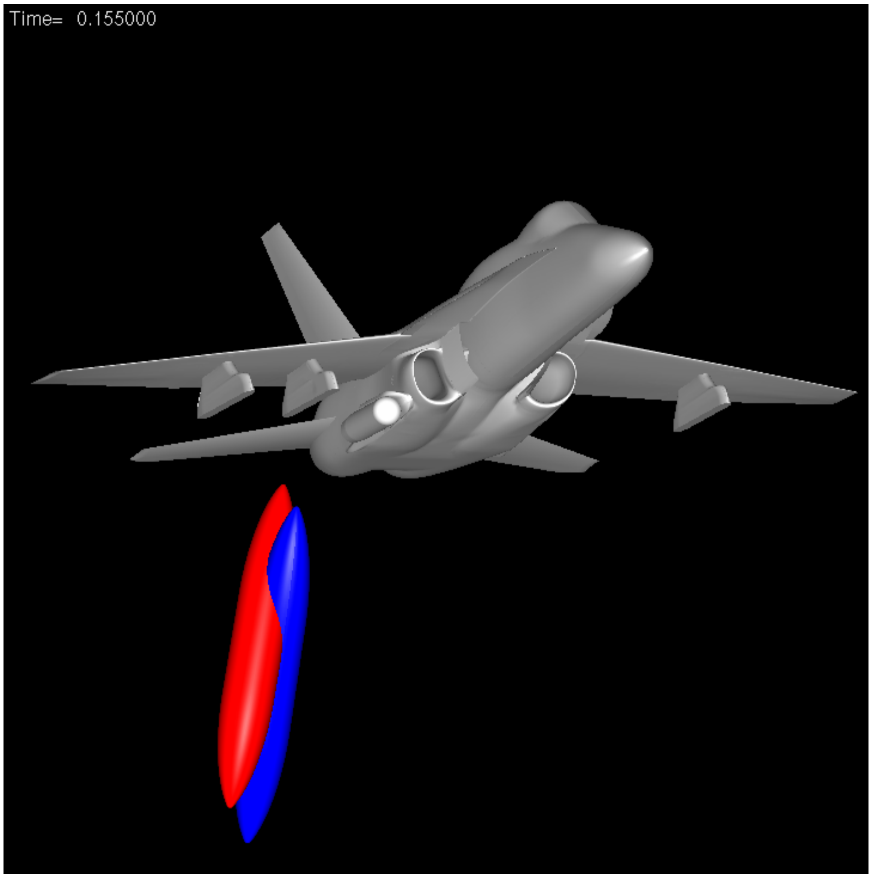

Figure 11 Tank Trajectory Comparison

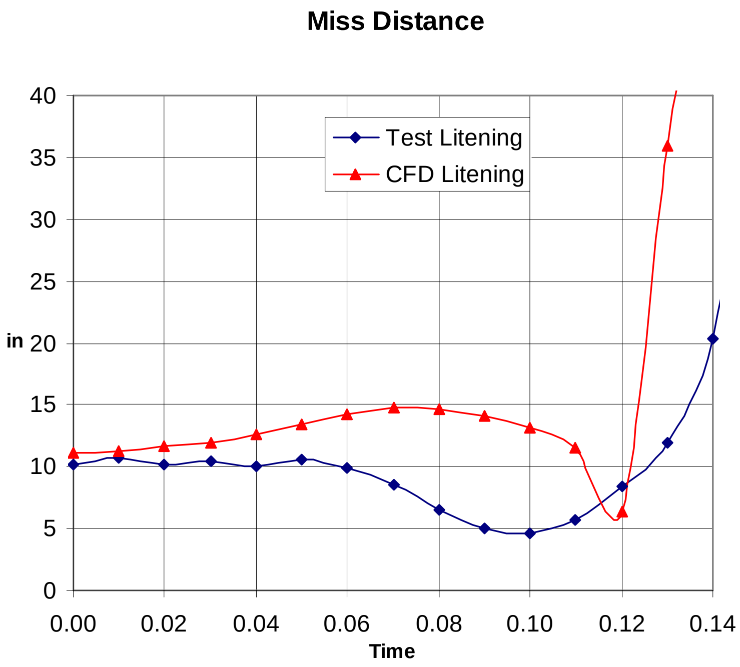

Figure 12 Tank Miss Distance comparison