ACFD APPLICATIONS TO STORE SEPARATION

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ABSTRACT

ACFD (Applied Computational Fluid Dynamics) is a tri-service project which has the purpose of verifying Computational Fluid Dynamics (CFD) tools for use by the aircraft-store certification organizations. The project is part of the Weapons Modification and Simulation Capability (WMASC) program, which is funded by the Office of the Secretary of Defense (OSD) Central Test and Evaluation Investment Program (CTEIP). During the past several years, several CFD codes have been evaluated for their ability to predict store loads in aircraft flowfields at transonic speeds. The paper will present the latest results of these evaluations for store external carriage loads and cavity flowfields.

NOMENCLATURE

BL: Aircraft Buttline positive outboard, in.
C_l: Rolling moment coefficient, rt wing down
C_m: Pitching moment coefficient, nose up
C_n: Yawing moment coefficient , nose right
FS: Aircraft Fuselage Station, positive aft, in.
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
PHI: Store roll angle positive rt wing down. deg.
PSI: Store yaw angle, positive nose right, deg.
THE: Store pitch angle positive nose up, deg.
WL: Aircraft Waterline, positive up, in.
Z: Store C.G. location, positive down, ft.
α: Angle of attack, deg.
α_ι : Upwash angle, positive up, deg.
δ_ι: Sidewash angle, positive outboard, deg.

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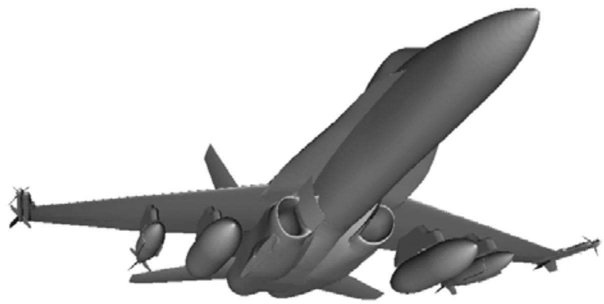
BACKGROUND

For CFD to be useful to a store separation flight test program the tool that is used must be able to provide reliable answers in a matter of hours or days. At the present time only panel methods that solve the linearized potential flow equations have this capability. The Navy has successfully employed potential flow techniques[1] to provide aircraft flowfield information in a qualitative sense. Unfortunately, these codes are not usable at transonic speeds, where most store separation problems occur. Although higher order methods (Euler and Navier Stokes) may have the potential to provide the correct answers at transonic speeds, at the present time these solutions may not be achieved until after the flight test program is completed.

The goal of the ACFD project is to provide the store separation engineer with a reliable CFD tool that can provide answers in times comparable to panel methods at transonic speeds. In 1996 the ACFD project funded several efforts to evaluate the ability of six different CFD codes to predict the flowfield for a generic store in the presence of the F-16 aircraft. The results[2-7] of these efforts were presented at an invited session at the AIAA Applied Aerodynamics Conference in 1996. Based on these evaluations, it was decided that one of these codes[2] appeared superior to the others in providing answers at transonic speeds in a reasonable amount of time. This code was selected to further evaluate its ability to actually quantitatively predict store trajectories by comparing to both wind tunnel and flight test data. This effort was conducted by the Navy, and the test case used was the JDAM on the F-18 outboard wing pylon and a 330 gallon fuel tank on the inboard pylon.



F/A-18/JDAM CONFIGURATION

EXTERNAL CARRIAGE

FLIGHT TEST RESULTS

For the F-18/JDAM the wind tunnel data predicted an anomaly in the aircraft flow-field. The aerodynamic coefficients decreased from M = 0.80 to M = 0.90, and then suddenly increased. This result was actually confirmed by the flight test results[8]. As may be seen in Figures 1 and 2, the trajectory for the clean aircraft with the store on the inboard pylon at M = 0.90 was more benign than that at M = 0.82. Since the dynamic pressure increased by 20% at the higher Mach number, if the aerodynamic moments were the same, the pitch attitude at M = 0.90 should have been at least 5 degrees larger.

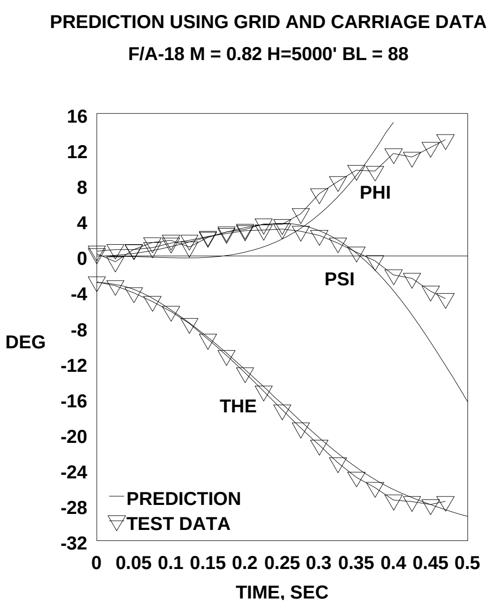


FIGURE 1 JDAM JETTISON COMPARISON

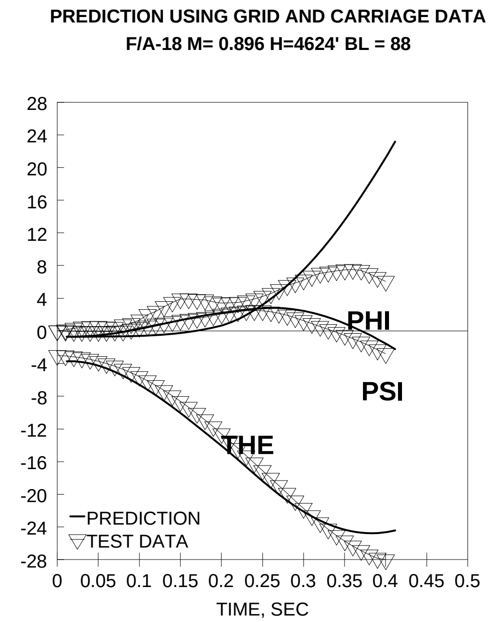


FIGURE 2 JDAM JETTISON COMPARISON

WIND TUNNEL TEST DATA

Both Captive Trajectory System (CTS) grid data, and store aerodynamic force and moment data measured on the wing pylon were available for this aircraft configuration (Config 1). When these data were input into a six-degree-of-freedom trajectory code, an excellent match with the flight test was achieved. This indicates that the wind tunnel test data accurately matched the flight test conditions. When carriage loads data were not used the trajectory predictions were[1] in much poorer agreement with the flight test results.

An explanation of the flight test behavior can be deduced by examining the store grid loads at these two Mach numbers. As may be seen in Figures 3 and 4, the pitching moment for the same aircraft configuration for this store at carriage actually decreases at M = 0.90 by 20%. The yawing moment is of similar magnitude for both Mach numbers. Only comparisons for moments are shown, since these have the principal impact on the trajectory.

F/A-18 ALPHA = 0

H = 5000' CONFIG-1 FLAPS = 0/0

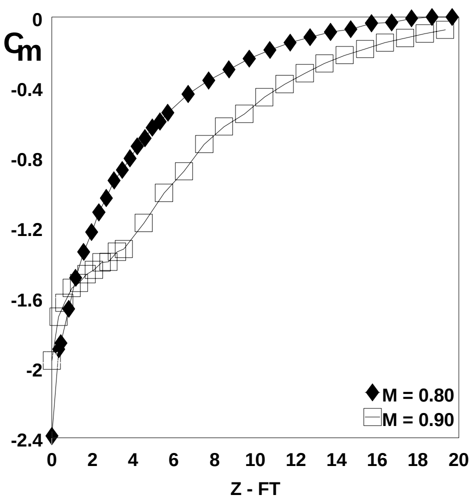


FIGURE 3 JDAM GRID COMPARISON

F/A-18 ALPHA = 0

H = 5000' CONFIG-1 FLAPS = 0/0

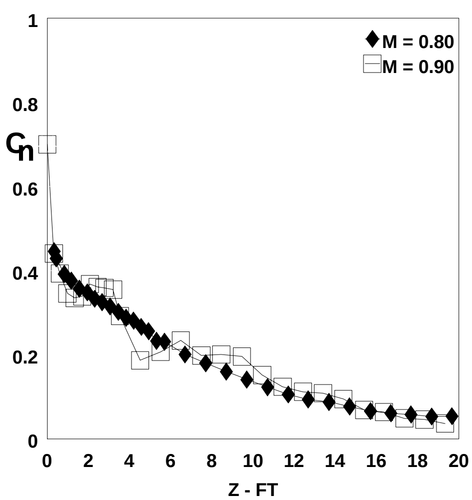


FIGURE 4 JDAM GRID COMPARISON

In an effort to better understand this behavior, wind tunnel test data for other stores for the F-18 configuration with a fuel tank on the inboard pylon and the store on the outboard pylon were examined. These data were selected because they exhibited the most severe variation with Mach number. Figures 5 and 6 show the change in moments for the JDAM, MK-84 and SLAMER stores with Mach number. The MK-84 and JDAM are both of similar size and shape; their behavior shows similar trends: a decrease in moments from M = 0.8 to M = 0.9, followed by a sudden increase. Note that this behavior is store dependent, since the SLAMER (a longer store) acts differently; it's pitching moment decreases with Mach number, while the yawing moment increases. For CFD to be a useful tool for store separation, it must be able to predict, at least qualitatively, this type of behavior.

STORE OUTBOARD, FUEL TANK INBOARD

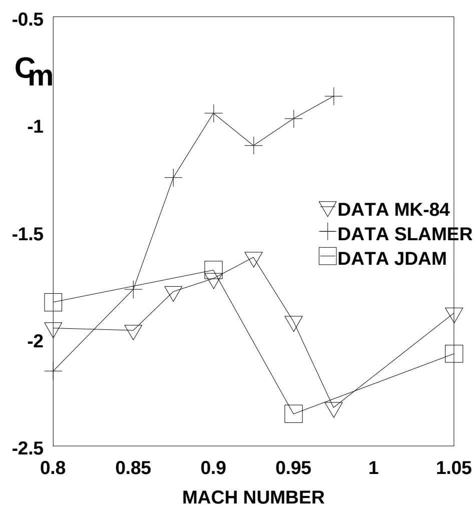


FIGURE 5 MACH EFFECT ON PITCHING MOMENT

STORE OUTBOARD, FUEL TANK

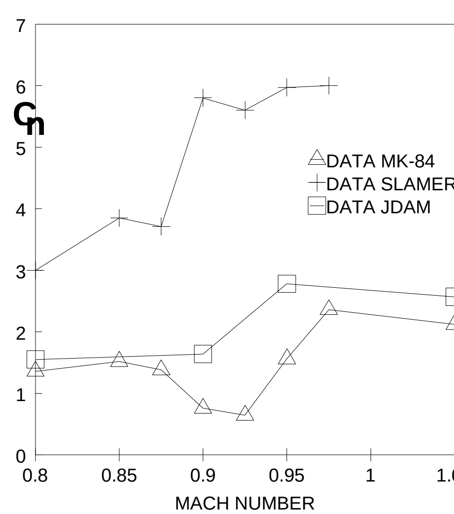


FIGURE 6 MACH EFFECT ON YAWING MOMENT

SPLITFLOW RESULTS

An attempt was made to see if the SPLITFLOW code could predict the sudden change in pitching and yawing moments seen in both the wind tunnel and flight test data.

A SPLITFLOW model was developed of F-18 aircraft with a 330 gallon tank on the inboard pylon and JDAM outboard.

SPLITFLOW is a Cartesian-based, unstructured, adaptive Euler/Navier-Stokes solver. The Cartesian approach generates cube-shaped cells that are aligned with the Cartesian coordinate axes. Grid refinement involves recursively sub-dividing each cell into eight cells which become "children" to the initial cell. Boundary geometry is defined by triangular faces, or facets. At boundaries, cells are "cut" to account for volume and flux changes. This feature allows SPLITFLOW to handle extremely complex geometries, and little care need be taken by the user to prepare or maintain the grid. Initial grid cell sizes are scaled from geometry facet sizes and are then refined or derefined, at specified iteration intervals, by the solver based on the user's choice of gradient adaptation functions (Mach number, pressure, etc.). The derefinement process uses statistical methods to look for low-gradient regions in the flowfield from which to remove cells, thus reducing grid density and computational requirements. The derefinement process is limited by a grid smoothing algorithm which requires adjacent cells to be no more than one "generation" apart. Further, cells are deleted by groups of eight only if all of the child cells in that group are flagged for derefinement. This is done to maintain the data structure. The refinement process follows, also applying statistical methods, and searches for high gradients to determine where cells need to be added. Since the code is "smart" enough to place cells where they are needed, the best initial grid is usually sparse and the flowfield is used to determine where new cells should be placed. With a sparse initial grid, flowfield information can propagate in fewer iterations, each of which take less time because there are fewer cells. For example, the original grid, which was limited to 800,000 cells, was appropriately initialized by slightly more than 100,000 cells. Another benefit of cutting boundary cells is that geometry changes can be made easily while salvaging a developed solution. For example, if the user has a converged solution of an aircraft with undeflected control surfaces, a new geometry model with deflected control surfaces can simply be substituted.

Originally, the F-18/JDAM was constrained to 800,000 grid cells. The SPLITFLOW model was run on an SGI ONYX which limited the size of the problem. For 800,000 Cartesian cells, using four processors, one case (i.e. one Mach number and aircraft angle of attack) took 167 hours for 2000 iterations.

As may be seen in Figures 7 and 8, SPLITFLOW considerably overpredicted the JDAM carriage pitching and yawing moments at Mach numbers less than 0.95. For the subsonic Mach numbers the solutions were not converged even after 2000 iterations. This was due to the fact that the shock interaction between the store and the adjacent fuel tank was continually refined and it's location kept changing.

The solutions at the higher transonic Mach numbers (M>0.925), as well as at the supersonic Mach numbers were well behaved and converged in 1000 iterations. The predictions at the higher Mach numbers were in closer agreement with the wind tunnel test data.

Since one of the purposes of the study was to determine the minimum time required to obtain a reasonable solution, the F-18/JDAM was rerun using 300,000 Cartesian cells at the same Mach numbers. For 300,000 Cartesian cells 2000 iterations took 93 hours on one processor.

As may be seen from Figures 7 and 8, the solutions using the reduced number of grid cells appeared to be in better agreement with the test data at M = 0.90. This can be attributed to the code's fortuitous inability to over-refine the shock location, since the solutions at the supersonic Mach numbers were much worse. SPLITFLOW also still considerably overpredicted the pitching and yawing moments at the lower Mach numbers. It appears that the code might be generating a subsonic shock that in real life would be dissipated by viscous forces. Since the solution for 800,000 cells was better than for 300,000, solutions for 1,5000,000 cells, as well as a viscous case, are planned.

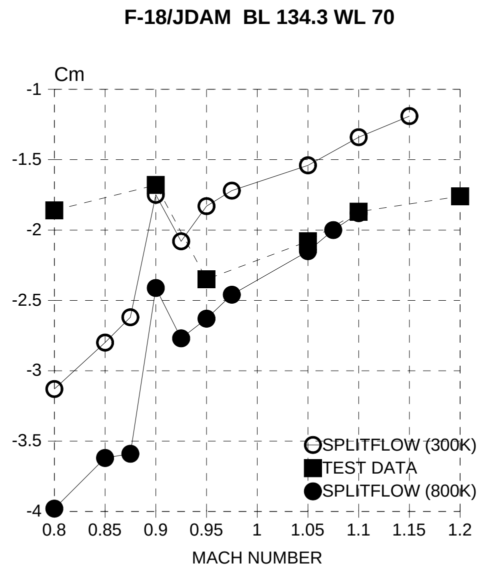


FIGURE 7 MACH EFFECT ON PITCHING MOMENT

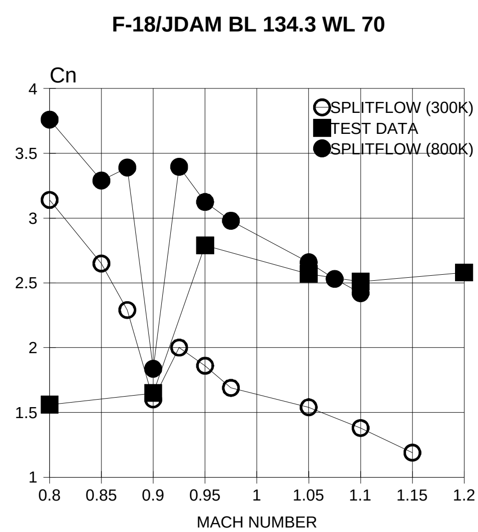


FIGURE 8 MACH EFFECT ON YAWING MOMENT

These comparisons will have to be done on a supercomputer, since the SGI workstation that we use has a storage capacity that limits the job size to 800,000 cells.

The forces were generally in better agreement with the test data than were the moments, Figure 9. This behavior has been previously noted, and can be attributed to the fact that forces, unlike moments, are not significantly affected by shock location. The correlation for the 300,000 cell case was significantly worse than for 800,000, Figure 10.

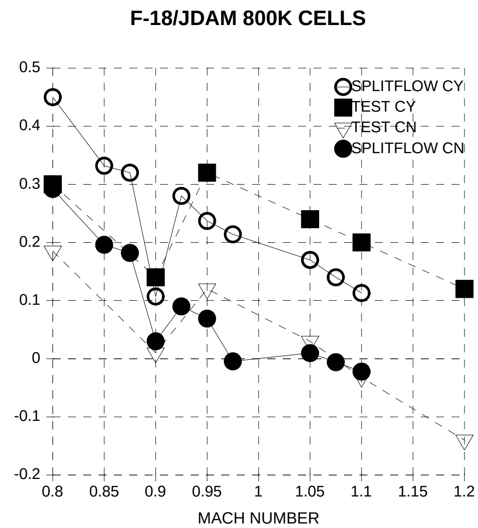


FIGURE 9 MACH EFFECT ON FORCES

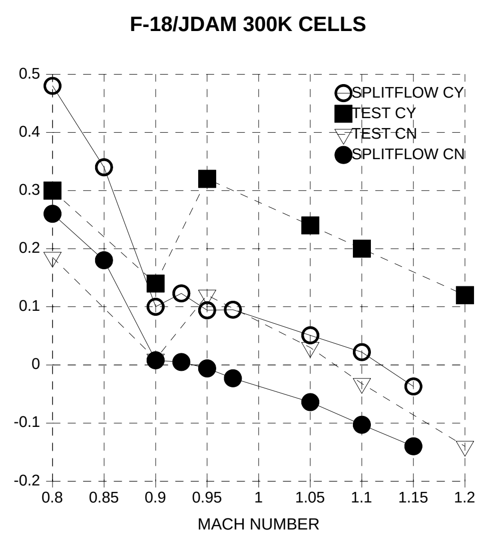


FIGURE 10 MACH EFFECT ON FORCES

TRAJECTORY PREDICTIONS

An indication of the trajectory errors that incorrect aerodynamic carriage loads can lead to may be seen in Figures 11 and 12. In both cases the 300,000 cell SPLITFLOW predicted carriage loads and moments from Figures 7 through 10 were used, in conjunction with wind tunnel JDAM freestream test data and the IFM[1] technique, to predict the trajectories at Mach 0.8 and 0.9. The 300,000 cell case was selected because the carriage predictions were in closer agreement for the subsonic cases.

The JDAM trajectories at the lower Mach number totally overpredict the pitch and yaw motion, and would be useless in planning a flight test program, Figure 11.

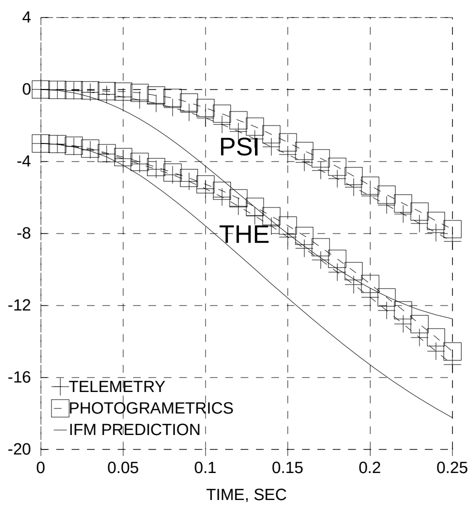


FIGURE 11 JDAM JETTISON COMPARISON

For M = 0.90, the SPLITFLOW carriage load prediction was in much closer agreement with the test data. As may be seen in Figure 12, the predicted trajectory is in good agreement with the flight test data. Obviously, if the carriage loads can be accurately predicted, there is a good chance that the flight test trajectories can also be matched.

INTERNAL CARRIAGE

For the internal carriage work the test case selected was the WICS cavity at Mach number 0.95 and RE 2.5 Ex10^6. Comparisons between sound pressure levels inside the cavity and pressure coefficients on the cavity walls were undertaken with six different algorithms (OVERFLOW[7], SPLITFLOW[2], NXAIR[10], BEGGAR[11], COBAL[12], and NASTD[13]). An evaluation of the preliminary results was made in January, 1988, at which time it was decided that more time would be required to complete the effort.

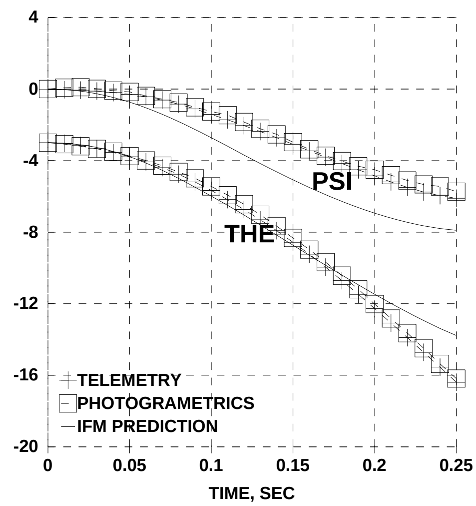


FIGURE 12 JDAM JETTISON COMPARISON

Preliminary results from these efforts indicate that all of the methods can predict the frequency, but miss the magnitude of the sound pressure level in the cavity. These results were not available in time to be included in this paper. These efforts are scheduled to be concluded in June of 1998, and will be presented at the ICAS meeting.

FUTURE DIRECTION

CFD CHALLANGE

Over the past several years there have been two notable organized efforts to validate, demonstrate and accelerate the insertion of CFD methods into the store certification processes for external stores carriage and release. These efforts have been documented in AIAA conference proceedings. These were the Generic Wing/Pylon/Finned Store[14-17] and the F-16/Generic Finned Store[2-6] test cases. Many important lessons were learned, however, neither experimental test case included flight test data ("real" store trajectories). Because of this limitation, store certification engineers continue to express skepticism towards the accuracy of CFD methods. Also, the CFD community raised concerns about the credibility of portions of the wind tunnel test data, criticizing scale, model support interference, and wall effects. Therefore, there is a desire within the ACFD program to reconcile these issues by conducting additional analysis by using a data set that includes both wind tunnel and flight test data.

SELECTION OF TEST CASE

Both large wind tunnel and flight test data exist for the F/A-18C JDAM configuration as a result of a recent Navy store certification effort. A 6% F/A-18C JDAM model was tested in the CALSPAN 8x8ft tunnel using both the Captive Trajectory System (CTS) and pylon mounted store approaches. Pylon mounted carriage loads, CTS grid data and CTS trajectories are available. During the flight test phase, both photogrametrics and telemetry were used to track the position of the store during releases. Out of these tests, two release conditions have been selected for this CFD Challenge. The basis for these two cases included the following considerations: 1) matching aircraft and store geometry in both wind tunnel and flight tests, 2) correlation between wind tunnel data and flight test data, 3) possession of both high transonic and low supersonic cases with interesting miss distance time histories, 4) ability to publicly release the wind tunnel and flight test data to an international audience.

TEST CASE PARAMETERS

	Case 1	Case 2
Mach	0.962	1.055
Altitude (ft)	6,332	10,832
AOA	0.46	-0.65
Dive Angle (deg)	43	44

For these two test cases, the configuration geometry for the wind tunnel and flight test are nearly identical. The only notable differences are: 1) the wing tip station #1 in the wind tunnel test had an AIM-9 and 2) the armpit station #4 in the wind tunnel test had an AIM-7. However, the Navy has completed a 6DOF trajectory analysis using the wind tunnel derived pylon mounted carriage loads and the predicted trajectories matched the flight test trajectories for these two cases. Therefore, based on this analysis the wind tunnel derived carriage loads correlate well with the flight test trajectories, in spite the two above discrepancies between the wind tunnel and flight tested configurations and other test issues such as scale, model support interference and wall effects for this Challenge.

SCHEDULE

The international community has been invited to participate in this CFD challenge. The meeting is to take place at the AIAA January 1999 meeting in Reno, Nevada. A series of invited papers will be presented at the meeting. The first paper will provide analysis of the wind tunnel and flight test data, as well as aerodynamic coefficients that were deduced from the flight test results. It is hoped that this meeting will finally help to determine the applicability of CFD to store separation.

CONCLUSIONS

It is clear that at the present time CFD can not be expected to accurately provide a good estimate of store carriage loads in a reasonable time frame. Although SPLITFLOW initially seemed promising, it appears that a large number of cells (meaning solution times on the order of months on a workstation) may be needed to achieve a convergent Euler solution. The code may have to be run using the Navier Stokes formulation to achieve the necessary convergence at subsonic speeds. The Navy plans to use SPLITFLOW with 1,5000,000 cells to take part in the CFD challenge next year.

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