Investigation of Store Separation and Trajectory of Weapons in Military Aircraft

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ABSTRACT

Flow separation, due to presence of weapon attachment and deployment leads both the aircraft and missile to be unstable. The study concentrates more on prediction of the separation movements of the external store weapons carried out on military aircraft wings under supersonic range and various angles of attack. It is an important task to define the safe operational-release envelopes, in perspective view of Aerodynamics. Predicting the trajectory of the store in highly dynamic separations such as the release of multiple store, during maneuvers is very difficult to simulate in a wind tunnel. Thus a computational approach is well suited, to predict the various underlying information about its physics of store separation.

Key Words: Store separation, Trajectory, Mach number, Dynamic Separation.

1. INTRODUCTION

Computational Fluid Dynamics is an integral part of flight testing and clearances for store separation problems. Trajectories of stores released from internal weapons bays have been shown in recent tests to diverge from predicted paths. It is critical to develop an accurate method of predicting the trajectory for a range of store configurations. The use of CFD to model the unsteady flow that is present inside and immediately around the weapons bay is both time consuming and problematic. The effect of this flow has the potential to make the store trajectories unrepeatable; an unacceptable condition for the purposes of providing a flight clearance for a particular configuration. Store separation analysis based on CFD has the potential to show significant savings in terms of cost and schedule for future weapons programs especially for complex store releases such as those released from a weapons bay.

During the 1960's, the Captive Trajectory System (CTS) method for store separation wind tunnel testing was developed. The CTS provided a considerable improvement over the hit or miss method, and became widely used in aircraft/store integration programs prior to flight testing. However, CTS was not utilized in an integrated approach, since the group conducting the wind tunnel test was generally separated both in organization and location from those responsible for conducting the flight test program and determining the safe separation envelope.

Generally, there are three approaches that have been used: Wind Tunnel Testing Computational Fluid Dynamics (CFD) analyses and Flight Testing. During the late 1970's and early 1980's, computational Aerodynamics had finally matured to the point of providing a solution for a store in an aircraft flow field. However, instead of leading to a renaissance in store separation methodology, it mostly led to an ongoing argument among the three groups. The Computational Fluid Dynamic (CFD) community claimed they could replace the wind tunnel, the Wind Tunnel (WT) engineers said (correctly, since one CFD calculation is useless in calculating a store's trajectory) the CFD were unaware of the complexity of the problem, and the Flight Test engineers (FT) said neither group could provide them with the necessary data to conduct a successful flight test program.

The Captive Trajectory Support (CTS) system is a model support which can move stores such as bombs or missiles along a predicted trajectory and can simultaneously measure the aerodynamic forces and moments acting on the stores. The CTS system can be used either trajectory mode or grid test mode. In the trajectory mode, the trajectory of the store is computed simultaneously with the measured aerodynamics as the store moves inside the wind tunnel as accordance to the solution of equations of motion of the store. Therefore, the store moves along the computed trajectory as if it separates from the aircraft. The CTS system software is an operating system for the CTS system, while the off-line 6-DOF simulation software is an engineering trajectory prediction program which uses the grid database generated by the aerodynamic database software from the grid tests and the free-stream tests.

The purpose of this paper is to demonstrate the accuracy and technique of using an unstructured dynamic mesh approach to store separation. The most significant advantage of utilizing unstructured meshes is the flexibility to handle complex geometries. Grid generation time is greatly reduced because the user's input is limited to mainly generation of a surface mesh. Though not utilized in this study, unstructured meshes additionally lend themselves very well to solution-adaptive mesh refinement/coarsening techniques, especially useful in capturing shocks. Finally, because there are no overlapping grid regions, fewer grid points are required.

The computational validation of the coupled 6-DOF and overset grid system is carried out using a simulation of a safe store separation event from underneath a delta wing under transonic conditions (Mach number 1.2) at an altitude of 11,600 m [15] and various angles of attack (0°, 3° and 5°) for a particular weapon configuration with appropriate ejection forces. An inviscid flow is assumed to simplify the above simulations.

2. WEAPONS DEPLOY MODELLING

In the present work store-separation numerically simulation events were demonstrated on a generic pylon/store geometric configuration attached to a clipped delta wing, as shown in FIGURE 2.1. Benchmark wind-tunnel experiments for these cases were conducted at the Results available from these studies include trajectory information and surface pressure distributions at multiple instants in time. The computational geometry matches the experimental model with the exception of the physical model being 1/20 scale.

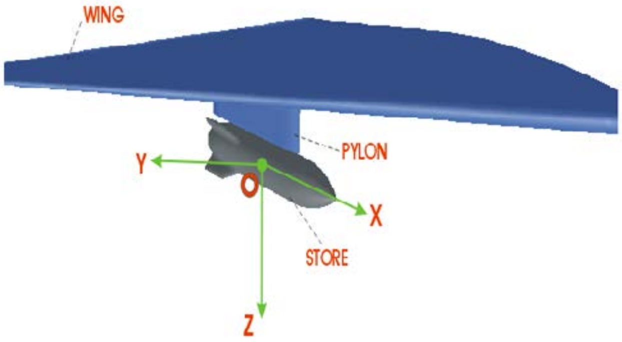


Figure.2.1- Global coordinate system OXYZ for store separation trajectory analysis.

The aircraft's wing is a 45-degree clipped delta with 7.62 m (full scale) root chord length, 6.6 m semi-span, and NACA 64A010 airfoil section. The ogive-flat plate-ogive pylon is located span wise 3.3 m from the root, and extends 61 cm below the wing leading edge. The store consists of a tangent-ogive fore body, clipped tangent-ogive after body and cylindrical centre body almost 50 cm in diameter. Overall, the store length is approximately 3.0 m. Four fins are attached; each consisting of a 45-degree sweep clipped delta wing with NACA 008 airfoil section. To accurately model the experimental setup, a small gap of 3.66 cm exists between the missile body and the pylon while in carriage. In the present analysis the projectile is forced away from its wing pylon by means of identical piston ejectors located in the lateral plane of the store, -18 cm forward of the centre of gravity (C.G.), and 33 cm aft. While the focus of the current work is not to develop an ejector model for the examined projectile configuration, simulating the store separation problem with an ejector model which has known inaccuracies serves little purpose.

The ejector forces were present and operate for the duration of 0.054 s after releasing the store. The ejectors extend during operation for 10 cm, and the force of each ejector is a constant function of this stroke extension with values 10.7 kN and 42.7 kN, respectively. The basic geometric properties of the store and ejector forces for this benchmark simulation problem are depicted in a more detail drawing in FIGURE 2.2.

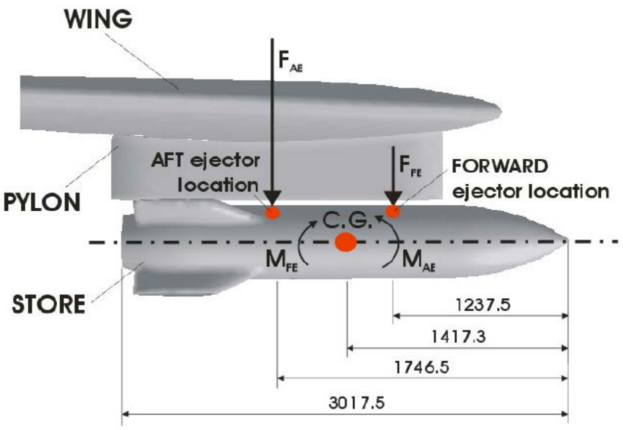


Figure.2.2-Ejector force model for the store separation problem

The last CFD Challenge was conducted under the auspices of The Technical Cooperative Program (TTCP) Key Technical area (KTa) 2-18 for the F-18C/MK-83 store; Comparisons were made with Pressure Sensitive Paint (PSP) data as well as flight test store trajectories. The best pressure comparisons were obtained using the FLUENT code run in a viscous mode. This seemed to imply that while viscous calculations were needed to correctly predict store pressures, inviscid results were adequate for predicting the trajectories. This is a very important consideration, since running a trajectory simulation requires many separate computations, either in a time dependent or grid mode.

3. ENGINEERING METHODS

Engineering methods all rely on a type of quasi-steady approximation. For example, a store can be positioned in the aircraft flow field and flow allowed to develop. Then aerodynamic loads are specified by modifying measured loads with a first-order correction to account for the fact that flow is allowed to develop over a finite time interval. In the wind tunnel, this process is finite time interval. In the wind tunnel, this process is called the dual-sting support or captive-trajectory support technique.

Yet another level of approximation has been successfully introduced in a class of methods in which the store is superimposed on a flow field and the loads are extracted from a database. One option for this approach involves generating a map of store loads for a range of orientations and positions in a region beneath the parent aircraft. Then loads for a store in a given orientation and position are interpolated from the load map. This method is called the store-loads survey approach. Another option is to generate only a map of the flow field over a region beneath the aircraft. Then, with the store in a given orientation and location, loads along the store are specified from a correlation between quasi-steady load sand flow conditions in the map. This method is called the flow-field survey approach.

Calculation of store loads using the flow-field survey approach does not account for mutual interference between the store and the aircraft. Mutual interference effects decay rapidly with distance from carriage and are significant only within the immediate vicinity of the parent aircraft. It is important to note that the steady flow fields required in the engineering methods can be obtained experimentally or computationally.

3.1. Trajectory Generation Program

Separation trajectories to be obtained using engineering methods are predicted using the Flow-field Loads Influence Prediction Trajectory Generation Loads Program (FLIP TGP). The FLIP TGP is a follow-on version of the Flow-angle Trajectory Get iteration Program (FLOW TGP). Separation trajectories are computed in a marching process starting at carriage. At a given time, the aerodynamic and non-aerodynamic loads acting on a store are determined. The loads are used in the rigid-body equations of motion to determine the time derivatives of the store state variables (position, orientation, velocity, and rotation rates). The known derivatives permit the state variables to be extrapolated over a small time step to predict the change in store position and orientation. The loads acting on the store at the new position and orientation are then determined. The process is repeated until the store is moved for a specified time or a collision is detected.

3.2. Load Determination Procedure

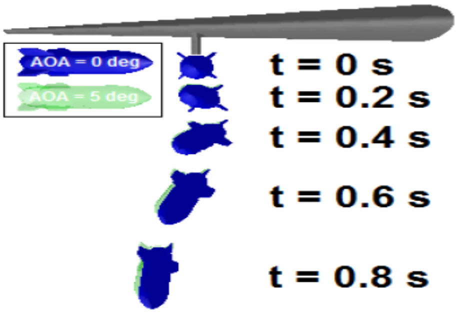
For the present engineering methods application, store aerodynamic loads were calculated according to the flow-field survey approach using the Missile Distributed Air loads (MDA) code. In the flow field survey approach, loads are determined by generating a flow field map over a grid situated beneath the parent aircraft. Mapping of the flow field involves determination of local flow variables (Mach number, dynamic pressure, and velocity components) on the specified grid without the store present.

Experimentally, this is accomplished by moving a probe from one grid location to another and making pressure measurements at each station. Computationally, this involves interpolating a CFD flow field solution on to the specified grid. As explained earlier, these flow conditions are correlated to quasi-steady store loads. The MDA code, which is an upgraded version of the Interference Distributed Loads (IDL) code, is a semi-empirical program capable of predicting aerodynamic loads for a wide range of missile and bomb configurations at subsonic, transonic, and supersonic Mach number. The MDA code may be operated either as a stand-alone program.

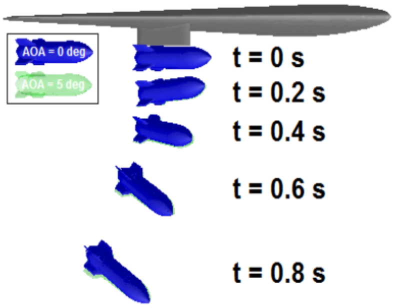
4. RESULT

The full-scale separation events are simulated under supersonic conditions (Mach number 1.2) at an altitude of 11,600 m and various angles of attack (0°, 3° and 5°) using CFD-FLUENT package. The initial condition used for the separation analysis was a fully converged steady-state solution. Because an implicit time stepping algorithm is used, the time step t is not limited by stability of the flow solver. Rather, t is chosen based on accuracy and stability of the dynamic meshing algorithm. Time step t = 0.002 sec is chosen for the convergence of store-separation trajectory simulations.

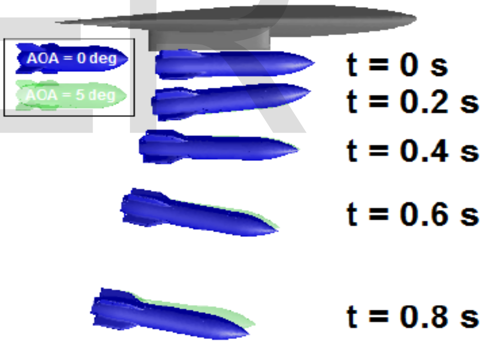
In which views of the simulated store movements at α = 0 and α= 5 deg, respectively, are compared at discrete instants in time throughout the separation for the first 0.8 seconds. In the examined two cases the stores pitch down even though the applied ejector forces causes a positive (nose up) ejector moment and roll inboard and yaw outboard. This downward pitch of the store is a desirable trait for safe separation of a store from a fighter aircraft. The fluid dynamics prediction analysis also gives pressure coefficient distributions for the total separation history along axial lines on the store body at four circumferential locations and three instants in time. The simulation data are compared with experimental surface pressure data from the wind tunnel tests.



a) Front view with side angle



b) Front view



c) Side view

Figure.4. Store separation with events ejectors at Mach no 1.2 for 0&5 AOA

5. CONCLUSION AND FUTURE WORK

The current work demonstrates an integrated package for performing 6-DOF simulations coupled with an Euler code. The feasibility of numerical simulation for store separation has been successfully demonstrated in this work. CFD has gradually become a valuable tool for supporting store separation studies and assessments. CFD is very useful and allows the complex geometries associated with real aircraft to be modelled. The modelling of a full aircraft configuration for the Navier-Stokes solution using structured grids is a challenge. This study has shown that CFD with unstructured dynamic meshing can be an effective and successful tool for modelling transonic store separation at various angles of attack. The simulation captured the experimental location, velocity, orientation, and angular rate trends. Surface pressure distributions were also in good agreement with experiments at three times during the whole separation event. This approach offers the ability to obtain accurate store separation predictions with quick turnaround times. Benefits include fast grid generation due to the use of unstructured tetrahedral meshes, and a fully parallelized, accurate, and stable solver that allows small grids and relatively large time steps. Grid generation can be accomplished in a matter of hours, and runs such as the nominal grid case with time step t = 0.002 seconds examined in this study can be completed overnight on a desktop workstation.

Future work is planned to address the viscous effects. Modelling of the boundary layer requires construction of a rigid viscous mesh attached to the store. Additionally, an adaptive grid refinement algorithm is to be added to the solution procedure, providing more accurate prediction of shock strengths and locations to improve the aerodynamic model.

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