Numerical Study of an External Store Released from a Fighter aircraft

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Abstract: The prediction of the separation trajectories of the external stores released from a military aircraft is an important task in the aircraft design area having the objective to define the operational and release envelopes. This paper presents the results obtained for store separation by employing commercial sorftwares, FLUENT and CFD-FASTRAN. FLUENT treats the rigid body motion by employing the remeshing scheme. CFD-FASTRAN uses the chimera(overset) grid and interpolations. It was found that, for the prediction of the trajectories and behavior of the stores separated from the wing, both codes shows the good agreement with the experimental results.

Keywords: CFD, Store Separation, FLUENT, CFD-FASTRAN, Chimera Grid, Remeshing Scheme

1. INTRODUCTION

Whenever the store is released from the wing in flight, it is supposed to clear without hitting or damaging it. Thus, designing a new fighter aircraft or integrating a new store into an existing aircraft requires the certification that that attached loads will be separated safely without colliding with the aircraft. The mission effectiveness and survivability of the military aircraft are also highly dependent upon the ability to deliver air-launched weapons with minimum risk during mission flight[1].

The store separation problems can be classified into three categories of problems depending upon the types of stores. The first category is the jettison problem: external stores are released from the aircraft during emergencies by using the jettison. The class of stores includes fuel tanks, gun pods, and bomb racks. The second category is referred to as the delivery problem. This problem not only requires the safe store separation from the aircraft, but it also requires a relatively smooth release for improved delivery accuracy. The weapons are unguided general purpose bombs and dispenser munitions and they are released in a package form for hitting a target. The third category is the launch transient problems: active control is required during release operation. The items are guided bombs and missiles that are locked on to a target before launch[2,3].

In this paper, the jettison problem is investigated by considering the effect of the existence of ejection. Generally, serious problems can occur in three distinct areas in the external store separation using the jettison: store-to-pylon/rack collisions, store-to-wing/body collisions, and store-to-store collisions. Thus, store jettison problems are fundamentally very complex. There are also many parameters that affect the store separation. Two major parameters are aerodynamic parameters (store shape and configuration of the aircraft,, flight velocity, attitude, load factor, and flow field surrounding the store) and physical parameters(mass and moment of inertia, center of gravity of the store, ejector location and impulse during ejection process, and bomb rack. The aerodynamic and physical parameters are highly coupled with each other in a most complicated manner[4]. Among the parameters that affect the store separation, the most significant ones are the store stability, the bomb-ejector-rack-induced moment, and the aircraft flow fields surrounding the store.

Typically, the study on the separation has been accomplished by flight or wind tunnel tests. For example, according to Barbero and Ferretti[5], the clearance of the JSOW from the F-18 at the Mach 0.95 took more than 400 hours of wind tunnel testing and 20 flights. Thus, both flight and wind tunnel tests require a large amount of time and costs. All the more, the flight test includes a certain amount of risk.

Recently, with the progress in the modeling and simulation in the related CFD research area and the improved computing capability, there have been increased efforts to validate, demonstrate and accelerate the insertion of CFD methods into the store certification process for external store carriage and release[6]. It was reported that, by using CFD, the MK-83 JDAM could be cleared after 60 hours of wind tunnel testing and five flights to the full F-18 aircraft envelope of Mach 1.3[7].

An extensive set of wind tunnel store carriage and separation data for the CFD code validation have been made available for a generic wing and store geometry. Cenko and Lutton[7] showed that a full-potential code could produce reasonable results. Encouraging predictions of steady-state surface pressure distributions and store loads in interference flow fields are obtained by various researchers[5,8-10]. However, these approaches are incapable of predicting the trajectory of the store in highly dynamic separations such as the release from within weapons bays or multiple store releases, fuel tank releases, and releases during maneuvers. These cases are very difficult to simulate in a wind tunnel.

The aim of the present paper is to simulate weapon separation by using the commercial CFD software[1,11]. The forces and moments on a store are computed with the time stepping procedure. The trajectories of the store is predicted and compared with the measured data.

2. CFD CODES

Two famous commercial codes (FLUENT and CFD-FASTRAN) are employed in order to simulate the store separation in a transonic flow regime. First, using Fluent, the time-accurate computational dynamic simulations of a transonic store separation can be performed with the dynamic unstructured tetrahedral mesh approach with a combination of spring-based smoothing and local remeshing. Second, CFD-FASTRAN can perform the unsteady full field simulation with or without viscous effects by using the Chimera overset grid approach.

FLUENT[1] employs the strong conservative formulation of the unsteady Euler equations based on a cell-centered finite volume method with the linear reconstruction scheme. A local remeshing algorithm is used to consider the moving body in

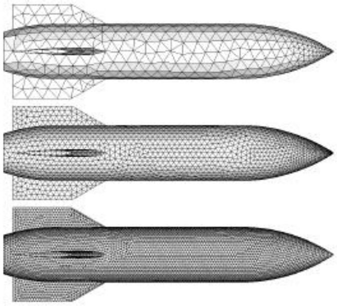
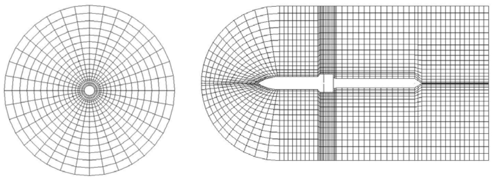


Fig. 1 Surface meshes for FLUENT[Copied from Ref.1].



(a) Sectional Cut (b) Axial Cut

Fig. 2 Store grid topology through sectional cuts for CFD-FASTRAN.

the discretized computational domain. When the motion of the body is small, the nodes are moved to new nodal locations by considering the cell edges as a set of interconnected springs between nodes. Thus, the movement of a boundary node is propagated into volume mesh due to the spring force generated by the boundary node without changing the connectivity between the nodes. When the motion of the moving body is large compared to the local size, a remeshing scheme is employed based on the volume and/or skew criteria.

The CFD-FASTRAN[11] includes CFD-GEOM and CFD-VIEW as pre- and post processors. Euler equations are also solved in order to provide a rapid aerodynamic analysis. The usages and specifications of the modules in the package can be explained as follows[11].

- CFD-GEOM: interactive 3D geometry modeling and mesh generation software (structured, unstructured, and mixed element meshes).
- CFD-FASTRAN: compressible flow solver that includes 6 DOF modeling for simulating the unsteady, dynamic motion of multi-body configurations. The CFD-FASTRAN is a density-based flow solver with finite volume scheme. Flux splitting algorithms such as Roe's FDS and Van Leer's FVS are included with several limiters.
- CFD-VIEW: interactive artificial 3D flow visualization.

3. STORE / EJCETOR CHARACTERISTICS

CASE I : Store Alone

In order to validate the accuracy of the CFD-FASTRAN solver, a test case[12] is selected in the published literature. The store has tangent-ogive cylindrical shapes at both forebody and afterbody. The store has four identical fins placed at the tail side in a cruciform style. The fin has a symmetrical airfoil section (NACA 0008) throughout the span. The leading edge sweep angle is 60 degrees. In order to validate the CFD results, the store has the sting mounted to it as it was used in the captive trajectory experiments. Fig. 1 and Fig. 2 show the coarse grid systems for the use in FLUENT and CFD-FASTRAN, respectively.

Fig. 3 Store configuration

CASE II: Store w. Ejector

The most significant parameters in the store separation problem are as follows: store stability, the store ejector rack induced moments, and the aircraft flow field (as a function of Mach number and aircraft attitude). Store ejection force, store weight and dynamic pressure have the secondary effects and approximately, it is the same for aerodynamically stable stores. These effects become more important as the store stability decreases. The moments of inertia of the store do not affect the store stability for aerodynamically stable stores but they become more important as the store stability decreases. The geometry of the store is shown in Fig. 3.

Dimensions of the store are given below.

- Weight : 900 kg
- Length : 4.6 m
- Diameter : 0.53 m
- No. of fins : 8
- Center of gravity : 2.74 m (aft. of store nose)
- Moment of inertia : I_{yy} (1158.13 kg·m²)
  I_{zz} (1142.97 kg·m²)

The store is released from its wing pylon by means of identically-shaped piston-type ejectors. The ejectors are located in the lateral plane of the store, one for 25cm forward and another for 25cm backward from the center of moment.

The ejectors operate for 0.025 second. The conditions of the store jettison are listed in Table 1.

4. COMPUTATIONS

1) FLUENT

The 6DOF rigid-body motion of the store is calculated by numerically integrating the Newton-Euler equations of motions, and it is accomplished by using a user-defined function. Thus, a function written by the user is dynamically linked with the FLUENT solver at run time. The aerodynamic forces and moments at each time are obtained by integrating the surface forces over the rigid body.

Table 1 The store jettison conditions

Altitude	5km
Velocity	550 knot (M=0.95)
Temperature	258.4 K
Pressure	57.181 N/m²
Density	0.7708 kg/m³
Speed of sound	322.27 m/s
Angle of attack	0° ~ 5°

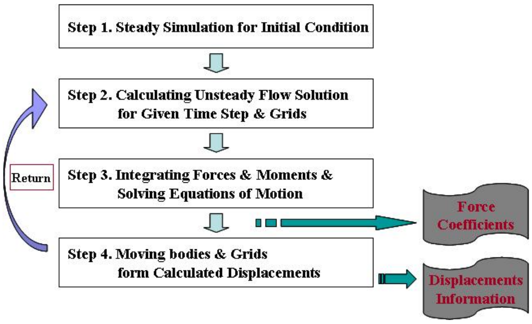


Fig. 4 Unsteady simulation procedure.

2) CFD-FASTRAN

Unlike FLUENT that is using the remeshing scheme for the unsteady moving-body simulation, CFD-FASTRAN adopts the overset grid system, Chimera[11].

The numerical procedures include an implicit solution algorithm for solution of the Euler Equations, grid remapping due to induced body motion, and Chimera overset grid.

Overall solution procedure is illustrated in Fig. 4.

Steady-State and implicit Euler solutions are obtained before the time accurate computations started. Roe's approximate Riemann solver scheme is used for flux computations, which is first order spatially accurate second order accuracy is obtained using Min-nod limiter. CFL number is increased from 0.1 ~ 1 iteration for steady-state calculation. A parallel computing cluster consists of one main node and 8 sub-node. The domain decomposition in structural grids for parallel computations is performed by assigning of blocks to different CPUs.

The rigid body equations of motion were chosen to be integrated with the code. The rigid body equations are available in many references[13, 14].

The basic procedures are summarized below.

① For a given time level, compute the forces and moments on the store using equation (1)

$$\sum \vec{F} = -\iint p\vec{n}ds$$
$$\sum \vec{r}_0 \times \vec{F} = -\iint p(\vec{r}_0 \times \vec{n})ds \tag{1}$$

Also, compute the angular momentum from equation(2)

$$\begin{aligned} h_x &= P(I_{yy}+I_{zz}) - QI_{xy} - RI_{xz} \\ h_y &= -PI_{xy} + Q(I_{xx}+I_{zz}) - RI_{yz} \\ h_z &= -PI_{xz} - QI_{yz} + R(I_{xx}+I_{yy}) \end{aligned} \tag{2}$$

Transform moments to the body-fixed reference frame and solve for h using equation (3)

$$\begin{aligned} F_x &= m(\dot{u} + QW - RV) \\ F_y &= m(\dot{v} + RV - PW) \\ F_z &= m(\dot{w} + PV - QU) \end{aligned} \tag{3}$$

② Solve for the h^{n+1} using $h^{n+1} = h^n + \Delta t\dot{h}$

③ Solve for the ω^{n+1} using h^{n+1} and equation (2)

④ Solve for the angle displacements using

$$\alpha = \frac{1}{2}(\omega^{n+1} + \omega^n)\Delta t \tag{4}$$

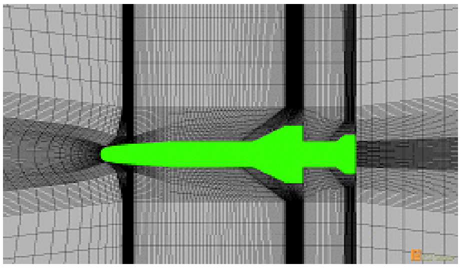


Fig. 5 Grid topology of store only.

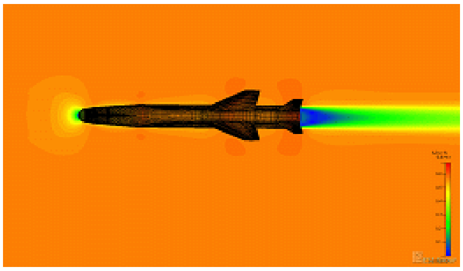


Fig. 6 Mach contour for store only(M=0.6, AOA=0°)

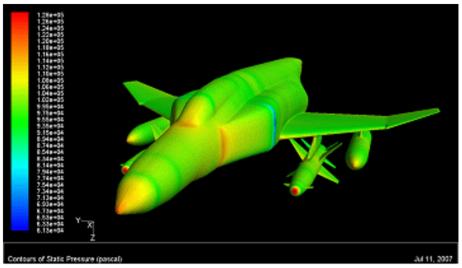


Fig. 7 The pressure contour of full configurations

⑤ Solve for the displacements using (5) and (6)

$$V^{n+1} = V^n + \Delta t V^n \tag{5}$$

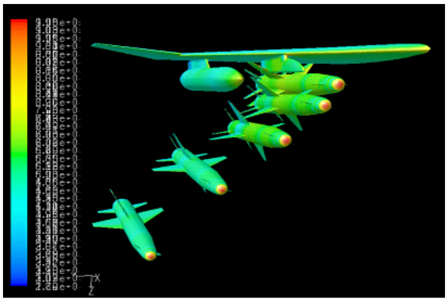
$$ds^{n+1} = \frac{1}{2}(V^n + V^{n+1})\Delta t \tag{6}$$

The details of this solution can be founded in many references[15, 16].

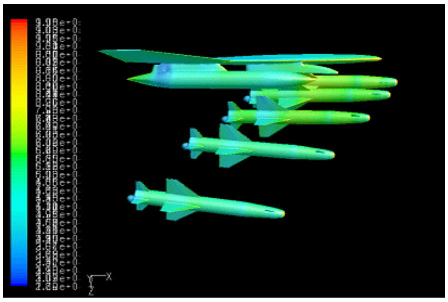
4. RESULTS AND DISCUSSION

Several store separation cases are solved using both FLUENT and CFD-FASTRAN. The results given below represent the linear and angular displacements as well as the velocity and pressure distributions on the store at four different angular positions and time history of the force coefficients. The several view illustrations obtained by using CFD-FASTRAN are included in Fig. 4 ~ Fig. 6 for selected cases. Fig. 7 and Fig. 8 shows the computations completed by using the FLUENT. It is observed that all of the major trends are captured when one compares the results with those given in the experimental results. In all cases, the store pitches down even though the applied ejector force causes a positive (nose up) ejector moment and the store rolls inboard and yaws outboard.

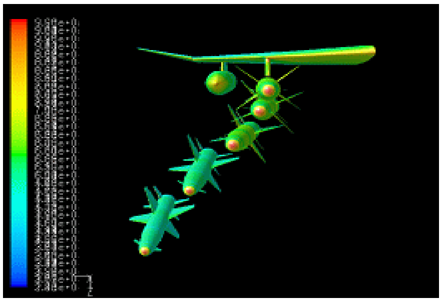
This downward pitch of the store is a desirable trait for safe separation of a store from a fighter aircraft. It is observed that



(a) Front view with side angles



(b) Side view



(c) Front view

Fig. 8 Results of store separation with ejectors (M=0.95, AOA=2°)

configuration effects, Mach number effects, altitude/dynamic pressure effects, angle of attack effects, damping derivative effects, varying mass properties effects exist.

5. SUMMARY AND FUTURE WORKS

The current work demonstrates the capability of integrated packages (FLUENT and CFD-FASTRAN) 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 allowed the complex geometries associated with real aircraft to be modeled. The modeling of a full aircraft configuration for the Navier-Stokes solution using structured grids is a challenge.

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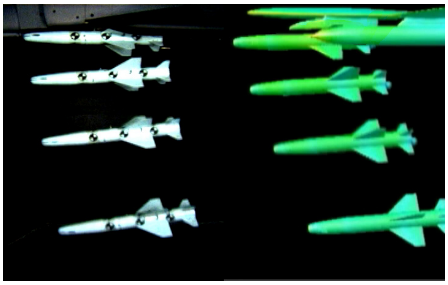

Fig.9 Comparison of experimental (left) and computational (right) separation results

REFERENCES

[1] 2003, Snyder, D.O., Koutsavdis, E.K., and Anttonen, J.S.R., "Transonic Store Separation Using Unstructured CFD with Dynamic Meshing," *FULENT Technical Notes 202*.

[2] 1981, Covert, E.E., "Conditions for Safe Separation of External Stores," *J. of Aircraft*, Vol.18-8.

[3] 1979, Mathews, C.B., "Store Separation," *Eglin Air Force Report*.

[4] 1986, Bogue, R.K., "Store Separation," *AGARD-AG-300*, Vol.5.

[5] 1994, Barbero, S. and Ferretti, A., " Application of Euler Code to Evaluation of Store Released in a Heavily Disturbed Aircraft Flow-Field," *ICAS Paper 94-2.6.4*.

[6] 2005, Zyluk, A., "Experimental Validation of mathematical Model Describing External Store Separation," *Journal of Theoretical and Applied Mechanics*, Vol.43-4, pp.855-873.

[7] 2000, Cenko, A. and Lutton, M., "A CFD Application to Store Separation- Status Report," *ICAS Paper 560.1*.

[8] 2000, Lee, S., Park, M. and Cho, K.W., "New Fully Automated Procedure for the Prediction of Store Trajectory," *Journal of Aircraft*, Vol.37-6.

[9] 1996, Ningia, R.K., Ross, J.A. and Peto, J.W., "Theoretical and Experimental Studies of Vectoring Jets Effects on Under-Wing Stores and Their Release Trajectories," *ICAS Paper, 96-1.3.2*.

[10] 2000, Tomaro, R.F., Witzeman, F.C., and Strang, W.Z., "Simulation of Store Separation for the F/A-18C Using Cobalt 60," *Journal of Aircraft*, Vol.37-3.

[11] 2006, *CFD Research Co*., CFD-FASTRAN User Manual, Version 2006.

[12] 1991, Heim, R.R., "CFD Wing/Pylon/Finned Store Manual Interference Wind Tunnel Experiment," *AEDC-TSR-91-P4*.

[13] 1997, Hall, L.H., Mitchell, C.R., and Parthasarathy, V., "An Unsteady Simulation Technique for Missile Guidance and Control Applications," *AIAA 1997-0636*.

[14] 2002, Westmoreland, S., "A Comparison of Inviscid and Viscous Approaches for Store Separations", *AIAA 2002-1413*.

[15] 1995, Thomas, R.D. and Jordan, J. K., "Investigation of Multiple Body Trajectory Prediction Using Time Accurate Computational Fluid Dynamics," *AIAA 1995-1870*.

[16] 2004, Lee, R.M., "Beggar Code Implementation of the 6 DOF Capability for Stores with Moving Components," *AIAA 2004-1251*.