Numerical Simulations of Store Separation Problems

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Abstract: The prediction of the separation trajectories of the external stores carried out on military aircraft is an important task in the aerodynamic design area having the objective to define the operational, release envelopes. This work consists of concept and some results for external store configurations. A Computational Fluid Dynamics technique is applied to calculate the aerodynamic forces. The CFD-FASTRAN with an implicit Euler solver is used for the present simulations. The computational results are validated against the experimental data.

Keywords: store separation, computational fluid dynamics, external store, motion of equation, ejector force, jettison problem

1. INTRODUCTION

The mission effectiveness and survivability of the military aircraft are highly dependent upon the ability to deliver air-launched weapons with minimum risk during mission flight.

The external store separation can be basically divided into three categories depending upon the type of store. The first category is the jettison problems which are released external stores from the aircraft during emergencies. The class of stores is fuel tanks, gun pods, and bomb racks. The second category is referred to as the delivery problem. This problem not only requires the store separate safely from the aircraft, but it also requires a relatively smooth release for good delivery accuracy. These weapons are unguided general purpose bomb and dispenser munitions released in a package for the purpose of hitting a target. The third category is the launch transient problems which are active control during release. The items are guided bomb and missile which are locked on to a target before launch.[1,2]

The major concern of this study is only safe jettison problem with/without ejections. Store jettison problems are very complex. Generally, serious problems in external store jettison can occur in three distinct areas: store-to-pylon/rack collisions, store-to-wing/body collisions, and store-to-store collisions. There are many parameters that affect store separation. Two major parameters are aerodynamic parameters and physical parameters. Aerodynamic parameters are the store shape and stability, and the velocity, attitude, load factor, and configuration of the aircraft, and flow field surrounding the store. Physical parameters include store (mass, moment of inertia), center of gravity, ejector (location, impulse), and bomb rack. The above parameters are highly coupled and react with each other in a most complicated manner.[3]

The most significant parameters are store stability, the bomb ejector rack induced moment, and the aircraft flow field.

Typically, the certification if a particular store/aircraft/flight condition combinations is accomplished by flight test. But the flight tests are very expensive and a certain amount of risk. Wind tunnel testing, although less expensive that flight testing, is still expensive. In recent years, modeling and simulation have been used to reduce certification cost and CFD truly became and invaluable approach.

The aim of the present paper is to validate the safe store separation under the given conditions, and to explore the advantages of using computational fluid dynamics to simulate weapon separation computationally.

The forces and moments on a store at carriage and various points in the flow field of the aircraft can be computed using CFD applied to the aircraft and store geometry.

2. THE CODE USED

The Euler version of the CFD-FASTRAN was used to provide a rapid aerodynamic analysis. The code showed the potential of predicting complex flow field aerodynamics at subsonic and transient speeds. The system is composed of several different integrated software pieces which are CFD-GEOM, CFD-GUI, CFD-FASTRAN, and CFD-VIEW modules as shown Figure 1. [4]

- CFD-GEOM is interactive 3D geometry modeling and mesh generation software (structured, unstructured, and mixed element meshes), which is the pre-processor of CFD-FASTRAN.

- CFD-FASTRAN is a compressible flow solver. This tool includes multi-domain grids, overset structured grids, and hybrid combinations of both structured and unstructured CFD methodologies. The software also provides 6 DOF modeling for simulating the unsteady, dynamic motion of multi-body configurations. Numerical features of the code are finite volume scheme, density-based flow solver, and Roe, Van Leer, Flux splitting algorithms.

- CFD-VIEW provides interactive 3D graphics, animation, and flow visualization.

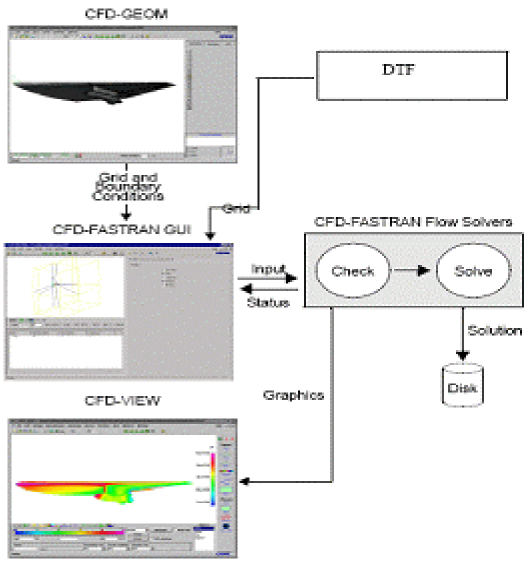


Fig.1 Diagram of software modules

3. STORE / EJECTOR CHARACTERISTICS

The most Significant parameters are store stability and the store ejector rack induced moments, the aircraft flow field (function of Mach number and aircraft attitude). The effects of store ejection force, store weight and dynamic pressure are secondary and approximately the same for aerodynamically stable stores. These effects become more important as store stability decrease. Store moments of inertia are relatively unimportant for aerodynamically stable stores but become more important as store stability decreases.

The geometry of the store is shown in Figure 2.

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)

Fig. 2 Store configuration

The store is forced away from its wing pylon by means of identical piston ejections located in the lateral plane of the store, 25cm forward of the center of moment, and 25cm after.

The ejectors operate for 0.025 second. As the store moves away from the pylon, it begins to pitch and yaw as a result of aerodynamic forces.

4. COMPUTATIONS

The numerical procedures used in this study 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 Figure 3.

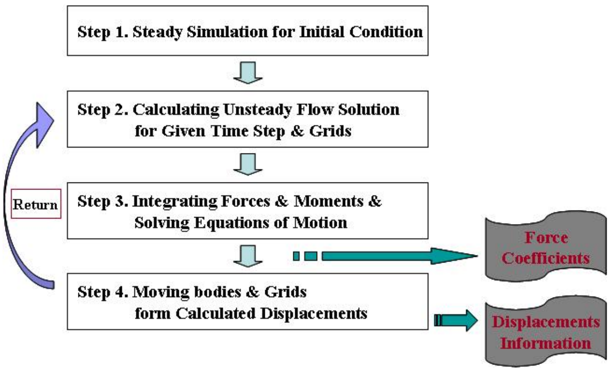


Fig. 3 Unsteady simulation procedure.

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 conditions of the store jettison are listed in Table 1.

Tab. 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°

The rigid body equations of motion were chosen to be integrated with the code. The rigid body equations are available in many references.[5,6]

The basic procedures are summarized below.

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

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

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

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

⑥ 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 [7,8].

5. RESULTS AND DISCUSION

Several tore separation cases are solved using 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 some view illustrations of representative configurations are included in Figure 4 through Figure 7 for selected cases. As shown in Figure 8, 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 configuration effects, Mach number effects, altitude/dynamic pressure effects, angle of attack effects, damping derivative effects, varying mass properties effects exist.

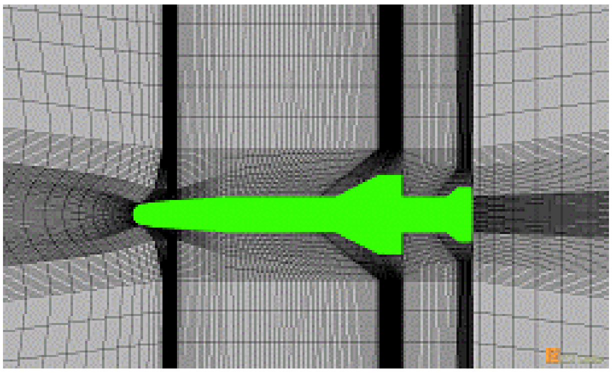


Fig. 4 Grid topology of store only

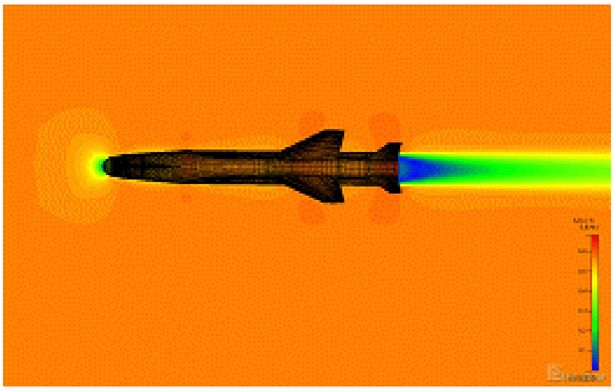


Fig. 5 Mach contour for store only(M=0.6, AOA=0^0)

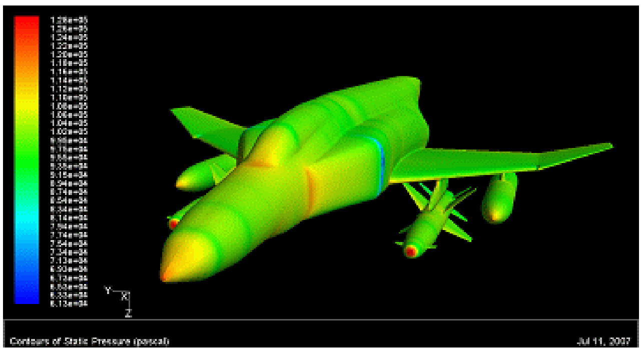
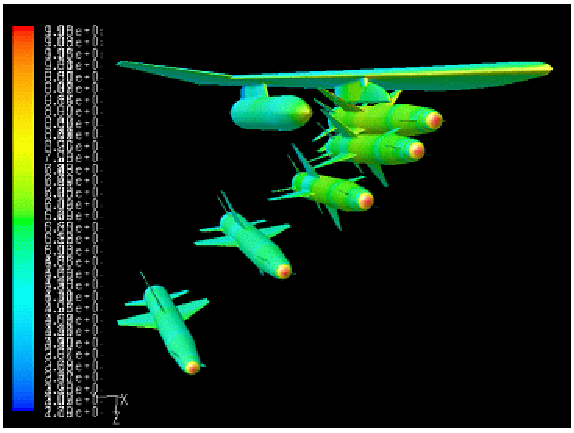
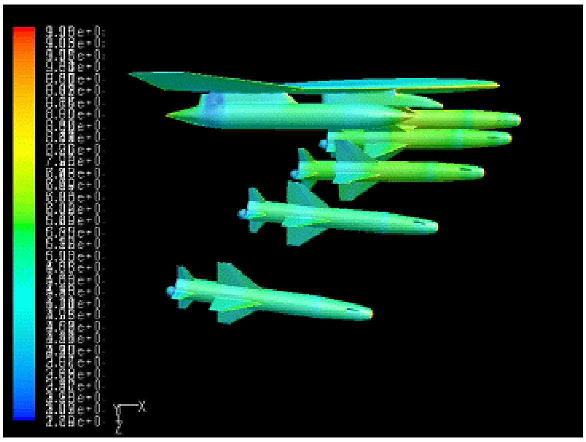


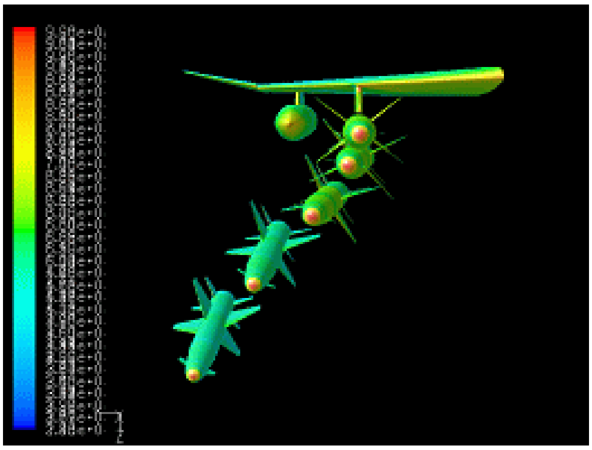
Fig. 6 The pressure contour of full configurations



(a) Front view with side angles



(b) Side view



(c) Front view

Fig. 7 Results of store separation with ejectors (M=0.95, AOA=2^0)

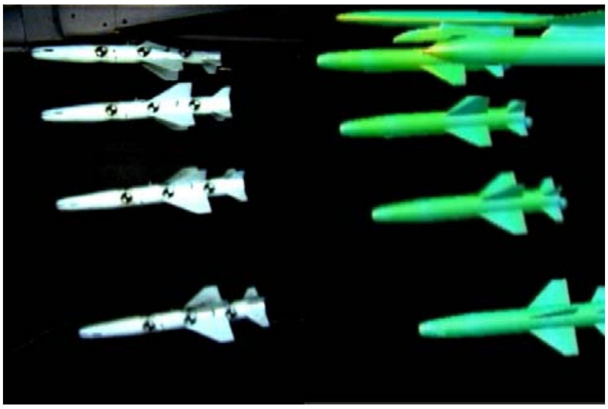


Fig.8 Comparison of experimental (left) and computational (right) separation results

6. CONCLUSIONS

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 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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