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CFD BASED SOLUTIONS OF RELEASE OF A TRANSONIC GENERIC STORE

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ABSTRACT

Store separation certification is vital of importance in order to eliminate potential hazardous risks for aircraft/weapon integration process [Panagiotopoulos E., 2010]. *Several solution techniques that are flight, wind tunnel and computational fluid dynamics (CFD) methods are developed to estimate the trajectory of a store for ensuring safe separation phenomena achieved. In this current study, time dependent behavior of a well-known generic store test case conducted in Arnold Research Development Center for transonic flow regime* [Lijewski L.E., 1994] *is determined with two various well-known wind tunnel techniques, that are captive trajectory simulation (CTS) and grid survey method implemented to CFD approach. Then, the trajectory of the store acquired from both methods are compared with the available wind tunnel results to demonstrate which method supplies sufficient approximation for such complicated problems.*

INTRODUCTION

Weapon integration process is one of the most significant and complex subject for airworthiness certification since jettisoning and launching of a store can have substantial impacts on aircraft and pilot's safety. Nowadays, people who are focusing on this issue are challenging to develop novel and rapid techniques to reduce weapon integration effort and the required time for designing of safe separation. Hence, three different validation and certification process, that are flight testing, wind tunnel testing and computer aided analyses, are utilized from past to today. [Cenko, A., 2006]

Flight testing is fundamental and essential procedure for weapon carriage of an aircraft due to reflecting the exact behavior of a store during the release process. Flight testing provides the most accurate and precise data for observing potential hazardous risks, however, telemetry installation and flight costs and time effort are too high. It also can be accomplished at the end of the design stage as well. Therefore, flight test campaigns should be prepared carefully and flight test matrix should be reduced.[Cenko A., 2017]

Wind tunnel testing techniques were introduced in 1960's for store separation certification process in order to eliminate the hazardous risks of flight testing. Firstly, the drop testing of a store was performed, however it could cause detrimental effects on the wind tunnel circuits. Therefore, two unusual wind tunnel techniques were developed; "Captive Trajectory Simulation" and "Grid Surveying Method". Captive trajectory simulation allows quasi-steady

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data collection of a store during moving away from aircraft. Firstly, aerodynamic forces and moments are computed at the initial position of the store. Then, new position and attitude of the store are determined using equations of motion and then the store is located to its new position with the help of a sting attached behind the store. The main disadvantage of this technique is that small scaled geometry and limited aircraft/store combinations are tested. On the other hand, grid surveying method is an off-line method that aerodynamic forces and moments are calculated at the predefined location of a store, then the trajectory of a store is calculated with using a standalone 6DOF computing algorithm. Thus, this technique allows significant flexibility for trajectory computations. However, the installation and procurement of wind tunnel are costly.[Carman J.,B., 1980]

Computer aided analysis methods become more popular for the time being due to the accelerating in powerful computer algorithms and numerical methods. Therefore, this method has an important role for store separation certification process and these computer aided analyses are highly preferred before flight and wind tunnel testing.

It is crucial to mention that these three techniques can not be used individually. These techniques intimately depend on each other. For instance, computer aided analyses can be used to reduce and plan wind tunnel and flight testing. Flight testing and wind tunnel techniques are used to validate computer aided analyses. Therefore, all these three methods should be used during the design of weapon integration process.

In this current study, “Captive trajectory simulation” and “Grid surveying method” are implemented into CFD techniques and the results acquired from both methods are compared. ANSYS Fluent which is a reliable flow solver and Matlab Simulink are used to calculate the trajectory of a generic store.

NUMERICAL SCHEME

Computational Model and Grid

Simulation model is identical with the geometry used in Arnold Engineering Development Center wind tunnel setup shown in Figure 1., however it is 5% scale of physical geometry [Lijewski L.E., 1994]. Wing is a swept delta wing which has 64A010 airfoil section. Cross section of aftbody and forebody of the pylon is ogive shape, however middle cross section of the pylon is flat surface. Store is a generic store which forebody has tangent ogive cross section and middle section is cylindrical. A sting geometry attached behind the store is included in the computational model. The coordinate system used in the CFD analyses is placed at the center of gravity of the store shown in Figure 2.

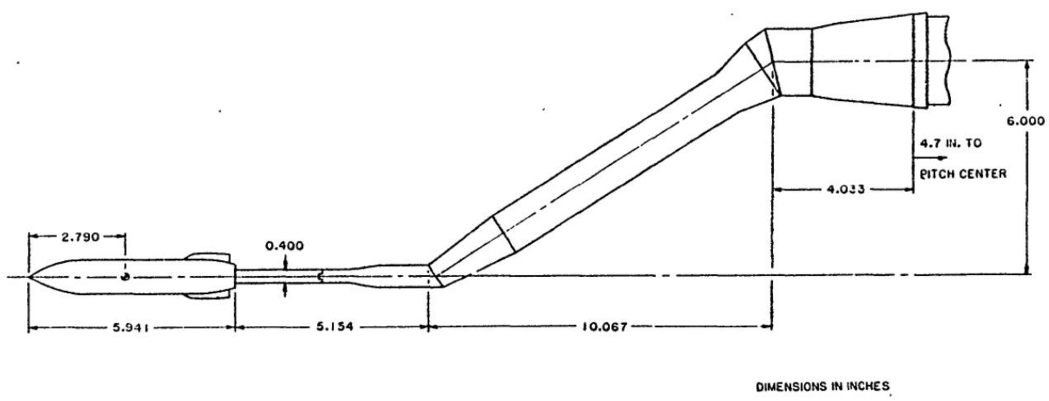

Figure 1: Wind tunnel setup dimensions

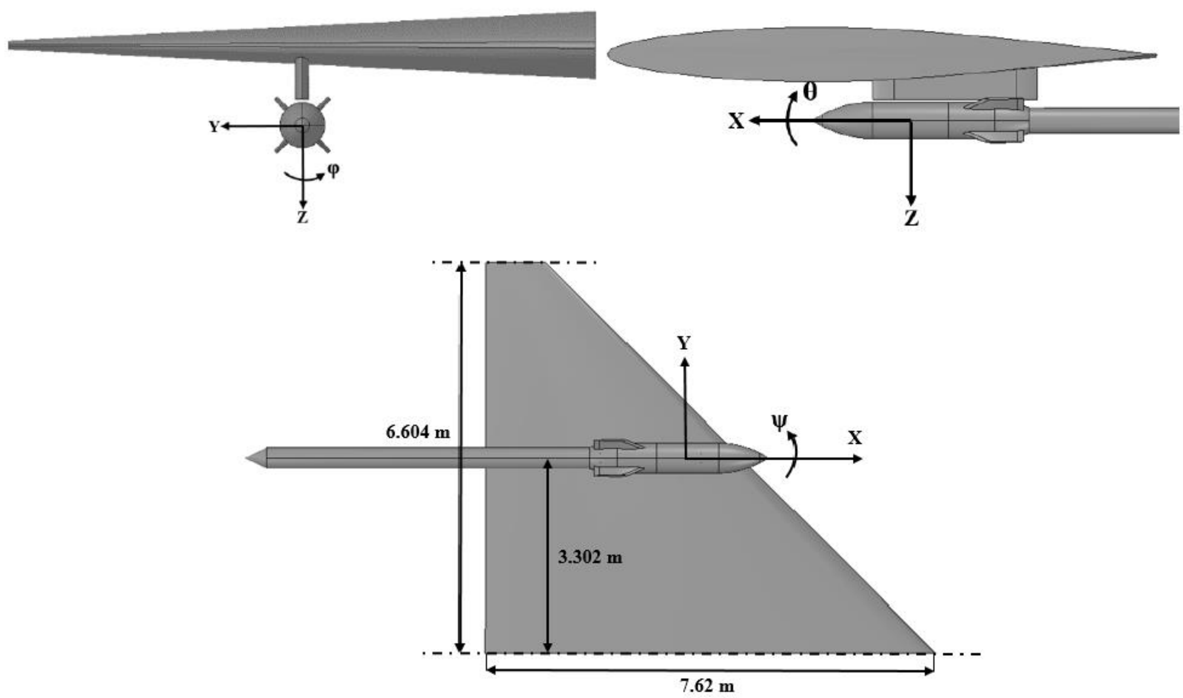

Figure 2: Geometrical details and coordinate system convention of computational model

Two different computational grids are generated for both captive trajectory simulation and grid survey method. Pointwise is used for surface mesh generation, whereas ANSYS Fluent Meshing is used for volumetric grid generation process to obtain more controllable and qualified computational grids. The computational grid used for wing-pylon-store geometry is given in Figure 3 and Figure 4.

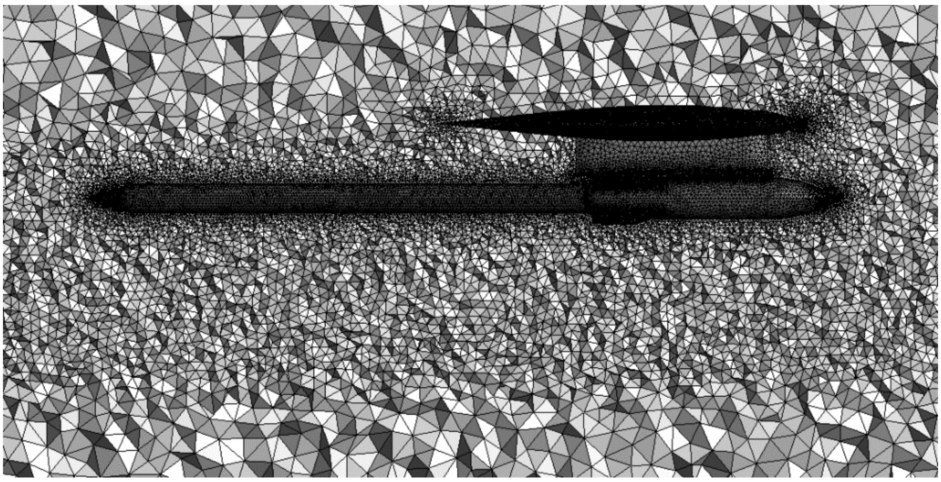

Figure 3: Section view of computational grid elements of whole domain

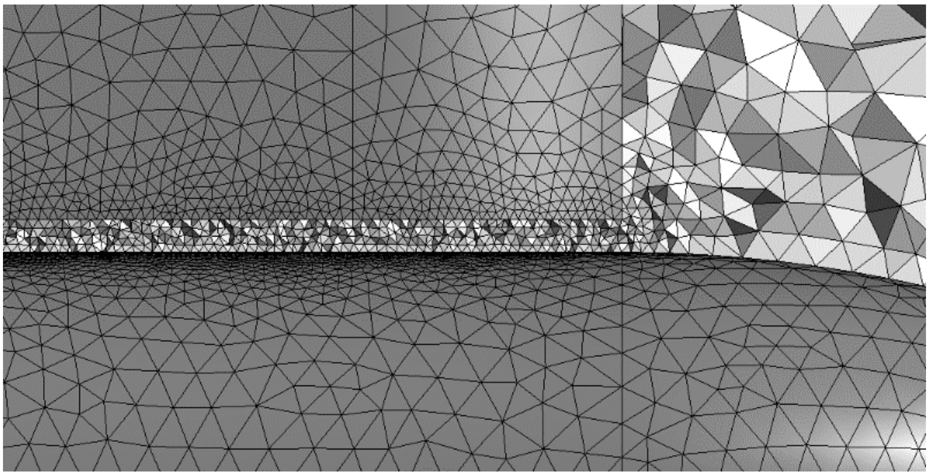

Figure 4: Detailed view of gap between pylon and store

Prism type boundary layer elements are not preferred since Euler computations are obtained. Hexahedral elements are generated at the region where the flow is nearly undisturbed flow in order to reduce the number of mesh elements. Tetrahedral elements are generated near the complicated geometric details, that are the wing, pylon and store in order to reduce computational grid generation time. Sufficient number of mesh elements are used in the required gap between pylon and store for performing captive trajectory simulation process.

Solver Validation and Verification Test Cases

Two different preliminary test cases are performed to observe and validate the capability of ANSYS Fluent in the solution of shock waves occurring at high speed flows. Analyses are simulated at a Mach number of 0.95 and pressure altitude of 26,000 ft. The numerical results are compared with the available wind tunnel results from Arnold Engineering Development Center. [Lijewski L., E., 1990]

Generic finned store configuration, excluding the wing and pylon geometries, is used for the first verification test case to observe the consistency of the pressure coefficient acquired from ANSYS Fluent with the available wind tunnel data. The computational grid near the store is shown in Figure 5.

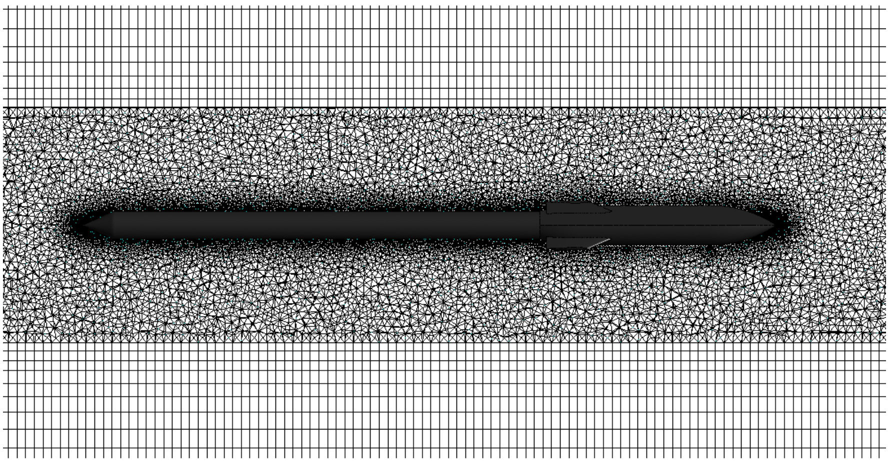

Figure 5: Computational grid around the store

Figure 6 clearly shows that the numerical results are in suitable agreement with the wind tunnel results. There are some discrepancies observed because shock waves cannot be effectively captured due to ignoring viscous effects.

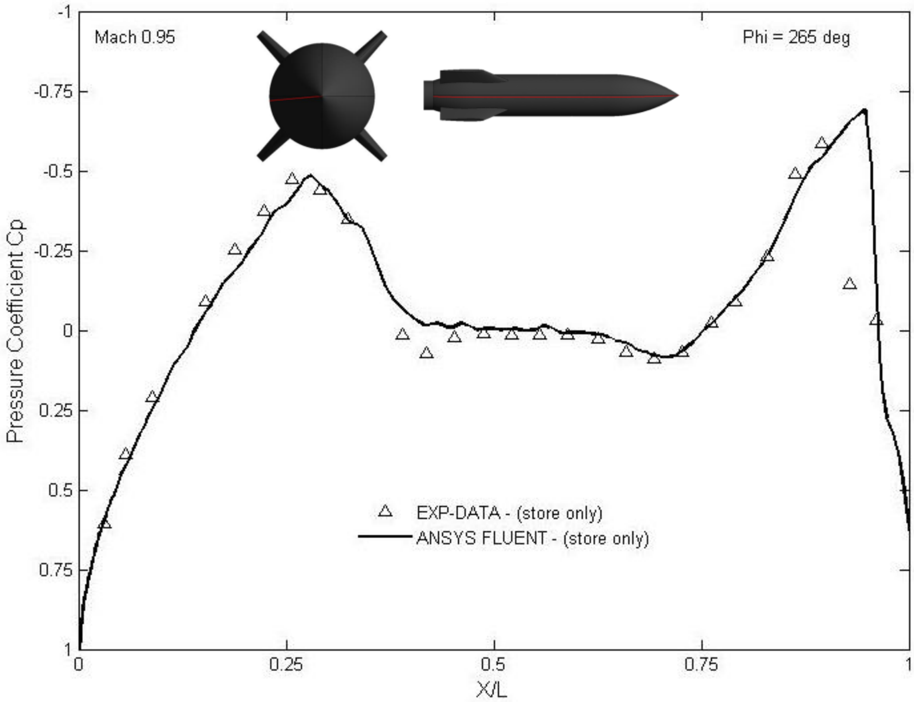

Figure 6: Pressure coefficient distribution of store-alone configuration

The purpose of the second validation test case is to observe whether ANSYS Fluent can determine the strong shock interaction between two wall boundary conditions. Two stores identical to the one used in the first validation test case. Test case are placed into the computational domain at a distance of 1.8 times the diameter of the store shown in Figure 7.

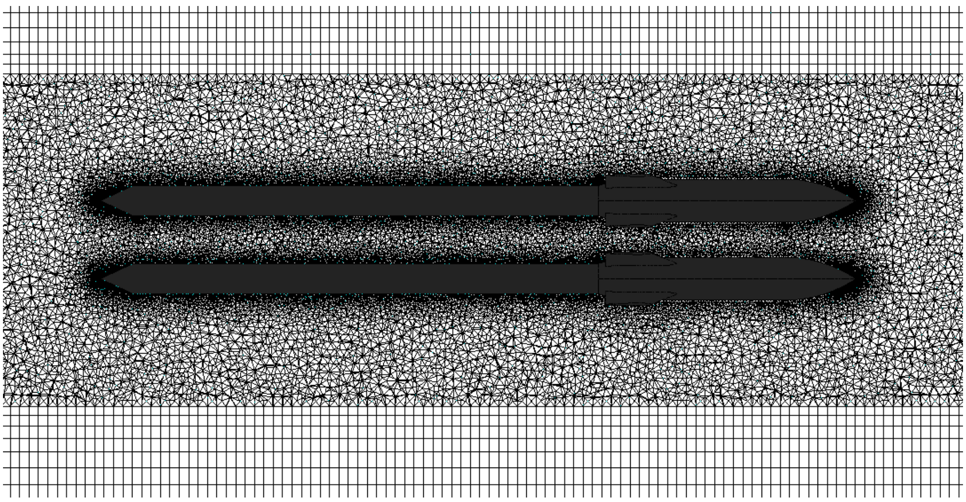

Figure 7: Computational grid domain of two store alone configuration

As in the previous verification test case, the pressure coefficient distribution on the store at a roll angle of 265 degrees is compared with the wind tunnel results. [Lijewski, L., E., 1990] It is apparent that the numerical results are compatible with the wind tunnel results. Difference between the results is observed because the viscous effects are emitted and the shock regions are predicted as overcompress and overexpansion.

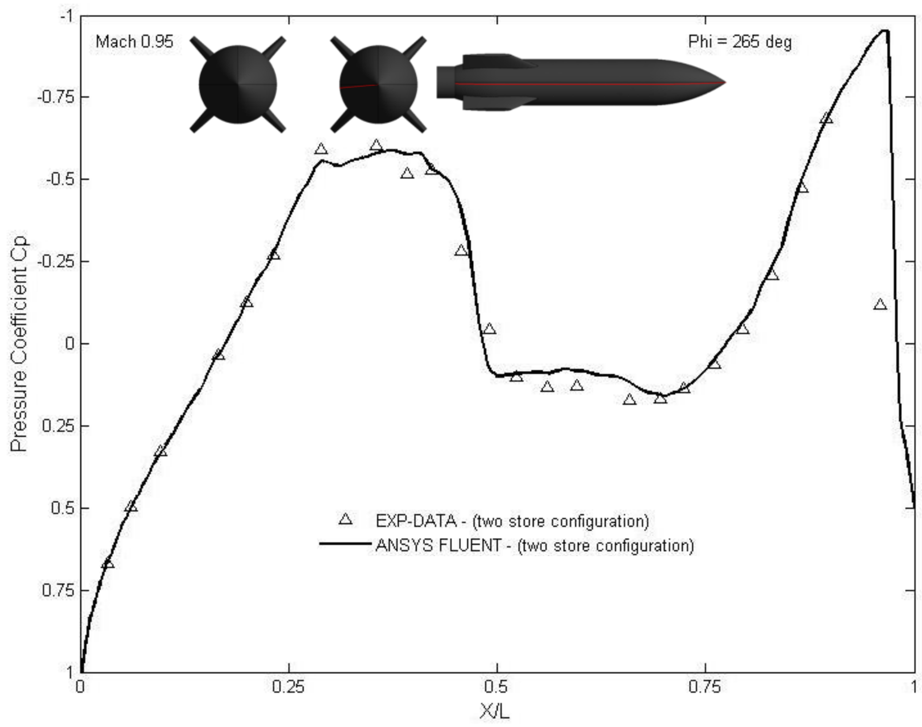

Figure 8: Pressure coefficient distribution for two store alone configuration

Simulation Process

Captive Trajectory Simulation Procedure

In accordance with the validation test cases, ANSYS Fluent is a proper CFD tool to compute aerodynamic forces and moments acting on the store. ANSYS Fluent also permits that both Navier-Stokes or Euler equations and equations of motion can be solved simultaneously. Therefore, this tool can handle trajectory estimation of the store during release process. Motion of the store is modelled using the moving grid technique [ANSYS Fluent, 2016].

Simulations are performed for Mach number of 0.95 and pressure altitude of 26,000 ft. The flow is considered as three dimensional, compressible, unsteady. In the literature, it is apparent that inviscid flow approximation is sufficient when the trajectory of a store is determined. Therefore, the problem is treated as inviscid flow [Cenko, 2006].

Computational domain is modelled as a rectangular domain. Symmetry boundary condition is applied on the side boundaries, pressure far field boundary condition which is an appropriate boundary condition for compressible flows is applied on the forward face and pressure outlet boundary condition is applied on the back side of the computational domain. The wing, pylon, store and sting geometry is modelled as no-slip wall boundary condition. The computational domain and boundary conditions are depicted in Figure 9 and Figure 10.

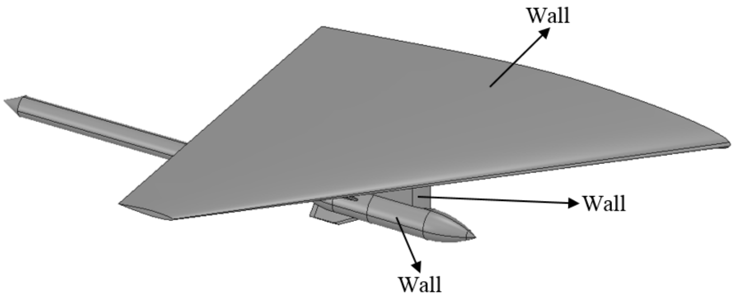

Figure 9: Boundary conditions of wing, pylon, store and sting

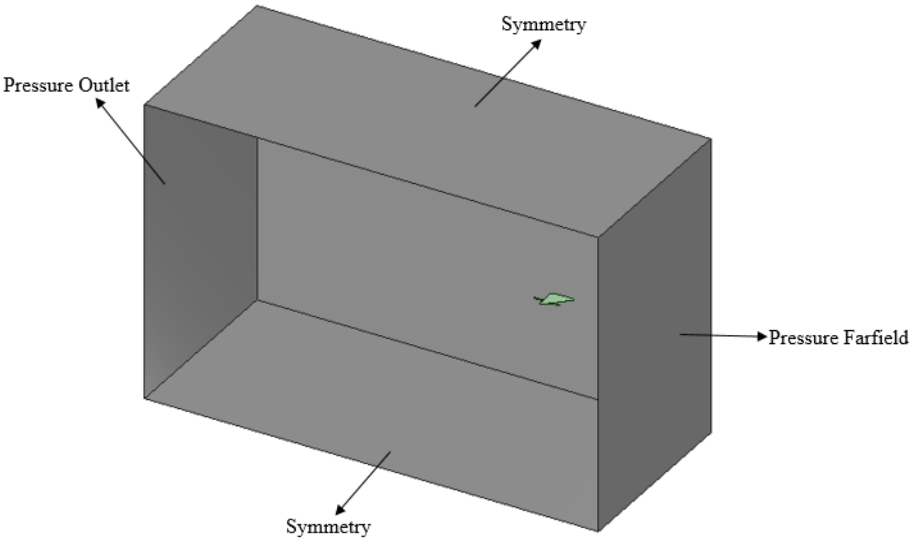

Figure 10: Boundary conditions of computational domain

Moving grid algorithm for captive trajectory simulations is used to control the deformation of computational grids during the motion of the store. Spring based smoothing algorithm is used to control the grid deformation when the deformation is small. Remeshing algorithm is used to generate new cells when the deformation is large or the mesh quality or size exceeds the specified criteria. The flow chart of moving grid algorithm is illustrated in Figure *11*.

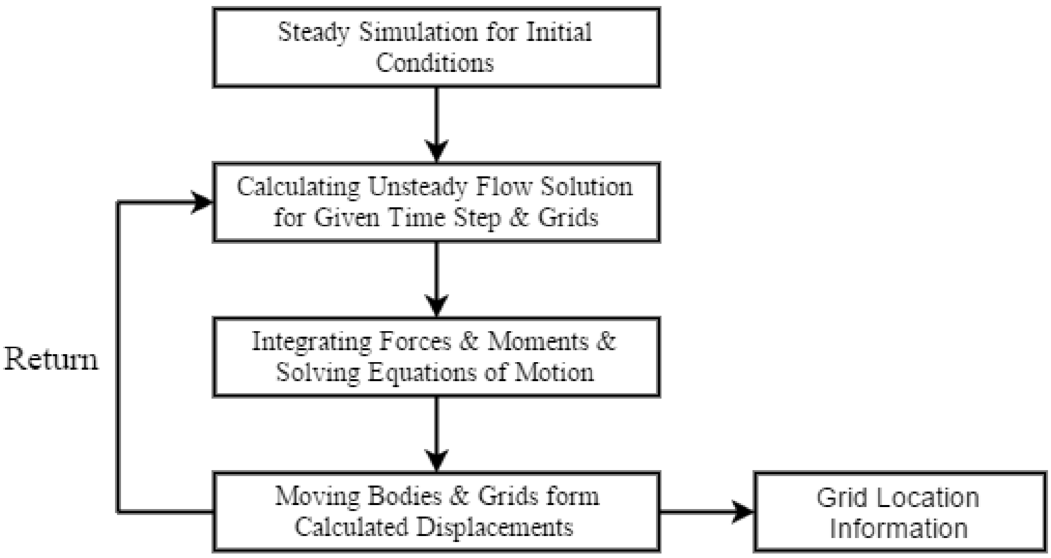

Figure 11: Flow chart of moving grid algorithm

Physical properties of the store and ejector forces required for avoiding fly back motion of the store to the wing after the release are given in Table 1. Unsymmetrical ejector forces are applied on the store shown in Figure 12 as constant during 0.06 seconds. [Lijewski L., E., 1994]

Table 1: Physical properties of the store and ejector forces acting on the store

Mass	907 kg
Center of gravity(aft of store nose)	1417 mm
Roll Moment of Inertia	27 kg.m2
Pitch Moment of Inertia	488 kg.m2
Yaw Moment of Inertia	488 kg.m2
Forward Ejector Location(aft of store nose)	1237.5 mm
Aft Ejector Location(aft of store nose)	1746.5 mm
Forward Ejector Force	10.7 kN
Aft Ejector Force	42.7 kN

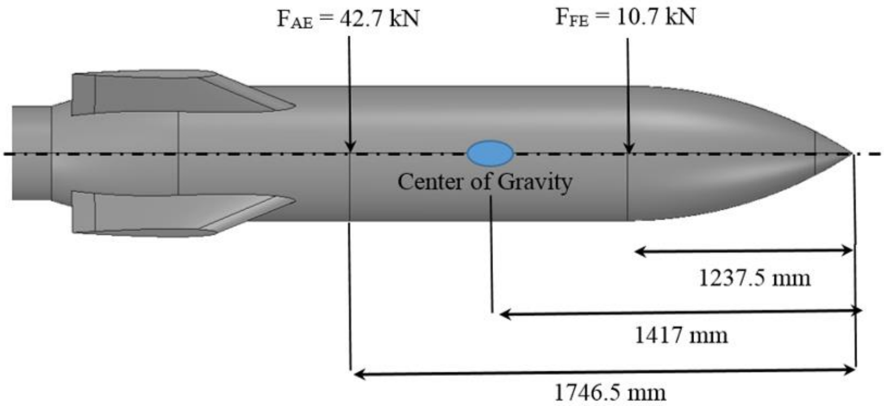

Figure 12: Location of ejector forces acting on the store

Grid Surveying Method Procedure

As it has mentioned from previous sections, in the grid surveying method, aerodynamic grid database is firstly generated, then trajectory of a store is computed using an off-line 6DOF solver. Therefore, in this present study, two different aerodynamic databases that are freestream and interference are generated, and trajectory of the store is determined using a store release code constituted in MATLAB Simulink R2015b. CFD analyses are performed for the same conditions stated in the previous section. However, the only difference is that the analyses are steady state to compute aerodynamic forces and moments. Store-only configuration is used to generate the freestream characteristic of the store for various orientations. It is accepted that only pitch and yaw angle orientation of the store are enough to generate freestream grid database. Then, wing/store configuration is used to involve interference effects of wing and pylon geometry on the store. In addition to pitch and yaw angle orientation, different vertical location of the store underneath the wing is analyzed to generate interference grid database. Nonetheless, it is noteworthy fact that the required simulations for pitch and yaw angle orientation in the interference aerodynamic database are relatively less than the required simulations for the freestream grid database [Finley D.,B., 2014]. The procedure of the grid surveying method is depicted in Figure 13.

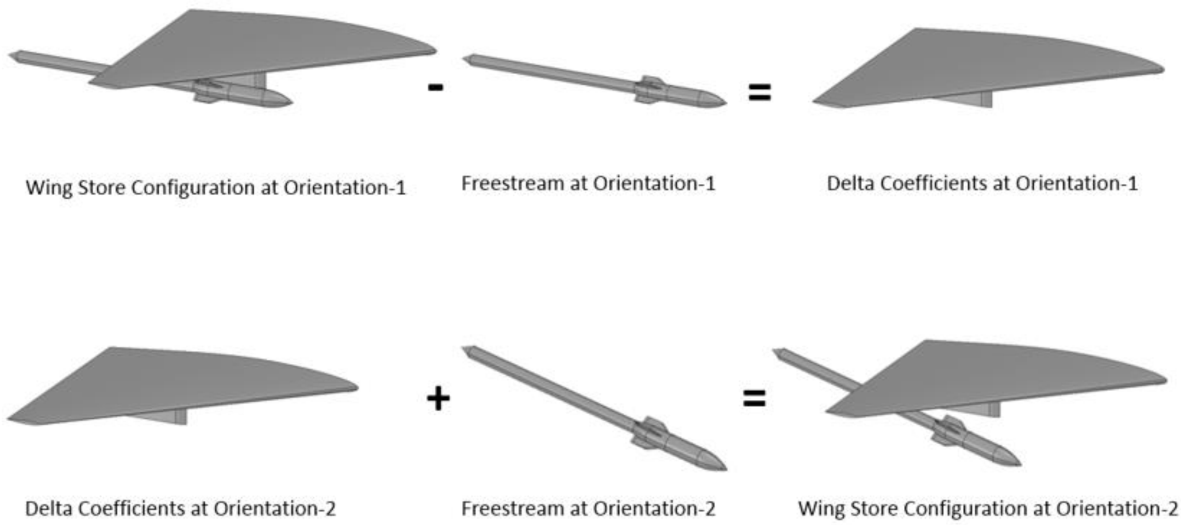

Figure 13: Grid surveying method procedure

Referring to the figure in above, the interference or delta coefficients are calculated from the subtracting of aerodynamic forces and moments obtained from store-only configuration from full wing/store configuration for specific orientation. If conditions resulting from computations are required to fall between these conditions, the linear interpolation method is employed to calculate the desired values at the indicated position. Then, the interpolated value is superimposed to the related freestream data in order to obtain the result for full wing/store configuration.

After the aerodynamic grid database generation, trajectory of the store is calculated using off-line 6DOF solver code. A store separation model has been designed in the MATLAB Simulink environment so as to compute the trajectory and the attitude of the store after being released. Model has been built as a non-linear system with subsystems of aerodynamic, equation of motions, mass properties, ejector and external forces-moments. Subsystem of equation of motion has been built with 6 degrees of freedom. Inputs of the subsystem are the forces, moments and initial states in the body axis. The subsystem evaluates the attitude and trajectory of the store as well as the minimum distance between the aircraft and store. Subsystem works with quaternions in order to eliminate the gimbal lock, existing when the pitch angle was equal to the 90 degrees. After the attitude being evaluated, Direction Cosine Matrix has been built in order to transform either Body Axis to Earth Axis or vice versa. Subsystem of aerodynamic uses the store's attitude as an input in order to evaluate the aerodynamic coefficients. In the subsystem, there are look-up tables for each coefficient. While using the look-up tables, linear interpolation method is employed in order to evaluate the intermediate values of the breakpoints. Subsystem of the mass properties outputs the mass and inertias. It was assumed that mass and inertias do not vary with time. Subsystem of ejector was built for either free fall or with ejector model. In the freefall mode, it applies no force to the store. However, in ejector model, it applies a force within 0.06 seconds only. While evaluating the force occurs on the store, firstly force was transformed from Inertial Axis to Body Axis with using the Direction Cosine Matrix evaluated in the subsystem of EOM. Subsystem of the external forces and moments has been built in order to sum the forces and moments acting on the body of the store. Here, the forces, which are not in the body axis, are transformed to body axis in which the subsystem of the EOM has been built. The subsystem outputs the load factor as well as the forces.

The flow of the data is shown below;

- Firstly, EOM requires the initial states of the store. Aerodynamic block evaluates the aerodynamic forces and moments regarding the initial states.
- All forces and moments acting on the store, consisting gravitational and aerodynamic forces and moments, are gathered in the subsystem of the external force and moments.
- EOM evaluates the next attitude and position with regards to forces and moments acting on the store.
- In each and every time step of the simulation the procedure is repeated. Then the current position and attitude are added to the previous position and attitude.

The flow chart of 6DOF store separation release model is shown in Figure 14.

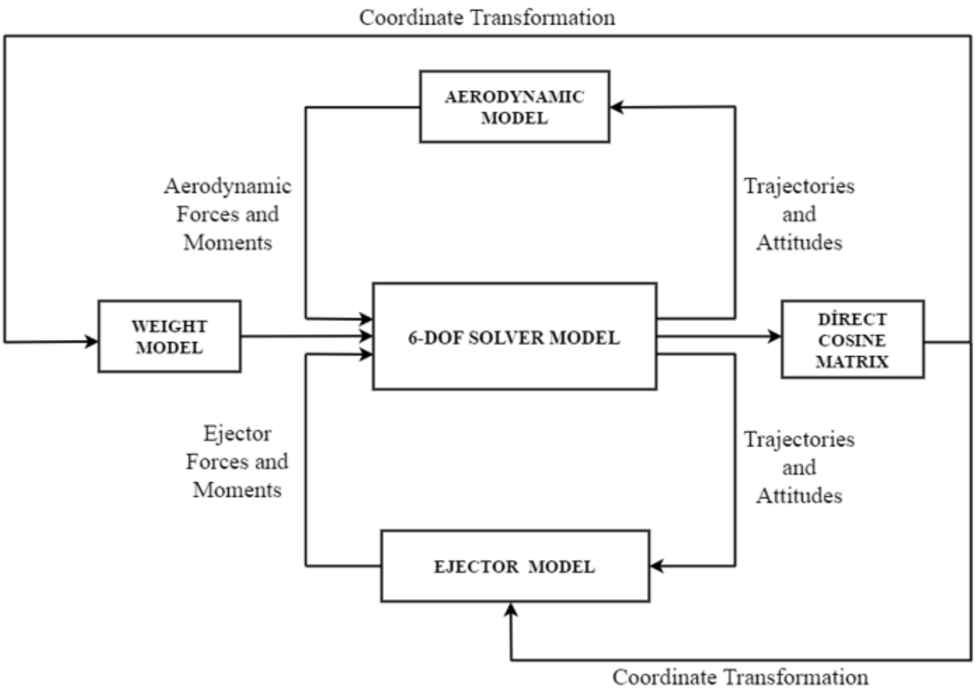

Figure 14: Flow chart of store release code

RESULTS

Trajectory Calculations for Sting Effect

Before starting unsteady simulations, steady state analysis is performed to be used as an initial conditions for trajectory estimations. Simulations are firstly performed to examine how the sting geometry attached to a store affects the behavior of the store during releasing process. The store with a smoothed end is modelled with and without a sting shown in Figure 15. The boundary conditions and physical properties of the store are identical. The non-dimensional pressure coefficient is compared with the wind tunnel data [Lijewski L.E., 1994], as shown in Figure 16.

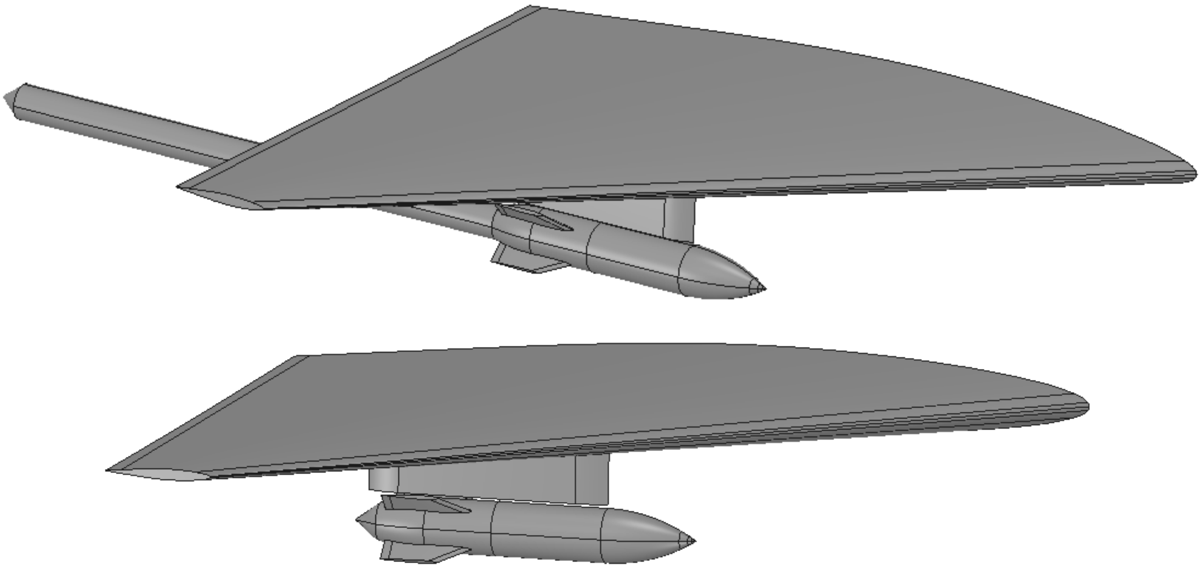

Figure 15: Isometric view of wing-pylon-smooth ended store configuration

Linear and angular displacement of the store with and without sting configuration are compared each other and available experimental data shown in Figure 16.

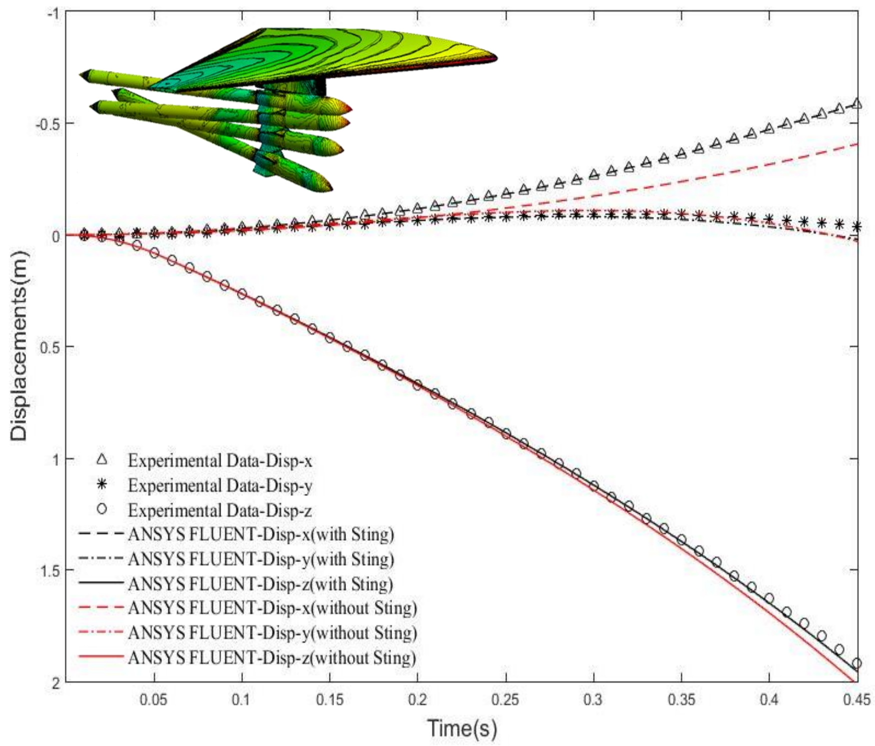

Figure 16: Comparison of estimated linear displacements for two store geometric configuration with experimental study

The most crucial parameter for linear displacements is vertical location of store since store can cause detrimental damage on the wing. Thus, vertical position of store should be investigated carefully. Gravitational and ejector forces effects have significant impact on vertical motion of the store. Therefore, both geometry gives sufficient results compared to wind tunnel data. However, sting attached behind the store greatly affects to horizontal motion of the store as it can be seen in Figure 16, therefore, geometry without sting does not reflect accurate results. Lateral position estimation of the store is almost same for both geometric configuration and matches with the experimental results.

Generally, the most utterly important parameter is the pitch angle change. On condition that abrupt change in pitch angle is observed during the beginning of separation process, it will be hazardous risk for aircraft or its main component. Therefore, this parameter should be calculated more accurately. Pitching moment acting on the store during release process is almost same for both geometry and is in well agreement with the experimental data. However, there is a small discrepancy for yaw angle orientation between two geometric configurations. Store with a sting configuration is more compatible with experimental data. Roll angle trend have similar pattern, however there are some deviations observed from the wind tunnel data due to smaller value of roll moment of inertia compared to other directions and absence of viscous effects in the solution. This difference can be neglected since roll angle orientation does not have significant effect on safe separation for symmetric stores.

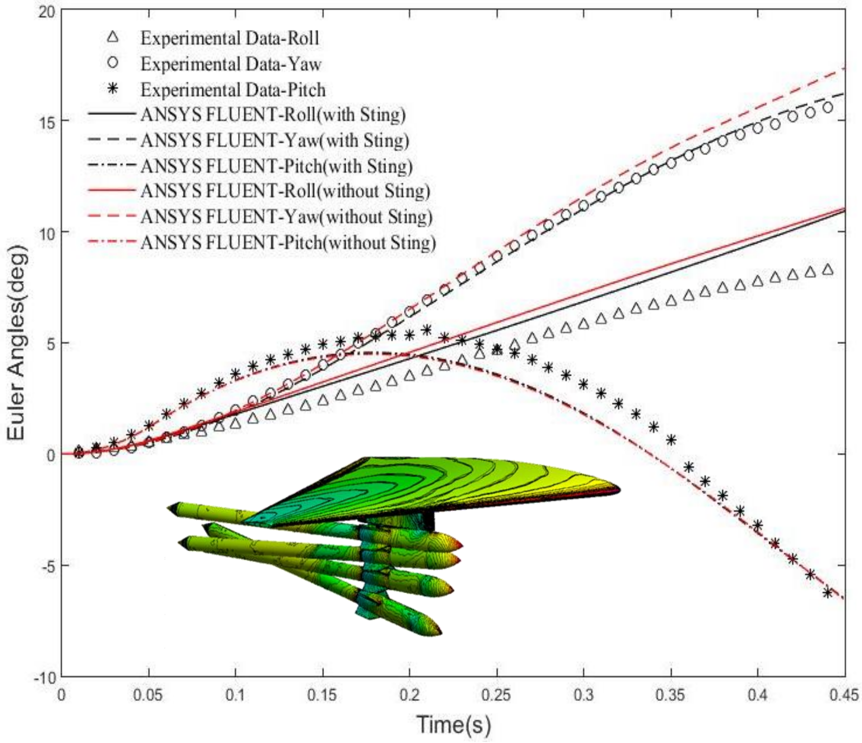

Figure 17: Comparison of estimated angular displacements for two store geometric configuration with experimental study

It is apparent that the results from the store with a sting case are closer to the wind tunnel data than the smooth-ended store. Hence, the sting geometry is included in the grid survey method simulations to generate the aerodynamic database.

Results Comparison for Captive Trajectory and Grid Surveying Method

In this section, the results obtained from captive trajectory and grid surveying method are compared with each other and available wind tunnel results. Linear and angular displacements for all three directions are obtained from both methods. The following figures show the comparison with the available wind tunnel results.

Linear displacements for all three directions obtained from both methods are highly consistent with the wind tunnel results. There are some discrepancies for especially horizontal displacement acquired from grid surveying method due to drag coefficient deviations, however, it can be neglected. Therefore, it can be easily said that no matter which method is used to determine linear displacements of a store.

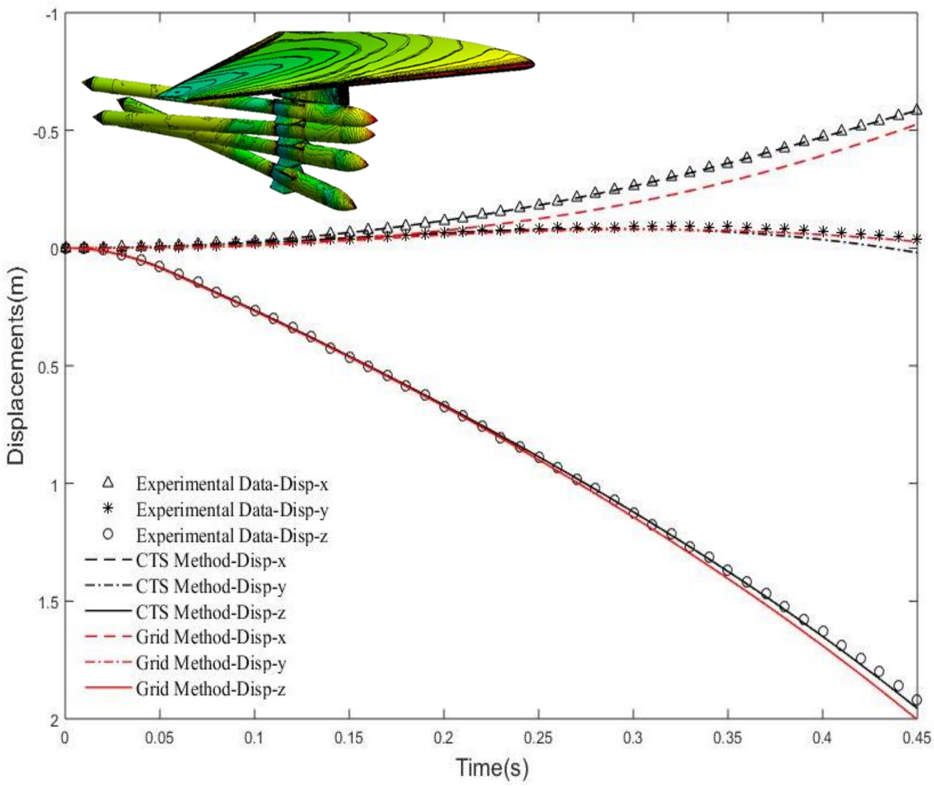

Figure 18: Comparison of estimated linear displacements for both techniques with experimental study

General trend of angular displacement change matches with the experimental data. However, the most difference is observed for roll angle change. Roll angle behavior acquired from grid surveying method has more difference than the wind tunnel and CTS results since the number of required simulations to generate aerodynamic grid database are not sufficient for especially small roll angles. However, roll angle changes does not have significant impact on the trajectory computations for symmetric stores. Therefore, this difference can be neglected for this problem. The numerical results obtained from both methods give accurate results for pitch angle orientation of the store. They are also in well agreement with the experimental results. Yaw angle change obtained from especially CTS method is greatly compatible with the wind tunnel data. There are some discrepancies observed for grid surveying method during the beginning of release process because of which there are not enough data for smaller yaw angles. However, this difference can be negligible. Therefore, it can be smoothly said that the results obtained from both methods give accurate results.

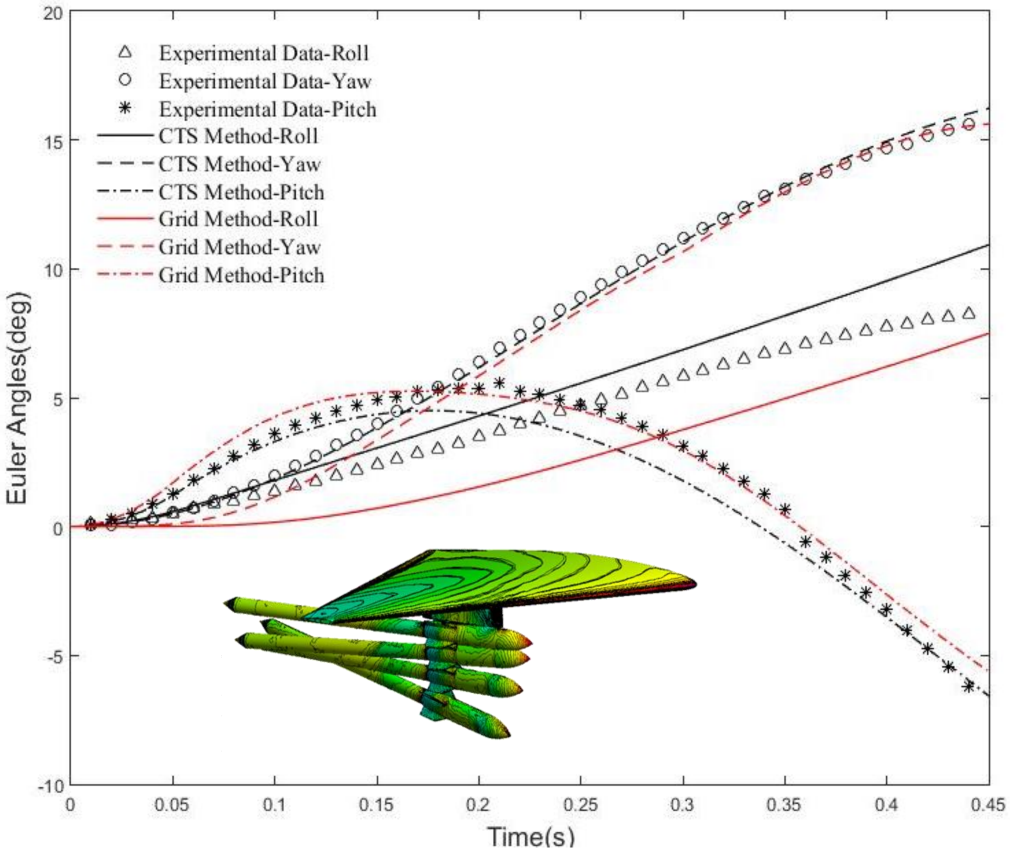

Figure 19: Comparison of estimated angular displacements for both techniques with experimental study

CONCLUSION

In this current study, two different wind tunnel techniques that are captive trajectory and grid surveying method are implemented to CFD methods. Numerical results obtained from both methods are compared with the available experimental results conducted in Arnold Research Development Center. In the light of the results, both methods can be used for store separation certification process. In other words, it can be said that grid surveying method is a viable alternative approach to estimate trajectory of a store during its design process.

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