CFD BASED SOLUTIONS OF RELEASE OF GENERIC STORE

Görkem Demir
Middle East Technical University
Ankara, Turkey

Prof. Dr. Nafiz ALEMDAROĞLU
Atılım University
Ankara, Turkey

ABSTRACT

Trajectory estimation of a store is of vital 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) techniques are developed during the investigation of store separation problem. In this current study, two various well-known wind tunnel techniques, that are captive trajectory simulation (CTS) and grid survey method are implemented to CFD approach in order to observe the time dependent behavior of a well-known test case conducted in EGLIN for transonic flow regime* [Lijewski L.E., 1994]. *Then, linear and angular displacements and velocities acquired from both methods are compared with the available wind tunnel results to demonstrate which method supplies sufficient approximation for such complicated problems.*

INTRODUCTION

Aircraft-store compatibility study should be managed in order to eliminate potential hazardous risks or detrimental effects that may have an impact on successful mission or aircraft and pilot's safety during release of any store. Therefore, different solution techniques are involved to ensure that the store is released without posing threats of aircraft or its main components. The most reliable solution technique is flight testing that reflects exact behavior of the store. However, flight testing technique has some disadvantages in terms of investment of money and time due to the cost of installing telemetry packages etc. Among these, the flight testing threats pilot and aircraft's safety and therefore it shall be performed at the final stage of design process [Cenko A., 2006].

To eliminate potential risks at the beginning of design process, wind tunnel testing techniques were developed. During the early years, dropping tests have been performed, however these were not efficient methods and could harm the wind tunnel circuits. Therefore, two different practical wind tunnel testing techniques called captive trajectory system and grid surveying method have been developed. Captive trajectory system which is an on-line method allows that the trajectory of a store can be determined simultaneously with using balance of strain gauge in the store. However, there are some limitations in small scaled geometry, test conditions and efficiency. On the other hand, grid surveying method which is an off-line technique allows flexibility in trajectory calculations. Aerodynamic forces and moments are determined for parent aircraft and store independently. Once aerodynamic grid database is

Researcher, E-mail: gorkemsdemir@gmail.com
Professor in School of Aviation, E-mail: nafiz.alemdaroglu@atilim.edu.tr

generated, trajectory of the store is computed using an off-line 6DOF solver code. Therefore, numerous trajectory calculations can be accomplished for various combinations [Demir G., 2017]. However, these wind tunnel techniques similarly does not practical in terms of money and time.

Lastly, computational fluid dynamics (CFD) techniques are developed with the advancements in powerful computing capacity and computer algorithms. Therefore, especially CFD techniques are of primary importance for airworthiness certification process since they have no significant hazard on pilot and aircraft's safety. Moreover, computational cost and money investment are much smaller compared than other techniques [Demir G., 2017]. Hence, the usage of CFD methods is accelerating in the solution of store separation problem.

The solution techniques explained in above concurrently depend on each other even if they have some disadvantages. For instance, flight testing and wind tunnel testing can be performed to validate CFD analyses, whereas flight and wind tunnel testing can be planned with using CFD approaches [Cenko A., 2006]. Thus, all these techniques shall be involved in airworthiness certification process.

In this present study, two different wind tunnel testing techniques that are captive trajectory system (CTS) and grid surveying method are implemented to CFD approach, and the trajectory of a generic store is determined and compared with the available wind tunnel results conducted in EGLIN.

NUMERICAL SCHEME

Computational Model and Grid

Simulation model is identical with the geometry used in EGLIN wind tunnel setup, 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 1.

Two different computational grids are generated for both captive trajectory simulation and grid survey method. ANSYS Meshing is used for surface mesh generation, whereas ANSYS Fluent Meshing is used for volumetric grid generation process. The computational grid used in captive trajectory simulation is given in Figure 2 and Figure 3.

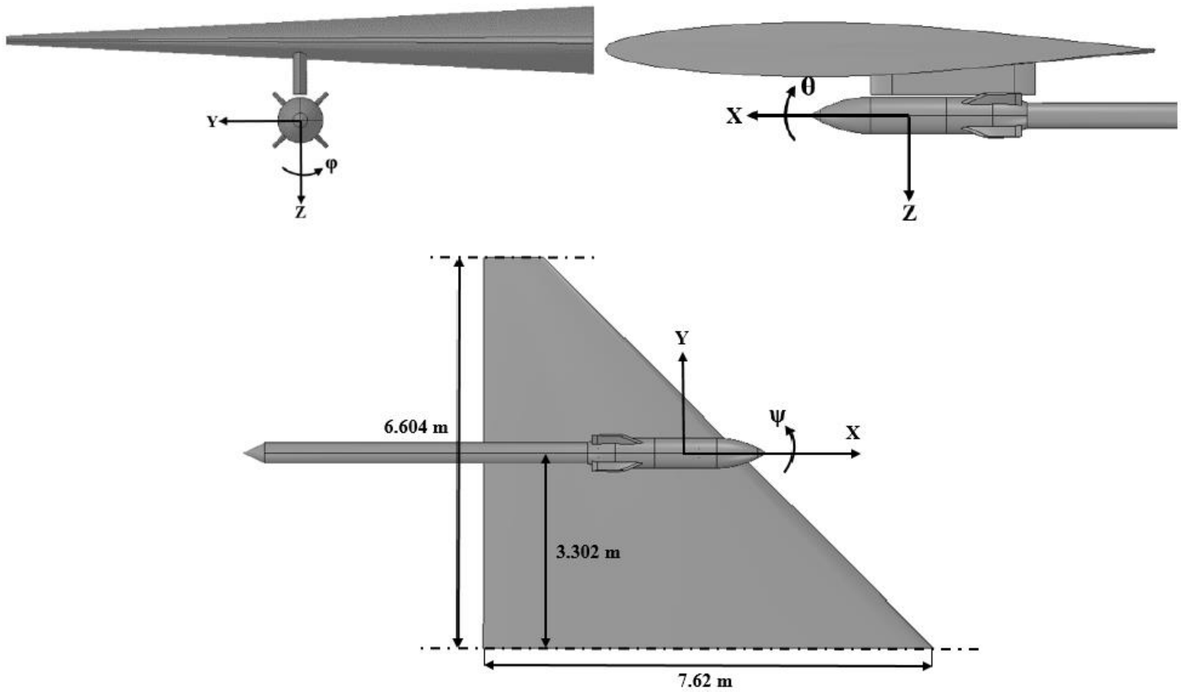

Figure 1: Geometrical details and coordinate system convention of computational model

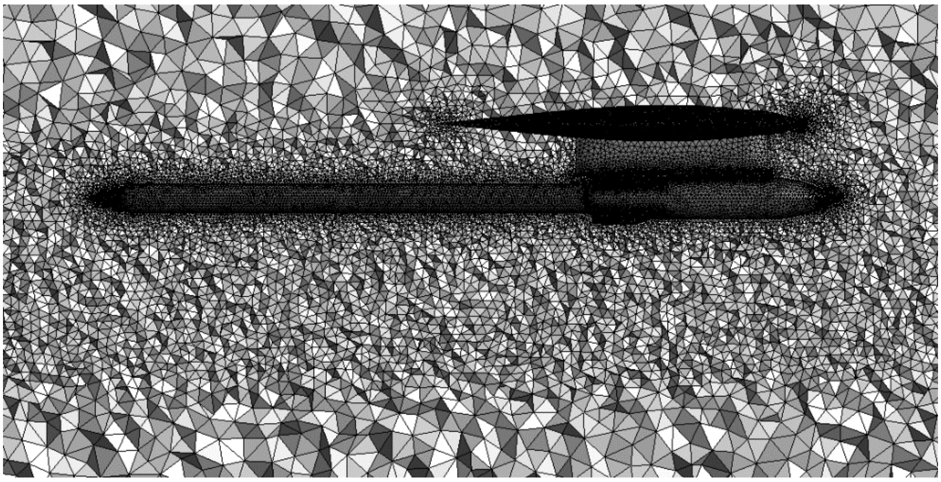

Figure 2: Section view of computational grid elements of whole domain

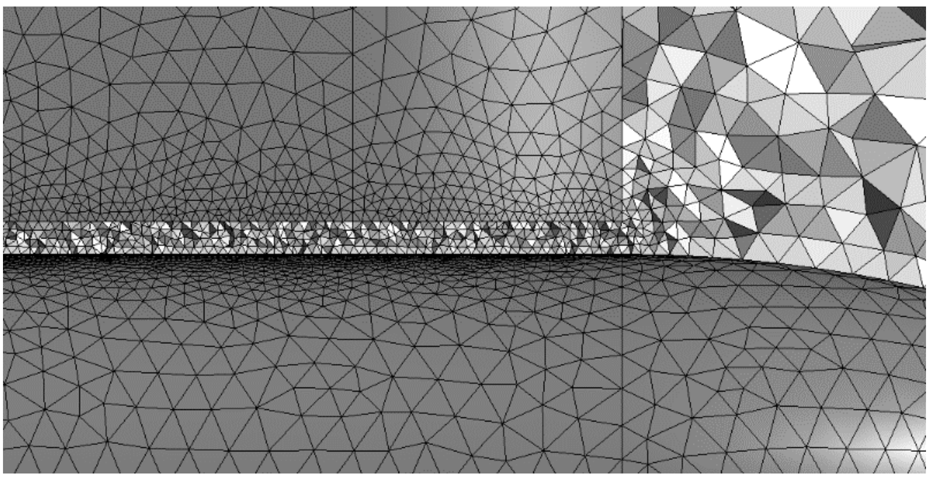

Figure 3: Detailed view of gap between pylon and store

From the figures in above, the computational grid around the wing, pylon and store is shown. Hybrid type mesh algorithm, in other words the combination of hexahedral and tetrahedral elements, is used. 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.

The computational grid used in the CFD analyses for grid survey method is shown in Figure 4. Tetrahedral elements are generated around the store, and more refined mesh elements are preferred near the store to obtain more accurate results.

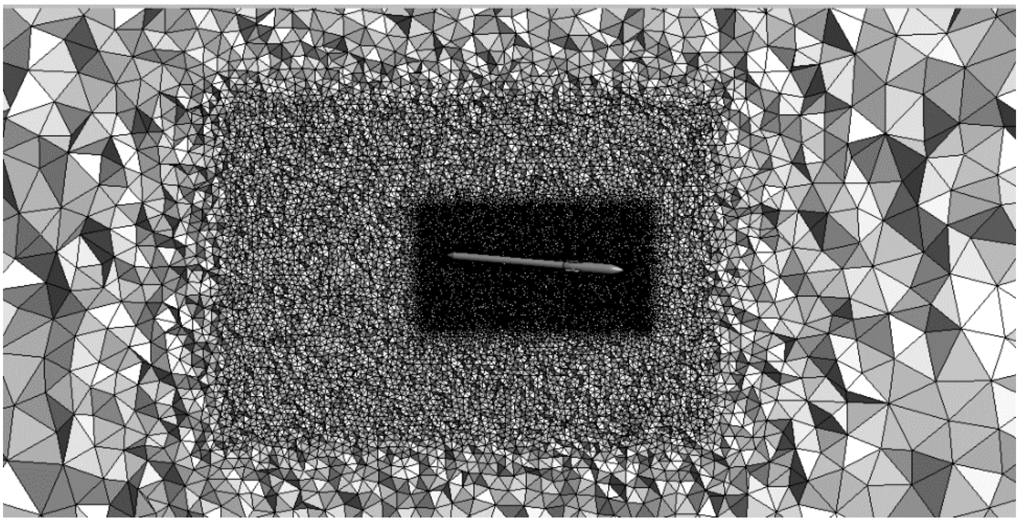

Figure 4: Section view of computational mesh elements around the store

Simulation Process

Captive Trajectory Simulation Procedure

Captive trajectory simulations are performed using ANSYS Fluent R16.2 flow solver which is a well-known and reliable commercial tool for solving such complex problems. ANSYS Fluent permits that both Navier-Stokes and equations of motion can be solved simultaneously. Therefore, this tool is the most appropriate tool for store separation problem. In ANSYS Fluent, the motion of 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].

The 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 5 and Figure 6.

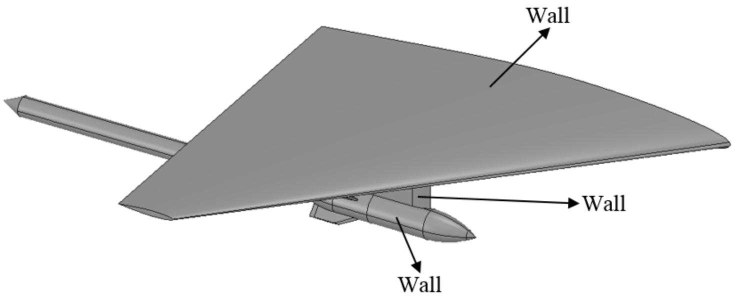

Figure 5: Boundary conditions of wing, pylon, store and sting

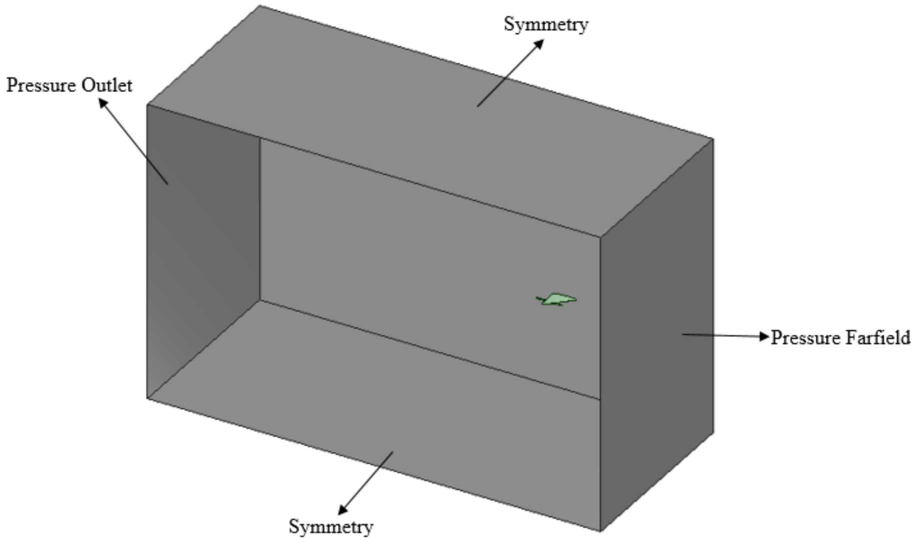

Figure 6: Boundary conditions of computational domain

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 *7*.

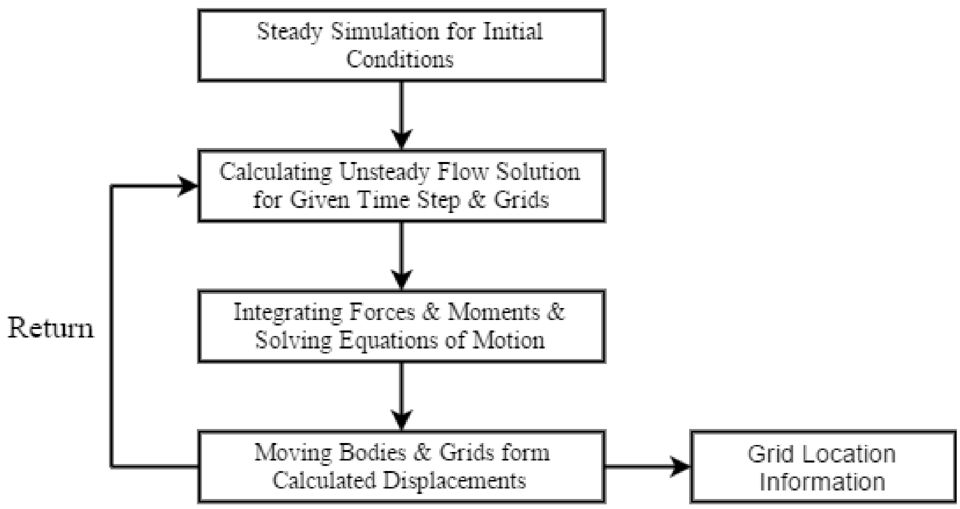

Figure 7: Flow chart of moving grid algorithm

The physical properties of store and ejector forces required for avoiding fly back motion of store to the wing after the release are given in Table 1. Unsymmetrical ejector forces are applied on the store shown in Figure 8 as constant during 0.06 seconds.

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.m^2
Pitch Moment of Inertia	488 kg.m^2
Yaw Moment of Inertia	488 kg.m^2
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

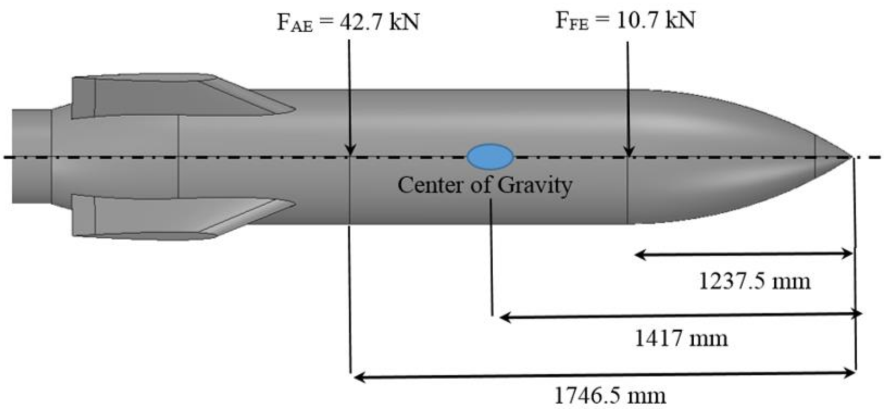

Figure 8: Location of ejector forces acting on the store

Grid Surveying Method Procedure

As it has mentioned from previous sections, in the grid surveying method, aerodynamic grid database is firstly generated, then the 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 the trajectory of the store is determined using a store release code constituted in MATLAB Simulink R2015b. The 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 [Demir, 2017]. The procedure of the grid surveying method is depicted in Figure 9.

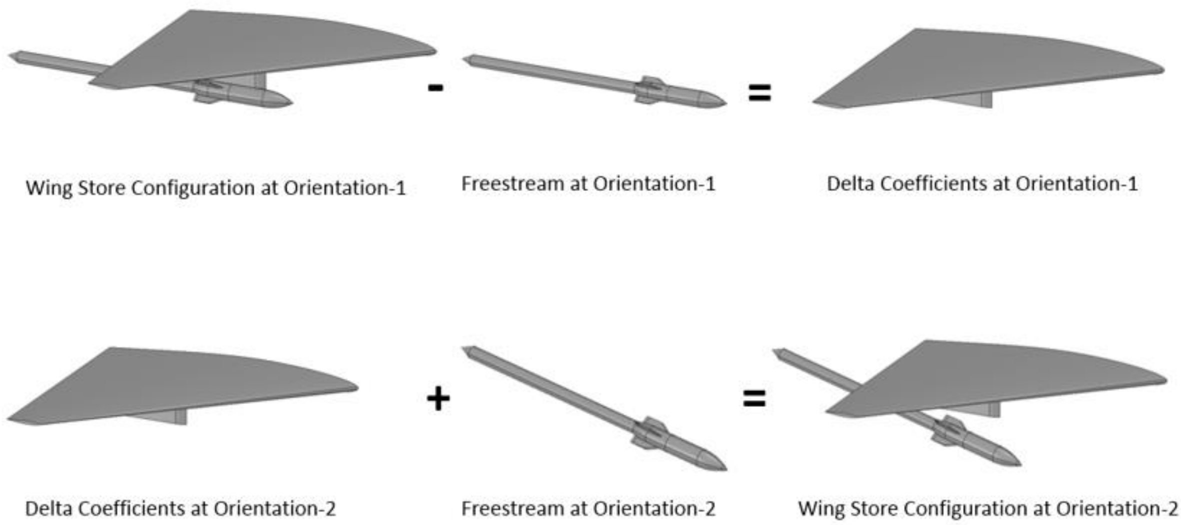

Figure 9: Grid surveying method procedure

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.

Store release code is used to determine the trajectory of the store. The store release code includes four different main modules that are aerodynamic, weight, ejector and 6DOF module. In the aerodynamic module, freestream and interference grid database are tabulated and stored as a certain look-up table. The required aerodynamic forces and moments are supplied with this module. The interpolation algorithm is also employed in this module.

In the weight module, the forces acting on the center of gravity of the store due to the gravitational effects are provided. The required coordinate transformation for equations of motion is accomplished with Direct Cosine Matrix (DCM).

In the ejector module, the piston forces acting on the store during 0.06 seconds are provided. Similarly, the required coordinate transformation for equations of motion is performed by DCM.

In the 6DOF module, the equations of motion required for the trajectory computations are provided. The trajectory and velocity of the store, and DCM are described as output parameters obtained from this module. The flow chart of the store release code is illustrated in Figure 10.

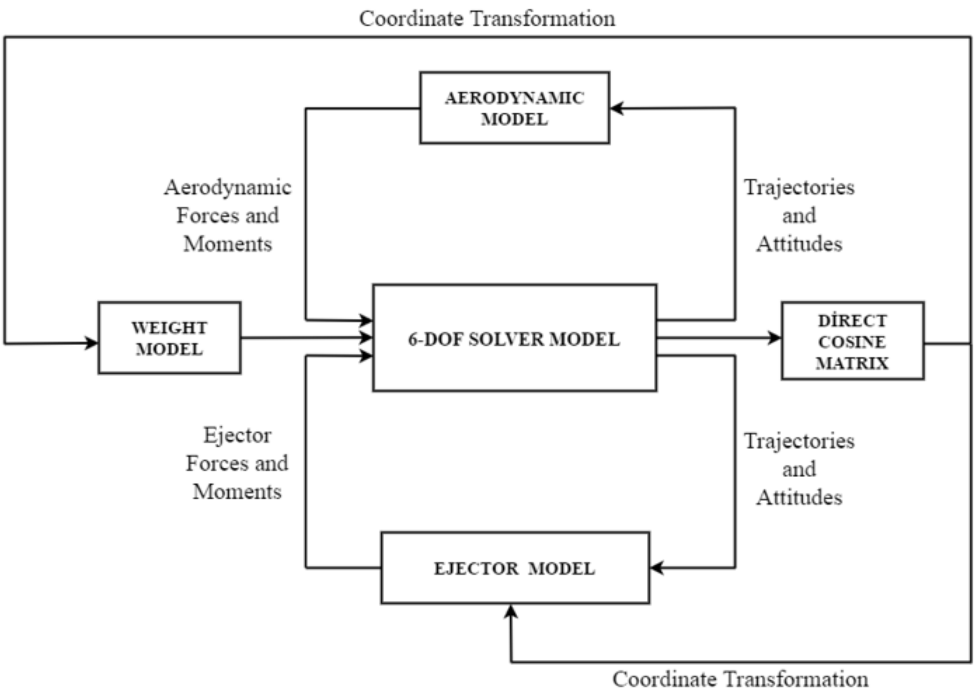

Figure 10: Flow chart of store release code

RESULTS

The linear and angular displacements and velocities for all three directions are obtained from both methods. The following figures show the comparison with the available wind tunnel results.

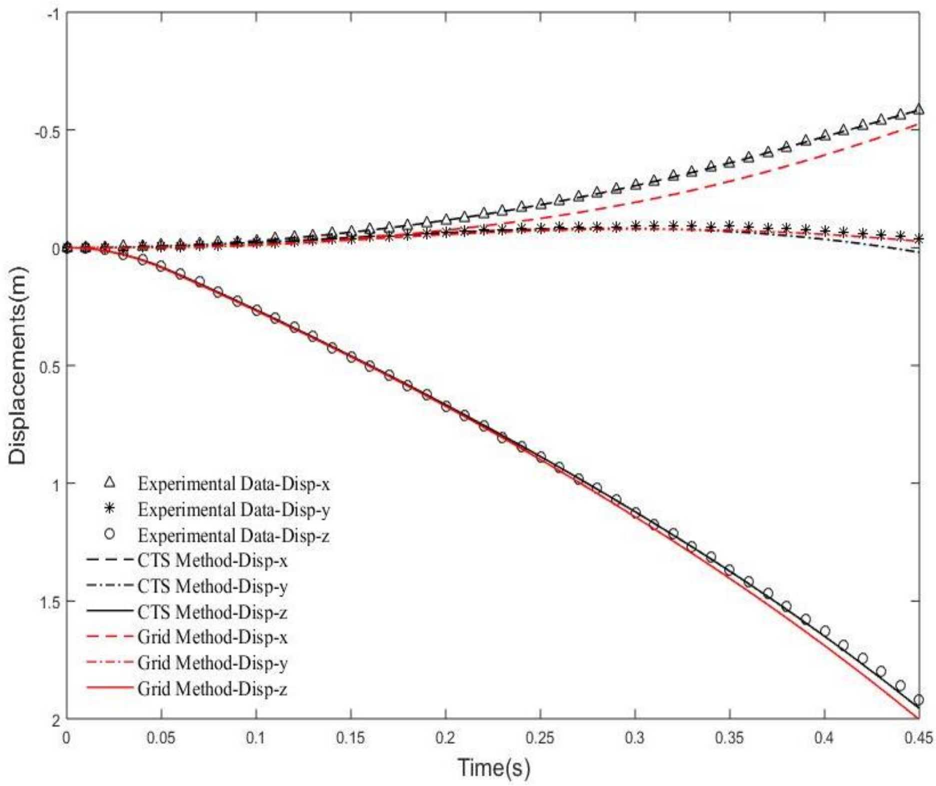

Figure 11: Linear displacement change for all three directions with time

The 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, 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. In other words, both methods can supply efficient results for linear displacements.

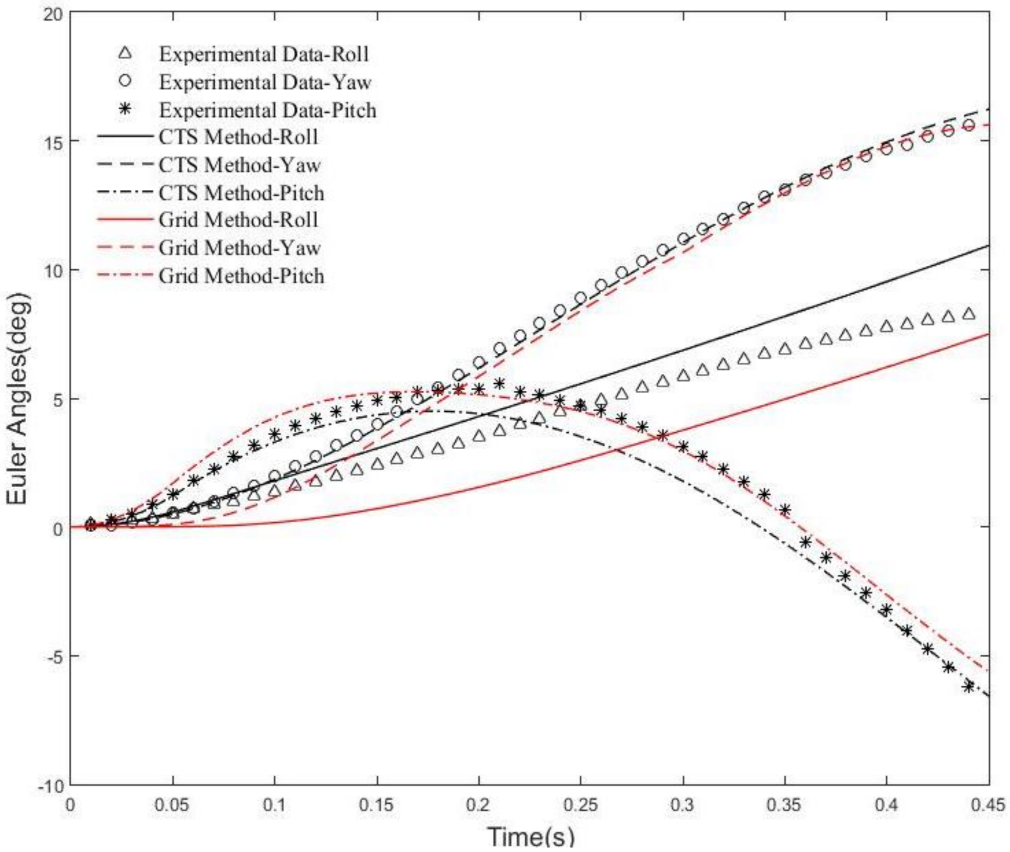

Figure 12: Angular displacement change for all three directions with time

The general trend of angular displacement change matches with the experimental data. However, the most difference is observed for roll angle change. The main chief reason is the fact that the roll moment of inertia is much smaller compared than the pitch and yaw moment of inertia. Therefore, this situation results that is hard to determine the roll angle change with the computational methods. Additionally, the 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. Lastly, the roll angles cannot be determined accurately due to the absence of viscous effects. 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.

Generally, the most utterly important parameter is the pitch angle change. On condition that abrupt change in pitch angle change 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. 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.

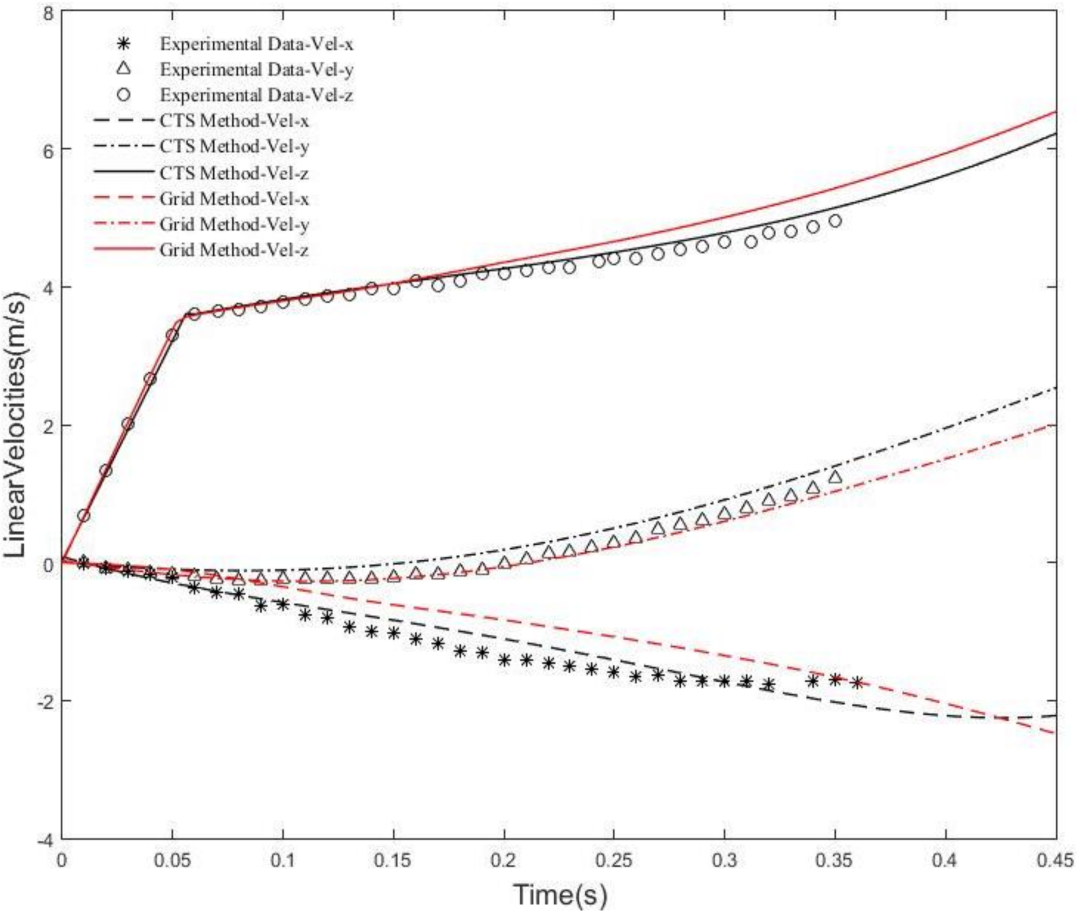

Figure 13: Linear velocity change for all three directions with time

Similarly with the linear displacements, the linear velocity change for all three directions obtained from both methods are compatible with the experimental results. There are some discrepancies, however, the major trend matches well. It is interestingly noted that the vertical velocity change during 0.06 seconds linearly increase since the ejector forces and gravitational effects are more dominant than the aerodynamic effects. When the ejector forces vanish, the store’s acceleration is declining. By the way of conclusion, the linear velocities can be determined with both methods accurately.

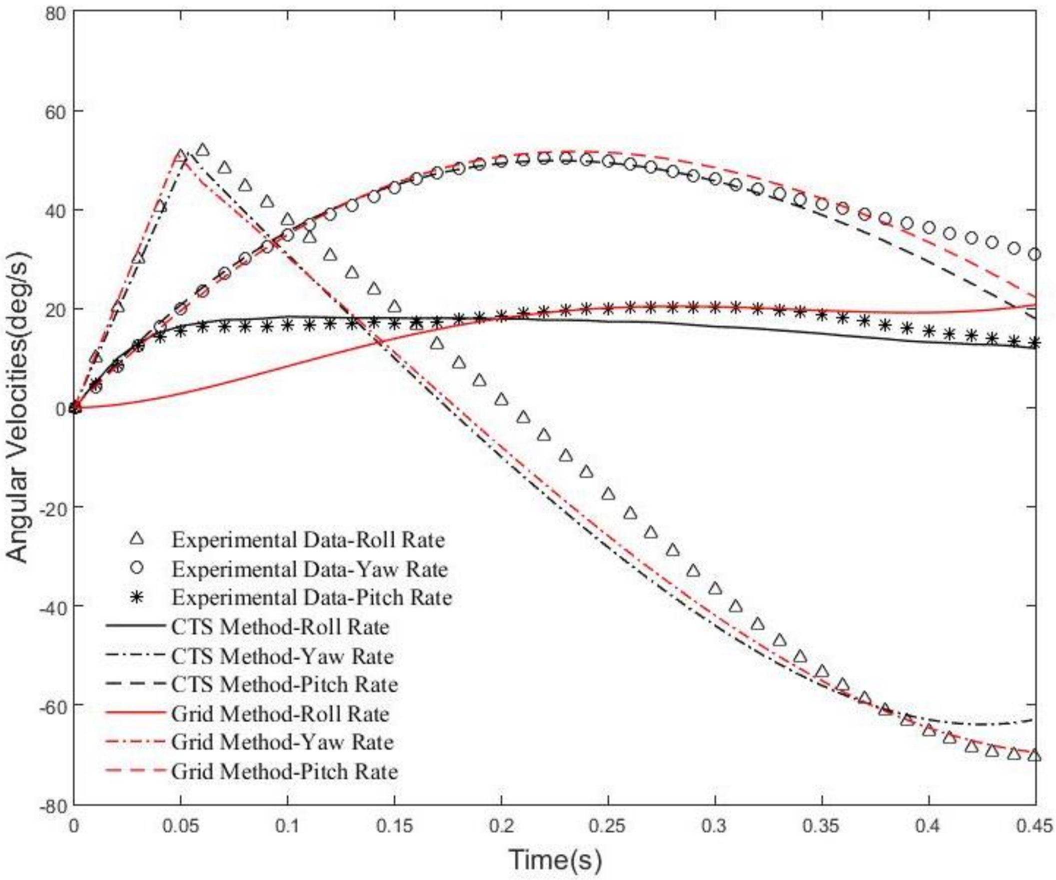

Figure 14: Angular velocity change for all three directions with time

The angular velocities obtained from both methods are consistent with the experimental results except for especially the roll rate acquired from grid surveying method. Since there is no aerodynamic forces and moments calculation for roll angle change, the roll angle behavior cannot be determined well. Therefore, grid survey method cannot give accurate results for the time rate of change of roll angle. However, as it has mentioned before, the roll angle change does not have significant impact on the store separation problem for symmetric stores. Hence, this discrepancies can be eliminated for this problem. For other angular rates, both results match well with the wind tunnel data.

Pressure and Mach number contours on the wing, pylon and store geometry as obtained from CTS analysis are shown in Figure 15 and Figure 16.

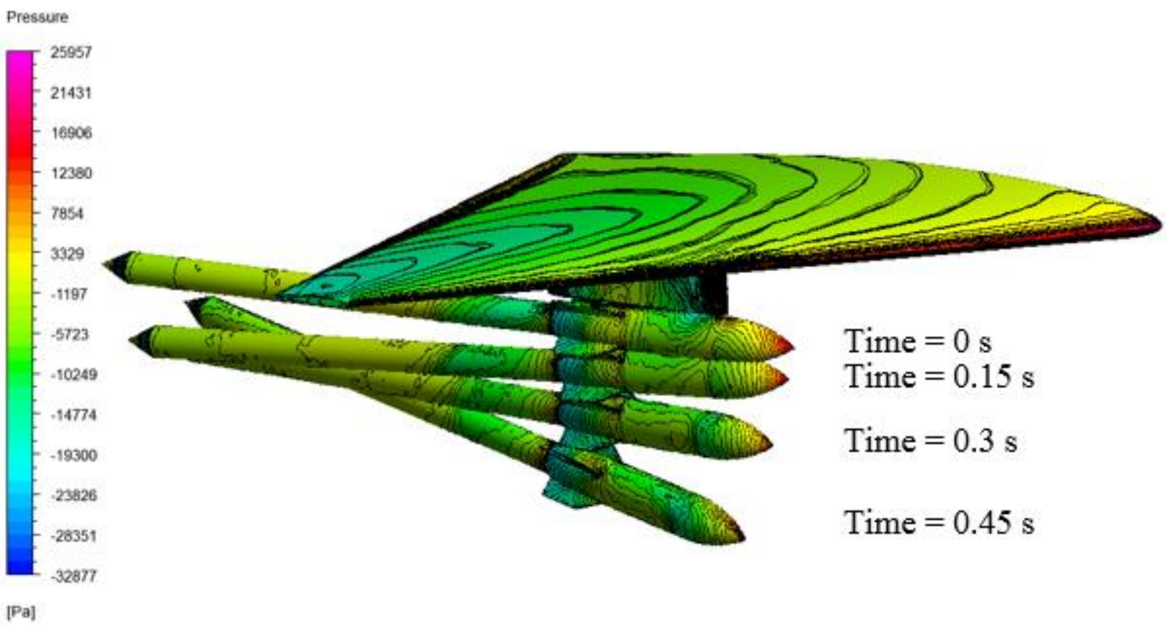

Figure 15: Pressure contours at different time steps

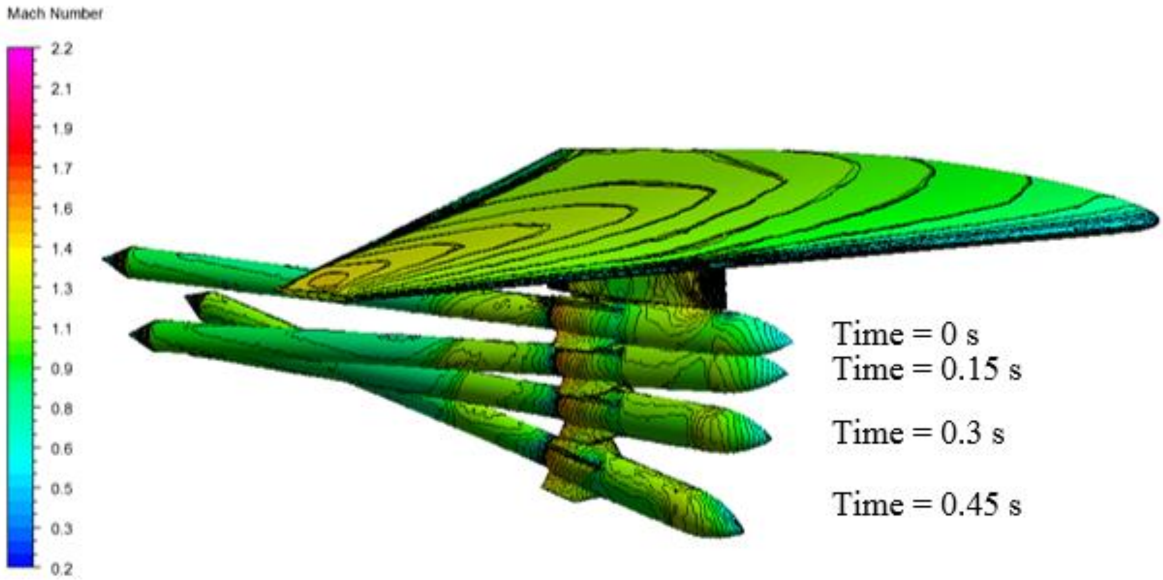

Figure 16: Mach contours at different time steps

Weight Effect on Trajectory Calculations

As it has mentioned before, grid surveying method provides flexibility for store separation applications because numerous trajectories of a store can be determined for different physical properties of the store and various ejector force characteristics in a very short time once the aerodynamic grid database is generated. Thus, to validate this statement, a trivial scenario with different store's mass property is analyzed. In the following results, the store's mass is taken as 1500 kg, however, the other parameters are exactly same with the geometrical details of the store, ejector forces, boundary conditions and physical properties mentioned in the previous section. Then, the linear and angular displacements obtained from both methods are compared with each other due to the absence of wind tunnel results. Figure 17 and Figure 18 demonstrate the comparison of the linear and angular displacements obtained from both methods.

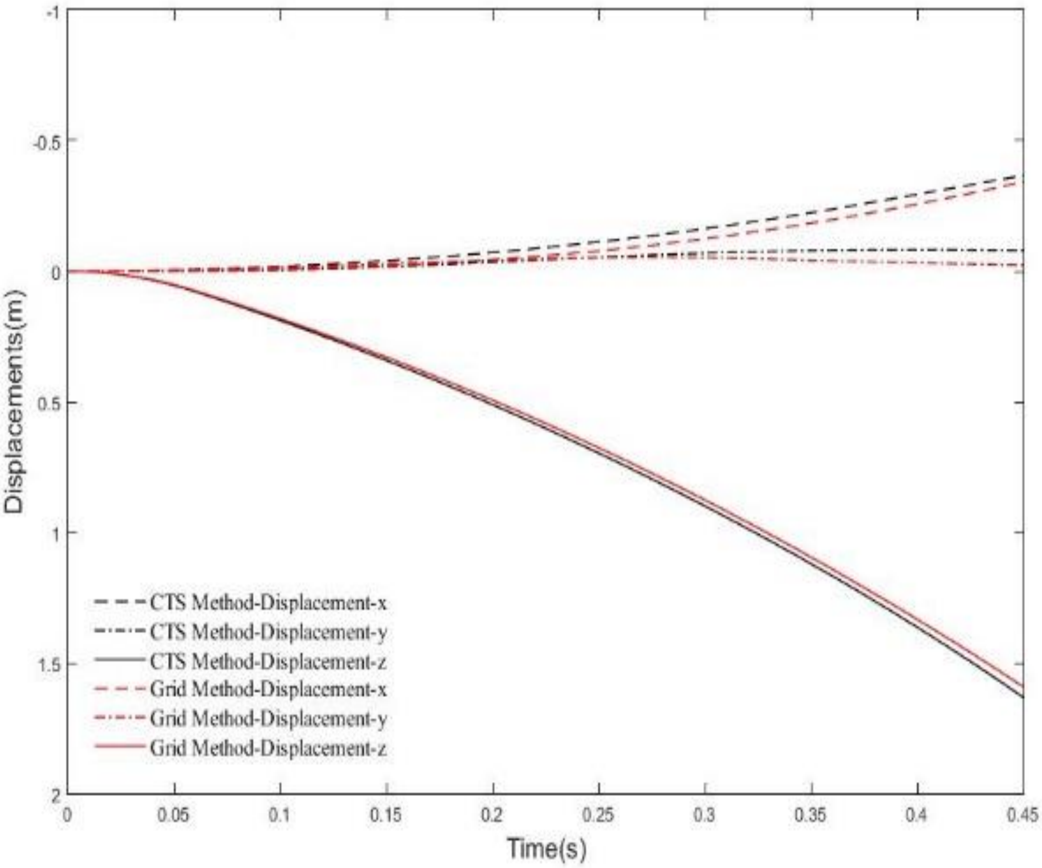

Figure 17: Linear displacement change for all three directions with time

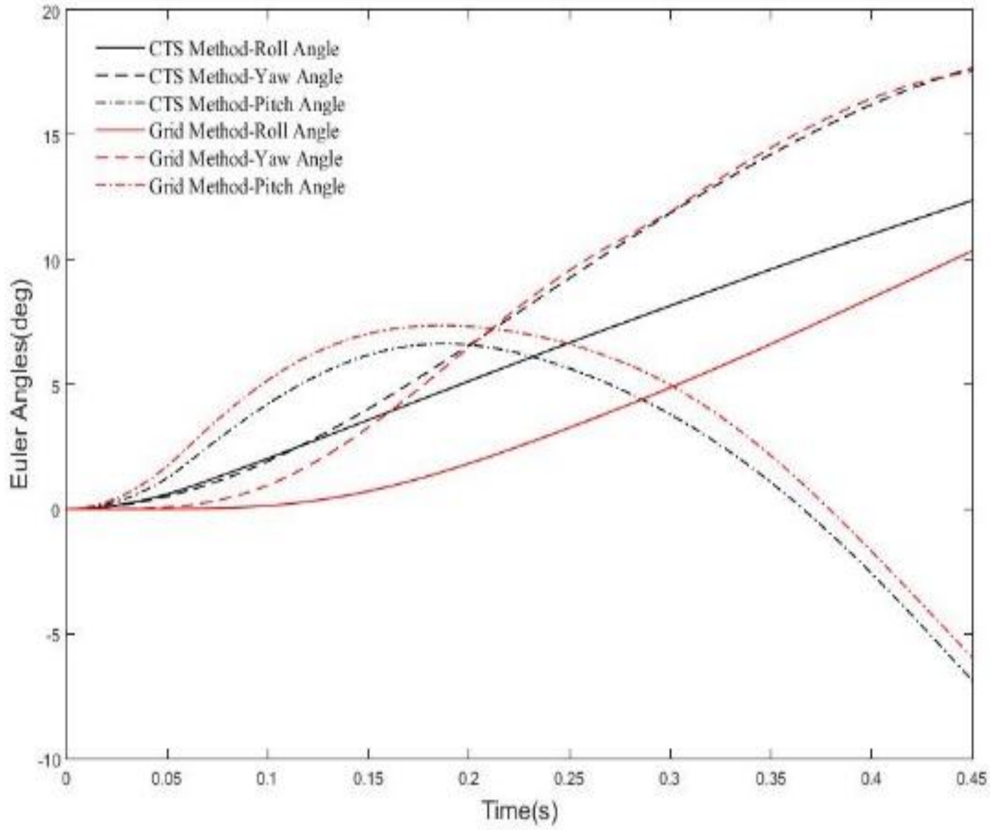

Figure 18: Angular displacements for all three directions with time

In the light of linear and angular displacement results, the trajectory of the store is computed with both methods similarly.

Ejector Forces Effect on Trajectory Calculations

Likewise, a trivial simulation with different ejector forces is performed in order to reveal the capability of grid surveying method. The ejector force acting on the store's forward location is taken as 15 kN whereas the aft ejector force is taken as 59.9 kN, and the store's mass is taken as 907 kg which is exactly same with the mass as described in the previous section. Figure 19 and Figure 20 show the linear and angular displacement change with time.

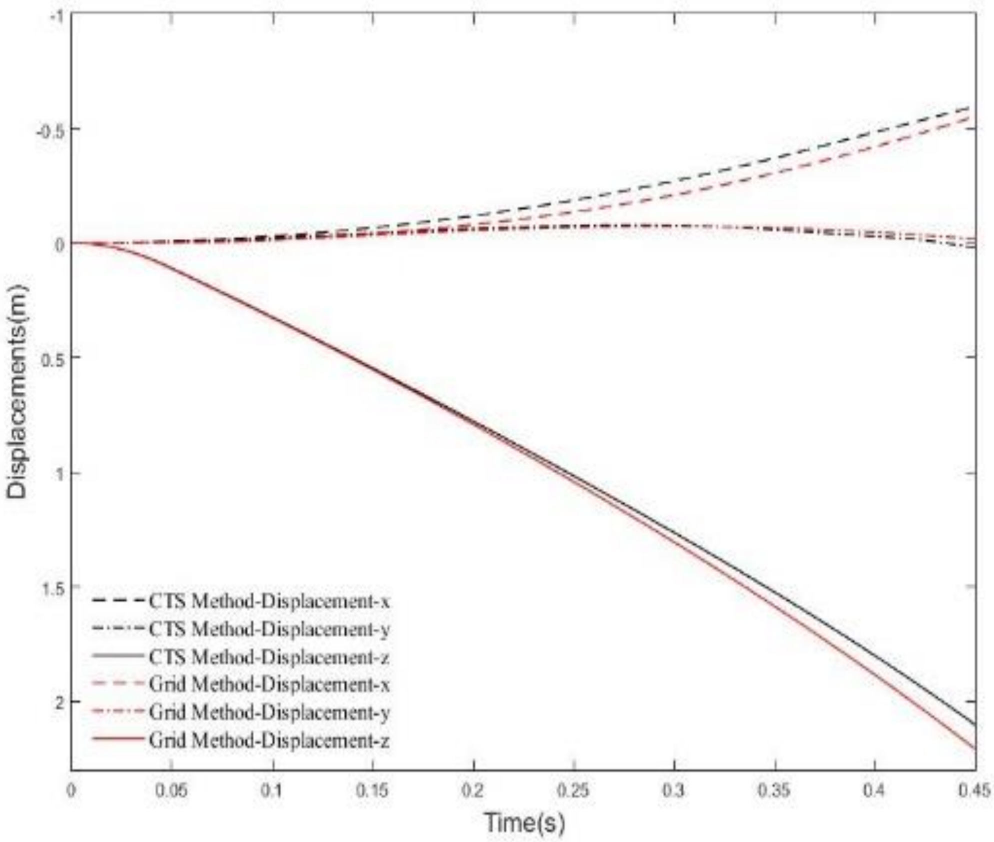

Figure 19: Linear displacement change for all three directions with time

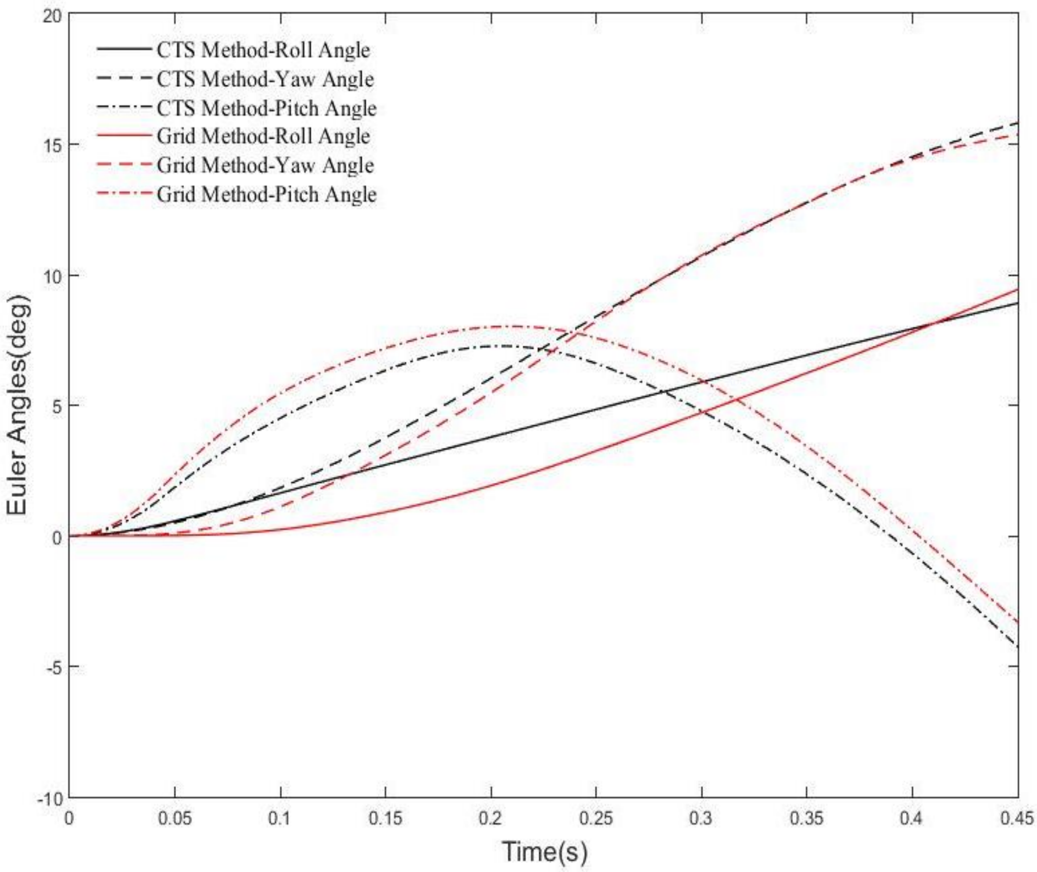

Figure 20: Angular displacement change for all three directions with time

The linear and angular displacements are in well agreement with the wind tunnel results.

To express the advantage of usage of grid surveying method, the computational time for both methods are compared and tabulated in Table 2.

Table 2 Computational time comparison

Solution Techniques	Captive Trajectory Simulation	Grid Method
Simulation Time	279.2 hours	110.8 hours

Table 2 indicates clearly that the computational time for grid surveying method takes considerably less time than CTS method. Aerodynamic grid database generation takes the primary part of computational time. Once it is generated, numerous trajectory estimation can be performed as it has mentioned before. Therefore, grid surveying method has a major advantage in terms of time gained.

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 EGLIN. In the light of the results, both methods can be used for store separation certification process. However, grid surveying method takes less computational effort than CTS. Once aerodynamic grid database is generated, subsequent trajectory calculations for other configurations do not require excessive computational times. Therefore, it can be said that grid surveying method is a viable alternative approach to investigate the effects of store's physical properties and ejector forces during its design process.

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