10th ANKARA INTERNATIONAL AEROSPACE CONFERENCE **AIAC-2019-100**
18-20 September 2019 - METU, Ankara TURKEY

STORE SEPARATION ANALYSIS FOR FIXED FIN GUIDANCE KITS

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18.09.2019

ABSTRACT

Guidance Kits are developed to increase the efficiency and delivery accuracy of air launched general purpose bombs like MK-82 and MK-84. In the early development stages of the guidance kits, the control actuator system was driven by hot or cold pressurized air. The fins are free to rotate up to the mechanical limits. The technological improvements in last few decades exposes a tendency to change the power source from pressurized air to electrical motors driven by thermal batteries. The result is more complex mechanisms to have the same free to rotate fins with same level of safety. However, fixing the fins in an aligned position with the bomb during captive flight and unguided portion of free flight will decrease the complexity in the mechanisms and increase reliability further. In this study, captive phase and store separation of Guided Bombs with fixed fins are investigated and compared to the guidance kits with free to rotate fins.The results show that the safe separation of the store is still satisfied even though fixing the fins can significantly effects the captive carry loads and the separation characteristics.

INTRODUCTION

It requires an extensive study and tests when a new aircraft or a new store (external fuel tanks, intelligence pods, air to ground missiles or bombs) enters service. In the military world, the requirements are driven by two major factors, both mission and safety. The success of the mission must be guaranteed without risking the pilot and the aircraft itself. Besides, the operations in military contain operation phases which are not common to civil operations. The external/internal stores can be dropped or ejected during flight. Therefore, the well known store separation phenomena must be examined thoroughly during the development and testing phases for each item.

During the early years of military aviation history, the store separation studies have been conducted as flight testing. The test speed was increased gradually until the store came closer to the aircraft than a set threshold [Cenko, 2010]. And, sometimes store hit the aircraft resulting the loss of platform. The need to be more confident before the actual flight tests has led to the search of better ways to analyze store separation phenomena ever since then.

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The Captive Trajectory System Wind Tunnel analysis [J. B. Carman and Christopher, 1980], Computational Fluid Dynamics (CFD) methods coupled with 6DoF equation of motion [Panagiotopoulos and Kyparissis, 2010], and Influnce Function Method (IFM) [Meyer and Yaros, 1981] are among the fundamental techniques to study the store separation phenomena before actual flight tests [Arnold and Bogue, 1986]. Although any single analysis method is not sufficient to certify a store and clear it for flight, the study brings confidence and gives clues what to expect during testing. Increase in computing power and the improvements in techniques to solve complex flow fields in the vicinity of an air platform for different speed regimes promotes the CFD methods a good starting point to begin the certification process.

Study Focus

Guided Bombs (GB) are the assembly of a General Purpose Bomb (GPB) and a Guidance Kit (GK) which results in higher accuracy on the target area. Generally, GKs are composed of three parts: a guidance and control unit (common to 500 lbs to 2000 lbs GPBs), control fins attached to a Guidance and Control Unit (GCU) and a tail assembly (different for each class of GPB). A seeker is generally mounted on a wind vane which is placed in front of the guidance and control unit. GKs give the ability to correct the trajectory of GBs when the seeker attached acquires the target. The general layout of a generic GB is given in Figure 1.

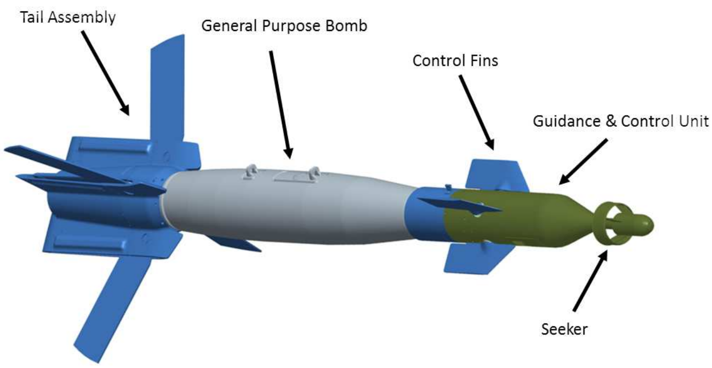

Figure 1: General GK Assembly

During the carriage phase, the tails wings are stowed inside a housing as shown in Figure 2 and the control fins are free to rotate around their hinge axis. GBs with stowed wings are generally statically unstable [Freeman, 2006] even with free to rotate control fins. If the control fins are fixed and aligned to GPB's longitudinal axis, the level of instability is expected to be increased, which means that the GB is more vulnerable to the complex flow field induced by the aircraft during separation. The tail wings are kept in their stowed position by a mechanical safety pin, which is released immediately after the employment of the store by a lanyard. The wings are forced to their final position by a preloaded spring mechanism in a very short duration when the mechanical safety pin is released. While the wings deploys, the GB becomes statically stable in some interim position of wings.

Figure 2: GK Assembly, Stowed Wings

In this study, separation behavior of a GB composed of a generic guidance kit and 500 lbs class GPB is investigated for one loading configuration of F-16[1] Aircraft. The study starts with an investigation of stability characteristics of the free to rotate control fins (FRF) and Fixed Control Fins (FCF) cases. The aerodynamics loads on the GB during the captive carry phase of the flight is also compared for the two cases. Finally, separation simulations are performed and compared for the different scenarios. The effect of fixing the fins during free flight after a successful separation is not included in the study. The deployment of the tail wings are considered as a function of time during the store separation and the mesh is updated accordingly during simulation.

METHOD

All the simulations in this study are performed using the commercial software named Fluent V16.20. Fluent is a finite-volume based Navier-Stokes solver that follows cell-centered solution approach with several turbulence models implemented. It can process both structured and unstructured grids and has moving mesh and reference frame capabilities. It can be used to model steady flows along with the unsteady flows with up to second order accuracy. The motion of the GB is solved by the six degree of freedom (6DoF) equation of motion module coupled with FLUENT software. The ejection force and deployment of the wings are controlled by user defined functions and implemented in solution process.

The loading configuration of the platform that is used in the analysis is given in Figure 3. For the considered configuration, all the wing stations are loaded and the GB is carried over the station in between the external fuel tank and the AIM-9 air-to-air missile.

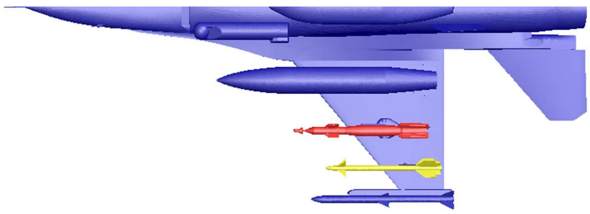

Figure 3: F-16 Loading Configuration

To perform the simulations, an unstructured solution domain with almost 20 million elements is created and shown in Figure 4.

The simulations of 6DoF motion of the GB are started from the steady state solutions of the store that is in captive carry position while the aircraft is in level flight trim condition for the specified altitude and the velocity. Once the convergence in forces and moments on the store is obtained, unsteady simulations of 2^{nd} order accuracy in time is started.

For the FRF case, since the fins have symmetrical geometry with respect to their chord lines, there will be no normal force and moments generated due to this force because the fins are aligned with the airflow. Even though Fluent solver enables users implement a function to solve separate equations of motion for the fins' motion, the above fact is used as excluding the forces and the moments due to the fins when solving the equations of motion of the GB to simply the solution process.

SIMULATION RESULTS

Comparison of Static Stability (FRF vs FCF cases)

As stated before, the GBs with stowed wings are usually statically unstable for either FRF or FCF cases. However, both configurations become stable at some tail wing angle during the wing deployment process. In order to find when the GB becomes statically stable, freestream CFD analysis of the GB geometry for different tail wing angles, that start from the stowed position and ends when the wings

[1]A simplified model of F-16 Block 40 A/C is used in the study

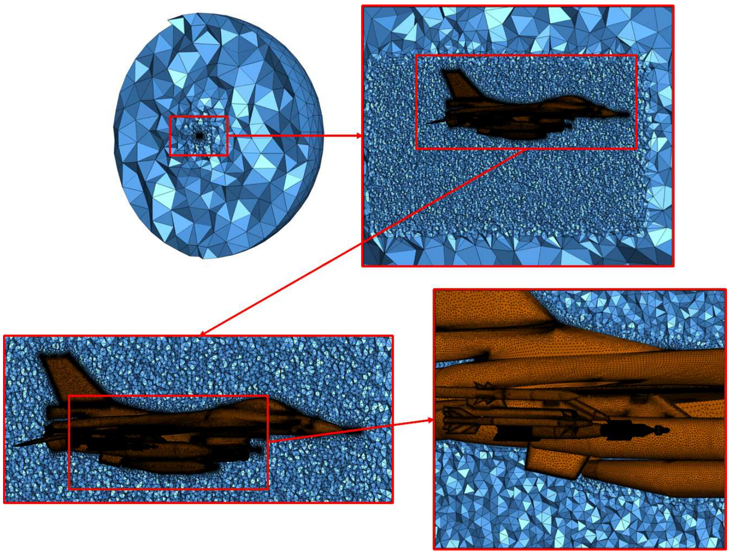

Figure 4: Solution Domain

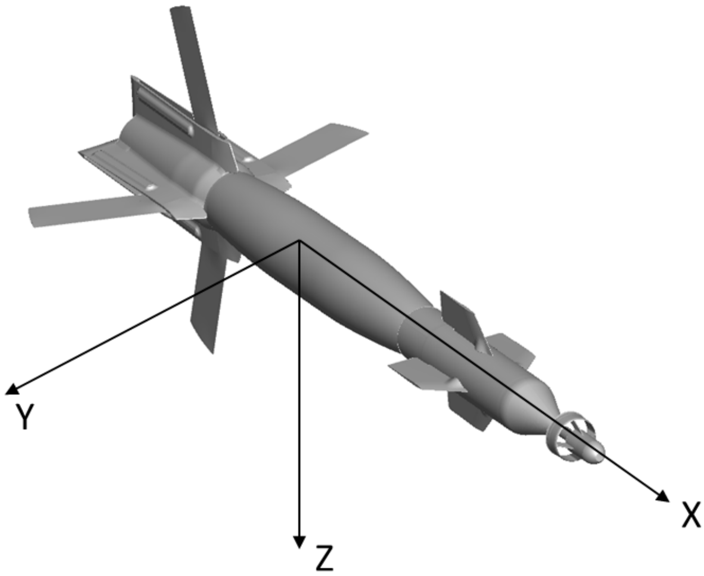

Figure 5: Guided Bomb Body Axis

are fully deployed, have been conducted. The simulated flight conditions for these analysis are given in Table 1. As can be seen, three flight conditions that are subsonic, transonic, and supersonic are considered for the simulations. The results for the FRF cases were obtained excluding the contribution from the fins to the total pitching moment assuming they are aligned with the flow.

Table 1: Flight Conditions

FC #	Altitude (ft)	Mach
1	2500	0.60
2	2500	0.95
3	18000	1.20

In Figure 6 and 7, the pitching moment values with respect to the center of gravity of the GB at some positive angle of attack is shown. Both FRF and FCF GB geometries are statically unstable when the tail wings are stowed for the simulated flow conditions. As the tail wings deployed, the FRF GB geometry becomes statically stable somewhere between $0° - 10°$ tail wing angles for all the flight conditions considered. Similarly, the GB geometry having FCF becomes statically stable between $10° - 20°$ tail wing angles. Hence, the geometry having free to rotate control fins is expected to become stable faster than the one with the fixed control fins considering the same wing deployment time for both cases.

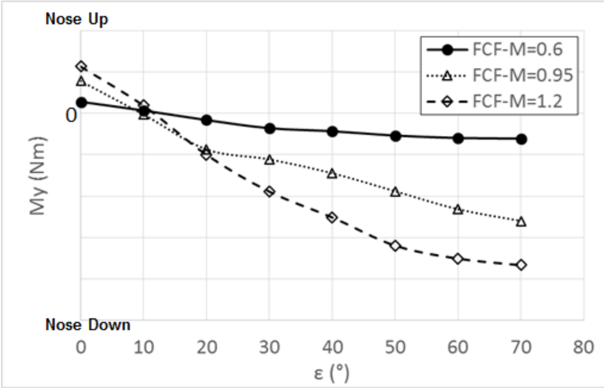

Figure 6: Fix Control Fins Configuration ($\alpha = 5°$)

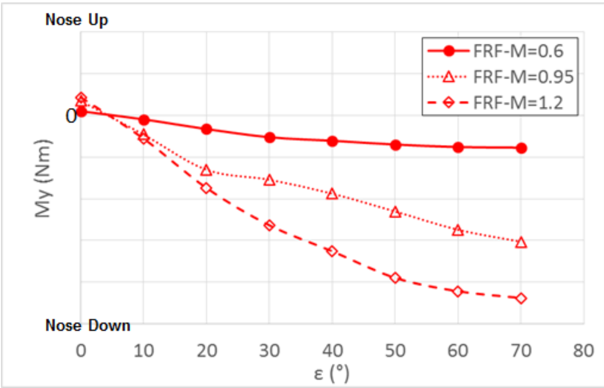

Figure 7: Free to Rotate Control Fins Configuration ($\alpha = 5°$)

To investigate the cases further, the pitching moment and angle of attack curves are plotted together at some wing angles for both configurations in Figures 8, 9 and 10. For the subsonic flight case (Figure 8), when the wings are stowed, both the FRF and FCF cases create nose-up moment when the angle of attack is positive (statically unstable). When the wings reach to 10 degrees, the FRF case generates nose-down moment while the FCF case still gives small value of nose-up moment. As the wings further moves to 20 degrees, both cases are statically stable with the FRF generating higher nose-down moment, hence becoming more stable. For 30 degrees wing angle, both cases are stable. For the transonic and supersonic flight conditions, similar results are observed (Figures 9 and 10, respectively).

Captive Carry

During the captive carry phase, the loads on the GB's are balanced by the reaction forces on the carriage lugs, and these loads have effect on the overall performance of the carrying platform. when the employment is performed and the store is free from the supporting points, i.e. no reaction to counter balance the aerodyamic loads / weight etc, the GB moves under the effect of the ejection forces, weight, and the aerodynamic forces as a result of the flow field under the carrying platform. The magnitude of the aerodynamic forces and moments, especially the aerodynamic pitching and

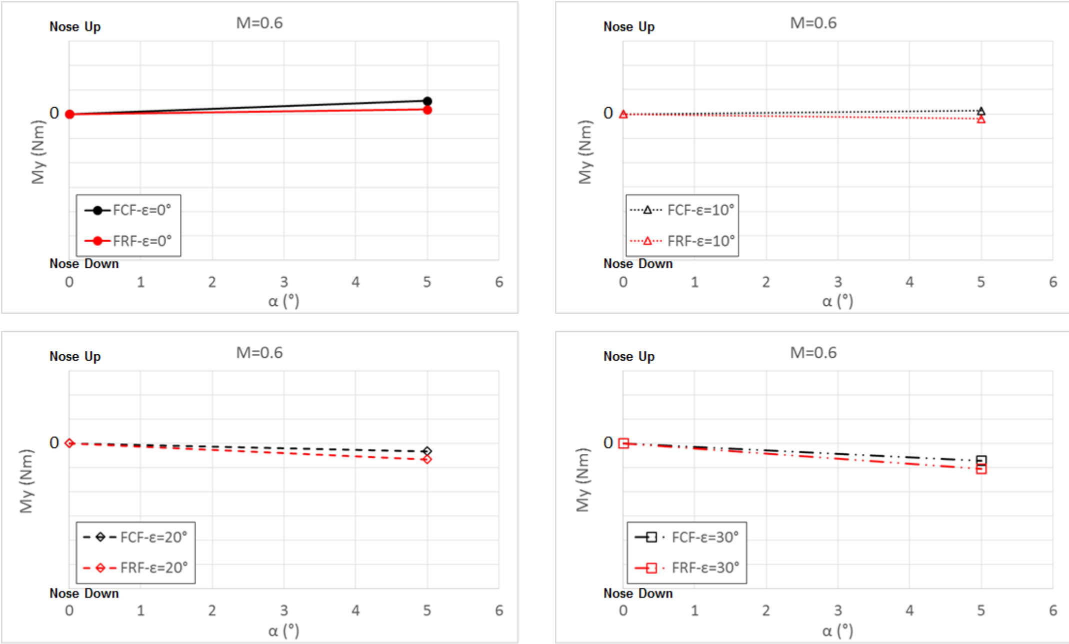

Figure 8: Pitching Moment vs α curves @M=0.60 for Wing Angles ($\epsilon = 0° - 30°$)

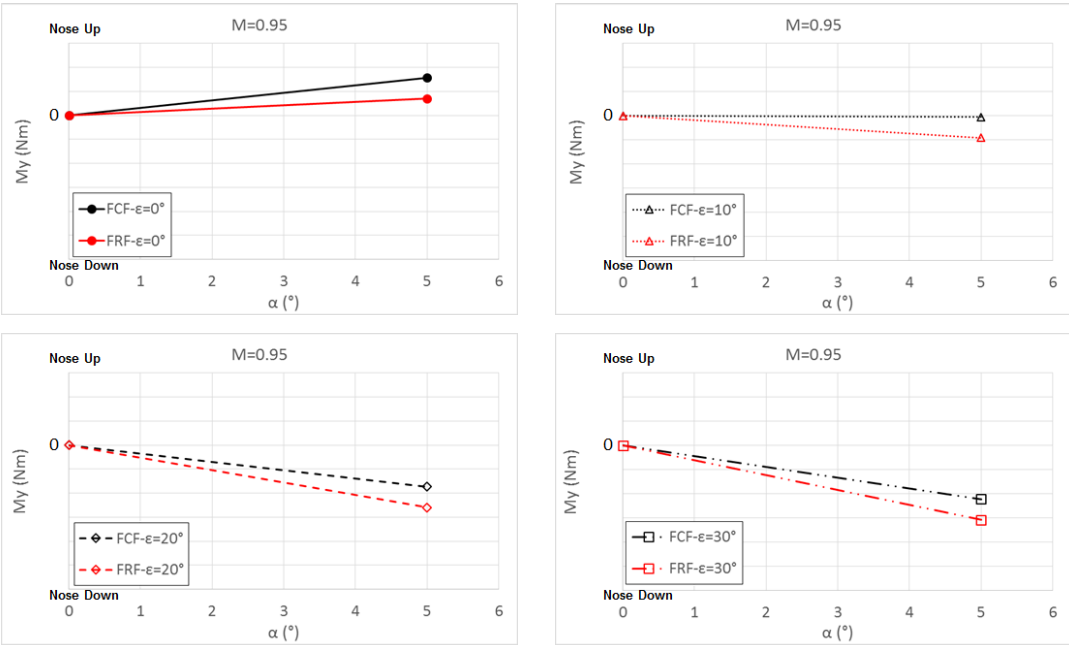

Figure 9: Pitching Moment vs α curves @M=0.95 for Wing Angles ($\epsilon = 0° - 30°$)

yawing moments, along with the ejector forces determines the initial tendency of the movement of the GB. In Table 2, the aerodynamics moments during the captive carry phase (steady level flight) is compared for both FRF and FCF cases. Here, the supersonic flight condition (M=1.2 flight at 18000 ft altitude) is considered and the results given in this table are normalized using the data computed for the FRF configuration.

Inspecting the data for the given flight condition, the pitch and yaw moments are increased 11% and 18% respectively in FCF configuration compared to the FRF case. This situation gives a clue that the GB with FCF will pitch and yaw more when it is released from the carrying platform.

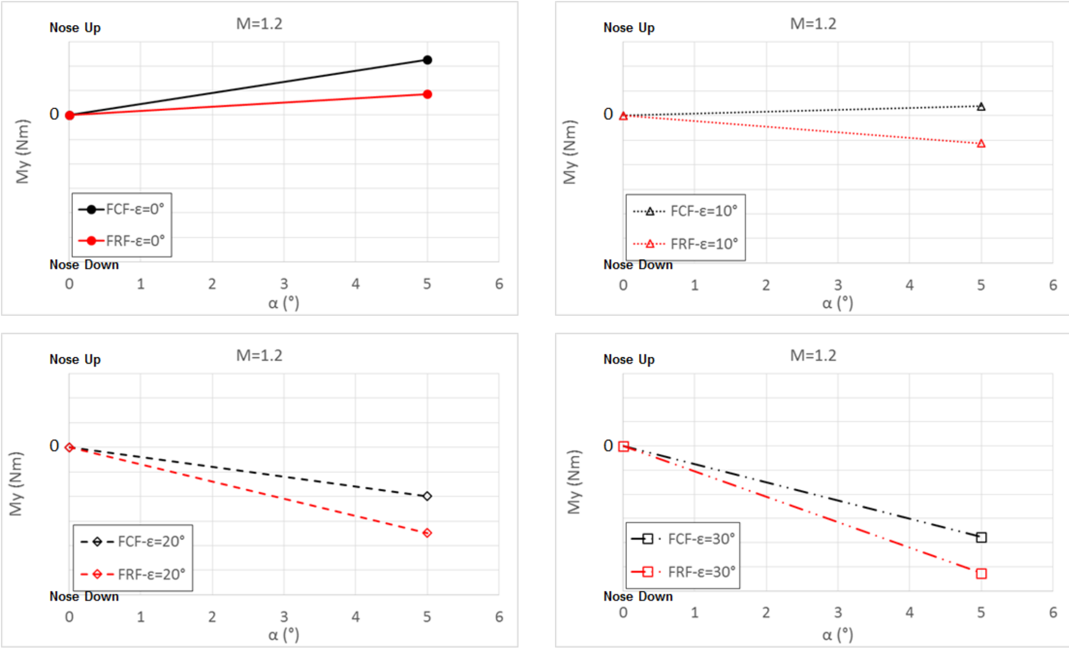

Figure 10: Pitching Moment vs α curves @M=1.20 for Wing Angles ($\epsilon = 0° - 30°$)

Table 2: Captive Carry Relative Load Comparison

Flight Condition				FRF			FCF		
Altitude ft	M	$\alpha(°)$	$\beta(°)$	Mx	My	Mz	Mx	My	Mz
18000	1.20	-2.1	0	1.00	1.00	1.00	1.00	1.11	1.18

Store Separation

Once the stability characteristics and the captive carry loads are determined for the FRF and the FCF cases, separation analysis are started. All the simulations are performed for the supersonic flight condition considered in the above sections.

The separation simulations start with the case that the tail wings are stowed. This case is considered keeping in mind that both the FRF and FCF geometries are statically unstable. This fact makes this case as the most conservative situation for the separation simulations meaning a successful separation for this case clears other cases that will be considered later.

In Figure 11, result of the stowed wing cases are shown together for the FRF and FCF cases. As can be seen from this figure, both the GB geometries with FRF and FCF moves outboards because of the yawing moment generated due to the existence of the large fuel tank just at the next wing station. As shown before, this yawing moment is larger in magnitude for the FCF case, causing more severe yawing motion. The similar situation occurs in longitudinal direction ending in more pitching motion. Even tough the geometries seem to be getting away from the aircraft and the miss distance is increasing consistently, the GBs are gaining excessive angle of attack and sideslip angle (see Figure 15) risking the success of the mission.

Next, the FRF case is considered both when the wings are stowed and deploying. When investigating the stability characteristics of the geometries, it was concluded that the FRF case becomes stable when the wings reach around to 10 degrees angle. This situation occurs in very short amount of time, since the wings deploys to full limit fast once the lanyard cable is detached. The result of these simulations are shown in Figure 12. As in the previous simulations, the initial tendency of the GBs is to yaw outboard and pitch down due to the carriage moments and ejector forces. But, while the wings are deploying, the GB is heading forward and gaining nose-up moment because of its stable nature. This situation can be better observed investigating the angle of attack and sideslip angle variations as

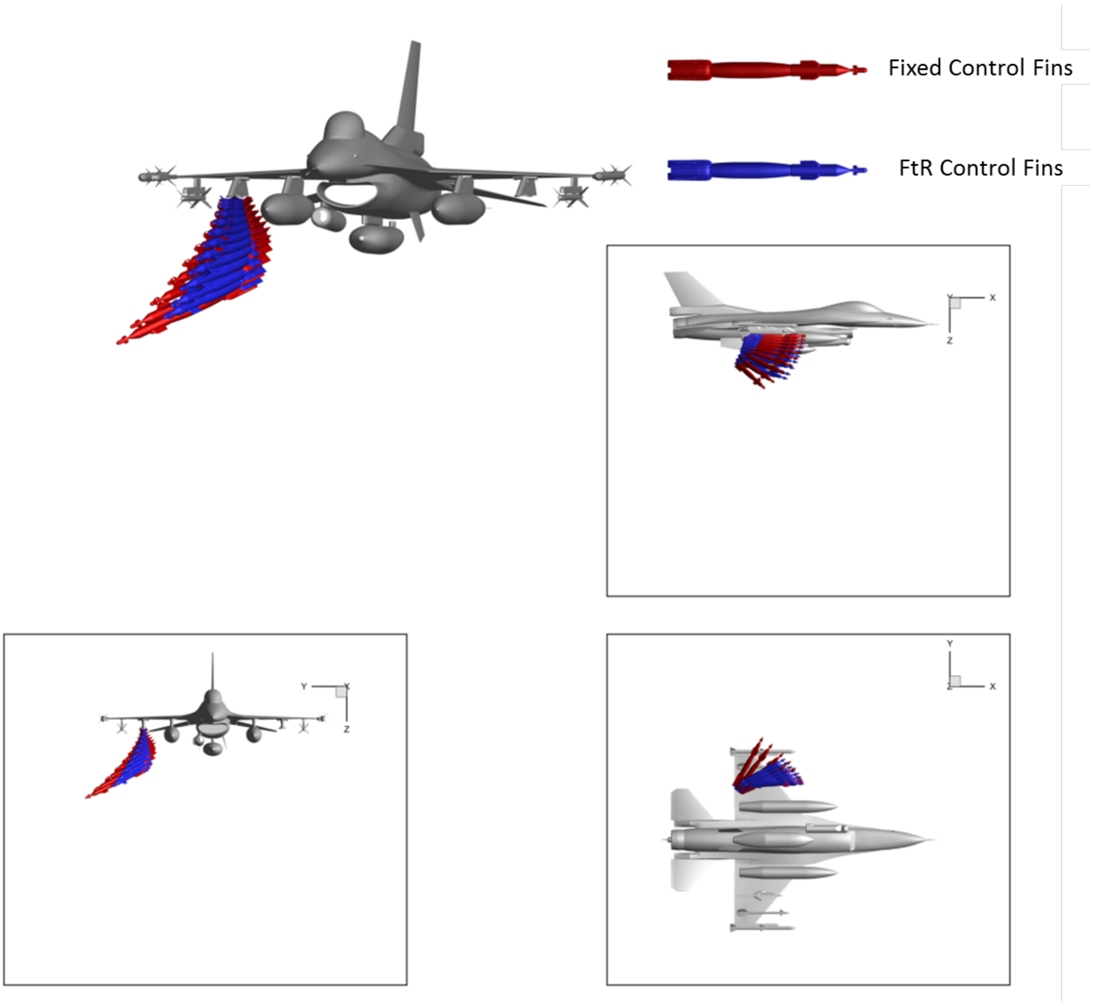

Figure 11: Stowed Wing FRF and FCF configuration

shown in Figure 15. As can be seen from this figure, even though these angles are fluctuating, they tend to converge at some value indicating stable behaviour.

To investigate the effect of deploying wings on the separation of the FCF geometry, another simulation of separation is performed. The result of this case is presented in Figure 13 along wing the stowed wing case. As for the FRF case, when the wings are deploying, the GB with FCF becomes stable in very short time. This fact can also be observed from the separation simulation results. The GB tends to correct initial yawing and pitch-down motion and heads forward as in the case for the FRF case (see Figure 15).

Finally, the simulation results of the FRF and the FCF cases with deploying wings are compared and shown in Figure 14. For both the cases, the GB separates from the aircraft with success. Even tough the simulation duration is same for the both cases, the geometry with FCF seems to get further from the carrying platform in both lateral and longitudinal directions. However, this situation is not expected to influence the overall performance of the GB to complete the intended mission.

CONCLUSION

The study is intended for a simpler mechanisms for the control actuation systems of guidance kits. For this purpose, captive phase and separation of a guided bomb with fixed fins are investigated and compared with the guidance kits with free to rotate fins. It has been concluded that safe separation of a store with fixed control fins can be achieved considering the preliminary simulation results obtained

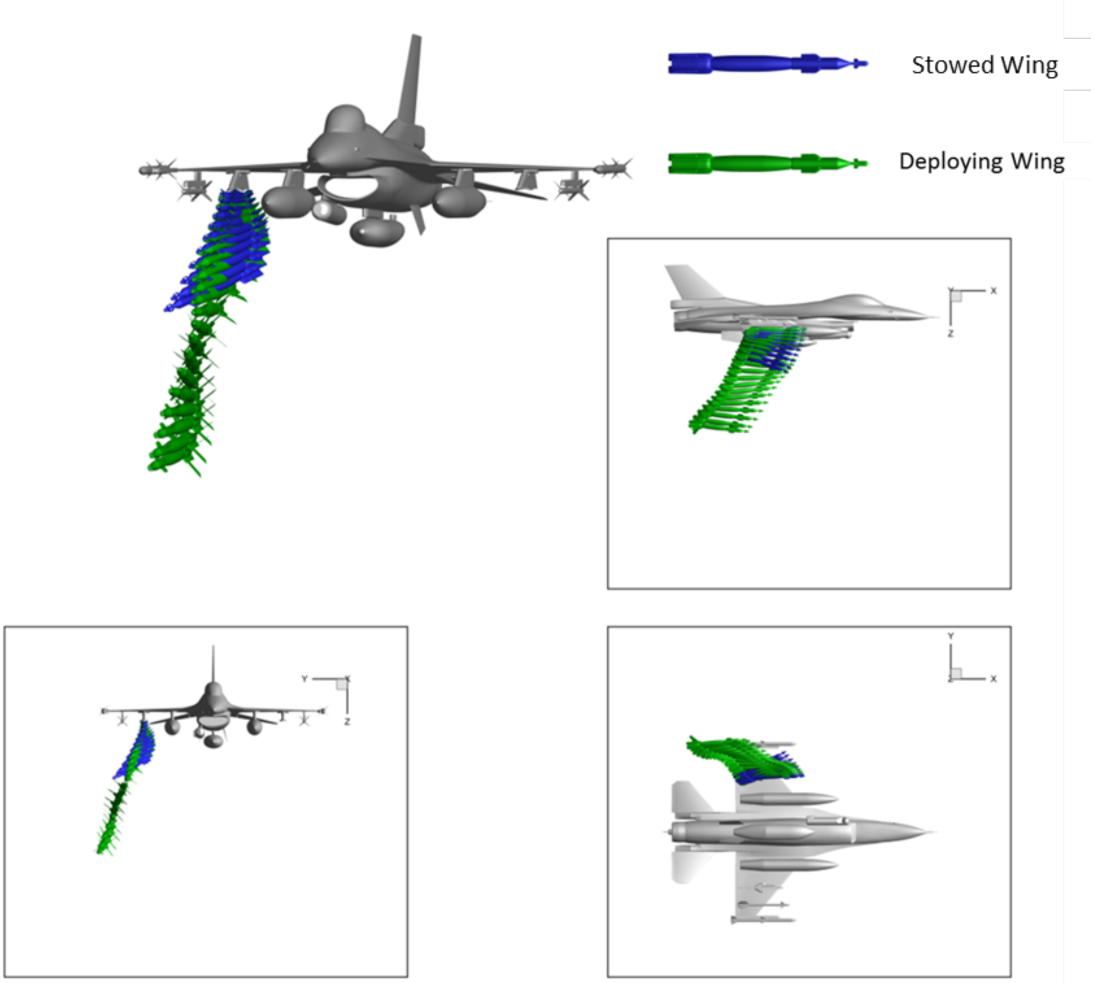

Figure 12: FRF Configuration wing effect

from the CFD and 6-DoF coupled methods., even though fixing the fins can significantly effects the captive carry loads and the separation characteristics. However, it must be keep in mind that CFD based methods are not sufficient for store separation certification. Simulations must be supported with wind tunnel flight tests. The historical data and user experience are also important in analysis. Besides, tools must be validated and verified with known stores and actual flight test data.

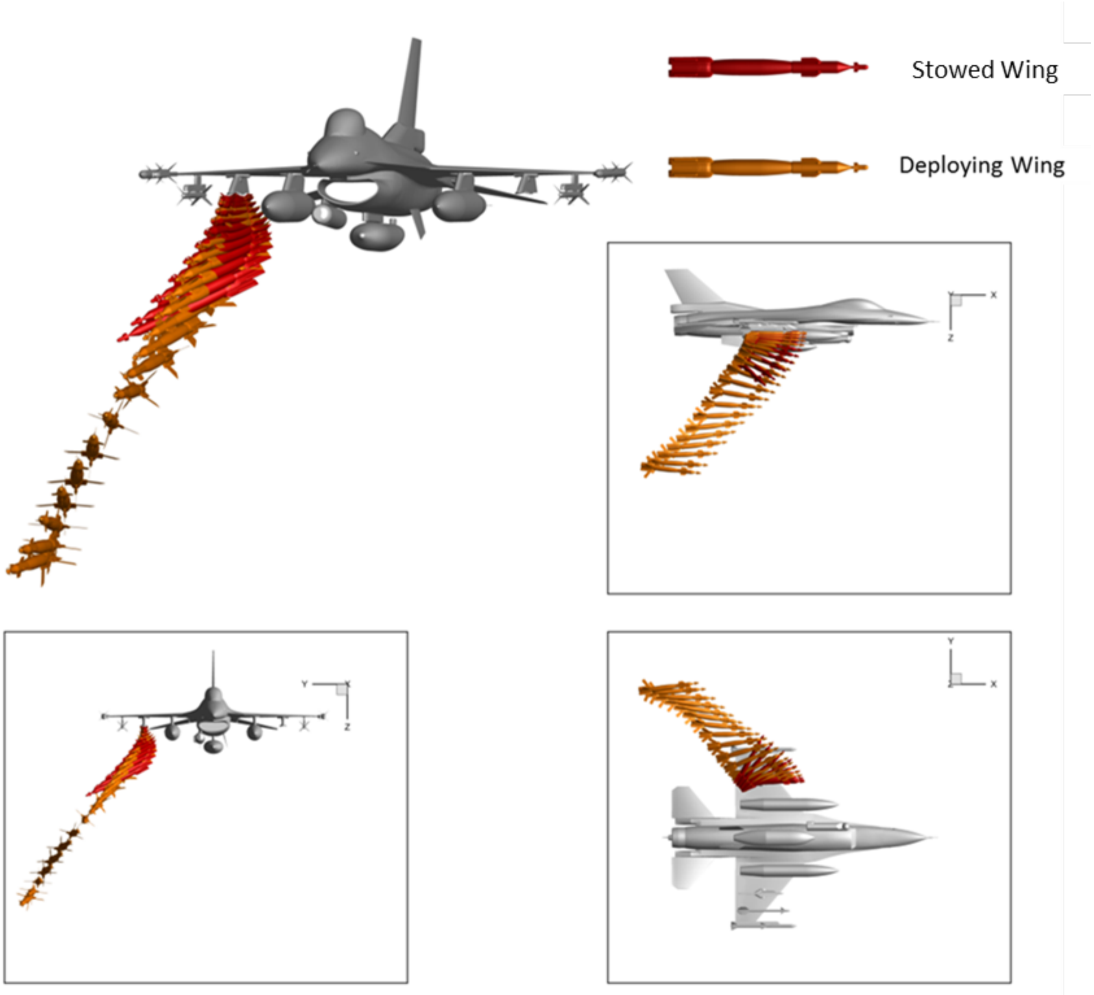

Figure 13: FCF configuration wing effect

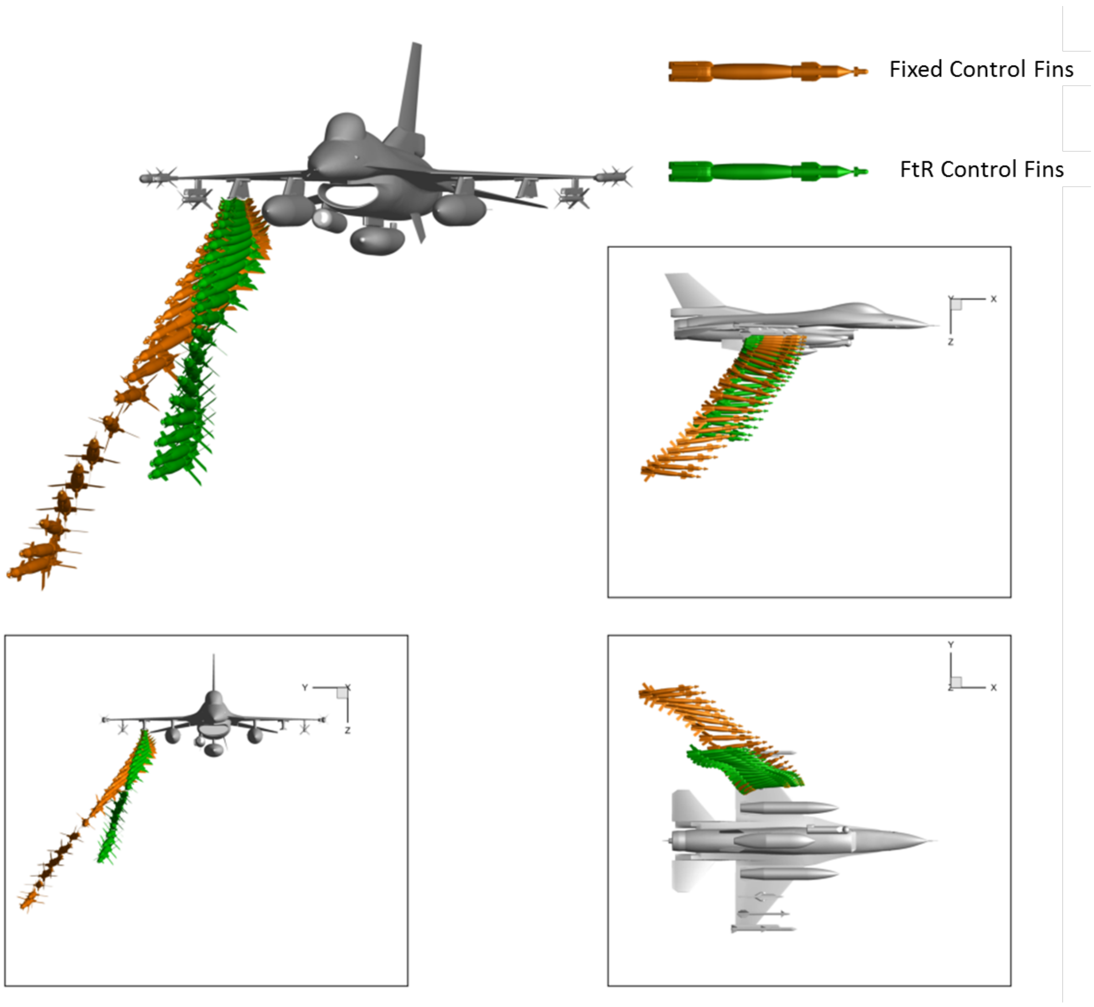

Figure 14: Deploying Wing FRF and FCF configuration

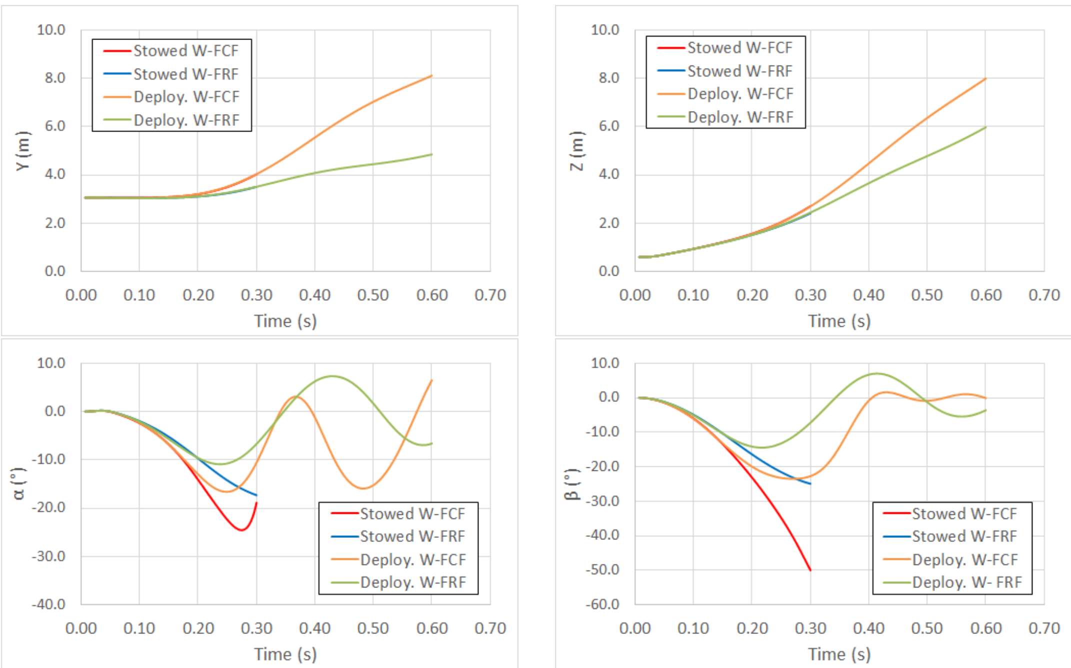

Figure 15: Trajectory History

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