AERODYNAMIC ANALYSIS OF STORE JETTISON ON A HELICOPTER

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Abstract
Aerodynamic analysis of the store jettison on a helicopter was performed in this paper. The objective of the present study is to investigate the aerodynamic characteristics of a jettisoned store from a helicopter. Transient, incompressible, three-dimensional and turbulent flow in the store jettison with rotor downwash was analyzed using commercial computational fluid dynamics software. Virtual blade method was adopted to describe the effect of rotor down wash. Overset meshes were used to consider a movement of the jettisoned store. Computational results are validated by dynamically scaled free drop wind tunnel testing. The wind tunnel testing was executed at low-speed tunnel of the German-Dutch wind tunnel (DNW-LST). Calculated results are good agreement with wind tunnel testing results. The trajectories of the store are mainly affected by the weight of jettisoned store.

1. INTRODUCTION

Armed helicopters have many advantages in a battlefield. It can take-off and land vertically and can carry various weapon system such as air to ground missile (AGM), air to air missile or bombs. Store separation is categorized by firing, release or jettison. The main goal of firing and release is to hit a target.

In an emergency situation, for example if and an engine fails, or the helicopter is under attack, a helicopter should perform emergency landing as soon as possible. In order to perform a safe emergency procedure, the store needs to be jettisoned to reduce weight and eliminate the risk of store explosion. Jettison can be classified by selective and emergency jettison. A store can be intentional separated (selective jettison) because the store is no longer required for the performance of the mission. Emergency jettison means all stores quickly jettisoned in emergency situation [1]. Safe jettison envelopes are provided to the pilot to allow safe jettison in emergency situation.

Traditionally determination of the safe jettison envelope was based on flight testing. Jettison flight tests are expensive due to dropping of actual stores. Recently, due to improvements in simulation methodology, integrated methods, consisting of simulation, wind tunnel testing and flight testing, are possible. Therefore, time and cost consuming flight testing can be reduced [2].

Korea Aerospace Industries (KAI) was developing a Light Armed Helicopter (LAH), which is based on EC155B1 by Airbus Helicopter, since 2015. The LAH can be equipped with unguided rockets in a store mounted to the stub-wing. The store can be gravitationally jettisoned without ejection force in an emergency.

The dynamically scaled stores were dropping during a wind tunnel test performed with Netherlands Aerospace Centre (NLR) at low-speed tunnel (LST) of the German-Dutch wind tunnels (DNW) [3, 4]. 6-degrees of freedom motion of the store was measured to validate computational data and to understand jettisoned store motion. To measure the store trajectory and attitude, the Stereo Pattern Recognition (SPR) method was used [5].

The goal of this paper is to investigate the aerodynamic characteristics of the store jettison from a helicopter. Transient, viscous and turbulent flow around the store jettison were simulated using commercial computational fluid dynamics (CFD) software. The calculated results are compared with wind tunnel testing data.

2. EXPERIMENTAL METHOD

2.1. Experimental setup

The store jettison test was performed in the LST wind tunnel of the DNW. The cross-section of the test section is 3 m × 2.25 m. Several store loading configurations (full, partially filled and empty) were tested. Other test parameters were wind speed and angle of sideslip of the fuselage. Rocket

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launcher model can be assembled with rocket.

Froude scaling is suitable and applied for the dynamic drop wind tunnel testing due to the low Mach number conditions of the helicopter (M<0.25). The geometrical scale is 1:8.5. Equation (1) defines the Froude number (v is the airspeed and l is a characteristic length), which has to be the same for flight and scaled tunnel condition [6].

$$Fr = v\sqrt{gl} \tag{1}$$

The store mass, physical and operational characteristics are defined by MIL-HDBK-1763 [7]. The wind tunnel model and the dynamically scaled store were designed and manufactured by NLR. The store was dropped by gravitational force using a reaction force free release mechanism. In high speed forward flight conditions, the main rotor down wash passes well above stub-wing [8]. Therefore, main rotor was not considered in the wind tunnel test.

Figure 1. shows store free drop wind tunnel model in the test section. The model was mounted on a sting from the top of the fuselage. The sting was mounted to a turn table on the upper surface of the test section, allowing angle of sideslip changes. A safety net was installed behind the model to collect the dropped store. Foam was placed at the floor of test section to prevent damaging of the store.

Figure 2. shows a fully loaded dynamically scaled rocket store model mounted on the stub-wing. The markers were randomly placed on the store. The marker weight can be ignored because the total marker weight is only 0.1% of total store weight.

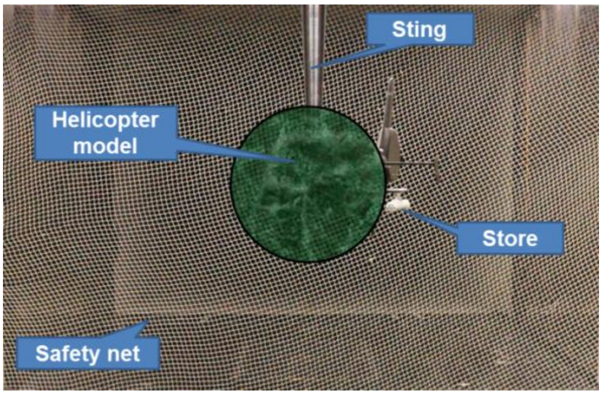

Figure 1. Front view of the wind tunnel test model on the test section of the DNW-LST

Figure 2. Fully loaded rocket launching store with markers, mounted to the stub wing

2.2. Experimental procedure

Figure 3. shows the wind tunnel testing procedure for store jettison. Prior to the actual test runs, the SPR camera was calibrated. After calibration step, the store configuration, sideslip angle, V_∞ were set. In the next step, the light in the test section was switched off and ultraviolet light was switched on to provide optimum light scatting from the markers. Applying an ultraviolet pass filter on the camera lenses then only shows the markers in the camera images (when tested in a dark room like the DNW-LST). The recording of the high-speed cameras is triggered by a store drop signal, just before actual release. The store was freely

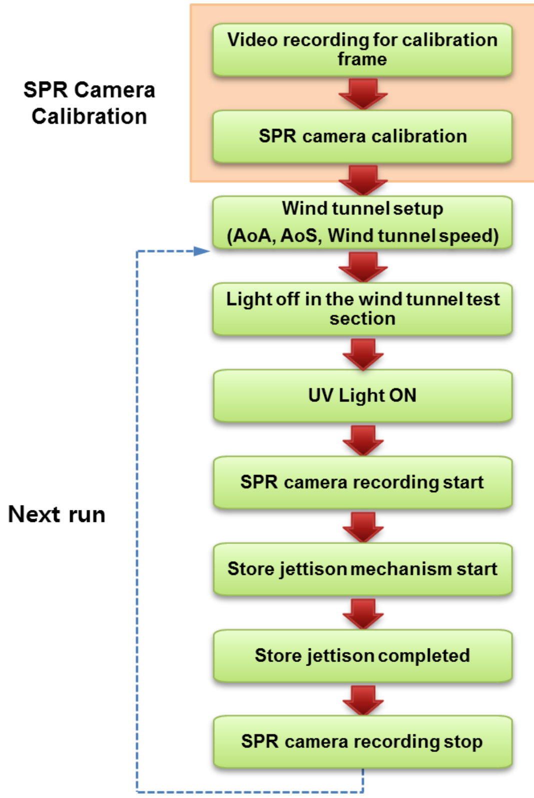

Figure 3. Procedure of the store jettison wind tunnel testing

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Figure 4. Long exposure video image of store release with UV LED on

dropped in the test section. After a complete store drop, trajectory recording is finished. Figure 4 shows the marker trajectories from the additional slow speed video camera that was used for monitoring purposes only. Trajectory and attitude of the jettisoned store were determined using SPR technique from high-speed cameras [3-4].

3. COMPUTATIONAL METHOD

3.1. CFD method

Unsteady, incompressible, three-dimensional and turbulent flow in the store jettison from the helicopter was calculated using the commercial CFD solver Star-ccm+ Ver. 10.06. This S/W solves the unsteady Reynolds-averaged Navier-stokes (URANS) equations using a k-ω based shear stress transport turbulence model. This turbulence model is well known for a good prediction of the adverse pressure gradient near the wall and flow separation [9].

In order to consider main rotor down wash effect, virtual blade method (VBM) is used in the CFD analysis. VBM requires limited computation time yet providing a good agreement with performance data from flight test. A distribution of momentum sources represents the rotor and the aerodynamic effect from the blade cross sections was modelled by VBM [10].

Figure 5. shows the local axis system of the store jettison. The store body axis is located in the centre of gravity (C.G) of the store. This orientation of the axis system is dependent on the store attitude. The initial flight axis of the store is corresponding to the situation when the store mounted on the bomb rack. Trajectories of the jettisoned store are calculated with respect to this initial flight axis. Trajectory angular orientations are calculated using Euler angle sequence.

Figure 6. shows computational domain and boundary conditions for CFD analysis. L means length of the helicopter. The domain consists of half-sphere and a cylinder shape. The boundary condition at the front surface was set to uniform airspeed. The velocity inlet direction can be changed to consider angle of attack and side slip angle. The outer domain surface was set to ambient pressure (P_{gage} = 0). The boundary condition of the fuselage and store were set to no-slip boundary conditions.

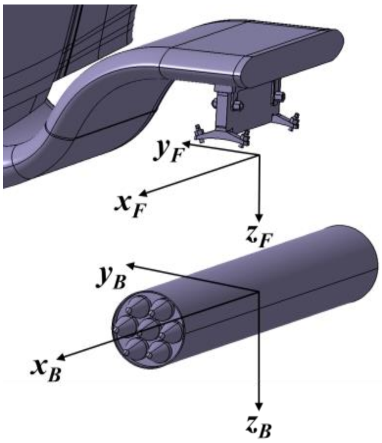

Figure 5. Axis system for store jettison

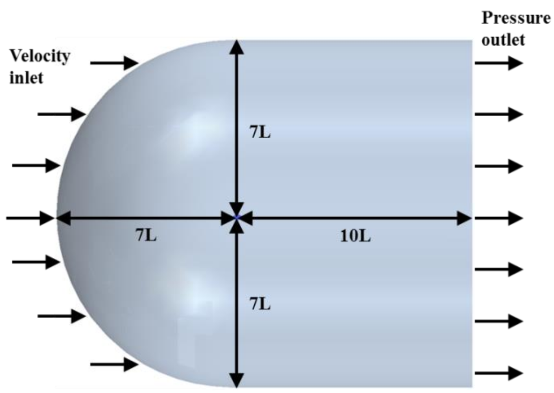

Figure 6. Domain and boundary conditions for CFD analysis(L = length of fuselage)

3.2. Overset meshes method

“Chimera” overset meshes were used to describe the movement of the store after jettison launch from the bomb rack. The store was set to dynamic fluid body interaction (DFBI), which can describe a rotation and translation motion of the object. The DFBI module can simulate the motion of a rigid body in response to pressure and shear forces. The solver calculates the resultant force and moment acting on the store to find the new position of the store [11]. This store can translate and rotate along each of the 3-axes.

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Figure 7. shows the local sub domain near the store. Two domains exist; background domain for the fuselage and sub domain for the store. The store model takes the centre of gravity, weight and moment of inertia of the store in the sub domain into account. The sub domain is moved by gravity and fluid forces.

Figure 8. (a) shows background mesh for the fuselage and overset mesh for the store. In the background region, there are mesh refinement regions for expected trajectories of the jettisoned store. The overset mesh is a polyhedral mesh type. The background mesh is set to trimmed mesh type to reduce the number of cells. The ratio of overset and background mesh cells is 1:3.

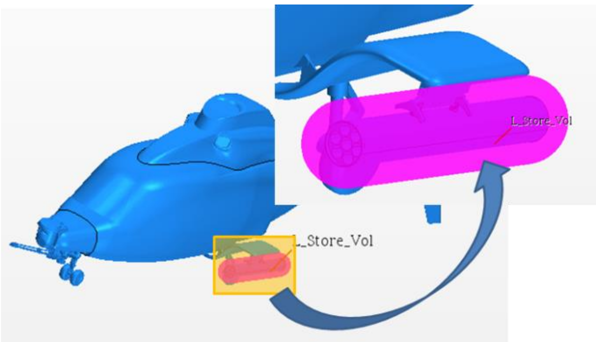
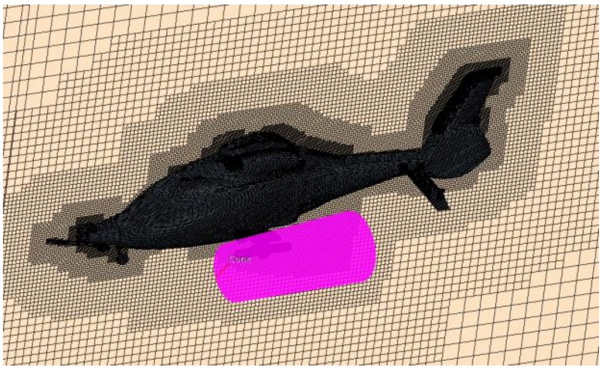
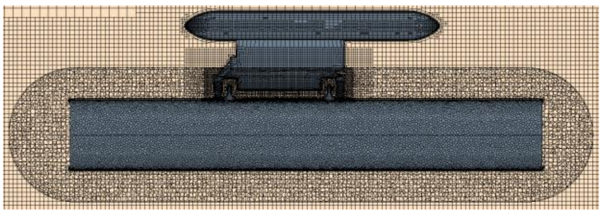


Figure 7. Overset domain of the store



(a) Background mesh for the fuselage with refined regions



(b) Overset mesh for the store

Figure 8. Calculation meshes for the store jettison

4. RESULTS

4.1. Computational results validation

Figure 9, 10. show the trajectory centre of gravity trajectory and the attitude of the fully loaded (max weight) rocket store. The helicopter angle of attack and side slip angle are 0º and the tunnel velocity is the Froude scaled maximum horizontal flight speed. CFD trajectory results seem to be in good agreement with experimental results. Small differences in angular orientations become visible starting from about t=0.25~0.3sec. This difference is ignorable. Because jettisoned store passed through a landing gear of the helicopter at t=0.2 sec.

Figure 11 shows the jettisoned store in CFD and wind tunnel testing, respectively. Trajectory and attitude of the jettisoned store is adapted to 3D CAD modelling in CATIA V5. The store is falling almost straight down with slightly pitching down

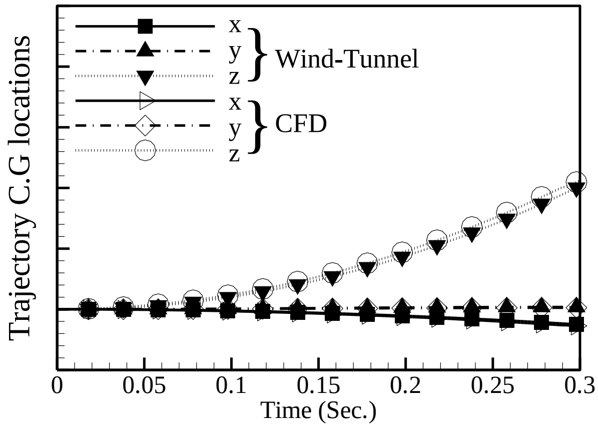


Figure 9. Comparison of the trajectory C.G locations for the rocket launcher with CFD and experimental results

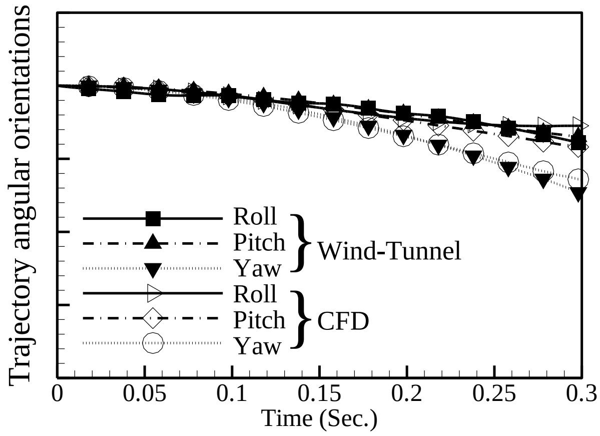


Figure 10. Comparison of the trajectory angular orientations for the rocket launcher with CFD and experimental results

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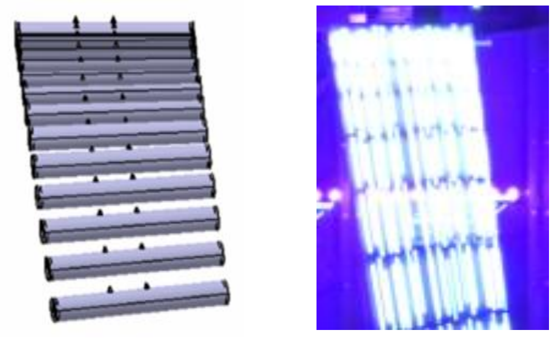


(a) CFD (b) Wind tunnel test

Figure 11. 3D modelling of jettisoned store using calculated trajectory and altitude

motion. This motion is captured in CFD and wind tunnel test results.

As can be seen, the trajectory is dominated by gravity due to the relatively large store weight of this configuration. CFD results show a similar trend and are in close agreement with experimental data, this serves as a good verification of the CFD results.

4.2. Store weight effect

Figure 12 ~ 13. show the trajectory and angular orientations of the jettisoned store for various store weights at Froude scaled maximum horizontal flight speed by wind tunnel testing. Rocket configurations are launcher full and empty, the rocket full means that all rocket are inserted in launcher. The most critical/interesting store configuration is empty launcher case [1]. Therefore, the rocket full, empty launcher configurations are compared in this section. The x-direction trajectory and yaw angular orientation are different with the empty launcher. Figure 14.

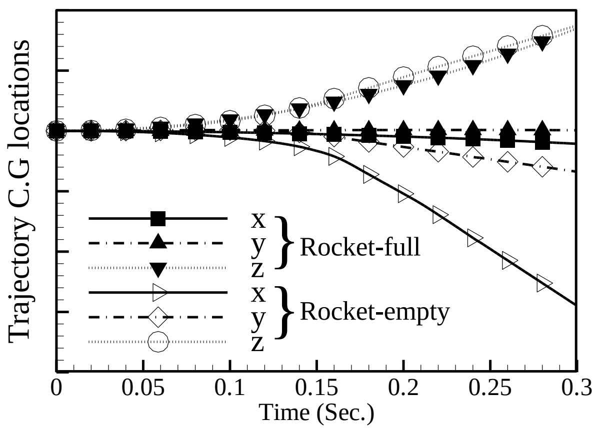


Figure 12. Trajectory C.G locations of the rocket for weight by wind tunnel testing

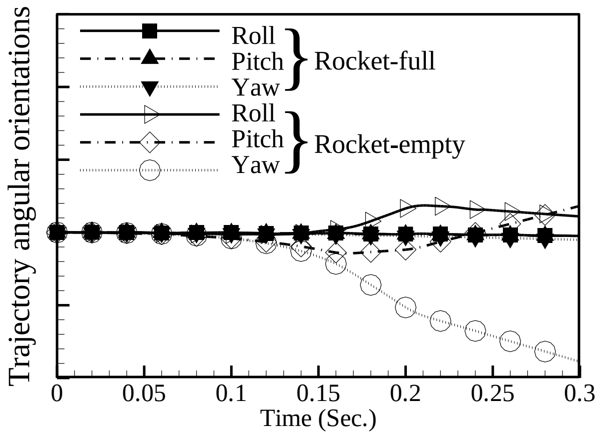
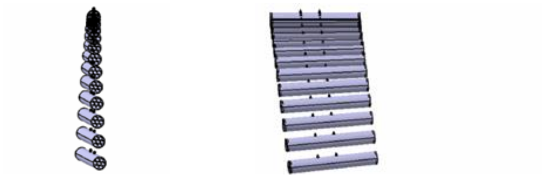


Figure 13. Trajectory angular orientations of the rocket for weight by wind tunnel testing



<front view> <side view>

(a) Rocket fully inserted launcher

<front view> <side view>

(b) Rocket empty launcher

Figure 14. Rocket trajectories at Froude scaled maximum horizontal flight speed by wind tunnel testing

shows jettisoned store motion using locations and roll, pitch, yaw angles from wind tunnel testing results. These are used as input parameters to the CATIA macro. Therefore, the smallest distance between rocket and helicopter can be calculated from CATIA. Weight of the store is main parameter to affect a motion of jettisoned store. There results are similar to reference [12, 13].

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4.3. Level flight speed effect

Figure 15 and 16. show the trajectory and angular orientations of jettisoned rocket full launcher for the hovering and the forward flight speeds using CFD analysis. Mainly x-direction distance is affected by forward flight speed. This is line with expectations since the aerodynamic force in x-direction increases with increasing x-velocity

As shown in Fig 16, pitch motion of the jettisoned rocket launcher shows larger changes with forward speed than the other motion angles. The pitch angle of the store increases when forward speed increases.

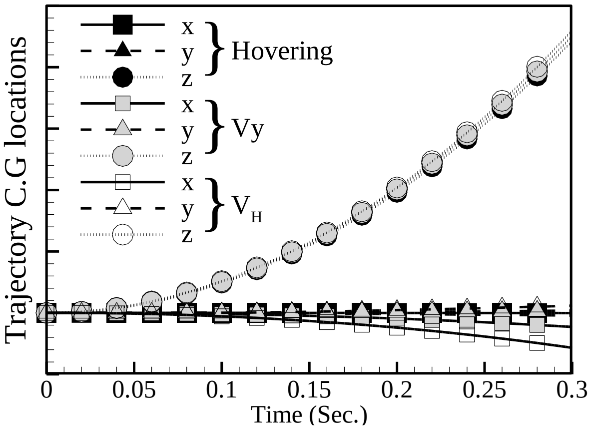

Figure 15. Trajectory C.G locations of the rocket for various helicopter forward speeds by CFD

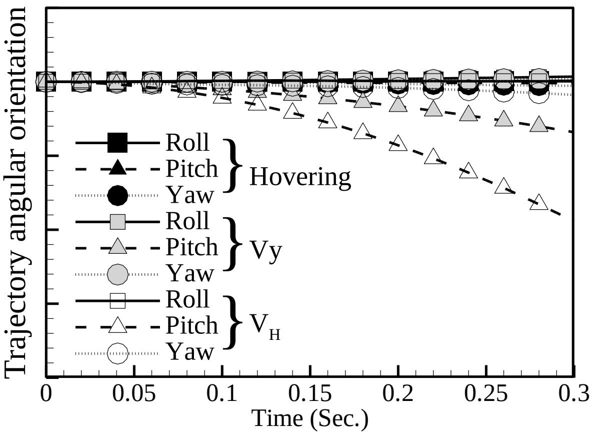

Figure 16. Trajectory angular orientations of the rocket for various helicopter speeds by CFD

4.4. Descent flight speed effect

The z-direction distance of the store for descent flight becomes smaller than during level flight, as shown in Fig 17. It means that the jettisoned store for level flight leaves the helicopter faster than during descent flight. Because descent flight the initial lift on the store is larger than during level flight.

Figure 18. shows the trajectory angular orientations of jettisoned store for level flight and descending flight conditions. Pitch and yaw angles of the store are dramatically changed for descent flight condition. A pitch up and turn right motion occurs in descent flight. In this case, no collision of jettisoned store and fuselage occurred. But the pitch up motion remains a dangerous motion in terms of safety.

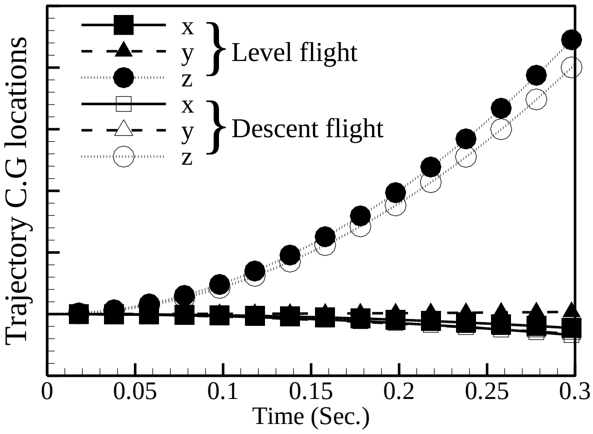

Figure 17. Trajectory C.G locations of the rocket for various flight conditions by CFD

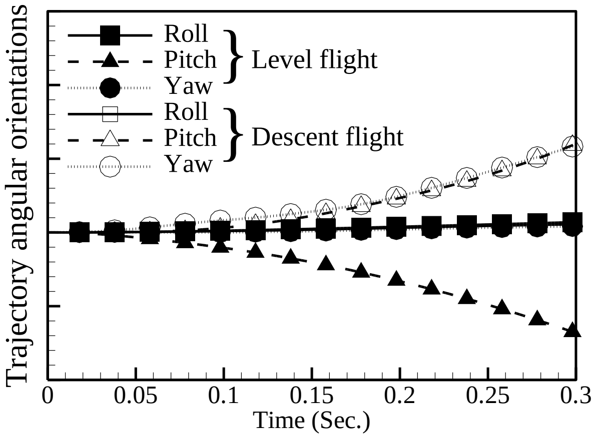

Figure 18. Trajectory angular orientations of the rocket for various flight conditions by CFD

5. CONCLUSION

In this paper, aerodynamic analysis of the jettisoned store from a helicopter was performed. A dynamically scaled free drop test was carried out at low speed wind tunnel of German-Dutch Tunnel. Trajectory and attitude of jettisoned store were measured by high-speed camera.

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The jettisoned store motion from a helicopter was calculated using commercial CFD solver. This model considers a main rotor down wash effect using virtual blade model. And the motion of jettisoned store was described using overset meshes. Calculated results for a fully loaded store are in good agreements with dynamically scaled wind-tunnel testing results.

Store weight dramatically affected the motion of jettisoned store from helicopter. In the level flight condition, the forward speed has a limited effect on the motion of the store. In descent flight, pitch and yaw rotation are appreciable. The combination of wind tunnel data and CFD data forms good input for the definition of the store release flight the envelope. With this approach the interesting test conditions are determined before flight testing, reducing the number of flight test points and thereby greatly reducing the costs and risks associated with flight testing.

For the future works, KAI will perform a store jettison flight test. Trajectory and attitude of the jettisoned store will be measured using on-board high-speed camera images.

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