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# RESEARCH ON THE INFLUENCE OF FLIGHT ATTITUDE ON UNILATERAL MISSILE SEPARATION FROM EMBEDDED BAY

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## Abstract

The technology of missile separation from embedded bay is one of the key technologies in the development of new generation of aircraft. By coupling of solving unsteady N-S equations in flow field and 6-DOF equations of rigid body based on dynamic embedded mesh, the accurate simulation of embedding separation is realized, and the influence of different flight attitudes of the aircraft on the missile separation is researched in which the missile was mounted in right side of the bay and the left side was empty. The results show that there is smaller effect on the missile separation when aircraft is being in positive angle of attack condition, the negative angle of attack condition will cause the missile to have a larger lateral motion and yaw in the opposite direction. There is smaller effect on the missile separation when aircraft is being in negative sideslip condition, and there is a strong fluctuation of aerodynamic forces and moments of the missile during in separation process in the positive sideslip condition.

**Keywords:** flight attitude; buried; separation; embedded mesh

## 1. Introduction

The new generation of fighters emphasize the performance of supersonic cruise, high stealth, high maneuverability and over-the-horizon combat [1]. It is difficult to achieve supersonic cruise with traditional external weapons because of their large aerodynamic drag, which also affects the maneuverability of the fighter aircraft. The external weapons will greatly increase the radar cross section (RCS) value of the fighter and reduce the stealth characteristics of the fighter. The use of embedded weapon can significantly reduce the drag of the aircraft and reduce the RCS value, and improve the performance of the fighter. The embedded weapon loading has become the preferred in the field of weapon loading in new generation of fighter.

The research on the missile separation from embedded bay is one of the key technologies in the development of a new generation of aircraft. Its main task is to ensure the safe separation of the weapon from the aircraft and to ensure that the weapon has a good flight attitude after separation, so as to determine the launch envelope of the weapon [2]. At present, there are mainly three methods to study the store separation: wind tunnel test, flight test and numerical simulation. With the development of computational fluid dynamics (CFD) and computer hardware, numerical simulation is favored by researchers because of its rich flow field information, easy to adjust parameters and save resources. Numerical simulation can also provide some reference for the determination of wind tunnel test and flight test conditions [3]. Due to the influence of the complex flow field of the strong unsteady flow in the embedded bomb bay, the release and separation of the embedded weapon will cause severe unstable changes of attitude in the process of separation, thus affecting the flight safety of aircraft. Atwood used the RANS method to study the influence of control measures on the falling trajectory of the bomb from embedded bay. After taking control measures, the nose of the bomb is far away from the bay during the separation process [4]. Through RANS method and wind tunnel test, Johnson and Davis found that the separation trajectory of the missile will change with different launch time under the same launch condition due to the influence of strong unsteady flow field in the bomb bay [5] [6]. Westmoreland studies have shown that the separation quality can be significantly improved by applying an appropriate ejection force when the missile is released [7]. Yang Jun studied the influence of ejection device on the falling trajectory of the missile based on RANS method [8]. Zhu studied the influence of Mach number on missile release separation, and the results showed that the missile separation quality deteriorated with the increase of Mach number [9]. Feng studied the influence of missile installation angle on the separation of embedded missile [10]. Through experimental research, Song found that the flight Mach number and angle of attack of the carrier aircraft have a greater impact on the separation compatibility of the embedded missile, and the remaining number of weapons in the cabin has a smaller impact on the separation characteristics of the embedded missile [11]. Generally speaking, the research on the separation of the buried object mainly focuses on the flight Mach number of the aircraft, the attitude angle of the missile and the release parameters, and there is little research on the influence of the flight attitude of aircraft on the release of the missile, especially on the influence of the separation of left weapon after the other weapon being released. In this paper, based on the embedded mesh technology the numerical simulation of the release of the embedded object is realized by solving the RANS equations and 6-DOF equations of the rigid body, and the influence of the angle of attack and sideslip angle of the aircraft on the separation trajectory of the unilateral missile separation from the embedded bay is studied.

## 2. Methods and Validation

### 2.1 Dynamic embedded mesh technology

The dynamic embedded mesh technology is used to simulate the relative motion between the missile and the aircraft during the separation process of buried missile. The main idea is to exchange information among multiple sets of overlapping grids by sharing overlapping areas [12] [13]. The method comprises the following steps: dividing a plurality of sets of grid regions which are mutually overlapped into a background grid region and an overlapped grid region; hiding grids which are shielded by the overlapped regions in the background grids during calculation to form a set of calculation grids, wherein the operation is generally called as' digging holes'; and after the overlapped regions move, re-digging holes according to a certain rule to obtain new calculation grids, so as to simulate the movement of the overlapping grid area.

### 2.2 Methods

The unsteady Reynolds-averaged N-S equation is solved by the finite volume method based on unstructured grid, and the governing equation in the form of three-dimensional integral conservation is expressed as formula (1)

$$\frac{\partial}{\partial t}\iiint_{\Omega} Q dV + \iint_{\partial\Omega} F(Q) \bullet \vec{n} dS = \iint_{\partial\Omega} G(Q) \bullet \vec{n} dS \tag{1}$$

Where $\Omega$ is the control volume, $\partial\Omega$ is the boundary of the control volume, $Q$ is the conserved quantity, $F(Q)$ is the inviscid flux through the surface of the element, $G(Q)$ is a viscous flux through the surface of the element, $\vec{n}$ is an outward normal vector of element, and $dS$ is an infinitesimal of the integrated surface

The trajectory and attitude of the missile during the separation process of the buried object is obtained by solving the 6-DOF equations of rigid body. See formula (2) for the expression of the 6-DOF equations:

$$\begin{cases} F_x = m\dfrac{dV_x}{dt} \\ F_y = m\dfrac{dV_y}{dt} \\ F_z = m\dfrac{dV_z}{dt} \\ M_x = I_x\dfrac{d\omega_x}{dt} - (I_y - I_z)\omega_y\omega_z \\ M_y = I_y\dfrac{d\omega_y}{dt} - (I_z - I_x)\omega_z\omega_x \\ M_z = I_z\dfrac{d\omega_z}{dt} - (I_x - I_y)\omega_x\omega_y \end{cases} \tag{2}$$

Where, $F_x$、$F_y$、$F_z$ is the force (including aerodynamic force and gravity, etc.) applied to the missile in the three coordinate directions based on the body coordinate system, $V_x$、$V_y$、$V_z$ is the velocity in the three directions, t is the time, m is the mass, and $M_x$、$M_y$、$M_z$ is the external moment applied to the missile rotating in the three principal axes, and $I_x$、$I_y$、$I_z$ is the moment of inertia of the missile rotating in the three principal axes. Since the missile is axisymmetric ally distributed, the product of inertia of the body has been ignored in the equations. $\omega_x$、$\omega_y$、$\omega_z$ is the angular rate.

The unsteady flow field control equation and the 6-DOF equations of rigid body are solved separately in each physical time step. First, the boundary of the embedded mesh is searched and the holes are dug according to the known state quantity of the missile. Second, the CFD program is called to calculate the flow field variables, and then the aerodynamic force and moment of the missile are extracted. Then the 6-DOF equations are solved to obtain the state variables of the missile in the next time step, and then the surface mesh and the embedded mesh of the missile are updated to realize the coupling solution of the flow field and the motion.

## 2.3 Validation

The standard model of wing/pylon/finned store (WPFS) released by Arnold Engineering Development Center in the United States is selected to verify the reliability of the calculation method based on dynamic embedded mesh in this paper, and the comparison test data is results of CTS wind tunnel test [14].

The standard model is shown in Figure 1. The geometric parameters of the missile are shown in Figure 2 and the parameters of the missile and computational conditions are shown in TABLE 1. Based on the idea of embedded mesh, the fixed domain in which the wing is located and the domain of the missile are respectively generated, and the falling trajectory area of the missile in the fixed domain of the wing is refined, the size of the refined grid is matched with that of the boundary area of the missile, the number of fixed domain meshes is about 2 million, and the number of motion domain meshes is about 1 million. The mesh of model is shown in Figure 2. The calculation condition is consistent with the test state, Mach number M = 0.95, flight altitude H = 7.924km, flight angle of attack α = 0 °, turbulence model is k-ε two-equation model, the total time of simulation is 0.3s, the time step is 0.001s, the steady flow field calculation is carried out before the simulation of unsteady flow, and the unsteady flow field calculation is carried out after the flow field is stable, coupling with the 6-DOF equations of rigid body.

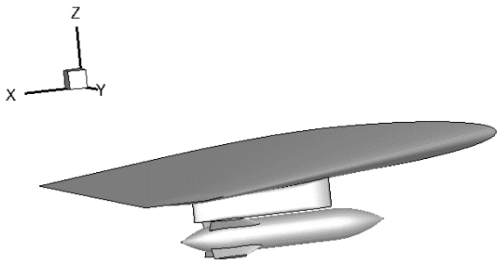


Figure 1 WPFS model

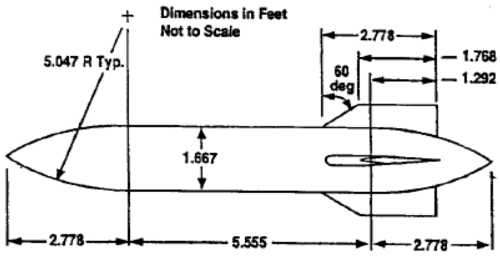


Figure 2 Geometric dimension of missile (unit: feet)

TABLE 1 Parameters of missile

| parameter | value |
|---|---|
| mass (kg) | 907 |
| centroid of mass (mm) | 1417 |
| Ixx (kg.m3) | 27 |
| Iyy，Izz (kg.m3) | 488 |
| leading edge ejection force (KN) | 10.7 |
| position of leading edge ejection force (mm) | 1237.5 |
| rearing edge ejection force (KN) | 42.7 |
| position of rearing edge ejection force (mm) | 1746.5 |
| displacement of operating force (mm) | 100 |

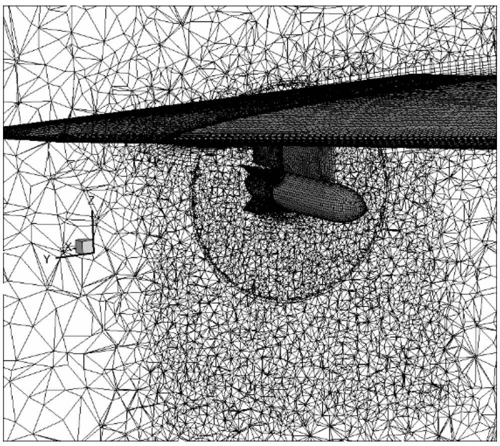

Figure 3 Mesh of the WPFS model

Figure 4~Figure 7 show the variation curves of the displacement of the centroid of mass, attitude angle,line velocity and angular rate of the missile with time during the falling process. The solid line in the figure is the calculation result, and the discrete points are the experimental values. It can be seen that the calculation result is in good agreement with the experimental result, and only the line velocity and roll angular rate of the missile in the y direction are slightly different from the experiment. The overall difference is small, and the application and withdrawal of ejection force and ejection moment are clearly reflected in the curve of vertical line velocity and pitch angular rate. In general, the method based on dynamic embedded mesh to solve the flow field N-S equations coupled with the 6DOF equations of rigid body can accurately simulate the separation process of the missile, and has a high credibility.

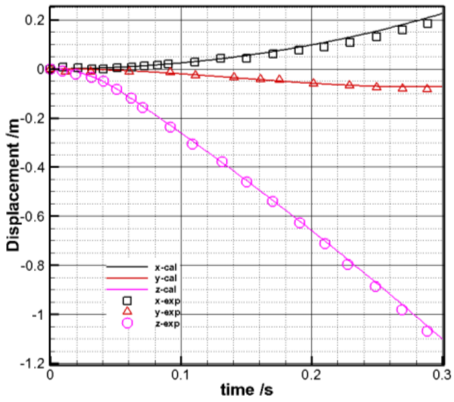


Figure 4 Variation of displacement of mass center with time

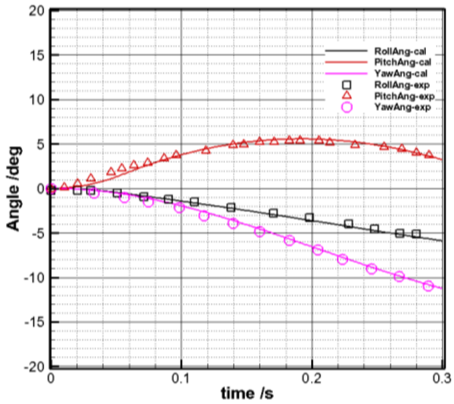


Figure 5 Variation of attitude angle of missile with time

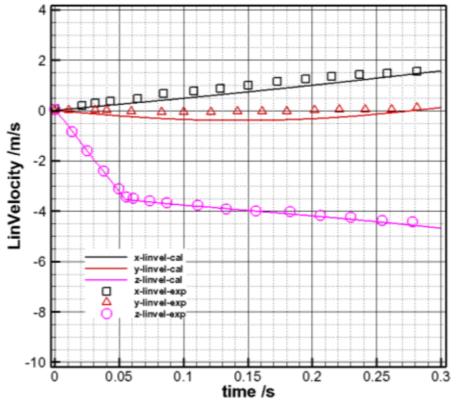


Figure 6 Variation of line velocity of missile with time

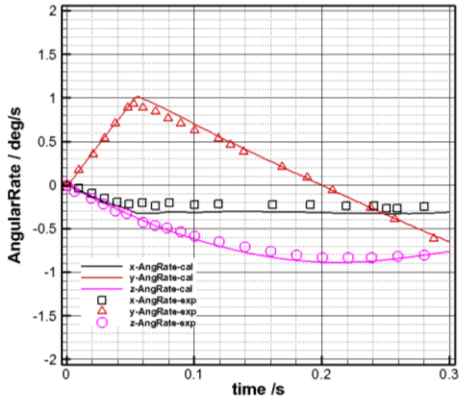


Figure 7 Variation of angle rate of missile with time

## 3. Model and Mesh generation

### 3.1 Model

The geometric model is a combination of an aircraft with an embedded bomb bay and missile mounted on the right side and the left side is empty in the bay. The length-depth ratio of the bay is L/D = 6.7. It has typical open cavity flow characteristics. The missile is the WPFS standard model. The bay doors are open on both sides. The geometric model is shown in Figure 8 and the pitch angles of aircraft and missile are zero. The coordinate system of the missile is defined as follows: the coordinate origin is the centroid of the body. The X axis points to the tail of the missile along the body axis, the y axis points to the right of the vertical symmetry plane, and the Z axis points upward.

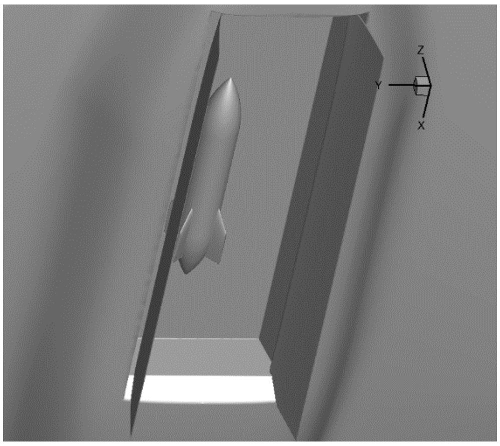

Figure 8 Geometric model.

### 3.2 Computational conditions and Mesh

The incoming flow Mach number M = 0.8, the aircraft flight altitude H = 10 km, the flight attitude is shown in TABLE 2, the missile is released without ejection force and ejection moment, the missile parameters are shown in

TABLE 1, the turbulence model is k-ε two-equation model, the time step is 0.001s, and the total simulation time is 0.5s. The grid domain of the aircraft and the grid domain of the missile are generated respectively, and the grid refinement is carried out in the falling area of the missile in the fixed grid domain. The surface grid and space grid diagram of the model are shown in Figure 9.

TABLE 2 Calculation condition

| | M | H (km) | α | β |
|---|---|---|---|---|
| Case1 | 0.8 | 10 | 0° | 0° |
| Case2 | 0.8 | 10 | 2° | 0° |
| Case3 | 0.8 | 10 | -2° | 0° |
| Case4 | 0.8 | 10 | 6° | 0° |
| Case5 | 0.8 | 10 | 0° | 3° |
| Case6 | 0.8 | 10 | 0° | -3° |

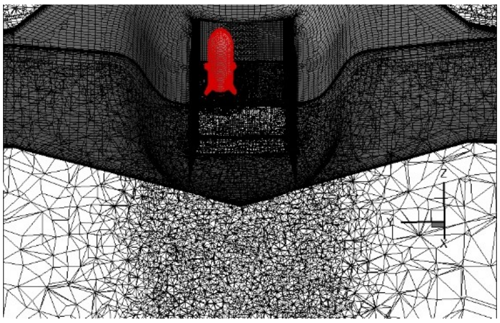

Figure 9 Mesh of geometric model

## 4. Results and Analysis

## 4.1 Effect of angle of attack

Figure 10~Figure 12 show the variation of the displacement and attitude angle of the missile separating from the embedded bay under different attack angles of the aircraft. It can be seen that under the state of α ≥ 0 °, the difference between the vertical displacement and lateral displacement of the missile is small, and also the difference between the pitch angle and yaw angle is small, and the pitch direction shows a rising trend. The yaw direction is to the left. When α = -2 °, the missile falls slightly slower in the vertical direction, the displacement decreases, and the lateral displacement increases. The direction of lateral displacement is opposite to that under the previous working conditions. Similarly, in terms of attitude angle, compared with the previous two working conditions, the pitch angle variation is slightly smaller, and the yaw angle variation increases. The pitch angle showed a trend of first lowering the head and then slowly raising the head, and the yaw angle showed a right yaw.

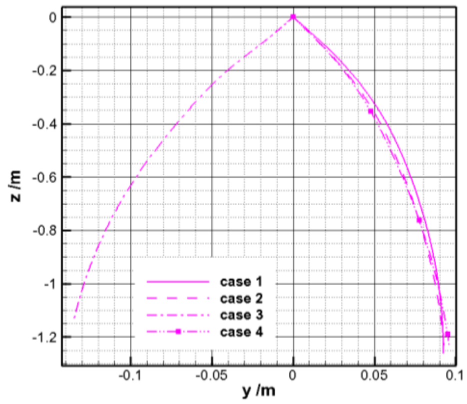


Figure 10 Vertical displacement versus lateral displacement

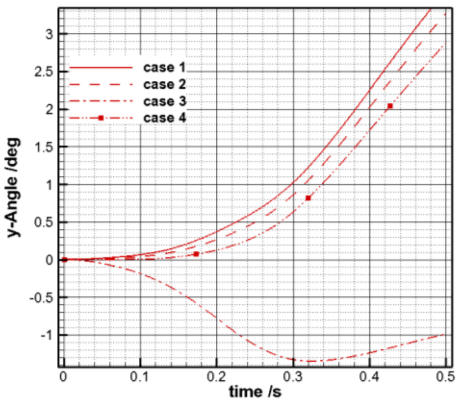


Figure 11 Variation of pitch angle with time

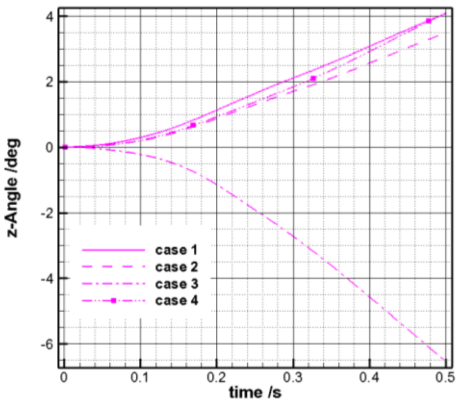


Figure 12 Variation of yaw angle with time

Figure 13~Figure 16 show the streamline of the flow around the missile body in the embedded bay at the initial time at different angles of attack. The displacement and attitude of the missile are determined by the aerodynamic force and moment applied to the missile, and the flow field characteristics in the embedded bay determine the aerodynamic force and moment. It can be seen that when α ≥ 0 °, at the initial time, the flow field in the bay is similar, there are some small vortices in the front of the missile head, there is a large vortex in the rear of the missile, the pressure distribution on the front and rear surfaces of the missile is quite different, which will cause a great change in the pitch angle during the falling process, and there is a big difference between the flow field in the bay and the first two conditions when α = -2 °. At the initial time, the flow field in the bay forms a larger vortex at the front and rear walls of the bomb bay respectively, and the size of the vortex is close, so the pressure distribution on the front and rear surfaces of the missile is relatively similary, the pitch angle of the missile changes little in the falling process, and there is a larger negative pressure area on the left side of the missile surface, which forms a larger negative lateral force and a negative yawing moment. This results in a large lateral displacement and yaw angle in the negative direction during the separation process.

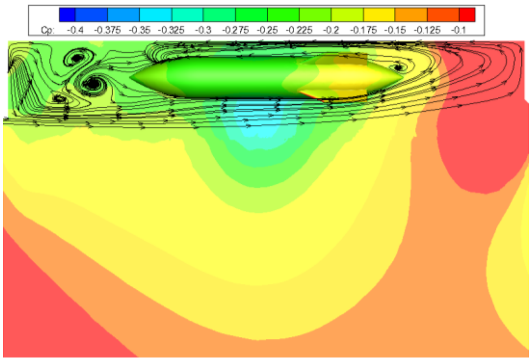


Figure 13 Streamlines around missile α=0° t=0s

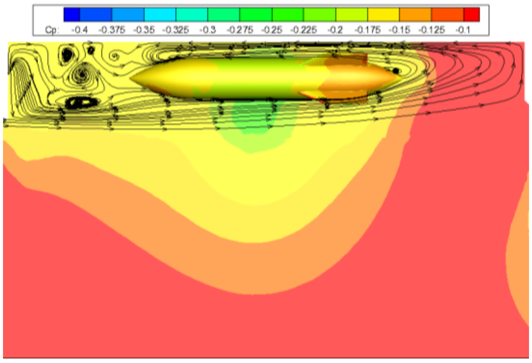


Figure 14 Streamlines around missile α=2° t=0s

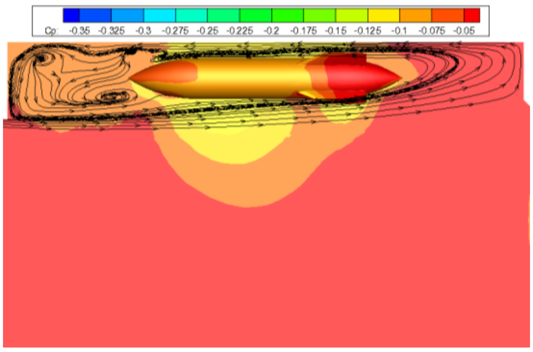


Figure 15 Streamlines around missile α=6° t=0s

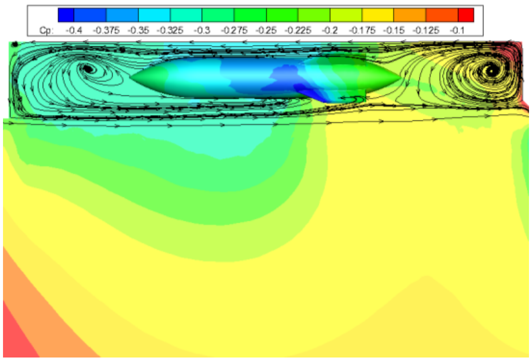


Figure 16 Streamlines around missile α=-2° t=0s

## 4.2 Effect of sideslip angle

Figure 17~Figure 20 show the variation of the displacement and attitude angle of the missile separating from the embedded bay under different sideslip angles of the aircraft. It can be seen that the variation of the displacement, pitch angle and yaw angle is consistent under the conditions of non-sideslip and negative sideslip, and the change value is small. Under the condition of non-sideslip, the right missile rolls left in the falling process. The negative sideslip will aggravate the left roll attitude of the missile and the variation of the roll attitude is the same as that in the non-sideslip condition. Under the positive sideslip condition, the variation of the lateral displacement and attitude angle of the missile is opposite to that in the non-sideslip conditions

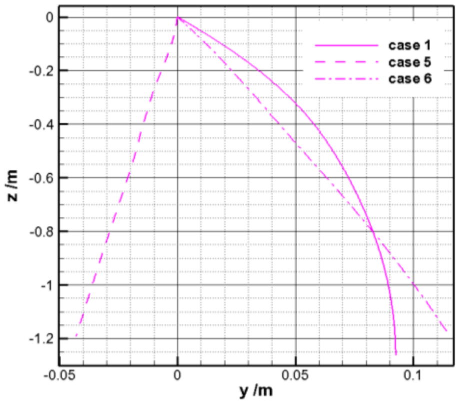


Figure 17 Vertical displacement versus lateral displacement

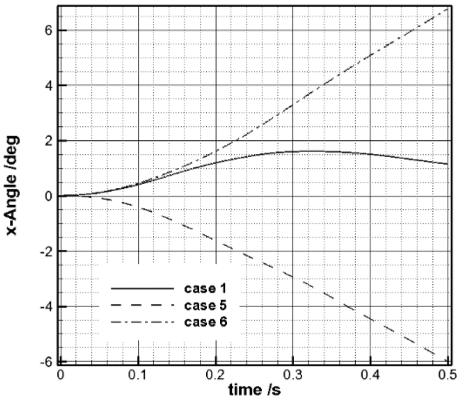


Figure 18 Variation of roll angle with time

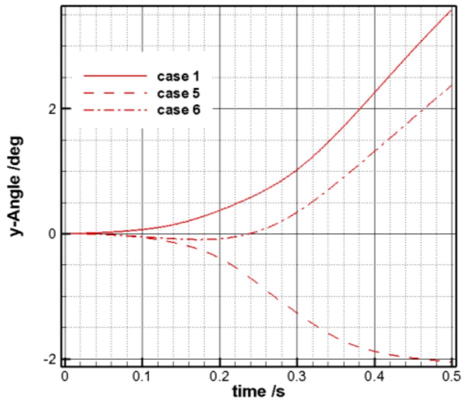


Figure 19 Variation of pitch angle with time

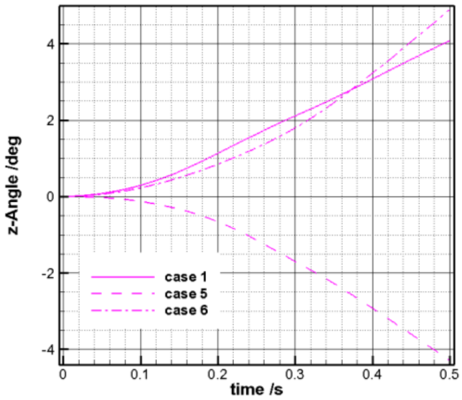


Figure 20 Variation of yaw angle with time

Figure 21 and Figure 22 show the variation of the side force and yawing moment of the missile with time under different sideslip angles. It can be seen from the figures that the side force and yawing moment of the missile in negative sideslip and non-sideslip conditions are relatively similar, and the fluctuation of the side force curve and the yawing moment curve is relatively small during the falling process. Under the positive sideslip condition, the side force and yawing moment of the missile have strong pulsation about at 0.3s, and at this time, the missile just passes through the shear layer of the hatch and does not break away from the influence area of the bomb bay door. Figure 23~Figure 25 are the schematic diagrams of the streamlines around the missile at different time in the positive sideslip condition. It can be seen from the figures that in the positive sideslip condition, the missile is located in the leeward area of the right side The interaction between the door and the missile is strong, and there is a strong separation vortex. With the further fall, the missile is far away from the right door, the interference between the leeward area of the door and the missile weakens, and the fluctuation amplitude of the aerodynamic force and moment decreases. Therefore, in order to improve the separation quality of buried object, it is necessary to avoid the release of object on the right side of the embedded bay when the sideslip is positive.

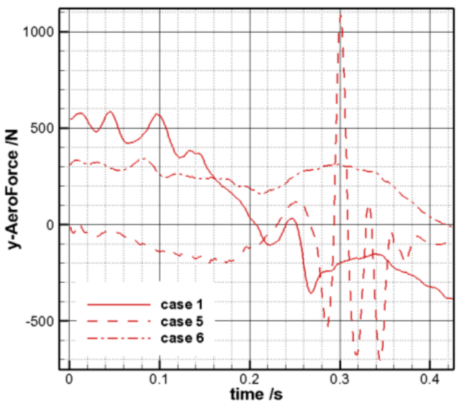


Figure 21 Variation of side force with time

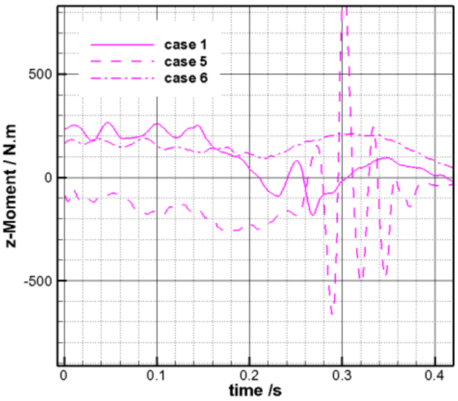


Figure 22 Variation of yaw moment with time

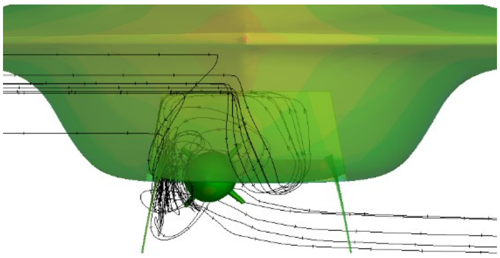

Figure 23 Streamlines around missile t=0.26s β=3°

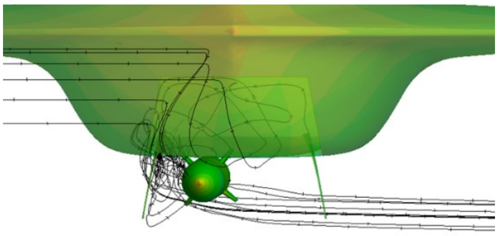

Figure 24 Streamlines around missile t=0.34s β=3°

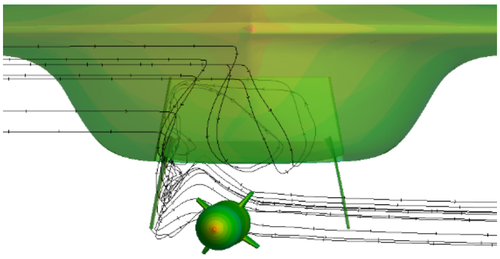

Figure 25 Streamlines around missile t=0.42s β=3°

## 5. Conclusion

In this paper, by coupling of solving the unsteady Navier-Stokes equations in the flow field and the 6-DOF equations of rigid body based on dynamic embedded mesh, the simulation of the release of a missile loaded on the right side of an embedded cabin is realized under the condition that there is no missile on the left side of the embedded cabin, and the influence of the flight attitude of an aircraft on the unilateral release of an embedded object is studied. The following conclusions are obtained:

1） The calculation method used in this paper can better simulate the simulation problem of buried object throwing, and has high engineering application value;

2） The negative angle of attack causes the change of the flow around the missile body in the cabin, a vortex with the same scale is formed in the front and back of the missile body, and the missile body has a large lateral displacement to the left and a large yaw to the left. There is little difference between the falling process of the projectile in the positive angle of attack and no angle of attack conditions, and the lateral displacement and attitude angle change of the projectile body are opposite to those in the negative angle of attack conditions;

3） The sideslip angle causes the increase of the roll angle during the dropping process of the missile body, the dropping process of the missile body in the negative sideslip condition is slightly different from that in the non-sideslip condition, and the displacement and attitude change trend of the projectile body is the same, and the aerodynamic force and moment have strong fluctuation changes due to the strong unsteady influence of the flow interference in the leeward area of the cabin door in the positive sideslips condition. And that lateral displacement and attitude angle change of the missile body are opposite to those of the non-sideslip and negative sideslip condition.

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## 7. Copyright Statement

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