Modeling of Stratosphere Airship

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Abstract: A modeling approach for the nonlinear dynamics simulation of stratosphere airships is proposed. In this model, the aerodynamics of airship is calculated based on a panel method and an engineering estimation approach. A new numerical method for calculating added masses of the airship is developed by using the CFD commercial software (Fluent) in this paper. This model can simulate the motion of stratosphere airships quickly and accurately.

Keywords: stratosphere airship; panel method; engineering estimation; added masses

I Introduction

Stratosphere Airship can be used as a platform for different purpose [15, 9, 18, 14, 10, 19]. We could analysis the motion, stability, manipulation and control of stratosphere aerodynamics in the course of design and using. The airship dynamics and kinematics model is very important for this purpose. In this paper, we build the nonlinear dynamics model by new approaches, which consist of a new method for calculating the nonlinear aerodynamic and a new method for calculating the added mass.

The aerodynamics of airship can be computed by some CFD software (FLUNET, CFX, STAR-CD and so on). Because of the large time consumption in computing, a quick method, which accurately and efficiently calculates the
aerodynamics of airships, is proposed in this paper. The aerodynamics of airship, which can be divided into the aerodynamics for airship body and those for fins, is composed of the linear aerodynamics and the nonlinear aerodynamics. The linear aerodynamics of airship hull is calculated in terms of Munk’s airship theory. While the nonlinear aerodynamics of it is calculated by Allen’s viscous cross flow theory. One the other hand, the linear aerodynamics of fins could be calculated by the approach of panel method. While the nonlinear aerodynamics of them could be calculated by the Polhamus-Lamar suction analogy method. The interference of the body and fins are also included in this model.

Moreover, a new numerical method for calculating the added mass of the airship is developed by the commercial codes Fluent. The accelerated motion of the object can be simulated by adopting the methods of the inviscid model and the Dynamic mesh technique in Fluent, and we can use the formula of force balancing resulted by Fluent to compute the added mass of any objects in six degree of freedom.
B The Estimation of Airship Aerodynamics

B.1 Airship Hull Aerodynamics\cite{13, 11, 8}

The aerodynamics of airship hull can be divided into the inviscid and viscid part. The inviscid aerodynamics can be calculated by the slender body theory. While the viscid aerodynamics can be calculated by Allen’s viscous cross flow theory.

B.1.1 Linear Aerodynamics

The hull of airship is a body of revolution. The lift and pitching moment can be calculated by the slender body theory. The potential cross force per unit length $f_p$ at any station along the hull is given by

$$f_p = (k_2 - k_1)q_\infty \frac{dS}{dx} \sin 2\alpha_e \cos(\alpha_e / 2)$$

where $k_1, k_2$ are the transverse and longitudinal apparent mass coefficients for the body, respectively. The variation of $k_2 - k_1$ is the function of fineness ratio. $\alpha_e$ is the free-stream dynamic pressure. $\rho$ is the air density, $V_\infty$ is the fluid velocity. $S$ is the cross-sectional area of the hull, $x$ is the distance along the hull from the bow.

The potential cross pitching moment per unit length $m_p$ at any station along the hull is given by

$$m_p = (k_2 - k_1)q_\infty \frac{dS}{dx} \sin 2\alpha_e \cos(\alpha_e / 2) (x_m - x)$$

where the torque center is $x_m$.

The total potential cross-force on airship hull can be expressed by

$$F_p = \int_0^{x_m} f_p \, dx = \int_0^{x_m} [(k_2 - k_1)q_\infty \frac{dS}{dx} \sin 2\alpha_e \cos(\alpha_e / 2)] \, dx = [(k_2 - k_1)q_\infty \sin(2\alpha_e) \cos(\alpha_e / 2)] \cdot S_{\infty}$$

The total potential cross-pitching moment on airship hull reads
where $l_r$ is the length of airship hull. $S_{lr}$ is the cross-sectional area of airship hull at the location of $l_r$. $Vol$ is the volume of airship hull.

Because of the contraction of airship hull in tail, the influence of boundary layer thickness to aerodynamics must be taken into consideration. Hence, we propose the boundary layer correct coefficient $\delta_{lr}$. Therefore, the cross sectional area of airship hull tail $S'_{lr}$ is

$$S'_{lr} = \delta_{lr} (S_{\text{max}} + S_{lr})$$

where $S_{\text{max}}$ is the maximum cross sectional area of airship hull.

### B.1.2 Nonlinear Aerodynamics

Here, we consider a body of revolution. It is again to be expected that the cross-force characteristics could be approximately predicted by treating each circular cross section as an element of an infinitely long circular cylinder of the same cross-sectional area. By this assumption, the local cross force of airship hull of per unit length due to viscosity $f_v$ could be given by

$$f_v = 2\eta krC_{dc} g_{\alpha} \sin^2 \alpha_c$$

where the correction factor of finite length of airship hull $\eta$ is the function of airship hull fineness ratio. $k$ is the correct coefficient of $C_{dc}$. $r$ is the body radius at any station $x$ from the bow, $C_{dc}$ is the drag coefficient of a circular cylinder at the Reynolds number and the Mach number, which are

$$Re_c = \frac{2rV_c \sin \alpha}{\nu} \quad M_c = \frac{V_c \sin \alpha}{a}$$

where, $\nu$ is the kinematic viscosity, and $a$ is the speed of sound in the undisturbed stream.
The total nonlinear cross force \( F_v \) and torque \( M_v \) of airship hull is

\[
F_v = \int_0^l f_v \, dx = \int_0^l [2\eta kr C_{p,\infty} q_\infty \sin^2 \alpha] \, dx
\]

\[
M_v = \int_0^l f_v (x_m - x) \, dx = \int_0^l [2\eta kr C_{p,\infty} q_\infty \sin^2 \alpha] (x_m - x) \, dx
\]

**B.1.3 Axial Drag of Airship Hull**

By the calculation method of Hoerner’s revolution drag, the axial drag of airship hull is:

\[
D_v = q_v S_{ref} \left( 0.172 \left( \frac{L}{D_{max}} \right)^{1/3} + 0.252 \left( \frac{D_{max}}{L} \right)^{1.2} + 1.032 \left( \frac{D_{max}}{L} \right)^{2.2} \right) / Re^{1/6}
\]

where \( L / D_{max} \) is the fineness ratio of airship hull. \( Re \) is the Reynolds number based on the airship hull length \( L_r \).

**C The Aerodynamics of Fins**

The aerodynamics of airship fins can also be divided into the linear and the nonlinear parts. The linear aerodynamics of fins is calculated by the approach of panel method \([17]\). The nonlinear aerodynamics of fins is calculated by the Polhamus-Lamar suction analogy method. The interference of body and fins are included in this model by considering the vortexes of airship hull.

The detail calculation formulas of airship fins can be found in reference.[16]

**D The Comparison of Calculation and Experiments**

Based on the formula of forces (moment) of airship hull and the calculation method of fins in the airship, we calculate three examples and compare the results with experiments.

**D.1 Comparison of Aerodynamics of Airship hull**

**D.1.1 Example 1 (LOTTE Airship)**\([5]\)

The main dimensions of airship LOTTE are as follows: a volume of \( V = 109 \, m^3 \), an overall length of \( L = 16 \, m \), a maximum diameter of \( D = 4 \, m \). The contour of LOTTE is defined in two sections by a root function:
\[ r_1(\bar{x}) = c\sqrt{\bar{x}} \quad \text{for} \quad 0 < \bar{x} < 0.08 \quad \text{and a polynomial function} \]

\[ r_2(\bar{x}) = c_0 + c_1\bar{x} + c_2\bar{x}^2 + c_3\bar{x}^3 + c_4\bar{x}^4 + c_5\bar{x}^5 \quad \text{for} \quad 0.08 < \bar{x} < 1. \]

\[ \bar{r} = r/L \quad \text{and} \quad \bar{x} = x/L \quad \text{are the normalized coordinates in radial resp. axial direction. The coefficients are given in Table 1.} \]

### Table 1  The coefficients of contour of LOTTE airship

<table>
<thead>
<tr>
<th>c</th>
<th>c_0</th>
<th>c_1</th>
<th>c_2</th>
<th>c_3</th>
<th>c_4</th>
<th>c_5</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>0.2277</td>
<td>0.0197</td>
<td>0.7184</td>
<td>-2.3751</td>
<td>5.0166</td>
<td>-5.8339</td>
</tr>
</tbody>
</table>

Figure 2 The hull shape of LOTTE airship

The results of computation and experiment are shown in figure 3 ( \( \delta_v = 0.37 \) )
Figure 3 The comparison of $C_l$, $C_d$, $C_m$ between experiments and computation of LOTTE airship hull

D.1.2 Example 2 (slender body)\cite{1}

Definition of the shape equation:

$$\frac{r}{r_0} = \left[1 - (1 - \frac{2x}{l_0})^2\right]^{3/4}$$

Geometric parameters: \( l = 3.912, r_0 = 0.198, l_0 = 4.962 \),

Figure 4 Body of revolution from reference 7

Mach number of the free stream: \( M_0 = 0.6 \).

The results of computation and experiment are shown in figure 5 \( \delta_{e} = 0.4889 \)
Figure 5 The comparison of $C_l$, $C_d$, $C_m$ between the experiment and the computation of slender body

D.1.3 Example 3 (U.S.S “Akron” airship)\cite{6}

Dimensions of model U.S.S “Akron” Scale 1/40 are given in Figure 6.


Figure 6 The shape of USS Akron airship

The results of computation and experiment are shown in figure 7 ($\delta_{x} = 0.40$)
Figure 7 The comparison of $C_l$, $C_d$, $C_m$ between the experiment and the computation of USS Akron airship

D.2 Comparison of Aerodynamics of Airship Hull and Fins

The example 1 and 2 used in this section is same as example 1 and example 3 in section D.1 respectively.

D.2.1 Example 1 ( $\delta = 0.37 \quad K_z = 0.2385, K_y = 0.0$ )
D.2.2 Example 2 \( \delta_s = 0.40 \quad K_L = 0.3406, K_d = 0.0 \) 

Through the comparison of calculated and experimental results for three examples, we can conclude that our new method can accurately and efficiently
calculate the aerodynamics of airship and can be applied in the area of Engineering calculations.

**III Computation Method for the Added Mass**

At present, there are different methods to compute the added mass of an object such as estimating method based on simple ellipsoid with three independently sized principal axes and the Hess Smith panel method \cite{7,3}.

With the development of computers and computing fluid dynamics technology, a new method is presented by the commercial CFD software FLUENT\cite{4}. This method can be used to compute the added mass of any object with a complex shape.

**A The New Computing Method for the Added Mass**

This method is based on the inviscid model and the Dynamic mesh technique in Fluent. By changing the forces under the condition of uniform motions and accelerated motions, we can obtain the added mass of an object by its definition:

\[
m = \frac{|F_a - F_u|}{a}
\]

where \(m\) is the added mass; \(F_a\) is the force or torque of an object in the condition of accelerated motions; \(F_u\) is the force or torque of an object in the condition of uniform motions.

**A.1 The Boundary Conditions of Uniform Motions**

**1 Transverse motion**

As an example, we show the boundary conditions of an object moving transversely in the x direction. The definition of boundary condition of other directions (y and z) is the same as x.

The computational region is shown in figure 10. The boundary conditions are given as follows:

Inlet: \(u_x = 1\text{ m/s}, \ u_y = 0\); Outlet: \(Q_{OUT} = Q_{IN}\).
2 Rotating motion

As an example, we show the boundary conditions for rotating motions in the z direction. The boundary conditions of other direction (x and y) are the same as x.

By using the technique of Moving Reference Frame in FLUENT, we can simulate the rotating motion of airships in the condition of $\omega_z = 1 \text{ rad/s}$. The boundary conditions are shown in figure 11.

A.2 The Boundary Conditions of Accelerated Motions

The unsteady solver is used to simulate the accelerated motion of airship. The out boundary conditions of the computational region are the same as the steady flow. The only different with the unsteady flow is that the airship must accelerate by changing of time.

1 Transverse accelerated motion

The accelerated velocity is defined by 1m/s2.

2 Rotating motion

The accelerated velocity is 1rad/s2.
A.3 Validation of the New Calculation Method

The new calculation method described in the previous sections has been verified with regard to the added mass computation for a ellipsoid with three independently sized principal axes.

The parameters of the ellipsoid are given as follows:

- x axes length: 2a=20m.
- y,z axes length: 2b=2c=5.333m.

The fluid density: \( \rho = 1.225 \, \text{kg} / \text{m}^3 \).

The new calculation method is compared to the results from theoretical approach and the Hess Smith panel method. Good agreements for the six added mass have been achieved.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>The results of the added masses of the ellipsoid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( m_{11} )</td>
</tr>
<tr>
<td>theory</td>
<td>295.12</td>
</tr>
<tr>
<td>Hess - Smith</td>
<td>307.93</td>
</tr>
<tr>
<td>New method</td>
<td>313.89</td>
</tr>
<tr>
<td>Relative error (( % ))</td>
<td>1.94</td>
</tr>
</tbody>
</table>

B  The Computation of Added Masses of the LOTTE Airship

We calculated the added mass of LOTTE airship (example 1 of section II) by this new calculation method in this section.

The parameters in this computation are as followed:

The fluid density: \( \rho = 1.0 \, \text{kg} / \text{m}^3 \); The center of Torque: \( x_m = 7.0 \text{m} \).

The results are given in Table 3.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>The added mass of LOTTE airship</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( m_{11} )</td>
</tr>
<tr>
<td></td>
<td>10.71</td>
</tr>
</tbody>
</table>

Based on the definition of added masses and using the commercial CFD software Fluent, the added mass of airship was calculated. This new method can be very readily, effectively and accurately used to compute the added mass of complex object such as ships, aircrafts and so on.
IV Stratosphere Airship Dynamics and Kinematics Model

A Airship Dynamics and Kinematics Model

We used three coordinates and two limiting assumptions\cite{2} (I. The airship forms a rigid body so that aeroelastic effects can be ignored; II. The airframe is symmetric about the $\alpha \beta \zeta$ plane so that both the Center of Volume and the Center of Gravity lie in the plane of symmetry.) in the process of building the dynamics model of an airship.

![Diagram of Earth coordinates $Ax_dy_dz_d$, body-fixed coordinates $Oxyz$ and velocity coordinates $Ox_gy_gz_g$](image)

Based on the theoretical mechanics, we can get the dynamics model of airships. The model in the body-fixed coordinates can be stated as:

$x$ Direction force equation is:

$$m[(\dot{u} - v\dot{r} + w\dot{q}) - x_G(q^2 + r^2) + y_G(pq - \dot{\rho}) + z_G(pr + \dot{\varrho})]$$

$$= X_x - X_a \sin \alpha \cos \beta + Y_x \cos \alpha \sin \beta + Z_a \sin \alpha + T + (B - G) \sin \vartheta$$

(1)

$y$ Direction force equation is:

$$m[(\dot{v} - w\dot{p} + u\dot{r}) - y_G(r^2 + p^2) + z_G(qr - \dot{\varrho}) + x_G(qp + \dot{\rho})]$$

$$= Y_y - X_a \sin \beta + Y_a \cos \beta + (G - B) \cos \vartheta \sin \phi$$

(2)

$z$ Direction force equation is:

$$m[(\dot{w} - u\dot{q} + v\dot{p}) - z_G(p^2 + q^2) + x_G(rp - \dot{\varrho}) + y_G(rq + \dot{\rho})]$$

$$= Z_z - X_a \sin \alpha \cos \beta + Y_a \sin \alpha \sin \beta - Z_a \cos \alpha + (G - B) \cos \vartheta \cos \phi$$

(3)

Roll moment equation is:
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\[ \begin{align*}
I_x \dot{p} + (I_z - I_y) qr - I_{xz} (\dot{r} + pq) + I_{xy} (pr - \dot{q}) + I_{yz} (r^2 - q^2) \\
+ my_G (\dot{w} + pv - qu) - mz_G (\dot{v} + ru - pw)
= L_I + L_a + y_G G \cos \theta \cos \phi - z_G G \cos \theta \sin \phi
\end{align*} \]  
(4)

Pitch moment equation is:

\[ \begin{align*}
I_y \dot{q} + (I_x - I_z) rp + I_{xz} (p^2 - r^2) - I_{xy} (\dot{p} + qr) + I_{xz} (qp - \dot{r}) \\
+ mz_G (\dot{u} + qw - rv) - mx_G (\dot{w} + pv - qu)
= M_I + M_a - z_G G \sin \theta - x_G G \cos \theta \cos \phi
\end{align*} \]  
(5)

Yaw moment equation is:

\[ \begin{align*}
I_z \dot{r} + (I_y - I_z) pq + I_{xz} (rq - \dot{p}) + I_{xy} (q^2 - p^2) - I_{yz} (\dot{q} + rp) \\
+ mx_G (\dot{v} + ru - pw) - my_G (\dot{u} + qw - rv)
= N_I + N_a + x_G G \cos \theta \sin \phi + y_G G \sin \theta
\end{align*} \]  
(6)

The kinematics equations are:

\[ \begin{align*}
\dot{x} &= (\cos \psi \cos \theta) u + (\cos \psi \sin \theta \sin \phi - \sin \psi \cos \phi)v \\
&+ (\cos \psi \sin \theta \cos \phi + \sin \psi \sin \phi)w
\end{align*} \]  
(7)

\[ \begin{align*}
\dot{y} &= (\sin \psi \cos \theta) u + (\sin \psi \sin \theta \sin \phi + \cos \psi \cos \phi)v \\
&+ (\sin \psi \sin \theta \cos \phi - \cos \psi \sin \phi)w
\end{align*} \]  
(8)

\[ \begin{align*}
\dot{z} &= (-\sin \theta) u + (\cos \theta \sin \phi)v + (\cos \theta \cos \phi)w
\end{align*} \]  
(9)

\[ \psi = \frac{1}{\cos \theta} (r \cos \phi + q \sin \phi) \]  
(10)

\[ \dot{\theta} = r \sin \phi + q \cos \phi \]  
(11)

\[ \dot{\phi} = p + tg \theta (r \cos \phi + q \sin \phi) \]  
(12)

where \( u, v, \) and \( w \) are the linear velocities in the airship \( x, y, \) and \( z \) directions; \( p, q, \) and \( r \) are the angular velocities about the airship \( x, y, \) and \( z \)-axes; \( \theta, \psi, \) and \( \phi \) are the pitch, yaw and roll angles; \( \alpha \) and \( \beta \) are the angle of attack and sideslip, respectively; \( x, y, \) and \( z \) are the global position coordinates; \( X_I, Y_I, \) and \( Z_I \) are inertia force in \( x, y, \) and \( z \) directions of body-fixed coordinates; \( L_I, M_I, \)
and $N_j$ are inertia torque in $x, y$, and $z$ directions of body-fixed coordinates respectively; $X_a, Y_a$ and $Z_a$ are aerodynamic forces of airships, respectively; $L_a, M_a$, and $N_a$ are aerodynamic moments of airships, respectively; $(x_G, y_G, z_G)$ are the coordinates of gravity center; $G$ and $B$ are the centers of gravity and buoyancy of airship, respectively; The moments of inertia around the $x, y$, and $z$ axes are $I_x, I_y$, and $I_z$; The product of inertia about $ox, oy$, and $oz$ are $I_{xz}, I_{yz}$, and $I_{xy}$.

We can get the state equation of the airship Eq. (13) from Eq. (1)-(12),

$$
\begin{align*}
\begin{bmatrix}
\dot{u} \\
\dot{v} \\
\dot{w} \\
\dot{p} \\
\dot{q} \\
\dot{r} \\
\dot{\vartheta} \\
\dot{\psi} \\
\dot{\phi}
\end{bmatrix} &=
\begin{bmatrix}
\sum_{j=1}^{6} M_{ai} f_i \\
\sum_{j=1}^{6} M_{ai} f_i \\
\sum_{j=1}^{6} M_{ai} f_i \\
\sum_{j=1}^{6} M_{ai} f_i \\
\sum_{j=1}^{6} M_{ai} f_i \\
\sum_{j=1}^{6} M_{ai} f_i \\
\sum_{j=1}^{6} M_{ai} f_i \\
\sum_{j=1}^{6} M_{ai} f_i \\
\sum_{j=1}^{6} M_{ai} f_i
\end{bmatrix}
\begin{bmatrix}
a_x \cdot u + b_x \cdot v + c_x \cdot w \\
a_y \cdot u + b_y \cdot v + c_y \cdot w \\
a_z \cdot u + b_z \cdot v + c_z \cdot w \\
- r \sin \phi + q \cos \phi \\
\frac{1}{\cos \vartheta} (r \cos \phi + q \sin \phi) \\
p + t g \vartheta (r \cos \phi + q \sin \phi)
\end{bmatrix} \\
\Rightarrow \dot{X} &= f(X, U)
\end{align*}
$$

(13)

Because of the symmetry of the airship about the plane of $Oxy, Oxz$, the products of inertia $I_{xz}$, and $I_{xy}$ are equal to zero.

The detail expressions of $f_i, M_{ij}$ in the equation (13) are as follows:

$$
f_i = -(m + m_0)wq + (m + m_z)vr - mz_gr pr + mx_gr (q^2 + r^2) - my_gr pq - m_z gr^2 + m_z r^2 + F_i + T + (B - G) \sin \vartheta + T_z
$$
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\[ f_2 = -(m + m_{11})ur + (m + m_{33})wp - mGq + my_G (r^2 + p^2) + (m_{35} - mx_G)qp + F_x + (G - B) \cos \theta \sin \phi + T_x \]

\[ f_3 = -(m + m_{22})wp + (m + m_{11})uq + mG (p^2 + q^2) - mx_G rp - my_G rq + F_y + (G - B) \cos \theta \cos \phi + T_z \]

\[ f_4 = (m_{35} - m_{11})I_z + I_r)rq + I_{11}pq - I_{11}pr - I_{11}p r^2 - p^2 - my_G (pv - qu) + mz_G (ru - pw)\]

\[ f_5 = (m_{35} - m_{11} - I_z + I_r)pr - I_{11}(p^2 - r^2) + I_{11}qr - I_{11}qp - mz_G (qv - rv) + mx_G (pv - qu) \]

\[ f_6 = (m_{35} - m_{11} - I_z + I_r)rp - I_{11}(q^2 - p^2) - mx_G (ru - pw) + my_G (qw - rv) \]

\[ -m_{33} wp + (m_{11} - m_{22})uv + m_G x_G \cos \theta \sin \phi + y_G G \sin \theta + (x_G c_G - y_G s_G) \]

\[ M = \begin{bmatrix}
  m + m_{11} & 0 & 0 & 0 & m_G & -my_G \\
  0 & m + m_{22} & 0 & -m_G & 0 & m_{35} + mx_G \\
  0 & 0 & m + m_{33} & my_G & m_{35} - mx_G & 0 \\
  0 & -m_G & my_G & I_z + m_{44} & -I_{xy} & -I_{xy} \\
  mz_G & 0 & -m_G & -I_{xy} & I_x + m_{55} & -I_{xy} \\
  -my_G & m_{62} + mx_G & 0 & I_{xy} & -I_{xy} & I_x + m_{66}
\end{bmatrix}^{-1} \]

V Summary

A new modeling approach for the nonlinear dynamics simulation of stratosphere airships is proposed. In this model, the aerodynamics of airships is calculated based on a panel method and engineering estimation approach. The added mass is obtained by the CFD commercial software (Fluent).

An efficient aerodynamic calculation method, based on a panel method and engineering estimation approach was developed. The aerodynamics of airship is divided into two parts: The aerodynamics of airship body and the fins. Every part is composed of the linear aerodynamics and nonlinear aerodynamics. The linear aerodynamics of the airship hull is calculated by Munk’s airship theory and the nonlinear aerodynamics of airship hull is calculated by Allen’s viscous cross flow theory. The linear aerodynamics of fins is calculated by the approach of panel method and the nonlinear aerodynamics of fins is calculated by the Polhamus-Lamar suction analogy method. The interference of body and fins is included in this model. It is shown by the results of computations and experiments that our model can efficiently estimate the aerodynamics of airships.
When the object accelerates, it will make fluid move and produce inertial forces which is defined as added masses. So far, the methods for computing the added mass of airships are not precise. A new numerical method for obtaining added mass of the airship is developed by using the commercial codes Fluent. The method uses the inviscid model and the Dynamic mesh technique in Fluent. The accelerated motion of the object can be simulated, and we can use the force equations of balancing to compute the added mass of an object in six degree of freedom, where the forces are obtained from Fluent. By comparing the results with those given by other methods, the high precision and efficiency of the method are verified. The added mass of the airship LOTTE is also computed for its numerical moving analysis.

References


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