Contrastive Analysis for Diversion Performance of Three Kinds of Deflector

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Abstract. Deflector is generally used as deflecting device of Vehicle-mounted Vertically Thermal Launched Missile. To study the features of three different kinds of deflectors, numerical simulation is used to simulate the jet flow around single-faced, double-faced, triple-faced deflector respectively in this dissertation. Pathlines, Mass flow rate through the observation surfaces built around the deflector, regions influenced by jet flow on ground are standards to be compared, characters of them can be concluded from an analysis.

1. Introduction
Vehicle-mounted missile is widely applied because of its excellent concealment and maneuverability, deflector, as an important part of Vehicle-mounted Vertically Thermal Launched system, bearing the impact of jet flow and guiding it to the direction that is favorable to launch [1], reduces the ablation and impact caused by jet flow with high speed and high temperature on launchers. At present, the type of the deflector on Vehicle-mounted missile mainly includes single-faced, double-faced, triple-faced, cone-type and so on [2]. JingSong Chen [3] studied the law of double-faced deflector, but no one compared the diversion performance of them.

Structured grid and unstructured grid are applied to modeling the jet flow field around the different kinds of deflectors, by numerical simulation, comparing and analyzing the result, it is concluded that the characteristics of different deflectors, the results will provide theoretical basis for rational selection.

2. Physical Model
Three-dimensional N-S equation is used for the numerical simulation. The Control Equations [4] are shown as follow:

Continuum equations is shown as follow

\[ \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0 \]  \hspace{1cm} (1)

Where, \( \rho \) is flow density, \( \vec{u} \) is flow velocity vector.

Momentum equations is shown as follow

\[ \frac{\partial (\rho \vec{u}_i)}{\partial t} + \frac{\partial (\rho \vec{u}_i \vec{u}_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} \]  \hspace{1cm} (2)

Where \( \vec{u}_i, \vec{u}_j \) are \( i \) and \( j \) weight flow velocity. \( p \) is the flow pressure. \( x_i, x_j \) are \( i \) and \( j \) direction coordinate. \( \tau_{ij} \) is the stress tensor. Its expression is shown as follow
\[ \tau_{ij} = [\mu(\partial u_i / \partial x_j + \partial u_j / \partial x_i)] - \frac{2}{3} \mu \frac{\partial u_i}{\partial x_i} \delta_{ij} \]  

Energy equations is shown as follow

\[ \frac{\partial}{\partial t} (\rho H) + \frac{\partial}{\partial x_j} (\rho u_j H) = \frac{\partial p}{\partial t} + \frac{\partial}{\partial x_j} (u_j \tau_{ij} - q_j) \]  

\( H \) is total enthalpy \( H = h + u_i^2 / 2 \), \( h = C_p T, C_p \) is stated specific heat, \( T \) is static temperature. \( q_j \) is heat flux.

Turbulence Equations is shown as follow

The Realizable k-\( \varepsilon \) model [5] equation was used. The transportation equation [6] of the turbulence kinetic energy \( k \) is

\[ \frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho ku_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k + G_b - \rho \varepsilon - Y_m + S_k \]  

The equation of the dissipation rate of the turbulence kinetic energy is

\[ \frac{\partial (\rho \varepsilon)}{\partial t} + \frac{\partial (\rho \varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + \rho C_1 S \varepsilon - \rho C_2 \frac{\varepsilon^2}{k + \sqrt{\varepsilon}} + C_4 \frac{\varepsilon}{k} C_{\varepsilon} G_b + S_\varepsilon \]  

Where \( \mu_t = \rho C_p k^2 / \varepsilon \)

3. Calculation Model

The computational model is shown in Figure 1. - Figure 3. , it includes nozzle, missile, deflector, baffle (except triple-faced deflector) and ground.

![Figure 1. calculation model of single-faced deflector](image1)

![Figure 2. calculation model of double-faced deflector](image2)
Figure 3. Calculation model of triple-faced deflector

The computational domain is shown in Figure 4 - Figure 6. Based on symmetry, the calculation model of single-faced deflector and triple-faced deflector adopt half model, the calculation model of double-faced deflector uses quart model. Structured grid is used in most regions except for some complicated regions near the deflector. The mesh number of three kinds of deflector is about 2 million.

Figure 4. Calculation model of single-faced deflector

Figure 5. Calculation model of double-faced deflector

Figure 6. Calculation model of triple-faced deflector
Two components, air and gas, are adopted for calculation, the boundary condition of the inlet of nozzle is pressure inlet, the total combustion chamber pressure is 7 MPa, the total temperature is 3200 K, free boundaries are set to pressure outlet, the pressure is 101325 Pa, and temperature is 300 K. The wall boundary [7] is adiabatic and stationary.

4. Results and Discussions

It is compared by three aspects in this paper, Pathlines, Mass flow rate through the observation surfaces built around the deflector, Regions influenced by jet flow on ground, respectively.

4.1. The pathlines

The pathlines of three kinds of deflector are shown in Figure 7 - Figure 9.

As shown in pictures of pathline , because of the deflector, jet flow is guided into deflecting side, which, thanks to the baffles, is mainly the back for single-faced deflector, the two sides for double-faced, however , not only both sides and back , but also the front for triple-faced without a baffle.
4.2. Mass flow rate through the observation surfaces
Observation surfaces are set around the deflector, which are shown in Figure 10. - Figure 12.

![Figure 10. Observation surfaces of single-faced deflector.](image)

![Figure 11. Observation surfaces of double-faced deflector.](image)

![Figure 12. Observation surfaces of triple-faced deflector.](image)

![Figure 13. The velocity vector near the bottom of missile.](image)

The mass flow rate through the observation surfaces is shown in table 1

|                | Front (kg/s) | Back (kg/s) | Sides (kg/s) | Upside (kg/s) | Inlet of nozzle (kg/s) |
|----------------|-------------|-------------|--------------|---------------|------------------------|
| Single-faced   | ---         | -38.850     | -7.148       | 0.166         | 45.581                 |
| Double-faced   | -5.373      | -5.373      | -35.968      | 0             | 47.946                 |
| Triple-faced   | -4.834      | -10.336     | -32.939      | 0             | 47.705                 |

It is shown that jet flow is mainly deflecting to backside of single-faced deflector, but it appears a little backwashing (the mass flow rate through upside is not zero), it also can be shown in Figure 13. While no backwashing in double-faced and triple-faced deflector. Meanwhile the input (inlet of nozzle) equals to output (the sum of different sides) as shown.

4.3. Regions influenced by jet flow on ground
Figure 14. - Figure 16. show the temperature contours on the ground (only display the region beyond 1000K).
Figure 14. The temperature contours of single-faced deflector on the ground

Figure 15. The temperature contours of double-faced deflector on the ground

Figure 16. The temperature contours of triple-faced deflector on the ground

Generally, due to the deflector, region affected by jet flow primarily concentrated in the guiding side, the region influenced by jet flow of single-faced deflector is the minimum, and it is at the back of deflector. The region influenced by jet flow of double-faced deflector is at either side of the deflector, it could influence the vehicle. The region influenced by jet flow of triple-faced deflector is the maximum, and without baffle, some jet flow is exhausted to the front of deflector which is more likely to damage the vehicle and other devices around the deflector.
5. Conclusions

1) Single-faced deflector has a simplest structure, jet flow will mostly be deflecting to the backside of deflector, it will not affect the launching vehicle basically and however, it appears a little backwashing which will causes ablation of the bottom of missile, but the backwashing can be reduced by optimizing the shape of deflector plate.

2) Double-faced deflector has the best guiding performance, no backwashing, jet flow is deflecting to the side of deflector, and it could influence the launching vehicle. Nevertheless, its profile is a little difficult to processing.

3) As for triple-faced deflector, without baffle, the jet flow will be guided to the front of the deflector which has a bad effect on launching vehicle. At the same time, its profile is the most complicated. Baffles and optimization of the shape of deflector are needed if you want to use it.

6. References

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