# THE CHARACTERISTICS STUDY OF DEBRIS CLOUD OF THE MESH SHIELDS UNDER HYPERVELOCITY IMPACT

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## ABSTRACT

The hypervelocity impact interaction of the sphere projectile with continuous shield and mesh shield, which were the same thickness, was investigated numerically. The study involved the differences in the morphology and the distribution of velocity, mass and momentum of the debris clouds generated by impacting two kinds of shields. The calculations show that the morphologies of the debris cloud vary with the impact locations when a p rojectile impact the mesh shield, and there is the banded distribution of debris in the front of debris cloud. Comparison between the continuous shields and the mesh shields with the same thickness, the maximum of momentum density in the mesh shield was higher than it in the continuous shield. The mesh shield does not effectively slow the projectile resulting from the impact, but break up it. The dynamical response of the projectile varies with the shields. Impacting the mesh shield, the main of debris are at the rear end of the debris cloud, which is different from the continuous shield.

**Key words:** mesh shield, debris cloud, numerical simulation, hypervelocity impact

## 1 INTRODUCTION

At the present time meteoroid and space debris protection systems of a spacecraft are based on shield schemes. With the growing deterioration of the space environment, the demand for valuable and lightweight shield protection is increased. The mesh is a valuable candidate during the development of new protection structures on account of its low area-density. The advantage of the mesh shield as an element of a multi-shields protective system was reported in [1,2]. The combination of mesh and continuous shields (so called "Mesh Double-Shield") allowed one to reduce the shield design weight by 30% as compared to a s ingle continuous shield with the same efficiency in [2]. Horz et al comprehensively studied the mesh shields in [3-5]. In these works the comparative study of high-velocity projectile destruction on mesh and continuous shields was fulfilled, and the dispersive and fragmentation properties of a pile of meshes in their interaction with the projectile were studied. Horz et al. depicted and described the most vivid distinction in the nature of the projectile fragments distribution at penetration into mesh shield. The theoretical evaluations describing the influence of the mesh parameters on the depth of mesh penetration into projectile were presented in [6].

The high efficiency of mesh shields aroused interest to study its properties. Compared with the single continuous shield, the study of mesh shields was carried out by the experiments, most of which were qualitative and inadequate for the characteristics of the debris cloud. The numerical simulation is an important method for the hypervelocity impact research. In this paper, the debris cloud characteristics would be studied by numerical method in order to get the quantitative and detailed results.

## 2 NUMERICAL SIMULATION

The numerical modeling was carried out by SPH method

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with the aid of the Ls- Dyna code of version 971 including SPH calculation module. The SPH(smoothed particle hydrodynamics ) is the meshfree method, which can effectively simulate the generation and movement of the debris cloud. Accordingly, in this work, the mesh and aluminium plate would be dispersed by SPH. It should be pointed out that, due to the complicated physics phenomena involved in the hypervelocity impact, the accuracy of computational results presented herein may hinge on the choice of material modes. The material models include EOS(equation of state), Strength equation, and so on. In this paper, the behavior of the projectile and shield was described by the Johnson-Cook strength equation(material type 15 in Ls-Dyna ) and Mie-Gruneisen equation of state(EOS type 4 in Ls-Dyna). The material of the projectile is the 2017-T4aluminium alloy, velocity of it is 4.0km/s, and the diameter is 4.0mm. The material of mesh shield and continuous shield was the 5A06 aluminium alloy, string diameter is 0.5mm, the distance between strings is 1.8mm,the thickness of the continuous shield is 1.0mm. Date in [7,8] on the projectile and mesh materials are presented in Tab.1 and Ta.2. In Tab.2, G is the shear modulus, $c_0$ is the bulk sound speed, S is the coefficient in shock adiabat, $\Gamma_0$ is the Gruneisen parameter.

Table 1 Johnson-cook material parameters

| Material | $A$/(GPa) | $B$/(GPa) | $N$ | $C$ | $M$ | $T_{room}$/(K) | $T_{melt}$/(K) |
|---|---|---|---|---|---|---|---|
| 2017-T4 | 0.270 | 0.426 | 0.34 | 0.015 | 1.0 | 300 | 775 |
| 5A06 | 0.265 | 0.426 | 0.34 | 0.015 | 1.0 | 300 | 864 |

Table 2 Mie-Gruneisen state equation parameters

| Material | $\rho_0$/(g/cm$^3$) | $G$/(GPa) | $C_0$/(km/s) | $S$ | $\Gamma_0$ |
|---|---|---|---|---|---|
| 2017-T4 | 2.79 | 27.6 | 5379 | 1.29 | 2.0 |
| 5A06 | 2.64 | 27.0 | 5328 | 1.338 | 2.0 |

## 3 THE ANALYSIS OF SIMULATION RESULT

### 3.1 The Morphology of Debris Cloud

Due to the discreteness of mesh shield, the effect of impact position would be considered. The projectile is aimed at the center, cross, line and offset of mesh respectively in Fig.1(a,b,c,d). Assuming the direction of initial velocity as z axis, the cartesian coordinates was set up.

When the projectile is aimed at the mesh center(Fig.1(e, i)), five main jets ejected from the front part of the projectile are formed(one central jet and four side accompanying jets). Besides, four cross jets almost are perpendicular to projectile movement direction and one central jet is parallel to z axis. The cross jets have significantly smaller mass than the jets ejected along the projectile movement. When the projectile is aimed at the cross of mesh(Fig.1(f, j)), the four main jets ejected from the front part of the projectile in the line of z-axis are formed, which are at the angle of 45°to mesh string direction respectively. When the projectile is aimed at the line of mesh(Fig.1(g, k)), the six main jets ejected from the front part of the projectile are formed. Most of the debris are concentrated in the strip zone, which is perpendicular to the line aimed by the projectile. When the projectile is aimed at the offset of mesh(Fig.1(h, l)), the four main jets ejected from the front part of the projectile are formed. The distribution of the jets is different from the previous cases, which is asymmetrical and others are symmetrical.

Through the above analysis, it shows that the morphologies of debris cloud varies greatly with the impact positions, which have difficulty in modeling the protection structures including mesh shield. But the characteristics of debris cloud, such as linear distribution of debris, have been well verified, so the randomness of impacting position should be consider in the simulation.

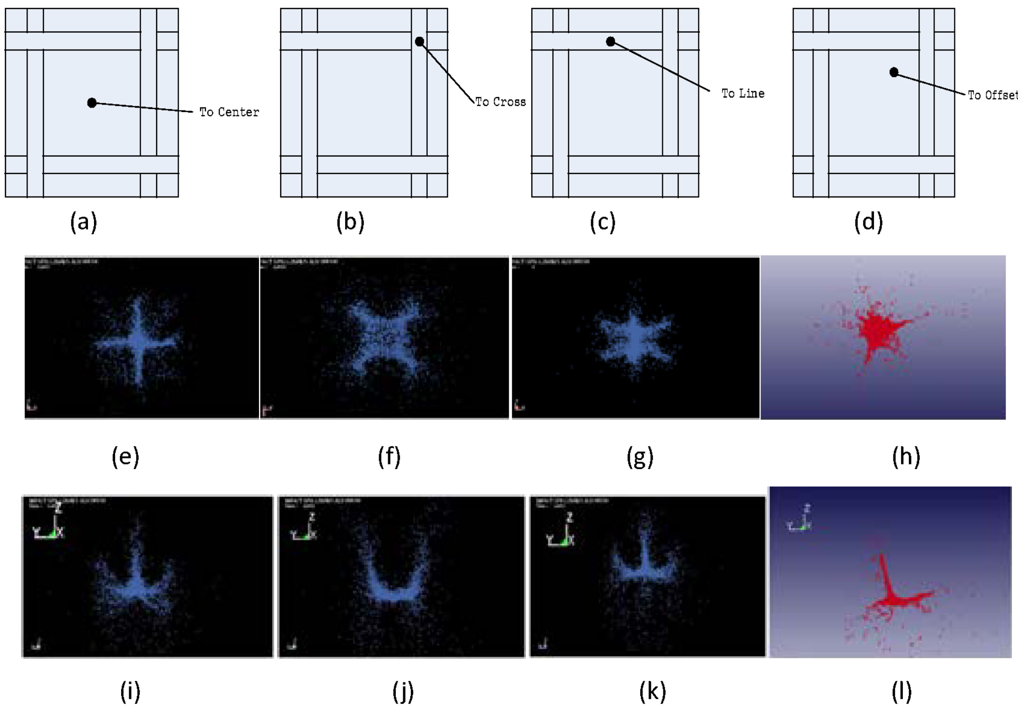



*Figure 1 The configuration of impact position and morphology of debris cloud. a)-d) are the four positions aimed by the center of projectile respectively; e)-h) are the morphologies of debris cloud at a front view; i)-l) are the morphologies of debris cloud at a side view;*

### 3.2 The Mass Distribution Characteristic

When the projectile respectively impacted the mesh shield and the continuous shield, the mass distribution appeared apparent difference. Fig.2 shows the mass distribution of the debris cloud along axis direction as the mesh shield and the continuous shield with the same thickness impacted by the projectile. The black bar indicates the debris cloud generated when the projectile impacted the continuous shield, the white bar indicates another.

When the projectile impacted the continuous shield, the debris of it mainly distribute in the of the debris cloud. 85.2% projectile fragments converge on the area which was range of [0mm, 3mm] from the front end. With the distance increase, the mass of debris cloud is less. When the projectile impacted the offset position of mesh shield, the mass distribution range is greater than the continuous shield. Compared to the continuous shield, there are less number of projectile fragments in the front end. The main fragments converge on the area range of [4mm, 8mm] from the front end. With the distance to the front end of the debris cloud increase, the mass of debris is firstly rise and then fall.

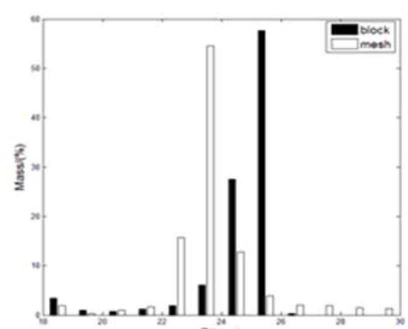



*Figure 2 mass distribution of the debris clouds along axis direction*

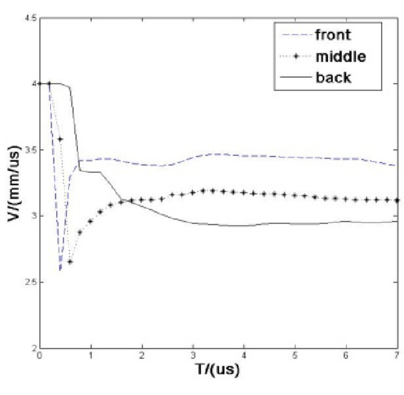
### 3.3 The Velocity Characteristic of Debris Cloud

Tab.3 shows the velocity characteristic of the debris cloud when the projectile impacted the two kinds of protection shields with the same thickness. As can be seen, the velocity characteristics of the debris clouds are clear difference.

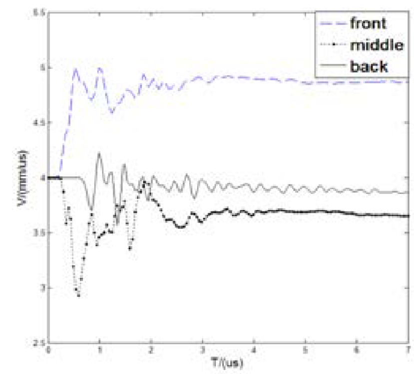
Table 3 comparison of velocity characteristics of continuous shield and mesh shield

| Position | *block* | *center* | *cross* | *line* | *offset* |
|---|---|---|---|---|---|
| Average velocity/(km/s) | 2.95 | 3.78 | 3.85 | 3.82 | 3.80 |
| Percentage of the particles /(%) | 0 | 6.21 | 4.07 | 8.57 | 7.87 |

The second line in Tab.3 represents the average velocity of debris cloud, which was produced after the projectile respectively impacted the four positions of the mesh shield and the continuous shield at the speed of 4 km/s; the quantity percentage of the particles, which velocity is higher than impact velocity, is shown in line 3. The average velocities vary slightly with impact positions of mesh shield. Their values are around 3.8km/s. However, the average velocity of the debris cloud generated by continuous shield is 2.95km/s. The mesh does not slow the particles resulting from the impact, the future of it is to breaking up the projectile into smaller particles. The second difference is that the velocities of some particles in the debris cloud are higher than impact velocity when impact on the mesh, while the phenomenon does not occur when impact on the continuous shield.




(a) Continuous




(b) mesh

*Figure 3 velocity of the nodes in projectile*

Fig.3 shows the velocity changes of nodes which locate respectively in the front, middle and rear of the projectile. Fig.3 (a) indicates the change when the projectile impacted the continuous shield, and Fig.3 (b) indicates the change when the projectile impacted the mesh shield. The velocity changes of nodes are similar when a projectile impacted the continuous shield from Fig.3 (a). The nodes velocities are all less than impact velocity. The front node velocity gradually reduces with time, on the contrary, the middle node and the rear node's velocities reduce before 1 us and increase after 1 us. The velocity changes of nodes are different in Fig.3 (b). The front node velocity is faster than impact velocity and the others are opposite. The front node velocity increase with time, the velocity changes of the middle and rear node are same in Fig.3 (a) and (b). As can be seen, the dynamical response is evidently dissimilar when a projectile interaction with the two kinds of shields.

### 3.4 The Momentum Characteristic

Fig.4 shows the resultant momentums of debris clouds at the impact velocity direction after impact the two kinds shields. The change of resultant momentums is very small after impact on the different position of mesh shield. On the other hand, the difference of resultant momentums is large between the mesh shield and the continuous shield, the ratio of the resultant momentum and the initial momentum is 0.735 for the continuous shield, the ratio is 0.942 for the mesh shield.

In the sight of the resultant momentum, it is not clear that the impact positions effect on the debris cloud, so we defined a new physical entity- $\widetilde{M}$(momentum density)-which represents the cumulate momentum per unit area without time effect, its unit is 103kg/s • m. The Fig.5 demonstrates the momentum density of the projectile fragments that impacted the two kinds shields with the same thickness at Z direction, the value is the cumulate momentum per square mm in Fig.5.

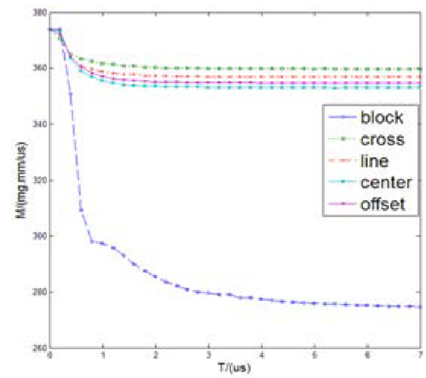
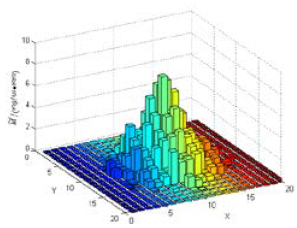
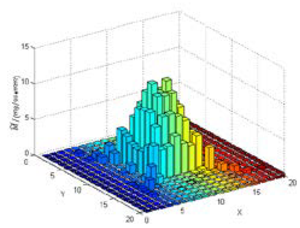


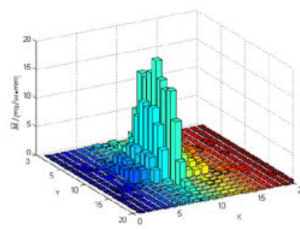

*Figure.4 resultant momentum*



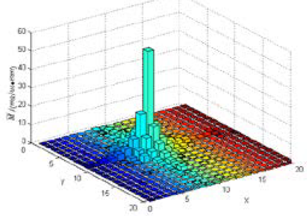
(a) block



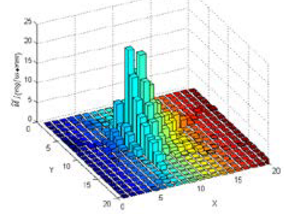
(b) cross



(c ) line



(d) center



( e) offset

*Figure.5 momentum density*

The momentum density of the projectile fragment is shown in Fig.5(a) after impact the continuous shield. Its maximum is 7.9×103 kg/s•m in the central location. It gradually decreases from center to periphery, its shadow is a circle in the X,Y plane. The momentum density is consistent with the damage morphology of the rear planet after a projectile impacting the continuous shield in Fig.5(a), so the momentum density can be fit for the damage evaluation.

The momentum density is shown in Fig.5(b) when the impact position is “cross”, the maximum is 11.76×103 kg/s•m and locates in the center area. The momentum density decreases with the increasing of the distance to the center. Its shadow is a rectangle in the X,Y plane, and the zonal debris can be found the four points of the rectangle, the angle between it and adjacent sides is 45. The momentum density in the belt is less than it in the center.

The momentum density is shown in Fig.5(c) when the impact position is “line”, the maximum is 19.4×103 kg/s•m and locates in the center. The momentum concentrates in a zone that is perpendicular to the X-axis.

Its shadow is an approximate rectangle, the values of momentum density in perpendicular bisector zone are larger.

The momentum density is shown in Fig.5(d) when the impact position is “center”, the maximum is 55.5×103 kg/s•m and locates in the center. The momentum density rapidly decreases with the increasing of the distance to the center. Its shadow is a cross.

The momentum density is shown in Fig.5(e) when the impact position is “offset”, the maximum is 22.2×103 kg/s•m. Most of the momentum is in the side of the area where the maximum locates. Its shadow is an irregular shape. The banded fragments could still be found, and the values of the momentum density in it are smaller.

The conclusion can be drawn from fig.5 that the maximum values of the momentum density generated by the projectile impact the mesh shield are larger than it when the projectile impacted the continuous shield, distribution symmetries vary with the impact position. The maximum of the momentum density increases with the sequence of cross, line, offset, center. The probability which the projectile impacts the offset position is highest from the viewpoint of probability. Therefore the distribution of the debris is irregular, most of damage to the rear panel is in the side of the largest crater, and there are a cer tain number of banded crater, they match the damage morphology of rear panel in most of the experiments.

## 4 CONCLUSION

We have studied the characteristic of debris cloud when a projectile impacted the mesh shield through the numerical method. And the simulation results were analyzed and compared with the continuous shield. We can draw the following conclusions.

1. The impact position is an important factor for the mesh shield. The morphology of debris cloud varies obviously with it. What’s more, other characteristics related to debris cloud would vary with impact positions.

2. Through the analysis of mass distribution of debris cloud, the main of fragments are at the rear end of the debris cloud, which is different from the continuous shield.

3. The dynamical response of two shields is different. When a projectile interaction with mesh shield, the changes of the various nodes in a projectile are unlike. The main function of mesh shield is to break up the projectile, not to slow it.

4. The damage of the debris cloud to rear panel was evaluated by application of the momentum density. The maximum values of the momentum density generated by the projectile impact the mesh shield are larger than it when the projectile impacted the continuous shield, this indicates that the momentum of debris cloud impacting the mesh shield is more concentrated than the it impacting the continuous shield.

The study will contribute to utilize the mesh shield in development of the protection system from space debris.

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