GEOMETRICAL SHAPES OF PROJECTILES EFFECT ON HYPERVELOCITY IMPACT

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ABSTRACT

Spherical projectiles are the most common shape used experiments and simulations related to hypervelocity impact. However, real space debris which is threat to spacecraft is not likely to be spherical. There is need to study the influence of projectile shape as different shapes may cause greater damage to spacecraft compared to spherical projectiles for the same impact conditions. The results in this paper originate from the initial stage of an MSc degree individual research project. The final objective of this work is to investigate the influence of projectile geometry on the performance of Whipple Bumper Shield. The SPH method is used to simulate spherical, cubic and cylindrical projectiles in hypervelocity region. The influence of the projectile shape on the shape of primary debris cloud observed in the initial results is discussed.

1. INTRODUCTION

Orbital space debris is one of the main threats to spacecraft survivability as all spacecraft will inevitably encounter micrometeoroids and orbital debris during their functional lifetime. The meteoroid threat has been a concern since the beginning of human spaceflight when the space debris has not yet accumulated and became an important issue of space hazards [1].

Space debris size in order of millimetre can cause serious damage in a high velocity to hypervelocity impact [2]. Shielding systems are needed to protect spacecraft from this threat. The classic shielding system is the Whipple Bumper Shield, which has one outer bumper placed at the short distance ahead of a primary structural system, was first proposed by Whipple in 1947 [3]. The concept is to fragment or vaporise the projectile through the impact with the bumper, typically metallic or composite thin plates. Spacecraft shielding systems have been continuously developed, varying both the number of bumpers and the materials used. Nevertheless, the main concept is remain to fragment or vaporise the projectile, the resulting the debris cloud expands and hits the next layer over a larger area, dispersing the energy of the projectile and the impulsive load [1, 3]. The characteristics of the debris cloud indicate ability of fragmenting and vaporising of bumper to projectiles. Spherical projectiles have been the conventional shape used in most of the experiments and researches, Morison [4] proved cylindrical shape is more dangerous than spherical projectiles. Buyuk [5] has recently studied on ellipsoidal projectile and found that it is not necessarily correct that the ideal spherical projectiles are the most dangerous threat and also presented that the most dangerous case of ellipsoidal projectiles orientation is not the case with the longest or shortest size of the ellipsoidal projectiles parallel or perpendicular to the impact direction.

Further study on other shapes and orientations is required in order to take them into account while designing spacecraft shielding. In this paper, the effect of projectiles with different geometrical shapes is to be investigated. Debris clouds generating from spherical, cubic and cylindrical shapes of projectiles are observed by numerical simulation. All projectiles are made of aluminium and have the same mass, 0.1813 g. The bumper is also made of aluminium with 0.2 cm-thickness. The characteristics of debris clouds of each shape are to be investigated.

2. NUMERICAL SIMULATION

Numerical method has been continuously developed for the last few decades [6]. Due to it is inexpensive compared to actual experiments, the Meshless Continuum Mechanics, MCM, code developed by Cranfield University is used to simulate spherical, cubic and cylindrical projectiles in hypervelocity region with smoothed particle hydrodynamics method applied. Simulations are illustrated in LS-PrePost®. Each projectile has the same mass hence the same impact energy.

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2.1 Validation of numerical simulation

Validation of the simulation was performed by comparing the results simulated from MCM with experimental data from Piekutowski [7]. Simulation results for two impact cases with spherical projectiles are compared with experimental data. The simulations were constructed following the experimental set up. Spherical projectile size is 0.935 cm. The bumper-to-thickness ratios (t/D) are 0.233, 0.424 and 0.504 cm. The velocities in each related point after impact are compared. The shapes of the debris cloud after specific time were compared. The average errors are 4.0 percents for debris cloud shape and 3.7 percent for normalised maximum axial velocities.

Although the spherical projectile results have been validated, cubic and cylindrical projectile results validations are required.

2.2 Numerical simulation set up

Spherical projectiles with diameter 0.500 cm, cubic projectiles with diameter 0.403 cm and cylindrical projectiles with diameter and height 0.437 cm are modelled. These three projectiles have the same volume. All of them made of aluminium hence the same mass 0.1813 g. The bumper with thickness 0.2 cm is also made of aluminium. In the SPH model the inter-particle distance is between 0.02000cm and 0.02185 cm. The Johnson-Cook strength model coupled with a shock equation of state is used to model the material.

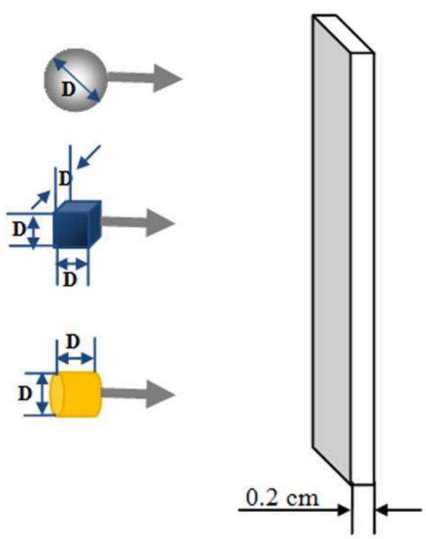

Figure 1. Numerical simulation set up

Simulations are performed using projectiles of different shapes but constant mass, hence the same impact energy. The orientation and size of each projectile are illustrated in Fig. 1 in order to show the set up of the numerical simulations.

Test	Shape	Size, D (cm)	Mass, m (g)
1	Sphere	0.500	0.1813
2	Cube	0.403	0.1813
3	Cylinder	0.437	0.1813

Table 1. Projectiles size of each shape

For each projectile impact with initial velocities of 3, 5, 7 and 9 km/s have been simulated.

3. RESULTS

Focusing on shape and velocity of debris cloud after hypervelocity impact, displacement of particles, particle velocities, and shape of debris cloud are to be discussed in results section.

The simulation set up is illustrated in Fig. 2, which are the perspective views of each projectile at the time of impact. A flat face of the cubic projectile is an impact size on bumper surface. A circular flat face of cylinder projectile is an impact size as well. Only spherical projectile has curvature impact on the bumper.

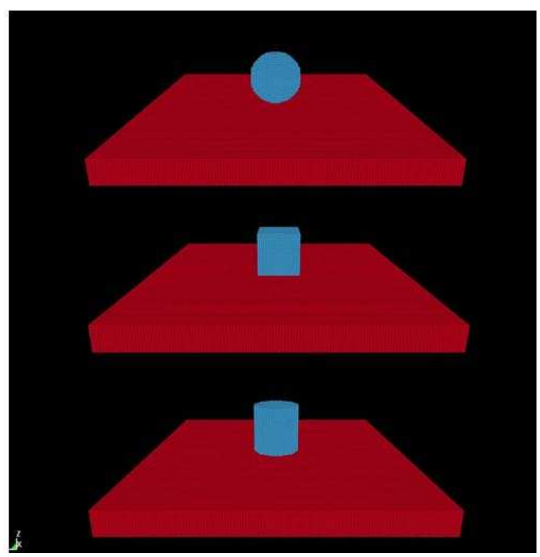

Figure 2. Each projectile at time of impact

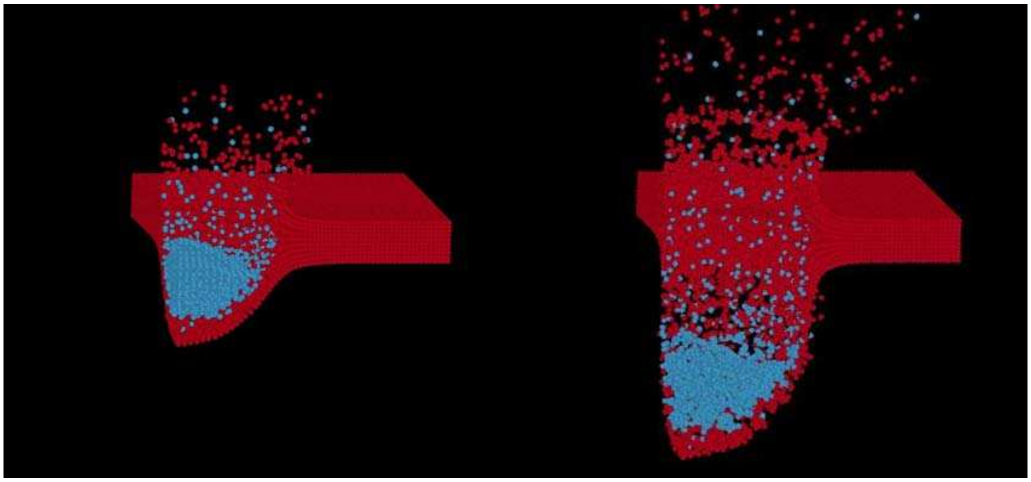

Figure 3. Sphere projectile with impact velocity 7 km/s at 1 μs (left) and 2 μs (right) after impact

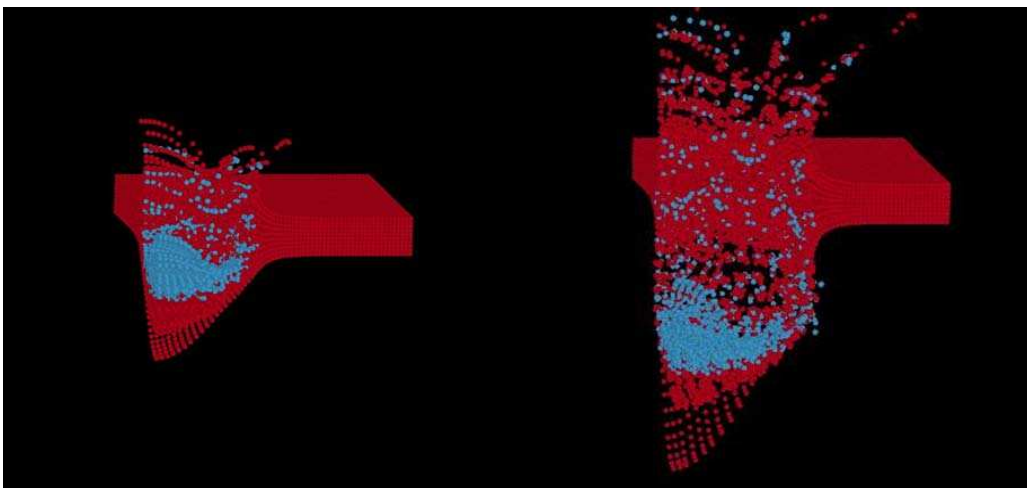

Figure 4. Cubic projectile with impact velocity 7 km/s at 1 μs (left) and 2 μs (right) after impact

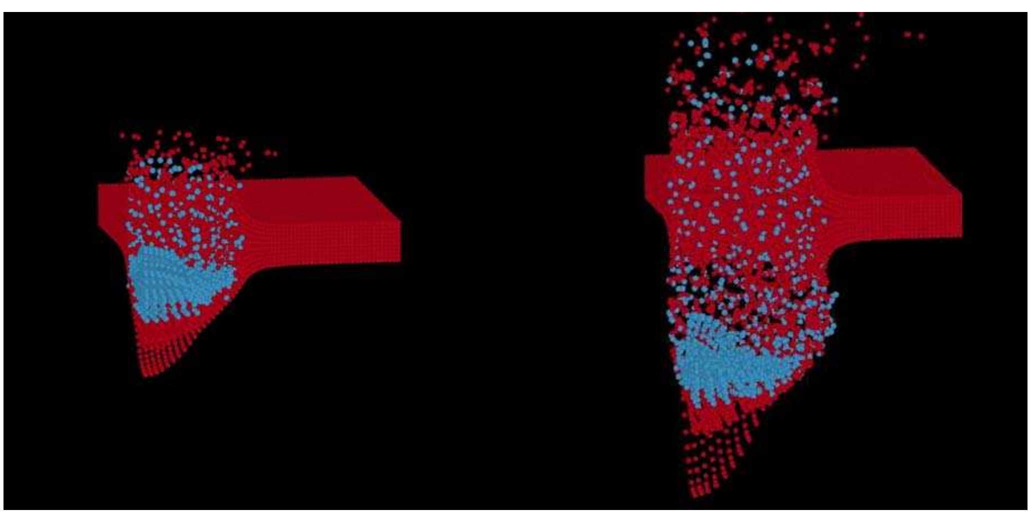

Figure 5. Cylindrical projectile with impact velocity 7 km/s at 1 μs (left) and 2 μs (right) after impact

Cross-section structures are illustrated in Fig. 3 thru Fig. 5 for better view of particles displacement of spherical, cubic and cylindrical projectiles at 1 μs and 2 μs after impact with impact velocity 7 km/s. In cubic and cylindrical projectile, the rear side of bumper particles largely displaced and continue travelling further creating crests of the bumper material in the front size the debris cloud while debris cloud of spherical projectile has no such crest.

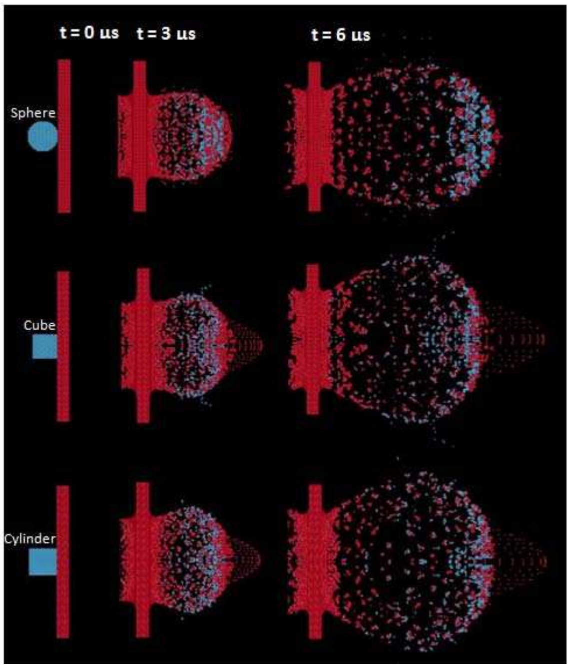

Figure 6. Comparison of debris cloud generated by spherical, cubic and cylinder projectiles (Top, middle, and bottom) impact on thin plate at impact, 3 μs and 6 μs after impact with impact velocity 7 km/s

Side views of the impact are illustrated in Fig. 6. Debris cloud of spherical, cubic and cylindrical projectiles are compared at impact point, 3 μs and 6 μs after impact with impact velocity 7 km/s. Comparison to spherical projectile with the same mass, debris cloud generated from cubic and cylindrical projectiles impact are larger in diameter. The crest-like debris cloud from cubic and cylindrical projectiles continue grow with elapse time.

The velocities of debris cloud after impact are observed. Axial velocity distributions of debris cloud at 6 μs for each projectile shape are illustrated in Fig. 7. Maximum axial velocities are in the middle frontal area of debris cloud. Maximum velocity varies with projectile shape; therefore in these illustrations the same velocity colour scale of different projectile might not represent the same velocity.

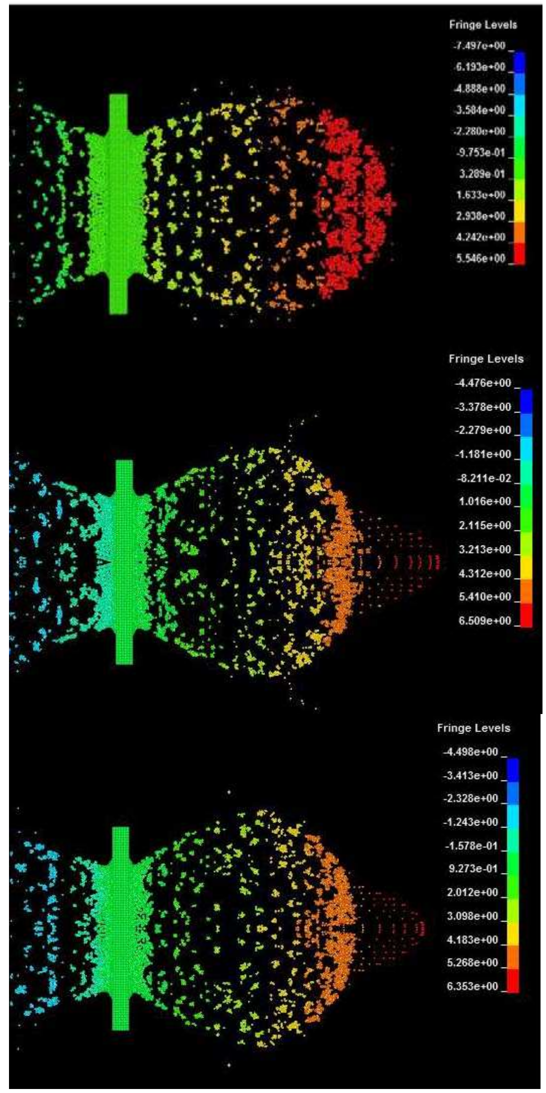

Figure 7. Comparison of axial velocity of debris cloud generated by spherical, cubic and cylinder projectiles (Top, middle, and bottom) impact on thin plate at impact 6 μs after impact with impact velocity 7 km/s

The maximum velocities of all projectile shapes are normalized as shown in Tab. 2.

Test	Shape	Maximum Axial Velocity (km/s)	Normalized
1	Sphere	5.54611	0.79230
2	Cube	6.50901	0.94144
3	Cylinder	6.35286	0.90755

Table 2. Maximum axial velocities and normalised maximum axial velocities of 6 μs after impact with impact velocity 7 km/s

Simulating each projectile shape with impact velocity 3, 5, 7 and 9 km/s, the normalized maximum axial velocities of all cases are plotted in Fig. 8.

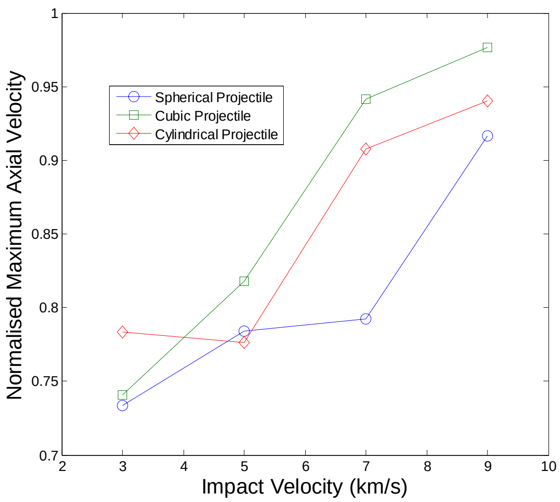

Figure 8. Normalised maximum axial velocities at 6 µs after impact for each projectile shape versus impact velocities

4. CONCLUSION

Simulations have been performed for the impact of spherical, cylindrical and cubic projectiles on thin bumper shields to investigate the effect of projectile shape. Further validation for spherical projectiles will be preformed. With validation for non-spherical projectiles is still required. From the initial simulation results the following basic trends are observed:

- With the same impact energy, material and other controlled parameters, geometrical shape of projectile does effects feature and velocities of debris cloud after impact.
- The debris cloud resulting from cubic and cylindrical projectiles, which impact the bumper with a flat surface, produce different debris cloud features.
- The cubic projectile gives a higher normalised axial velocity after impact than cylindrical projectile in 3 – 9 km/s impact velocity range.
- The debris cloud from a spherical projectile has lower normalised velocity than cubic and cylindrical projectile in most case of impact velocity range of 3 – 9 km/s. Normalised maximum velocity of spherical projectile is only slightly higher than ones of cylindrical projectile at 5 km/s, and lower than cubic projectiles in all cases.

The further phases of the research are to study the effect of projectile shape and orientation for a Whipple Bumper shield. Then to investigate the effect on a ballistic limit curve, after validation of the debris cloud in cubic and cylindrical projectiles has been performed.

5. REFERENCES

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