Characteristics of Whipple shield performance in the shatter regime

S. Ryan[1], M. Bjorkman[2], E.L. Christiansen[3]
[1]USRA Lunar and Planetary Institute, Houston
[2]Jacobs Engineering (ESCG), Houston
[3]NASA Johnson Space Center, Houston

Between the onset of projectile fragmentation and the assumption of rear wall failure due to an impulsive load, multi-wall ballistic limit equations are linearly interpolated to provide reasonable yet conservative predictions of perforation thresholds with conveniently simple mathematics. Although low velocity and hypervelocity regime predictions are based on analytical expressions, there is no such scientific foundation for predictions in the intermediate (or shatter) regime. As the debris flux in low earth orbit (LEO) becomes increasingly dominated by manmade pollution, the profile of micrometeoroid and orbital debris (MMOD) risk shifts continually towards lower velocities. For the International Space Station (ISS), encounter velocities below 7 km/s now constitute approximately 50% of the penetration risk. Considering that the transition velocity from shatter to hypervelocity impact regimes described by common ballistic limit equations (e.g. new non-optimum Whipple shield equation [1]) occurs at 7 km/s, 50% of station risk is now calculated based on failure limit equations with little analytical foundation.

To investigate projectile and shield behavior for impact conditions leading to projectile fragmentation and melt, a series of hypervelocity impact tests have been performed on aluminum Whipple shields. In the experiments projectile diameter, bumper thickness, and shield spacing were kept constant, while rear wall thickness was adjusted to determine spallation and perforation limits at various impact velocities and angles. The results, shown in Figure 1 for normal and 45° impacts, demonstrated behavior that was not sufficiently described by the simplified linear interpolation of the NNO equation (also shown in Figure 1).
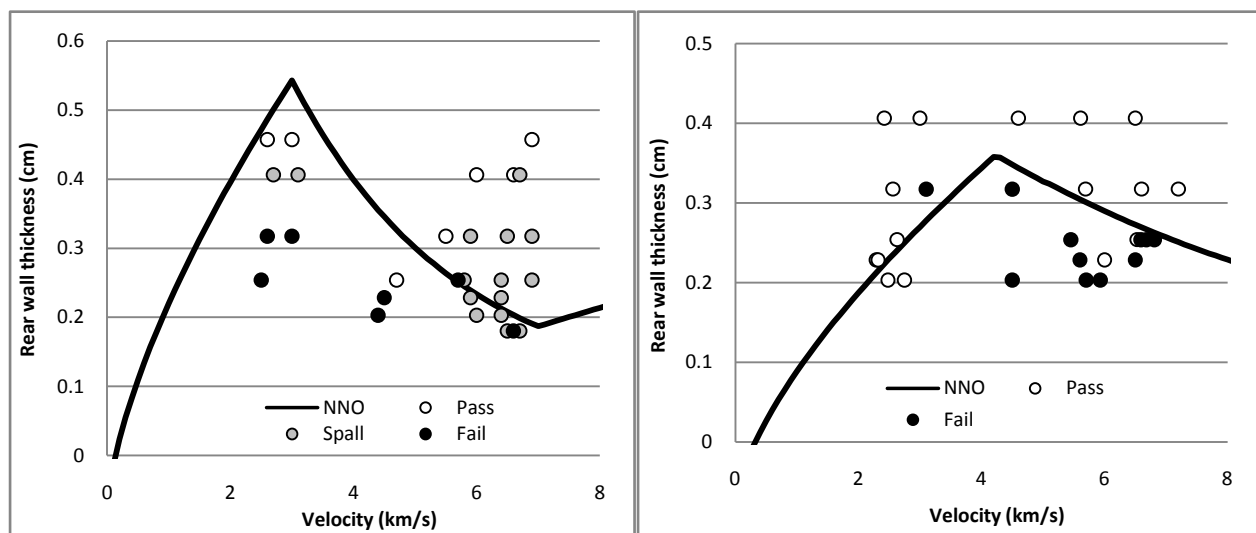

Figure 1: HVI test results and predicted failure limits for an aluminum Whipple shield at normal (left) and 45° (right) impact.

Hopkins et al. [2] investigated the performance of a nominally-identical aluminum Whipple shield, identifying the effects of phase change in the shatter regime. The results (conceptually represented in Figure 2) were found to agree well with those obtained in this study at normal incidence, suggesting that shielding performance in the shatter regime could be well described by considering more complex phase conditions than currently implemented in most BLEs. Furthermore, evidence of these phase effects were found in the oblique test results, providing the basis for an empirical description of these effects that can be applied in MMOD risk assessment software.
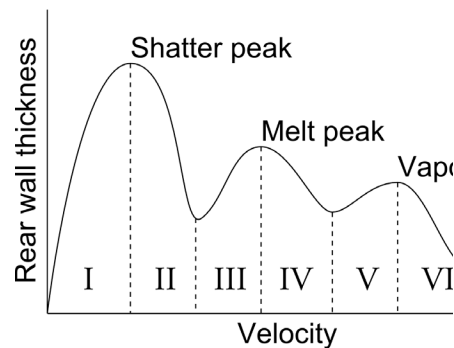

Figure 2: Schematic ballistic limit curve showing the debris character regions (reproduced from [2]).

In this paper, results of the impact experiments are presented, and characteristics of target damage are evaluated. A comparison of intermediate velocity impact failure mechanisms in current BLEs are discussed and compared to the findings of the experimental study. Risk assessment calculations have been made on a simplified structure using currently implemented penetration equations and predicted limits from the experimental program, and the variation in perceived mission risk is discussed. It was found that ballistic limit curves that explicitly incorporated phase change effects within the intermediate regime lead to a decrease in predicted MMOD risk for ISS-representative orbits. When considered for all Whipple-based shielding configurations onboard the ISS, intermediate phase change effects could lead to significant variations in predicted mission risk.

References:

[1] E.L. Christiansen, "*Design and Performance Equations for Advanced Meteoroid and Debris Shields*", International Journal of Impact Engineering; 14:145-156, 1993.

[2] A.K. Hopkins, T.W. Lee, H.F. Swift, "*Material Phase Transformation Effects upon Performance of Spaced Bumper Systems*", Journal of Spacecraft and Rockets; 9(5): 342-345, 1972.