

Performance of Whipple Shields at Impact Velocities above 9 km/s

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Whipple shields were first proposed as a means of protecting spacecraft from the impact of micrometeoroids in 1947 [1] and are currently in use as micrometeoroid and orbital debris shields on modern spacecraft. In the intervening years, the function of the thin bumper used to shatter or melt threatening particles has been augmented and enhanced by the use of various types and configurations of intermediate layers of various materials. All shield designs serve to minimize the threat of a spall failure or perforation of the main wall of the spacecraft as a result of the impact of the fragments.

With increasing use of Whipple shields, various ballistic limit equations (BLEs) for guiding the design and estimating the performance of shield systems have been developed. Perhaps the best known and most used are the “new” modified Cour-Palais (Christiansen) equations [2]. These equations address the three phases of impact: (1) ballistic (<3 km/s), where the projectile is moving too slowly to fragment and essentially penetrates as an intact projectile; (2) shatter (3 to 7 km/s), where the projectile fragments at impact and forms an expanding cloud of debris fragments; and (3) melt/vaporization (>7 km/s), where the projectile melts or vaporizes at impact. The performance of Whipple shields and the adequacy of the BLEs have been examined for the first two phases using the results of impact tests obtained from two-stage, light-gas gun test firings. Shield performance and the adequacy of the BLEs has not been evaluated in the melt/vaporization phase until now because of the limitations of launchers used to accelerate projectiles with controlled properties to velocities above 7.5 km/s.

A three-stage, light-gas gun, developed at the University of Dayton Research Institute (UDRI) [3], is capable of launching small, aluminum spheres to velocities above 9 km/s. This launcher was used to evaluate the ballistic performance of two Whipple shield systems, various thermal protection system materials, and other spacecraft-related materials to the impact of 1.6-mm- to 2.6-mm-diameter, 2017-T4 aluminum spheres at impact velocities ranging from 8.91 km/s to 9.28 km/s. Test results, details of the shield systems, and nominal ballistic limits for the two Whipple shields are shown in Figures 1 and 2.

The Whipple shield shown in Figure 1 is a 0.46-scale version of a shield presented in Figure 2 of Reference 2. The scale factor was simply determined to be the ratio of the scaled rear wall thickness to the full-size rear wall thickness. For these scaled tests, a 6061-T6 aluminum rear wall was substituted for the 2219-T87 aluminum rear wall used for the full-scale shield. The second shield (Fig. 2) is a one-third scale version of the shielding used on a portion of the U.S. Laboratory Module of Space Station.

In these figures, the Whipple shield was considered to fail when it was perforated or when a detached spall was formed on the rear surface of the rear wall. Spall failures which formed on the rear walls of both of the shields in the 0-degree configuration were approximately 2.5 mm in diameter and located on the shot-line axis. The failure of the one-third-scale shield at 45 degrees obliquity was more extensive with a detached spall that was about 7.6 mm x 10.2 mm, a 0.75-mm-diameter perforation, and a through crack that was at least 2 mm long. The rear wall for the shield with the multilayer insulation (MLI) blanket did not exhibit any spall but had a 1-mm-diameter perforation on the shot-line axis.

This paper will provide further descriptions and analyses of the results of the tests shown in Figs. 1 and 2, and the results of several additional tests. These additional tests will examine the effect of a change in the rear wall material to 2219-T87 aluminum for the 0.46-scale shield, shield performance for other oblique impact angles, and the effects of a change in the bumper-sheet-thickness-to-projectile-diameter ratio to values above the range of applicability of the current BLEs. In most cases, these

additional tests will be performed using higher impact velocities as the launch capabilities of the UDRI three-stage, light-gas gun are expanded.

REFERENCES

1. Whipple, FL, *The Astronomical Journal*, No. 1161, 132, February 1947.
2. Christiansen, EL, *Int. J. Impact Engng.* **14**, pp. 145-156, 1993.
3. Piekutowski, AJ, Poormon, KL, *Int. J. Impact Engng.* **33**, pp. 615-624, 2006.

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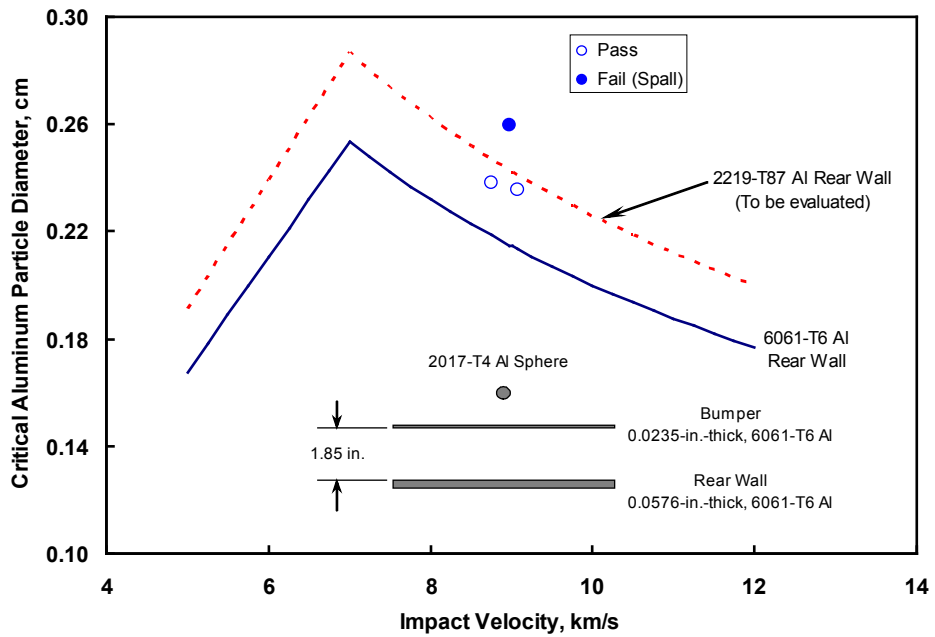


Figure 1. Results of impact tests using a 0.46-scale version of the shield shown in Reference 2.

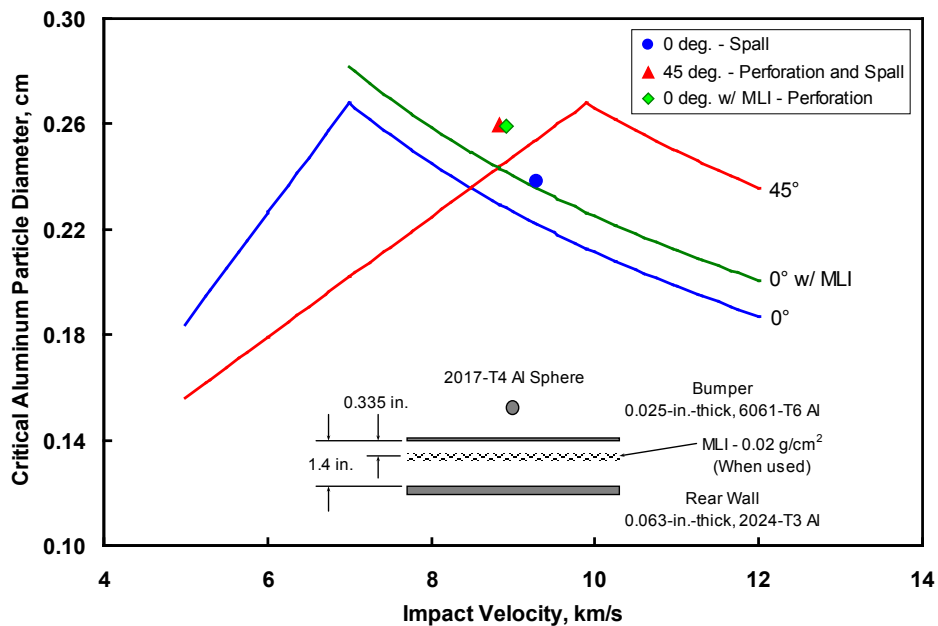


Figure 2. Results of impact tests using a one-third-scale version of the shielding used on portions of the U.S. Laboratory Module on Space Station.