HVI BALLISTIC PERFORMANCE CHARACTERIZATION OF NON-PARALLEL WALLS

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The Double-Wall, "Whipple" Shield [1] has been the subject of many hypervelocity impact studies and has proven to be an effective shield system for Micro-Meteoroid and Orbital Debris (MMOD) impacts for spacecraft. The US modules of the International Space Station (ISS), with their "bumper shields" offset from their pressure holding rear walls provide good examples of effective on-orbit use of the double wall shield. The concentric cylinder shield configuration with its large radius of curvature relative to separation distance is easily and effectively represented for testing and analysis as a system of two parallel plates. The parallel plate double wall configuration has been heavily tested and characterized for shield performance for normal and oblique impacts for the ISS and other programs. The double wall shield and principally similar Stuffed Whipple Shield are very common shield types for MMOD protection.

However, in some locations with many spacecraft designs, the rear wall cannot be modeled as being parallel or concentric with the outer bumper wall. As represented in Figure 1, there is an included angle between the two walls. And, with a cylindrical outer wall, the effective included angle constantly changes. This complicates assessment of critical spacecraft components located within outer spacecraft walls when using software tools such as NASA's BumperII. In addition, the validity of the risk assessment comes into question when using the standard double wall shield equations, especially since verification testing of every set of double wall included angles is impossible.

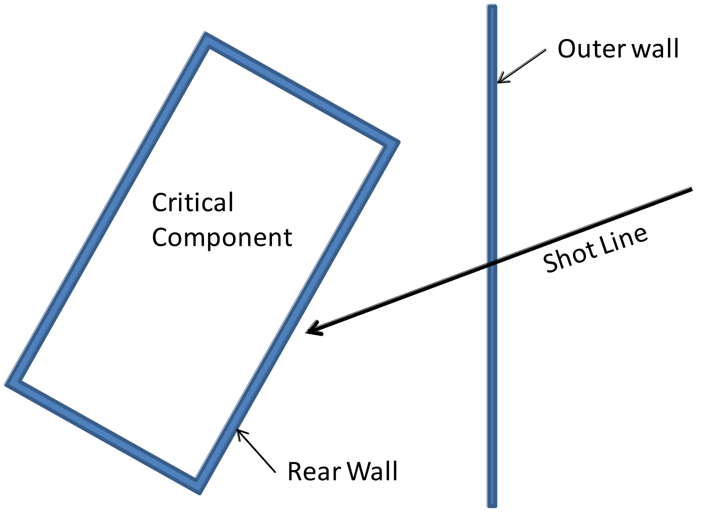

Figure 1, Non-Parallel Plate Double Wall MMOD Shielding

Hypervelocity impact tests have been performed on this arrangement and are shown in Figure 2 [2]. The target was a series of bumper, rear wall and witness plates with the perforation of a witness film parallel to the rear wall considered the failure point. In this test configuration the angle between the bumper and the rear wall is 56°. In the figure, two representative images of the back of the rear wall from the test series are shown. The tests are for ~7 km/s impacts at 60° obliquity for the first wall but nearly normal impact for the second wall along the flight path. A 3/16” (4.76 mm) Al2017-T4 projectile considered in the test HITF10372 (left image) is a non-penetration of the shield; whereas, a 7/32” (5.56 mm) Al2017-T4 projectile considered in test HITF10373 (right image) penetrated the shield. These projectiles compare with a parallel plate ballistic limit equation that has the critical predicted diameter of 7 mm.

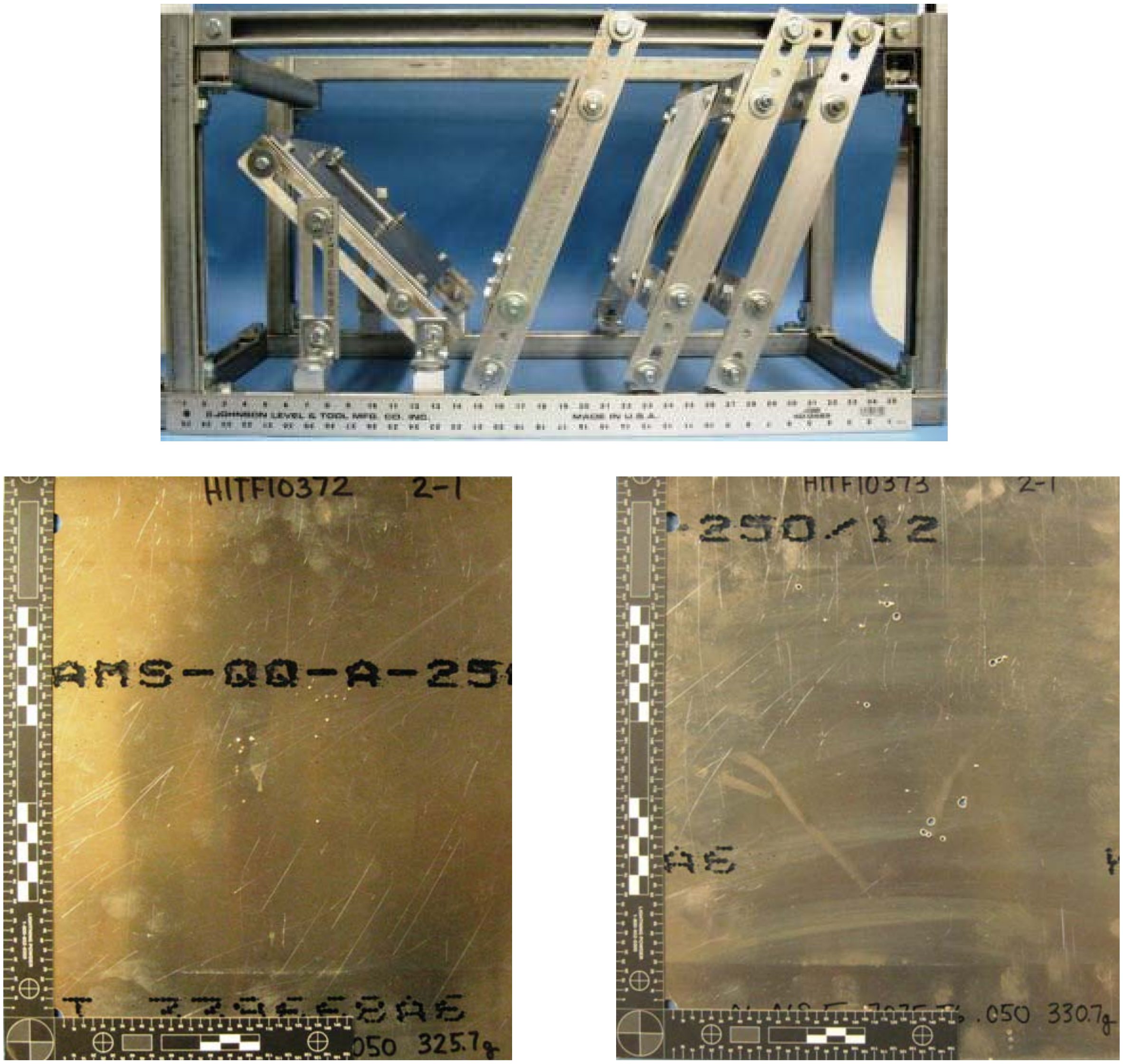

Figure 3, Non-Parallel Double Wall Testing

An adaptation to the current double wall shield has been derived that assumes the angular dependencies in the double wall shield are a product of the perpendicular components of the wall stack

$$m_c \propto Cos[\theta]^{-n/2}\; Sin[\theta + \alpha]^{-n/2},$$

where m_c and n are the critical particle mass and an empirical exponent from the standard double wall equations. The angles θ and α are defined in Figure 3. For the standard double wall shield the angle α is 90° which reduces to the standard $Cos[\theta]^{-n}$, and for a set of perpendicular walls where α is 0°, the scaling of the critical mass increases to very large values for a normal impact as that wall is no longer the limiting shield.

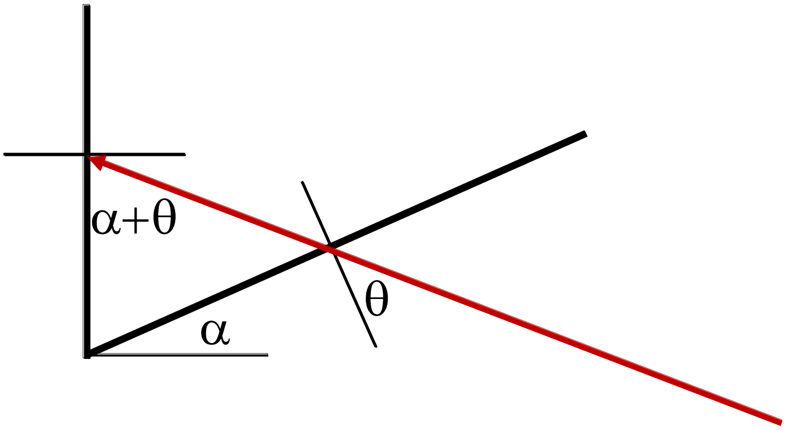

Figure 3, Double Wall Angles

Using this model the ballistic limit curves are shown in Figure 4 for the considered test configuration all with the test findings. Closed diamonds are passes of the shield and open diamonds are failures of the shield. The tests considered obliquities of 45° and 60° and color coded with their respective ballistic limit curve. A 45° impact obliquity of a 7/32” (5.6 mm) Al2017-T4 projectile at ~7 km/s is a pinhole failure with and compares to the modeled performance of 5.3 mm and contrasts to a parallel plate failure prediction of 5.9 mm. The passing 4.76 mm and failing 5.56 mm Al2017-T4 projectiles impacting a 60° to normal of the bumper and at ~7 km/s compare with the non-parallel plate adapted equation prediction of 5 mm.

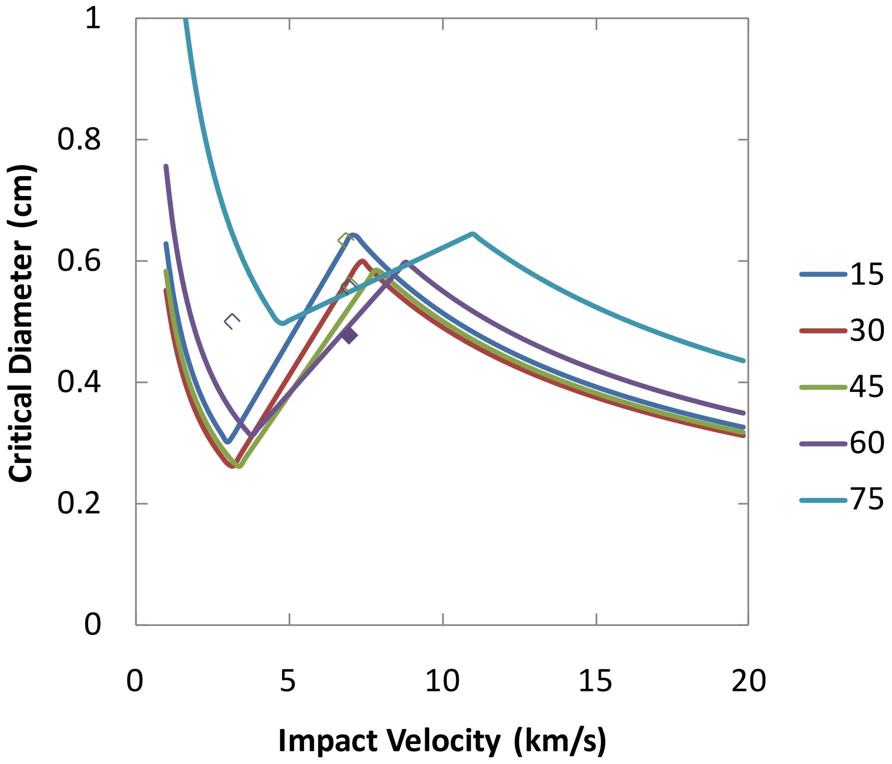

Figure 4, HVI Test Points

Based on a study with multiple shield configurations including bumpers and rear walls of aluminum and composite, this paper provides equation adjustments for use with the double wall Ballistic Limit Equation (BLE) for cases with a variety of impact speeds and obliquities, impactor materials and t/d ratios.

References

[1] Christiansen EL. Meteoroid/Debris Shielding. NASA/TP-2003-210788. August 2003. P. 45-49.

[2] Davis BA. Hypervelocity Impact (HVI) Test Report for Multipurpose Crew Vehicle (NPCV) Avionics Ring (AR) and Propulsion Sub-Assembly (PSA) Shielding Phase – 3: Tests on AR side-wall and aft-wall regions. JSC-66207. May 2011.