3M™ Nextel™ Ceramic Fabric Offers Space Age Protection

Extensive testing by NASA researchers has confirmed that 3M™ Nextel™ ceramic fabric is a key component in the development of a strong, lightweight space debris shield, for planned use on the Space Station Laboratory Habitation and other U.S. manned modules. This shield helps protect spacecraft from being disabled by collisions with space debris.

Results of hypervelocity impact testing, conducted by NASA scientists at the Marshall Space Flight Center in Huntsville, AL and the Johnson Space Center in Houston, TX, were published in the *International Journal of Impact Engineering* (Vol. 17), Proceedings of the 1994 Hypervelocity Impact Symposium, Santa Fe, NM. These results show that:

Some 3,750 space launches over the past 39 years have led to more than 23,000 observable objects larger than 10 cm, 7,500 of which are still in orbit.

- A shield using a Nextel/Kevlar™ fabric blanket as the intermediate bumper "represents an innovative, low-weight technique to provide protection when spacing is constrained."

- A Nextel/Kevlar shield provides better protection than double-aluminum bumper shields of equal weight by stopping 50% to 300% more massive projectiles.

- Nextel improves shield performance (compared to aluminum) because it is better at shocking projectile fragments, while Kevlar improves shield performance because it is better at slowing debris cloud expansion.

Above: The Stuffed Whipple Shield offers greater protection and requires less space in protecting spacecraft from being disabled by collisions with space debris. The shield, produced at NASA Marshall Space Center in Huntsville, AL, and the Johnson Space Center in Houston, TX, contains 3M™ Nextel™ Ceramic Fabric. Nextel was shown to be a key component in the development of this lightweight improvement to conventional shielding.*

*International Journal of Impact Engineering, Vol. 17, *Enhanced Meteoroid and Orbital Debris Shielding*, E.L. Christiansen, J.L. Crews – NASA Johnson, J.E. Williamsen, J.H. Robinson, A.M. Nolen – NASA Marshall.

- When using a Nextel/Kevlar intermediate shield, the particle size of bumper materials within the debris cloud is smaller than for aluminum intermediate shields. This means that the object protected by the shield will sustain less damage after an impact with space debris compared to damage it would sustain from the larger fragments produced by aluminum intermediate bumpers.

THE PHENOMENON OF SPACE DEBRIS

According to the European Space Agency (ESA), space debris is in a growth mode; that is to say, collisions of existing spacecraft and man-made objects with each other, as well as with meteorites, have generated and continue to generate new space debris. Some 3,750 space launches over the past 39 years have led to more than 23,000 observable objects larger than 10 cm, 7,500 of which are still in orbit. Just 6% of the known orbit population are operational spacecraft, while 50% can be attributed to old satellites, spent stages, and mission-related objects.

NASA scientists showed that the Stuffed Whipple shield using Nextel™/Kevlar™ materials…significantly improves the protection performance of the shield.

The remaining 44% have appeared as the result of "on-orbit fragmentations which have been recorded since 1961," according to the ESA. These on-orbit fragmentations have generated between 70,000 and 120,000 new space debris objects larger than 1 cm.

This is consistent with information offered by the NASA-JSC (Johnson Space Center) Space Science Branch. In the *Interagency Report on Orbital Debris* published by the National Science and Technology Council Committee on Transportation Research and Development, scientists conclude that "there are over 100,000 debris fragments in orbit with sizes down to 1 cm."

Perhaps of even greater interest is the report's comment on litter in space, which it describes as "millions of objects the size of a B-B gun pellet (which) are believed to orbit the earth, passing one another at speeds that average about 22,000 miles per hour."

All of this debris is of great concern to scientists because as pieces collide with each other, they create more debris. At the moment, scientists are trying to figure out just how fast the debris population is growing and what can be done to slow that growth.

Meanwhile, the space debris phenomenon has raised the issue of spacecraft shielding, specifically to protect spacecraft from the effects of inevitable encounters with space debris. The *Interagency Report on Orbital Debris* notes that one type of shield "uses several layers of light-weight ceramic fabric to act as "bumpers" which repeatedly shock a projectile to such high energy levels that it melts or vaporizes before it can penetrate a spacecraft's walls".

THE RESEARCH

A Whipple shield is a conventional means for providing protection to spacecraft from meteoroid and orbital debris impacts. It consists of an exterior bumper spaced at a given standoff distance. It is a fact of life that spacecraft volume available for shielding is constrained; the result is sub-optimum standoff distances that substantially decrease the protection performance of or increase the weight of the Whipple shield.

Using Hypervelocity impact (HVI) testing, NASA scientists showed that the Stuffed Whipple shield using Nextel/Kevlar materials, as an intermediate shield between an exterior wall and spacecraft rear pressurewall, significantly improves the protection performance of the shield. These findings affirmed one of the objectives set forth by the group prior to conducting the tests: to-

> "demonstrate the capability of the Nextel™/Kevlar™ material combination, to determine whether they provide a superior combination of material properties compared to other alternatives, such as aluminum, Nextel and Kevlar alone."

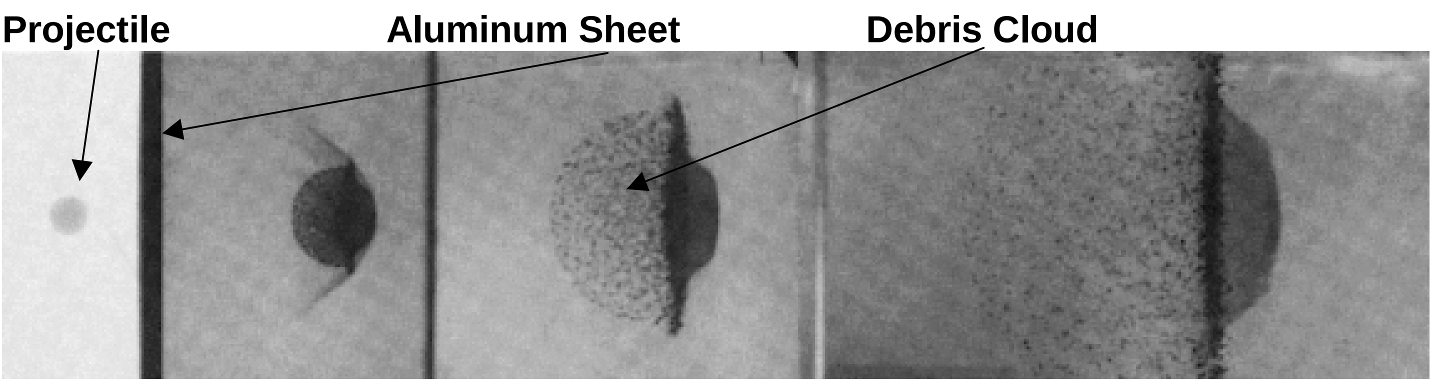
The tests showed success. In the *International Journal of Impact Engineering* article, "Enhanced Meteoroid and Orbital Debris Shielding," mentioned above, NASA scientists provide a detailed account of their work, which they summarize (in part) as follows:

An innovative, low-weight shield system has been developed by NASA…engineered to enhance the protection of conventional Whipple shields. This shield, the “Stuffed Whipple” shield, includes a flexible blanket combining Nextel ceramic fabric and Kevlar fabric (or “stuffing”) between the aluminum bumper and the rear wall of a Whipple shield. The Stuffed Whipple (SW) shield is particularly effective if shield standoffs are short . . . . Alternative shields using aluminum, Nextel and Kevlar alone as the intermediate bumper were tested but did not provide the same level of protection performance for the weight as a combination of Nextel/Kevlar.

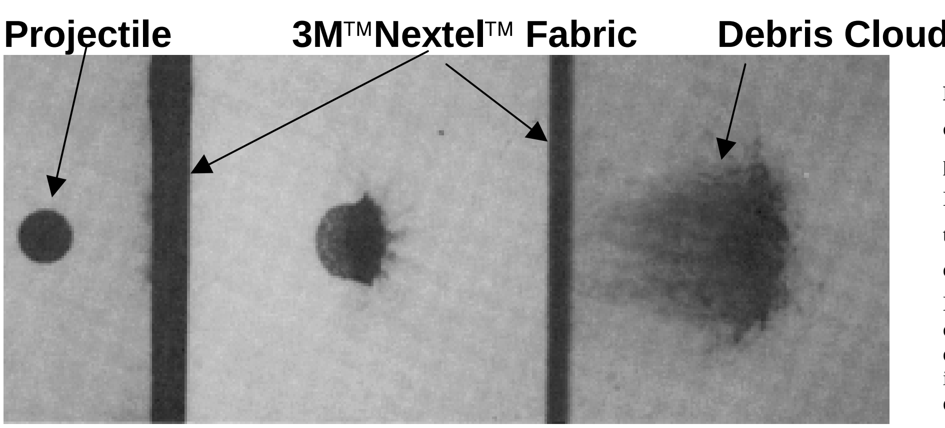
TESTING HIGHLIGHTS AND REPORT EXCERPTS

CONCLUSION

Overall, the scientists concluded: “The Nextel/ Kevlar blanket provides a combination of materials with greater HVI protection effectiveness than a solid-aluminum second-bumper of equal mass per unit area. The Nextel ceramic cloth in the blanket is more effective than aluminum at shocking and disrupting fragments of projectile and bumper.



Above: This sequence of high-speed x-ray photography shows the high velocity impact of a 3/8” (9.53 mm) aluminum projectile, penetrating a .2753” thick aluminum sheet. The projectile is traveling at 14,976 mph (6.7 km/sec). Space debris and micrometeorites are a significant threat to spacecraft and satellites.



Left: This series of x-ray images shows the debris cloud caused by the impact of a 3/8” (9.53 mm) aluminum projectile, penetrating two sheets of 3M™AF-62 Nextel Fabric, spaced at 3” (7.62 cm). The projectile is traveling at 14,733 mph (6.59 km/sec). Protective devices for spacecraft and satellites, which contain Nextel ceramic fibers, offer weight and space advantages over traditional aluminum alternatives. The dispersion of debris has shown to better shock the projectile fragments and is better than aluminum alternatives at slowing debris cloud expansion, according to NASA data.

X-ray photography and data was provided by NASA Marshall Space Center and have been published in NASA Contractor Report, 4707, *Formational and Description of Debris Clouds Produced by Hypervelocity Impact*, February 1996., A.J. Pikutowski, University of Dayton Research Institute.

The Kevlar™, with a greater strength to weight ratio than aluminum, provides superior capability to slow the expansion speed of the debris cloud before impact with the inner wall of the shield. The bumper materials from the Nextel/Kevlar intermediate layer (small size due to small diameter fibers) are less damaging contributors to debris cloud lethality than fragments from a solid metal bumper."

HYPERVELOCITY IMPACT TESTING

The scientists noted that during HVI testing at ballistic limits, the Stuffed Whipple shield exhibited an impulsive loading condition on the rear wall of the shield package, at high velocities. The main characteristic of impulsive loading is bulging with little or no cratering damage on the rear wall from projectile particles or bumper material. Basically, the Stuffed Whipple shield using Nextel/Kevlar tended to bulge, but not crack or fail. The scientists wrote:

> Impulsive loads, on the rear wall, were the predominant damage mode for the SW shield above 6.5 km/sec (for normal impacts) because projectile fragments were defeated by the Nextel/Kevlar fabric layer. In addition, the fibrous nature of the Nextel/Kevlar second bumper did not contribute damaging fragments to the debris cloud that impacted the rear wall.

NEXTEL/KEVLAR VS. ALL-ALUMINUM

All tests "indicate that the Stuffed Whipple shield provides better protection than an aluminum double-bumper shield of equivalent weight."

For instance, data indicate that the full-scale aluminum double-bumper shield protects against a 0.98 cm projectile at 7 km/sec and 45°, while the Stuffed Whipple shield can protect against a 1.54 cm aluminum projectile at the same impact conditions (indicating that the SW stops projectiles with approximately three times greater mass than the aluminum shield).

Data further show that the aluminum shield was completely perforated by a 1g projectile at 11 km/sec and 45° while the SW was not penetrated by a 1.5 g projectile (50% heavier).

The performance advantage for Nextel/Kevlar SW shields compared to an all-aluminum shield is indicated in these tests which failed the all-aluminum shield's rear wall while similar impacts on the Stuffed Whipple shield did not fail the rear wall.

A NOTE ON WEIGHT

Based on the study's developed equations, to provide protection from a 1.35 cm diameter projectile traveling at 7 km/sec (normal), a regular Whipple shield with an 11 cm standoff would weigh approximately 2.5 times as much as a Stuffed Whipple shield using Nextel/Kevlar construction.

Compiled from Published Reports:

Intl. Journal of Impact Engineering, Vol. 17, *Enhanced Meteoroid and Orbital Debris Shielding,* E.L. Christiansen, J.L. Crews-NASA Johnson, J.E. Williamsen, J.H. Robinson, A.M. Nolen-NASA Marshall.

NASA-JSC Space Science Branch, on-line report (2/28/96) *Interagency Report on Orbital Debris.*

European Space Agency: Space Debris Activities at ESOC (on-line)

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