NASA-CR-200968

Final Report
Attachment 5

October 17, 1995

CONTRACT NAS8-38856

Structural Damage Prediction and Analysis for Hypervelocity Impact

AIAA 92-1588
Properties of Largest Fragment Produced by Hypervelocity Impact of Aluminum Spheres with Thin Aluminum Sheets

Prepared for:
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LOCKHEED MARTIN

MAF/MMA 31-100 (3/95)

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AIAA Space Programs and Technologies Conference
March 24-27, 1992 / Huntsville, AL

PROPERTIES OF LARGEST FRAGMENT PRODUCED BY HYPERVELOCITY IMPACT OF ALUMINUM SPHERES WITH THIN ALUMINUM SHEETS

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ABSTRACT

Results of a series of hypervelocity impact tests are presented. In these tests, 1.275-g, 9.53-mm-diameter, 2017-T4 aluminum spheres were fired at normal incidence at eight thicknesses of 6061-T6 aluminum sheet. Bumper thickness to projectile diameter (t/D) ratio ranged from 0.026 to 0.424. Nominal impact velocity was 6.7 km/s. Results of five tests using 6.35, 9.53, and 12.70-mm-diameter aluminum spheres and other aluminum alloy bumpers are also given. A large chunky fragment of projectile was observed at the center of the debris clouds produced by the impacts. The equivalent diameter of this large fragment ranged from 5.5 mm for the lowest t/D ratio to a minimum of 0.6 mm for the case where maximum breakup of the projectile occurred (t/D ~ 0.2 to 0.3). When the t/D ratio was 0.42, numerous large flaky fragments were evenly distributed in the external bubble of bumper debris. Velocity of the large central fragments decreased continuously with increasing t/D ratio, ranging from about 99 percent to less than 80 percent of the impact velocity. The change in the velocity of small fragments spalling from the rear of the projectile was used to obtain a relationship showing a linear increase in the size of the central projectile fragment with decrease in the shock-induced stress in the projectile.

NOMENCLATURE

D	diameter of projectile
H	height of largest fragment
T	thickness of largest fragment
V_f	velocity of largest fragment
V_o	impact velocity of projectile
V_r	expansion velocity of hemispherical shell of fragments from rear surface of projectile
$V_{r\ opt}$	expansion velocity, V_r, at optimum t/D ratio
d_f	equivalent diameter of largest fragment
$d_{f\ opt}$	equivalent diameter of largest fragment at optimum t/D ratio
t	thickness of bumper sheet

INTRODUCTION

Hypervelocity impacts of aluminum spheres with aluminum plates have been studied for more than 30 years. Most of these studies have been directed toward optimizing a spacecraft shield design against a particular threat, i.e., providing maximum protection with a minimum weight and space penalty. The optimum or most effective shield produced maximum breakup and dispersion of the threatening particle, thereby spreading the debris over a large area and inflicting minimal damage on the rear wall. Wilkinson's[1] penetration criterion, for example, assumes "that the front sheet completely fragments or vaporizes the incoming particle, and that no large solid fragments remain." Optimization of a shield design against a range of fragment sizes, e.g., the orbital debris environment, is not a simple task. Of particular concern is the situation where the impacting fragments overmatch or undermatch the shield. In either of these cases, complete breakup of the fragment and/or bumper does not occur.

A recent study of debris clouds produced by the impact of aluminum spheres with thin aluminum plates[2] has examined the behavior of non-optimum shields. In this study, a variety of quantitative data were obtained from multiple-exposure, orthogonal pair, flash radiographs of the debris clouds produced by the impacts. For cases where the bumper was overmatched, i.e., the projectile did not breakup completely, a large single fragment of projectile remained at the center of the debris cloud. When the projectile was overmatched, numerous large bumper fragments were distributed throughout the bubble of bumper debris. Both types of fragments pose a penetration threat to the rear wall of a double sheet structure. This paper provides quantitative data regarding the size and velocity of these large fragments for impacts at 6.7 km/s.

EXPERIMENTAL DESIGN

Test results presented in this paper were obtained from tests performed for two sponsors, Martin Marietta Manned Space Systems and McDonnell Douglas Space Systems Company, and from range and/or equipment performance tests conducted by the University of Dayton Research Institute (UDRI). Appropriate recognition of support for each test is given in the radiographs of debris clouds as they are presented. All tests were performed in the UDRI Impact Physics Laboratory using a 50/20 mm, two-stage, light gas gun.

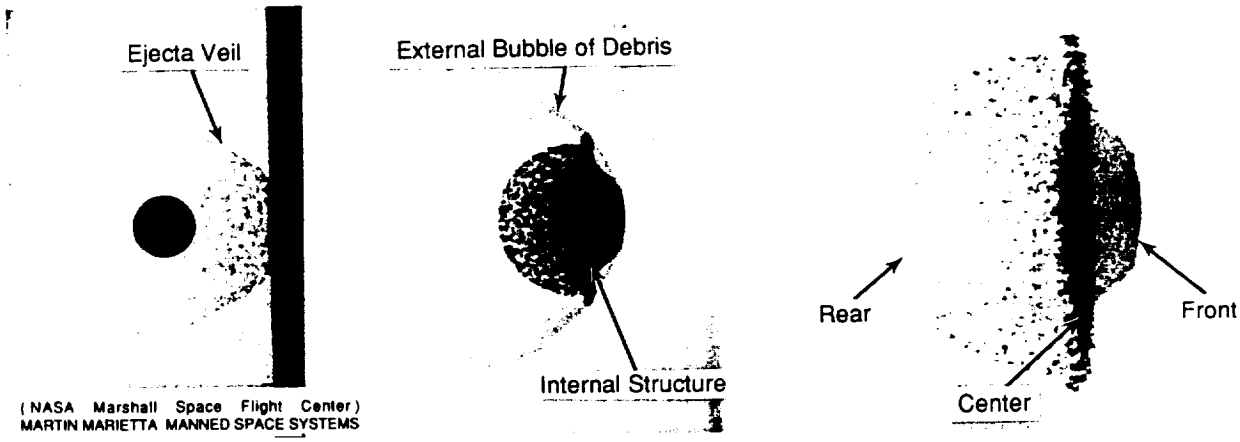


Fig. 3. Close up of radiograph shown in Fig. 2. Various morphological features and elements of the debris cloud structure are identified.

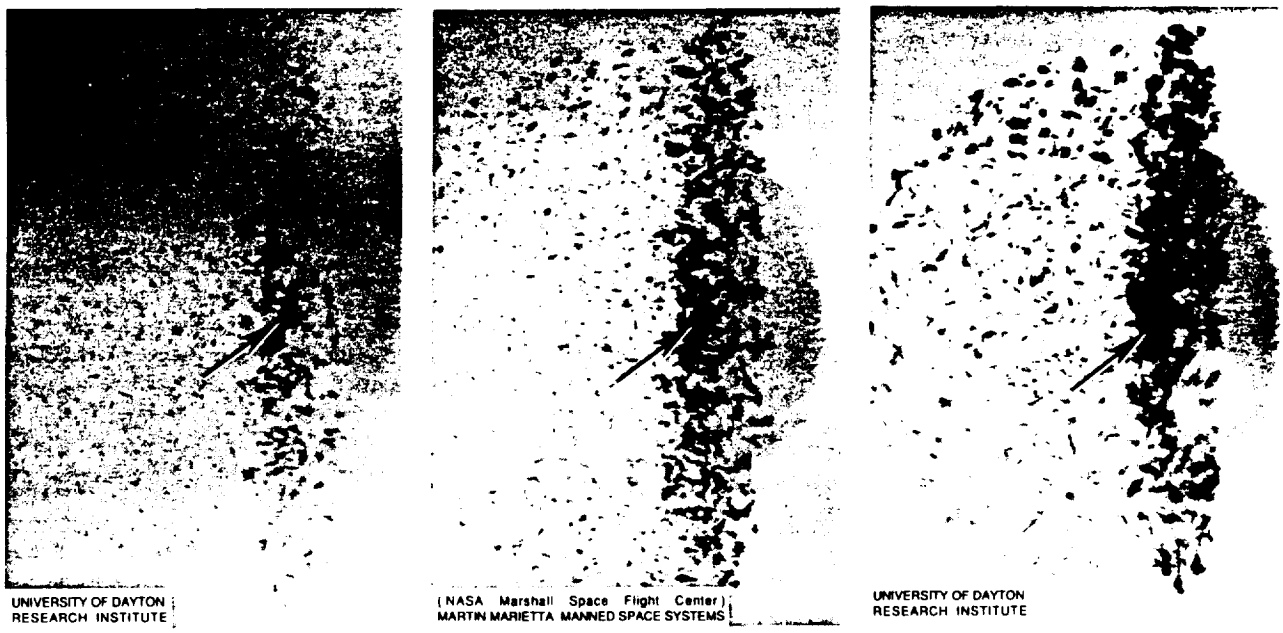


Fig. 7. Views of largest fragment produced by impacts of various diameters of aluminum spheres (t/D ratio held constant at 0.048). Left--6.35-mm-diameter, 0.373-g, 2017-T4 aluminum sphere; 0.302-mm-thick, 1100-0 aluminum bumper; V_0 = 6.67 km/s. Center--9.53-mm-diameter, 1.275-g, 2017-T4 aluminum sphere; 0.465-mm-thick, 6061-T6 aluminum bumper; V_0 = 6.62 km/s. Right--12.70-mm-diameter, 3.000-g, 2024-T3 aluminum sphere; 0.592-mm-thick, 6061-T6 aluminum bumper; V_0 = 6.26 km/s.

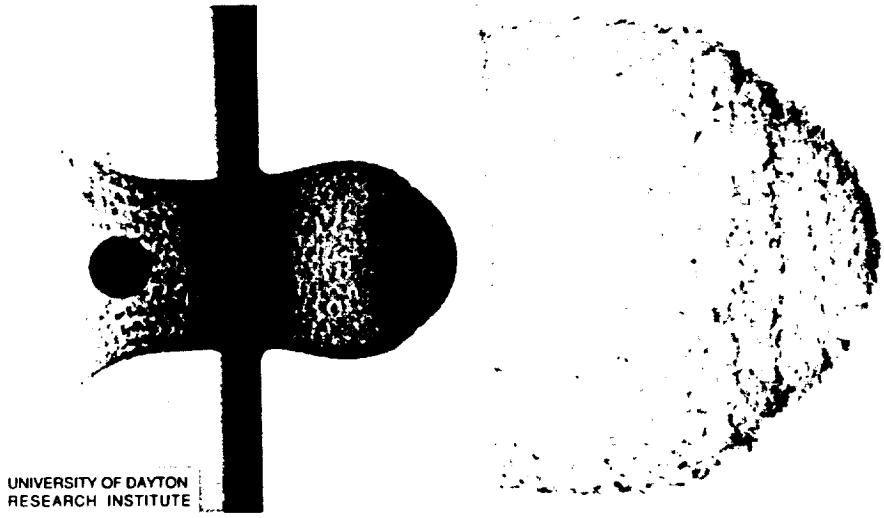
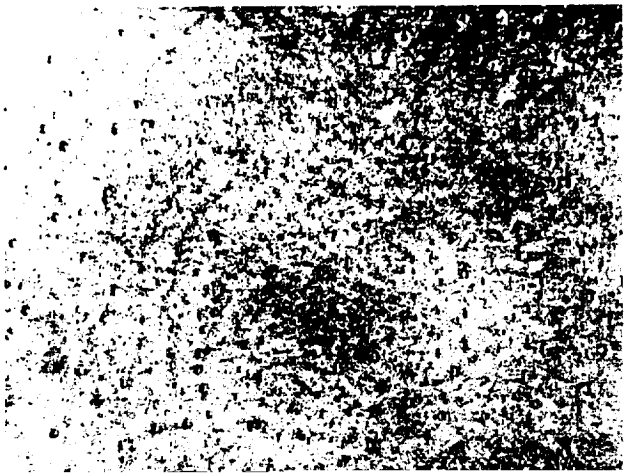


Fig. 8. View of external bubble of debris cloud produced by impact of 9.53-mm-diameter, 1.275-g, 2017-T4 aluminum sphere with a 4.039-mm-thick, 6061-T6 aluminum plate at 6.68 km/s.

view. In making the measurements, every precaution was taken to insure that the measurement was of the large fragment alone and not several overlapping fragments. To further insure the most reliable measurements were used to determine the volume of the largest fragment, the smaller of the two thickness measurements was used in the computation. The measured values of largest fragment height, H; width, W; and thickness, T; were used as the dimensions of an ellipsoid as shown in Fig. 9. The volume of the ellipsoid was used to determine the diameter of a sphere having the same volume as the ellipsoid. The diameter of this sphere, d_f, was termed the equivalent diameter of the largest fragment. The fragments produced when the t/D ratio was low tended to have length-to-diameter ratios of just less than one. The length-to-diameter ratio of the fragments with the higher t/D ratios tended towards values of 0.5 to 0.6. The large fragments in the external bubble of the test where the t/D ratio was 0.424, were very flaky, with length-to-diameter ratios of about 0.2.

Damage produced by the large fragments in the debris cloud shown in Fig. 8 is shown in Fig. 15. Impact of these fragments produced fairly large and deep craters over the entire surface of the 38-cm-square witness plate. Penetration resulting from the impact of a single fragment did not occur. However, local spall was produced on the rear of the plate below many of the larger craters. In the witness plate shown in Fig. 15, the diameter of the damage pattern produced by the projectile fragments was slightly smaller than for the test with t/D ratio of 0.234.



Understanding the debris cloud formation process for impact velocities beyond the current range of test capabilities, and the effects of the impact of this cloud on a rear wall, remain an issue of great interest. Analysis of select tests at velocities below 6.7 km/s will provide insights to debris cloud formation at velocities above 6.7 km/s.

Finally, a thorough understanding of the debris cloud formation at normal impact is required before meaningful study of the oblique impact is undertaken.

ACKNOWLEDGEMENT

The analytical effort described in this paper and a portion of the test program was performed under contract A71447 with Martin Marietta Manned Space System as a subcontract under prime contract NAS8-38856. The author wishes to gratefully acknowledge Dr. Normal Elfer of Martin Marietta and Mr. Joel Williamsen of Marshall Space Flight Center for their support of this work. He also wishes to express his appreciation to Mr. Burton Cour-Palais of McDonnell Douglas Space Systems Company for the use of his test results, and to Dr. Robert Schmidt of Boeing Defense and Space Group for providing several of the thinner 6061-T6 bumper sheet materials used in the tests.