REPEATABILITY AND UNCERTAINTY ANALYSES OF NASA/MSFC LIGHT GAS GUN TEST DATA

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FINAL REPORT

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1.0 INTRODUCTION

1.1 Introductory Comments

All large spacecraft are susceptible to impacts by meteoroids and pieces of orbiting space debris. These impacts occur at extremely high speeds and can damage flight-critical systems, which can in turn lead to catastrophic failure of the spacecraft. Numerous impact craters have been found on Space Shuttle Orbiter windows and on the Shuttle's heat resistant tiles while a preliminary examination of the recently recovered LDEF satellite revealed tens of thousands of craters, pits, and holes. While it is not precisely known how many of these are due to orbital debris impacts and how many are due to meteoroid impacts, the susceptibility of earth-orbiting spacecraft to high-speed impacts is clearly evident. Naturally, the susceptibility of such spacecraft increases with increased mission duration. Therefore, the design of a spacecraft for a long-duration mission must take into account the possibility of such impacts and their effects on the spacecraft structure and on all of its exposed subsystem components.

One of the ways to obtain information on the response of a structure to a meteoroid impact or an orbital debris impact is to simulate the impact conditions of interest and analyze the resulting damage to a target structure. Hypervelocity impact testing began at the NASA/Marshall Space Flight Center in 1964 with the installation of a light gas gun in what is now known as the Materials and Processes Laboratory. The initial need and function of the facility was to provide a means of simulating meteoroid impacts on spacecraft and to provide the data required to determine the perforation probability of candidate spacecraft wall designs by such impacts. In the 1970's, the interest in testing for protection against meteoroid impacts declined. However, the increased launch activity in recent years has renewed interest in high speed impact testing at the NASA/MSFC facility and at other such facilities around the world. The attention of this new wave of testing has been focused on mitigating the threat posed by orbital debris particle impacts.

1.2 Report Contents

This Final Report presents an overview of the impact tests performed at NASA/MSFC in the time period 1985 to 1991 and the results of phenomena repeatability and data uncertainty studies performed using the information obtained from those tests. An analysis of the data from over 400 tests conducted between 1989 and 1991 was performed to generate a database to supplement the Hypervelocity Impact Damage Database developed under a previous effort [1.1]. The database in Reference [1.1] contains the results of 540 high speed impact tests performed at the NASA/MSFC between 1985 and 1989.

In addition to the repeatability and uncertainty studies described herein, the analyses performed during the course of this study included the following tasks:

1) a study of the effects of internal module wall pressure on perforation resistance [1.2];

2) a study the effects of MLI thickness and placement within a dual-wall system [1.3];

3) a study of the differences in perforation resistance of aluminum 2219-T87 and 5456-H116 under similar impact conditions [1.4]; and,

4) a comparison of HULL code predictions with experimental results for dual-wall structures under hypervelocity projectile impact [1.5,1.6,1.7].

The supplemental database developed as part of this investigation consists of two parts. The first part contains the geometric, material, and impact parameters for each test, including test number, projectile velocity, diameter, material, and shape, trajectory obliquity, bumper plate material and thickness, pressure wall plate material and thickness, the thickness and location of MLI (if applicable), and the total stand-off distance between the bumper and pressure wall plate. The second part contains a summary of the damage sustained by the impact targets, including bumper plate hole dimension(s), whether or not the pressure wall was perforated or spalled, the equivalent pressure wall single hole diameter (if applicable), the diameter of the three largest perforated holes in the pressure wall plate (if applicable), the depth of the three deepest craters on the pressure wall plate and corresponding surface diameters, the total area of front-surface pressure wall plate damage, and the total area of rear-side pressure wall spall (if applicable).

The next section presents an overview of hypervelocity impact testing that has been done at NASA/MSFC since 1985. Section 3.0 presents the results of the repeatability and uncertainty studies; conclusions and recommendations for future work are presented in Section 4.0. Complete printouts of the supplemental parameter and damage databases can be found in Appendix I and II, respectively, at the end of this report. The names of the LOTUS files in which the data in Appendix I and II can be found on the accompanying floppy disk is also provided.

1.3 References

1.1 Schonberg, W.P., Bean, A.J., and Darzi, K., Hypervelocity Impact Physics, NASA CR-4343, January, 1991.

1.2 Schonberg, W.P., "Effect of Internal Stress Fields on the Perforation Resistance of Dual-Wall Structures Under Hypervelocity Impact", International Journal of Impact Engineering, in press, 1992.

1.3 Schonberg, W.P., "Effect of Multi-Layer Thermal Insulation Thickness and Location on the Hypervelocity Impact Response of Dual-Wall Structures", submitted for publication consideration, Acta Astronautica, 1993.

1.4 Schonberg, W.P., "Aluminum 2219-T87 and 5456-H116: A comparative Study of Pressure Wall Materials in Dual-Wall Structures Under Hypervelocity Impact", Acta Astronautica, Vol. 26, No. 11, pp. 799-812, 1992.

1.5 Schonberg, W.P., and Peck, J.A., "HULL Code Prediction of Multi-Wall Structural Response to Hypervelocity Projectile Impact", International Journal of Impact Engineering, in press, 1992.

1.6 Schonberg, W.P., and Peck, J.A., "Paramteric Investigation of Multi-Wall Structural Response to Hypervelocity Cylindrical Projectile Impact", Computers and Structures, submitted for publication, 1992.

1.7 Schonberg, W.P., Predicting Multi-Wall Structural Response to Hypervelocity Impact Using the HULL Code, NASA CR-4486, January, 1993.

2.0 HYPERVELOCITY IMPACT TESTING AT THE NASA/MARSHALL SPACE FLIGHT CENTER

2.1 An Overview of Hypervelocity Impact Testing at NASA/MSFC

Orbital debris impact testing began at NASA/MSFC in July, 1985 at the Space Debris Simulation Facility of the Materials and Processes Laboratory at the NASA/Marshall Space Flight Center. The facility consists of an instrumented two-stage light gas gun capable of launching 2.5 mm to 12.7 mm projectiles at velocities of 2 to 8 km/sec. Projectile velocity measurements are accomplished via pulsed X-ray, laser diode detectors, and a Hall photographic station. For a detailed description of the gun and its instrumentation, the reader is referred to Reference [2.1].

As part of the Phase B development activities for the Space Station Freedom, 540 impact tests were performed using the NASA/MSFC light gas gun through March 1989; an additional 410 were performed as part of the Phase C/D activities through February 1991. Testing has been focused primarily on multi-wall target structures that were designed to simulate possible Space Station module wall Configurations. These target systems consisted of 'bumper', 'pressure wall', and 'witness' plates and multi-layer thermal insulations (MLI). The parameters of the tests, as well as the results of the Phase B damage analyses, can be found in Reference [2.2].

In the Phase C/D tests, aluminum projectiles ranging in diameter from 3.175 mm to 9.53 mm were fired at velocities ranging from approximately 2 to 8 km/sec. The target structures consisted primarily of aluminum plates of various thicknesses and spaced apart at various distances. Tests were performed with and without multi-layer insulation (MLI) of various thicknesses and at various positions within the spacing between the bumper plate and the pressure wall plate in the test specimens. Although the majority of the testing was performed normal to the plane of the target, a significant number of oblique impact tests was performed as well. A general summary of the Phase B and Phase C/D tests is presented in Section 2.3 where test shots are grouped in broad categories such as Impact Obliquity, Configuration, and Stand-off Distance. Examination of the information in these tables reveals several features about NASA/MSFC impact testing through February 1991.

1) The number of tests conducted at impact velocities in excess of 7 km/sec is relatively small -- only approximately 12.7% of all the tests conducted were in this impact velocity regime.

2) Only a few shots (approximately 2.9% of all the tests conducted) have been fired using very large projectiles (i.e. greater than 1 cm in diameter).

3) Of the 950 total tests in Phase B and Phase C/D, approximately 57.3% were fired normal to the plane of the target and and only 16.1% were conducted at trajectory obliquities at or above 60^0.

4) Nearly 82.9% of the impact tests through February 1991 have been performed on single bumper all-aluminum target structures.

5) All but 16 of the tests through February 1991 (i.e. approximately 98.3%) have been performed using spherical projectiles.

Section 2.4 contains a series of charts that detail the distribution of all the single bumper tests performed through February 1991. Only single bumper testing was considered in the development of these charts because of the scarcity of multi-bumper testing and the increased number and complexity of test parameters that describe such test shots. The test and configuration parameters for the single bumper shots are defined on the first page of Section 2.4. Any deviations from these baseline parameters are signified with footnotes, a legend for which is also provided in Section 2.4.

The test distribution charts in Section 2.4 categorize the test shots according to the presence of MLI, the projectile diameter D (in inches), the impact velocity V (in km/sec), and the thickness of the bumper plate (in inches). The number in the upper right hand corner of these charts is a number that identifies the impact obliquity, velocity range, and spacing for the test shots in a particular chart. For example, the number 45V23S4 implies that the test shots in that chart were all fired at 45 degrees with velocities between 2 and 3 km/sec and that the target was a single bumper specimen with a stand-off distance of 4 inches (approximately 10 cm).

It is noted that the charts in Section 2.4 contain the distribution of the Phase C/D tests as well as the Phase B tests. The Phase C/D tests can be distinguished from the Phase B tests by the different numbering systems used in the two test phases. The Phase C/D tests all begin with four numbers followed by a letter or a dash and another number; all other tests are Phase B tests. From these test distribution charts, it is evident that many gaps still exist in the current NASA/MSFC test database. These charts can be used as a guide in the selection of impact parameters for future hypervelocity impact test programs. Specific recommendations are presented in Section 4.2.

2.2 References

2.1 Taylor, R.A., "A Space Debris Simulation Facility for Spacecraft Materials Evaluation", SAMPE Quarterly, Vol. 18, No. 2, 1987, pp. 28-34.

2.2 Schonberg, W.P., Bean, A.J., and Darzi, K., Hypervelocity Impact Physics, NASA CR-4343, January, 1991.

Section 2.3

Summary of NASA/MSFC Hypervelocity Impact Testing

Through February, 1991

		Number of Tests Performed		
		Phase B	Phase C/D	Combined
Velocity (km/sec)	$7.0 \leq V < 8.0^{+}$	61	60	121 (12.7%)
	$6.0 \leq V < 7.0$	165	137	302 (31.8%)
	$5.0 \leq V < 6.0$	94	82	176 (18.5%)
	$4.0 \leq V < 5.0$	103	57	160 (16.8%)
	$3.0 \leq V < 4.0$	85	60	145 (15.3%)
	$2.0 \leq V < 3.0$	31	14	45 (4.8%)
	$1.0 \leq V < 2.0$	1	0	1 (0.1%)
		540	410	950 (100 %)
Diameter (cm)	$1.00 \leq D \leq 1.25$	16	12	28 (2.9%)
	$0.75 \leq D < 1.00$	218	173	391 (41.1%)
	$0.50 \leq D < 0.75$	200	137	337 (35.5%)
	$0.25 \leq D < 0.50$	106	88	194 (20.5%)
		540	410	950 (100 %)
Obliquity (deg.)	0^{o}	337	207	544 (57.3%)
	15^{o}	1	0	1 (0.1%)
	25^{o}	1	0	1 (0.1%)
	30^{o}	11	11	22 (2.3%)
	45^{o}	128	99	227 (23.8%)
	55^{o}	3	0	3 (0.3%)
	60^{o}	10	40	40 (5.3%)
	65^{o}	44	20	64 (6.7%)
	75^{o}	5	33	38 (4.1%)
		540	410	950 (100 %)
Configuration	Single Wall	11	0	11 (1.1%)
	1 Bumper	396	392	788 (82.9%)
	2 Bumpers	89	13	102 (10.7%)
	3 Bumpers	6	5	11 (1.1%)
	4 Bumpers	3	0	3 (0.3%)
	6 Bumpers	1	1	1 (0.1%)
	Windows	26	0	26 (2.8%)
	Bottles	8	8	8 (1.0%)
		540	410	950 (100 %)
Stand-Off Distance (Single Bumper)	10.16 cm	334	333	667 (84.6%)
	15.24 cm	52	11	63 (8.0%)
	17.78 cm	1	0	1 (0.1%)
	20.32 cm	3	0	3 (0.3%)
	30.48 cm	5	48	53 (6.8%)
	40.64 cm	1	0	1 (0.1%)
		396	410	950 (100 %)

<u>Miscellaneous</u>	Cadmium Bumpers	10
<u>(Totals)</u>	Cadmium Projectiles	10
	Composite Bumpers	45
	Corrugated Bumpers	11
	Non-1100 Projectiles	36
	Cylindrical Projectiles	16
	Non-2219 Walls	48
	Non-Standard MLI	4
	Stressed Pressure Walls	34
	MLI on Bumper	11
	MLI 0.635 cm off Bumper	148
	MLI 5.08 cm off Bumper	21

Section 2.4

Detailed NASA/MSFC Hypervelocity Impact Test Shot Distribution

Through February, 1991

BASELINE PARAMETERS

Pressure Wall Thickness ... 0.125 in.

Stand-Off Distance .... 4.0 in.

Number of Bumper Plates ... 1

Projectile Shape .... Sphere

Projectile Material .... Al 1100

Bumper Plate Material ..... Al 6061-T6

Pressure Wall Material .... Al 2219-T87

MLI Thickness .... 30 layers

MLI Materials .... Kapton/β-cloth

MLI Location .... On Pressure Wall

IDENTIFICATION CODE: 45V23S4

$\theta = 45^{\circ}$ | S=4in.

$2 < V < 3$ km/s

FOOTNOTES

[1]Pressure Wall Material ... Al 5456-H116

[2]Projectile Material ...... Al 6061-T6

[3]Backwall Thickness .... 0.188 in.

[4]Projectile Material ...... Al 6061-T6; L/D = 1.0

[5]Bumper Plate Material .... Al 2219-T87

[6]Stand-Off Distance .... 12 in.

[7]Stand-Off Distance .... 6 in.

[8]Projectile Material ...... Steel

[9]Projectile Material ...... Lexan

[10]Stand-Off Distance ...... 8 in.

[11]Cylindrical Projectile

[12]Backwall Thickness ...... 0.175 in.

[13]Backwall Thickness ...... 0.200 in.

[14]Backwall Thickness ...... 0.225 in.

[15]Backwall Thickness ...... 0.160 in.

[16]Backwall Thickness ...... 0.100 in.

[17]Backwall Thickness ...... 0.063 in.

[18]MLI on Rear of Bumper

[19]MLI Composition Is Non-Standard

[20]Impact Angle is 5^0

[21]MLI is 0.9 in. Above Pressure Wall

[22]Bumper Thickness .... 0.050 in.

[23]MLI 2.0 in. Beneath Bumper

[24]MLI Has 20 Standard Layers Instead of 30

[25]MLI is 0.25 in. Away From Bumper Plate

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI		T2-19B[7]		
	w/o MLI				
$0.2 < D < 0.3$	w/MLI		P-007 P-008		
	w/o MLI		P-001 P-002 T2-13[11]		
$0.1 < D < 0.2$	w/MLI		MD-TEST-A MD-TEST-B P-014E[7] P-014F[7] P-015B[7] P-027E P-027F	T2-1	
	w/o MLI	109C 109D	P-015[7] P-025B[2,7] P-025C[2,7]		

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI			319	
	w/o MLI				
$0.2 < D < 0.3$	w/MLI		301[15]		
	w/o MLI				
$0.1 < D < 0.2$	w/MLI			333	
	w/o MLI				

		t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI			4105A[22] 4105A-1[22]	
	w/o MLI				
0.2 < D < 0.3	w/MLI	4113A			
	w/o MLI				
0.1 < D < 0.2	w/MLI			4103A[22]	
	w/o MLI				

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI			203C	
	w/o MLI				
$0.2 < D < 0.3$	w/MLI				
	w/o MLI				
$0.1 < D < 0.2$	w/MLI				
	w/o MLI		231B		

		t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI	102D 229B [3] 229C [3] 3034B	P-016M [7] P-016N [7] T2-19A [7] T2-7 T2-7A	T2-5	
	w/o MLI		T2-8		
0.2 < D < 0.3	w/MLI	3033A 3033B 3301A [18]	P-012D P-013E [7] T2-3 3407B 3406A [23] 3405A [23] 3405B [23] 3102A [3]	T2-14 [11]	
	w/o MLI		PT4A		
0.1 < D < 0.2	w/MLI		P-014C [7] P-027C P-027D 3305C 3101A 3101C [3]	334 3012C	3001A
	w/o MLI	101 101A	P-014 [7] P-014B [7] P-014D [7] P-015C [7] P-025 [2,7] P-025A [2,7] P-027A P-028 2001A [7] 2001B [7]	T2-2	

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI	321 4001A 4111B	303A[15] 320 4003A 4003C		
$0.3 < D < 0.4$	w/o MLI	105	114A[2]		114B
$0.2 < D < 0.3$	w/MLI	4110A 4110B	205E	4101A[22]	
$0.2 < D < 0.3$	w/o MLI		113A[2]		
$0.1 < D < 0.2$	w/MLI	4109A	230B 3131B[6] 3131C[6]	334	
$0.1 < D < 0.2$	w/o MLI		206D 206E	202A 202B 222C	

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI	4114A 4114B			
	w/o MLI		114[2]		
$0.2 < D < 0.3$	w/MLI	4113B			
	w/o MLI		113[2]		
$0.1 < D < 0.2$	w/MLI	4112A		4103B[22] 4106A[22]	
	w/o MLI				

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI		3031B	203B 203F 3212	3212-1
	w/o MLI				
$0.2 < D < 0.3$	w/MLI			224C[4]	3008
	w/o MLI		208C	204D	
$0.1 < D < 0.2$	w/MLI		3029C 3030A		3007C
	w/o MLI		231A		

		t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI	4002B 4002A 4117A	4004A	4108B[22] 4108A[22]	
	w/o MLI	105B			
0.2 < D < 0.3	w/MLI			4107A[22] 4106A1[22] 4106B1[22]	
	w/o MLI				
0.1 < D < 0.2	w/MLI	4115A			
	w/o MLI				

		t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI	102C	P-016L[7] P-016P[7] P-020F[7] P-020G[7] p-020H[7] T2-17 T2-19[7] 3130A[6]	215A[3]	3121B[6]
	w/o MLI	213A[3]	PT8A PT8B T2-20[7] T2-6A	225B[7] 225C[7] PT6A T2-6	
0.2 < D < 0.3	w/MLI	3301B[18] 3301E	P-012C P-024G[2,7] T2-4 P-034C-1[16] 3406B[23] 3129A[6] 3102B[3] 3129B[6] 3102D[3] 3407C	P-033B	3120A[6]
	w/o MLI	213C[3]	PT4B P-003 P-004 P-013[7]	214C[10,3] 214D[10,3]	
0.1 < D < 0.2	w/MLI		3305B 3305A 3101B[3] 3128B[6]		3019A[6] 3019B[6]
	w/o MLI	101B 109A	P-014A P-027 P-027B		

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI				
	w/o MLI				
$0.2 < D < 0.3$	w/MLI				
	w/o MLI				
$0.1 < D < 0.2$	w/MLI		3022C 3022D	3012D	
	w/o MLI				

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI	326 4001B	303[15] 303B[15] 325	324 4102B[22]	
	w/o MLI				
$0.2 < D < 0.3$	w/MLI		205A 205B 3105A[3] 3105B[3]	201A 335 336 4101B[22]	226A[16]
	w/o MLI		EHSS-5A[1]		
$0.1 < D < 0.2$	w/MLI	4109B	230A 3307A	221C 221D	
	w/o MLI		206A		

		t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI				
	w/o MLI	105A			
0.2 < D < 0.3	w/MLI				
	w/o MLI				
0.1 < D < 0.2	w/MLI				
	w/o MLI				

D	MLI	$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
0.3 < D < 0.4	w/MLI			203A 203G 3213	3009B
	w/o MLI				
0.2 < D < 0.3	w/MLI	3039B	209A	224B[4] 3017C 3209-1	3008A 3008B
	w/o MLI		EHSS-5D[1] 208A 208B	204A 204C	
0.1 < D < 0.2	w/MLI				3007B
	w/o MLI		156C		

		t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI	102A 102B 229A[3]	MD-TEST-D P-021D P-035C[7] 3401D[23] 3402D[23] 3403D[24] 3404D[23] 3103A[3] 3130A[6] 3223A[6] 3226B[6] 3226A[6] 3226C[6] 3103B[3]	215B[3] T2-15	3121A[6] 3220A[6] 3225[6] 3225A[6]
	w/o MLI	213B[3]	P-016[7] T2-18	225A[9] T2-16	228A[3]
0.2 < D < 0.3	w/MLI	3301D	P-009 P-010 P-013D[7] P-034C-2[16] P-034C[16] 3407D 3406C[23] 3405C[23] 3224B[6] 3224A[6] 3406D[23] 3306A 3102C[3] 3102E[3]	P-033B-1 P-033C	3121B[6]
	w/o MLI	213D[3]	EHSS-2B P-013C[7] P-022[11] P-024C[2,7] P-024F[2,7]	214A[10,3]	
0.1 < D < 0.2	w/MLI				3222A[6]
	w/o MLI				

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI				
	w/o MLI				
$0.2 < D < 0.3$	w/MLI				
	w/o MLI		135A		
$0.1 < D < 0.2$	w/MLI				
	w/o MLI		162B		

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI	3035A 3035A-1 4111C	211B	218A[3]	
	w/o MLI	216A[3]			
$0.2 < D < 0.3$	w/MLI	4110C	205C 3308A 9001-1	201B 223C[4] 336A 9001A[22] 9001B[22] 9001C[22]	226B[16] 227A[17]
	w/o MLI		EHSS-4C[1] 230C 230D		
$0.1 < D < 0.2$	w/MLI	3303D		221B 4100C[22]	
	w/o MLI		206B 206C	154B 202C 222A 222B	

		t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI		207A 210B	203D 3214 3215	3009A
	w/o MLI				
0.2 < D < 0.3	w/MLI	3039A		3009 3211	3210
	w/o MLI		EHSS-5C[1] 208D	204B	
0.1 < D < 0.2	w/MLI	3038A			
	w/o MLI		156B		

D	MLI	t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI	3302E 3202A[18] 3202B[18] 3202C[18]	EH2-B EH2-C EH2-D EH2-E EH4-A PR-EH2[5] P-016J[7] P-016K[7] * P-021B P-021C P-035B[7] EH4-B N2-P1 BL-AL1 BL-AL2 3227A 3227D[18] 3227B[21]	215C[3] 215D[3] 3011A 3011B	3220B[6] 3225C[6]
0.3 < D < 0.4	w/o MLI	107[12] 107A[13] 107B[14] 108[6] 121-1[7] 121-2[7]	EH3-A EHSS-6A[1] EHSS-6B[1] EHSS-6C P-016A[7] P-016B[7] P-016C[7] P-016E[7] P-020B[7] P-020C[7] P-021 P-021A P-035[7]	225D-1[9,11]	228B[3]
0.2 < D < 0.3	w/MLI	3301C[18] 3306B	P-011 P-012B P-022A[11] 3405D[23] 3406D1[23] 3306D	3206 3010-1-B	3002A 3221A[6] 3221B[6]
0.2 < D < 0.3	w/o MLI		EHSS-1A[1] EHSS-1B[1] EHSS-1C[1] EHSS-2A P-005 P-006A P-013B[7] P-022B[11] 2003B[17] 2003A[17] P-034[16] 2002A[7] 2002B[7] 2002C[7] 2004A 2004B 2003A[7] 2003B[7]		228C[3] 228D[3]
0.1 < D < 0.2	w/MLI			3010B	3001C 3001E
0.1 < D < 0.2	w/o MLI		146A[8]		

*
MLI-B2
3401C[2]
3402C[2]
3403C[2]
3404A[2]
3404B[2]
3103E[3]
3103D[3]
3103C[3]
3404C[2]
3227C[6]

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI		3024B		
	w/o MLI				
$0.2 < D < 0.3$	w/MLI		3023B 3023A	3013A	
	w/o MLI		EHSS-3A[1] EHSS-3C 135C 135D		
$0.1 < D < 0.2$	w/MLI				
	w/o MLI		162A		

		t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI	001B 4001C 4001D 4003D 4111D	002B 211D 212B 306[15] 4003B	003A 218B[3] 218C[3] 337 339 4102C[22] 4102C1[22] 4102C2[22]	3124B[6] 3124C[6]
	w/o MLI	106 216B[3] 216C[3]	EHRP-3[1] EHSS-7A[1] 002A 3132B[6] 3132C[6]	217A[3]	
0.2 < D < 0.3	w/MLI	3036B 4110D 3304A 3304B 3304C 3304D	205D 3308B	223A[4] 223B[4] 4101C[22] 9001D[22] 9002A[22] 9002B[22] 9002C[22] 9002D[22]	226C[16] 3007 3122B[6]
	w/o MLI	151A	EHSS-4A[1] EHSS-4B[1] 230E	217C[3] 217D[3]	
0.1 < D < 0.2	w/MLI	4109C 3303A 3303B 3303C	3307B	221A	3003 3004A 3004B
	w/o MLI		206F	154A 202D	

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
0.3 < D < 0.4	w/MLI				
	w/o MLI	106A 106-1	EHRP-1[1]		
0.2 < D < 0.3	w/MLI				
	w/o MLI				
0.1 < D < 0.2	w/MLI				
	w/o MLI				

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI	004A 3040A	207B 210D 3031C	203E 3216 3218	3217
	w/o MLI		EHRP-2[1] 231C		
$0.2 < D < 0.3$	w/MLI	3039C	209B	224A[4] 3017A 3017B	
	w/o MLI		208E		
$0.1 < D < 0.2$	w/MLI	3038B			3007A
	w/o MLI				

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI	4002C 4002E 4117C 4117D	4004B 4004C		
	w/o MLI	106B 106-2			
$0.2 < D < 0.3$	w/MLI	4116C		4107C[22]	
	w/o MLI				
$0.1 < D < 0.2$	w/MLI	4115C			
	w/o MLI				

		t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI		EH2-A PR-EH1[5] P-016H[7] MLI-B[24] MLI-TB2[24] 3402A[23] 3402B[23] 3403A[24] 3403B[24]		
	w/o MLI	102 110	P-016G[7] P-017		
0.2 < D < 0.3	w/MLI		3306C	3010-1A 3205	3002B 3002C
	w/o MLI		P-018RV[7] P-034B[16] 2003C[7,20]	P-033	
0.1 < D < 0.2	w/MLI			3010C 3001 3202	3001D MLI-B3[18] MLI-B4[18]
	w/o MLI	109	146B[8]		

		t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI				
	w/o MLI		EH1A		
0.2 < D < 0.3	w/MLI				
	w/o MLI		EHSS-3B[1] 135B 135E		
0.1 < D < 0.2	w/MLI				
	w/o MLI				

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI	3037A		338	3006A
	w/o MLI		EHSS-7B[1] EH1B	217B[3]	
$0.2 < D < 0.3$	w/MLI			201C 201D	227B[17] 3005B 3123A[6] 3123B[6]
	w/o MLI		EHRP-6[1] 150A	217E[3]	
$0.1 < D < 0.2$	w/MLI				3005A 3004 3122A[6]
	w/o MLI		EHRP-8 155A	202E 202F	

		t_B = 0.080	t_B = 0.063	t_B = 0.040	t_B = 0.032
0.3 < D < 0.4	w/MLI	4114D		4105D[22]	
	w/o MLI		EH1C		
0.2 < D < 0.3	w/MLI	4113D		4104A[22] 4103D[22] 4104D[22]	
	w/o MLI		EHRP-4[1]		
0.1 < D < 0.2	w/MLI	4112D		4110D[22]	
	w/o MLI		EHRP-7 157A		

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI		207C		
	w/o MLI		231D		
$0.2 < D < 0.3$	w/MLI		209D		
	w/o MLI		EHRP-5[1]		
$0.1 < D < 0.2$	w/MLI				
	w/o MLI		EHRP-9 156A		

		$t_B = 0.080$	$t_B = 0.063$	$t_B = 0.040$	$t_B = 0.032$
$0.3 < D < 0.4$	w/MLI				
	w/o MLI		EHSS-8A[1] EH1D		
$0.2 < D < 0.3$	w/MLI				
	w/o MLI				
$0.1 < D < 0.2$	w/MLI				
	w/o MLI				

3.0 REPEATABILITY AND UNCERTAINTY ANALYSES

3.1 Introductory Comments

This section presents the results of the experimental phenomena repeatability and data uncertainty analyses performed using the NASA/MSFC Phase B and Phase C/D hypervelocity impact test data. Following a summary of the principles involved in uncertainty analysis, the methodologies used in the analyses is described. The principles discussed are a synopsis of those presented in Ref. [3.1] and can be explored in greater detail by consulting that text. The results of the analysis are then presented and discussed. Recommendations are offered for future test programs that would enhance and expand the results presented herein.

3.2 Concepts in Uncertainty Analysis

In any experimental procedure, a question exists as to whether or not the procedure will yield the same results if the experiment were to be repeated under identical conditions. In almost all cases, the answer is negative. A simple explanation for this is that there is no such thing as a perfect experiment with a perfect measuring device. All measurements are bound to contain errors that may vary from trial run to trial run, even under the same experimental conditions. The nature of these errors must be well understood if experimental results are to be used in subsequent calculations, comparisons, or design exercises.

Measurement error, i.e. the difference between a measured value and the true value of a measureable quantity, can be said to consist of two parts. One part, called 'bias error', refers to a fixed component of the total error that is present in all measurements of a specified quantity. Another part, the 'precision error', refers to the random component of the total error that varies from one measurement to the next, even of the same quantity by the same individual.

Unfortunately, we never know the true value of any quantity we measure. Therefore, it is impossible to explicitly state what the error is in the measurement of an experimental quantity. However, it is still possible to make a statement about our perception of the true value of a quantity based on our measurements of it. This statement typically consists of specifying how confident we are (usually in the form of a percentage) that the true value lies within an interval about the mean value of our measurements of a specific quantity. The extent of that interval about that mean value is called the uncertainty in the quantity for our specified confidence value. For example, we can say that we are 95% sure that the actual elastic modulus of a material is 100 GPa $\pm$ 20 GPa, but only 75% confident that it is 100 GPa $\pm$ 5 GPa. As illustrated in this example, our confidence that the true value of a quantity lies within a certain interval decreases as the interval decreases.

The analysis of uncertainties in experimental measurements provides the user of experimental data with an estimate of experimental error. It also provides a measure of how 'good' the experimental results really are. Traditional uncertainty analysis requires that a relatively large number of experimental runs be performed under the same conditions in order to have a fairly large level of confidence that the results obtained are either representative of the true value or are all off by a fixed amount. However, if an experiment is performed only once or just a few times, it is very difficult to assess the level of uncertainty in the experimental results.

3.3 Methodology

3.3.1 Overview and Objectives

The objectives of the analyses performed were two-fold: first, to quantify the repeatability of the phenomena ocurring in dual-wall structures under hypervelocity impact based on the testing performed at the NASA/MSFC light gas gun during the time period 1985-1991; and second, to determine the uncertainty of the measurements taken from damaged test specimens. These objectives were achieved through the following two stage analysis procedure.

The first stage of the analysis was concerned with simply whether or not identical dual-wall structures would be perforated or exhibit rear-side spallation under the same impact conditions. This issue was concerned only with consistency in overall response -- perforation vs. no perforation or spall vs. no spall -- under the same impact conditions. Since no measureable quantity was involved in this stage of the analysis, standard uncertainty analysis procedures were not used; only an approximate quantifiable measure of the overall repeatability of the phenomena ocurring in dual-wall structures under hypervelocity impact based on testing at the NASA/MSFC light gas gun facility was obtained.

The second stage of the analysis focussed on the uncertainty of the measurements of detailed response characteristics for identical structures under the same impact conditions. Response characteristics such as pressure wall equivalent single hole diameter, pressure wall damage area and rear-side spall area were analyzed to determine level of uncertainty in the data produced by the test facility as well as the consistency of the damage levels found in dual-wall structures under hypervelocity impact.

A review of the Phase B and Phase C/D impact test parameter databases revealed an unfortunate circumstance: very few of the impact tests were repeated under the same impact conditions. Thus, a traditional repeatability analysis of the phenomena involved in the response of dual-wall structures to hypervelocity projectile impact and a traditional uncertainty analysis of the measured test data were impossible to perform. However, rather than abandon the entire exercise, modified repeatability and uncertainty analyses were performed by pooling together several related groups of tests. This resulted in sample sizes of at least 5 to 10 related tests per group. While the pooled test groups were by no means large, at least some sort of comparison and assessment of phenomena repeatability and test data uncertainty became possible. For example, one such grouping was all tests on dual-wall structures without MLI and with t_s=1.6 mm, t_w=3.175 mm, and S=10.16 cm. Within that group, tests were then paired according to similarity in projectile diameter, trajectory obliquity and impact velocity.

All test groups possible using the Phase B and Phase C/D data are shown in Tables 3.10-3.13 in Section 3.8. In Tables 3.10-3.13, the position of the MLI in a particular test is denoted by one of the abbreviations RB, BB, HW, or PWP. The abbreviations correspond to on the rear of the bumper plate, 0.25 inches in back of the bumper plate, half-way between the bumper and pressure wall plates, and one the pressure wall plate, respectively. In these tables, it can be seen that the velocities of 'identical' tests are not equal. With a complex test apparatus such as a light gas gun, it is virtually impossible to duplicate impact velocity. At best, one can expect velocities to be within 0.1 or 0.2 km/sec of each other. Thus, in the pairing of the tests in each group, tests with impact velocities within 0.2 km/sec of each other were considered to be similar enough so that their results could be compared against each other. This presumption is justified by the following argument.

The response of the dual-wall structure is governed by the extent to which the projectile and the impacted outer wall fragment, melt, and/or vaporize. The extent of fragmentation, melting, and/or vaporization is in turn governed by the shock pressures generated by the initial impact. A simple one-dimensional shock physics analysis using the shock jump conditions and a linear relationship between shock velocity and particle velocity shows that shock pressures are found by the addition of two terms. The first term is linearly related to particle velocity while the second is a function of particle velocity squared. Since the particle velocity is directly related to the impact velocity, it follows that shock pressures are a function of linear and quadratic terms in impact velocity.

In light of this reasoning, the effect of a difference of 0.2 km/sec in impact velocity would only be significant in the linear term; its effect would be negligible in the quadratic term. For an impact velocity of of 3 km/sec, a change of 0.2 km/sec would represent a change of approximately 6.7% in shock pressure, while at 7 km/sec the change in shock pressure would be only 2.9%. In either case, if these low changes in shock pressures do not result in a change in the physical nature of the response (i.e. so long as both velocities are below the velocity required to fragment the projectile and bumper plate, or so long as both are below the incipient melt velocity, etc.), then the effects of a 0.2 km/sec difference in impact velocity can be ignored.

3.3.2 Phenomena Repeatability Methodology

In the first stage of the repeatability analysis, a quantifiable level of repeatability for dual-wall systems tested in the NASA/MSFC light gas gun was determined by calculating how many test pairs within a group of tests sustained pressure wall perforation or rear-side spall in both tests of each pair and how many did not. The repeatability for that group of tests was then stated as the percentage of test pairs that were in agreement with regard to pressure wall perforation or rear-side spallation. This quantity will be referred to as the 'Repeatability Index' for the specific group of tests under consideration. The results of the analyses performed in this stage are summarized for the various test groupings in Tables 3.1-3.5.

In the test groups presented in these Tables, the position of the MLI within the dual-wall system is accounted for only in the pairing of the tests used in direct comparisons (see Section 3.8). In presenting a summary of the results in Tables 3.1 through 3.5, no distinction is made between the various MLI positions noted in the tables in Section 3.8. Also, whereas Table 3.1 presents Repeatability Indices for stand-off distances of 10.16, 15.24, and 30.48 cm, the results presented in Tables 3.2 through 3.5 are only for tests with a 10.16 stand-off distance. The small number of tests at the other larger stand-off distances precluded any further more detailed analyses being performed. Finally, entries of 'N/A' in Tables 3.4a and 3.5 indicate the absence of any test pairs with the particular experimental parameter under consideration (i.e. impact velocity and bumper thickness in Tables 3.4a and 3.5, respectively).

3.3.3 Uncertainty Analysis Methodology

The second stage of the analysis consisted of a more traditional uncertainty analysis of the experimental data obtained from the high speed impact tests. These methods were somewhat modified to account for the paucity of tests under identical test conditions. In addition, two different but related approaches were used in performing the uncertainty analyses. Because of the scarcity of tests with the same impact parameters, it was not possible to determine the uncertainty in actual test results for bumper plate hole diameter, for example, or for pressure wall damage area. However, by pooling together the results of several related tests, it became possible to determine the uncertainty in the ratios of, for example, pressure wall damage area for all the pairs of tests within a specific group.

The first approach was based on the presumption that the lack of sufficient information precluded making any specific comments regarding the 'true' value of any parameter based on the experimental data available. However, in this case, it was still possible to calculate for a given confidence level 'c' and for the parameters of the test group under consideration, the interval within which 'c%' of the response parameter ratios would be expected to fall if more tests were performed under similar impact conditions. These results can also be used to state that there would be a 'c%' probability that a test ratio pair would lie in the calculated response parameter ratio interval.

The second approach differed from the first in that it was used to calculate, for a given confidence level 'c' and for the parameters of the test group under consideration, the interval within which it can be supposed lay the 'true' value of a damage response parameter for a given set of impact parameters relative to test data obtained at those same parameters. In both approaches, the calculations performed assumed that there were no bias errors present in the data. These two approaches are discussed in more detail in Sections 3.3.3.1 and 3.3.3.2, respectively.

Since the analysis in this stage of the effort required comparisons between response characteristics that were sensitive to impact velocity, it was originally thought that the quantities being considered should be adjusted to reflect any difference in velocity between two tests. However, the only way this could have been done was by using an empirical predictor equation for the response characteristic under consideration to determine some sort of 'adjustment factor' for the results of one of the tests. Since the predictions of such equations themselves have some inherent error, such adjustments would be counter-productive and would confuse rather than clarify the issue. Thus, actual test results were used in the second phase of the repeatability study even though the impact velocities for a test pair may have differed by 0.2 km/sec.

3.3.3.1 Uncertainty Analysis -- First Approach

Mathematically, a 'c%' response parameter ratio interval can be defined as follows:

$$\mu_\rho - \eta_c\sigma_\rho < \rho < \mu_\rho + \eta_c\sigma_\rho \tag{1}$$

where μ_ρ and σ_ρ are the mean and standard deviations of the ratios ρ for a particular quantity (i.e. hole diameter, damage area, etc.) for the test pairs within a specific test group. The quantity η_c is a numerical multiplier that is obtained from statistical tables (see, e.g. [3.1,3.2]) and is a function of the number of ratios considered in calculating μ_ρ and σ_ρ and the level of confidence 'c' specified.

At this point it should be noted that there are two basic ways of calculating the ratios described above. The first is to force all the ratios within a test group to be less than unity by dividing the smaller of the two quantities in the test pairs by the larger; the second is to force all the ratios within a test group to be greater than unity by doing the exact opposite. If all the ratios are less than one, the following modified version of equation (1) provides the interval of interest for a specified confidence level:

$$\mu_{\rho<1} - \eta_c \sigma_{\rho<1} < \rho < \mu_{\rho<1} + \eta_c \sigma_{\rho<1} \tag{2a}$$

where $\mu_{\rho<1}$ and $\sigma_{\rho<1}$ are the mean and standard deviation of the ratios for a particular response quantity, respectively, when all the ratios are less than one. If all the ratios are greater than one, the following equation will provide the required interval:

$$\mu_{\rho>1} - \eta_c \sigma_{\rho>1} < \rho < \mu_{\rho>1} + \eta_c \sigma_{\rho>1} \tag{2b}$$

where $\mu_{\rho>1}$ and $\sigma_{\rho>1}$ are the mean and standard deviation of the ratios for a particular response quantity, respectively, when all the ratios are greater than one.

Since there is no reason to suppose that the next response parameter ratio will be less than or greater one, it may be argued that the appropriate interval to be calculated for a given confidence level is one whose lower limit given by equation (2a) and whose upper limit given by equation (2b), that is,

$$\mu_{\rho<1} - \eta_c \sigma_{\rho<1} < \rho_o < \mu_{\rho>1} + \eta_c \sigma_{\rho>1} \tag{3}$$

where ρ_o represents the ratio of two response parameter values without any specification that the ratio be less than or greater than one. It is this modified c% confidence interval that will be used to specify the range within which 'c%' of the response parameter ratios would be expected to fall if a large number of tests were to be performed under similar test conditions.

The analyses described in the previous paragraphs require the assumption of a certain confidence level 'c' to determine a modified 'c%' confidence interval. The specified value of 'c' and the number of degrees-of-freedom 'n' in a particular test group (which equals one less than the number of tests 'N' within a specific group) is the information required to obtain the appropriate value of η_c to be used in equation (3). Values of η_c for certain values of 'c' and n=N-1 are given in Table 3.6; Tables 3.7-3.9 contain means and standard deviations for the various test groupings considered in this portion of the study.

3.3.3.2 <u>Uncertainty Analysis -- Second Approach</u>

The equations required for the second approach are obtained using the same principles as those which were used in the derivation of the equations for the first approach. Specifically, to obtain a c% confidence interval for a test value-to-true value ratio that is less than one, equation (2a) is re-written as

$$\mu_{\rho<1} - \eta_c \sigma_{\rho<1} < X_{test}/X_{true} < \mu_{\rho<1} + \eta_c \sigma_{\rho<1} \tag{4a}$$

where X_{test} is a test value for a response parameter under specific test conditions, X_{true} is the 'true' value of that parameter under the same test conditions, and the quantities η_c, $\mu_{\rho<1}$ and $\sigma_{\rho<1}$ are as defined in Section 3.3.3.1. Similarly, equation (2b) then becomes

$$\mu_{\rho>1} - \eta_c \sigma_{\rho>1} < X_{true}/X_{test} < \mu_{\rho>1} + \eta_c \sigma_{\rho>1} \tag{4b}$$

As before, since we do not know if the 'true' value of a response parameter under consideration is less than or greater than an existing (or a future) test value, equations (4a) and (4b) are combined to yield

$$\mu_{\rho<1} - \eta_c \sigma_{\rho<1} < \rho_o < \mu_{\rho>1} + \eta_c \sigma_{\rho>1} \tag{5}$$

where again ρ_o represents the ratio of the true value to a test value without any specification that the ratio be less than or greater than one. Values for η_c are again found using Table 3.6 and as before, Tables 3.7 through 3.9 are used to obtain means and standard deviations for the various test groupings considered.

3.4 Results and Discussion -- Repeatability Analysis

3.4.1 Introductory Comments

The results of the phenomena repeatability analysis (i.e. phase one of the total effort) presented in Tables 3.1 through 3.5 show that if 3 identical dual-wall structures with t_w=3.175 mm and S=10.16 cm were tested using the NASA/MSFC light gas gun under similar impact conditions (i.e. identical projectile diameter and trajectory obliquity, impact velocity within 0.2 km/sec), then it is entirely likely that either the pressure walls in 2 of these 3 tests will be perforated and 1 will not or the pressure walls in 2 of these tests will not be perforated and 1 will. These Tables also show that the repeatability of rear-side spallation (or the lack thereof) in such dual-wall structures is considerably higher: of 10 tests performed, it is highly likely that 9 of them will all either show some sort of rear-side spallation and 1 will not or 9 of them will all either not be spalled and 1 of them will. A more detailed review of Tables 3.2 through 3.5 reveals the following trends in perforation and spallation repeatability for dual-wall structures based on the Phase B and Phase C/D impact testing performed using the NASA/MSFC light gas gun.

3.4.2 Repeatability as Function of Stand-Off Distance

Although the number of tests with a 10.16 cm stand-off distance was much greater than the number of tests with a stand-off distance larger than 10.16 cm, certain trends are still discernable in the data in Table 3.1. Most apparent in Table 3.1 is that the perforation and spallation Repeatability Indices for S=15.24 and 30.48 cm are much lower than those for S=10.16 cm. This can be explained by the following considerations.

The most significant effect that increasing the stand-off distance has on the response of a dual-wall structure is that it allows the debris cloud created by the initial impact to expand still further before sriking the pressure wall plate. When S=10.16 cm, the debris cloud is more compact than when S=30.48 cm. Any inhomogeneities in the debris cloud (e.g. pockets of air, solid particle concentrations, etc.) are more likely to have a significant effect when the debris cloud is allowed to expand as much as possible. Otherwise, when the debris cloud is relatively compact, debris cloud inhomogeneities are overwhelmed by the overall debris cloud loading. Thus, the response among tests with S=30.48 cm will vary more from test to test because debris cloud inhomogeneities, which are a function of material defects and metallurgical imperfections, will vary from test to test.

3.4.3 Repeatability as Function of MLI Presence

Where comparisons between perforation Repeatability Indices for structures with and without MLI were possible (ie. in Table 3.2: θ=0°,30°; in Table 3.3: D=0.635 cm, and D=0.795,0.953 cm; in Table 3.4b: 6<V<7 km/sec; and, in Table 3.5: t_s=1.6 mm), the perforation Repeatability Indices for structures without MLI were greater than those for structures with MLI by approximately 23%. This increased perforation repeatability for dual-wall structures without MLI is probably due to the fact adding the MLI introduced another variable into the processes underway as a dual-wall system responds intially to the projectile impact loading and then the loading(s) due to the impact of the debris cloud(s) created by the initial impact. This extra variable in the response would naturally affect the interaction of the various processes, increase the range of possible response characteristics, and therefore decrease repeatability as compared to systems in which it was not present.

3.4.4 Repeatability as Function of Impact Angle

As the impact angle was increased from 0° to 75°, the repeatability indices for dual-wall structures with MLI hovered around 72% and then decreased to approximately 63% (Table 3.2). When the impact angle is below the critical angle of obliquity [3.3], the majority of debris cloud material is forced into the dual-wall system; only a small amount is expelled rearward as backsplash or ricochet debris. However, then the impact angle exceeds the critical angle, the majority of the debris cloud material is expelled as ricochet debris. For aluminum projectile impacting thin aluminum plates, this angle has been shown to have a value of approximately 60-65° [3.3].

Thus tests performed near the critical angle (i.e. at 60^{o} and 65^{o}) may show a wide variation in response characteristics as the response of the dual-wall system transitions from one mode of response (inward travelling debris clouds) to another (outward travelling or ricochet debris clouds).

While the Repeatability Index for dual-wall structures without MLI was relatively high for near-normal impacts (nearly 80%), sufficient information was not available at other trajectory obliquities to be able to quantify repeatability. With regard to spallation repeatability, for dual-wall structures with MLI, the Repeatability Indices increased as the impact angle increased. As noted previously, the presence of MLI effectively eliminates the possbility of rear-side spallation [3.3]. Hence, the agreement observed is for the most part agreement in the fact that spall will not occur. Since the amount of rear-side spall also decreases as impact angle increases, the repeatability of spall not occurring will naturally increase as impact angle increases.

3.4.5 Repeatability as Function of Projectile Diameter

Based on Table 3.3, both the perforation and the spallation repeatability indices increased as projectile diameter increased. This can be explained by considering the nature of pressure wall perforation as a function of impact energy, which is directly related to projectile diameter. When impact energy is relatively low, pressure wall perforation is driven by mechanical processes like fracture. These processes are very sensitive to mechanical or metallurgical imperfections so that in low energy impact, the repeatability of pressure wall perforation will be dependent on metallurgical consistency from test to test. If such consistency is not maintained, perforation repeatability in relatively low energy impacts (i.e. relatively small projectile diameters) will be relatively low. It is noted that when the impact energy is low enough so that perforation of the pressure wall is not likely to occur, we can expect repeatability to go up again since the response (i.e. non-perforation) will be more consistent. Alternatively, for a high energy impact, pressure wall perforation is driven by hydrodynamical considerations which are not as sensitive to mechanical defects as mechanical processes. Thus, for high energy impacts (i.e. for impacts with larger projectile diameters), the response will be relatively uniform.

3.4.6 Repeatability as Function of Impact Velocity

According to the arguments presented in the discussion of repeatability as a function of projectile diameter, it would be expected that repeatability would be relatively high for impact velocities below approximately 3 to 4 km/sec and above approximately 6 km/sec. Between 3 and 6 km/sec, where mechanical processes dominate the perforation of the pressure wall plate, repeatability would be expected to be lower than in the other two cases. As can be seen in Tables 3.4a and 3.4b, this is indeed the case for dual-wall structures with MLI: the perforation Repeatability Index varies from 90% at impact velocities below 4 km/sec to 57% for velocities between 5 and 6 km/sec to 90% again for speeds in excess of 7 km/sec.

3.4.7 Repeatability as Function of Bumper Thickness

From Table 3.5, it can be seen that the perforation Repeatability Index increases from only 50% at t_s=1.02 mm to 80% at t_s=2.03 mm for dual-wall structures with MLI. The scarcity of data for structures without MLI except in one test group prevents any conclusions from being drawn regarding the effect of bumper thickness on repeatability for such structures. With regard to spallation for dual-wall structures with MLI, the repeatability index starts out quite high for very thin bumper plates, decreases slightly as the bumper thickness increases, and then increases to a high level for the thickest bumper plate. Because MLI is present in these dual-wall systems, the agreement is with respect to the non-occurrence of rear-side spall; the spall that did occur in the tests with medium-thickness bumper plates was minimal. Therefore, the variation in the Repeatability Index for rear-side spall as a function of bumper thickness is not very significant.

Table 3.1 Overview of Perforation and Spallation Repeatability

Test Group	BP/BNP[1]	OP/ONP[2]	PRI[3]	BS/BNS[4]	OS/ONS[5]	SRI[6]
$2.9<V<7.3$ km/s $\theta=0^{0},45^{0},60^{0},65^{0},75^{0}$ D=0.475,0.635 cm 0.795,0.953 cm S=10.16 cm t_s=1.02,1.27,1.60, 2.03 mm With MLI	36	16	69.2%	46	6	88.5%
$5.1<V<6.9$ km/s $\theta=0^{0},45^{0}$ D=0.635,0.795 cm 0.953 cm S=30.48 cm t_s=1.6 mm With MLI	3	2	60.0%	2	3	40.0%
$3.6<V<7.2$ km/s $\theta=0^{0},30^{0}$ D=0.475,0.635 cm 0.795 cm S=10.16 cm t_s=1.60,2.03 mm Without MLI	10	2	83.3%	12	0	100.0%
$3.7<V<7.1$ km/s $\theta=0^{0}$ D=0.475,0.635 cm S=15.24 cm t_s=1.6 mm Without MLI	4	3	57.1%	3	4	42.9%
Overall	53	23	69.7%	63	13	82.9%

[1]Both tests perforated or both tests not perforated
[2]One test perforated and one test not perforated
[3]Perforation Repeatability Index
[4]Both tests spalled or both tests not spalled
[5]One test spalled and one test not spalled
[6]Spallation Repeatability Index

Table 3.2 Perforation and Spallation Repeatability as a Function of Impact Angle (S=10.16 cm)

Test Group	BP/BNP	OP/ONP	PRI	BS/BNS	OS/ONS	SRI
			$\theta=0^0, 30^0$			
.9<V<7.3km/s D=0.475,0.635 cm 0.795,0.953 cm t_s=1.02,1.60 mm With MLI	18	7	72.0%	23	2	92.0%
3.6<V<7.2km/s D=0.475,0.635 cm 0.795 cm t_s=1.60,2.03 mm Without MLI	7	2	77.8%	9	0	100.0%
			$\theta=45^0$			
3.1<V<6.9 km/s D=0.475,0.635 cm 0.953 cm t_s=1.27,2.03 mm With MLI	13	6	72.2%	16	3	88.9%
6.6<V<7.0 km/s D=0.635,0.795 cm t_s=1.60 mm Without MLI	2	0	(1)[7]	2	0	(1)[7]
			$\theta=60^0, 65^0, 75^0$			
2.9<V<6.5 km/s D=0.635,0.795 cm t_s=1.02,1.27 mm 2.03 mm With MLI	5	3	63.5%	8	0	100.0%
7.1<V<7.3km/s D=0.475 cm t_s=1.60 mm Without MLI	1	0	(1)	1	0	(1)
Overall	46	18	71.9%	59	5	92.2%

[7]Sufficient no. of tests not available for Repeatability Index calculation

Table 3.3 Perforation and Spallation Repeatability as a Function of Projectile Diameter (S=10.16 cm)

Test Group	BP/BNP	OP/ONP	PRI	BS/BNS	OS/ONS	SRI
			D=0.475 cm			
6.4<V<7.3 km/s θ=0°,45° t_s=1.02,2.03 mm With MLI	1	1	(1)	2	0	(1)
3.6<V<7.3 km/s θ=0°,65° t_s=1.60,2.03 mm Without MLI	2	1	66.7%	3	0	100.0%
			D=0.635 cm			
2.9<V<6.9 km/s θ=0°,45°,65° t_s=1.02,1.27 mm 1.60,2.03 mm With MLI	16	10	61.5%	21	5	76.9%
4.9<V<7.2 km/s θ=0°,30°,45° t_s=1.60 mm Without MLI	4	1	80.0%	5	0	100.0%
			D=0.795,0.953 cm			
2.9<V<7.2 km/s θ=0°,45°,60°,75° t_s=1.02,1.27 mm 1.60,2.03 mm With MLI	19	5	79.2%	24	0	100.0%
4.3<V<6.8 km/s θ=0°,45° t_s=1.60 mm Without MLI	4	0	100.0%	4	0	100.0%
Overall	46	18	71.9%	59	5	92.2%

Table 3.4a Perforation and Spallation Repeatability as a Function of Impact Velocity ($S=10.16$ cm, $2.9<V<6$ km/sec)

Test Group	BP/BNP	OP/ONP	PRI	BS/BNS	OS/ONS	SRI
			$2.9<V<4$ km/sec			
$\theta=0^{\circ},45^{\circ},75^{\circ}$ D=0.635,0.795 cm t_s=1.60,2.03 mm With MLI	9	1	90.0%	9	1	90.0%
$\theta=0^{\circ}$ D=0.475 cm t_s=2.03 mm Without MLI	0	1	(1)	1	0	(1)
			$4<V<5$ km/sec			
$\theta=0^{\circ},65^{\circ}$ D=0.635 cm t_s=1.60 mm With MLI	1	1	(1)	1	1	(1)
$\theta=0^{\circ}$ D=0.475,0.635 cm 0.795 cm t_s=1.60,2.03 mm Without MLI	3	0	100.0%	3	0	100.0%
			$5<V<6$ km/sec			
$\theta=45^{\circ}$ D=0.635 cm t_s=1.27 mm With MLI	4	3	57.1%	4	3	57.1%
Without MLI	N/A	N/A	N/A	N/A	N/A	N/A

Table 3.4b Perforation and Spallation Repeatability as a Function of Impact Velocity (S=10.16 cm, 6<V<8 km/sec)

Test Group	BP/BNP	OP/ONP	PRI	BS/BNS	OS/ONS	SRI
			6<V<7 km/sec			
θ=0°,45°,75° D=0.475,0.635 cm 0.795,0.953 cm t_s=1.02,1.27 mm 1.60,2.03 mm With MLI	15	10	60.0%	24	0	100.0%
θ=0°,30°,45° D=0.635,0.795 cm t_s=1.60 mm Without MLI	5	1	83.3%	6	0	100.0%
			7<V<8 km/sec			
θ=0° D=0.475,0.795 cm t_s=1.02,1.60 mm With MLI	7	1	87.5%	9	0	100.0%
θ=30°,65° D=0.475,0.635 cm t_s=1.60 mm Without MLI	2	0	(1)	2	0	(1)
Overall†	46	18	71.9%	49	5	92.2%

†Includes Tables X-4a and X-4b

Table 3.5 Perforation and Spallation Repeatability as a Function of Bumper Thickness (S=10.16 cm)

Test Group	BP/BNP	OP/ONP	PRI	BS/BNS	OS/ONS	SRI
		t_s=1.02 mm				
4.6<V<7.3 km/s D=0.475,0.635 cm 0.795 cm $\theta=0^0,65^0$ With MLI	3	3	50.0%	6	0	100.0%
Without MLI	N/A	N/A	N/A	N/A	N/A	N/A
		t_s=1.27 mm				
2.9<V<6.4 km/s D=0.635,0.953 cm $\theta=45^0,60^0$ With MLI	8	7	53.3%	12	3	80.0%
Without MLI	N/A	N/A	N/A	N/A	N/A	N/A
		t_s=1.60 mm				
2.9<V<7.2 km/s D=0.635,0.795 cm 0.953 cm $\theta=0^0$ With MLI	17	4	80.9%	19	2	90.4%
4.3<V<7.3 km/s D=0.475,0.635 cm 0.795 cm $\theta=0^0,30^0,45^0,65^0$ Without MLI	9	1	90.0%	10	0	100.0%
		t_s=2.03 mm				
3.1<V<6.9 km/s D=0.475,0.635 cm 0.795 cm $\theta=45^0,75^0$ With MLI	8	2	80.0%	10	0	100.0%
3.6<V<4.3 km/s D=0.475 cm $\theta=0^0$ Without MLI	1	1	(1)	2	0	(1)
Overall	46	18	71.9%	59	5	92.2%

3.5 Results and Discussion -- Uncertainty Analysis

3.5.1 Introductory Comments

This section consists of a discussion of the results obtained using the two approaches to the data uncertainty analysis developed in Section 3.3.3. Also presented are several examples using the equations derived and the information provided in Tables 3.6-3.9. The use of the Tables and equations for the two approaches is demonstrated first, followed by a discussion of the observable trends in the uncertainty analysis data. It is noted that in Table 3.7, for a non-zero impact angle, the first and second lines of information pertain to the minimum and maximum hole dimensions, respectively.

3.5.2 Illustrative Examples -- First Approach

The data in Tables 3.6-3.9 can be used to calculate intervals within which a certain percentage of response parameter ratios can be expected to lie, given a certain level of confidence. Alternatively, the specified confidence level is the probability that the a particular response parameter ratio is within the calculated interval. In either case, it is assumed that there is no fixed or bias error present in the experimental readings.

As an example, consider a test series in which 0.795 cm (0.313 in.) diameter projectiles normally impact a dual-wall system at a speed of 6.5 km/sec. We wish to know what are the extents of the intervals within which lie 75% and 90% of the bumper plate hole diameter ratios for the given impact conditions. Using equation (3) together with the values of $\mu_{\rho<1}, \sigma_{\rho<1}$ and $\mu_{\rho>1}, \sigma_{\rho>1}$ in Table 3.7 for a 0^{o} impact, we have

$$0.944 - 0.050\eta_c < \rho_o < 1.062 + 0.058\eta_c \qquad (6)$$

where η_c is dependent on the specified level of confidence 'c' and the number of degrees of freedom n=N-1 in the test group under consideration. In this case, N=20 so that n=19; if we specify a 75% confidence level, then from Table 3.6 we see that η_c=0.688. Substituting η_c=0.688 into equation (4) tells us that there is a 75% probability that, if fixed errors in data collection are ignored, the ratio of the bumper plate hole diameters for two additional tests at similar impact conditions will lie between 0.906 and 1.102.

For a 90% confidence level, Table 3.6 tells us that η_c=1.328. Substituting this value into equation (6) results in an interval that extends from 0.878 to 1.139. In this case, as for the previous confidence level considered, the extent of the interval about unity is relatively small (only 10-12% on either side of unity). This is due to the small deviations of the ratios of recorded hole diameter ratios about a value of 1.0 as is evidenced by the proximity of the means $\mu_{\rho<1}$ and $\mu_{\rho>1}$ to 1.0 and the small values of the standard deviations $\sigma_{\rho<1}$ and $\sigma_{\rho>1}$ in Table 3.7.

The same procedure can be used to determine modified confidence intervals for the pressure wall hole diameter data (in the event of a perforation) and the pressure wall damage area data. For example, for a test series using dual-wall systems with MLI at V=6.5 km/sec where pressure wall perforation does occur, equation (3) and the information in Table 3.8 yields

$$0.712 - 0.301\eta_c < \rho_o < 1.398 + 0.150\eta_c \tag{7}$$

For a 75% confidence level with, in this case, n=13-1=12, Table 3.6 tells us that η_c=0.695. Thus, the 75% modified confidence interval for a test series under these conditions extends from 0.503 to 1.502. In turn, this tells us that there is a 75% probability that the ratio between the pressure wall hole diameters in two tests in which perforation had occurred will lie between 0.503 and 1.502. Similarly, for a test on dual-wall structure with MLI and in which t_s=0.050 in., equation (3) and the information in Table 3.9 yield the equation

$$0.777 - 0.277\eta_c < \rho_o < 1.280 + 0.367\eta_c \qquad (8)$$

For a 75% confidence interval with, in this case, n=14-1=13, Table 3.6 tells us that η_c=0.694. This results in a 75% modified confidence interval that extends from 0.585 to 1.534.

As can be seen from these examples, the extent of the modified confidence intervals for the pressure wall hole diameter and damage area data are significantly larger than that for the bumper plate hole diameter data for the same level of confidence. Possible explanations for this as well as a discussion of other observed trends in the uncertainty analysis data are presented in Section 3.5.4.

3.5.3 Illustrative Examples -- Second Approach

The data in Tables 3.6-3.9 can also be used to calculate intervals within which it may supposed that the 'true' value of a response parameter lies, given a certain level of confidence. Alternatively, the specified confidence level is the probability that the supposed 'true' value of a response parameter is within the calculated interval. In either case, as before, it is assumed that there is no fixed or bias error present in the experimental readings.

For the first example, consider Test No. ESSH-6A (see Section 3.8, Table 3.11) in which a 0.795 cm (0.313 in.) diameter projectile normally impacted a dual-wall system at a speed of 6.55 km/sec. The recorded diameter of the hole in the bumper plate is 1.636 cm (0.644 in). We wish to know how representative of the actual or true bumper plate hole diameter is the recorded value for the given impact conditions. Using equation (5), we can determine an interval for a given level of confidence within which the true value of hole diameter for the given conditions is expected to be. Specifically, using the values of $\mu_{\rho<1}, \sigma_{\rho<1}$ and $\mu_{\rho>1}, \sigma_{\rho>1}$ in Table 3.7 for a 0^o impact, equation (5) becomes

$$0.944 - 0.050\eta_c < \rho_o < 1.062 + 0.058\eta_c \tag{9}$$

where η_c is dependent on the specified level of confidence 'c' and the number of degrees of freedom n=N-1 in the test group under consideration. In this case, N=20 so that n=19; if we specify a 75% confidence level, then from Table 3.6 we see that η_c=0.688. Substituting η_c=0.688 into equation (9) tells us that there is a 75% probability that, if fixed errors in data collection are ignored, the actual or true value of the bumper hole diameter lies between 0.906 and 1.102 times the recorded value, or between 1.481 and 1.801 cm (0.583 and 0.709 in.).

For this example, if we wish to increase our confidence in the interval within which the true value of hole diameter lies, then that interval must increase in size. Thus, for a 90% confidence level, Table 3.6 tells us that η_c=1.328. Substituting this value into equation (9) results in an interval that extends from 0.878 to 1.139 times the recorded value or between 1.435 and 1.864 cm (0.565 and 0.734 in.). In this case, as for the previous confidence level considered, the extent of the interval about the recorded value is relatively small (only 10-12% on either side of the recorded value). This is due to the small deviations of the ratios of recorded hole diameters about a value of 1.0 as is evidenced by the proximity of the means $\mu_{\rho<1}$ and $\mu_{\rho>1}$ to 1.0 and the small values of the standard deviations $\sigma_{\rho<1}$ and $\sigma_{\rho>1}$ in Table 3.7.

The same procedure can be used to determine modified confidence intervals for the pressure wall hole diameter data (in the event of a perforation) and the pressure wall damage area data. For example, for a test on a dual-wall system with MLI at V=6.5 km/sec where pressure wall perforation occurs, equation (5) and the information in Table 3.8 yields

$$0.712 - 0.301\eta_c < \rho_o < 1.398 + 0.150\eta_c \tag{10}$$

For a 75% confidence level with, in this case, n=13-1=12, Table 3.6 tells us that η_c=0.695. Thus, the true value of pressure wall hole diameter for a test in which perforation occurs would lie between 0.503 and 1.502 times a recorded value. Similarly, for a test on dual-wall structure with MLI and in which t_s=0.050 in., equation (5) and the information in Table 3.9 yield the equation

$$0.777 - 0.277\eta_c < \rho_o < 1.280 + 0.367\eta_c \tag{11}$$

For a 75% confidence interval with, in this case, n=14-1=13, Table 3.6 tells us that η_c=0.694. This implies that the true value of pressure wall damage area would lie between 0.585 and 1.534 times the recorded value.

3.5.4 Observations on the Data

As can be seen by inspecting the value of the means and standard deviations in for the various test groups in Table 3.7-3.9, the level of uncertainty in the response data can vary significantly depending on the response considered. Specifically, as stated previously, the means of the bumper plate diameter data are all fairly close to 1.0 and the standard deviations are all fairly small (Table 3.8). This implies that we can be fairly confident that the recorded values of bumper plate hole diameters are fairly consistent and may indeed be representative of the actual or true hole diameter values. However, this is not necessarily the case for the pressure wall hole diameter or pressure wall damage area values: there can be a significant amount of uncertainty in the pressure wall response data. This issue is discussed in detail in the following paragraphs.

For pressure wall hole diameter in the event of a perforation (Table 3.8), the means are larger and the standard deviations are smaller for 0^o impacts than for 45^o impacts. For pressure wall damage area (Table 3.9), they are similar for 0^0 and 45^0 impacts but in general smaller than those for 60^o,65^o, and 75^o impacts. Tests with lower impact velocities (ie. below approximately 5.5 km/sec) also exhibited less variability in pressure wall hole diameter data than did tests with impact velocities above 5.5 km/sec (Table 3.8); however, the variability in pressure wall damage area data was approximately the same for all impact velocities. In terms of bumper thickness, the variability in the pressure wall hole diameter and damage area data decreased (ie. larger means, smaller standard deviations) as bumper thickness increased. As a function of projectile diameter, the variability in the data was relatively the similar for the 0.635 and 0.795 cm (0.250 and 0.313 in.) diameter projectiles, but smaller than that for those with a 0.475 cm (0.187 in.) diameter.

The observations in the previous paragraph can be explained by the following considerations. First, at lower impact velocities and in normal impacts there are fewer competing processes at work during the impact event than at higher impact velocities (where fragmentation and melting occur simultaneously) and in oblique impacts (where two or three debris clouds are created instead of just one). This would result in more consistent pressure wall response values such as hole diameter and damage area. Second, the larger projectiles were deformed less in their flights through the light gas gun than were the 0.475 cm (0.187 in.) diameter projectile. This in-flight projectile deformation for the smaller projectiles naturally affected the orientation of the smaller projectile at impact which significantly affected the consistency of system response in such cases.

While the information presented in Tables 3.7-3.9 has been used in this report to assess the uncertainty in the impact test data obtained thus far, it also can be used in another related manner. Specifically, the data in Tables 3.7-3.9 to provide insight into the sensitivity of dual-wall system response to minute differences in impact conditions, material composition, specimen thickness, etc. This use of the data is discussed in the following paragraphs.

Consider a response paramter, such as bumper plate hole diameter, whose modified confidence interval is relatively small (e.g. $\pm$10%) at a relatively high confidence level (e.g. 90%). In this case, it can be said that the parameter is relatively insensitive to small changes such as those listed in the previous paragraph, and that the data for this parameter are expected to be consistent from one test to another, despite the fact that there may be small unavoidable differences present. This in turn implies that a relatively small number of tests will be required to characterize such a parameter under the test conditions of interest.

Alternatively, consider a response parameter, such as pressure wall damage area, whose modified confidence interval is relatively large (e.g. ±50%) even at relatively low confidence levels (e.g. 75%). In this case, it may be argued that the parameter is in fact highly sensitive to minute changes in test conditions. The data for this parameter are highly scattered and are not expected to be consistent from one test to another. However, this does not imply that there is necessarily anything wrong with the data. On the contrary, the results of the individual tests are appropriate for the specific conditions of a specific test. For such a response parameter, small unavoidable variations from test to test will apparently result in differences in response which will in turn result in the unsightly scatter of the test data. The final implication is that a relatively large number of tests will be required to characterize such a response parameter under the test conditions of interest.

Table 3.6 Values of η_c as a Function of Number-of-Degrees-of-Freedom (n) and Confidence Level (c) [3.2]

n \ c	.60	.75	.90	.95	.975	.99	.995	.9995
1	.325	1.000	3.078	6.314	12.706	31.821	63.657	636.619
2	.289	.816	1.886	2.920	4.303	6.965	9.925	31.598
3	.277	.765	1.638	2.353	3.182	4.541	5.841	12.924
4	.271	.741	1.533	2.132	2.776	3.747	4.604	8.610
5	.267	.727	1.476	2.015	2.571	3.365	4.032	6.869
6	.265	.718	1.440	1.943	2.447	3.143	3.707	5.959
7	.263	.711	1.415	1.895	2.365	2.998	3.499	5.408
8	.262	.706	1.397	1.860	2.306	2.896	3.355	5.041
9	.261	.703	1.383	1.833	2.262	2.821	3.250	4.781
10	.260	.700	1.372	1.812	2.228	2.764	3.169	4.587
11	.260	.697	1.363	1.796	2.201	2.718	3.106	4.437
12	.259	.695	1.356	1.782	2.179	2.681	3.055	4.318
13	.259	.694	1.350	1.771	2.160	2.650	3.012	4.221
14	.258	.692	1.345	1.761	2.145	2.624	2.977	4.140
15	.258	.691	1.341	1.753	2.131	2.602	2.947	4.073
16	.258	.690	1.337	1.746	2.120	2.583	2.921	4.015
17	.257	.689	1.333	1.740	2.110	2.567	2.898	3.965
18	.257	.688	1.330	1.734	2.101	2.552	2.878	3.922
19	.257	.688	1.328	1.729	2.093	2.539	2.861	3.883
20	.257	.687	1.325	1.725	2.086	2.528	2.845	3.850
21	.257	.686	1.323	1.721	2.080	2.518	2.831	3.819
22	.256	.686	1.321	1.717	2.074	2.508	2.819	3.792
23	.256	.685	1.319	1.714	2.069	2.500	2.807	3.767
24	.256	.685	1.318	1.711	2.064	2.492	2.797	3.745
25	.256	.684	1.316	1.708	2.060	2.485	2.787	3.725
26	.256	.684	1.315	1.706	2.056	2.479	2.779	3.707
27	.256	.684	1.314	1.703	2.052	2.473	2.771	3.690
28	.256	.683	1.313	1.701	2.048	2.467	2.763	3.674
29	.256	.683	1.311	1.699	2.045	2.462	2.756	3.659
30	.256	.683	1.310	1.697	2.042	2.457	2.750	3.646
40	.255	.681	1.303	1.684	2.021	2.423	2.704	3.551
60	.254	.679	1.296	1.671	2.000	2.390	2.660	3.460
120	.254	.677	1.289	1.658	1.980	2.358	2.617	3.373
∞	.253	.674	1.282	1.645	1.960	2.326	2.576	3.291

Table 3.7 Bumper Plate Hole Diameter Ratio Uncertainty Data

θ	N	$\mu_{\rho<1}$	$\sigma_{\rho<1}$	$\mu_{\rho>1}$	$\sigma_{\rho>1}$
0°	20	0.944	0.050	1.062	0.058
45°	18	0.940	0.060	1.068	0.074
		0.953	0.036	1.051	0.040
$60^{\circ}, 65^{\circ}$	9	0.937	0.055	1.070	0.067
75°		0.937	0.049	1.070	0.058

Table 3.8 Pressure Wall Hole Diameter Ratio Uncertainty Data

	MLI	N	$\mu_{\rho<1}$	$\sigma_{\rho<1}$	$\mu_{\rho>1}$	$\sigma_{\rho>1}$
As a Function of Impact Angle θ (in degrees)						
$\theta=0^{o}$	Y	11	0.855	0.117	1.152	0.185
	N	5	0.723	0.147	1.439	0.343
$\theta=45^{o}$	Y	7	0.698	0.250	1.616	0.613
	N	---	---	---	---	---
As a Function of Bumper Thickness t_s (in inches)						
$t_s=0.050$	Y	4	0.601	0.272	1.887	0.675
	N	---	---	---	---	---
$t_s=0.080$	Y	3	0.827	0.181	1.253	0.305
	N	---	---	---	---	---
As a Function of Impact Velocity V (in km/sec)						
$3<V<5.5$	Y	5	0.854	0.093	1.184	0.150
	N	2	0.822	0.038	1.218	0.056
$5.5<V<8$	Y	13	0.712	0.301	1.398	0.150
	N	3	0.656	0.162	1.586	0.391
As a Function of Projectile Diameter D (in inches)						
D=0.250	Y	8	0.735	0.235	1.522	0.592
	N	2	0.837	0.017	1.195	0.024
D=0.313	Y	8	0.646	0.146	1.169	0.221
	N	3	0.876	0.123	1.601	0.369

Table 3.9 Pressure Wall Damage Area Ratio Uncertainty Data

	MLI	N	$\mu_{\rho<1}$	$\sigma_{\rho<1}$	$\mu_{\rho>1}$	$\sigma_{\rho>1}$
As a Function of Impact Angle θ (in degrees)						
$\theta=0^o$	Y	21	0.746	0.223	1.510	0.610
	N	8	0.735	0.172	1.448	0.442
$\theta=45^o$	Y	18	0.864	0.092	1.170	0.135
	N	---	---	---	---	---
$\theta=60^o$, 65^o, 75^o	Y	8	0.571	0.181	1.953	0.762
	N	---	---	---	---	---
As a Function of Bumper Thickness t_s (in inches)						
$t_s=0.040$	Y	6	0.610	0.240	1.864	0.699
	N	---	---	---	---	---
$t_s=0.050$	Y	14	0.777	0.277	1.280	0.367
	N	---	---	---	---	---
$t_s=0.063$	Y	16	0.784	0.192	1.388	0.570
	N	8	0.689	0.166	1.534	0.399
$t_s=0.080$	Y	10	0.739	0.166	1.452	0.517
	N	---	---	---	---	---
As a Function of Impact Velocity V (in km/sec)						
$3<V<5.5$	Y	12	0.776	0.226	1.448	0.612
	N	4	0.568	0.451	1.456	0.649
$5.5<V<8$	Y	34	0.763	0.185	1.442	0.490
	N	6	0.677	0.114	1.518	0.299
As a Function of Projectile Diameter D (in inches)						
D=0.187	Y	---	---	---	---	---
	N	3	0.520	0.345	2.552	1.519
D=0.250	Y	25	0.803	0.181	1.338	0.432
	N	4	0.664	0.147	1.577	0.423
D=0.313	Y	18	0.725	0.194	1.514	0.555
	N	4	0.714	0.202	1.489	0.430

3.6 Concluding Comments

By examining Tables 3.1-3.5 and 3.7-3.9, it is possible to see where additional testing is needed to supplement data already in existence. Additional data will allow the calculation of repeatability indices for test groups for which at present it is not possible. Specifically for dual-wall systems with a 10.16 cm stand-off distance without MLI, test results are needed at impact angles above 30°, with small and large projectiles, at impact velocities other than between 6 and 7 km/sec, and with bumper thicknesses other than 1.6 mm. For similar systems with MLI, additional testing is needed at impact angles above 60°, with small projectile diameters, and also at speeds other than between 6 and 7 km/sec.

It should be noted that the variations in perforation and rear-side spallation indicated in the various Tables in Section 3.8 are probably not due to an inability to properly control the experimental parameters of the tests performed. Geometric parameters (thicknesses and wall-to-wall spacing), material properties (density, modulus, etc.) and impact conditions (diameter, angle, and velocity) can all be controlled to within acceptable tolerances. Rather, the variations observed are probably due to an factor that to date has not be measured, accounted for, or controlled. Such factors include manufacturing defects, metallurgical inconsistencies, and location of the initial impact on the bumper plate, to name a few. Increased attention must be paid to these and other here-to-fore unconsiderd factors if it is desired to increase the repeatability of the phenomena observed through hypervelocity impact testing using the NASA/MSFC light gas gun.

Finally, it is worthy of note that the observations made in the uncertainty analysis phase of this investigation reinforce those made during the repeatability phase of the study. Since both phases of the study utilized the same pool of data, this is hardly surprising. Specifically, both phases of this study conclude that repeatability increases (or, conversely, variability decreases) as the impact angle decreases, the projectile diameter increases, and as the bumper thickness increases.

For impact velocity, the repeatability analysis show that repeatability was relatively similarly high for speeds below 4 to 5 km/sec and above 6 km/sec and relatively low for impact speeds between 5 and 6 km/sec. The uncertainty analysis showed lower variability in response for tests with impact velocities below approximately 5.5 km/sec than for tests with velocities greater than 5.5 km/sec. While in not as great detail as are the results of the repeatability analysis for impact velocity, the results of the uncertainty analysis at least support those of the repeatability analysis in the lower impact velocity regime. The apparent contradiction at the higher impact velocities is probably due to the fact that all tests with velocities above 5.5 km/sec were included in one test group in the uncertainty analysis and not broken down into two groups as in the repeatability study.

3.7 References

3.1 Coleman, H.W. and Steele, W.G., Experimentation and Uncertainty Analysis for Engineers, John Wiley, New York, 1989.

3.2 Fisher, R.A., and Yates, F., Statistical Tables, Oliver and Boyd, Ltd., London, 1938.

3.3 Schonberg, W.P., Bean, A.J., and Darzi, K., Hypervelocity Impact Physics, NASA CR-4343, January, 1991.

3.8 Uncertainty Analysis Data Tables

IMPACT ANGLE (DEG)	PROJECTILE DIAMETER (IN)	TEST NUMBER	IMPACT VELOCITY (KM/SEC)	SHIELD THICKNESS (IN)	STAND-OFF DISTANCE (IN)	MLI LOCATION	BUMPER HOLE DIAMETER (IN)	PRESSURE WALL HOLE DIAMETER (IN)	NUMBER OF HOLES	DAMAGE AREA (SQ.IN.)	MAXIMUM PETAL LENGTH (IN)	SPALL AREA (SQ.IN.)
0.000	0.250	3224B	5.260	0.063	12.000	PWP	0.521	---	---	41.280	---	---
		3224A	5.150	0.063	12.000	PWP	0.486	0.115	1	47.170	---	0.010
0.000	0.313	3220A	5.960	0.032	12.000	PWP	0.474	0.073	2	30.680	---	---
		3223A	5.850	0.032	12.000	PWP	0.595	---	---	45.720	---	0.090
0.000	0.375	3225	5.940	0.032	12.000	PWP	0.493	7.790	1	88.750	4.000	---
		3225A	5.910	0.032	12.000	PWP	0.483	6.630	1	34.520	2.300	---
0.000	0.375	3226B	5.550	0.063	12.000	PWP	0.638	0.624	5	35.790	---	---
		3226A	5.620	0.063	12.000	PWP	0.618	0.187	3	88.580	---	0.090
45.000	0.313	3133C	6.910	0.063	12.000	PWP	0.641/0.830	---/0.422	---/3	16.76/11.05	---/---	---/---
		3133D	6.780	0.063	12.000	PWP	0.642/0.818	---/0.518	---/3	8.30/38.49	---/---	---/---
0.000	0.187	P14	3.720	0.063	6.000	---	0.391	0.459	3	7.350	---	---
		P14B	3.710	0.063	6.000	---	0.417	---	---	20.910	---	0.050
0.000	0.187	2001A	3.770	0.063	6.000	---	0.353	0.273	2	23.760	---	---
		2001B	3.930	0.063	6.000	---	0.350	0.204	2	41.280	---	0.040
0.000	0.187	2001A	3.770	0.063	6.000	---	0.353	0.273	2	23.760	---	---
		2001C	4.050	0.063	6.000	---	0.377	---	---	30.680	---	0.010
0.000	0.187	2001B	3.930	0.063	6.000	---	0.350	0.204	2	41.280	---	0.040
		2001C	4.050	0.063	6.000	---	0.377	---	---	30.680	---	0.010
0.000	0.187	P24C	5.800	0.063	6.000	---	0.560	0.190	3	22.370	---	0.480
		P24F	5.880	0.063	6.000	---	0.530	0.190	3	25.800	---	0.340
0.000	0.250	2003A	7.000	0.063	6.000	---	0.542	0.209	5	78.540	---	0.240
		2003B	7.100	0.063	6.000	---	0.522	0.296	4	70.880	---	---
0.000	0.300	P16C	6.630	0.063	6.000	---	0.600	0.695	1	20.620	---	2.030
		P16E	6.780	0.063	6.000	---	0.620	0.920	1	28.270	---	1.960

Table 3.10 Dual-Wall Structures, With and Without MLI, S>4 inches

IMPACT ANGLE (DEG)	PROJECTILE DIAMETER (IN)	TEST NUMBER	IMPACT VELOCITY (KM/SEC)	SHIELD THICKNESS (IN)	MIN BUMPER HOLE DIA. (IN)	MAX BUMPER HOLE DIA. (IN)	NORMAL: PRESSURE WALL HOLE DIAMETER (IN)	NORMAL: NUMBER OF HOLES	NORMAL: DAMAGE AREA (SQ.IN.)	NORMAL: MAXIMUM PETAL LENGTH (IN)	NORMAL: SPALL AREA (SQ.IN.)	OBLIQUE: PRESSURE WALL HOLE DIAMETER (IN)	OBLIQUE: NUMBER OF HOLES	OBLIQUE: DAMAGE AREA (SQ.IN.)	OBLIQUE: MAXIMUM PETAL LENGTH (IN)	OBLIQUE: SPALL AREA (SQ.IN.)
0.000	0.187	101A	3.700	0.080	0.370	0.370	0.171	2	3.970	---	---	---	---	---	---	---
		109B	3.610	0.080	0.400	0.400	---	---	9.620	---	---	---	---	---	---	---
0.000	0.187	101B	4.260	0.080	0.560	0.560	---	---	12.560	---	---	---	---	---	---	---
		109A	4.060	0.080	0.429	0.429	---	---	13.850	---	---	---	---	---	---	---
0.000	0.250	P03	4.900	0.063	0.491	0.491	0.358	1	12.560	---	0.530	---	---	---	---	---
		P04	4.950	0.063	0.491	0.491	0.304	1	10.010	---	0.310	---	---	---	---	---
0.000	0.250	P05	6.900	0.063	0.560	0.560	0.185	1	14.190	---	0.030	---	---	---	---	---
		P06A	6.950	0.063	0.572	0.572	---	---	19.640	---	0.720	---	---	---	---	---
0.000	0.313	PT8A	4.350	0.063	0.490	0.490	1.850	1	12.620	---	0.960	---	---	---	---	---
		PT8B	4.370	0.063	0.500	0.500	1.470	2	13.210	---	0.220	---	---	---	---	---
0.000	0.313	EH3A	6.640	0.063	0.611	0.611	1.960	2	31.960	---	1.110	---	---	---	---	---
		EHSS6C	6.690	0.063	0.622	0.622	1.260	1	19.630	---	0.840	---	---	---	---	---
0.000	0.313	EHSS6B	6.630	0.063	0.578	0.578	2.230	7	16.800	---	0.050	---	---	---	---	---
		EHSS6A	6.550	0.063	0.644	0.644	1.120	1	13.360	---	1.020	---	---	---	---	---
30.000	0.250	EHSS3C	6.810	0.063	0.491	0.542	0.790	1	10.320	---	---	---	---	---	---	---
		135D	6.850	0.063	0.521	0.561	0.957	1	15.210	---	---	---	---	---	---	---
45.000	0.250	EHSS4A	6.780	0.063	0.573	0.747	---	---	2.410	---	---	0.330	2	1.480	---	---
		EHSS4B	6.970	0.063	0.563	0.697	0.155	1	3.140	---	---	0.510	4	5.410	---	---
45.000	0.313	EHRP3	6.830	0.063	0.625	0.781	---	---	6.490	---	---	1.010	3	7.070	---	---
		EHSS7A	6.630	0.063	0.656	0.822	---	---	3.140	---	---	0.900	4	3.550	---	---
65.000	0.187	EHRP9	7.320	0.063	0.472	0.669	---	---	15.710	---	---	---	---	---	---	---
		156A	7.120	0.063	0.537	0.680	---	---	3.800	---	---	---	---	---	---	---

Table 3.11 Dual-Wall Structures, Without MLI, Normal and Oblique Impact, S=4 inches

IMPACT ANGLE (DEG)	PROJECTILE DIAMETER (IN)	TEST NUMBER	IMPACT VELOCITY (KM/SEC)	SHIELD THICKNESS (IN)	MLI LOCATION	BUMPER HOLE DIAMETER (IN)	PRESSURE WALL HOLE DIAMETER (IN)	NUMBER OF HOLES	DAMAGE AREA (SQ.IN.)	MAXIMUM PETAL LENGTH (IN)	SPALL AREA (SQ.IN.)
0.000	0.187	3010C	7.320	0.040	PWP	0.439	0.068	1	1.770	---	---
		3202	7.200	0.040	PWP	0.424	---	---	4.910	---	---
0.000	0.250	3405A	3.030	0.063	HW	0.407	0.335	1	5.390	---	---
		3406A	3.060	0.063	HW	0.420	0.231	1	4.910	---	---
0.000	0.250	3405B	3.830	0.063	HW	0.460	---	1	8.920	---	---
		3406B	4.050	0.063	HW	0.456	---	1	8.300	---	---
0.000	0.250	3405C	5.100	0.063	HW	0.494	---	1	9.620	---	---
		3406C	5.160	0.063	HW	0.459	---	---	10.290	---	---
0.000	0.250	3405D	6.200	0.063	HW	0.516	---	---	8.970	---	---
		3406D1	6.290	0.063	HW	0.485	0.265	2	8.310	---	---
0.000	0.250	3206	6.800	0.040	PWP	0.447	0.236	4	3.140	---	---
		3205	6.750	0.040	PWP	0.489	---	---	7.650	---	---
0.000	0.250	3206	6.800	0.040	PWP	0.447	0.236	4	3.140	---	---
		3010-1B	6.760	0.040	PWP	0.442	0.250	1	3.560	---	---
0.000	0.250	3010-1B	6.760	0.040	PWP	0.442	0.250	1	3.560	---	---
		3205	6.750	0.040	PWP	0.489	---	---	7.650	---	---
0.000	0.250	P07	2.930	0.063	HW	0.420	0.360	1	2.240	---	---
		P08	2.960	0.063	HW	0.430	0.390	1	3.140	---	0.330
0.000	0.250	3406A	3.060	0.063	PWP	0.420	0.231	1	4.910	---	---
		3405A	3.060	0.063	PWP	0.407	0.261	1	5.390	---	---
0.000	0.250	P12C	4.330	0.063	PWP	0.470	---	---	3.300	---	---
		T2-4	4.320	0.063	PWP	0.438	0.528	5	7.670	---	0.560

Table 3.12 Dual-Wall Structures, With MLI, Normal Impact, S=4 inches

IMPACT ANGLE (DEG)	PROJECTILE DIAMETER (IN)	TEST NUMBER	IMPACT VELOCITY (KM/SEC)	SHIELD THICKNESS (IN)	MLI LOCATION	BUMPER HOLE DIAMETER (IN)	PRESSURE WALL HOLE DIAMETER (IN)	NUMBER OF HOLES	DAMAGE AREA (SQ.IN.)	MAXIMUM PETAL LENGTH (IN)	SPALL AREA (SQ.IN.)
0.000	0.313	T2-7	3.260	0.063	PWP	0.488	0.564	1	7.670	---	---
		T2-7A	3.260	0.063	PWP	0.547	0.632	1	7.670	1.500	---
0.000	0.313	EH2B	6.670	0.063	PWP	0.751	---	---	4.910	---	---
		EH2C	6.640	0.063	PWP	0.631	0.410	1	2.760	4.500	---
0.000	0.313	EH2B	6.670	0.063	PWP	0.751	---	---	4.910	---	---
		EH2D	6.660	0.063	PWP	0.635	1.516	1	7.740	4.400	---
0.000	0.313	EH2C	6.640	0.063	PWP	0.631	0.410	1	2.760	4.500	---
		EH2D	6.660	0.063	PWP	0.635	1.516	1	7.740	4.400	---
0.000	0.313	3401C	6.120	0.063	HW	0.620	2.430	1	8.970	1.600	---
		3402C	6.170	0.063	HW	0.610	2.550	1	7.070	1.700	---
0.000	0.313	3401A	7.220	0.063	HW	0.686	2.960	1	11.040	1.500	---
		3401B	7.090	0.063	HW	0.653	2.810	1	9.620	2.000	---
0.000	0.313	3402A	7.180	0.063	HW	0.673	2.600	1	9.620	1.250	---
		3402B	7.100	0.063	HW	0.674	2.240	1	8.290	1.250	---
0.000	0.313	3403A	7.150	0.063	BB	0.636	0.806	1	16.760	---	0.670
		3403B	7.100	0.063	BB	0.639	0.731	1	18.700	---	0.640
0.000	0.375	3404A	6.850	0.063	HW	0.654	8.000	1	50.270	4.500	---
		3404B	6.850	0.063	HW	0.654	5.750	1	25.970	3.250	---
0.000	0.375	3227D	6.900	0.063	RB	0.674	2.383	2	11.050	---	---
		MLI-B2	6.880	0.063	RB	0.738	3.740	1	13.400	1.630	

Table 3.12 Continued

IMPACT ANGLE (DEG)	PROJECTILE DIAMETER (IN)	TEST NUMBER	IMPACT VELOCITY (KM/SEC)	SHIELD THICKNESS (IN)	MLI LOCATION	MIN BUMPER HOLE DIA. (IN)	MAX BUMPER HOLE DIA. (IN)	<---- NORMAL: PRESSURE WALL HOLE DIAMETER (IN)	NUMBER OF HOLES	DAMAGE AREA (SQ.IN.)	MAXIMUM PETAL LENGTH (IN)	SPALL AREA (SQ.IN.) ---->	<---- OBLIQUE: PRESSURE WALL HOLE DIAMETER (IN)	NUMBER OF HOLES	DAMAGE AREA (SQ.IN.)	MAXIMUM PETAL LENGTH (IN)	SPALL AREA (SQ.IN.) ---->
45.000	0.187	4109C	6.530	0.080	BB	0.482	0.550	---	---	5.940	---	---	---	---	1.770	---	---
		3303A	6.410	0.080	BB	0.472	0.550	---	---	4.910	---	---	---	---	1.910	---	---
45.000	0.250	9001A	5.970	0.050	BB	0.593	0.636	---	---	8.280	---	---	0.195	2	2.090	---	---
		9001B	5.920	0.050	BB	0.464	0.625	---	---	7.690	---	---	0.474	2	3.560	---	0.016
45.000	0.250	9001A	5.970	0.050	BB	0.593	0.636	---	---	8.280	---	---	0.195	2	2.090	---	---
		9001C	5.940	0.050	BB	0.506	0.661	---	---	8.920	---	---	---	---	1.230	---	---
45.000	0.250	9001B	5.920	0.050	BB	0.464	0.625	---	---	7.690	---	---	0.474	2	3.560	---	0.016
		9001C	5.940	0.050	BB	0.506	0.661	---	---	8.920	---	---	---	---	1.230	---	---
45.000	0.250	9001A	5.970	0.050	BB	0.593	0.636	---	---	8.280	---	---	0.195	2	2.090	---	---
		9001D	6.110	0.050	BB	0.460	0.661	---	---	7.070	---	---	0.197	2	3.560	---	---
45.000	0.250	9001B	5.920	0.050	BB	0.464	0.625	---	---	7.690	---	---	0.474	2	3.560	---	0.016
		9001D	6.110	0.050	BB	0.460	0.661	---	---	7.070	---	---	0.197	2	3.560	---	---
45.000	0.250	9001C	5.940	0.050	BB	0.506	0.661	---	---	8.920	---	---	---	---	1.230	---	---
		9001D	6.110	0.050	BB	0.460	0.661	---	---	7.070	---	---	0.197	2	3.560	---	---
45.000	0.250	9002A	6.390	0.050	BB	0.489	0.624	---	---	4.910	---	---	0.433	2	3.560	---	---
		9002B	6.400	0.050	BB	0.502	0.585	---	---	8.300	---	---	---	---	3.140	---	---
45.000	0.250	9002A	6.390	0.050	BB	0.489	0.624	---	---	4.910	---	---	0.433	2	3.560	---	---
		9002C	6.350	0.050	BB	0.514	0.586	---	---	9.620	---	---	---	---	2.780	---	---
45.000	0.250	9002A	6.390	0.050	BB	0.489	0.624	---	---	4.910	---	---	0.433	2	3.560	---	---
		9002D	6.370	0.050	BB	0.510	0.624	---	---	7.070	---	---	---	---	3.530	---	---
45.000	0.250	9002B	6.400	0.050	BB	0.502	0.585	---	---	8.300	---	---	---	---	3.140	---	---
		9002C	6.350	0.050	BB	0.514	0.586	---	---	9.620	---	---	---	---	2.780	---	---
45.000	0.250	9002B	6.400	0.050	BB	0.502	0.585	---	---	8.300	---	---	---	---	3.140	---	---
		9002D	6.370	0.050	BB	0.510	0.624	---	---	7.070	---	---	---	---	3.530	---	---
45.000	0.250	9002C	6.350	0.050	BB	0.514	0.586	---	---	9.620	---	---	---	---	2.780	---	---
		9002D	6.370	0.050	BB	0.510	0.624	---	---	7.070	---	---	---	---	3.530	---	---
45.000	0.250	4101C	6.140	0.050	BB	0.536	0.649			4.410			0.731	3	1.470		
		9001D	6.110	0.050	BB	0.460	0.639	---	---	7.070	---	---	0.197	1	5.390	---	---

Table 3.13 Dual-Wall Str[illegible]es, With MLI, Oblique Impact, S-4 inches

IMPACT ANGLE (DEG)	PROJECTILE DIAMETER (IN)	TEST NUMBER	IMPACT VELOCITY (KM/SEC)	SHIELD THICKNESS (IN)	MLI LOCATION	MIN BUMPER HOLE DIA. (IN)	MAX BUMPER HOLE DIA. (IN)	<---- NORMAL: PRESSURE WALL HOLE DIAMETER (IN)	NUMBER OF HOLES	DAMAGE AREA (SQ.IN.)	MAXIMUM PETAL LENGTH (IN)	SPALL AREA (SQ.IN.) ---->	<---- OBLIQUE: PRESSURE WALL HOLE DIAMETER (IN)	NUMBER OF HOLES	DAMAGE AREA (SQ.IN.)	MAXIMUM PETAL LENGTH (IN)	SPALL AREA (SQ.IN.) ---->
45.000	0.250	3304A	6.200	0.080	BB	0.592	0.700	---	---	3.970	---	---	0.050	1	3.140	---	---
		3304B	6.280	0.080	BB	0.674	0.790	---	---	4.910	---	---	0.080	1	4.910	---	---
45.000	0.250	3304C	6.840	0.080	BB	0.684	0.761	---	---	4.910	---	---	0.598	3	5.940	---	---
		3304D	6.910	0.080	BB	0.687	0.783	---	---	3.140	---	---	0.063	1	4.910	---	---
45.000	0.313	4102-C1	6.050	0.050	BB	0.585	0.782	---	---	8.300	---	---	0.566	2	4.910	---	---
		4102-C2	6.020	0.050	BB	0.578	0.765	---	---	8.920	---	---	0.964	7	7.070	---	---
45.000	0.313	4001A	3.150	0.080	BB	0.535	0.704	---	---	3.560	---	0.250	0.445	1	3.560	---	---
		4003C	3.180	0.080	BB	0.511	0.674	---	---	3.980	---	---	0.504	1	2.410	---	---
45.000	0.313	4001C	6.120	0.080	BB	0.655	0.851	---	---	3.140	---	---	0.523	1	4.910	---	---
		4003D	6.220	0.080	BB	0.617	0.887	---	---	3.140	---	---	0.510	2	6.470	---	---
60.000	0.313	4105A	2.920	0.050	BB	0.500	0.831	---	---	5.940	---	---	0.385	1	2.410	---	---
		4105A-1	2.980	0.050	BB	0.502	0.887	---	---	11.840	---	---	---	---	5.390	---	---
65.000	0.250	3017C	4.700	0.040	PWP	0.456	0.808	---	---	15.070	---	---	---	---	4.450	---	---
		3029-1	4.610	0.040	PWP	0.440	0.873	---	---	9.620	---	---	---	---	11.760	---	---
65.000	0.313	3216	6.310	0.040	BB	0.568	1.101	---	---	5.430	---	---	---	---	3.980	---	---
		3218	6.490	0.040	BB	0.550	1.057	---	---	3.530	---	---	---	---	2.410	---	---
75.000	0.313	4002A	3.200	0.080	BB	0.460	1.041	---	---	5.940	---	---	---	---	---	---	---
		4117A	3.110	0.080	BB	0.441	0.909	---	---	2.090	---	---	---	---	---	---	---
75.000	0.313	4002A	3.200	0.080	BB	0.460	1.041	---	---	5.940	---	---	---	---	---	---	---
		4004A	3.190	0.080	BB	0.427	1.042	---	---	7.070	---	---	---	---	---	---	---
75.000	0.313	4117A	3.110	0.080	BB	0.441	0.909	---	---	2.090	---	---	---	---	---	---	---
		4004A	3.190	0.080	BB	0.427	1.042	---	---	7.070	---	---	---	---	---	---	---
75.000	0.313	4002C	6.300	0.080	BB	0.533	1.349	0.162	1	4.910	---	---	---	---	---	---	---
		4002E	6.410	0.080	BB	0.561	1.191	---	---	8.300	---	---	---	---	---	---	---
75.000	0.313	4004B	6.080	0.080	BB	0.673	1.366	0.105	1	7.690	---	---	---	---	---	---	---
		4004C	6.190	0.080	BB	0.522	1.315	---	---	5.390	---	---	---	---	---	---	---

Table 3.13 Continued

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary and Conclusions

Phenomena repeatability and data uncertainty analyses were performed using the NASA/MSFC Phase B and Phase C/D hypervelocity impact test data was performed. The information used consisted of the 540 Phase B tests in the Hypervelocity Impact Damage Database developed under a previous effort and a supplemental database of 410 Phase C/D tests. The analyses sought to quantify the repeatability of the phenomena ocurring in dual-wall structures under hypervelocity impact based on the testing performed at the NASA/MSFC light gas gun during the time period 1985-1991 and to determine the uncertainty of the measurements taken from damaged test specimens.

The results of the phenomena repeatability analysis show that if 3 identical dual-wall structures were to be tested using the NASA/MSFC light gas gun under similar impact conditions, then it is entirely likely that either the pressure walls in 2 of these 3 tests will be perforated and 1 will not or the pressure walls in 2 of these tests will not be perforated and 1 will. The results obtained also show that the repeatability of rear-side spallation (or the lack thereof) in such dual-wall structures is considerably higher: of 10 tests performed, it is highly likely that 9 of them will all either show some sort of rear-side spallation and 1 will not or 9 of them will all either not be spalled and 1 of them will. The results of the uncertainty analysis show that the level of uncertainty in the response data can vary significantly depending on the response considered. However, the observations made in the uncertainty analysis in general reinforce those made during the repeatability analysis.

4.2 Recommendations

An extensive program of spacecraft materials testing and evaluation under hypervelocity projectile impact has been underway at NASA/MSFC since its inception over almost three decades ago. While an extensive test database has been established, it is evident that further testing is still required to fully understand the phenomena associated with hypervelocity impact and for a more comprehensive hypervelocity impact test database. Additional data will also allow the calculation of Repeatability Indices for test groups for which at present it is not possible. The following recommendations are made for a future high speed impact test program to address current needs.

1) Perform additional testing at higher impact velocities. While an impact velocity of 7 km/sec is near the upper limit of the velocities attainable by the light gas gun, it is clear that more testing must be performed at these high velocities in order to be able to even come close to duplicating the anticipated on-orbit impact velocities.

2) Perform additional testing using larger projectiles. Although impacts by smaller pieces of orbital debris are more probable than impacts by excessively large pieces, the effects of large particle impact must be fully understood in order to decide whether or not such impacts can be withstood by existing or newly-developed protective measures.

3) Perform additional testing at higher impact obliquities. With the increasing concern for the pollution of the orbital environment by the secondary ricochet debris particles that are formed in an oblique hypervelocity impact, additional oblique impact testing is necessary, especially in the high obliquity regime (ie. obliquities greater than 60^0) to fully understand the damage potential of these secondary debris particles.

4) Perform additional testing of alternate bumper plate materials and alternate wall configurations. With the recent development of many new high-strength materials, it is imperative that additional testing be performed with bumper plates made from materials other than aluminum. Additionally, alternative configurations, such as double or triple bumpers at stand-off distances other than 10 cm, should be test with bumper plates made from these new materials.

5) Perform additional tests using non-spherical projectiles. While this has been done mainly for reasons of consistency and repeatability, it is clear that orbital debris particles are not round, but are rather jagged with varying length-to-diameter ratios. Additional testing must be performed using non-spherical projectiles in order to be able to extrapolate the response of a structure under spherical projectile impact to a structure that is impacted by a non-spherical projectile.

6) Perform additional tests with different density projectiles. It has become evident that the original constant density approximation for orbital debris particles is inaccurate, especially for particles larger than 0.6 cm in diameter. While the testing to date has produced results that are certainly applicable to small particle impacts, whether or not they can be extended to large particle impact remains to be seen.

7) Perform tests to determine the effects of pressure wall curvature on module wall response. All the tests to date have been performed using flat bumper and pressure wall plates. Does the curvature of the module have an effect on the perforation resistance of a dual-wall structure? Additional testing must be performed with curved inner and outer walls to adequately address this issue.

APPENDIX I -- PHASE C/D TESTING PARAMETER DATABASE

SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACK WALL MATERIAL	BACK WALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTILE DIAMETER (IN)	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
960	2001-A	6061-T6	0.063	6	NO	2219-T87	0.125	AL-1100	0.187	0	3.77
962	2001-B	6061-T6	0.063	6	NO	2219-T87	0.125	AL-1100	0.187	0	3.93
961	2001-C	6061-T6	0.063	6	NO	2219-T87	0.125	AL-1100	0.187	0	4.05
929	2002-A	6061-T6	0.063	6	NO	2219-T87	0.125	AL-1100	0.250	0	6.08
930	2002-B	6061-T6	0.063	6	NO	2219-T87	0.125	AL-1100	0.250	0	6.50
940	2002-C	6061-T6	0.063	6	NO	2219-T87	0.125	AL-1100	0.250	0	6.75
949	2003-A	6061-T6	0.063	6	NO	2219-T87	0.125	AL-1100	0.250	0	7.00
944	2003-B	6061-T6	0.063	6	NO	2219-T87	0.125	AL-1100	0.250	0	7.10
945	2003-C	6061-T6	0.063	6	NO	2219-T87	0.125	AL-1100	0.250	0	7.28
959	2003-A1	6061-T6	0.063	6	NO	2219-T87	0.125	AL-1100	0.250	0	5.98
956	2003-B1	6061-T6	0.063	6	NO	2219-T87	0.125	AL-1100	0.250	0	6.58
941	2004-A	6061-T6	0.063	4	NO	2219-T87	0.125	AL-1100	0.250	0	7.20
939	2004-B	6061-T6	0.063	4	NO	2219-T87	0.125	AL-1100	0.250	0	6.92
931	2004-C	6061-T6	0.063	4	NO	2219-T87	0.125	AL-1100	0.250	0	5.95

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SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACKWALL MATERIAL	BACKWALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTILE DIAMETER	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
965	3001	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.187	0	6.63
798	3001-A	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	0	3.90
799	3001-B	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	0	5.76
800	3001-C	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	0	6.22
801	3001-D	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	0	7.19
802	3001-E	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	0	6.76
803	3002-A	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.250	0	6.99
804	3002-B	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.250	0	7.33
806	3002-C	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.250	0	7.52
963	3003	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	45	6.10
964	3004	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	45	7.70
807	3004-A	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	45	6.81
810	3004-B	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	45	6.57
808	3005-A	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	45	7.35
811	3005-B	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.250	45	7.60
812	3006-A	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.313	45	7.01
818	3007-A	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	65	6.53
819	3007-B	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	65	4.78
820	3007-C	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	65	3.35
821	3008-A	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.250	65	4.61
822	3008-B	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.25	65	4.25
823	3009-A	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.313	65	5.12
824	3009-B	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.313	65	4.54
813	3010-A	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.313	0	5.86
814	3010-B	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.187	0	6.82
815	3010-C	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.187	0	7.32
816	3010-1-A	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.250	0	7.22
817	3010-1-B	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.250	0	6.76
826	3011-A	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.313	0	7.02
825	3011-B	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.313	0	6.75
827	3012-B	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.313	30	2.67
828	3012-D	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.187	30	4.31
830	3013-A	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.250	30	6.98
831	3017-A	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.250	65	6.97
832	3017-B	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.250	65	6.25

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SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACKWALL MATERIAL	BACKWALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTILE DIAMETER	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
833	3017-C	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.250	65	4.70
876	3019-A	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	0	4.25
877	3019-B	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	0	4.76
844	3020-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	0	6.65
834	3020-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	0	7.05
845	3021-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	0	7.18
836	3022-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	30	2.15
835	3022-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	30	3.25
842	3022-C	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	30	4.06
843	3022-D	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	30	4.86
840	3023-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.250	30	6.90
839	3023-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.250	30	6.15
841	3024-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	30	7.02
847	3027-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.250	45	6.90
846	3028-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	45	7.01
848	3029-C	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	65	3.88
849	3030-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	65	3.49
851	3031-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	65	3.36
850	3031-C	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	65	6.99
852	3033-A	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.250	0	3.86
853	3033-B	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.250	0	3.40
869	3033-C	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.250	0	5.57
854	3034-A	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.313	0	4.50
855	3034-B	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.313	0	3.63
856	3034-C	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.313	0	5.60
863	3035-A	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.313	45	5.28
864	3035-B	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.313	45	5.90
857	3036-A	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.250	45	5.53
858	3036-B	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.250	45	6.44
861	3037-A	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.313	45	7.12
870	3038-A	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.187	65	5.01
871	3038-B	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.187	65	6.38
866	3039-A	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.250	65	5.66
867	3039-B	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.250	65	4.54
868	3039-C	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.250	65	6.26
865	3040-A	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.313	65	6.92

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SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACKWALL MATERIAL	BACKWALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTIL DIAMETER "	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
1212	3101-A	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.187	0	3.82
1213	3101-B	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.187	0	4.32
1214	3101-C	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.187	0	3.51
1215	3102-A	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.250	0	3.77
1217	3102-B	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.250	0	4.65
1218	3102-C	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.250	0	5.25
1219	3102-D	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.250	0	4.84
1220	3102-E	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.250	0	5.14
1221	3103-A	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.313	0	5.93
1222	3103-B	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.313	0	5.79
1223	3103-C	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.313	0	6.37
1224	3103-D	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.313	0	6.5
1225	3103-E	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.313	0	6.75
1226	3105-A	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.250	45	4.87
1228	3105-B	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.188	AL-1100	0.250	45	4.43
874	3120-A	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.250	0	4.95
875	3120-B	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.250	0	5.42
872	3121-A	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.313	0	5.6
873	3121-B	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.313	0	4.64
890	3122-A	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.187	45	7.41
895	3122-B	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.187	45	6.27
900	3122-C	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.187	45	4.93
901	3122-D	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.187	45	5.42
888	3123-A	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.250	45	7.18
889	3123-B	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.250	45	7.55
884	3124-A	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.313	45	4.96
885	3124-B	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.313	45	6.24
886	3124-C	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.313	45	6.62
882	3128-A	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.187	0	3.64
883	3128-B	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.187	0	4.23
880	3129-A	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.250	0	4.25
881	3129-B	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.250	0	4.75
878	3130-A	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.313	0	5.26
879	3130-A	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.313	0	4.57
902	3131-A	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.187	45	4.13
903	3131-B	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.187	45	3.91
918	3131-C	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.187	45	3.6
915	3132-A	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.250	45	5.36
916	3132-B	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.250	45	6.96
917	3132-C	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.250	45	6.42
904	3133-A	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.313	45	5.13
910	3133-B	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.313	45	6.36
911	3133-C	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.313	45	6.91
914	3133-D	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.313	45	6.78

P3100SER.WK1

SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACKWALL MATERIAL	BACKWALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTILE DIAMETER	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
966	3202	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.187	0	7.20
1010	3202-A	6061-T6	0.080	4	YES/O.B.	2219-T87	0.125	AL-1100	0.313	0	6.23
1011	3202-B	6061-T6	0.080	4	YES/O.B.	2219-T87	0.125	AL-1100	0.313	0	6.43
1012	3202-C	6061-T6	0.080	4	YES/O.B.	2219-T87	0.125	AL-1100	0.313	0	6.72
967	3205	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.25	0	6.75
969	3206	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.25	0	6.80
970	3207	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.25	45	6.48
971	3208	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.25	65	3.80
972	3209	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.25	65	5.83
983	3209-1	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.25	65	4.61
974	3210	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.25	65	5.60
973	3211	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.25	65	5.67
975	3212	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.313	65	3.43
982	3212-1	6061-T6	.032	4	YES	2219-T87	0.125	AL-1100	0.313	65	3.57
976	3213	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.313	65	4.46
977	3214	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.313	65	5.16
978	3215	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.313	65	5.65
980	3216	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.313	65	6.31
979	3217	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.313	65	6.05
981	3218	6061-T6	0.040	4	YES	2219-T87	0.125	AL-1100	0.313	65	6.49
984	3220-A	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.313	0	5.96
985	3220-B	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.313	0	6.48
986	3221-A	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.25	0	6.20
987	3221-B	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.25	0	6.37
988	3222-A	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.187	0	5.55
991	3223-A	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.313	0	5.85
990	3224-A	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.25	0	5.15
989	3224-B	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.25	0	5.26
992	3225	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.375	0	5.94
993	3225-A	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.375	0	5.91
1009	3225-C	6061-T6	0.032	12	YES	2219-T87	0.125	AL-1100	0.375	0	6.24
995	3226-A	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.375	0	5.62
994	3226-B	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.375	0	5.55
996	3226-C	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.375	0	5.97
997	3227-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.375	0	6.80
1002	3227-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.375	0	6.70
998	3227-C	6061-T6	0.063	12	YES	2219-T87	0.125	AL-1100	0.375	0	6.56
1000	3227-D	6061-T6	0.063	4	YES/OB	2219-T87	0.125	AL-1100	0.375	0	6.90

P3200SER.WK1

SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACKWALL MATERIAL	BACKWALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTIL DIAMETER	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
1005	3301-A	6061-T6	0.08	4	YES/O.B.	2219-T87	0.125	AL-1100	0.250	0	3.93
1006	3301-B	6061-T6	0.08	4	YES/O.B.	2219-T87	0.125	AL-1100	0.250	0	4.27
1007	3301-C	6061-T6	0.08	4	YES/O.B.	2219-T87	0.125	AL-1100	0.250	0	6.27
1008	3301-D	6061-T6	0.08	4	YES/O.B.	2219-T87	0.125	AL-1100	0.250	0	5.48
1029	3301-E	6061-T6	0.08	4	YES/0.25"	2219-T87	0.125	AL-1100	0.250	0	4.98
1030	3302-E	6061-T6	0.08	4	YES/0.25"	2219-T87	0.125	AL-1100	0.313	0	6.22
1014	3303-A	6061-T6	0.08	4	YES/0.25"	2219-T87	0.125	AL-1100	0.187	45	6.41
1015	3303-B	6061-T6	0.08	4	YES/0.25"	2219-T87	0.125	AL-1100	0.187	45	6.77
1016	3303-C	6061-T6	0.08	4	YES/0.25"	2219-T87	0.125	AL-1100	0.187	45	6.13
1021	3303-D	6061-T6	0.08	4	YES/0.25"	2219-T87	0.125	AL-1100	0.187	45	5.65
1017	3304-A	6061-T6	0.08	4	YES/0.25"	2219-T87	0.125	AL-1100	0.250	45	6.2
1018	3304-B	6061-T6	0.08	4	YES/0.25"	2219-T87	0.125	AL-1100	0.250	45	6.28
1019	3304-C	6061-T6	0.08	4	YES/0.25"	2219-T87	0.125	AL-1100	0.250	45	6.84
1020	3304-D	6061-T6	0.08	4	YES/0.25"	2219-T87	0.125	AL-1100	0.250	45	6.91
1025	3305-A	6061-T6	0.063	4	YES/0.25"	2219-T87	0.125	AL-1100	0.187	0	4.63
1023	3305-B	6061-T6	0.063	4	YES/0.25"	2219-T87	0.125	AL-1100	0.187	0	4.18
1024	3305-C	6061-T6	0.063	4	YES/0.25"	2219-T87	0.125	AL-1100	0.187	0	3.79
1026	3306-A	6061-T6	0.063	4	YES/0.25"	2219-T87	0.125	AL-1100	0.250	0	5.22
1031	3306-B	6061-T6	0.063	4	YES/0.25"	2219-T87	0.125	AL-1100	0.250	0	6.98
1027	3306-C	6061-T6	0.063	4	YES/0.25"	2219-T87	0.125	AL-1100	0.250	0	7.05
1028	3306-D	6061-T6	0.063	4	YES/0.25"	2219-T87	0.125	AL-1100	0.250	0	6.98
1032	3307-A	6061-T6	0.063	4	YES/0.25"	2219-T87	0.125	AL-1100	0.187	45	4.75
1033	3307-B	6061-T6	0.063	4	YES/0.25"	2219-T87	0.125	AL-1100	0.187	45	6.28
1034	3038-A	6061-T6	0.063	4	YES/0.25"	2219-T87	0.125	AL-1100	0.250	45	5.2
1035	3308-B	6061-T6	0.063	4	YES/0.25"	2219-T87	0.125	AL-1100	0.250	45	6.21

P3300SER.WK1

SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACKWALL MATERIAL	BACKWALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTILE DIAMETER	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
1140	3401-A	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.313	0	7.22
1144	3401-B	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.313	0	7.09
1139	3401-C	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.313	0	6.12
1138	3401-D	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.313	0	5.25
1143	3402-A	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.313	0	7.18
1145	3402-B	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.313	0	7.1
1142	3402-C	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.313	0	6.17
1141	3402-D	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.313	0	5.02
1149	3403-A	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	0	7.15
1148	3403-B	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	0	7.1
1147	3403-C	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	0	6.2
1146	3403-D	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	0	5.03
1152	3404-A	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.375	0	6.85
1153	3404-B	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.375	0	6.85
1154	3404-C	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.375	0	6.23
1156	3404-D	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.375	0	5.5
1165	3405-A	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.250	0	3.03
1166	3405-B	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.250	0	3.83
1167	3405-C	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.250	0	5.1
1168	3405-D	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.250	0	6.2
1161	3406-A	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.250	0	3.06
1162	3406-B	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.250	0	4.05
1163	3406-C	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.250	0	5.16
1164	3406-D	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.250	0	5.58
1169	3406-D1	6061-T6	0.063	4	YES/2" O.B.	2219-T87	0.125	AL-1100	0.250	0	6.09
1160	3407-A	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	0	2.91
1159	3407-B	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	0	3.94
1158	3407-C	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	0	4.81
1157	3407-D	6061-T6	0.063	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.375	0	5.81

P3400SER.WK1

SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACK WALL MATERIAL	BACK WALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTILE DIAMETER (IN)	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
1042	4001-A	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	45	3.15
1040	4001-B	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	45	4.29
1041	4001-C	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	45	6.12
1043	4001-D	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	45	6.71
1046	4002-A	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	75	3.20
1044	4002-B	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	75	3.97
1045	4002-C	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	75	6.30
1047	4002-D	6061-T6	0.063	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	75	7.14
1056	4002-E	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	75	6.41
1048	4003-A	6061-T6	0.063	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	45	3.43
1049	4003-B	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	45	6.29
1051	4003-C	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	45	3.18
1050	4003-D	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	45	6.22
1052	4004-A	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	75	3.19
1053	4004-B	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	75	6.08
1054	4004-C	6061-T6	0.080	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	75	6.19

P4000SER.WK1

SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACKWALL MATERIAL	BACKWALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTILE DIAMETER	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
1105	4100-A	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	45	3
1106	4100-B	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	45	3.78
1108	4100-C	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	45	5.66
1109	4100-D	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	45	7.2
1110	4101-A	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	45	3.14
1111	4101-B	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	45	4.13
1112	4101-C	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	45	6.14
1113	4101-D	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	45	7.52
1190	4102-A	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	45	2.95
1189	4102-B	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	45	4.12
1191	4102-C	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	45	6.24
1209	4102-C1	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	45	6.05
1210	4102-C2	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	45	6.02
1211	4102-D	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	45	7.18
1114	4103-A	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	60	2.94
1115	4103-B	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	60	3.98
1116	4103-C	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	60	5.88
1121	4103-D	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	60	7.37
1118	4104-A	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	60	7.23
1122	4104-B	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	60	4.19
1123	4104-C	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	60	6.12
1124	4104-D	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	60	7.52
1185	4105-A	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	60	2.92
1187	4105-A1	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	60	2.98
1184	4105-B	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	60	4.02
1182	4105-C	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	60	6.15
1183	4105-D	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	60	7.23
1125	4106-A	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	60	3.05
1133	4106-A1	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	75	3.1
1126	4106-B	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	60	4.12
1134	4106-B1	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	75	3.99
1137	4106-C	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	75	5.95
1136	4106-D	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	75	7.56
1128	4107-A	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	75	3.05
1130	4107-B	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	75	4.11
1131	4107-C	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	75	6.2
1132	4107-D	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	75	7.64

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SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACKWALL MATERIAL	BACKWALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTILE DIAMETER	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
1186	4108-A	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	75	3.12
1188	4108-A1	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	75	2.95
1179	4108-B	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	75	3.97
1180	4108-C	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	75	5.96
1181	4108-D	6061-T6	0.05	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	75	7.07
1058	4109-A	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	45	3.27
1059	4109-B	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	45	4.14
1060	4109-C	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	45	6.53
1062	4109-D	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	45	7.46
1064	4110-A	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	45	3.25
1065	4110-B	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	45	4
1068	4110-C	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	45	5.76
1069	4110-D	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	45	6.96
1070	4111-A	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	45	2.85
1071	4111-B	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	45	3.94
1072	4111-C	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	45	5.97
1073	4111-D	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	45	6.81
1074	4112-A	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	60	3.33
1075	4112-B	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	60	4.05
1076	4112-C	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	60	5.87
1077	4112-D	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	60	7.5
1078	4113-A	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	60	2.97
1079	4113-B	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	60	3.77
1080	4113-C	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	60	6.3
1082	4113-D	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	60	7.12
1083	4114-A	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	60	3.13
1084	4114-B	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	60	3.98
1085	4114-C	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	60	5.92
1086	4114-D	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	60	7.4
1089	4115-A	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	75	3.13
1088	4115-B	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	75	4.08
1090	4115-C	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	75	6.06
1091	4115-D	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.187	75	7.3
1092	4116-A	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	75	2.92
1093	4116-B	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	75	4.48
1094	4116-C	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	75	6.24
1095	4116-D	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.250	75	7.36
1096	4117-A	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	75	3.11
1097	4117-B	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	75	4.05
1098	4117-C	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	75	6.03
1103	4117-D	6061-T6	0.08	4	YES/0.25" O.B.	2219-T87	0.125	AL-1100	0.313	75	7.2

SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACK WALL MATERIAL	BACK WALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTILE DIAMETER (IN)	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
1170	9001-1	6061-T6	0.063	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.250	45	6.00
1171	9001-A	6061-T6	0.050	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.250	45	5.97
1172	9001-B	6061-T6	0.050	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.250	45	5.92
1173	9001-C	6061-T6	0.050	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.250	45	5.94
1174	9001-D	6061-T6	0.050	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.250	45	6.11
1175	9002-A	6061-T6	0.050	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.250	45	6.39
1176	9002-B	6061-T6	0.050	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.250	45	6.40
1177	9002-C	6061-T6	0.050	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.250	45	6.35
1178	9002-D	6061-T6	0.050	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.250	45	6.37

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SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACK WALL MATERIAL	BACK WALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTILE DIAMETER (IN)	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
769	CAMERA-T1	6061-T6	0.063	4	NO	2219-T87	0.063	AL-1100	0.313	0	7.10
771	STRESS	6061-T6	0.063	4	YES	2219-T87	0.125	AL-6061	0.500	0	45.0
772	STRESS	6061-T6	0.063	4	YES	5456-H116	0.125	AL-6061	0.500	0	5.99
774	STRESS	6061-T6	0.063	4	YES	2219-T87	0.125	AL-6061	0.500	0	4.77
919	FL-1	6061-T6	0.08	4	AL/NYLON	2219-T87	0.125	LEXAN	0.500	0	6.25
920	FL-2	6061-T6	0.08	4	AL/NYLON	5456-H116	0.125	LEXAN	0.500	0	6.39
894	MLI-ON-B-1	6061-T6	0.063	4	YES/REAR OF BMPR	2219-T87	0.125	AL-1100	0.313	0	7.13
896	MLI-ON-B-2	6061-T6	0.063	4	YES/REAR OF BMPR	2219-T87	0.125	AL-1100	0.375	0	6.88
897	MLI-ON-B-3	6061-T6	0.032	4	YES/REAR OF BMPR	2219-T87	0.125	AL-1100	0.187	0	7.25
898	MLI-ON-B-4	6061-T6	0.032	4	YES	2219-T87	0.125	AL-1100	0.187	0	7.75
1150	MLI-T-2	6061-T6	0.063	4	YES/0.25"O.B.	2219-T87	0.125	AL-1100	0.313	0	7.15
859	MLI-PURGE-1	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	0	6.85
905	BL-AL-1	6061-T6	0.063	4	AL FOIL	2219-T87	0.125	AL-1100	0.313	0	6.93
909	BL-AL-2	6061-T6	0.063	4	AL FOIL	2219-T87	0.125	AL-1100	0.313	0	6.83
734	CAM-1	6061-T6	0.063	4	NO	2219-T87	0.125	AL-1100	0.250	0	5.27
735	CAM-2	6061-T6	0.063	4	NO	2219-T87	0.125	AL-1100	0.250	0	5.27
745	EHSS-M1	6061-T6	0.063	4	YES	5456-H116	0.125	AL-1100	0.313	0	7.00
746	EHSS-M2	6061-T6	0.063	4	YES	5456-H116	0.125	AL-1100	0.313	45	7.08
747	EHSS-M3	6061-T6	0.063	4	YES	5456-H116	0.125	AL-1100	0.313	0	7.00
756	EHSS-M4	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	0	6.92
736	T5A	6061-T6	0.063	4	NO	5456-H116	0.125	AL-1100	0.375	0	6.86
737	T5B	6061-T6	0.063	4	NO	2219-T87	0.125	AL-1100	0.375	0	6.85
738	T5C	6061-T6	0.063	4	NO	5456-H116	0.125	AL-1100	0.375	0	6.96
739	T5D	6061-T6	0.063	4	NO	2219-T87	0.125	AL-1100	0.375	0	6.88
740	T5E	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.375	0	6.85
741	T5F	6061-T6	0.063	4	YES	5456-H116	0.125	AL-1100	0.375	0	6.83
742	T5G	6061-T6	0.063	4	YES	5456-H116	0.125	AL-1100	0.375	0	6.84
748	T5H	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.250	0	5.55
749	T5I	6061-T6	0.063	4	YES	5456-H116	0.125	AL-1100	0.250	0	5.82
750	T5J	6061-T6	0.063	4	YES	5456-H116	0.125	AL-1100	0.250	0	4.67
751	T5K	6061-T6	0.063	4	YES	5456-H116	0.125	AL-1100	0.250	0	5.87
752	T5L	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.250	0	5.65
754	T5M	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.250	0	5.45

SHOT NO.	TEST NO.	BUMPER MATERIAL	BUMPER THICKNESS (IN)	BUMPER STANDOFF (IN)	MLI (Y/N)	BACK WALL MATERIAL	BACK WALL THICKNESS (IN)	PROJECTILE MATERIAL	PROJECTILE DIAMETER (IN)	IMPACT ANGLE (DEG)	AVERAGE VELOCITY (KM/S)
906	WG01	6061-T6	0.063	4	YES	5456-H116	WAFFLE	AL-1100	0.375	0	6.92
907	WG02	6061-T6	0.063	4	YES	2219-T87	WAFFLE	AL-1100	0.375	0	6.86
912	WG03	6061-T6	0.063	4	YES	2219-T87	WAFFLE	AL-1100	0.375	0	6.88
913	WG04	6061-T6	0.063	4	YES	5456-H116	WAFFLE	AL-1100	0.375	0	6.85
921	WG05	6061-T6	0.080	12	YES	2219-T87	WAFFLE	AL-1100	0.500 CYL	0	5.1
922	WG06	6061-T6	0.080	12	YES	5456-H116	WAFFLE	AL-1100	0.500 CYL	0	5.1
925	WG07	6061-T6	0.080	12	YES	2219-T87	WAFFLE	AL-1100	0.500 CYL	0	5.18
926	WG08	6061-T6	0.080	12	YES	5456-H116	WAFFLE	AL-1100	0.500 CYL	0	5.18
927	WG09	6061-T6	0.080	4	YES	2219-T87	WAFFLE	AL-1100	0.500 CYL	0	5.18
887	FP-01	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.375	0	6.88
892	FP-02	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.375	0	6.93
893	FP-03	6061-T6	0.063	4	YES	5456-H116	0.125	AL-1100	0.375	0	6.86
899	FP-04	6061-T6	0.080	4	YES	2219-T87	0.125	AL-1100	0.375	0	6.87
932	FP-05	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.375	0	6.83
933	FP-06	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.375	0	7.06
934	FP-07	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.375	0	6.99
937	FP-08	6061-T6	0.080/KEV CL	4.5/1.5	NO	2219-T87	0.125	AL-1100	0.500	0	6.03
938	FP-09	6061-T6	0.080/KEV CL	4.5/1.5	NO	2219-T87	0.125	AL-1100	0.500	0	5.84
942	FP-10/1001-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	0	2.47
946	FP-11/1001-C	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	0	3.07
947	FP-12/1001-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	0	2.02
948	FP-13/1002-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	0	4.14
950	FP-14/1004-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	45	3.26
951	FP-15/1004-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.187	45	4.34
952	FP-16/1002-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.250	0	2.6
953	FP-17/1002-C	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.250	0	4.35
954	FP-18/1005-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.250	45	5.32
955	FP-19/1005-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.250	45	6.5
957	FP-20/1005-C	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.250	45	7.05
958	FP-21/1003-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	0	5.19
1099	FP-22/1003-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	0	5.98
1100	FP-23/1003-C	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	0	7.21
1101	FP-24/1006-A	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	45	6.90
1102	FP-25/1006-B	6061-T6	0.063	4	YES	2219-T87	0.125	AL-1100	0.313	45	7.29

PMISC.WK1 (Continued)

APPENDIX II -- PHASE C/D TESTING DAMAGE DATABASE

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN	BUMPER PLATE HOLE DMAX	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
960	2001-A	0.353	0.353	YES	0.273	23.758	NO		0.172	0.212		0.233	0.125	0.111	0.110	0.250	0.134
962	2001-B	0.350	0.350	YES	0.204	41.282	YES	0.035	0.121	0.164		0.233	0.134	0.246	0.108	0.173	0.067
961	2001-C	0.377	0.377	NO		30.68	YES	0.010				0.173	0.092	0.159	0.085	0.091	0.158
929	2002-A	0.503	0.503	YES	0.429	53.456	YES	0.153	0.218	0.229	0.180	0.179	0.119	0.201	0.132	0.192	0.129
930	2002-B	0.555	0.555	YES		53.846	YES	0.026	0.122			0.156	0.105	0.170	0.094	0.145	0.107
940	2002-C	0.521	0.521	YES	0.288	27.155	YES	0.389	0.105	0.211	0.098	0.184	0.132	0.145	0.115	0.111	0.090
949	2003-A	0.542	0.542	YES	0.209	78.540	YES	0.24	0.130	0.098	0.085	0.255	0.133	0.121	0.082	0.170	0.120
944	2003-B	0.522	0.522	YES	0.296	70.882	NO		0.130	0.148	0.221	0.155	0.085	0.212	0.095	0.157	0.079
945	2003-C	0.544	0.544	YES	0.707	50.27	NO		0.707								
959	2003-A1	0.559	0.559	NO		67.201	NO					0.161	0.085	0.136	0.090	0.141	0.075
956	2003-B1	0.508	0.508	YES	0.556	60.132	YES	0.023	0.122	0.166	0.499	0.186	0.110	0.197	0.089	0.141	0.149
941	2004-A	0.542	0.542	YES	0.355	22.733	YES	0.570	0.106	0.301	0.122	0.173	0.096	0.163	0.060	0.128	0.070
939	2004-B	0.546	0.546	NO		17.721	YES	0.494				0.184	0.108	0.132	0.080	0.110	0.073
931	2004-C	0.514	0.514	YES	0.765	25.967	YES	0.029	0.765			0.181	0.075	0.173	0.097	0.134	0.068

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SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN (IN)	BUMPER PLATE HOLE DMAX (IN)	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
965	3001	0.328	0.39	YES	0.126	0.608	NO		0.126								
798	3001-A	0.282	0.282	YES	0.384	3.98	NO		0.384			0.068	0.042	0.06	0.046	0.066	0.03
799	3001-B	0.334	0.334	YES	0.153	4.91	NO		0.153			0.091	0.038	0.074	0.035	0.058	0.018
800	3001-C	0.315	0.349	YES	0.176	1.72	NO		0.176	0.069	0.038	0.112	0.127	0.077	0.029	0.105	0.019
801	3001-D	0.395	0.405	NO		0.196	NO					0.077	0.1	0.099	0.061	0.078	0.055
802	3001-E	0.32	0.345	YES	0.124	0.785	NO		0.124			0.042	0.016	0.025	0.006		
803	3002-A	0.463	0.463	YES	1.0	2.41	NO		1.0			0.136	0.132	0.085	0.065	0.057	0.04
804	3002-B	0.385	0.385	YES	1.387	5.94	NO		1.387	0.108		0.081	0.06				
806	3002-C	0.425	0.425	NO		1.77	NO					0.061	0.021				
963	3003	0.397	0.442	NO		3.142	NO					0.128	0.09	0.081	0.027	0.065	0.019
964	3004	0.38	0.539	NO		0.0	NO					0.067	0.024	0.049	0.011	0.06	0.01
807	3004-A	0.355	0.431	NO		4.41	NO										
810	3004-B	0.309	0.481	NO		1.23	NO					0.07	0.01				
808	3005-A	0.47	0.614	NO		0.196	NO					0.07	0.002				
811	3005-B	0.461	0.636	NO		1.767	NO					0.036	0.004	0.046	0.002		
812	3006-A	0.543	0.768	NO		0.0	NO					0.071	0.019	0.031	0.006		
818	3007-A	0.408	0.882	NO		4.91	NO										
819	3007-B	0.336	0.53	NO		4.91	NO					0.115	0.031	0.082	0.03	0.093	0.03
820	3007-C	0.289	0.581	NO		19.635	NO					0.103	0.052	0.106	0.024	0.081	0.009
821	3008-A	0.431	0.842	NO		8.973	NO					0.058	0.005				
822	3008-B	0.424	0.747	NO		11.045	NO					0.111	0.013	0.121	0.01	0.064	0.016
823	3009-A	0.504	0.921	NO		8.301	NO					0.088	0.019	0.065	0.012	0.098	0.011
824	3009-B	0.528	1.095	NO		12.566	NO					0.122	0.051	0.11	0.019	0.091	0.022
813	3010-A	0.295	0.34	YES	0.122	3.53	NO		0.108	0.057		0.096	0.03	0.076	0.015	0.118	0.01
814	3010-B	0.292	0.372	YES	0.153	2.087	NO		0.138	0.065		0.112	0.066	0.108	0.062	0.075	0.035
815	3010-C	0.439	0.439	YES	0.068	1.767	NO		0.068			0.062	0.082	0.067	0.053	0.065	0.066
816	3010-1-A	0.508	0.508	NO		3.53	NO					0.132	0.065	0.04	0.023	0.028	0.003
817	3010-1-B	0.429	0.456	YES	0.25	3.56	NO		0.25			0.077	0.104	0.052	0.06	0.071	0.033
826	3011-A	0.524	0.524	YES	7.0	38.485	NO		7.0			0.09	0.106	0.088	0.096	0.091	0.075
825	3011-B	0.508	0.508	YES	7.5	44.89	NO		7.5								
827	3012-B	0.289	0.327	NO		3.563	NO										
829	3012-C	0.321	0.36	NO		2.405	NO					0.115	0.004				
828	3012-D	0.327	0.389	NO		2.53	NO					0.076	0.007	0.082	0.005	0.054	0.003
830	3013-A	0.426	0.478	NO		0.0	NO					0.091	0.027	0.076	0.012	0.08	0.005
831	3017-A	0.475	0.846	NO		11.763	NO					0.079	0.036				
832	3017-B	0.438	0.794	YES	0.111	9.621	NO		0.111			0.21	0.07	0.115	0.031	0.097	0.03
833	3017-C	0.456	0.808	NO		15.067	NO					0.097	0.04	0.108	0.036	0.088	0.029
876	3019-A	0.281	0.281	YES	0.391	11.045	NO		0.375	0.031		0.096	0.032	0.098	0.025	0.114	0.025
877	3019-B	0.302	0.302	NO		25.428	NO					0.146	0.031	0.131	0.043	0.067	0.016
844	3020-A	0.63	0.63	YES	8.16	63.62	NO		8.16			0.287	0.054	0.085	0.02	0.099	0.021
834	3020-B	0.639	0.639	YES	7.12	39.76	NO		7.12								

IN-LINE

SHOT NO.	TEST NO.	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA 1 (IN)	HOLE 1 DIA 2 (IN)	HOLE 2 DIA 1 (IN)	HOLE 2 DIA 2 (IN)	HOLE 3 DIA 1 (IN)	HOLE 3 DIA 2 (IN)	CRATER 1 DIA 1 (IN)	CRATER 1 DIA 2 (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA 1 (IN)	CRATER 2 DIA 2 (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA 1 (IN)	CRATER 3 DIA 2 (IN)	CRATER 3 DEPTH (IN)
965	3001	NO		0.0	NO																
798	3001-A	NO		0.0	NO																
799	3001-B	NO		0.0	NO																
800	3001-C	NO		0.0	NO																
801	3001-D	NO		0.0	NO																
802	3001-E	NO		0.0	NO																
803	3002-A	NO		0.0	NO																
804	3002-B	NO		0.0	NO																
806	3002-C	NO		0.0	NO																
963	3003	YES	0.275	0.785	NO		0.275						0.073	0.049	0.015	0.053	0.04	0.011	0.076	0.046	0.006
964	3004	NO		3.976	NO								0.271	0.211	0.085	0.162	0.108	0.048	0.128	0.113	0.039
807	3004-A	YES	PINHOLE	0.0	NO								0.173	0.118	0.081	0.135	0.106	0.063	0.138	0.099	0.052
810	3004-B	YES	0.102	1.496	NO		0.139	0.075					0.367	0.305	0.14	0.059	0.038	0.06	0.073	0.054	0.011
808	3005-A	YES	0.215	5.94	NO		0.291	0.145	0.099	0.042			0.128	0.092	0.125	0.151	0.11	0.04	0.113	0.092	0.026
811	3005-B	NO		1.227	NO								0.114	0.084	0.086	0.128	0.085	0.094	0.124	0.088	0.055
812	3006-A	YES	0.658	5.94	NO		0.558	0.775					0.133	0.093	0.025	0.14	0.095	0.055	0.06	0.042	0.015
818	3007-A	NO		0.0	NO																
819	3007-B	NO		0.246	NO								0.258	0.145	0.038	0.058	0.037	0.006			
820	3007-C	NO		0.0	NO																
821	3008-A	NO		2.087	NO								0.334	0.226	0.076	0.125	0.099	0.006			
822	3008-B	YES	0.124	5.391	NO		0.139	0.11					0.177	0.09	0.05	0.07	0.051	0.008	0.08	0.046	0.002
823	3009-A	YES	PINHOLE	3.56	NO								0.195	0.148	0.122	0.269	0.235	0.058	0.28	0.214	0.158
824	3009-B	NO		5.391	NO								0.29	0.21	0.16	0.104	0.067	0.036	0.103	0.075	0.015
813	3010-A	NO		0.0	NO																
814	3010-B	NO		0.0	NO																
815	3010-C	NO		0.0	NO																
816	3010-1-A	NO		0.0	NO																
817	3010-1-B	NO		0.0	NO																
826	3011-A	NO		0.0	NO																
825	3011-B	NO		0.0	NO																
827	3012-B	YES	0.286	0.196	NO		0.258	0.318					0.049	0.08	0.003						
829	3012-C	NO		2.405	NO								0.165	0.118	0.095	0.135	0.109	0.091	0.144	0.112	0.045
828	3012-D	NO		2.405	NO								0.152	0.167	0.112	0.236	0.152	0.08	0.195	0.139	0.108
830	3013-A	YES	2.25	4.909	NO								0.135	0.098	0.032	0.099	0.058	0.025			
831	3017-A	NO		0.0	NO																
832	3017-B	YES	0.117	4.909	NO		0.142	0.096					0.052	0.045	0.023	0.081	0.051	0.014	0.066	0.056	0.005
833	3017-C	NO		4.449	NO								0.157	0.121	0.02	0.091	0.075	0.015	0.139	0.103	0.006
876	3019-A	NO		0.0	NO																
877	3019-B	NO		0.0	NO																
844	3020-A	NO		0.0	NO																
834	3020-B	NO		0.0	NO																

D3000SER.WK1 (Continued)

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN (IN)	DMAX (IN)	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	NORMAL HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRA'ER 2 DIA (IN)	CRA'ER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
845	3021-A	0.654	0.654	NO		7.069	NO										
836	3022-A	0.299	0.337	NO		1.227	NO					0.112	0.008				
835	3022-B	0.331	0.372	NO		1.496	NO										
842	3022-C	0.362	0.413	NO		3.142	NO					0.106	0.025	0.089	0.016	0.099	0.037
843	3022-D	0.385	0.438	NO		2.405	NO					0.095	0.024	0.08	0.019	0.07	0.01
840	3023-A	0.54	0.627	NO		0.0	NO										
839	3023-B	0.542	0.609	NO		0.0	NO										
841	3024-B	0.661	0.722	NO		0.0	NO										
847	3027-A	0.554	0.694	NO		4.909	NO					0.058	0.028	0.056	0.007	0.047	0.002
846	3028-A	0.67	0.829	NO		10.292	NO					0.087	0.013	0.053	0.015	0.042	0.005
848	3029-C	0.372	0.435	NO		6.514	NO					0.073	0.01	0.1	0.002		
849	3030-A	0.422	0.922	NO		14.186	NO					0.188	0.04	0.17	0.071	0.129	0.02
851	3031-B	0.528	0.922	NO		11.045	NO					0.192	0.071	0.152	0.038	0.177	0.042
850	3031-C	0.627	1.11	NO		12.566	NO					0.21	0.051	0.17	0.085	0.147	0.055
852	3033-A	0.469	0.469	YES	THRUCRACK	10.292	NO					0.189	0.125	0.162	0.105	0.23	0.095
853	3033-B	0.466	0.466	NO		8.296	NO					0.13	0.06	0.148	0.049	0.127	0.03
869	3033-C	0.556	0.556	YES	THRUCRACK	10.292	NO					0.174	0.085	0.136	0.021	0.094	0.024
854	3034-A	0.622	0.622	YES	0.866	14.999	NO		0.866			0.119	0.075	0.126	0.085	0.087	0.042
855	3034-B	0.563	0.563	NO	0.926	14.186	NO		0.249	0.18		0.123	0.066	0.109	0.075	0.158	0.057
856	3034-C	0.657	0.657	NO	5.75	24.806	NO		5.75			0.149	0.064	0.114	0.065	0.093	0.05
863	3035-A	0.424	0.523	NO		8.296	NO					0.105	0.061	0.097	0.026	0.12	0.026
864	3035-B	0.462	0.574	NO	THRUCRACK	3.53	NO					0.149	0.138	0.126	0.047	0.118	0.024
857	3036-A	0.551	0.657	NO		5.94	NO					0.158	0.096	0.122	0.055	0.101	0.038
858	3036-B	0.6	0.752	NO		2.087	NO					0.128	0.042	0.083	0.02	0.078	0.044
861	3037-A	0.722	0.852	NO			NO					0.042	0.004	0.037	0.007		
870	3038-A	0.379	0.691	NO		11.824	NO					0.202	0.032	0.124	0.021	0.151	0.009
871	3038-B	0.431	0.705	NO		7.069	NO					0.162	0.029	0.126	0.016	0.118	0.015
866	3039-A	0.514	0.819	YES	0.1	12.566	NO		0.1			0.138	0.047	0.225	0.052	0.206	0.03
867	3039-B	0.473	0.738	NO		11.824	NO					0.232	0.072	0.194	0.047	0.211	0.046
868	3039-C	0.524	0.866	YES	0.249	9.621	NO		0.186	0.165		0.154	0.083	0.137	0.05	0.184	0.052
865	3040-A	0.641	1.085	YES	0.224	15.904	NO		0.11	0.195		0.154	0.135	0.184	0.08	0.146	0.065

D3000SER.WK1 (Continued)

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SHOT NO.	TEST NO.	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA 1 (IN)	HOLE 1 DIA 2 (IN)	HOLE 2 DIA 1 (IN)	HOLE 2 DIA 2 (IN)	HOLE 3 DIA 1 (IN)	HOLE 3 DIA 2 (IN)	CRATER 1 DIA 1 (IN)	CRATER 1 DIA 2 (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA 1 (IN)	CRATER 2 DIA 2 (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA 1 (IN)	CRATER 3 DIA 2 (IN)	CRATER 3 DEPTH (IN)
845	3021-A	NO		0.0	NO																
836	3022-A	NO		1.003	NO								0.178	0.112	0.057	0.141	0.077	0.036	0.09	0.11	0.045
835	3022-B	NO		2.405	NO								0.278	0.257	0.09	0.125	0.098	0.038	0.105	0.069	0.01
842	3022-C	YES	0.232	2.087	NO		0.245	0.22					0.128	0.097	0.026	0.172	0.135	0.09	0.112	0.098	0.028
843	3022-D	YES	0.17	2.243	NO		0.18	0.124	0.11	0.059			0.099	0.083	0.045	0.096	0.066	0.0421	0.101	0.079	0.046
840	3023-A	NO		3.142	NO								0.142	0.119	0.075	0.078	0.11	0.065	0.131	0.106	0.123
839	3023-B	YES	PINHOLE/THRUCRA	7.694	NO								0.256	0.202	0.14	0.186	0.167	0.105	0.139	0.11	0.069
841	3024-B	YES	1.837	37.068	NO		1.837						0.145	0.099	0.056	0.088	0.068	0.039	0.156	0.114	0.067
847	3027-A	YES	0.036	3.142	NO		0.036						0.163	0.137	0.101	0.155	0.128	0.063	0.165	0.135	0.107
846	3028-A	YES	1.2	6.469	NO		1.2						0.255	0.2	0.075	0.133	0.101	0.032	0.208	0.123	0.104
848	3029-C	NO		2.405	NO								0.158	0.129	0.048	0.113	0.107	0.026	0.09	0.112	0.043
849	3030-A	NO		0.0	NO																
851	3031-B	NO		0.108	NO								0.212	0.133	0.015						
850	3031-C	NO		7.694	NO								0.09	0.066	0.012	0.064	0.09	0.007	0.131	0.114	0.008
852	3033-A	NO		0.0	NO																
853	3033-B	NO		0.0	NO																
869	3033-C	NO		0.0	NO																
854	3034-A	NO		0.0	NO																
855	3034-B	NO		0.0	NO																
856	3034-C	NO		0.0	NO																
863	3035-A	YES	0.189	2.746	NO		0.212	0.169					0.078	0.07	0.02	0.084	0.079	0.026	0.064	0.056	0.024
864	3035-B	NO		4.412	NO								0.121	0.099	0.026	0.076	0.099	0.023	0.086	0.066	0.01
857	3036-A	YES	0.392	4.449	NO		0.339	0.369	0.17	0.17			0.198	0.164	0.133	0.124	0.111	0.055	0.156	0.128	0.073
858	3036-B	NO		3.733	NO								0.145	0.129	0.063	0.13	0.111	0.034	0.14	0.089	0.038
861	3037-A	YES	0.081	4.909	NO		0.07	0.093					0.15	0.125	0.036	0.112	0.107	0.085	0.129	0.114	0.086
870	3038-A	NO		0.0	NO																
871	3038-B	NO		0.0	NO																
866	3039-A	NO		0.0	NO																
867	3039-B	NO		0.0	NO																
868	3039-C	NO		0.0	NO																
865	3040-A	NO		0.0	NO																

D3000SER.WK1 (Continued)

<-- NORMAL -->

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN (IN)	DMAX (IN)	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
1212	3101-A	0.357	0.357	NO		3.98	NO					0.206	0.143	0.196	0.125	0.163	0.045
1213	3101-B	0.405	0.405	NO		6.51	NO					0.167	0.068	0.092	0.035	0.137	0.049
1214	3101-C	0.371	0.371	NO		7.07	NO					0.14	0.04	0.11	0.05		
1215	3102-A	0.461	0.461	NO		9.62	NO					0.603	0.163				
1217	3102-B	0.471	0.471	YES	0.176	4.41	NO		0.176			0.201	0.137	0.16	0.118	0.188	0.115
1218	3102-C	0.489	0.489	NO		7.69	NO					0.243	0.136	0.216	0.126	0.175	0.086
1219	3102-D	0.482	0.482	YES	0.31	4.91	YES	0.38	0.194	0.31							
1220	3102-E	0.475	0.475	NO		5.94	NO					0.12	0.129	0.166	0.09	0.193	0.095
1221	3103-A	0.6	0.6	NO		12.57	YES	0.49									
1222	3103-B	0.604	0.604	YES	0.186	12.57	YES	0.65	0.186								
1223	3103-C	0.62	0.62	YES	0.325	7.07	YES	0.17	THRUCRACK								
1224	3103-D	0.609	0.609	YES	0.237	7.07	YES	0.48	0.237								
1225	3103-E	0.626	0.626	YES	THRUCRACK	9.62	YES	0.36									
1226	3105-A	0.497	0.659	NO		7.07	NO										
1228	3105-B	0.487	0.621	NO		4.41	NO										
874	3120-A	0.398	0.398	YES	0.228	16.403	NO		0.171	0.124	0.086	0.207	0.135	0.151	0.075	0.153	0.08
875	3120-B	0.436	0.436	YES	0.092	47.173	NO		0.092			0.11	0.055	0.078	0.051	0.09	0.02
872	3121-A	0.462	0.462	YES	0.089	33.183	NO		0.082	0.035		0.141	0.065	0.168	0.077	0.146	0.063
873	3121-B	0.463	0.463	YES	0.515	42.776	no		0.431	0.201	0.162	0.162	0.093	0.145	0.075	0.129	0.111
890	3122-A	0.428	0.568	NO			NO										
895	3122-B	0.359	0.484	NO		8.296	NO					0.11	0.029	0.088	0.023	0.041	0.003
900	3122-C	0.339	0.454	NO		15.904	NO					0.148	0.037	0.118	0.044	0.11	0.029
901	3122-D	0.351	0.468	NO		16.331	NO					0.147	0.048	0.104	0.049	0.106	0.034
888	3123-A	0.438	0.6116	NO		6.469	NO					0.062	0.024	0.055	0.019	0.035	0.005
889	3123-B	0.393	0.606	NO			NO										
884	3124-A	0.58	0.679	NO		33.183	NO					0.107	0.052	0.094	0.032	0.073	0.018
885	3124-B	0.523	0.784	NO		11.045	NO					0.093	0.009	0.074	0.005	0.034	0.001
886	3124-C	0.514	0.719	NO		0	NO										
882	3128-A	0.362	0.362	YES	0.204	37.828	NO		0.204			0.104	0.015	0.181	0.052	0.112	0.04
883	3128-B	0.38	0.38	NO		38.485	NO					0.155	0.099	0.126	0.025	0.094	0.026
880	3129-A	0.454	0.454	YES	0.361	42.776	NO		0.198	0.125	0.175	0.194	0.061	0.155	0.04	0.118	0.047
881	3129-B	0.464	0.464	YES	0.268	39.815	NO		0.228	0.138	0.031	0.138	0.042	0.151	0.054	0.111	0.067
878	3130-A	0.608	0.608	NO		67.201	NO					0.167	83	0.197	0.061	0.182	0.05
879	3130-A	0.559	0.559	YES	0.407	38.485	NO		0.166	0.28	0.226	0.211	0.108	0.151	0.079	0.186	0.107
902	3131-A	0.382	0.501	NO		54.367	NO					0.136	0.04	0.139	0.015	0.114	0.017
903	3131-B	0.37	0.486	NO		17.721	NO					0.19	0.056	0.17	0.04	0.133	0.029
918	3131-C	0.362	0.455	NO		9.621	NO					0.148	0.028	0.103	0.005	0.133	0.01
915	3132-A	0.514	0.667	NO		11.045	NO					0.2	0.055	0.107	0.043	0.088	0.02
916	3132-B	0.556	0.694	NO		19.635	NO					0.132	0.024	0.075	0.026	0.112	0.021
917	3132-C	0.543	0.682	NO		9.621	NO					0.096	0.046	0.079	0.021	0.117	0.012
904	3133-A	0.598	0.76	NO		21.237	NO					0.178	0.05	0.148	0.025	0.1	0.025
910	3133-B	0.626	0.819	NO		24.806	NO					0.085	0.02	0.098	0.022	0.091	0.026
911	3133-C	0.641	0.83	NO		16.764	NO					0.171	0.063	0.075	0.014	0.059	0.016
914	3133-D	0.642	0.818	NO		8.296	NO					0.086	0.015	0.05	0.025	0.13	0.032

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							HOLE 1		HOLE 2		HOLE 3			CRATER 1			CRATER 2			CRATER 3	
SHOT NO.	TEST NO.	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	DIA 1 (IN)	DIA 2 (IN)	DIA 1 (IN)	DIA 2 (IN)	DIA 1 (IN)	DIA 2 (IN)	DIA 1 (IN)	DIA 2 (IN)	DEPTH (IN)	DIA 1 (IN)	DIA 2 (IN)	DEPTH (IN)	DIA 1 (IN)	DIA 2 (IN)	DEPTH (IN)
1212	3101-A																				
1213	3101-B																				
1214	3101-C																				
1215	3102-A																				
1217	3102-B																				
1218	3102-C																				
1219	3102-D																				
1220	3102-E																				
1221	3103-A																				
1222	3103-B																				
1223	3103-C																				
1224	3103-D																				
1225	3103-E																				
1226	3105-A	NO		3.14	NO								0.336	0.259	0.137	0.321	0.226	0.176	0.289	0.298	0.136
1228	3105-B	NO		2.41	NO								0.285	0.285	0.078	0.18	0.18	0.053	0.238	0.238	0.072
874	3120-A																				
875	3120-B																				
872	3121-A																				
873	3121-B																				
890	3122-A	NO		6.514	NO								0.141	0.134	0.025	0.053	0.033	0.002			
895	3122-B	NO		39.927	NO								0.18	0.137	0.048	0.212	0.16	0.04	0.12	0.07	0.057
900	3122-C	YES	0.289	5.147	NO		0.301	0.277					0.211	0.108	0.011	0.246	0.115	0.029	0.192	0.154	0.048
901	3122-D	NO		0.694	NO								0.218	0.138	0.065	0.184	0.115	0.059	0.28	0.186	0.048
888	3123-A	YES	0.331	47.173	NO		0.376	0.291					0.387	0.227	0.121	0.212	0.224	0.087	0.273	0.196	0.055
889	3123-B	YES	0.235	37.068	NO		0.255	0.179	0.108	0.088			0.235	0.161	0.117	0.22	0.193	0.047	0.197	0.095	0.053
884	3124-A	YES	0.718	19.635	NO		0.693	0.744					0.124	0.11	0.034	0.289	0.213	0.095	0.224	0.212	0.12
885	3124-B	YES	0.674	17.721	NO		0.368	0.298	0.411	0.682	0.261	0.201	0.2	0.159	0.065	0.176	0.143	0.108	0.177	0.16	0.087
886	3124-C	YES	0.66	13.332	NO		0.181	0.077	0.255	0.136	0.159	0.126	0.165	0.122	0.07	0.229	0.112	0.042	0.144	0.087	0.035
882	3128-A																				
883	3128-B																				
880	3129-A																				
881	3129-B																				
878	3130-A																				
879	3130-A																				
902	3131-A	NO		9.621	NO								0.358	0.204	0.055						
903	3131-B	NO		4.909	NO								0.306	0.347	0.11	0.125	0.075	0.011	0.115	0.091	0.015
918	3131-C	NO		9.624	NO								0.338	0.284	0.039	0.193	0.122	0.007	0.129	0.087	0.003
915	3132-A	YES	0.234	33.183	NO		0.237	0.231					0.208	0.189	0.086	0.279	0.198	0.042	0.254	0.189	0.064
916	3132-B	NO		7.645	NO								0.224	0.238	0.099	0.159	0.119	0.039	0.151	0.079	0.024
917	3132-C	YES	0.134	44.179	NO		0.149	0.12					0.241	0.279	0.11	0.227	0.212	0.105	0.175	0.268	0.126
904	3133-A	YES	0.636	38.485	NO		0.367	0.206	0.429	0.275	0.412	0.3	0.245	0.176	0.055	0.213	0.16	0.053	0.206	0.261	0.109
910	3133-B	YES	0.297	22.732	NO		0.107	0.098	0.286	0.271			0.236	0.18	0.071	0.248	[illegible]	0.076	0.194	0.151	0.075
911	3133-C	YES	0.422	11.045	NO		0.261	0.31	0.18	0.252	0.25	0.208	0.242	0.203	0.076	0.522	[illegible]	0.098	0.206	0.12	0.031
914	3133-D	YES	0.518	38.485	NO		0.105	0.071	0.358	0.628	0.205	0.174	0.188	0.208	0.08	0.238	0.196	0.065	0.282	0.211	0.128

D3100SER.WK1 (Continued)

<------------ NORMAL ------------>

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN (IN)	BUMPER PLATE HOLE DMAX (IN)	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
966	3202	0.424	0.424	NO		4.909	NO					0.032	0.003				
1010	3202-A	0.682	0.682	YES	0.298	3.14	NO		0.298								
1011	3202-B	0.637	0.637	YES	0.51	8.29	NO		0.806			0.056	0.05	0.096	0.034	0.082	0.032
1012	3202-C	0.724	0.724	YES	0.506	9.62	NO		0.506								
967	3205	0.489	0.489	NO		7.645	NO					0.069	0.025	0.048	0.014	0.082	0.034
969	3206	0.54	0.54	YES	0.236	3.142	NO		0.183	0.081	0.097	0.129	0.064	0.077	0.065	0.091	0.035
970	3207	0.442	0.552	NO		0.785	NO					0.13	0.035	0.059	0.004	0.075	0.021
971	3208	0.387	0.777	NO		9.621	NO					0.07	0.005	0.104	0.008	0.125	0.004
972	3209	0.451	0.798	NO		11.763	NO					0.166	0.058	0.117	0.042	0.107	0.05
983	3209-1	0.44	0.873	NO		9.621	NO					0.126	0.035	0.228	0.06	0.133	0.033
974	3210	0.448	0.982	NO		5.94	NO					0.149	0.03	0.125	0.033	0.105	0.014
973	3211	0.46	0.797	NO		22.648	NO					0.105	0.026	0.152	0.027	0.163	0.025
975	3212	0.492	0.922	NO		17.721	NO					0.157	0.032	0.16	0.027	0.205	0.025
982	3212-1	0.505	1.018	NO		9.621	NO					0.115	0.047	0.123	0.036	0.134	0.008
976	3213	0.512	1.047	NO		13.396	NO					0.147	0.075	0.162	0.067	0.165	0.038
977	3214	0.513	0.978	NO		9.621	NO					0.171	0.062	0.122	0.059	0.159	0.055
978	3215	0.575	1.06	NO		11.824	NO					0.162	0.096	0.187	0.065	0.111	0.088
980	3216	0.568	1.033	NO		5.433	NO					0.254	0.125	0.155	0.065	0.132	0.062
979	3217	0.548	1.057	NO		4.909	NO					0.178	0.134	0.155	0.048	0.158	0.056
981	3218	0.55	1.101	NO		3.53	NO					0.183	0.045	0.154	0.056	0.186	0.05
984	3220-A	0.474	0.474	YES	0.073	30.68	YES	0.008	0.066	0.031		0.153	0.077	0.13	0.106	0.149	0.076
985	3220-B	0.466	0.466	YES	0.23	29.513	NO		0.161	0.144	0.078	0.141	0.063	0.113	0.073	0.103	0.062
986	3221-A	0.386	0.386	YES	0.336	8.973	YES	0.052	0.064	0.183	0.24	0.126	0.065	0.171	0.104	0.205	0.085
987	3221-B	0.381	0.381	YES	0.299	12.566	NO		0.094	0.16	0.108	0.188	0.077	0.2	0.136	0.09	0.05
988	3222-A	0.308	0.308	YES	0.111	17.721	NO		0.111			0.113	0.053	0.124	0.055	0.156	0.05
991	3223-A	0.595	0.595	NO		45.723	NO					0.175	0.07	0.119	0.058	0.153	0.042
990	3224-A	0.486	0.486	YES	0.115	47.173	YES	0.007	0.115			0.199	0.1	0.181	0.067	0.16	0.063
989	3224-B	0.521	0.521	NO		41.282	NO					0.099	0.039	0.13	0.037	0.137	0.032
992	3225	0.493	0.493	YES	7.79	88.748	NO		7.79			0.11	0.053	0.138	0.065	0.196	0.056
993	3225-A	0.483	0.483	YES	6.63	34.524	NO		6.63			0.221	0.0085	0.1177	0.082	0.139	0.069
1009	3225-C	0.587	0.587	NO		54.19	NO					0.157	0.124	0.063	0.055	0.064	0.026
995	3226-A	0.618	0.618	YES	0.187	88.581	YES	0.089	0.11	0.12	0.092	0.18	0.126	0.152	0.061	0.259	0.13
994	3226-B	0.638	0.638	YES	0.624	35.785	NO		0.24	0.281	0.425	0.173	0.125	0.157	0.066	0.17	0.075
996	3226-C	0.638	0.638	NO		48.769	YES	0.006				0.178	0.052	0.226	0.077	0.157	0.063
997	3227-A	0.696	0.696	YES	8.5	88.748	NO		8.5			0.148	0.072	0.16	0.065	0.1	0.066
1002	3227-B	0.645	0.645	YES	3.742	48.645	NO		3.742								
998	3227-C	0.654	0.654	NO		51.912	NO					0.147	0.045	0.166	0.075	0.134	0.096
1000	3227-D	0.674	0.674	YES	2.387	11.045	NO		2.382	0.149		0.132	0.037	0.125	0.06	0.188	0.059

D3200SER.WK1

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SHOT NO.	TEST NO.	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA 1 (IN)	HOLE 1 DIA 2 (IN)	HOLE 2 DIA 1 (IN)	HOLE 2 DIA 2 (IN)	HOLE 3 DIA 1 (IN)	HOLE 3 DIA 2 (IN)	CRATER 1 DIA 1 (IN)	CRATER 1 DIA 2 (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA 1 (IN)	CRATER 2 DIA 2 (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA 1 (IN)	CRATER 3 DIA 2 (IN)	CRATER 3 DEPTH (IN)
966	3202																				
1010	3202-A																				
1011	3202-B																				
1012	3202-C																				
967	3205																				
969	3206																				
970	3207	YES	0.453	2.747	NO		0.512	0.4					0.111	0.102	0.038	0.149	0.1	0.03	0.175	0.092	0.08
971	3208	NO		1.227	NO								0.232	0.181	0.017	0.322	0.22	0.01			
972	3209	NO		2.061	NO								0.172	0.14	0.027	0.17	0.096	0.013			
983	3209-1	NO		11.763	NO								0.164	0.153	0.029	0.238	0.145	0.02			
974	3210	NO		7.645	NO								0.174	0.161	0.034	0.186	0.133	0.039	0.15	0.127	0.045
973	3211	NO		0.302	NO																
975	3212	YES	0.161	0.785	NO		0.151	0.172					0.145	0.074	0.023						
982	3212-1	YES	0.28	2.405	NO		0.283	0.276					0.175	0.124	0.01	0.175	0.119	0.008	0.081	0.052	0.01
976	3213	NO		3.53	NO								0.49	0.3	0.094	0.266	0.229	0.07	0.205	0.128	0.045
977	3214	NO		0.442	NO								0.394	0.236	0.068	0.228	0.142	0.035			
978	3215	NO		5.931	NO								0.356	0.238	0.105	0.116	0.079	0.044	0.147	0.124	0.058
980	3216	NO		3.976	YES	0.016							0.321	0.232	0.08	0.14	0.096	0.025	0.132	0.09	0.028
979	3217	NO		3.976	NO								0.227	0.192	0.054	0.242	0.144	0.057	0.27	0.148	0.056
981	3218	NO		2.405	NO								0.298	0.177	0.041	0.18	0.152	0.03	0.162	0.109	0.025
984	3220-A																				
985	3220-B																				
986	3221-A																				
987	3221-B																				
988	3222-A																				
991	3223-A																				
990	3224-A																				
989	3224-B																				
992	3225																				
993	3225-A																				
1009	3225-C																				
995	3226-A																				
994	3226-B																				
996	3226-C																				
997	3227-A																				
1002	3227-B																				
998	3227-C																				
1000	3227-D																				

D3200SER.WK1 (Continued)

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN (IN)	DMAX (IN)	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
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1005	3301-A	0.485	0.485	YES	0.173	14.19	NO		0.113	0.131		0.115	0.111	0.192	0.099	0.137	0.085
1006	301-B	0.485	0.485	YES	0.566	12.57	NO		0.566			0.149	0.063	0.154	0.067	0.128	0.073
1007	3301-C	0.548	0.548	NO		7.07	NO					0.056	0.062	0.11	0.094	0.106	0.063
1008	3301-D	0.563	0.563	NO		25.97	NO					0.116	0.103	0.123	0.083	0.072	0.084
1029	3301-E	0.51	0.51	THRUCRACKS		11.95	NO					0.181	0.125	0.173	0.175	0.147	0.125
1030	3302-E	0.675	0.675	YES	1.873	28.27	NO		1.823	0.281	0.264	0.144	0.095	0.086	0.097	0.111	0.084
1014	3303-A	0.472	0.55	NO		4.91	NO					0.11	0.032	0.059	0.02	0.051	0.017
1015	3303-B	0.491	0.532	NO		2.45	NO					0.074	0.041	0.069	0.035	0.051	0.023
1016	3303-C	0.455	0.525	NO		0.594	NO					0.069	0.03	0.04	0.017	0.067	0.028
1021	3303-D	0.455	0.506	YES	<.0625	0.594	NO		<.0625			0.2	0.125	0.08	0.042	0.071	0.042
1017	3304-A	0.592	0.7	NO		3.97	NO										
1018	3304-B	0.674	0.79	NO		4.91	NO					0.056	0.035	0.14	0.012		
1019	3304-C	0.684	0.761	NO		4.91	NO					0.072	0.037	0.083	0.033		
1020	3304-D	0.687	0.783	NO		3.24	NO										
1025	3305-A	0.36	0.36	NO		9.62	NO					0.192	0.125	0.18	0.097	0.122	0.072
1023	3305-B	0.39	0.39	NO		5.94	NO					0.12	0.07	0.109	0.054	0.086	0.035
1024	3305-C	0.425	0.425	NO		7.07	NO					0.089	0.096	0.114	0.079	0.296	0.065
1026	3306-A	0.5	0.5	NO		8.04	NO					0.126	0.025	0.04	0.048	0.072	0.085
1031	3306-B	0.496	0.496	NO		7.55	NO					0.059	0.092	0.015	0.025		
1027	3306-C	0.507	0.507	YES	0.185	11.34	YES	<0.25	0.175	0.059		0.119	0.078	0.064	0.03	0.098	0.05
1028	3306-D	0.506	0.506	YES	0.105	7.55	NO		0.105			0.153	0.125	0.112	0.125	0.111	0.053
1032	3307-A	0.375	0.438	NO		3.14	NO					0.137	0.044				
1033	3307-B	0.438	0.563	NO		0.79	NO					0.099	0.015	0.109	0.031	0.09	0.023
1034	3038-A	0.5	0.594	NO		2.41	NO					0.084	0.012	0.093	0.13	0.112	0.009
1035	3308-B	0.519	0.652	NO		3.56	NO					0.174	0.063				

D3300SER.WK1

SHOT NO.	TEST NO.	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA 1 (IN)	HOLE 1 DIA 2 (IN)	HOLE 2 DIA 1 (IN)	HOLE 2 DIA 2 (IN)	HOLE 3 DIA 1 (IN)	HOLE 3 DIA 2 (IN)	CRATER 1 DIA 1 (IN)	CRATER 1 DIA 2 (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA 1 (IN)	CRATER 2 DIA 2 (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA 1 (IN)	CRATER 3 DIA 2 (IN)	CRATER 3 DEPTH (IN)
		<-----------	---------	---------	---------	---------	---------	---------	---------	-------- IN-LINE	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	--------->
1005	3301-A																				
1006	301-B																				
1007	3301-C																				
1008	3301-D																				
1029	3301-E																				
1030	3302-E																				
1014	3303-A	NO		4.91	NO								0.242	0.153	0.125	0.11	0.105	0.075	0.08	0.083	0.03
1015	3303-B	NO		2.45	NO								0.107	0.099	0.062	0.119	0.087	0.029	0.057	0.055	0.01
1016	3303-C	NO		4.91	NO								0.144	0.107	0.07	0.072	0.079	0.061	0.085	0.11	0.045
1021	3303-D	NO		3.98	NO								0.145	0.193	0.1	0.083	0.08	0.045	0.096	0.129	0.032
1017	3304-A	YES	0.05	3.14	NO		0.27	0.209					0.111	0.163	0.104	0.117	0.141	0.106	0.116	0.116	0.058
1018	3304-B	YES	0.08	4.91	NO		0.321	0.389					0.087	0.121	0.059	0.063	0.132	0.052	0.055	0.098	0.022
1019	3304-C	YES	0.014	5.94	NO		0.282	0.271	0.132	0.243	0.274	0.293	0.091	0.107	0.125	0.053	0.053	0.086	0.071	0.083	0.032
1020	3304-D	YES	<.0625	4.91	NO		PINHOLE	PINHOLE					0.166	0.15	0.125	0.144	0.181	0.125	0.162	0.276	0.125
1025	3305-A																				
1023	3305-B				NO																
1024	3305-C																				
1026	3306-A																				
1031	3306-B																				
1027	3306-C																				
1028	3306-D																				
1032	3307-A	NO		7.07	NO								0.214	0.214	0.045	0.207	0.182	0.039	0.214	0.214	0.045
1033	3307-B	NO		2.06	NO								0.124	0.124	0.014	0.133	0.09	0.033			
1034	3038-A	NO		1.77	NO								0.155	0.114	.139	0.208	0.146	.139	0.196	0.112	0.084
1035	3308-B	YES	0.408	2.77	YES	0.04	0.352	0.234	0.334	0.242	0.056	0.056	0.329	0.202	0.11	0.235	0.14	0.042	0.229	0.156	0.076

D3300SER.WK1 (Continued)

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN (IN)	DMAX (IN)	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
1140	3401-A	0.686	0.686	YES	2.96	8.3	NO		6.87								
1144	3401-B	0.653	0.653	YES	2.81	7.07	NO		2.81								
1139	3401-C	0.62	0.62	YES	2.43	8.97	NO		2.43								
1138	3401-D	0.579	0.579	YES	1.63	8.3	NO		1.63								
1143	3402-A	0.673	0.673	YES	2.41	7.07	NO		2.4								
1145	3402-B	0.674	0.674	YES	2.09	7.07	NO		2.09								
1142	3402-C	0.61	0.61	YES	2.55	7.07	NO		2.55								
1141	3402-D	0.561	0.561	YES	1.5	8.97	NO		1.5								
1149	3403-A	0.636	0.636	YES	0.806	16.76	YES	0.67	0.806								
1148	3403-B	0.639	0.639	YES	0.731	18.7	YES	0.64	0.731								
1147	3403-C	0.62	0.62	YES	2.49	15.9	NO		2.49								
1146	3403-D	0.573	0.573	YES	0.852	14.19	NO		0.852								
1152	3404-A	0.654	0.654	YES	8	50.27	NO		8								
1153	3404-B	0.654	0.654	YES	5.75	25.97	NO		5.75								
1154	3404-C	0.641	0.641	YES	5.5	23.76	NO		5.5								
1156	3404-D	0.623	0.623	YES	4.5	15.9	NO		4.5								
1165	3405-A	0.407	0.407	YES	0.261	5.39	NO		0.261			0.151	0.073	0.12	0.056	0.119	0.076
1166	3405-B	0.46	0.46	YES	0.169	8.92	NO		0.169			0.126	0.047	0.109	0.018		
1167	3405-C	0.494	0.494	NO		9.62	NO										
1168	3405-D	0.516	0.516	NO		8.97	NO										
1161	3406-A	0.42	0.42	YES	0.231	4.91	NO		0.231			0.195	0.13	0.181	0.062	0.198	0.121
1162	3406-B	0.456	0.456	NO		8.3	NO					0.16	0.039	0.149	0.097	0.167	0.082
1163	3406-C	0.459	0.459	NO		10.29	NO					0.076	0.047	0.119	0.038	0.115	0.031
1164	3406-D	0.478	0.478	NO		7.07	NO					0.125	0.118				
1169	3406-D1	0.485	0.485	YES	0.265	5.94	NO		0.26	0.05							
1160	3407-A	0.414	0.414	YES	0.445	5.94	NO		0.445			0.129	0.096	0.164	0.087	0.214	0.085
1159	3407-B	0.431	0.431	YES	0.638	7.07	NO		0.638			0.169	0.112	0.158	0.064	0.132	0.056
1158	3407-C	0.477	0.477	YES	0.109	11.04	NO		0.109			0.124	0.039	0.135	0.029	0.122	0.03
1157	3407-D	0.503	0.503	NO		15.9	NO					0.138	0.109	0.136	0.107		

D3400SER.WK1

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN (IN)	DMAX (IN)	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
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1042	4001-A	0.535	0.704	NO		3.56	YES	0.25				0.165	0.024	0.122	0.018	0.254	0.015
1040	4001-B	0.596	0.755	NO		3.98	NO					0.128	0.043	0.158	0.015	0.121	0.023
1041	4001-C	0.655	0.851	NO		3.14	NO					0.135	0.027	0.11	0.03	0.077	0.019
1043	4001-D	0.665	0.81	NO		5.39	NO										
1046	4002-A	0.46	1.041	NO		5.49	NO										
1044	4002-B	0.482	1.057	NO		2.41	NO										
1045	4002-C	0.533	1.349	YES	0.162	4.91	NO		0.162			0.197	0.032	0.223	0.062	0.243	0.105
1047	4002-D	0.571	1.41	NO		7.07	NO										
1056	4002-E	0.561	1.191	NO		8.3	NO										
1048	4003-A	0.519	0.696	NO		7.07	NO										
1049	4003-B	0.622	0.795	NO		5.94	NO										
1051	4003-C	0.511	0.674	NO		3.98	NO					0.18	0.05	0.104	0.015		
1050	4003-D	0.617	0.887	NO		NO DAMAGE	NO										
1052	4004-A	0.427	1.042	NO		7.07	NO										
1053	4004-B	0.673	1.366	YES	0.105	7.69	NO		0.105			0.158	0.034	0.135	0.053	0.169	0.058
1054	4004-C	0.552	1.315	NO		5.39	NO					0.167	0.1	0.11	0.125	0.159	0.073

SHOT NO.	TEST NO.	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA 1 (IN)	HOLE 1 DIA 2 (IN)	HOLE 2 DIA 1 (IN)	HOLE 2 DIA 2 (IN)	HOLE 3 DIA 1 (IN)	HOLE 3 DIA 2 (IN)	CRATER 1 DIA 1 (IN)	CRATER 1 DIA 2 (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA 1 (IN)	CRATER 2 DIA 2 (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA 1 (IN)	CRATER 3 DIA 2 (IN)	CRATER 3 DEPTH (IN)
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1042	4001-A	YES	0.445	3.56	NO		0.445	0.455					0.304	0.26	0.083	0.313	0.274	0.038	0.14	0.105	0.01
1040	4001-B	YES	0.633	4.45	NO		0.9	0.4	0.4	0.3			0.231	0.191	0.054	0.234	0.204	0.061	0.164	0.131	0.029
1041	4001-C	YES	0.523	4.91	NO		0.8	0.34					0.156	0.127	0.017	0.191	0.131	0.052	0.244	0.147	0.054
1043	4001-D	YES	0.434	4.91	NO		0.323	0.251	0.242	0.277	0.178	0.125									
1046	4002-A	NO		NO DAMAGE	NO																
1044	4002-B	NO		NO DAMAGE	NO																
1045	4002-C	NO		NO DAMAGE	NO																
1047	4002-D	NO		NO DAMAGE	NO																
1056	4002-E	NO		NO DAMAGE	NO																
1048	4003-A	YES	0.602	2.41	NO		0.71	0.51													
1049	4003-B	YES	0.711	3.98	NO		0.6	0.4	0.49	0.34	0.3	0.3	0.146	0.146	0.053	0.171	[illegible]	0.035	0.18	0.131	0.079
1051	4003-C	YES	0.504	2.41	NO		0.504	0.504					0.151	0.174	0.048	0.123	0.207	0.073			
1050	4003-D	YES	0.51	6.47	NO		0.6	0.33	0.25	0.25			0.192	0.208	0.063	0.138	0.174	0.065	0.167	0.148	0.129
1052	4004-A	NO		NO DAMAGE	NO																
1053	4004-B	NO		NO DAMAGE	NO																
1054	4004-C	NO		NO DAMAGE	NO																

<-- NORMAL -->

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN (IN)	DMAX (IN)	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
1105	4100-A	0.324	0.649	NO		3.14	NO										
1106	4100-B	0.351	0.448	NO		3.56	NO					0.129	0.01	0.118	0.004		
1108	4100-C	0.362	0.453	NO		4.41	NO										
1109	4100-D	0.406	0.523	NO			NO										
1110	4101-A	0.411	0.598	NO		3.14	NO										
1111	4101-B	0.456	0.61	NO		3.53	NO										
1112	4101-C	0.536	0.649	NO		4.41	NO					0.105	0.029				
1113	4101-D	0.5	0.681	NO		4.91	NO					0.113	0.044	0.105	0.029		
1190	4102-A	0.482	0.665	NO		3.14	NO										
1189	4102-B	0.519	0.709	NO		4.91	NO					0.138	0.025				
1191	4102-C	0.582	0.757	NO		9.62	NO										
1209	4102-C1	0.585	0.782	NO		8.3	NO					0.086	0.05				
1210	4102-C2	0.578	0.765	NO		8.92	NO										
1211	4102-D	0.625	0.812	NO		12.57	NO										
1114	4103-A	0.308	0.561	NO		1.23	NO										
1115	4103-B	0.342	0.539	NO		3.56	NO					0.11	0.001				
1116	4103-C	0.422	0.683	NO		11.04	NO					0.104	0.012	0.103	0.004	0.126	0.019
1121	4103-D	0.398	0.818	NO		15.9	NO					0.136	0.021	0.126	0.024	0.124	0.019
1118	4104-A	0.429	0.709	NO		4.41	NO					0.13	0.027	0.121	0.026	0.091	0.015
1122	4104-B	0.458	0.761	NO		4.91	NO					0.137	0.022				
1123	4104-C	0.489	0.826	NO		7.65	NO					0.132	0.024	0.122	0.023	0.154	0.026
1124	4104-D	0.536	0.765	NO		5.94	NO					0.124	0.027	0.094	0.01	0.125	0.019
1185	4105-A	0.5	0.831	NO		5.94	NO										
1187	4105-A1	0.502	0.856	NO		11.84	NO					0.121	0.035	0.117	0.027	0.142	0.006
1184	4105-B	0.536	0.844	NO		9.62	NO					0.141	0.019	0.15	0.024		
1182	4105-C	0.595	0.949	NO		7.07	NO					0.151	0.011	0.138	0.032	0.141	0.026
1183	4105-D	0.609	0.984	NO		0.83	NO										
1125	4106-A	0.314	0.521	NO		0.314	NO										
1133	4106-A1	0.244	0.711	NO			NO										
1126	4106-B	0.357	0.581	NO		5.94	NO										
1134	4106-B1	0.318	0.588	NO		3.14	NO					0.105	0.012				
1137	4106-C	0.314	0.719	NO		1.23	NO										
1136	4106-D	0.327	0.932	NO		1.77	NO										
1128	4107-A	0.384	1.056	NO			NO										
1130	4107-B	0.476	1.042	NO		9.62	NO										
1131	4107-C	0.505	1.361	NO		4.91	NO										
1132	4107-D	0.532	0.855	NO		11.83	NO					0.139	0.024	0.137	0.016	0.108	0.025
1186	4108-A	0.526	1.081	NO			NO					0.135	0.064	0.126	0.032	0.091	0.027
1188	4108-A1	0.471	1.249	NO			NO										
1179	4108-B	0.514	1.241	NO			NO										
1180	4108-C	0.551	1.496	NO			NO										
1181	4108-D	0.581	1.521	NO		11.04	NO					0.126	0.04	0.142	0.066	0.126	0.098

D4100SER.WK1

SHOT NO.	TEST NO.	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA 1 (IN)	HOLE 1 DIA 2 (IN)	HOLE 2 DIA 1 (IN)	HOLE 2 DIA 2 (IN)	HOLE 3 DIA 1 (IN)	HOLE 3 DIA 2 (IN)	CRATER 1 DIA 1 (IN)	CRATER 1 DIA 2 (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA 1 (IN)	CRATER 2 DIA 2 (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA 1 (IN)	CRATER 3 DIA 2 (IN)	CRATER 3 DEPTH (IN)
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1105	4100-A	NO		0.302	NO								0.224	0.161	0.0056	0.208	0.17	0.033			
1106	4100-B	NO		2.41	NO								0.197	0.162	0.052	0.216	0.164	0.027			
1108	4100-C	NO		3.14	NO								0.226	0.226	0.103	0.16	0.16	0.058	0.241	0.176	0.071
1109	4100-D	NO		1.77	NO								0.132	0.132	0.047	0.108	0.108	0.034	0.106	0.106	0.015
1110	4101-A	YES	0.39	0.785	NO		0.42	0.362					0.169	0.105	0.038						
1111	4101-B	YES	0.39	2.41	NO		0.339	0.449					0.146	0.146	0.026						
1112	4101-C	YES	0.479	1.47	NO		0.479	0.479	0.252	0.252	0.113	0.113	0.17	0.17	0.091	0.115	0.115	0.038	0.152	0.112	0.09
1113	4101-D	YES		0.129	NO		0.104	0.081	0.099	0.084											
1190	4102-A	YES	0.696	7.12	NO								0.122	0.122	0.054	0.318	0.195	0.093	0.163	0.163	0.027
1189	4102-B	YES	0.829	9.82	NO																
1191	4102-C	YES	0.874	14.53	YES	0.014	0.17	0.121	0.229	0.147	0.576	0.311	0.255	0.168	0.137	0.192	0.192	0.139	0.24	0.152	0.105
1209	4102-C1	YES	0.566	13.21	NO		0.193	0.141					0.237	0.237	0.12						
1210	4102-C2	YES	0.964	15.99	NO		0.158	0.085	0.197	0.144	0.224	0.16	0.214	0.172	0.04						
1211	4102-D	YES	0.906	19.64	NO		0.137	0.137	0.3009	0.309	0.288	0.288	0.218	0.218	0.13	0.144	0.144	0.068	0.175	0.146	0.074
1114	4103-A	NO		1.23	NO								0.182	0.182	0.001						
1115	4103-B	NO		1.5	NO								0.155	0.143	0.01	0.138	0.132	0.004			
1116	4103-C	NO			NO																
1121	4103-D	NO			NO																
1118	4104-A	NO		0.61	NO								0.271	0.126	0.043						
1122	4104-B	NO		2.09	NO								0.309	0.241	0.052	0.214	0.214	0.034	0.212	0.121	0.028
1123	4104-C	NO		4.59	NO								0.129	0.129	0.041	0.103	0.103	0.017	0.092	0.092	0.01
1124	4104-D	YES	THRUCRACK	3.14	NO								0.223	0.195	0.125	0.188	0.1124	0.037	0.215	0.141	0.083
1185	4105-A	YES	0.385	8.35	NO		0.413	0.358													
1187	4105-A1	NO		17.23	NO								0.272	0.272	0.05	0.182	0.182	0.09			
1184	4105-B	NO		19.24	NO								0.232	0.232	0.07	0.311	0.255	0.073	0.42	0.271	0.095
1182	4105-C	NO		15.37	NO								0.161	0.148	0.068	0.222	0.176	0.04	0.199	0.166	0.035
1183	4105-D	NO		18.65	NO								0.145	0.145	0.032	0.202	0.158	0.056			
1125	4106-A	NO		1.77	NO																
1133	4106-A1	NO			NO																
1126	4106-B	NO		2.09	NO								0.215	0.1131	0.027						
1134	4106-B1	NO			NO																
1137	4106-C	NO			NO																
1136	4106-D	NO			NO																
1128	4107-A	NO			NO																
1130	4107-B	NO			NO																
1131	4107-C	NO			NO																
1132	4107-D	NO			NO																
1186	4108-A	NO		9.62	NO																
1188	4108-A1	NO		7.07	NO																
1179	4108-B	NO		10.35	NO								0.221	0.122	0.035	0.171	0.101	0.026	0.212	0.144	0.029
1180	4108-C	NO		15.07	NO								0.174	0.174	0.074	0.141	0.141	0.071	0.128	0.128	0.053
1181	4108-D	NO			NO																

D4100SER.WK1 (Continued)

<-- NORMAL -->

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN (IN)	DMAX (IN)	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
1058	4109-A	0.361	0.456	NO		3.14	NO					0.176	0.042				
1059	4109-B	0.414	0.466	NO		3.98	NO					0.165	0.043	0.224	0.048	0.132	0.041
1060	4109-C	0.482	0.55	NO		5.94	NO					0.11	0.017	0.1	0.041	0.08	0.011
1062	4109-D	0.494	0.58	NO		10.35	NO					0.114	0.032	0.1	0.023	0.096	0.004
1064	4110-A	0.468	0.569	NO		2.41	NO					0.188	0.034	0.119	0.043	0.1	0.019
1065	4110-B	0.502	0.61	NO		2.41	NO					0.345	0.082	0.215	0.115		
1068	4110-C	5.62	7.51	NO		4.71	NO					0.119	0.062				
1069	4110-D	0.584	0.689	NO		5.39	NO										
1070	4111-A	0.515	0.693	NO		3.53	NO					0.148	0.024	0.102	0.015		
1071	4111-B	5.575	0.721	NO		8.3	NO					0.116	0.029	0.135	0.036	0.132	0.041
1072	4111-C	0.66	0.821	NO		8.3	NO										
1073	4111-D	0.681	0.76	NO		6.47	NO										
1074	4112-A	0.33	0.544	NO		1.77	NO					0.206	0.011	0.109	0.001	0.28	0.021
1075	4112-B	0.455	0.509	NO		7.07	NO					0.111	0.03	0.1	0.015	0.047	0.007
1076	4112-C	0.429	0.6	NO		3.14	NO					0.114	0.036	0.141	0.033	0.139	0.027
1077	4112-D	0.556	0.78	NO		5.94	NO					0.147	0.033	0.1	0.048	0.118	0.049
1078	4113-A	0.4	0.785	NO		9.62	NO					0.22	0.007	0.16	0.007		
1079	4113-B	0.446	0.79	NO		3.14	NO					0.183	0.035	0.121	0.037	0.09	0.05
1080	4113-C	0.668	0.872	YES	0.053	2.41	NO		0.053			0.133	0.06	0.136	0.057	0.123	0.023
1082	4113-D	0.601	0.778	NO		2.41	NO					0.166	0.043	0.142	0.024	0.125	0.021
1083	4114-A	0.532	0.827	NO		4.91	NO					0.151	0.014	0.197	0.024	0.164	0.011
1084	4114-B	0.559	0.897	NO		7.07	NO					0.181	0.054	0.201	0.106	0.185	0.076
1085	4114-C	0.659	0.956	NO		9.62	NO					0.179	0.104	0.131	0.028	0.145	0.033
1086	4114-D	0.7	1.039	NO		11.04	NO					0.183	0.077	0.174	0.097	0.189	0.125
1089	4115-A	0.207	0.238	NO			NO										
1088	4115-B	0.251	0.354	NO			NO										
1090	4115-C	0.348	0.461	NO		2.41	NO					0.181	0.017	0.112	0.016		
1091	4115-D	0.391	0.509	NO		7.69	NO					0.148	0.019	0.136	0.012		
1092	4116-A	0.277	0.623	NO			NO										
1093	4116-B	0.364	0.837	NO			NO										
1094	4116-C	0.478	0.942	NO		1.77	NO					0.275	0.034	0.194	0.011	0.204	0.003
1095	4116-D	.518/.218	.75/.377	NO		5.94	NO					0.165	0.009	0.106	0.025	0.151	0.021
1096	4117-A	0.444	0.909	NO		2.09	NO										
1097	4117-B	0.474	1.162	NO			NO					0.375	0.062				
1098	4117-C	0.55	1.232	NO		6.51	NO					0.183	0.108	0.209	0.073	0.179	0.064
1103	4117-D	0.692	1.443	NO		8.29	NO					0.176	0.078	0.289	0.059	0.184	0.046

D4100SER.WK1 (Continued)

SHOT NO.	TEST NO.	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA 1 (IN)	HOLE 1 DIA 2 (IN)	HOLE 2 DIA 1 (IN)	HOLE 2 DIA 2 (IN)	HOLE 3 DIA 1 (IN)	HOLE 3 DIA 2 (IN)	CRATER 1 DIA 1 (IN)	CRATER 1 DIA 2 (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA 1 (IN)	CRATER 2 DIA 2 (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA 1 (IN)	CRATER 3 DIA 2 (IN)	CRATER 3 DEPTH (IN)
		<---------- IN-LINE																			---------->
1058	4109-A	NO		2.78	NO								0.292	0.266	0.035						
1059	4109-B	NO		1.77	NO								0.258	0.191	0.01						
1060	4109-C	NO		1.77	NO																
1062	4109-D	NO		2.78	NO								0.085	0.064	0.014	0.08	0.067	0.011			
1064	4110-A	NO		2.06	NO								0.327	0.202	0.059	0.237	0.16	0.065	0.219	0.187	0.081
1065	4110-B	NO		3.98	NO								0.28	0.184	0.067	0.21	0.17	0.064	0.204	0.142	0.041
1068	4110-C	NO		3.14	NO		0.142	0.09					0.185	0.154	0.139	0.156	0.156	0.145	0.084	0.084	0.034
1069	4110-D	NO		4.91	NO								0.119	0.119	0.044	0.114	0.114	0.045	0.13	0.13	0.057
1070	4111-A	NO		3.56	NO		0.371	0.201					0.36	0.239	0.095	0.217	0.171	0.065			
1071	4111-B	NO		3.14	NO		0.576	0.241					0.342	0.269	0.18	0.325	0.234	0.115	0.189	0.142	0.082
1072	4111-C	YES	0.553	4.91	NO								0.182	0.182	0.153						
1073	4111-D	YES	0.321	6.47	NO		0.26	0.167	0.234	0.234	0.07	0.07	0.203	0.19	0.127	0.169	0.148	0.094	0.205	0.134	0.124
1074	4112-A	NO			NO																
1075	4112-B	NO			NO																
1076	4112-C	NO			NO																
1077	4112-D	NO			NO																
1078	4113-A	NO			NO																
1079	4113-B	NO		3.98	NO								0.376	0.179	0.047	0.12	0.054	0.016			
1080	4113-C	NO		14.19	NO								0.136	0.073	0.02	0.103	0.061	0.025	0.099	0.056	0.013
1082	4113-D	NO		9.62	NO								0.154	0.129	0.084	0.192	0.152	0.047	0.132	0.106	0.026
1083	4114-A	NO		5.94	NO								0.206	0.16	0.008						
1084	4114-B	NO		3.53	NO								0.201	0.198	0.086	0.229	0.188	0.073	0.228	0.171	0.077
1085	4114-C	YES	THRUCRACK	5.94	NO								0.292	0.174	0.137	0.226	0.139	0.046			
1086	4114-D	NO		2.41	NO								0.242	0.174	0.119	0.187	0.147				
1089	4115-A	NO			NO																
1088	4115-B	NO			NO																
1090	4115-C	NO			NO																
1091	4115-D	NO			NO																
1092	4116-A	NO			NO																
1093	4116-B	NO			NO																
1094	4116-C	NO			NO																
1095	4116-D	NO			NO																
1096	4117-A	NO			NO																
1097	4117-B	NO			NO																
1098	4117-C	NO			NO																
1103	4117-D	NO			NO																

D4100SER.WK1 (Continued)

NORMAL

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN (IN)	BUMPER PLATE HOLE DMAX (IN)	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
1170	9001-1	0.538	0.711	NO		8.30	NO										
1171	9001-A	0.593	0.636	NO			NO										
1172	9001-B	0.464	0.625	NO		7.69	NO										
1173	9001-C	0.506	0.661	NO		8.92	NO										
1174	9001-D	0.460	0.639	NO		7.07	NO										
1175	9002-A	0.489	0.624	NO		4.91	NO										
1176	9002-B	0.502	0.685	NO		8.30	NO										
1177	9002-C	0.514	0.686	NO		9.62	NO										
1178	9002-D	0.510	0.624	NO		7.07	NO										

IN-LINE

SHOT NO.	TEST NO.	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA 1 (IN)	HOLE 1 DIA 2 (IN)	HOLE 2 DIA 1 (IN)	HOLE 2 DIA 2 (IN)	HOLE 3 DIA 1 (IN)	HOLE 3 DIA 2 (IN)	CRATER 1 DIA 1 (IN)	CRATER 1 DIA 2 (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA 1 (IN)	CRATER 2 DIA 2 (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA 1 (IN)	CRATER 3 DIA 2 (IN)	CRATER 3 DEPTH (IN)
1170	9001-1	YES	1.12	0.99	NO								0.339	0.201	0.104	0.204	0.165	0.088	0.174	0.122	0.021
1171	9001-A	YES	0.195		NO		0.250	0.152					0.178	0.160	0.041	0.198	0.145	0.068	0.205	0.133	0.067
1172	9001-B	YES	0.474	3.56	YES	0.016	0.095	0.095	0.636	0.340			0.325	0.271	0.131	0.214	0.200	0.129			
1173	9001-C	NO		1.23	NO								0.192	0.158	0.049	0.154	0.154	0.050	0.258	0.181	0.108
1174	9001-D	YES	0.197	5.39	NO		0.218	0.179					0.216	0.146	0.123	0.196	0.185	0.101	0.195	0.162	0.097
1175	9002-A	YES	0.433	3.56	NO		0.287	0.337	0.224	0.269											
1176	9002-B	NO		3.14	NO								0.172	0.133	0.088	0.239	0.144	0.106	0.159	0.159	0.087
1177	9002-C	NO		2.78	NO								0.196	0.196	0.128	0.154	0.137	0.096	0.217	0.133	0.103
1178	9002-D	NO		3.53	NO								0.174	0.174	0.043	0.158	0.146	0.085	0.158	0.158	0.069

D9000SER.WK1

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN	DMAX	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
769	CAMERA-T1	0.583	0.583	YES	1.31	32.81	YES	1.30	1.313			0.1	0.077	0.085	0.063	0.095	0.064
771	STRESS	0.688	0.76	YES	2.87	6.5	NO		2.87								
772	STRESS	0.586	0.664	YES	1.15	21.65	NO		1.15								
774	STRESS	0.628	0.786	YES	1.86	19.65	NO		1.86								
919	FL-1	0.838	1.019	YES	4.77	44.18	NO		4.77								
920	FL-2	0.86	0.98	YES	5.267	44.18	NO		5.27								
894	MLI-ON-B1	0.651	0.651	YES	1.84	6.54	NO		1.84			0.075	0.016	0.136	0.051	0.094	0.035
896	MLI-ON-B2	0.738	0.738	YES	3.74	13.4	NO		3.74			0.141	0.051	0.15	0.05	0.101	0.053
897	MLI-ON-B3	0.338	0.338	YES	0.301	7.07	NO		0.115	0.195	0.156	0.113	0.022	0.091	0.038	0.01	0.023
898	MLI-ON-B4	0.342	0.342	NO	0.342	5.64	YES	0.018				0.097	0.092	0.101	0.053	0.166	9.097
1150	MLI-T-2	0.655	0.655	YES	0.774	12.56	YES	0.45	0.774								
859	MLI-PURGE-1	0.692	0.692	YES	8.38	55.03	NO		8.38			0.206	0.07	0.146	0.065	0.048	0.077
905	BL-AL-1	0.674	0.674	YES	0.782	7.69	NO		0.782			0.082	0.024	0.084	0.02	0.073	0.01
909	BL-AL-2			YES	5.91	45.36	NO		5.91								
734	CAM-1	0.531	0.531	YES	0.517	15.9	YES	0.253	0.527			0.11	0.055	0.112	0.07	0.126	0.066
735	CAM-2	0.5	0.51	NO		10.99	NO					0.125	0.076	0.104	0.108	0.122	0.062
745	EHSS-M1	0.73	0.73	YES	1.22	44.18	NO		1.22								
746	EHSS-M2	0.682	0.852	YES	0.4	1	NO		0.4								
747	EHSS-M3	0.647	0.647	NO		12.56	NO					0.15	0.02	0.15	0.02	0.15	0.02
756	EHSS-M4	0.636	0.636	YES	0.8	31	NO		0.8								
736	T5A	0.656	0.688	YES	2.23	32.99	YES	1.74	2.23			0.1	0.126	0.106	0.058	0.075	0.092
737	T5B	0.625	0.656	YES	2.19	38.29	YES	1.28	2.17	0.108	0.24	0.102	0.035	0.1	0.135	0.108	0.135
738	T5C	0.656	0.656	YES	2.18	35.74	YES	1.47	2.16	0.23	0.138	0.1	0.125	0.097	0.071	0.075	0.075
739	T5D	0.625	0.688	YES	2.47	28.27	YES	1.2	2.462	0.1163	0.075	0.17	0.108	0.102	0.076	0.063	0.042
740	T5E	0.656	0.688	YES	11.5	103.67	NO										
741	T5F	0.625	0.625	YES	7.5	43.98	NO										
742	T5G	0.625	0.625	YES	6.5	32.98	NO										
748	T5H	0.5	0.5	YES	0.12	6.87	NO		0.12			0.105	0.031	0.167	0.089	0.149	0.05
749	T5I	0.531	0.563	NO		7.66	NO										
750	T5J	0.469	0.469	YES	0.267	8.25	NO		0.267			0.11	0.05	0.1	0.041	0.12	0.033
751	T5K	0.469	0.5	NO		5.89	NO					0.135	0.095	0.085	0.017	0.1	0.045
752	T5L	0.5	0.5	NO		7.66	NO					0.063	0.03	0.075	0.024	0.086	0.02
754	T5M	0.5	0.5	NO		10.31	NO					0.08	0.055	0.102	0.078	0.12	0.032

DMISC.WK1

SHOT NO.	TEST NO.	BUMPER PLATE HOLE DMIN	DMAX	BACKWALL PERFORATED?	BACKWALL EQ HOLE DIAMETER (IN)	BACKWALL DAMAGE AREA (SQ. IN.)	BACKWALL SPALLED?	BACKWALL SPALL AREA (SQ. IN.)	HOLE 1 DIA (IN)	HOLE 2 DIA (IN)	HOLE 3 DIA (IN)	CRATER 1 DIA (IN)	CRATER 1 DEPTH (IN)	CRATER 2 DIA (IN)	CRATER 2 DEPTH (IN)	CRATER 3 DIA (IN)	CRATER 3 DEPTH (IN)
906	WG01	0.673	0.673	YES	7.43		NO		7.43								
907	WG02	0.671	0.671	YES	8.22		NO		8.22								
912	WG03	0.665	0.665	YES	10.39		NO		10.39								
913	WG04	0.669	0.669	YES	7.5		NO		7.5								
921	WG05	0.805	0.805	YES	0.497	45.84	YES		0.262	0.25	0.162						
922	WG06	0.807	0.807	YES	4.05	12.88	NO		4.05								
925	WG07	0.621	0.973	YES	1.324	25.78	NO		0.841	0.899	0.252						
926	WG08	0.683	0.998	YES	2.78	12.56	NO		2.78								
927	WG09	0.673	0.997	YES	3.742		NO										
887	FP-01	0.687	0.687	YES	9.798	70.88	NO		9.798								
892	FP-02	0.688	0.688	YES	9.949	70.88	NO		9.949								
893	FP-03	0.678	0.678	YES	9.22	56.74	NO		9.22								
899	FP-04	0.678	0.678	YES	9.381	63.62	NO		9.381								
932	FP-5	0.656	0.656	YES	3.54	95	NO		3.54								
933	FP-6	0.656	0.656	YES	3	78.54	NO		3								
934	FP-7	0.656	0.656	YES	3.5	78.54	NO		3.5								
937	FP-08	0.878	0.878	YES	7.258		NO		7.258								
938	FP-09	0.868	0.868	YES	5.19		NO		5.19								
942	1001-B/FP-1	0.3125	0.3125	NO		3.14	NO										
946	1001-C/FP-1	0.344	0.344	NO		1.76	NO					0.16	0.053	0.14	0.022	0.19	0.023
947	1001-A/FP-1	0.25	0.25	NO		0.79	NO					0.154	0.03	0.121	0.034	0.14	0.026
948	1002-B/FP-1	0.4375	0.4375	YES	0.3	5.93	YES	0.055	0.203			0.23	0.037	0.236	0.054	0.11	0.012
950	1004-A/FP-1	0.344	0.438	NO		9.62	NO					0.11	0.115	0.111	0.65	0.084	0.04
951	1004-B/FP-1	0.375	0.438	NO		12.56	NO					0.17	0.05	0.168	0.054	0.124	0.034
952	1002-A/FP-1	0.375	0.375	YES	0.437	4.91	YES	0.16	0.437			0.06	0.034	0.073	0.031	0.084	0.013
953	1002-C/FP-1	0.468	0.468	NO		3.14	NO					0.246	0.029	0.073	0.044	0.069	0.012
954	1005-A/FP-1	0.5	0.656	YES	THRUCRACK	5.55	NO		0.1 THRUCRACK			0.1	0.125	0.073	0.057	0.09	0.049
955	1005-B/FP-1	0.656	0.688	YES	0.171	7.51	NO		0.171			.311/.311	>0.125	.236/.145	>.125	.251/.157	0.06
957	1005-C/FP-2	0.563	0.688	YES	0.178	6.34	NO		0.178			0.114	0.066	0.167	0.054	0.058	0.027
958	1003-A/FP-2	0.5625	0.5625	YES	2.81	7.07	NO		2.81			0.1	0.07	0.078	0.058	0.15	0.028
1099	1003-B/FP-2	0.565	0.565	YES	0.411	28.27	NO		1.62			0.155	0.035	0.09	0.05	0.053	0.048
1100	1003-C/FP-2	0.631	0.631	YES	7.541	45.36	NO		7.54								
1101	1006-A/FP-2	0.65	0.778	NO/YES		4.41/2.09	NO		INLINE=.64	.276/.276	0.113/0.113						
1102	1006-B/FP-2	0.654	0.86	NO /YES	1.65	11.05	NO		INLINE=.4/.4								

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16.Abstract

This Final Report presents an overview of the impact tests performed at NASA/MSFC in the time period 1985 to 1991 and the results of phenomena repeatability and data uncertainty studies peformed using the information obtained from those tests. An analysis of the data from over 400 tests conducted between 1989 and 1991 was performed to generate a database to supplement the Hypervelocity Impact Damage Database developed under a previous effort.

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