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Secondary Impact Hazard Assessment

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Foreword

This study was conducted between June 1, 1985 and June 1, 1986 for the Solar System Exploration Division of the Johnson Space Center. The purpose of this study was to make a preliminary assessment of the danger of damage to the Space Station caused by secondary particles (ejecta and spall) from meteoroid and orbital debris impact. A second purpose was to characterize the nature of spall and ejecta from hypervelocity impacts on graphite/epoxy composites.

Ms. Jeanne L. Crews was the NASA technical monitor. Mr. Tommy Thompson (Lockheed) and Mr. Kenny Oser (Lockheed) performed the data shots with the Johnson Space Center Light Gas Gun. Mr. Earl Brownfield (Lockheed) provided photographic support. Valuable advise and other data were provided by Mr. Burton G. Cour-Palais (NASA JSC) and Dr. Ching Yew (Univ. of Texas).

Mr. Bill Stump was the Eagle Project Manager. Mr. Eric Christiansen performed the major part of the Eagle contribution. Mr. Norman Smith, an Eagle Co-op, also assisted.

1.0 Executive Summary

A series of light gas gun shots (4 to 7 km/sec) were performed with 5 mg nylon and aluminum projectiles to determine the size, mass, velocity, and spatial distribution of spall and ejecta from a number of graphite/epoxy targets. Similar determinations were also performed on a few aluminum targets. Target thickness and material were chosen to be representative of proposed Space Station structure.

The data from these shots and other information were used to predict the hazard to Space Station elements from secondary particles resulting from impacts of micrometeoroids and orbital debris on the Space Station. This hazard was quantified as an additional flux over and above the primary micrometeoriod and orbital debris flux that must be considered in the design process. In order to simplify the calculations, eject and spall mass were assumed to scale directly with the energy of the projectile. Other scaling systems may be closer to reality.

The secondary particles considered are only those particles that may impact other structure immediately after the primary impact. The addition to the orbital debris problem from these primary impacts was not addressed. Data from this study should be fed into the orbital debris model to see if Space Station secondaries make a significant contribution to orbital debris.

The hazard to a Space Station element from secondary particles above and beyond the micrometeoriod and orbital debris hazard is catagorized in terms of two factors: 1) The "view factor" of the element to other Space Station structure or the geometry of placement of the element, and 2) The sensitivity to damage, stated in terms of energy.

Several example cases were chosen, the Space Station module windows, windows of a Shuttle docked to the Space Station, the habitat module walls, and the photovoltaic solar cell arrays. For the examples chosen the secondary flux contributed no more than 10 percent to the total flux (primary and secondary) above a given calculated critical energy. A key assumption in these calculations is that above a certain critical energy, significant damage will be done. This is not true for all structures. Double-walled, bumpered structures are an example for which damage may be reduced as energy goes up. The critical energy assumption is probably conservative, however, in terms of secondary damage.

To understand why the secondary impacts seem to, in general, contribute less than 10 percent of the flux above a given critical energy, consider the case of a meteoroid impact of a given energy on a fixed, large surface. This impact results in a variety of secondary particles, all of which have much less energy than the original impact. Conservation of energy prohibits any other situation. Thus if damage is linked to a critical energy of a particle, the primary flux will always deliver particles of much greater energy. Even if all the secondary particles impacted other Space Station structure, none would have a kinetic energy more than a fraction of the primary impact energy.

2.0 Introduction

This study was a low cost "quick look" with three basic purposes: 1) to assess, in a preliminary manner, the hazards from secondary spall and ejecta from meteoriod and orbital debris impact on the Space Station, 2) to begin to characterize the nature of graphite/epoxy spall and ejecta resulting from hypervelocity impact, and 3) to compare graphite/epoxy and aluminum spall and ejecta in terms of damage potential. In a more basic sense, this study was to search out directions for future work in this area.

In this report, spall is defined as the material that comes off of the back side of an impacted target. Ejecta is defined as the material that comes off of the front side.

The characterization of aluminum and graphite/epoxy spall and ejecta was limited to the following parameters resulting from a single impact:

- a) numbers of particles
- size distribution of particles b)
- c) mass distribution of particles
- velocity distribution of particles d)
- e) energy distribution of particles
- angular distribution or angle of dispersion of ejecta/spall f) particles

These ejecta/spall parameters vary with the following projectile and target parameters. This variation was studied and empiracal relationships were developed in some cases.

- a) target types - aluminum (6061-T6) and graphite/epoxy (different layups, with and without cloth, thick and thin)
- ь) projectile energy
- c) projectile density
- d) oblique and normal impacts

There are other variables and relationships that could (and perhaps should) be studied also. Equipment and funding limitations on this study required that the number of variables and relationships studied be kept small. The above variables were therefore chosen as the most important.

Orbital debris and micrometeoriods are significant hazards to the Space Station and must be taken into account in its design. Meteoriod or orbital debris impacts have been shown to break off 10 to 100 times their own mass from the target material. Some of this ejected and spalled secondary mass will be traveling at hypervelocity. This study was initiated based on these facts. By themselves, these facts indicate that designers may have to protect against these secondary impacts as well as primary orbital debris and meteoriods. Other factors also play a part however. The

three most important are: 1) the number, velocity, and size of hypervelocity particles generated at an impact, 2) the fraction of these particles that may impact other sensitive Space Station structure, and 3) the sensitivity of Space Station structure to damage from these particles. This study attempts to determine or otherwise quantify these variables.

The dual keel Space Station is predicted to have three major structural components in terms of surface area: the graphite/epoxy truss structure, the modules, and the solar power system. Table 6-1 shows how these break down in terms of area for one design. OTV hangars may also have significant area on a growth Space Station.

The modules will probably have aluminum meteor and orbital debris shields protecting their inner hulls. The bumper material has not been selected as of this date, however, and graphite/epoxy or other non-metallic materials are also in the running. The truss structure will be graphite/epoxy with some type of coating (not selected at present - it may be an aluminum foil). The solar arrays will likely be solar cell material (very thin - 14 mils for cover glass and cell according to one estimate) on a thin flexible substrate or perhaps thicker (1 cm) aluminum honeycomb structure. Solar dynamic reflectors will probably be aluminum. The Space Station configuration and materials are still in the design process at this time, but, as far as impacts are concerned, the two major materials will be aluminum and/or graphite/epoxy.

The first major effort in this study was therefore to acquire data on the spall and ejecta characteristics of graphite/epoxy and aluminum material. Hypervelocity impacts on aluminum have been studied for many years and a number of good references exist (Ref. 1 - 2). More attention has been paid to the spall than to the ejecta however, but some aluminum ejecta data was available in the literature (Ref. 1). Only a few actual aluminum shots were therefore performed as a part of this effort (see section 4.0). On the other hand, no one (to our knowledge) has previously studied the spall and ejecta characteristics of graphite/epoxy, so considerable experimental work was required. Section 3.0 documents the experimental work performed on graphite/epoxy as a part of this effort.

Given experimental data in hand, scaling equations were derived that can be used in an overall prediction of hazards to the Space Station. Section 5.0 describes this work.

Section 6.0 describes the assessment of damage to Space Station elements based on the equations generated in section 5.0. Section 7.0 and 8.0 contain conclusions and recommendations. Appendix A contains a complete listing of all shots of interest to this study (ordered by shot number) and data associated with them. Appendix B contains the raw data from shots for which particle counts were made. Appendix C contains some single frame photos of graphite/epoxy targets shortly after impact.

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3.0 Graphite/Epoxy Targets

Table 3-1 lists the graphite/epoxy targets that were ordered from Hercules as a part of this testing effort. The reader should refer to Table 3-1 for a detailed description of the size and properties of the targets used. Some of the targets were used in other test programs and their shots will be documented elsewhere.

The graphite/epoxy shots are divided into four categories: shots into semi-infinite targets (section 3.1) with no camera data, but with ejecta mass collected; shots into thin targets (section 3.2) with no camera data, but with ejecta and spall mass collected; additional shots into thin targets used to determine projectile density effects (section 3.3); and shots for which high speed film data was available (section 3.4).

Table 3-2 summarizes the section 3.1 and 3.2 shots. An aluminum shot (see section 4.0) is also included at the bottom of Table 3-2. Table 3-2 includes all the shots for which ejecta and spall particles were collected, counted, and weighed. Numbers of interest in Table 3-2 include:

- a. the ratio of spall and ejecta mass to projectile mass (average around 35)
- b. average cone angle or angle between the spall or ejecta velocity vectors and a normal to the target surface coming out of the impact point
- c. average calculated particulate velocity (see Appendix B for how this velocity was calculated)
- d. fraction of the secondary mass that was spall or percent spall
- e. fraction of the secondary mass that was dust or percent dust. This is the difference between the total spall and ejecta mass (determined by before and after weighing of the target) and the sum of the masses of particles collected from catcher material and in the chamber. The percent dust represents that fraction of the total secondary mass that disappeared, vaporized, or was crushed to dust too small to recover (<<0.0001 gms particles). The percent dust also represents larger particles that may have been lost in handling, and so could probably be arbitrarily reduced 5 or 10 percent

Summary tables with similar information for section 3.3 and 3.4 data are contained at the start of each of those sections.

Table 3-1, Test Specimens Ordered

s/n	MARPOTAT		WEIGHT	THICKNESS	JSC
JSC-01A-001	MAIDKIAL	LAI UP	<u>(GN)</u>	<u>(IN)</u>	SHOT
-002	AS4/3501-6		512.6	.528	900
-003		$\pm 45 \pm 45 = 0$	513.0	•528	899
-004		9045.45	508.2	.520	883
-005			504.0	.515	
-006		0,12,CLOTH	508.6	.524	901
-007	A193PW/3501-6		511 7	• 7 4 6 7 9	
-008	CLOTH		508 0	+JZ0 504	
-009			513 A	•524 520	
010			509.8	•330 525	
JSC-01B-001			502.0	-518	
-002		CLOTE, {0,	503.7	.518	884
-003	AS4/3501-6	+45,-45,90,	503.8	.519	004
-004		90,-45,+45,	505.0	.519	
-005		0}12	503.1	-517	
-006	A193PW/3501-6		502.1	.516	
-007	CLOTH		503.5	.518	
-008			505.7	.520	
-009			502.4	.516	
			502.6	.517	
			96.4	.105	988
-002	384/2501 6	CLOTH, {+45,	101.7	.113	990
-003	A34/3301-0 A1930W/2501 C	-45,0,0,+45,	99.9	.111	
-005	CI'ULR VI 2254/2201-0	~45,0,90}5,	99.7	.111	
JSC-02B-001			97.5	.107	
-002		{+4545.0	80.4 95 0	.095	889
-003	AS4/3501-6	0.+4545	05.9	.094	893
-004	•	0,90}-	05.5	.093	894
005			86 4	.095	981
JSC-03A-001		CLOTH.0.0.	114.0	125	923
-002	AS4/3501-6	0,0,0,0,0,	113.0	.124	911
-003		+45,-45,90,	114.3	.127	917
-004	A193PW/3501-6	-45.+45,0,	116.1	.129	521
-005	Cloth	0,0,0,0,	115.8	.127	
700 025 001		0,0,CLOTH			
JSC-03B-001	AS4/3501-6	0,0,0,0,0,	103.3	.115	895
-002		0,0,+45,-45,	101.3	.112	890
		90,-45,+45,			
		0,0,0,0,0,			
JSC-042-001	120001 201/2501 6			·····	
-001 -002	TTO A OPWW 2201-0	ICLUTH, ILO,	151.7	.157	*
	TM6/3501_4	+0U,-0UJIM6	148.9	.153	
	S-2/3501-6	(-00,+00, 01) ;			
	HYBRID	S2,512,212			

C/N	NATERIAL	LAY UP	WEIGHT (CM)	THICKNESS (IN)	JSC Shot #
JSC-05A-001 -002	S-2/3501-6 120VOLAN/3501-6 CLOTH	{CLOTH,0,-60, +60,0,0,+60, -60,-60,+60, 0}5	113.1 113.4	.104 .106	913 *
JSC-06A-001 -002	IM6/8551 A193PW/3501-6 CLOTH	CLOTH,[{0,+60, -60} ₅]4,CLOTH	174.0 171.3	.194 .191	910 912

IM6 - GRAPHITE 120VOLAN - GLASS CLOTH S-2 - GLASS AS-4 - GRAPHITE 3501-6 - STANDARD RESIN A193PW - GRAPHITE CLOTH 8551 - TOUGHENED RESIN

*CUT INTO FOUR PIECES

Table 3-2, Shots for Which Particulate Counts Were Made

Data from JSC Light Gas Gun Shots

Projectile vs. Ejecta/Spall Mass Summary

Percent Dust	67.2	35.1	18.8	37.5	22.8	49.1
Dust ((0.0001 g Part, Mass (g)	0.07391	0.06845	0.02445	0.073782	0.057044	0.0589
Percent Spall	0	•	63.1	69.9	62.4	71.2
Average Calc. Part. Velocity (ko/sec)	939	0.84	۰.	0.269 0.334	0. 266 0. 432	4.33
Average Cone Angle (degrees)	50.17	57.14	• •	34,66 41,09	47.05 49.90	37.13 18.00
c c	-1.143	-0, 954	-1.127 -1.280 -1.325	-1.294 -1.676 -1.502	-1.015 -0.920 -0.965	-1.332 -0.527 -0.997
[W] € of particles of mass M & greater M = K w (M / M total) ~ K	0.0206	0.1075	0.0780 0.0266 0.0192	0.0194 0.0014 0.0038	0.0909 0.2133 0.1499	0.0081 0.8191 0.0873
(Gamma) Ratio of secondary to Projectile Mass	22.31	40.97	9.72 16.59 26.32	15.47 35.97 51.44	16, 22 26, 88 43, 10	6.94 17.15 24.10
Sec. Nass (g)	0.11	0.195	0.04803 0.08197 0.13	0.075164 0.174836 0.25	0.09407 0.15593 0.25	0.03457 0.08543 0.12
Secondary Particle Type	Ejecta	Ejecta	Ejecta Spall Total	Ejecta Spall Total	Ejecta Spall Total	Ejecta Spall Total
Impact Angle (deg)	•	•	•	•	8	6
Proj. Nass (ag)	4.93	4.76	4.94	4.86	5.80	4.98
Velocity (ka/sec)	6.42	6.26	4.75	5.99	7.02	6.3
Projectije Type	Nylon	Nyton	Ny Ion , 893, 923)	Nylon 911)	Ny Lan 893, 894)	Ny i on
JSC Target Shot 8 Description	883 Graphite/Epoxy Cloth	884 Graphite/Epoxy No Cloth	894 Graphite/Epory Thin, Wo Cloth Isimilar to 889,	917 Graphite/Epoxy Thin, Cloth (similar to 909,	923 Graphite/Epoxy Thin, No Cloth (similar to 889,	933

9

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3.1 Semi-Infinite (thick) Targets - Ejecta and Spall Collected

When this study was initiated, the high speed camera was not available and the techniques later developed were untried. In addition, other restrictions existed on testing. For these reasons, a number of thick targets which would not be penetrated and produced only ejecta were ordered for testing. The mass of ejecta was easily and reliably determined by weighing the target before and after the shot. This ejected mass was then compared with the mass of material collected in a catcher box attached to the front of the target.

The data from these shots was used in developing the relationship for number of graphite/epoxy ejecta particles with a given energy and greater. The data was not used in the relationship giving total ejecta/spall mass as a function of projectile energy because only ejecta was produced in these tests, resulting in less total particle mass for a given projectile energy than with thin targets which were penetrated.

3.1.1 Discussion of Test Setup

A small styrofoam box was placed on the front of the target, with a hole cut in the center of the end to let the projectile enter. When the target was impacted, much of the ejecta stuck in the styrofoam. The individual ejecta particles were extracted from styrofoam and their location (x, y, z), mass, length, and depth of penetration measured. Mass measurements were accurate to 0.0001 g except where groups of very small particles were counted and weighed together to get an average mass. Distance measurements were accurate to 1 mm. The location (x, y, z coordinates) of the projectile impact was also recorded.

This data allowed an accurate estimate of the total ejected mass, an approximate determination of the particle size distribution and velocity vector direction, and a crude estimate of the velocity of each particle based on the penetration distance into the stryofoam. When the high speed camera was acquired later in the testing this velocity approximation was checked and found to be reasonably accurate for the graphite/epoxy tests (see section 3.4.4). It was somewhat less accurate for the aluminum shots (see section 4.4), though only one aluminum high speed camera shot was available to check against it.

3.1.2 Shot #883 (1/2" thick, cloth on front)

This target (JSC-01A-003) had a layer of Hercules Al93PW cloth on both front and back sides. The cloth layer on the back was to help prevent spall. The cloth layer on the front reduced the amount of ejecta when compared to the next shot.

Table 3-2 summarizes the basic parameters of this shot. A nylon projectile of roughly 5 mg going 6.42 km/sec impacted a 1/2 inch thick graphite/epoxy (G/E) target in a vacuum chamber (with a vacuum of 200 microns of mercury. The Johnson Space Center (JSC) light gas gun was used. A styrofoam box fixed to the front of the target was used to collect the individual pieces of ejecta.

Following the shot, each piece of ejecta was removed from the styrofoam, weighed, and its location noted. The raw data from this considerable effort is given in appendix B. The difference between the before and after weights and the total mass collected from the styrofoam was assumed to represent vapor or dust. For this shot it was 67.2 percent of the total mass. Some of this may be due to loss of large particles through the projectile entry hole and in handling with this first attempt at particle collection.

Figure 3-1 shows the target front and back after the shot. Compare this with Figure 3-13, a no-cloth shot. The cloth reduces the amount of large ejecta.

Figures 3-2 and 3-3 plot ejecta mass versus length and diameter. Most of the mass of recovered composite ejecta is in the form of long thin slivers of material. The diameters plotted are actually an average calculated value. The length and mass of the slivers were measured, and given the density and assuming a cylindrical particle, an average diameter was calculated.

Figures 3-4 through 3-7 plot ejecta mass and velocity versus theta and phi (see appendix A for a definition of theta and phi).

Figures 3-8 and 3-9 plot ejecta mass and velocity versus cone angle. The cone angle is the angle between a normal to the target face at the impact point and the ejecta particle's velocity vector. The mass distribution (in Figure 3-8) seems to center around a cone angle of 50 to 60 degrees. The velocity distribution does also, but not as clearly.

Figure 3-10 plots mass versus velocity and illustrates that, in general, only small particles travel at high velocities.

Figure 3-11 shows a small scale plot of the Log(number of particles of mass Mi and larger) versus the Log(Mi/Mtotal ejecta mass). Figure 3-12 shows a least squares fit linear relationship

for these two quantities and the derived equation (without the Logs) that results. A similar equation for aluminum taken from reference 1 is also plotted.

-
Figure 3-1, Photos of Target (Shot #883)

JSC 01A-003, 1/2 inch thick, graphite/epoxy

Front

Back



1		2	3		1		5	6
91 FL EL	ส่น เป	01	6 ¥	 9	ç	÷	E	1 10 5









Ejecta Particle Length (mm)



06 70 Π EJECTA MASS DISTRIBUTION 8 50 ٥ 30 JSC Shot No. 883 - Cloth Theta Location (Degrees) 10 D 010 -30 ▫┛ -50 ₽ -70 ٥ 06-T Ejecta 0.0003 0.0006 1.0005 ранісіе ранісіе ранісіе ранісіе S 0.0012 0.0002 0.0004 0.0001 (0,0013) (0,0013) 0.0003 0.0016 0.0017 0.0018 0.0015 0.0019







Ejecta Particle Velocity (Km/sec)





Ejecta Particle Velocity (Km/sec)









Ejecta Particle Velacity (Km/sec)







LOG (N) - N number part. of mass Mi & >

3.1.3 Shot #884 (1/2" thick, no cloth on front)

This shot is almost identical to the previous one, except this target (JSC-01B-002) had no cloth on the front surface. This shot was predicted to result in more ejecta.

Table 3-2 summarizes the parameters. A 4.76 mg nylon projectile going 6.26 km/sec impacted a 1/2 inch thick graphite/epoxy target. A styrofoam box fixed to the front of the target was used to collect the individual pieces of ejecta as explained in the previous shot.

Table 3-2 shows, as predicted, that this target, with no cloth on the front, produced almost twice as much total ejecta. There is roughly 50 percent less dust, indicating that much, if not all of this additional ejecta is in the form of large, collectable particles. Figure 3-13 shows the target front and back after the shot. Compare it with Figure 3-1.

Figures 3-14 and 3-15 plot ejecta mass versus length and diameter. A comparison with Figure 3-2 shows that the particle lengths for this shot were almost ten times greater. The masses are also almost ten times larger. The diameters plotted are calculated using the lengths and masses of the slivers and a given density, and an assumed cylindrical particle.

Figures 3-16 through 3-19 plot ejecta mass and velocity versus theta and phi (see figure A-1 in the appendix for a definition of theta and phi). Comparing the velocity versus theta plots (3-5 and 3-17) it is clear that the no cloth shot resulted in many higher calculated-velocity particles. See section 3.4 for a comparison of measured and calculated velocity.

Figures 3-20 and 3-21 plot ejecta mass and velocity versus cone angle. The cone angle is the angle between a normal to the target face at the impact point and the ejecta particle's velocity vector. The mass distribution (in Figure 3-20) seems to center around a cone angle of 60 to 70 degrees, a somewhat greater cone angle than for the previous shot with cloth covering. The velocity distribution also centers around the 60 to 70 degree cone angle, more clearly than the with cloth case.

Figure 3-22 plots mass versus velocity. It shows far more clearly than the cloth covered shot, that the small particles are faster than the large particles.

Figure 3-23 shows a small scale plot of the Log(number of particles of mass Mi and larger) versus the Log(Mi/Mtotal ejecta mass) and a least squares fit linear relationship for these two quantities and the derived equations (with and without the Logs) that results. The same plot, with a similar equation for aluminum taken from reference 1, is also plotted in Figure 3-24.

Figure 3-13, Photos of Target (Shot #884)

JSC 01A-003, 1/2 inch thick, graphite/epoxy, no cloth on front

Front

Back



1 2	ή÷Ω+	3	110	nni, ti t	(1944) 4	iη	5 5	<u>6</u>	
SI HI EL 21 11 01	6	Ħ	L	9	8	•	C	t the start	
		ند سلد.	لسبيل						





EJECTA MASS/LENGTH RELATIONSHIP 0.014 0.012 0.01 Ejecta Particle Mass (g) 0.008 0.006 0.004 0.002 70 -60 1 50 -0 I Т 80 40 30 20 10 0

(mm) digna Length (mm)

27

0.014 EJECTA MASS/DIAMETER RELATIONSHIP 0.012 0.01 Ejecta Particle Mass (9) 0.008 0.006 Figure 3-15 0.004 0.002 80 •□ B 0 Ι 0 <u>ی</u>.0 0.2 **4**.0 0.5 0.0 0.1

Ejecta Particle Diameter (mm)









Ejecta Particle Mass (g)

Figure 3-19



Ejecta Particle Velocity (Km/sec)













- 1.1 – 1.5 EJECTA MASS AND PARTICLE NUMBER Log(N) = -0.9537 * Log(M_{part}./M_{total}) - 0.9685 -1.7 ejecta -1.9 LOG (Mi/Mt) - Mi Part. & Mt Total Mass + K=0.1075,n=-0.954 $N = 0.1075 * (M/M_{total})^{-0.9537}$ JSC Shot Nc. 884 - No Cloth -2.1 ejecta -2.3 -2.5 or -2.7 DATA -2.9 -3.1 で. で ー 1 T T I 1 ł I ł 0.2 0.6 4.0 0.8 4.1 1.2 1.6 1.8 -2.2 2 5.4

Figure 3-23

LOG (N) - N number part, of mass Mi & >



LOG (N) - N number part. of mass Mi & >

3.2 Thin Graphite/Bpoxy Targets - Ejecta and Spall Collected

Once a capture technique was developed and some other restrictions removed, it was clearly desirable to acquire data on spall as well as ejecta. Thin targets representative of truss element walls and possible module bumpers (.06 to .10 inches thick) were then tested.

This data was used both in developing the particle number/particle energy relationship and also the total mass/projectile energy relationship.

3.2.1 Discussion of Test Setup

Shots 894, 917 and 923 used a plexiglass box enclosing the target in the vacuum chamber to catch and separate the ejecta from the spall. Initially, the purpose of this setup was merely to determine the ratio of spall to ejecta for these targets. It was very successful. Some of the photos in Figure 3-55 show the In addition to styrofoam, two other catcher overall setup. materials were tried. For shot 894, a sheet of plastic wool matting was placed at either end of the box to catch some of the ejecta/spall particles. See Figure 3-25. This setup was not as effective as the styrofoam because velocity estimation from depth of penetration was not practical. A flexible sponge-type foam was also tried and had the same problem. They were sufficient to obtain a size & mass distribution of the ejecta and spall, but did not allow even a crude estimation of the particle velocities. In all subsequent shots, styrofoam was used (see Figure 3-55).

For shot 917 and 923, sheets of styrofoam were installed at the ends, along the sides, and on the bottom and top of the box See Figure 3-55. This worked well for getting the spatial particle distribution as well as size and mass distribution. An approximate particle velocity was calculated from the depth of particle penetration into the styrofoam, particle geometry parameters, and styrofoam shear strength. This allowed the estimation of the particle kinetic energy distribution.

Single frame photography data is available for shots 917 and 894. This data is contained in appendix C.

3.2.2 Shot #894 (0.093" thick, no cloth)

Table 3-2 summarizes the parameters. A 4.94 mg nylon projectile travelling at 4.75 km/sec impacted a .093 inch thick graphite/epoxy target with no cloth covering (JSC-02B-003). The impact velocity was somewhat lower than the rest of the shots; this should be kept in mind when comparing it with other shots. The velocity is still within the range of interest, however. Shots 894, 917, and 923, as shown in Table 3-2, represent roughly 5, 6, and 7 km/sec shots with approximately the same conditions. Shot 917 had a cloth covering, while 894 and 923 did not. All shots were into approximately 0.10 inch thick G/E targets.

Figure 3-25 shows the overall setup for catching the spall and ejecta. The target was encased in a plexiglass box to separate spall from ejecta. The projectile enters through a small hole at one end. After the shot, the individual particles of ejecta and spall are collected and weighed. This shot used a woven batting inside the box to try to catch the individual particles where they impacted the box. This batting had been effective previously at catching aluminum particles.

Some approximate velocity data on particles is available from the single frame photograph of this shot (see Appendix C).

Figures 3-26 and 3-27 plot ejecta and spall mass versus particle length and diameter. The length plot, looking at ejecta only, shows about the same results as the semi-infinite shot without a cloth covering (see Figure 3-14, shot #884). The diameters plotted are actually an average calculated value. The length and mass of the slivers were measured, and given the density and assuming a cylindrical partical, an average diameter was calculated.

The cloth batting was only at the ends of the plexiglass box. Most of the particles bounced off at the plexiglass and ended up on the bottom of the box. A spatial estimate (Theta and Phi, etc.) of particle location was therefore not produced.

Figure 3-28 shows a plot of the Log(number of ejecta particles of mass Mi and larger) versus the Log(Mi/Mtotal ejecta mass) and a least squares fit linear relationship for these two quantities and the derived equations (with and without the Logs) that result. Figure 3-29 shows the same thing for spall. Figure 3-30 shows the spall, ejecta, and total spall plus ejecta plotted together on the same graph. The lines are all close together, indicating they all might be approximated by one curve.

Figure 3-31 shows the total spall and ejecta Log curve with a curve for aluminum (taken from Ref. 1). The aluminum line shows more particles of a given mass and greater once Log(Mi/Mt) goes above -3.2. In other words, there are more small graphite/epoxy particles, but more medium sized and greater aluminum particles. A form of these equations is used elsewhere in the estimate of hazards to the Space Station.

Figure 3-25, Photos of Catcher Box (Shot #894)

JSC 02B-003, 0.093 inch thick, graphite/epoxy, no cloth on front



Projectile enters here

Side View



Figure 3-25, Continued, Photos of Catcher Box (Shot #894) JSC 02B-003, 0.093 inch thick, graphite/epoxy, no cloth on front







Particle Length (mm)







LOG (N) - N number part. of mass Mi & >



LOG (N) - N number part, of mass Mi & >



LOG (N) - N number part, of mass Mi & >



LOG (N) - N number part. of mass Mi & >

3.2.3 Shot #917 (0.127" thick, with cloth)

This shot is similar to the previous one, except this target (JSC-03A-003) had cloth on the front and back surfaces, predicted to result in less ejecta and spall. This shot was also at a higher velocity (5.99 km/sec versus 4.75 for the previous shot, \ddagger 894). Figure 3-32 shows photos of the the target after impact. Compare it to Figure 3-56, from the next shot, with no cloth. The cloth reduces the number of large particles, but not the total mass of ejecta and spall as shown in Table 3-2. This may be due to other factors, such as the velocity difference, however. Another variable that was not easily measured or controlled at this point in the testing is the way in which the non-symmetrical projectile (which is a cylinder) impacts the target. See Figure 5-4.

Table 3-2 summarizes the parameters. A 4.86 mg nylon projectile going 5.99 km/sec impacted a 0.127 inch thick graphite/epoxy target with a cloth covering on the front and back. A plexiglass box with styrofoam placed around the inside (see Figure 3-55) was used to catch the individual pieces of ejecta.

Figures 3-33 and 3-34 plot ejecta mass versus length and diameter. A comparison with Figure 3-26 shows that the largest particle lengths for this shot (with cloth on the front) were almost ten times less than those for the shot with no cloth ($\ddagger894$).

Figures 3-35 through 3-38 plot ejecta mass and calculated velocity versus theta and phi (see figure A-1 in the appendix for a definition of theta and phi). Other approximate velocity data is available from the single frame photo of the impact in Appendix C.

Figures 3-39 and 3-40 plot ejecta mass and velocity versus cone angle. The cone angle, in this case, is the angle between the incoming projectile's velocity vector and the ejecta particle's velocity vector. The mass distribution (in Figure 3-39) seems to center around a cone angle of 30 to 40 degrees, smaller than the 60 to 70 degree averages for semi-infinite shots. Table 3-2, which calculates an average cone angle, also shows this. The velocity distribution shows the same centering, around 40 degrees or so.

In other hypervelocity impacts, evidence is said to exist of very high speed ejecta particles coming off at angles near 90 degrees, almost parallel to the face of the target plate. Our data (including high speed camera photos in later sections) do not show this occurring with graphite/epoxy.

Figure 3-41 plots ejecta mass versus velocity. This plot does not include all particles. It only includes those that were recovered and their velocity estimated, and as such it should be
considered representative of a fraction of the data only. The very small particles, which are likely to be moving at even higher velocities, could not be captured and are thus not shown on this plot.

Figure 3-42 plots the Log(number of ejecta particles of mass Mi and larger) versus the Log(Mi/Mtotal ejecta mass). A least squares fit linear relationship for these two quantities and the derived equations (with and without the Logs) that result are also shown. These equations are used elsewhere in the estimate of hazards to the Space Station.

Figures 3-43 and 3-44 plot spall mass versus length and diameter. Except for a few large slivers, the data is similar to that for the ejecta.

Figures 3-45 through 3-48 plot spall mass and velocity versus theta and phi (see figure A-1 in the appendix for a definition of theta and phi).

Figures 3-49 and 3-50 plot spall mass and velocity versus cone angle. The cone angle is the angle between a normal to the target face at the impact point and the ejecta particle's velocity vector. The distributions seem somewhat more spread out than in previous plots.

Figure 3-51 plots spall mass versus velocity.

Figure 3-52 plots the Log(number of spall particles of mass Mi and larger) versus the Log(Mi/Mtotal spall mass). A least squares fit linear relationship for these two quantities and the derived equations (with and without the Logs) are also shown.

Figure 3-53 plots the equations derived from Figures 3-42 and 3-52 and the Log Log plot of total ejecta and spall. The lines are all close together, indicating they could all be approximated by one line.

Figure 3-54 plots the Log-Log total ejecta and spall line along with an aluminum line (from Ref. 1). The results are similar to previous plots. The equations derived will be used to estimate the damage hazard to the Space Station.

49

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Figure 3-32, Photos of Target (Shot #917)

JSC 03A-003, 0.127 inch thick, graphite/epoxy, with cloth

Front

Back



ORIGINAL PAGE IS OF POOR QUALITY



Ejecta Particle Length (mm)





52









Ejecta Particle Velocity (km/sec)

B EJECTA MASS DISTRIBUTION B 8 JSC No. 917 – Thin Plate, with Cloth ۵ 8 8 ₿ 0.0008 -0.0007 -T 0.0001 -I 0.0002 -0.0009 0.0006 0.0004 0.0005 0.0003

70

50

0 E

9

-10

-30

-50

-70

06-

Phi Location (Degrees)

Ejecta Particle Mass (g)





80 EJECTA MASS DISTRIBUTION JSC No. 917 – Thin Plate, with Cloth 60 4 ۵ ٥ 日 Ф 20 8 目 88 ۵ 0.0008 -0.0007 | 0.0006 -0 0.0009 0.0002 -Т 0.0005 0.0004 0.0003 0.0001 0 Ejecta Particle Mass (g)

Figure 3-39

Cone Angle (Degrees)



Ejecta Particle Velocity (km/sec)

58



Ejecta Particle Velocity (km/sec)

59

-1.2 Log(N) = -1.2937 * Log(M_{part}./M_{total}) - 1.7121 ejecta - 1.6 EJECTA MASS AND PARTICLE NUMBER $N = 0.0194 * (M/M_{total})^{-1.2937}$ LOG (Mi/Mt) - Mi Part. & Mt Total Mass K=.0194,n=-1.294 21 ejecta JSC No. 917 - with Cloth -2.4 or E -2.8 Data -3.2 -3.6 ł 0.6 0 0.8 **4**. 0.2 4.4 2.2 ω. 1.6 4.1 €1 -2.6 2.8 2 M

Figure 3-42

LOG (N) - N number part. of Mass Mi & >

60



0.006

0.004

0.002

0

Spall Particle Mass (g)

Spall Particle Length (mm)



Spall Particle Diameter (mm)





80 60 SPALL VELOCITY DISTRIBUTION В 4 ۵ JSC No. 917 - Thin Plate, with Cloth 0 0 8 Theta Location (Degrees) Ð 20 8 ₀₽ 0 8 ٥ ┏▫ -20 8 ₽ -40 -60 0.5 L Т 0 T Ι T Т _. ບ 2.5 2 3.5 n 4

Spall Particle Velocity (km/sec)

Figure 16







Spall Particle Velocity (km/sec)







Spall Particle Velocity (km/sec)







LOG (N) — N number part, of Mass Mi & >

70





LOG (N) - N number part. of Mass Mi & >



LOG (N) - N number part. of Mass Mi & >

3.2.4 Shot #923 (0.095", without cloth, 30 deg. oblique impact)

This shot is similar to the previous two, except this target (JSC-02B-005) was angled 30 degrees to the projectile velocity vector and had no cloth covering, predicted to result in more ejecta and spall. This shot was also at a higher velocity (7.02 km/sec versus roughly 5 and 6 km/sec for the previous two thin G/E shots).

Figure 3-55 shows the catcher box made of plexiglass and lined with styrofoam. The large holes in two of the styrofoam side panels were to allow single frame photography, which didn't work on this shot. Appendix C shows some single frames that did work on graphite/epoxy shots. Approximate velocity data can be deduced from the single frame shots.

Figure 3-56 shows photos of the the target after impact. Compare it to Figure 3-32, from the previous shot, with cloth. The cloth reduces the number of large particles, but not the total mass of ejecta and spall as shown in Table 3-2. The total mass ejected and spalled in this shot was exactly the same as for the previous shot, even though the velocity and angle of impact were different. This indicates that cloth covering (and perhaps 1 km/sec velocity and 30 degree angle) do not have large effects on the total mass of ejecta and spall. The factors could be offsetting however, and hidden variables such as projectile impact attitude could also be playing a part. In any event, given the low level of approximation needed in this rough assessment of damage hazard, these factors (30 deg. angle, w/wo cloth, 1 km/sec) are assumed unimportant when equations that describe the spall and ejecta are A many shot program focusing on these factors alone will be needed to see their effects.

Figures 3-57 and 3-58 plot ejecta mass versus length and diameter. A comparison with Figures 3-26 and 3-33 shows that the largest particle lengths for the two no cloth shots are about the same. The no cloth, 30 degree angle shot has the most massive piece of ejecta however, by a factor of three.

Figures 3-59 through 3-62 plot ejecta mass and calculated velocity versus theta and phi (see Appendix B for a definition of theta and phi).

Figures 3-63 and 3-64 plot ejecta mass and velocity versus cone angle. The cone angle, in this case, is the angle between the outgoing ejecta or spall particle's velocity vector and a normal to the plane of the target's face, coming out of the impact point. The mass distribution seems fairly uniform between 20 and 70 degrees. Table 3-2, which calculates an average cone angle, shows an average of 47 degrees. Figure 3-65 plots ejecta mass versus velocity. This plot shows the small particles going faster than the big ones, fairly clearly.

Figure 3-66 plots the Log(number of ejecta particles of mass Mi and larger) versus the Log(Mi/Mtotal ejecta mass). A least squares fit linear relationship for these two quantities and the derived equations (with and without the Logs) that result are also shown.

Figures 3-67 and 3-68 plot spall mass versus length and diameter. Compare the plots with Figures 3-57 and 3-58.

Figures 3-69 through 3-72 plot spall mass and velocity versus theta and phi.

Figures 3-73 and 3-74 plot spall mass and velocity versus cone angle. The cone angle is the angle between a normal to the target surface at the impact point and the ejecta particle's velocity vector.

Figure 3-75 plots spall mass versus velocity.

Figure 3-76 plots the Log(number of spall particles of mass Mi and larger) versus the Log(Mi/Mtotal spall mass). A least squares fit linear relationship for these two quantities and the derived equations (with and without the Logs) are also shown.

Figure 3-77 plots the equations from Figures 3-66 and 3-76 and the Log Log plot of total ejecta and spall. The lines are all close together, indicating they could all be approximated by one line.

Figure 3-78 plots the Log Log total ejecta and spall line along with an aluminum line (from Ref. 1). The results are similar to previous plots. The equations derived will be used to estimate the damage hazard to the Space Station. Figure 3-55, Photos of Catcher Box (Shot #923) JSC 02B-005, 0.095 inch thick, graphite/epoxy, no cloth on front



Side View

Projectile . enters



Top View

Figure 3-55, Continued, Photos of Catcher Box (Shot #923) JSC 02B-005, 0.095 inch thick, graphite/epoxy, no cloth on front



Top View

Spall on back wall

Figure 3-56, Photos of Target (Shot #923)

JSC 02B-005, 0.095 inch thick, graphite/epoxy, no cloth on front

Front

Back







(mm) digned Length (mm)





Ejecta Particle Diameter (mm)

EJECTA MASS DISTRIBUTION
























85 C-2

0.008 EJECTA MASS & VELOCITY 0.006 JSC No. 923 — No Cloth, 30 deg Impact Ejecta Particle Mass (g) 0.004 0.002 ₽ ▫▫ 0 2.8 1.8 1.6 0.8 3.2 2.6 2.4 2.2 4.1 1.2 0.6 0.4 0.2 М 2

Figure 3-65









Spall Particle Length (mm)













Spall Particle Velocity (km/sec)





Spall Particle Velocity (km/sec)

Figure 3-72

SPALL MASS DISTRIBUTION





Cone Angle (Degrees)



Spall Particle Velocity (km/sec)

SPALL MASS & VELOCITY

Figure 3-75



Spall Particle Velocity (km/sec)



LOG (N) — N number part. of Mass Mi & >



LOG (N) - N number part. of Mass Mi & >



LOG (N) - N number part. of Mass Mi & >

3.3 Thin Graphite/Epoxy Targets - Projectile Density Effects

Table 3-3 shows a series of additional shots, some performed in conjunction with a University of Texas effort to determine projectile density effects. Aluminum and nylon projectiles were used at velocities around 5 km/sec. In Shots #889, 890, and 895 ejecta and spall particles were collected separately, but detailed data, as shown previously, was not collected. Some of the shots used a toughened resin system. A shot using a fiberglass target (#913) is also shown for comparison.

More data is needed (at different projectile energies) to conclude decisively, but it appears that the higher density aluminum shots produced more ejecta/spall versus equivalent energy nylon shots. Figure 5-3, taken from Ref. 2 shows the same relationship between projectile density and ejecta/spall mass for aluminum.

From the data shown in Table 3-3 it also appears that toughened resin offers no significant advantage in reducing the mass of ejecta/spall produced from hypervelocity impacts. The toughened resin may have other advantages, however. The data collected in these shots was primarily used in developing the total ejecta/spall mass versus projectile energy relationship.

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Data from additional JSC Light Gas Gun Shots

Projectile vs. Ejecta/Spall Mass Summary

(Gamma) Ratio of secondary to Projectile Mass	60.00	42.60	36.07	26.21	74.15	56.00	44.00	32.00	20.08
Percent Spall	80.0	81.0		76.9					
Sec. Mass (g)	0.06 0.24 0.3	0.04	0.18	0.03	0.37	0.28	0.22	0.16	0.1
Secondary Particle Type	Ejecta Spall Total	Ejecta Spall Total	Total	Ejecta Spall Total	Total	Total	Total	Total	Total
Impact Angle (deg)	0	0	0	0	ō	0	0	0	0
Proj. Mass (mg)	5.00	4.93	4.99	4.96	4.99	5.00	5.00	5.00	4.98
Velocity (Km/sec) 	5.02	4.5	4.75	4.82	6.20	6.11	5.17	4.57	4.00
Projectile Type	Al 6061 3,894,923)	Al 6061 rup, No Cloth 5)	Nylon),894,923)	up, No Cloth	Nylon up, Cloth ,917)	Nylon ughened Resin)	Al 6061 up, Cloth ,917)	Al 6061 Jghened Resin)	A1 6061
Target Description	Graphite/Epoxy Thin, No Cloth (similar to 89:	Graphite/Epoxy Thin, Truss la (similar to 89	Graphite/Epoxy Thin, No Cloth (similar to 886	Graphite/Epoxy Thin, Truss lay (similar to 890	Jraphite/Epoxy Thin, Truss lay (similar to 911	Jraphite Thin, Cloth, To Similar to 912	iraphite/Epoxy hin, Truss lay similar to 909	iraphite hin, Cloth, Tou similar to 910	lberglass
JSC Shot # 	889	890	893	895	606	910 (911 6 T (912 G T (913 F

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3.4 Thin Graphite/Bpoxy Targets with High Speed Camera

Accurate velocity measurements of ejecta and spall are critical to assessing the hazard to the Space Station. In the first series of shots done in this study, accurate velocity measurement was unavailable. A crude method for estimating the velocity of the larger particles based on their penetration into styrofoam was used and checked with a few single photos and one film. Once the Orbital Debris Lab High Speed Camera became operational it was possible to check the estimates more carefully. The camera data was also used to check the projectile velocity.

Table 3-4 summarizes the shots for which high speed camera data was taken. Three graphite/epoxy targets and one aluminum target were used.

The new camera system is a custom designed, state-of-the-art ultra-high-speed rotating mirror framing camera, utilizing a laser diode for image illumination. The camera is capable of exposing 80 frames of 35mm IR film at 2 x 106 frames/sec. Even at that framing rate, conventional illuminating systems (on the order of 10 to 15 nsec.) were not fast enough to "freeze" a 300 micron particle traveling at speeds in excess of 7km/sec. The 860nm, 100 watt laser diode used for this system has a pulse duration of 5 nanosec. The "exposure time" is therefore 5 nanoseconds and there is one microsecond between exposures.

Table 3-4

Data from JSC Light Gas Bun Shots with Mi-Speed Camera

Projectile vs. Ejecta/Spall Nass Summary

SFALL Typical Meas. Jarge Particle Velocity (ka/sec)		0.25	,	,
SPALL Maxisum Measured Velocity (ka/sec)	2.71	1.44	2.78	0.75
SPALL Maxiaum Dispersion Angle (degrees)	¥î	ħ	11	22
EJECTA Typical Meas. Jarge Particle Velocity (kn/sec)		0.7	0.8	•
EJECTA Naxiaue Neasured Velocity fka/sec]	5.30	3.74	2.63	4.89
EJECTA Maxinue Cone Angle (degrees)	S.	31	24	99
(Samea) Ratio of secondary to Projectile Mass	66.00	21.74	61.10	39.84
Percent Spall	•	•	ı	ı
Sec. Nass (g)	0.33	0.1	0.30	0.20
Secondary Particle Type	Total	Total	Total	Total
impact Angie (deg)	0	0	0	90
Proj. Nass (mg)	5.00	4.60	4.91	5.02
Velocity (Ka/sec)	7.19	6.66	1.38	6.29
Projectile Type	Nylon 3° thickness	Ny lon is	Mylon	Nylon
JSC Target Shot # Description	972 G/E, generic na ciath, 0.071	975 Al 6061-T6 0.089" thickne	981 6/6, no cloth JSC-028-004	990 6/E, cloth JSC-02A-003

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3.4.1 Shot #972

Figure 3-79 shows the raw film data. The target used in this test was a generic graphite/epoxy sample, similar to the roughly 0.10 inch samples used in the other shots, but not listed in Table 3-1.

Table 3-5 illustrates how the raw data from the film was turned into velocity estimates.

3.4.2 Shot #981

Figure 3-80 shows the raw film data. The Figure 3-80 photographs and analysis shown in Figure 3-81 were provided by Dr. Ching Yew of the Univ. of Texas.

Figure 3-81 plots the progress of the spall front, indicating a constant velocity consistent with velocities calculated for graphite/epoxy particles.

Table 3-6 is the data worksheet.

3.4.3 Shot #990

Figure 3-82 shows the raw film data. The negative was not high quality, but data could be taken from it.

Table 3-7 is the worksheet.

3.4.4 Comparison of Calculated and Measured Velocity

Figure 3-83 compares measured and estimated ejecta velocities over the range of masses. The plot indicates the calculated values are fairly accurate.

Figure 3-84 compares measured and estimated spall velocities for a range of masses. The two data points fall within the same general range as the calculted values.

Overall, the calculated graphite/epoxy spall and ejecta velocities appear to be roughly accurate.

1 ORIGINAL PAGE IS OF POOR QUALITY 2 m .0695 inches = projectile diameter High Speed Camera Data for Generic Graphite/Epoxy Target (Shot #972) 1.13 microseconds between frames S - <u>S</u> 9 7 1 ω δ 10 11

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Figure 3-79

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Ejecta and Spall Velocities deternined from Mi-Speed Camera

972

#

Work Sheet for Shot

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Table 3-5

972 6r /Ep 0.0695 Actual Projectile larget type JSC Shot 8

Diameter (in)

1.13 Franing Period Ti ae between

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frames (micro-sec)

1.85333333 Correction Factor Distance

5.86 tinaccurate) Calt. Proj. Vel.

(ka/sec)

Jncremental Overall Velocity Velocity (Kø/sec) (Kø/sec) 2.93 3.09 2.71 2.93 3.25 1.95 0.98 SPALL SIDE 5.53 angle of crater of crater front front front front front front front front (deg) (ia) (aa) (Ka/sec) (Ka/sac) (Ka first second first second front front front Overall Velocity Overall corrected for Apparent Velocity cone angle 5.07 4.56 3.58 3.16 5.53 2.37 second front Incremental Velocity corrected Apparent Velocity for cone angle CALCULATED VALUES (currected with distance factor) Incremental 3.23 5.07 5.53 first first second front front 2.60 4.56 1.95 EJECTA SIDE 2.28 3.58 3.91 4.413 5.884 8.091 8.827 9.562 10.298 Nidth 0.174 0.232 0.319 0.348 0.348 0.376 Nar. cone 0.1719 0.2188 0.0234 Width from impact SPALL SIDE distance Perpen-dicular point (in) of crater 0.0938 0.1250 0.1719 0.1875 0.2031 0.2188 (in) 33.56 36.87 39.72 34.56 Max. cone Max. cone Max. cone (perpendicular dist. angle - normal fram impart point) at zero deg. at zero deg. at zero deg. second Nax. cone front (deg) 54.31 48.19 45.10 first front (deg) MEASUREMENTS (uncorrected by distance factor) 0.0625 0.1719 0.2188 second front (in) Froj. from impact point! 0.0547 0.1406 0.2344 EJECTA SIDE front (in) first Proj. dist. from 0.1406 piaeter plate (in) 1 0.0375 Fraee (in) 106

¥.

36.87 33.56

Figure 3-80 Shot # 981 Provided by Univ. of Texas, Dr. Yew





t=0 μ sec

 $t = 1.0246 \mu sec$





t=2.0492 μ sec

t=3.0738 µ sec

ORIGINAL FROM IS OF POOR QUALITY







t=5.123 μ sec



 $t=6.1476 \ \mu \ sec$



 $t=7.1722 \mu sec$

Figure 3-80 (cont'd)

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t=8.1968 μ sec

÷.



t=9.2214 μ sec



t=13.3198 μ sec

Figure 3-80 (cont'd)



 $t = 16.3936 \ \mu \ sec$

t=20.492 μ sec



 $t = 28.6888 \ \mu \ sec$



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Table 3-6

Worksheet for Shot # 981

Ejecta and Spall Velocities deterained froa H1-Speed Camera

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JSC Snat # Target type	Actual Projectile Diameter fin)	Fraeing Period	liae between frames (micro-sec)	Distance Correction Factor	Calc. Proj. Vel. (ke/sec)

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$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$				EJECTA SIDE		G	PALL SIDE		•	2 2	ECIA SIDE	increeental Velocity corrected	Over al 1	Overall Velocity corrected for				
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Velocities of Large Particles

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Figure 3-82 High Speed Camera Data (Shot # 990) 1.04 microseconds between frames





Table 3-7 Worksheet for Shot # 990 _

circts and Small Velocities determined from Hi-Spred Camera

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4.0 Aluminum Targets

A significant fraction, if not most of the Space Station, will be built of aluminum. Some data on aluminum spall and ejecta exists in the literature. The following shots supplement this information.

All of the targets used in these shots were $6 \times 6 \times 0.089$ inch thick 6061 T-6 aluminum. This material is representative of what might be expected in a bumper or outer wall protecting the inner hull of a habitation module.

4.1 Shot #933 (0.089 " Thick 6061 T-6 Aluminum)

The test setup for this shot was exactly the same as for the graphite/epoxy shots #917 and 923. The target was inside a plexiglass box, with styrofoam all around to catch the spall and ejecta.

Table 3-2 summarizes the data for this shot. A 4.98 mg nylon projectile impacted a 0.089 inch thick target of 6061 T-6 aluminum traveling at 6.3 km/sec. 0.12 grams of ejecta and spall were collected, making up 50.9 percent of the mass change of the target. 71.2 percent of the collected material was spall.

Figure 4-1 shows the target after the shot.

Figures 4-2 and 4-3 plot ejecta mass versus length and diameter. The length and diameter terms are somewhat misleading holdovers from the graphite/epoxy plots. The aluminum particles are small chips or flakes rather than slivers.

Figures 4-4 through 4-7 plot ejecta mass and calculated velocity versus theta and phi (see appendix B for a definition of theta and phi). The calculated velocities are, in general much higher than for the graphite epoxy shots. The high speed film data (see section 4.2) indicates that while these estimated velocities are in the correct range for the large particles, they may be a factor of two or so too high for the small particles. Thus the highest velocities indicated in these graphs may need to be reduced by a factor of two.

Figures 4-8 and 4-9 plot ejecta mass and velocity versus cone angle. The cone angle, in this case, is the angle between a normal to the target face at the impact point and the ejecta particle's velocity vector.

Figure 4-10 plots ejecta mass versus velocity. This plot is estimated to include about half the total ejecta mass.

Figure 4-11 plots the Log(number of ejecta particles of mass Mi and larger) versus the Log(Mi/Mtotal ejecta mass). A least





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Figure 4-1, Photos of Target (Shot #933)

0.089 inch thick, 6061 T-6 Aluminum

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Ejecta Particle Velocity (km/sec)





Ejecta Particle Velocity (km/sec)









Ejecta Particle Velocity (km/sec)



Ejecta Particle Velocity (km/sec)





Figure 4-11









Spall Particle Diameter (mm)





Spall Particle Velocity (km/sec)



¹³⁴



SPALL MASS DISTRIBUTION















(mm) ritened eloitro9



Particle Diameter (mm)









Figure 4-25

4.2 Shot #975 - High Speed Camera Shot

Shot #975 was performed to determine accurate ejecta and spall particle velocities. A 4.6 mg nylon projectile, traveling at 6.66 km/sec impacted a .089 inch thick, 6061 T-6 aluminum target. 0.10 grams of spall and ejecta were produced as measured by weighing the target before and after the shot. More data on the shot is contained in Appendix A, which lists all the shots and their basic parameters.

Figure 4-26 shows the high speed film raw data.

Table 4-1 shows the worksheet used to calculate the particle velocity.

4.3 Shot #979 - Additional Data

Though no high speed film or particle count data was taken with this shot, the total ejecta and spall and energy were used in later derivations of equations.

A 4.60 mg projectile traveling at an estimated 5.6 km/sec impacted a 6061 T-6 aluminum target and produced a total of 0.07 grams of spall and ejecta. Appendix A documents the shot in more detail.

High Speed Camera Data (Shot#975) 1.015 Microseconds between frames 0.0297 inches = projectile diameter







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Worksheet for Shot # 975

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4.4 Comparison of Calculated and Measured Velocity Data

Figure 4-27 shows calculated ejecta velocity from shot #933 and measured (with the high speed camera film) velocity from shot #975. The calculated data indicates smaller high speed particles (max velocity = 7.5 km/sec). The measured data shows a single point for the small particles of around 4 km/sec. This single data point represents a maximum velocity for the small particles as measured on the film for shot #975. This indicates the calculated velocities for the small aluminum particles may be high by as much as a factor of two. Since this error is conservative for damage estimation, and since projectiles with densities higher than nylon (which was used in these tests) are likely to occur in the real case, the calculated velocities were used in later damage calculations. Higher density projectiles are predicted to result in more spall and ejecta coming off at higher velocities.

Figure 4-28 shows a similar plot for spall. Once again, the maximum calculated velocities for the small particles are much higher than the maximum measured velocity.



Ejecta Particle Velocity (km/sec)



5.0 Derived Relationships from Graphite/Bpoxy and Aluminum Impact Data

Several empirically derived relationships for ejecta/spall were developed to help determine the relative damage potential from secondary impacts. They were generally developed for both graphite/epoxy and aluminum targets by least squares fits of data from the shots described in Sections 3 and 4. Two basic equations used in the damage assessment program (described in Section 6) One correlated the total mass of the ejecta/spall particles with the energy of the projectile, while the other related the number of ejecta/spall particles of a given energy and above to the total mass of ejecta/spall. These two relationships could have been combined into a single relationship that expresses the number of ejecta/spall particles with a given energy and above to the particle and projectile energies, although this was not done in this study. Both relationships were developed separately for graphite/epoxy and aluminum targets and are therefore valid only for the specific target type.

The following sections describe all relationships developed in the study.

5.1 Total Ejecta/Spall Mass Scaled with Projectile Energy

As a rough approximation in this limited study, the total combined mass of ejecta and spall produced from hypervelocity impact was scaled as a function of projectile energy. This approach may be conservative in that the mass of ejecta/spall is probably over-estimated as projectile energy increases.

In Figure 5-1, the total combined ejecta and spall mass is plotted versus projectile energy for all shots with sufficient data listed in Appendix A. The labels indicate whether a target is graphite/epoxy or aluminum, differences in ply orientation, cloth or no-cloth covering, thin or semi-infinite (0.5 in. thick) target, aluminum or nylon projectile, and normal or oblique impact angles. The impact obliquity angle is the angle between the target surface normal and the projectile flight path (30 deg. in the two oblique shots in this study).



Total Ejecta & Spall Mass (g)

Figure 5-1

5.1.1 Graphite/Epoxy Targets

In Figure 5-2, a least-squares linear fit to the thin plate graphite/epoxy data (with and without cloth covering) is given by the equation and line. The equation relates the combined mass of ejecta/spall, M_{es} (g), to projectile energy, Eproj (J).

This equation is valid for thin (approximately 0.1 in. thick) graphite/epoxy targets. It does not include the effects of projectile density, obliquity angle, or target surface covering. Several shots from late in the study were not included in this earlier formulation but were used for other purposes (primarily ejecta and spall particle velocity verification using the Cardin high speed camera).

Generally, more ejecta/spall was produced from the thin plates than the thick for equal energy projectiles. This effect also seems to play a role in the oblique angle shots on the thin plates; because the projectile passes through the plate at an angle, it "sees" more plate, ie. the plate is relatively thicker for the oblique impacts. In the limited number of oblique shots, the ejecta/spall mass was slightly less for equal energy projectiles. Given more data, ejecta/spall mass versus projectile energy curves could be constructed for different target thickness to projectile diameter ratios.

Slightly more ejecta/spall was produced from equal energy impacts with higher density (2.7 g/cc) aluminum (6061-T6) projectiles than with nylon projectiles (1.14 g/cc) for the thin targets. This phenomenon for semi-infinite targets is illustrated by the increase in crater volume with projectile density in Figure 5-3. The impact velocity for the data plotted in Figure 5-3 was 6.6 tm/sec. It has been reported that the influence of projectile density on crater volume and presumably ejecta mass decreases with increasing projectile velocity, and may become negligible at meteoroid velocities (Ref.2, p.467).

The projectile density effect was not quantified for additional reasons. First, for identical shots at nearly equivalent projectile energies (#893 and #894), the ejecta/spall mass varied by 0.05 g or approximately 25 percent. Thus, the apparent increase in ejecta/spall mass with density increases was not appreciably greater than the accuracy of the data. Second, the length to diameter ratio for the aluminum cylindrical projectiles was approximately 0.5 while the nylon projectiles' L/D ratio was approximately 1.0. As the L/D ratio decreases, the crater volume (and perhaps ejecta/spall mass) also decreases as shown in Figure 5-4. Thus, the full effect of higher projectile density was masked by lower projectile L/D ratio. Also, occasionally the projectile will yaw (crater volume is a function of the cosine of yaw angle). Yaw is especially a problem with the aluminum projectiles with a low L/D. All this results in uncertainties that led us to disregard the projectile density in these approximate calculations.

A cloth covering significantly reduced the amount of ejecta produced from equivalent energy projectiles for thick plates tested in this study (shots #883 and #884). However, the effect of cloth is not nearly as apparent for the thin plate data which was used to generate the above equation. The quantitative advantage of cloth in terms of reducing the mass of ejecta/spall appears to be a function of the target thickness to projectile diameter ratio. More data will be needed to develop the exact relationship.



Total Ejecta & Spall Mass (g)

Projectile Density Effects (Taken from Ref. 2)



Crater depth and volume for equal-mass spheres of various densities. (a) Photographic representation; (b) graphical representation: (Δ) volume versus ρ_p ; (\odot) penetration versus ρ_p . Target: 110-F Al, semiinfinite. Impact velocity: 6.6 km/sec. Projectile: Zelux-type M ($\rho_p = 1.20$, diam = 0.313); 2017 Al ($\rho_p = 2.70$, diam = 0.240); C1020 steel ($\rho_p = 7.80$ g/cm, diam = 0.169 in.). All projectiles same mass-0.32 g.

Figure 5-4 Projectile L/D Effects (Taken from Ref. 2)



Crater depth and volume for projectiles of equal mass and various shapes. (a) Photographic representation; (b) graphical representation versus l/d_s ; (O) penetration versus l/d_s ; (Δ) volume versus l/d_s . Target: 1100-F Al, semiinfinite. Impact velocity: 6.6 km/sec. Projectile: 2017 Al. All projectiles same mass-0.32 g.
5.1.2 Aluminum Targets

Figure 5-5 illustrates a linear fit to the 6061-T6 aluminum total ejecta and spall mass versus projectile energy data. The equation relates the combined mass of ejecta/spall, M_{es} (g), to projectile energy, E_{proj} (J), for thin (0.089 in. thick) 6061-T6 aluminum targets.

Mes = 0.00301 * Eproj - 0.178

When this equation was developed, only two early data points at basically the same projectile energy were available (shots $\ddagger933$ and $\ddagger975$). Therefore, an empirical equation for aluminum developed from experimental results for use at 10 km/sec projectile speeds (Ref. 1, p.2640) was used to generate another point at higher projectile energies. This equation related the ejecta mass to

$$M_e = 115 * M_{proj}$$

The linear fit was through these three data points. Shot #979 was an additional later nylon projectile data point that fell near the aluminum linear scaling line. The last two shots (#991 and #992) were with aluminum (6061-T6) projectiles and seem to indicate that the projectile density effect for aluminum targets may be greater than for graphite/epoxy because of the large amounts of ejecta/spall that were produced (especially in shot #991). More data will be necessary to confirm this however.



Total Ejecta & Spall Mass (g)

5.2 Number of Ejecta/Spall Particles of a Given Mass and Above

From the data of individual ejecta and spall particles, a linear Log-Log relationship was found relating the number of particles of a given mass and greater, N, to the ratio of the particle mass, M (g), over the total ejecta/spall mass, M_{es} (g). The functional form of this equation is useful to get an idea of the mass distribution of the ejecta and spall particles, but was not used as such in the damage assessment model explained in Section 6. The general form of the equation reduces to

 $N = k \star (M / M_{es})^n$

where the constants, k and n, for various specific target groups are given in the following sub-sections.

5.2.1 Graphite/Bpoxy Targets

The least-squares linear fits for the graphite/epoxy ejecta particles given in Figures 3-11, 3-23, 3-28, 3-42, and 3-66 are all plotted in Figure 5-6 together with the overall graphite/epoxy ejecta average. Similarly, the linear fits for the graphite/epoxy spall particles given in Figures 3-29, 3-52, and 3-76 are all plotted in Figure 5-7 with the overall graphite/epoxy spall average. The ejecta and spall average lines as well as the overall graphite/epoxy average are plotted in Figure 5-8. Spall is typically about 60 to 70 percent of the total ejecta and spall mass for the plate thicknesses (approximately 0.1 in.) tested in this study as is indicated in Table 3-2.

From Figure 5-8, it is evident that although there is about twice as much spall mass as ejecta mass, the number of particles of a given particle mass and greater for the same ratio of particle mass to total particle mass (ejecta or spall) is nearly the same for ejecta and spall (for typical particle to total mass ratios of 0.0001 to 0.05). In other words, there are approximately twice as many spall particles as ejecta particles for a given particle mass. (The real factor is ½ raised to the n power when total spall mass is twice the ejecta mass which, because n approximately equals -1, makes $N_g = 2 * N_e$). The k and n constants for the general equation are:

		<u> </u>	<u>n</u>
G/E	Ejecta	0.0276	-1.155
G/E	Spall	0.0070	-1.382
G/E	Avg.	0.0131	-1.253

In Figure 5-9, the average equation for graphite/epoxy with cloth is plotted with the average equation for graphite/epoxy without cloth. In Section 5.1.1, it was mentioned that for a given energy projectile there was little observable difference between cloth and no-cloth covered graphite/epoxy in terms of the total ejecta/spall mass. Given that information, it is apparent from Figure 5-9 that, in the typical particle to total mass ratio range of 0.0001 to 0.05, there are more ejecta/spall particles that have large relative masses (particle to total mass ratio of 0.001 and greater) for graphite/epoxy targets without cloth than with cloth. The reverse holds true for ejecta/spall particles of lower relative masses (particle to total mass ratio of less than 0.001). The k and n constants for the general form of the equation are:

	<u> </u>	<u> </u>
G/E w/ Cloth G/E w/out Cloth	0.0036	-1.426 -1.157





(N)DOT



гос(и)

Figure 5-8



гос(и)

5.2.2 Aluminum Targets

In Figure 5-10, the overall average graphite/epoxy equation (from Section 5.2.1) is plotted with the average aluminum equation of Figure 4-24 and a equation from the literature for the mass distribution of particles resulting from a 10 Km/sec impact on an aluminum spacecraft (Ref. 1, p.2640). From Figure 5-10 it is clear that the aluminum test where particle counts were taken (shot \$933) resulted in somewhat fewer particles of a given mass and greater than the literature equation for orbital debris impacting into an aluminum spacecraft. This may be due to the lower density for the nylon projectile (1.14 g/cc) used in shot \$933 versus the presumed higher projectile density in the tests that resulted in the reported spacecraft particle distribution (typically 2.8 g/cc is used for orbital debris density). The k and n constants for the general form of the equation are:

	<u>k</u>	<u>n</u>
G/E average	0.0276	-1.155
Al average	0.0873	-0.997
Al Spacecraft	0.8	-0.8

5.3 Number of Ejecta/Spall Particles of a Given Energy and Above

A key pair of equations developed for the damage assessment model (described in Section 6) relates the number of ejecta and spall particles of a given energy and above to the particle energy and the total ejecta and spall mass for both graphite/epoxy and aluminum (6061-T6) targets. The general form of the equation is:

$$Log(N) = a * (Log(E / M_{es}))^2 + b * Log(E / M_{es}) + c$$

where the number, N, of ejecta/spall particles of a given particle energy, E (J), and greater related in a second-order Log-Log expression to the particle energy and total ejecta/spall mass, M_{es} (g). The total ejecta and spall mass, M_{es} (g), is related to the projectile energy as explained in section 5.1. The equations and constants (a,b,c) for both graphite/epoxy and aluminum targets are described in the following sections.



гос(и)

5.3.1 Graphite/Bpoxy Targets

Figure 5-11 shows the least-squares fit to all the graphite/epoxy data for which particle counts were completed (shots #883, #884, #894, #917, and #923). Curve-fits were also developed for graphite/epoxy with and without a cloth covering as given in Figures 5-12 and 5-13, and to describe the graphite/epoxy ejecta and spall particle energies as given in Figures 5-14 and 5-15. The curves for cloth and no-cloth covered graphite/epoxy are compared in Figure 5-16. From this figure it is obvious that a cloth covering reduces the energy of the ejecta/spall particles. As will be seen in section 5.4, this is due to the reduction of the ejecta/spall particle velocity. Ejecta and spall particle energy curves are compared in Figure 5-17. There is not a large difference between ejecta and spall particle energies (on a ratio basis of particle energy to total particle mass; remember that spall mass was found to be approximately twice ejecta mass in this study) but a slight tendency exists for spall to have more higher energy particles and fewer lower energy particles than ejecta (on a ratio basis). The graphite/epoxy coefficients for the general equation (a,b,c) are:

		<u>a</u>	b	C
G/E ov	verall	-0.168	-0.851	+1.695
G/E w/	' Cloth	-0.322	-1.227	+1.203
G/E w/	out Cloth	-0.163	-0.663	+1.822
G/E E	iecta	-0.218	-0.897	+1.602
G/E ST	all	-0.169	-0.674	+1.737

5.3.2 Aluminum Targets

Figure 5-18 shows the quadratic form of the ejecta/spall particle energy distribution for aluminum (shot #933). The aluminum ejecta equation and curve appears in Figure 5-19, the aluminum spall equation is in Figure 5-20, and a comparison between them in Figure 5-21. There were significantly more higher energy and less lower energy spall particles than ejecta particles. This was due to the mass distribution of the aluminum ejecta/spall particles, not a difference in observed velocity between ejecta and spall. There were many more large particles (chunks) in the aluminum spall, while the aluminum ejecta was mainly very small particles (less than/equal to 0.0001 g) and dust. A comparison between the overall graphite/epoxy and overall aluminum particle energy curves is given in Figure 5-22. These curves were used in the damage assessment model as discussed in Section 6. Basically, there were significantly more high energy and less low energy aluminum ejecta/spall particles observed than graphite/epoxy ejecta/spall particles for the limited number of shots made during this study.







LOG (N) N-# part w/ energy >= E



170

Figure 5-13



LOG (N) N-# part w/ energy >= E

Figure 5-14



FOG (N) N-# back w/ evergy >= E



FOC (N) N-# bacf M\ euergy >= E











Log(N) N=number of part w/ energy >= E





Figure 5-21



LOG(N) N=number of part w/ energy >= E



5.4 Bjecta/Spall Particle Velocity and Mass

Figure 5-23 is a combination of Figures 3-9, 3-22, 3-41, 3-51, 3-65, and 3-75. It gives an idea of how the calculated particle velocity varies with particle mass. Some of the lower mass ejecta/spall particles can travel relatively fast while all higher mass particles tend to travel slowly. For each individual shot, a line was constructed that delineated the maximum particle velocity boundary. There was little real difference between ejecta and spall particle velocities. However, the particle velocities for cloth covered graphite/epoxy were significantly lower than for graphite/epoxy without cloth. Figure 5-23 shows three lines which are averages of the individual boundaries:

G/E	w/out cloth	V =	-540	* 1	M + ·	4.65
G/E	average	V =	-1543	*	M +	4.09
G/E	w/ cloth	V =	-2546	*	<u>M</u> +	3.53

where the maximum ejecta/spall particle velocity, V (km/sec), is related to particle mass, M (g). These equations were not used in the damage assessment model described in Section 6, but are presented to indicate calculated particle velocity distributions.

<u>fi</u>u Eproj=102J Eproj=93 J Ъ Ъ Eproj=143J Eproj=143J Eproj=87 Eproj=87Cloth G/E ----Ŭ. (Cloth) (No-C1) (Cloth) Cloth) No-C1) (No-CI *-*-*-÷ V KEY LLEC TA SEPALL Ejecta Ejecta Ejecta Ejecta Spall Spall <u>ال</u> 883 884 917 917 923 923 in right t Avg. G/E Parkine Marie [g] A B C C B F General Contract 1 -1D r L i. 1 -9--9- No Cloth G/E ٤., ti. ز نے دید / ------ $\{ \underline{\cdot}, \underline{i} \}$ -1 і. L £3 ì. i. 1 inden State F 4 t indi F. uşi. -43 \mathbf{E} r_{2} :4 Ċ 21

Figure 5-23

Case/ Lang Allerand

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6.0 Bstimate of Damage Potential to the Space Station

Based on the scaling relationships developed in the previous section, a preliminary assessment was made of the relative amounts of damage that can be expected from impacts by ejecta and spall particles on particular Space Station structures. The flux from primary impacts (meteoroids and orbital debris) is compared to the flux from secondary impacts (ejecta and spall) with a given critical kinetic energy that will result in damage to the particular Space Station structure of interest. A spreadsheet program for IBM compatible PC computers was developed to perform the damage assessment calculations.

This section describes the damage assessment model; specifically summarizing the empirical equations used for relating the primary/secondary fluxes and explaining the main model assumptions. Then, the results from applying the model to cases of interest (Station module window, docked Space Shuttle window, habitat module wall, and solar panels) are described.

6.1 Damage From Primary Impacts - Meteoroids and Orbital Debris

Spacecraft, space stations, and satellites in Earth orbit are susceptible to potential damage from collisions with both meteoroids and orbital debris. Meteoroids occur naturally while orbital debris (or space junk) originate from man-made objects. Generally, because orbital debris are Earth-orbiting while meteoroids follow interplanetary trajectories, the relative velocities are lower for collisions between orbital debris and spacecraft (average approximately 10 km/sec) than for meteoroid collisions (average approximately 20 km/sec). The average density of orbital debris is approximately that of aluminum, 2.8 g/cc, while cometary meteoroids have a typical density of 0.5 g/cc. Both types of objects are assumed to be spherical.

The level of hazard to a spacecraft from primary impacts depends on the size of the spacecraft, the number and size of primary objects in its operating environment and the time-in-orbit for the spacecraft. The number of impacts, N_i , over a time period, t (yrs), is related to the primary flux, F (impacts/m²) of surface area - yr), and spacecraft surface area, A (m²), by:

 $N_i = F * A * t$

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6.1.1 Meteoroid Model

The NASA recommended meteoroid model (Ref. 7) was used in this study. The average near-Earth meteoroid flux, F_{met} (impacts/m²) of surface area - yr), with meteoroid mass, M_{met} (g), and larger is given by the following equations:

for $M_{met} > = 10^{-6}$,

Log(F_{met}) = -1.213 * Log(M_{met}) - 6.871

and for M_{met}<10-6,

 $Log(Fmet) = -0.063 * (Log(M_{met}))^2 - 1.584 * Log(M_{met}) - 6.840$

This meteoroid flux is assumed to be omnidirectional although recent work (Ref. 8) indicates a directional dependence with most meteoroids coming from the direction of motion. The Earth partially shields the Space Station from meteoroids and the extent of shielding is a function of altitude (Ref. 9). The equation used to multiplicatively compensate the meteoroid flux for this effect is:

 $SF = (R + H + (H^2 + 2RH)^{\frac{1}{3}})/(2R + H)$

where SF is the shielding factor which depends on the radius of the Earth, R, and the altitude of the Space Station, H. Because meteoroids are attracted by the Earth's gravity field, the meteoroid flux is also factored by a Earth defocusing factor, DF, which depends on the distance from the Space Station to the center of Earth in units of Earth's radius, r:

DF = 0.568 + (0.432/r)

6.1.2 Orbital Debris Model

Orbital debris are different size particles, fragments, and objects in orbit that result mainly from satellite breakups/explosions and subsequent collisions with operational and nonoperational payloads, rocket casings, etc. Unlike meteoroids which just pass through, orbital debris tends to accumulate (with every launch) and build (from subsequent collisions with other objects) in orbit, especially for frequently used low Earth and geosynchronous orbits. The only natural mechanism for debris removal is atmospheric drag, which acts slowly except at the lowest altitudes. Thus, orbital debris is of particular concern for future space missions (Refs. 2, 10-13). The 1990's predicted orbital debris flux, F_{od} (impacts/m² surface area - yr), with debris mass, M_{od} (g), and greater for a

Space Station in 30 degree inclination, 500 km circular orbit is given by (Ref. 14):

for $M_{od} \le 1.47$ g

 $Log(F_{od}) = -0.84 * Log(M_{od}) - 5.320$

and for $M_{od} > 1.47$ g,

 $Log(F_{od}) = 0.0391 * (Log(M_{od}))^2 - 0.466 * Log(M_{od}) - 5.384$

The orbital debris flux is highly directional (essentially only impacting a spacecraft from the direction of flight), but because the above flux equations are expressed in terms of total surface area and the effect of oblique impacts on total ejecta/spall mass was not quantified, flux directionality was not included in this study. An illustration of how quickly the primary fluxes decrease with increasing primary particle size is given in Figure 6-1 (from Ref. 14).

6.1.3 Space Station Area Model and Probability of Impact

A model of the dual keel Space Station was developed early in this study to determine the surface area to be used in calculating the total number of primary impacts expected during the Space Station operating lifetime. The total Space Station surface area (including truss, pressurized volumes, solar arrays, radiators, and major payload/experiment packages) as given in Table 6-1 is approximately $11,500 \text{ m}^2$. The subject of the model was an IOC Space Station reference configuration prior to March 1986 (Ref. 15). Since that time the configuration has further evolved (Ref. 16,17) and this model requires updating. However, it is presented here because the surface area was used in the damage assessment model. Changes in Space Station surface area should not change the relative damage potential between primary and secondary impacts much.

The meteoroid and orbital debris fluxes are calculated using the equations in Sections 6.1.1 and 6.1.2. The sum of the impacts from orbital debris with a diameter of 1 cm and greater and from meteoroids with an equal energy to the 1 cm debris particle is calculated using the equation in Section 6.1. Finally, the probability of no impact, P_{ni} , during the 30 year assumed lifetime of the Space Station is calculated from Poisson's probability:

 $P_{ni} = exp(-(F_{met} * SF * DF + F_{od}) * t * A)$

6.2 Damage From Secondary Impacts - Bjecta and Spall

A model was constructed and programmed in a spreadsheet format to estimate the amount of damage that can be expected from secondary impacts. That program is described below.

6.2.1 Damage Assessment Worksheet

An example worksheet is given in Table 6-2. A couple of Space Station variables need to be set by the user: station surface area (from Table 6-1) and station lifetime. In addition, several variables need to be set that describe the structure for which the damage assessment is being made.

One of the key variables to be defined is a critical energy for a particle that would result in unacceptable damage to the sensitive area (or structure that is being assessed).

For this particular example, the critical energy was arbitrarily set at 120 joules. Another variable is the sensitive area's surface area which was set at 200 m² in this example. This variable is not particularly important because it is only used in the calculation for the total number of impacts on the sensitive surface. An assessment of the relative amount of damage from primary and secondary impacts can be made simply by looking at the fluxes of primary/secondary particles on the sensitive surface. The flux calculation does not involve the sensitive area surface area directly.

However, the surface area is involved indirectly in another important parameter--the fraction of surface area of the Space Station that faces the sensitive area. In other words, this factor gives the fraction of Space Station surface area that produces ejecta/spall that can potentially hit the sensitive surface (ie. the fraction of station area that is within line-ofsight of the sensitive surface). It has to be calculated/estimated by the user based on the geometry of the station and the size of the sensitive surface. Naturally, as the sensitive surface area decreases, less station surface area is within the line-of-sight of the sensitive surface. This factor will be referred to as the "station surface area fraction" or SAF through the remainder of

Another important user supplied factor is the fraction of sky covered by the station as seen from the sensitive surface (using hemispherical geometry). Because it is geometry related, no calculation exists in the present program and it must be calculated/estimated by the user. This factor will be referred to as the "view factor" or VF. The fraction of the ejecta/spall produced by primary impacts on the Space Station that immediately hits the sensitive surface is thus calculated as the product of SAF and VF (this product will be referred to as the secondary impact fraction or SF).

For a given critical energy, the flux of primary particles that have this energy and greater is calculated based on the flux equations in Sections 6.1.1 and 6.1.2, and the average velocities for meteoroids and orbital debris. These fluxes for the example critical energy of 120 J are given on the first page of Table 6-2 (within the highlighted box). The meteoroid flux is greater in this case but as critical energy increases, the orbital debris flux becomes the more important primary flux.

The ejecta/spall flux of particles having the critical energy and greater is determined by integrating over the entire range of appropriate projectile masses (the model now integrates from 0.001 g and above). For a given projectile mass and velocity (using the averages for orbital debris and meteoroids), the mass of ejecta and spall is calculated from the equations in Section 5.1. Two sets of calculations are made--one for the case of having the entire Space Station made of aluminum (and thus all ejecta/spall produced from primary impacts would be aluminum), and the other set for the case of the Space Station being entirely graphite/epoxy. A comparison is then possible between the relative damage potential of graphite/epoxy ejecta/spall and aluminum

If the results from applying this model to sensitive areas of interest indicate that secondary impacts may create as much or more of a problem than primary impacts, then it might be advisable to make the model more realistic by setting it up with different materials for various Space Station structures and calculating a more accurate picture of the amount of secondary damage to expect on the sensitive surface.

After the total ejecta/spall mass is calculated, the equations described in Section 5.3 are applied to determine the number (or flux) of ejecta/spall particles having the critical energy and greater. The secondary impact fraction (SF) is then used to factor the total Space Station secondaries flux having the critical energy and greater to determine the amount of secondaries flux In the example of Table 6-2, striking the sensitive surface. with a SAF of 25% and a VF of 25%, the resulting SF is 0.0625 which results in the ejecta/spall flux being about 7% of the total number of critical energy impacts on the sensitive surface if the Space Station was entirely graphite/epoxy and about 6% if This example indicates that a designer for the it was aluminum. sensitive surface that was concerned about meteoroid/orbital debris damage should factor the total primary flux (sum of meteoroid and orbital debris fluxes) by approximately 1.07 to compensate for damage from secondary impacts.

Figure 6-2 is a graph of the Table 6-2 example that plots the secondary flux versus SF. The graphite/epoxy secondaries flux is slightly above the aluminum secondaries flux primarily because of an assumption that significantly reduced the number of potentially damaging aluminum ejecta/spall particles. This assumption is explained in Section 6.2.2 (letter d).



Log Flux (Impacts/m² (surfacearea) - yr)

Table 6-1 (page 1 of 3)

Properties Concosite density (g/cc) Neteoroid density (g/cc) Drbital Debris density (g/cc)	Value 1.5775 0.5 2.8	Aluninun den. (g/cc)	2.712
Heteoroid critical mass (g) Drbital Debris crit, mass (g)	3.6652E-01 1.4661E+00	Ave. Vel. (ka/s) Ave. Vel. (ka/s)	20 14
Space station structure life (Logistics module life (yrs)	(yrs)	30 1	
Ejecta station view factor		0.25	
Neteerbid Energy (3) Brbital Bebris Energy (3)	73303.8 73303.8		
a64/3501-4 Unidirectional Fil	er.		
It (mina Pa) 1.72000 5 (jiga Pa) 0.12	110	
Ic (giga Pa) -2.27000 K (jiga Pa) 0.14	204	
Yt (giga Pa) 0.04216			
Yc (giga Pa) -0.09308			
Memorization Energy (3/6)	3578.5		
Vaperization Energy (1/g)	12059.0		

Al 2219-T8 yield stress (giga Pa) 0.317159

Table 6-1, Continued

(page 2 of 3)

OPACE STATION Sunface mea tanalation

BUAL KEEL REFERENCE CONFIGURATION

JTEN	SHAPE	LENGTH Ft	NIDTH OR Biameter Ft	DEPTH Ft	SURFACE Area Ft Sord.	KARDE R	TDT.SURF. Anea Ft Bord.	NATERIAL Type	BK1H TW1CKNESS JAICHES	TOTAL Surf. Area Neters so.	TINE YEARS
Common Module	Cylinder	42	14	-	2,155.1	4	8,420.5	Alaniaue	9.86	800.27	30
CON 1202	Cylinder	21	14	•	1,231.5	1	1,231.5	Al vai sua	0.06	134.41	30
Legistics Mod.	Cylinder	28	13.2	-	1,849.5	1	1,849.5	Composite	0. 1	171.82	1
Solar Arrays	Flat Plate	80	32.5		5,200.0	8	41,600.0	Coranic		3,864.77	30
Radiators	Flat Plate	50	24		2,400.0	2	4,800.0	Metallic		445.93	30
Radiators	Flat Plate	50	6		600.0	2	1,200.0	Netallic		211.46	30
Hangar (IDN 2520)	B OX	60	27		25 7,590.0	1	7,590.0	Cooposite		705.13	30
SAT Instr.Stor.	Boz	45	10		10 2,000.0	1	2,000.0	Composite		· i#5.81	30
SAA 0006	Box	20	10		10 1,000.0	1	0.0 00 ,1	Camposite		92.90	30
TDN 2010	Doz	10	10		10 400.0	1	600.0	Composite		55.74	30
SAA 0005	Boz	15	10		10 800.0	1	800.0	Composite		74.32	30
SAA 0207	Joz	10	10		10 400.0	1	60 0.0	Composite		55.74	30
SA4 0009	Bor	15	• 12		10 900.0	1	900.0	Composite		83.61	30
SAT Stor. Bay	Box	70	30		30 10,200.0	t	30,200.6	Coopesite		947.61	30
SAT SVE Bay	Je z	70	30		30 10,200.0	1	30,200.0	Coopesite		······································	34
TBH 2200	Box	32	•		6 840.0	1	810.0 (Conposite		78.04	30
Refueling Day	Boz	70	30	į	30 10,200.0	I	10,200.0 (Composite		947.61	30

Truss Elements

(in a 16.4042 foot cube truss, there is app. 255.3029 linear feet of

2 inch 00 tubes.)

		Boca Len. (ft)	Lin. ft of truss	Width (ft)						
Dual Keel	Cylander	311.7	4,850.8	0.167	2,539.9	2	5,079.7 Composite	. 0.1	471.92	30
Upper Boom	Cylinder	147.6	2,297.7	0.167	1,203.1	1	1,203.1 Composite	0. 1	111.77	30
Lower Boom	Cylinder	147.6	2,297.7	0.167	1,203.1	ı	1,203.1 Composite	0. 1	111.77	30
Mid Boom	Cylinder	114.8	1,787.1	0.167	935.7	1	935.7 Composite	0.1	84.93	30
Transv. Boom (inboard and	Cylinder outboard)	147.6	2,297.7	0.147	1,203.1	2	2,406.2 Composite	0.1	223.54	30
Madule Suppor Boom Elements	t Cylinder	213.3	3,318.9	0.167	1,737.8	1	1,737.8 Composite	0.1	161.45	30
Truss Total							12,565.6		1,167.30	30
ONV	Cylinder	2	15	-	141.4	2	282.7 Aluminum	0.66	24.27	30
Airlocks	Cylinder	10	,	-	219.9	2	439.8 Aluninun	9.66	40.86	30
Antenna (TDN 2060/20	Dish 70)	-	100	-	7 ,85 1.0	1	7,854.0 Composite/Net	al III	729.44	30

Station Jotal

125, 373. 6

Table 6-1, Continued (page 3 of 3)

INPACT PROBABILITY CALCULATIONS

ITEM	DEBRIS CRIT. MASS GRAMS	DEBRIS AVE. VOL. (CC)	DEBRIS Ave. Dia (CH)	DEDRIS FLUI ABOVE .CRIT. MASS B/M^2/YR	NO DEBRIS INPACT PROBABILITY CRIT. MASS OR GREATER	NETEORDID AVE. DIA. (CN)	EARTH DEFOCUSING FACTOR	EARTH Shielding Factor	METEORDID Flux Above Crit. NASS 8/H^2/VR	NO MET. INPACT PROBABILITY CRIT. MASS OR GREATER	CONDINED NO INPACT PROB. CAIT. MASS OR GREATER	LIFETINE IN Crit. Mass & Greater MET.	PACTS & Debris
Common Module	1.4061	5.24E-01	1.000	3.597E-06	0.91720	1.12E+00	0.9675	0.717	4.185E-07	7 0.9 930	9.11E-0	0.0070	0.08.
COM 1202	1.4661	5.24E-01	1.000	3.597E-06	0.98773	1.12E+00	0.9675	•••• 0.71	4185E-0	0.9990	9.87E-0	0.0010	0.0123
Logistics Hod.	1.4661	5.24E-01	1.000	3.5972-06	0.99938	1.12E+0	0.9675	i 0.71	4.185E-0	7 1.0000	9.992-0	0.0000	0.00
Solar Arrays	1,4661	5.24E-01	1.000	3.597E-06	0.65895	i 1.12E+0	0.9675	0.71	4,185E-0	7 0.9669	6.37E-0	1 0.0337	0.4171
Radiators	1.4661	5.24E-0	1 1.000) 3.597E-06	0.95301	1.12E+0	0 0.967	5 0.71	7 4.185E-0	7 0.996	9,49E-0	1 0.0039	0.04
(Nodule) Radiators	1.4661	5.24E-0	1 1.000) 3.597E-04	0.98804	1.12E+0	0 0.967	5 0.71	7 4.185E-0	7 0.999	9.87E-0	1 0.0010	0.0120
(Pør sys.) Hangar	1.4651	5.24E-0	1 1.000) 3.597E-04	0.92672	2 1.12E+0	0 0.967	5 0.71	7 4.185 E-0	0.993	9 9.21E-0	0.0061	0.07
(TD: 2570) SAT Instr.Stor	. 1.4661	5.24E-0	1 1.00	0 3.597E-0/	6 0.9801	5 1.12E+0	0 0.967	5 0.71	7 4.1852-0)7 0 . 998	4 9.79E-0	0.0016	0.0201
SAA 0006	1.4661	5.24E-0	1 1.00	0 3.597E-0	6 0.9900	2 1.12E+0	6 .0.967	5 0.71	7 4.185E-0)7 - 0 . 999	2 9 .8 9E-0	0.0008	0.01
TDM 2010	1.466	1 5.24E-0	1 1.00	0 3.597E-0	6 0.9940	0 1.12E+0	0 0.967	5 0.71	7 4.185E-(0.999	5 9.94E-6	0.0005	0.0060
5AA 0003	1.460	1 5.24E-0	1 1.00	0 3.597E-0	6 0.9920	1 1.12E+0	0.967	5 0.7	.7 4.185 E-0	0.999	4 9.91E-0	0.0006	0.00
SAA 0207	1.466	1 5.24E-0)1 1.00	0 3.597E-0	6 0.9940	0 1.12E+(0.967	5 0.7	17 4.185E-1	07 0 .9 99	5 9.94E-	01 0.0005	0.0 0
542 0009	1.466	1 5.24E-(01 1.00	0 3.597E-0	6 0.9910)2 1.12E+(0.961	5 0.7	17 4.185E-	07 0.999	9.90E-	01 0.0007	0.0090
SAT Stor. Bay	1.466	1 5.24E-(01 1.00	0 3.597E-0	0.9027	19 1.12E+	00 0.96	75 0.7	17 4.185 E-	07 0 .9 91	8 8.955-	01 0.008	3 0.10
SAT SVC Bay	1.466	1 5.24E-0	01 1.00)0 3.597E-0	0.9027	79 1.12E+	00 0.96	75 0.7	17 4.185 E-	07 0.99	IB 8.95E-	01 0.008	3 0.1023
TDM 2260	1.466	5.24E-	01 1.00	00 3.597E-0	0.991	61 i.12E+	00 0.96	75 0.7	17 4.185 E-	07 0.99	73 9.91E-	01 0.000	7 0.001
Refueling Bay	1.466	5.24E-	01 1.00	00 3.597E-0	0.902	79 1.12E+	00 0.96	75 0.7	17 4.185E-	07 0.99	18 8.95E-	01 0.008	3 0.102
Dual Keel	1.46	61 5.24E-	-01 1.0	00 3.597E-	06 0.950	34 1.126	00 0.96	.75 O.	17 4.185E	-07 0.99	59 9.468	-01 0.004	0.050
Upper Boom	1.46	61 5.24E-	-01 1.0	00 3.597E-	06 0.988	101 1.12	00 0.98	i75 0.1	17 4.105E	-07 0.99	90 9.87E	-01 0.001	0 0.017
Lower Boos	1.46	61 5.24E-	-01 1.0	000 3.577E-	-06 0.988	101 I.12E	+00 0.9/	575 Q.	717 4.185E	-07 0.91	90 9 . 87E	-01 0.00	10 0.012
Mid Boom	1.46	61 5.24E-	-01 1.0	100 3 .5 97E-	-06 0.990	66 1.12E	190 0. 9(575 0 .	717 4.185E	-07 0.91	92 9.90 E	-01 0.000	0.009
Transv. Boos Linboard and	: 1.46 Du	61 5.24 E	-01 1.0	100 3 .5 97E-	06 0.971	ili 1.12E	+00 0.9	675 0.	717 4 .185 E	-07 0.9	181 9 . 74E	-01 0.003	19 0.024
Noaule Supp: Boon Element	ort 1.46	61 5.24 E	-01 1.0	000 3.597 E-	-06 0.982	273 1.12E	+00 0.9	675 0.	717 4.18 5E	-07 . 0.9	786 9.81E	-01 0.00	14 0.01
Truss Total	1.46	5.24E	-01 1.0	000 3.4674E-	-06 9.85 65E	-01 1.12E	+00 0.9	675 0.	717 4.1858	-07 0.9	899 8. 77E	-01 0.01	02 0.12
0HV	1.46	561 5.24E	-01 1.4	000 3.5 97E	-06 0.99	71 7 1.12 E	+00 0.9	675 0.	717 4.1856	-07 0.9	998 9.976	-01 0.00	02 0.00
Airlocks	1.4	661 5.24E	-01 1.	000 3.597E	-06 0.99	560 1.12E	.+00 0.9	675 0.	717 4.1856	-07 0.9	996 9.956	-01 0.00	04 0.00
Antenni (TDM 2060/	1.40 2070	661 5.24E	-01 1.1	000 3.597E	-06 0.92	427 i.12E	+00 0.9	675 0.	717 4.1856	-07 0.9	937 9.18	-01 0.00	64 0.07

Station Total

1.4661 5.24E-01 1.000 3.597E-06

2.8449E-01 1.12E+00

0.9675 0.717 4.185E-07

9.0353E-01

0.1014

2.57E-01

1.25

Worksheet	
Assessment	l of 4)
Damage	(paye
6-2,	
Table	

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Flux of Ejecta/Spall Particles of Critical Energy and Breater on a Sensitive Area of Space Station

-

Surface Area of Station (⊕^2) 	1416.1	Fraction of facing semi	f surface ar sitive area	ea of Station 0.	25		Earth's radius Station orbital Altitude in Ear	(km) altitude (km) th radii	6378.145 500 1.078392
Orbital Life (yrs)	02	Fraction of area (heais	f sky covera spherical Vi	d by Station as ew Factor) 0.	seen fron sen 25	si ti ve	Earth defocusin Earth shimlding	g factor factor	0.768596 0.713070
Critical Energy to damage sensitive wurface (Joules)	120	Fraction of Spall strik (Station SA	F Station Ej ting the sen Fraction #	ecta & 0.06 sitive area view factor)	8	L	Percent of total tepacts	Percent of total impacts	
Surface Area of critical surface la^2)	200	Particle	Flux with and great (Number i	tritical energy er on sens. area mpacts/m²2-yr)	Number of area with greater o	f impacts on sensitive h critical energy and over Station lifetime	om sensitive area if S/S ej. & sp. all G/E	on sensitive area if S/S ej. & sp. all Algoinum	Probability of no impact on sens. area with critical energy & greater (percent)
Jrb. Debris Average Alority (to/cor)	۲. ۵	Neteoroids		1.09E-03	è.	.532354	57.611	58, 351	1.101
resourcy samples		Orb. Debris		6.71E-04	÷	114820.	35.531	35.991	1. 781
(g/cc)	8.7	Ejecta/Spal tif S/S all	l] graphite/e	1.30E-04 pary)	ö	.778045	6.86I		45.93
receddig Average Jelocity (km/sec)	20	Ejecta/Spal	[1.06E-04	•	.633604		5.642	53.071
Meteoroid Density Ig/cc)	0.5								
elocity above which il targets vaporize ka/secl	~	Average Bra Average Alu Orbital Deb Urb. Debris	sphite-Epoxy minum Ejecti ris Fractio Average Ve	Ejecta/Spall ve a/Spall velocity n below vaporiza 1. (ka/sec) below	locity (ka/sec (ka/sec) lion velocity • vaporization	c) 0.5 4.232 0.235359 1 velocity 4.83798	-		

0.0001 0.0001 0.0011 0.1781 1.1081 2.9141 5.3321 8.0851 10.9741 13.8731 16.7101 19.4451 22.6561 24.5351 26.8821 29.1001 30.8731 0.3010 0.3446 0.3793 0.4086 0.5148 0.5893 0.6486 0.4987 0.7424 0.7816 0.8172 0.8499 0.8803 0.9087 0.9354 0.9607 0.9847 1.0077 7.14E-05 5.08E-05 3.99E-05 3.31E-05 1.88E-05 1.31E-05 1.03E-05 8.58E-06 7.34E-06 6.45E-06 5.77E-06 5.22E-06 4.41E-06 4.10E-06 3.84E-06 3.60E-06 3.43E-06 0.0001 0.0001 0.0001 Orbital Debris Flux 1.58E-03 2.29E-04 1.28E-04 Orb. Deb. Dia. (ca) 0.0880 0.1896 0.2389 given mass & greater per a^2 surface - year) Probability of no impacts on Station (8 of inpacts of

2.04E-05 1.07E-05 6.82E-06 1.44E-05 5.33E-04 1.74E-04 1.74E-04 1.22E-04 8.92E-07 6.82E-01 5.43E-07 4.42E-07 3.14E-07 3.14E-07 2.32E-07 1.73E-07 3.43E-06

increeental Orbital 1.33E-03 1.01E-04 5.64E-05 Debris Flux

1.5 1.)

1:1

1.3

1.2

1.1

-

0.9

0.8

0.7

0.6

0.5

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0.3

0.2

0.1

0.08

0.06

0.04

0.02

0.01

Frojectile Mass (g) 0.001

Orbital Debris Parameters

0.05 0.05 0.05 0.15 0.15 0.15 0.15 1.13 1.13 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.13 1.14 1.14 1.14 1.14 1.14 1.14 1.14 1.14 1.14 1.14 1.14 1.144 1.146 1.149<	(= 0.01 g, 0.005 for 0.01 € proj. mass € 0.02, 0.01 g	(p age for 0.02 (proj.	ass (0.1g, #	nd 0.05 g wh	en proj. es	is >= 0.1 g	per =^2 -)	ear)				
1,041 3.135 2.148 5,040 1,027 0,464 0,416 0,316 1,316 <th< th=""><th>0.05 0.07 0.09 0.15</th><th>0.25 0.35</th><th>0.45 0.</th><th>55 0.65</th><th>0.75</th><th>(.85</th><th>0.95 1.6</th><th>5 1.15</th><th>1.25</th><th>1.35</th><th>1.45</th><th>1.5</th></th<>	0.05 0.07 0.09 0.15	0.25 0.35	0.45 0.	55 0.65	0.75	(.85	0.95 1.6	5 1.15	1.25	1.35	1.45	1.5
0 0.514 0.412 0.412 0.414 1.1518 1.286 1.286 1.156 1.786 1.	7.061 3.735 2.336 5.000	1.827 0.966	0.664 0.4	16 0.305	0.234	0.186 (.152 0.1	16 v. 107	0.691	0.019	0.057 1	511.
1 0.534 0.410 0.735 0.410 0.735 0.410 1.151 1.200 1.316 1.300 1.301 1.302 1.301 1.301 1.302 1.301 1.301 1.302 1.301 1.301 1.302 1.301 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.401 1.4												. and .
(5) LARE-16 LARE-16 LARE-16 LARE-10	43 0.5346 0.6120 0.6736 0.7256	0.9142 1.0464	1.1518 1.24	107 1.3184	1.3880	1.4511 1.	5092 1.56	32 1.6136	1.6611	1.7060	1. /48/ 1.	1.81
27.11 20.6413 38.6711 59.4712 79.1631 92.3861 44.236 55.2141 59.4141 94.4661 97.2051 97.4611 97.1711 77.7001 96.40 cb 2.587-64 1.206-64 6.481-67 1.716-07 1.487-69 1.487-69 1.477-691 1.497-69 1.491-97 1.81-97 1.491 8.126 0.125 0.135 0.45 0.55 0.45 0.55 0.45 0.55 1.45	c5 6.68E-06 4.08E-06 2.88E-06 2.20E-06 9.	1,48E-07 5,80E-07	4.09E-07 3.12E-	-07 2.50E-07	2.07E-07 1.	76E-07 1.5	K-07 1.35E-	07 1.20E-07	1.08E-07). 79E - (18 8.	94E-08 B.2	80-35
E-0 2.59E-06 [1.20E-06 1.05E-06 1.05E-06 1.01E-07 1.11E-07 1.06E-06 0.19E-06 0.19E-06 1.20E-06 1.00E-06 0.40E-06 0.40E-07 1.11E-07 1.18E-07 0.128E-07 0.128E-07 0.121E-07 1.18E-07 0.128E-07 0.128E-07 0.121E-07 1.18E-07 0.128E-07 0.128E-07 0.128E-07 0.128E-07 0.128E-07 0.128E-07 0.121E-07 1.18E-07 0.128E-07 0.128E-05 0.148E-05 0.128E-05 0.148E-05 0.128E-05 0.148E-05 0.128E-05 0.148E-05 0.148E-05 0.148E-05 0.128E-05 0.148E-05 0.128E-05 0.128E-05 0.148E-05 0.128E-05 0.148E-05 0.128E-05 0.148E-05 0.128E-05 0.128E-05 0.128E-05 0.148E-05 0.128E-05 0.148E-05 0.128E-05 0.148E-05 0.128E-05 0.128E-05 0.128E-05 0.128E-05 0.128E-05 0.128E-05 0.128E-05 0.148E-05 0.128E-05 0.148E-05 0.128E-05 0.148E-05 0.128E-05 0.128E-05 0	.5711 20.6151 38.0731 50.6011 59.4721	79.9181 87.190	z 90.7833 92.1	8891 94.258	2 95.2147	95.9142 9	6, 4491 96.E	601 97.205	I 97.481I	97.7121	97.9062 91	8.0/51
1 1 0.005 for 0.01 (proj. mass (0.02, 0.01 g for 0.02 (proj. mass (0.19, mud 0.05 g minen proj. mass)= 0.1 g per m ²² - year) 0.03 0.05 0.01 0.05 0.01 0.05 0.15 1	E-06 2.59E-06 1.20E-06 6.83E-07 1.25E-06 3	3.686-07 1.716-07	9.696-08 6.196	-08 4.26E-08	3,106-08 2	35E-08 1.8	3E-08 1.47E	08 1.206-08	1 9.9BE-09	8.41E-09 7	186-09 8.2	3E-08
0.03 0.05 0.07 0.09 0.15 0.25 0.25 0.45 0.55 0.45 0.55 0.65 0.75 0.65 0.75 0.65 1.65 1.15 1.15 1.15 1.15 1.45 1. 2.082 0.613 0.204 0.102 0.293 0.087 0.040 0.0229 0.0146 0.0101 0.0013 0.0055 0.0043 0.0023 0.0024 0.0029 0.0017 0.017 0.017 0.011 0.142 7.7 0.16 13.66 2.111 38.51 53.7 20.49 1.15.54 130.75 146.35 141.76 177.16 122.57 201.97 233.38 231. 1,43 2.76 1.17 1.16 122.57 201.97 233.38 231. 1,43 2.76 1.17 1.5 1.25 13.07 11.5 12.77 20.197 233.38 231. 1,43 2.76 11.5 12.76 1.17 116 122.57 201.97 223.38 231. 1,43 2.76 1.17 5.62 10.00 17.113 23.73 30.39 36.50 42.37 47.35 146.35 141.76 177.16 177.16 177.16 177.5 15. 1,45 17.70 10.76 177 1.5 12.72 1.79 17.70 11.5 12.55 1.56 1.17 1.5 12.55 1.50 13.10 2.113 2.13 2.13 2.13 2.15 12.07 11.25 2.134 28.56 6.3.47 80.27 7.24 177.6 11.75 85. 145.55 1.55 1.55 1.55 1.55 1.55 1.55	01 g, 0.005 tor 0.01 < proj. mass < 0.02, 0.01 g	g far 0.02 (proj	. eass < 0.1g.	and 0.05 g w	hen proj. 🖷	ass)= 0.1	9 per a^2 -	year)				
1.082 0.613 0.284 0.112 0.295 0.087 0.001 0.0013 0.013 0.014 115.54 130.55 146.35 161.76 171.16 192.57 201.97 231.38 231.1 1.43 2.16 4.17 5.42 10.00 11.13 21.93 30.39 36.53 146.35 161.76 171.40 81.75 83.14 18.26 83.14 14.93 78 1.43 2.16 19.47 15.54 130.75 53.34 58.56 63.47 68.27 12.91 71.46 17.40 81.75 131.36 78 21.60 19.48 </td <td>0.03 0.05 0.07 0.09 0.15</td> <td>0.25 0.35</td> <td>0.45</td> <td>. 55 0. 65</td> <td>0.75</td> <td>0.85</td> <td>0.95 1</td> <td>05 1.15</td> <td>5 1.25</td> <td>1.35</td> <td>1.45</td> <td>1.5</td>	0.03 0.05 0.07 0.09 0.15	0.25 0.35	0.45	. 55 0. 65	0.75	0.85	0.95 1	05 1.15	5 1.25	1.35	1.45	1.5
Composite Structures 4.62 7.70 10.78 13.66 23.11 38.51 53.92 49.32 84.73 100.14 115.54 130.95 146.35 141.76 177.16 192.57 207.97 233.38 231. 1.43 2.76 4.17 5.62 10.00 17.13 23.93 30.38 36.52 42.37 47.97 53.34 58.50 63.47 68.27 72.91 77.40 81.75 85. 5 of given average assonithin assormage. 27.60 19.48 15.58 13.12 50.00 31.30 23.13 18.36 15.20 12.94 11.25 9.92 8.66 8.00 7.27 6.66 6.14 4.83 9 acts over lifetime of station. Diet cover lifetime of station.	2.082 0.613 0.284 0.162 0.295	0.087 0.040	0.0229 0.0	146 0.0101	0.0073	0.0055	. 0043 0.0	0.0026	0.0024	Q. 0020	0.001/	c/10.0
4.62 7.70 10.78 13.66 23.11 38.51 53.92 69.73 100.14 115.54 130.75 144.35 161.76 177.16 192.57 207.97 233.38 231. 1.43 2.76 4.17 5.62 10.00 17.13 21.93 30.38 36.52 42.37 47.97 53.34 58.50 63.47 68.27 72.91 77.40 81.75 83. 5 of given average ass within ass range. 21.93 30.38 36.52 42.37 47.97 53.34 58.50 63.47 68.27 72.91 77.40 81.75 83. 21.60 19.48 15.58 13.12 50.00 31.30 23.13 18.36 12.94 11.25 9.92 48.00 7.27 6.66 6.14 4.83 9. 21.60 19.48 15.58 13.12 50.00 31.30 23.13 18.36 5.93 63.47 68.66 5.06 61.17 6.66 6.14 4.83 9 28 5.6 5.66 5.12 6.76 5.66 5.12 6	composite Structures											
4.62 7.70 10.78 15.66 23.11 38.51 53.92 69.73 100.14 115.54 130.95 146.35 161.76 177.16 172.91 77.97 20.79 83.47 1.43 2.76 4.17 5.62 10.00 17.13 21.93 30.38 36.52 42.37 47.97 53.34 58.50 63.47 68.27 72.91 77.40 81.75 83. 5 of given average ass within ass range. 2.760 13.13 21.93 30.38 36.52 42.37 47.97 51.34 58.50 63.47 68.27 72.91 77.40 81.75 83. 2 0 f given average ass within ass range. 23.18 16.520 12.94 11.25 9.92 63.47 68.27 72.91 77.40 81.75 9.8 27.60 19.48 15.58 15.12 50.00 31.30 15.20 12.94 11.25 9.92 9.96 5.366-05 1.246-05 1.416-05 1.416-05 1.416 78 9.18 5.06 5.566-05 2.366-05 1.246-05 1.416 78								:		70 TOC	81 100	10 116
1,43 2.76 4.17 5.62 10.00 17.13 23.93 30.39 36.52 42.37 47.97 53.34 58.50 63.47 68.27 72.91 77.40 81.73 83. 5 of given average ass within mass range. 27.60 19.48 15.58 13.12 50.00 31.30 23.13 18.36 15.20 12.94 11.25 9.92 8.86 8.00 7.27 6.66 6.14 4.83 9.8 acts over lifetime of statuon. 6.05 5.67E-05 4.55E-05 1.84E-04 9.14E-05 6.75E-05 5.36E-05 3.78E-05 2.90E-05 2.59E-05 2.13E-05 1.94E-05 1.79E-05 1.41E-05 2.88E	4.62 7.70 10.78 13.86 23.11	38.51 53.9.	2 69.32 8	1.73 100.1	115.54	130.95	146. 33	1.11 0/.	10.11			
77.60 19.48 15.58 13.12 50.00 31.30 23.13 18.36 15.20 12.94 11.25 9.92 8.86 8.00 7.27 6.66 5.14 4.83 9. acts over lifetime of station. bf-05 5.67E-05 4.55E-05 3.83E-05 1.46E-04 9.14E-05 6.75E-05 4.44E-05 3.78E-05 3.28E-05 2.90E-05 2.59E-05 2.12E-05 1.74E-05 1.74E-05 1.41E-05 2.88E	1.43 2.76 4.17 5.62 10.00 s of given average mass within mass range.	17.13 23.9	3 30.38 3	6.52 42.3	7 47.97	53.34	58.50	. 47 68.2	12.91	17.40	c/ 18	6. 5
6E-05 5.69E-05 4.55E-05 1.86E-05 1.46E-04 9.14E-05 6.75E-05 5.36E-05 4.44E-05 3.78E-05 3.28E-05 2.59E-05 2.59E-05 2.12E-05 1.79E-05 1.79E-05 1.79E-05 1.79E-05 1.79E-05 1.79E-05 1.79E-05 2.68E-05 2.68	27.60 19.48 15.58 13.12 50.00 acts over lifetime of station.	31.30 23.1	3 18.36 1	5.20 12.9	4 11.25	9.92	8.96	1.00 7.1	27 6.66	6.14	4.83	68.53
306 E NUELUNE IN 1 UNEL 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	E-05 5.67E-05 4.55E-05 3.83E-05 1.46E-04	9.14E-05 6.75E-0	15 3.36E-05 4.44	E-05 J. 78E-0	5 3.28E-05	2.90E-05 2.	59E-05 2.34	E-05 2.12E-(05 1.94E-05	1.79E-05	1.41E-05 2.	886-04

^f cr Inpacts from Meteoroids					7	Jage	0 n	г 4)											
Mass eigeta & spall 3.92 10.69 21.39 Fer reteoroid iepact (g)	35.65	19.91	64.17	106.95	178.25	249.55	320.84	1 392.14	463.44	534.74	606.01	677.34	748.64	Po 613	5				
Wber of ejecta & 1.15 4.13 9.19 spall particles of critical energy and preter per Japact from meteoroids of giver	15.83 average mass	22.19 #ithin =	28.26	44.88	68.60	88.86	106.65	122.56	136.99	150.21	162.42	173.76	184.35	194.23	203.66	212.52	279.91	1069.48 224.95	
Wutter of critical 149.10 19.92 15.12 Particles created from meteoroid in order	17.9	6.31	12.4	13.26	5.97	3.50 2.50	7.45	- 10	;										
Ketter of critical 6.30E-04 8.42E-05 3.08E-05 Prefigy particles per ± 2 - year.		tion. 2.67E-05	1.936-05	5.61E-05	2.53E-05	1.52E-05	1.036-05	7.58E-06	1.38 5.84E-06	1.10 1.445-04	0.90 1 815-04	0.75	0.64	U.55	0.48	0.42	0.38	4.38	
Flux of critical 1.04E-03 4.13E-04 3.29E-04 energy particles of critical energy and greater	2.485-04 froe meteoros	2.07E-04 1 imaets	1.806-04	1.61E-04	1.05E-04	7. 95E -05	6.446-05	5.40E-05 4	1.64E-05	1.066-05	J. 60E-05	3. 215-05	2./1E-06 2 GDE-05	2. 33E-06	2.03E-06	1.79E-06	1.596-06	• 85E ~ 05	
Ejecta/Spall Flux 2.07E-03 1.47E-03 1.36E-03 from both Erbital Debris and Meteoroid Tapacts	1.22E-03	L. 14E-03	1.086-03	1.02E-03	J. 39E-04	7.30E-04	6.52E-04	5.916-04 5	.41E-04 5	. 00E-04	1.64E-04	1. 32E -01	1. D4E-04	2.79E-04	2. 59E-05	2.19E-05 3.35E-04	2.01E-05 5.16F-04 3	.856-05 016405	
lf Ejecta/Spail all from Gluminum Structures																			
For lipacts from Urbital Debris																			
Mass Precta & spail 0.02 0.35 0.88 Fer ispact .g ¹	1.59	2.29	3.60	5.11	8.64	12.17	15.70	19.23	22.76	26.28	29.81	11.14	10 71		:	:		-	
Muster of ejecta 4 0.21 3.32 6.36 Steil Berticles of reiteral communi	9.28	11.55	13.46	17.87	23.01	26.79	71 00	10 ST	;				19.0%	01-01	26.34	47.45	50.98	52.75	
and greater per lapact from projectile's of given	åverage mass	within m	iss range.				8	2.50	34.36	36.21	37.84	39.31	40.64	41.85	42.97	44.00	44.95	45.40	
Murter of critical 23.19 22.01 28.95 Particles created from impacts over lifetiae of s	15.42 tation.	10.16	7.40	21.03	9.89	6.09	4.23	3.16	2.47	2.00	1.66	1.40	1.21	50.1		r c	:		
Wutter of critical 6.77E-05 7.89E-05 8.45E-05 €nergy particles per m°2 - year.	4.50E-05 2.	97E-05 2.	16E-05 6.	14E-05 2.	39E-05 1.	78E-05 1.	24E-05 9.	22E-06 7.2	1E-06 5.6	33E-06 4.	84E - 06 4.	1 10-360	5.36-04 2		74.7	78.0	0.63	12.56	
Flux of critical 5.29E-04 4.61E-04 3.83E-04 energy particles of critical energy and greater	2.98E-04 2.9	i3E-04 2.	23E-04 2.1	02E-04 1.	IOE-04 1.1	12E-04 9.	37E-05 8.1	14E-05 7.2	2E-05 6.4	96-05 5.9	11E-05 5.	13E-05 5.(22E-05 4.4	005-700 2. 57E-05 4.3	/UE - US 2. 36E - OS 4. (40E-06 1.1 09E-05 3.1	83E-06 3.6 95E-05 3.6	7E-05 7E-05	
^f cr lepacts fro r Meteoroids																		2	
Mass electa & spall 0.23 0.93 2.04 Per seterroid irpact (g)	3.52	4.99	6.47	10.90	18. 29	25.67	33.06	40.45	17.83	55.22	62.60	69.99	BC.17	R4 7.6	15		1		
Muster of ejecta 3 2,38 6.60 10,79 Sfall Firticles of critical energy and master or occord	14.68	17.65	20.07	25.53	31.62	16.21	39.20	41.87 4	4.10	16.01	89.(1	9.15	50.46	51.64		- •C··Li		0.61	
and determine the set of de the set of de the set of th	rage mass with	in mass i	r ange.													13.61	C 4C.40	5.01	

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Table 6-2, Continued (page 3 of 4) Table 6-2, Continued (page 4 of 4)

1.07 0.09 0.11 0.12 0.15 0.18 0.21 0.26 0.34 0.44 0.61 0.90 2.75 1.45 7.54 3.24 Wumber of critical 309.61 31.85 22.46 9.01 5.02 particles created from meteoroid impacts over lifetime of station.

3.81E-05 2.12E-05 1.37E-05 1.19E-05 1.16E-05 4.13E-06 3.80E-06 1.88E-06 1.43E-06 1.12E-06 9.01E-07 7.41E-07 6.20E-07 5.26E-07 4.53E-07 4.53E-06 Mumber of critical 1.316-03 1.356-04 9.496-05 energy particles per m°2 - year.

Flux of critical 1.68E-03 3.71E-04 1.42E-04 1.04E-04 B.24E-05 8.84E-05 3.67E-05 1.90E-05 1.52E-05 1.26E-05 1.07E-05 9.28E-06 B.16E-06 5.26E-06 6.51E-06 5.37E-06 4.92E-06 4.53E-06 4.53E-06 e.55E-06 4.55E-06 4.55E-06 e.55E-06 4.55E-06 e.55E-06 e.5

3.946-04 3.256-04 2.806-04 2.496-04 1.296-04 1.076-04 9.196-05 8.086-05 7.236-05 6.556-05 5.496-05 5.126-05 4.776-05 4.466-05 4.196-05 3.986-05 Ejecta/Spall Flux 1.69E-03 7.18E-04 5.44E-04 from both Orbital Debris and Meteoroid Impacts

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6.2.2 Model Assumptions and Approximations

The worksheet model included a number of assumptions/approximations which are explained below. The specific model applications described in Section 6.3 were all determined using these assumptions.

- a) The model includes both ejecta and spall in the mass and number of secondary particles produced from primary impacts. Because some of the spall produced in an impact might be contained and prevented from further impacts on other surfaces, this assumption contributes to increasing the estimate of potential damage from secondary impacts. The location of the specific sensitive area relative to the rest of the station will determine if it is subject to secondary ejecta, spall, or both. When using the tables generated, this can be taken into account by choice of SF.
- b) The user must supply a "critical energy" that will result in damage to a surface of interest. There may be more appropriate parameters than kinetic energy to scale on.
- c) The flux of ejecta/spall particles having the critical energy and above is determined using empirical equations developed in this study. These equations are necessarily extrapolated beyond the bounds of the tests run in this study (due to the tremendous velocities of meteoroids/debris which we are trying to model) which implies that an unknown amount of uncertainity is introduced into the calculation.
- It was assumed that aluminum vaporizes with projectile d) velocities above 7 km/sec (Ref.2, p.489--the user can easily change this variable) and above this velocity, impacts on aluminum structures will not produce any damaging ejecta/spall particles (only vapor or very small particles which would be a problem to structures only a relatively few inches away from This limit acts to reduce the total the impact point). (secondary producing) flux of orbital debris on aluminum to about a quarter of its original. This 25% factor is calculated within the model from the orbital debris velocity distribution (Ref. 14) and is equal to the orbital debris fraction with velocities less than 7 km/sec. This limit also reduces the average orbital debris velocity that will produce any damaging ejecta/spall from the actual average (9.3 km/sec) to the average below 7 km/sec (or approximately 4.2 km/sec). This assumption also nearly eliminates meteoroids as a source of damaging ejecta/spall on aluminum structures because of the high relative meteoroid velocities.

Because no information was available on meteoroid velocity distributions when this part of the study was developed, the meteoroid relative velocity for aluminum structures was taken as the assumed aluminum vaporization velocity, ie. 7 km/sec. No corresponding vaporization velocity is assumed for graphite/epoxy targets, pushing the aluminum-graphite/epoxy comparison toward aluminum's favor.

- e) The slopes of the mass distribution curves (Section 5.2) are assumed to not change significantly at higher impact velocities. From reported results of fragmentation distributions due to different energy explosions (Ref. 18), this is probably not quite true (higher energy impacts may produce relatively more small particles and less large particles).
- f) The Space Station nominal altitude was assumed at 500 km (270 nm). Recently, the baseline <u>operating</u> altitude was reduced to 463 km (250 nm) to lower launch costs (Ref. 19). This change will result in somewhat reduced orbital debris flux.
- g) Self-shielding of various Space Station elements is not considered--the entire Space Station surface area is assumed exposed to orbital debris/meteoroid damage.
- h) The program under-estimates the secondaries damage potential at very low critical energies because the lower projectile mass limit in the secondaries flux integration (presently set at 0.001 g) is not low enough.
- i) It is assumed that if ejecta or spall particles hit the sensitive surface, they will do so immediately after being produced. No attempt is made to calculate through orbital mechanics whether any secondary collisions are possible several orbits after the primary impact event.

Figure 6-4



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Figure 6-6



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6.3 Application of Model to Cases of Interest

The damage assessment model was applied to several common cases for Space Station operations: a habitat module window, a window of a docked Shuttle, a habitat module wall, and solar panels. Refer to Figure 6-8 for a current International Space Station (ISS) configuration (Ref.17, p.82) that can be used to visualize general geometry and view factors.





6.3.1 Module Window

The module window design discussed in this section was taken from a NASA white paper (Ref. 22). Current window/viewing requirements are under review (Ref. 25) but the window damage assessment technique discussed here could certainly be applied to new window designs. Primary and secondary fluxes are calculated for one of four windows in a module; each window being 16 inches in diameter, double pane, with a 1 inch thick pane of fused silica glass.

Several impacts on previous space station (Skylab, Salyut) windows have been recorded (Ref.23,24). For instance a Soviet Salyut 7 space station window was struck on July 27, 1983 causing a loud crack heard by the two-man cosmonaut crew. The Soviets characterized the impact as "an unpleasant surprise," although the 0.15 in. diameter crater on the window did not threaten the pressure integrity of the pane (Ref.24, p.125).

6.3.1.1 Critical Bnergy Calculation

The critical energy calculation given in Table 6-3 utilizes a penetration equation developed for Apollo windows and a criterion to prevent spallation (Ref.26). The penetration equation related crater depth, P (cm), to projectile density, p (g/cc), projectile diameter, D (cm), and to projectile velocity, V (km/sec).

 $P = 0.53 \pm p0.5 \pm p1.06 \pm v0.67$

The no-spall criterion related the minimum window thickness to prevent spallation, t (cm), to the crater depth.

t = 7 * P

From the penetration equation and failure criterion, the window pane thickness of 1 in., and known orbital debris/meteoroid density and velocity, the critical size and energy of the projectiles was calculated as given in Table 6-3. From the fluxes of orbital debris and meteoroids having this critical size and greater (equations given in Section 6.1.1 and 6.1.2), the weighted average critical energy for failure of a 1 inch thick glass pane was calculated as approximately 100 joules.

6.3.1.2 Discussion

Table 6-4 is the output of the one module window damage assessment program. The window critical energy of 100 J and surface area of 0.13 m² has been entered. A SAF factor of 25% was calculated/estimated and a VF of only 10% was estimated because the module window for this analysis was oriented facing away from the other modules (facing mainly truss, radiators and solar arrays). With these factors a very low SF of 0.025 was



McDonnell Douglas

Honeywell

IBM

Lockheed

RCA

Table 6-3, Window Worksheet

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Spacecraft Window Critical Energy Determination

Glass Thickness (cm) (outer of two panes)	2.54	
Particle Density (g/cc) Particle Velocity (km/s)	Meteoroid 0.5 20	Debris 2.8 9.3
Particle Critical Diameter (cm) to avoid spall on silica glass p	0.1460 Danes (from	0.1051 Cour-Palais)
Particle Mass (g) Particle Energy (J)	8.15E-04 163.03	1.70E-03 73.65
Particle Flux (#/m^2-yr) with critical diameter and great	5.19E-04 ter	1.01E-03
Percent Flux	33.87	66.13

Average Critical Energy (J) 103.92 above which results in spalling of the first glass pane from Meteoroid & Orbital Debris Impacts calculated. The important output is within the highlighted block on the first page of the table. Given the low SF, ejecta/spall adds only 2-3% to the total critical energy flux expected on the window. The design factor for compensating the primary flux would be 1.03 in this case.

However, viewing requirements may require that some of the pressurized volume viewing ports have unrestricted views of a large part of the station. For instance, some recent designs call for a 5-window-sided workstation cupola positioned at a Space Station node hatch (Ref.25, pp.2B-25,2B-39,2B-40) which would be designed for good station viewing (Figure 6-9 and 6-10). If the VF went as high as 50% and SAF decreases to 20% (the SAF decreases as VF goes up because less of the total station is seen by the sensitive surface), the SF would be 0.1. From Figure 6-11, a 10% SF would increase the ejecta/spall fraction of the total critical energy flux on the cupola windows to about 0.09. Thus, a design factor of 1.1 should be applied to the primary flux on the cupolas to compensate for the secondaries flux.

		1.35 1.45 1.5 ·	0.079 0.059 1.175		1.7060 1.7487 1.7894	.79E -08 8.94E -08 8.23E -08	97.712X 97.906L 98.073X	.41E-09 7.18E-09 8.23E-08		1.35 1.45 1.5	0.0020 0.0017 0.0195			207.97 223.36 231.08	28. 87 93. 69 96. 04	7.05 5.54 112.87		1.66E-04 3.46E-04 3.30E-04
		1.25	160.0		1.6611	I. 08E -07 9.	97.4812	8 60-386-6		1.25	0.0024			192.57	83.6 8	7.66	2.24E-05 2	3.89E-04 3
	2	1.15	0.107		1.6136	1.206-07	97.2051	1.206-08	Ĺ,	1.15	0.0028			177.16	78.72	8.39	2.45E-05	4.13E-04
	a^2 - yea	1.05	0.126		1.5632	1.356-07	I 96.8681	1.47E-00	a* - 5*e	1.05	0.0035			161.74	0 73.36	9.24	; 2.70E-05	4,405-04
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	,	0.65	0.196		1.4511	1,746-07	II 95.914	1 2.35E-08	NIS Y	6.85	5 0.005A			1 130.95	4 62.00	2 11.54	5 3.376-04	4 5. 04E-04
	ihen proj.	0.75	5 0.234		4 1.3880	7 2.07E-07	BI 95.214	8 3.106-01	when proj.	5 0.7	1 0.007			4 115.5	53.9	5 13.1	15 3. B3E-0)4 5.42E-0
nued	d 0.05 g 1	5 0.65	6 0.30		1 1.318	17 2,50E-0	191 94. 25	8 4.26E-0	4 0.02 A	5 0.6	16 0.010			73 100.1	1.9.4	87 15.1	05 4.42E-0	04 5.86E-C
Conti of 4)	(- , -) (0.1g, an	15 0.5	04 0.41		18 1.240	0) 3.12E-0	831 92.86	08 6.195-((0.19, ar	4 5 0.1	29 0.01			32 84.	4 2.	.n n.	-05 5.2ZE-	-04 6.39E-
-4, e2,) in ass	35 0.	766 Q.6		1.15	-07 4. 09E-	190X 90.7	-07 9.69E-	roj. nass	. 35 0.	040 0.02			.92 69.	.48 35.	.53 21	-05 6,34E	-04 7.02E
le 6 (pag	0.02 (pr	.25 0.	827 0.9	•	142 1.01	-07 5.806-	9181 87.1	-07 1.71E	0.02 (pi	. 25 0	087 0.			1.51 53	0*28	7. 27	E-04 8.04E	E-04 7.82E
Tab	0.01 g for	0.15 0	000 1.		7256 0.9	E-06 9,48E	.4721 79.	E-06 3,68E	0.01 g for	0.15 (.295 0.			3.11 3	2.17 2	0.86 3	E-04 1.10	re-03 8.92
	1 (0.0 2, (0.0 9	1.336 5		.6736 0.	¥E-06 2.20	0.6011 59	3E-07 1.25	s < 0.02,	0.09	0.162 0			13.86 2	e. 93 1 Se. ange.	16.19	3E-05 1.71	2E-03 1.0) ts
	proj. Asl	0.07	3.735		.6120 0.	18E-06 2.BI	1 9.0731 54	20E-06 6.8	proj. nas	0.07	0.284			10.78	5.18 s within e	19.35 station.	65E-05 4.7	176-03 1.1 bris impac
	.005 for 0.01 (0.05	7.061		0.5346 (6,68E-06 4.(20.6151	2.596-06 1.).005 for 0.01 (0.05	0.613	ite Structures		7.70	3.46 iven average nas	24.42 ver lifetime of	7.13E-05 5.	1.24E-03 1. from orbital de
	0.01 9, 0	0.03	19.326		0.4243	1. 55E - 05	2.5712	8.805-04	0.01 9, 0	0.03	2.082	te Conposi		4.62	1.81 Óris of yì	35.06 impacts pr	1.02E-04	1.35E-03 d greater
	1855 . 8856 (=	0.015	34.594		0.3368	3.59E-05	1 0.021X	2.04E-05	nass j. nass (=	0.015	4.826	bon-Graphi	ris	2.31	0.71 mergy orbital de	24.61 al debris	7.19E-05 ear.	1.42E-03 energy an
	ven avg. A When proj	0.0055 calcs.	463.821		0.1563	5.86E-04 r ear)	0.0001	5.50E-04	ven avg. I	0.0055 calcs.	130.100	froe Carl	bital Debi	i 0.85 impact (gl	0.16 critical (lact from (75.17 iron orbit:	2.19E-04 ir =^2 - yi	1.64E-03 F critical
	(8 of impacts of gi plus or minus 0.004	Average Debris Mass (g) for incremental	Number of Impacts from Orbital Debris	Neteoroid Parameter:	Neteoroid Dia. (ca)	Meteoroid Flux 18 of impacts of given eass & greate per a^2 surface - y	Probability of no impacts on Station	Incremental Met.	lt of impacts of gi plus or minus 0.004	Average Net. Nass (g) for incremental	Nucher of lepacts from Meteoroids	lf Ejecta/Spall atl	For lepacts from Or	Mass ejecta & spall per orbital debris	Muober of ejecta 4 spall particles of and greater per imp	Mumber of critical particles created f	Number of critical energy particles pe	Flux of critical energy particles of
										210								

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Table 6-4, Critical Energy Calculation for Module Windows

(page 1 of 4)

Flux of Ejecta/Spall Particles of Critical Energy and Greater on a Sensitive Area of Space Station

Surface Area of Station (m^2) &	1416.1	Fraction of facing sensi	surface area of Station itive area	0.25	,	tarth's radius Station orbital	(ke) altitude (km)	6378.145 500
Orbital Life (yrs)	8	Fraction of area (hemis	sty covered by Station . pherical View Factor)	is seen from sens. 0.1	jîtive	Aititude in Ear Earth defocusin Earth shielding	th radii Ag factor I factor	1.078392 0.968596 0.713070
Critical Energy to damage sensitive surface (Joules)	100	Fraction of Spall striki (Station SA	Station Ejecta & ing the sensitive area fraction # view factor)	. 025		Percent of total impacts	Percent of total impacts	
Surface Area of crítical surface (a^2)	0.13	Particle	Flux with critical ener and greater on sens. a (Number impacts/m²-yr)	gy Number of ea area with greater on	impacts on sensitive critical energy and wer Station lifetime	on sensitive area if S/S ej. k sp. all G/E	om sensitive area if S/S ej. & sp. all Alusinee	Probability of no impact on sens. area with critical energy & greater (percent)
)rb. Debris Average Jelocity (ta/car)	1.0	Neteoroids	1.36E-03	0.4	005296	61.621	62.061	99.631
	, I , I	Orb. Debris	7.836-04	0.1	003051	35.501	35.751	101 °66
(g/cc)	B.7	Ejecta/Spall (if S/S all	l 6.33E-05 graphite/epoxy)	0.0	000246	2.872		186°66
feteoroid Average felocity (ka/sec)	20	Ejecta/Spall	4.795-05	0.0	000186		2.192	X86°66
leteoroid Density 1g/ccl	0.5	11f S/S 411	al uai nue)					
elocity above which l targets vaporize ka/secl	2	Average Grap Average Alum Orbita] Debr	bhite-Epoxy Ejecta/Spall uimue Ejecta/Spall veloci is Fraction below vapori	velocity (ka/sec) ty (ka/sec) zation velocity	1 0.5 4.232 0.235359			

Orbital Debris Parameters

0.0001 0.0001 0.0001 0.0012 0.1781 1.1081 2.9141 5.3321 8.0851 10.9741 13.8731 16.7101 19.4452 22.0561 24.5351 26.8827 29.1001 30.8731 1.0077 7.14E-05 5.00E-05 3.31E-05 1.31E-05 1.31E-05 1.03E-05 8.56E-06 7.34E-06 4.45E-06 5.77E-06 5.22E-06 4.76E-06 4.41E-06 4.10E-06 3.40E-04 3.40E-06 3.43E-06 0.3010 0.3446 0.3743 0.4086 0.5148 0.5893 0.6486 0.6987 0.7424 0.7816 0.8172 0.8499 0.8803 0.9087 0.9354 0.9607 0.9847 0.0002 0.0001 0.0001 Orbital Debris Flux 1.586-03 2.296-04 1.286-04 Orb. Deb. Dia. (cm) 0.0880 0.1896 0.2389 per e^2 surface - year) given mass & greater Prebability of no impacts on Station (* of ispacts of

2.06E-05 1.07E-05 6.82E-06 1.46E-05 5.33E-06 2.82E-06 1.76E-06 8.92E-07 6.85E-07 5.43E-07 4.42E-07 3.68E-07 3.11E-07 2.67E-07 1.73E-07 1.43E-06

Incremental Orbital 1.35E-03 1.01E-04 5.64E-05 Debris Flux

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Mumber of critical 1.51E-03 1.52E-04 1.00E-04 4.20E-05 2.33E-05 1.35E-05 1.25E-05 4.03E-04 4.03E-04 1.98E-04 1.50E-04 1.18E-04 9.45E-07 7.74E-07 4.48E-07 4.71E-07 4.71E-04 4.71E-04 4.03E-04 4.03E-04 4.03E-04 4.03E-04 4.03E-04 4.71E-04 4.71E-04 4.03E-04 4.03E-04 4.04E-04 4.65E-07 7.74E-07 4.48E-07 4.71E-07 4.71E-04

1.54E-04 1.12E-04 8.84E-05 7.34E-05 3.90E-05 2.65E-05 1.99E-05 1.59E-05 1.12E-05 9.68E-06 8.50E-06 7.56E-06 6.14E-06 5.59E-06 5.12E-06 4.71E-06 Flux of critical 1.926-03 4.116-04 2.596-04 1.546-04 1.126-04 8. energy particles of critical unergy and greater from meteoroid impacts

4.30E-04 3.51E-04 3.02E-04 1.77E-04 1.37E-04 1.13E-04 9.72E-05 8.54E-05 7.63E-05 6.91E-05 6.31E-05 5.81E-05 5.39E-05 5.02E-05 4.69E-05 4.19E-05 4.19F-05 Ejecta/Spall Flux 1.92E-03 7.94E-04 5.99E-04 from both Orbital Debris and Meteoroid Impacts

	1069.48	247.27	4.81	. 03E -05	.03E-05	.44E-04			52.75	47.82	13.23	865-05	99E - 05		10.61	57.23
	1033.83	243.05	0.41	.75E-06 2	.21E-05 2	616-04 3			50.98	47.37	0.66	72E-04 3.I	5E-95 J.I		06.92	54.82
	962.53	234.25	0.47	.97E-06 1	41E-05 2	83E-04 3.			47.45	46.42	0.87	536-06 1.	31E-05 4.(99.54	55.96
	891.24	224.95	0.53	.24E-06 1	. 63E-05 2	.07E-04 J.			43.92	45.39	86.0	85E-06 2.1	59E-05 4.:		92.15	55.01
	819.94	215.08	0.61	.586-06 2	.89£-05 2,	.33E-04 4.			40.40	44.28	1.11	24E-06 2.1	72E-05 4.		84.76	53.96
	748.64	204.57	0.71	.00E-06 2	.19E-05 2	.62E-04 4			36.87	43.06	1.29	73E-06 3.	79E-05 4.1		77.38	52. BI
	677.34	193.33	0.84	.55E-06 3	.546-05 3	, 95E-04 4.			33.34	41.72	1.49	35E-06 3.	72E-05 5.2		66.99	51.52
	606.04	181.25	1.01	.26E-06 3	. 97E-05 3	.31E-04 4			29.81	40.24	1.76	156-06 4.:	24E-05 5.1		42.60	50.07
	534.74	168.19	1.23	. 21E-06 4	. 49E-05 3	.73E-04 S.			26.28	38.5 8	2.13	22E-06 5.	86E-05 6.3		55.22	4 8 . 43
nued)	463, 44	153.97	1.35	.56E-06 5	. 15E-05 4	.22E-04 5.			22.76	36.70	2.64	70E-06 4.	63E-05 6.I		47,83	46.53
onti of 4	392.14	138.37	2.03	1.56E-06 6	• 00E-05 5	9 10-308.			19.23	ы.ы	3.38	886-04 7,	62E-05 7.		40.45	44.30
e 4 3 0	320.84	121.04	2.78	. 17E-05 8	186-05 6	.52E-04 4		:	15.70	31.99	4.55	JJE-05 9.	95E-05 8.		33.06	41.61
e 6- (pag	249.55	101.53	4.10	• 73E-05 1	1, 91E-05 7	.44E-04 7		:	12.17	28.90	6.57	92E-05 1.	19E-04 9,		25.67	38.28
Tabl	178.25	79.09	6.89	2.91E-05 1	. 186-04 6	. 74E-04 B			B.64	24.98	10.74	146-05 1.	50E-04 I.		18.29	33.90
	106.95	52.44	15.50	.55E-05	. 84E-04	.20E-03 9			5.11	19.57	23.03	726-05 3.	17E-04 1.		10.90	27.41
	64.17	33.48 55 range.	5.41	2.29E-05 /	2.07E-04	.26E-03 1			3.00	i4.87 ass range.	8.17	39E-05 6.	41E-04 2.		6.47	21.90 r ange.
	49.91	26.47 within me	7.53 tion.	3.18E-05	2.386-04 2 1 impacts	I.34E-03 1			2.29	12.82 within m	127	.29E-05 2.	74E-04 2.		4.99	19.33 thin mass
	35.65	19.05 average mass	11.69 ifetiæe of sta	4.946-05	2.88E-04 ; from meteoraid	1.44E-03 1			1.59	10.36 N average mass	17.21 station.	5.03E-05 3.	3,24E-04 2,		3.52	l6.18 verage aass mi
	21.39	11.20 i of given	23.32 ts over 1	9.866-05	3.86E-04 Øreater	1.61E-03 Inpacts	tures		0.88	7.18 s of give	32.64 etime of	. 536 - 05	, 20E-04 greater		2.04	12.00 if given a
	10.69	5.13 nergy leteoroids	24.76 oid impac	J. 05E-04 ar.	4.91E-04 Prergy an	1.76E-03 Heteoroid	inue Struc		0.35	3.80 ergy ojectile'	30.93 over lif	. 03E-05 9	.10E-04 4. Hergy and		0.93	7.44 rgy eoraids a
t eor oi ds	3.92 t (g)	1.46 critical (act from a	190.27 'on atteor	8.04E-04 . #^2 - ye	1.30E-03 critical	2.53E-03 bris and l	froe Alum	ital Debri	9.02	0.26 ritical en :t from pr	27.95 • i apacts	1, 16E-05 9 #^2 - year	i, 92E-04 5. ritical e	oraids	0.23 (g)	2.74 itical ene t from met
for lepacts from Ne	Mass ejecta & spall per seteoroid impact	Wueber of ejecta å spall particles of c and greater per impa	Number of critical particles created fr	Number of critical energy particles per	Flux of critical energy particles of 1	Ejecta/Spall Flum from both Orbital De	If Ejecta/Spall all (For lepacts from Orbi	Nass ejecta & spall per ispact (g)	Number of ejecta & spall particles of cr and greater per impac	Number of critical particles created fro	Number of critical 8 energy particles per	Flux of critical 5 energy particles of c	for lepacts from Neter	Mass ejecta & spall per aeleoroid impact (Nueber of ejecta 4 spall particles of cri and greater per impact
									211							





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6.3.2 Orbiter Window with Orbiter Docked to Space Station

Figure 6-12 illustrates an orbiter docked to a Space Station module (Ref.25, 2B-39). The orbiter windows comprise three panes with the outer pane being 5/8 inch thick silica glass. The two underlying panes provide a primary and secondary cabin pressure integrity seal. Impact incidents involving the shuttle have happened before. In June 1983, a micrometeorite or debris particle struck Challenger's right-hand middle windshield (window no.5) during STS-7. The crater measured 0.0178 in. deep by 0.0892 in. diameter. Including flaws in the glass, the total damaged area was 0.2 in. wide. Although the pressure integrity of the pane was not compromised, the window was replaced due to fears the damage could expand to dangerous levels when subjected to aerodynamic and heating loads during a later launch or re-entry (Ref.24, p.125).

6.3.2.1 Critical Energy Calculation

The failure criterion and penetration equation for orbiter windows was taken from a study on solid rocket product impingement on shuttle surfaces (Ref.28). The penetration equation was very similar to Cour-Palais (described in Section 6.3.1.1). The crater diameter (with spall), D_c (cm), is related to the projectile diameter, D (cm), projectile density, p (g/cc), and projectile velocity, V (km/sec).

$$D_{c} = 2.1 + D + 0.5 + 0.6$$

Applying this equation with orbital debris/meteoroid average velocity and density parameters to the size crater that resulted in replacement of the STS-7 window, enabled the calculation of the approximate energy of the impacting object (which differs between orbital debris and meteoroids):

	<u>Dia. (cm)</u>	<u>Mass (g)</u>	<u>Energy (J)</u>
Meteoroids	0.0207	2.32E-6	0.465
Orbital Debris	0.0146	4.54E-6	0.196

The proposed failure criterion for orbiter windows (Ref.28, pp.3-16,6-15) was influenced by experimental evidence on the size of a flaw that would continue to spread after the impact event due to internal stress relief and thermal stress during entry. The failure criterion is in terms of the projectile diameter, D (cm), and velocity, V (km/sec). Above this value, an impacting projectile will have enough energy to make it necessary to replace the orbiter's window.

 $D * V^{0.67} >= 11$

Figure 6-11







As given in Table 6-5, this failure criterion results in a critical energy of 8.72E-7 joules which is too low for the model in its present state to accept without significantly underestimating the ejecta/spall effect (see Section 6.2.2, assumption h). Therefore, a critical energy equal to 0.2 joules was used in for this calculation.

6.3.2.2 Discussion

The orbiter window critical energy (0.2 J), surface area for one window (0.15 m^2) , and docking period (0.019 yrs or 7 days) were input into the model as given in Table 6-6. The SAF factor was estimated as only 10% (because the orbiter is so close to the Space Station when docked to a module) while the VF was 50% resulting in a SF of 0.05. At the low critical energy of the orbiter window, graphite/epoxy ejecta/spall particles having the critical energy and greater are more numerous than aluminum. However, the secondary flux in this case is less that a percent of the total critical energy flux, whether the secondary flux is graphite/epoxy or aluminum. Therefore, a flux design factor for hazard assessment studies on the orbiter windows while docked to the Space Station would be approximately 1.01. Figure 6-13 illustrates the dependence of the secondary fluxes on the SF factor. Table 6-6, Orbiter Window Damage Assessment Worksheet (page 1 of 4)

Surface Area of Station (a^2)	11416.1		Fraction of sur facing sensitive	face area of e area	Station	0.1			ш м «	larth's rad itation orb Ititude in	ius (ka) ital alti Earth rae	tude (ka) Lič	6378. 1.078	145 500 392				-
Orbital Life (yrs)	0.019178 (7 days	•	Fraction of sky area themispheri	covered by . ical View Fa	Station al ctor)	seen from 0.5	sensitive		נשישי	arth defoc arth shiel	using fact	j r	0.713	9650				
Critical Energy to daeage sensitive surface (Joules)	0.2	1	Fraction of Stal Spall striking ((Station SA frac	tion Ejecta the sensitiv ction + view	e area factor)	. 05				tercent of otal impac	ts to Be	rcent of tal impacts				1		
Surface Area of critical surface (m^2)	0.15	L	Particle Fli and (Mi	ux with crit d greater on umber impactu	ical ener sens. arı s/a^2-yr)	y Nuebi a area great	r of impac with criti er over St	ts on sens cal energy ation life		m sensici rea if S/G i. & sp. il 6/E		sensitive ea if S/S . E sp. Aluainue	Probi on se enery	bility of ms. area iy & greati	no impact with critic er (percent			
Orb. Debris Average	F	-	Neteoroids	2.55	E+00		0.007103			116.59		94.572		66	.511			
Velocity (Ka/Sec)			Orb. Bebris	1.45	E-01		0.000402			5.331		5.361		6	196.			
Orb. Debris Densit} (g/cc)	8		Ejecta/Spall (if S/S al] graj	2.07 phite/epoxy ¹	E-02		0.00057			0.761				8	166.			
C Neteoroid Average Velocity (ka/sec)	30		Ejecta/Spall (if S/S all alu	1.75 1.75	E-03		0.00004					0.061		[00]	.001			
Meteoroid Density (g/cc)	0.5	1														'1		
Velocity above whic Al targets vaporize (ka/sec)	~		Average Graphit Average Alusinu Orbital Debris I Orb. Debris Ave	e-Epoxy Ejec a Ejecta/Spa Fraction bel rage Vel. (k	ta/Spall - il velocit ow vaporis a/sec) bel	relocity (kr y (ka/sec) ation veloc on vaporiza	sec) aty tion veloc	0.5 4.232 0.235359 ity	t 837984									
Projectile Mass (g)	0.001 0.0	1 0.02	0.04	0.06	0.08	0.1 0.	2 0.3	0.4	0.5	0.6	0.7	0.8	0.9		L.1 L.	2 1.1	•	
Orbital Debris Para	neters																	
Orb. Deb. Dia. (ca)	0.0880 0.189	6 0.2389	0.3010	0.3446 0.	3793 0.4	086 0.51	IB 0.5893	0.6486	0.4987	0.7424	0.7816	0.8172 0.	8499 0.4	3803 0.9	067 0.935	1094-0 15	1 0.9847	1.007
Orbital Debris Flui 18 of impacts of given mass & greate	1.58E-03 2.29E-0 r	if 1.28E-04	7.14E-05 5	. 08E-05 3. 99	E-05 3.31	(-05 1.85 €-(1.31E-05	i 1.03E-05	8.56E-06 1	7,34E-06 6.	45E-06 5.	77E-06 5.2ï	12-06 4.78K	E-06 4.41E	-06 4.10E-0	04 3 .8 4E-01	5 3.40E-06	3.436-01

98.4481 98.8941 99.1301 99.2781 99.5741 99.7131 99.8131 99.8331 99.8391 99.8541 99.8841 99.8951 99.9031 99.9101 99.9161 99.9211 99.9251

1.54 >

Incremental Orbital 1.35E-03 1.01E-04 S.64E-05 1.09E-05 1.09E-05 8.82E-06 1.46E-05 S.13E-06 2.82E-06 1.74E-06 1.22E-06 8.92E-07 6.85E-07 S.43E-07 3.68E-07 3.68E-07 3.61E-07 2.67E-07 1.73E-07 3.43E-06 Debris Flux

70.7051 95.1151 97.2401

Frobability of no impacts on Station

Continued	of 4)
le 6-6,	(page 3
Tab	

for Impacts from Meteoroids

1033.83 1069.48 341.29 345.94 962.53 355.75 366.33 891.24 748.64 819.94 377.78 390.22 403.83 677.34 606.04 418.78 435.33 534.74 463.44 453.78 392.14 474.52 320. B4 497.99 524.66 249.55 178.25 554.57 106.95 584.49 64.17 593.01 49.91 35.45 21.39 10.49 3.92 per meteoroid impact (q) Mass ejecta & spall

Mueber of ejecta 4 327.01 461.67 537.69 575.21 588.94 593.01 spall particles of critical energy and greater per impact from meteoroids of given average mass within mass range.

0.00 0.0 0.00 **8**.8 0.0 °.8 0.00 0.8 8 0.00 0.0 8 0.00 0.01 0.01 0.03 0.11 0.06 0.11 Number of critical 27.20 1.42 0.72 0.23 0. Particles created from meteoroid impacts over lifetime of station.

1.49E-03 7.08E-04 4.05E-04 7.30E-04 2.04E-04 8.96E-05 4.83E-05 2.94E-05 1.33E-05 1.33E-05 9.83E-06 7.41E-06 5.73E-06 4.53E-06 3.64E-06 2.99E-06 2.48E-06 2.48E-06 2.81E-05 Mumber of critical 1.80E-01 9.42E-03 4.73E-03 energy particles per m^2 - year.

3.80E-03 2.31E-03 1.60E-03 1.20E-03 4.69E-04 2.65E-04 1.75E-04 9.76E-05 7.82E-05 6.47E-05 5.49E-05 4.17E-05 3.72E-05 3.34E-05 3.06E-05 2.81E-05 energy particles of critical energy and greater from meteoroid impacts 1.98E-01 1.80E-02 8.54E-03 Flux of critical

3.82E-02 2.85E-02 2.30E-02 1.94E-02 1.09E-02 7.47E-03 5.94E-03 4.86E-03 4.12E-03 3.59E-03 3.18E-03 2.46E-03 2.39E-03 2.22E-03 2.07E-03 1.94E-03 1.84E-03 Ejecta/Spall Flux 4.15E-01 9.37E-02 6.12E-02 from both Orbital Debris and Meteoroid Lapacts

If Ejecta/Spall all from Aluminum Structures

For Impacts from Orbital Bebri

52.75 45.61 0.01 1.84E-04 1.16E-04 2.41E-04 8.34E-05 4.21E-05 2.57E-05 1.67E-05 8.81E-05 8.87E-06 6.79E-06 5.38E-06 4.34E-06 3.60E-06 3.07E-04 2.54E-06 3.68E-05 1.15E-03 7.96E-04 6.10E-04 4.94E-04 2.53E-04 1.69E-04 1.27E-04 1.02E-04 8.51E-05 7.33E-05 6.44E-05 5.26E-05 4.79E-05 4.43E-05 4.13E-05 3.87E-05 3.68E-05 50.98 46.06 0.0 8 47.45 47.01 8. 8 43.92 48.03 8.0 40.40 49.14 0.00 36.87 50.33 8.0 ы.ы 51.64 **9**.0 53.07 <u>.</u>8 29.81 26.28 54.45 **0**.0 22.76 56.43 0.8 0 19.23 58.43 0.8 8 15.70 60.73 0.0 12.17 63.40 0.01 8.64 66.56 0.02 70.23 0.05 5.11 Mueber of ejecta & 24.22 62.42 69.98 72.30 72.62 72.28 spall particles of critical energy and greater per impact from projectile's of given average mass within mass range 3.00 0.03 2.29 0.0 0.08 3.51E-04 1.59 Number of critical 1.69 0.32 0.20 0. Particles created from impacts over lifetime of station. 0.88 Flex of critical 1.13E-02 3.56E-03 2.08E-03 energy particles of critical energy and greater Mumber of critical 7.72E-03 1.40E-03 9.29E-04 0.35 energy particles per m^2 - year. 0.02 Mass ejecta è spall per inpact (g)

For lepacts from Neteoroids

110.61 35.84 104.92 36.28 99.54 37.20 92.15 38.21 84.76 39.31 77.39 40.51 64.96 41.84 62.60 43.32 45.00 55.22 46.90 47.83 40.45 49.12 33.06 51.74 54.95 25.67 18.29 59.01 10.90 64.47 6.47 68.77 spall particles of critical energy and greater per impact from meteoroids of given average mass within mass range. 70.36 4.99 71.86 3.52 7.04 72.61 0.93 70.28 57.61 0.23 per meteoroid impact (g) Number of ejecta **b** Mass ejecta & spall

Orbiter Window Critical Energy Determination

0.9525 Glass Thickness (cm) (outer of three panes) Meteoroid Debris 0.5 2.8 Particle Density (g/cc) 9.3 Particle Velocity (km/s) 20 Particle Critical Diameter (cm) 0.00018729 0.000248 (from Ref.28 study) 1.72E-12 2.26E-11 Particle Mass (g) 3.44E-07 9.76E-07 Particle Energy (J) 8.22E+02 4.20E+03 Particle Flux (#/m^2-yr) with critical diameter and greater 16.38 83.62 Percent Flux

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Average Critical Energy (J) 8.72E-07 above which results in unacceptable damage to the first glass pane from Meteoroid & Orbital Debris Impacts

								Tabl(e 6-1 page	6, CC 2 of	ontin : 4)	ned									
(8 of impacts of 9 plus or minus 0.00	i ven avg. a 4 when proj	455 . 8258 (=	0.01 g, 0	1.005 for 0.0	ll { proj.	nass (0.	02, 0.01 9	for 0.02	(proj. i	nass (0.1	lg, and O.	05 g when	proj. maj	56)= 0.1	i per e ^r i	- year)					<u> </u>
Average Debris Mas (g) for incresenta	s 0.0055 I calcs.	0.015	0.03	0.05	0.07	0.09	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95	1.05	1.15	1.25	1.35	1.45	-:
Number of Impacts from Orbital Debri	0.297 5	0.022	0.012	0.005	0.002	0.001	0.003	0.001	0.001	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Neteoroid Paramete	5																				
Meteoroid Dia. (ca	0.1563	0.3368	0.4243	0.5346	0.6120	0.6736	0.7256	0.9142	1.0464	1.1518	1.2407	1.3184	1.3880	1.4511	1.5092	. 5632	. 6136	1.6611	1.7060	1.7487	1.7894
Meteoroid Flux (\$ of ispacts of given ass & great) per a^2 surface	5.86E-04 er year)	3.596-05	1.55€-05	6.6BE-06	4.086-06	2.88E-06	2.20E-06	2.48E-07 5	. 806-07 4	. 09E-07 3.	.12E-07 2.	50E-07 2.	07E-07 1.	76E-07 1.	53E-07 1.	ISE-07 1.2	:0E-07 1.(08E-07 9.	79E -08 B.	94E-08 8.	2.K-08
Probability of no impacts on Station	91.5221	792.459T	7667	1668°66	195.9381	1954-66	1196.99	99.9862	7199.991I	99.9941	99. 9 95I	1966-66	1/99.9971	1799.99	1866 - 64	19-9982 5	19.9982	1866.99	1666.96	7666-66	1669.94
Incremental Met. Flux (8 of impacts of 9 plus or minus 0,00	5.50E-04 iven avg. m f when proj	2.04E-05 ass . aass (=	8.806-06 0.01 . 0	2.59E-06 .005 for 0.0	1.20E-06 1 < proj.	6.83E-07	1.25E-06 : 02. 0.01 -	1.68E-07 1	.71E-07 9 (proj. 1).69E-08 6. Bass < 0.1	.19E-08 4.	26E-08 3. 05 a when	10E-08 2.	35E-08 1.1	B3E-08 1.4	7E-08 1.3	0E-08 9.9	98E - 09 B.	41E-09 7.	JBE -09 B.	23E-08
, Average Met. Mass (g) for incrementa	0.0055 caics.	0.015	0.03	0.05	0.07	0.09	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.65	0.95	1.05	1.15	1.75	1.35	1.45	1.5
Number of Impacts from Neteoroids	0.083	0.003	0.001	0.000	0.00	000-0	0.000	9.000	0.00	0.000	0.000	0.000	0.000	0.000	0.0000	0000 (. 0000	0.000	0.000	0.000	0.000
If Ejecta/Spall al.	l froe Carb	on-Graphi	te Coapasi	te Structure																	-
For lepacts from D	rbital Debr	is																			
Nass ejecta k spal per orbital debris	l 0.85 inpact (g)	2.31	4.62	7.70	10.78	13.86	23.11	38.51	53.92	69.32	84.73	100.14	115.54	130.95	146.35	1 11.76	17.16	192.57	207.97	223.30	231.08
Mubber of ejecta & spall particles of and greater per im	145.45 critical e pact from o	257.00 nergy rbital del	349.51 Dris of gi	419.15 ven average	462.71 nass withi	492.83 A 8455 Fa	544.54 Nge.	579.18	590.78	593. 16	591.15	586.84	581.28	575.06	64.49	591.78 2	35.04	28.32	541.76	515.30	532.12
Mumber of critical particles created	43.13 from orbita	5.68] debris	4.32 impacts ov	1.89 er lifeti se	1.10 of station		1.14	0.68	0.37	0.23	0.16	0.11	0.09	0.07	0.66	0.05	0.04	0.03	0.03	0.02	0.40
Mueber of critical energy particles p	1.97E-01 er m^2 - ye	2.60E-02 ar.	1.975-02	8.64E-03	5.05E-03	3.366-03	7.95E-03	5.096-03 1	.67E-03 1	. 05E-03 7.	. 186 - 04 5.	236-04 3.	986-04 3.	12E-04 2.	52E-04 2.1	7E-04 1.7	'3E-04 1.4	19E-04 1.	25E-04 9.	24E-05 1.	81E-03
Flux of critical energy particles o	2.78E-01 f critical	8.13E-02 energy an	5.53E-02 greater	3.56E-02 froe orbital	2.69E-02 debris im	2. 19E-02 pacts	1.85E-02	I. 06E-02 7	. 49E-03 5	i, 82E-03 4.	. <i>11</i> E-03 4.	05E-03 3.	53E-03 3.	13E-03 2.1	92E-03 2.1	17E-03 2.3	6E-03 2.1	196-03 2.	04E-03 1.	92E-03 1.	83E-03

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Al Ejecta & Spall 120 -© Graphite/Epoxly **Orbital Debris** - Meteoroids * Auminum Primary and Secondary Particle Fluxes 100 х % of S/S Ej+Sp Flux Striking Sens. Area G/E Ejecta & Spall 80 vs % S/S crit energy ej/sp flux on area 60 Figure 6-13 0.2 Critical Energy (J) = 4 ٥ 20 0 T -0.5 --1.5 -3.5 0.5 . 2 -2.5 m 1 0 ī

Log Flux (number of impacts/m² – yr)

1×63

00 0.00 0.00 0.00 0.00	07 4.72E-07 3.81E-07 3.13E-07 2.60E-07 2.95E-06	04 4.37E-04 3.90E-06 3.52E-06 3.21E-06 2.9 5E -06	05 5.09E-05 4.70E-05 4.17E-05 4.09E-05 3.89E-05		
0.00	67E-07 5.95E	74E-06 4.97E	I&E-05 5.57E		
0.00	.02E-06 7.1	. 75E-06 5.7	.91E-05 4.1		
0.00	1.40E-06 1	8.15E-06 é	7.806-05 6		
0 0.00	16 2.00E-06	5 1.016-05	4 9.21E-05		
Of 4 .0 0.0	-06 3.04E-0	-05 1.32E-0	-04 1.11E-0		
age 4 0.00	BE-06 5.02E	KE-05 1.82E	1, 40E		
(pa 0.0	.17E-05 9.3	93E-05 2.71	876-04 1.86		
0.01	8.05E-05 2.	1.30E-04 4.	5.84E-04 2.		
1 0.01	5 4,70E-05	4 1.77E-04 ts	4 7.32E-04		
)3 0.0 station.)4 B,46E-0.	14 2.61E-0. roid impact	13 9.77E-0.		
0.(ifeti ne of	I.86E-1	4.40E-(from meteo	1.46E-6		
4.79 0.22 0.10 Maeteoroid impacts over 1:	3.17E-02 1.43E-03 6.39E-04 ∎^2 - year.	3.42E-02 2.52E-03 1.09E-03 tritical energy and greater	3.49E-02 5.30E-03 2.83E-03 Iris and Neteoroid Japacts		
Mumber of critical particles created fro	Number of critical tenergy particles per	Flwx of critical 1 energy particles of c	Ejecta/Spall Flux 3 from both Orbital Deb		
					22

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Table 6-7, Habitat Module Wall Damage Assessment Worksheet

4) (page l of

C4.41. 5 .

Surface Area of Station 1m^2)	1416.1		Fraction of facing sensi	surface area tive area	of Station	0.5				Earth's rad Station orb Attitude in	lius (ke) nital alti(serth car	tude (ka) tii	6378.14 50 1.07835	10 Q N				
Orbital Life (yrs)	92		Fraction of area (hemisp	sty covered l herical View	y Station a Factor)	s seen fr 0.1	oe sensitiv	•		Earth defoc Earth shiel	cusing fact	5 5	0.9685					
Critical Energy to damage sensitive surface (Joules)	63400		Fraction of Spall striki (Station SA	Station Eject ng the sensit fraction & vi	ta t live area len factor)	0.05				Percent of total ispa	ts to B	rcent of tal impacts				1		
Surface Area of critical surface (a^2)	350		Particle	Flux with C and greater (Number imp	ritical emer on sens. ar ncts/m^2-yr)	53 2 2 2	uber of ing ea with cri eater over	lacts on se itical ener Station li	nsitive gy and fetime	on sensiti area if S// ej. k sp. all S/E		ea if S/S . t sp. . Aluainum	Probabi on seni energy	lity.of no 1. area with 8 greater (impact h critical (percent)			
orb. Debris Average			Neteoroids	5	.426-07		0.005	169		13.462		12.531		619.46				
Velocity (ka/sec)	9.3		Orb. Debris	r	.476-06		0.036	362		86.081		80.151		96.43	м			
Ork. Debris Density (g/cc}	2.8		Ejecta/Spal (if S/S all	l graphite/epo	.83E-08 xy ¹		000 0	192		0,461				86.94	-			
Meteoroid Average Velocity (km/sec)	20		Ejecta/Spal Lif S/S all	l aluninun)	., 17E-07		0.003	325				1.321		99.67	**			
Neteoroid Density (g/cc)	0.5															1		
Velocity above which Al targets vaporize (ka/sec)	~		Average Gra Average Alu Orbital Deb Orb. Debrig	phite-Epory l minum Ejectav ris Fraction Average Vel.	ijecta/Spall Spall veloc below vapor (ka/sec) b	velocity ity (ka/s ization v ization vapo	lka/sec) ec) elocity rization ve	0 4.2 0.2353 ilocity	.5 32 4.837984	_								
Projectile Mass (g)	0.001 0.1	01 0.	02 0.1	14 0.06	0.08	0.1	0.2	0.3		3 0.6	0.7	0.8	0.9	-	1 1.2	1.3	:	1.5
Orbital Debris Paras	sters																	
Orb. Deb. Dia. (cs)	0.0680 0.16	96 0.2	389 0.30	10 0.3446	0.3793 (. 4086	.5148 0.1	5893 0.64	86 0.698	7 0.7424	0.7816	0.8172 0	.8499 0.8	303 0.908	7 0.9354	0.9607	0.9847	1.00/1
Orbital Debris Flux	1.506-03 2.296-	04 1.28E	-04 7.14E-i	15 5.086-05	3.99E-05 3.3	JE-05 J.E	ISE-05 1.31	E-05 1.03E	05 8.56E-0	6 7.346-06	6.45E-06 5	.77E-06 5.2	2E-06 4.78E	-06 4.41E-0(6 4.10E-06	3.84E-06	5.60E-06 3	. 13E-06

1.54 >

0.0001 0.0001 0.0001 0.0011 0.1781 1.1081 2.9141 5.3321 8.0851 10.9741 13.8731 16.7101 19.4451 22.0561 24.5352 26.8827 29.1001 30.8731

0.0001 0.0001 0.0001

Prokability of no impacts on Station

(ŧ of iepacts of given mass & greater per m^2 surface - year)

Increantal Orbital 1.35E-03 1.01E-04 5.64E-05 2.06E-05 1.09E-05 6.82E-06 1.44E-05 5.33E-06 2.82E-06 1.74E-06 1.22E-06 8.92E-07 4.85E-07 3.43E-07 3.68E-07 3.11E-07 2.67E-07 2.32E-07 1.73E-07 3.43E-06 2.67E-07 2.67E-07 2.32E-07 1.73E-07 3.43E-06

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6.3.3 Habitat Module Wall

It is likely that all pressurized volumes will be the most protected places on Space Station in terms of resistance to meteoroid/orbital debris penetration. The habitat module wall, therefore, is an example of the damage assessment model using a high critical energy.

6.3.3.1 Critical Energy Calculation

The module double wall system may likely have to resist penetration from a 1 cm diameter orbital debris particle (density 2.8 g/cc, velocity 9.3 km/sec) which has an average kinetic energy of approximately 60,000 joules (Ref.27).

6.3.3.2 Discussion

Table 6-7 gives the relative contribution of ejecta/spall to the total critical energy flux on two modules. Two 42 ft. long, 14 ft. diameter modules will have approximately 350 m^2 surface area. Since the modules are situated at the center of the Space Station, the SAF was estimated at 50%. The VF was calculated at approximately 10% which results in a SF of 0.05. The effect of different SF's on the calculated primary and secondary fluxes can be checked in Figure 6-14.

The contribution of graphite/epoxy ejecta/spall to the total critical energy flux was practically negligible. However, because aluminum targets produce many more large, high energy ejecta/spall particles, the aluminum secondary flux contributed a surprisingly large fraction of the total critical energy flux or about 7%. If the Space Station was primarily aluminum, then module wall designers may want to multiply the combined orbital debris/meteoroid flux by a 1.075 factor in their hazards analysis calculations to compensate for the secondaries flux.

	for impacts from Me	teoroids							Tabl	е 6- (рад	, C e , C	onti: of 4)	nued (
	Mass ejecta & spall per meteoroid impac	l 3.92 :t (g)	10.69	21.39	35.65	49.91	64.17	106.95	178.25	249.55	320.84	392.14	463, 44	534.74	606.04	177.34	748.64	819.94	12.14	962.53 10	033.83 1	069.48
	Mumber of ejecta 4 spall particles of and greater per imp	0.00 critical en lact from me	0.00 ergy teoroids	0.00 of given	0.00 average mass	0.00 within mas	0.00 s range.	0.01	0.03	0.05	0.07	0.10	0.13	0.16	0 .20	0.23	0.27	0.31	0.35	0.39	0.43	0.45
	Number of critical particles created fi	0.00 roe meteoro	0.00 id impact	0.00 s over 1	0.00 fetime of sta	0.00 tion.	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Number of critical energy particles per	7.51E-09 2 r a^2 - yea	.51E-09 4	1.556-09	3.69E-09	3.26E-09 2	. 976-09	.386-08-9,	, 90E-09 B.	,09E-09 6.	.94E-09 6.	12E-09 5.4	19E-09 4.'	** 60-36 6	58E-09 4.:	24E-09 3.5	95E-09 3.8	59E-09 3.4	17E-09 3.2	20E-09 3.1	11E-09 3.	74E - 08
	flux of critical emergy particles of	1.436-07 1. critical en	.36E-07 1 vergy and	, 33E-07 greater i	1.29E-07 froe neteoroi:	L.25E-07 J. d impacts	.22E-07 I.	.196-07 1.	.05E-07 9.	536-08 8.	726-08 8.	03E-08 7.4	12E-08 6.1	B7E-08 6.	376-08 5.4	11E-08 5.4	19E-08 5.()9E-08 4.7	'2E-08 4.1	BE-08 4.()SE-00 3.	74E-08
	Ejecta/Spall Flum from both Orbital Di	3.67E-07 3. ebris and Ma	.61E-07 3. rteoroid	t, 59E-07 Inpacts	3.54E-07	3.51E-07 3.	47E-07 3.	44E-07 3,	256-07 3.	.10E-07 2.	956-07 2.	81E-07 2.4		56E-07 2.4	4E-07 2.1	2E-07 2.2	11E-07 2.1	OE-07 1.9	9E-07 1.8	1.1	19E-07 1.4	10-361
	If Ejecta/Spall all	froe Aluein	nue Struct	tures																		
	For impacts from Orl	bital Debris																				
228	Nass ejecta & spall per impact (g)	0.02	0.35	0.88	1.59	2.29	3.00	5.11	8.64	12.17	15.70	19.23	22.76	26.28	18.92	33. 34	36.87	40.40	43.92	47.45	20. %	52.75
	Mumber of ejecta & spall particles of c and greater per impa	0.00 critical ene act froe pro	0.00 Hgy Dectile's	0.02 5 of given	0.03 1 average mass	0.05 5 within ma	0.07 Iss range.	0.12	0.22	0.31	0.39	0.48	0.56	0.64	0.72	0.80	0.87	0.95	1.02	1.09	1.16	1.20
	Number of critical particles created fr	0.01 rom impacts	0.04 over life	0.07 etime of s	0.05 itation.	0.04	0.04	0.15	60 0	-0.07	0.06	-0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.33
	Mumber of critical energy particles per	1.73E-08 1. • •^2 - year	18E-07 2.	146-07	1.60E-07	1.30E-07 1.	10E-07 4.	26E-07 2.	71E-07 2.1	03E-07 1.	63E-07 1.1	1.1	8E-07 1.0	JE-07 9.2	2E-08 8.3	ZE-08 7.5	7E-08 6.9	5E-08 6.4	2E-08 5.9	6E-08 4.7	3E-08 9.4	9E-07
	flux of critical mergy particles of	3.63E-06 3. critical em	61E-06 3. ergy and	,49E-06 greater	3.286-06	3.12E-06 2.	99E-06 2.	885-06 2.	45E-06 2.	105-06 1.	98E-06 1.4	12E-06 1.6	BE-06 1.5	6E-06 1.4	6E-04 1.3	TE-06 1.2	9E-06 1.2	1E-06 1.1	4E-09 1.0	BE-04 1.0	2E-06 9.4	YE-07
	For lepacts from Met	toroids																				
	Mass ejecta å spall per meteoroid impact	0.23 (y)	0.93	2.04	3.52	4.99	6.47	10.70	18.29	25.67	33.06	40.45	17.83	22.23	\$2.60	66.99	77.38	84.76	2.15	99.54 11	1 24.90	10.61
	Mueber of ejecta t spall particles of ci and greater per impai	0.00 ritical ener ct from metu	0.02 rgy toroids o:	0.04 If given an	0.08 verage mass w	0.12 ithin auss	0.16 range.	0.27	0.46	0.63	0.79	0.95	1.10	1.25	1.39	1.53	1.66	1.79	1.72	2.04	2.16	1.17

tå of impacts of giv glus or minus 0,004	ven avg. må when proj.	155 1855 (s	0.01 9, 0	.005 for 0.0	1 (proj. 1	Nass < 0.0	T 2, 0.01 g	able (] for 0.02	6-7 page (ruj	, Cor 2 o1 86 ().l,	ntinı f4) g, and 0.(Jed ⁵ g when	proj. ma	is >= 0.1	9 per a^2	- year)					
Average Debris Mass (g) for incremental	0.0055 calcs.	0.015	0.03	0.05	0.07	0.0	0.15	0.25	0.35	0.45	0.55	0.45	0.75	0.85	0.95	1.05	1.15	1.25	1.35	1.45	1.5
Number of Impacts from Orbital Debris	463.881	34.594	19.326	7.061	3.735	2.336	5.000	1.827	0.966	0.404	0.416	0.305	0.234	0.186	0.152	0.126	0.107 0	160.0	0.079	0.059	1.175
Neteoroid Parameters									•												
Meteoroid Dia. (cm)	0.1563	0.3368	0.4243	0.5346	0.4120	0.6736	0.7256	0.9142	1.0464	1.1518	1.2407	1.3184	1.3880	.4511 1	.5092	.5432 1.	.6136 1.	.6611 1.	.7060 1.	7487 1.	.7894
Meteoroid Flwx 18 of impacts of given mass & greater per a^2 surface - ye	5.86E-04]	1.59E-05 1	1.556-05	6.685-06	4.08E-06	2.885-04 2	, 20E -06 9 ,	485-07 5.	806-07 4.	09E-07 3.	126-07 2.	50E-07 2.(076-07 1.1	6E-07 1.5	IJE-07 1.3	5E-07 1.21	К-07 1.08	IE-07 9.79)€-08 8,94	IE-08 8.2;	3E -09
Probability of no impacts on Station	0.0001	0.0211	2.5711	20.6151	38.0731	50.4011	59.4721	79.9182	87. 1901	90.7831 1	92 .88 9 1 9	14.2582 5	15.2141 9	5.9142 9	1 6 - 44 92 91	16 1898.9	1.2051 97	.481Z 91	16 IZI1.1	16 1906"	8.0732
Incremental Met. Flax (8 of ispacts of giv plus or minus 0.004	5.50E-04 2 en avg. ma when proj.	., 04E-05 g ss ass (=	3.80E-06 0.01 g, 0.	2.59E-06 .005 for 0.01	1.20E-06 (< proj. m	6.83E-07 1	.25E-06 3. 2, 0.01 g	686-07 1 for 0.02 (71E-07 9.1 (proj. ma	69E-08 6.1 155 (0.1g	19E-08 4.2), and 0.0	26E-08 3.1 5 g when	10E-08 2.] proj. aas	5E-08 1.8 5 >= 0.1	tte-08 1.4. 9 per ∎^2	7E-08 1.2(- year)	E-08 9.98	ft-09 8.4]	IE-09 7.18	E-09 8.2;	3E - 08
Average Net. Nass (g) for incremental	0.0055 calcs.	0.015	0.03	0.05	0.07	0.09	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95	1.05	1.15	1.25	1.35	1.45	1.5
Number of Impacts from Meteoroids	130,100	4.826	2.082	0.613	0.284	0.162	0.295	0.087	0.040	0.0229 0	0.0146 0	.0101 0	0,0073 0	0 9500 .	.0043 0.	.0035 0.	0028 0.	0024 0.	0020 0.	0017 0.	-0195
lf Ejecta/Spall all	fron Carbo	n-6r aphi t	e Composit	e Structures	*																
For lepacts from Orb	ital Debri:	5																			
Mass ejecta & spall per orbital debris j	0.85 mpact (g)	2.31	4.62	7.70	10.78	13.86	23.11	38.51	53.92	69.32	84.73 1	00.14 1	15.54 1	30.95	16.35 14	11.76 17	7.16 19:	2.57 20	1.91 22	3.38 23	31.08
Number of ejecta å spall particles of ci and greater per impai	0.00 ritical m u ct from ort	0.00 rrgy Jital debi	0.00 ris of giv	0.00 en average m	0.00 Hass mithin	0.00 Dass rang	0.00 Je.	0.00	0.00	10.0	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04
Musber of critical particles created fr	0.00 be prbital	0.00 debris in	0.00 mpacts over	0.00 r lifeti ne o	0.00 f station.	0.00	0.00	0.0	0.00	0.00	0.00	o. 6	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Musber of critical energy particles per	4.84E-10 4. m^2 - year	066-10 1	. IZE-09	1.26E-09	1.37E-09 1	. 45E-09 8.	826-09 8.	81E-09 B.5	16E-09 B.B	156-09 8.8	11E-09 8.7	4E-09 8.6	6E-09 8.5	JE-09 8.4)	7E-09 B.37	1E-09 8.28	E-09 8.186	E-09 8.09	E-09 6.80	E-09 1.43	(0-3)
Flux of critical energy particles of c	2.67E-07 2. critical en	.67E-07 2. Iergy and	.67E-07 greater fi	2.65E-07 roe orbital	2.64E-07 2 debris imp	.63E-07 2. acts	.61E-07 2.	53E-07 2.4	14E-07 2.3	15E-07 2.2	66-07 2.1	7E-07 2.0	8E-07 2.0	16-07 1.91	IE-07 1.83	E-07 1.74	E-07 1.66E	E-07 1.58	E-07 1.50	E-07,1.43	- 101 -

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Figure 6-14



Log Flux (number of impacts/m²2 - yr)
	0.04	83E-07	83E-07	90-340												-		
	0.00	55E-08 I.)8E-07 1.	ISE-06 J.														
	0.00	ZE-08 1.:	SE-07 1.9	2E-06 1.1														
	0.00	E-08 1.7	ie-07 2.1	E-06 1.2														
	0.01	E-08 1.91	E-07 2.35	E-06 1.30		,												
	10.	-08 2.15	-07 2.56	-06 1.39														
	0 10	-08 2.44E	07 2 . 80E	-06 1.485														
	1 0.	8 2.80E-	7 3.006-	6 1.586-														
	0.0	3, 26E-0	3.41E-0	1.70E-0														
	0.01	3.87E-08	3.806-07	i.83E-06														
ned	10.0	. 70E-08	.27E-07	90-386.														
ntin 1)	10.0	885-08 4	86E-07 4	15E-06 1														
, Co	5.5	66E-08 5.	62E-07 4.	37E-04 2.		r -	÷											
6-7 1	2.2.2	JE-07 7.	0E-07 5.	5E-06 Z.			:											
uble (na	2 10 10	3E-07 1.0	7E-07 6.7	JE-06 2.6			: ; ;							•				
Ча	0.08	E-07 1.6	E-06 8.3	E-06 3.0			•											
	0.03	:-07 3.4I	:-06 1.18	:-06 3.69														
	50.	-07 1.091	-06 1.296 acts	-06 3.88	-													
	5 0 station.	7 1.456	6 1.43E roid imp	6 4.11E														
	0.0 time of	2.1JE-0	1.65E-0 'De meteo	4.42E-0														
	0.09 over life	9E-07	3E-06 reater fr	0E-06 pacts														
	0.08 iapacts :	2E-07 J.8	75-06 2.0 gy and gi	6-06 4.9. oroid In														
	0,36 eteoroid	E-06 3.52 - year.	E-06 2.35 ical ener	E-06 5.26 and Mete														
	al (i fron m	al 1.53(per e^2	J.916 of criti	6.33E Debris														
	f critica s created	f critica articles	critical Inticles	pell Flux 1 Orbitel														
	Mumber of particles	Nueber of Inergy pa	Flux of t Pnergy pa	Ejecta/Sµ From both					-	· _					-		Ψ.	
		- •	v	- +						229	9							

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material. Including secondary impacts, the number of critical impacts on one solar array would climb to about 35,000. Over a 10 year design lifetime, a solar array would receive about 11,500 critical impacts. A solar array covered with the large area silicon cells that are 5.9 cm by 5.9 cm (Ref.4, p.409) has about 64,000 solar cells. Each impact that completely penetrates the solar array probably has the potential of causing a solar cell to fail. If each penetrating impact did cause a solar cell to fail, approximately 18 percent of the solar cells in a solar array would be inoperative after 10 years. Thus, the solar arrays may potentially need to be replaced every 5 years if only a 10 percent degradation in solar array performance is allowed.

6.3.4 Solar Panels

The International Space Station configuration (Fig. 6-8) has four photovoltaic solar arrays. Each array measures 80 ft. by 32.5 ft. (Ref.4, p.407). The Space Station reference description stated that solar cell performance is expected to degrade by 10 percent over 10 years (Ref.4, p.409) and solar array components would necessarily need to be changed-out.

6.3.4.1 Critical Energy Calculation

An early design for the solar cells called for a 0.008 in. thick silicon cell with a 0.006 in. thick cover glass. The penetration equation by Cour-Palais (Ref.26 - same as Section 6.3.1) was used to calculate the size of orbital debris/meteoroid particles that would penetrate the solar array. The penetration equation related crater depth, P (cm), to projectile density, p (g/cc), projectile diameter, D (cm), and to projectile velocity, V (km/sec).

$$P = 0.53 \pm 0.5 \pm 1.06 \pm 0.67$$

As given in Table 6-8, the diameter of the orbital debris/meteoroid particles that would create a crater with a depth equal to the total thickness of the solar cell (0.014 in.) was calculated. This failure criterion does not take into account spall effects which can be several times the crater depth and is therefore considered a high estimate. It is also assumed that silicon has similar penetration resistance as silica glass. The solar cell critical energy was calculated from a weighted average of the orbital debris/meteoroid critical energies as 0.21 joules.

6.3.4.2 Discussion

The 0.21 J critical energy and 446 m² surface area of one solar array (front and back surfaces) was used in the damage assessment model given in Table 6-9. Because of the large area of the solar array, the SAF factor was estimated as 50% while the VF factor was calculated as approximately 25%. This gave a SF of 0.125. The calculated contribution of graphite/epoxy secondary flux was about 2% of the total primary and secondary flux having the critical energy and above. Because fewer numbers of aluminum particles were counted in this study's tests, the calculated contribution from aluminum secondary flux was less at the low critical energy of the solar cells than graphite/epoxy secondary flux. Thus, a primary flux design factor of 1.02 would include the effects of secondary impacts. Figure 6-15 gives the effect of SF on the calculated secondary fluxes.

Over the 30 year Space Station lifetime, one solar array will likely receive over 34,000 primary impacts from orbital debris and meteoroids that will completely penetrate the solar array Table 6-9, Solar Array Damage Assessment Worksheet

(page 1 of 4)

Flux of Eiecta/Small Particles of Critical Energy and Greater on a Sensitive Area of Space Station

v , 0	Surface Area of Station (e^2)	11416.1		55	action of su cing sensiti	urfizre area ive area	of Station	 				Earth's Station Alfitud	radius (ke orbital al e in Eacth) titude (ha) radii	- -	78.145 500 578392					
5	Orbital Life (yrs)	30		5 1	action of sl ea (hemispho	ty covered prical View	by Station Factor)	as sem f 0.25	irce sensil	ti ve		Earth d Earth s	efocusing f hielding fa	actor		113070					
M	Critical Energy to damage sensitive Harface (Joules)	0.21		F SP SP	action of S all strikin tation SA fi	tation Ejec g the sensi raction 4 v	ta t tive area ien factori	0.125				Percent total i	of apacts i tive	Percent of total ispac on sensitiv	륀			1			
	Surface Area of critical surface (a^2)	416.14 (1 	of 4 sol	Ľ,	rticle	Flux with c and greater (Number inp.	ritical em un sens. acts/a^2-yi	46.4 7.6.4	under of i brea with a preater ove	impacts un critical e er Station	sensitive nergy and lifetime	area 11 e). t. 1 all 6/t	S/S	area if S/I ej. k sp. all Alweim	· · · ·	obability i sens. ari ergy & gra	of mo imp ea with cr eater (per	act itical centi			
	Orb. Debris Average Valorito (bo/cor)	ŭ 		, 2 ,	teoroids	2	.40E+00		321	90.53		1.24	161	94.382			0.001				
-	110111 June 201	2		5	b. Debris	-	. 396-01		81	6.710		u .	195	5.451			0.001				
-	Orb. Debris Density (g/cc)	2.8		5.5	jecta/Spail f S/S all g	raphite∕epo	1, 06E-02 ¤y)		677.	. 3892		1.	15				0.001				
221	Meteoroid Average Velocity (ka/sec)	8		33	iecta/Spall f S/S all a	4 Luainua)	.316-03		51.	72133				0.172			0.001				
	Meteoroid Density (g/cc)	0.5																٦			
-	Velocity above which Al targets vaporize (ta/sec)	•			verage Graph verage Alusi rbital Đebris A	ite-Epory € inum Ejecta/ is Fraction iverage Vel.	ijecta/Spal Spali velo below vapo (ka/sec)	ll velocit city (ka/) rization below vap	y (ka/sec) sec) velocity brization	0.23 velocity	0.5 1,232 15359 4,837	786									
_	Projectile Nass (g)	0.001	0.01	0.02	0.04	0.06	0.08	0.1	0.2	0.3	0.4	0.5 0	.6 0.7	8.0	6.0	-		1.2	1.3	3	-
_	Orbital Debris Parae	eters																			
	Drb. Deb. Dia. (ca)	0.0880	0.1896	0.2389	0.3010	0.3446	0.3793	0.4086	0.5148 0).5893 0 .	.6486 0.6	141 O.74	24 0.7816	0.8172	0.8499	0.8803	0.9087	0.9354	0.9607	0.9847	1.007
	Drbital Debris Flux (1 of impacts of	1.58E-03 2.	. 296-04 1	.28E-04	7.14E-05	5.086-05	3, 99E-05 3,	.316-05 1.	BSE-05 1.3	31E-05 1.0	3E-05 8.56	:-06 7.34E-	06 4.45E-06	5.77E-06	5.226-06 4	.786-06 4.	,41E-06 4.	10E-06 3.	.84E-06 3.	40E-06 3.	436-06

0.0001 0.0001 0.0001 given mass & greater per m^2 surface - year)

0.0002 0.0001 0.0001 0.0011 0.1781 1.1081 2.9141 5.3321 8.0651 10.9741 13.8731 16.7101 19.4451 22.0561 24.5351 26.8821 29.1001 30.8731 2.04E-05 1.09F-05 6.82E-06 1.44E-05 5.33E-06 2.82E-06 1.78E-06 1.22E-06 8.92E-07 6.85E-07 5.43E-07 4.42E-07 3.68E-07 3.61E-07 2.67E-07 2.37E-07 1.73E-07 3.43E-06 Incremental Drbital 1.35E-03 1.01E-04 5.64E-05 Debris Flur Probability of no impacts on Station

1.54 >

Solar Cell Critical Energy Determination Glass Thickness (cm) 0.03556 (8 mil silicon cell with 6 mil cover glass) Meteoroid Debris Particle Density (g/cc) 0.5 2.8 Particle Velocity (km/s) 20 9.3 Particle Critical Diameter (cm) 0.0163 0.0117 for crater depth to completely penetrate silica glass (from Ref.26) Particle Mass (g) 1.14E-06 2.38E-06 Particle Energy (J) ۰. 0.23 0.10 Particle Flux (#/m^2-yr) 1.51E+00 2.53E-01 with critical diameter and greater Percent Flux 85.61 14.39

Average Critical Energy (J) 0.21 above which results in complete penetration of the solar cell from Meteoroid & Orbital Debris Impacts

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								Ĕ	able	6-9	Con	tinu	ed									
	for lapacts from Ne	teornids							įd)	age	3 of	4)										
	Nass ejecta è spall per metroroid impac	(3.92 :t (g)	10.69	21.39	35.65	49.91	64.17	106.95	178.25	249.55	320. B4	392.14	463, 44	534.74	606.04	677.34	748.64 8	19.94 8	91.24 9.	62.53 10	33.83 10	69.48
	Number of ejecta & spall particles of and greater per im	320.37 critical en pact from me	455.54 lergy teornids	533,18 of given	572.46 average mass	587.54 within aas	592.65 s range.	586.26	559.27	529.44	503.42	480.38	459.94	441.68	425.27	410.41	396.87	584.46 3	73.03 3	62.46 3	52.64 3	47.98
	Number of critical particles created f	41680.67 froe exteoro	2198.26 iid inpact	1109.87 ts over li	351.19 ifetiae of sta	167.13 Ition.	95.73	173.24	48.62	21.38	11.54	7.03	4.64	3.24	2.36	1.78	1.30	1.09	0.88	0.72	0.60	6.77
	Mumber of critical energy particles po	1.76E-01 5 M 8^2 - 783	9. 29E-03 - Ir .	4.69E-03	1,486-03	7.07E-04 4	1.056-04	, 32E-04 2	. 096-04 9	,04E-05 4	.886-05 2.	97E-05 1.	96E-05 1.	37E-05 9.	.7 6 0-7.	53E-06 5.	83E-06 4.1	61E-06 3.7	'2E-06 J.O	5E-06 2.5	3E-04 2.1	SO- 39
	Flux of critical energy particles of	1.94E-01 F critical e	1, 786-02 Hergy an	8.49E-03 d greater	3.60E-03 froe aeteoroi	2.32E-03 d impacts	1. 6 1E-03	I.21E-03 4	. 74E-04 2	. 686-04 1	. 78E-04 1.	.296-04 9.	92E-05 7.	965-05 6.	.5 20-362.	59E-05 4.	B4E-05 4.	256-05 3.7	19E-05 3.4	ize-05 3.1	2E-05 2.4	S0-398
	Ejecta/Spall Flur from both Drbital i	4.05E-01 1 Debris and A	9.23E-02 leteoroid	6.05E-02 Impacts	3. 79E-02	2.94E-02 ;	2.2 1 E-02	1.936-02 1	.09E-02 7	. 70E-03 5	. 97E-03 4.	.B9E-03 4.	ISE-03 3.	.61E-03 3.	.206-03 2.	.006-03 2.	62E-03 2.4	41E-03 2.3	23E-03 2.0)8E-03 1.9	1.1 Jee-03	86E-03
	f Ejecta/Spall al	l free Aluei	inun Stru	ctures																		-
	for lepacts from U	rbital Debri																				
236	Nass ejecta & spal per impact (g)	1 0.02	0.35	0.88	1.59	2.29	3.00	5.11	8.64	12.17	15.70	19.23	22.76	26.28	29.01	33. 34	36.87	40.40	43.92	47.45	50.38	52.75
	Number of ejecta & spail particles of and greater per im	: 23.69 critical ex pact from p	61.90 nergy rojectile	69.69 i's of giv	72.19 en average mai	72.63 65 within I	72.38 Hass rangi	70.49	66.96	63.88	61.26	58.99	57.01	55.26	53.69	52.26	50.97	49.77	48.68	47.66	46.71	46.25
	Mumber of critical particles created	2586.39 froe ispact	504.03 5 ever 1j	316.97 fetime of	119.97 station.	63.85	39.79	82.96	28.79	14.53	8.71	5.78	4.10	3.05	2.35	1.86	1.51	1.75	1.05	0.89	0.65	12.79
	Number of critical energy particles p	7.55E-03 er =^2 - ye	1.47E-03 ar.	9.26E-04	3.50E-04	i.86E-04	I. 16E-04	2.42E-04	9.41E-05 (1.24E-05 2	2.54E-05 1	.49E-05 1.	.20E-05 B	.90E-04 6	.86E-06 5.	.44E-06 4.	.41E-06 3.	64E-06 3.1	06E-06 2.(40 E-06 1.	90E-04 3.	74E-05
	Flux of critical energy particles o	1.11E-02 of critical	3.55E-03 emergy an	2.08E-03 W greater	1.15E-03	8.005-04	6.13E-04	4.97E-04	2.55E-04	1.71E-04 1	1.286-04 1	.03E-04 8.	.61E-05 7	• 50-321	. 536-05 5	.84E-05 5	.306-05 4.	.B6E-05 4.	49E-05 4.	196-05 3.	93E-05 3.	74E-05
	for lepacts from M	let eor oi d's																				
	Mass ejecta & spal per meteoroid impa	ti 0.23 ict (g)	0.93	2.04	3.52	4.99	6.47	10.90	18.29	25.67	33.06	40.45	47.83	55.22	62.60	66-69	17.38	84.76	92.15	99.54	106.92	110.61
	Number of ejecta l spail particles of and greater per in	k 57.02 F critical e spact froe e	70.01 mergy keteoroids	72.59 s of giver	72.01 • average mass	70.61 i within ma	69.10 55 range.	64.93	59.57	55.55	52.37	49.76	47.55	45.45	43.97	42.49	41.16	39.95	39.85	37.84	36.91	36.47

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	(† of impacts of g	i ven avg. e	455					H	able (pi	6-9, age 2	, Cor 2 of	tinu 4)	led									
		M when proj	i. eass (=	: 0.01 g, (.005 for 0.01	l < proj. #	uss < 0.0	2, 0.01 g	for 0.02 (proj. 🖬	155 (0. 19	, and 0.0	is g when	proj. mai	is)= 0.1	i per e	2 - year)					
	Average Debris Mas (g) for incremental	is 0.0055 I calcs.	0.015	0.03	0.05	0.01	0.09	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95	1.05	1.15	1.25	1.35	1.45	1.5
	Number of Impacts from Orbital Debri	463.881 s	34.594	19.326	7.061	3.735	2.336	5.000	1.827	0.966	0.604	0.416	0.305	0.234	0.186	0.152	0.126	0.107	0.091	6.079	0.059	1.175
	Neteoroid Parameter	rs																				
	Neteoroid Dia. (cm	0.1563	0.3368	0.4243	0.5346	0.6120	0.6736	0.7256	0.9142 1	. 0464	. 1518 1	.2407 1	.3184	. 3880	. 4511	.5092	. 5632	. 6136	1 1166.	1.7060	1.7487	. 7894
	Meteoroid Flux (# of impacts of given mass & greatu per m'2 surface - j	5.86E-04 er year)	3. 59E -05	1.55E-05	6.68E-06	4.085-06 2	, BBE-06 2,	206-06 9.	48E-07 5.8	IOE -07 4.0	96-02 3.1	2E-07 2.5	0E-07 2.0	7E-07 1.7	6E-07 1.:	3E-07 1.	1.2 IV	:0E-07 1.ú	BE - 07 9. 7	19E-08 B.9)4E-08 8.2	
	Probability of no impacts on Station	0.0001	0.0211	2.5711	20.6152	38, 073 1	50.6012	59.472%	9 2816.4/	7.190X 9	0.7831 9	2.889X 9	4.2581 9	5.2142	5.914Z)6. 449 <u>7</u>	·6.8682 §	17.2051 9	7.4812 9	71.7121 9	7.906Z	18.073X
	Incremental Met.	5. 50E-04	2.04E-05	8.80E-06	2.595-06	1.20E-06 6	.83E-07 1.	25E-06 3.	68E-07 1.7	1E-07 9.6	9E-08 6.1	9E-08 4.2	6E-08 3.1	0E-08 2.3	SE-08 1.1	JE-08 1.	IZE-08 1.2	0E-08 9.5	BE-09 B.4	IIE-09 7.1	18E-09 B.2	80-3C
23	rlux if of impacts of g plus or minus 0.00	iven avg. a 4 when proj	455 • 8855 (=	0.01 9, 0	.005 for 0.01	(proj. e	10.0 > sse	, 0.01 g	far 0.02 (proj. ez	ss < 0.1g	, and 0.0	5 g when	proj. nas	s)= 0.1	ça ve e	(- year)					
35	Average Met. Mass (g) for incremental	0.0055 l calcs.	0.015	0.03	0.05	0.07	0.09	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95	1.05	1.15	1.25	1.35	1.45	1.5
	Number of Japacts from Neteoroids	130.100	4.826	2.082	0.613	0.284	0.162	0.295	0.087	0.040 0	.0229 0	.0146 0	.0101	. 0073 0	. 0056 0	. 0043	. 0035 0	.0028 0	. 0024 0	0.0020	0.0017 0	.0195
	lf Ejecta/Spall all	l from Carb	on-Graphi	te Composi	te Structures																	:
	For lapacts from 0	rbital Debr	i.																			
	Mass ejecta & spall per orbital debris	1 0.85 inpact (g)	2.31	4.62	7.70	10.78	13.86	23.11	38.51	53.92	69.32	84.73 1	90.14	15.54 1	30.95	46.35	61.76 1	77.16 1	92.57 2	07.97 2	23.38 2	31.08
	Number of ejecta & spall particles of	140.95 critical en	250.84 hergy	342.81	412.62	456.59	487.18	540.26	576.73 5	89.69 5	93.13 5	91.96 5	88.34 5	83.37 5	77.63 3	61.49	65.14 5	58.73 5	52.32	42.99 3	39.75 5	36.67
	and greater per ta	pact from G	rbital de	eris of gi	ven average m	ass within	nass rang															
	Number of critical particles created f	65385.34 from orbita	8677.44 debris	6625.10 iepacts ovi	2913.37 er lifeti ne o	1705.54 f station.	1137.89 2	701.48 11	053.63 5	69.93 3	58.45 2	46.40 1	19.72	34.77 1	07.48	84.60	71.21	59.53	50.46	43.29	31.91 6	30.75
	Number of critical energy particles pe	1.91E-01 . Pr #^2 - ye	2.53E-02 ar.	I.93E-02	8.51E-03	4,986-03 3	. 32E-03 7.	89E-03 3.(DBE-03 1.6	6E-03 1.0	5E-03 7.1	9E-04 5.2	5E-04 3.9	9E-04 3.1	4E-04 2.5	3E-04 2.0	86-04 1.7	4E-04 1.4	7E-04 1.2	(PE-04 9.3	1.B	4E - 03
	Flux of critical energy particles of	2.71E-01	8.00E-02 energy an	5.46E-02 d greater	3.53E-02 from orbital	2.68E-02 2 debris imp	.106-02 1. acts	BSE-02 1.(D6E-02 7.5	IE-03 5.8	5E-03 4.8	0E-03 4.0	BE-03 3.5	6E-03 3.1	6E-03 2.8	4E-03 2.5	9E-03 2.3	BE-03 2.2	IE-03 2.0	6E-03 1.9	3E-03 1.8	4E-03

Figure 6-15



Log Flux (number of impacts/m²2 - y_f)

Continued	of 4)
•	4
Table 6-9	(page

0.14 0.18 0.24 0.33 0.48 0.73 1.20 2.24 5.19 19.19 Number of critical 7418.84 337.84 151.09 44.17 20.09 11.16 particles created from meteoroid impacts over lifetime of station.

0.71

0.06

0.08

0.09

0.11

1.87E-04 8.49E-05 4.72E-05 8.11E-05 2.19E-05 9.48E-06 5.08E-06 3.08E-06 2.03E-06 1.42E-06 1.03E-06 7.79E-07 6.04E-07 4.80E-07 3.88E-07 3.18E-07 2.65E-07 3.00E-06 Wueber of critical 3.14E-02 1.43E-03 6.39E-04 energy particles per m^2 - year.

4.50E-04 2.63E-04 1.78E-04 1.31E-04 4.99E-05 2.79E-05 1.34E-05 1.03E-05 8.28E-06 6.87E-06 5.83E-06 3.45E-06 3.97E-06 3.58E-06 3.28E-06 3.26E-06 3.00E-06 Flux of critical 3.39E-02 2.52E-03 1.09E-03 4.50E-04 2.63E-04 1. Pnergy particles of critical energy and greater from meteoroid impacts

1.46E-03 9.81E-04 7.36E-04 5.88E-04 2.89E-04 1.40E-04 1.41E-04 1.12E-04 9.33E-05 7.99E-05 7.00E-05 6.24E-05 5.65E-05 5.16E-05 4.77E-05 4.43E-05 4.15E-05 3.94E-05 Ejecta/Spall Flux 3.45E-02 5.29E-03 2.83E-03 from both Orbital Debris and Meteoroid lepacts secondary flux, whether from aluminum or graphite/epoxy will be significantly less than primary fluxes having the critical energy or greater. A conservative rule of thumb would be to add 10 percent to meteoroid and orbital debris flux to account for secondary impacts.

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7.0 Conclusions

- 1. Spall mass made up approximately 70% of the total mass of ejecta/spall particles (for the thin, 0.1 inch thick, targets used in this study).
- 2. Total ejecta/spall mass was 20-100 times more than projectile mass (with projectile energy ranging from 50-120 Joules). Ejecta/spall mass increased as projectile energy increased (with constant projectile mass). Higher target density and lower projectile density reduced total ejecta/spall mass.
- 3. Some small ejecta/spall particles are fast while all large ejecta/spall particles are slow.
- 4. Aluminum structures produce more high energy but fewer low energy ejecta/spall particles than graphite epoxy structures for a given energy impact.
- 5. For thick graphite/epoxy targets, a cloth covering significantly reduced (by almost 50%) the total ejecta mass. However, it was not apparent that a cloth covering significantly reduced the total ejecta/spall mass for thin graphite/epoxy targets.
- 6. For most structural elements of interest on the International Space Station, the secondary flux from ejecta/spall particles will contribute no more than 10% to the total flux (primary and secondary) having a given critical energy or greater. Thus, in hazards assessment analysis, designers should multiply the total primary flux by 1.1 to compensate for secondary impact effects.
- 7. It is predicted that over 35,000 primary and secondary impacts will have sufficient energy to completely penetrate each 80 ft. by 32.5 ft. solar array over the 30 year Space Station lifetime. It has been reported that the solar array performance should degrade only 10 percent before replacement. If each complete penetration causes a solar cell to fail, the solar arrays may need to be replaced every 5 years.

8.0 Recommendations

Further work needs to be done to assess the effect of hypervelocity impacts on solar cells. Depending on the sensitivity of the cells to impact damage, significant loss of power could occur over long time periods (10-30 years).

Designers need only include effects (flux) of secondary impacts on surfaces that have high exposure to ejecta/spall produced from the rest of the Space Station. Even on very sensitive surfaces (ones with low critical energy of projectiles that result in damage), unless the exposure fraction is high, the

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JSC	Date			1	F	arget			
Shot #		Target type	Material	Thickness (inches)	Length (inches)	Width (inches)	Mass before (grams)	Mass after (grams)	Damage Notes
756	09-Jul-85	Bumper Inner Wall Standoff Dist	Fiberglass (suit) Aluminum (6061-T6) ance Bumper Mass 0.00543 lbm	0.076 0.032 3.875 //unit area =	4 0	5.25			Small hole, elliptical delam- ination, 1" diameter. Little damage. No bumps on back of inner wall. No large craters on inner wall front.
861	12-Nov-85	Thick plate	Aluminum with paper Mass/unit a 0.0245	0.250 backing. rrea = i lbm/in ²	4				Perforated. Circular 8 mm dia. crater on front surface with petaling. Rear crater is 2.5 mm diameter and raised. Slight secondary surface marks on front.
862	12-Nov-85	Thick plate	Graphite/ Epoxy (gene Mass/unit a 0.0237	0.416 pric). rea = / lbm/in ²	G	ω			Did.not perforate plate. Large spall on back surface. Circular crater on front surface 4mm dia. Peelings in vertical orientation both front and back surfaces. Slight secondary surface marks on front.
863	13-Nov-85	i Thick plate	Graphite/ Epoxy (gent Mass/unit a 0.0136	0.239 eric). area = 6 lbm/in ²	60			•	Perforated plate. Circular crater on front 6 mm dia. Peelings on front surface in +45 deg phi, -90 deg theta; -45 deg phi, +90 deg theta orientation. Rear surface in +45 phi, +90 theta; -45 phi, -90 theta orientation.
88 98 -	14-Nov-85	5 Thick plate	Graphite/ Epoxy (gen Mass/unit { 0.010	0.191 eric). area = 9 lbm/in ²	60	.			Perforated plate. Elliptical crater on front 2 mm long, 1 mm wide; on back circular 4 mm diameter crater. Peelings on front surface in +45 deg phi, +90 deg theta; -45 deg phi, -90 deg theta orientation. Rear surface in +45 phi, -90 theta; -45 phi, +90 theta orientation.

	Other	Purpose of Shot	To test a fiberglass bumper.	Test to check ability to shoot steel projectile. Also for UT model verification.	Test ability to shoot steel projectile. Also for UT model verification.	Test ability to shoot steel projectile. Aiso for UT model verification.	Test ability to shoot steel projectile. Also for UT model verification.
		Doc. Photo?	Yes	Yes	Yes	s S	Yes sey
		Impact Photo?	No	° Z	°N N	° Z	°N N
as Gun Shots	:	Velocity (km/sec)	6.55	3.5	3.29	3.58	3.02
JSC Light G		Length (inches)	0.0731	0.0324	0.0335	0.035	0.034
ther Data on	rojectile	Diameter (inches)	0.0692	0.0695	0.0695	0.0693	0.0695
0	ă.	Mass (milligrams)	5.16	15.3	13.91	14.59	14.54
		Projectile Material (Nylon	304 S/S (Stainless- Steel)	304 S/S (Stainless- iteel)	304 S/S Stainless- ;teel)	04 S/S Stainless- iteel)
	# ot ot	- - 	756	861	898 898	863	865 3 5

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JSC Sho

A-3

Target Data on JSC Light Gas Gun Shots	Target	1 Thickness Length Width Mass before Mass after Damage Notes (inches) (inches) (inches) (grams) (grams)	02 peelings (2.5 - 3") horizontally area = (0 deg ph1, +90 & -90 deg theta) from crater. No penetration(tape on back - no spall), slightly raised behind impact point.	0.095 6 6 86.6 86.3 Ejecta wt.=.06g 14/3501-6 01 WN3 area = 53 lbm/in^2	 0.112 6 6 101.61 101.4 Ejecta wt.=.04g7 4/3501-6 WN5 area = 62 lbm/in²2 	<pre></pre>	 0.093 6 85.79 Complete penetration. Surface 14/3501-6 14/3501-6 14/3501-6 16 animations (peelings) on both sides: On ejecta side peelings in +45 deg phi, +90 deg theta. On spall side peelings in +45 deg phi, +90 deg theta. 153 lbm/in²2 90 deg theta orientation. 	/ 0.115 6 6 103.64 103.41 Ejecta wt.=.03g 54/3501-6 101 WN6 63 lbm/ln^2	0.528 6 6 512.6 -aphite 34/A193PW/ 32-01A-001 WN2
Target Data on JSC Light	Tar	Thickness Length (inches) (inches) (1	2 area = 3 lbm∕in^2	0.095 6 /3501-6 1 WN3 area = 3 lbm/in^2	0.112 6 /3501-6 2 WN5 area = 2 lbm/in^2	0.094 6 /3501-6 2 WN4 area = 3 lbm/in^2	0.093 6 (3501-6 3 area = 3 lbm/in~2	0.115 6 /3501-6 1 WN6 area = 3 lbm/ln^2	0.528 6 phite /A193PW/ -01A-001 WN2
		be Material	JSC-01B-00: Mass/unit (0.031:	Graphite/ Epoxy, AS4, JSC-02B-00 Mass/unit	- Graphite/ Epoxy. AS4, JSC-03B-00; Mass/unit,	Graphite/ Epoxy. AS4 JSC-02B-001 Mass/unit	<pre>Graphite/ Graphite/ Spury AS4 U JSC-02B-00 Mass/unit 0.005</pre>	la- Graphite/ oth.Epoxy. A54 JSC-03B-00 Mass/unit 0.006	Grphite/ oth Epoxy, Gra cloth. AS4 3501-6 JSC Masse/init
		Target typ	No Cloth.	-85 Thin. No cloth	:-85 Truss simu- lator. No cloth. Thin.	:-85 Thin. No cloth.	2-85 Thin (trust type) Plate Replacement for WN4.	:-85 Truss simul tor. No cld Thin.	5-85 Thick. Cloth on be sides.
	Date	*		189 10-Dec	90 11-Dec	193 12-Dec	394 13-Dec	395 18-Dec	900 18-Dec

JSC Shot

Other Data on JSC Light Gas Gun Shots Projectile	Diameter Length Velocity Impact Doc. Photo? Purpose of Shot s) (inches) (inches) (km/sec) Photo?	0 0.0686 0.072 6.32 Yes No Impact photograph used to estimate ejecta velocity.	1 0.0703 0.0336 6.19 No Yes To test another fiberglass bumper.	3 0.0704 0.0317 4.3 No Yes To test fiberglass/composite hybrid bumper.	l 0.0704 0.0344 6.08 No Yes To test another fiberglass bumper.	0.0697 0.0709 6.42 No. Styro- Yes Generic shot to characterize ejecta. Compare results for target with cloth to Shot No. 884 (without cloth). Used to col- lect ejecta	0.0696 0.0682 6.26 No, Styro- Yes Generic shot to characterize
Other Data Projectile	Diameter (inches)	0.0686	0.0703	0.0704	0.0704	0.0697	0.0696
	Mass (milligrams)	5.0	5.1	4.43	4.84	4 . 9 3	4.76
	Frojectile Material	Nylon	Aluminum 6061-T6	Aluminum 6061-T6	Aluminum 6061-T6	Nylon	Nylon
JSC	Shot #	873	878	879	881	883 1	884 1

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Ē ¢ 10, 11, 14, 0,

		Damage Notes		-		-			emetration. Elliptical front surface 3mm in imm in horizontal imm in diam. On front in the diam. On front increased square ions on top and bottom irater; cloth ripped orizontal delaminations iright of crater(fac- front) and 6mm to left irface, checkerboard
				310w out					Complete F crater on vertical 4 On back su approx. 5 aurface, c delaminati edges of c delaminati edges of c delaminati edges of c off and hc off and hc off and hc off rear su
		Mass after (grams)		112.92 1	173.82	114.02	171.26	113.2	114.5 1st weight 114.31 2nd weight (without label)
hots		lass before (grams)	508.6	113.29	174.1	114.24	171.42	113.3	114.75
t Gas Gun S	arget	Width M (inches)	Q	B	ن	ω	ى ت		со
on JSC Ligh	Ĥ	Length (inches)	ω	60	ω	ω	ω	۲	60
arget Data		Thickness (inches)	0.524 01-6 N2 an = bm/in~2	0.124 01-6 NB a = bm/in^2	0.194 N10 bm∕in^2	0.125 01-6 NN7 bm/in^2	0.191 NN7 5a = .bm/1n^2	0.104 4N11 5a = 1bm/in~2	0.127 501-6 8a = 1bm/1n^2
Ĩ		Material '	Graph./Epoxy Graphite coth AS4/A193PW/35 JSC-01A-005 W Mass/unit are 0.0311 1	Graphite/ Epoxy. AS4/35 JSC-03A-002 W Mass/unit are 0.0069 1	Graphite IM6/8551 JSC-06A-001 W Mass/unit are 0.0107 1	Graphite/ Epoxy. AS4/35 JSC-03A-001 W Mass/unit are 0.0070 1	Graphite IM6/8551 JSC-06A-002 W Mass/unit are 0.0105 1	Fiberglass. S-2/3501-6 JSC-05A-001 V Mass/unit are 0.0069]	Graphite/ Epoxy, AS4/3 JSC-03A-003 Mass/unit ar 0.0070
		Target type	Thick. Cloth on both sides.	Thin. Cloth on both sides.	Thin. Tough ene d resin.	Thin. Cloth on both sides.	Thin. Toughened resin.	Thin. Fiberglass with cloth.	Thin (truss- type) plate. Cloth on both sides.
	Date	# #	901 18-Dec-85	909 30-Dec-85	910 31-Dec-85	911 02-Jan-86	912 03-Jan-86	913 03-Jan-86	917 13-Jan-86
	JSC	Sho							

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ttile Other eter Length Velocity Impact Doc. Photo? Purpose of Shc hes) (inches) (km/sec) Photo?	(completely target without cloth closed) No. 883 (with cloth) used to col- lect ejecta	.0703 0.033 5.02 No Test shot for Dr. Yev (The University of Te	.0703 0.032 4.5 No Test shot for Dr. Yew (The University of Te	.0696 0.0754 4.75 No Test shot for Dr. Yew (The University of Te	.0695 0.0718 4.75 Yes Yes Generic shot to chara after impact), tribution for both ej and spall. No cloth, impact. Also used as test shot for Dr. Yew (The University of Te	.0696 0.0713 4.82 No Test shot for Dr. Yew (The University of Te
elocity Impact km/sec) Photo?	(completely closed) used to col lect ejecta	5.02 No	4.5 No	4.75 No	4.75 Yes (30-35 micro after impact	4.82 No
Length V (inches) (1		0.033	0.032	0.0754	0.0718	0.0713
rojectile Diameter (inches)	}	0.0703	0.0703	0.0696	0.0695	0.0696
P. Mass (milligrams)		ىن	4.93	4.99	4.94 4	4.96
# Projectile Material		189 Al 6061	90 Al 6061	193 Nylon	194 Nylon	95 Nylon

Other Data on JSC Light Gas Gun Shots

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A-7

				Target vava	1911 ACA 110				-
JSC Date					-	arget			
Shot #	Targe	t type	Material	Thickness (inches)	Length (inches)	Width (inches)	Mass before (grams)	Mass after (grams)	Damage Notes
									square delamanations around crater preferentially on right side (facing plate back). Surface raised aroung crater (both sides).
923 21-J	an-86 Thin (type) No clo Clo	(truss- plate. oth.	Graphite/ Epoxy, AS4/3 JSC-02B-005 Mass/unit ar 0.0053	0.095 1501-6 rea = Ibm/in ² 2	ن	6	ຍ. 98	86.35	Complete penetration. Surface delaminations (peelings) on both sides. On ejecta side peelings in +45 deg phi, +90 deg theta; -45 deg phi, -90 deg theta. On spall side peelings in +45 deg phi, -90 deg theta; -45 deg phi, +90 deg theta orientation. Elliptical crater 5 mm long, 4mm wide measured on front surface; 6mm long and 5mm wide(horizontal) on rear surface. Surface not raised around crater.
933 29-J	an-86 Thin type)	(bumper- plate.	Aluminum 6061-T6 Mass/unita: 0.0086	0.089 rea = lbm∕in^2	ن	æ	139.62	139.5	Complete penetration with approx. 6mm diameter circular crater. Petaling on front crater. Petaling on front surface. Only slightly raised lip on rear surface. Obvious Circular ejecta spray pattern in styrofoam catcher for front surface. Only random aluminum fragments imbedded in styrofoam catcher for rear surface spall.
969 14-/	Apr-86 Semi- plate	-Infinite 9.	Graphite/ Epoxy, No c (Generic) Mass/unit a 0.0147	0.276 .loth .rea = .lbm/1n ⁻ 2	G		3 240.6	240.49	<pre>Approx. 3mm dia. surface crater that does not penetrate plate (approx. 1.5mm deep). Some spall off back.</pre>
972 15-,	Apr-86 Bump(Ъ	Graphite/ Epoxy, No c (Generic) Mass/unit a	0.078 :loth irea =	4	·	4 36.94	36.6	<pre>1 Complete penetration, 5.6mm dia. circular hole. Multi- ple small craters on back- up sheet, but not pene- trated. 0.31g ejecta/</pre>
	Inne	r Wall	0.0051 Al 6061-T6	lbm/in ² 0.032	G	-	6 45.72	2 45.7	0 spall collected.

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Target Data on JSC Light Gas Gun Shots

Other	o? Purpose of Shot	Test shot for Dr. Yew's model (The University of Texas).	Test shot for Dr. Yew's model (The University of Texas).	Test shot for Dr. Yew's model (The University of Texas).	Test shot for Dr. Yew's model (The University of Texas).	Test shot for Dr. Yew's model (The University of Texas).	Test shot for Dr. Yew's model (The University of Texas).	Secondary shot to quantify ejecta and spall character- istics (mass, size, distri- bution, velocity). With cloth, normal impact.
	Doc. Photo							Yes 30 micro-sec :t)
o ¹	Impact Photo?	N	No	N N	° N	Ň	<mark>с</mark> N	Yes (of spall 3 after impac
	Velocity (km/sec)	6.19	8	6.11	5.17	4.57	4	5.89
	Length (inches)	0.0709	0.0739	0.0736	0.034	0.034	0.0354	0.0676
rojectile	Diameter (inches)	0.0697	0.0693	0.0698	0.0705	0.0706	0.0706	0.0716
P. T	Mass (milligrams)	5.07	4 .99	Ω	ŝ	Q	4.98	4.86
	Projectile Material	Nylon	Nylon	Nylon	A1 6061	Al 6061	Al 6061	Nylon
JSC Shot #		901	606	910	911	912	913	617

Other Data on JSC Light Gas Gun Shots

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Target Data on JSC Light Gas Gun Shots

JSC Shot #

1	Date					Target			
ະ ວ		Target type	Material	Thickness (inches)	Length (inches)	Width (inches)	Mass before (grams)	Mass after (grams)	Damage Notes
		Standoff Dist	ance	4.000					
975	16-Apr-86	Bumper	Al 6061-T6 Mass/unit ar	0.089 •a =	9	9	138.32	138.22	Complete penetration of bumper, 5mm dia. circular
		Inner Wall	0,0085 Al 6061-T6	1bm/1n^2 0.032	5.75	5.75	45.51	45.50	hole. Multiple craters on backup front surface
		Standoff Dist	ance	4.000					with dimpling on back, but did not penetrate. 0.09g ejecta/spall collected.
979	18-Apr-86	Bumper	Al 6061-T6 Mass/unit ar	0.089 cea =	Q	9	138.25	138.25	Complete penetration of bumper, 5.2mm dia. circular
		Inner Wall	0.0085 Al 6061-T6	1b m/in^2 0.032	5.75	5.75	43.21	43.2	hole. A few small craters on backup front surface
		Standoff Dist	ance	4.000					With some dimpling on back, but did not penetrate. 0.02g ejecta/spall collected.
981	22-Apr-86	Bumper	Graphite/ Epoxy, AS4/3 JSC-02B-004 Mass/unit at	0.095 3501-6 (no cloth)	ß		86.3	86.0	Complete penetration of bumper with 6mm dia. hole. Numerous very small craters on surface of backup plate
		Inner Wall	0.0053	1bm/in ² 0.032	5.75	5.75	44.24	44.21	but no dimpling or pene- tration. 0.2g ejecta/spall collected (slight amount of
		Standoff Dist	ance	4.000					aluminum contained in ej/sp)
986	29-Apr-86	Bumper	Graphite/ Epoxy, AS4/3 JSC-02A-001 Maec/unit =	0.105 3501-6 (cloth)	9	G	96.75	96.52	Complete penetration of bumper with 5mm dia. hole. Numerous very small craters and shallow short cuta on
		Inner Wall Standoff Dist	0.0059	1bm/1n^2 0.032 4.000	5.75	. 5.75	46.08	46.09	surface of backup plate. 4-5 small dimples on back of backup but no penetration. 0.1g ejecta/spall collected.
066	30-Apr-86	Bumper (30 deg.	Graphite/ Epoxy, AS4/3	0.111 3501-6 (B	60	96.9	96.6	Complete penetration of bumper with 4.5mm dia. hole. Numerous your small craters
		opiique impact) Inner Wall	Mass/unit ar 0.0059	(стоси) rea = lbm/in^2 0.032	5.75	5.75	45.3	45.3	and shallow short cuts on surface of backup plate, but no small dimples on back of backup

A-12

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	Other	o? Purpose of Shot	Secondary shot to quantify ejecta and spall character- istics (mass, size, distri- bution, velocity). No cloth, oblique impact (-30 deg phi from front surface normal).	Secondary shot to quantify ejecta and spall character- istics (mass, size, distri- bution, velocity). Normal impact. This shot on aluminum target is for comparison purposes with composite targets.	University of Texas test to check for projectile in ejecta/spall. 0.01 g ejecta/spall collected.	Test shot to check new high-speed camera.
		Doc. Phot	Yes	Yes	°N N	No Camera)
67		Impact Photo?	° z	0 2	No	Yes High-Speed
as Gun Shot:		Velocity (km/sec)	7.02	9	5.12	7.19
NSC Light (Length (inches)	0.080	0.0705	0.031	0.072
ther Data on	rojectile	Diameter (inches)	0.071	0.0714	0.0695	0.0695
0	<u>0</u> ,	Mass (milligrams)	8 9	4 98	4.86	5.00
	JSC Shot #	Frojectile Material	923 Nylon	933 Nylon	969 Al 6061	972 Nylon

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A-11

Target Data on JSC Light Gas Gun Shots

137.3 Complete penetration of bumper, 3.5mm dia. circular hole. 30-40 craters on
45.36 backup front surface with no penetration or near penetrations. 0.06g ejecta bumper, 4.8mm dia. circular hole. 40-50 craters on backup front surface with some dimpling on back, 3-4 near penetrations, 1 did penetrate. 0.02g ejecta and spall collected. some dimpling on back, but 0.18 Damage Notes and no penetration. 0. ejecta/spall collected. 137.32 Complete penetration of 45.21 Mass after (grams) Mass before 45.35 138.85 137.32 45.21 (grams) 5.75 5.75 ဖ ω (inches) Width Target 5.75 ဖ 5.75 G (inches) Length Thickness (inches) 4.000 Al 6061-T6 0.089 Mass/unit area = 0.0085 lbm/in²2 Al 6061-T6 0.032 4.000 4.000 0.089 0.032 0.0085 lbm/in² Al 6061-T6 0.03 H Al 6061-T6 Mass/unit area Material Standoff Distance Standoff Distance Standoff Distance (exactly same as 991) Target type Inner Wall Inner Wall 992 02-May-86 Bumper 991 U1-May-86 Bumper Date JSC Shot #

A-14

and spall collected.

	Shot	of low h aluminum minum	of low h aluminum minum
her	Purpose of	condaries test ergy impact wit ojectile on alu rget using the gh-speed camera	condaries test ergy impact wit ojectile on alu rget using the gh-speed camera
ot	Photo?	No en ta hi	No Se en ta hi
	Doc.	act)	act)
a	Impact Photo?	No (missed imp	No (missed imp
	Velocity (km/sec)	5.72	4.12
	Length (inches)	0.0297	0.0309
rojectile	Dlameter (inches)	0.0719	0.0719
, ц	Mass (milligrams)	4.87	5.08
	Projectile Material	Al 6061	A1 6061
JSC Shot #		991	665

Other Data on JSC Light Gas Gun Shots

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Appendix A - Listing of All Shots with Characteristics and Notes

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	Damage Notes		all hole, delamination on ont75"dia., back-1"dia. all raised bumps on back of ate. Plate was almost pene- ated. Some deep craters front.	all hole, visible lamination (.5" dia.). most no damage, less an fiberglass only. No aters or bumps.	all hole, elliptical delami- tion, 75" dia. front & back. me small raised bumps on ck, not as many as 878, worse an 765.	rcular crater (0.16" dia,0.15" iep). Front surface noticably dised around crater, no peel- igs, small checker-board areas oken away from surface around ater. No penetration (taped ick - no spall), slightly raised hind impact point.	.ightly rectangular crater(0.16 0.2" and 0.14" deep). Long
	Mass after (grams)		r P Srr P C T C C C C C C C C C C C C C C C C C	A de A de C t h		513.58 C de 11 12 11 12 12 12 12 12 12 12 12 12 12	510.125 SJ x
	lass before h (grams)		28.04	34.83		513.69	510.32
arget	Width M (inches)	မ	2.875 5.75	2.875 5.25	2.875 5.75	©	9
E.	Length (inches)	0	2.875 6	2.875 6	2.875 6	ω	9
	Thickness (inches)	0,667 ric). rea = lbm/in ² 2	05A-002 05A-002 0.032 4.000 4.000 1 lbm/ln ² 2	. 0.158 04A-001 0.032 4.000 1/unit area = 1 lbm/in ²	(suit) 0.075 0.032 4.000 *rea = */in^2	0.5 /3501-6 3 area = 5 lbm/in^2	/3501-6
	Material	Graphite/ Epoxy (gene Mass/unit a 0.0380	Fiberglass B86-1, JSC- Aluminum (6061-T6) ance Bumper Mass Bumper Mass	Hybrid Comp B86-2, JSC- Aluminum (6061-T6) ance Bumper Mass Bumper Mass	Fiberglass(B86-3 Aluminum (6061-T6) ance Mass/unit a 0.00529 lbn	Graphite/ Epoxy, AS4, JSC-01A-003 Mass/unit a 0.031	Graphite/ Epoxy, AS4,
	Target type	Thick plate	Bumper Inner Wall Standoff Dist	Bumper Inner Wall Standoff Dist	Bumper Inner Wall Standoff Dist	Semi-infinite Plate. Cloth.	Semi-infinite Plate.
SC Date	Shot #	873 20-Nov-85	878 25-Nov-85	879 26-Nov-85	881 27-Nov-85	883 02-Dec-85	884 03-Dec-85

Target Data on JSC Light Gas Gun Shots

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A-4

her	Purpose of Shot	condaries test for gh-speed film on aluminum rget.	condaries test to t low energy impact ta on aluminum target. gh-speed film did not pture impact.	condaries test of high ergy impact on this type aphite/epoxy target with jh-speed camera capability.	condaries test of high sigy impact on this type uphite/epoxy target with gh-speed camera capability. to baselines this type uposite.	condaries test of high srgy impact on this type phite/epoxy target at deg. oblique impact, with h-speed camera capability.
ŧ	Doc. Photo?	No Se Amera) hi ta	N S S S S S S S S S S S S S S S S S S S	Lm No Ser Bari hit	No Sec m en pact) arr Alt Alt	ы No Sec ent в ra 30 hig
_	Impact Photo?	Yes High-Speed C	Ŷ	Yes 1gh-speed fil	Yes Igh-speed fil arts after im	Yes Igh-speed fil
Jas Gun Shote	Velocity (km/sec)	6.66	5.4 (Est.)	7.38 H	7.01 H (but stu	6.29 HI
n JSC Light G	Length (inches)	0.066	0.0716	0.0696	0.0747	0.0711
ther Data or rojectile	Diameter (inches)	0.0695	0.0694	0.0695	0.0708	0.0715
P G	Mass (milligrams)	4.60	4.60	4.91	4.97	5.02
	Projectile Material	975 Nylon	979 Nylon	981 Nylon	988 Nylon	990 Nylon

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A-13

Appendix B - Raw Data for shots 883,884,894,917,923,933

(also includes calculations for theta, phi, cone angle, diameter, velocity, energy)

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B-1

3. Phi angle, Phi (deg), is the angle from the impact point to the ejecta/spall particle in the vertical plane (see diagram). The following equation is for an ejecta particle with the position origin in the lower left-hand corner of a thin plate.

4. Cone angle, CA (deg), is the angle from the impact point to the ejecta/spall particle. Zero degree cone angle is normal to surface at impact point.

 $CA = acos ((Z - Z_0)/R) * 180/pi$

5. Particle diameter, D (mm), is determined from the particle density, p (g/cc), and assuming cylindrical particle geometry.

 $D = 2 * (M * 1000/(pi * L * p))^{0.5}$

6. Particle cross-sectional area, A (mm²).

 $A = (D/2)^2 * pi$

7. Particle velocity, V (km/sec), is derived from particle kinetic energy considerations.

 $V = ((2 * S_{c} * (A + (pi * D * P)) * P / M)^{0.5})/1000$

8. Particle kinetic energy, KE (joules).

 $KE = 0.5 * M * V^2 * 1000$

Appendix B

Measured and Calculated Data

Measured Parameters

For each ejecta/spall particle collected in the styrofoam catchers, the following parameters were measured.

- Position from suitable origin--for the ejecta side of a thin plate this is typically the lower left hand corner of the plate--in X, Y, Z coordinates (mm).
- 2. Length of ejecta/spall particle, L (mm).
- 3. Depth of particle penetration into the styrofoam, P (mm).
- 4. Mass of particle, M (g).
- 5. Point of impact: X₀, Y₀, Z₀ (mm).

<u>Constants</u>

- -

- 1. Graphite/epoxy density, PGE, is 1.5775 g/cc.
- 2. Aluminum density, P_A, is 2.712 g/cc.
- 3. Styrofoam shear strength, S_s, is 55M pascals (Ref.29, p.585).

Calculated Parameters

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1. Distance from impact point to particle, R (mm):

 $R = ((X - X_0)^2 + (Y - Y_0)^2 + (Z - Z_0)^2)^{-0.5}$

2. Theta angle, Th (deg), is the angle from the impact point to the ejecta/spall particle in the horizontal plane (see diagram below). The following equation is for an ejecta particle with the position origin in the lower left-hand corner of a thin plate.

Th = asin
$$((X - X_0)/((Z - Z_0)^2 + (X - X_0)^2)^{0.5}) * 180/pi$$

Looking Down
On Target
X-Z plane
Proj.
Surface
Normal
- 90
- $\frac{-\theta}{+\theta}$
Ejecta + 90
Target
- $\frac{-\theta}{+\theta}$
Spall Side
B-2

JSC Shot No. 983 12/23/85

			Measured Val	les							Calculated Val	lues		_
Particle No.	K location of impact (origin at e	Y location of impact) (origin at 4)	2 location of impact (origin at e	Penetration Depth	Length of Particle	E	125	R location of impact (origin at ee	Theta locatio of impact 1) (origin at ee	m Phi location of impact)(origin at eel	Cone Angle (from normal)to surface) (origin at ##)	Average Biaseter	Average Area	Velocity
	2	2	2	8	1		sei	:	Deyr ees	Degr ees	Degrees	:	oo squared	Ka/sec
4	12	5 148	4	0.5		2	0.00025	96.96	1 53.47	61.61	66.41	0.10	0.01	0.60
. .	12	2 148		2 0.5		. ~	0.00025	116.52	36.87	45.78	51.83	0.10	0.01	0.60
*		2 148		5 0.2			0.000025	123.20	1 40.48	44.62	52.53	0.14	0.02	0.30
	12	148	-			-	0.0002	148.60	1 24.78	32.31	38.06	0.20	0.03	1.19
84	, in	7 115		. 0		~	0.0003	146.55	5-71	16.32	17.20	0.28	0.06	1.74
64	เที	06 0	Ĩ			~~~	0.001	142.47	-8.53	6.52	10.68	0.20	0.03	1.69
20		7 110	Ĩ	0 2.5		2.5	0.0001	154.31	-21.09	14.42	24.87	0.18	0.03	1.99
15	1	1 51	Ĩ	0		2	0.0005	141.16	\$ 2.45	-6.92	7.34	0.43	6 0.16	1.15
52	7	6 82	Ĩ.	0 1.1		1.5	0.004	140.32	7 2.05	3.27	3.66	0.46	0.17	0.59
53	Ň	16 8	Ť		.	2	0.0001	147.44	1 -17.07	. 6.92	18.28	0.20	0.03	1.69
2	CÓ	5 55	1	0 1.5		1.5	0.0001	141.96	9 S.71	-1.13	9.57	0.21	0.04	1.37
55	đ	5 87	Í	0.1	-	-	0.00005	141.30	0 5.71	5.31	1.11	0.20	0.03	0.62
56	¢	3 82	1	•	_	-	20000-0	141.94	• 8.93	1 3.27	9.49	0.21	0.03	1.21
5,	12	6 46	Ť.	•	_	m	1000'0	153.00	9 21.45	11.31	23.79	0.14	0.02	0.77
28	•	18 61	-	.7	~	7	0.0002	141.85	9 8.93	2.86	9.36	0.2	0.06	1.43
ы 23	=	2 27	•		~ 4	2	C0000 0	97.24	6 56.50	-15.00	61.10	0.1	20.0	2.00
99			- 1	0	~	-0 1	0.0009	11.05	5 62.24	-62.30	82.54	2.9 2.5	0.10	1.11
19	-	2			_	~ •	1000.0	83.64 	71.91- 2.12		AR-17	2. 2		
79		9		0 e		~ ~	0.0001	124.51	5 8.13 7 -77.47	-55. 05	22.02 11	0.14	0.02	(1.0 (7.0
79	r ñ			C	. ~	• -	0. MOM5	10.01 P. R.	1 -42,16	56-67-	BZ 71	0.26	0.03	0.26
59	4 14	2				• ~	0.001	92.72	2 -44.27	-61.61	64.44	0.20	0.03	1.69
99	. 5			2	~		0.0001	118.39	9 35.75	-44.62	50.69	0.20	0.03	0.44
67	60	9 8			~	2	1000.0	106.02	2 12.94	1 -45.00	45.74	0.2(0.03	1.69
89	1	•	=	3 0.1	2	•	0.0001	135.06	8 -0.51	-33.22	33.22	0.14	0.02	0.39
63	_	7	5	`		~	0.000Z	165.61		-28.20	33.58	0.2	0.04	0.65
2	- 1	6 i		2		~ 1	0000	120.7	-33.02		48.51	N	0.03	G.0
<				.0.	o -	~ ~	0.000	1.98.14	14°C 7		32.67	17 O	0.07	1.57
	-			2 00		а и з	0.0002	115.43	3 28.30	-43.49	47.49	0.15	0.03	2.24
2	9			-		-	0.0005	118.61	1 20.19	9 -40.38	1 42.82	0.21	0.03	1.21
22	(55 loose pa	rticles on bott	100 -	-	-	'n	0.0002418182	0.0	0 -90.00	1 -90.00	•	0.2	0.03	0.00
76	average 5 en	long, .0003 g,	_	-	•	'n	0.0002418182	0.0	0.09- 0	90.00	•	0.21	0.03	0.00
"	0.0133 g tot	•I)		-	•	Ċ,	0.0002418182	0.0	0 90.00		•	0.21	0.03	0.00
78	•			-	•	n	0.0002418182	0.0	0 -90.00		•	0.2	0.03	0.00
79	•			-	6	'n	0.0002418182	0.0	0 -90.00	00.06- N	•	0.21	0.03	0 [.] 0
80	•			-	•	'n	0.0002418182	0.0	0 -90.06	-90.00	•	0.21	0.03	0.00
18	•			-	~	ŝ	0.0002418182	0.0	0 -90.06	1 -90 . 00	c	0.21	0.03	0.00
62	•			-	•	'n	0.0002418182	0.0	0 -90.00	90.06	•	0.21	0.03	0.00
83	•			-	6	'n	0.0002418182	0.0	00.04- 0	00.06- 0	•	0.2(0 0.03	0.00
8	•			-	•	ŝ	0.0002418182	0.0	0 -90.00	90.06- (•	0.2	0.03	0.00
38	•			-	6	n	0.0002418182	0.0	0 -90.00	00.06- 0	•	0.2	0.03	0.00
98	•			-	0	'n	0.0002418182	0.0			-	- S	0.03	0.00
68	•			-	•	5	0.0002418182	6 .0	-90°0	-90.00	•	0.21	0.03	0.00

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¥89	
JSC Shot No.	

Measured Values

			Reasured Val	lues						_	Calculated Val	nes			
Particle No.	K location of impact forigin at 4	Y location of impact !) forigin at f	<pre>2 location of impact) lorigin at 4</pre>	Fenetration Depth	Length of Particle	Has	~	R location of ispact (origin at #s)	Theta Jocation of impact (origin at ##)	Phi location (of impact (origin at ##)	Cone Angle (from norsal to surface) (origin at ee)	Aver age Di aneter	Average Area	Velocity	-
	2	:	1	2	:		ĩ	:	Degrees	Degrees	Degrees	=	as squared	Ka/sec	
-	-	5		5 0.5		••	0.0002	72.75	-85.97	-12.65	84.07	0.0	0.04	0.11	
		• •		-	. –		0.0001	15.67	-87.58	-83.42	87.73	1.0	0.02	0.77	
3		. 0	0	- 60	~	- 10	0.0003	13.22	-83.57	63.43	83.73	0.2	0.04	1.52	
	-	0				3.5	0.001	82.98	-15.17	-45.22	11.47	0.1	0.02	0.74	
•,	2	0		25		œ	0.0017	78.15	-70.60	-40.03	71.34	0.4	0.13	0.89	
		0 10	. ~ .		. ~	-	0.0002	84.21	-65.07	43.21	66.93	0.2	0.03	1.19	
~		Г О	-	0	~	1	0.003	83.05	-60.60	-21,80	61.21	0.1	0.03	0.94	
	~	8	7	75	~	2	0.0001	104.09	-43.43	9.83	43.90	0.2	0.03	1.69	
.	•	0	7 11	10		5	0.0006	132.02	-32.84	-8.79	33.57	0.3	0.08	1.29	
1	~	0	7	1 1	_	m	0.00007	84.73	-58.80	-21.57	59.50	0.1	10.0 8	0.85	
1	-	0 0		52 0.5	2	2	0.0002	89.45	-53.78	-17.10	54.46	0.0	0.01	0.62	
=	~	0 0	2	51 0.5	2	1.5	0.00003	95.51	-49.33	-17.30	50.31	0.1	0.01	0.61	
-	~	0	5	00 0.5	5	2	0.0004	136.10	-35.37	-30,54	42.71	0.1	5 0.01	0.53	
=	-	0		C 18	2	'n	0.0001	121.84	-40.54	-33.05	47.06	0.1	0.01	1.95	
	~	0 10		10 1	~	•	0.00002	133.48	-32.84	13.30	34.50	0.0	00.0	2.20	
1	~	•	•	58	-	~	0.0008	80.01	-68.48	-40.60	69.51	9.4	. 0.17	1.82	
-	-	0 10		•••	~	m	0.0001	90.31	-57.63	36.25	60.11	0.1	6.02	1.52	
7	œ	0 · 11	2		~	2.5	0.0001	111.76	-42.68	26.86	46.45	0.11	9 0.03	1.59	
-	•	0	5	87	_	2	0.0001	116.49	-39.22	19.61	41.68	0.2	0.03	0.85	
ž	6	0	_	.7	2	2	0.001	14.71	-68, 48	-39.40	69.44	0.2	0.03	1.69	
2	-	8	9	20		2	0.0019	74.01	14.27	16.70	74.32	0.3	9 0.12	0.15	
2	5	11 23	-	2	~	~	0.0003	92.67	57.63	10.91	60.95	0.2	0.04	1.52	
2	1	42 6	0	32	~	ŝ	0.0003	78.40	65.74	-15.71	65.91	0.2	0.04	1.02	
2		12 2	5	.7	~	ŝ	0.0002	98.72	55.94	-45.59	16.04	0.1	9 0.03	1.13	
N		5 5		42	-	-	0.0002	91.84	57.63	-39.43	60.66	0.2	0.03	2.37	
2	<u> </u>			62 0.		-	1000.0	94.27	48.87	-0.92	48.87	0.1	0.02	0.36	
2	-	24	9	65		3.5	0.0001	11.99	47.53	21.80	49.32	0.1	0.02	0.74	
77		a : 21	~ `	0		•	0.002	131.06	32.84	3.12	32.93	0.2	0.03	0.60	
5		21			_	-	0.001	64.70	28.80	38.33	61.36	0.2	• •	1.03	
5				5	~	•	1000.0	89.46	54.51	20.43	35.24		0.02	1.1	
5		12		38	~ .	•	1000.0	104.24	68.48	68.48	74.42	0.1	0.02		
51	~	2	= '	0.2	~ 1	7	0.000	138.00		20.02	42.34	0.2	0.03	0.44	
Ś	× ×	12 12	0	20 0Z	~	-	50000.0	114.35	19.41	38.66	52.26	0.2	0.03	0.26	
ž		14 14	2	52	~	~	0.0001	118.01	48.87	48.87	58.31	0.2	0.03	1.69	
ы	2 14	12 17	r	31 1	2	-	0.0001	78.30	65.07	-1.74	65.07	0.1	0.02	1.41	
10	رب م	52 14		20	~	2	1000.0	91.31	-20.81	55.95	56.80	0.2	0.03	1.69	
13	~	57 14		52	~	-	0.0002	91.52	-15.07	54.90	55.38	0.2	0.03	1.19	
ž	-	14		30	_	2	0.0001	80.47	IB.43	67.93	68.11	0.2(0.03	0.85	
5	•	77 14		55	_	2	0.0001	92.40	6.23	53.38	53.47	0.2	0.03	0.85	
Ŧ	e	79 14		42 0.1	20	2	0.0001	85.46	10.78	60.42	60.56	0.2	0.03	0.44	
	_	11 8/	8	26	~	2	0.0001	93.06	7.13	52.88	53.01	0.21	0.03	1.67	
		50 Di	B Ø	20	2	7	0.00005	81.96	55.41	74.88	75.88		0.02	2.00	
-	1 1	07 14		75	_		0.000025	111.34	25.64	44.62	47.65	0.1	0.02	1.43	

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	, , , , , , , , , , , , , , , , , , ,		Keasured Vali	et s						Calculated Val	ues		
Particle W	io. X location of impact (origin at (Y focation of impact e) torigin at el	Z location of impact) (origin at fl	Penetration Depth	Length of Particle	Mass	R location of impact (origin at =	Theta location of iopact :*) (origin at **)	<pre>* Phi focation of ispact (origin at ##)</pre>	Come Angle (from normal)to surface) (origin at **)	Average Di søeter	Average Area	Velocity
	1	2	8	2	4	saų	1	Degrees	Degr ees	Degrees	2	oo squared	Ka/sec
	. 132			6		0.0022	0.0		-90.00	•	0.1	40 0.13	0.00
	. 133			0	-	6 0.006	0.0	-90.00	-90.00	0	0.1	28 0.06	0.00
	134 (44 small 1.	oose particles,		ð	-	3 0.000590909	0.0	N -90.00	-90.00	0	0.1	13 0.01	0.00
	135 average 3 m	a. 0.0026 a tota	(]•	•	-	3 0.000590949	0.0	-40.00	-90.00	•	0.1	13 0.01	0.0
	136					3 0.000590909	0.0	-90.00	-90.00	•		13 0.01	0.0
	. 137			•	-	3 0.000590909	0.0	10 -90.00	-90.00	•	0.1	13 0.01	0.00
	. 138					3 0.000590999	0.0	-90.00	-90.00	•	0	13 0.01	0.00
	. 139			ø	-	3 0.0000590909	0.0	N -90.00	-90.00	•	0.1	13 0.01	0.00
	. 140			•	-	3 0.000590909	0.0	N -90.00	-90.00	•		13 0.01	0.00
	. 11			.3	.=	3 0.000590909	0.0	00.00- 01	-90.00	6	0.1	13 0.01	00.0
	142 .			•	-	3 0.000590709	0.0	N -90.00	-90.00	•		13 0.01	0.00
				•		3 0.000590909	0.0	00.00	-90.00	•		13 0.01	0.00
	. 11			•	-	3 0.000590909	0.0	-90.00	-90.00	•	.0	13 0.01	0.00
I				•	-	3 0.000590909	0.0	10 -90.00	-90.00	•	0.1	13 0.01	0.0
3-	146 .			0	-	3 0.000590909	0.0	-90.00	-90.09	•	.0	13 0.01	0.00
•7				•	-	3 0.000590909	0.0	10 -90.00	-90.00	•	0.1	13 0.01	0.0
	148 .			3	_	3 0.000590909	0.0	-90.00	-90.00	•		13 0.01	0.00
				3	_	3 0.000590909	0.0	N -90.00	-90.00	•		13 0.01	0.00
	150 -	•		3	_	3 0.000590909	0.0	30 -90.00	-90.00	e	0.1	13 0.01	0.0
	. 131			3	_	3 0.000590909	0.0	-90.00	-90.00	æ	0	13 0.01	0.00
	152 .			3	_	3 0.000590909	0.0	N -90.00	-90.00	•	0.1	13 0.01	0.00
	. 121			3	_	3 0.0000590909	0.0	-90.00	-90.00	•	•	13 0.01	0.00
	. 124			-3	_	3 0.000590909	0.0	-90.00	-90.00	•		13 0.01	0.00
	155 ·					3 0.000590909	0.0	-90.00	-90.00	0		13 0.01	0.00
	126			، د	-	3 0.000590909	0.0		00.09-	•		13 0°0	0.0
				•	_	2 0.00000000 0		00.04- 00.00	-90.09	•		13 0.01	0.0
				• •	_	2 0.000299999		00.0Y- 00.0V	0.04-			13 0.01	0.0
						7 A AAASSAAAAB		M. W. M.	00 04-		j e	10.01 CI	8 S
						3 V. VVVVJ7777777777777777777777777777777		00'04- 00'04-	W U0-				8 e
				. 9		3 0.0000590909	0.0	-40.00	00.00-			13 0.01	0.00
						3 0.000590909	0.0	00 -90.00	-90.00	•		13 0.01	0.00
	164 .			0	-	3 0.000590909	0.0	-90.00	-90.00	0		13 0.01	0.00
	. 591			0	_	3 0.000590909	0.0	-90,00	-90.00	•	.0	13 0.01	0.00
	166 .			3	_	3 0.0001590909	0.0	N -90.00	-90.00	•		13 0.01	0.00
	. 191			3		3 0.000590909	0.0	-90.00	-90.00	•	.0	13 0.01	0.00
	168 .			3	_	3 0.000590909	0.0	30 -90.00	-90.00	0	.0	13 0.01	0.00
	. 191			3	_	3 0.000590909	0.0	-90.00	-90.00	•	0.1	13 0.01	0.00
	. 0/1			3	_	3 0.000590909	0.0	-40.00	-90.00	•		13 0.01	0.00
	• 1/1			9	_	3 0.000590909	0.0	-90.00	-90.00	-	•	13 0.01	0.00.0
	. 2/1			5	_	3 0.000590909	0.0	-90.00	-90.00	•	0.1	13 0.01	0.00
	• 113			5	-	3 0.000590909	0.0		-90.00	•		12 0.01	0.00
	. 1/1				_	3 0.000590909	0.0		-90.00	c	0	13 0.01	0.00
	. 5/1				_	3 0.0000590909	0.0	-90.00	-90.00	Đ	0.1	13 0.01	00"0
12/23/85 883 JSC Shot No.

Neasured Values

Particle No.	I locati	ion Y location	Z location	Penetration	Length of	Kass	# location 1	heta location	hi location Cr	one Anale	Aver and	
	of inpac	ct of inpact	of impact	Depth	Particle		of impact o	f ispact .	of impact (fros neres!	Dianeter	
	(or 1 ju	at #) (origin at	<pre>f) (origin at f)</pre>				(origin at ee)(origin at es) ((rigin at ##)to	o surface)		
	:								3	origin at **)	_	
	i	2	2	8	2	i.	2	Degrees	Degrees	Degr ees	1	
176	•			•		3 0.000590909	9.00	-90.00	-90.00	e		-
171	•			0		3 0.000590909	0.0	-90.00	-90.00	• •		~ ~
178	(approx.	, 40 small bose -	.0008 g total)	•		1 0.0002	0.00	-90.00	-90.00			
179	•			•		1 0.0002	0.00	-90.00	-90.00			~ ~
180	•			•		1 0.0002	0.00	-90.00	-90.00			~ ~
181	•			•		1 0.000Z	0.00	-90.00	-40.00	> c		
182	•			•		1 0.00002	0.0	-90.00	00 00-	• •		~ ~
183	•			•		1 0.0002	0.00	-90.00	00.00-	> c		-
184	•			0		0.0002	0.00	-90,00	00 00-	•	~ •	< -
185	•			•		1 0.00002	0.00	-90.00	00.00-	> c		÷ -
186	-			•		1 0.0002	0.00	- 40, 00	-90.00	~ =	> c	÷ -
181	•			•		1 0.0002	0.00	-90.00	-90.00	• -	• c	š –
188	•			•		1 0.0002	0.0	-90.00	-90.00	÷	> c	÷
189	•			0		1 0.0002	0.0	-90.00	-90.00	• e	> c	÷ -
190	•			•		1 0.00002	0.0	-90.00	-40,00	÷	>	
161	-			•		1 0.00002	0.0	-90,00	-90.00	Ċ	> c	
192	-			•		1 0.0002	0.0	-90.00	-90.00		> o	
Σbl	•			0		1 0.0002	0.00	-90,00	-90.00	• =	• •	
194	-			•		1 0.0002	0.0	-90.00	-90.00	• e	• •	
195	-			0		1 0.0002	0.0	-90.00	-90,00	. 6	• 6	
196	•			•		1 0.0002	0.0	-90.00	-90.00	• •	• •	
191	•			0		1 0.0002	0.00	-90.00	-90.00	c	. 0	
391	• •			0		i 0.00002	0.0	-90.00	-90.00	•		_
199	•			•		1 0.0002	0.0	-90.00	-90.00	•	0	•
00Z	• •			0		1 0.00002	0.0	-90.00	-90.00	0	0	·•
107	• •			0		1 0.00002	0.0	-90.00	-90.00	•	0	. •
707	•			0		1 0.0002	0.0	90.00	-90.00	•	0	
	•			0		0.0002	0.00	-90.00	-30.00	•	0	•
200	-			0		0.0002	0.00	-90.00	-90.00	•	0	
2017 2017	•			•		0.0002	0.0	-90.00	-90.00	¢	0	
207	-			•		0.0002	0.0	-90.00	-90.00	c	0	
208	•			> <			0.0	-90.00	-90.00	c	o	•
904 904	•			> <		1 0.0002	0.00	-90.00	-90.00	•	•	
010	•			~		1 0.0002	0.00	-90.00	-70.00	•	Ó	•
211	•			••		I 0.0000Z	0.00	-90.00	-90.00	¢	0	•
117	•			•		0.0002	0.0	-90.00	-90.00	•	Ó	•
17	•			•		I 0.0002	0.0	-90.00	-90.00	0	0	•
C17	•			0		0.0002	0.00	-90,00	-90.00	•	0	
+ 17 3 1 C	•			0		I 0.0002	0.0	-90.00	-90.00	c	6	
112	-			•		1 0.0002	0.0	-90.00	-90.00	•	5	
217	-			0		0.0002	0.0	-90.00	-90.00	0	0	•
117				Ð		1 0.00002	0.00	-90.00	-90.00	0	0.	-
					Total Nace =	0V71V V					•	
						V.V.0V7						

Calculated Values

Velocity

Average Area

•

Ka/sec

an squared

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	Average Velocity Area	an squared Ka/sec	.16 0.02 9.01	.45 0.16 1.15	.35 0.10 1.29	.19 0.03 2.30	.28 0.06 1.03	20 0.03 1.69	.22 0.04 0.01	.15 0.02 0.01		.15 0.02 0.52	.16 0.02 0.77	.16 0.02 0.77	.16 0.02 0.38		.18 0.03 1.13	.11 0.01 2.44	.13 0.01 0.67	.14 0.07 0.71		.23 0.04 1.28	.16 0.02 2.14	.20 0.03 I.94	.20 0.03 1.94	.20 0.03 1.94	.20 0.03 1.91	. Zo o o o o o o o o o o o o o o o o o o		20 0.03 1.94	.20 0.03 1.94	. 20 0.03 1.94	. 20 0.03 1.94	.11 0.01 3.05			
culated Values	one Angle Average rom noreal Diameter surface) inin at **)	Degrees as	23.09 0.	6.84 0.	11.16 0.	16.68 0.	11.40 21 11	10.84 0.	23.16 0.	24.56 0.	46.36 25 20	40.63 0.	24.85 0.	27.39 0.	75.62 0.	76.33 0.	74.28	71.40	68.71 0.	81.64 0.	11.11	73.89 0.	74.62 0.	67.39 0. Le os	68.56	68.05 0.	67.93 0.	6/.Y2 50 50	0 81.5M	64.83	71.86 0	75.62 0.	79.51 0	66.16 0.	65.42 45.12	01.16 11 11	
Cale	n Phi location C of impact (fi)(origin at ##) to (ori	Deyrees	-20.11	0.40		-6.83	-4.83	3.22	-21.87	-21.87	-38.66	-33.21	22.22	20.47	35.84	32.91	40.36	34.87	35.54	45.00	13. W	16.70	1 48.99	45.00	32.74	15.95	6.12	40. 1	18.80	21.50	29.48	35.84	45.00	24.51	19.77		
	Theta locatio of lepact >> (origin at ++	Degrees	12.32	-6.83		-15.36	10.39 -17.47		6.41	12.32	34.13	20.07 20.01	12.32	2 19.76	9 75.38	1 76.16 2 2 2 2 2	73.84	1 70.82	91 67.91	5 BI.73	1.9.1 1.6.1	-73.84	3 -73.84	-67.91	14°79-	967.91	16.73- 2	-6./9- 	10.8C- 0		-11.51	8 -75.38	1 -79.33	8 65.12	2 65.12	21.00	
	R location of impact (origin at ##	:	154.37	143.02	144.74	148.24	144.86	14.54	154.45	156.12	150.40	76-88	156.49	159.92	72.48	71.91 24 56	73.87	75.24	77.10	14.02	10.21	72.09	75.43		76.61	74.89	74.51		97 97 10 87	11.5	73.8	72.48	11.11	. 79.16	76.97		
-	:		.0004	5000.	.0003	.0002	.0001	0001	.0003	. 0062	1000.	.0002	1000	1000	.0004	.0003	.0002	1000.	1000"	.0001	00002 00005	.0002	.0002	.0003 all in 30 mm dia	.0003 contered at	.0003 (0,85,28)	. 0003	- 0003		. 0003	. 0003	. 0003	. 0003	.0001 all in 42 as dia	.0001 circular area	. VVVL CENTERED AL	
	Nas	suð	13 0	2 0	0	<u>5</u>		> 0 > 0		0	<u> </u>				13 0			~ ~	2	•	•		9	-0 -	• •	0	-9 ·	- -	• •	» •		9	9	•	~ ~	~ •	
	Length of Particle	3			·	•																															
	Penetration Depth	1	0.01	2	2	•		- ~	0.01	0.01	0.01				-	= '		• -	-	1			-			•	-	•	• •		• •	•	•	eo.	.	~ `	
Neasured Value	<pre>% focation of impact (origin at e)</pre>	1	142	142	142	142	23	21	142	142	6	9	142	142	18	27	5 8	24	28	9 :	9 1	2 2	20	28	87	58	58	81 :		8 19	23	81	13	22		7.	
	Y focation of impact (origin at 4)	:	20	13	8	8	09		12	15	•		130	125	85			6	42	28 28	88 8	8 2	5	<u>8</u>	6	8	2	21	6 1	3 2	38	62	85	94	83.5	5, 1, 1, 1,	
	I location of impact (origin at *)	1	100	52	4	8	8 ×	3 5	5 g	100	130	071	8	120	138	138	971 811	138	138	138	138	0	•	•	• •			•		• •	• •	•	•	138		9.5	
	icl e Ko.		45	9 4	4	46	4	8 6	22	23	51	8 1	6	5	56	9	10	63	99	; ;;;	85) 9	69	2;	2 2	22	E.	5	2 C		÷.	8	18	82	88	5	ŝ

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12/16/85 98

JSC Shot No.

Reasured Values

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Average Area	eo squared	0.02	0.02	0.0	0.0	0.0	70°0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6 6 6 6		0.0	0.0	0.0	0.0	0.0			0.0	•				0.0	0.0	0.2	0.0	0.0		0.0
Average Di anet er	9	0.17	0.15 • • •	0.26	0.19	0, 12	0, 23	0.18 0.79	0.34	0.11	0.11	0.20	0.12	0.10	0.16	0.13	0.23	0.27	0.10	0.16	0.16	0.16	0.16	0.14	0.31	0.18	0.21	0.20	0.17	1.0 1.0	0.20	0.21	0.59	0.19	0.17	0.38	0.04 0.05
Cone Angle (from normal to surface) origin at #4)	Degrees	81.75	80.15 25 25	70.87	80.28	81.87	75.66	78.08 75. V	66.64	60.25	63.11	56, 38	71.03	53.64	56.50	43.84	44°.35	51.43	46.12	60°.24	44. [1] 40 BI	44.05	91°49	44.06	36.09	45.86	42.70	81.86	16.11	01.12	64.67	73.99	67.56	52.43	14.97	71.33	55.58
<pre>>hi location of impact origin at ++) { (</pre>	Degr ees	5.71	18.43 A 200	-11.77	45.00	50.19	37.87	48.58 50.44	40.16	34.90	-1.64	-6.20	42.61 T7 01	33.23	42.95	33. 15	30.77	57.43	43.83	43.08	12.71	43.83	12.71	11.65	34.44	45.40	32.93	47.73	38.66	20.74	-16.86	-26.57	-24.15	-37.69	-71.57	-68.75	-54.16
eta location f of i s pact rigin at ##) (c	Degrees	-81.75	-80, 13	-70.82	-80.13	-81.75	-75.38	11.74 - 74.60	-65.12	-58.07	-63.10	-56.31	-70.08	54 ° 64 -	-49.95	-35.15	-37.79	-06.00	-21.80	61.1- 	-16.45	-6.84	18.43	20.94	13.91	-10.38	-33.31	81.75	77.74	01.1C	14.41 44.44	73.84	67.20	46.27	65.64	55.67	24.78
R location Th of impact (origin at ee) (o	:	69.73	70.15	13.23	71.06	70.75	72.67	72.63	80.71	86.66	77.38	81. nB	76.91	10.07	105.08	135.87	124.46	85.44	108.21	105.44	108.61 108.47	104.36	109.29	112.72	111.4/	101.95	142.86	70.58	71.62	6/.10 97 95		72.53	75.97	108.25	92.57	87.46	92.00
5		0.0003	0.0009	C000.0	0.0012	0.0002	0.0008	0.0007 A Anei	0.0115	0.0001	0.0001	0.0004	0.0002	2000.0 0 0001	0.0004	0.0001	0.0003	0.0004 0.0004	0.0001	0.0001	0.0001	1000.0	0.0001	0.0001	0.0001	0.0001	0.0002	0.0003	0.0014	0.0131	0.0031 A AAAA	0.001	0.006	0.0005	0.0014	0.0011	0.0001
5 7	6			2 J	2 22	2		8.		. ~	~		= :	2 0	2	5	<u>.</u>	2 5	80	~			~	-	• •	1	.5	-9	6 :	3 :	•	• ā	: =		8	4	9.5
ength of Particle	2						12	5	-							Ī		-							•									=			-
-	-																																				
Penetration L Depth	1	0.8	6.1 0	20 0	- 0-	4.5	•	5°5	 10	1.5	0.5	2.5		c	, <u> </u>	0.5	- :	= *	0.5	-	~ ~	. 5.1	0.5	2	0.5 		2	3.5	24	-	<i>с</i> , г	ч -e	, - α	1.5	-	-	0.5
Z location Penetration L of iapact Depth lorigin at +)	1	10 0.8	12 6.1	18 8 28 9	12 12	10 4.5	18 4	15 9.5	10 10 10	43 1.5	35 0.5	46 2.5	25		, - 29	98 0.5		27 II 46 J	75 0.5	1 1	78 2	75 1.5	78 0.5	81 2 2	C.0 28 7.1 201	71 1.5	105 2	10 3.5	15 24	97 I		20 70 k		66 1.5	24 1	28 1	52 0.5
Y location Z location Penetration L of impact of impact Depth lorigin at +) (origin at +)	-	73 10 0.8	76 12 6.1	72 18 8 47 24 9	84 12 9	84 10 4.5	86 18 4		C.C TI CT 01 CT 09	102 43 1.5	71 35 0.5	67 46 2.5	95 25 7 25 7		110 56 58 1	136 98 0.5	125 89 1 	94 27 11 144 46 3	144 75 0.5	144 77 1	144 78 2 114 78 2		144 78 0.5		2.0 58 941 2.1 201 341	14 71 1.5	140 105 2	B 3 10 3.5	84 15 24			04 33 64 42 70 4	59 . 29 6	21 66 1.5	0 24 1	0 28 1	0 52 0.5
It location Y location Z location Penetration L of impact of impact Depth (origin at 4) (origin at 4)	-	0 73 10 0.8		0 72 18 8 0 47 24 9		0 84 10 4.5	0 86 18 4		C.C 71 CY V 0 99 G		0 71 35 0.5	0 67 46 2.5			o 126 58 1	0 136 99 0.5	0 125 89 1	0 94 27 11 49 144 46 3	39 144 75 0.5	67 144 77 1	46 144 78 2 20 111 11	2 1 1 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 2 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1	95 144 78 0.5	100 144 81 2		56 144 71 1.5	0 140 105 2	138 83 10 3.5	138 84 15 24			1.00 01 0.00 f	138 59 29 6	138 21 A6 1.5	122 0 24 1	110 0 28 1	93 0 52 0.5

0.55 1.26 1.26 2.75 2.71 1.26 2.75 2.71 1.26 2.71 2.75 2.71 2.75 2.71 2.75 2.71 2.75

Calculated Values

Velocity

Ka/sec

12/16/85

Calculated Values

JSC Shot No. 884

Values	
Neasured	

(origin a	ct of impact t+) (origin at+)	of impact (origin at 4)	Bepth	Lengta or Particle	-	555	и лосации of impact (origin at ##)	of jepact (origin at te)	tru rocación of impact (origin at 44)	three normal (from normal) to surface) (origin at 24)	Diaveter	Pi in	
:	:	2	2	8	~	sat	1	Degr ees	Degr ees	Degr ees	:	en squared	Ka/sec
. 81				8		0.00028	0.00	-90.00	-90.00	0	0.17	0.02	0.0
136				-	-	0.00028	0.0	-90.00	-90.00	0	0.17	0.02	0.0
137				8	8	0.00028	0.00	-90.00	-90.00	c	0.17	0.02	0
138				¢0	~	0.0002B	0.0	-90.00	-30.00	•	0.17	0.02	°.
139				æ	(1)	0.00028	0.00	-90.00	-90.00	¢	0.17	0.02	°.
						0.00028	8.0	-90.00	-90,00	6	0.17	0.02	0.
					. =	A. 00078	0.00	00'04-	-90.00	. 0	0.17	0.02	.0
						0.00020		00 UA-	00.09-	• •	0.17	0.07	
761				. 8		0 00070		00.00-	00 00-	• c	0.17	0.07	
				9 6		87000 V		00.00		• c			: -
					D 4	87000.0		00 00 V	A . A .	~ <		10-0 0 0	
-	•					8700.0	M-7	00'04-	10 · A -	> <		20.0	Š
146 Loose	particles (total of	(sag \$700.)		5.2	~	C1000 0	0.0	- 10.02	M'n4-	- •	6 - 14 - 14	6. 61 •	÷ •
147 (49 pa	rticles)			3.5	5	0.00015	0.00	-90.00	-90.00	0	0.19	0.03	
148				3.5	.	0.00015	0.0	-90.00	-90.00	•	0.19	0.03	.
. 61				3.5	\$	0.00015	0.0	-90.00	-90.00	•	0.19	0.03	°.
150				3.5	5	0.00015	0.00	-70.00	-90.00	0	0.19	0.03	0
. 151				3.5		0.00015	0.0	-90.00	-90.00	•	0.19	0.03	.0
						0.0015	0.00	-90.00	-90.00	0	0.19	0.03	0
. 151				5.5		0.00015	0.00	-90.00	-90.00	•	0.19	0.03	ō
						0.00015	0.00	-90.00	-90.00	•	0.19	0.03	ċ
				5.2	. 107	0.00015	0.0	-90.00	-90.00	•	0.19	0.03	¢.
156				3.5		0.00015	0.0	-90.00	-30.00	c	0.19	0.03	
. 121				3.5	s	0.00015	0.0	-90.09	-90.00	8	0.19	0.03	Ö
158				3.5	~	0.00015	0.0	90.00	-90.00	•	0.19	0.03	Ó
				3.5	2	0.00015	0.0	-90.00	-90.00	c	0.19	0.03	ć
. 091				3.5	~	0.00015	0.0	-90.00	-90.00	•	0.19	0.03	ē
. 191				3.5		0.00015	0.00	-90.00	-90.00	•	0.19	0.03	•
162				3.5	\$	0.00015	0.0	-90.00	-90.00	•	0.19	0.03	0
163				3.5	5	0.00015	0.00	-90.00	-90.00	•	0.19	0.03	•
. 161				3.5	ŝ	0.00015	0.00	-90.00	-90.00	•	0.19	0.03	•
. 591				2.5	2	0.00015	0.0	-90.00	-90.00	e	0.19	0.03	0
. 991				3.5	5	0.00015	0.00	-90.00	-90.00	c	0.19	0.03	•
					. 107	0.00015	0.0	-90,00	-90.00	c	0.19	0.03	0
. 891						0.00015	0.00	-90.00	-90.00	0	0.19	0.03	0
						0.00015	0.00	-90.00	-90.00	0	0.19	0.03	0
						0.00015	0.00	-90.00	-90.00	0	0.19	0.03	0
• 161					, r	0.00015	0.0	-90.09	-90.00	•	0.19	0.03	•
•						A AMAIS	0.0	-90.00	-90.06-	. 0	0.19	0.03	o
						0.0015	0.00	-90.00	-90.00	0	0.19	0.03	-
						0.00015	0.00	-90.00	-90,00	c	0.19	0.03	
						0 00015	0.0	-90.00	-90.00	•	0.19	0.03	0
						21000.0			-90.00		0.19	0.03	0
						0 00015	0.0	-90.00	-90.00	•	0.19	0.03	•
											u , v	20 0	•
					r		0°.0	- 90.00	-40.00	>	V.17	U.V.	>

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Measured Values

							ļ				Calculated Valu	2		
Particle No.	X location of impact (origin at e) (Y location of iepact (origin at +)	2 location of impact forigin at f)	Penetration Depth	Length of Particle	Nass		R location of impact forigin at H	Theta Jocation of impact	n fhi location of impact (origin at ex)	Cone Angle (from normal to surface)	Average Dianeter	Åver age Årea	Velocity
	3	1	=	2	1	506		:	Degrees	Degrees	(origin at ee) Degrees	:	mø squared	Ka/ser
68	138	2:	32	3		.0	- 1000	14.01	11 11	-		:		
213	170	~;	21.5	م			- 1000	72.28	72.69	1. 1 1	21.00	0.11	10.0	3.05
2.0	901 901	~	= :	ŝ		.0	- 1000	69.68	BO 94		12.00 00.00	0.11	0.01	3.05
20	2	:	67	•	-	0.1	0001 all in 20 m dia.	105.80	00.02-		80. ye	0.11	0.01	3.05
10	9 :	E	67	n	-	0.1	2001 circular area	109.89	- 14.18	8.4	1/ .00	0,14	0.02	2.11
	2 8	2	67	•	-	0.	2001 centered at	114.49	11.11-	90.75		0.14	0.02	2.11
6 8	R 2	Ŧ	"	5	-	0.6	201 (20, 144, 67)	26 YII	10.14- 11.14	47.06	54.25	0.14	0.02	2.11
01	8	Ē	67	3	-	0.0	. 100	109.88	01 72 -	90°C	48.52	0.14	0.02	2.11
8	07 3 C1	23	21	ſ	•	0.6	. 100	104.09	01 '0C-	47.08 51.13	57.45 57	0.14	0.02	2.11
28	2.20	1	80	2	m	0.0	MOUL all in 25 am dia.	107.83	-1 15	00.10	08.90	0.14	0.02	2.11
1001	C./C	ŧ	80	2	*7	0.6	1001 circular area	112.14	01 10-	11.11	01.24	0.16	0.02	1.52
101	È S	1	92.5	2	'n	0.0	001 centered at	118.75	11-11-	44.1 4	44.44 11.11	0.16	0.02	1.52
		: :	67.5	2	•	0.0	001 (50,144,80)	100.50	-15 27	31.10 11 BE	J6.8)	0.16	0.02	1.52
201	C'79		67.5	2	2	0.0	002 all in 15 m dia.	19.99	12-11	C0.01	19.19	0.16	0.02	1.52
20		•	90	2	2	0.0	002 circle at	10.79	14.5			0.28	0.06	1.43
105	5./0 1-:1-:)44)	52.5	~	2	0.0	002 (75,144,60)	89.12	1.6	51.00	77.0C	0.28	0.06	1.43
707		101 CHAA1 101	ai bass for all	â	13	0.0	600	0.00	10.0	00.00	14.00	0.28	0.06	1.43
107	•				13	0.0		0.00	-30.00	00 00-		0.24	0.04	0.00
	•	-			51	0.0	600	0.00	00 00-	00.01	- •	0.24	0.04	0.00
801 011	•	•			13	0.0	007	0.00	-90.00	00.06-	2 0	0.24	0.04	0.90
	Real sear land	' :			13	0.0	600	0.00	-90.00	00.04-	2 <	0.24	0.04	0.00
E	Sail lone o	artirlar (AAC	11 - 1 - 1 - L		33	0.0	014	0.00	-90.00	-20.00	> c	67 · 0	0.0	0.00
112	(33 nartirles		/TE101 596 71			0.00	028	0.00	-90.00	-90.00	• c		0.03	0.00
113		_				0.00	820	0.00	-90.00	-90.00	• c		0.02	0.0
11	•					8.0	028	0.00	-90.00	-90.00	• c	110	7 0 .0	0.00
115	•					0.0	028	0.00	-90.00	-90.00	• e	21 Q	70'A	0.0
116	•					0.0)28	0.0	-90.00	-90.00	• •	0.17	20.0	0.0
117	•					0.00	82.	0.00	-90.00	-90.00	0	0.17	0.02	
118	•					00.0		0.00	-90.00	-90.00	6	0.17	0.07	
611	-							0.0	-90.00	-90.00	e	0.17	0.02	0.0
120	•					0.000		8.8	-90.00	-90.00	0	0.17	0.02	0.00
121	• •				. 60	0.000	82	38	-00.04	-90.00	6	0.17	0.02	0.0
21					8	0.000	R	8.9	M.UT-	-00.07	c (0.17	0.02	0.00
31					80	0.000	38	0.00	-40.00	-00 M	• •	0.17	0.02	0.00
S K	•				80	0.000	28	0.00	00.09-			0.17	0.02	0.00
721	•				80	0.000	58	0.00	-90.00	-00.00	-	/ 1.0	0.02	0.00
121	•				•	0.000	BZ.	0.00	-90.00	-90 M	- e	1.0	0.02	0.00
128	•					000.0	28	0.00	-90.00	-90.00	> c	2 . A	0.02	0.00
129	-					0.000	62	0.00	-90.00	-90.00		21.0	70.0	0.00
130	•					0.000	28	0.00	-90.00	-90,00	~ c		20.0	0.00
133	•					0.00	58	0.00	-90.00	-90.00	¢	0 17	7 0 0	0.00
136	•				жо (0.000	58	0.00	-90.00	-90.00	. c	0.17	7 V.V	2 2
					Ø	000.0	58	0.00	-90.00	-90.00		0.17	0.02	. v.

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						JSC Shot No. 85	24 (Thin Plate	58/11/21				
			Measured Valu	2					Calculated V	Values		
Particle No.	I location of impact (origin at +)	Y location of impact	Z location of inpact +) (origin at +)	Penetration Depth	Length of Particle	hass	R location of ispact forigin at	Theta locat of impact **) forigin at	ion Phi locatic of impact H)(origin at t	on Ave. D	ianeter Ave.	Âr ea
	1	1	:	1	2	ĩ	I	Degrees	ðegr ee s	1	2	uar ed
				Target 152 x	152 x 2 m	(1SC-02B-003)						
EJECTA												
-	(Loose of	* botton)			- •	47 0.036					0.249	0.049
~ •						0.0035 11 0.0055					0°, X00	0.071
° ₩	•					10000					0.135	0.014
	-					79 0.0007					0.140	0.015
•	•	laverage of	2)			21 0.0004					0.157	0.019
~ (21 0.00064					/21.0	0.019
						10 0.0004					0.157	0.019
	•	-				21 0.0064					0.157	0.019
:= 1	•	laverage of	approx. 190)		-	3 0.0000616667					0.129	0.013
8-	•	•				3 0.0000616667					0.129	0.013
-1						3 0.0000616667					0.129	0.015
± ≚ 5						3 0.000061666/					0.179	0.013
	-	-				3 0.000616667					0.129	0.013
: 1	•	•				3 0.000616667					0.129	0.013
	-	•				3 0.000616667					0.129	0.013
<u> </u>						3 0.00061666/					0.179	0.013
~ ~	•	•				3 0.000616667					0.129	0.013
. 22	•	•				3 0.0000616667					0.129	0.013
23	-	•				3 0.0000616667					0.129	0.013
7. 7	• •	• •				5 0.000061666/					0.129	0.013
3 %	•	•				3 0.000616667					0.129	0.013
12	•	-				3 0.0000416667					0.129	0.013
58	•	•				3 0.000616647					9.129 8.138	0.015
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ŧ.	•	•				3 0.000616667					0.129	0.013
8.						3 0.0000616667					0.179	0.013
5 F		• •				3 0.0000416667					0.129	0.013
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Measured Values

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	Total = Total = Combined me (Tess circle (compensate)))))	Total = Total = Combined me (less circle less circle (less circle compensate (compensate)) (compensate (compensate)) (compensate)) (compensate) (compensate))) (compensate)) (compensate)) (compensate))) (compe	Total = Total = Combined me (less circle less circle represented to target bi target b	Total = Total = Total = Total = Combined metalisment of box trigin 4, At lower left hand corner of box trigin 4, At center of open end trigin 4, At center of open end Total from end. Total from end trigin 4, and the open end trigin 4, At center of open end

Calculated Values

age Velocity ea	uared ka/sec	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	0.03 0.00	
Average Aver Diaseter Ar	bs an	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.17	0.19	0.19	0.19	0.19	0.19	0.17	0.19	
Cone Angle (froe normal to surface) lorigin at ee)	Degrees	c	0	c	•	•	0	0	•	¢	c	0	c	c	0	•	
Phi location of impact origin at **)	Degrees	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90,00	-90.00	-90.00	-90.00	
heta location of ispact lorigin at **)(Degr ees	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	
		00.00	8.0	8.0	0.00	8.	.00	8.0	8.	8.	8.	8.0	8.	8.	8.	60.1	

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(Thin Plate) 12/17/85

JSC Shot No. 894

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Traction (matched (matched)) Traction (matched) Traction (matched) Traction (matched) Traction (matched) Traction (matched) <	Traction of sector of s	Trans. Trans. Textus Textus<			Reasured Val	ues					Calculated Va	lues		
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(Thin Plate) 12/17/85 JSC Shot No. 894

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na squared

				Keasured Vali	sa					Calculated Va	l ues		
Far	ticle Ko.	X location of impact (origin at *)	Y location of impact (origin at e	<pre>2 location 0f impact) (origin at e)</pre>	Penetration Depth	Length of Particle	Aass	R location of impact forigin at	Theta locati of impact	on Phi location of impact #) forigin at #*	Ave. D	ianeter Ave.	Area
		2	=	8	:	:	ĝas	I	Degr ees	Degr ees	2	5	quared
	42	•	•				3 0.000616667					0,179	c
	1	•	•				3 0.000616667					0.129	
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			• •				3 0.0000616667					0.129	0.
	2 2	•••	• •				3 0.000616667					0.129	
	59		• •				3 0.000616667					0.129	
	5 5	•	•				3 V. UVUVD1000/					0.129	6
	22	•	•				3 U. UV(U01866/					0.129	
	13	•	-				3 0.0000616667					0.129	
	5	•	•				3 0.000616667					0.129	
E	22 22	•	•				3 0.0000616667					0.129	
3-	29 I	•	•				3 0.000616667					0.129	°.
16	5	••					3 0.0000616667					0.129	<u>.</u>
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	63	•	-				3 0.000616647					0.129	
	5	•	-				3 0.0000616667					0.129	<u>.</u>
	5 : 5	•••	• •				3 0.000616667					0.129	°.
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	ò 9	•	•				5 0.000616667 3 0.0000414447					0.129	
	69	•	•				3 0.000616667					0.120	
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	~	• •	•				3 0.000616667					0.129	0.0
	2;						3 0.000616667					0.129	°.
	2 -						3 0.000616667					0.129	0.0
		-	•				5 0.000616667					0.129	0.0
	2 2	-	•				0 0.00001000/					0.179	0.0
		•	•				0.UUVV&1666/					0.129	0
	: B2	•	•			•) U.UUV01860/ 7 A AAAA114447					0.129	
	52	-	•				0.000045447					0.170	
	80	-	•				5 0.000616667					0.179	
	81	•	•				5 0.000616667					0.129	0.0
	82	•	-				§ 0.0000616667					0.129	0.0
	8						0.0000616667					0.127	0.0
	28	• •					5 0.000616667					0.129	0.0
	3		•			-	0.000614667					0.129	0.0

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0.013 0.013

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JSC Shot No. 894

(Thin Plate) 12/17/85

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Calculated Values

R location Theta location Phi location Ave. Diameter Ave. Area of impact of impact of impact foreign and foreign of any contract of contents of the sector o

	origin at .	*/ (0/) # 1	18 ulåt.01/14	1		
	1	Degrees	Degrees	2	1	juar ed
1					0.129	0.013
7					0.129	0.013
1					0.129	0.013
1	•				0.129	0.013
~ *					0.129	0.015 0.012
					0.179	0.013
					0.129	0.013
					0.129	0.013
1					0.129	0.013
1					0.129	0.013
7					0.129	0.013
-					0.129	0.013
					0.129	0.013
					0,179	0.013
					0.129	0.013
					0.098	0.008
					0.078	0.008
					860.0	0.008
80					860.0	0. MB
6 •					0.098	0.008
• •					8 12 72 72	0.010
					0.156	0.019
					0.156	0.019
•					0.156	0.019
÷					0.156	0.019
					0.156	0.019
.9					0.156	0.019
•					0.156	0.019
		-			0.154	010 V
o -e					0.156	0.019
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· -0					0.156	0.019
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9					0.156	0.019
6					0.156	0.019
-9					0.156	0.019
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<u>ب</u> و.					0.136	0.019
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18 9.0000 18 9.0000 18 9.0000 18 9.0000 19 (Ejecta under catcher, total 0.0033 gl 20 (Ejecta under catcher, total 0.0			•	•					0.0000616667
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18 3 0.0000 19 (Ejecta under catcher, total 0.0033 g) 3 0.0000 192 laverage of 5) 3 0.0000 193 - laverage of 5) 3 0.0000 193 - laverage of 5) 15 9 194 - - 15 9 195 - - 15 9 194 - - 15 9 195 - - 15 9 196 - - 15 9 197 - - 15 9 198 - - 16 15 15 199 - - 16 15 15 201 - - 16 2 16 201 - - 16 2 16 201 - - 16 2 16 2 16 201 - - - 16 2 16 2 16	8		•	•					0.000616667
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191 (Ejecta under catcher, total 0.0033 g) 13 15 15 15 192 laverage of 5) 13 15 15 15 193 laverage of 5) 13 15 15 15 194 laverage of approx. 40) 2 2 2 2 199 laverage of approx. 40) 2	š	_	•	•				m	0.0000616667
172 laverage of 51 13 15 15 15 193 iaverage of approx. 40) iaverage of approx. 40) 25 2 2 199 iaverage of approx. 40) 2 2 2 2 2 2 201 202 2	161	l (Ejecta	pus	er catcher,	total 0.0033 g)			2	0.00018
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212	Ξ	_	•	•				~	0.0006
	212	~	•	•				2	0.00006
216 • • • 2 215 • • • • 2 216 • • • • • 2 217 • • • • • • 2 217 • • • • • • 2 217 • • • • • • • • • • • • • • • • • • •	21	-	•	•				~	0.0006
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216 · · 2 0 21 · · 2 0 21 · 2 0	3	5	-	•				2	0.0006
217 • • 2 (3		•	•				2	0.0006
	21)	-	•	•				~	0.0006

(Thin Plate) 12/17/85 JSC Shot No. 894

Reasured Values

R location of impact (origin at	:																																								
Mass	sab	1 0 0004111117	3 0.00041447	3 0.000616667	3 0.000616667	3 0.000616667	3 0.000616667	3 0.000614647	3 0.000616667	J 0.000614447	3 0.000614647	3 0.000616667	3 0.000616667	3 0.0000416667	3 0.000616667	3 0.0000616667	3 0.000616667	3 0.000616667	0 000001666/	0.000616667	0.000616667	0.000616667	0.000616667	0.000616667	0.0000616667	0.0000616667	0.000616667	0.000616667	0.000616647	0.0000616667	0.000616667	0.000041447	0.0000414447	0.0000616667	0. (1000616667	0.000616667	0.0000616667	0.0000616667	0.0000616667	0.0000616667	677117000 V
Length of Particle	:															-,	- , ,		а Ра			5	n	~ I		~ ~	· ••	5	m	m (⊷ •				5	~	r	r	~	r	•
Penetration Depth	:																																								
Z location of impact) forigin at +)	2																																								
T LOCATION Of impact torigin at f	:	-	•	•	•	•	•	•	•	•	•	-	• •	• •	• •	•	•	•	-	-	•		• •	•	•	•	•		• -	•	•	•	•	-	•	-	•	• •	• •		-
i location of inpact iorigin at +)	•	•	•	•	•	-	•	-	•	•	•	• •		•	•	•	•	•	•	-	-		•	•	•	•	•		• •	•	-	•	•	•	•		• •		• -	, .	•
	•	130	131	132	NET I		135	136	131	8	139	140	E	211		1	:≝ 10	ŧ	148	149	150	161	151	154	155	156	157	158	161	191	162	163	164	165	166	167	168	169	2	::	111

Calculated Values

Theta location Phi location Ave. Diameter Ave. Area of impact of impact

squared		0.015	214.0	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0 017
:	961 0	0.129	0.170	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.179
2																																												
Begrees																																												
Degrees																																												

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			Resoured Val	SIN						Calculated	Values		
Farticle No.	A location of impact (origin at e	Y location of impact () (origin at f	<pre>2 location 0 impact) forigin at *</pre>	Penetration Depth	Length of Particle	flass		R location of impact torigin at	Theta Jocati of impact ++) (origin at 1	ion Phi locati of impact w)(origin at	ion Ave. ++}	Diameter Ave.	År ea
	1	1	1	2	:	ĩ		1	Degrees	begrees	:	1	iquar ed
176		-					0.0001					0.164	0.021
		-				3 F	0.001					0,144	0.071
707		•				s •						0.144	0.021
797	•	•				. .	0.0001					0, 166	0.071
67 C		•				, M	0.0001					0.164	0.021
266		•					0.0001					0.164	0.021
267		•					0.0001					0.164	0.021
268	-	•				5	0.0001					0.164	0.021
265		•				5	0.0001					0.164	0.021
275	<i>c</i> .	•				5	0.0001					0.164	120.0
2		• •				m .	0.0001					0.164	0.021
17	~ -	• •				~ •						0 144	0 071
		•				~ ~	0.0001					0.144	0.071
177		•				• •	0.0001					0.164	0.021
126		•				, m	0.0001					0.164	0.021
112		•					0.0001					0.164	0.021
276		•					0.0001					0.164	0.021
27		•					0.0001					0.164	0.021
28(•	•				•	0.0001					0.164	0.021
281	-	•				5	0.0001					0.164	0.021
Total Ejecti	-				1		0.039	36.92 Percent E	ijecta				
SPALL (total	l less spall t	behind & in Cal tablack	tcher = . 044/ j	6		¥	1440-0 0 0014					191.0	0.079
	4 1L0056 UN					2 9	0.0035					0.217	0.037
. •1	•					22	0.0016					0.201	0.032
	•					42	- 8000 * 0					0.124	0.012
	•					52	0.0001					0.053	0.002
	•					2	0.0009	:				0.126	0.019
	•					5 1	0.0016					0.182	0.026
	•						0.005					0.000 0.000	CNU.U
-	•					22	C000.0					0.460	000.9
= :	•••					5 F	0.0015					181.0	870.0
						3 :	0.000					200°0	0.007
- 1		, and read	17 5			36 0.001	1777777					0.151	0.018
	•		6			26 0.00	FFFFF/					0.151	0.018
. =	•	•				26 0.00	17333333					0.151	0.018
-	• •	•				26 0.00	17333333					0.151	0.018
-	• •	•				26 0.00	17333333					0.151	0.018
÷	•	•				26 0.00	9733333					0, 151	0.018
	•	average o	f 17)			11	0.0003					V.117	

(Thin Plate) 12/17/85

B-21

[[hin Plate] 12/17/85

JSC Shot No. 894

Measured Values

an squared Theta location Phi location Ave. Diameter Ave. Area 0.156 0.156 0.156 0.156 0.156 0.156 0.156 0.156 0.156 0.156 0.156 0.156 0.156 0.1640 0.197 2 (origin at 44) (origin at 44) (origin at 44) 22.54 of impact Degrees 1.72 of impact Degrees 108.31 R location of impact 2 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 0.00006 Hass ĩ Ejecta in catcher (170 x 165 mm) origin at lower left looking at catcher 23 Length of Particle 2 Penetration Depth In periphery - outer 40 mm (approx 45) 2 (origin at 4) (origin at 4) (origin at 4) 8 2 location of impact 2 Y location of impact 124 2 88 Particle No. X location ----of impact 2

Calculated Values

0.019 0.017 0.017 0.019 0.019 0.019 0.019 0.019 0.019 0.019 0.019 0.019 0.019

0.019

0.019 0.019 0.019 0.019

0.030 0.021

(Thin Plate) 12/17/85

JSC Shot No. 894

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Calculated Values

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Diameter Ave. Area		
on Phi location Ave.	of impact e){origin at es}	
Theta locati	of impact ++)(origin at +	
R location	of impact lorigin at	

squar eð	0.010	0.010	010.0	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	010.0	0.010	0.010	0.010	0.010
2	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116
8																																												
Degrees																																												
Degrees																																											•	
														•																														

•

			Heasured Valu	5			
Farticle No.	X location of impact forigin at e	Y location of impact) forigin at +)	Z location of impact forigin at #}	Penetration Depth	Length of Particle	Hass	
	1	I	I	:	:	suí	
17	-	•				•	00009825
	•	•				•	00006625
44	•	•				•	00006625
5	•	•				• •	00006625
89	•	•				•	00006625
	-	•				• •	00006625
20	•	•				- -	00006625
2	•	- 1				ة د ج ع	00006625
2	•					• •	00004675
		• •				; ; ; ;	00006625
	•	•				-	00006625
. 7	•	•				•	.00006625
1	•	•				•	\$2990000
R							00006625
21		• •				• •	22990000
م ة م	•••	• •				• •	.00006625
	•	•				•	.00006625
	•	•				•	.00006625
	•	-				•	.00006625
ξ	•	•				••	22990000.
	-0.	• •				••	00006675
		•				•	.00006425
	•	•				+	.00006625
6	•	-				-	CZ990000"
6- C							.00006625
~ 0	•	•				-	.00006625
	•	•				•	.00006625
. 6	•	•				-	.00006625
D - 1		• •					00006625
~ 0		•					.00006625
- 0		•				-	.00006625
10	•	•				•	.00006625
10		•				•	.00006625
10		•				-	00006625
10		•					22990000000
= :		• •				• •	27999999970
===	 2 3	• •					0.0006625
- 2		•				-	0.00006625

(Thin Plate) 12/17/85 JSC Shot No. 894

						Keas	ured Valu	les.			1		
L	Particle 1	2	X location of impact lorigin at	3	Y location of impact (origin at #)	2 10 0f 10 (arit	cation spact jin at #)	Penetration Depth	Length of Particle	ž	555	R location of impact forigin at	Theta of in ++) (or ig
		-	:	_	1	1		1	1	÷		1	Degr
		20	-	-	•					11	0.0003		
		21	-		-					1	0.0003		
		21	_ •		• •					- :	0.0003		
		23								2 5	0.0003		
		5			•					2 2	0.0003		
		3 %	5	•	•					: =	0.0003		
		3 2	-	•	-					: =	0.0003		
		8 8	-		•					1	0.0003		
		53	-		•					1	0.0003		
		8	-		•					1	0.0003		
		31	-		•					1	0.0003		
		2			•					2	0.0003		
P		8			•					21	0.0003		
<u> </u>		あり			•					2	0.0003		
2		13		•	•		:	:		2	0.0003		
2		2		•	average of ap	pprox.	240 (lei	ss dust)		•	0.0006625		
		5	_		• •					•	0.0000623		
		B 8	-							• •	0.0000423		
		5	-		•						0 00001175		
		2 :	-		•					• •	0.00004475		
		2	-		•						0.0000425		
		1		-	•						0.00006675		
		: =	-		•					•	0.0006625		
		¥	-		•					-	0.0006625		
		\$	-		•					-	0.0006625		
		11	-		•					-	0.00006625		
		ŧ	_		•					+	0.00006625		
		4	-		•					-	0.0006625		
		ŝ	-	•	•					-	0.00006625		
		2	-		•					-	0.00006625		
		2	-		•					-	0.00006625		
		6	-	-	•					-	0.0006625		
		5			•					*	0.00006625		
		5		•	•					-	0.00006625		
		26		-	•					+	0.00006625		
		57			•					-	0.0006625		
		ŝ			•					-	0.00006625		
		5			•					-	0.00006625		
		69			•					-	0.00006625		
		19			•					-	0.0006625		
		3	-							-	0.0000623		
		3			•					٠	0,00006425		

Calculated Values

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as squared a location Phi location Ave. Diameter Ave. Area mpact of impact jin at settorigin at set 2 Degrees 5

(Thin Flate) 12/17/85

JSC Shot No. 894

			Neasured Val	kes					5	Ĕ
Particle No.	K location of impact torigin at E	Y location of impact) (origin at 4	<pre>¿ location</pre>	Penetration Depth	lemgth of Particle	÷		R location of impact (origin at	Theta location of impact ++) (origin at ++) (
	2	2	1	:	2	Ï.		3	Degrees	- de
157	•	•				-	0.00006625			
151	•	•				+	0.0006625			
151	•	•				+	0.0006625			
155	•	•				-	0.0006625			
156	•	•				-	0.0006625			
121	•	•				•	0.0006625			
151	•	•				-	0.0006625			
	•	•				-	0.0004625			
140	•	•					0.0004675			
	•	•					36770000 0			
	•	•					27984444			
		•				• •	0.00001175			
16.		• •				•	C7990000 0			
164	•	•				•	C7990000.0			
B	•	•				-	0.00006625			
191 3-	•	•				+	0.0006625			
2	•	•				+	0.0004625			
₹ 5	•	•				+	0.00006625			
1 1 1 1	•	•				-	0.0006625			
11	•	•				+	0.0006625			
1	•	•				+	0.0006625			
2 2 2	•	•				-	0.0006625			
, 	•	•				-	0.0006625			
/	•	•				-	0.0004475			
/	•	•					36770000			
2	•••	•					0,0000117E			
2	•••	•					C. 00001 100			
		•				• •	0 00001175			
							207000000 V			
		•				•	67000000 0	•		
		•					C700000.0			
		•				• •	5000000 V			
		•					0, 00000 C15			
		•				• •	0,0000 475			
		• •				• •	0.000012E			
		• •				•	C2660000.0			
181	•	•				-	0.00006625			
181	•	•				-	0.00006625			
18	•	•				-	0.00006625			
18	•	•				-	0.00006625			
19(•	•				-	0.00006625	•		
121	•	•				+	0.0006625			
191	•	•				-	0.00006625			
19	•	•				-	0.00006625			
6	•	•				-	0.0006625			
161	•	•				•	0.00006625			

Calculated Values

no squared

8

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Jocation Ave. Diameter Ave. Area impact gin at **}

(Thin Plate) 12/17/85

JSC Shot No. 894

Measured Values

Parl	ticle Mo.	X location of impact forigin at el	Y location of impact (forigin at t)	I location of impact (origin at t)	Fenetration Depth	Length of Particle	Nass	R locat of impa forigin
		:	2	:	1	:	jes	I
	111	_	•				0.0001	
	514		•				0.0001	
	416 15						0.0001	
	2		•				1000"0	
			• •			-	0.0001	,
					ġ		0.000	
	12		CENCET NITE JA	ee dia. (appr	(DC . XG		0.00025	
	171		•				0.00025	
	12		•					
			•					
	524		•			•	0.000025	
	426	_	•				0.00025	
F	421		•			-	0.000025	
<u>ء</u> _	4 28		•			-	0.00025	
<u>م</u> .	62 6		• •				0.00025	
1	5	_	• •				0.000025	
	2 E		• •				0.00025	
			•				0.00025	
		_	•				0.00025	
			•				C24000.0	
	136		•				0.00075	
	437		•			. –	0.00025	
	438		•				0.00025	
	439		•			-	0.00025	
			•			_	0.000025	
	; ;		• •				0.00025	
	264						0.00025	
	Ì		•				320000.0	
	545		•				0.000055	
	446		•				0.000025	
	147		•			-	0.00025	•
	81		•			-	0.00025	
	443		•			-	0.00025	
	420		•			-	0.000025	
	5		•			-	0.000025	
	225		•			-	0.000025	
			• •				0.000025	
							0.000025	
	32		• •				0.00025	
	2 2 2		•				C20000.0	
	į					•	F7AAAA*A	

Calculated Values

Pegres Pegres 0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.	-	.016	.016	.016	.016	.016	910		910	917	016	016	016	910	910	016	016	016	919	916	917 917	016	016	016	019 019	016	016	010	016 016	016	016	016	916	919	910	017 017	916
Pegres legres le	square	0	0	Ó		o	o (5 0	o e	s c		e	o.	Ö	. .	.	o' 0			.	5 c		•	.		0	ċ	-		°.	ò.	ċ	.	. .	- -	; -	
	2	12	21	2	2 :	2	2 2	2 9	2 2	2 0	. 5	2	2	2	2	2	2 5			~ '	4 F		2	<u>ю</u> г	, r	. ~	2	. r	- C	2	2	~ `	~ •	~ -	~ ~	~ ~	. ~
Segret Se		0.1	0.1			0	•			5		0.14	0.14	0.14	0.1		2 3 0 0		0	0.14		0.1	0.14		0.1	0.14	0.1			0.14	0.14	- : 0					0.1
Segres	I																																				
8 2 8	E.																																				
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	z																																				

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(Thin Plate) 12/17/85 JSC Shot No. 894

Parti	cle No.	X location	Y location	Neasured Valı 2 İocation	tes Penatration	l santh of		P location	Thete term	Calculated Va	l ves	and and and and a	
		a socarson of impact forigin at 4	<pre>ispact forigin at #</pre>	<pre>6 location 6 limpact 1) (origin at 4)</pre>	bepth	Lemgin of Particle	: 552	K location of impact forigin at 4	lheta locati of impact slorigin at s	on Phi location of impact +) (origin at ++	. Ave. D	iaaeter Ave. f	ir ea
		1	1	2	2	1	je 5	:	Degr ees	Degr ees	2	nbs 🖬	iar ed
	283	•	-				0.0001233333					0.182	0.026
	R I	• •					0.0001233333					0.182	0.026
			• •				0.000123333					0.182	0.026
	087 787	•	•				0.0001233333 0.0001233333					0.182	0.026
		•	•				A AAA1913133					781.0	970.0
	289	•	•				0.0001233333					V. 162 0. 187	0.076
	290	•	•		•		0.0001233333					0.182	0.026
	2	•	-				0.0001233333					0.182	0.026
	292	•••	• •				0.0001233333					0.182	0.026
	67 TB2	•	• •				0.0001233333					0.182	0.026
	282	•	•				0.0001233333					0.182	0.026
	296	-	•			,	0.00123333					v. 102 D. 182	0,026
B-	297	•	•				0.0001233335					0.182	0.026
-2	298	•	-				0.0001233333					0.182	0.026
8	299	•	-				0.0001233333					0.182	0.026
	00 <u>2</u>						0.0001233333					0.182	0.026
	19 C	• •	• •			- 1	0.0001233333					0.182	0.026
	202	-	-				0.0001233335 0.0001218878					0.182	0.026
	1 de la	•	•				0.0001233333	•				0, 182	0.076
	305	•	•				0.0001233333					0.182	0.026
	902	•	•			••	0.0001233333					0.182	0.026
	10 <u>2</u>	• •	• •			**)	0.0001233333	:				0.182	0.026
							0.0001233333					0.162	0.026
	310	•					0.0001233333					0.182 A 182	0.026
	E	•	•			,	0.0001233333					0.187	0.026
	312	•	•			•	0.0001233333					0.182	0.026
	fi:	•••	• •				0.0001233333					0.182	0.026
		•	•			~ •	0.0001255555					0.182	0.026
	11	•	-				0.0001233335 A AAA1777777					0.182	0.026
	115	•	•				0.0001233333					0.187	0.026
	318	•	•				0.0001233333					0.187	970.0
	61£	•	-				0.0001233333					0.182	0.026
	320	•	•			-	0.0001233333					0.182	0.026
	321	•	-			n	0.0001233333					0.182	0.026
	322	•	•			£	0.0001233333					0.182	0.026
		• •	• •				0.0001233333					0.182	0.026
	525	• •					0.0001233333					0.182	0.026
	92	• •					0.0001233333					0.182	0.026
	940		i			-	0.0001233333					0.182	0.026

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(Thin Plate) 12/17/85 JSC Shot No. 894

Reasured Values

<pre>Article Mo. 1 location / loc</pre>	Rloca Nass Rloca of inp		0.00004475	0.00004425	0.00006625	0.00006625	0.0006625	0.00004625	0.00006625	0-00006625	0.0006625	0.00004475	0.00006625	0.0006625	0.00006625	0.0006625	0.0006625	0.0006625	0,00006625 2,0000400	0.00004475	0.0006625	0.00006625	0.0006625	0.0006625		0.00004475	0.0006625	0.0006625	0.0006625	0.0006625	0.00006625	0.00006625	0.00006625		0.00004475	0.0006625	0.0006625	0.00006625	0.00006625	A AAAALISE
Article No. I location I location Hend origination origination torigination Penetration Penetration origination origination torigination Penetration Penetration origination origination torigination Penetration Penetration 19 19 <td< td=""><td>th of icle</td><td></td><td>4</td><td>-</td><td>•</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>* •</td><td>• •</td><td>•</td><td>-</td><td>-</td><td>-</td><td>•</td><td>•••</td><td>* •</td><td></td><td>-</td><td>•</td><td>-</td><td>-</td><td>• •</td><td>• •</td><td>-</td><td>-</td><td>-</td><td>-</td><td>•</td><td>•</td><td></td><td>• •</td><td></td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></td<>	th of icle		4	-	•	-	-	-	-	-	* •	• •	•	-	-	-	•	•••	* •		-	•	-	-	• •	• •	-	-	-	-	•	•		• •		-	-	-	-	-
article Mo. I location I location Penetration of ispact of ispact of ispact Depth of ispact of ispact of ispact Depth 196	a Leng	2																																						
article Mo. 1 location 7 location 1 location of impact of impact of impact [9] 19 19 19 19 200 201 201 203 204 205 206 204 203 204 203 204 204 205 206 206 206 206 206 206 206 206 206 206	Penetratio Depth	2																																						
article Mo. 1 location Y location of impact of impact 196 197 198 199 199 199 199 199 200 201 201 201 201 201 201 201 201 201	l location of impact (origin at #	:																																						
article Mo. 1 location of impact 196 198 199 199 199 199 199 200 201 201 200 201 200 201 201 200 201 201	/ location of impact iorigin at e)	-	•	•	•	•	•	-	-		•	•	•	•				-	•	•	•	•		• •	-	-	•	-	-	• •	• •	-	•	-	•	-	•	•	•	-
article 20 article 20 1 locat 19 19 19 201 201 201 201 201 201 202 203 204 201 204 201 205 204 201 205 205 205 205 205 205 205 205	ion at 5 1	-	•	•	•	•	•		•		•	•	•	•			• •	•	-	•	•	•	• •	•	•	•	-	-			•	•	•	•	•	•	•	•	•	•
article 60 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	I locat of impa forigin	2																																						
	article No.		196	197	198	199	200	102	Z0Z		205	206	207	208	209	017	11	11	12	215	216	217	812	270	ន	222	223	224	522	922	177	077	230	231	122	523	234	235	236	121

Calculated Values

Theta location Phi location Ave. Diameter Ave. Area •

	squar ed	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	010.0	0.010	0.010	0.010	0.010	0.010	0,010	0.010	0.010	010.0		010.0	0.010	0.010	0.010	0.010	0.010	0.010	0.010	010.0	0.010	0.010	0.010	0.010	0.010	0.010	0.010	010.0
	1	0.116	0.116	0.116	911.0	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	011.0	0.116	0117A	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0 1 1 F	0.11.0	0.116	0.116	0.116	0.116	0.116	0.116	0.116
Î	z																																								
of impact **) (origin at	Degrees																																								
of impact se) (origin at i	Degrees																																								
impact igin æt i																																									

(Thin Plate) 12/17/85

JSC Shet No. 894

				Resured	d Valu	2			1			
Particle No.	- 7 ⁰	location inpact rigin at +)	Y location of impact	<pre>¿ locati of impac) (prigin</pre>	÷ ≉tto	Penetration Depth	Length of Particle	Nas	2	R location of impact lorigin at F	Theta loca of impact •) (origin at	ition (==)
	2	_	:	:			2	Ĩ.		:	Degr ees	
÷	2	-	•					~	11111111111			
 -		•	-					5 0 7 M	0001233333			
- i	2 2	•						5 c				
-	5;	•	• •					5 < 7 F	. UVUL 6.34333			
ni	8	• •	• •									
й	2	•	•					0 10	.0001233333			
M	2	•	•					o n	.0001233333			
**	12	•	•					o n	.0001233333			
й	E	•	•					o n	.0001233333			
м	33	•	•					o n	.0001233333			
ň	92	•	•					0 10	.0001233333			
i iri	3	•	•					0	.0001233333			
m		•	•					30	.0001233333			
	. 65	•	•					0	.0001233333			
	; 4	•	-						1212121000			
_	-	-	•						0001233333			
, r [.]	: 5	•	•						0001233333			
		•	•						1233333			
5 F	2	•	•						.0001233333			
	5	-	-						100121111			
3 F	2 3	•	-					5 C 7 M	.000171111			
		•	•						2222221000			
	9	•	•						.000123333			
5 P*	9	-	•						0001233333			
· •		•	•						1000	·		
9 P	57	•	•						0001273733			
5 M	5 P	•	•						.000123333			
3 F	1	•	•						222222000			
5 M	3 2	•	•						000121111			
	5	•	•						000123333			
. ••	3	•	•					0	0001233333			
	5	•	•					5	.0001233333			
	28	-	•					3 0	.0001233333			
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	20	•	•					° 2	0001233333			
	09	•	•					20	.0001233333			
••	19	•	•					3	.0001233333			
**	62	•	•					0 2	.0001233333			
5	29	•	•					3	.0001233333			
n	19	•	•					3	.0001233333			
P)	59	•	•					° ~	.0001233333			
•	99	•	-					30	.0001233333			
Spall in c	atche	er (160 x 1)	70 mm) origin	at lower	left	looking at cat	cher					
+3	(9)	2	1	89	5	5		62	0.0026	1.911	۲- ۱	1.54
**	89	0	2	0	5	6		22	0.0005	128.0	z	7.20
r	64	15	12	20	6	5		5	0.001	126.1	S- 00	8.29

0.027 0.014 0.127

0.184 0.135 0.402

2.41 -41.82 -20.22

Area	squ <b>ar ed</b>	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	970.0	0.026	970.0	07A.V	0.026	0.076	0.026	0.026	0.026
i aaster Ave.	2	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.152	281.0	781.0	781 °A	0 187	0.182	0.182	0.182	0.182
on Ave. D ++)	8																																							
ion Phi locati of impact ss)(origin at	begrees																																							
a locat mpact gin at	ĩ																																							

**Calculated Values** 

(Ihin Plate) 12/17/85

JSC Shot No. 894

**Calculated Values** 

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Reasured Values

									**********					
2	rticl <b>e No.</b>	. X location of impact forigin at	Y location of impact +) (origin at (	<pre>// location of impact */ (origin at 4)</pre>	Penetration Depth 5)	Length of Particle	Nass		R tocation of impact forigin at ##	Theta locati of impact ) torigin at (	ion Phi locati of impact Helforigin at	on Ave. [+]	Diameter Ave. I	<b>.</b>
		:	2	1	:	2	gas		I	Degrees	Degrees	2	165 <b></b>	iared
	37	10	periphery -	outer 40 mm (a	approx. 50)		-	0.0001					0.142	0.016
	27 T		•				+	0.0001					0.142	0.016
	2	72	-				-	0.0001					0.142	0.016
	21	5	-				-	0.0001					0.142	0.016
	5	*	-				-	0.0001					0.142	0.016
	11	25	-				-	0.0001					0.142	0.016
	5	16	-				-	0.0001					0.142	0.016
	21	"	•				•	0.0001					0.142	0.016
	2	18	•				-	0.0001					0.142	0.016
	2	5	•				-	0.0001					0.142	0.016
	2	06	•				-	0.0001					0.142	0.016
	92 92	=	•				•	0.0001					0.142	0.016
	27	<b>1</b> 2	•				-	0.0001					0.142	0.016
в	8		•				<b>.</b>	0.0001					0.142	0.016
- :	2						-	0.001					0.142	0.016
30	35	G =						0.0001					0.142	0.016
)	25	8	• •				-	0.001					0.142	0.016
	2	5	• •					0.001					0.142	0.016
	3		• •				-	0.0001					0.142	0.016
	5	39	• •					0.001					0.142	0.016
	51	<b>e</b> :	• •				-	0.0001					0.142	0.016
	5	c •	• •				-	0.0001					0.142	0.016
	5 8	2	•••				-	0.0001					0.142	0.016
	5	2	• •				- •	0.000					0.142	0.016
		t	• •				•	0.001					0.142	0.016
		2 =	• •				• •	0.0001					0.142	0.016
	5, 2	e =	•					0.0001					0.142	0.016
			•					0.001					0.142	0.016
	ς μ		•				* -	0.000					0.142	0.016
			•					0.000					761.0	0.016
	-		•					0.001					0.147	0 014
	ġ.	2	•					0.0001					0.142	0.016
	9	1	•				*	0.0001					0, 142	0.016
	9	7	•				-	0.0001					0.142	0.016
	,0 <del>4</del>	č	•				+	0.0001					0.142	0.016
	0	16	•				-	0.0001					0.142	0.016
	<b>9</b>	1	•					0.0001					0.142	0.016
	9	œ	•				-	0.0001					0.142	0.016
	9	٩	•				-	0.0001					0.142	0.016
	-	0	•				-	0.0001					0.142	0.016
	=		•				-	0.0001					0.142	0.016
			• •				-	0.0001					0,142	0.016
	Ŧ	~	•				-	0.0001					0.142	0.016

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(Thin Plate) 12/17/85

JSC Shot No. 894

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Measured Values

0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.009 0.026 0.026 0.026 0.026 0.026 on squared Theta location Phi location Ave. Diameter Ave. Area 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.116 0.182 0.182 0.182 0.182 0.182 0.182 0.109 **Calculated Values** 2 (origin at 69) (origin at 64) (origin at 64) of ispact Degrees of impact Degrees R location of impact 3 9.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.0006625 0.00006625 0.00006625 0.00006625 0.00006625 0.000123333 0.0001233333 0.0001233333 0.0001233333 0.0001233333 0.0001233333 0.0004 Nass ĩ **mm**mm 27 Length of Particle 2 Penetration Depth average of approx. 90 (less dust) 2 of impact of impact of impact (torigin at e) ¿ location 2 0.0042 ges Particle No. X location Y location of impact of impact 276 Spall under catcher 277 Spall under catcher 278 average 279 average 280 average 281 average 281 average 3 -----Spall Dust Loose on Bottom 3 

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JSC Shot No. 894

(Thin Plate) 12/17/85

			Measured Valu	5					Calculated V	alues		
Farticle No.	I location Dí impact (origin at f	Y location of impact ) lorigin at #)	2 location of impact (origin at +)	Penetration Depth	Length of Particle	Kass	R location of impact (origin at #	Theta locat of impact e)(origin at	ion Phi locatio of ispact ++}{origin at *	n Ave. (s)	Diameter Ave.	Area
	1	2	1	:	:	sag	2	Degrees	Degrees	Z		uared
108	•	•				1 0.0006625					0.116	0.010
109	•	•				I 0.0006625					0.116	0.010
110	•	•				I 0.0006625					0.116	0.010
Ш	•	•				1 0.0006625					0.116	010.0
112	•	•				1 0.0006625					0.116	0.010
113	•	•				I 0.0006625					0.116	010.0
Ħ	•	•				i 0.00006625					0.116	0.010
511	•	•				1 0.0006625					0.116	0.010
116	•	•				0.0006625					0.116	0.010
111						0.0006625					0.116	010.0
811	• •	• •				1 0.0006625					0.116	0.010
114	• •	• •				0.0006625	1				0.116	010.0
21						0.0006625					0.116	0.010
	••	• •				C7990/00/ 0					0.116	010.0
201	•	•				27990000 0 9					0.116	010.0
	•	-				1 0 000423					1110	0 050
4	•	•				1 0 0004425					0 116	010.0
121	•	•				1 0.0004475					0.116	0.010
127	•	•				0.0006625					0.116	0.010
128	•	•				1 0.0006625					0.116	0.010
129	•	•				I 0.0006625					0.116	0.010
130	•	•				1 0.00006625					0.116	0.010
131	•	•				9.00006625					0.116	0.010
132	•	•				0.0006625					0.116	010.0
133	•	•				0.0006625					0.116	0.010
	• •					0.0006623					0.116	0.010
551 174	• •	• •				C7990000 0 1					0.116	010.0
<u> </u>	•	•				1 0.0004675					0.116	0.010
138	•	•				0.0006625					0.116	0.010
139	•	•				I 0.0006625					0.116	0.010
140	•	•				9.00006625					0.116	0.010
I.	•	•				0.0006625					0.116	0.010
142	•	•				0.0006625					0.116	0.010
143	•	-				I 0.0006625					0.116	0.010
141	•	•				9 0.0006625					0.116	0.010
142	•	•				0.0006625					0.116	0.010
146	•	•				0.0006625					0.116	010.0
E	•					0.0006625					0.116	0.010
81						0.0006625					0.116	010.0
SH(		• •				0.0000623					0.116	010.0
nc: 191	•	• •				0.00004625					0.116 0.116	010.0
2												

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0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010

12/23/85 JSC Shot No. 883

			Reasured Valu	san						alculated Va	lues		
Particle No.	X location of impact torigin at e	Y location of impact ) (origin at 6)	Z location of impact ) (origin at #)	Penetration Depth	Length of Particle	Nass	R location of impact (origin at ••	Theta location of impact )(origin at ee)	Phi location ( of impact (origin at ##):	Cone Angle (from normal to surface) (orinin at ##	Average Diameter )	Aver age Area	Velocity
	2	2	1	1	1	jas	:	begr ees	Degrees	Degrees	2	nn squared	Ka/sec
ä	•			6	-	5 0.0002418182	0.0	-90.00	-90.00	6		20 0.03	0.00
56	•			- 9		5 0.0002418182	0.0		-90.00	•		20 0.03	0.00
• ē	•			. 0		5 0.0002418182	0.0		-90.00	•		20 0.03	0.00
	•			. 0		5 0.000241B1B2	0.0	-90.00	-90.00	0		20 0.03	0.00
Đ	•				-	5 0.0002418182	0.0		-90.00	•	0	20 0.03	0.00
	•			. 0		5 0.00024181B2	0.0	-90.00	-90.00	•		20 0.03	0.00
. đ	•			. 3		5 0.0002418182	0.0	-90.00	00'04-	e	0	20 0.03	0.00
	•					5 0.0002418182	0.0	00.07- 0	-90.00	•	0	20 0.03	0.00
ē	•			•	~	5 0.00024181B2	0.0	0 -90.00	-90.00	•	0	20 0.03	0.00
	•					5 0.0002418182	0.0	0 -90.00	-90.00	•	0	20 0.03	0.00
ō	•					5 0.0002418182	0.0	00.00-00.00	-90.00	•	0	20 0.03	0.00
ŏ	•					5 0.0002418182	0.0	90.00	-90.00	•	0	20 0.03	0.00
10	•					5 0.0002418182	0.0	0 -90.00	-90.00	•	.0	20 0.03	0.00
i e I	•				~	5 0.0002418182	0.0	00.09-00.00	-90.00	c	.0	20 0.03	0.00
3- 3-	•			-	~	5 0.0002418182	0.0	0 -90.00	-90.00	0	0	20 0.03	0.00
.≘ •6	•			-	~	5 0.0002418182	0.0	00.09-00.00	-90.00	0		20 0.03	0.00
10	•			-	•	5 0.0002418182	0.0	0 -90.00	-90-06-	0	•	20 0.03	0.00
10	•			-	6	5 0.0002418182	0.0		-90.00	0	<b>.</b>	20 0.03	0.00
10	•			-	•	5 0.0002418182	0.0	0 00.00	-90.00		<b>.</b>	Z0 0.03	0.0
10	•			-	6	5 0.0002418182	0.0		-90.00	0	• •	Z0 0.03	0.00
10	. 6			-	Ď	5 0.0002418182	0.0	0 -90.00	-90.00		<b>.</b>	20 0.03	0.00
10				-	0	5 0.0002418182	0.0	0	-90.00		6	20 0.03	0.00
=	•			-	0	5 0.0002418182	0.0	0 -90.00	-90.09				0.00
=	•			-	0	5 0.0002418182	0.0	0 -90.00	-90.00			50°0 07	(A.V
=					•	5 0.0002418182	0.0	0.07-0	00.04-		o e	50.0 10 0 10 0	
=	•					5 0.0002418182	0.0 0	00.09- 00.09-	00 00-		; ;		000
= :	• •					7 0.001418182 2 0.0001418182			00.04-			20 0.03	0.00
= :	•			-		5 0.0002418187	0.0	0 -90.00	-90.00			20 0.01	0.00
= =	•					5 0.0002418182	0.0	00.00	-90.00	U	ö	20 0.03	0.00
: =	•			_		5 0.0002418182	0.0	0 -90.00	-90.00	-		20 0.01	0.00
. =	•			~	0	5 0.0002418182	0.0	0 -90.00	-70.00	•		20 0.01	0.0
12	•			-	•	5 0.0002418182	0.0	0.00- 0	-90.00	•	0.	20 0.0	0.00
12	•			-	0	5 0.0002418182	0.0	0 -90.00	-90.00	•	°.	20 0.0	0.00
12	• •				0	5 0.000241B182	0.0	0 -40.00	-90.00	•		20 0.0	0.00
12	•			-	0	5 0.0002418182	0.0	0.09-00.00	-90.00	•	•	.20 0.03	0.00
2	•				0	5 0.000241B182	0.0	0 -90.00	-90.00	-	0	.20 0.01	0.00
12	•				0	5 0.0002418182	0.0	-90.00	-90.00	•		20 0.0	0.00
1					0	5 0.000241B1B2	0.0	0.09- 0.00	00.09-	-	•	.20 0.0	0.00
: 2	•				0	5 0.0002418182	0.0	-70.00	-90.00	•	。 。	.20 0.01	0.00
2	9				0	5 0.0002418182	0.0	00 00.00	-90.00	-	• •	20 0.0	0.00
	•				•	5 0.000241B1B2	0.0		-90.07			20 0.0	0.0 •
	•				0	5 0.0002418182	0.0	00 90.00	-90.09			20	8.0
=	il (3 Jarge lo	ose particles)			•	8 0.0012	0.0	00 - A0.00	-40° M	-		11-A CC.	

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	,			•			
		Velocity	Ka/sec				
		Åver age Årea	es squared				
	lues	Average Diameter	:				
	Calculated Va	Cone Angle (froe normal to surface)	begrees				
		Phi location ( of impact (origin at ++)(	begr ees				
		Theta location of impact (origin at #*)	Degrees			_	
12/23/85		R location of impact (origin at ##)	1			67.192	
83	:					Percent of total	
Shat Ne	•		ĩ	0.0352	0.11 fter	0.07391	
35		Nası		bsured	ass Hore & al	seal   fust	
		Length of Particle	:	Coebined Nev	Total from a of target be	Total calc. particles (s	-
	£	Penetration Bepth	2	5		• -	t,
	Neasured Valu	l location of impact (origin at f)	8	l cornor of ba	1 end - je.	7,	ised in veloci 55
		Y location of impact (origin at +)	I	ower left hand 4	center of oper	74	(Estinated) : Pascals
		X location of impact (brigin at +)	2	Origin e, at 1. or the pape an	Origin 11, at	at the leader X, an 71	Shear Strength calculation, M
		Particle No.					

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(Thin Plate) 12/17/85 JSC Shot No. 894

		Measured Val	ses.						Calculated	Val nes		
Farticle No. X loc of is locig	cation Y local pact of imp	tion Zlocation act of impact mate) (originate	Penetration Depth	Length of Particle	<b>A</b> 25		location f impact origin at 4	Theta locati of impact e) forigin at f	ion Phi locatio of lepact ie)(origin at 1	on Åve. **)	Diameter Ave.	Area
1	:	:	:	:	ĝes	-	•	Degrees	Degrees	1	2	quared
ł	-			-	300000						0 147	0.016
428	-				220000.0						0 117	0 0 1 A
459	-				0.00015						0.147	0.016
160					C20000 0						0 147	0.014
191	_				0.000075						0.147	0.016
79 <b>5</b>					0.000025						0.142	0.016
501 171	1	-		•	0.000025						0.142	0.016
101 145	-				0.000025						0.142	0.016
444	_				0.000025						0.142	0.016
467	-	-		. –	0.000025						0.142	0.016
879		-		-	0.000025						0.142	0.016
49	-	•		-	0.000025						0.142	0.016
Total Spall					0.06655	63.11	Percent S	pall				
			Taraat ases	hainea	<b>15.</b> 17							
			Taroet bass	after	85.79							
~~~			Total expect	ted Ejecta/Spall	0.13							
			Neasured Eji Neasvred Spi Total measur	ecta ill red Ejecta/Spall	0.039 0.04655 0.10555	36.91 63.12	Percent E Percent S	jecta pall				
P			Unac counted	(Dust)	0.02445	18.81	Percent D	ust				
RECEDING			Compensated Compensated Total Compe	Ejecta Mass Spall Mass asated Mass	0.04803 0.08197 0.13	36.97 63.12	Percent 5 Percent 5	jecta pall				
F												

1/11/186

Ka/sec

Velocity

117

-	-
	12
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5	c
S	Ē
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			Neasured Valu	57			·			Calculated Val	lues		
Particle No.	K location of iapact (origin at e)	Y location of impact lorigin at 4	Z location of impact) (origin at 4)	Penetration Depth	Length of Particle	La se	R location of ispact (origin at	Theta location of impact selforigin at ee	Phi location of impact (origin at #4)	Cone Angle Langle from Limpact pt. to surf noral	Åver age Di anet er	Aver ag Area	e
	2	3	2	2	8	sui	1	Degr ees	Degrees	Begrees	2	-	quared
. 4	4 78	-	11:	3 0.5		1 0.0000464667	511	40 11.02	4.05	11.70	0	61.	0.01
•	5 57		8	0.5		1 0.00046667		00 0.51	7.56	7.58	0	-19	0.03
.	6 36	~	35 111	-		1 0.0000466667	120	-12.96	15.81	20.05	•	- 19	0.01
	7 125		78 112	3 0.5		.5 0.000466667	133	.25 31.41	7.56	32.00	¢	.16	0.02
	8 94	-	33 W	3 2		.5 0.000466667	122	.93 18.59	-14.87	23.19	•	.16	0.02
	9 104	× ×	11 11	3		2 0.0000466667	131	.17 23.87	21.27	30.52	0	Ξ	0.0
I	6 6 7 8 7 8 7 8 7		22 22	~ ~ ~		2 0.000466667	8	.29 12.96	15.81	20.05	•	= :	0.0
~ ~				~ ~		1 0.00046666/ t 0 000444447		CO.P. 04.	15.92	16.41 14 94		14	6 e
э н а	36					1 0.000046467		10.01 - 10.01	3.04	10.47	> 0		0.0
, 1 2			0	2.0.2		1 0.0004	8	.74 -2.60	-70.75	70.75		. 9	0.0
50	5		8	5.0		1 0.0004	118	.33 -31.94	-36.54	44.09	e	81.	0.0
ŝ	6 85	2	0 24	-		1 0.0004	13	.39 50.39	-69.15	70.91	•	81.	0.0
~ ~	7 23		•	1.5		.5 0.00004	51	.23 -4.18	-56.94	56.97	•	.15	0.02
	8	_	0	8 .0		0.0004	119	.37 -14.86	-32.74	34.82	•	9	0.0
			9 9			.5 0.0001	54 54	.90 IZ.44	-42.81	43.60		51.5	0.02
a .4	1 20				_	1 0.0004 2 0.0004	10 10	-19 10.21 77 10.21	9C.Y'-	30°.//		2:	0.0
• -4			~ T			1 0 0001	28		-74 B0			2 8	
j -có	3 82		× •		-	.5 0.0004	11	03 52.43	-72.39	73.65	• •	. 6	0.0
9	4 Loose on) bottom				9 0.0035	0	- 00	06-	•	•	-56	0.25
-0	•	•				8 0.0005	ø	-00	06-	•	•	.22	0.0
4	•	•				6 0°005	•	06- 00'	06-	0	•	.21	0.0
-0	•	•				6 0.005		06- 00.	06-	•	•	2	0.0
-0 -		•••				7 0.0005	•	- 00 - 60	6-		-	<u>6</u> ;	0.0
	•	•				7 0.0004		06- 00		• •	•••		0.0
1	•	•				5 0.0023		06- 00	96-	•		19	0.29
7.	2	•				7 0.0014	0	06- 00'	06-	•	•	ę.	0.13
~	•	•				5 0.0008	•	06- 00'	06-	•	•	35	9. I
~ 1						6 0.0035			06-	0		69	0.3
~ '		•				2000 0 8		94- 10- 10-	06- 12	•	•	;;	0.0
	-	•				6 V.VVV/ 4 0.0004	> 0	00- 00-	F 7	• •	> 0	5.5	20
. ~	•	•				6 0.00025	Ģ		06-	. 0		; =	0.0
. ~	•	•				6 0.00025	. 0	- 06- 00	: 8	. 0		: 8	0.0
80	•	•				6 0.00025	c	- 00	0 6-	•	•	81.	0.0
œ	•	-				6 0.00025	6		06-	•	0	81.	0.0
60	- ·	•				6 0.00025	c	- 00-	06-	•	•	81.	0.0
		• •				6 0.00025	0	-90	6- i	•	<u> </u>	= :	0.0
in Ó		•••				4 0.0002642857	•	06- 00'	0 <u>6</u> -	00		5. F	0.0 6
9 6		•				10002041892000 0 4	> <	00- 00-	00-	> <	> <	ġF	5 6
		•				4 0.0002642857	• •	06- 00	06-	. 8		12	0.0

0.03 0.03 0.03 0.02 0.02 0.03

1/17/86	
917	with Clath)
JSC Shot No.	(Thin Plate

Measured Values

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1/17/86

JSC Shot No. 917 (Thin Plate with Cloth)

			Reasured Val	sau							Calculated Va	lues			
Particle No.	X location of impact forigin at	Y location of impact *) (origin at	Z location of impact 4) (origin at e	Penetration Depth	Length of Particle	Has	57	R location of ispact (origin at fe	Theta location of impact)(origin at #0	n Phi Jocation of impect Morigin at te	Come Angle (angle from) impact pt.	Aver age Di anet er	Åver age År ea	Velocity	
	1	1	:	1	1	596		2	Degrees	Degrees	Begrees	I	an squared	Ka/sec	
132	•	•			_		0.000105	0.00	06-	06-	0	0.7	4 0.04	0.0	
131	•	•			-		0.000105	0.0		06-	• •	0.2	10.01	0.00	
21	•	•				<u>.</u>	0.000105	0.00	06-	- P-		0.2	0.04	0.00	
[2]	•	•			-		0.000105	0.00	-90	06-	. 0	0.2	4 0.04	0.00	
136	•	•			-	:	0.000105	0.00	06-	06-		0.2	0.04	0-00	
137	•	•			-	.5	0.000105	0.00	06-	06-	Ċ	0.7	1 0.01	0.0	
138	•	•			-		0.000105	0.0	06-	06-		0.2	0.04	0.0	
139	•	•			-		0.000105	0.00	06-	6-	•••	0.2	4 0.04	0.0	
140	•	•			U	0.5	C18180000.	0.00	06-	6-	. 0	0.3	6 0.10	0.0	
141	•	•			•		. 000081875	0.00	06-	06-	•	0.3	6 0.10	0.00	
142	•	-			Ū	0.5 0	.000081875	0.00	06-	06-	•	0.3	6 0.10	0.00	
143	•	•			•	.5 0	.000081875	0.0	06-	06-	•	0.3	6 0.10	0.00	
4	•	-			•	.5	.000081875	0.0	06-	06-	0	0.3	6 0.10	0.00	
£ I	•	•			0	0.5	- 0000B1875	0.00	06-	06-	•	0.3	6 0.10	0.00	
≝ : 3	•	-					.000081875	0.0	06-	06-	¢	0.3	6 0.10	0.0	
3	•				0	.5 0	.000081875	0.00	06-	06-	•	0.3	6 0.10	0-00	
₹ : 6	• •	• •					.000081875	0.00	06-	06-	•	0.3	6 0.10	0.00	-
6 + 1	• •	• •			9	.5	.000081875	0.00	06-	06-	•	0.3	6 0.10	0.00	_
		• •					.000081875	0.00	06-	06-	•	0.3	6 0.10	0.00	
151	• •				•		.000081875	0.00	06-	06-	•	0.3	6 0.10	0.00	
121	•				•	5.0	.000081875	0.0	06-	06	•	e. 3	6 0.10	0.00	
151	• •	•			0		.000081875	0.00	06	06-	•	0.3	6 0.10	0.00	_
5	• •				•	0.5	.000081875	0.00	06-	06-	•	0.3	6 0.10	0.00	
	• •				•	0 		0.0	06-	06-	•	0.3	6 0.10	00.0	
100	•	•					C/8180000	0.00	04-	06-	0	0.3	6 0.10	0.00	
(C) 831	-	-				<u> </u>	2/8180000	0.00	6- i	6 - 1	•	0.3	6 0.10	0.00	
	•	•			> <		C/A180000	00°0	6 -1	6 -		0.3	6 0.10	0.00	
091	•	•					.000001872	0.0 0	0Å-	P 1		5 F	0.10 •	00.0	
161	-	•			• •		000081875		06- -	06-	> c		0.10	00'0 0	
162	•	•				10	ODDRIA75	0.0			• -			2. e	
163	•	•			•	5	000081875	0.00	-30	- 8-	• •	0.5	9°10	0.00	
164	•	•			e	.5	279180000.	0.00	06-	-90	0	0.3	6 0.10	0.0	
145	•	•			•		.000081875	0.00	06-	06-	•	0.3	6 0.10	0.00	
166	•	•			•	5	.00081875	0.00	06-	06-	•	0.3	6 0.10	0.00	
167	•	•			•		.000081875	0.00	06-	06-	•	0.3	6 0.10	0.00	
168	•	-			•	.5 0	.000081875	0.0	04-	06-	•	0.3	6 0.10	0.00	
169	•	-			•	2	.000081875	0.00	06-	06-	¢	0.3	6 0.10	0.00	
170	•	•			•	o n	.000081875	0.00	06-	06-	•	0.3	6 0.10	0.00	
E	•	-			•		.000081875	0.00	06-	06-	¢	0.34	6 0.10	0.00	
241					•		.000081875	0.00	06-	06-	•	0.36	6 0.10	0.00	
\$ <u>1</u>		•••			•		000081875	0.00	-90	-90	•	0.34	5 0 .10	0.00	
		•••			•	ين م	000081875	0.0	06-	06-	0	0.36	6 0.10	0.00	
C/1	,	•			Ð	e r	000081875	0.00	04-	06-	•	0.36	6.10	0.00	

JSC Shot No. 917 1/17/86 (Thin Plate with Cloth)

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Measured Values

			Measured Val	ues						Calculated Va	lues			
Farticle No.	X location of impact forigin at	Y location of impact e) (origin at (<pre>2 location of impact b) forigin at #</pre>	Penetration Depth	Length of Particle	Hass	R location of impact (origin at ##	Theta location of impact)(origin at ##)	Phi location of impact (origin at #0)	Cone Angle Langle from Langle trom Langle from	Åver age Di aneter	Average Area	Velocity	
	1	:	:	1	:	ŝeĉ	I	Degrees	Degrees	Begrees	1	an squared	ka/sec	-
ő	•	•				4 0.0002642857	0.00	06-	06-	•	0.0	0.04	00.0	
Ċ	•	•				4 0.0002642857	0.00	06-	06-	. 6	0.2	0.04	00-0	
6	•	•				4 0.0002642857	0.00	06-	06-	0	0.2	0.04	0.00	
0-	•	•				4 0.0002642857	0.00	06-	06-		0.0	0.04	0.00	
•	•	•				4 0.0002642857	0.00	06-	06-	. 0	e	0.04	0.00	
₽.	•	•				4 0.0002642857	0.00	06-	06-	. 0		0.04	0.00	
¢	•	•				4 0.0002642857	0.00	06-	06-		.0	0.04	0.00	
0	•	•				4 0.0002642857	0.00	04-	06-		0.2	0.04	00"0	
0 ⁻	•	•				4 0.0002642857	0.00	06-	06-	0		13 0.04	0.00	
	• •	•				4 0.0002642857	0.00	06-	06-	•	0.2	13 0.04	0.00	
Ċ,	•	•				3 0.0001363636	0.00	06-	06-	0	0.1	9 0.03	0.00	
•	•	•				3 0.0001363636	0.00	06-	06-	•	0.1	9 0.03	0.00	
10	•	•				3 0.0001363636	0.00	06-	06-	0	0.1	9 0.03	0.00	
e E	•	•				3 0.0001363636	0.0	06-	-90	0	0.1	9 0.03	0.00	
2 -	• 2	•				3 0.0001363636	0.00	06-	06-	•	0.1	9 0.03	0.00	
≅ 3!	•	•				3 0.0001363636	0.00	06-	06-	•	0.1	9 0.03	0.00	
° 5	•	-				3 0.0001363636	0.0	06-	06-	•	0.1	9 0.03	9.00	
0	•	•				3 0.0001363636	0.0	06-	06-	•	0.1	9 0.03	0.00	
10	• •	•				3 0.0001363636	0.00	06-	06-	•	0.1	9 0.03	0.00	
10	• •	•				3 0.0001363636	0.00	06-	06-	•	0.1	9 0.03	0.00	
01	•	-				3 0.0001363636	0.0	06-	06-	•	0.1	9 0.03	0.00	-
10	•	•				3 0.0001363636	0.0	06-	06-	•	0.1	9 0.03	0.00	
11	•	-				3 0.0001363636	0.00	06-	06-	ô	0.1	9 0.03	0.00	
=	•	-				3 0.0001363636	0.00	06-	06-	•	0.1	9 0.03	0.00	
=	•	•				3 0.0001363636	0.00	06-	96 -	•	0.1	9 0.03	0.00	
=	•					3 0.0001363636	0.0	-90	06-	•	0.1	9 0.03	0.00	
=	•					3 0.0001363636	0.0	06-	06-	•	9. I	9 0.03	0.00	
=		- ·				3 0.0001363636	0.00	06-	06-	•	0.1	9 0.03	0.00	
=	•	•				3 0.0001363636	0.0	06-	06-	0	o. I	9 0.03	0.00	
	• •					3 0.0001363636	0.0	06- -	06-	•	0.1	9 0.03	0.00	
		•				5 0.0001565656	0.00	04-	04- 12	•		9 0.03	0.00	
= !		• •			•	3 0. VUU J63836	0U	04-	06-	D .		9.03	0.00	
21		• •			-	.5 0.000105	0.00	06-	06-		0.2		0.00	
2		. (.5 0.000105	0.0	06-	-90	0	0.2	1 0.4	0.00	
12	-	•			_	.5 0.000105	0.00	06-	-90	•	0.2	10.04	0.00	
1	•	•				.5 0.000105	0.00	06-	06-	•	0.2	0.04	0.0	
12	-	•			-	.5 0.000105	0.00	06-	06-	•	0.2	1 0°0	0.00	
12	•	•				.5 0.000105	0.00	06-	06-	•	0.2	.04	0.0	
121	•	•			-	.5 0.000105	0.00	06-	-90	0	0.2	10.04	0.00	
11	•	-			-	.5 0.000105	0.00	06-	06-	•	0.2	0.01	0.00	
12	•	-			-	.5 0.000105	0.00	06-	06-	•	0.2	0.04	0.00	
21	•	-			-	.5 0.000105	0.00	06-	-70	•	0.2	4 0.04	0.00	
13.	•	•			-	.5 0.000105	0.00	06-	06-	•	0.2	0.04	0.00	
11	•	-			-	.5 0.000105	0.00	06-	06-	•	0.2	4 0.04	0.00	

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1/17/86

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JSC Shot No. 917 (Thin Plate with Cloth)

1			Reasured Vi	al ues			,				Calculated Va	iues		
Particle Mo. X lc of i (ori	cation mpact gim at	Y locati of impaci e) (origin a	on 2 location t of impact at *) forigin at	Penetration Depth	Length of Particle	Ϋ́.	2	R location of ispact (origin_at te	Theta locati of impact 1) (origin at 4	ion Phi Jocation of Impact H! forigin at H	<pre>a Cone Angle (angle from) impact pt. to swrf more)</pre>	Average Diameter	Average Area	Vel ocity
	1	1	3	2	:	sı,		2	ومؤر ومه	Degrees	Begrees	1	na squared	ka/sec
220	•	•			6	0.5	000081875	0.0	Ϋ́)6- 04	•	0.3	6 0.10	0.00
221	•	-			ð	9.5 0		0.00	T	- 0L	•	0.3	6 0.10	0.0
222	•	•			0	9.5 0	. 000081875	0.06	T .	7- 8	•	0.3	6 0.10	0.00
223	•	•			0	1.5 0	. 000081875	0.00	۳ -	- 0L	•	0.3	6 0.10	00.00
224	•	•			0	3.5 0	. 000081875	0.00	- T	-96- 04		0.3	6 0.10	0.00
522	•	-			•	0.5 0	000081875	0.00	Ĩ	J6- 04	•	0.3	6 0.10	0.0
226	•	-			÷	9.5 0		0.0	1	36- 04	•	0.3	6 0.10	0.00
112	•	•			•	3.5 0.	.000081875	0.0	۲ ۲	36- OL	•	0.3	6 0.10	0.00
228	•	-			0	9.5 0.	. 000081875	0.00	T	70 -94	•	0.3	6 0.10	0.00
522	•	•			•	9.5 0.		0.00	۳ د	96- Ot	•	0.3	6 0.10	0.00
230	•	•			•	0.5	000061875	0.0	T -	16- 04	•	0.3	6 0.10	0.00
231	•	-			•	3.5 0.	· 000081875	0.0	۳ -	76- OL	•	0.3	6 0.10	0.0
232	•	•			•	0°2°0	.000081875	0.0	T	36- Od	•	0.3	6 0.10	0.0
233	•	•			•	9.5	.000081875	0.00	۳ -	36- OL	•	0.3	6 0.10	0.00
234	•	-				3.5 0.	.000081875	0.0	۳ -	36- OL	•	0.3	6 0.10	0.00
232	•	•			•	7.5 0.	. 000081875	0.0	ĩ	36- OL	•	0.3	6 0.10	0.00
236	•	•			0	9.5 0.		00°U	۳ -	36- OL	•	0.3	6 0.10	0.0
237	•	•			•	5.5 O.	. 000081875	0.00	۳ -	26- 04	•	0.3	6 0.10	0.00
238	•	-			o	7.5 0.	. 000081875	0.00	۳ -	76- 01	•	0.3	6 0.10	0.0
239	•	- -			•	0°.5 0.	.000081875	0.0	5	96- 04	•	0.3	6 0.10	0.00
240	•	•			•	5°5 0.		0.0	۳ -	36- OL	•	0.3	6 0.10	0.00
211	•	•			•	7.5 0.	.000081875	0.0	۳ -	96- 04	•	0.3	6 0.10	0.00
242	•	-			•	0.5	.000081875	0.00	۳ ۲	96- OL	•	0.3	6 0.10	0.0
243	•	- •			•	.5	.000081875	0.00	۳ ۲	-96-	•	0.3	6 0.10	0.0
ŧ.	• •	•			0		.000081875	0.00	••	96- 04	•	0.3	6 0.10	0.00
	• •				0	9 9 9	\$18180000	0.0	T	96- 06	•	0.3	6 0.10	0.00
2 2	• •	• •			•	9 1 2 1	. 000081875	0.0	7	-96-	•	0.3	6 0.10	0.00
147	•	•••			0		5/8180000 *	0.0	~	96	•	0.3	6 0.10	0.00
847 870	•	•			•	0 0 0 1	C/8190000 *	0.0	-	96- 01-	•	5°0	6 0 .10	0.00
750	-	•			> <		. 0000018/3	0.0	,		-	0.3	6 0.10	0.00
5 E	•	•			> ¢		- vovueters	0.0	19		-	5 F	6 0.10	6.9 5
253	•	•			• •		21010000				•			3
1 2	•	-					. VUVU16/2		-				9.10 9.10	8. A
17	•	•			·c		DOMORINTS	0.0	- 0		•		010 010	8.6
52	•	•					000081875	0.0			> c		010	
256	•	•					000081875	0.0	- P	V0-				00.0
257	٠	•				.5	000081875	0.0		06- 0		1.0		0.00
258	•	•			ō	.5	000081875	0.00		06- 0	• •	1.0	0.10	0.00
259	•	-			ō		000081875	0.00		06- 0	, ,	0.3	0.10	0.00
260	•	-			Ó	.5 0.	000081875	0.0		06- 0,		0.3	6.10	0.0
261	•	•			ō	.5	5/8180000	0.00	Ť	06-	•	0.31	6.10	0.00
262	•	•			ō	.5 0.	.000081875	0.0	6-	05- 0.	•	0.3	6 0.10	0.00
243	•	•			ō	.5 0.	,000081875	0.00	6 7	06- 0.	•	0.3	6 0.10	0.00

1/17/86	
617	iith Cloth)
JSC Shet No.	(Thin Plate w

Calculated Values

Measured Values

																																			-		•			
Velocity	ke/sec	0.00	0.00	0.00	0.00	0.00	0-00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	00.0	0.00	0.00	0.00	0.00	0.0	0.0	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.0	0.0	00.0	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.00
aðe	a squared	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	2.0	0.10	0.10	0.10	0.10	01.0	0.10	0.10	0.10	01.0	0.10	0.10	0.10	0.10	0.10	01.0 0	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Ave Are	•	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36		0.36 0.36	0.36	0.36	0.36	0.26	0.36	0.36	0.36	0.36 0.76	0.36	0.36	0.36	0.36	0.36	00 1.0	0.36	0.76	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Average Dianeter	1																																							
Come Angle Langle from Lapact pt. o surf norm)	Degrees	0	°	•	•	•	• •	•	•	•	0	•	•	•	• •	2 6	- 0	• •	•	•	> e	• •	0	0	~	• •	•	•	0	•	> (•	•	0	0	c	•
hi location [f impact (rigin at ##) t	Degrees	06-	-90	06-	06-	06-	-90	06-	06-	06-	06-	06-	-90	06-	06-		06-	6-	06-	0 <u>6</u> -		- 6 -	06-	8- 8 -	04-	96-	06-	06-	- 10	6 - 6		06-	06-	06-	06-	06-	06-	06-	06-	-90
ta location P impact o igin at FF) (o	Degrees	06-	-90	-90	06-	06-	06-	06-	06-	06-	06-	06-	06-	0 6 -	06-	6	P 6-	06-	06-	8- 8-		96-	06-	<u>ę</u> 8	A 8-	06-	06-	-90	06-	06- -		06-	06-	06-	06-	06-	06-	06-	-90	-90
R location The of inpact of forigin at es) (or	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.0	0.00	0.0	0.00	0.00	0.00	0.00	0.0	00*0	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	00.0	0.00	0.00	0.00
10		081875	0081875	000081875	.000081875	. 000081875	0.00081875	.000081875	.000081875	000081875	000081875	200081875	00081875	C/818000	C/818000	D000B1875	000081875	00081875	000081875	. 000081875	0.000081875	0.000081875	0.000081875	0.000081875	0.00081875	.000081875	.000081875	.000081875	C/818000	0081875	MORT 875	081875	081875	0081875	00081875	00081875	000081875	.000081875	.000081875	. 000081875
ίλ)		0.9	2		0	_			•	ō.	o`	ã.	2	2		: -	: ~	2	~		_	<u> </u>	•			0	•			38	8	ŝ	8	8	٩.	· ·	•	0	•	•
	i	0.5 0.000	0.5 0.00	0.5	0.5	0.5	0.5	0.5	0.5 0	0"2 0	0.5	0.5 0.(0.5 0.0	0.0 	0.0	0.5 0.	0.5 0.	0.5 0.0	0.5 0.	0 0 0 0 0 0		0.5	5.0	0 K		0.5	0.5		0.0 2 0 0.0	0.5 0.00	0.5 0.00(0.5 0.000	0.5 0.000	0.5 0.00	0.5 0.0	0.5 0.0	0.5 0.	o.5	<u>ہ</u>	°.
Length of Nas Particle		0.5 0.000	0.5 0.0	0.5 0.	0.5 0	0.5 0	0.5 (0.5	0.5 0	0.5	0.5	0.5 0.6	0.5 0.0		0.0 2.0	0.5	0.5 0.	0.5 0.(0.5 0.	0 C		0.5	0.5	0.0	0.5	0.5	0.5	0.0		0.5 0.00	0.5 0.00	0.5 0.000	0.5 0.000	0.5 0.00	0.5 0.0	0.5 0.0	0.5 0.	0.5	0.5	0.5
rementation Length of Nas Depth Particle	1	0.5 0.000	0.5 0.9	0.5 0.	0.5	0.5 0	0.5 (0.5 (0.5 0	0.5	0.5	0.2 0.0	0.5 0.0		0.0 2.0	0.5 0.	0.5 0.	0.5 0.0	0.5 0.	0.5.0	5.9	0.5	0.5	0.0 2.0	0.5	0.5	0.5	6 0 1 0 0 1 0		0.5 0.00	0.5 0.000	0.5 0.00	0.5 0.000	0.5 0.00	0.5 0.0	0.5 0.0	0.5 0.	0.5	0.5	0.2
/ location renetration Length of Nas of impact Depth Particle (origin at 4)	40 EE 40 402	0.5 0.000	0.5 0.0	0.5 0.	0.5 0	0.5 0	0.5 (0.5 (0.5 0	0.5 0	0.5	0.2 0.0	0.2 0.0				0.5 0.	0.5 0.1	0.5 0.	0 Y 0	5.0	0.5		0.0 Y 0	0.5	0.5	0.5			0.5 0.50	0.5 0.00	0.5 0.000	0.5 0.000	0.5 0.00	0.5 0.0	0.5 0.0	0.5 0.	0.5	0.5	0.5
r rocarrom k rocarrom remetration Length of Nas of impact of impact Depth Particle (origin at #) (origin at #)		0.5 0.000	0.5 0.0	0.2 0.	0.5 0	0.5 0	0.5 (0.5	0.5 0		0.5 0	0.2		- 0.0 	0.0 C.9 0.6 2.0			• 0.5 0.1	0.5 0.			0.5	0.5		. 0.5	0.5	0.5			0.0 0.00 °		• • • • • • • • • • • • • • • • • • • •	.5 0.000	• • • • • • • • • • • • • • • • • • • •	0.5 0.0	0.5 0.0	0.5 0.	0.5	0.5	0.5
x rockrow y rockariom z rockriom remetration Length of Mas of japact of japact of japact Depth Particle forigia at 4) forigin at 4)		0.5 0.00			0.5 0	0.5 0	0.5 (0.5 (0.5 0	0.2 0	0.5 0	0.2 0.0					• • •	• • • • • • • • • • • • • • • • • • • •	9.2 0.			0.5				0.5	0.5					• • •			0.5 0.0	0.5 0.0	0.5 0.	0.5	0.5	0.5
ruccerus a uscarus a uscarus a locarus renefratum Length of Mas of impact of impact of impact Depth Particle (origin at 4) (origin at 4) (origin at 4)						180 0.5 0											192 • • •	133 • • • • • • • • • • • • • • • • • •				198 • • • • • • • • • • • • • • • • • • •			202 • • • 0.5	203 0.5				208 • • 0.50 208	209 0.5 0.001	210 • • • • 000	211 • • • • • • • • • • • • • • • • • •	212 • • • • • • • • • • • • • • • • • •			215 0.5 0.			

		Velocity	ka/sec						
		Aver age Area	ne squared						
	lues	Aver age Di ameter	1						
	Calculated Va	<pre>Cone Angle (angle from) impact pt. to surf norm)</pre>	Degrees						
		m Phi location of impact (lorigin at **	Degrees						
		Theta locatio of impact }torigin at 60	Degrees						
1/17/86		R location of impact (origin at e	I)7 percent Eject	13 percent Spall	·		ól percent Dust
917 h Cloth)					30.0	69.9			37.5
hot No. 9 Plate with				0.25	0.075164	0.174836	0.028196	0.063586	0.093782
JSC S (Thin		Nass	sui		-	-	-	-	-
		Length of Particle	3	iass Hore & after	ecta Hass =	all Nass =	i Dust =	bust =	Dust ≖
	s	Penetration Depth	2	Total from m of target be	Corrected Ej	Corrected Sp	Calc. Ejecta	Calc. Spall	Total Calc.
	Measured Valu	2 Jocation of impact (origin at 4)	1		206				
		Y location of impact {origin at 4}	3	ight corner face)	m target surf	1,	0		.# VELOCITY 55
		location iepact rigin at £)	I	At lower ri t target sur	pact point d	:	43		1 9269 (11260) 9869 (11260)
	ł	e No. I 0f		Drigin 4, larget (a	H, At ie	۲.	3		tion, M P
		Particl		Ejecta	Origin	•••••••••••••••••••••••••••••••••••••••			calcula calcula

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1/17/86 JSC Shot No. 917 (Thin Plate with Cloth)

			Reasured Val	ues							Calculated Va	lues			
Farticle No.	X location of impact (origin at	Y location of impact •) (origin at (/ location of impact e) (origin at e	Penetration Depth	Length of Particle	Nass		R location of impact (origin at em	Theta location of impact)(origin at #1	t Phi location of impact (origin at #	Cone Angle (angle from 1 impact pt. to surf norm)	Aver age Di aneter	Average Area	Velocity	
	:	:	2	2	:	ŝuŝ		I	Degrees	Degr ees	Begrees	:	nn squared	Ka/sec	
264	•	•			J	.5 0.0000	81875	0.00	06-	04-	0	0.1	6 0.10	0,00	
265	•	•				.5 0.0000	61875	0.0	06-	06-			6 0.10	0.0	
264	•	•				.5 0.000	01075	0.00	06-	06-		0.1	6 0.10	0.0	
26)	•	•				.5 0.0000	81875	0.0	06-	06-			6 0.10	00.0	-
266	•	•				.5 0.000	61875	0.00	06-	06-	. 0	0.1	6 0.10	0.00	
265	•	•				.5 0.000	81875	0.0	06-	06-		0.3	6 0.10	0.00	
7/2	•	-				.5 0.000	61875	0.00	06-	06-		0.1	6 0.10	0.00	
175	•	•				.5 0.000	61875	0.0	06-	06-		0.3	6 0.10	0.00	
27.	•	•				.5 0.000	81875	0.00	06-	06-	ē	0.3	6 0.10	0.00	
275	•	•			0	.5 0.0000	81875	0.00	06-	06-	•	0.3	6 0.10	0.0	
274	•	•				.5 0.000	81875	0.00	06-	06-	•	0.3	6 0.10	0.00	
275	•	•			•	.5 0.0000	91875	0.00	06-	06-	•	0.3	6 0.10	0.00	
271	•	•			U	.5 0.0000	81875	0.00	06-	06-	0	0.1	6 0.10	0.00	
12 12	•	•			0	.5 0.0000	81875	0.00	06-	06-	•	0.3	6 0.10	0.00	
รี: B-	•	-				.5 0.0000	81875	0.00	06-	06-	0	0.3	6 0.10	0.00	-
يّ ع	•	•			0	.5 0.000	81875	0.00	06-	06-	•	0.3	6 0.10	0.0	
₹ 9	•	•			J	.5 0.0000	81875	0.00	06-	06-	0	0.3	6 0.10	0.00	
281	•	•			J	.5 0.000	81875	0.00	06-	06-	•	0.3	6 0.10	0.0	
28.	•	•			J	.5 0.000	81875	0.00	U6 -	06-	0	0.3	é 0.10	0.00	
282	•	•			•	.5 0.0000	81875	0.00	06-	06-	•	0.3	6 0.10	0.00	
281	•	•			•	.5 0.000	61875	0.00	06-	06-	•	0.3	6 0.10	0.00	
ΞĘ,	•	•			•	.5 0.000	81875	00.0	06-	06-	•	0.3	6 0.10	0.00	
28(•	•			•	.5 0.000	81875	0.00	06-	06-	•	0.3	6 0.10	0.00	
58)	•	•			•	.5 0.000	81875	0.00	06-	06-	•	0.3	6 0.10	0.00	
281	•	•			•	.5 0.000	81875	0.00	06-	06-	•	0.1	6 0.10	0.00	-
58	•	•			0	.5 0.000	81875	0.00	06-	06-	•	0.3	6 0.10	0.00	
291	•	•				.5 0.000	81875	0.0	06-	06-	•	0.3	6 0.10	0.00	
591	•	-			0	.5 0.000	61875	0.0	-30	06-	•	0.3	6 0.10	0.00	
292	•	-			•	.5 0.000	81875	0.00	06-	06-	•	0.3	é 0.10	0.00	
292	•	•			0	.5 0.000	01875	0.00	06-	06-	•	0.3	6 0.10	0.00	
594	•	•			Ū	.5 0.000	61875	0.00	06-	06-	0	0.3	6 0.10	0.00	
295	•	•			0	.5 0.000	01875	0.00	06-	06-	•	0.3	6 0.10	0.00	
296	•	•			0	.5 0.0000	01875	0.00	06-	06-	•	0.3	6 0.10	0.00	
(62	•	•			0	.5 0.000	81875	0.0	06-	06-	•	0.3	6 0.10	0.00	
296	•	•			0	.5 0.000	81875	0.00	06-	06-	•	0.3	6 0.10	0,00	
295	•	•			•	.5 0.0000	81875	0.00	06-	06-	•	0.3	6 0.10	0.00	
						•									
				Total typecta	a L'ainte -	5.0	46948								
				10191 669201	- EJJAČA DJ	>	Catv.								
				Total Spall =		0.	10925								
				3		•									
				Total Mass =		0.1	5621B								

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1/17/86

JSC Shot No. 917 (Thin Flate with Clath)

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JSC Shot No. 917 1/1//86 (Thin Plate with Cloth) Calculated Values

Ressured Values

Particle No.	X location	Y location	7 location	Fenetration	Length of	Kas	5	R location	lheta location	Phi lecation C	ione Angle	Aver age	âver age	Velocity	
	forigin at 4	or impact •) (origin at •.	or repact) (origin at	t) (+	Farlicle			of impact lorigin at 44)	of impact (origin at ee)	of impact ((crigin at 44)	angle from impact pt.	Dianeter	Area		
	5	:	:	1	2		suộ	:	Degrees	Degrees	Degrees	2	ee squared	ka/sec	
SFALL															
(0	0	60		ŝ	0.000800	87.78	-44.52	22.62	46.88	0.3(6 0.10	1.5	•
~ 1		0 13		"	-	ŝ	0.000600	120.21	-37.46	42.68	50.17	0.31	1 0.08	1.1	
		0		11	5	2	0.000200	94.05	- 38.95	4.70	39.09	0.25	B 0.06	2.1	•
•		0	œ	64	2	5	0.000200	87.10	-42.67	2.68	42.71	0.2	10.04	1.2	. ~
ŝ			-	11 0.	5	ŝ	0.000200	135.28	-27.99	-24.25	34.87	0.1	8.0.0		
9	_	0	~	68 0.	2	2	0.000300	103.97	-40.95	-37.41	19.15		0.0		
1	_	0	•	91	2	2.5	0.000100	108.57	-32.96	3.14	33.05	0.15	10 ⁰		
æ		0 15!	'n	50 0.	5	m,	0.000200	118.66	-49.72	60.95	65. OR	0.21	1.04		
•	_	۲ 0	6	45	1	1.5	0.000100	18.96	-52.67	-30,96	55.26	0.23	0.04		. .
10	_	0 5(•	55	-	2	0.000100	82.04	-47.01	-15.26	47.90	0.20	0.03		
=		1 0		60	2	ŝ	0.000300	85.15	-44.52	12.23	45.20	0.22	0.04		. .
12		0 6	G P-	96 0.	5	2	0.000075	112.72	-31.57	1.79	31.61	0.17	0.02	0	
-		0 8	•7	90	2	2	0.000075	109.11	-33.25	11.31	34.43	0.17	0.02	1.8	
- :		1 8 0	~	84	2	2	0.000075	104.05	-35.08	11.44	34.17	0.17	0.02	18.1	
5		ں وہ	-	02	2	2	0.000075	117.87	-30.05	1.68	30.08	0.17	0.02	18.1	
- [6		0 131	2	50 0.	5	2	0.000075	104.31	-49.72	54.46	61.36	0.17	0.02	0.47	
11		36 0	G .	60 0.	2	-	0.00075	90.39	-44.52	28.81	48.41	0°.25	0.05	0.5	
81		¥	b *•	14	2	5	0.000200	81.22	-4.09	80.07	B0.07	0.23	0.04	1.28	
6		14:		23 0.	2	-	0.000100	88.48	-52.52	73.96	74.93	0.28	90.06	0.5	
22		3	10	28		1.5	0.000100	99.66	-42.88	70.71	71.59	ñ.23	0.04	0.92	
25	•			-	- ,	~ `	0.000100	91.44	-25.41	63.43	64.06	0.20	0.03	0.85	
77 77	ŕ			5	~ •		0.000300	109.20	-47.73	51.99	62.75	0.22	0.04	1.52	
3 1	4 F ²						0.000100	102.86	-31.72	55.49	57.68		0.01	0.31	_
: 22	, 60	5 I I I		9	• -	• •	0.00000	101.02	-19.90	8. 5	54.96	0.45	0.16	1.60	-
72	. 4	145		- 1		r <i>v</i>		14.84 15 30			74.74		20.0	0.71	
27	ń	2 145	4	02		5 6 7	0.000400	94.951		1.05	10.4C	91.0 25 c	0.03	1.68	-
28	10	9 145		42 0.			0.001000	103.27	49.97	47.70	44 00	0.57			
29	10.	3 145		50	2	22	0.001000	104.10	41.35	57.99	61.79	0.19	17.A		
30	60	3 145		53	2	2	0.00063	24.89	24.36	56.48	57.60	0.16	0.02	98 J	
F		145		61	2	2.5	0.00063	100.62	-1.86	52.67	52.66	0.14	0.02	1.79	-
2	ai i	0 143		67		ŝ	0.00063	104.36	0.86	50.05	50.06	0.10	0.01	3.74	~
	⇒ i	G#1 0				2	0.00063	91.22	45.00	68.82	70.13	0.16	0.02	0.76	
51	n i			41 O.	2		0.00063	92.92	-6.07	59.57	59.41	0.22	0.04	0.59	-
с ;				67 0.			0.00063	116.59	37.82	50.05	54.92	0.22	0.04	0.57	c
2		51		¥2	~	m	0.00063	103.58	-46.85	60.64	64.25	0.13	0.01	1.71	
5	- 1	9112	<u> </u>	0	2	-	0.00063	138.60	-27.92	38.66	43.82	0.22	0.04	2.26	
8		142	-	10	6	•	0.000300	136.25	-4.16	36.03	36.16	0.28	0.06	1.74	
62	6	0 142		70	-	-	0.000200	110.73	23.89	48.81	50.79	0.20	0.03	2.37	
e :	12	2 21	-	10		-0	0.000400	77.49	80.98	-11.20	82.59	0.23	0.04	0.24	
Ŧ	12.	2		7 0.		1	0.000800	77.16	83.66	-80.96	£4.80	0.30	0.07	0.19	
4	23	2 21	- '	17		~	0.000500	78.70	74.90	-68.89	17.53	0.24	0.05	0.22	
2	17	H 7	~	.0 0.	0	-	0.000067	118.91	35.91	- 30, 38	42.97	0.23	0.04	0.58	

B-41

JSC Shot No. 917 1/17/86 (Thin Plate with Cloth)

			Measured Val.	ves							Calculated Va	lues			
Particle No.	X location of impact (origin at e	Y lucation of impact) (origin at 4	<pre>2 location 0 ispact 1) (origin at e)</pre>	Fenetration Depth	Length af Particle	Hass		R location of impact (origin at ee	Thete location of impact Morigin at #4)	Phi location of impact forigin at ##	Cone Angle fangle from impact pt.	Åverage Dianeter	Aver age Ar ea	Velocity	
	2	2	=	2	I		sub	1	Degrees	Degrees	Degrees	:	an squared	Ka/sec	
13.	•	-				-0	0.000344	0.00	-90.00	-90.00		0.7	0.04		0.00
132	•	-				-9	0.000344	0.00	-90.00	-90,00	• •	0.27	0.06		0.0
13,	•	•				•	0.000344	0.00	-90.00	-90.00	0	0.23	0.04		0.00
8	•	•				-9	0.000344	0.0	-90.00	-90.00	•	0.22	0.04		0.00
121	•	•				9	0.000344	0.00	-90.00	-90.00	•••	0.22	0.04		0,00
131	•	•				4	0.000344	0.00	-90.00	-90.00	•	0.22	0.04		0.0
RI	•	•				9	0.000344	0.0	-90.00	-90.00		0.22	0.0		0.00
121	•	•				9	0.000344	0.00	-90.00	- 90.00	•	0.22	0.04		0.0
Ŧ	•	•				9	0.000344	0.0	-90.00	-90.00	•••	0.22	0.04		0.00
1	•	•				-9	0.000344	0.00	-90,09-	-90.00	•	0.22	0.04		0.0
141	•	•				9	0.000344	0.00	-90.00	-90.00	•	0.22	0.04	_	0.00
14	•	-				9	0.000344	0.00	-90.09-	-90.00	•	0.22	0.04		0.0
141	•	-				9	0.000344	0.00	-90.00	-90.00	•	0.22	2 0.04	_	0.0
≅ E	•	-				- -9	0.000344	0.00	-90.00	00"04-	•	0.22	2 0.04		0.00
₹ }-	•	•				9	0.000344	0.00	-90.00	-90.00	•	0.22	2 0.04		0.00
€	•	•				- -9	0.000344	0.0	-90,00	-90.00-	•	0.22	0.04		0.00
₹ 4	•	-				9	0.000344	0.00	-90.00	-90.00	•	0.22	0.01		0.00
÷.	•	•				9	0.000344	0.0	-90.00	-90.00	•	0.22	0.04		0.00
15	•	-				9	0.000344	0.0	-90.00	-90.00	•	0.22	2 0.04		0.00
151	•	•				-	0.000344	0.00	-90.00	-90.00	•	0.22	0.04	-	0.00
12	•	-				9	0.000344	0.00	-90.00	-90.00	•	0.22	2 0.04		0.00
15	•	•				9	0.000344	0.0	-90.00	-90.00	•	0.22	0.04		0.0
154	•	•				9	0.000344	0.00	-90.00	-50.00	•	0.22	0.04		0.00
151	•	-				9	0.000344	00-0	-90.00	-90.00	•	0.22	0.04	-	0.00
156	•	•				•	0.000344	0.00	-90.00	-90.09	•	0.22	0.04		0.00
		• •				-0	0.000344	0.00	-90.00	-90.00	0	0.22	0°0	-	0.00
		• •				- -	0.000344	0.00	-90.00	-90.00	•	0.22	2 0.01	-	0.00
5 <u>6</u>	• •	• •				•	0.000344	0.00	-90.00	-90.00	•	0.22	0.04	-	0.00
901 101	•	•				- ` • •	0.000344	0 . 0	-90.00	-00.04	•	0.22	0.04		9.9
101	•						0.000344	0.0	00.06-	-90.06		0.22	0.04	-	0.0
271	•	•				•	0.000244	0.0	00°N-	-90.09	•	0.72	10.0		8.0
144	•	•					0.000311		00.04-	00.0V-		77.0			M .0
: 165	•	•				• •	0. MARX45		AA . NT-	44 48-	> e	77 N			B 8
166	•	•				•		9 0	AA*A4_	00 VQ-	> <				~~~
167	•	•				ت. به د	0.000344	0.00	00 00-		> c	11.V			3.5
168	•	•					0.000344	0.00	00.04-	-60.09-	• •				~~~~
169	•	•					0.000344	0.00	-90.00	-90.00		0.27	10.0		
170	•	•	-			, 9	0.000344	0.0	-90.00	-90.00	0	0.22	0.04		0.00
171	•	•				, 9	0.000344	0.00	-90.00	-90.00	•	0.22	0.04	-	0.00
21	•	•				- 9	0.000344	0.00	-90.00	-90.09	•	0.22	0.04	Ū	0° 0
2	•	•				9	0.000344	0.00	-90.00	-90.00	e	0.22	0.04	J	0.00
121	•	•				ý 9	0.000344	0.00	-90.00	-90.00	•	0.22	0.04	Ū	0.00
2	•	-				• •	0.000344	0.00	-90.00	-90.00	•	0.22	0.04	Ū	0.00

1/17/86 JSC Shot No. 917 (Thin Plate with Cloth) ____

	t,		1.59	1.59	0.97		17.7		1.1	1.84	0.83	D7 -1	V. //	1.43	1.28	0.85		1.28	1.28		0.00 0.00 0.00				0.00 0.00 0.00 0.00 0.00 0.00	1.28 0.90 0.00 0.00 0.00 0.00 0.00	1.28 1.53 0.00 0.00 0.00 0.00 0.00 0.00	1.28 1.53 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0	1.28 1.28 1.28 0.00	1.28 1.28 1.29 0.00	1.28 1.28 0.00	1.28 1.29 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0	1.28 1.29 1	1.28 1.29 1	1.28 1.28 1.29 1	1. 28 1.	1.28 1.28 1.28 1.29 1	1. 28 1.	1. 23 1. 23 1. 23 1. 25 1. 20 1.	1. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2.	1. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2.	1. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2.	1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1
	Vel oc	ed ka/sec	.04	.04	80.	5	70°		2	5.5	101		20.	8	10.	.03	1.04		90	355	- 06 - 05 - 05	- 06 - 05 - 05 - 05	5 5 6 6 7 5 5 5 6 6 7 5 5 5 6 6 7 5 5 7 5 5																				
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	age et er	1	0.23	0.23	0.32		0.37	10.7	c	11.0	1. JT	0.16	0.16	0.28	0.23	0.20	0.23	0° 28		8 . 22 .	0.25	0.25 0.25 0.25	0.25 0.25 0.25	0.25 0.25 0.25 0.25		0.27 0.27 0.28 0.28 0.28	0.27 0.27 0.28 0.28 0.29 0.29	0.27 0.27 0.36 0.30 0.30 0.30 0.30 0.30 0.30 0.30	0.25 0.27 0.36 0.30 0.30 0.30 0.30 0.30 0.30 0.30	0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	• • • • • • • • • • • • • • • • • • •	••••••••••••••••••••••••••••••••••••••	••••••••••••••••••••••••••••••••••••••	• • • • • • • • • • • • • • • • • • •	• • • • • • • • • • • • • • • • • • •	••••••••••••••••••••••••••••••••••••••	• • • • • • • • • • • • • • • • • • •	••••••••••••••••••••••••••••••••••••••	••••••••••••••••••••••••••••••••••••••	••••••••••••••••••••••••••••••••••••••	••••••••••••••••••••••••••••••••••••••	••• ••25 ••26 ••27 ••27 ••28 ••28 ••28 ••28 ••28 ••28	••••••••••••••••••••••••••••••••••••••
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Cal culated	Cone Angle (angle from impact pt. to surf nor	Degrees	21.	12.	ŝ	ŝ	23		ร่ะ	ន់ ដ	2 E	2	5	3	53.	4 9.	63.	42.																									
	i location impact igin at ##)	Degrees	21.63	12.16	-1.31	17 10-			10.00-	1.2C-	-1.7C-	18.97-	-51.88	-48.75	-59.04	-46.82	-63.08	- 39.04	01.07-	THE PART	00'06-	-90.00 -90.00	-90.00 -90.00 -90.00	-90.09 -90.09 -90.09	00.09- 00.09- 00.09- 00.09-	- 70.09 - 90.09 - 90.09 - 90.09 - 90.09 - 90.09	00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09-	0.06- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09-	00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09-	00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09-	90.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06-	00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09-	90.06- 90.06- 90.06- 90.06- 90.06- 90.06- 90.06- 90.06- 90.06- 90.06- 90.06- 90.06- 90.06- 90.06- 90.06- 90.06- 90.06-	00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09-	00.09- 00- 00.09- 00.09- 00.09- 000- 00- 00- 000- 0	00.09- 00- 00.09- 00.09- 00.09- 000- 00- 00- 00- 00- 00- 00- 00- 00-	00.06- 00	00.09- 00- 00- 00- 00- 00- 00- 00- 00- 00-	00.09- 00- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00- 00- 00- 00- 00- 00- 00- 00- 00-	00.06- 00	00.09- 00- 00- 00- 00- 00- 00- 00- 00- 00-	00.09- 00- 00- 00- 00- 00- 00- 00- 00- 00-	00.09- 00- 00.09- 00.09- 00.09- 000-00- 00-00-00-00-00-00-00-00-00-00-
	location Ph pact of in at #1 {or	Jrees	-1.97	-3.45	19.47	10 10	-47.14			-32.62	21.12 - 1	97.7	-32.11	-43.45	7.31	-26.94	-5.19	-23.03	-90.00	A> -> -> ->	-90.00	-90.09-	-90.00 - 90.00 - 90.00	-90.00 -90.00 -90.00	00°06- 00°06- 00°06-	00.09- 00.09- 00.09- 00.09- 00.09-	00°04- 00°04- 00°04- 00°04-	00°04- 00°04- 00°04- 00°04- 00°04- 00°04-	00.09-00.00 00.09-00.00 00.09-00.00 00.09-00.09-00.00 00.09-00.09-00.00 00.09-00-00-00-00 00.09-00-00-00-00-00 00.09-00-00-00-00-00-00 00.09-00-00-00-00-00-00-00-00-00-00-00-00-0	00 004- 00 004- 00 004- 00 004- 00 004- 00 004- 00 004- 00 004- 00 004- 00 004-	00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06-	00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09	00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06-	00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06- 00.06-	00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09 00.09	00.09- 00- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00.09- 00- 00- 00- 00- 00- 00- 00- 00- 00-	00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06- 00'06-	00.06 00000000	00.09- 00.09-	00.09- 00- 00- 00- 00- 00- 00- 00- 00- 00-	00.09- 00- 00- 00- 00- 00- 00- 00- 00- 00-	00.09 00.09	00.09 00 00 00 00 00 00 00 00 00
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	R location of impact (origin at	1	124.	118.	123.	¥	2.38	8 8	9		-00 14	101	. 8	101.	75.	94.	2.2	1 0 1	50			: .		:	:																		
		3eS	0.000128	0.000128	0.000128	0.00000	0.000500	0 000100	0.000100	0. UUUUU ^ 666766	0.00000	0.000100	0-000100	0.000200	0.000200	0.000100	0.000200	0.000100	0.000700	0.000400	0.000800		0.001500	0.001500	0.001500 0.001100 0.000700	0.001500 0.001100 0.000700 0.000800	0.001500 0.001100 0.000800 0.000800	0.001500 0.001100 0.000700 0.000775 0.000775	0.001500 0.001100 0.000700 0.000775 0.000775 0.000775	0.001500 0.001100 0.000700 0.000775 0.000775 0.000775 0.000775	0. 001500 0. 001100 0. 000705 0. 000775 0. 000775 0. 000775 0. 000775 0. 000775	0.001500 0.001100 0.000700 0.00075 0.000775 0.000775 0.000775 0.000775 0.000775	0.001500 0.001100 0.000700 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775	0.001500 0.001100 0.000700 0.00075 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775	0.001500 0.001100 0.000700 0.00075 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775	0.001500 0.001100 0.000700 0.00075 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775	0.001500 0.001100 0.001100 0.00075 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775	0.001500 0.001100 0.001100 0.00075 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775	0.001500 0.001100 0.001100 0.00075 0.00075 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775	0.001500 0.001100 0.001100 0.00075 0.00075 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775	0.001500 0.001100 0.000700 0.00075 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775 0.000775	0.001500 0.001100 0.000700 0.00075 0.00075 0.00075 0.00075 0.00075 0.00075 0.00075 0.00075 0.00075 0.00075 0.00075 0.000	0.001500 0.00100 0.00100 0.00075 0.00075 0.00075 0.00075 0.00075 0.00075 0.00075 0.0
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cantex bay	ation Fi pact De in at f)	I	116	116	116	-	42 42	1	2 2	86	3 5	2 92	215	15	39	61	R	0B																									
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JSC Shot No. 917 (Thin Plate with Cloth)

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			Reasured Val	urs						Calculated Va	lues			
Particle No.	X location of impact forigin at	Y location of impact 4) (origin at (Z location of impact *) (origin at *	Penetration Depth	Length of Particle	Rass	R location of impact torigin at ee	Theta location of impact Morigin at 44	Phi location of impact (origin at ++	Cone Angle (angle from impact pt.	Average Diameter	Åver age År ea	Velocity	
	1	I	2	2	I	seb	2	Degr ees	Degrees	to surt norm) Degrees	:	an squared	Ka/sec	
220	•	-				4 0.000219	0.00	-90,00	-90.00	-	10.0	10 0	c	ē
221	•	•				4 0.000219	0.00	-90.00	-90.00		12:0	0.07	÷	3 8
222	• •					4 0.000219	0.00	-90.00	-90.00	0	0.21	0.03		2 8
273	•	-				4 0.000219	0.00	-90.00	-90.00	• •	0.21	0.07		8
224		•				4 0.000219	00.0	-90.00	-90.00	• •	0.21	0.03		28
222	•	-				4 0.000219	0.0	-90.00	-90.00	•	0.21	0.01	; -	2
226	• •					4 0.000219	0.00	-90.00	-90.00	• •	0.21	0.03	: e	3 2
122	• •	•				4 0.000219	0.0	-90.00	-90.00	•	0.21	0.03	: -	2
822	• •	• •				4 0.000219	0.00	-90.00	-90.00	•	0.21	0.03		8
677 672	• •					4 0.000219	0.00	-90.00	-90.00	0	0.21	0.03		8
230	• •	• •				4 0.600219	0.00	-90.00	-90.00	•	0.21	0.03		8
107	• •					4 0.000219	0.00	- 90.00	-90.00	•	0.21	0.03		8
707	•	•••				4 0.000219	0.00	-90.00	-90.00	•	0.21	0.03	e.	8
122	•	• •				0.000219	0.00	-90.00	-90.00	•	0.21	0.03	0.	8
275	•	•••				4 0.000219	0.00	-90.00	-90.00	0	0.21	0.03	°.	8
112	•	•				4 0.000/50	0.0	-90.00	-90.00	•	0.39	0.12		8
237	-	•				00/001.0	0.00	-90.09	-90.00	•	0.39	0.12	°.	8
PX4	•	•				42/000 0 4	0.0	00.04-	-90.09	0	0.39	0.12	0	8
239	-	•					0.00	-90.09	-90.00	с .	0. 39	0.12	0.	8
240	•	•				2 0.12000 0	0.00	00.04-	-90.00	0	0.30	0.07	-0	8
241	•	•				2 0,00016 2 0,00016	0.0	00.07-	-90.09	•	0.30	0.07	ċ	8
202	•	•				2 0.000216	00 0	01.04-	00°04-	5 4	0.0	0.07		8
243	•	•				2 0.000216	0.0	00°04-		> <	9. 9 9. 9	10.0		8 8
244	•	•				2 0.000216	0.0	-90.00	00.07-	> e	00	10.0 10.0	5	88
245	•	•				2 0.000216	0.00	-90.00	-90.00	è	01.0	0.0		8 8
246	•	-				2 0.000216	0.00	-90.00	-90.00	• •	0.30	0.07	; -	2 8
247	• •	•				2 0.000216	0.00	-90.00	-90.00	0	0.30	0.07	0.0	8
847	• •	• •				2 0.000216	0.00	-90.00	-90.00	•	0.30	0.07	6	8
750	•	•				2 0.000216	0.00	-90.00	-90.00	•	0.30	0.07	0.0	8
2152	•	•			•••	41700.0 Z	0.0	-90.00	-90.00	0	0.30	0.01	0.	8
222	•	•				2 0 000114	0.00	00.04-	00.07-	•	0.30	0.01		8
253	•	•				2 0.000216		00°04-	00.07-	•	0.30	0.07		8 8
254	•	•				0.000216	9-0 -	00 00-	WU U0-	,	70.V	10.0		8 1
255	•	•				0.000216	0.00	00.04-	00'04-		00	10.9		88
256	•	•				0.000216	0.00	-90.09	00 00-		0.00			3 8
257	•	•				2 0.000216	0.0	-90.00	-90.00	• •	0.30	0.07		2 8
258	•	•				2 0.000216	0.00	-90.00	-90,00		0.0	0.0		2 8
229	•	-			~	2 0.000216	0.00	-90.00	-90.00	• •	0.30	0.07		38
260	•	•			~	2 0.000216	0.00	-90.00	-90.00	. 0	0.30	0.07	0.0	3 2
192		• •			7	2 0.000216	0.0	-90.00	-90.00	0	0.30	0.07	0.0	: 2
292		•••			-	0.000216	0.00	-90.00	-90.00	0	0.30	0.07	0.0	: 2
(a)	,	•			7	0.000216	0.00	-90.00	-90.00	•	0.30	0.07	0.0	2

1/17/86	
116	with Cloth)
JSC Shot No.	(Thin Plate

Calculated Values

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Measured Values

CICLE 40.	a sucerson of impact (origin at i	r rocacion of impact i) (origin at	<pre>c location of impact #) (origin at #)</pre>	Fenelration Depth	length of Particle	Mass	R location 1 cfiepact o {origin at **)(heta location f impact origin at ##)	Phi location of impact (origin at **)	Cone Angle langle from impact pt.	Average Diaseter	Average Area	Velocity	
	1	:	2	2	1	seb	:	Degr ees	Degrees	to surf nore) Degrees	I	en squared	Ka/sec	
176	•	•				6 0.000344	0.00	-90.00	-90.00	0	0.7			90
12	•	-				6 0.000344	0.00	-90.00	-90.00		0.2	2 0.0		8
1/8	• •	• •				6 0.000344	00.0	-90.00	-90.00	0	0.2	2 0.0		8
6/1	• •	• •				6 0.000344	0.00	-90.00	-90.09	0	0.2	2 0.0		8
081	• •	• •				6 0.000344	0.00	00.04-	-90.09	•	0.2	2 0.0		00
181	• •	• •				6 0.000344	0.00	-90.00	-90.00	0	0.2	2 0.0		8
7 R I	• •	• •				6 0.000344	0.00	-90.00	-90.00	0	0.2	2 0.0		00
		• •				6 0.000344	0.00	-90.00	-90.00	•	0.2	2 0.0		8
5	•	• •				6 0.000344	0.00	-90.00	-90.00	•	0.2	2 0.0		8
58 1	• •	•				6 0.000344	0.00	-90.00	-90.00	0	0.2	2 0.0		00
981	• •	• •				6 0.000344	0.0	-90.00	-90.(10	•	0.2	2 0.0		00
181		• •				4 0.000219	0.00	-90.00	-90.00	•	0.2	0.0		8
8 (• •				4 0.000219	0.00	-90.00	-90.00	•	0.2	1 0.0		8
681						4 0.000219	0.00	-90.00	-90.00	0	0.2	1 0.0	· •	8
A .	• •					4 0.000219	0.00	-90.00	-90.00	0	0.2	1 0.0		8
Ξ						0.00219	0.00	-90.00	-90.00	0	0.2	0.0		8
741	• •					4 0.000219	0.0	-90.00	-90.00	0	0.2	1 0.0	. 0	8
2	• •					4 0.000219	0.00	-90.00	-90.00	0	0.2	1 0.0	0 2	8
	•	•				4 0.00219	0.0	-90.00	-90.00	٥	0.2	1 0.0	0	8
21	-	•				4 0.000219	0.00	-90.00	-90.00	•	0.21	1 0.0	•	8.
197	•	•				417000.0	00.0	-90.00	00.09-	0	0.2	0.0	•	8
861	-	•					0.0	00.04-	00.09-	0	0.21	0.0	•	8
261	•	•					00.0	-90.00	-90.00	0	0.2	0.0	~	e.
200	•	•					00.0	00.07-	00.04-	0	0.21	0.0	•	8
201	•	•				4 0 000217	0.0	00.09-	00°04-		0.21	0.0	•	ខុះ
202	-	•				0.000219	0.0	00.09-	00.04-	- -	17-0			8 8
203	•	•				4 0.000219	0.00	00-04-	00 04-	¢				e e
204	•	•				4 0.000219	0.0	-90.00	-90.00		0.21			8
205	-	•				4 0.000219	0.00	-90.00	-90.00	•	0.21	0.0	• •	8
206	-	•				4 0.000219	0.00	-90.00	-90.00	•	0.21	0.0		8
202		• •				4 0.000219	0.00	-90.00	-90.00	•	0.21	0.03		8
8 07		•••				4 0.000219	0.00	-90.00	-90.00	•	0.21	0.03	•	8
407		• •				4 0.000219	0.00	-90.00	-90.00	•	0.21	0.03	0	8
117		• •				0.000219	0.00	-90.00	-90.00	•	0.21	0.01	•	8
117	• •	• •				4 0.000219	0.0	-90.00	-90.00	•	0.21	0.03	•	8
717	-	•				4 0.000219	00.0	-90.00	-90.00	•	0.21	0.03	0	8
112	•	•				4 0.00219	0.00	-90.00	-90.00	•	0.21	0.03	ō	9
117	•	•				• 0.00219	0.00	-90.00	-90.00	•	0.21	0.03	e	8
212	•	•				• 0.000219	0.00	-90.00	-90.04	•	0.21	0.03	c	8
217	•	•				412000.0	00	-00.07	-90.00	•	0.21	0.03	ō	8
218	•	•				0 000219	0.0	- 40.00	-90.00 - 20.00	•	0.21	0.03	.	8
219	•	•				4 0.000219	0.00	00.00-	00 00-	> c	10 0	0. V. V.	5 e	88
							****	AV . VI	AA • A4 -	>	11.7	52°3	с.	20

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1/17/86	
JSC Shot No. 917	(Ihin Plate with Cloth)

(Ihin

			heasured Val	ues							Calculated Va	lues			
Fartıcle Mo.	K location of impact (origin at f	Y location of impact) forigin at 4	<pre>2 location of impact •) forigin at #</pre>	Penetration Depth	Length of Farticle	Kass		R location of impact (origin at ##)	Theta location of impact (origin at se)	Phi location of impact forigin at ee	Cone Angle (angle from impact pt.	Aver age Di aneter	Average Area	Velocity	1
	2	2	1	:	2		sub	2	Degr ees	Degrees	to surt nora) Degrees	I	nn squared	Ka/sec	
308	•	•				2	0.000216	0.00	-90,00	-90.00	c	02 V	10 0		
205	-	-				2	0.000216	0.00	-90.00	-90.00			0.0		00°0
210	•	-				2	0.000216	0.0	-90.00	-90.00		0.10	0.0		
	-					2	0.000216	0.00	-90.00	-90.00		01.0	0.0		3.9
312		•				2	0.000216	0.00	00"04-	-90.00		01.0	0.0		
213	•	-				2	0.000216	0.00	-40.00	-90.00	• c	02.0		_ •	8 6
112	•	-				2	0.000216	0.00	-90.00	00.04-	> c	0.00	0.0		0.0
315	•	•				2	0.000216	0.00	-90.00	-90.00	> c	02.0			8.6
316	•	•				2	0.000216	0.0	-90.00	-90-00	•	01.0			
317	-	-				2	0.000216	0.00	-90.00	-90.09	• •	0.0	0.0		
518	•	•				2	0.000216	0.00	-90.00	-90.00		0.10	0.0		
319		•				2	0.000216	0.00	-90.00	-90.00		0.30	0.07		
9	• •	•				2	0.00216	0.00	-90.00	-90.00		0.30	0.07		
		• •				2	0.000216	0.00	-90.00	-90.00	•	0.30	0.07		
7		• •				7	0.000216	0.00	-90.00	00-05-	•	0.30	0.07		0.00
170 161	•	• •				~	0.000216	0.00	-90.00	-50.00	•	0.30	0.07		0.0
	-	•				~ ~	0.000216	0.00	-90.09	-90.00	c	0.30	0.07		0.00
961	•	•				~	0.000216	0.00	-90.00	-90.00	0	02.0	0.07	Ŭ	00.0
177	•	•				~ ~	0.000216	0.00	-90.00	-90.00	•	0.30	0.07	Ū	0.00
328	•	-				~ ~	0.000216	0.0	-90.00	-90.00	•	0.30	0.07	č	.00
328	•	•				~ •	0.000216	0.00	-90.00	-90.09	•	e. 30	0.07	Ū	00.00
130	-	•				~ •	0.000216	0.00	-90.00	-90.00	0	0.30	0.07	9	.00
121	•	•				~ ~	0.000216	0.00	-90.00	- 90.00	0	0.30	0.07	•	.00
E	•	•					0.00016	0.0	-90.09	-90.09	0	0.30	0.07	0	.00
333	•	•				• •	0.00016	0. 00 00	00°0A-	00.09-	0	0.30	0.07	•	00.0
334	•	•					0.000216	00-0	00.04-	00°04-	•	0.30	0.07	6	2
315	•	•					0.000716	0.0	00.04-	00.07-		0.30	0.07	0	8.
336	•	•					0.000216	0.0	00°04-	00.00-	•	00	0.0	5 •	8
337	-	-				~	0.000216	0.00	-90.00	-90.00	è	0.0	10.0 10.0		8 8
338	•	•				~	0.000216	0.0	-90.00	-90.00	• •	0.30	0.01		
955						~	0.000216	0.00	-90.00	-90.00	• •	0.30	0.07	• •	
	•••	•				~	0.000216	0.0	-90.00	-90.00	•	0.30	0.07		8
1 A	-	•				~ .	0.000216	0.00	-90.00	-90.00	•	0.30	0.07	0	8
IN	•	•				~ ·	0.000216	0.00	-90.00	-90.00	•	0.30	0.01	•	00.
141	•	•				~	0.000216	0.00	-90.00	-90.00	•	0.30	0.01	c	.00
SPE	•	•			•		0.00216	0.0	-90.00	-90.00	0	n. 30	0.07	c	00
346	•	•	-			~ ~	0.000216	0.00	- 90.00	-90.00	•	0.30	0.07	¢	. 00.
141	•	-				~ .	0.00216	0.00	-90.00	-90.00	Q	02*0	0.07	0	.00
948	•	•			•••	~ ~	9120001	0.00	-90.00	-90.00	•	0.30	0.01	•	w.
349	•	•			- •	~ ~	9170001	0.00	-90.00	-90.00	0	0.30	0.07	0	.00
350	•	•					017000 V	0.00	-90.09-	-90.00	•	0.30	0.07	Ö	8.
351	•	•				~ ~	917000	0.00	-90.00	-90.00	0	0.30	0.07	c	00.
					•	_	917AAA*/	U. U	-70,00	-90.00	•	0.30	0.07	0	8

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JSC Shot No. 917 (Thin Plate with Cloth)

				Neasured Val	res								Calculated Va	lues
Particle No.	X location of ispact forigin at	Y] of for	ocation impact igin at e)	Z location of impact forigin at f	Penetration Depth	Length of Particle	Hass			R location of impact (origin at ++)	Theta location of impact (origin at **)	Phi location of impact (origin at **)	Cone Angle (angle from impact pt.	Averag Diamet
	1		:	1	1	:		ŝwô		1	Degrees	Degrees	to surt nora/ Degrees	-
26	•	•					2	0.000216		0.00	-90.00	-90.00	0	
26	•	•					2	0.000216		0.00	-90.00	00.08-	•••	
26	• 9	•				*	2	0.000216		0.00	-90.00	-90.00	0	
38	•	• •	•				2	0.000216		0.00	00.04-	-90.00	•	
26	•						~	0.000216		0.00	-90.00	-90.00	•	
2	•••	• •					• •	0.000216	:	0.0	-90.09	-90.00	0	
2 2	• •	•					, ,	0.000216		0.0	-90.09-	00°04-	00	
	•	•	-				• ~	0.000216		0.00	-90.00	-90.00	> 0	
27.	•	•					. ~	0.000216		0.00	-90.00	-90.00	• •	
12	•	•	•				2	0.000216		0.00	-90.00	-90.00	•	
~ !	•••		• •				~ ~	0.000216		0.00	-90,00	-90.00	0	
2	• •						~ •	0.000216		0.0	-90.00	- 00°00-	•	
12	•	-	-				<i>.</i> .	0.00016		8.0	00.04-	00.04-	> c	
2	•	•					• ~	0.000216		0.0	-90.00	-90.00	>	
28	•	•	-				2	0.000216		0.00	-90.00	-90.09	•••	
28	•	•					2	0.000216		0.00	-90.09	-90.00	0	
		-					2 .	0.000216		0.00	-90.00	-90.00	0	
58	•••	• •					2	0.000216		0.00	-90.00	-90.00	0	
	•••	•••					~ 0	0.000216		0.00	-90.09	-90.00	•	
67 167	••	•					, ,	0.000216 A AAA214		0.00	00.04-	- 10.00	5 6	
	•	•					• •	0.000215			00 0a-	00.01-	> <	
2 2	•	•	-				- ~	0.000216		0.0	-90.00	90.00	> 0	
28	•	-	•				2	0.000216		0.00	-90.00	-90.00	0	
29.	•	•	•				2	0.000216		0.00	-90.09	-90.09	•	
52	• •	•					2	0.000216		0.00	-90.00	-90.00	0	
	•••	• •					~ •	0.000216		0.0	-90.09	00°04-	0 (
- EC	•	•					, .	0.00016		0.0	00.01-	00.04-	5 0	
20	•	•					• ~	0.000216		0.0	-90.00	-90.00	• •	
24	•	•					. 2	0.000216		0.00	-90.00	-90.00		
52	•	•	_				2	0.000216		0.00	-90.00	-90.00	0	
291	•	•	-				2	0.000216		00.0	-90,09	-90.00	•	
29	•	•	_				2	0.000216		0.00	-90.00	-90.00	•	
8	•••						~ •	0.000216		0.00	-90.00	-90.09		
2							~	0.000216		0.00	00.06-	-00.09	0	
10C		• •						0.000216		0.00	00.04-	00.07-		
ŝ	•	•						0.000216			0.04-	00.04-		
30	•	•	_				• ~	0.000216		0.00	-90.00	-90.00	. 0	
30	•	•					~ ~	0.000216		0.00	-90.00	-90.00	0	
30	•	•					2	0.000216		0.00	-90.00	-90,00	0	

Velocity

Average Area

Average Di aneter

an squared ka/sec

2

		5
117/86		nor aal
-	Cloth)	thi true
529	ith no (1 dan
-	-	7

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	ejecta
	8
	nornal
2	from
5	Ĩ
	ż

			ffeasured Val	lues		JSC Shot No. (Thin Plate wi (Impact at -34	923 ith na Cloth) 0 deg. phi froe	1/17/86 • normal on ej	ecta side)		Calculated Va	lues			
Particle W	o. X location of impact forigin at 41	Y location of impact) (origin at +)	Z location of impact) (origin at 4	Fenetration Depth	Length of Particle	Rass		R location of impact (origin at te	Theta location of impact (origin at #+)	Phi location of impact (origin at ee)	Cone Angle Langle from Surf. normal) Lorini af 44	Aver age Diameter	Average Area	Velocity	
	2	1	2	1	E	səb		2	Begrees	Degrees	Begrees	2	aa squared	Ka/sec	
SFALL	-	0	~	۲۶	-	4 0.000100		109.16	-76.90	80.97	82.53	0.1	4 0.02	0.71	
	2	9 136		58 0.		5 0.00100		104.93	-50.56	74.73	15.47	0.1	3 0.01	0.34	
	. M	136		99		11 0.000300		19.19	-52.19	78.14	78.55	0.1	5 0.02	1.25	
	-	0	3	18		6 0.00600		88.15	-56.18	-50.05	62.38	0.2	B 0.06	1.23	
	5			6 :	ю.	16 0.001300		89.50	-48.90	-35.66	53.52	0.2	6 0.05	1.1	
	•	61 61		= =		14 U. U00600 87 A AA77AA		1/ -08 11 -08	-2/.18	10°51-	Ce.19		K 0.03	0.33	
	~ 66	0 22				17 0.00500		11.39	-57.08	-36.49	60°.34		5 0.02	0.33	
		0 21		60	. 2	14 0.000300		78.21	-56.97	- 35.68	59.53	0.1	3 0.01	0.78	
	10	0	2	12		45 0.000800		76.92	-59.06	-38.73	61.62	0.1	2 0.01	0.69	
	=	0 24	-	0	-	33 0.001400		77.08	-56.82	-32.17	28.84		9 0.03	0.86	
B-	12	0 51	= ·	= ;	~ ~	25 0.000600 7 0.000600		21.11 21.11	-58.13	CO.BC-	50.79 10 05		10.02	10.0	
-5	21	0 01 0 45		22 DC		2 0.000100	_	21.121	N7-17-	11.07	20-02 17-51	0.2	0.01	0.85	
0	12	0 22		42	• ••	2 0.000100		113.77	-32.52	16.4	32.76	0.2	0 0.03	2.52	
	16	0 36		50	3	3 0.000100		104.13	-36.23	9.41	36.91	0.1	6 0.02	2.27	
	17	9		4	2	3 0.000275		101.97	-35.05	12.58	36.36	0.2	7 0.06	1.19	
	8	0		馬	m -	4 0.000275		115.15	-33.09	16.58	35.62 29 25	0.2	• 0.01	1.65	
	1	17 0		8		2/2000.0 Z	_	44.701	17.97-	74 41	40.00 44.97	6.6 6	2 0.04 2 0.04	- 59 1971	_
	21	0 99		51		5 0.000100	_	10.69	-11.73	28.77	46.33		10.0	0.67	
	33	69 0		20		4 0.000150		69.87	-42.42	32.41	48.05	0.1	7 0.02	0.65	
	23	0 81	•••	52	-	4 0.000150		100.97	-47.95	46.85	56.98	0.1	7 0.02	0.65	
	24	(6 0)	~ •	1 3	F	3 0.000150	_	105.37	-48,68	51.38	29.41	0°.7	0 0.03 • • • • •	0.70	
	- - 			- -	7	021000.0		123.85	-38.79	15.24	52.20	0.1	7 0.02	0.65	
	5	0 109		99	- 2	4 0.000150		101.78	-58.02	62.13	68.02	9.1	7 0.02	1.28	
	28	0 12	2	92	2	6 0.000150		84.28	-46.01	-25.42	48.74		4 0.02	1.15	
	74	0 32 0	~ •	%	7 6	4 0.000150		79.60 09 07	14-14- 14-14-	12.52-	10./C		/ 0.02 A 0.07	1.28	
		0 V		26	.	1 0.000150		94.70	-48,19	13.35	55.65	0.1	7 0.02	0.65	
	35	2		33		5 0.000200	•	18.79	-44.69	34.25	50.92	0.1	9 0.03	1.68	
		9 50	•	10	ę	10 0.000500	-	141.31	-25.85	9.00	27.01	0.2	0 0.03	2.25	
	5	0 23		02 0.	ň.	7 0.000200		79.19	-53.75	-27.68	53.62 55		5 0.02	0.2/	
	33	79 FC 0 C	- 9	42 11	. .	4 0.00400		10.01	-40.04	-41.44 -41.44	Fa.CF 62.72	0.1	8 (8 0.03	0.29	
	31	30		; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ;	. –	2 0.00067		116.01	-32.54	14.32	34.50	0.1	6 0.02	0.94	
	89	9 31	n	20 0.		2 0.00067		129.11	- 28.85	13.31	30.94	0.1	6 0.02	0.48	
	39	0		56 0.	2	2 0.00067	_	96.26	-40.85	18.63	42.86		6 0.02 202	84°0	
	Q :	0	0.1	55 : :	انت	2 0.00067	_	11.17	-40.30	18.05	47°74		6 V.V.		_
	14		• •	1	vi.	4 V. VVVV6/		85. 73 86. 64	17.00-	-45.89	60.38		7 0.00	1.24 1.24	- .
	13	. ~	. =	3		3 0.00047	_	87.98	-50.59	-31.75	55.27	0.1	3 0.01	0.83	

- _ ·

			Neasured Valu	Sa						-	Calculated Val	ues			
Farticle No.	X location of impact (origin at e)	Y location of impact (origin at #)	ł location of impact (origin at +)	Fenetration Depth	Length of -Particle	Kass		R location of impact (origin at te)	Theta Tocation of impact forigin at #9 (Phi location of impact origin at ++)	Cone Angle Langle from impact pt. to surf norm)	Average Diameter	Average Area	Velocity	
	1	2	2	1	:	÷	2	2	Degr ees	Degrees	Degrees	2	na squared	Ka/sec	
352	•	•				2 0	.000216	0.00	-90.00	-90.00	0	0.30	0.0	0.0	8
333	•	•				2 0	.000216	0.00	-90.00	-90.00	0	0.30	0.0	0.0	8
354	•	•				2 0	.000216	0.00	-90.00	-90.00	0	0.30	0.0	0.0	8
355	•	•				2 0	.000216	0.00	-90.00	-90,00	0	0.30	0.0	0.0	8
356	•	•				2 0	.000216	0.00	-90.00	-90.00	0	0.30	0.0	0.0	8
357	-	•				2 0	.000216	0.0	-90.00	-90.00	•	0.30	0.0	0.0	8
358	-	-				2	000216	0.00	-90.00	-90.09	•	0.30	0.0	0.0	8
				Total Spail A Total measure	lass = d Spall =). 10925 0. 1081								
Spell Origin 4 farion faroef	, At lower lef (at tarnet sur	it corner farai		Total Ejecta	Mass =	õ	.046968								
		19161		Total Kass =		0	.156218								
H '++ " B-49	iepact point c Y, am	on target surf. 2, mm	ace	Total from ma of target bef	iss ore & after		0.25								
24	65	0	_	Corrected Eje	icta Nass =	0	075164 30.	07 percent Ejecta	_						
				Corrected Spa	di Nass ≖	o	174836 69.	93 percent Spall							
Shear Strength	(est.) used i	n velocity		Calc. Ejecta	Dust =	ō	028196								
		R	_	Calc. Spall D	ust =	0	065586								
				Totai Calc. D	ust =	Ó	093782 37.	51 percent Dust							

JSC Shot No. 917 1/17/86 (fhin Plate with Cloth)

JSC Shot Mo. 923 1/17/86 [fhin Plate with no Cloth] [lepact at -30 deg. phi from normal on ejecta side)

Resured Values

0.65 0.65 0.65 0.73 0.65 0.73 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 Ka/sec Velocity squared Average Area 2 Average Diameter 2 **Calculated Values** (origin at ee) Degrees 33, 17 34, 75 36, 45 37, 76 36, 45 37, 76 36, 45 37, 70 36, 45 36, 45 36, 45 36, 45 36, 55 37, 57 37 Cone Angle (angle from of impact of impact of impact (angle from (origin at #1)(origin at #1)surf, normal) Theta location Phi location Degrees Degrees 97.42 89.41 117.07 117.07 1115.07 98.88 99.88 105.55 117.07 115.07 105.55 117.07 115.07 115.05 115.5 R location of impact -----2 se Mass Length of Particle 8 - 55 -0.5 0.5 0.5 0.5 0.5 Penetration Depth 2 Y location 2 location of impact of impact lorigin at 9 (origin at 4) • 22255555555 ~ ~ ~ ~ 00 0 0000 0 108 108 116 116 70 82 82 Z 2 ÷ of impact (origin at f X location 2 • Particle No.

Calculated Values

-

Reasured Values

0.038 1.86 1.86 0.38 0.38 0.38 0.39 0.59 0.59 0.59 0.59 0.59 0.53 ka/sec Velocity 0.02 ne squared Average Area Average Diameter ā forigin at EE) Degrees R location Theta location Phi location Cone Angle of impact of impact of impact (angle from (origin at **)(origin at **)surf. normal) e. 59 59. 10 59. 10 59. 10 59. 10 59. 10 59. 10 50. 12 50. 12 50. 10 50. 11. 23 20. 97 20. 97 20. 97 20. 97 20. 97 20. 97 20. 70 20. 73 20. 74 20 Degrees Degrees 100.57 116.93 106.32 99.22 101.12 99.22 99.25 99.25 101.12 111.08 101.48 101.10.83 101.48 101.48 101.48 101.54 101.55 99.65 101.55 99.55 99.55 99.55 101.54 101.54 101.55 100.55 2 9.001000 0.002300 0.002300 0.000500 0.000300 0.000300 0.000300 0.000300 0.000300 0.000300 0.000300 0.000300 0.000300 0.000300 0.000100 0.000100 0.000200 0.00065 0.00065 0.00065 0.00065 0.00065 0.00065 0.00065 0.000506 0.001506 0.001506 0.001506 0.001506 0.002506 0.002506 0.002506 S Rass **NNNNA** Length of Particle 8 0.5 0.5 2 2 7 - 2 ° Penetration Depth 0.5 ******* - 2 0.5 8 ÷ Z location of impact forigin at 4 3 (origin at 6) Y location of impact 3 (origin at e) X location of inpact ۲. ŝ Particle

JSC Shet No. 923 I/17/86 (Thin Plate with no Cloth) (Impact at -30 deg. phi from normal on ejecta side)

							:					528		
Farticle No.	K location of impact forigin at f	Y location of impact !) (origin at (l location of impact 1) (origin at 4)	Penetration Depth	Length of Particle	N	z	R location of impact (origin at me)	lheta locatio of impact)(origin at eo	on Phi location of impact +) (origin at ++)	Come Angle (angle from Surf. normal)	Average Dianeter	Average Area	Velocity
	:	2	I	2	2		Seb	1	0egr ees	Begrees	(origin at tel Begrees	1	an squared	Ka/sec
17,	•	•				5	0.000256	0.00	90°08-	W W-	Se e	ć	10 0	50
17.	•	•					0.000256	0.00	-90.06	00.00-				0.0 0
17	•	•				ŝ	0.000256	0.0	-90.00	00.09- 0	0.00		0 0 0	00.0
17	•	•				5	0.000256	0.00	-90.00	-40-06	0.0			000
18	•	•				'n	0.000256	0.0	-90.00	00.04-	0.0	6.0	0 0.03	
181	•	-				5	0.000256	0.0	-90.06	00.09- 0	0.00	0.2	0.03	0-0
<u>e</u>	•	- ,				5	0.000256	0.00	-90.06	-90.00	0.00	0.2	0 0.03	0,00
	•	•				\$	0.000256	0.00	-90.00	-90.00-	0.00	0.2	0 0.03	0.00
8	•					ŝ	0.000256	0.00	-90.00	-90.09	0.00	0.2	0 0.03	0.00
181 1		• •				5	0.000256	0.00	-90.09-	00.07- 0	0.00	0.2	0 0.03	0.00
A.		•				ŝ	0.000256	0.0	-90.06	90.00	0.00	0.21	0 0.03	0.00
	•	•				5	0.000256	0.0	10.01-	90.00	0.00	0.21	0.03	0.00
		• -				5	0.000256	0.00	-90.06	-90.00	0.00	0.21	0.03	0.0
						~	0.000129	0.00	90.07-	-90.00	0.00	0.11	9 0.03	0.00
							0.000129	Ú.00	-90.06	00.09- (0.00	0.1	9 0.03	0.00
	•	• •				•	0.000129	0.00	-90.06		0.00	0.11	9 0.03	0.00
·41		•				m 1	0.000129	0.0	-90.06		0.00	0.15	9 0.03	0.00
		• •				m 1	0.000129	0.00	-90.06	-90.00	0.0	0.15	9 0.03	0.00
105	•	•				m 1	0.000129	0.00	90.02-	00-06- (0	0.00	0.11	9 0.03	0.00
701	•	-				~ '	621000.0	0.0	-00.04	00.09- 0	0.00	0.15	9 0.03	0.0
161	•	-				••	421000.0	0.00	00°04-		0.0	0.1	9 0.03	0.00
198	•	•				~ ~	471000'0	0.00	0.04-	00°04-	0.0		0.03	0.00
661	•	•					0.000129 A AMAINE	0.0	90.04-	- -	0.00	0.1	0.03	0.00
200	•	•				. .	0.000128	0.00	-90.04 20.04	-40.00	0.0	0.15	0.03	0.00
102	•	•				5 r	0 MM178	8.9 8	-90.07	00.07-	6.8 •	0.15	0.03	0.00
202	•	•					0.000170	8.5	90'04-	8.8- 8-	8.8		0.03	0.0
203	•	•				• ••	0.000129		00.04-	00.01-	89	1.0	0.03	00.0
204	•	•				•	0.000129	0.00	-40.00	-90,00	00.0	51.0	100	
202	•	•				5	0.000129	0.00	-90.09	-90.00	0.00	0.19	0.03	0.00
206	-	•				m	0.000129	0.00	-90.00	-90.00	0.00	0.19	0.03	0.00
102	• •	• •				m	0.000129	0.0	-90.09	-90.00	0.00	0.19	0.03	0.00
80Z	• •	•				m	0.000129	0.00	-90.00	-90.00	0.00	0.15	0.03	0.00
607						•	0.000129	0.00	-90.04	-90.00	0.0	0.15	0.03	0.0
210	•••	• •				•	0.000129	0.00	-90.00	-90.00	0.00	0.19	0.03	0.00
112						n	0.000129	0.00	-90.00	-90.00	0.00	0.19	0.03	0.00
717		• •				-	0.000129	0.00	-90.08-	-90.09-	0.0	0.19	0.03	0.00
		• •				m 1	0.000129	0.0	-90.00	-90.00	0.00	0.19	0.03	0.00
91C	•	• •				n 1	0.000129	0.0	-90.00	-90.00	0.00	0.19	0.03	0.00
C17	•					n 1	0.000129	0.00	-90.00	-90.00	0.00	0.19	Si.0	00"0
1 17	•	•				5	0.000129	0.00	-90.00	-90.00	0.00	0.19	0.01	0.00
ALC:	-	•				~ ·	621000.0	0.0	-90.00	-90.04	0.00	0.19	0.03	0.00
910	•	•				. ,	0.000129	0.00	-90.07	- 90.00	0.00	0.19	0.03	0.00
						~	0.000129	0.00	-90.00	-90.09	0.00	0.19	0.03	0.00

JSC Shot Mo. 923 i/17/86 (Thin Plate with no Cloth) (Impact at -30 deg. phi from normal on ejecta side)

			Measured Val	ue s							Calculated Val	ues		
Particle No.	X location of impact forigin at	Y location of impact +) (origin at •	Z location of impact) (origin at e	Penetration Depth	Length of Particle	2	5	R location of impact forigin at to	Theta location of impact !(origin at **)	Phi location of impact forigin at fm	Cone Angle (angle from)surf. normal) (origin at #9)	Average Di aneter	Average Area	Velocity
	2	2	2	2	2		ŠuŠ	:	Degrees	Degrees	Degrees	2	nn squared	Ka/sec
11	5	22	55 0	8	_	-	0.000100	11.65	-5.02	-28.02	28.34	0.14	0.02	0.71
11	3	1	.6	2	_	-	0.000100	90.46	-37.62	-30.60	44.17	0.10	0.02	0.71
13	-	=	0 2.	7		~	0.000100	131.21	22.42	-2.78	22.56	0.16	0.02	0.77
11	5	01	0	2 0.5		2	0.000100	134.77	21.33	-1.54	21.37	0.20	0.03	0.44
3		10	0	7	_	~	0.000100	16.18	38.98	-34.02	46.50	0.16	0.02	0.77
1	1	85	· •	5 6	~	-	0.000067	92.14	15.80	-17.59	23.02	0.23	0.04	2.22
11	8	20		8			0.000067	129.44	-4.88	-0.61	16.4	0.23	0.04	1.13
11	6	10	0	5 2	~	-9	0.000067	141.10	-21.19	0.05	21.19	0.09	10.0	1.4
14	0		0 11 0	0		2	0.000067	89.66	-49.64	-43.86	56.65	0.16	0.02	0.94
=	1	-	0 115	5	~	ŝ	0.000067	88.73	-52.22	-47.97	59.55	0.10	0.01	1.48
1	12	30	0 10	0 0.5		7	0.000067	78.20	-28.14	-36.18	42.18	0.16	0.02	0.48
=	IS LOOSE	ON BOTTON				89	0.002600	0.00	-90.00	-90.00	0.00	0.18	0.02	0.00
≍ E	•	•				45	0.000800	0.00	-90.00	-90.00	0.00	0.12	0.01	0.00
= 3-	•	•				33	0.004600	0.0	-90.00	-90.00	0.00	0.32	0.08	0.00
= 5	•	•				Ŧ	0.001400	0.0	-90.00	-90.00	0.00	0.17	0.02	0.00
≍ 3	•	-				82	0.003700	0.0	-90.00	-90.00	0.00	0.33	0.08	0.00
Ξ	. 8	•				8	0.002100	0.00	-90.00	-90.00	0.00	0.21	0.04	0.00
Ξ	•	-				71	0.001300	0.00	-90.00	-90.00	0.00	0.22	0.04	0.00
=						9	0.001700	0.00	-90.09	00.04-	0.0	0.29	0.01	00*0
		-				11	006000.0	0.00	-90.00	-90.06	0.00	0.21	0.03	0.00
						=	0.000500	0.0	-90.09	-90.00	0.0	0.11	0.01	0.00
29		• ·				<u> </u>	0.000300	0.00	-90.00	-90.00	0.00	0.14	0.01	0.00
		• •				•	0.000600	0.00	-90.00	-90.00	0.00	0.23	0.04	0.0
2		• •				= :	0.000200	0.00	-90,09-	00.04-	0.00	0.12	0.01	00-0
		• •				2 8	0.00000	0.0	-90,00	00.0Y-	00.0	0.20	0.02	0.00
: £		•				3 2	0.2000.00		0.04	00.04-	8.0			
: 13	•	•					0.000200	0.00	-90.00	-90.07	0.00	0.15	0.07	00.0
16	•	•				~	0.000164	0.0	-90.00	-90.09	0.00	0.1	0.01	0.00
16	•	•				•	0.000164	0.0	-90.00	-90.00	0.00	0.14	10.0	0.00
16	• •	•				-	0.000164	0.0	-90.00	-90.00	0.00	0.14	0.01	0.00
16	<u>ع</u>	-				-	0.000164	0.00	-90.00	-90.00	0.00	0.14	0.01	0.00
16	•	-				~	0.000164	0.00	-90.00	-90.09	0.00	0.14	0.01	0.00
91	• •	•				~	0.000164	0.00	-90.00	-90.00	0.00	0.14	0.01	0.00
16						~	0.000164	0.00	-90.00	- 40.00	0.00	0.1	0.01	0.00
16	•••					- '	0.000164	0.00	-90.09-	00.09-	0.00	0.14	0.0	0.00
= :		• •				~ '	0.000164	0.00	-90.09	-90.09-	0.00	0.1	0.01	0.00
2 :						- •	0.000164	0.00	-90.09	00.04-	0.0 2	1.º	6.9 •	0.00
- :		· -					0.000164	00	00.04-	00'0A-	0.0		10.0	0.00
::	•	•				.	967000 V		00.04-	00.04-	00.0	07.0	0.03	00.0
: 1	•	•				3 M	A.000756	0.00	-90.00	-40.00	0.00	0.70	0.01	0.00
. []	•	•					0.000256	0.00	-90.00	-90.00	0.00	0.20	0.03	0.00
11	•	•				2	0.000256	0.0	-90.00	-90.00	0.0	0.20	0.03	0.00

seity	ka/sec	0.00	0.00	0.00	0.00	0.0	8.0	0.00	0.00	0.00	0.00	0.0		0.0	00.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	88	8.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	V.VV
age Vel) squared	0.04	0.04	0.04	0.0	0.04	0.04	0.04	0.04	0.04	0.04	5. S		0.04	0.0	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04		0.0	0.04	0.04	0.04	0.04	0.04	0.04	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.05	c) -0	C) 0	cv.v
Aver Area	I	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.25	() 'I		0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	(7 m)	0.23	0.23	0.23	0.23	0.25	0.23	0.73	0.23	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	97.0	Q. (b
Average Diameter	2																																										
one Angle angle from urf. noreal) orisin at ee	Degrees	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0°.0	0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8°:	8.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0°.9	6 .0	0.00	0.00	0.00	0.00	0.00	0.0	0.00	00.0 0	V. VV
ii location C i inpact (igin at ee)si (Degr ees	-90,00	-90.00	-90.09	-90.00	-90.00	-90.00	-00.04	-70.00	-90.00	00 .04-	60.0V-	N 00-	-90.00	-90,00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.09	-90.00	-90.00	-9°9	00.04-	-90.00-	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90,00	-90.00	-90.00	-90.00	-90.00	00.04-	00.07-	- 70,04
eta location Ph impact of rigin at es)(or	Degrees	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.09	-90.09	-90.09	00°06-	00.04-	00.00-	-90.00	-90.00	-90.00	-90,09	-90,00	-90.00	-90.00	-90,00	-90.00	-90.00	-90.06	00.04-	-90.00	-90.00	-90.00	-90.00	-90.00	-90.00	-90.09	-90.00	00.04-	-90.00	-90.00	00.04-	-90.00	-90.00	-90.00	-90.00	00.04-	-70.00
R location Th of impact of (origin at #0)(o	1	0.00	0.0	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.0	000	0.0	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.0	0 .0	0.0	0.0	0.00	0.00	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.00	0.00	0.0	0.00	0.0	0.0	V.V
Hass No.	546	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	901000 U	0.000134	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	971000°0	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136	0.000121	0.000121	0.000121	0.000121	0.000121	0.000121	0.000121	0.000121	121000.0	0.0W121
Length of Particle	2	2	2	2	2	2	2	7	7	2 0	~ ~			• •	.~	2	2	2	2	2	2	5	~ '	~ ~		• ~		2	2	2	7	2	2 1	5.	1.5	1.5	1.5	1.5	1.5	1.5			5.3
Penetration Depth	2																																										
2 location of impact) (origin at 4)	:																																				-						
-																							_			_																	
Y location of impact H (origin at	:	•	-	-	•	•	• •	•	• •	•••	• •	•	•	•	•	•	•	•	•	•	•	• •					•		•	•	•				•	•	-	•	•	• •		•••	•
location Y location 4 impact of impact origin at 4) (origin at	1		-	-		-	• •	• •		• •	-	- - -	•	•	•	•	•	•	•	•	•		•		•	•	•	• •	•	•	•	• •	• •	•	•	-	-	-	•	•	• •	•••	•

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JSC Shot Wo. 923 1/17/86 (Thin Plate with no Cloth) (Impact at -30 deg. phi from normal on ejecta side)

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			Neasured Val.	ues						-	alculated Val	tes		
Particle Mo.	X location of impact forigin at	Y location of impact E) forigin at (Z location of impact i) forigin at f	Penetration Depth	Length of Particle	Hass		R location of impact (origin at ##	Theta location of impact !(origin at ee)	Phi location (of impact origin at ##3:	one Angle langle from urf. normal) lorigin at 40	Åver age Di dæt er	Åverage Årea	Velocity
	:	2	I	2	:	4	Seb	2	Begrees	Degrees	Degrees	1	en squared	Ka/sec
220	•	•				n	0.000129	0.00	-90.00	-90,09-	0.00	0.1	9 0.03	00-0
221	•	•				m	0.000129	0.00	-90.00	-90.00	0.00		9 0.03	0.00
222	•	•				ñ	0.000129	0.00	-90.00	-90.09	0.00	0.1	9 0.03	0.00
223	•	•				m	0.000129	0.00	-90.04	-90.00	0.0	0.1	9 0.03	0.00
524	-	•				n	0.000129	0.00	-90.00	-90.00	0.00		9 0.03	0.00
225	•	•				m	0.000129	0.00	-90.00	-90.00	0.00	0.1	9 0.03	0.00
226	•	•				n	0.000129	0.00	-90.00	-90.00	0.00	0.1	9 0.03	0.00
22)	•	•				n	0.000129	0.0	-90.00	-90.00	0.00	0.1	9 0.03	0.00
228	•	•				•	0.000129	0.0	-90.00	-90,00	0.00	0.1	9 0.03	0.00
229	•	•				n	0.000129	0.00	-90.00	-90.00	0.00	1.0	9 0.03	0.00
230	•	•				-	0.000129	0.0	-90.00	-90.00	0.00	0.1	9 0.03	0.00
122	•	•				~	0-000129	0.00	-90.06	-90.00	0.00	0.1	9 0.03	0.00
233	•					m	0.000129	0.00	-90.00	-90.00	0.00	0.1	9 0.03	0.00
8 B-	•	•				m	0.000129	0.00	-90,00	-90.00	0.00	0.1	9 0.03	0.00
ະ 5	•	•				-	0.000129	0.0	-90.00	-90.00	0.00	0.1	9 0.03	0.00
5		• •				m	0.000129	0.00	00.00-	-90.00	0.00	0.1	9 0.03	0.00
236	• •	•				-	0.000129	0.00	-90.00	-90.00	0.00	0.1	9 0.03	0.00
13	• •	• •					0.000129	0.00	-90.00	- 30.00	0.00	0.1	9 0.03	0.00
107		• •					0.000129	0.0	-90.00	-90.00	0.00	0.1	3 0.03	0.00
107		•				~	0.000129	0.0	-90.00	-90.00	0.00	0.1	9 0.03	0.00
0 4 2	• •	•					0.000257	0.00	-90.09	-90.00	0.00	0.2	0 0.03	0.00
147		• •				- ` 	0.000257	0.0	-90.04-	-90.00	0.00	0.2	0 0.03	0.00
767	•	•				0 1	/27000.0	0.0	00.09-	00.04-	0.00	0.2	0 0.03	0.00
	-	•				<u> </u>	127000.0	0.0	-90°06-	-90.04-	0.00	0.2	0.03	0.00
	•	•				~ ¥	10,000,0	0.0	00°04-	- 20.07	0.0	2.0	0 0.03	0.0
786	•	•					102000	0.0	00.09-00	00.04-	0.00		0 0.03	0.0
247	•	•					1000 0		00.07-	00°04-	0.0			0.00
248	•	•					0.000 Table 1		00.07-	00.07-	8 0 0			0.0
249	•	•				. ~	0.000136	0.00	-90.00	-90.00	0.00	0.2	3 0.04	0.00
250	•	•				~	0.000136	0.0	-90.00	-90.00	0.00	0.2	3 0.04	0.00
251	•	•				7	0.000136	0.00	-90.00	-90.00	0.00	0.2	3 0.04	0.00
252	•	•				7	0.000136	0.0	-90.00	-90.00	0.00	0.2	3 0.04	0.00
253	•	-				2	0.000136	0.00	-90.00	-90.00	0.00	0.2	3 0.04	0.00
254	•	-				7	0.000136	0.0	-90.09	-90.00	0.00	0.2	1 0.04	0.00
222	•	-				2	0.000136	0.00	-90,00	-90.00	0.00	0.2	3 0.04	0.00
256	•	-				7	0.000136	0.00	-90.09	-90.00	0.00	0.2	3 0.04	0.00
257	•	•				2	0.000136	0.00	-90.00	-90.00	0.00	0.2	3 0.04	0.00
258	•	•				2	9.000136	0.00	00"06-	-90.00	0.00	0.2	3 0.04	0.00
259	•	•				2	9.000136	0.00	-90.00	-90.00	0.00	0.2	3 0.04	0.00
260	•	•				~	9.000136	0.00	-90,00	-90,00	0.00	0.2	3 0.04	0.00
192	•					2	9.000136	0.00	-90.09	00.04-	0.00	0.2	3 0.04	0.00
262	•	•				~	0.000136	0.00	-90.00	-90.00	0.00	0.2	3 0.04	0.00
263	•	•				2	0.000136	0.00	-90.00	-90.00	0.00	0.2	3 0.04	0.00

JSC Shot No. 923 1/17/86 (Thin Plate with no Cloth)

												•		Aver and	
	rticle No.	X location of immert	Y location of immert	n 7 location of immet	Penetration Danth	Length of Partirle	Nass		R location of impert	Theta location of issued	Phi location	Cone Angle Lanis fras	Average Di soot er	Ares Ares	VELOCITY
1 1		(origin at	t) (origin a	t +) forigin at	()				torigin at ee)	(origin at ##)	(origin at ##).	surf. normal) (origin at #1)			
		I	3	2	2	2		seő	I	Begr ees	Degrees	Degrees	:	en squared	Ka/sec
	321	•	•				5.1	0.000121	0.00	-90.00	-90.04	0.00		26 0.05	0
	35	•	•			-		0.000121	0.00	-90.00	-90.09	0.00		26 0.05	3
	35	•	•			-	1.5	0.000121	0.00	-90.00	-90.00	0.0	0.	26 0.05	-
	32	•	•			-	1.5	0.000121	0.00	-90.00	-90.00	0.00	0	26 0.05	
	35	•	•			-	1.5	0.000121	0.0	-90.00	-90.00	0.00		26 0.05	3
	12	•	•			-		0.000121	0.0	-90.00	-90.00	0.00		26 0.05	0
9 1 0 10 <td>321</td> <td>•</td> <td>•</td> <td></td> <td></td> <td>-</td> <td>1.5</td> <td>0.000121</td> <td>0.00</td> <td>-90.00</td> <td>-90.00</td> <td>0.00</td> <td>0</td> <td>26 0.05</td> <td>3</td>	321	•	•			-	1.5	0.000121	0.00	-90.00	-90.00	0.00	0	26 0.05	3
	121	•	•			-	1.5	0.000121	0.00	-90.00	-90.00	0.00	Ċ	26 0.05	3
	191	•	•			-	1.5	0.000121	0.00	-90.00	-90.09	0.00		26 0.05	
	361	•	•				1.5	0.000121	0.0	-90.00	-90.00	0.0	•	26 0.05	-
	9	•	•				1.5	0.000121	0.00	-90.00	-90.00	0.00	°.	26 0.05	
	36	•	•			-	1.5	0.000121	0.0	-90.00	-90.00	0.00	•	26 0.05	-
	36	•	•				1.5	0.000121	0.00	-90.00	-90.00	0.00	ċ	26 0.05	
34 -	36	•	•			-	1.5	0.000121	0.0	-90.00	-90.00	0.00	.	26 0.05	
	19°	•	•			-	1.5	0.000121	0.0	-90.00	-90.00	0.00	°.	26 0.05	
30 1 0 100 100 0.00 100 0.00	36	•	•				1.5	0.000121	0.0	-90.00	-90.00	0.00	•	26 0.05	•
3.0 •	361	•	•					0.000121	0.00	-90.00	-90.00	0.0	e.	26 0.05	-
	92	•	•			-		0.000121	0.00	-90.00	-90.00	0.00	•	26 0.05	
777 777 777 770 <td>E I</td> <td>•</td> <td>•</td> <td></td> <td></td> <td></td> <td>.</td> <td>0.000121</td> <td>0.0</td> <td>-90.09</td> <td>-90.09</td> <td>0.00</td> <td>.</td> <td>26 0.05</td> <td></td>	E I	•	•				.	0.000121	0.0	-90.09	-90.09	0.00	.	26 0.05	
7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/7 7/	2		• •			- •	<u>.</u>	0.000121	0.00	00.04-	M . W -	0.00	5 (CN*N 97	- •
773 773 770 770 770 770 770 770 773 773 771 771 771 771 771 771 773 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 774 771 771 771 771 771 771 771 775 771 771 771 771 771 771 771 775 771 771 771 <t< td=""><td>5</td><td></td><td>• ·</td><td></td><td></td><td></td><td></td><td>0.000121</td><td>0.0</td><td>-90.00</td><td>00.04-</td><td>0.00</td><td>•</td><td>29 0 9Z</td><td>- •</td></t<>	5		• ·					0.000121	0.0	-90.00	00.04-	0.00	•	29 0 9Z	- •
773 773 770 770 770 770 770 770 773 771 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 771 773 771 771 771 771 771 771 771 771 773 771 771 771 771 771 771 773 773 774 771 771 771 771 771 771 773 773 775 771 771 771 771 771 771 773 773 775 771 771 771 771 771 773 773 773 771 771	37.	•	-				<u>.</u>	0.000121	0.00	-90.09-	-90.00	0.00	•	219 0.03	
773 773 770 700 700 700 700 700 700 773 773 771 770 700 700 700 700 700 773 773 770 700 700 700 700 700 700 773 773 770 700 700 700 700 700 700 773 770 770 700 700 700 700 700 700 773 770 770 700 700 700 700 700 700 773 770 770 770 700 700 700 700 700 773 770 770 770 700 700 700 700 700 781 7 7 7 700 700 700 700 700 783 7 7 7 700 700 700 700 700 784 7 7 7 7 7 7 7 7 784 7 7 7 7 7 7 7 7 784 7 7 7	ĥ	•	•				<u>.</u>	0.000121	00.00	-00.09	-90.09	0.00	•	26 0.02	- •
77 77 70 70.00	5	•	•				. .	0.000121	0.00	-90.00	-90,09-	0.0	.	26 0.05	<u> </u>
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	ĥ		•				<u>.</u>	0.000121	0.0	-90.04-	00"04-	0.0	•	20°0 9Z	- •
778 778 -70,00	15	•	•				2	0.000121	0.00	-40.00	00.04-	0.0		26 0.02	
379	Ē	•					<u>.</u>	0.000121	0.00	-00.09	00.09-	0.00	6	20°0 9Z	- •
380 -9.00 -90.00 -90.00 -90.00 -0.00 -0.00 0.00 <td>ĥ</td> <td>•</td> <td>•</td> <td></td> <td></td> <td></td> <td><u>.</u></td> <td>0.000121</td> <td>0.00</td> <td></td> <td>-90.09</td> <td>0.00</td> <td>.</td> <td>Z6 0.02</td> <td></td>	ĥ	•	•				<u>.</u>	0.000121	0.00		-90.09	0.00	.	Z6 0.02	
381 - 70.00 -70.00 -70.00 -70.00 0.025 0.05 382 - 1 - 70.00 -70.00 -70.00 0.026 0.05 0.05 383 - 1 - 70.00 -70.00 -70.00 0.06 0.07 0.05 0.05 384 - 1 - 70.00 -70.00 -70.00 0.00 0.00 0.05 0.05 384 - 1 - 70.00 -70.00 -70.00 -70.00 0.00 0.05 0.05 384 - 1 - 1 - 1.5 0.000121 0.00 -70.00 0.07 0.05 0.05 385 - 1 - 1 - 1.5 0.000121 0.00 -70.00 0.00 0.00 0.00 0.05 0.05 386 - 1 - 1 0.00 -70.00 -70.00 0.05 0.05 0.05 387 - 1 - 1 0.00 -70.00 -70.00 0.00 0.05 0.05 0.05 388 - 1 - 1 0.00 -70.00 -70.00 0.06 0	Ŕ	•	-					0.000121	0.00	-90.00	-90.09	0.00		276 0°02	
382 •	Ĩ	•	•			-		0.000121	0.00	-90.00	-90.00	0.0		26 0.02	
383 -	38.	•	•			-	5	0.000121	0.00	- 70.00	- 90.00	0.00	• •	26 0.02	
38 - - - - - - - 0.03 -0.03 <	Ř	•	•					0.000121	0.00	-90.00	-90.00-	0.0	•	26 0.03	- ·
385 -7 -70.00 -70.00 -70.00 0.00 0.05 0.0 384 - - - 0.00 -70.00 -70.00 0.00 0.05 0.0 387 - - - 0.00 -70.00 -70.00 0.05 0.05 0.05 387 - - 0.00 -70.00 -79.00 0.07 0.05 0.05 387 - - 0.00 -70.00 -79.00 0.07 0.05 0.05 389 - - 0.00 -70.00 -79.00 0.06 0.05 0.05 389 - - 0.00 -70.00 -79.00 0.07 0.05 0.05 389 - - 0.00 -79.00 -79.00 0.07 0.05 0.05 379 - - 0.00 -79.00 -79.00 0.07 0.05 0.05 0.05 371 - - 0.00 -79.00 -79.00 0.06 0.05 0.05 0.05 0.05	ē.	•	•				<u>.</u>	0.000121	0.0		-90.09-	0.0	.	26 0.03	- •
386 - - - - - - 0.03 -0.03 0.03 387 - - - 0.03 - - 0.03 - 0.03 0.03 387 - - 0.03 - - 0.03 - 0.03 0.03 0.03 387 - - 0.03 - 0.00 - - 0.03 0.12 0.03 0.03 389 - - 0.03 -90.00 -90.00 -90.00 0.03 0.05 0.05 389 - - 0.00 -90.00 -90.00 -90.00 0.03 0.05 389 - - 0.00 -90.00 -90.00 -90.00 0.03 0.05 379 - - 0.00 -90.00 -90.00 -90.00 0.05 0.05 373 - - 0.00 -90.00 -90.00 0.00 0.05 0.05 373 - - - 0.00 -90.00 -90.00 0.05 0.05 373 - - - 0.00 -90.00 -90.00 0.05 0.05 374	ġ,	•	•				2	0.000121	0.00	-40.00	-00.04-	0.00	•	CO-O 97	
387 -90.00 -90.00 -90.00 -90.00 0.02 0.03 0.0 389 - - - 0.00 -90.00 -90.00 0.03 0.05 0.0 389 - - - - 0.00 -90.00 -90.00 0.03 0.05 0.05 389 - - - - - - 0.00 -90.00 0.05 0.05 391 - - - - - - - - 0.05 0.05 319 - - - - - - - - 0.05 0.05 0.05 319 - - - - - - - - 0.05 0.05 319 - - - 0.00 - - 0.00 - 0.05 0.05 319 - - - - 0.00 - - 0.00 0.05 0.05 317 - - - 0.00 - - 0.00 0.05 0.05 313 - - - 0.00 - - 0.00 <td< td=""><td>e,</td><td>•</td><td>•</td><td></td><td></td><td></td><td><u>.</u></td><td>0.000121</td><td>0.00</td><td>-90.09</td><td>-90.09</td><td>0.0</td><td>.</td><td>.76 0.03</td><td>- •</td></td<>	e,	•	•				<u>.</u>	0.000121	0.00	-90.09	-90.09	0.0	.	.76 0.03	- •
338 -70.00 -70.00 -70.00 -70.00 0.42 0.03 0.0 379 - - - 0.00 -70.00 -70.00 0.12 0.03 0.0 379 - - - 0.00 -70.00 -70.00 0.12 0.03 0.0 379 - - - - 0.00 -70.00 -70.00 0.12 0.05 0.0 379 - - - - - - - - 0.05 0.0 379 - - - - - - - - 0.05 0.05 371 - - - 0.00 - - 0.00 - 0.05 0.05 373 - - - 0.00 - 0.00 - - 0.05 0.05 373 - - - - - - 0.00 - 0.05 0.05 373 - - - - 0.00 - - 0.00 0.05 0.05 374 - - - - 0.00 - - 0.00	H.	•	•				<u>.</u> .	0.000121	0.0	-00.06-	-90.09	0.0	.	C00 42	- •
397 -70.00 -70.00 -70.00 -70.00 0.03 0.03 0.03 370 - - - 0.00 -70.00 -70.00 0.03 0.05 0.05 371 - - 0.00 -90.00 -90.00 -90.00 0.01 0.05 0.05 0.05 373 - - 1.5 0.000121 0.00 -90.00 0.00 0.26 0.05 0.05 373 - - - - - - -90.00 -90.00 0.05 0.05 0.05 373 - - - - - - - - - 0.05 0		• •	• •			•	<u>.</u>	0.000121	8.0	-90.00	00.04-	0.0	.	29°0 97	- •
371 1.2 0.000121 0.00 -70.00 -70.00 0.00 <td>BC.</td> <td></td> <td>• •</td> <td></td> <td></td> <td></td> <td><u> </u></td> <td>0.000121</td> <td>0.00</td> <td>00.04-</td> <td>00 04-</td> <td>00°0</td> <td>.</td> <td>CU.U 07.</td> <td>- •</td>	BC.		• •				<u> </u>	0.000121	0.00	00.04-	00 04-	00°0	.	CU.U 07.	- •
371 1.5 0.000121 0.00 90.00 90.00 0.00 0.00 372 1 1 5 0.000121 0.00 10.0 0.15 0.05 373 1 1 5 0.000121 0.00 10.0 1.00 0.26 0.05 373 1 1 5 0.000121 0.00 10.0 90.00 0.00 0.05 0.05 374 1 1 5 0.000121 0.00 10.0 0.00 0.05 0.05 0.05 374 1 1 0.00 1.5 0.000121 0.00 0.00 0.05 0.05 0.05 374 1 1 0.00 -90.00 -90.00 0.00 0.05 0.05 0.05	101	-	•••					121000.0	00.0	00.01-	00°04-	0.0		50 0 72	
371 9.00	101							171000.0	8-0 6	00.06-	00 00-	00.0	; c	SU U 97.	
373 373 374 90.00 90.00 90.00 90.00 90.00 90.00 90.00 90.00 0.03 90.00 105 105 0.00 100 100 100 0.03 0.05 0.05 0.05 0.05 105 105 0.00 100 0.00 0.05 0.05 0.05 0.05 0.05 0.05	5 F	•	-					171000.0		00.00	00.04	000	• •	SV 0 76	
	101	•	· •				<u>:</u>	121000 0	0.00	-90.00	-90.00	0.00	: 0	20.05	. 3
	, 10L	•	•					161000 0		00 00-	00 00-	0.0	ć	50.0	

JSC Shot Mo. 923 1/17/86 (Thin Plate with no Cloth) (lapact at -30 deg. phi from normal on ejecta side)

Calculated Values

Reasured Values

	1016 70.	of impact forigin at	ef (or	impact 'igin at fi	of impact) (origin at t)	Depth	Particle		of impact c (origin at #+)(of ispact lorigis at sel	of impact (origin at ++);	(angle from surf. normal)	Dianeter	Ar ea	
		:		3	1	1	I	saŭ	=	Degrees	Degrees	lorigin at te) Degrees	I	ae squared	Ka/sec
	308	•		•			1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.00
	309	-	•				1.5	0.000121	0.00	-90.00	-90.07	0.00	0.26	0.(5	0.00
	2	-	-				1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.00
	E	•	•	_			1.5	0.000121	0.00	-90.00	-90.00	0.0	0.26	0.05	0.00
	312	•		-			1.5	0.000121	0.00	-90.00	-90.00	0.0	0.26	0.05	0.00
	313	-	-	_			1.5	0.000121	0.00	-90.09	-90.09	0.00	0.26	0.05	0.0
	E	•	•	_			1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.00
	315	•	•				1.5	0.000121	0.00	-90.00	-90.00	0.0	0.26	0.05	0.00
	316	•	•	_			1.5	0.000121	0.00	-90.00	-90,00	0.00	0.26	0.05	0.00
	11	•	-	_			1.5	0.000121	0.00	-90.00	-90.00	0.00	9.26	0.05	0.0
			-	_			1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.00
	615	-	•	_			1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.00
	22	-	-	_			1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.00
	2	•		_			1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.0
	22	•	•	-			1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.0
37 37 37 40012 0.00 40.00 40.00 0.00 37 37 0.00012 0.00 40.00 40.00 0.00 0.00 37 37 0.00012 0.00 40.00 40.00 0.00 0.00 37 37 0.00012 0.00012 0.00 40.00 40.00 0.00 0.00 38 0.00012 0.00 40.00 40.00 40.00 0.00 0.00 39 0.00012 0.00012 0.00 40.00 40.00 0.00 0.00 39 0.00012 0.0012 0.00 40.00 40.00 0.00 0.00 39 0.00121 0.00121 0.00 40.00 40.00 0.00 0.00 39 0.00121 0.00121 0.00 40.00 40.00 0.00 0.00 39 0.00121 0.00121 0.00 40.00 40.00 0.00 0.00 39 0.00121 0.00121 0.00 40.00 40.00 0.00 0.00 39 0.00121 0.00121 0.00 40.00 40.00 0.00 0.00 39 0.00121 0.00121 <	321	•	•	_			1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	00"0 .
XX XX XX YX YX YX YX YX YX XX XX YX YX YX YX YX YX YX XX YX YX YX YX YX YX YX YX XX YX YX YX YX YX YX YX YX YX XX YX XX YX XX YX XX YX XX YX XX YX XX YX YX YX YX YX YX YX YX YX YX	ē.			_			1.5	0.000121	0.00	-90.00	-90.00	0.00	0.76	0.05	0.00
	81	• •		_			5.1	0.000121	0.00	-90.09	-90.08	0.00	0.26	0.05	0.00
XXX XXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXXX XXXXXX XXXXXX XXXXXXXXXXX XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX	91	-					5.1	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.00
11 0.000121 0.000121 0.00 -70.00 -70.00 0.00 0.00 12 0.000121 0.00 -90.00 -90.00 0.00 0.00 0.00 13 0.000121 0.00 -90.00 -90.00 0.00 0.00 0.00 13 0.000121 0.00 -90.00 -90.00 0.00 0.00 0.00 14 0.00 -90.00 -90.00 0.00 -90.00 0.00 0.00 15 0.000121 0.00 -90.00 -90.00 0.00 0.00 0.00 15 0.000121 0.00 -90.00 -90.00 0.00 0.00 0.00 16 0.00 -90.00 -90.00 0.00 0.00 0.00 0.00 15 0.000121 0.00 -90.00 0.00 0.00 0.00 0.00 18 0.00121 0.00 -90.00 0.00 0.00 0.00 0.00 19 0.00 -90.00 -90.00 0.00 0.00 0.00 0.00 19 0.00 -90.00 -90.00 0.00 0.00 0.00 0.00 10 0.00 -90.00 -90.00 <td>35</td> <td>•</td> <td>•</td> <td></td> <td></td> <td></td> <td></td> <td>0.000121</td> <td>0.00</td> <td>00.04-</td> <td>-90.00</td> <td>0.00</td> <td>0.26</td> <td>0.05</td> <td>0.00</td>	35	•	•					0.000121	0.00	00.04-	-90.00	0.00	0.26	0.05	0.00
XX XX XXX YXX YXXX YXXX YXXXX YXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX	5	-	•					171200 0	0.0	00.04-	-90.04	0.10	0.26	0.05	0.0
XI XI 0.001 0.00 0.00 0.00 0.00 0.00 0.00 XI XI 0.001 0.00 0.00 0.00 0.00 0.00 0.00 XI XI 0.001 0.00 0.00 0.00 0.00 0.00 0.00 XI XI 0.001 0.00 0.00 0.00 0.00 0.00 0.00 XI 0.001 0.00 0.00 0.00 0.00 0.00 0.00 0.00 XI 0.001 0.00 0.00 0.00 0.00 0.00 0.00 0.00 XI 0.001 0.00 0.00 0.00 0.00 0.00 0.00 0.00 XI 0.001 0.00 0.00 0.00 0.00 0.00 XI 0.00 <td< td=""><td>2</td><td>•</td><td>•</td><td>_</td><td></td><td></td><td></td><td>0.000121</td><td></td><td>-90.00</td><td>-90.00</td><td>0.0</td><td>0.26</td><td>0.05</td><td>0.0</td></td<>	2	•	•	_				0.000121		-90.00	-90.00	0.0	0.26	0.05	0.0
XX XX -90.01 -90.01 -90.00 -90.00 -90.00 -90.00 XX XX -000121 0.00 -90.00 -90.00 0.00 0.00 XX XX -000121 0.00 -90.00 0.00 0.00 0.00 XX -000121 0.00 -90.00 -90.00 0.00 0.00 0.00 XX -00.01 0.00 -90.00 -90.00 0.00 0.00 0.00 XX -00.01 -00.01 0.00 0.00 <td>Ξ</td> <td>-</td> <td>•</td> <td>Ē</td> <td></td> <td></td> <td>1.5</td> <td>0.000121</td> <td>0.00</td> <td>-90.00</td> <td>- 30.00</td> <td>0.00</td> <td>97.0</td> <td>50 Q</td> <td></td>	Ξ	-	•	Ē			1.5	0.000121	0.00	-90.00	- 30.00	0.00	97.0	50 Q	
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	795 795	-	•	_			1.5	0.000121	0.0	-90.00	-90.00	0.0	0.26	0.05	0.0
134 - - 0.00 - - 0.00 - 0.00	5	-	•	_			1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.00
313 1.5 0.000121 0.00 -90.00 -90.00 -90.00 0.26 0.15 314 1.5 0.000121 0.00 -90.00 -90.00 -90.00 0.26 0.15 318 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.00 319 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.00 319 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.00 319 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.00 314 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.01 314 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.01 314 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.01 314 1.5 0.00121 0.00 -90.00 -90.00 0.00 0.26 0	R	-	•	_			1.5	0.000121	0.00	-90.00	-90.09	0.00	0.26	0.05	0.00
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	55						1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.00
33 9.000121 0.00 -90.00 0.26 0.0 33 9.000121 0.00 -90.00 0.00 0.26 0.0 34 1.5 0.000121 0.00 -90.00 0.00 0.26 0.0 34 1.5 0.000121 0.00 -90.00 0.00 0.00 0.26 0.0 34 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.0 34 1.5 0.000121 0.00 -90.00 0.00 0.26 0.0 34 1.5 0.000121 0.00 -90.00 0.00 0.26 0.0 34 1.5 0.000121 0.00 -90.00 0.00 0.26 0.0 34 1.5 0.000121 0.00 -90.00 0.00 0.26 0.1 34 1.5 0.00121 0.00 -90.00 0.00 0.00 0.26 0.1 34 1.5 0.00121 0.00 -90.00 0.00 0.00 0.26 0.1 34	3		•••	_				0.000121	0.00	-90.00	00.04-	0.00	0.26	0.05	0.00
3.9	100						1.5	0.000121	0.00	-90.04	-90.00	0.00	0.26	0.05	0.00
310 -70.00 -70.00 -70.00 0.00 0.25 0.12 311 -10.01 -70.00 -70.00 -70.00 0.00 0.25 0.12 311 -11.5 0.000121 0.00 -70.00 -70.00 0.00 0.25 0.12 312 -11.5 0.000121 0.00 -70.00 -70.00 0.00 0.25 0.12 313 -11.5 0.000121 0.00 -70.00 -70.00 0.00 0.25 0.12 314 -11.5 0.000121 0.00 -70.00 0.00 0.00 0.25 0.12 315 -11.5 0.000121 0.00 -70.00 0.00 0.00 0.12	800	•					· · ·	0.000121	00.0	-90.00	-90.00	0.00	0.26	0.05	0.00
341 1.3 0.000121 0.00 -70.00 0.00 0.26 0.13 341 1.5 0.000121 0.00 -70.00 -70.00 0.00 0.26 0.13 341 1.5 0.000121 0.00 -70.00 -70.00 0.00 0.26 0.13 342 1.5 0.000121 0.00 -70.00 -70.00 0.00 0.26 0.13 343 1.5 0.000121 0.00 -70.00 -70.00 0.00 0.26 0.13 345 1.5 0.000121 0.00 -70.00 -70.00 0.00 0.26 0.13 345 1.5 0.000121 0.00 -70.00 -70.00 0.00 0.26 0.13 346 1.5 0.000121 0.00 -70.00 0.00 0.26 0.13 347 1.5 0.000121 0.00 -70.00 0.00 0.26 0.13 348 1.15 0.000121 0.00 -70.00 0.00 0.26 0.13 349 1.15 0.000121 0.00 -70.00 0.00 0.00 0.26 0.13 349 1.15 0.000121 0.00 -70.00 0		-	•					0.000121	0.00	- 70.00	00.07-	0.00	0.26	0.05	0.0
313 314 910 -70.00 -70.00 9.00 0.02 0.0 314 1 0.00 -70.00 -70.00 0.00 0.00 0.26 0.0 314 1 0.00 -70.00 -70.00 0.00 0.00 0.26 0.0 315 1 0.00 -70.00 -70.00 0.00 0.00 0.26 0.0 315 1 0.00 -70.00 -70.00 0.00 0.00 0.26 0.0 316 1 1.5 0.000121 0.00 -70.00 0.00 0.26 0.0 316 1 1.5 0.000121 0.00 -70.00 0.00 0.26 0.0 317 1 1.5 0.000121 0.00 -70.00 0.00 0.26 0.0 318 1 0.00 -70.00 1.00 0.00 0.00 0.26 0.0 318 1 1.5 0.000121 0.00 -70.00 0.00 0.00 0.00 319 1 1.5 0.000121 0.00 -70.00 0.00 0.00 0.00 319 1 1.5 0.000121 0.00 -70.00		•	•					0.000121	0.0	00.07-	00.04-	00'0	0.26	0.05	0.0
343 -70.00 -70.00 -70.00 0.00 0.26 0.0 344 - - 0.00 -90.00 -90.00 0.00 0.26 0.0 345 - 0.00 -90.00 -90.00 -90.00 0.00 0.26 0.0 345 - 0.00 -90.00 -90.00 -90.00 0.00 0.26 0.0 345 - 0.00 -90.00 -90.00 -90.00 0.00 0.26 0.1 345 - 0.00 -90.01 -90.00 -90.00 -90.00 0.00 0.26 0.1 346 - - 0.00 -90.00 -90.00 -90.00 0.26 0.1 347 - - 0.00 -90.00 -90.00 -90.00 0.26 0.1 348 - - 0.00 -90.00 -90.00 0.00 0.26 0.1 349 - - -90.00 -90.00 -90.00 0.26 0.1 349 - - - 0.00 -90.00 0.00 0.26 0.1 349 - - - 0.00 -90.00 -90.00 0.00		-					<u>.</u>	0.000121	0.0	-90,00-	-00.04	0.00	0.26	0.05	0.00
34 -79.00 -79.00 -79.00 -79.00 0.00 0.26 0.0 34 -70.00 -79.00 -79.00 -79.00 0.00 0.26 0.0 34 -70.00 -79.00 -79.00 -79.00 0.00 0.26 0.0 34 -70.00 -79.00 -79.00 -79.00 0.00 0.26 0.0 34 -70.00 -79.00 -79.00 0.00 0.26 0.0 34 -70.00 -79.00 -79.00 0.00 0.26 0.0 34 -70.00 -79.00 -79.00 0.00 0.26 0.0 34 -70.00 -79.00 -79.00 0.00 0.26 0.0 34 -70.00 -79.00 0.00 0.00 0.26 0.0 34 -70.00 -79.00 -79.00 0.00 0.00 0.0 34 -70.00 -79.00 -79.00 0.00 0.0 0.0 34 -70.00 -79.00 -79.00 0.00 0.0 0.0 34 -70.00 -79.00 -70.00 0.00 0.0 0.0 34 -70.00 -70.00 0.00 0.00 <td>1</td> <td>-</td> <td>•</td> <td></td> <td></td> <td></td> <td></td> <td>0.000121</td> <td>0.00</td> <td>-90.00</td> <td>-90.09</td> <td>0.00</td> <td>0.26</td> <td>0.05</td> <td>0.00</td>	1	-	•					0.000121	0.00	-90.00	-90.09	0.00	0.26	0.05	0.00
345 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.1 345 1.5 0.000121 0.00 -90.00 -90.00 -90.00 0.02 0.1 346 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.00 0.26 0.1 346 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.1 347 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.1 348 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.1 349 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.1 349 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.1 349 1.5 0.000121 0.00 -90.00 90.00 0.00 0.26 0.1 351 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.26 0.1 351 1.5 0.000121 0.00 -90.00 -90.00 0.00 0.00 0.1		•	•					0.00121	0.00	00.04-	-90.00	0.00	0.26	0.05	0.00
34 9.00 -70.00 -70.00 -70.00 0.00 0.26 0.0 34 - 0.00 -70.00 -70.00 0.00 0.00 0.26 0.0 34 - 0.00 -70.00 -70.00 0.00 0.00 0.26 0.0 34 - 0.00 -70.00 -70.00 0.00 0.00 0.26 0.0 34 - 0.00 -70.00 -70.00 0.00 0.00 0.26 0.0 34 - 0.00 -70.00 -70.00 0.00 0.00 0.26 0.0 34 - 0.00 -70.00 -70.00 0.00 0.26 0.0 34 - - 0.00 -70.00 -70.00 0.00 0.26 0.0 34 - - 0.00 -70.00 -70.00 0.00 0.26 0.0 35 - - -70.00 -70.00 0.00 0.00 0.00 0.00 35 - 0.00 -70.00 -70.00 0.00 0.00 0.00 36 - 0.00 -70.00 0.00 0.00 0.00 0.00 0.00		-						0.000121	0.0	00.04-	-90.09	0.00	0.26	0.05	0.00
347 -70.00 -70.00 -70.00 0.00 0.26 0.1 347 - - 0.00 -90.00 -90.00 0.00 0.00 0.26 0.1 348 - - 0.00 -90.00 -90.00 0.00 0.26 0.1 348 - - 0.00 -90.00 -90.00 0.00 0.26 0.1 349 - - 0.00 -90.00 -90.00 0.00 0.26 0.1 349 - - 0.00 -90.00 -90.00 0.00 0.26 0.1 351 - - - -90.00 -90.00 0.00 0.26 0.1 351 - - - -90.00 -90.00 0.00 0.26 0.1		-	•					0.000121	0.00	-90.09	00.09-	0.00	0.26	0.05	0.00
348 -79.00 -79.00 -79.00 -79.00 0.00 </td <td>117</td> <td>•</td> <td>•</td> <td></td> <td></td> <td></td> <td></td> <td>121000.0</td> <td>0.00</td> <td>-90.07</td> <td>-90.09</td> <td>0.0</td> <td>0.26</td> <td>0.05</td> <td>0.00</td>	117	•	•					121000.0	0.00	-90.07	-90.09	0.0	0.26	0.05	0.00
349 •<	148	•	•				<u>.</u>	171001.0	00.0	00.00-	00°04-	0.0	0.26	0.05	0.0
350 - -90.00 -90.00 -90.00 0.00 0.26 0.1 351 - - - - - - - 0.00 0.26 0.1 351 - - - 0.00 - 90.00 - 90.00 0.00	÷÷,	-	•					0.000121	0.00	- 90.00	00.04-	00-0	0.20	50.0	0.0
351 • • • • • • • • • • • • • • • • • • •	350	-	•				1.5	0.000121	0.0	-90.00	-90.00	00.0	0.76	0.05	0.00
	351	-	•				1.5	0.000121	0.00	-90.00	-90.00	0.00	0.26	0.05	0.00

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JSC Shot Mo. 923 1/17/86 (Thin Plate with no Cloth) (lapact at -30 drg. phi from normal on ejecta side)

Calculated Values

			Measured Valu	le S			-				Calculated Val	sa			
Particle No.	I location of impact (origin at +)	Y location of impact) forigin at el	<pre>2 location</pre>	Penetration Depth	Length of Particle	Aa ss		R location of impact (origin at 1	Theta location of impact	Phi location of impact (origin at **)	Come Angle (angle from)surf, normal)	Åver age Di anet er	Average Area	Velocity	~
	1	1	1	:	:	señ		2	Degr ee s	Degrees	Degrees	1	ne squared	Ka/sec	• •
Origin 44, A	lt impact point	on target sur	face	Corrected Spal	= ssey []	0.15593	62.37	X percent S	pell						
1		₩ ¹		Corrected Ejec	cta Nass =	0.09407	37.63	X percent E.	jecta						
•	63.67	1 12	5	Calc. Spall Br	ust =	0.03559									
Shear Streng	ith (Estimated)	used in veloc.	ity	Calc. Ejecta l	Dust =	0.02147									
calculation,	n rascais	n	8	Total Calc. D	ust =	0.057064	1 22.83	X percent D	ust						

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						JSC (Thi) (Lep.	Shot Mo. 923 n Plate with no Cloth) act at +30 deg Phi)	1/28/86						
		*	Reasured Val	ues							Calculated Va	lues		
Farticle No.	X location of impact (origin at #	Y location of ispact) (origin at ¹	<pre>2 location 0 impact 1) (origin at #</pre>	Penetration Depth	Length of Particle	Nass		R location of inpact lorigin at #	Theta location of impact ! (origin at ##)	<pre>Phi location of impact (origin at ex</pre>	Cone Angle (angle from)impact pt. to surf. norm	Average Diameter .)	Average Area	Velocity
	I	2	:	2	2		seb	:	Degrees	Begrees	Degrees	2	ee squared	Ka/sec
EJECTA 1	_		3	0		63	0.0019	89.51	-81.47	-81.71	84.03	0.11	6.02	0.51
• ~			12		e	6 2	0.0029	87.94	-81.34	-81.30	83.84	0.1	0.03	0.92
. 15			3			9	0.0006	88.63	-83.04	-83.13	85.10	0.1	0.01	1.26
•		. 0	18 7.	2	1	52	0.0003	64.97	-85.20	-85.42	89.68	0.0	0.01	2.27
1 0 •		•		<u>.</u>		= •	0.0003	86°.74	-77.04	-11.30	90.92 56 30		5 0.02	2.07
0 F			2 2 2				0.0007	10.00	10-18-	70°60-	81.47 81.47			47 n
~ 60			22				0.0001	91.89	-65.85	-65.80	72.39		0.01	1.28
						•••	0.0001	89.75	-72.35	-72.30	77.30	9.1	0.02	0.39
10		0	53 4	10 0.1	5	m	0.0001	104.10	-60.87	-65.60	70.62	0.11	0.02	0.39
= :		0	12	<u> </u>	- 1	.	0.0001	96.51	-40.01	10.5	40.01	0.1	0.02	0.77
E E				2 5	2 6		0.0001	97.40 104.72	54.7- 12 11 -	/C-1	9C.92		1 0.07	
3 = 1 3 - 1		• •	30		•	4 0.0	000571429	87.73	-72.96	-72.18	77.49	0.11	0.01	0.82
:≘ 62						3 0.0	000571429	89.35	-58.32	-53.52	64.65	0.1	0.01	0.88
16		•	25 25	12 0.1	5	5 0.0	000571429	114.36	-51.45	-59.06	64.40	0.1(0.01	0.39
11		0	35	5		0.0	000571429	112.18	-42.64	-53.10	59.97	0.1	0.01	0.82
81						0.0 0 0	4741/2000	112.61	/0-04-		1.12			0.68
61 Q2		- 0		2	47	2 0.0	000571429	14.27 87.22	-97.48	-12-00	51.M	1.0	0.02	0.50
21	50		31 9	2	- 2	-	0.0001	60.13	-5.47	46.72	46.84	0.1	0.02	1.1
22	in.	13 E	31 9		2	9	0.0003	60.60	-4.28	48.56	48.63	0.2(0.03	0.97
23			31 10	2	~	ۍ ه موس	0.0005	8.3	-6.24	52.32	52.42	0.2	6 0.02	0.96
5 K		2 9	7 T		» —	2 0 0 7 0 7	000777777	60.43 60.43		67°67	14.74	0.0	0.0	1.11
3 2	~ ~~		31 10	0.1	- 2	.5 0.0	000222222	60.30	-9.10	51.37	21.60	0.1	0.01	0.67
27	5	13 F.	31 10)2 O.(5	1 0.0	000222222	60.41	-14.14	53.27	53.75	0.1	5 0.01	0.75
38	9		31 8		-	1 0.0	2222222000	76.24	40.27	38.81	49.43	0.0	0.00	1.03
52			21 2	26 -	~ ~	2 0.0	000222222	65.46 Le er	-6.45	12°51	35.8) 75.37	0.0	0.01	2.4
90 15		 2 =			7 -		00077777	40°69	19.91-	14.01	20.02		0.01	1.47
	· •					0.0	000222222	110.47	-3.12	2.53	10.4	0.1	0.01	1.47
	. 6-			1	2	2 0.0	000222222	95.40	21.96	11.95	24.46	0.0	9 0.01	2.44
55 15	Ξ		12 3	12 0.1	5	'n	0.0001	111.38	55.69	-67.78	70.68	0.1	5 0.02	0.39
35	Ξ	9	78 2	20 O.1	2		0.0001	104.29	33.94	-25.93	39.70	0.2	9 0.09	0.53
22	= :			2	2 .	n 1	0.0001	94.99	36.36	-20.18	39.92 10.11		0.02	1.52
1.5	= :	<u>e</u> -	0.4	2.		~ •	1000.0		70.05	av ci -	21.12 1 UT		10 0 0 01	1.42
87 87	= =						0.001	78.76	14.45	-17.59	46.06	0.1	6.02	0.39
0	: =	2.0				. ~	0.0004	96.10	34.87	-12.94	36.27	0.1	0.01	1.06
4	=	- P	07 2	24 0.5		2	0.0004	106.72	30.61	-7.43	31.21	0.1	3 0.01	0.54
23	=	ę 1	15 3	35	_	2	0.00004	101.34	32.20	0.35	32.20	0.1	0.01	1.06
14	1		1 0	20	_	-	0.0000	80.73	43.32	-18.20	44° A0	V. 11	3 U.VJ	1.21

1/28/86

JSC Shot No. 923 (This Blais sitt of Co

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			Neasured Valu	z		(Thin Plate with no Cloth) (Impact at +30 deg Phi)				Calculated V	ilues			
Particle Ko.	K location of impact forigin at f	Y location of impact !) forigin at (Z location of impact +) (origin at +)	Penetration Depth	Jength of Particle	Nass	R location of impact forigin at ##	Theta locatio of impact !(origin at #*	n Phi location of impact)(origin at +	n Cone Angle (angle from the surf, nori	Aver age Di anet er	Average Area	Velocity	
	1	2	2	3	1	\$eb	2	Degrees	Degr ees	Begrees	1	ee squared	Ka/sec	
11.	•	•				0.0001	0.0	06-	Ē	•	0.5	0 0.01	0.00	
13.	•	•				3 0.0001833333	0.0	06-			0.2	2 0.04	0.00	
11	•	•				3 0.0001833333	0.0	-90	Ē		0.2	2 0.04	0.00	
13	•	•				3 0.0001833333	0.0	-90	ē-	•	0.2	2 0.04	0.00	
13(•	•				3 0.0001833333	0-0	-90	Ē		0.2	2 0.04	0.00	
11	•	•				J 0.0001833333	0.0	06-	6-	•	0.2	2 0.04	0.00	
13	•	•				3 0.0001833333	0.00	06-	Ē	•	0.2	2 0.04	0.00	
13	•	-				3 0.0001833333	0.0	-90	Ē	•	0.2	2 0.04	0.00	
	•	-				3 0.0001833333	0.00	- 06-	6 -	•	0.2	2 0.04	0.0	-
= :						3 0.0001833333	0.0	06-		•	0.2	0.01	0.00	
1	•••	•••				J 0.0001833555	0.0 0	04-				2 0°0	0.00	
12	•	•				0 0.00018333333 7 0 0.00018333333		06-				2 0.01	0.00	
: ≝ ₽	•	•				5 0.000666667	0.0						8.0	
: Ē	•	•				5 0.000666647	0.0	06-	Ŧ			0.01	0.00	
±	•	•				5 0.000666667	0.0	06-	ē.	•	0.1	0.01	0.0	
11	•	•				5 0.000666667	0.00	06-	ē	•	0.1	0 0.01	0.00	
Ξ	•	•				5 0.0006666667	0.00	06-	ē-	•	0.1	p 0.01	0.00	
	•	-				5 0.000666667	0.0	-90	Ō	•	0.1	0°0 0.01	0.00	
15	•	•				5 0.0000666647	0.0	6 -	ē	•	0.1	0.01	0.00	
5	•					5 0.000666647	0.00	-90	6	•	0.1	0 0.01	0.00	
	• •					5 0.000666667	0.0	6-		•	0.1	0.01	0.00	
<u> </u>		•••				1 0.0001	0.0	F 8	F a		0.2		0.0	• •
	•	•				3 0.000080734 -						0.02 0.02		-
121	•	-				3 0.000809524	0.00	8-			1.0	0.02	8-0	-
121	•	•				3 0.000809524	0.00	06-	Ē		0.1	5 0.02	0.00	
12	•	•				3 0.000809524	0.0	06-	Ĕ-	Ĭ	0.1	5 0.02	0.0	
16(•	•				3 0.000809524	0.0	06-	Ŧ	•		5 0.02	0.00	-
9	• •	• •				3 0.000809524	0.00	06-	6-		0.1	5 0.02	0.0	-
10	•	•••				3 0° 0000809524	0.0	6- 8		-		0.02	0.00	
141	•	•				J V. UWWWWYJ F	~~~~	AK-					9 90 e	
161	•	-				3 0.000809524 3 0.000809524	0.00		F F			5 0.02	0.0	
161	•	-				J 0.000809524	0.00	- 06-	Ĩ		0.1	5 0.02	0.00	
[9]	•	•				3 0.000809524	0.00	06-	Ē			0.02	0.0	
16{	•	•				3 0.000009524	0.00	06-	6-		0.1	5 0.02	0.00	
191	• •	•				3 0.000809524	0.00	-90	ē-	•	0.1	5 0.02	0.00	
21	• •					3 0.000809524	0.0	-90	6-	•	0.1	5 0.02	0.00	
Ξ:	•••					3 0.000809524	0.00	6- 6-	F 1	~		5 0.02	0.00	
28	•	• •				3 0°000809524	0.0	06-	5- 6			5 0.02	0.00	
	•					1.00000000 A	V.V	0Å- 1				0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 00 U	
175	•	•				X D.000809524	0.00						0.0	

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JSC Shot Wo. 923 1/28/86 (Thin Plate with no Cloth) (lapact at +30 deg Phi)

			Keasured Valu	es							Calculated Val	ives			
Farticle Mo.	X location of impact (origin at	Y location of impact +) (origin at	Z location of impact +) (origin at +	Penetration Depth	Length of Particle	Hass		R location of impact (origin at e	Theta locati of inpact (origin at #	on Phi location of impact e) forigin at ee)	Cone Angle (angle froe iepact pt. to surf. nore.	Average Dianeter	Aver age Area	Velocity	
	2	1	2	1	1	æ		2	Degrees	Degrees	Degrees	T	ea squared	Ka/sec	
~	•	•				Ş	0.0012	0.0	6-	06- 0	0	ě	15 0.02	0.00	
Ţ	•	-				50	0.0015	0.00	- D	- 06-	•	. 0	25 0.05	00.0	
~	•	•				20	0.0009	0.00	6-	06- 0	0	.0	19 0.03	0.0	
~	•	•				54	0.0006	0.0	6-	06- 0	0		14 0.02	0.0	
~		•				8	0.0008	0.00	ē-	06- 0	•	•	19 0.03	0.00	
~	• •	•				8	0.0005	0.0	5	06- 0	•		15 0.02	0.00	
~	•	•				8	0.0003	0.00	ē	06- 0	•••	0	12 0.01	0.00	
~	•	•				20	0.0003	0.0	ō-	0 -30	•		11 0.01	0.00	
~	• 9	•				13	0.0003	0.0	ē-	06- 0	•	0	14 0.01	00.0	-
~	• •	•				16	0.0002	0.00	Ē	06- 0	•	ċ	10 0.01	00.0	-
~	•	•				1	0.00005	0.00	ē-	06- 0	•		02 0.00	0.00	
~	•	•				-	0.00005	0.0	6-	06- 0	0	0.0	02 0.00	0.00	
11	•	•				=	0.0005	0.00	6-	06- 0	•	0.0	05 0.00	0.00	
≌ B∙	•	•				±	0.0005	0.00	6-	06- (0	0.0	02 0.00	0.00	
≚ -6	- 2	•				-	0.0005	0.0	6-	06- 0	•	<u>.</u> .	0.00	0.00	
= 53	•	-				- -	0.0005	0.00	ē-	06- (0	0.0	02 0.00	0.00	
×	•	•				Ξ	0.0005	0.00	6-	06- 0	0	0.0	02 0.00	0.00	
X.	•	• ·				±	0.00005	0.0	6-	06- 0	0	0.0	02 0.00	0.00	
×	•	•				-	0.0005	0.0	6-	06- 0	•	0.0	0.00	0.00	
×	•	-				<u> </u>	0.00005	0.00	6-	06- (•	0.0	02 0.00	0.00	
≚ :						-	0.0005	0.00	6-	06- (•	0.0	05 0.00	0.00	
2:							0.00005	0.0	- 6	00	•		05 0.00	0.00	
= :		• •				2 0.00	4666667	0.00	6-	06- (•	0.1	27 0.06	0.00	
2:		• •				5 0.000	466667	6.0	6-	06-	•		27 0.06	0.00	
= :		• •				5 0.000	1666667	0.00	16-	- 06-	•	0.1	27 0.06	0.00	
= :	•	• •				• •	0.0009	0.00	-4 -	06-	0	.0	43 0.14	0.00	
= =		•••					0.0006	0.0	F	0 <u>6</u> -	0		35 0.10	0.00	
= =	•	•			ſ	• •		00°0	ř	04-	•		22 0°0	0.00	
	•	•			-	2 9	2000	0.0			.		G.) 	0.00	
: =	•	•				2	22000 CC000 C	40°0		04-			13 0.01	0.00	
	•	•				2 9	0.00022	00.0			> c			0.0	
0 0	•	•					0.00022	00.0		2 6-		5		0.0	
r≌ R∳ ₽	•	•					0.00022	0.00	- 16	04-	• •	ē	10 0 01	0.00	
Gi Pi	•	•				000.000	111111	0.0	-	- 40		c	00 0 50		
≊ Ni Où	•	•				000.000	333333	0.00	÷ Þ	06-	• •	0.0	02 0.00	0.00	
≃ Al XR	•	•				0 0.000	1333333	0.00	- 06	06- (Ð	0.0	02 0.00	0.00	
≃	•	•				0 0.000	3333333	0.0	6-	06-	•		05 0.00	0.00	
ב אל לפ	•	•				0 0.000	333333	0.00	3 6-	06- (•	0.0	05 0.00	0.00	
18 7€	•	•			_	0 0.000	0333333	0.0	- 96	06- 0	¢	0.0	05 0.00	0.00	
≃ :E	•	•				1	0.001	0.0	-90	06- 0	¢	0.1	11 0.01	0.00	
	•	•				1	0.0001	0.0	-90	06- 0	c	0.1	11 0.01	00°ŭ	
≃ S Y		•				1	0.0001	0.00	-90	06- 0	•	0.1	11 0.01	0.00	
.	•	•				1	0.0001	0.0	06-	06-	•	0.1	0.01	0.00	

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1/28/86 E 923

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5	Phi)
th no	deg
te mi	t +30
F Pia	act a
CTN:	1
	(Thin Plate with no Clot

			Reasured Val	lues						Calculated Val	828			
Particle No.	X location of impact (origin at	Y location of impact +) (origin at	<pre>¿ location of impact e) lorigin at e</pre>	Penetration Depth	Length of Particle	Nass	R location of impact forigin at fe	Theta locati of impact }{origin at ⊧	on Phi location of impact =)(origin at ++)	Come Angle (angle from impact pt.	Aver age Di aneter	Åver age År ea	Velocity	
	2	:	:	2	1	3#8	3	Degrees	Begrees	Degrees	1	en squared	Ka/sec	
22	•	•				2 0.0000175	0.00	6	06-	e	e	14 0.03	00 0	
2	•	•				2 0.000475	0.00	. 87	06- 0			0.02	0.0	
2	•	•				2 0.000475	0.0	•	06- 0			0.02	0.0	
22	•	•				2 0.0000175	0.00	6-	06- 0	•	0.1	0.02	0,0	
22	•	•				2 0.0000175	0.00	6 1	06- 0	•	0.1	0.02	0.00	
22		•				2 0.000475	0.00	6-	06- 0	•	0.1	.02	0.00	
22	•••	• ·				2 0.000475	0.0	6 -	06- 0	•	0.1	10.02	0.00	
·77	•	• •				2 0.000475	0.00	6 1	06- 0	•	0.1	14 0.02	00.0	
966		•				2 0.000475	0.0	6-	06- 0	•	0.1	14 0.02	0.00	
11	•	•				2/1000010 2	0.00	6 - 1	06- 0	0	0.1	e 0.02	0.00	
152	•	•				2 0.0004/5	0.00	φ. ι	06- 0	•		1 0.02	0.00	
23	•	•				2/10000 V C	00.0	5	06- 0	0		0.02	0.00	
B	•	•				2 0.00001/2	0.0		06- 0	0		1 0.02	0.00	
1 234	•	•				1 0 000581447	00°0	κ. α	0	-		0.02	0.0	
56	•	•.				1 0.0000591667	00.0 0	7 9	0Å- 0		~~~		0.00	
236	•	•				1 0 0000201771				•	7 C	10°0 2	0.0	
23)	•	•				1 0.000591667	00.0	F •	06- 08-	> c	2.9 0	2 0.04	0) 0	
236	•	•				1 0.000591667	0.00							
235	•	•				1 0.0000591667	0.0	Ţ		• •	0.7	2 0.06	0-0	
21	•					1 0.000591647	0.00	ē.	06- 0	•	0.2	2 0.01	0.0	
12	• •	•				1 0.000591667	0.00	6-	06- 0	•	0.2	2 0.04	0.00	
112	• •	• •				1 0.0000591667	0.00	5-	0f- 0	•	0.2	2 0.04	0.00	
147 116		•••				0.0000591647	0.00	Ŧ	06- 0	•	0.2	2 0.04	0.00	
200	•	• •				1 0.000591667	0.00	1	٩ ٩	•	0.2	2 0.01	0.00	
245	•	•				/991400000.0	8.9		6 -1	0	0.2	2 0.04	0.00	
747	•	•				/991406000 0 .	0.00	F, i	6 - 1	0	0.2	2 0.04	0.00	
248	•	•				1 0.000037160/	00.0	<u> </u>	6- 8	•	2.0	2 0.04	0.0	
249	•	•				1 DOMASPILES			04-	2 (50°0	0.0	
250	•	•				1 0.000591667	0.0			> -			8.6	
251	•	•				1 0.0000591667	0.00		06-	• •	0.7	2 0.0t	00-0	
252	•	•				1 0.000591667	0.00	Ĩ	06-	. 0	0.2	2 0.04	0.0	
223	•	•				1 0.000591667	0.00	6 -	06-	• •	0.2	2 0.04	0.00	
2	•	•				1 0.000591667	0.00	ş	06- (•	0.2	2 0.04	0.0	
ន៍រ	•					1 0.000591667	0.00	6-	06- (•	0.2	2 0.04	0.00	
22	• •	• •				1 0.000591667	0.00	- 6	06- (•	0.2	2 0.04	0.00	
	•					1 0.000591667	0.00	06-	06- 0	¢	0.2	2 0.04	0.00	
9C)	•					1 0.0000591667	0.00	-90	06- (•	0.2	2 0.04	0.00	
177	•					1 0.000591667	0.00	06-	60	•	0.2	2 0.04	0.00	
176 107		•				1 0.000591667	0.00	-90	06-	•	0.2	2 0.04	0.00	
197	•	•				1 0.000591667	0.00	6- i	96-	•	0.2	2 0.04	0.0	
145	•	-				/991AC0000.0 [0.00	6-1	06-	0	0.2	2 0.01	0.00	
						AMINCUUND 1	20 W		51	5			~~~~	

1/28/86

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9.0 ******* Xa/sec Velocity 0.03 0.02 0.02 0.02 an squared -----------Average Area Average Diameter 2 **Calculated Values** to surf. norm.) Degrees R location Theta location Phi location Come Angle of impact of impact of impact (angle from forigin at eoltorigin at eoltorigin at eolimpact pt. 0 • 0 0 0 0 0 Degrees Degrees 8 JSC Shot No. 923 (Thin Plate with no Cloth) (Impact at +30 deg Phi) 0.0000475 0.0000475 0.0000475 0.0000475 0.0000475 0.0000475 0.0000475 0.0000475 0.0000475 0.0000475 0.0000475 0.0000475 0.0000475 0.0000475 S. Aass ~~~~~ Length of Particle 1 Penetration Depth 3 Reasured Values of impact of impact *) (origin at *) (origin at *) Z location 3 Y location 2 of impact forigin at f X location 2 **Farticle No.** B-65

JSC Shot No. 923 1/28/86 (Thin Plate with no Cloth) (Impact at +30 deg Phi)

			Neasured Val	ues		I Lud das Ack 18 136deri			Calcu	lated Val	sa		
Particle No.	X location of impact forigin at	Y location of impact +) (origin at +	Z location of impact) (origin at +	Penetration Depth	Length of Particle	Aass	R location of impact (origin at e	Theta location of inpact b) (origin at 44) (Phi location Cone of impact (angl origin at estimpac	Angle e froa t pt.	åver age Di anet er	Aver age År ea	Velocity
	2	1	1	2	3	sab	I	Begrees	to su Degrees Dev	rf. nore. grees	I	ee squared	Ka/sec
30	•	•				1 0.000591447	0.0	V8- 0	¥a'	•			:
30	•	•				1 0.000591667	0.0			> <	77 - A		00°0
31	•	•				1 0.000591667	0.0	96-	06-	> c	77 N		00.0
31.	•	-				1 0.000591667			6.	> <	77.0 62.0		0.0
H	•	•				1 0.000591667	0.0		6	> a	0 77		0.0
	•	•				1 0.000591667	0.0	6-	8-	• •	0.27		8
Ē	•••					1 0.000591667	0.0	06-	06-	• •	0.22	0.0	0.0
31.	•••					1 0.000591667	e.e	0 6-	06-	0	0.22	0.04	0.00
110	•••	• •				1 0.000591667	0.0	06-	-90	•	0.22	0.04	0.00
10	•	-				1 0.000591667	0.0	06- 0	6 -	•	0.72	0.04	0.00
8 12	•	•				/991620000.0	0.0	-90	06 -	•	0.22	0.04	0.00
370	•	•				/991620000.0 1	0.0		06-	•	0.22	0.04	0.00
E	•	•				1 0 000000 1 1000000 0	0.0	<u>8</u> -	0 6-	•	0.22	0.01	0.00
322	•	•				1 0000501100/		04-	6 -	•	0.22	0.04	0.00
61	•	•				1 0.0000591467		04-	04- -		22.0	0.04	0.00
	•	•				1 0 0000501477			2	• •	77 N	10.01	0.00
325	•	-				1 0.000591667	00.0	0.6-	0.6-	•	0.22	0.04	0.00
324	•	•				1 0.000591667	90'e		4 -	,			00.V
22	•	-				i 0.0000591667	0.0	06-	06-	`	0.77	10-0	
77 17	• •	• •				1 0.000591667	00.0	06-	06-	•	0.22	0.04	0.00
() () 411						1 0.000591667	0.0	06-	06-	0	0.22	0.04	0.00
17.0 18.1		•••				1 0.000591667	0.00	06-	06-	•	0.22	0.04	0.00
100	•	• •				1 0.000591647	0.00	06-	06-	•	0.22	0.04	0.0
	•	•				2000001 1 0.000000 1	0.0	06-	06-	•	0.22	0.04	0.00
10	-	•				1 0.000071146/	0.0	8 1	6 - 1	0	0.22	0.04	0.00
222	•	•				1 0 000591447	00.0	? 8	06-	• •	0.22	0.04	0.00
336	•	•				1 0.000591447			0.4	• •	0.22	0.04	0.00
237	•	•			_	0.000591667	0.00	6-	6	• e	22.0		
338	•	•			_	1 0.000591667	0.00	- 6-	- 8-		0.27	0.0	- 00 0
539	• •	•			-	1 0.000591667	0.00	06-	06-	•	0.22	0.04	00.0
04-0 		• •			-	1 0.000591667	0.0	06-	0 6 -	•	0.22	0.04	0.00
115						1 0.000591667	0.0	06-	06-	•	0.22	0.04	0.00
24C 241	•	•				0.000591667	0.0	06-	06-	•	0.22	0.01	0.00
	•	•				0.0000591667	0.0	06-	06-	•	0.22	0.04	0.00
	-	•				0.0000591667	0.00	06-	06-	•	0.22	0.04	0.00
346	•	•	-			0.000074166/	0.00	-90	06-	•	0.22	0.04	0.00
347	•	•				2000000	0.0	06-	06-	•	0.22	0.04	0.00
842	•	•				79914CNUVQ.U	0.0	06-	06-	0	0.22	0.04	0.00
149	•	•				0.00003166/	0.0 0	0 6 -	0 <u>6</u> -	•	0.22	0.04	0.00
350	•	•				0 000591447	200 200	∩. -	06-	• •	12.0	9.04 0.04	0.00
351	•	•				0.0000591467	0.0	26-	06- -	> o	0.77	10.0	00 0
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1/28/86

0.00 Xa/sec Velocity en squared Average Area Average Diameter 2 **Calculated Values** to surf. nora.) Degrees of impact fangle from Theta location Phi location Cone Angle Degrees Degrees R location 2 1 JSC Shot No. 923 (Thin Plate with no Cloth) (Impact at +30 deg Phi) 0.000591667 0.000591667 0.000591667 0.000591667 0.000591667 0.000591667 0.000591667 0.000591667 0.000591667 0.000591667 0.000591667 0.000591667 0.0000591667 0.0000591667 0.000591667 0.000591667 0.000591667 0.000591667 0.000591667 0.000591667 0.000591647 0.000591647 0.0000591667 0.0000591667 0.0000591667 0.0000591667 Se lass Length of Particle 2 Penetration Depth 2 Measured Values of impact (origin at ^a) 2 location 3 ÷ of impact (origin at f Y location 2 Ŧ forigin at 4 X location of impact 2 Particle No.

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2	Plate)
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						JSL Shot (Thin 60	mo. 755 61-16 Aluminum Plate	9 0 / AT / 7						
			Reasured Val	lues							Calculated Va	lues		
article Mo.	X location of impact (origin at	Y location of impact •) torigin at •)	Z location of impact (forigin at 1	Penetration Depth	Length of Particle	Hass	-	R location of impact (origin at **	Theta location of impact)(origin at ++)	Phi location of impact (origin at ++)	Come Angle (Angle from surface norma	Åver age Di ameter	Avera ge Area	Velocity
	2	2	3	2	1	suć		:	beyrees	Begrees	to particle) Degrees	:	an squared	Ko/sec
SPALL														
		96 131 27		70	- 	• •	00490 Voora	96.05	-23.89	39.64 25 BN	43.21	0.75	0.452	0.368
		17 89 17			•	. ~	0140	121.05	-1.42	2. 2. 2.	1.71	0.57	0.258	4.541
		75 22		31	2 1	.5	00130	134.13	-4.72	-25.22	25.54	0.63	0.320	0.856
	.	95 121 27	36			- 7	00060 20078 (The fellenion	130.91	-13.92	18.29	22.45 X X	0.37	5 0.111	5.601
	•	27 41					00078 particles hit	131.05	11.43	-15.26	52.55	0.60	0.286	6-239 b.259
	50	55 51	1	1 12	2	.5 0.	D0117 and penetrated	123.39	4.72	-10.30	11.29	0.60	0.286	5.110
	.	33		2	7	1.	00078 styrofoan on	125.64	14.81	-5.19	15.62	0.69	0.286	6.259
	. -	22 20			~ ~		00078 back wall. The 20078 disember of	128.42	19.56	-1.42	19.61	0.60	1 0.286	6.259
		86 5		3	. ~		0078 the hole (in	125.53	58.4-	-12.13	15.44	0.60	0.286	6.259
	5	48 71	5 11	1 12	2	2 0.	00155 the length	122.25	8.00	-1.89	8.21	0.60	0.286	4.426
B-		35		21		 	00117 col.) was used	124.67	13.92	6.0	13.93	0°°0	0.286	5.110
70	.				2	~ ~ ~	VVIJJ TO CALC MASS./ 90194	121.04	-1.42	74·1-		09.0	0.786	974-4 3.958
-	1	62 BI	5	1 12	2	2 0.	00155	121.19	1.42	2.84	3.17	0.60	(4.426
		30		21	00		00039	123.66	-11.67	-2.37	11.90	0.60	0.2Rb	8.851
- ~		-/ CA			2 6		000,59 AAA TO	124. X	-15.92	-1.12	13.99	09.0	1 0.286	8.831
. ~		86 90		1			00039	128.01	-18.72	3.78	19.05	0.60	0.286	8.851
	6-1	45 91		21 1	2	1 0.	00078	123.96	9.39	8.46	12.54	0.60	0.286	6.259
r u r i	~ -	10 10 10 10 12 12 12 12 12 12 12 12 12 12 12 12 12		1 1		· ·	00117	124.60	-10.30	67°6	13.81 19 97	0.60	1 0.286	5.110
		78 121		3	0	. 5	00039	130.82	-6.13	21.64	22.34	0.60	0.286	8.851
~ `		24		62	3		08000	100.23	-36.75	-12.84	37.98	0.50	0.197	1.424
74 E	/ 7 [nnce nn B	82 atta	-	/3 0.	ņ	2 2 2 2	003/0 VALTA	109.63	-13.11 -00 00	-4/.62 -80 00	48.23	0.76		0.157
		-				- 0 - 1	00430	0.0	-90.00	-90.00	0,000	0.82	0.529	0.00
13	•	•				3 0.	90370	0.0	-90.00	-90.00	0.000	0.76	0.455	0.00
en i	•••				~ ~	.s.	00420	8.0	-90.00	-90.00	000"0	0.88	619.0	0.000
~ r	•	•					09100	5.5	-90.00	- 00.00	00.0	0.0	9.395 1 0.395	0.00
, m	•	•			2		0010	0.0	-90.00	-90.00	0.000	0.36	0.103	0.000
M	••••	•				.5 0.	00060	0.0	-90.00	-90.00	0.000	0.43	3 0.147	0.000
₩ F	•••						00100	9.9 9	-90.00	-90.00	0.000	0.55	9 0.246	0.00
- Fi	•	•	-		-	 	04000	0.0 0.0	00.04-	-90.00	0.000	0.44	0.166	0.000
n	• • •	•			1	.5	00020	0.00	-90.00	-90.00	0.000	0.39	6 0.123	0.000
-	•••	- •			-	5	00000	0.0	-90.00	-90.00	0.000	0.53	0.221	0.0.0
	•••	•••					00040	0.0		-90.00	0.00	0.30	0.0/4	0.000
• •	•	•					00032	0.00	-90.00	-90.00	000-0	0.58	0.118	0,000

Calculated Values

JSC Shot Mo. 923 1/17/86 (Thim Plate with no Cloth) (Impact at -30 deg. phi from normal on ejecta side)

Measured Values

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Particle No. X	location	Y location	Z location	Penetration	Length of	Aass	R location	Theta location	on Phi locatio	h Cone Anale	åver ane	Överade	Valueitu
1 0	i epact	of impact	of impact	Depth	Particle		of issued	of incet	nf imart	(and from		Ares aye	
ē	'igin at 6)	(origin at +)	forigin at e.				forigin at a	*) (origin at a	I) (origin at 6	bsurf. normal)			
							•	n		forioin at 46	-		
	2	1	2	2	2	suð	I	Degr ees	Degrees	Degrees	=	me squared	Ka/sec
396	•	•			-	2 0 000	131						:
391	•	•				5 0.000				0.00	0.76	20-0 20-0	0.00
398	•	•			-	5 0000					97·A	c).v	0.00
399	•	-					1010 IC1		0.04-	0.0	0-26	0.03	0.0
100	•						111	0.04- 0	-40.0	0.0	0.26	0.05	0.00
104	•	•				5 0.000	121 0.0	0 -90.00	-40.0	0.00	0.26	0.05	0.00
10	•	•				5 0.000	121 0.0	0.09- 0	0.09- 0	0.0	0.26	0.05	0.00
204	•	-			-	5 0.000	121 0.0	0 -90.00	- 40°.04	0.00	0.26	20.0	
403	•	•				5 0.000	121 0.0	- 40.00	10 ⁻ 04-	0.0	0.26	20.0	8.0
404	•	•			.1	5 0.000	121 0.0	- 40.05	10.09-		0.76	20.0	0.0
405	•	•				5 0.000	121 0.0	0	10.09-		47 U	200	00.0
404	•	•			-	5 0.000	121 0.0		00-		97°A		0.0
407	•	•				5 0.000	121				97 A	70 0 30 0	00.0
408	•	•			i	5 0.000					97 D	0.0	00-0
50€ B	•	-								20-0 -	97.0	CA.U	0.00
1 410	•				: -			-70°07		0.0	0.26	0.05	00.0
5	•	•					171 0.0		00	0.00	0.26	0.05	0.00
9 9	•	•			<u>.</u>	000.0	121 0.0	-90.00	-90.00	0.00	0.26	0.02	0.00
71	•••				-	5 0.000	121 0.0	00.09- 0	-90.00	0.0	0.26	0.05	0.00
Î	• •				-	5 0.000	121 0.0	00"06- (-90.00	0.00	0.26	0.05	0.00
=	•				1.	5 0.000	121 0.0	00-06- 00	-90.02	0.00	0.26	0.05	0.00
412	•	-			-	5 0.00	121 0.0	-40.00	-90.00	0.00	0.26	0.05	0.00
416	-	-			-	5 0.000	121 0.0	00.09- 0	-90.00	0.00	0-26	0.05	0.00
417	•	•			-	5 0.000	121 0.0		-90.00	0.00	0.75	0.05	8.0
418	•	•			-	5 0.000	121 0.0	00.04- 0	-90.00	0.00	0.76	0.0	000
419	•	•			-	5 0.00	121 0.0	-90,09	-90.00	0.00	12.0	0.05	8.0
420	•	•			-	5 0.000	121 0.0		-90.00	0.0	0.74	20.0	
124	•	•				5 0,000	21 0.0		00.08-	0.0	77 U	20.0	
422	•	•			-	0.000		00.09-	90 00-	90 V		0.01	
423	•	•				0000				8.0			8.5
424	•	•			:			00.00-					0.0
(22	•	•			:					00.0		CO.O	0. v
426	•	•			:	0.000		00.09-		0.0	87°A	50-0 30 0	0.0
121	•	•			:	0.000		00 00-		00.0	9.0	50.V	00
428	•	•			:	0.000					97°n	50.0	B.9
629	•	•			: -					8.0	97 · A	50°0	0.0
					:		N'A 17	10-04-	- 40 . 04 -	0.00	0.26	C0.0	0.00
			-	Total Spall Ma	- 55	0.120	136						
				Tatal Ciacta I			7						
						>.>	07						
	•	-		Total Nass =		0.1929	36						
spall Urigin 4, A.	Lower righ	t hand corner											
Of DACK SLYFD+DAN	surtace tal	ing surface.		Total from mas	5 t -(two	ō	24						
				10 נפן אבו שביט									

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JSC Shot No. 923	1/28/8/
(Thin Plate with no Cloth)	
(Impact at +30 deg Phi)	

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			Reasured Val	lues							Calculated Vi	lues			
Particle No.	X location of impact lorigin at +	Y location of impact) forigin at e	<pre>2 location 0 impact) (origin at 4</pre>	Penetration Depta	Length of Particle	<u>k</u>		R location of impact ((origin at 4+)	Theta location of impact forigin at sel	Phi location of impact forigin at #	Cone Angle (angle from)iepact pt. to surf, nore	Åver age Di aneter L)	Åver age Årea	Velocity	
	:	1	2	1	1		seó	:	Degr ees	Degrees	Deyrees	2	ee squared	Xa/sec	
4	=	101	1	67	-	2	0.0004	15.24	46.06	6.72	46.2	l 0.	13 0.01	1.06	
2	: 1	6 13		56	. ~	-	0.0002	80.71	52.60	ft.30	59.2		23 0.04	1.28	
9 7	: =	•		63	. ~	~	0.0001	76.76	44.74	2.52	14.21		20 0.03	1.69	
	:	. •		. •		-	0.0002	129.84	-38.64	-47.17	53.3	د د	15 0.02	1.55	
		•	9		2	. m	0.0001	128.39	-31.31	-46.20	52.2	.0.	16 0.0	1.52	
- T						2	0.0006	130.53	-38.15	-51.84	54.2		16 0.02	0.96	
95	*7		9			. ~	0.0006	115.38	-20.35	-41.25	43.5	۰ ٥.	16 0.0	0.96	
21	רא י	6	2	0	_	2	0.0006	111.83	-1.85	-17.92	18.4	°.	16 0.02	0.96	
22				0	2	2	0.0006	124.38	-17.91	-6.91	19.0		16 0.03	1.91	
15		9		•	_	2.5	90000	123.79	-17.03	- 6 .91	18.2	5	14 0.0	0.91	
5		11		0.0	5	2	0.0006	120.16	16.20	-10.43	19.0	e.	16 0.0	0.49	
23	П	2		0	-	-	0.0006	121.22	30.30	-39.21	42.1	• •	22 0.0	1.16	
2	10	5 11	2	0	2	-	0.0006	124.93	20.33	-8.33	21.7	° °	22 0.0	2.28	
B	10	2	5	•	-	m	0.0006	118.05	20.84	-18.93	27.1	°.	13 0.0	0.87	
8 - (••	11 9	12	•	_	-	0.0006	111.42	-6.01	-19.41	20.2	· •	22 0.0	1.16	
5	1	10 10	8	0	*	-	0.0002	129.62	28.06	-11-21	29.7		20 0.0	2.37	
99	ت		12	0	v	2	0.0002	121.40	8.56	2 : S	6 6				
19	-		=	1	-	67	0.0083	00.9	53.18	65.86 .0	e./e			57°0	
62	≍ '	3		18 0.	• ترم	~ '	1000.0	73.82	65.04	99.99		÷ <		10.1	
61		 2		24	7	- :	0.0002	11.20	70.04					1.78 0.78	
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70 7				24 0.		-	0.0001	62.17	33.42	74.14	74.4		14 0.0	0.36	
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		1		30 0.		~	0.0002	66.34	61.34	19.4	9.08	•	18 0.0	c 0.29	
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92	-	72 13	1 1	122	2	2	0.0003	61.55	28.52	72.31	12.6	0	11 0.0	1.77	
17	~	72 13	1 1	0. 0.	ň	2	0.00003	66.48	45.32	60.0	63.5	• •	11 0.0	0.58	_
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こ)	_			2	·> -	· · ·	0.00005	7/ 19	19*0C				11 0.0	2.27	
				20	. -	. -	0.0001	44.26	48.77	12.21	73.3		16 0.0	2 1.36	
2 6					- ~	- ~	0.00003	69.47	-85.88	89.4	90.5	0	11 0.0	1 2.27	
52				50	. ~	. ~	0.00003	67.08	55.89	55.5	1 64.2	6 0	.11 0.0	1 2.27	
62	=	16	02	02	- 2	Ξ	0.0003	72.80	60.76	51.7	65.4	7 0.	.15 0.0	2 0.83	
	-		22	16	13	28	0.0021	74.15	70.52	67.9	2 75.0	7 0.	.25 0.0	5 2.62	
8	1	19	1. 12	124	_	28	0.0012	78.75	74.80	75.1	1 79.2	و ٩	.19 0.0	3 0.24	_
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6	=	16 12	1 92	118	-	0	0.0004	77.13	70.27	69.4	1.27	، ٩	18 0.0	1.58 	_
F4	1	16 15	22 1	112 0.	ŝ	-	0.0001	13.68	67.32	63.4	12.2	5	16 0.0	2 0.59	
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78	1 TOOSE 1	ON ROTTON				83	0.0176	0.00	06-	6 - 1	•	с . о .		0.0 0	_
8	•	•				BS	0.0013	0.00	04-	¥-	~	> >		۲. ۱۰	

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2/10/86	Plate)
933	Al vai nue
JSC Shot No.	(Thin 6061-T6

, Measured Values

	laci ty	Ka/sec	000	0.00	0.000	0.000	0.000	0.00	0.000	0.000	0.000	000-0				1.483	7.499	7.499	7.499	2.553	5.027	219.9	5.027	7.499	5.027	5.027	2.553	2 555	5.027	9.972	7.499	2.255 5	1.316
	verage Vi	ee squared	0.118	0.118	0.118	0.025	0.025	0.025	0.052	0.022	0.052	0.052				0.074	0.055	0.055	0.055	0.055	0.055	0.055	CC0.0	0.055	0.055	0.055	0.00	0.055	0.055	0.055	0.055	660.0 220.0	0.055
Le s	Average A Diameter A	E	0.388	0.388	0.388	0.177	0.177	0.177	907.0	0.254	0.256	0.256				0.306	0.265	0.265	0.265	0.265	0.265	0.265	0.265	0.265	0.265	0.265	0, 203 215	0.265	0.265	0.265	0.265	0.265	0.265
Calculated Val	Cone Angle (Angle from Lurface normal	Degrees	0.000	0.000	0.000	0.000	0.00	0.000	0.00	0.00	0.000	0.000				52.90	36.80	39.48 An ol	37.80	40.66	41.63	38.41	17.29	38.36	42.13	40.34	14.16	32.31	30.32	31.90	35.07	34.00	35.04
	Phi location (of impact (origin at #1)	Degrees	- 90.00	-90.00	-90.00	-90.00	-90.00	-90.00	00.06-	-90,00	-90.00	-90.00				- 19.44	23.94	10./1-	-1.37	-4.51	-7.70	0.70	17.5	9.46	12.20	16.96	07.77 51 8-	-11.63	-5.92	-0.58	-1.97	5.41	14.89
	heta location if impact origin at **)(Degrees	-90.00	-90.00	-90.00	-20,00	-90.00	-90.09	-90.00	-90.00	-90.00	-90.00				51.88	31.04	14.10	37.41	40.54	41.30	38.40 42.40	B0.75	37.73	41.30	38.40 33 EE	-15 47	-30.88	-29.92	-31.90	-35.04	-32.70	-32.98
	location 1 f impact o origin at ee)(:	0.00	0.00	0.00	0.00	0.0 0	8.6	0.0	0.00	0.00	0.0	Spall			84.56	134.88	107.30	107.57	100.18	99.00	104.64 05 71	108.10	107.13	99.78	107.58	105.54	120.69	122.79	115.44	106.30	113.26	114.81
luninun Plate)													71.19 2				ote: approx.	P in area	ntered at	e indicated	cation with	diameter of an for sil	llowing pts.	. Bostly	st).								
[hin 606]-76 A	55	seő	0.00032	0.00032	0.00032	0.00003	0.0003	0.0003	0.00014	0.00014	0.00014	0.00014	0.04350	0.04370		0.00020	0.00001 (N	0.00001 ar	0.00001 Ce	0.00001 th	0.00001 10	0 00001 5	0.00001 40	0.00001 je.	0.00001 du	0.0001	0.0001	0.0001	0.00001	10000.0	0.00001	0.0001	0.0001
-	ngth of Na rticle	:	-						•	-				asur ed				0.1	0.1	0.1	0.1	1.0	0.1	0.1	0.1		0.1	9.1	0.1		0.1	0.1	0.1
	netration Le pth Pa	2											tai Spail Nass	obined Spall Ne	,		~ ~	, m	m	-	~ •	• •	• •	•	2	- 7	•	-	2		γ		0.5
easured Values	location Pe fimpact De originate)	1											10	8	i	12	6) 58	82	82	92		02 72	98	8	2 8	28 78	82	, 102	106	86	. 2	95	76
E	flocation 2 ofispact o (originate) (:													:	79	5	19	69	21		. 20	88	76	96 10E	C01	99	53	69	5 5	: 88	68	105
	X location of impact (origin at e)	:	• • • •	•••	•	•	•	•	•	•	•••				•	.	• •	•	0	-			•	•	•		126	126	126	97	126	126	126
	Farticle No.		4	; :	9 G	8		20	51	22		5		B-71	EJECTA	- r	22	42	62	28	122	142	162	182	202 272	212	262	282	302	275 775	362	182	40 5

JSC Shot Mo. 923 1/28/86 Thin Plate with no Cloth) Llepact at +30 deg Phi) -

0.0 0.0 Xa/sec Velocity 0.04 an squared Average Area 0.22 0.22 2 of impact of impact of impact (angle from Diameter forigin at ##!forigin at ##!forigin at ##!impact pt. Theta location Phi location Cone Angle Average **Calculated Values** to surf. norm.) Degrees 0 0 8- 8-Degrees 8- 8-Degrees 37.63 percent Ejecta 62.37 percent Spall 0.00 R location 22.83 percent Dust 2 1 0.0000591667 1 0.0000591667 0.0726 0.120336 0.192936 0.25 0.15593 0.09407 0.02147 0.03559 0.057064 ŝ Nass Length of of target before & after Particle Corrected Ejecta Nass = 2 Corrected Spail Mass = Total Ejecta Mass = Calc. Ejecta Dust = Total Spall Mass = Calc. Spall Dust = Total Calc. Dust = Total from mass 2 location Penetration Total Mass = 2 Depth **Neasured Values** of impact of impact of impact (origin at 4) (origin at 4) 3 Origin 44, At impact point on target surface Shear Strength (estimated) used in velocity calculation, M Pascals of back styrofoan surface (facing surface). Ejecta Origin 4, At lower left hand corner 3 109 Y location 3 . 1, ... ٠ . 62 71.674337148 Particle No. I location of impact 2 • Y, ... 351 **:** B-69

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						JSC Shot No. (Thin 6061-T6	933 2/10/86 Aluainun Plate)						
			Heasured Val	lues						Calculated Va	lues		
Particle No. X loca of iep (origi)	ition act c a at +) (llocation if impact origin at f)	l location of impact forigin at f	Penetration Depth	length of Particle	liass .	R location of impact (origin at fi	Theta Bocatio of impact E) (origin at ee	n Phi lecation of impact !(origin at es	Cone Angle (Angle from)surface norma	Average Diameter I	Aver age Area	Velocity
-	:	I	2	1	:	ias	2	saa sõag	Degrees	Degrees	2	no squared	Ka/sec
423	89	136		58	ю.	.1 0.0001	80.6	-2.96	43.99	44.04	0.2	165 0.055	1.316
442 462	89 99	136		5		.1 0.0001 .1 0.0001	92.8	5 -2.64	40.75 37.87	37.91	0.2	65 0.055 65 0.055	2.553
482	8	136				10000.0	95.24	-2.23	36.03	36.07	0.2	65 0.055	2.553
502	1 9 4	136	•	8 9		10000.0 1.	7.79		14.91 14.91	35.03	0.2	165 0.055 145 0.055	2.553
542	3 12	136		2	2	.1 0.0001	98.14 11.86	-7.13	14. H	35.42	0.2	65 0.955	5.027
562	ę2	136				.1 0.0001	100.94	0.00	33.69	33.69	0.2	65 0.055	7.499
582	2	136	I	16		.1 0.0001	101.4	5 -6.79	33.69	34.11	0.2	i65 0.055	7.499
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642 642	2 8	136	- -			.10000.0	107.3	10.70	91.B9	33.03	0.2	65 0.055	2.553
652	88	136	5	40	1	.1 0.0001	108.4		31.89	33.93	0.2	le5 0.055	2.553
682	F	136		95 0 .	ر م	.1 0.0001	113.5	5 15.87	30.52	33.20	0.2	65 0.055	1.316
702	27	136		95 		-1 0.0001 	111.0	61.1- 1. X	30.52	31.18		121 0.022 04 0.171	1.316
221	3 7	۹ A	1	80	7	.5 0.0003	115.50	20.79	-1.59	20.84		101 0 101 101 101 101 101 101 101 101 1	3.370 6.200
124	28	14	×		2	.5 0.00053	112.7	15.03	7.39	16.60	0.	09 0.131	6.200
22	39	••	4	75 0.	<u>.</u>	.1 0.0001	4.601	-0.76	58·9 1 -	46.85	0.2	(65 0.055 15 0.055	1.316
CP/	8 9			88 25			7.811 52.921		-42.21-	42.27		60.0 0.055	SCC.2
785	3 5	••	Ξ		20	.1 0.0001	128.91	12.2-	B82 -	38.42	0.2	45 0.055	5.027
805	9	0	÷.	02		.1 0.0001	129.7	3 2.81	-38.11	38.16	0.2	65 0°.055	7.499
528 578	R 2	••	= =	96		- 1 0.0001 - 0.0001	132.9	3.78	-37.04	37.15	0.2	65 0.055 45 0.055	2.353
865	3 5	> o		15		0.0001	141.9	11.31	-34.82	35.90	0.2	65 0.055	1.316
885	2	0	×	10		.1 0.0001	129.4	-6.78	-38.38	38.69	0.2	65 0.055	2.553
506	8	0	Ξ	20	_	00001	130.1	1 (°.71	-38.11	38.42	0.2	65 0.055	2.553
925	8 8	•		05	~~ <	.1 0.0001	134° 37	-13.39	-37.30	38.60	0.0	(65 0.055 15 0.055	1.316
965 Lonse	, as Batto	> ,	-		- ••	.5 0.0020	2.971	00.00-	0.00- 00.00-	00.00 0.00		61 0.071	0.000
466	•	2				.5 0.00130	5.0	90.00	-90.00	0.0		94 0.192	0.00
. 196	•					2 0.00156	0.0	00.09- 0	-90.00	0.0		93 0.277	0.000
Ejecta Origin e, At	lower lef	t corner and		Total Ejecta	Kass	0.01766	28.81 % Ejecta						
Spall Drigin 4, At I Facing target fat tai	ower rigt rget surf	it corner ace)		Total Spall R Total Spall &	ass Ejecta	0.04354	[1645 I 91.17						
Drigin ++, At impact 1, me Y, me	point of 2	i target surfi , en	IC	Total from ma of target bef	ss oreåafter	0.12							
65	8	•		Corrected Eje	cta Nass 11 Mars	0.03457							
				TULLER LE SAG	11 7455	"LP0A'A							

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Appendix C - Single Frame Photography Data

Appendix C - Single Frame Photography Data

The following three photographs were taken shortly after the impact of hypervelocity projectiles on composite targets. Due to various problems with time measurement and scaling, only approximate velocity data can be derived from these photos. They still provide useful information however, and are therefore documented here.

Shot # 873

5 mg nylon projectile, 6.32 km/sec velocity

.416 inch thick composite plate from Hercules (generic graphite/epoxy plate)

Photo is of ejecta approximately 15 microseconds after impact

Scaling - 16 threads per inch in photo = .15875 cm/thread

Threads are 10 inches from camera. Centerline of shot is 12 inches. Therefore Real Distance = $1.2 \times Measured$ from thread.

Therefore scaling for shot centerline is $1.2 \times .1575 = .1905$ cm/thread.

The furthest particles from the target are roughly 19 threads out, assuming they are on the centerline. $19 \times .1905 = 3.62 \text{ cm}$.

3.62 cm / 15 microseconds = .0362 m / .000015 sec = 2.41 km/sec

Therefore the highest velocity ejecta appears to be traveling in the range of 2.4 km/sec, which agrees with calculated and other data measured with the high speed movie camera.

Shot **# 917**

See section 3.2.3 for more discussion of this shot.

5 mg nylon projectile, 5.39 km/sec velocity

.127 inch thick graphite epoxy target (JSC-03A-003) with cloth covering on both sides.

Photo was taken of spall an estimated 20 to 50 microseconds after impact.

A couple of threads are visible in the photo. As calculated above, 1 thread = .1905 cm.

The fastest particles are roughly 15 threads out. 15 x .1905 = 2.86 cm.

		Velocity	Ka/sec	
		Aver age Area	an squared	
	urs	Average Diameter	:	
	Calculated Val	Cone Angle (Angle from)surface normal	Degrees	
		a Phi location of impact (origin at ee	begrees	
		Theta location of impact (origin at ee)	Degrees	
2/10/86 Fiate)		R location of impact (origin at #9	1	49.08 Z Dust
ISC Shat No. 933 [Thin 6061-T6 Aluminum	1	1955	suð	0.0147 0.04193 0.0589
•		Length of Particle	I	ust ist
	£	Fenetration Depth	1	Calc. Ejecta D Calc. Spall Du Total Calc. Du
	Neasured Value	I location of impact forigin at f)	2	
		Y location of ispact (origin at +)	1	in velocity 55
		X location of impact forigin at 4)	1	h (est.) used M Pascals
		Particle No.		Shear Strengt calculation,

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2.86 cm / 20 microseconds = .0286 m/.000020 sec. = 1.43 km/sec

2.86 cm / 50 microseconds = .0286 m/.000050 sec. = .57 km/sec

The one high speed camera shot (#990) for a .111 inch thick, cloth covered graphite/epoxy sample (JSC-02A-003), at a 30 deg. angle, indicated a maximum spall velocity of .75 km/sec.

Shot #894

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See section 3.2.2 for more discussion of this shot.

4.94 mg nylon projectile, 4.75 km/sec velocity.

Target - .093 inch thick graphite/epoxy with no cloth covering (JSC-02B-003).

Photo shows ejecta (on the right) and spall (on the left) approx. 30 to 35 microseconds after impact.

No good scaling parameter is available in this shot. The thickness of the sample could be used, but appears to be uncertain due to angle and depth by a factor of 1.5 to 2. The extent of the ejecta and spall clouds are also off the photo, adding to the uncertainty in calculating fastest particle velocity. Nevertheless, using the same scale as the other two photos, the ejecta cloud is estimated to extend 16 threads or 16 x .1905 = 3.05 cm.

3.05 cm / 32 microseconds = .0305 m / .000032 sec. = .953 km/sec

This velocity does not agree well with high speed camera numbers of 2 to 5 km/sec, but the uncertainty in this measurement is high.

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