NASA TECHNICAL MEMORANDUM

NASA TM X-64597

HYPERVELOCITY IMPACT TESTS ON A PROPOSED LUNAR TUG FUEL TANK CONFIGURATION

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Marshall Space Flight Center, Alabama

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16. ABSTRACT

The testing of a proposed configuration for lunar tug fuel tanks impacted by an aluminum projectile is discussed. The subsequent damage incurred is discribed and evaluated. Also schematic diagrams and actual photographs of the impact damage are included.

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TECHNICAL MEMORANDUM X-64597

HYPERVELOCITY IMPACT TESTS ON A PROPOSED LUNAR TUG FUEL TANK CONFIGURATION

SUMMARY

It was found that an aluminum projectile, with a mass of 4.5 mg and a velocity of 6 km/sec, did not represent a high potential hazard to the configuration employed.

No survival ratio or area-time calculations were available to determine what class (most likely, remote) of meteoroid this might represent. However, the debris particles were in the solid state which represents the highest potential hazard as far as structural damage to a pressure vessel is concerned.

INTRODUCTION

This test series was performed to evaluate the possible damage posed by the meteoroid environment to a proposed lunar tug fuel configuration.

Definition of the actual meteoroid environment is still under investigation. The best information available was published as NASA-SP-8013, entitled, "Meteoroid Environmental Model - 1969 (Near Earth to Lunar Surface)." This document states that the average velocity of meteoroids is 20 km/sec. The present state of the art for accelerating laboratory meteoroids is below this velocity. Therefore, the results or conclusions of laboratory experiments must be extrapolated in one way or another.

This report presents the laboratory results and information, and allows the reader to extrapolate in the manner he feels most confident, since no survival ratio or area-time figures were given.

EXPERIMENTS PERFORMED

The target configuration is shown in Figure 1. The nylon stringer was under a tension of 22.65 kg. An aluminum projectile with a mass of 4.5 mg and a velocity of 6 km/sec was the impacting particle. The damage of the debris cloud formed from the impact of this projectile and the following were evaluated:

1. The bumper sheet only (with and without thermal blanket).

2. One brace and the bumper (no thermal blanket).

3. One brace, bumper, and second brace (no thermal blanket).

4. Brace only.

The three components examined were the nylon stringer, thermal blanket, and the backup sheet.

The location of each impact on the front configuration is shown in Figure 2. After each shot, the backup sheet and nylon stringer were examined.

Impact of Bumper Only (Without Thermal Blanket)

The damage to the front configuration on the impact of the bumper only, with no thermal blanket, is shown in Figure 3. The damage to the backup sheet is shown in Figure 4. There was no observable damage to the nylon stringer.

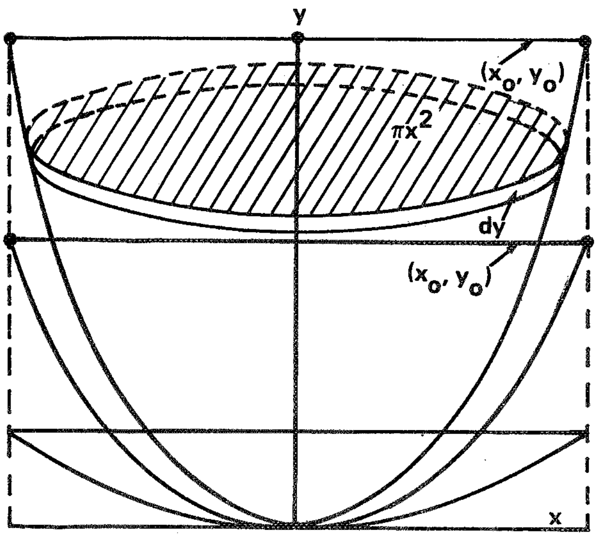
To impact the bumper only, the projectile was constrained to impact no closed than 3.81 cm from the center of the nylon stringer. The actual impact was 5.715 cm from the center of the stringer to ensure no interaction with the braces. The diameter of the hole in the bumper was 0.335 cm while the cylindrical projectile was 0.159 cm in diameter.

The number of craters formed by debris particles resulting from this impact are listed in Table 1 as a function of the distance from the intersection of the backup sheet and primary line of flight. The distinction between significant debris craters and all craters was based on visual observation of the damage sustained by the backup. A deep, hemispherical crater was considered a significant crater, while a shallow or uneven crater would not be considered significant since the debris particle forming such a crater would not be a dangerous hypervelocity debris particle.

The 20 deepest craters were measured. It was assumed that the energy (E) of the incoming debris particle is proportional to the volume (V_c) of the crater formed:

$$E \propto V_c \;.$$

Therefore, the volume of these 20 craters was calculated assuming all measured craters were parabolic in shape;



$$y = cx^2, \qquad x^2 = \frac{y}{c} \quad \text{and} \quad c = \frac{y_o}{x_o^2}$$

$$V_c = \int_0^{y_o} \pi x^2\, dy = \frac{\pi}{c} \int_0^{y_o} y\, dy = \frac{\pi y_o^2}{2c}$$

$$= \frac{\pi x_o^2\, y_o}{2}$$

where x_o is the diameter and y_o is the depth. The results are listed in Table 2.

Impact of Bumper Only (With Thermal Blanket)

The thermal blanket consisted of two pieces of quilted aluminum foil, one at the front and one at the rear, with 30 sheets of aluminized mylar between them. On the back side of each mylar sheet were small pieces of cotton, alternately spaced 1.27 cm apart, to keep each sheet separated from the others.

The hole in the front configuration on this impact is shown in Figure 5. This impact was 4.76 cm from the center of the nylon stringer and 0.335 cm in diameter.

The thermal blanket was resting against the backup sheet. This placement allows the debris particles to spread out a maximum distance from one another for maximum interaction of the individual particle with each sheet of blanket. The damage sustained by the first sheet of the blanket is shown in Figure 6. The 15th sheet of the blanket is shown in Figure 7, and the quilted aluminum sheet at the rear of the blanket is shown in Figure 8. The damage sustained by the backup sheet is shown in Figure 9.

There are several items of interest in these figures. Figure 7 shows that the bulk of the small debris particles is stopped before they reach the 15th sheet of the blanket. It also shows that the diameters of the more energetic, large particles are larger at this point than they were on the first sheet. Especially note that where there were at least three large particles on the first sheet, evidenced by separate distinct holes, there now appears one large hole (Fig. 10). In Figure 10a, the particles are traveling as separate particles. As they come in contact with the first sheet, the interaction results in a piece of the sheet wrapped around the particle, thereby increasing its diameter by the thickness of the sheet (T). Each additional sheet penetrated contributes in a like fashion until the two particles have increased in diameter until they are in contact (Fig. 10b). At this point, one large hole will be created in the next sheets instead of two as shown in Figure 10c.

To support this explanation we will again refer to Figures 8 and 9. The quilted aluminum sheet shows evidence of only three large holes, while the backup sheet shows eight individual craters under these three holes. It is, therefore, assumed that the above explanation is correct. Again there was no observable damage to the nylon stringer.

One Brace and Bumper (Without Thermal Blanket)

The impact of the projectile on the front configuration and the damage to the backup sheet are shown in Figures 11 and 12.

It is obvious that there was no damage to the backup or stringer that warrants investigation.

One Brace, Bumper, and Second Brace (Without Thermal Blanket)

The impact of the projectile on the front configuration and the damage to the backup sheet are shown in Figures 13 and 14.

Again, it is obvious that there was no damage of interest.

Brace Only

To this point, no damage to the stringer had been observed, either because of the low probability that a piece of debris would encounter it under the impact conditions or that it had been impacted by some debris and not damaged. It was therefore decided that we would impact as close to the stringer as possible, creating the highest possible threat to the stringer.

The impact on the brace is shown in Figure 15. This impact was on the crest of the brace and therefore allowed the primary debris to spread and interact with the stringer to the maximum before being further broken up by the second encounter with the bumper. The distribution and damage of the primary debris to the bumper is shown in Figure 16. The second brace immediately behind the bumper prevented any debris from going further. The impact of primary debris on the bumper also created front ejects, which could interact with the stringer during its flight in an opposite direction to the first debris particles.

A magnified view of the stringer is shown in Figure 17. It can be seen that although a small amount of damage was sustained, it did not cause the stringer to sever under the tension of 22.65 kg.

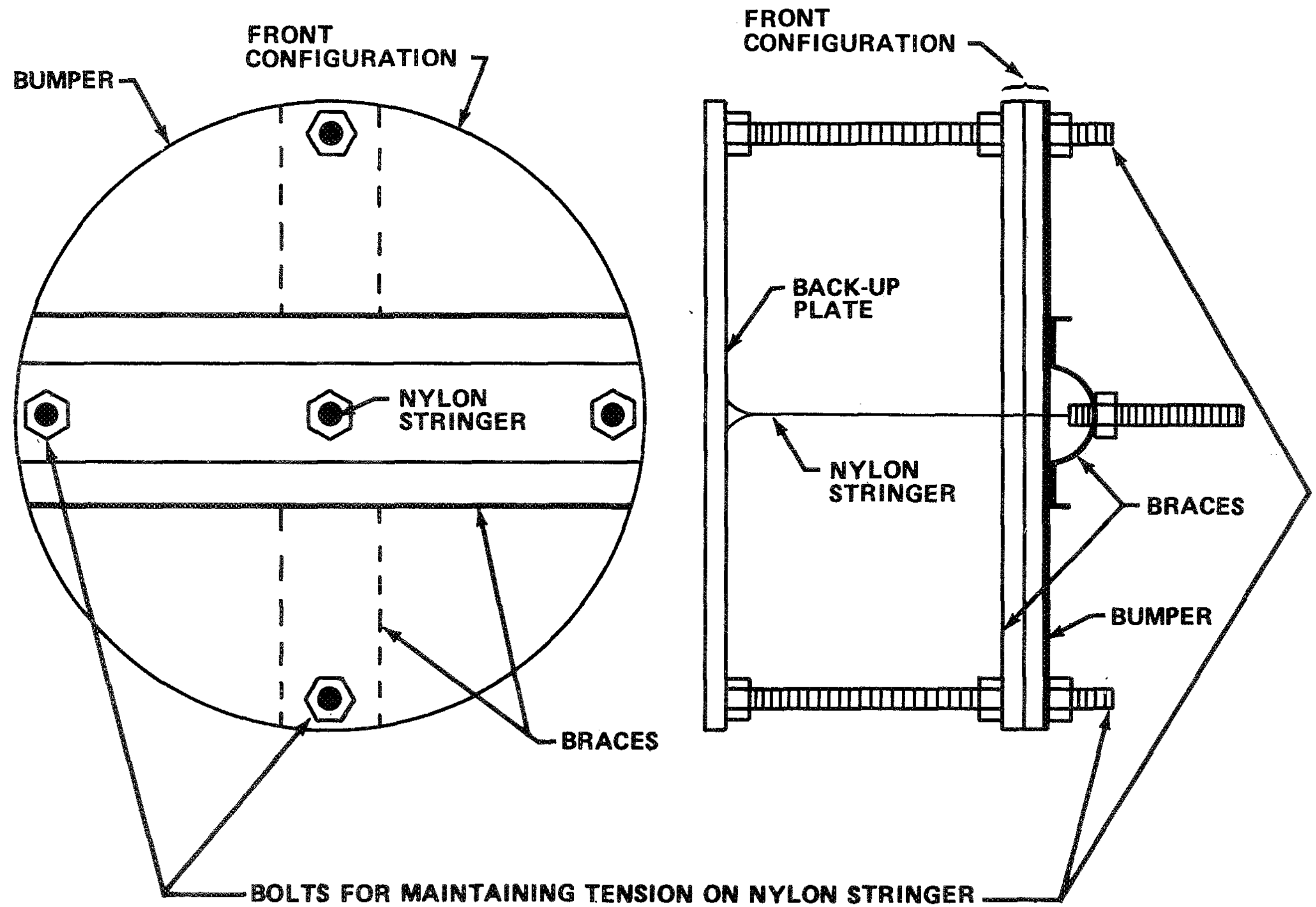
CONCLUSIONS

In using the results of these tests to conclude any information about the vulnerability of this configuration in the meteoroid environment, the following should be remembered:

1. The actual meteoroid environment is noticeably different from the parameters of simulated laboratory meteoroids.

2. This test series represents the effects of solid-state debris particles. Gaseous or liquid state debris may interact differently with the nylon stringer, although the solid debris probably represent the most lethal hazard.

3. This projectile-velocity combination does not necessarily extrapolate to represent the most hazardous meteoroid expected to be encountered, since no survival ratio or area-time exposure to the environment was calculated.



BUMPER: .0005 m (.020 in.) ALUMINUM 6061-T6
BRACES: .0011 m (.045 in.) ALUMINUM
BACK-UP SHEET: .0016 m (.063 in.) ALUMINUM 6061-T6
NYLON STRINGER: 22.56 kg TENSION
SPACING: 8.99 cm BETWEEN BUMPER AND BACK-UP SHEETS

Figure 1. Target configuration.

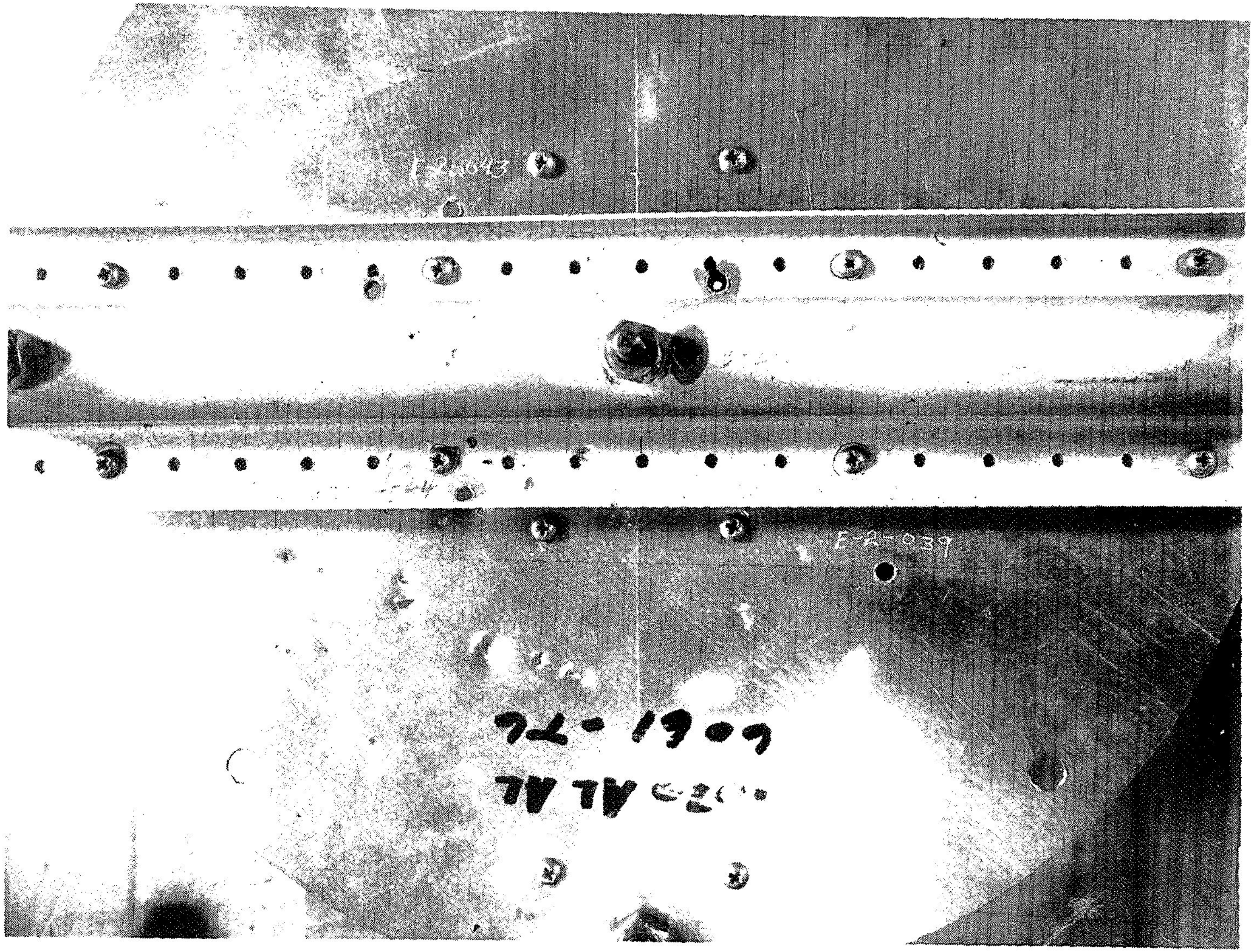


Figure 2. Location of each shot on the front configuration.

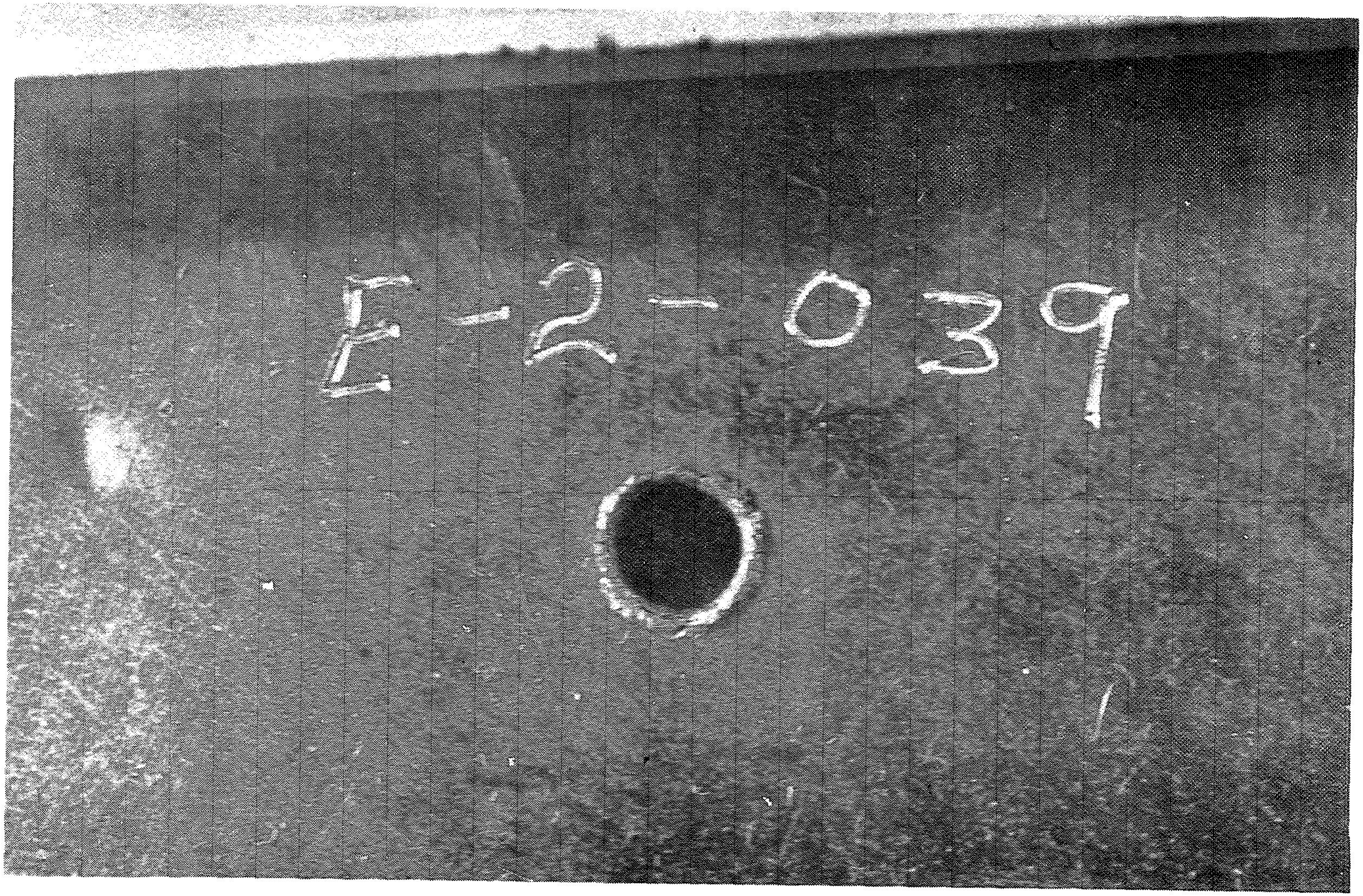


Figure 3. Damage of projectile impact on bumper only, without thermal blanket.

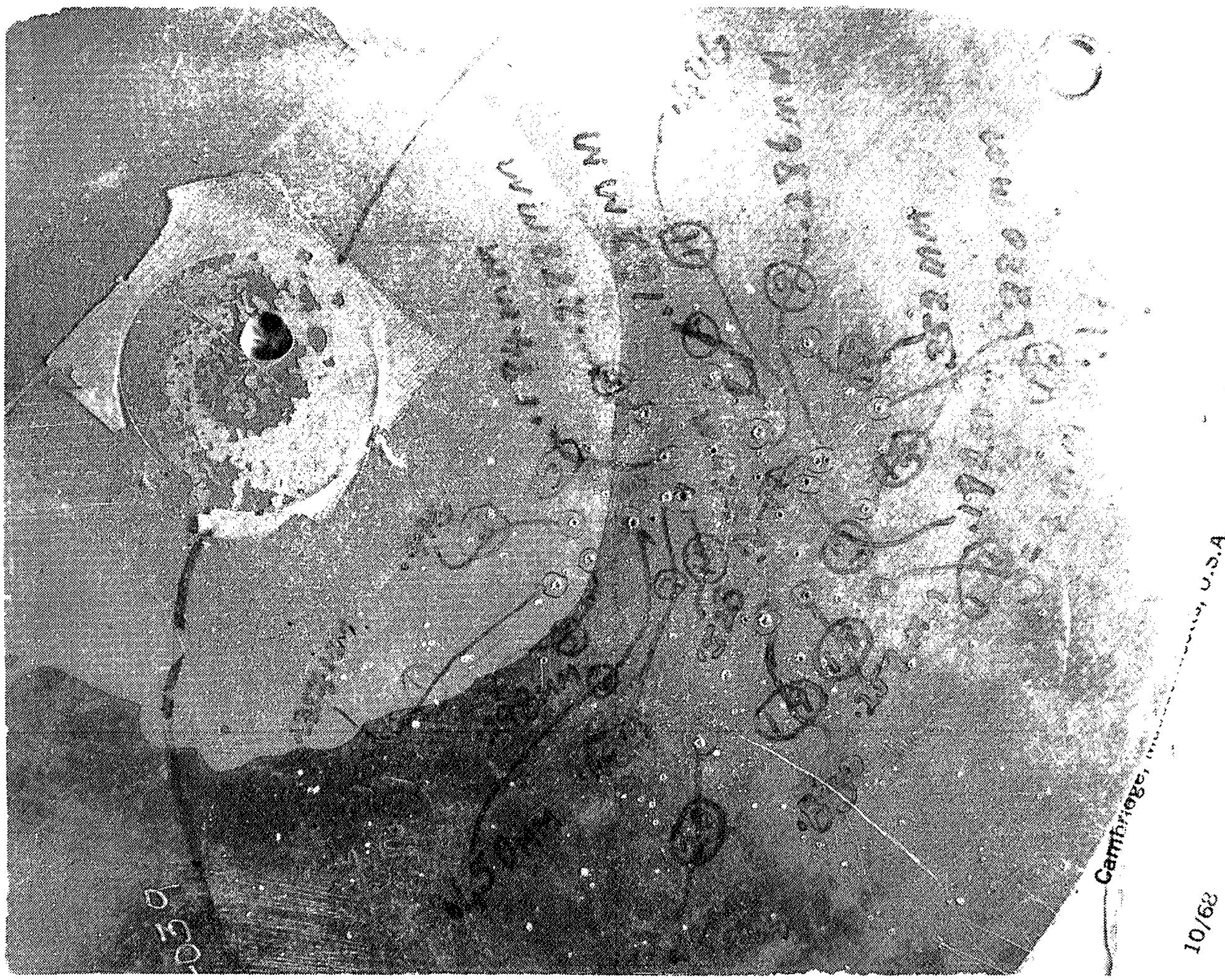


Figure 4. Damage incurred on backup sheet for bumper only, no thermal blanket.

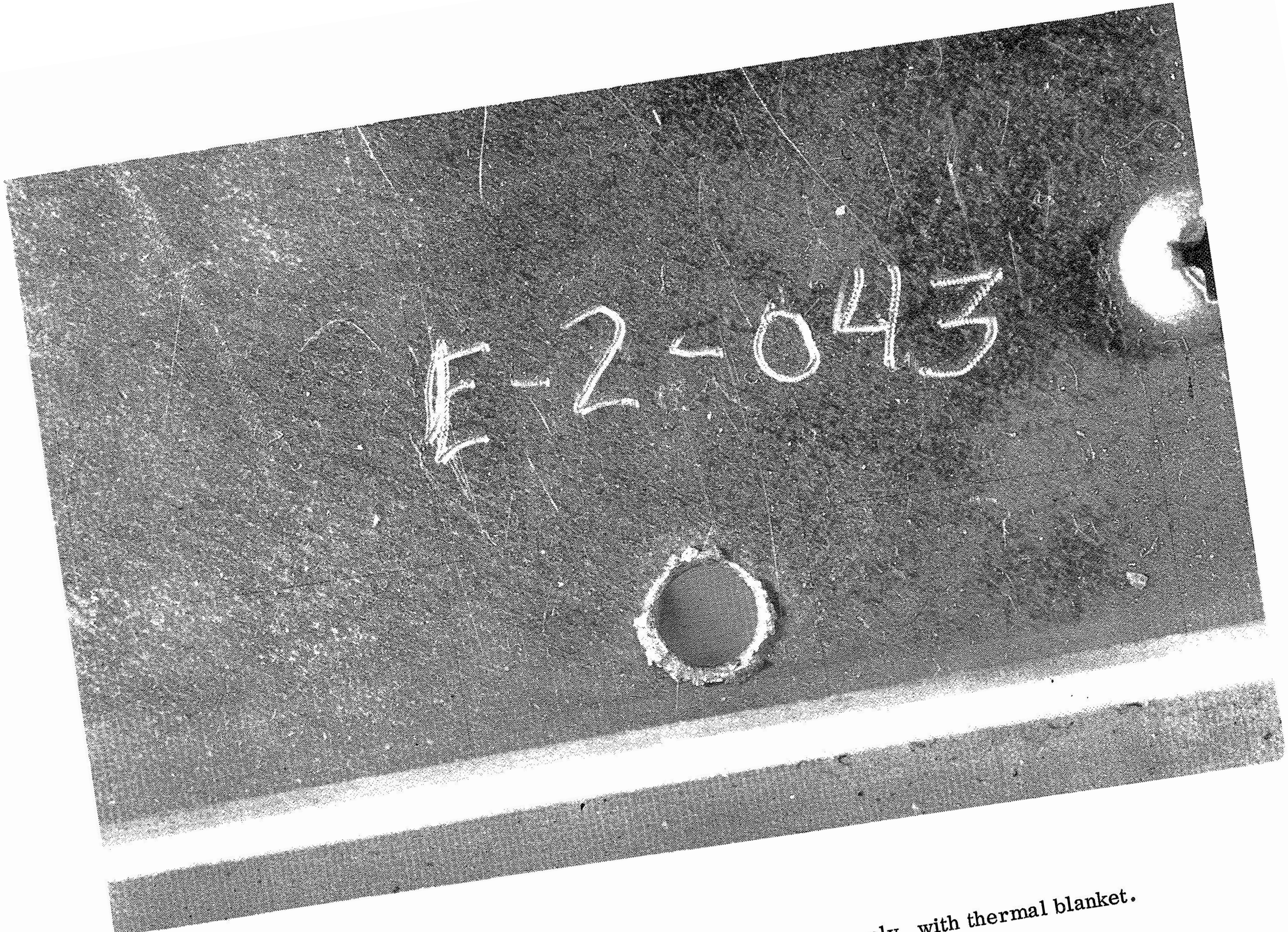


Figure 5. Damage of projectile impact on bumper only, with thermal blanket.

Figure 6. Damage to first aluminized mylar sheet in thermal blanket.

Figure 7. Damage to 15th aluminized mylar sheet in thermal blanket.

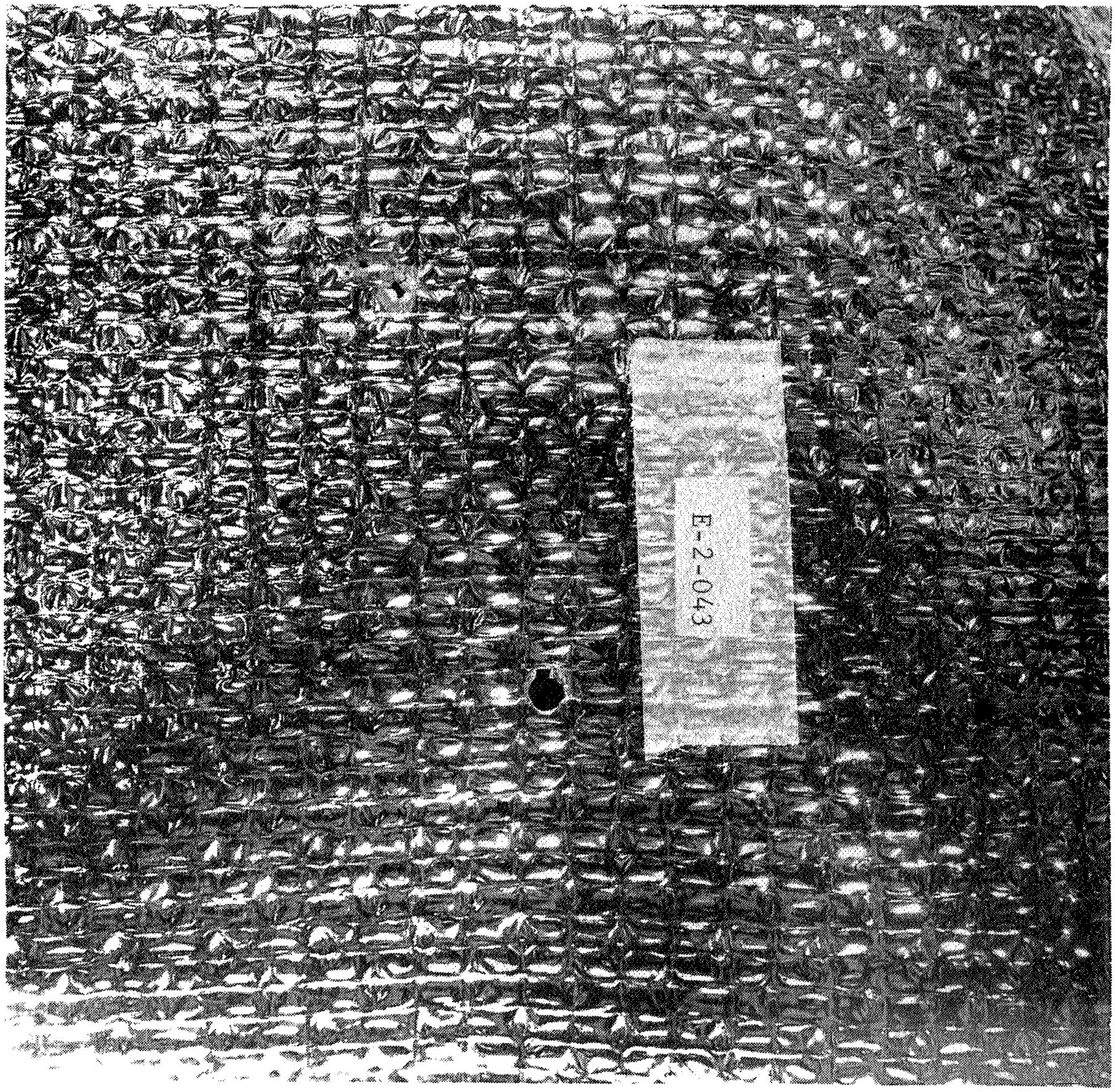


Figure 8. Damage to quilted aluminum rear sheet of thermal blanket.

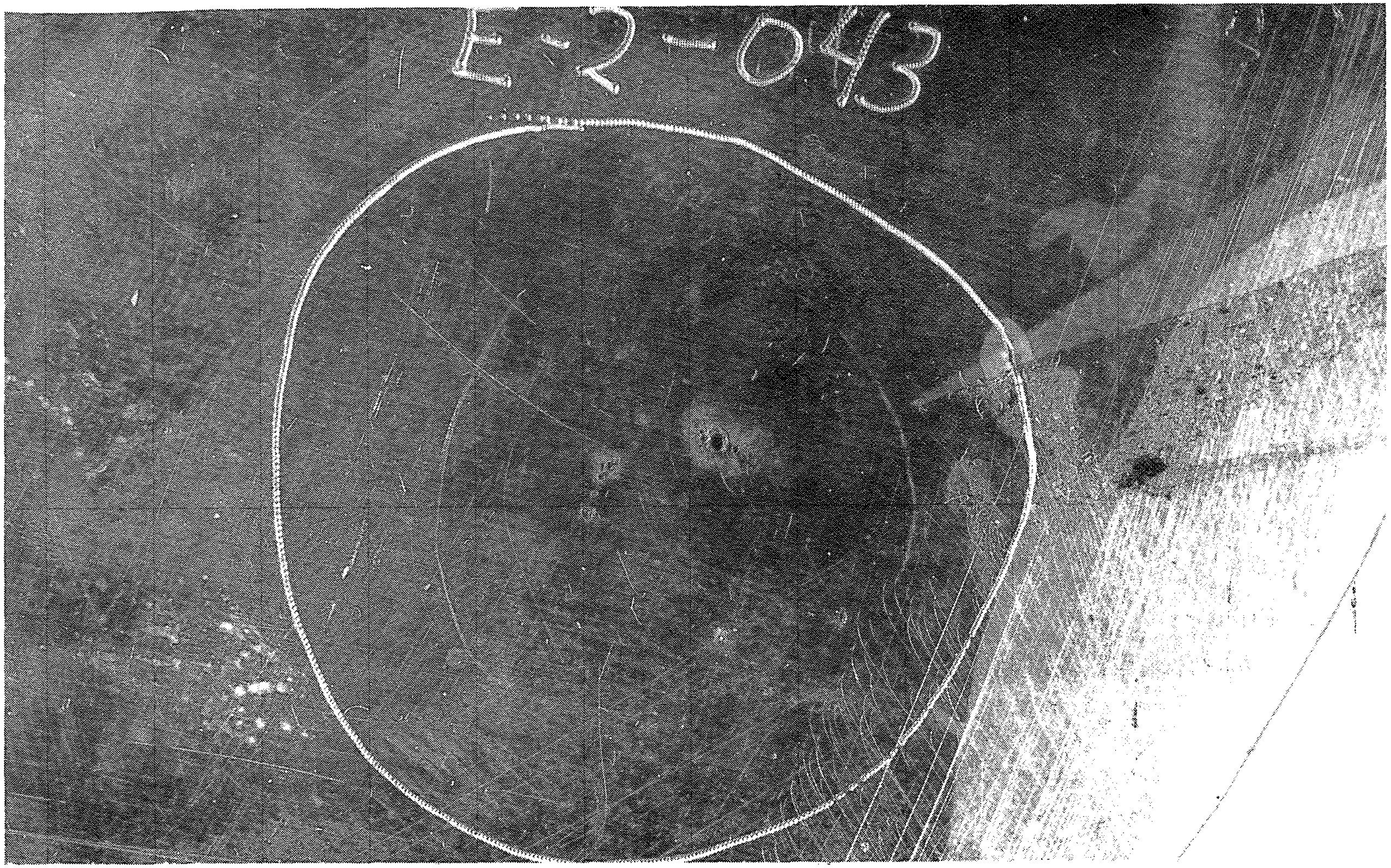


Figure 9. Damage incurred on backup sheet for bumper only after interaction with thermal blanket.

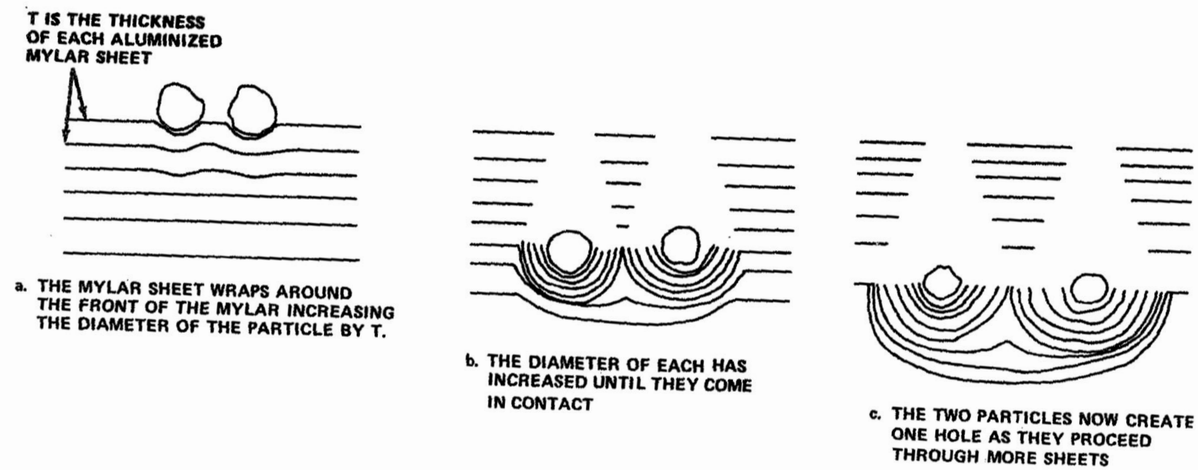


Figure 10. Explanation of thermal blanket interaction with debris particles as evidenced by examination of blanket.

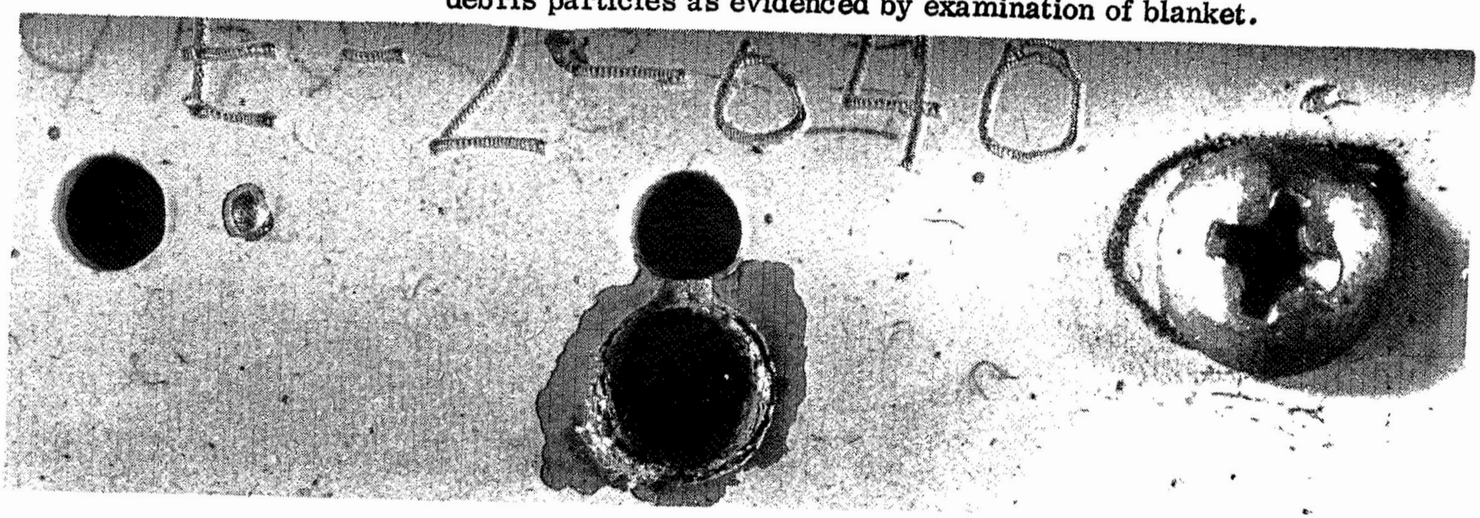


Figure 11. Damage of projectile impact on brace and bumper, without thermal blanket.

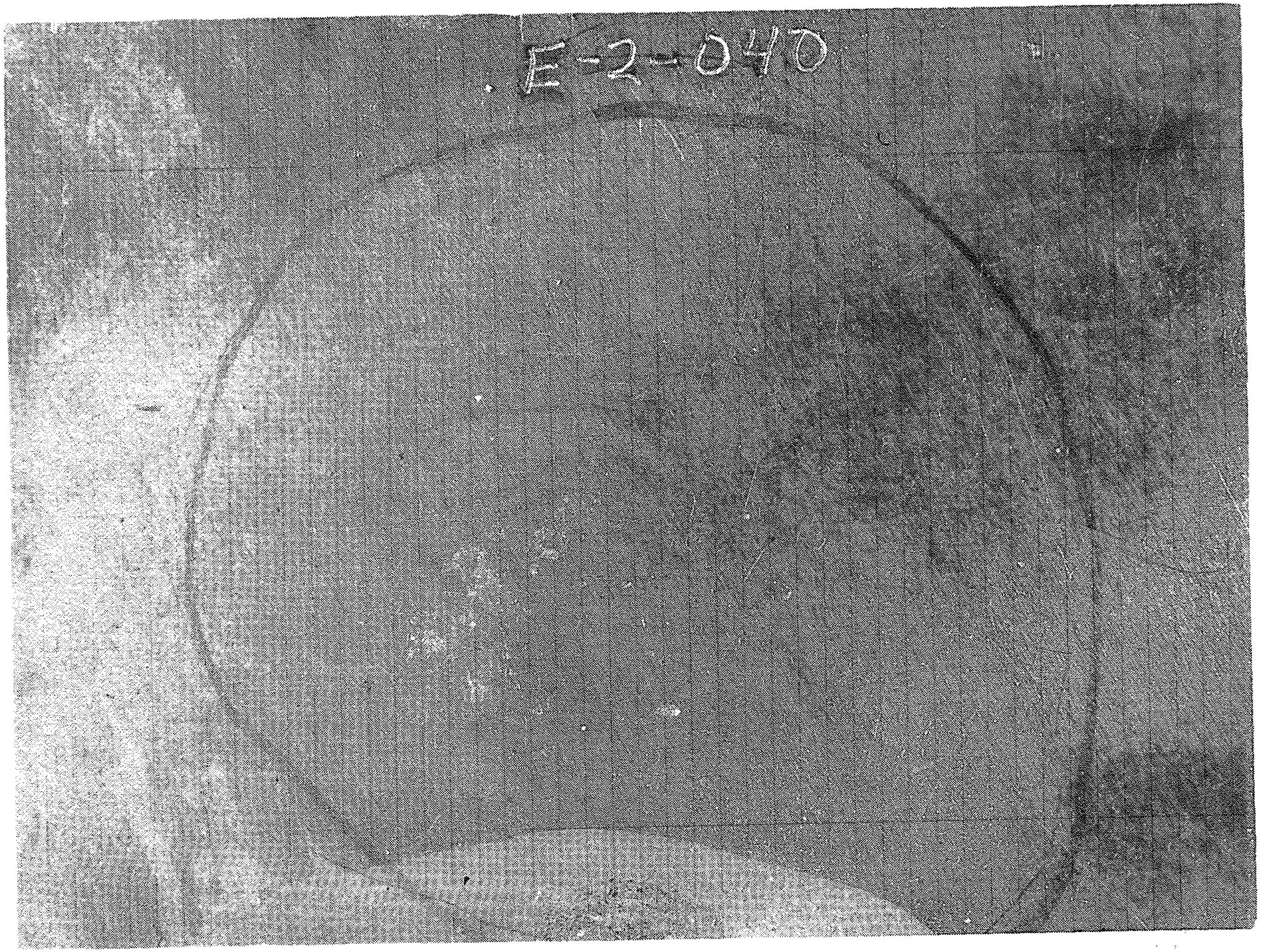


Figure 12. Damage incurred on backup for one brace and bumper impact, without thermal blanket.

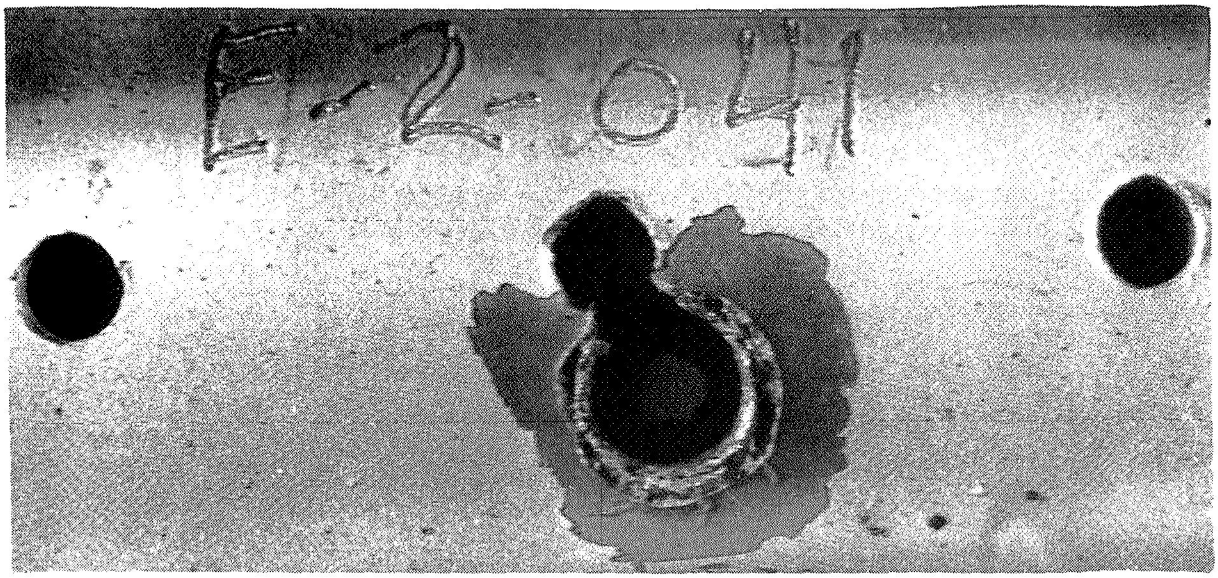


Figure 13. Damage of projectile impact on one brace, bumper, and second brace without thermal blanket.

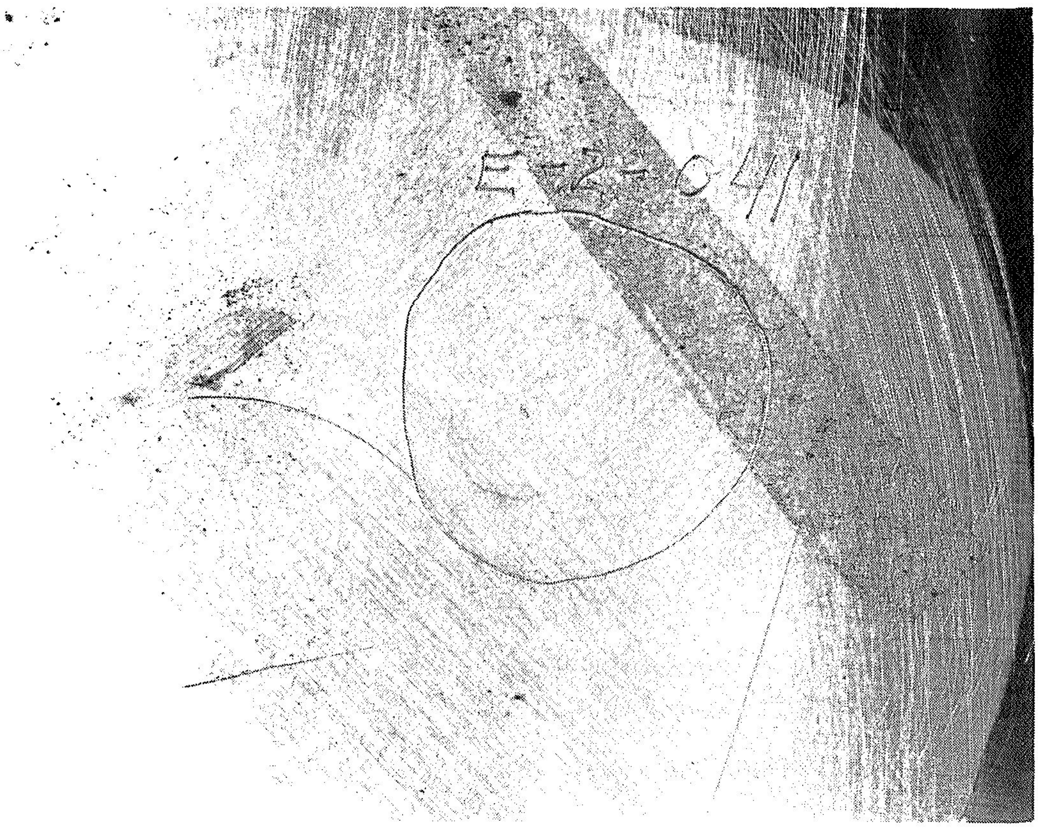


Figure 14. Damage incurred on backup for one brace, bumper, and second brace impact, without thermal blanket.

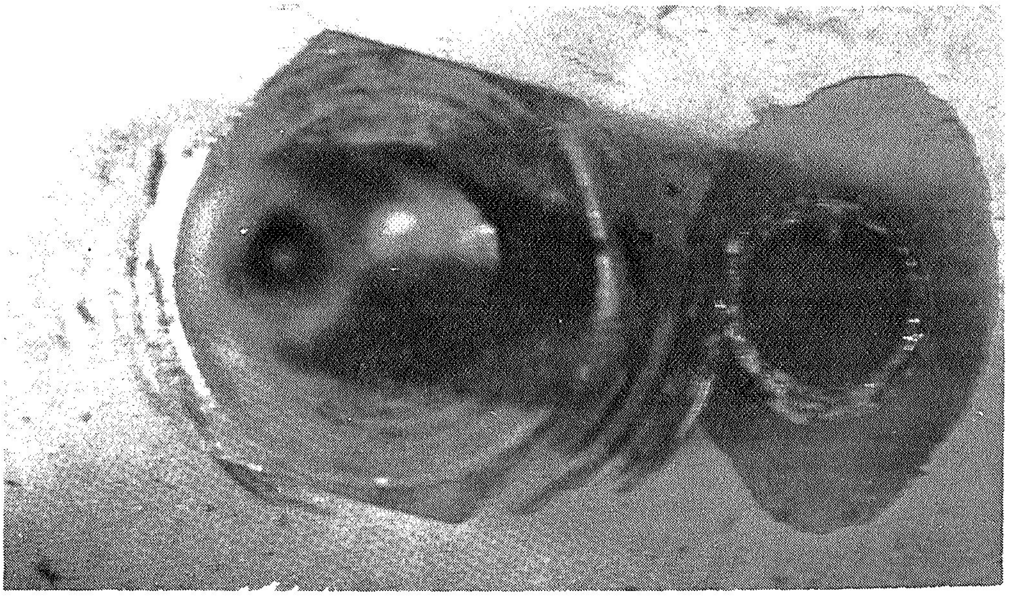


Figure 15. Damage of projectile impact on brace only.

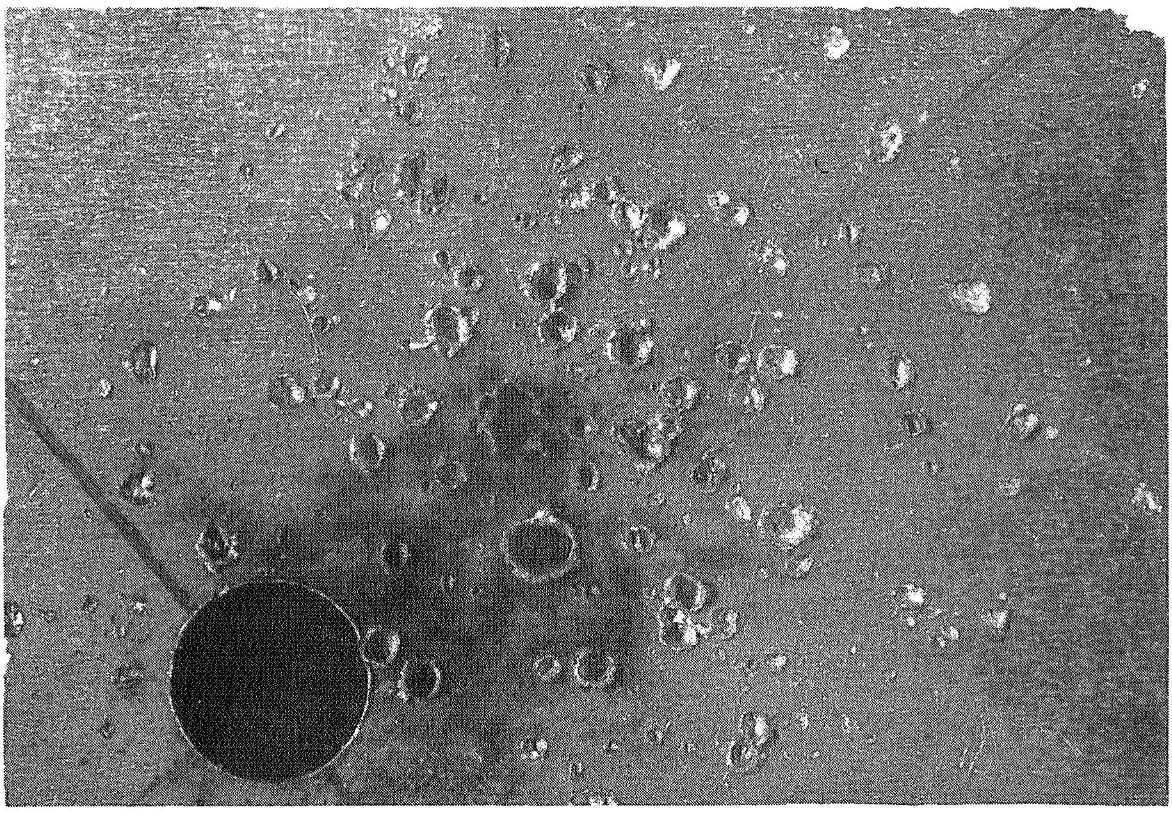


Figure 16. Distribution and damage of primary debris to the bumper for impact on brace only.

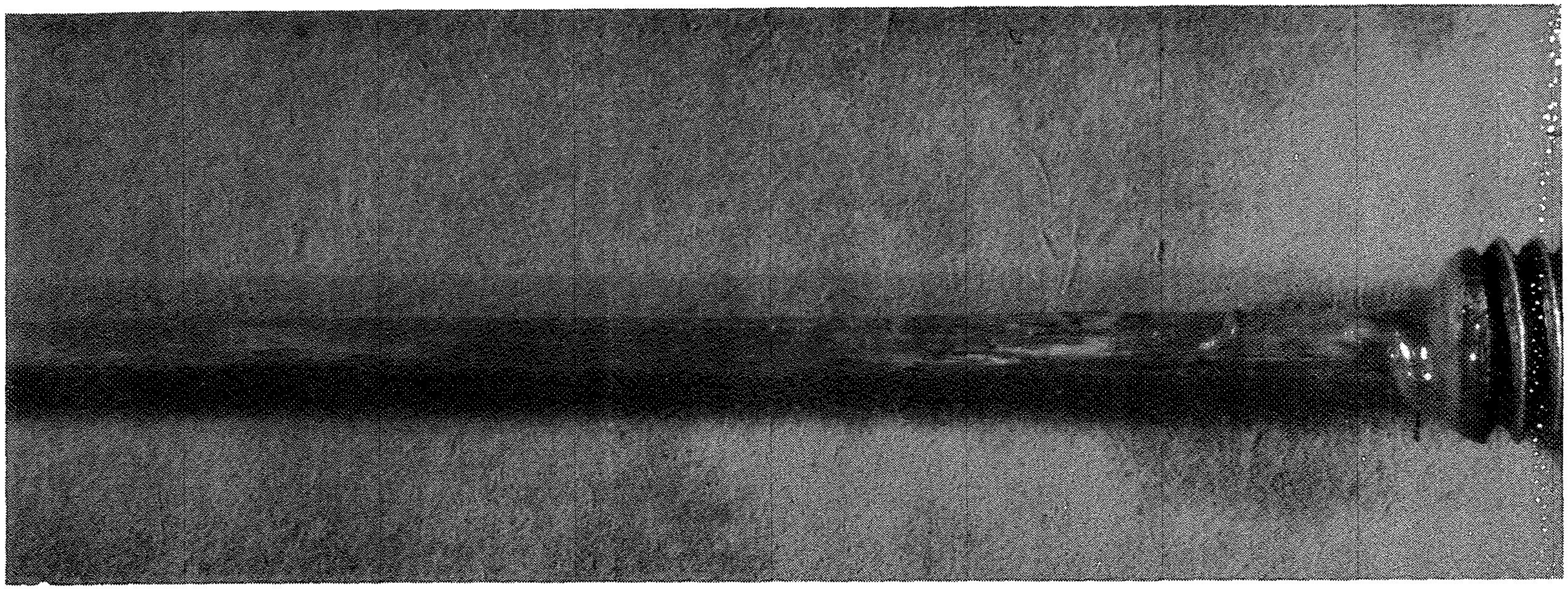


Figure 17. Magnified view of stringer on the impact of brace only.

TABLE 1. BACKUP SHEET EXAMINATION OF DISTRIBUTION OF CRATERS FOR IMPACTS ON BUMPER ONLY WITH AND WITHOUT THE THERMAL BLANKET

														Total
	Diameter (cm) of circle that encompasses craters, centered at intersection of backup sheet and projectile line of flight	1.27	1.91	2.54	3.18	3.81	4.45	5.08	5.72	6.35	6.99	7.62	8.26	8.89	17.78
	Maximum angle of trajectory (deg) for particles creating craters within circles mentioned above.	4	6	8	10	12	14	16	18	20	21	23	25	27	45
Without Thermal Blanket	Significant craters (accumu-lative)	2	7	19	27	38	46	56	65	73	84	93	100	110	165
	All craters (accumulative)	4	12	28	37	52	64	79	92	111	134	154	172	193	346
	Percent of all significant craters (accumulative)	50	58	68	73	73	72	71	71	66	63	60	58	57	48
	New significant craters not counted in a previous circle	2	5	12	8	11	8	10	9	8	11	9	7	10	55
	All new craters not counted in a previous circle	4	8	16	9	15	12	15	13	19	23	20	18	21	153
	Percent of all new significant craters that have not been counted in a previous circle	50	63	75	89	73	67	67	69	42	48	45	39	48	36
With Thermal Blanket	Significant craters (accumu-lative)	0	0	0	0	3	3	3	3	3	3	3	3	3	3
	All craters (accumulative)	0	1	1	1	9	10	10	10	10	10	10	10	10	10
	Percent of all significant craters (accumulative)	0	0	0	0	33	30	30	30	30	30	30	30	30	30
	New significant craters not counted in a previous circle	0	0	0	0	3	0	0	0	0	0	0	0	0	0
	All new craters not counted in a previous circle	0	1	0	0	8	1	0	0	0	0	0	0	0	0
	Percent of all new significant craters that have not been counted in a previous circle	0	0	0	0	38	0	0	0	0	0	0	0	0	0

TABLE 2. CRATER MEASUREMENTS FOR IMPACTS ON BUMPER ONLY WITH AND WITHOUT THE THERMAL BLANKET.

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Diameter (cm) of Circle that Encompasses Crater as in Table 1	Without Thermal Blanket					With Thermal Blanket				
		Crater					Crater			
	Ref. No.	Diameter (cm)	x_o Radius (cm)	y_o Depth (cm)	Volume $\frac{\pi x_o^2 y_o}{2}$ (cm^3)	Ref. No.	Diameter (cm)	x_o Radius (cm)	y_o Depth (cm)	Volume $\frac{\pi x_o^2 y_o}{2}$ (cm^3)
1.27	10	0.131	0.066	0.053	3.63×10^{-4}					
1.91	7	0.082	0.041	0.040	1.06×10^{-4}					
2.54	3 6 19	0.082 0.077 0.208	0.041 0.039 0.104	0.018 0.045 0.083	0.48×10^{-4} 1.08×10^{-4} 14.10×10^{-4}					
3.18	5 11 13 18	0.109 0.130 0.086 0.073	0.055 0.065 0.043 0.037	0.030 0.041 0.019 0.026	1.43×10^{-4} 2.72×10^{-4} 0.55×10^{-4} 0.56×10^{-4}	1 2 3	0.108 0.131 0.124	0.054 0.066 0.062	0.054 0.029 0.003	2.47×10^{-4} 1.98×10^{-4} 0.18×10^{-4}
3.81	2 4 9 12	0.084 0.098 0.084 0.100	0.042 0.049 0.042 0.050	0.042 0.029 0.029 0.029	1.16×10^{-4} 1.09×10^{-4} 0.80×10^{-4} 1.14×10^{-4}					
4.45	1 8 14	0.100 0.103 0.085	0.050 0.052 0.043	0.025 0.016 0.028	0.98×10^{-4} 0.68×10^{-4} 0.81×10^{-4}					
5.08	17 20	0.071 0.096	0.036 0.048	0.039 0.073	0.79×10^{-4} 2.64×10^{-4}					
5.72	15 16	0.083 0.088	0.042 0.044	0.035 0.020	0.97×10^{-4} 0.61×10^{-4}					

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APPROVAL

HYPERVELOCITY IMPACT TESTS ON A PROPOSED LUNAR TUB FUEL

By David William Jex

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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