HYPERVELOCITY IMPACT EVALUATION OF METAL FOAM CORE SANDWICH STRUCTURES

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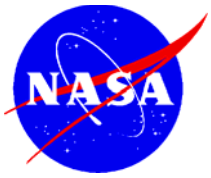

National Aeronautics and
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Houston, TX

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NASA Johnson Space Center (NASA JSC)

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Prepared for the JSC Center Director Discretionary Fund (CDDF) Research Project

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TITLE

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1. INTRODUCTION

A series of hypervelocity impact (HVI) tests were conducted by the NASA Johnson Space Center (JSC) Hypervelocity Impact Technology Facility (HITF) [1], building 267 (Houston, Texas) between January 2003 and December 2005 to test the HVI performance of metal foams, as compared to the metal honeycomb panels currently in service. The HITF testing was conducted at the NASA JSC White Sands Testing Facility (WSTF) at Las Cruces, New Mexico. Eric L. Christiansen, Ph.D., and NASA Lead for Micro-Meteoroid Orbital Debris (MMOD) Protection requested these hypervelocity impact tests as part of shielding research conducted for the JSC Center Director Discretionary Fund (CDDF) project.

The structure tested is a metal foam sandwich structure; a metal foam core between two metal facesheets. Aluminum and Titanium metals were tested for foam sandwich and honeycomb sandwich structures.

Aluminum honeycomb core material is currently used in Orbiter Vehicle (OV) radiator panels and in other places in space structures. It has many desirable characteristics and performs well by many measures, especially when normalized by density.

Aluminum honeycomb does not perform well in Hypervelocity Impact (HVI) Testing. This is a concern, as honeycomb panels are often exposed to space environments, and take on the role of Micrometeoroid / Orbital Debris (MMOD) shielding. Therefore, information on possible replacement core materials which perform adequately in all necessary functions of the material would be useful.

In this report, HVI data is gathered for these two core materials in certain configurations and compared to gain understanding of the metal foam HVI performance.

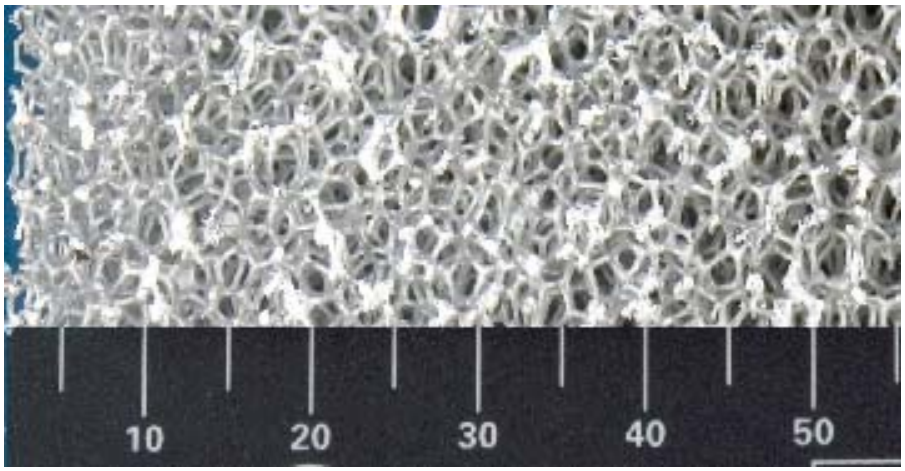

Figure 1-1
Example of metal foam core material with mm scale

2. TEST OBJECTIVES

The focus of this testing series is the HVI performance of the metal foam sandwich structure. HVI testing is performed on samples of honeycomb and foamed metal samples to make a comparison between them. The comparison will be between the performances of each configuration to determine which of them performs the best when impacted at hypervelocity.

The objective is to determine the performance of the considered configurations and compare them. This information is intended to aid in the comparison of foam and honeycomb, which are possible core materials in OV radiator panels.

Data will also be gathered to aid in the creation and verification of ballistic limit equations. This will be done by varying one shot parameter to determine when failure is expected to occur. Projectile diameter will be increased until failure occurs while all other shot parameters are kept constant, or impact velocity will be increased while all other shot parameters are kept constant.

3. GLOSSARY OF TERMS

The following terms appear throughout the test report. Test articles will receive a more full explanation in 4. DESCRIPTION OF TEST ARTICLE CONFIGURATIONS.

0.5” Al HC - A test article with the following parameters: 0.5” thick sandwich structure, aluminum facesheets, aluminum honeycomb core

0.5” Al F10 - A test article with the following parameters: 0.5” thick sandwich structure, aluminum facesheets, aluminum foam core, the foam core has a pore size such that there are 10 pores along a linear inch of foam

0.5” Al F40 - A test article with the following parameters: 0.5” thick sandwich structure, aluminum facesheets, aluminum foam core, the foam core has a pore size such that there are 40 pores along a linear inch of foam

0.5” Ti HC - A test article with the following parameters: 0.5” thick sandwich structure, titanium facesheets, titanium honeycomb core

0.5” Ti F60-1 - A test article with the following parameters: 0.5” thick sandwich structure, titanium facesheets, titanium foam core, the foam core has a pore size such that there are 60 pores along a linear inch of foam

0.5” Ti F60-2 - A test article with the following parameters: 0.5” thick sandwich structure, titanium facesheets, titanium foam core, the foam core has a pore size such that there are 60 pores along a linear inch of foam

2” Al HC - A test article with the following parameters: 2” thick sandwich structure, aluminum facesheets, aluminum honeycomb core

2” Al F10 - A test article with the following parameters: 2” thick sandwich structure, aluminum facesheets, aluminum foam core, the foam core has a pore size such that there are 10 pores along a linear inch of foam

2” Al F40 - A test article with the following parameters: 2” thick sandwich structure, aluminum facesheets, aluminum foam core, the foam core has a pore size such that there are 40 pores along a linear inch of foam

Metal foam – a metal processed such that it retains an open porosity with a designated pore size; see Figure 1-1

Nominal density – in the foam core, it is the percentage of the volume of the core that is occupied by metal

Sandwich structure – a three-layer construction configuration in which a core material is bonded to a facesheet on opposite sides

4. DESCRIPTION OF TEST ARTICLE CONFIGURATIONS

The Test Articles in this series are of 8 major configurations: 0.5” Al F10, 0.5” Al F40, 2” Al F10, 2” Al F40, 0.5” Al HC, 2” Al HC, 0.5” Ti F60, 0.5” Ti HC.

4.1 0.5” Al F10

The 0.5” Al F10 is a 0.5” thick aluminum 6101-T6 foam core with 0.010” thick aluminum 6061-T6 facesheets. F10 indicates that the metal foam pore size is such that there are (10) pores per inch. This article has multiple shots on a 12” x 12” panel, with a witness plate at a 2” standoff behind the back of the panel. Facesheets are bonded to the core with adhesive. The nominal density of the foam core ranges from 6% to 8%.

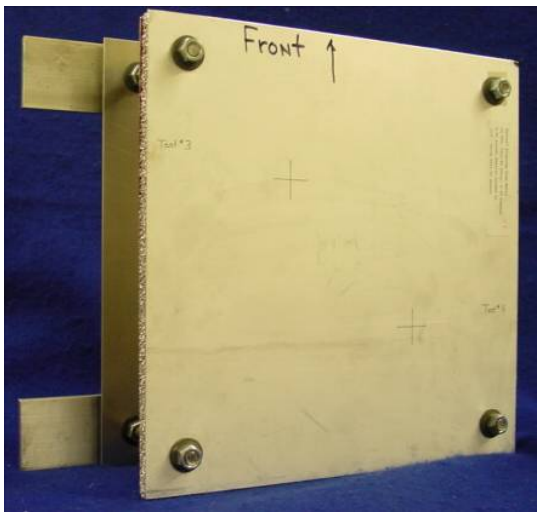

Figure 4.1-1
HITF03147 Pretest Photo,
Example 0.5” Al F10 Target Article

4.2 0.5” Al F40

The 0.5” Al F40 is a 0.5” thick aluminum 6101-T6 foam core with 0.010” thick aluminum 6061-T6 facesheets. F40 indicates that the metal foam pore size is such that there are (40) pores per inch. This article has multiple shots on a 12” x 12” panel, with a witness plate at a 2” standoff behind the back of the panel. Facesheets are bonded to the core with adhesive. The nominal density of the foam core ranges from 6% to 8%.

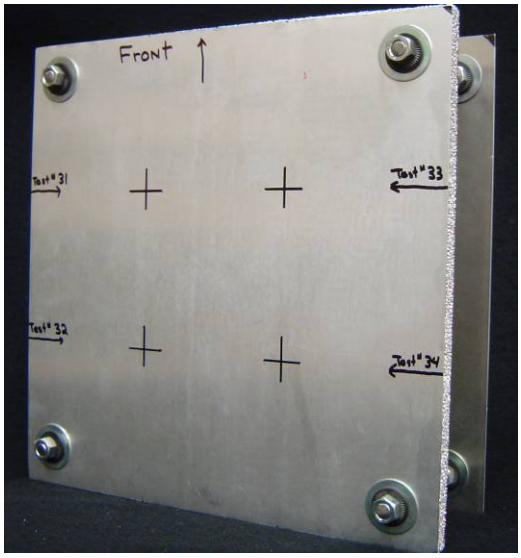

Figure 4.2-1
HITF05037 Pretest Photo,
Example 0.5” Al F40 Target Article

4.3 2” Al F10

The 2” Al F10 is a 2” thick aluminum 6101-T6 foam core with 0.010” thick aluminum 6061-T6 facesheets. F10 indicates that the metal foam pore size is such that there are (10) pores per inch. This article has a single shot on a 6” x 6” panel, mounted to a frame plate or directly held by bolts, with a witness plate at a 2” standoff behind the back of the panel. Facesheets are bonded to the core with adhesive. The nominal density of the foam core ranges from 6% to 8%.

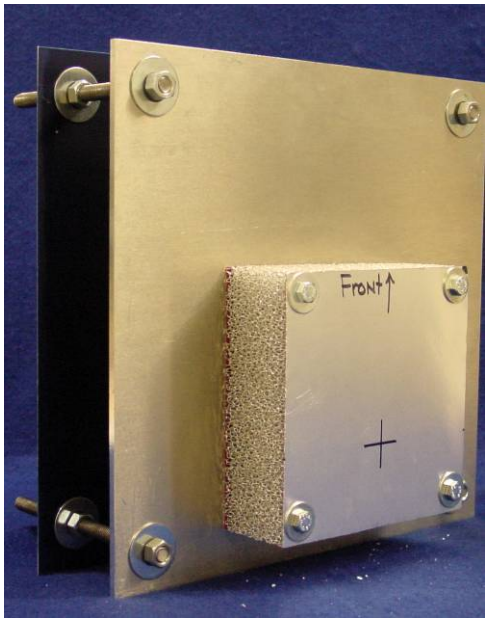

Figure 4.3-1
HITF04162 Pretest Photo,
Example 2” Al F10 Target Article

4.4 2” Al F40

The 2” Al F40 is a 2” thick aluminum 6101-T6 foam core with 0.010” thick aluminum 6061-T6 facesheets. F40 indicates that the metal foam pore size is such that there are (40) pores per inch. This article has a single shot on a 6” x 6” panel, mounted to a frame plate or directly held by bolts, with a witness plate at a 2” standoff behind the back of the panel. Facesheets are bonded to the core with adhesive. The nominal density of the foam core ranges from 6% to 8%.

Figure 4.4-1
HITF04163 Pretest Photo,
Example 2” Al F40 Target Article

4.5 0.5” Al HC

The 0.5” Al HC is a 0.5” thick aluminum honeycomb core with 0.016” thick aluminum facesheets. This article has multiple shots on a 12” x 12” panel, with a witness plate at a 2” standoff behind the back of the panel. Facesheets are bonded to the core with adhesive.

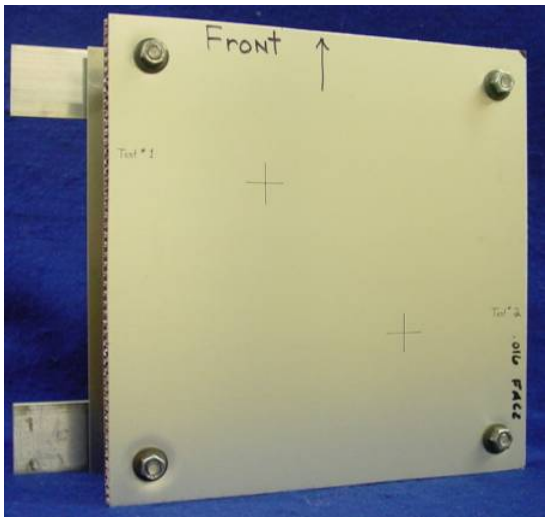

Figure 4.5-1
HITF03145 Pretest Photo,
Example 0.5” Al HC Target Article

4.6 2” Al HC

The 2” Al HC is a 2” thick aluminum honeycomb core with 0.050” thick aluminum facesheets. This article has a single shot on a 6” x 6” panel, mounted to a frame plate or directly held by bolts, with a witness plate at a 2” standoff behind the back of the panel. Facesheets are bonded to the core with adhesive.

Figure 4.6-1
HITF04160 Pretest Photo,
Example 2” Al HC Target Article

4.7 0.5" Ti F60-1

The 0.5" Ti F60-1 is a 0.5" thick titanium foam core with 0.028" thick Ti-6-2-4-2 (6% Al, 2% Sn, 4% Zr, 2% Mo by weight) titanium alloy facesheets. F60 indicates that the metal foam pore size is such that there are (60) pores per inch. This article has multiple shots on a 12" x 12" panel, with a witness plate at a 2" standoff behind the back of the panel. Adherence between the core and the facesheets is achieved by hot pressing the sandwich structure. The nominal density of the foam core is 8.21%.

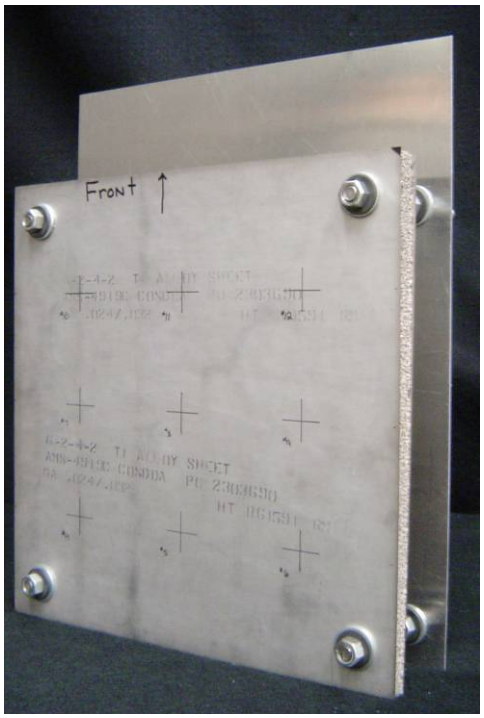

Figure 4.7-1
HITF05293 Pretest Photo,
Example 0.5" Ti F60-1 Target Article

4.8 0.5" Ti F60-2

The 0.5" Ti F60-1 is a 0.5" thick titanium foam core with 0.034" thick Ti-6-2-4-2 titanium alloy facesheets. F60 indicates that the metal foam pore size is such that there are (60) pores per inch. This article has multiple shots on a 12" x 12" panel, with a witness plate at a 2" standoff behind the back of the panel. Adherence between the core and the facesheets is achieved by hot pressing the sandwich structure. The nominal density of the foam core is 10.1%.

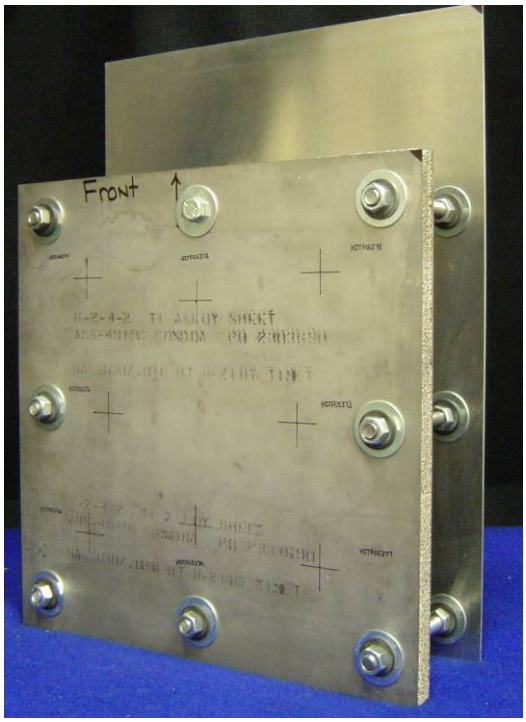

Figure 4.8-1
HITF05372 Pretest Photo,
Example 0.5" Ti F60-2 Target Article

4.9 0.5" Ti HC

The 0.5" Ti HC is an approximately 0.5" thick titanium honeycomb core with 0.034" thick 6-2-4-2 Titanium facesheets. This article has multiple shots on a 12" x 12" panel, with a witness plate at a 2" standoff behind the back of the panel. Facesheets are weld-bonded to the core.

Figure 4.9-1
HITF05292 Pretest Photo,
Example 0.5" Ti HC Target Article

5. TEST SUCCESS CRITERIA

Only Successful Tests will be considered as acceptable data. A Successful Test will be one with:

- Clean impact by the projectile within 0.25” of the aim point and no secondary impacts
- Determination of projectile impact velocity
- Verification of projectile integrity prior to impact

6. TARGET PASS/FAIL CRITERIA

Pass/fail criteria will be determined by perforation of the second facesheet on a Successful Test. If there is no perforation of the second facesheet, then the test is a pass. A fail will be when there is any perforation of the second facesheet.

7. HVI TEST MATRIX

Note: All projectiles are Al 2017-T4 unless otherwise noted

HITF Number	Target Type	Panel Areal Density (g/cm^2)	Projectile Diameter (mm)	Impact Velocity (km/s)	Impact Angle (deg)
HITF03147-1	0.5" Al F10	0.51	1.0	6.95	0
HITF03147-2	0.5" Al F10	0.51	1.1	6.89	0
HITF03147-3	0.5" Al F10	0.51	1.2	6.83	0
HITF03147-4	0.5" Al F10	0.51	1.2	6.87	0
HITF05036-1	0.5" Al F40	0.49	1.0	6.88	0
HITF05036-2	0.5" Al F40	0.49	1.2	6.90	0
HITF05036-3	0.5" Al F40	0.49	1.4	6.45	0
HITF05037-1	0.5" Al F40	0.49	1.2	7.05	45
HITF05037-2	0.5" Al F40	0.49	1.4	6.92	45
HITF03145-2	0.5" Al HC	0.37	0.8	6.75	0
HITF03145-1	0.5" Al HC	0.37	1.0	6.86	0
HITF05069-4	0.5" Al HC	0.37	1.3	6.99	60
HITF05293-2	0.5" Ti F60-1	1.279	2.4	3.45	0
HITF05293-4	0.5" Ti F60-1	1.279	2.6	7.00	0
HITF05293-5	0.5" Ti F60-1	1.279	2.8	6.93	0
HITF05293-6	0.5" Ti F60-1	1.279	2.4	6.80	45
HITF05379	0.5" Ti F60-2	1.535	2.8	4.09	0
HITF05373	0.5" Ti F60-2	1.535	3.0	6.71	45
HITF05372	0.5" Ti F60-2	1.535	3.2	6.77	45
HITF05376	0.5" Ti F60-2	1.535	3.2	6.62	45
HITF05377	0.5" Ti F60-2	1.535	3.2	4.00	45
HITF05378	0.5" Ti F60-2	1.535	3.2	7.16	45
HITF05374	0.5" Ti F60-2	1.535	3.4	6.60	60
HITF05375	0.5" Ti F60-2	1.535	3.6	6.76	60
HITF05292-1	0.5" Ti HC	0.93	1.5	6.74	0
HITF05292-2	0.5" Ti HC	0.93	1.6	6.79	45
HITF05292-3	0.5" Ti HC	0.93	1.7	6.90	60
HITF04151	2" Al F10	1.25	3.6	6.76	0
HITF04161	2" Al F10	1.25	4.0	6.89	0
HITF04155	2" Al F10	1.25	4.0	6.89	45
HITF04162	2" Al F10	1.25	4.4	6.92	45
HITF04152	2" Al F40	1.18	3.6	6.79	0
HITF04163	2" Al F40	1.18	4.0	6.79	0
HITF04164	2" Al F40	1.18	4.4	6.70	45
HITF05068	2" Al F40	1.18	4.8	6.93	45
HITF04159	2" Al HC	1.59	3.2	6.86	0
HITF04150	2" Al HC	1.59	3.6	6.22	0
HITF04160	2" Al HC	1.59	3.2	6.74	45
HITF04153	2" Al HC	1.59	3.6	6.87	45

* - Projectile used was Al 2219-T4

8. SUMMARY OF TEST RESULTS

HITF Number	WSTF Number	Target Type	Projectile Diameter (mm)	Impact Velocity (km/s)	Impact Angle (deg)	Pass/Fail
HITF03147-1	WSTF03-38055	0.5" Al F10	1.0	6.95	0	Pass
HITF03147-2	WSTF03-38055	0.5" Al F10	1.1	6.89	0	Pass
HITF03147-3	WSTF04-38140	0.5" Al F10	1.2	6.83	0	Fail
HITF03147-4	WSTF04-38140	0.5" Al F10	1.2	6.87	0	Fail
HITF05036-1	WSTF05-39292	0.5" Al F40	1.0	6.88	0	Pass
HITF05036-2	WSTF05-39654	0.5" Al F40	1.2	6.90	0	Pass
HITF05036-3	WSTF05-39658	0.5" Al F40	1.4	6.45	0	Fail
HITF05037-1	WSTF05-39293	0.5" Al F40	1.2	7.05	45	Pass
HITF05037-2	WSTF05-39655	0.5" Al F40	1.4	6.92	45	Fail
HITF03145-2	WSTF03-38052	0.5" Al HC	0.8	6.75	0	Pass
HITF03145-1	WSTF03-38052	0.5" Al HC	1.0	6.86	0	Fail
HITF05069-4	WSTF05-39414	0.5" Al HC	1.3	6.99	60	Fail
HITF05293-2	WSTF05-39960	0.5" Ti F60-1	2.4	3.45	0	Pass
HITF05293-4	WSTF05-39994	0.5" Ti F60-1	2.6	7.00	0	Pass
HITF05293-5	WSTF05-40074	0.5" Ti F60-1	2.8	6.93	0	Fail
HITF05293-6	WSTF05-40104	0.5" Ti F60-1	2.4	6.80	45	Pass
HITF05379	WSTF06-40325	0.5" Ti F60-2	2.8	4.09	0	Pass
HITF05373	WSTF05-40123	0.5" Ti F60-2	3.0	6.71	45	Pass
HITF05372	WSTF05-40123	0.5" Ti F60-2	3.2	6.77	45	Fail
HITF05376	WSTF06-40252	0.5" Ti F60-2	3.2	6.62	45	Pass
HITF05377	WSTF06-40283	0.5" Ti F60-2	3.2	4.00	45	Pass
HITF05378	WSTF06-40234	0.5" Ti F60-2	3.2	7.16	45	Fail
HITF05374	WSTF06-40201	0.5" Ti F60-2	3.4	6.60	60	Pass
HITF05375	WSTF06-40243	0.5" Ti F60-2	3.6	6.76	60	Pass
HITF05292-1	WSTF05-39540	0.5" Ti HC	1.5	6.74	0	Pass
HITF05292-2	WSTF05-39941	0.5" Ti HC	1.6	6.79	45	Pass
HITF05292-3	WSTF05-39542	0.5" Ti HC	1.7	6.90	60	Fail
HITF04151	WSTF04-38183	2" Al F10	3.6	6.76	0	Pass
HITF04161	WSTF04-38186	2" Al F10	4.0	6.89	0	Fail
HITF04155	WSTF04-38194	2" Al F10	4.0	6.89	45	Pass
HITF04162	WSTF04-38199	2" Al F10	4.4	6.92	45	Pass
HITF04152	WSTF04-38184	2" Al F40	3.6	6.79	0	Pass
HITF04163	WSTF04-38187	2" Al F40	4.0	6.79	0	Fail
HITF04164	WSTF04-38200	2" Al F40	4.4	6.70	45	Pass
HITF05068	WSTF05-39413	2" Al F40	4.8	6.93	45	Pass
HITF04159	WSTF04-38185	2" Al HC	3.2	6.86	0	Fail
HITF04150	WSTF04-38174	2" Al HC	3.6	6.22	0	Fail
HITF04160	WSTF04-38198	2" Al HC	3.2	6.74	45	Fail
HITF04153	WSTF03-38192	2" Al HC	3.6	6.87	45	Fail

Measurements from the test articles are in Appendix B.

8.1 BALLISTIC LIMIT OBSERVATIONS

An observation relevant to the Ballistic Limit is one in which one variable is changed while the others are constant (or nearly constant in the case of velocity). In these observations the Target Type and Impact Angle are constant. Additionally, either the Impact Velocity or the Projectile Diameter is constant, but the other increases causing failure. We then know the Ballistic limit is between these tests in terms of the varied parameter.

HITF Number	WSTF Number	Target Type	Projectile Diameter (mm)	Impact Velocity (km/s)	Impact Angle (deg)	Pass/Fail
HITF03147-2	WSTF03-38055	0.5" Al F10	1.1	6.89	0	Pass
HITF03147-3	WSTF04-38140	0.5" Al F10	1.2	6.83	0	Fail
HITF05036-2	WSTF05-39654	0.5" Al F40	1.2	6.90	0	Pass
HITF05036-3	WSTF05-39658	0.5" Al F40	1.4	6.45	0	Fail
HITF05037-1	WSTF05-39293	0.5" Al F40	1.2	7.05	45	Pass
HITF05037-2	WSTF05-39655	0.5" Al F40	1.4	6.92	45	Fail
HITF03145-2	WSTF03-38052	0.5" Al HC	0.8	6.75	0	Pass
HITF03145-1	WSTF03-38052	0.5" Al HC	1.0	6.86	0	Fail
HITF05293-4	WSTF05-39994	0.5" Ti F60-1	2.6	7.00	0	Pass
HITF05293-5	WSTF05-40074	0.5" Ti F60-1	2.8	6.93	0	Fail
HITF05379	WSTF06-40325	0.5" Ti F60-2	2.8	4.09	0	Pass
HITF05293-5	WSTF05-40074	0.5" Ti F60-1	2.8	6.93	0	Fail
HITF05373	WSTF05-40123	0.5" Ti F60-2	3.0	6.71	45	Pass
HITF05372	WSTF05-40123	0.5" Ti F60-2	3.2	6.77	45	Fail
HITF05377	WSTF06-40283	0.5" Ti F60-2	3.2	4.00	45	Pass
HITF05372	WSTF05-40123	0.5" Ti F60-2	3.2	6.77	45	Fail
HITF04151	WSTF04-38183	2" Al F10	3.6	6.76	0	Pass
HITF04161	WSTF04-38186	2" Al F10	4.0	6.89	0	Fail
HITF04152	WSTF04-38184	2" Al F40	3.6	6.79	0	Pass
HITF04163	WSTF04-38187	2" Al F40	4.0	6.79	0	Fail

From these pairings, we can say that the ballistic limit for the Target Type in question is in between the two data points. In the case where the velocity is relatively constant, the Projectile Diameter/Mass ballistic limit for that Impact Velocity/Impact Angle/Target Type combination is isolated. The performance of the different Target Types can then be compared.

8.2 TARGET ARTICLE TYPE COMPARISON OBSERVATIONS

A relevant Comparison Observation is when one target type passes and another fails when the Impact Velocity is constant and the Projectile Diameter is constant or decreased. In these observations, the Impact Velocity, Impact Angle, and Target Article core thickness are constant. If the Projectile Diameter that causes failure in a Target Type is the same or less than the Projectile Diameter that causes failure in another Target Type, than we can get information toward the superior ballistic performance of a certain Target Type.

HITF Number	WSTF Number	Target Type	Projectile Diameter (mm)	Impact Velocity (km/s)	Impact Angle (deg)	Pass/Fail
HITF03147-2	WSTF03-38055	0.5" Al F10	1.1	6.89	0	Pass
HITF03145-1	WSTF03-38052	0.5" Al HC	1.0	6.86	0	Fail
HITF05036-2	WSTF05-39654	0.5" Al F40	1.2	6.90	0	Pass
HITF03145-1	WSTF03-38052	0.5" Al HC	1.0	6.86	0	Fail
HITF05036-2	WSTF05-39654	0.5" Al F40	1.2	6.90	0	Pass
HITF03147-3	WSTF04-38140	0.5" Al F10	1.2	6.83	0	Fail
HITF05375	WSTF06-40243	0.5" Ti F60-2	3.6	6.76	60	Pass
HITF05292-3	WSTF05-39542	0.5" Ti HC	1.7	6.90	60	Fail
HITF04151	WSTF04-38183	2" Al F10	3.6	6.76	0	Pass
HITF04159	WSTF04-38185	2" Al HC	3.2	6.86	0	Fail
HITF04162	WSTF04-38199	2" Al F10	4.4	6.92	45	Pass
HITF04160	WSTF04-38198	2" Al HC	3.2	6.74	45	Fail
HITF04152	WSTF04-38184	2" Al F40	3.6	6.79	0	Pass
HITF04159	WSTF04-38185	2" Al HC	3.2	6.86	0	Fail
HITF05068	WSTF05-39413	2" Al F40	4.8	6.93	45	Pass
HITF04160	WSTF04-38198	2" Al HC	3.2	6.74	45	Fail

This comparison shows that for the given configurations and conditions:

0.5” Al F10 performed better than 0.5” Al HC.
0.5” Al F40 performed better than 0.5” Al HC.
0.5” Al F40 performed better than 0.5” Al F10.
0.5” Ti F60-2 performed better than 0.5” Ti HC.
2” Al F10 performed better than 2” Al HC.
2” Al F40 performed better than 2” Al HC.

8.3 COMPARISON OF STRUCTURES

It is expected that a higher panel areal density would perform better (have a higher ballistic limit), but it is not the only factor. Areal density is the mass per unit area (g/cm^2), and is useful when examining possible shield materials. In these observations, the higher panel areal density article failed at a lower projectile diameter than the lower panel areal density article. This would imply that the lower panel areal density article is a more efficient shield.

HITF Number	WSTF Number	Target Type	Panel Areal Density (g/cm^2)	Projectile Diameter (mm)	Impact Velocity (km/s)	Impact Angle (deg)	Pass/ Fail
HITF04151	WSTF04-38183	2" Al F10	1.25	3.6	6.76	0	Pass
HITF05293-5	WSTF05-40074	0.5" Ti F60-1	1.28	2.8	6.93	0	Fail
HITF04159	WSTF04-38185	2" Al HC	1.59	3.2	6.86	0	Fail
HITF04162	WSTF04-38199	2" Al F10	1.25	4.4	6.92	45	Pass
HITF05372	WSTF05-40123	0.5" Ti F60-2	1.54	3.2	6.77	45	Fail
HITF04160	WSTF04-38198	2" Al HC	1.59	3.2	6.74	45	Fail
HITF04152	WSTF04-38184	2" Al F40	1.18	3.6	6.79	0	Pass
HITF05293-5	WSTF05-40074	0.5" Ti F60-1	1.28	2.8	6.93	0	Fail
HITF04159	WSTF04-38185	2" Al HC	1.59	3.2	6.86	0	Fail

Another factor that changes the ballistic limit is spacing between the first facesheet and the second facesheet, which can be used to help understand how despite the lower areal density:

2” Al F10 performed better than 0.5” Ti F60-1 and
2” Al F10 performed better than 0.5” Ti F60-2

But configuration of facesheet thickness and what is between the facesheets can have an effect greater than the areal density:

2” Al F10 performed better than 2” Al HC and
2” Al F40 performed better than 2” Al HC.

In this case, the 2” aluminum foam sandwich with the lower areal density and equal spacing performed better than the 2” aluminum honeycomb sandwich which had 25% - 35% greater areal density (25% - 35% higher mass).

9. CONCLUSIONS

In this series, the metal foam configurations performed better than the comparable honeycomb configurations. Even when the foam had a lower areal density, it performed better than the comparable honeycomb configurations.

The following comparison of pictures show the damage done to the aluminum foam compared to the aluminum honeycomb. The foam article in these images performs better, has a lower areal density, and was impacted by the same size projectile as compared to the honeycomb.

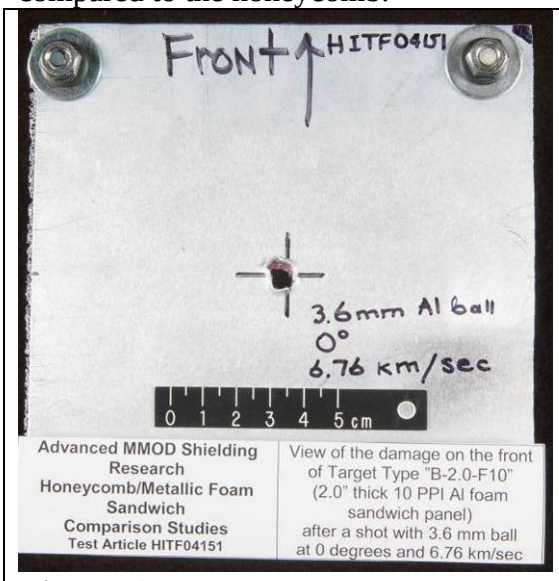

Figure 9-1
Jsc2005e11412 HITF04151 Front, first facesheet

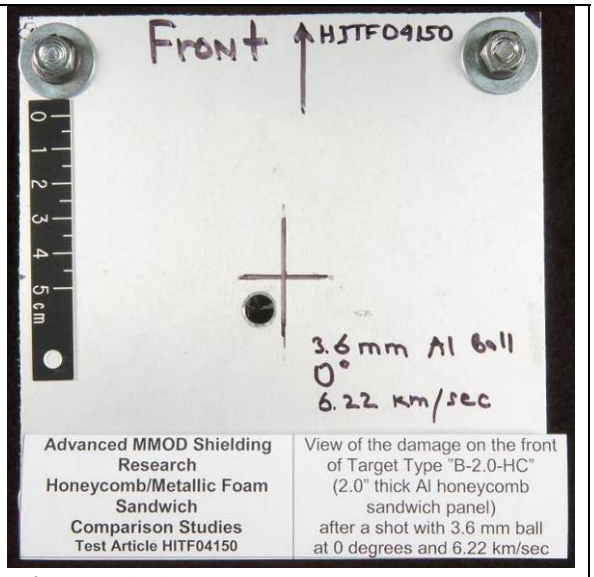

Figure 9-2
Jsc2005e11402 HITF04150 Front, first facesheet

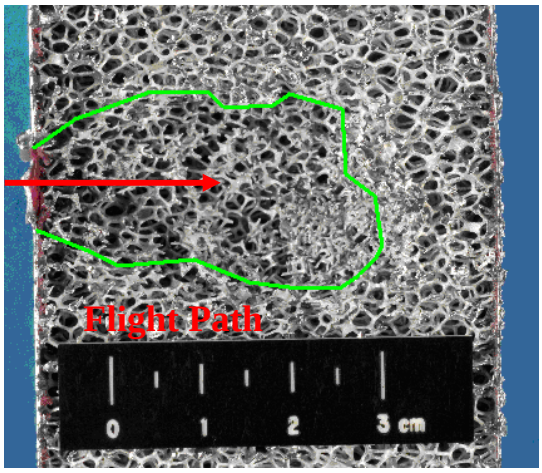

Figure 9-3
Jsc2007e21473 HITF04151 Cross section of foam sandwich structure

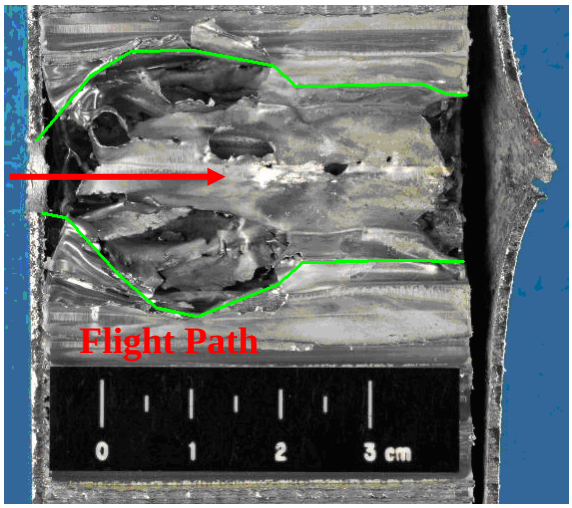

Figure 9-4
Jsc2007e21476 HITF04150 Cross section

	of honeycomb sandwich structure
 **Figure 9-5** Jsc2005e11416 HITF04151 Rear, second facesheet	 **Figure 9-6** Jsc2005e11409 HITF04150 Rear, second facesheet
Pass	Fail

Forward work will examine other factors of the shield configuration (thickness of facesheet, thickness of core, multiple sandwiches, etc.) as well as the properties of the core material.

These tests have provided data on hypervelocity penetration resistance of metal foam core sandwich structures which may have applications replacing honeycomb core panels on spacecraft to improve micro-meteoroid and orbital debris (MMOD) protection.

10. REFERENCES

[1] J. L. Crews, E. L. Christiansen; The NASA JSC Hypervelocity Impact Test Facility (HITF); AIAA 92-1640; 1992

11. APPENDIX A: PHOTOGRAPHS

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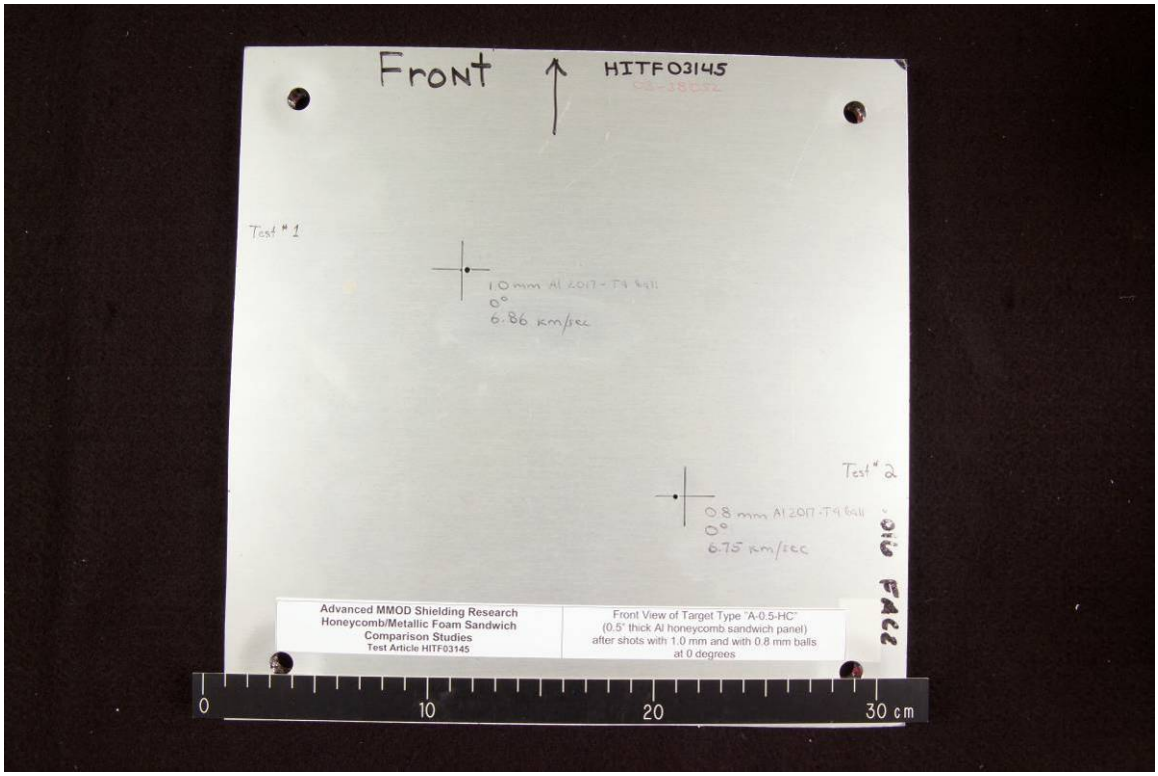

Figure A-1
Jsc2005e11293 HITF03145 Front, first facesheet

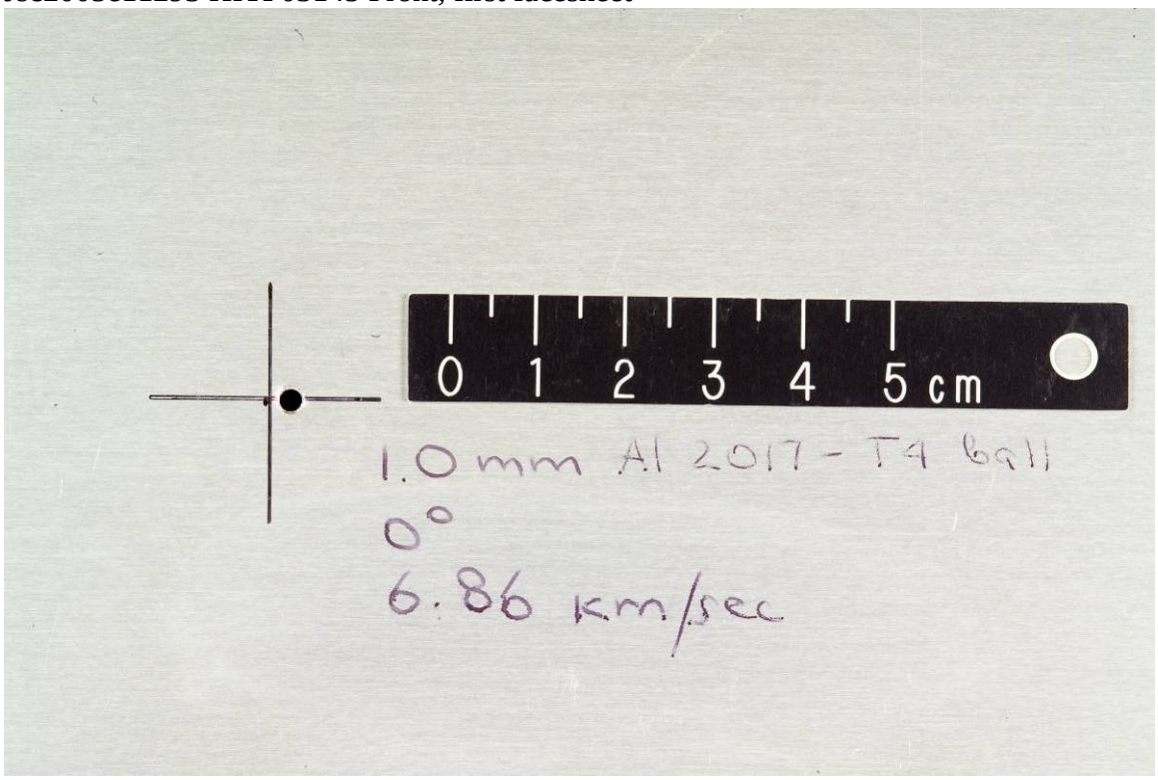

Figure A-2
Jsc2005e11291 HITF03145-1 Front, first facesheet

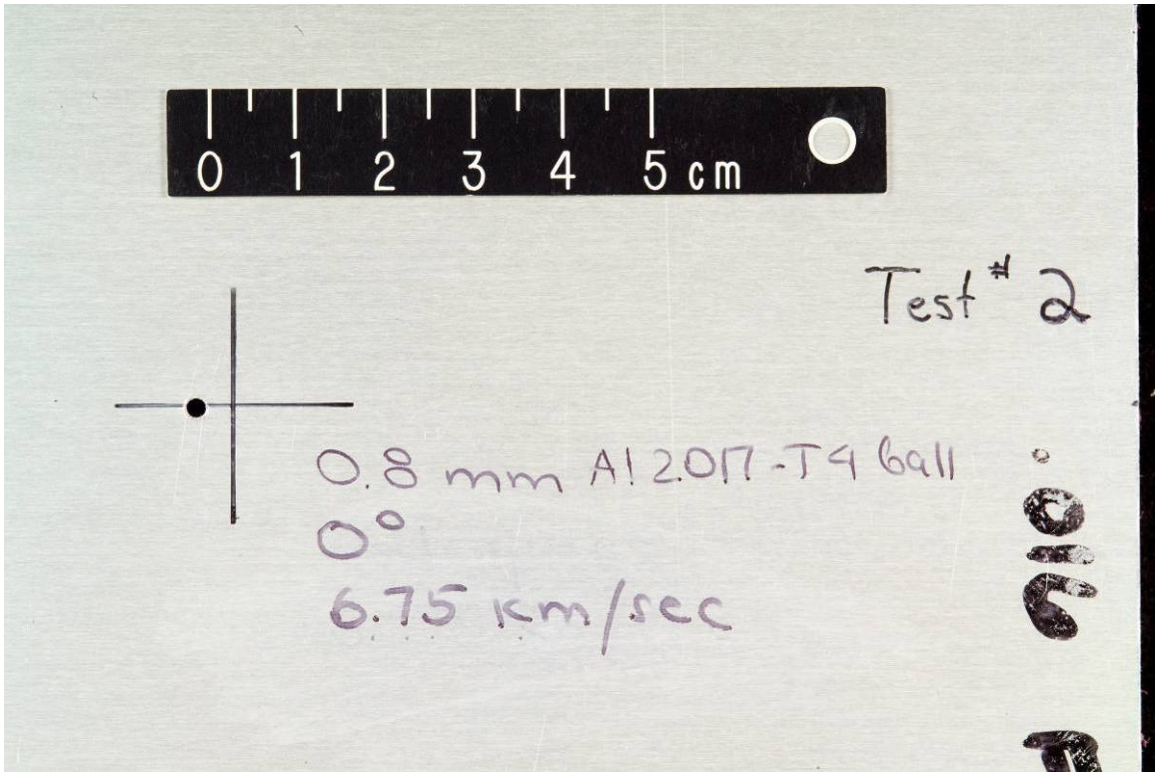

Figure A-3
Jsc2005e11292 HITF03145-2 Front, first facesheet

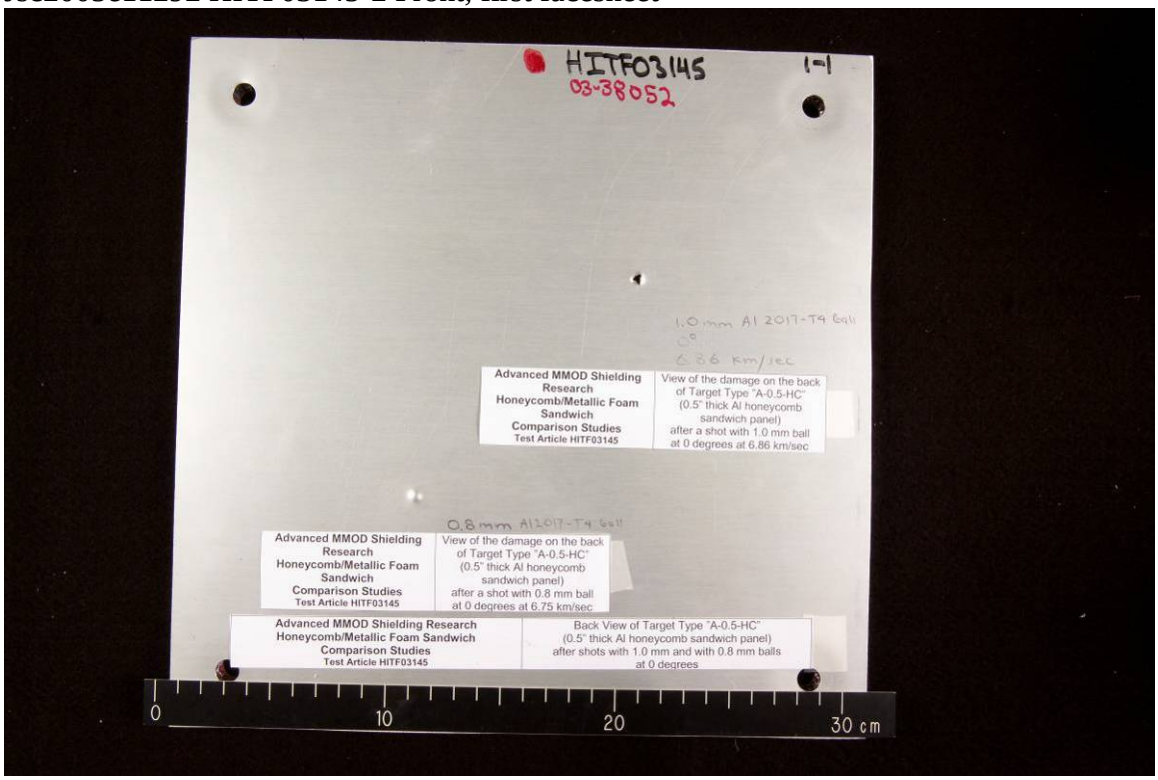

Figure A-4
Jsc2005e11288 HITF03145 Rear, second facesheet

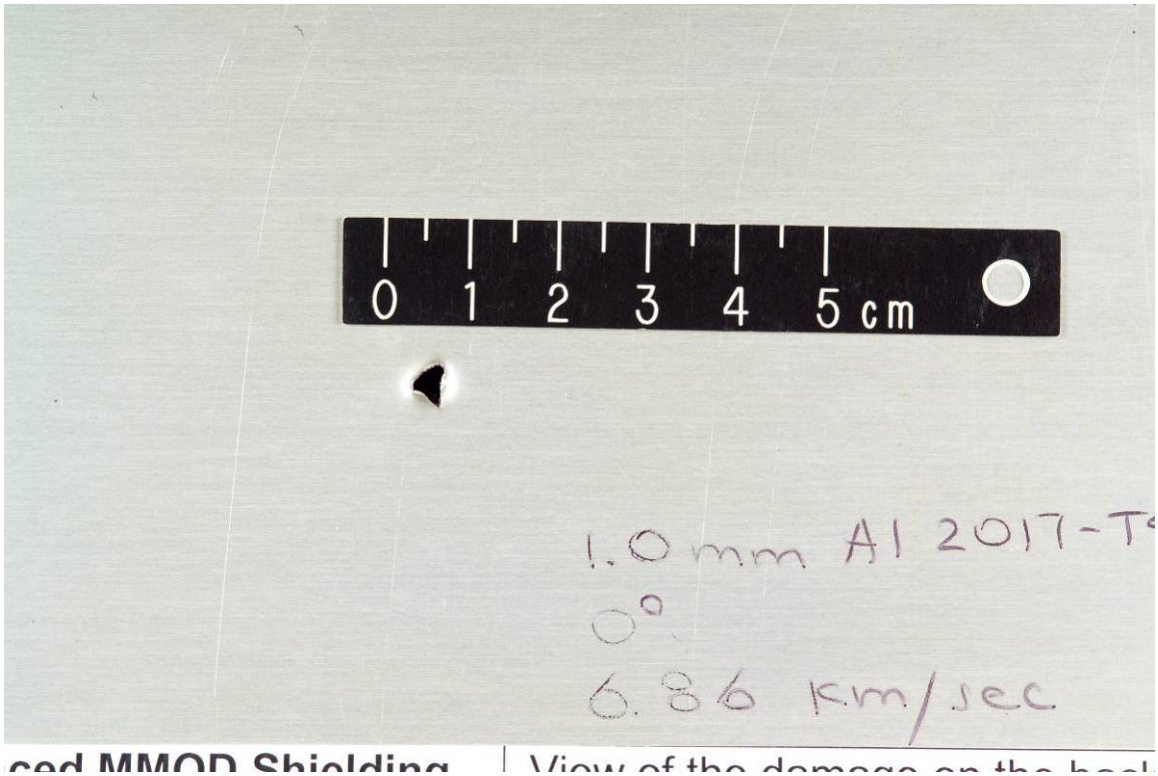

Figure A-5
Jsc2005e11289 HITF03145-1 Rear, second facesheet

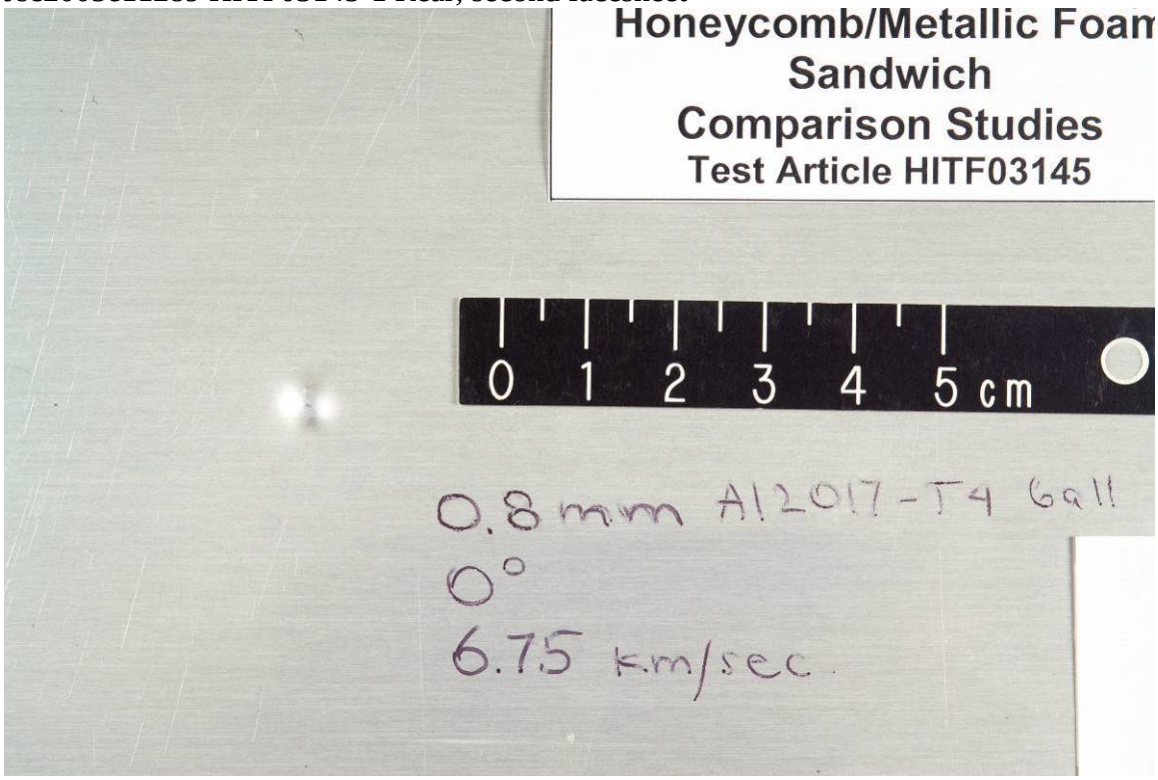

Figure A-6
Jsc2005e11290 HITF03145-2 Rear, second facesheet

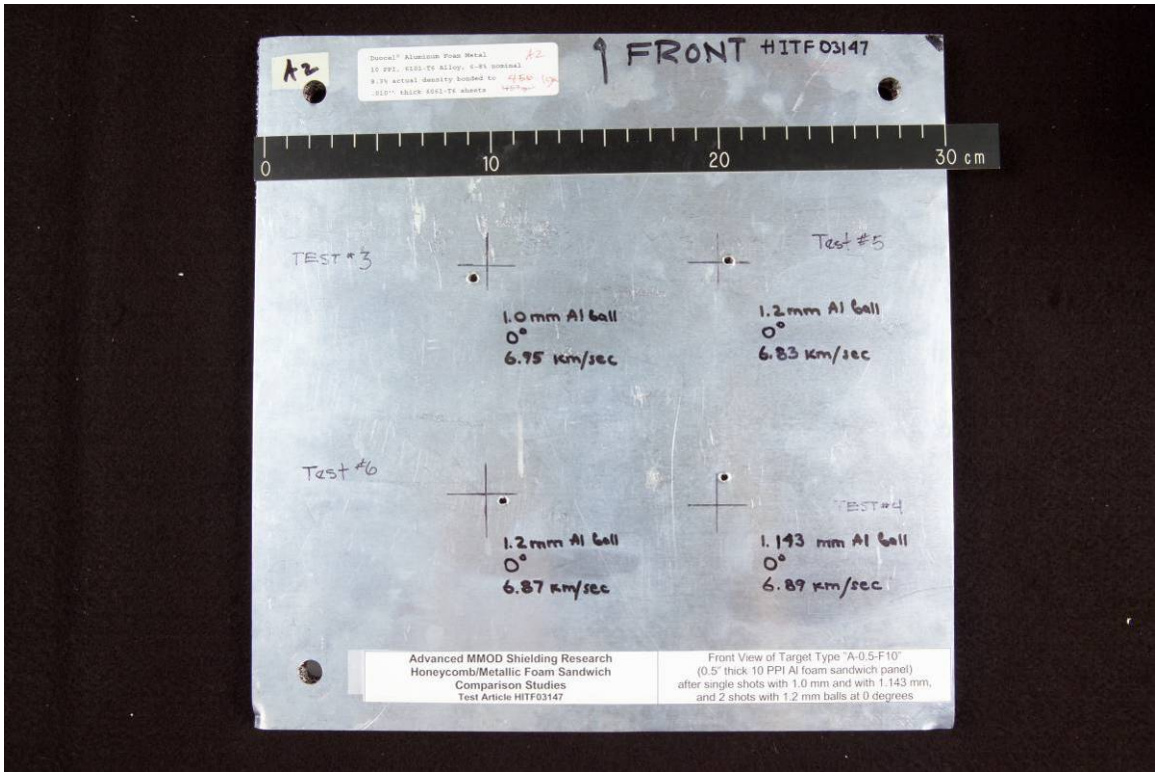

Figure A-7
Jsc2005e11299 HITF03147 Front, first facesheet

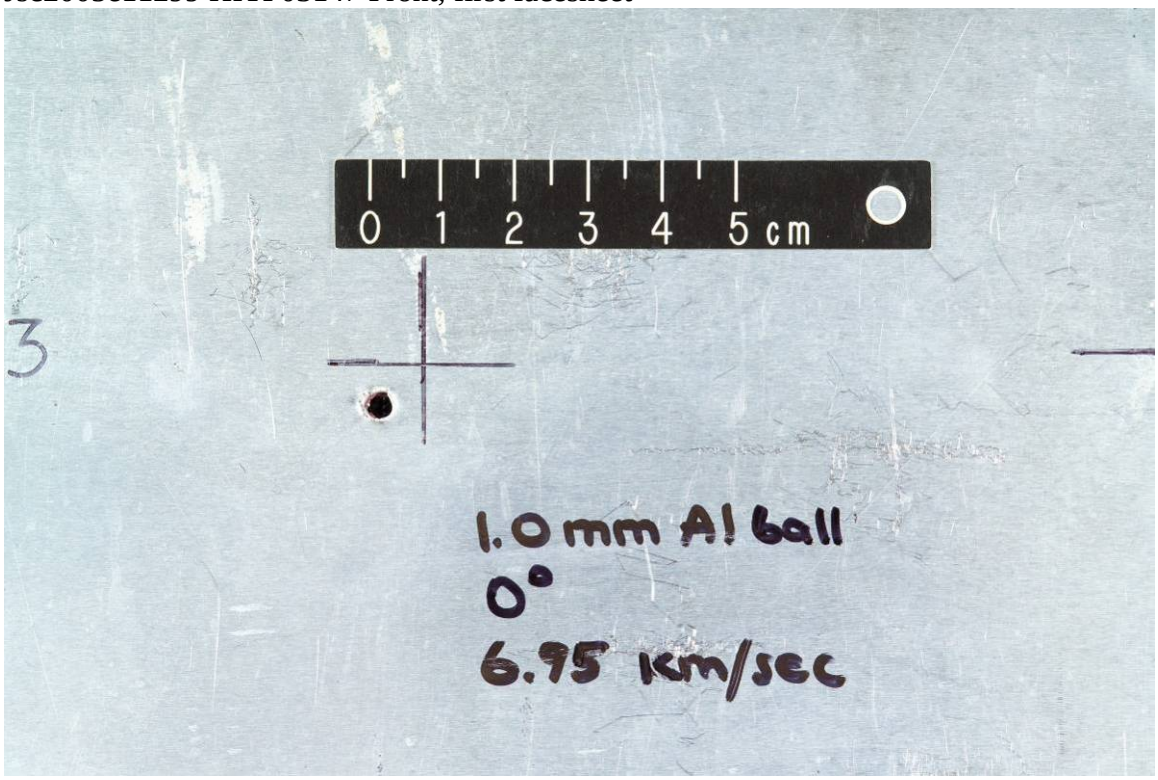

Figure A-8
Jsc2005e11300 HITF03147-1 Front, first facesheet

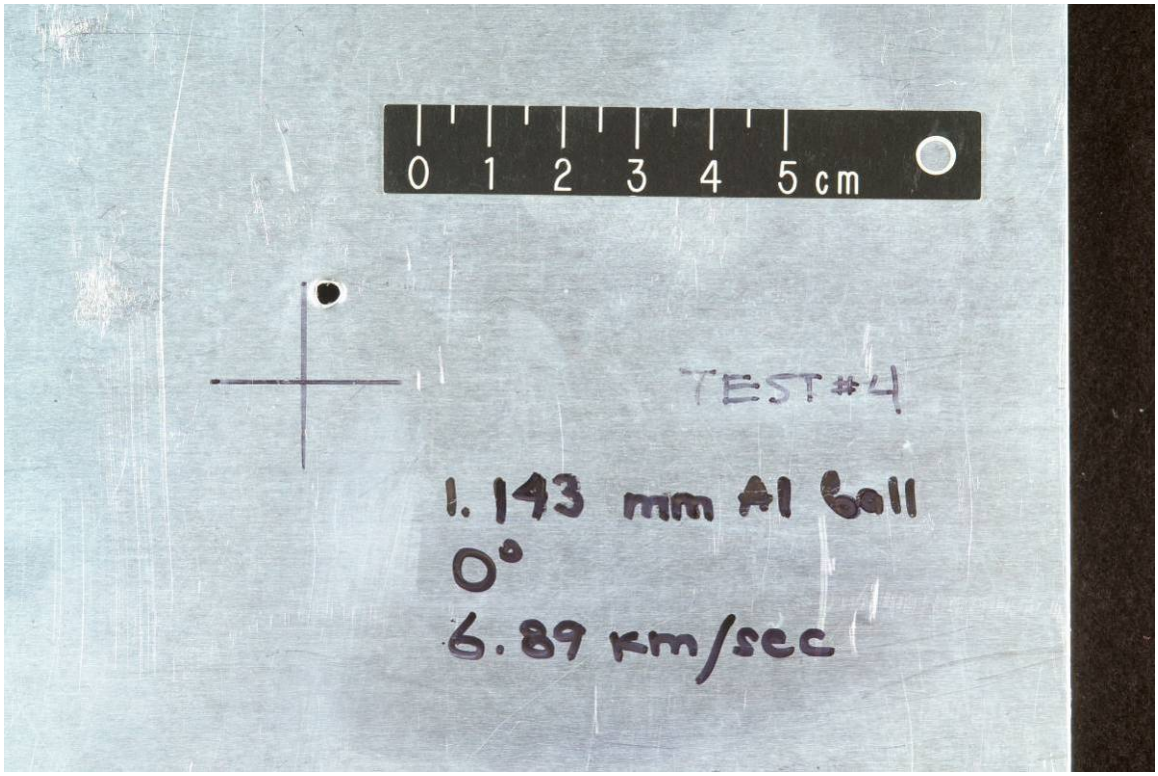

Figure A-9
Jsc2005e11303 HITF03147-2 Front, first facesheet

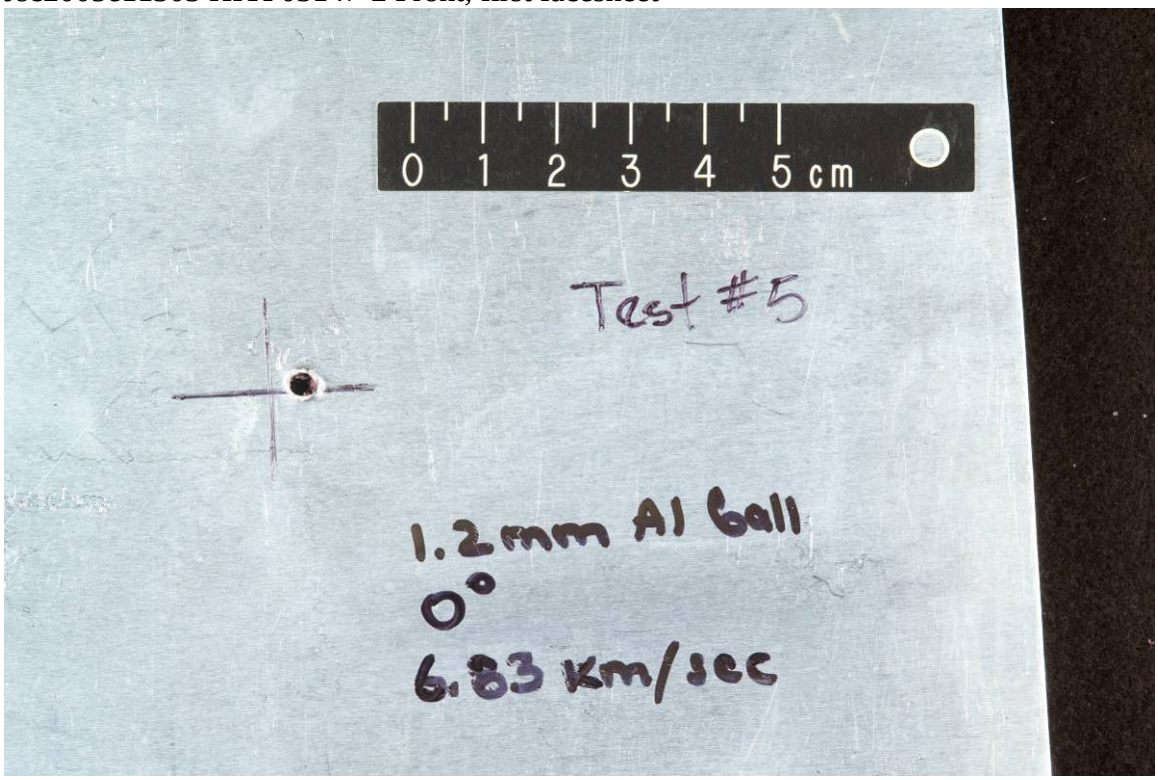

Figure A-10
Jsc2005e11301 HITF03147-3 Front, first facesheet

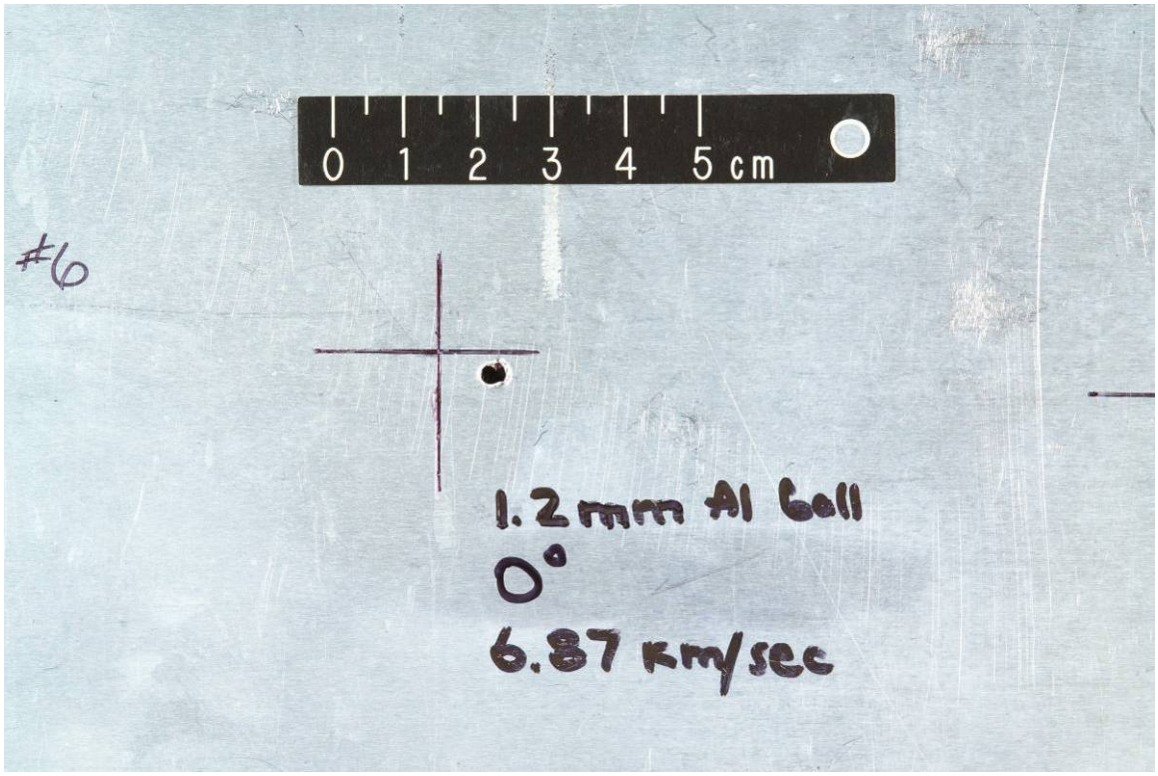

Figure A-11
Jsc2005e11302 HITF03147-4 Front, first facesheet

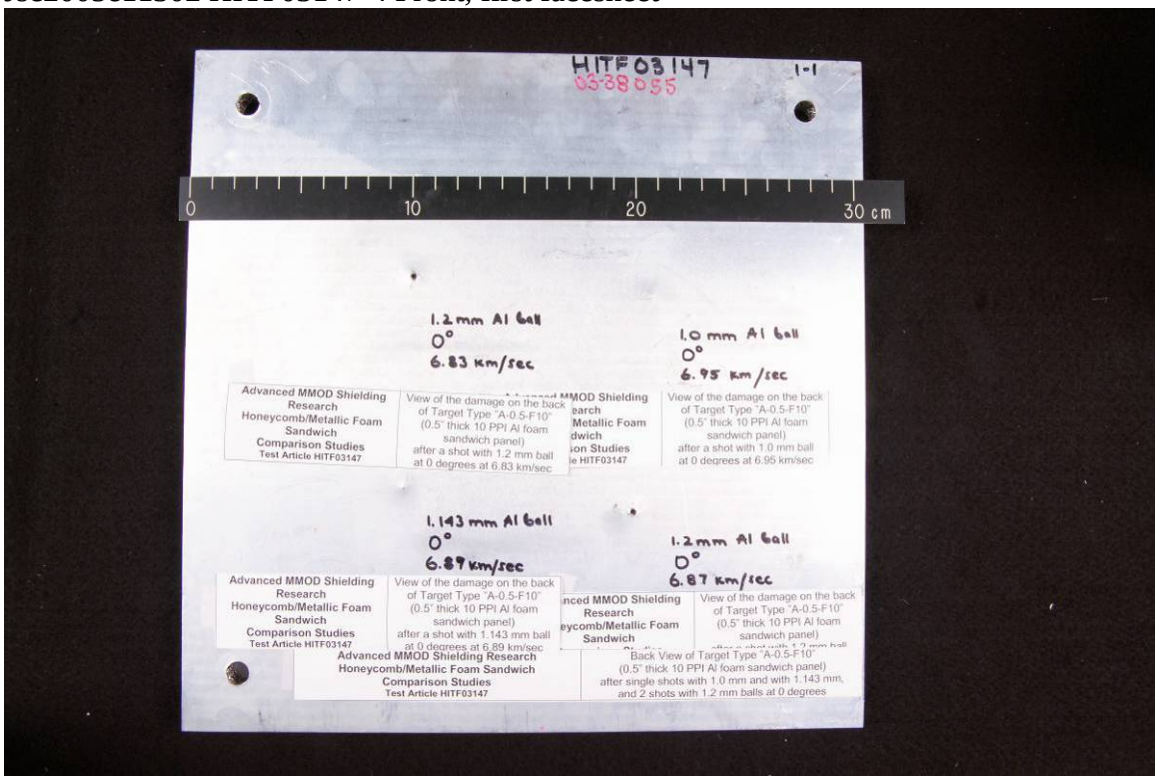

Figure A-12
Jsc2005e11294 HITF03147 Rear, second facesheet

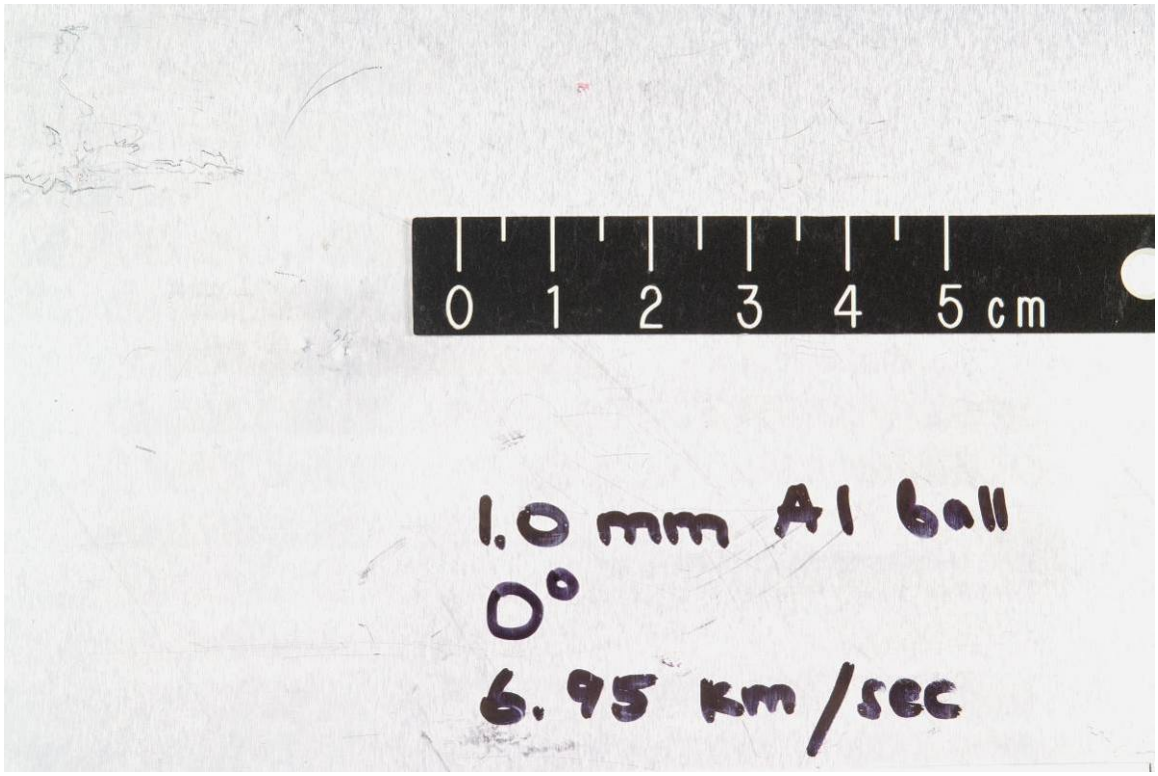

Figure A-13
Jsc2005e11296 HITF03147-1 Rear, second facesheet

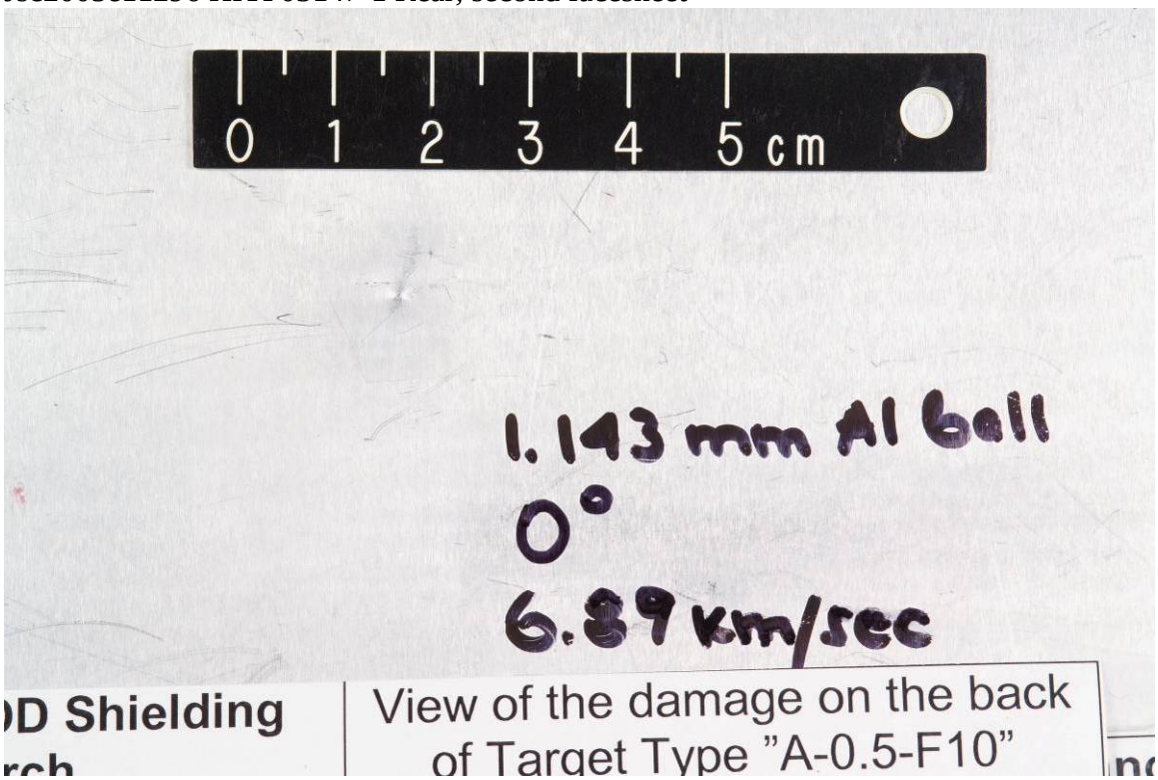

Figure A-14
Jsc2005e11297 HITF03147-2 Rear, second facesheet

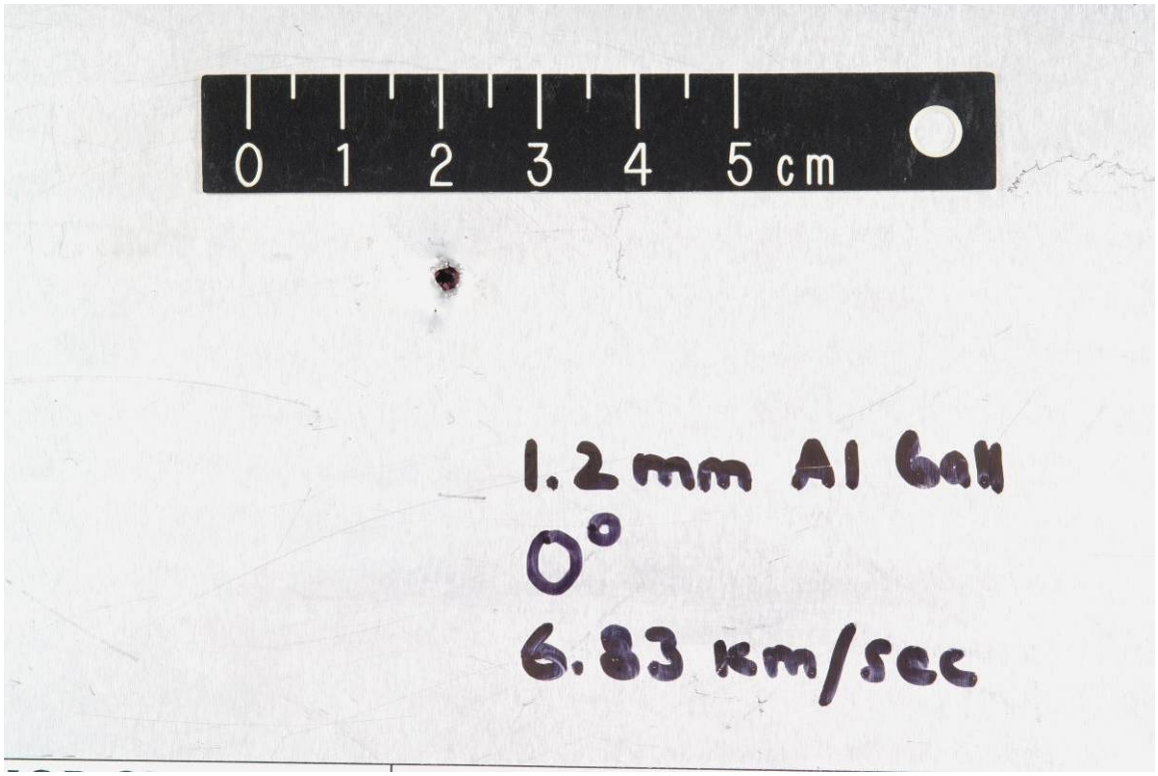

Figure A-15
Jsc2005e11295 HITF03147-3 Rear, second facesheet

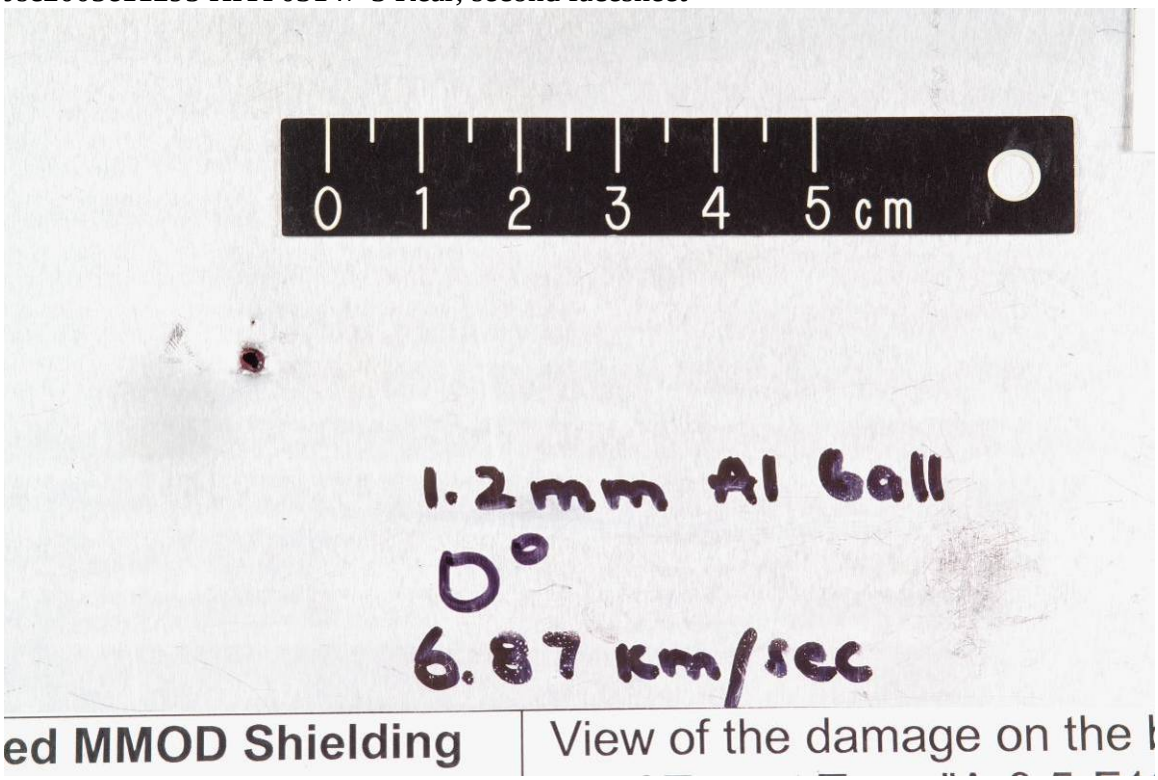

Figure A-16
Jsc2005e11298 HITF03147-4 Rear, second facesheet

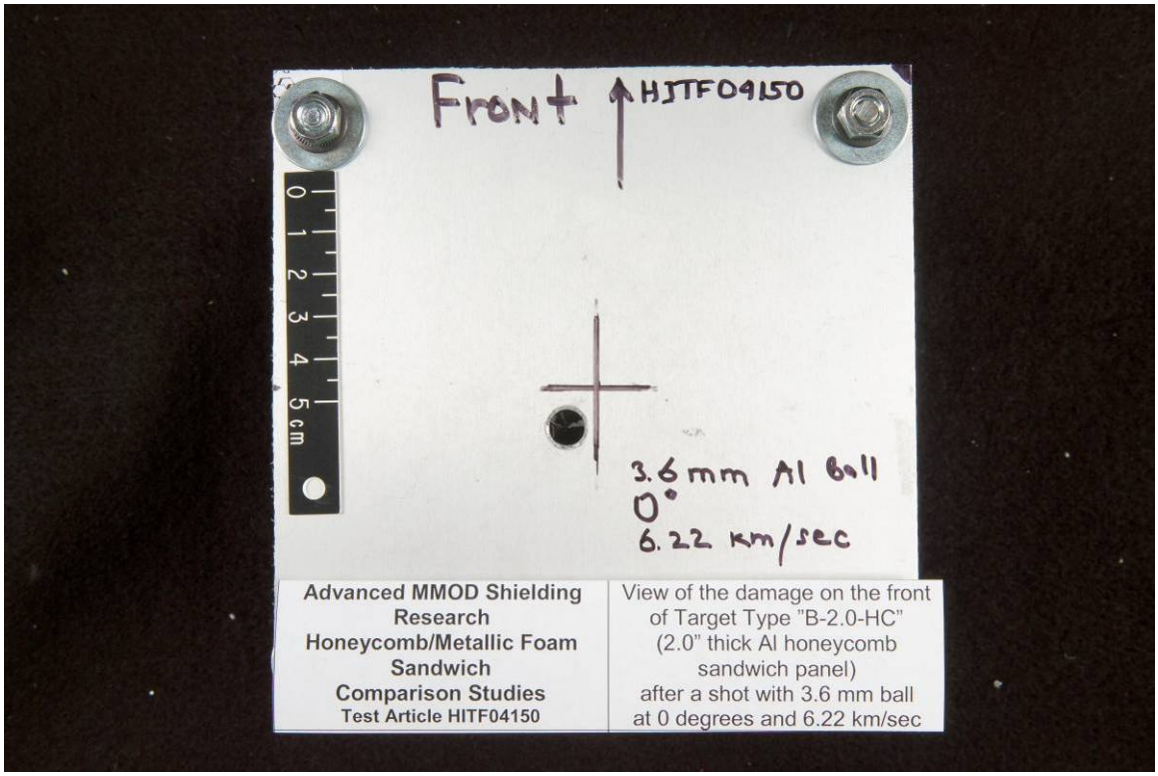

Figure A-17
Jsc2005e11402 HITF04150 Front, first facesheet

Figure A-18
Jsc2005e11409 HITF04150 Rear, second facesheet

Figure A-19
Jsc2005e11410 HITF04150 Rear, second facesheet

Figure A-20
Jsc2005e11408 HITF04150 Front witness plate

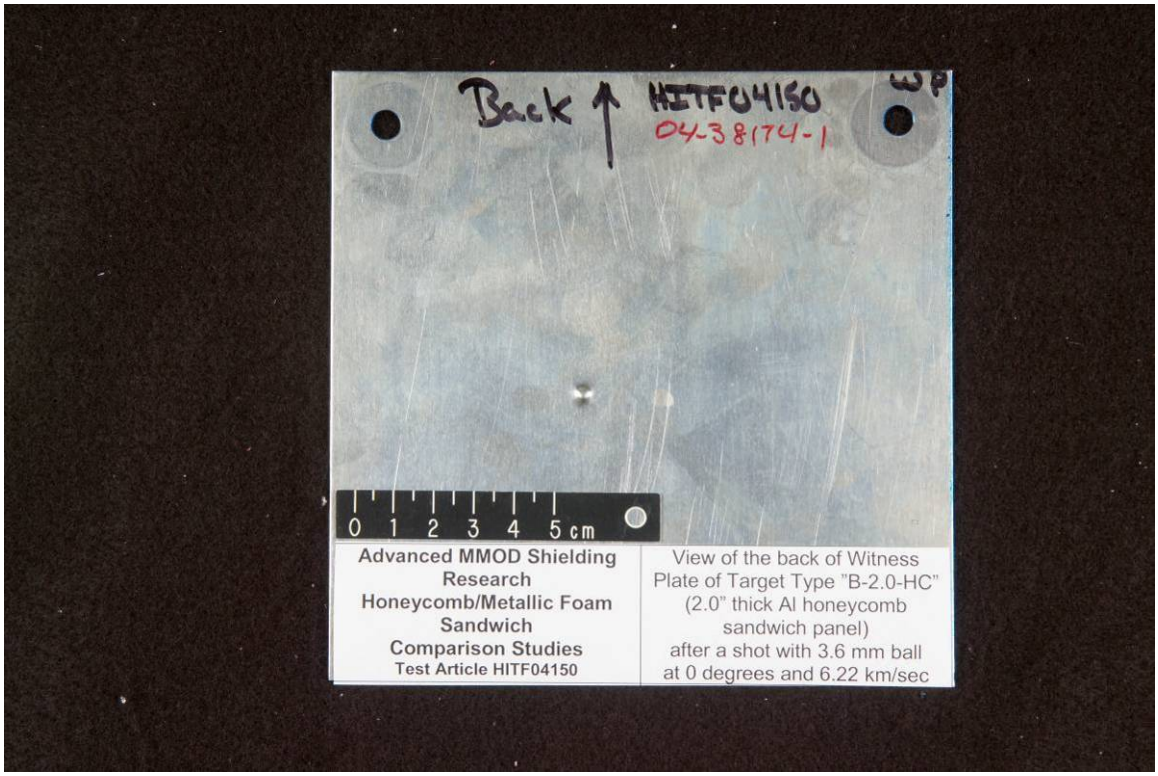

Figure A-21
Jsc2005e11406 HITF04150 Rear witness plate

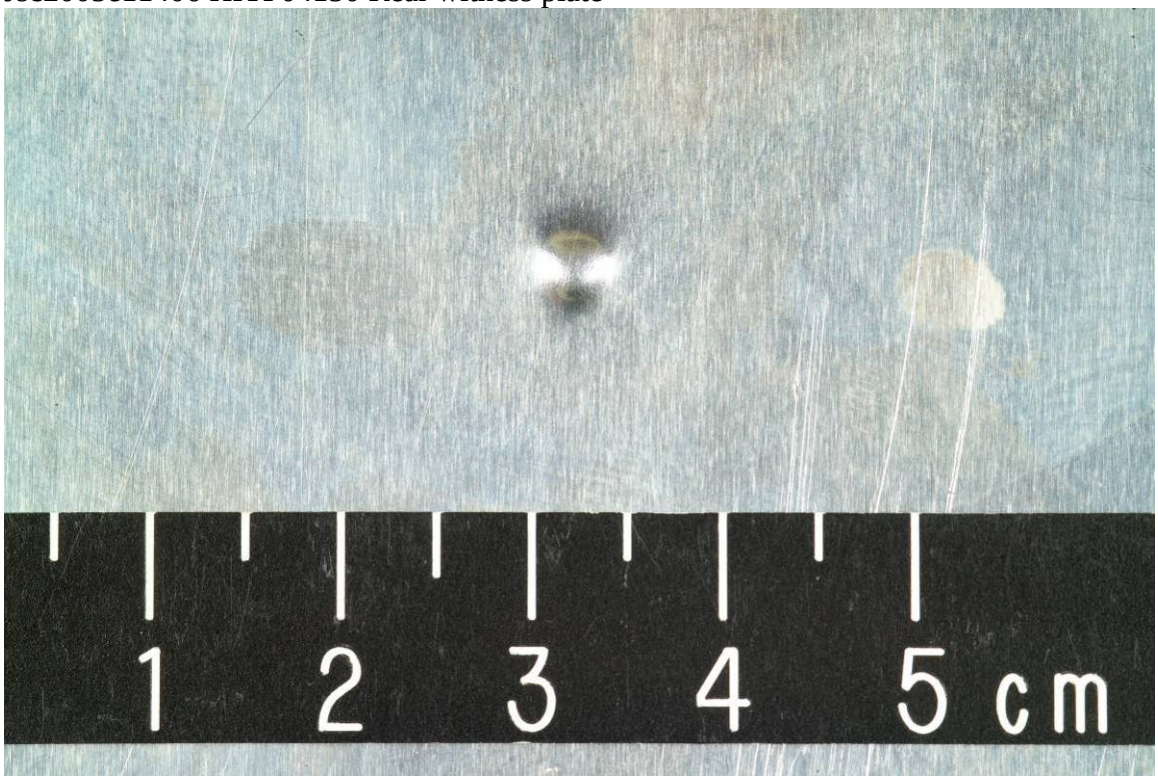

Figure A-22
Jsc2005e11407 HITF04150 Rear witness plate

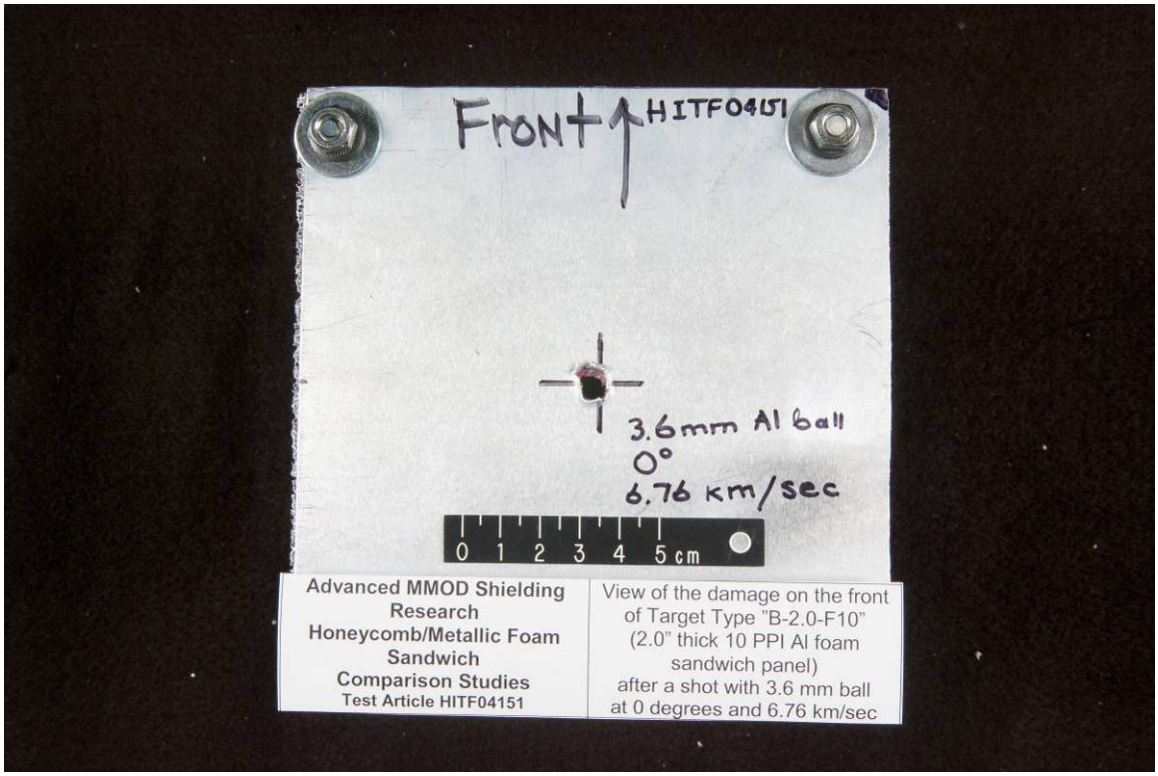

Figure A-23
Jsc2005e11412 HITF04151 Front, first facesheet

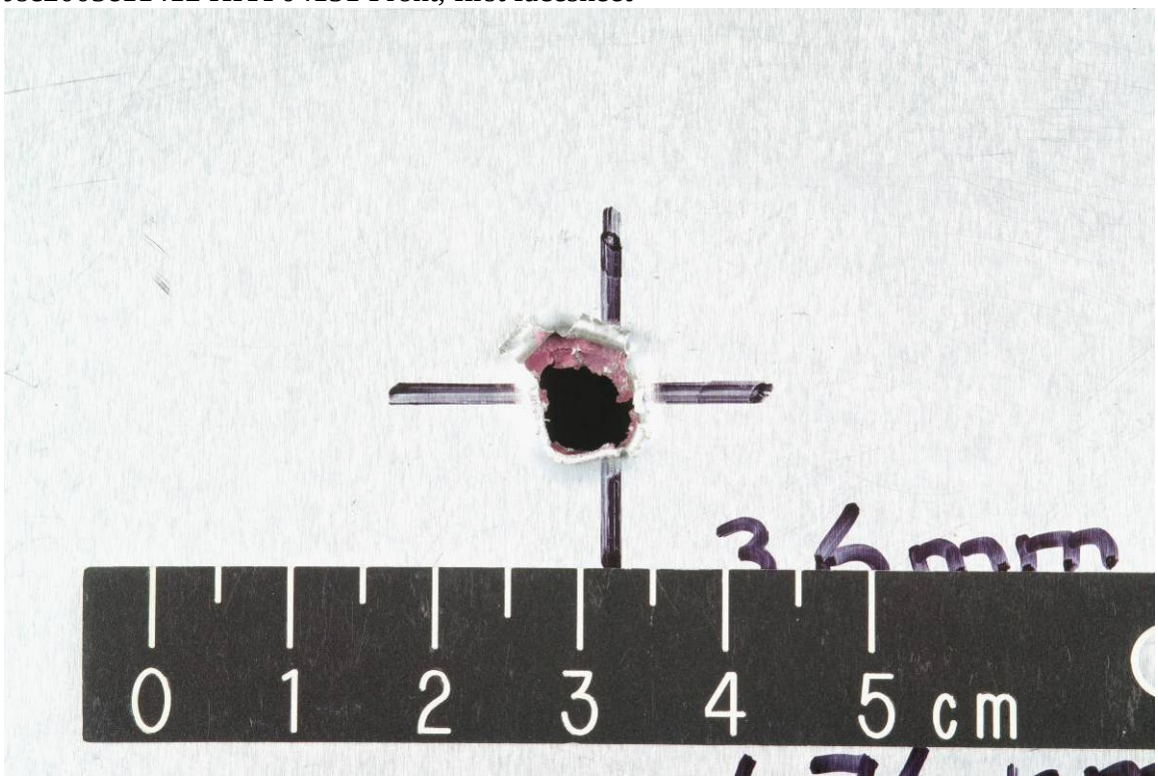

Figure A-24
Jsc2005e11411 HITF04151 Front, first facesheet

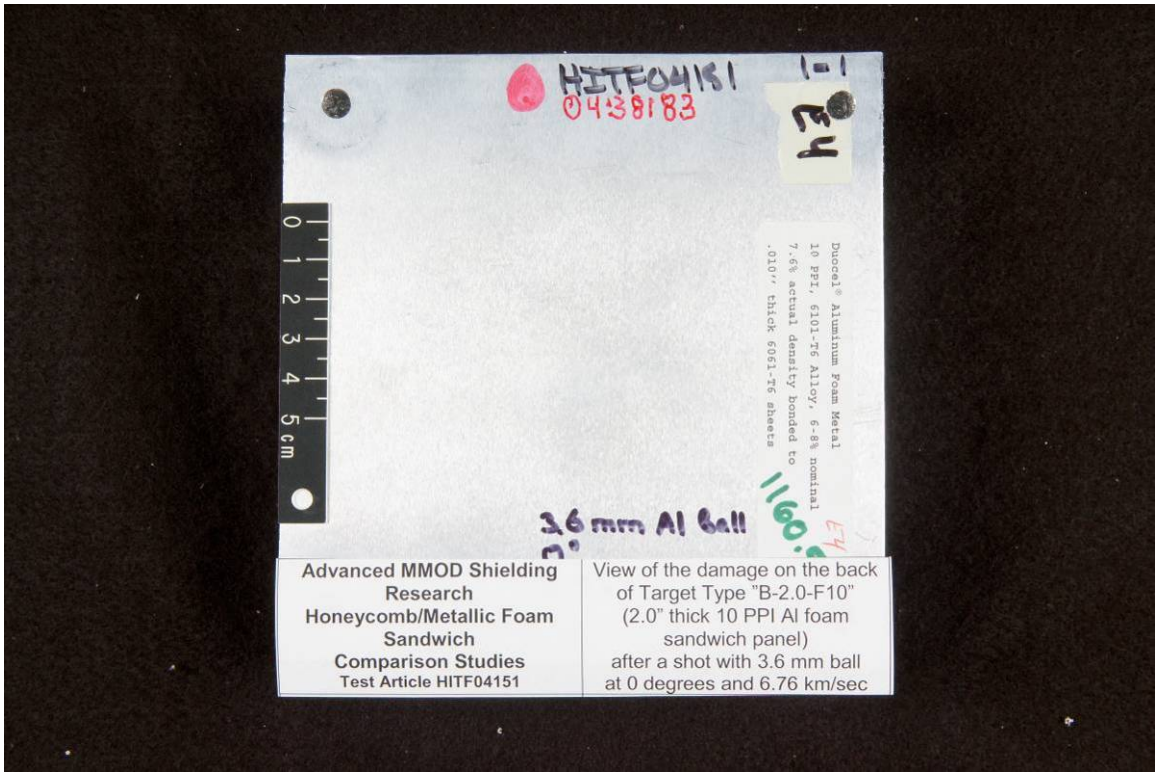

Figure A-25
Jsc2005e11416 HITF04151 Rear, second facesheet

Figure A-26
Jsc2005e11415 HITF04151 Front witness plate

Figure A-27
Jsc2005e11414 HITF04151 Rear witness plate

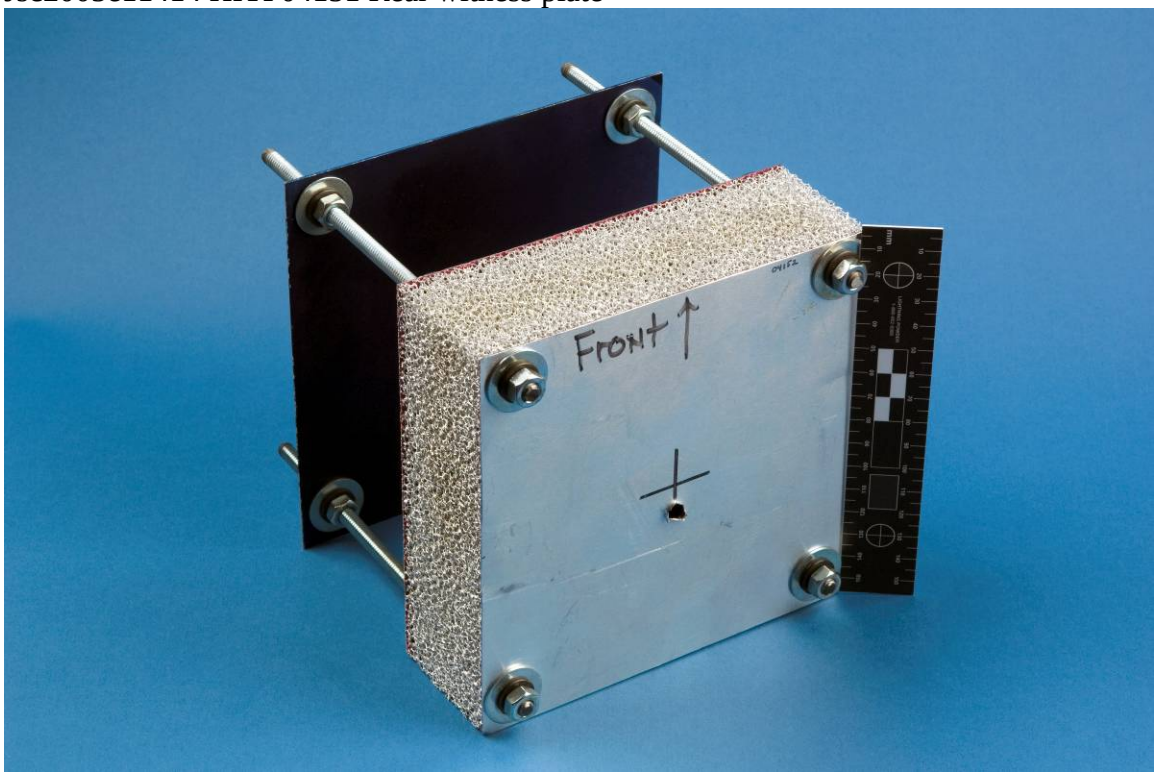

Figure A-28
Jsc2007e21462 HITF04152 Oblique

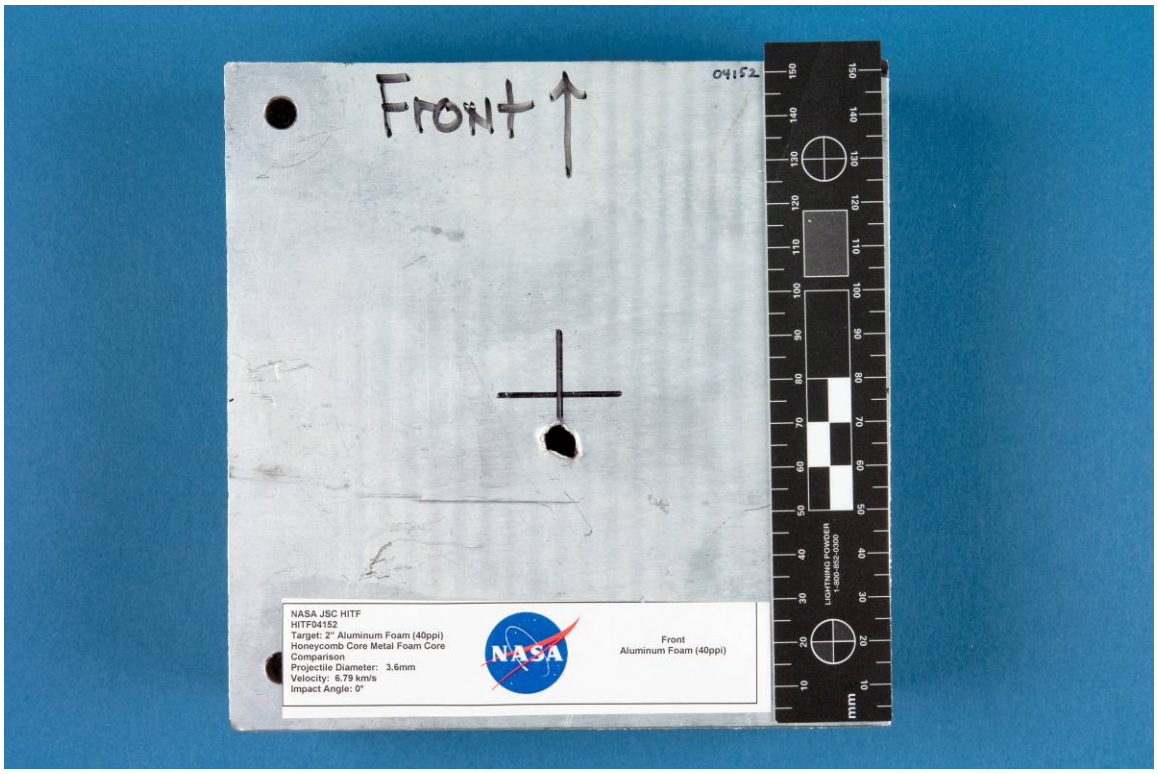

Figure A-29
Jsc2007e21467 HITF04152 Front, first facesheet

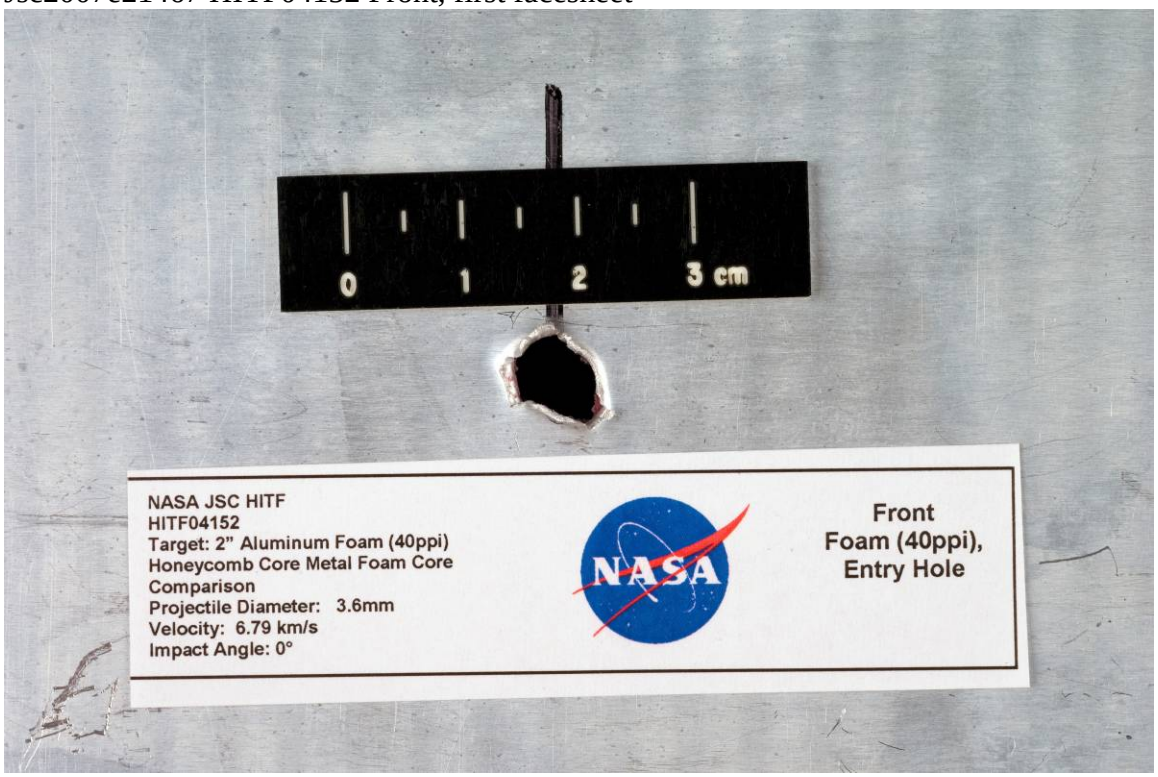

Figure A-30
Jsc2007e21477 HITF04152 Front, first facesheet

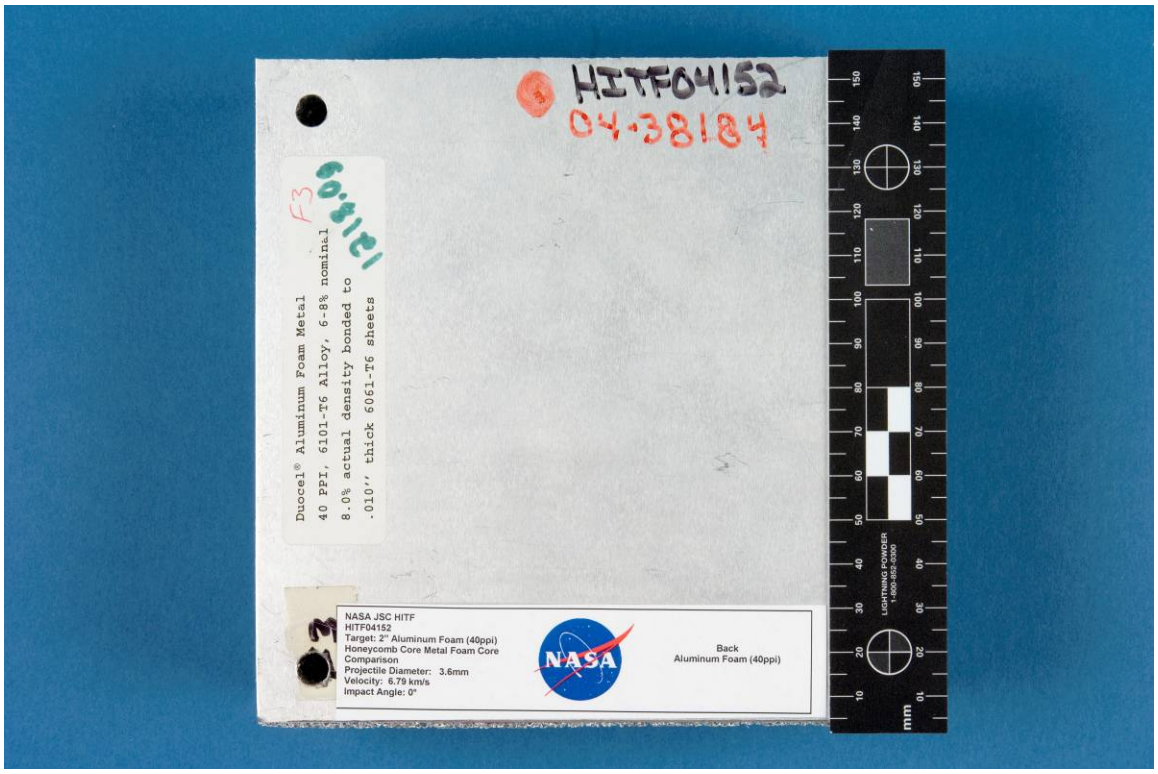

Figure A-31
Jsc2007e21468 HITF04152 Rear, second facesheet

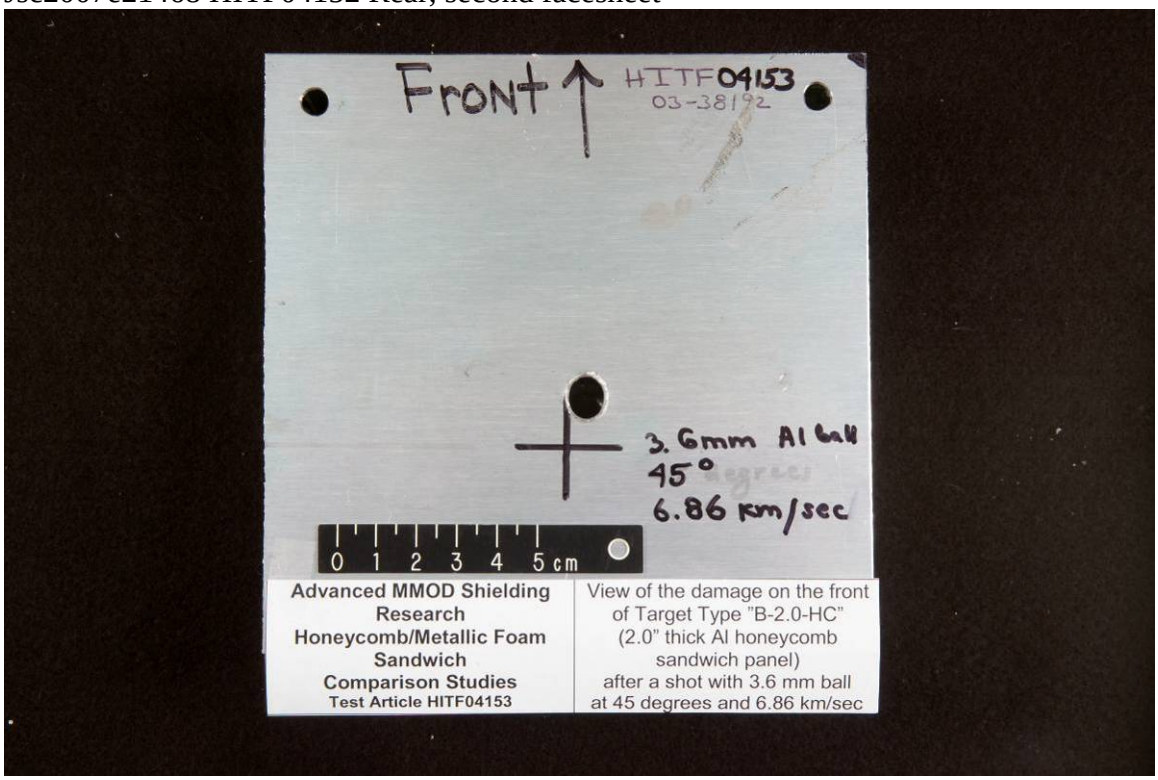

Figure A-32
Jsc2005e11286 HITF04153 Front, first facesheet

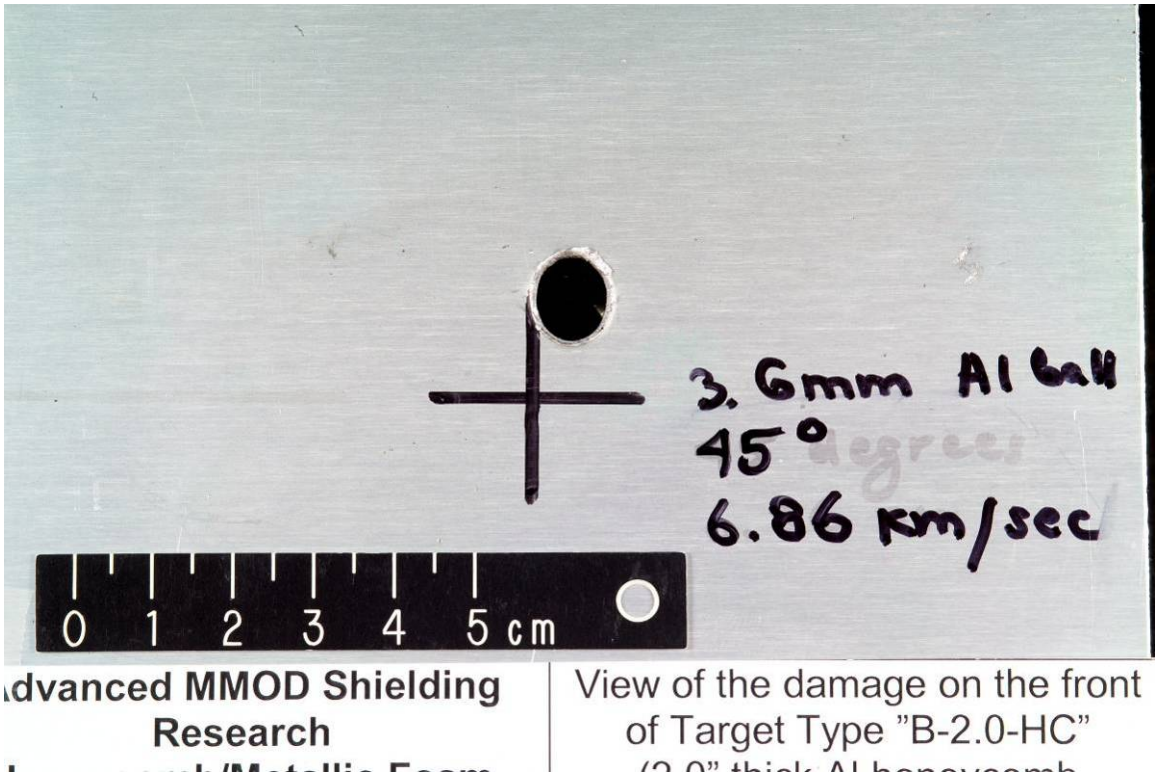

Figure A-33
Jsc2005e11287 HITF04153 Front, first facesheet

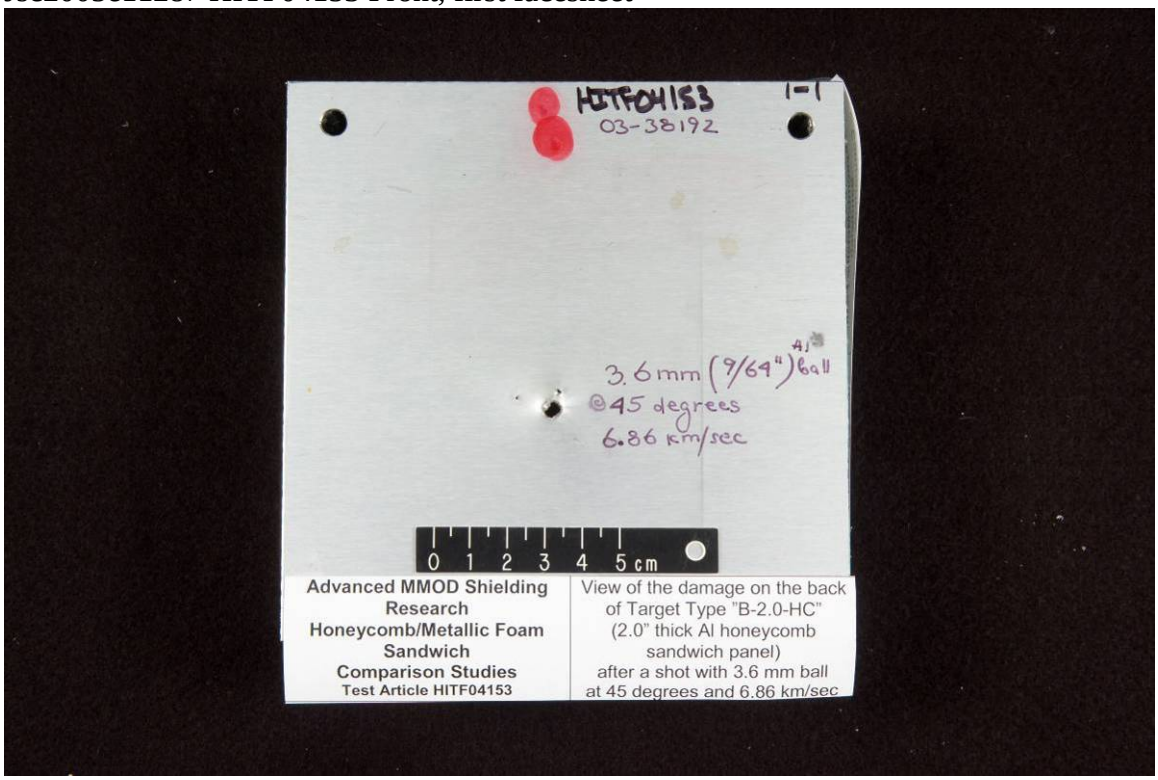

Figure A-34
Jsc2005e11283 HITF04153 Rear, second facesheet

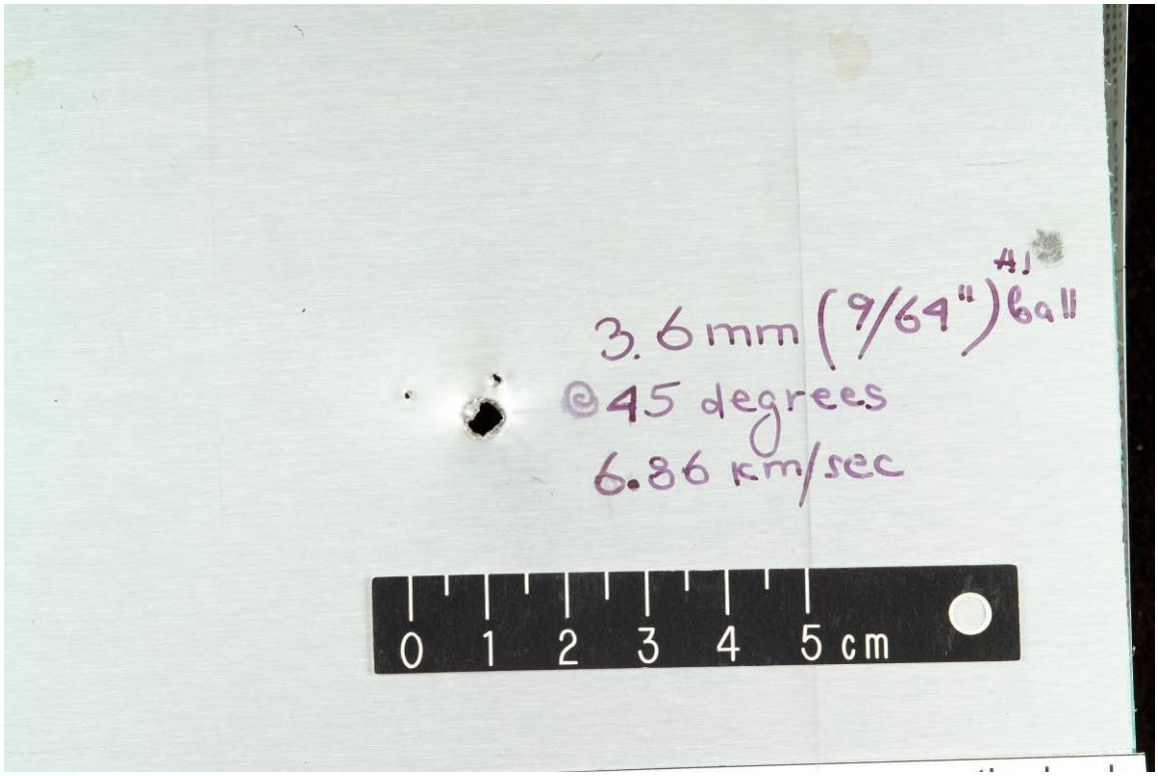

Figure A-35
Jsc2005e11284 HITF04153 Rear, second facesheet

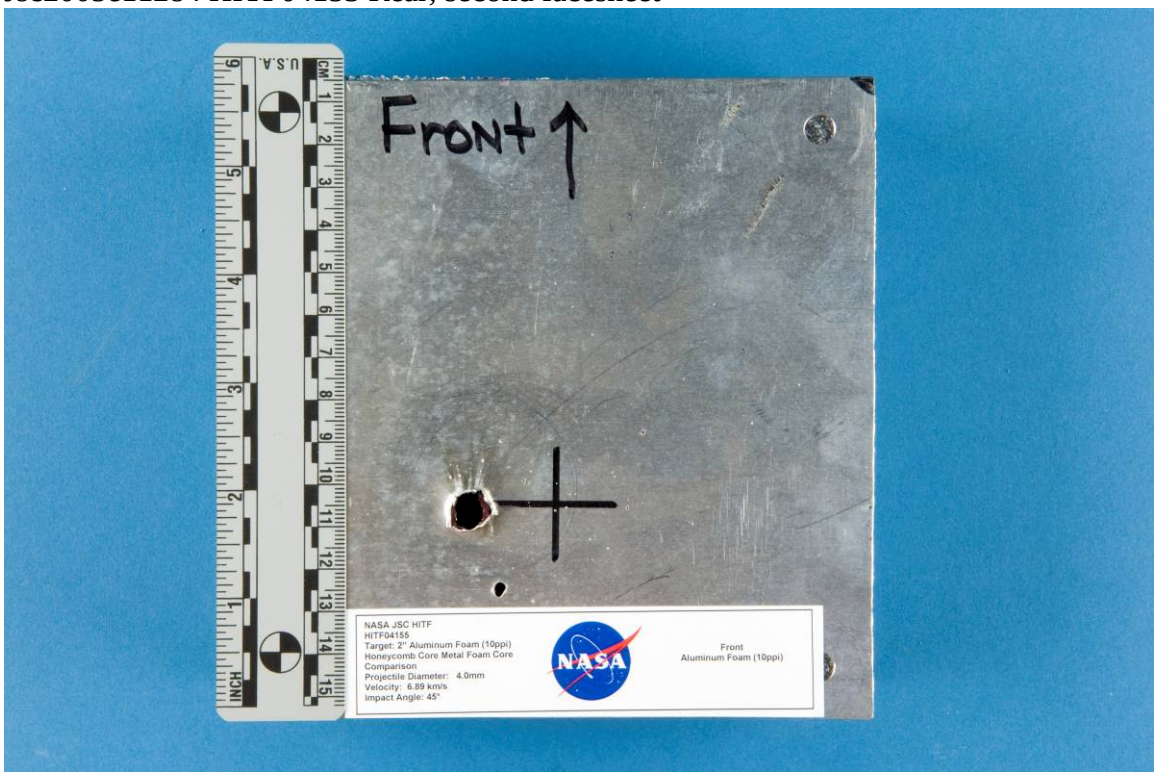

Figure A-36
Jsc2007e14139 HITF04155 Front, first facesheet

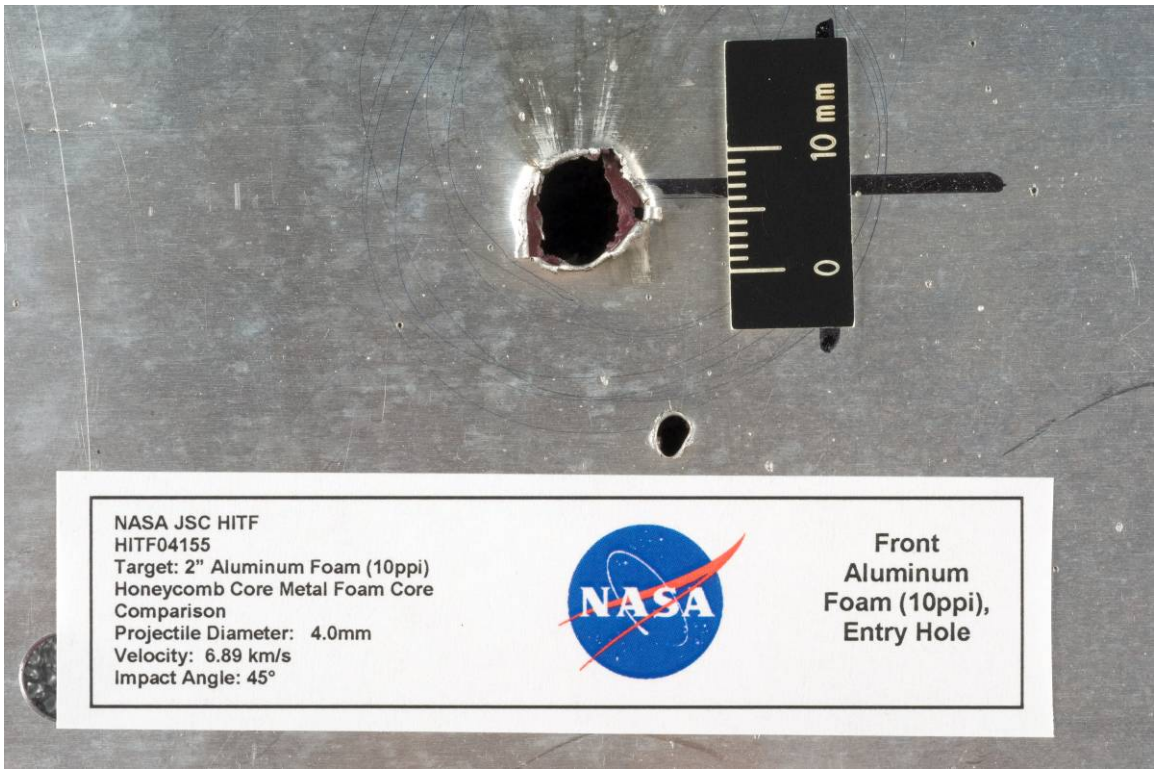

Figure A-37
Jsc2007e14196 HITF04155 Front, first facesheet

Figure A-38
Jsc2007e14140 HITF04155 Rear, second facesheet

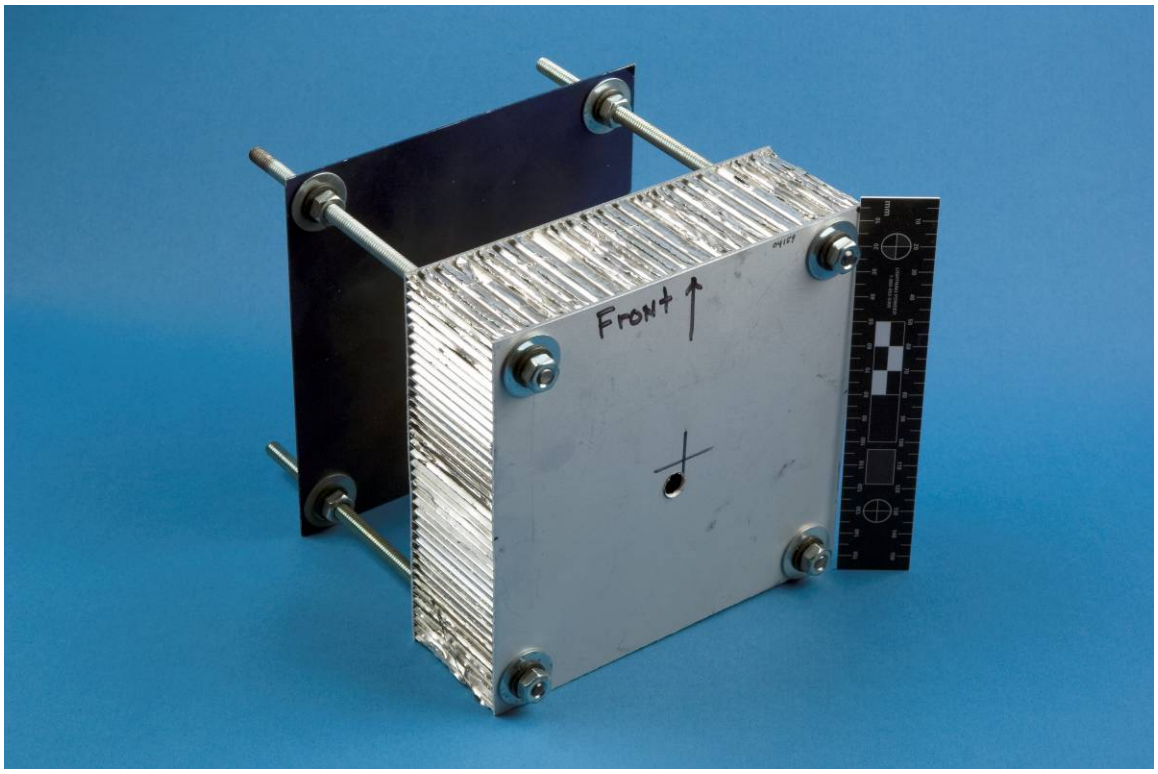

Figure A-39
Jsc2007e21461 HITF04159 Oblique

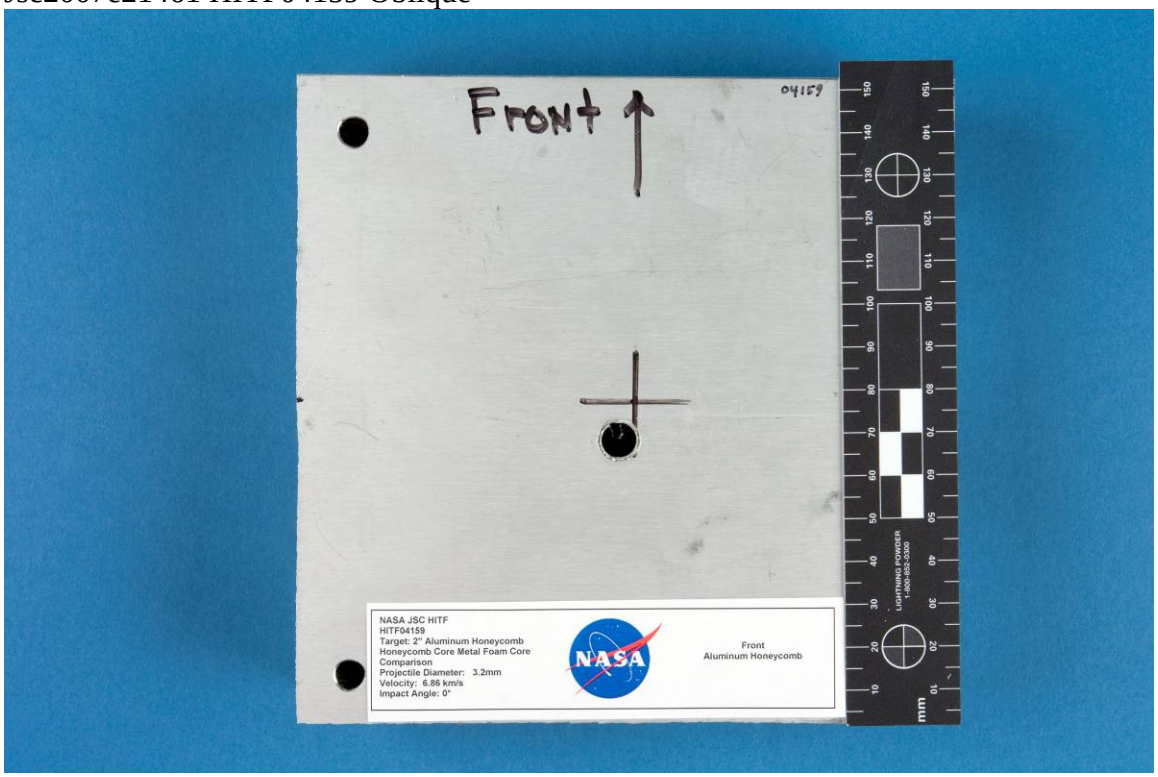

Figure A-40
Jsc2007e21463 HITF04159 Front, facesheet

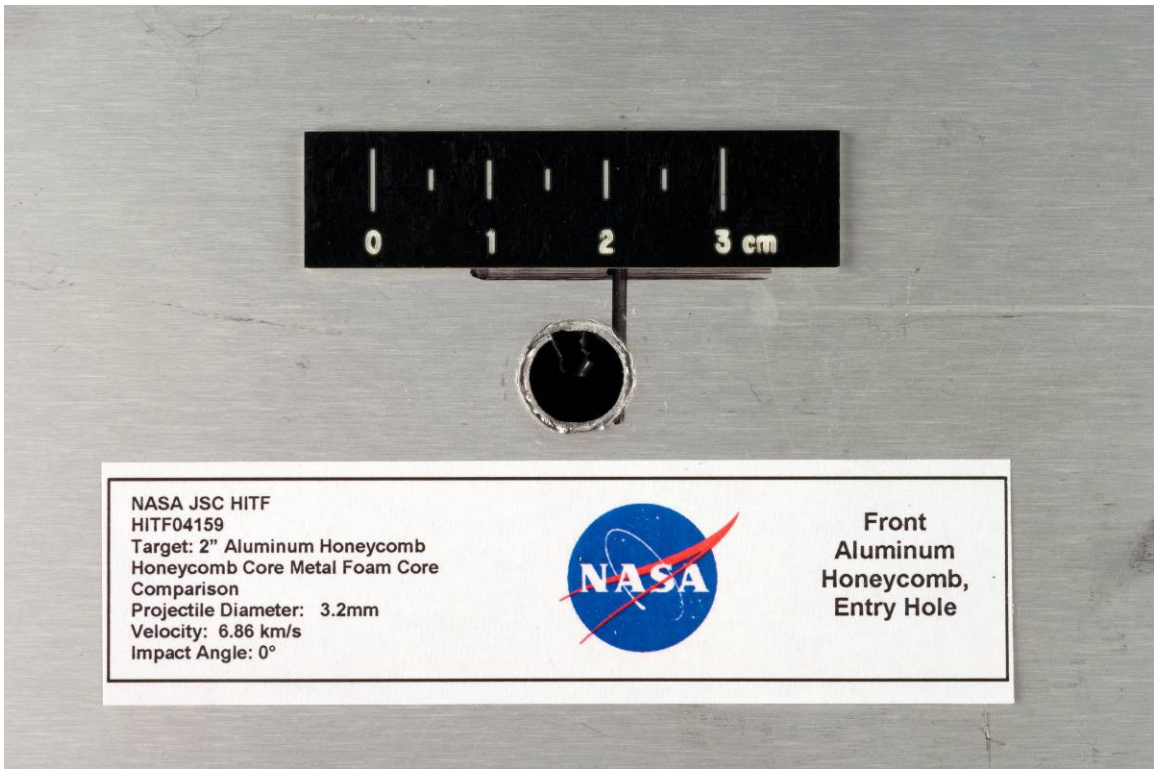

Figure A-41
Jsc2007e21478 HITF04159 Front, first facesheet

Figure A-42
Jsc2007e21464 HITF04159 Rear, second facesheet

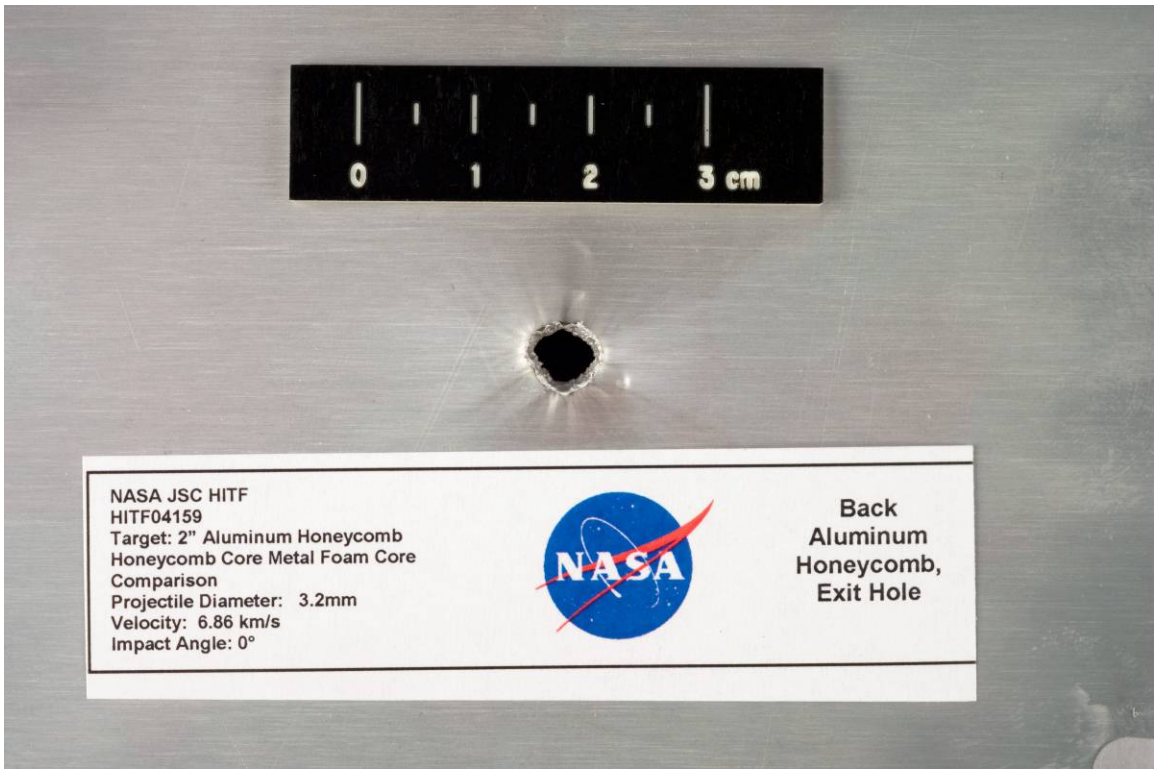

Figure A-43
Jsc2007e21479 HITF04159 Rear, second facesheet

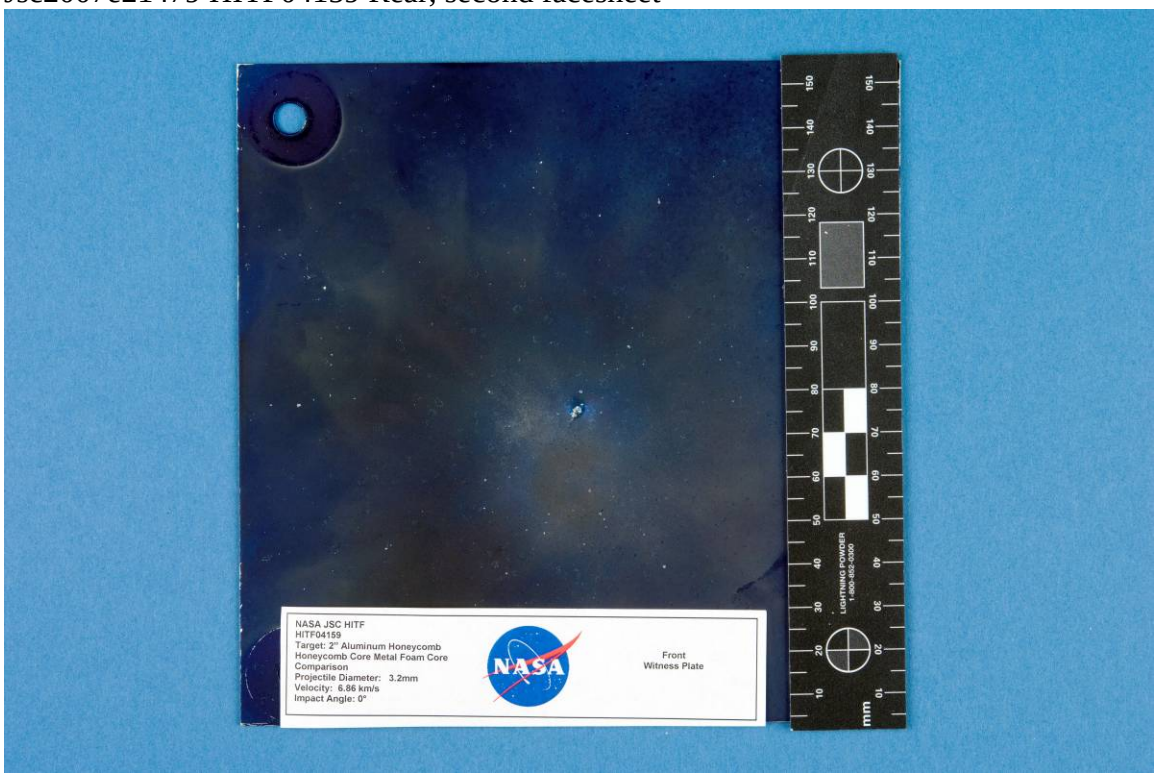

Figure A-44
Jsc2007e21465 HITF04159 Front, witness plate

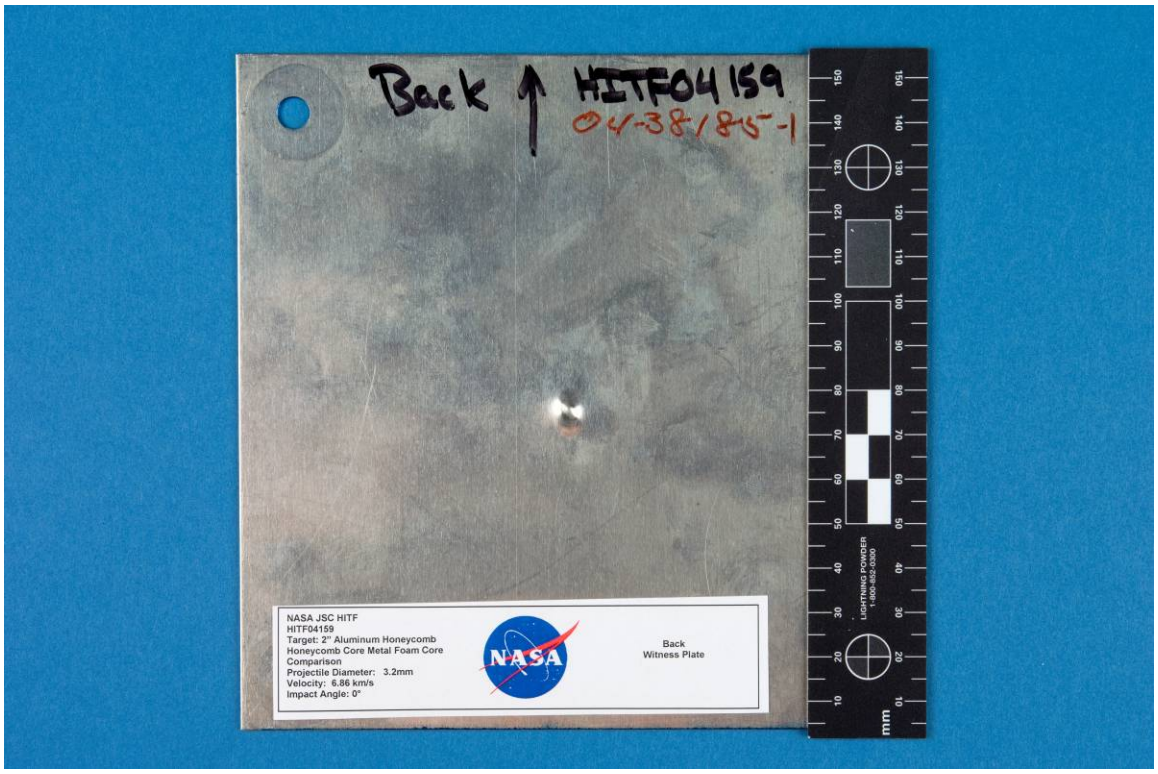

Figure A-45
Jsc2007e21466 HITF04159 Rear, witness plate

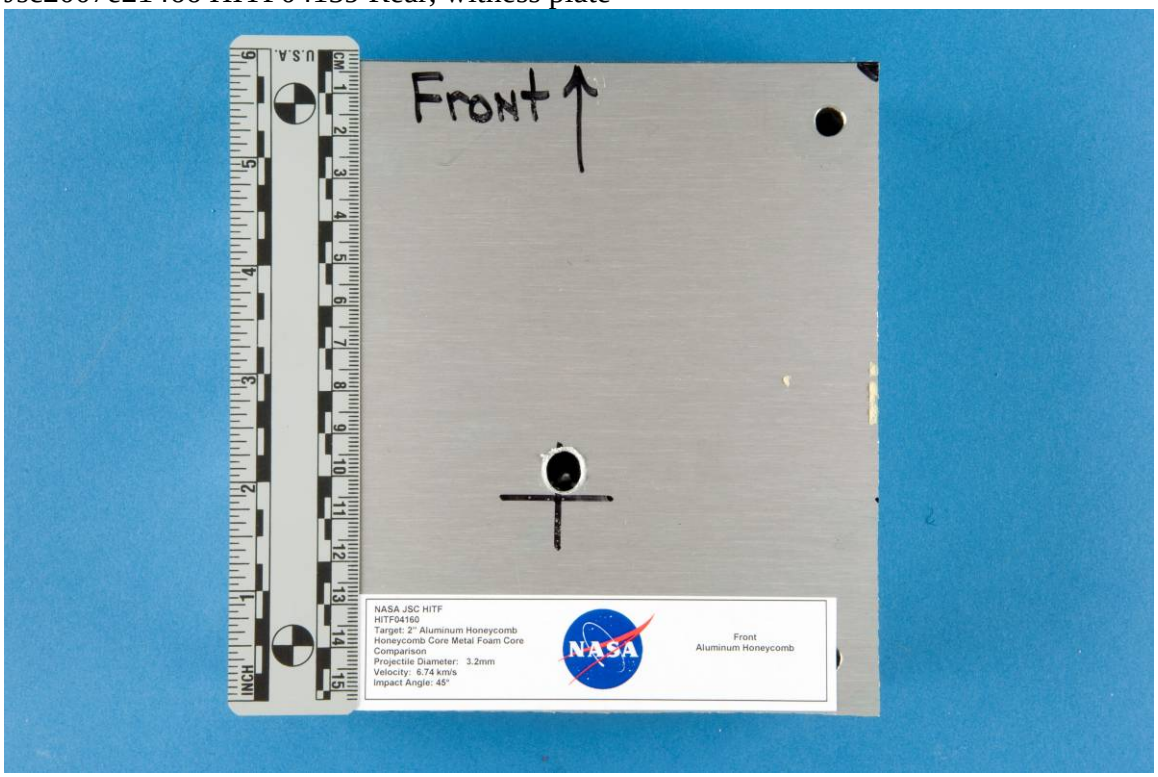

Figure A-46
Jsc2007e14147 HITF04160 Front, first facesheet

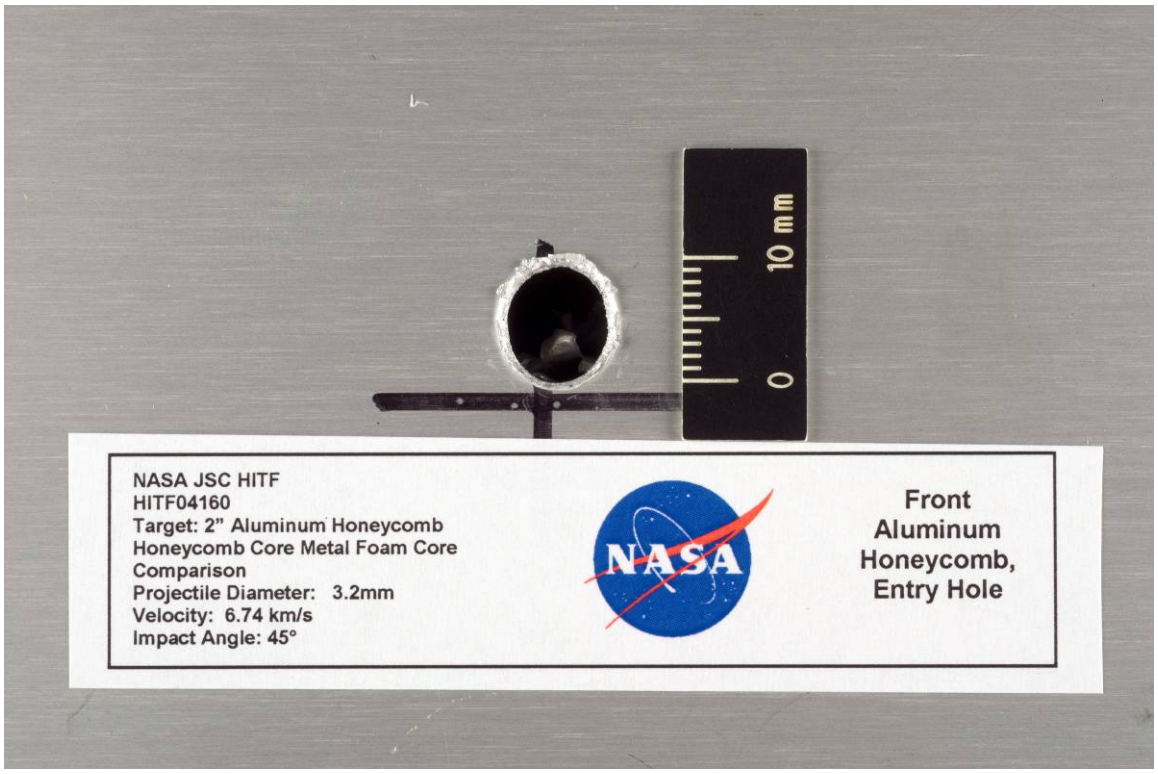

Figure A-47
Jsc2007e14197 HITF04160 Front, first facesheet

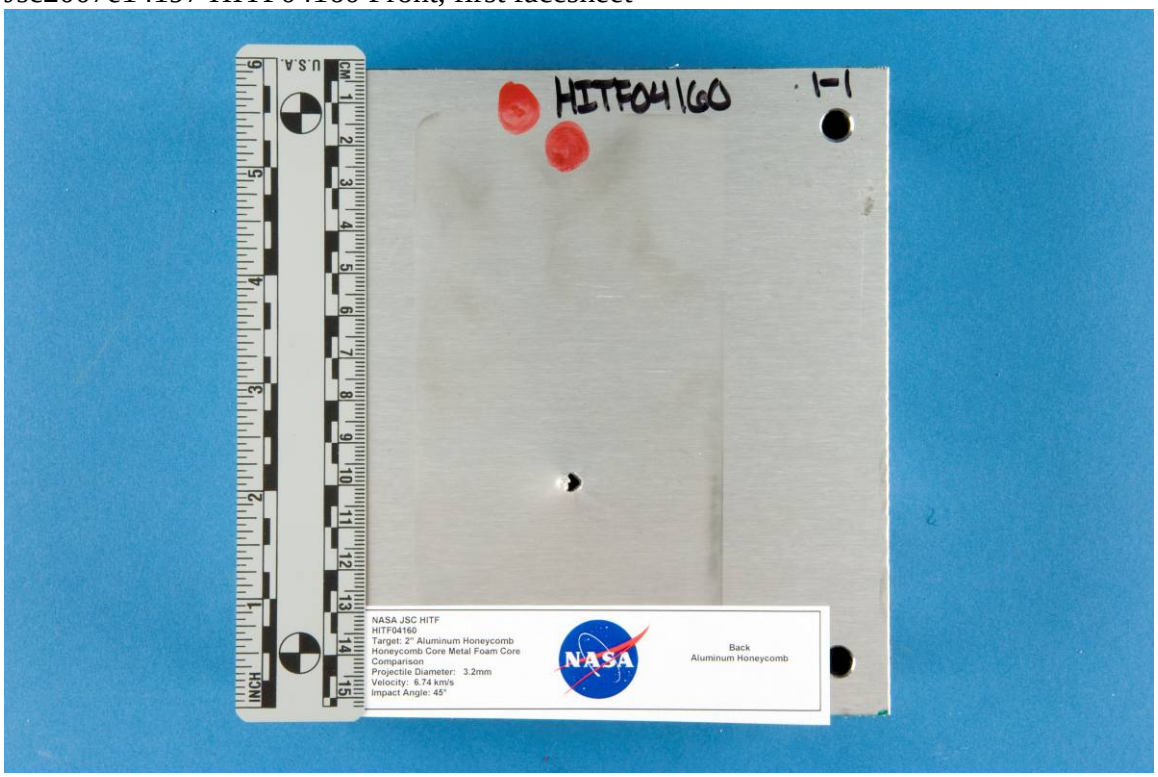

Figure A-48
Jsc2007e14148 HITF04160 Rear, second facesheet

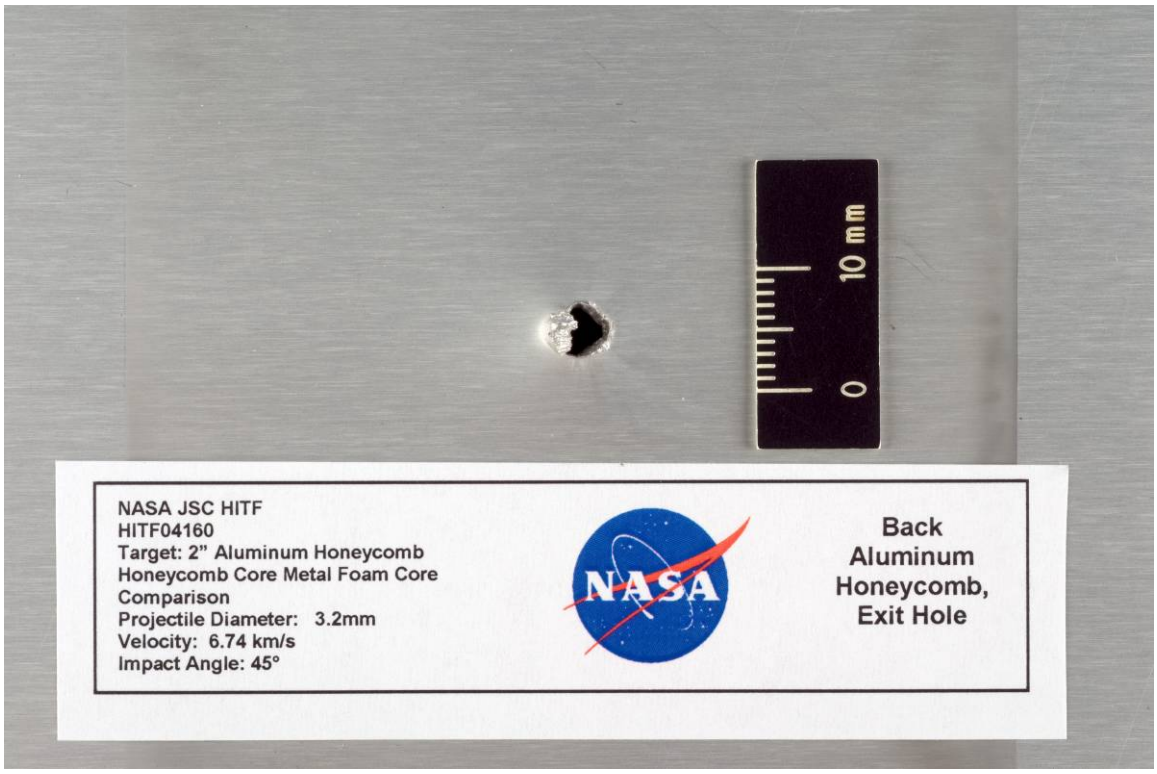

Figure A-49
Jsc2007e14198 HITF04160 Rear, second facesheet

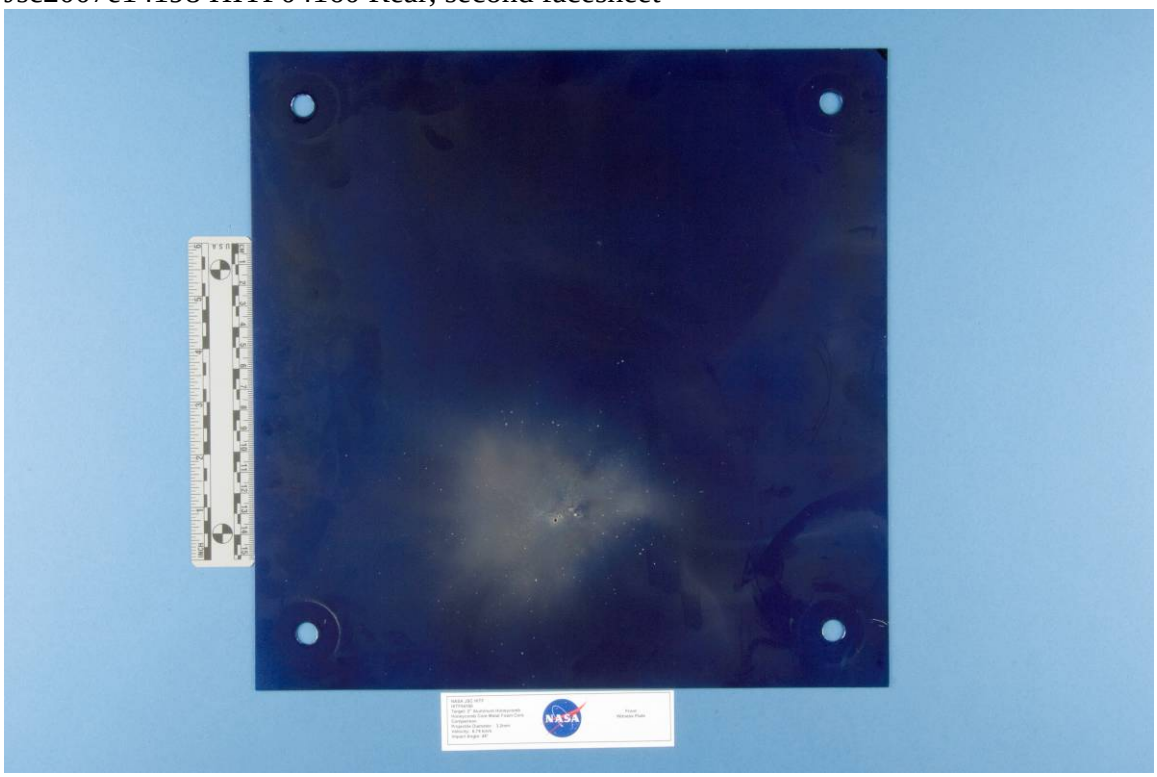

Figure A-50
Jsc2007e14149 HITF04160 Front, witness plate

Figure A-51
Jsc2007e14150 HITF04160 Rear, witness plate

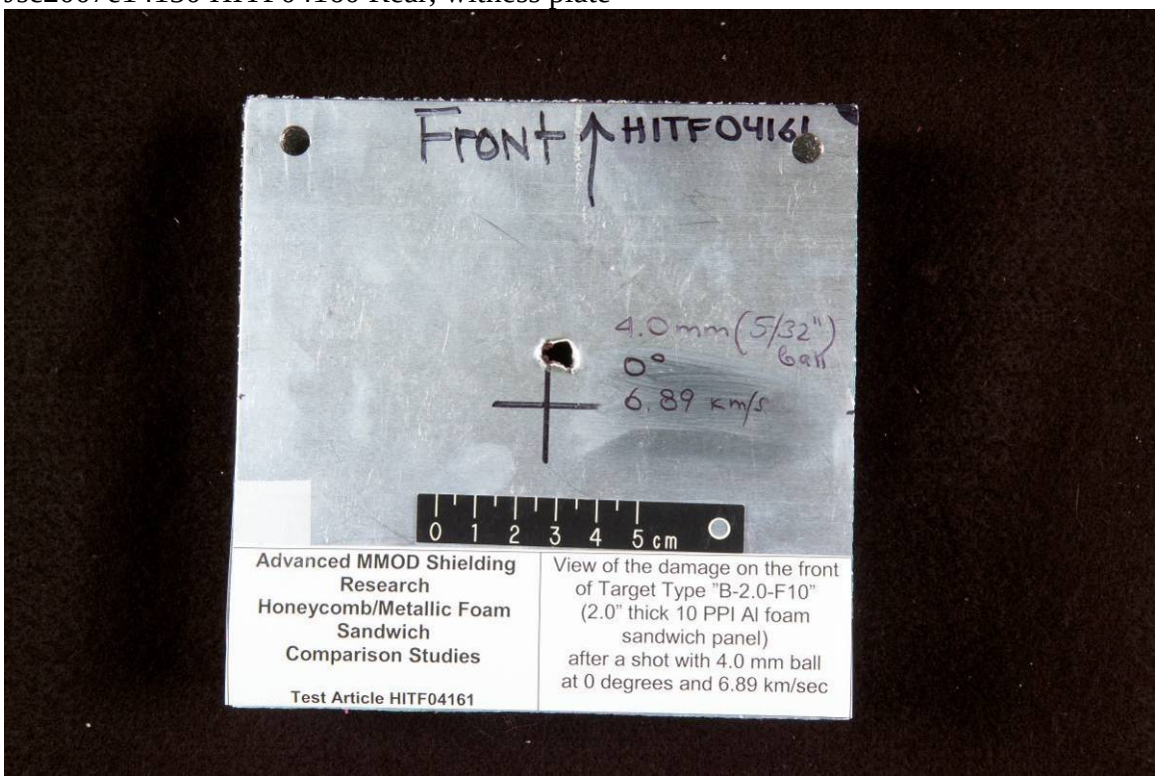

Figure A-52
Jsc2005e11323 HITF04161 Front, first facesheet

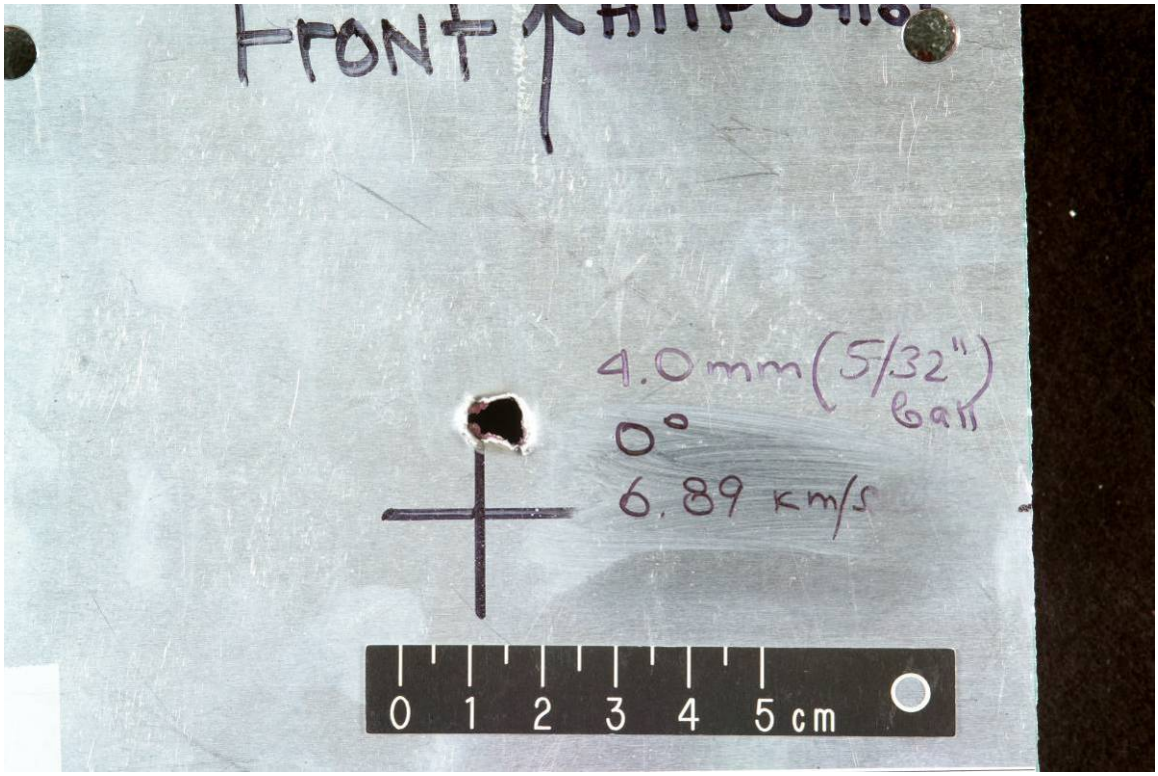

Figure A-53
Jsc2005e11322 HITF04161 Front, first facesheet

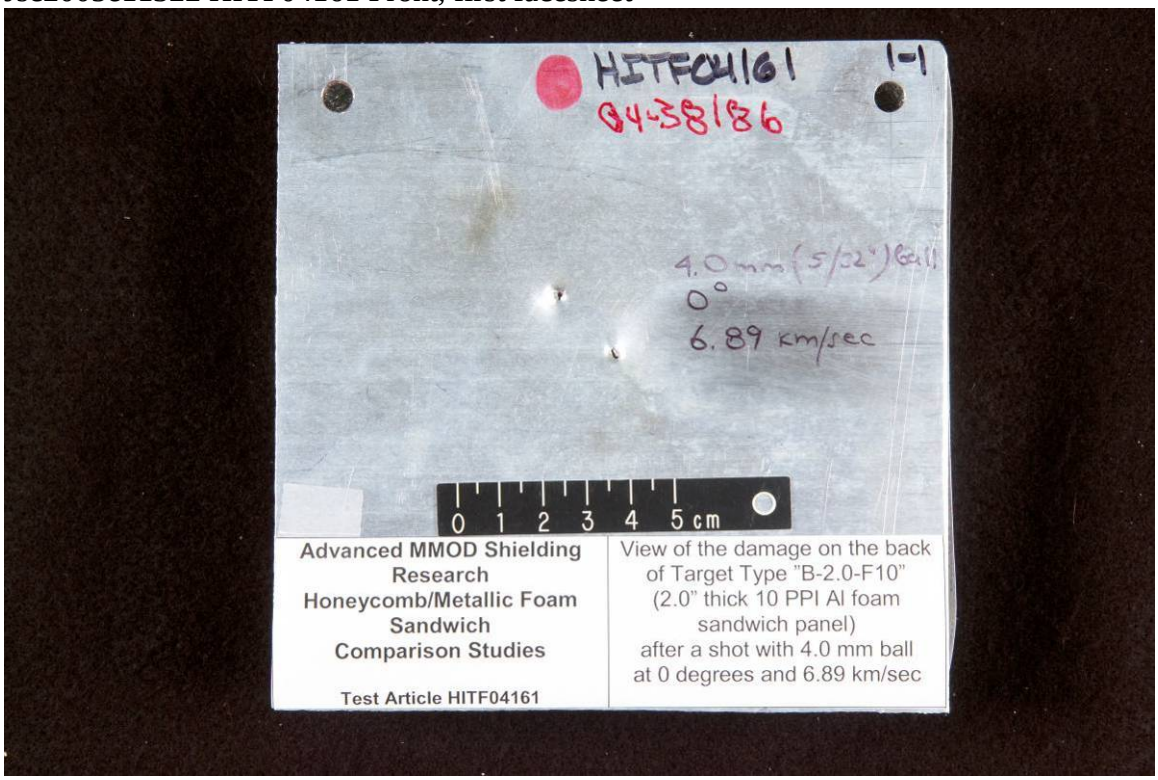

Figure A-54
Jsc2005e11320 HITF04161 Rear, second facesheet

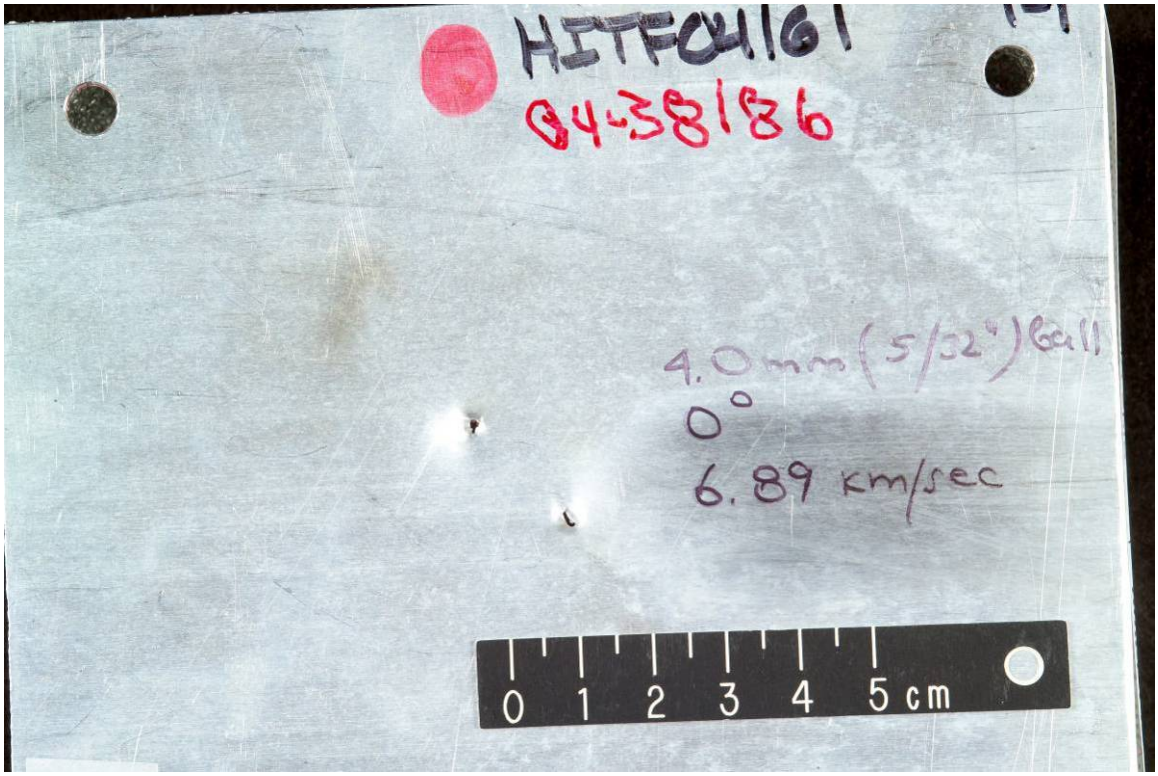

Figure A-55
Jsc2005e11321 HITF04161 Rear, second facesheet

Figure A-56
Jsc2005e11326 HITF04161 Front witness plate

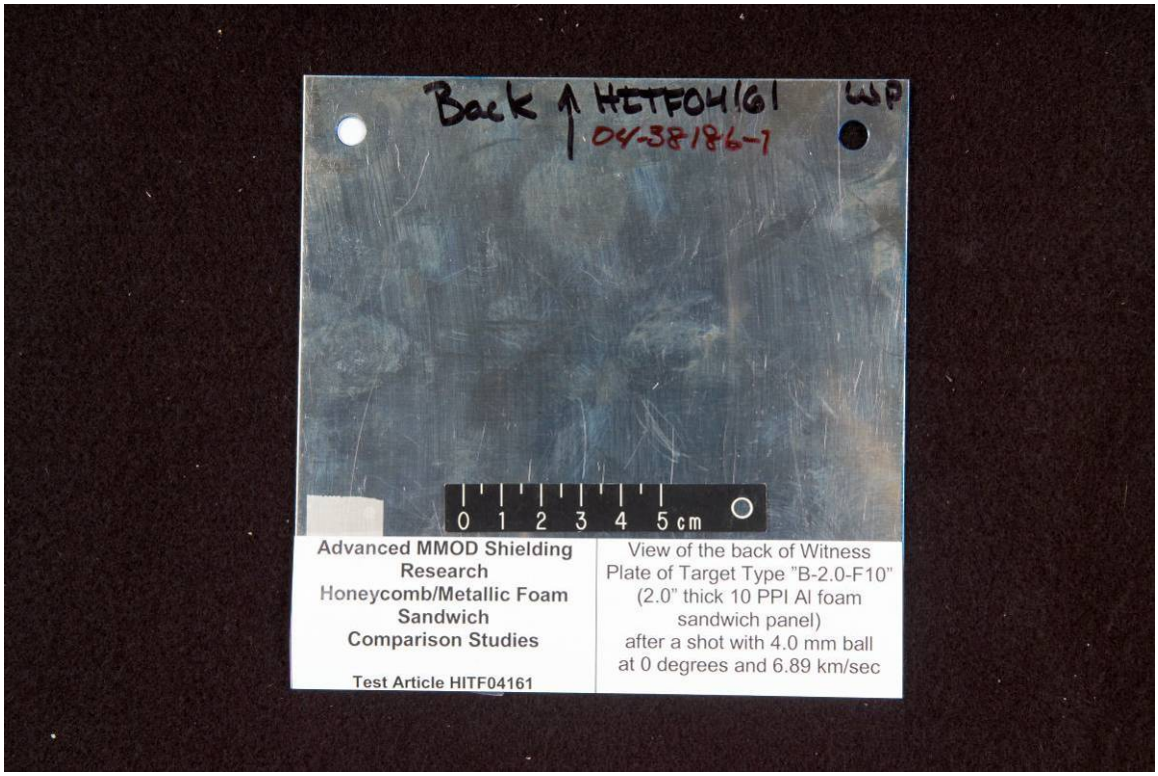

Figure A-57
Jsc2005e11325 HITF04161 Rear witness plate

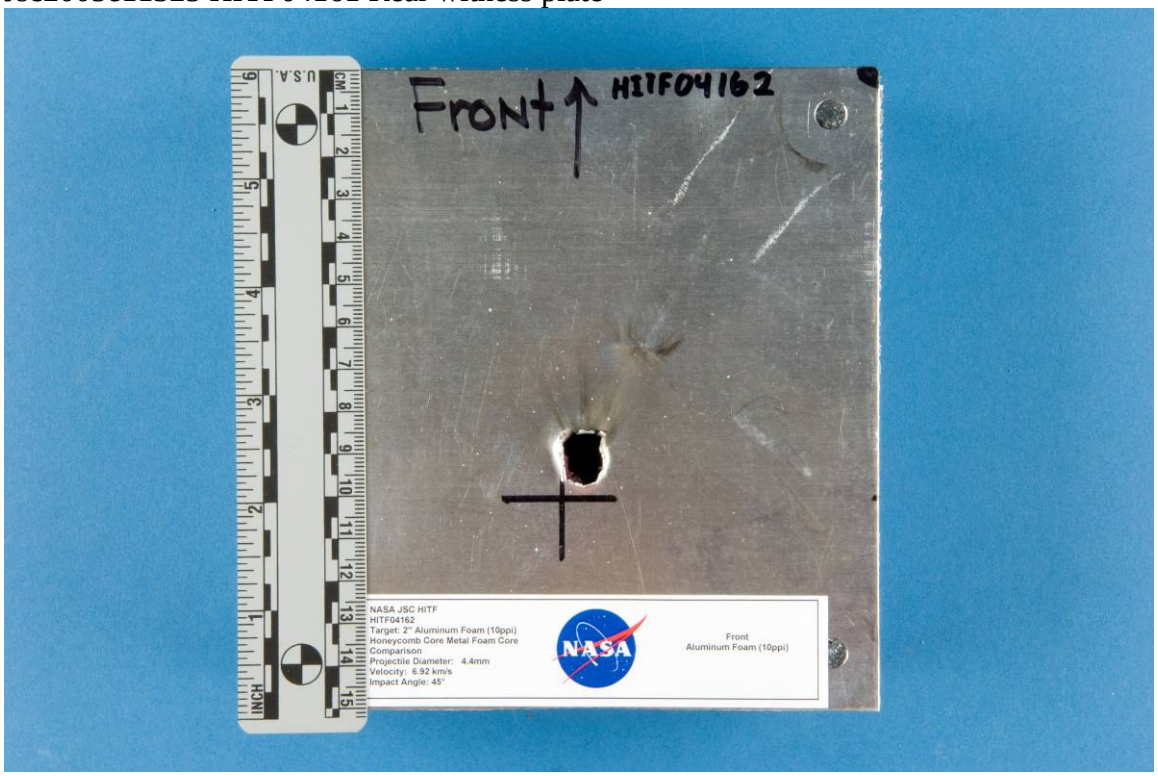

Figure A-58
Jsc2007e14141 HITF04162 Front, first facesheet

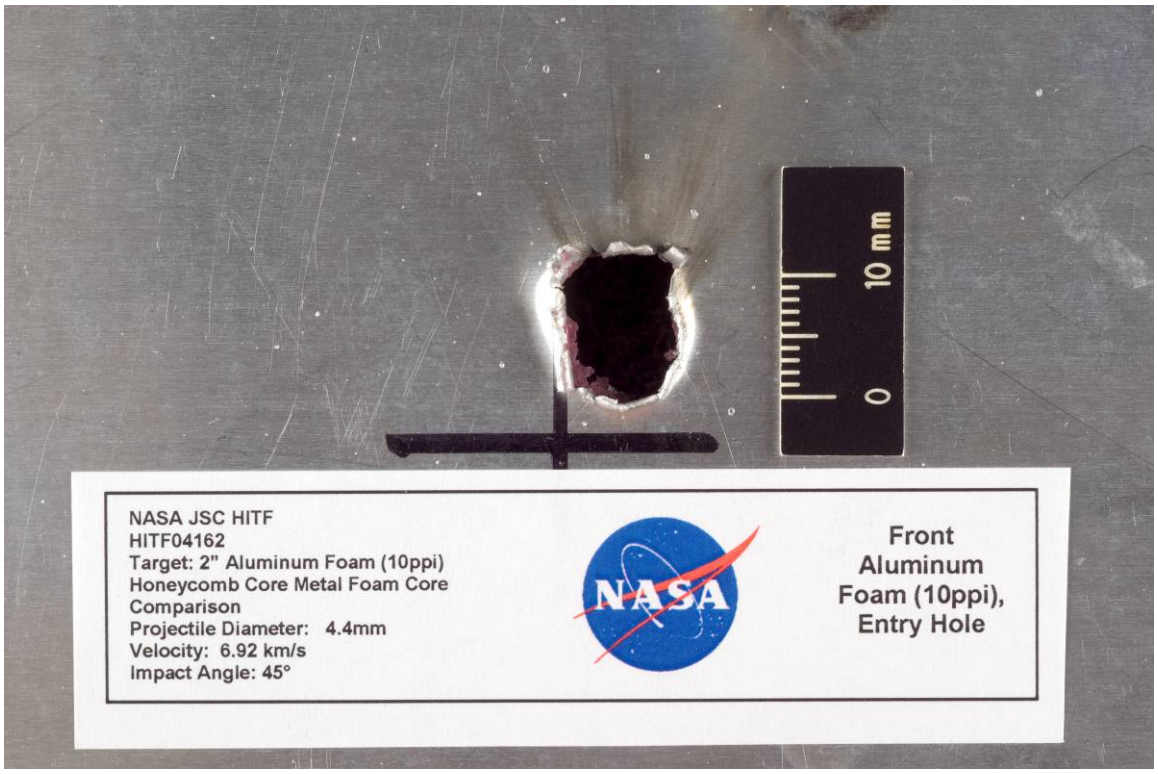

Figure A-59
Jsc2007e14199 HITF04162 Front, first facesheet

Figure A-60
Jsc2007e14142 HITF04162 Rear, second facesheet

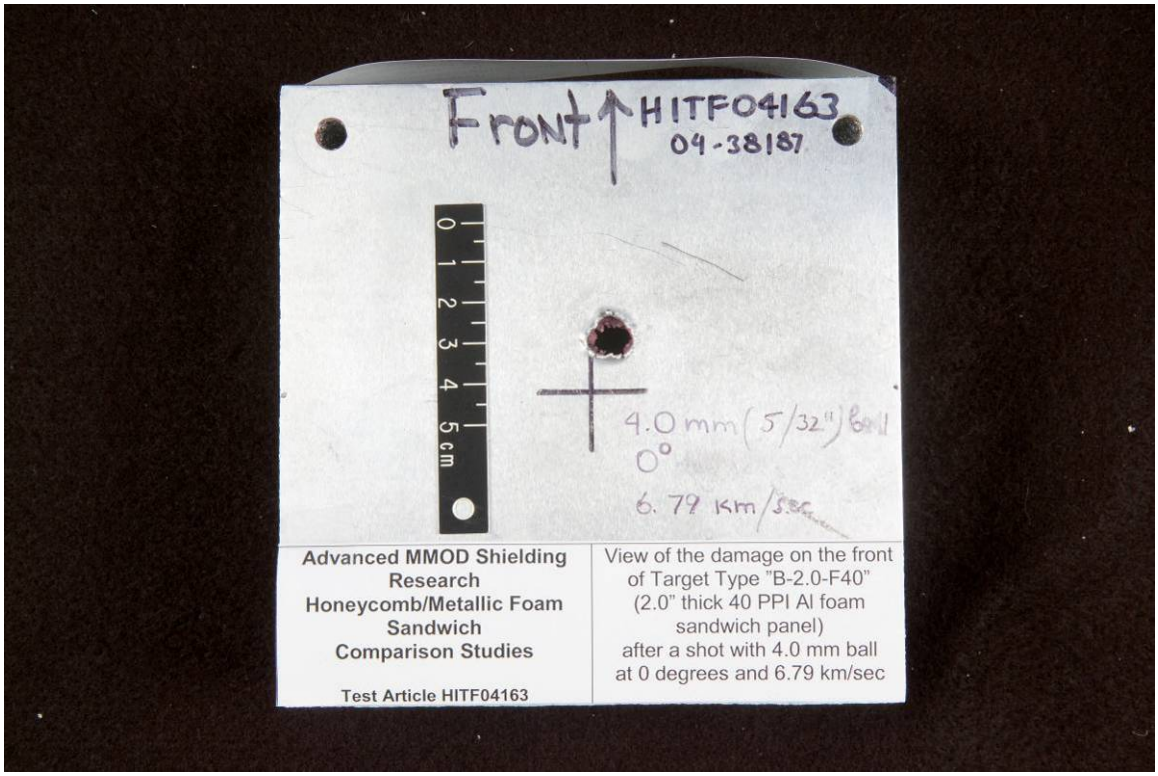

Figure A-61
Jsc2005e11314 HITF04163 Front, first facesheet

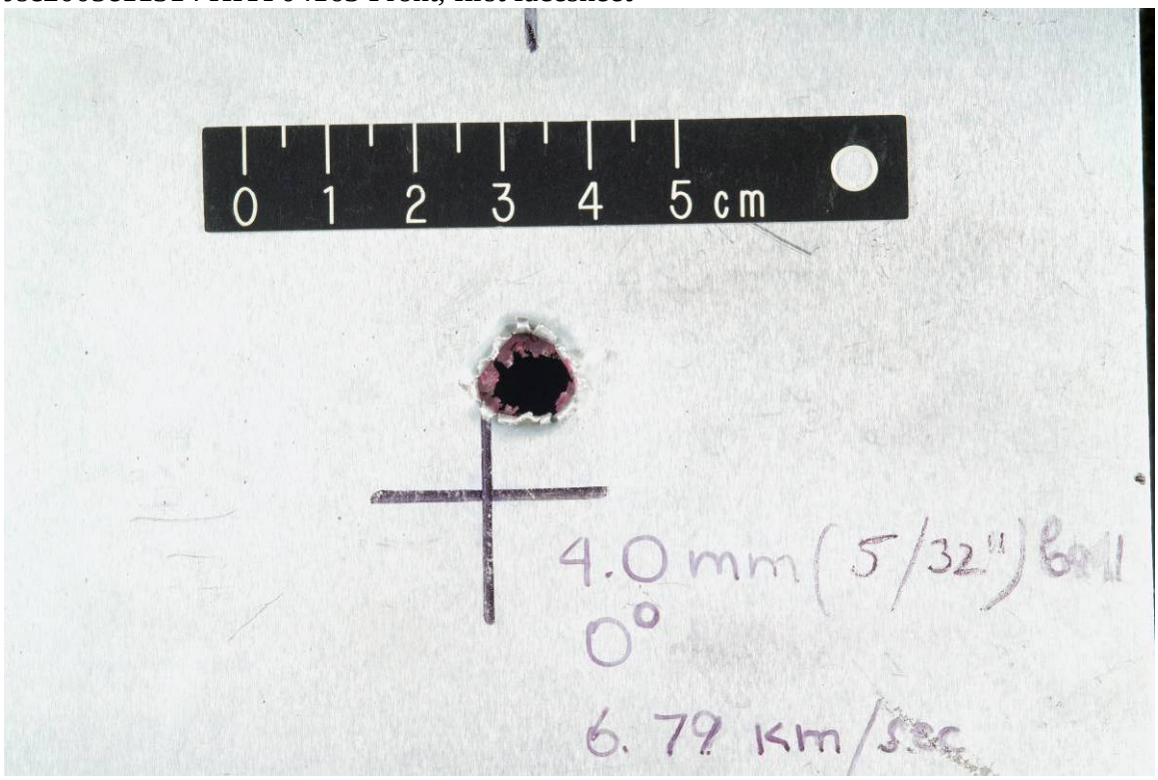

Figure A-62
Jsc2005e11315 HITF04163 Front, first facesheet

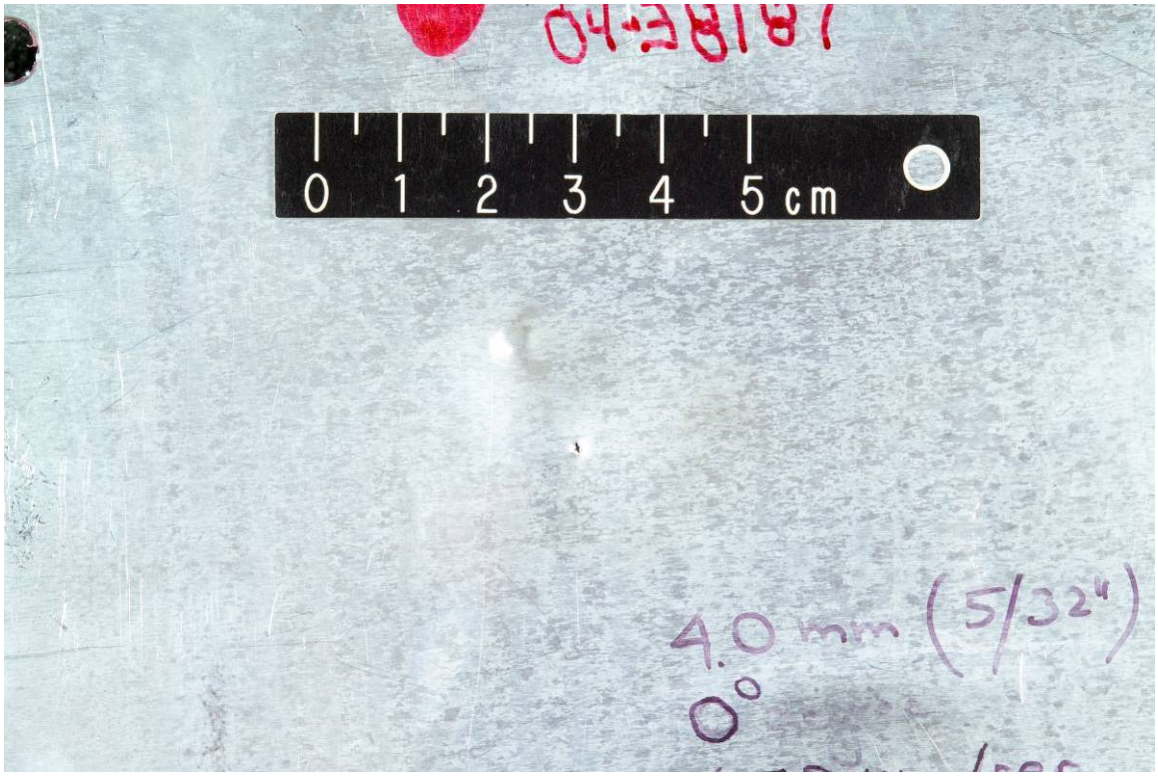

Figure A-63
Jsc2005e11316 HITF04163 Rear, second facesheet

Figure A-64
Jsc2005e11319 HITF04163 Front witness plate

Figure A-65
Jsc2005e11318 HITF04163 Rear, second facesheet

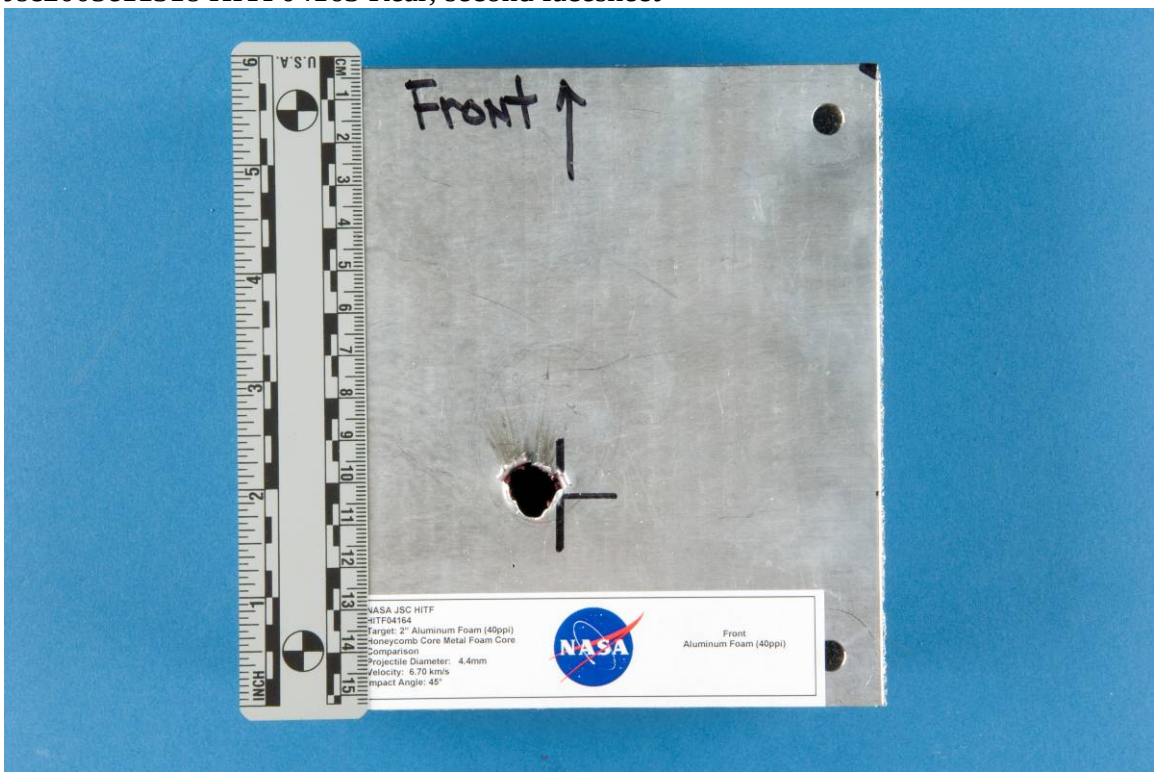

Figure A-66
Jsc2007e14143 HITF04164 Front, first facesheet

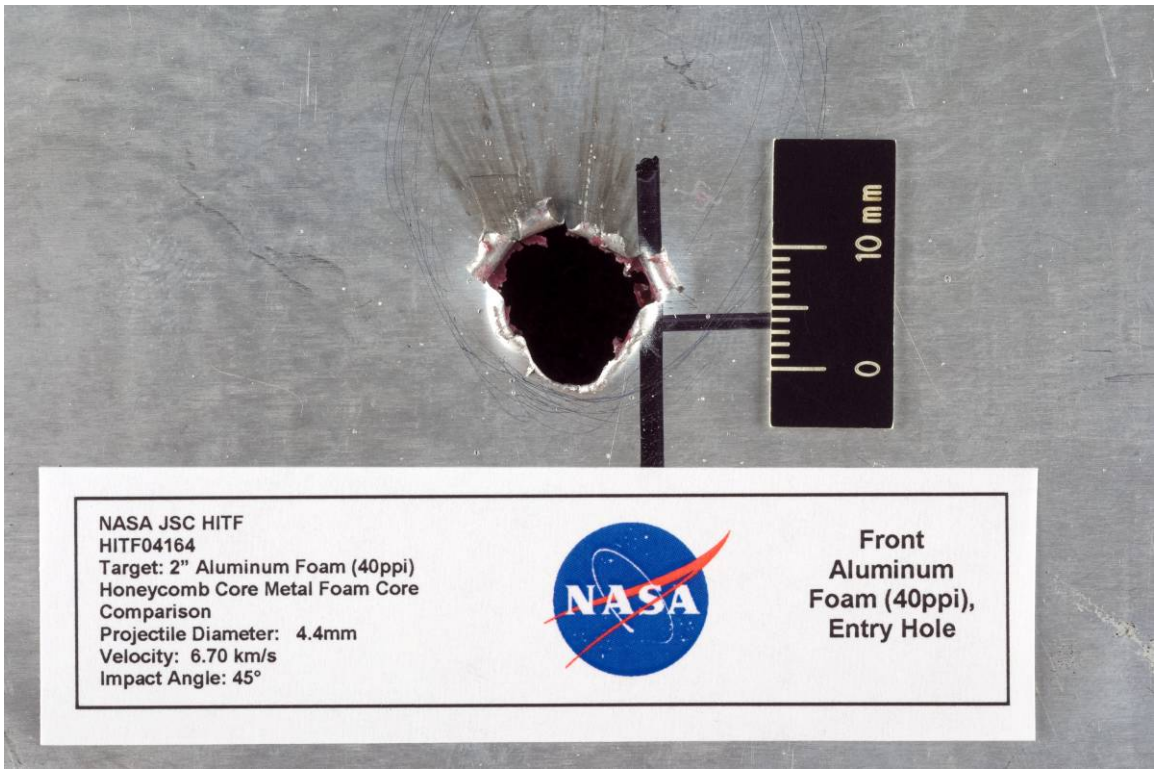

Figure A-67
Jsc2007e14200 HITF04164 Front, first facesheet

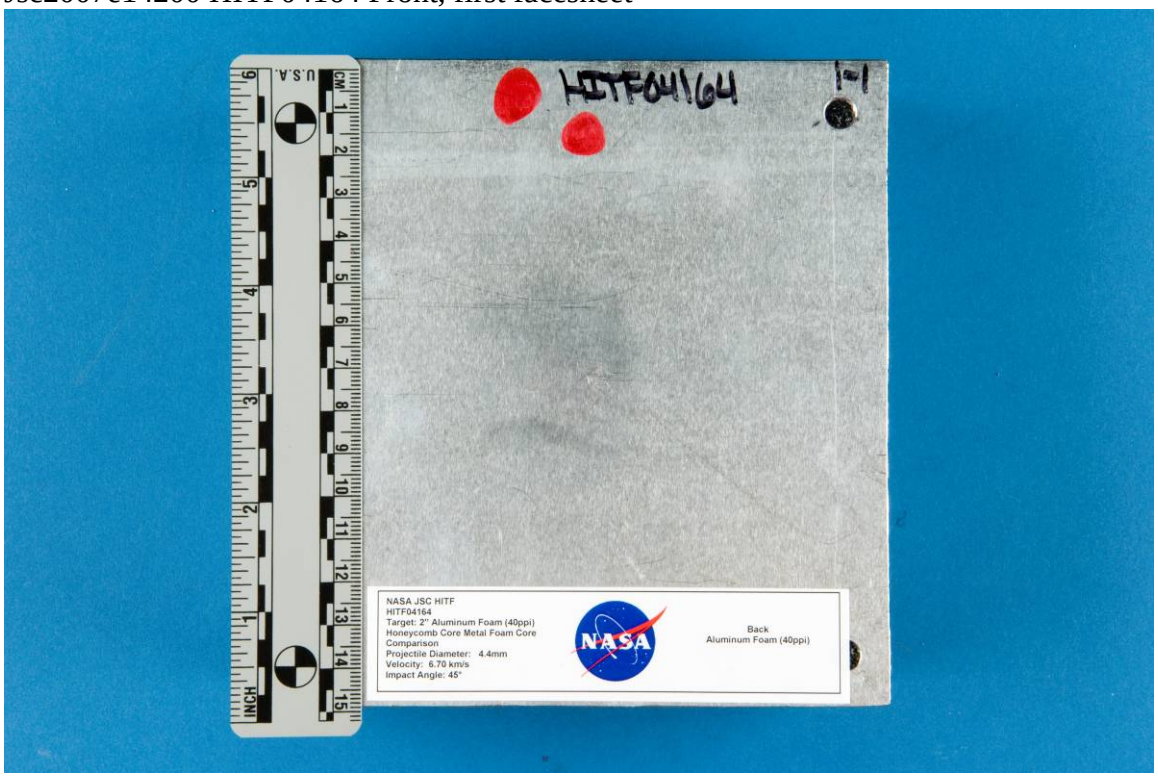

Figure A-68
Jsc2007e14144 HITF04164 Rear, second facesheet

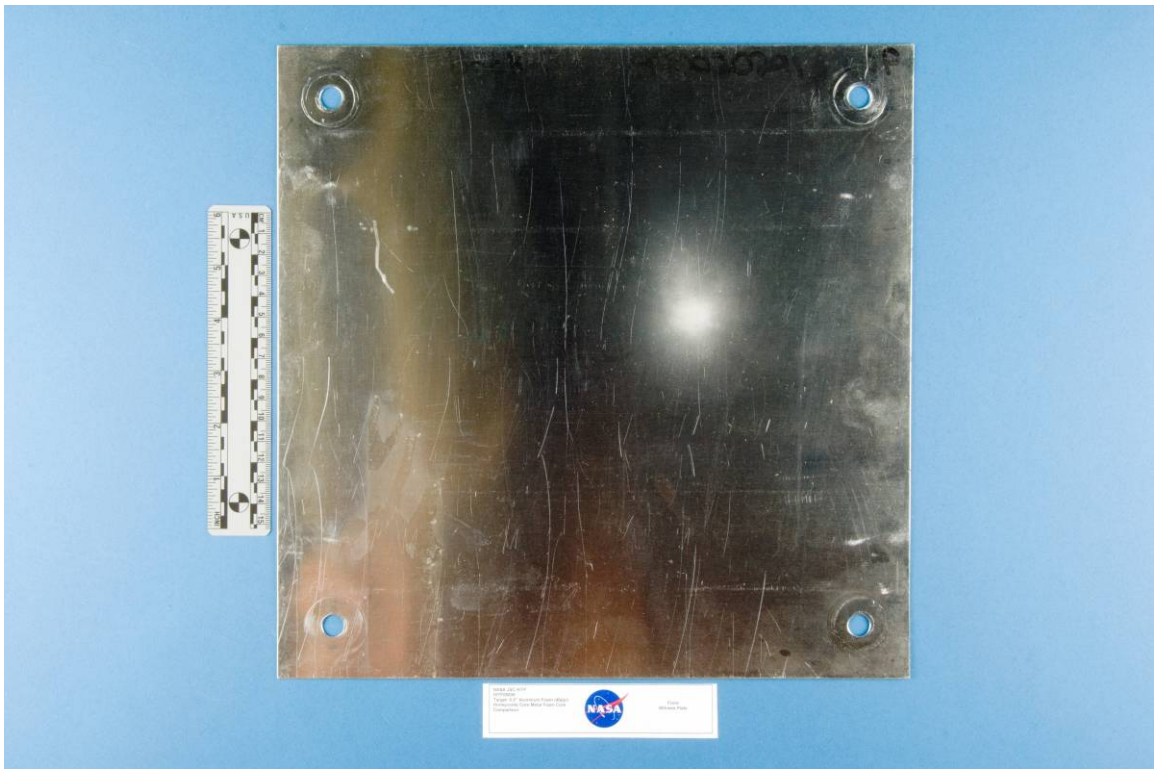

Figure A-69
Jsc2007e14151 HITF05036 Front, witness plate

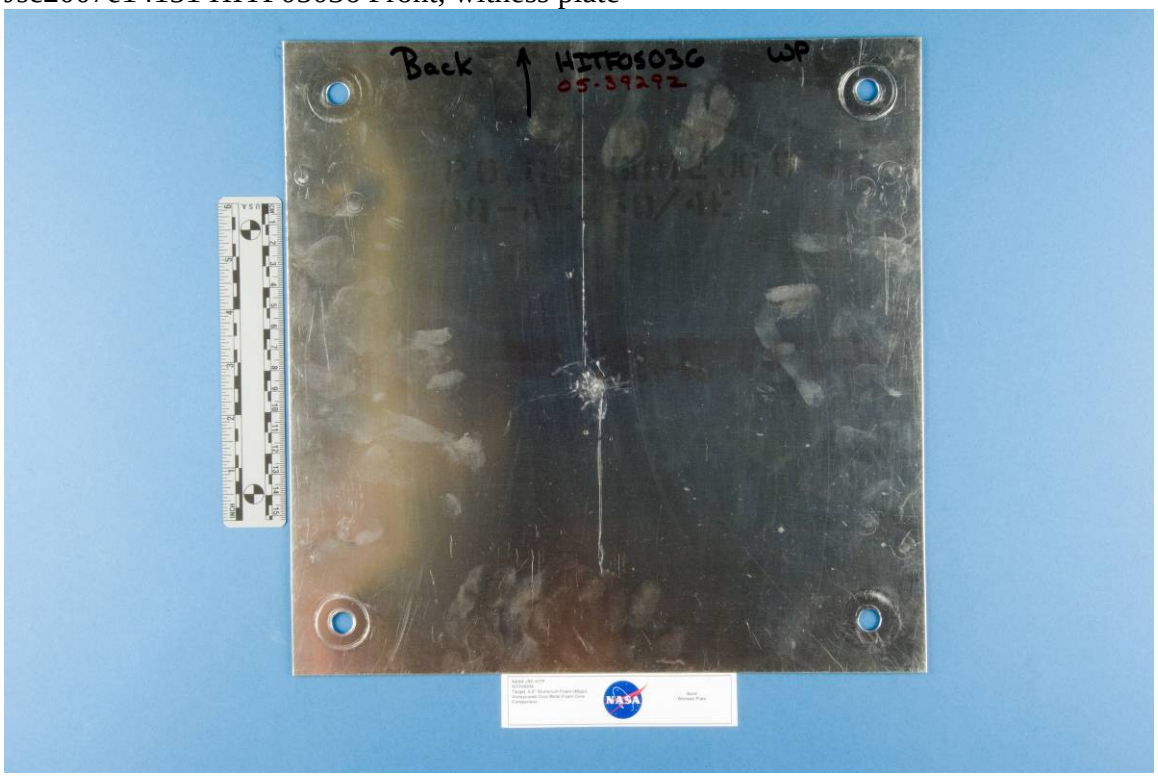

Figure A-70
Jsc2007e14152 HITF05036 Rear, witness plate

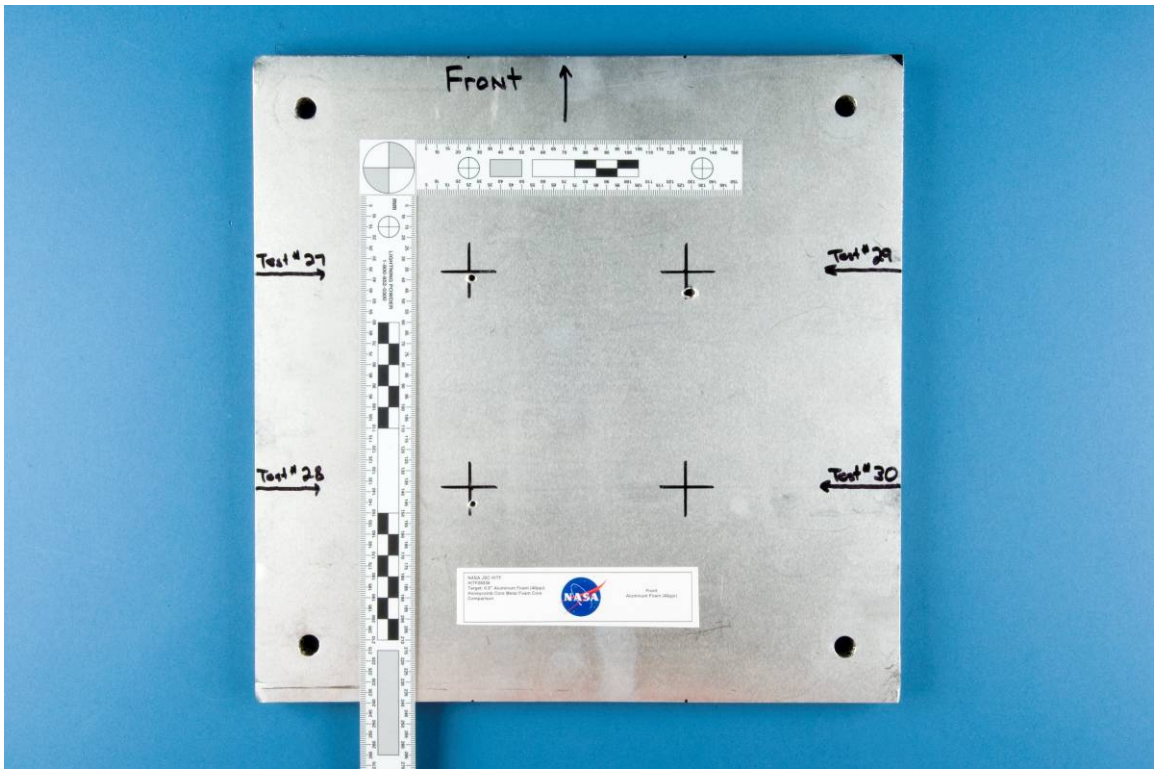

Figure A-71
Jsc2007e14153 HITF05036 Front, first facesheet

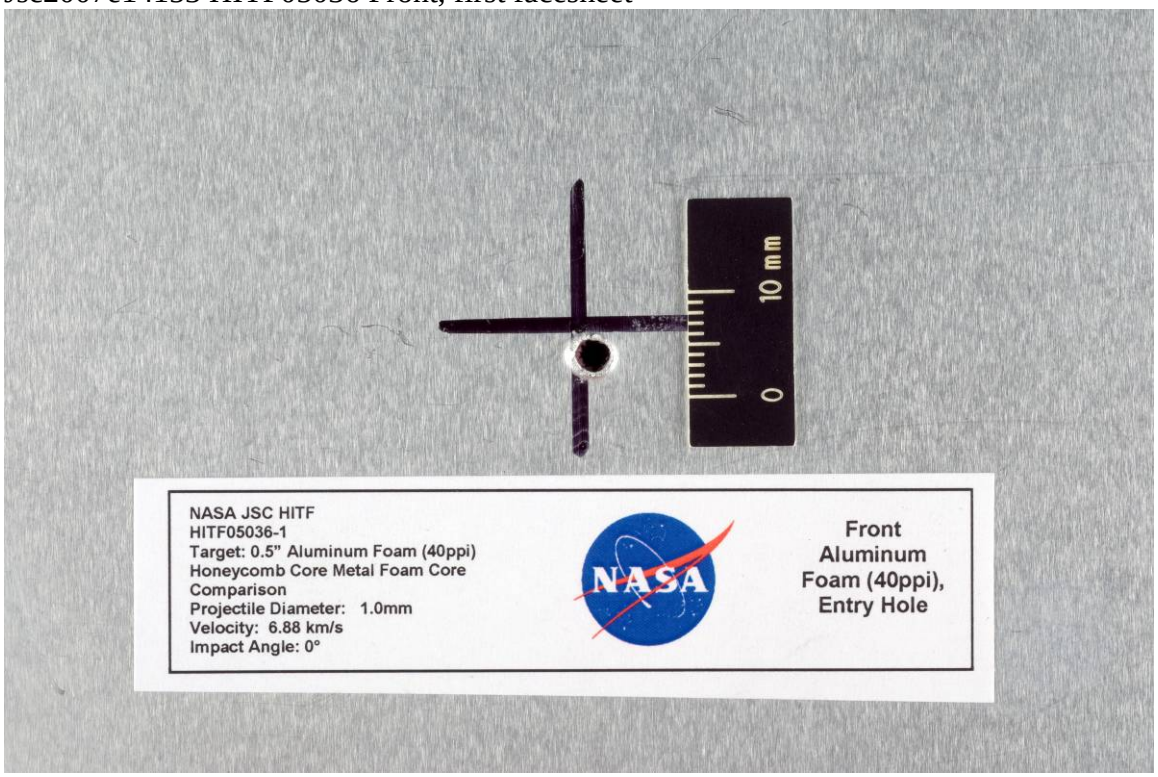

Figure A-72
Jsc2007e14179 HITF05036-1 Front, first facesheet

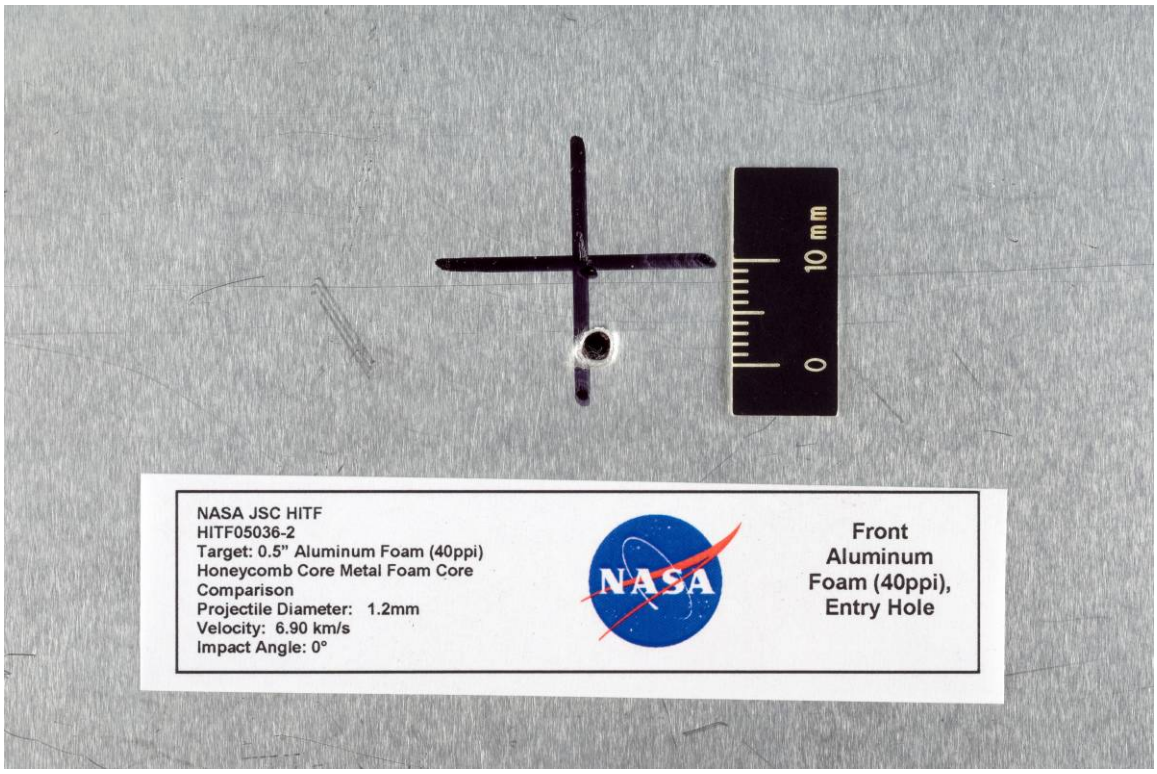

Figure A-73
Jsc2007e14180 HITF05036-2 Front, first facesheet

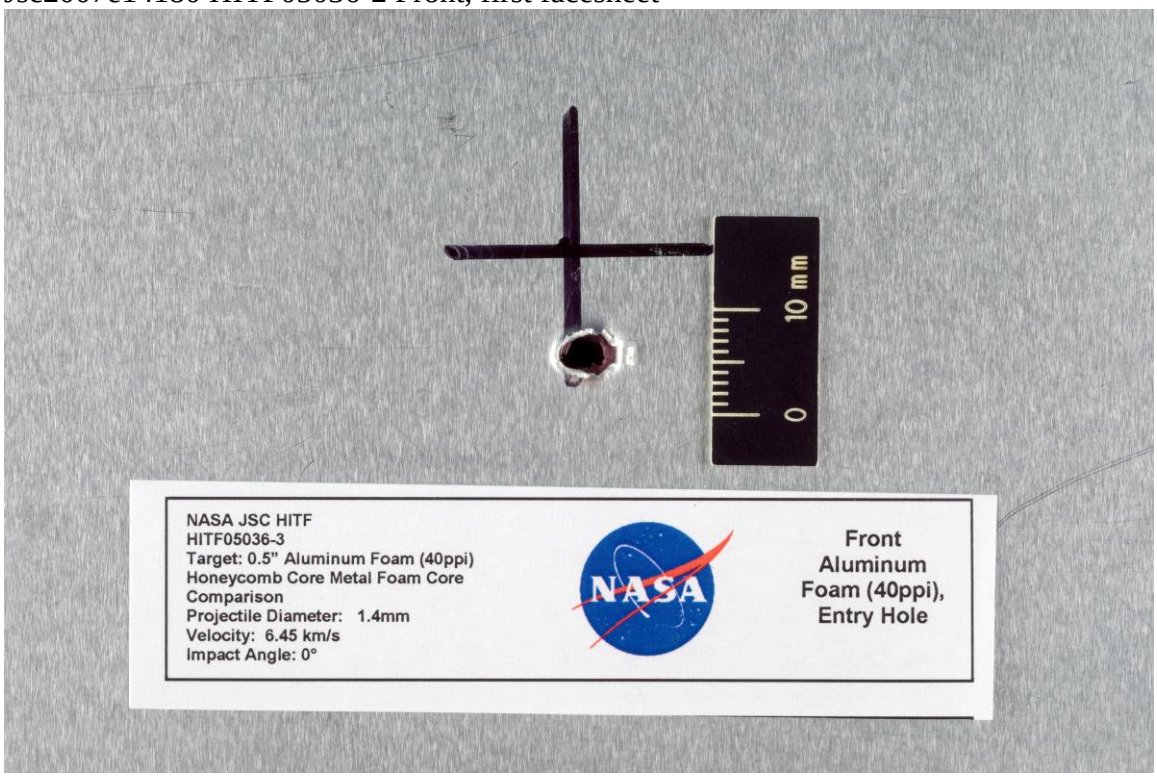

Figure A-74
Jsc2007e14181 HITF05036-3 Front, first facesheet

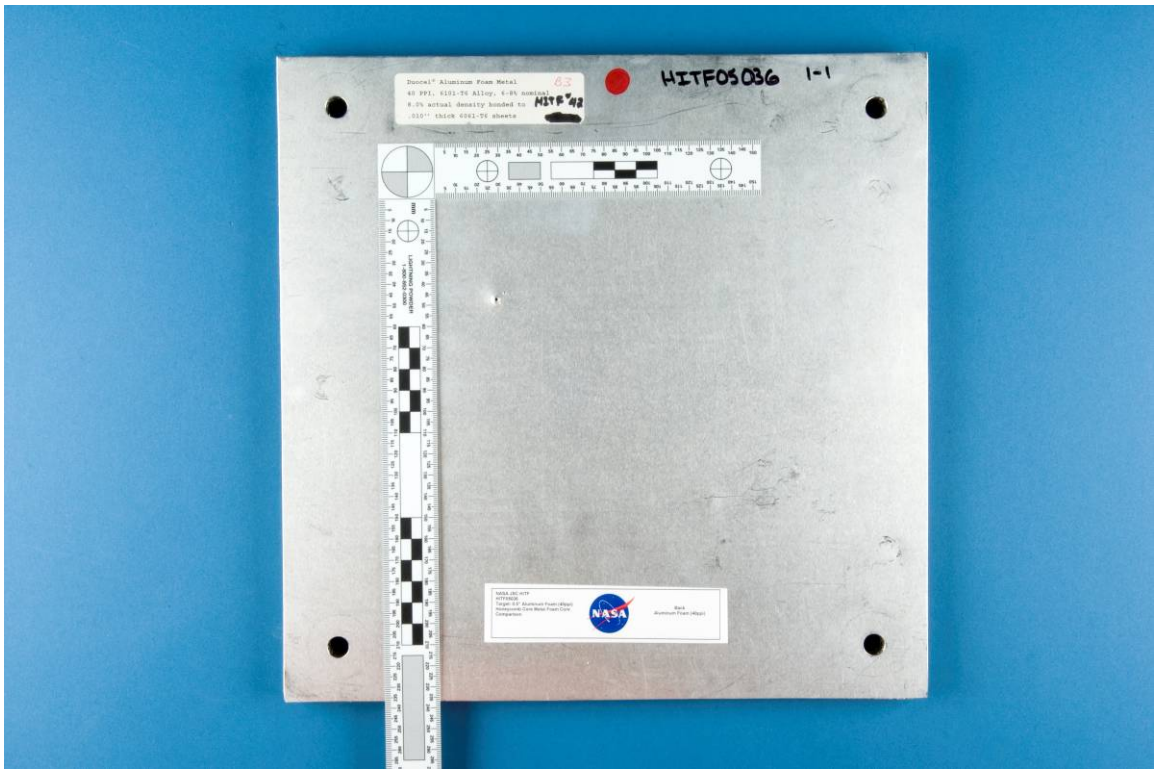

Figure A-75
Jsc2007e14154 HITF05036 Rear, second facesheet

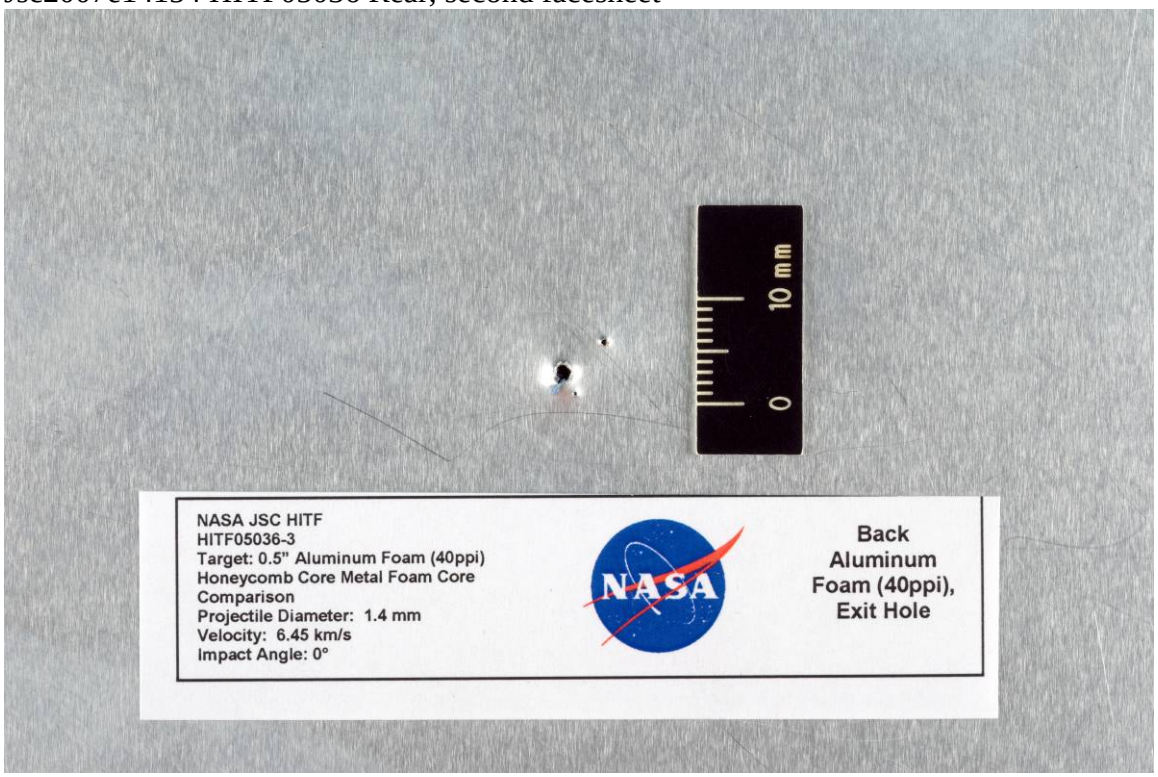

Figure A-76
Jsc2007e14182 HITF05036-3 Rear, second facesheet

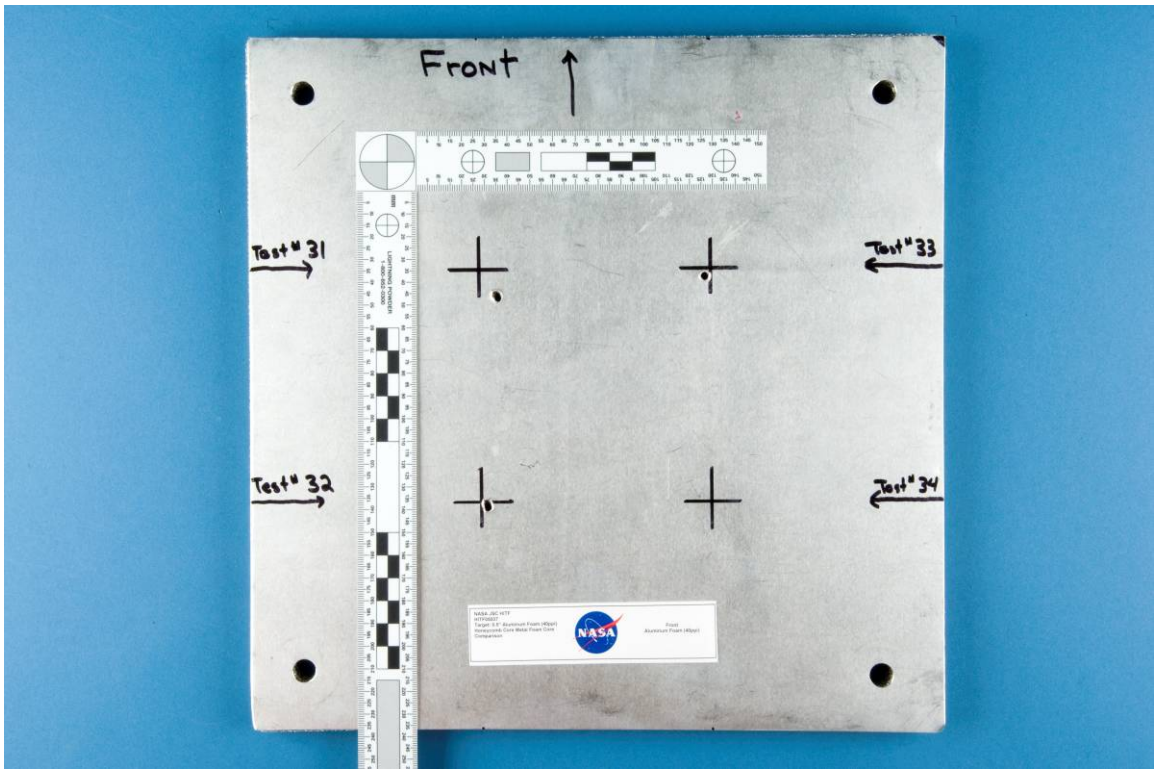

Figure A-77
Jsc2007e14157 HITF05037 Front, first facesheet

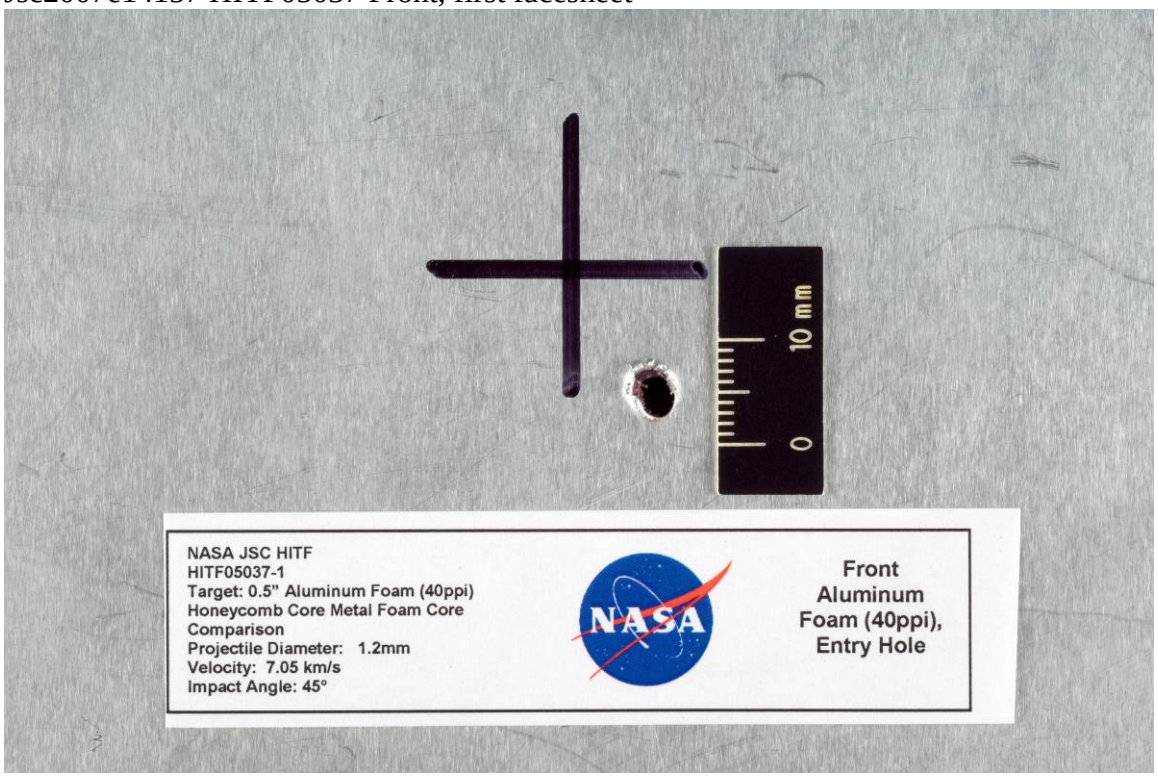

Figure A-78
Jsc2007e14183 HITF05037-1 Front, first facesheet

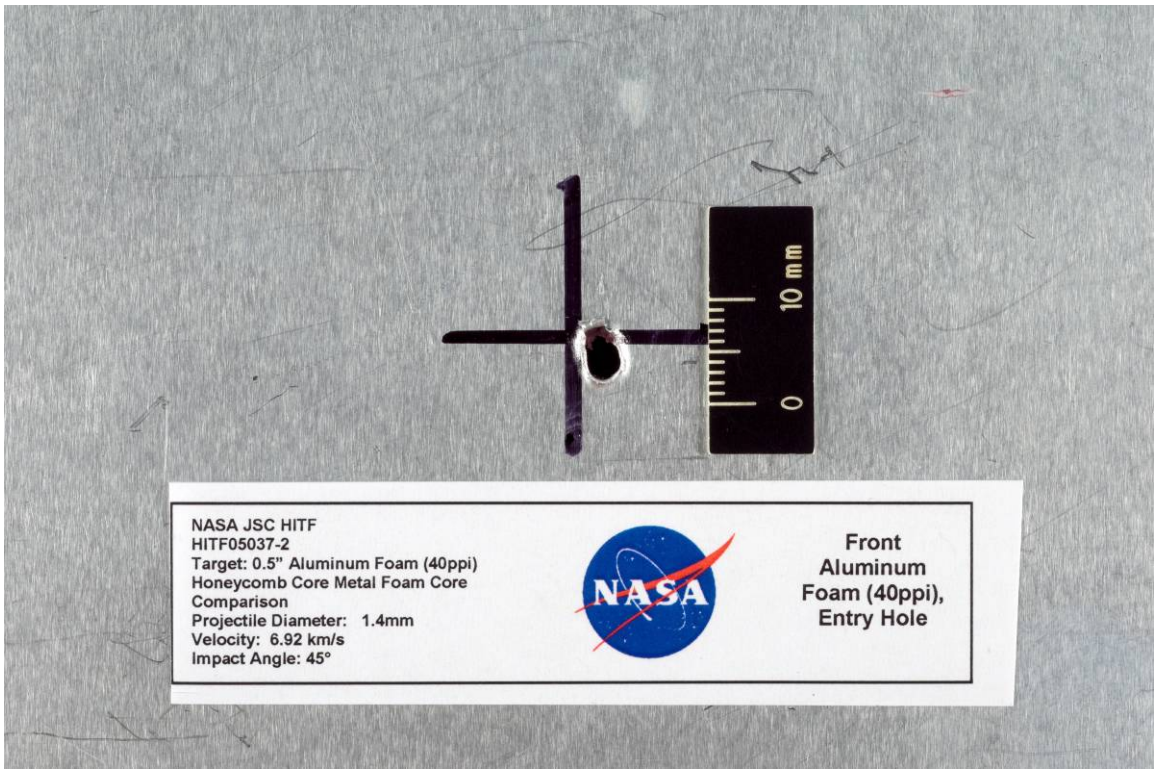

Figure A-79
Jsc2007e14184 HITF05037-2 Front, first facesheet

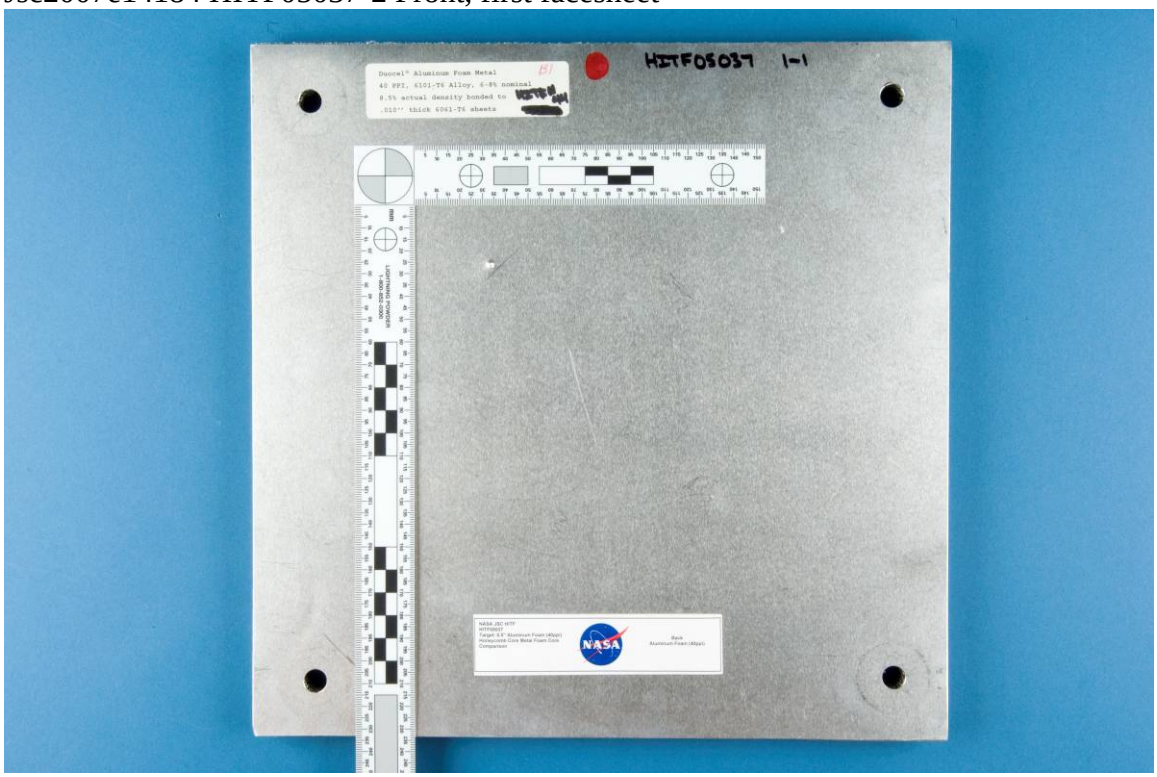

Figure A-80
Jsc2007e14158 HITF05037 Rear, second facesheet

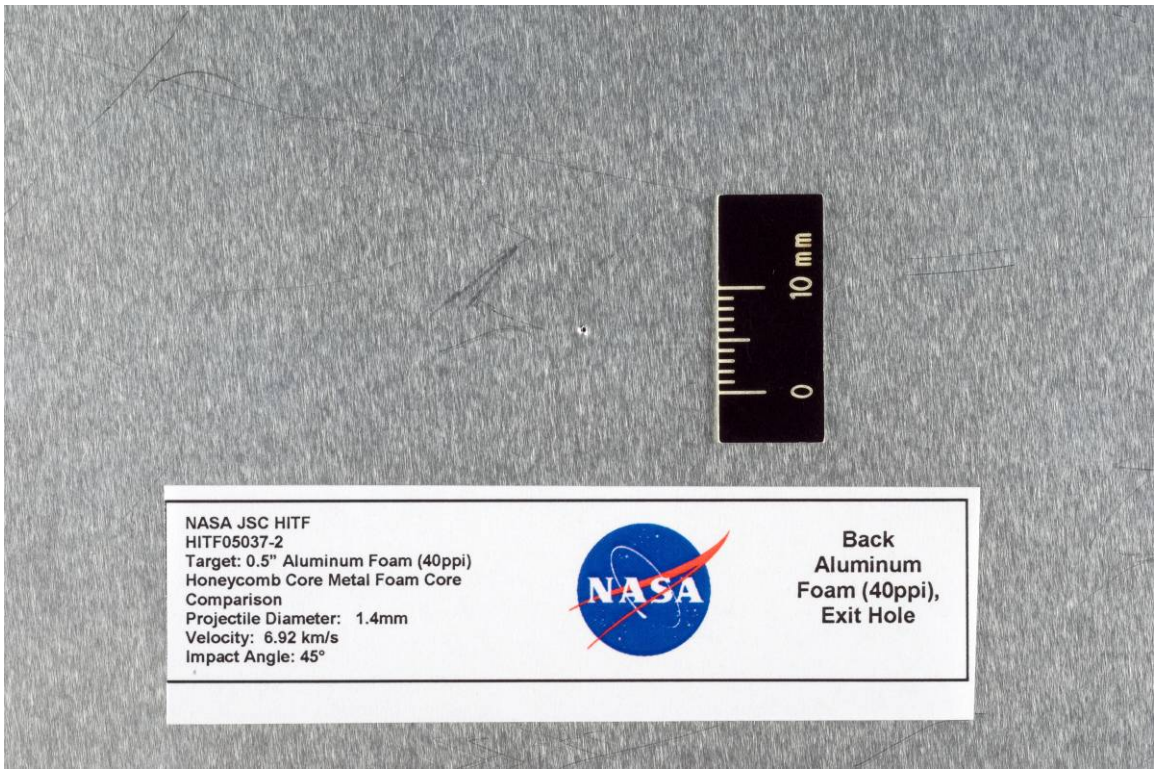

Figure A-81
Jsc2007e14185 HITF05037-2 Rear, second facesheet

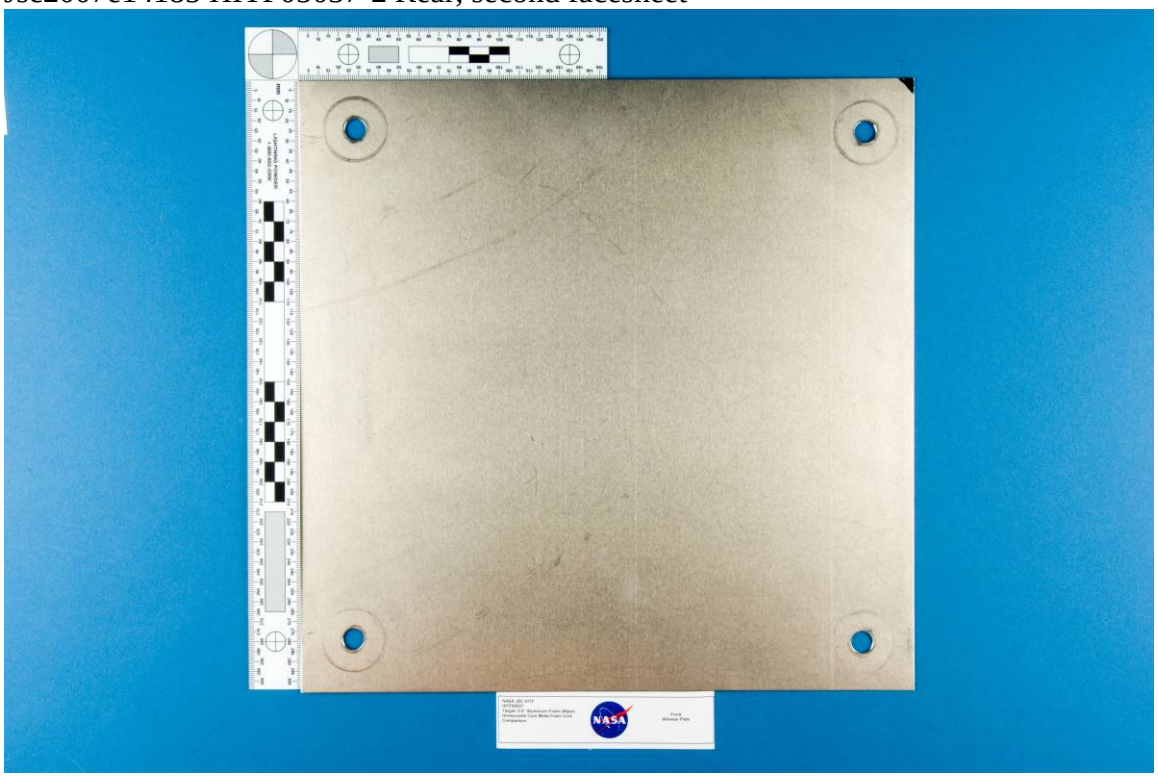

Figure A-82
Jsc2007e14155 HITF05037 Front, witness plate

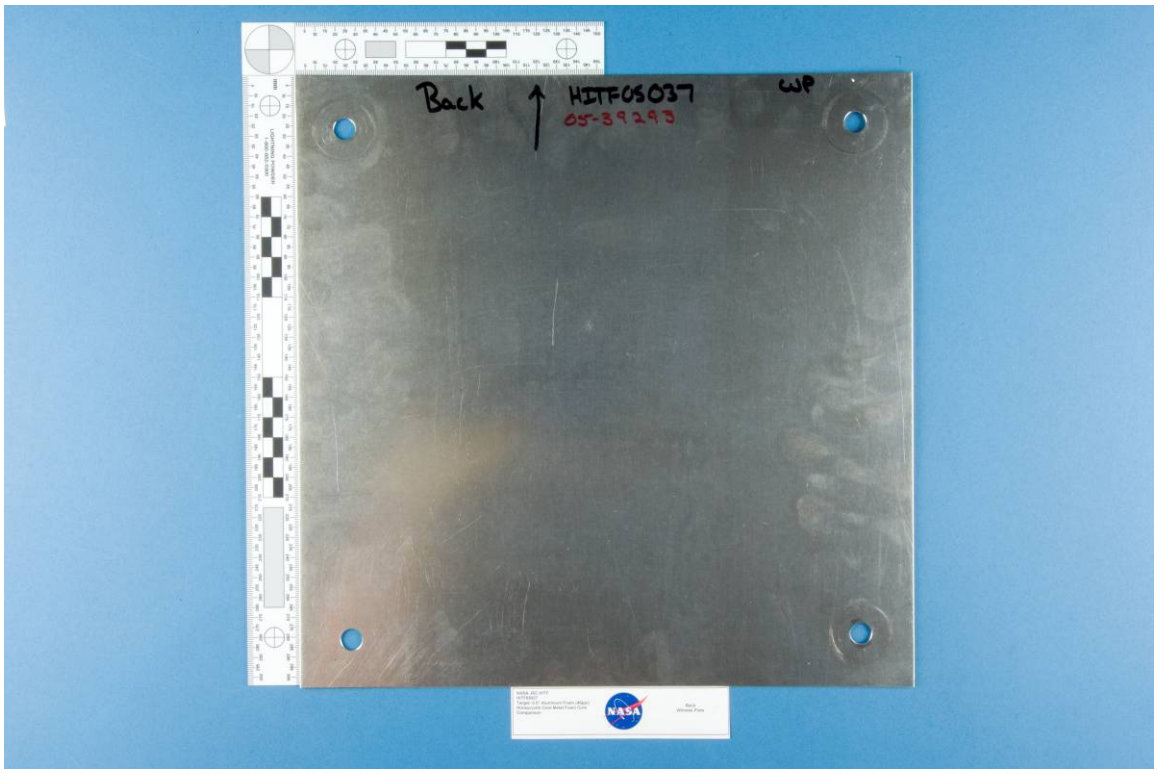

Figure A-83
Jsc2007e14156 HITF05037 Rear, witness plate

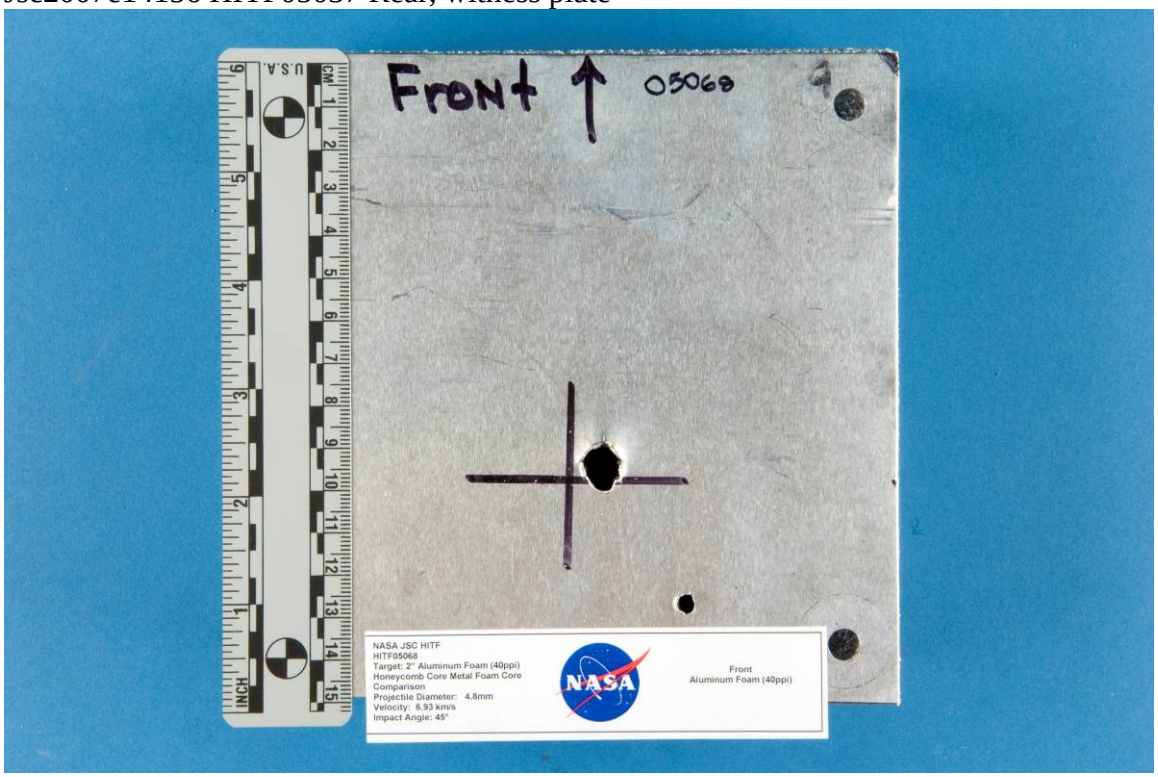

Figure A-84
Jsc2007e14145 HITF05068 Front, first facesheet

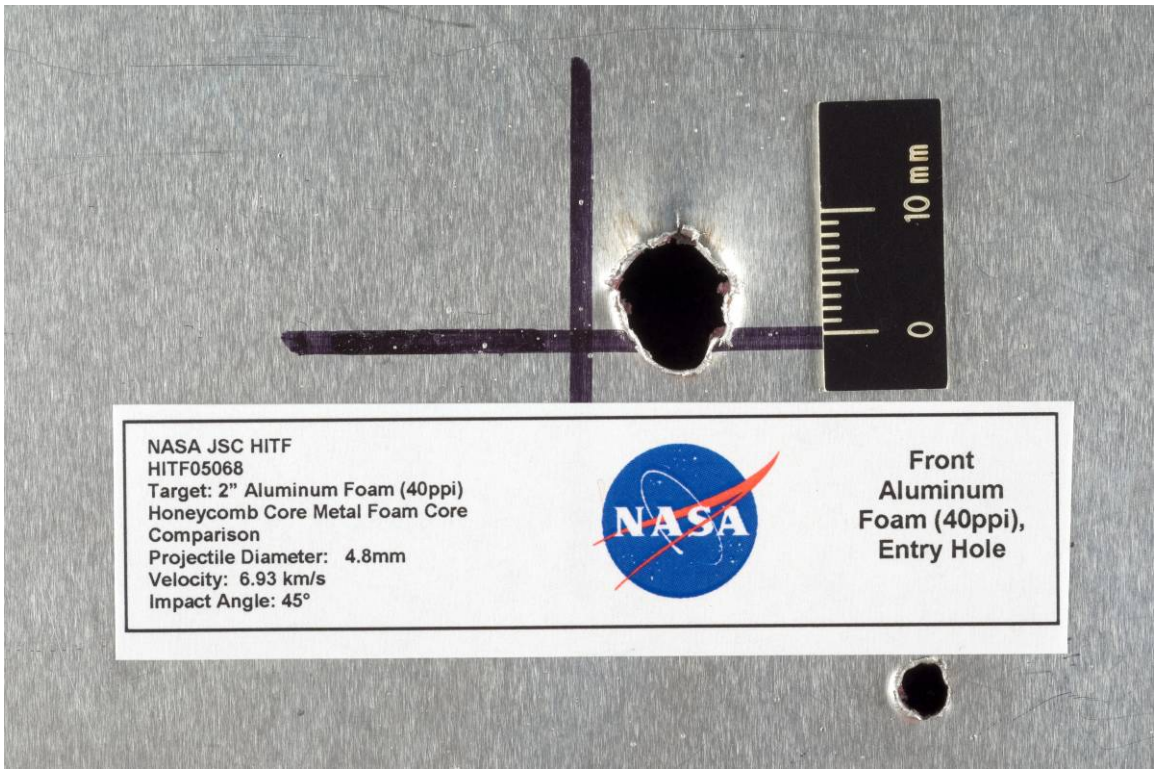

Figure A-85
Jsc2007e14201 HITF05068 Front, first facesheet

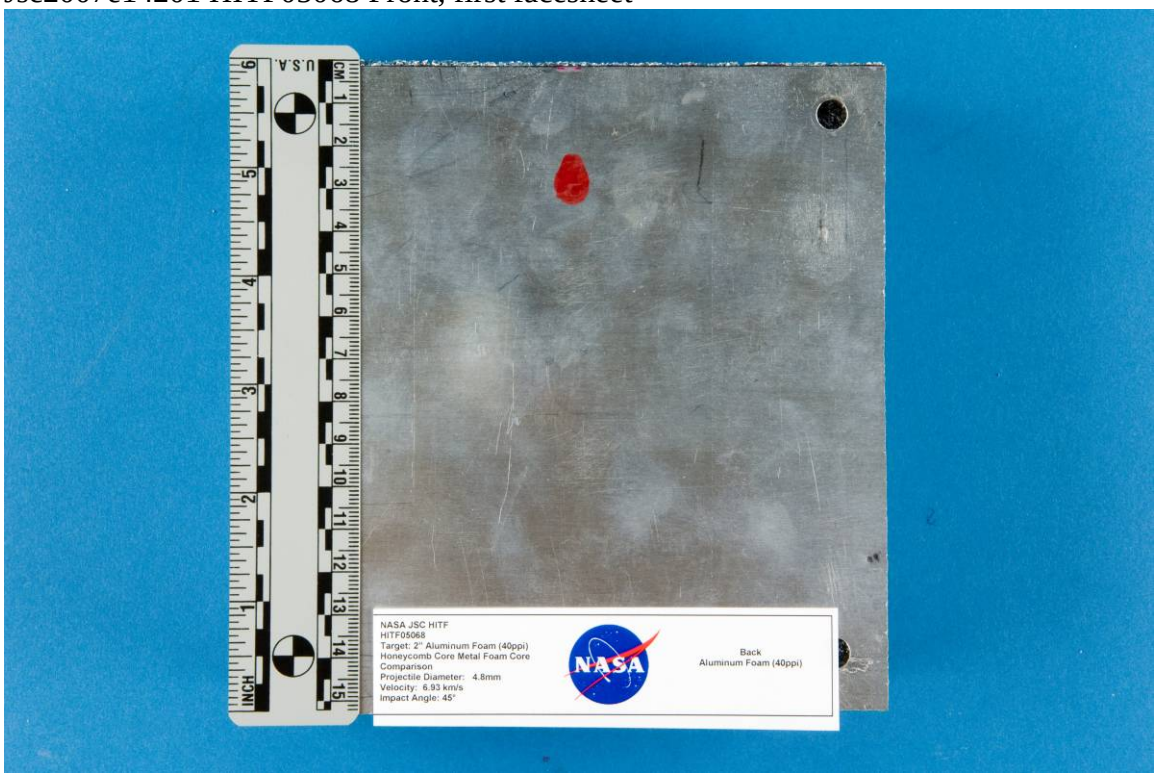

Figure A-86
Jsc2007e14146 HITF05068 Rear, second facesheet

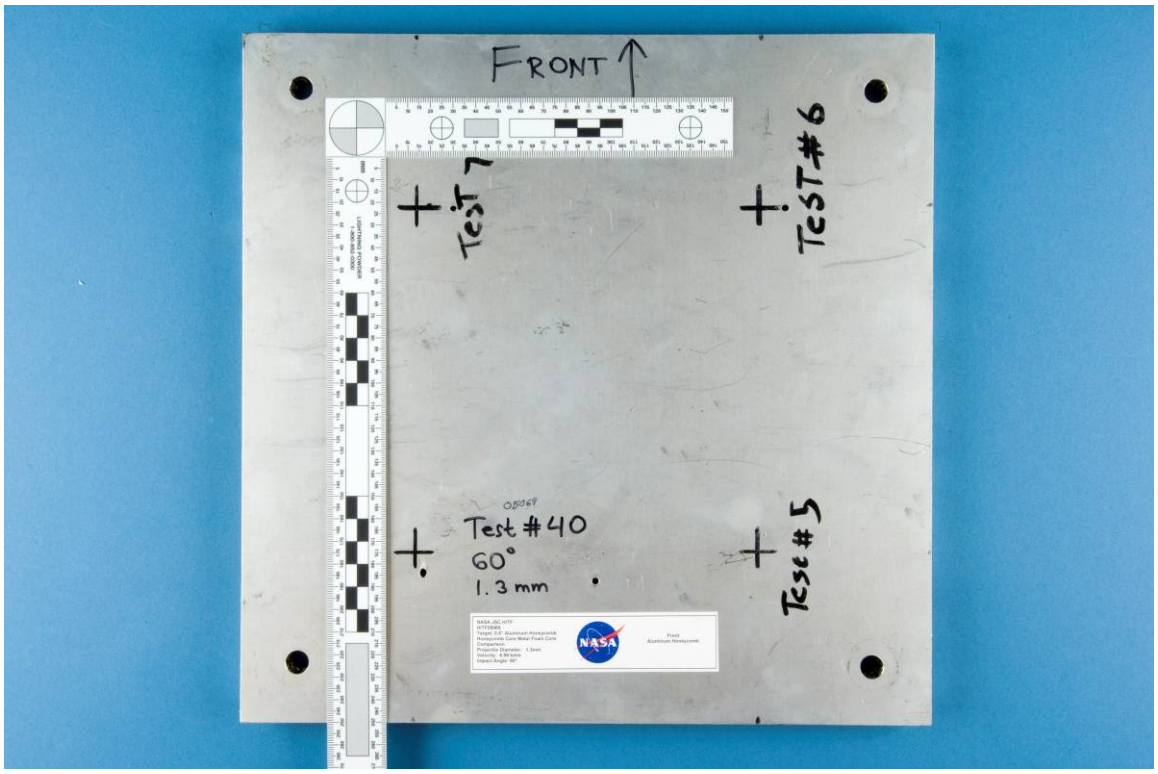

Figure A-87
Jsc2007e14161 HITF05069 Front, first facesheet

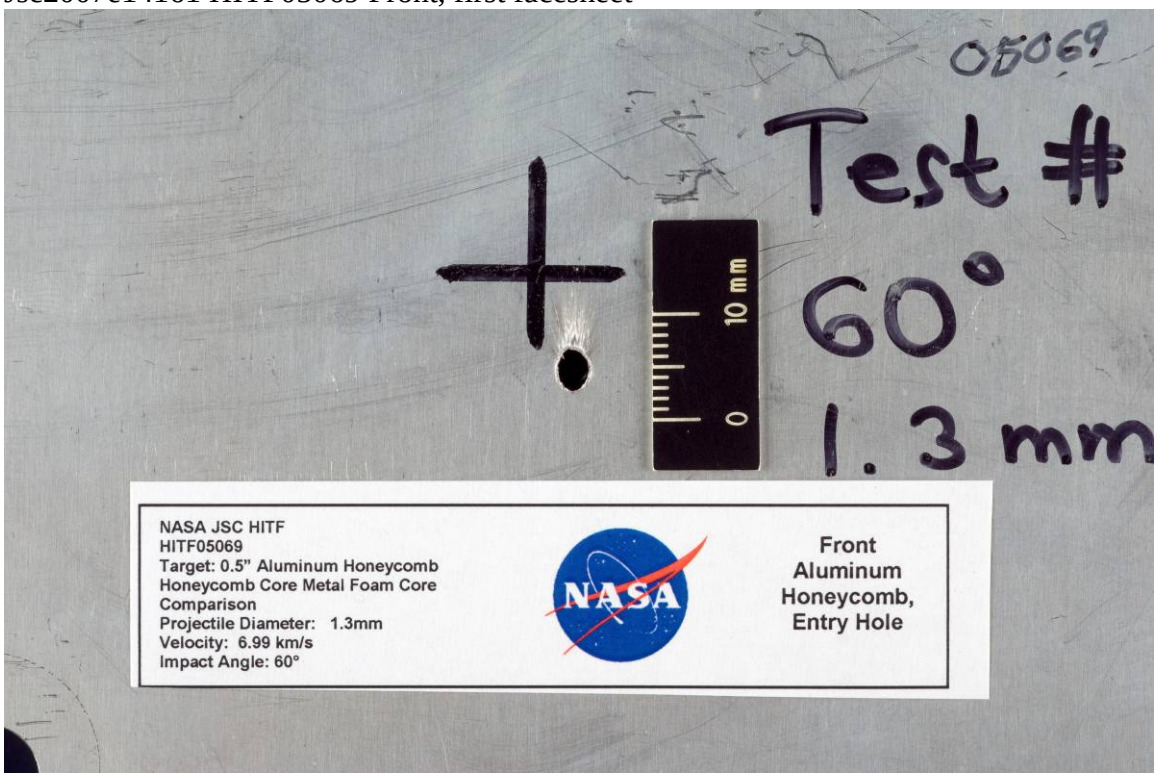

Figure A-88
Jsc2007e14186 HITF05069 Front, first facesheet

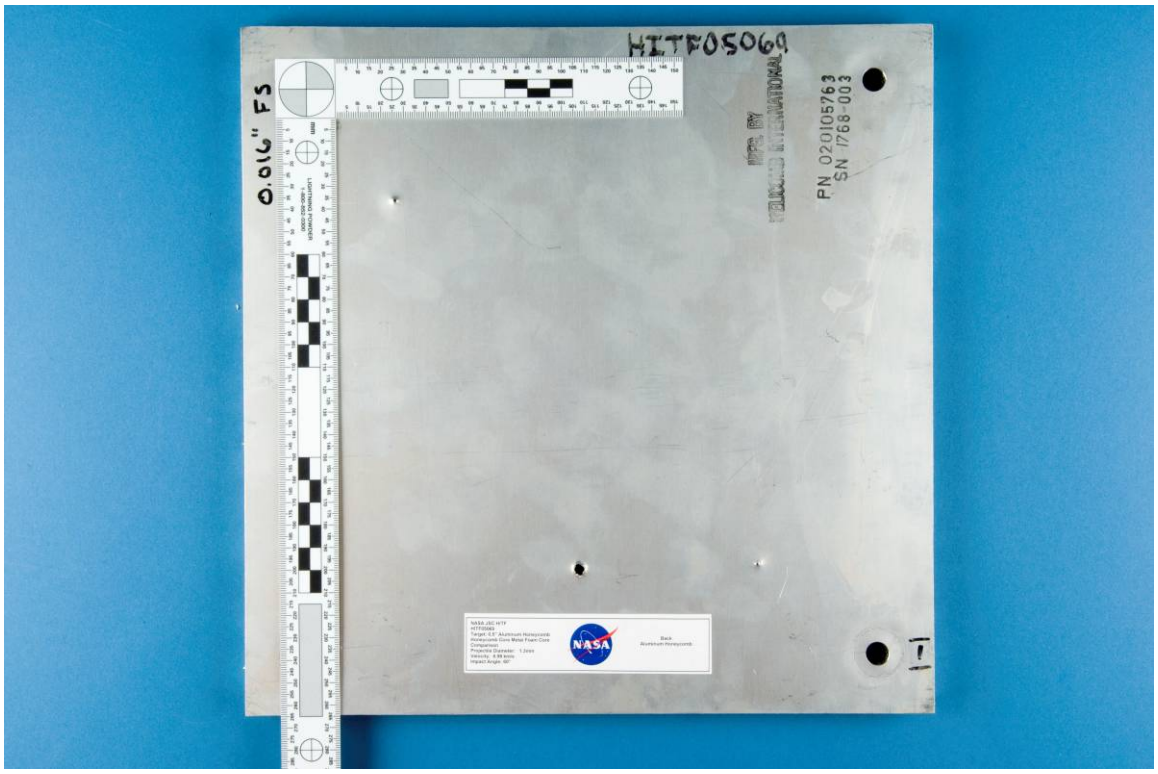

Figure A-89
Jsc2007e14162 HITF05069 Rear, second facesheet

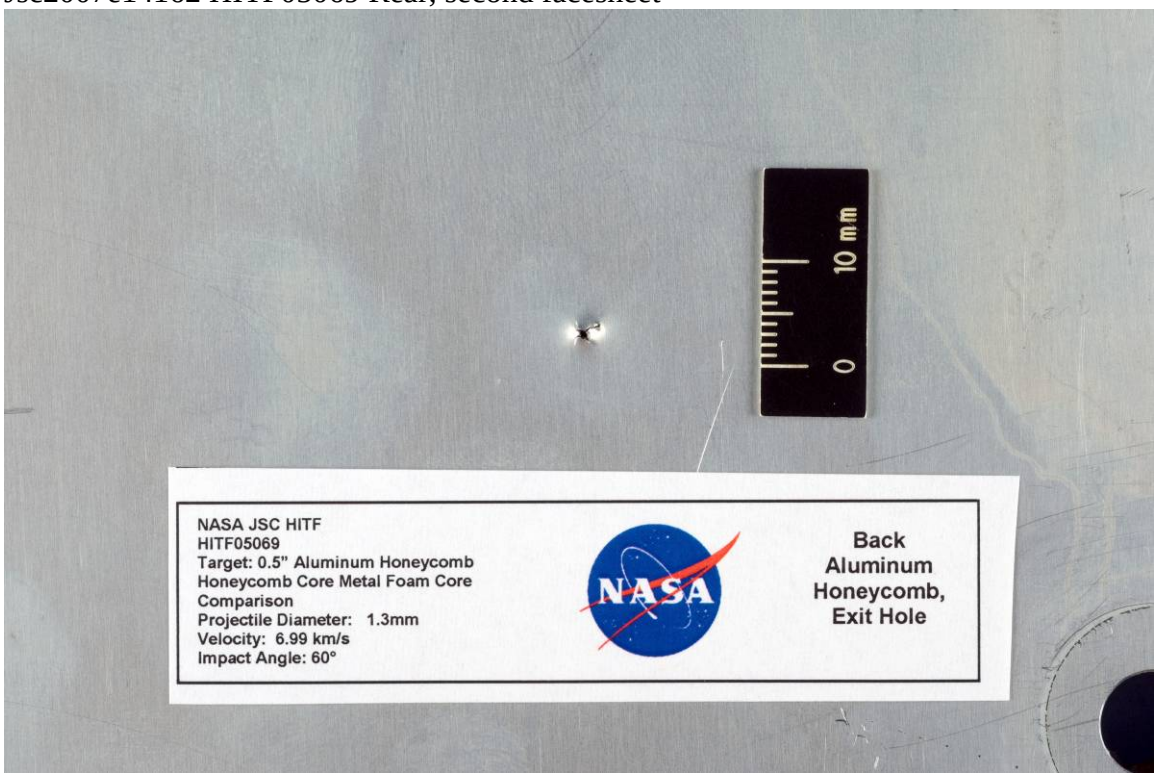

Figure A-90
Jsc2007e14187 HITF05069 Rear, second facesheet

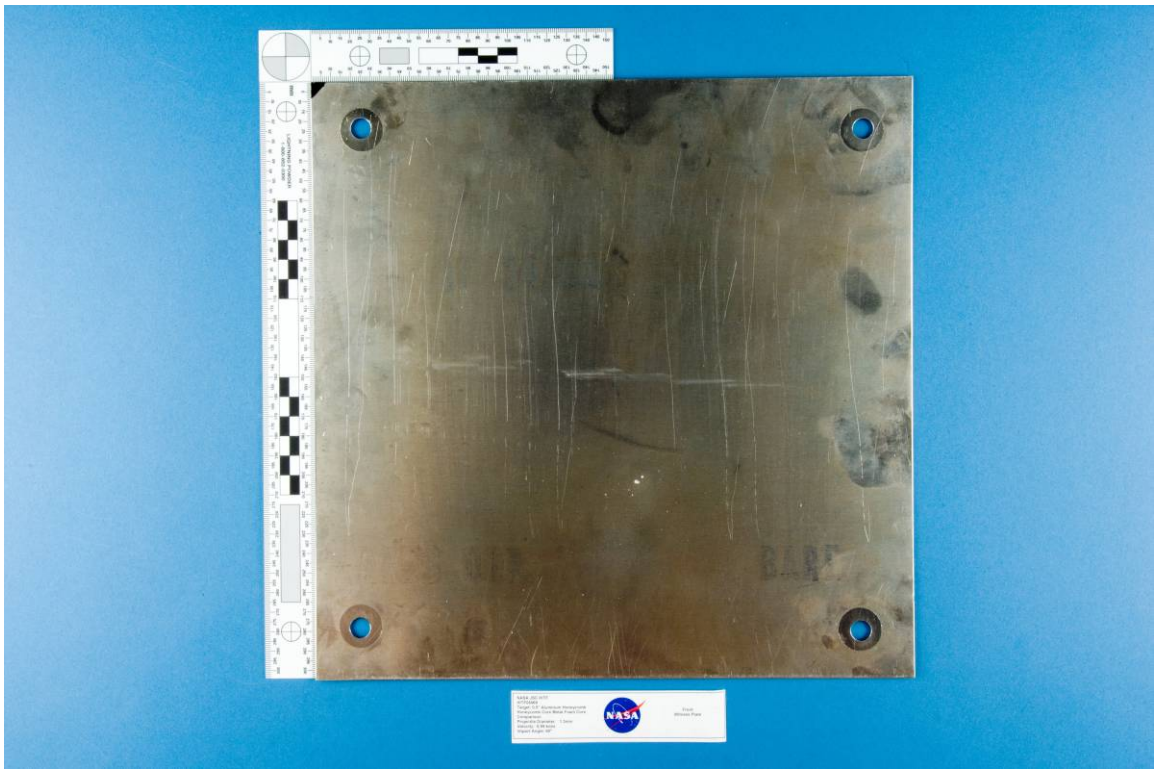

Figure A-91
Jsc2007e14159 HITF05069 Front, witness plate

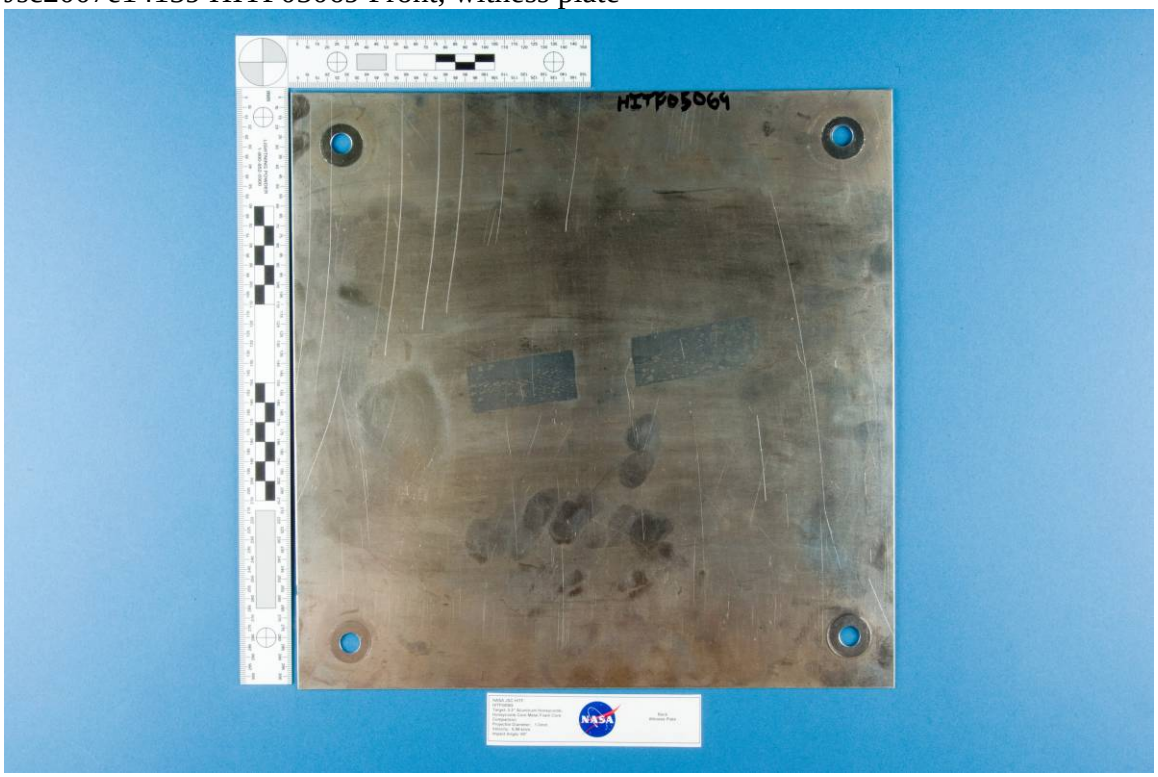

Figure A-92
Jsc2007e14160 HITF05069 Rear, witness plate

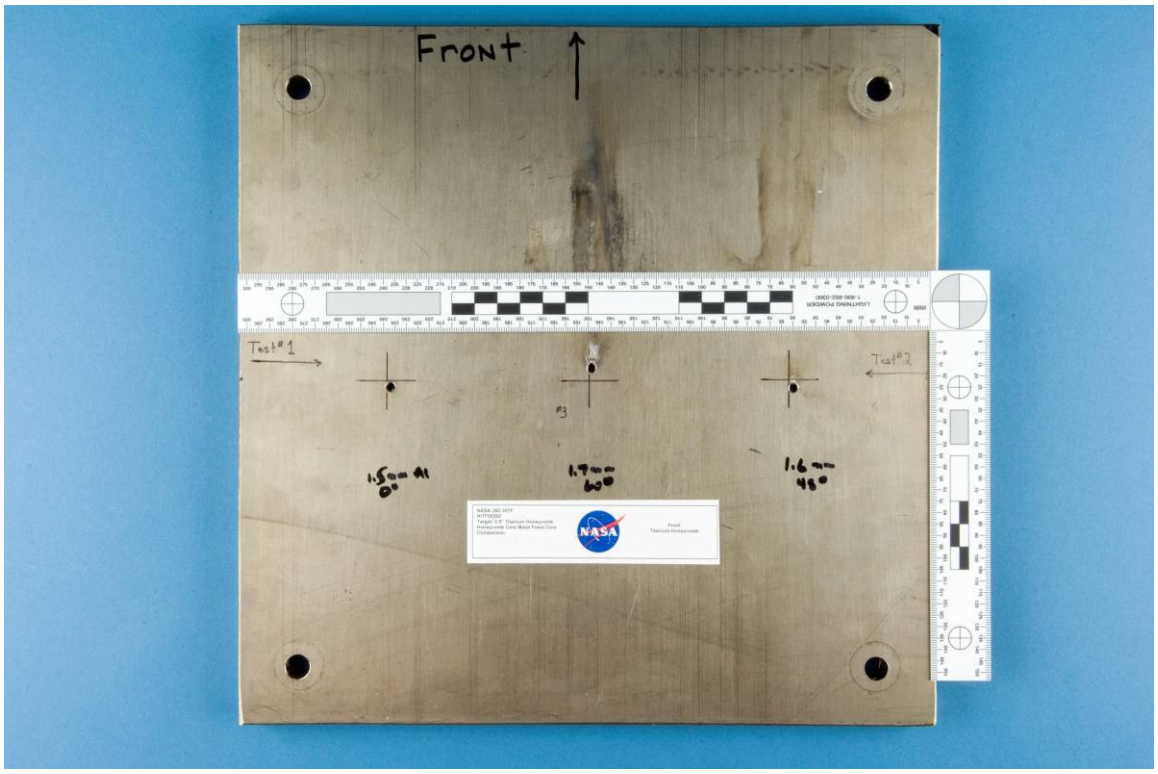

Figure A-93
Jsc2007e14165 HITF05292 Front, first facesheet

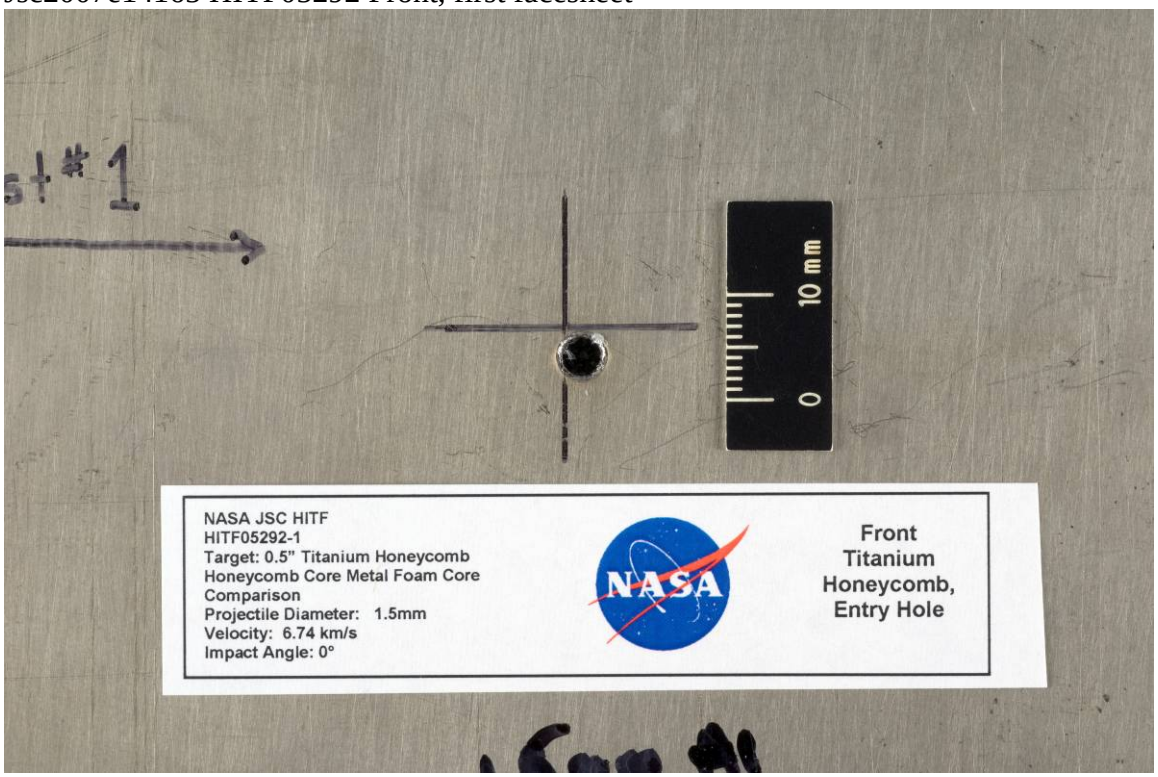

Figure A-94
Jsc2007e14188 HITF05292-1 Front, first facesheet

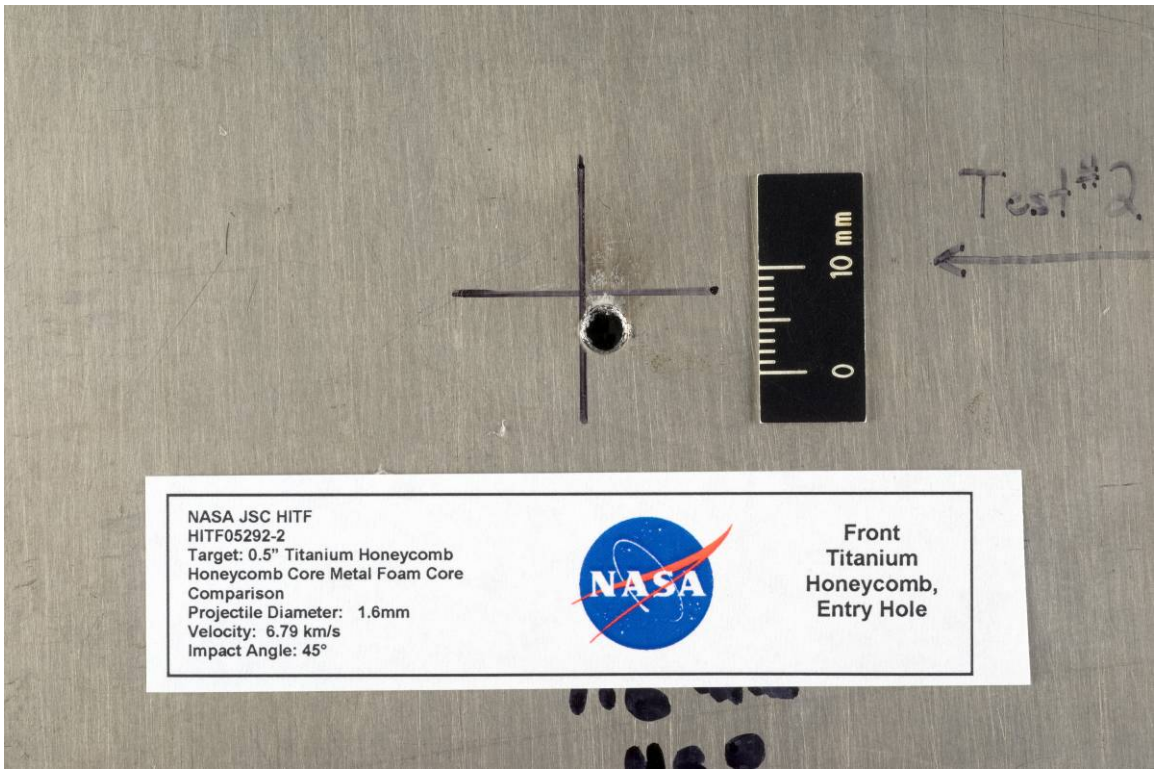

Figure A-95
Jsc2007e14189 HITF05292-2 Front, first facesheet

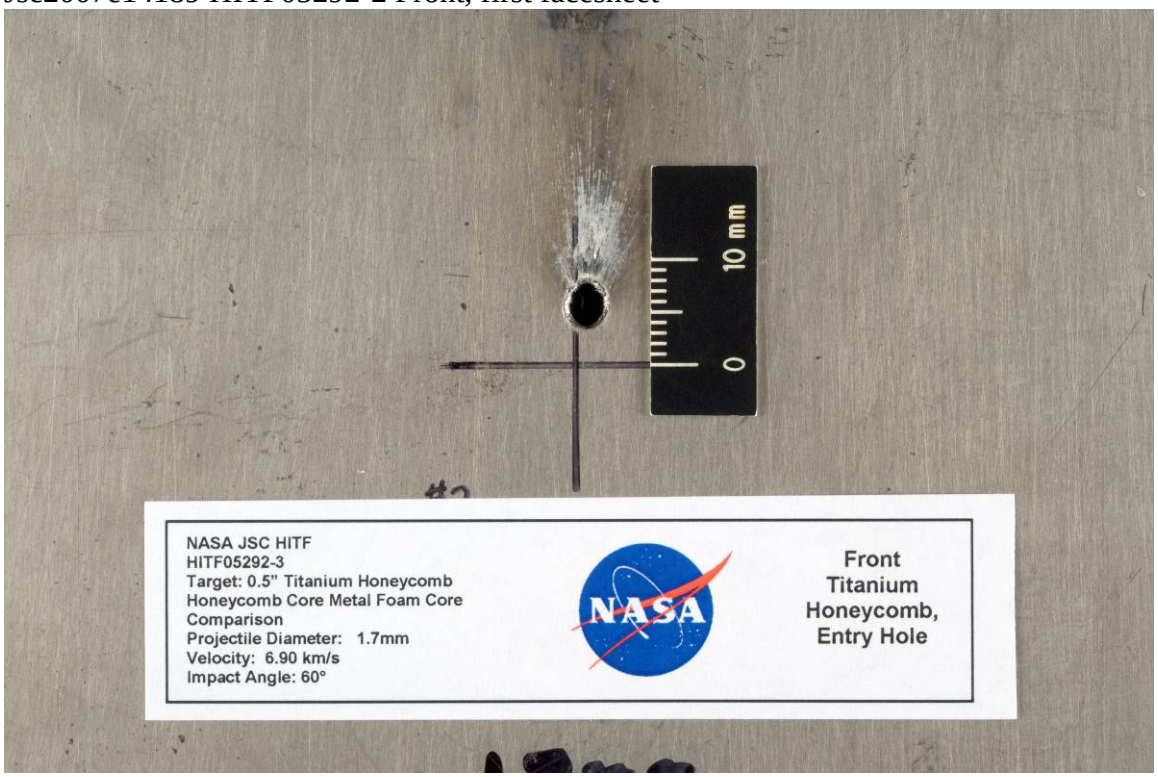

Figure A-96
Jsc2007e14190 HITF05292-3 Front, first facesheet

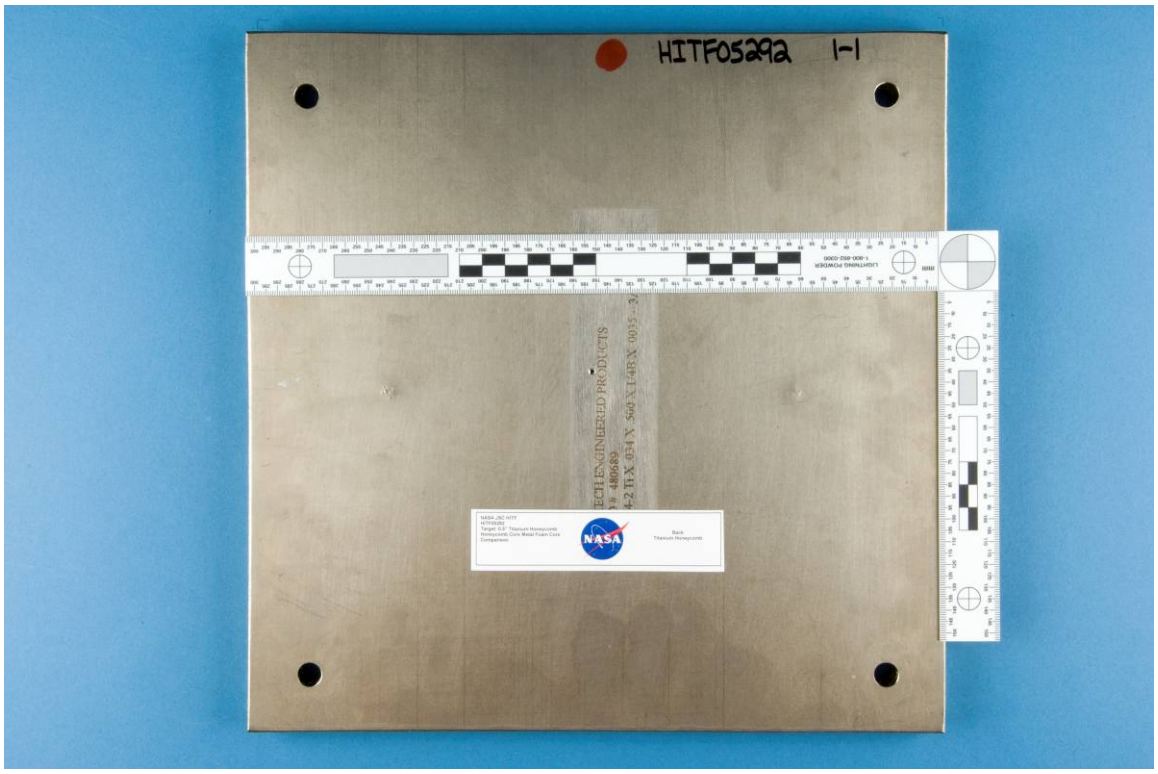

Figure A-97
Jsc2007e14166 HITF05292 Rear, second facesheet

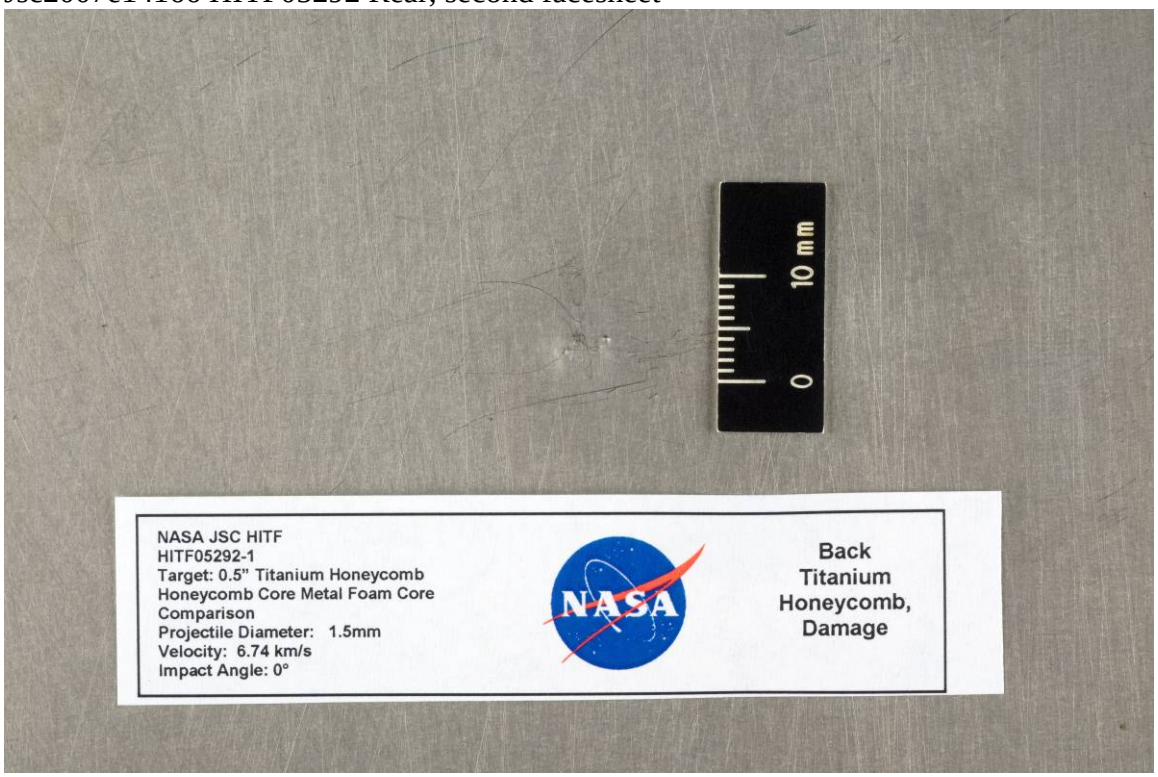

Figure A-98
Jsc2007e14191 HITF05292-1 Rear, second facesheet

Figure A-99
Jsc2007e14192 HITF05292-2 Rear, second facesheet

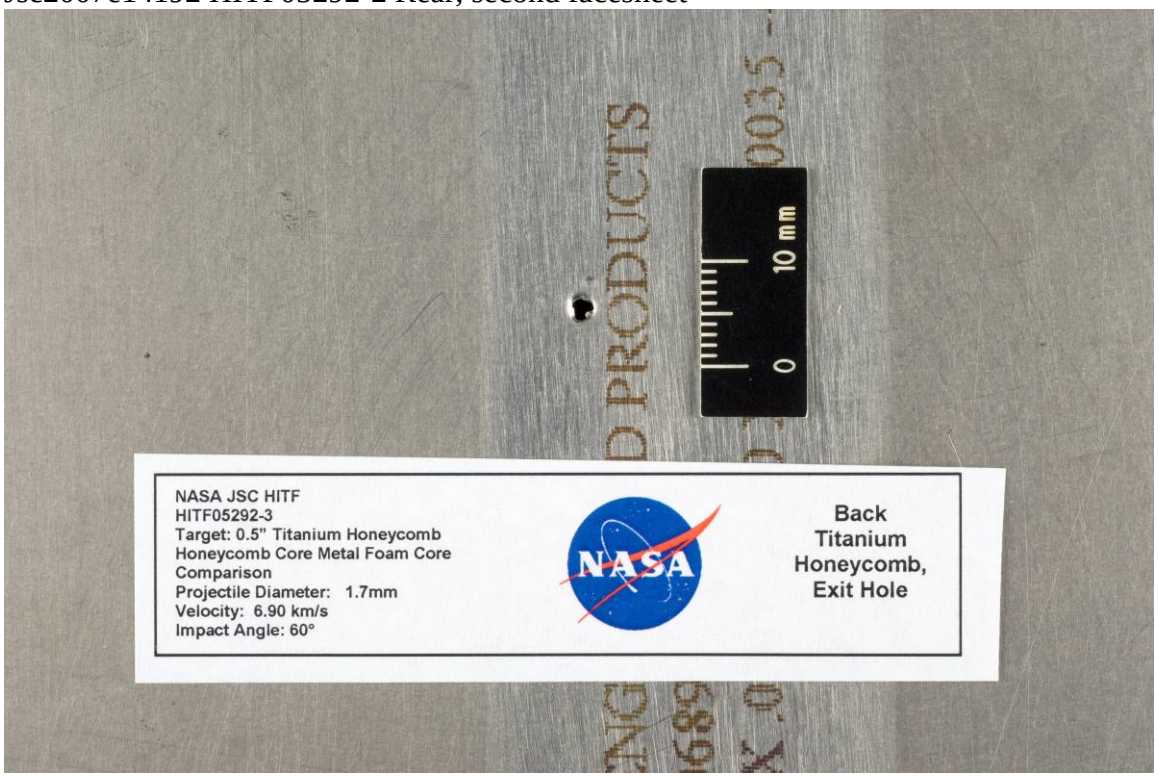

Figure A-100
Jsc2007e14193 HITF05292-3 Rear, second facesheet

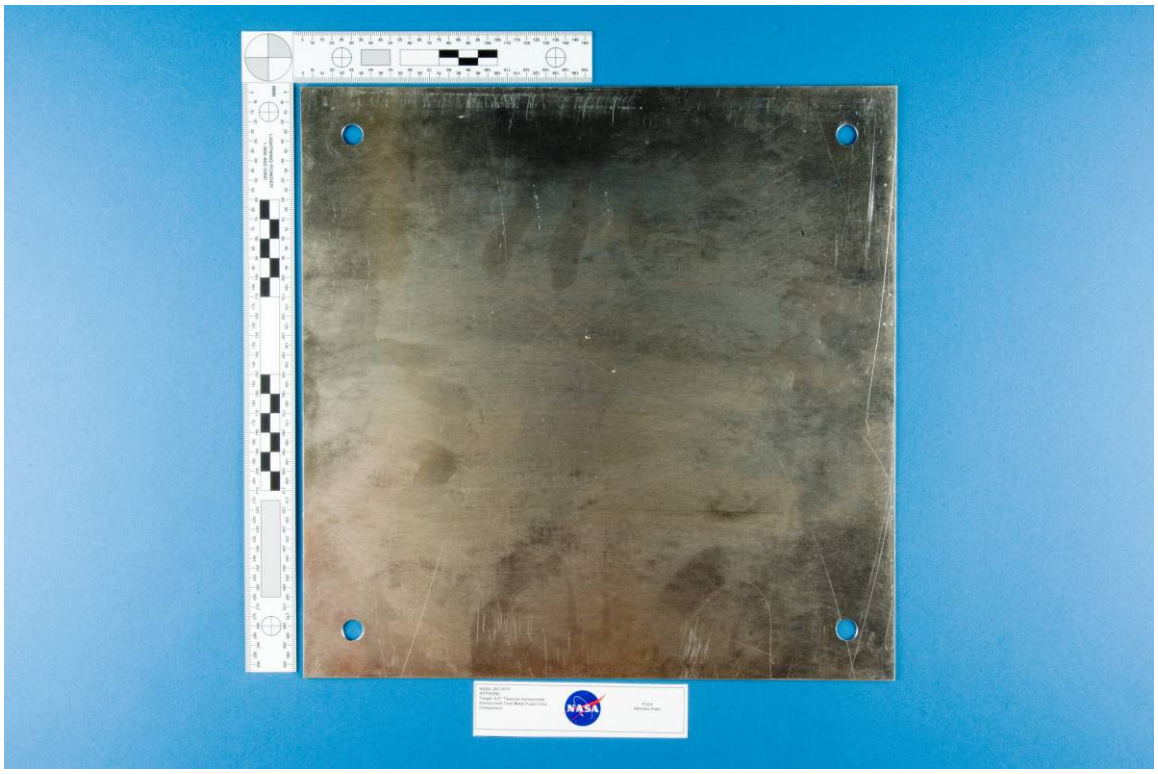

Figure A-101
Jsc2007e14163 HITF05292 Front, witness plate

Figure A-102
Jsc2007e14164 HITF05292 Rear, witness plate

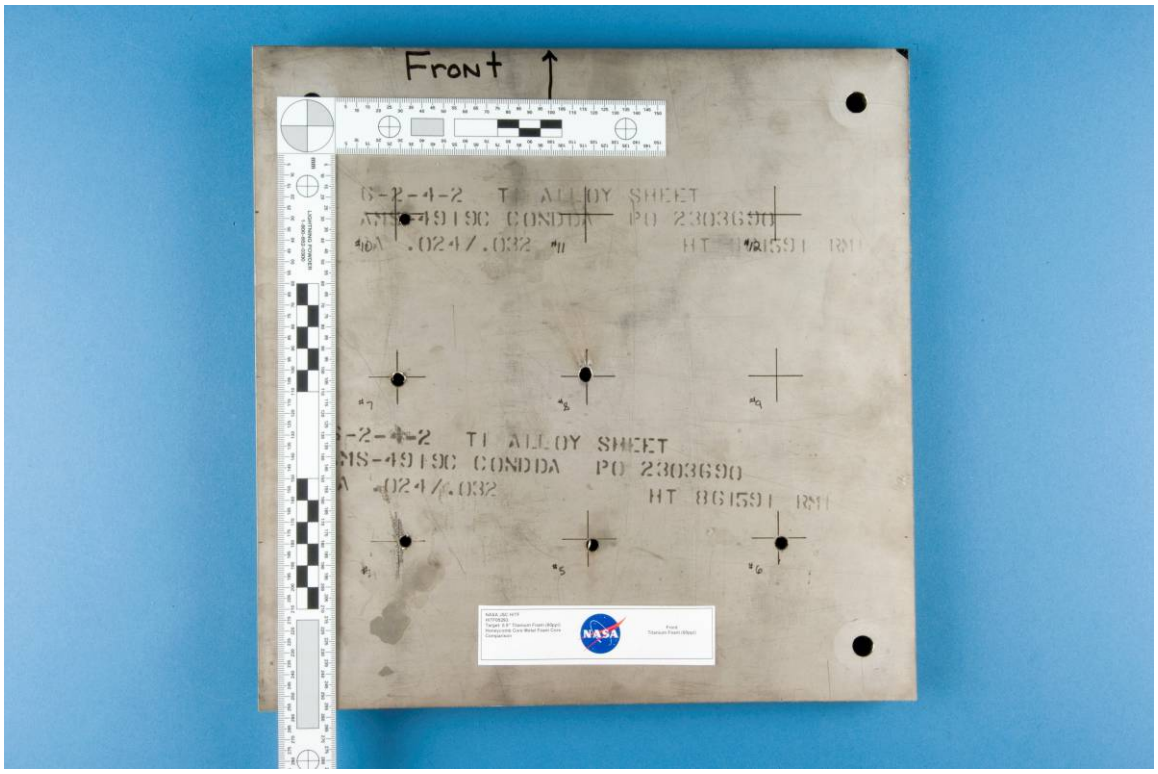

Figure A-103
Jsc2007e14169 HITF05293 Front, first facesheet

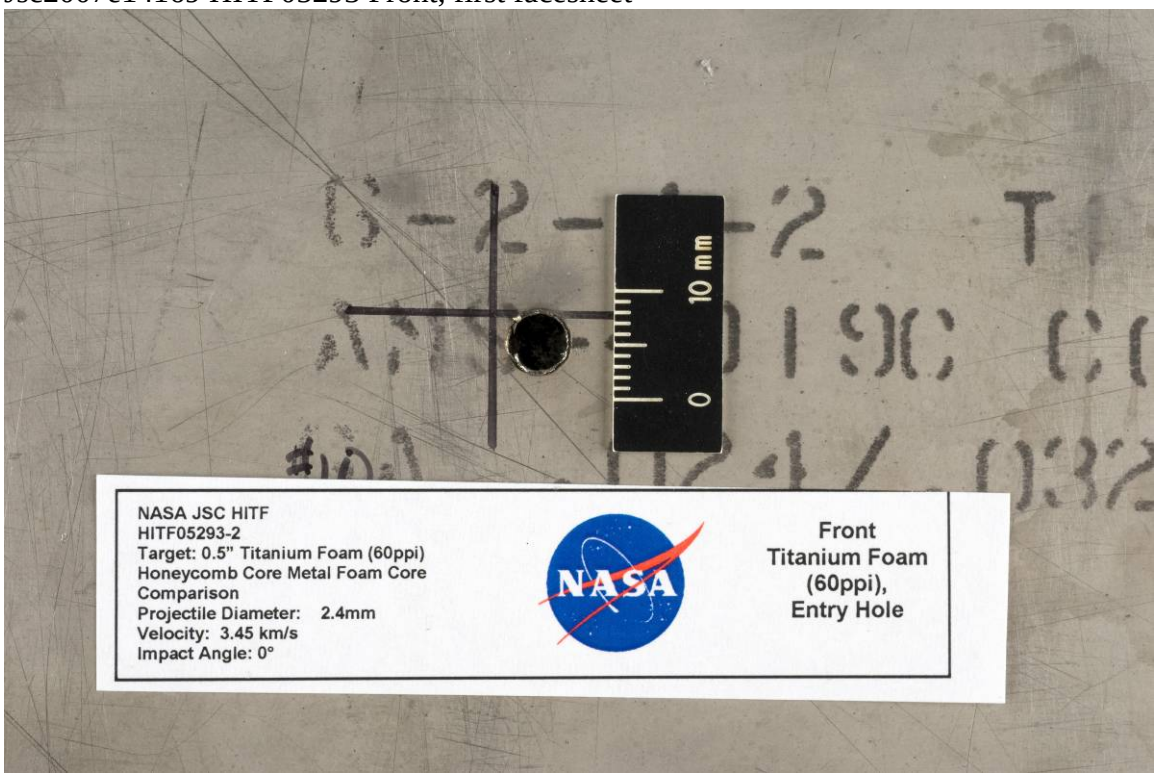

Figure A-104
Jsc2007e14171 HITF05293-2 Front, first facesheet

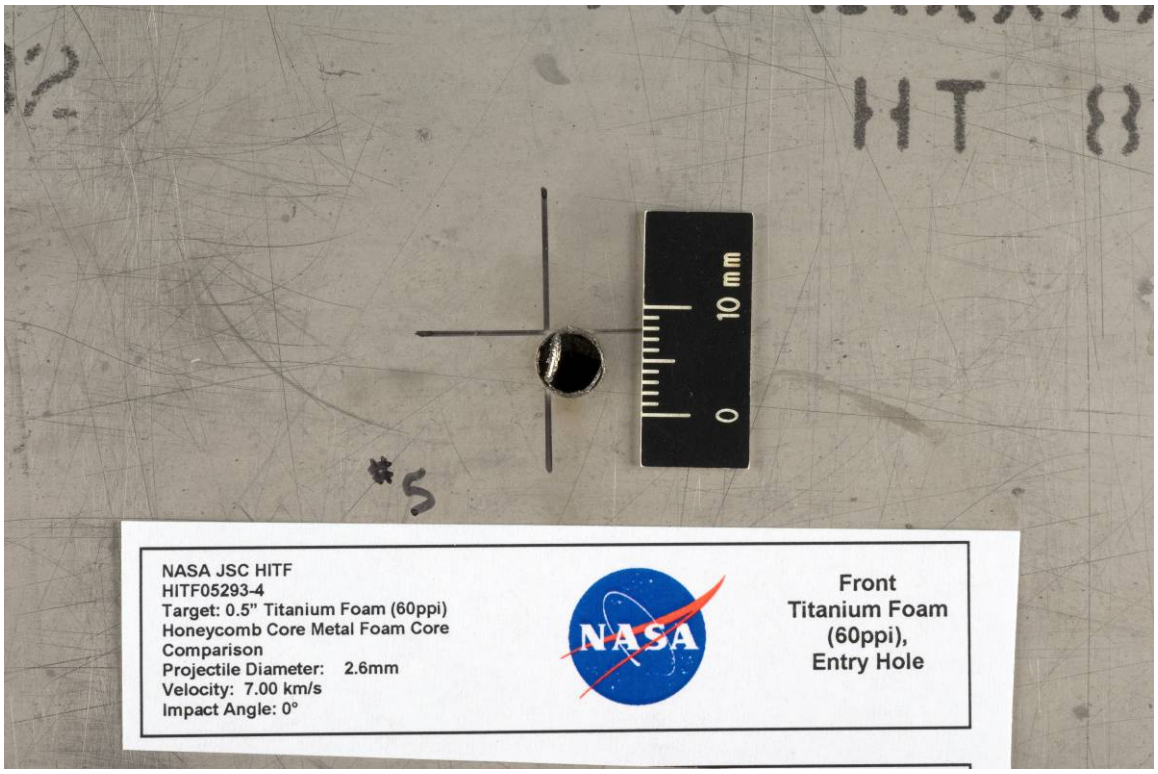

Figure A-105
Jsc2007e14172 HITF05293-4 Front, first facesheet

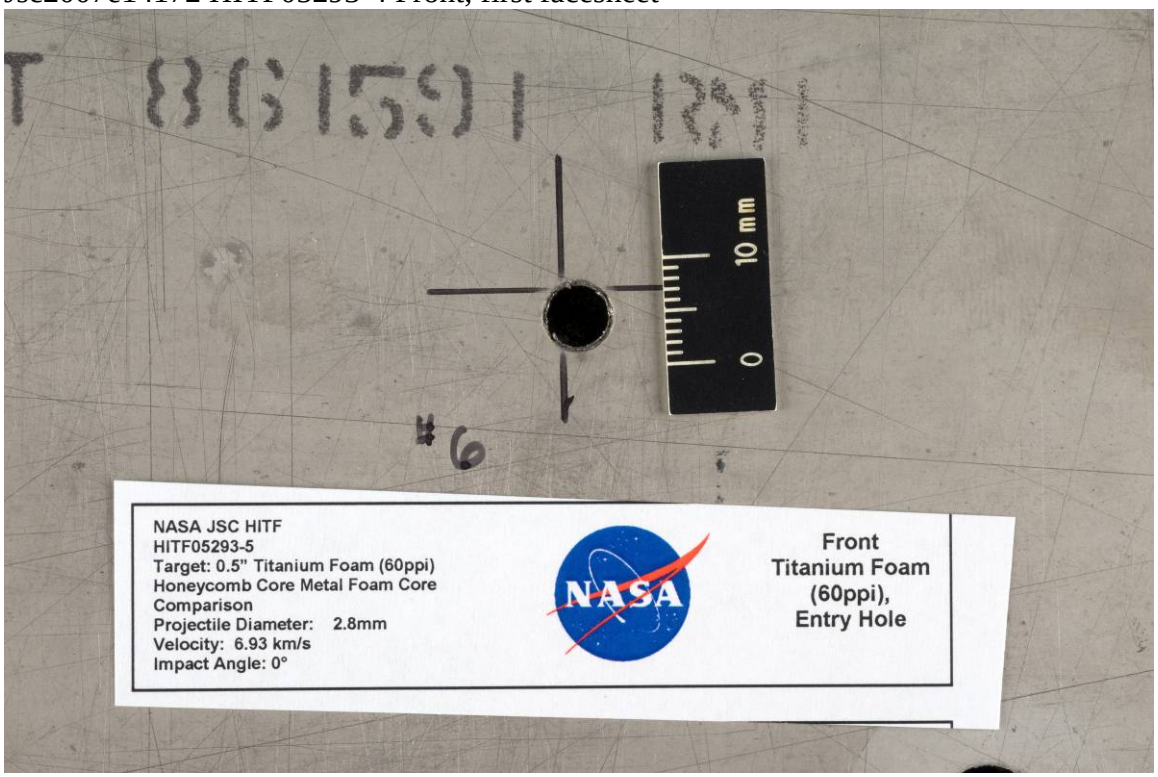

Figure A-106
Jsc2007e14173 HITF05293-5 Front, first facesheet

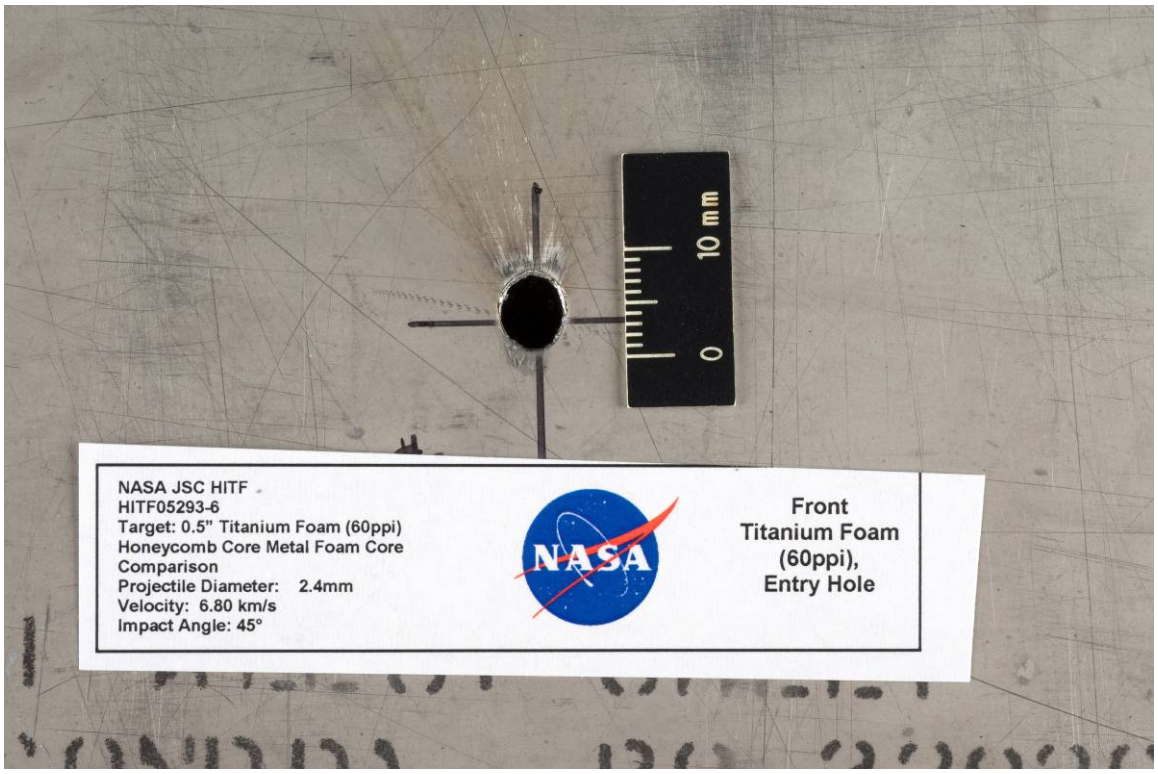

Figure A-107
Jsc2007e14174 HITF05293-6 Front, first facesheet

Figure A-108
Jsc2007e14170 HITF05293 Rear, second facesheet

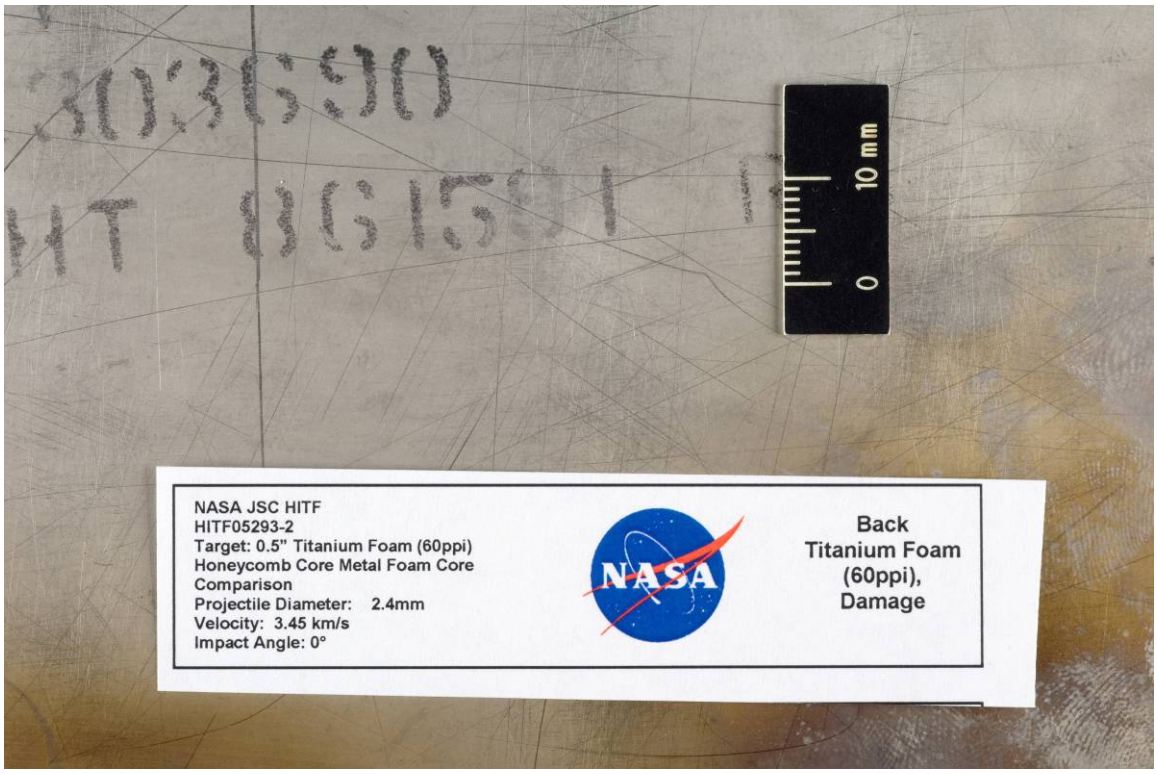

Figure A-109
Jsc2007e14175 HITF05293-2 Rear, second facesheet

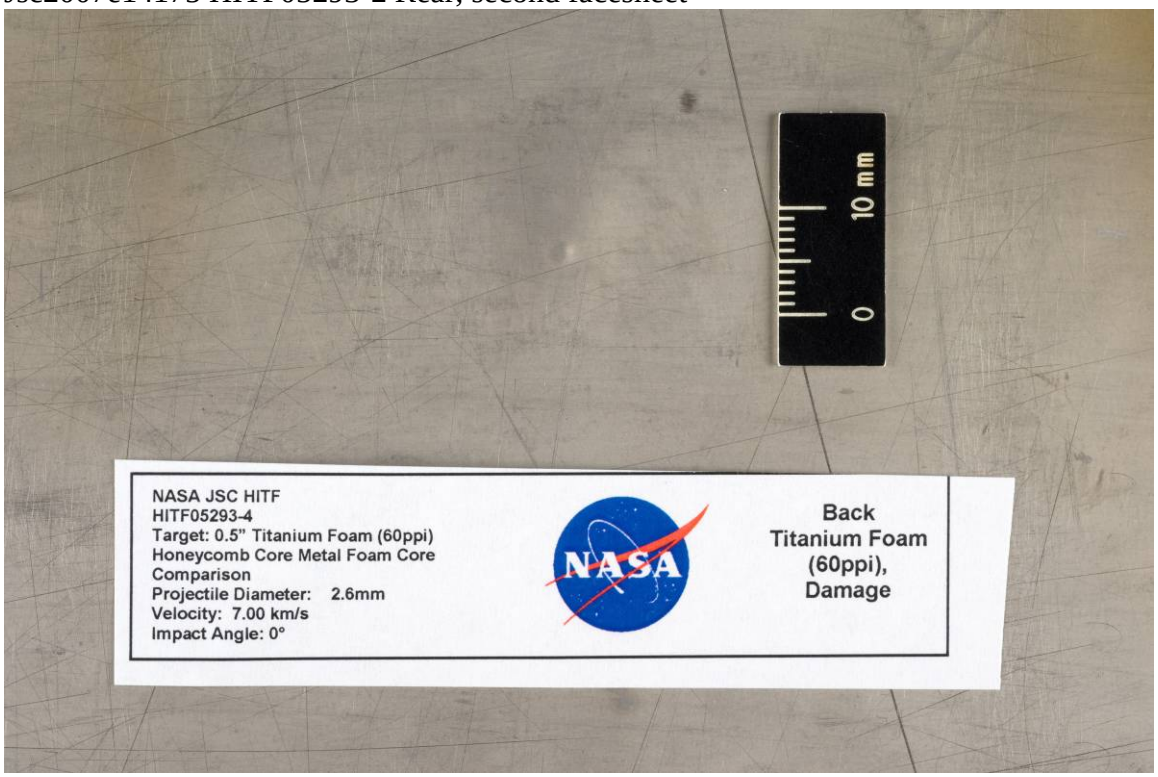

Figure A-110
Jsc2007e14176 HITF05293-4 Rear, second facesheet

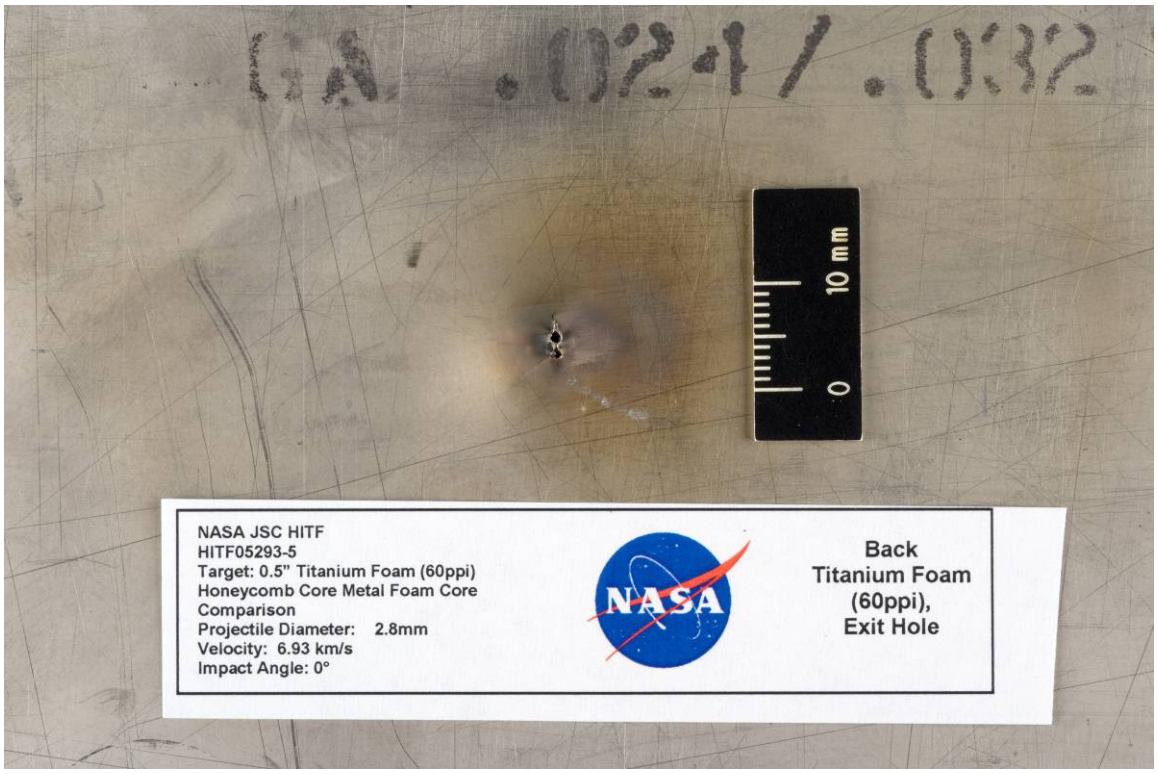

Figure A-111
Jsc2007e14177 HITF05293-5 Rear, second facesheet

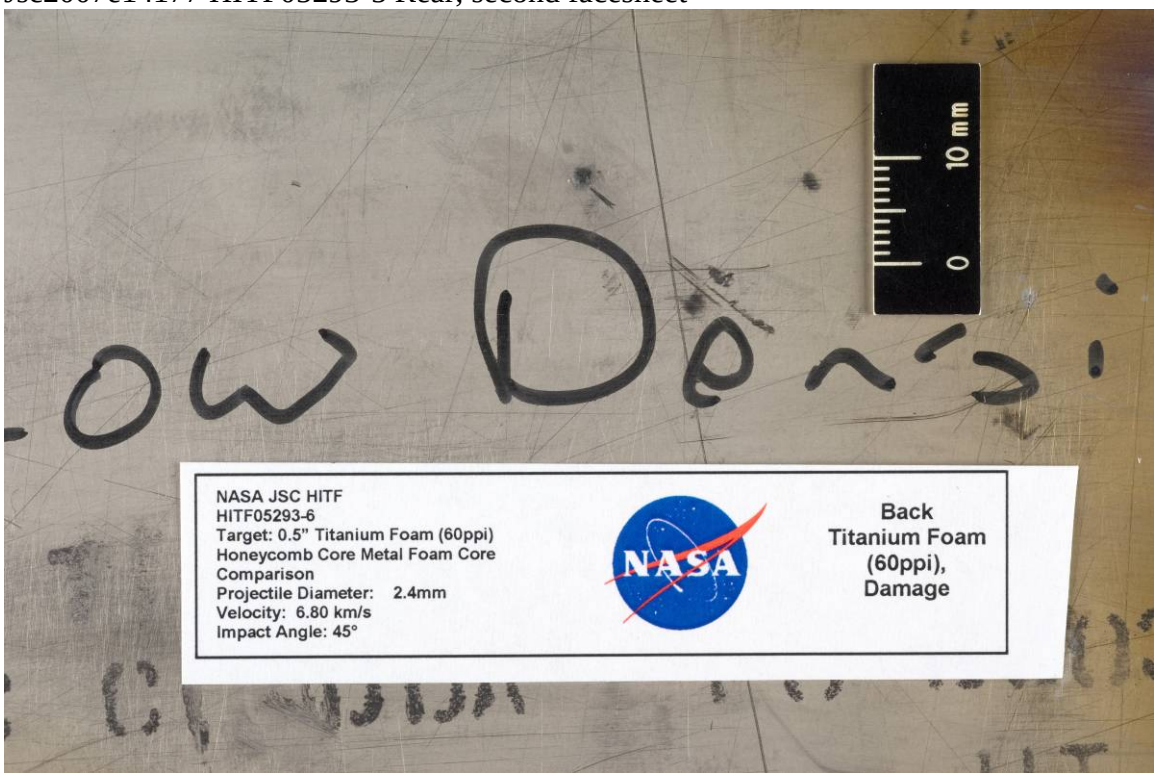

Figure A-112
Jsc2007e14178 HITF05293-6 Rear, second facesheet

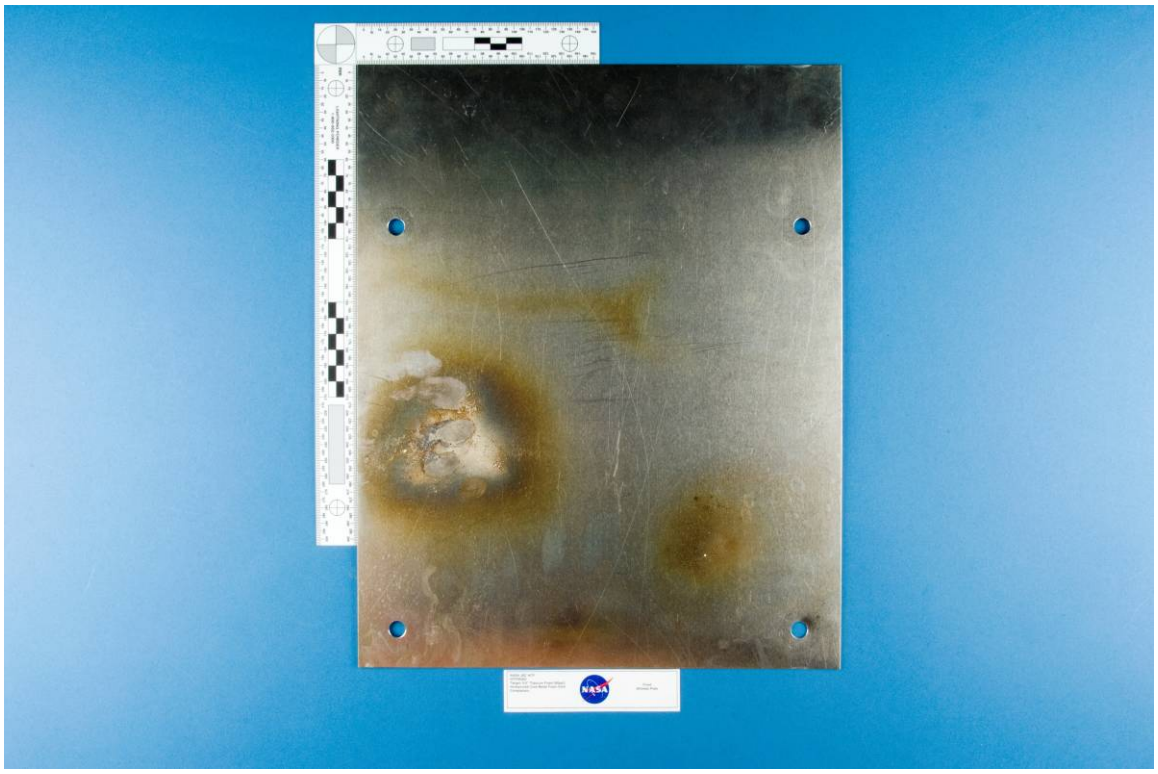

Figure A-113
Jsc2007e14167 HITF05293 Front, witness plate

Figure A-114
Jsc2007e14168 HITF05293 Rear, witness plate

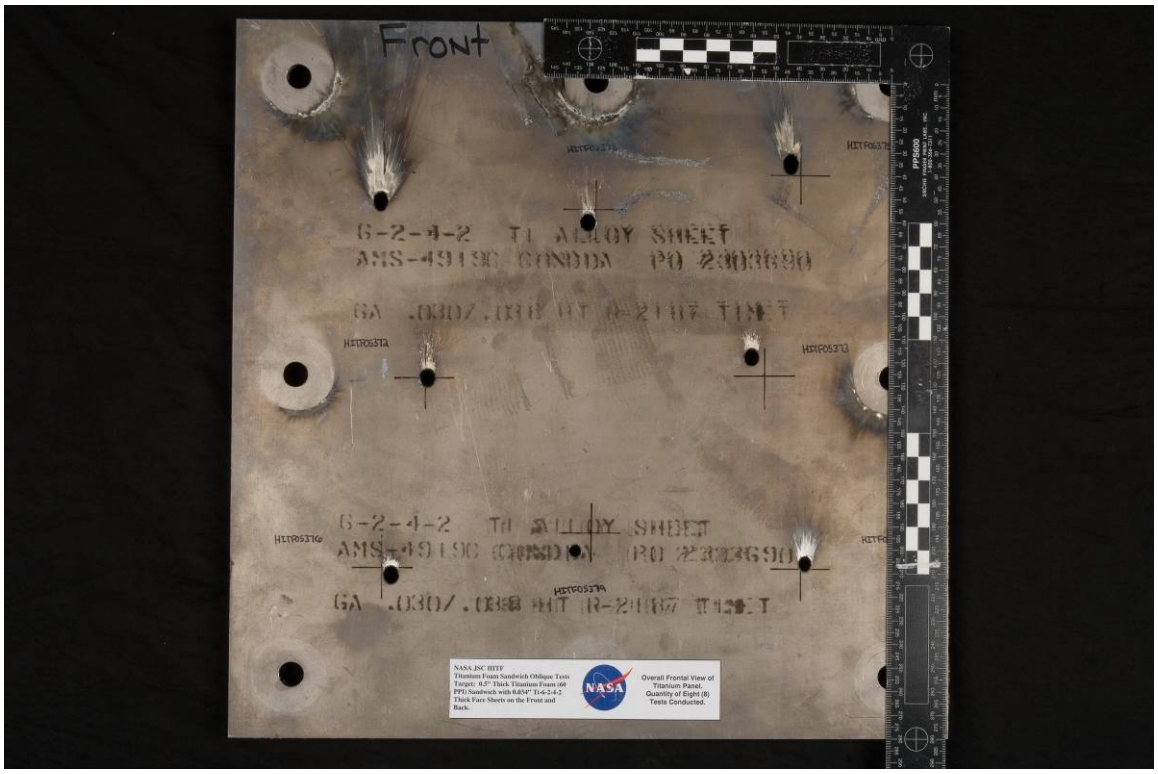

Figure A-115
Jsc2006e13229 HITF05372 – HITF05379 Front, first facesheet

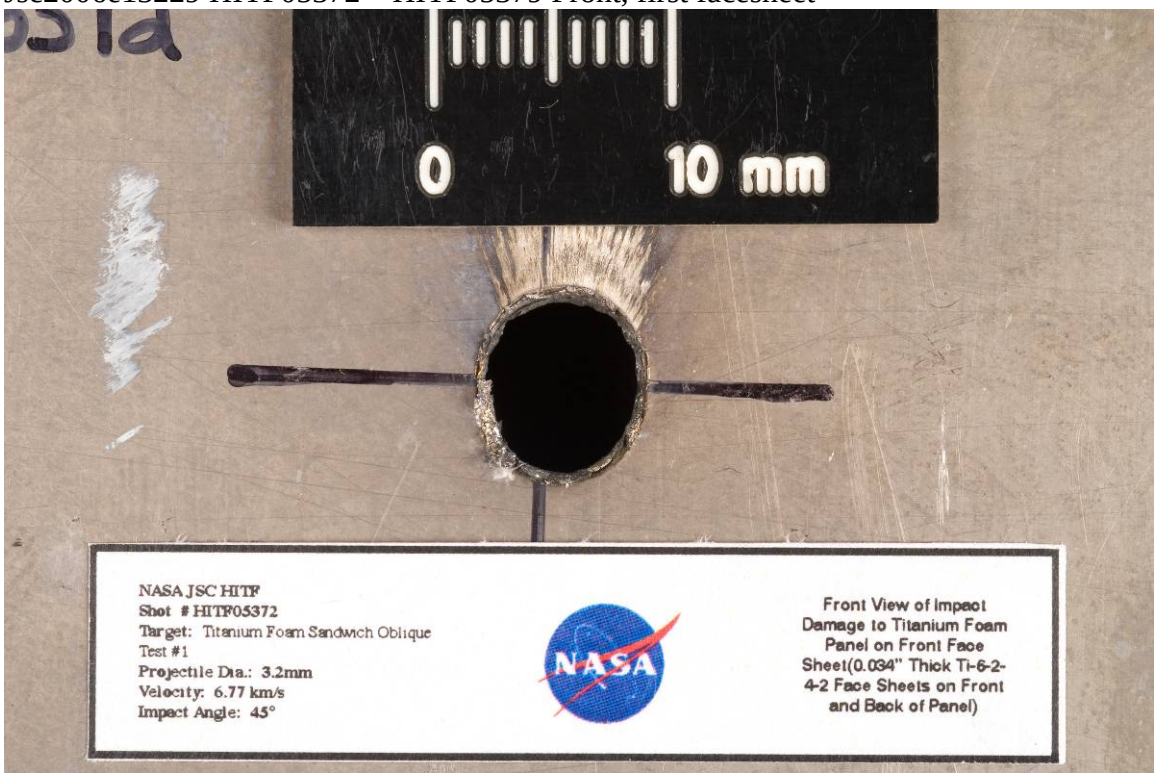

Figure A-116
Jsc2006e13234 HITF05372 Front, first facesheet

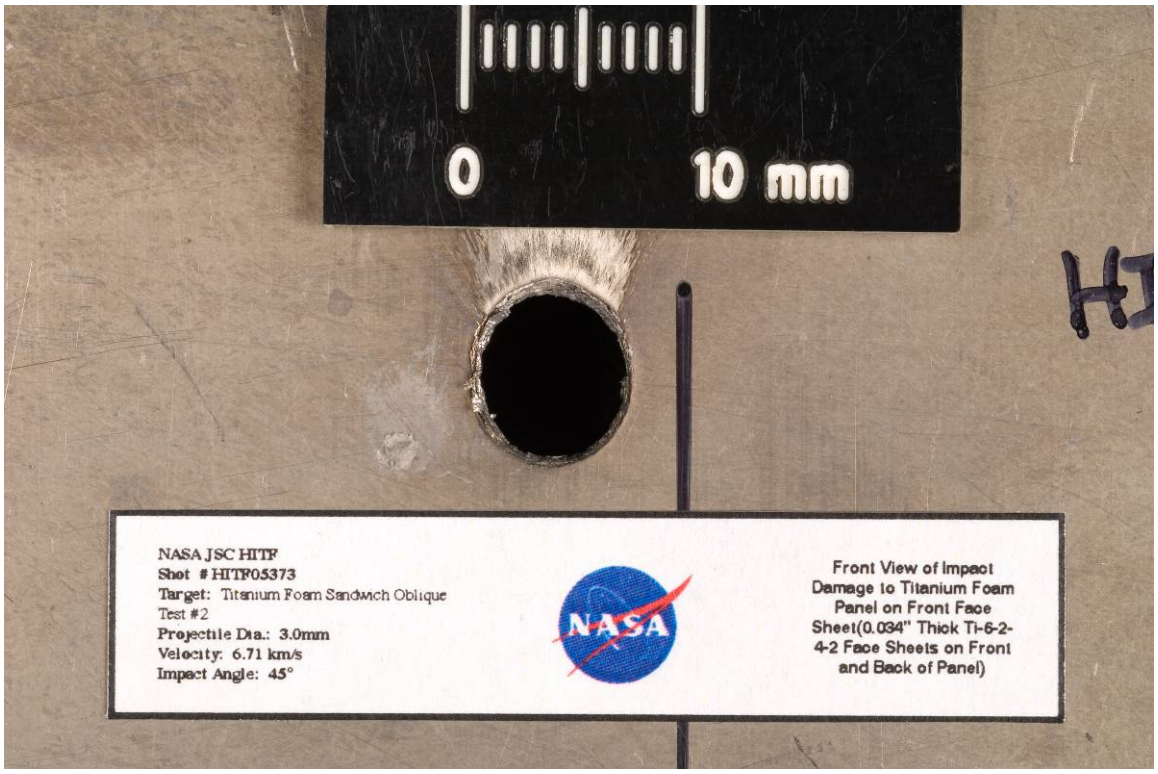

Figure A-117
Jsc2006e13235 HITF05373 Front, first facesheet

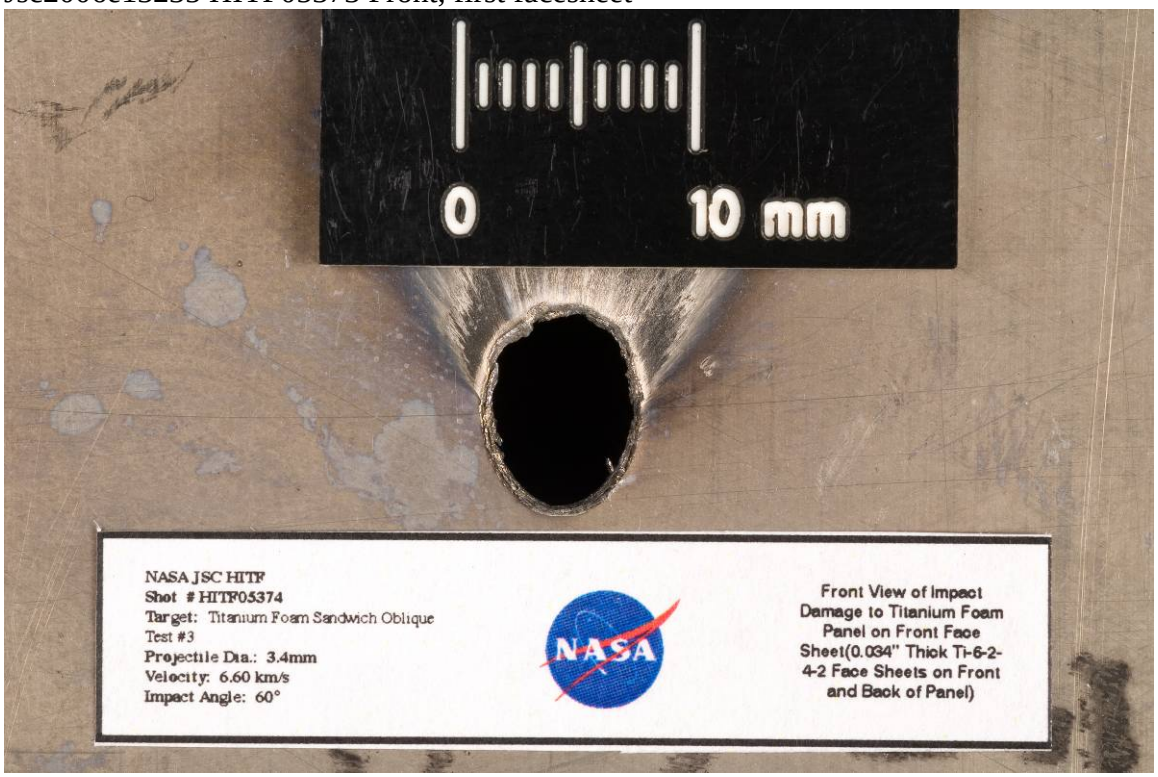

Figure A-118
Jsc2006e13236 HITF05374 Front, first facesheet

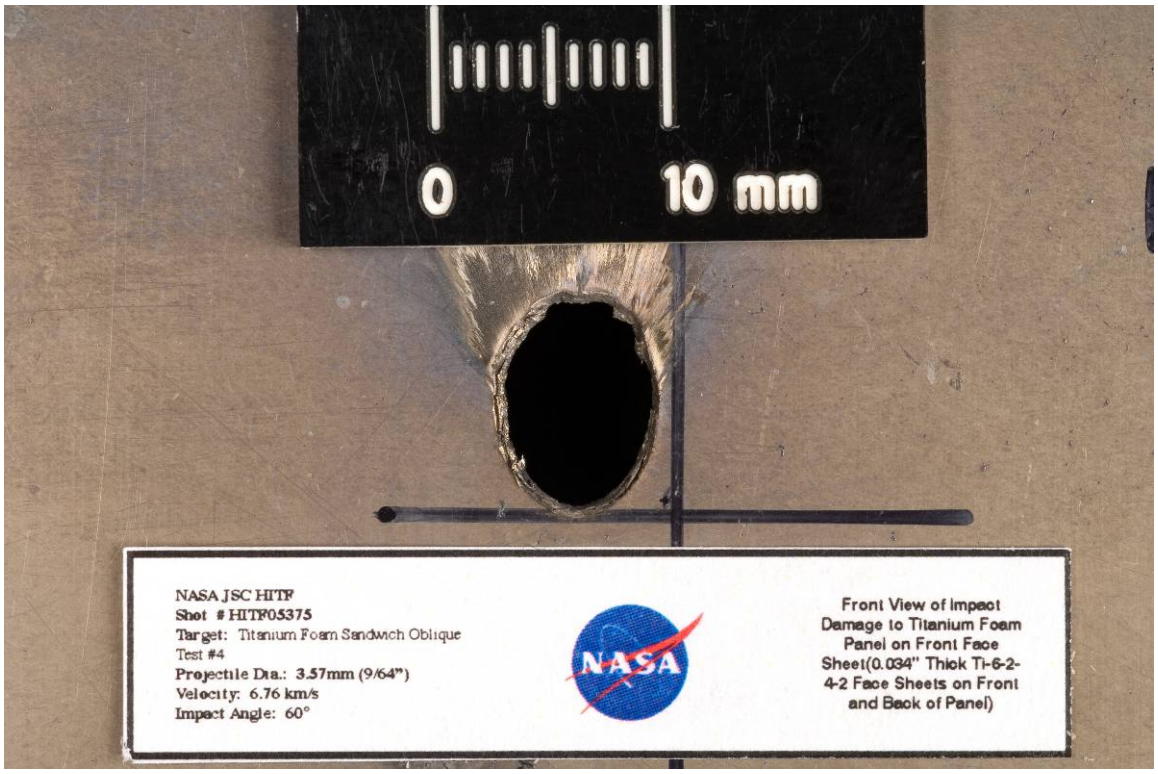

Figure A-119
Jsc2006e13237 HITF05375 Front, first facesheet

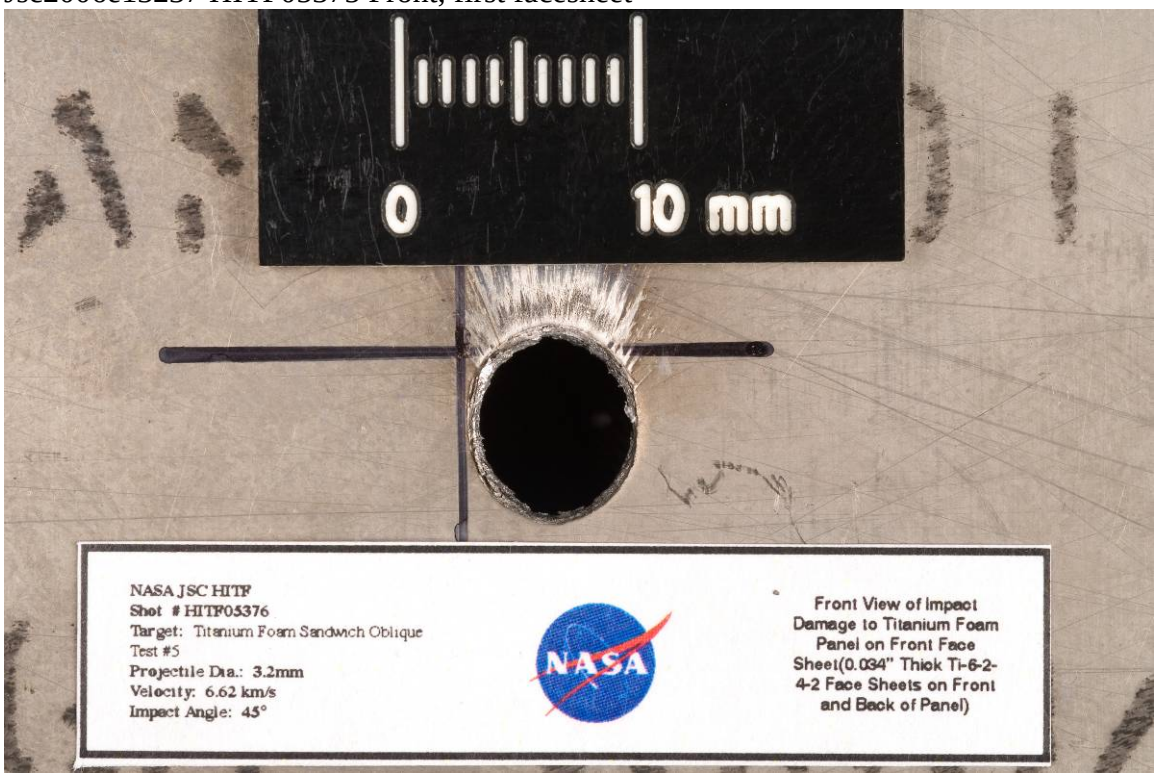

Figure A-120
Jsc2006e13238 HITF05376 Front, first facesheet

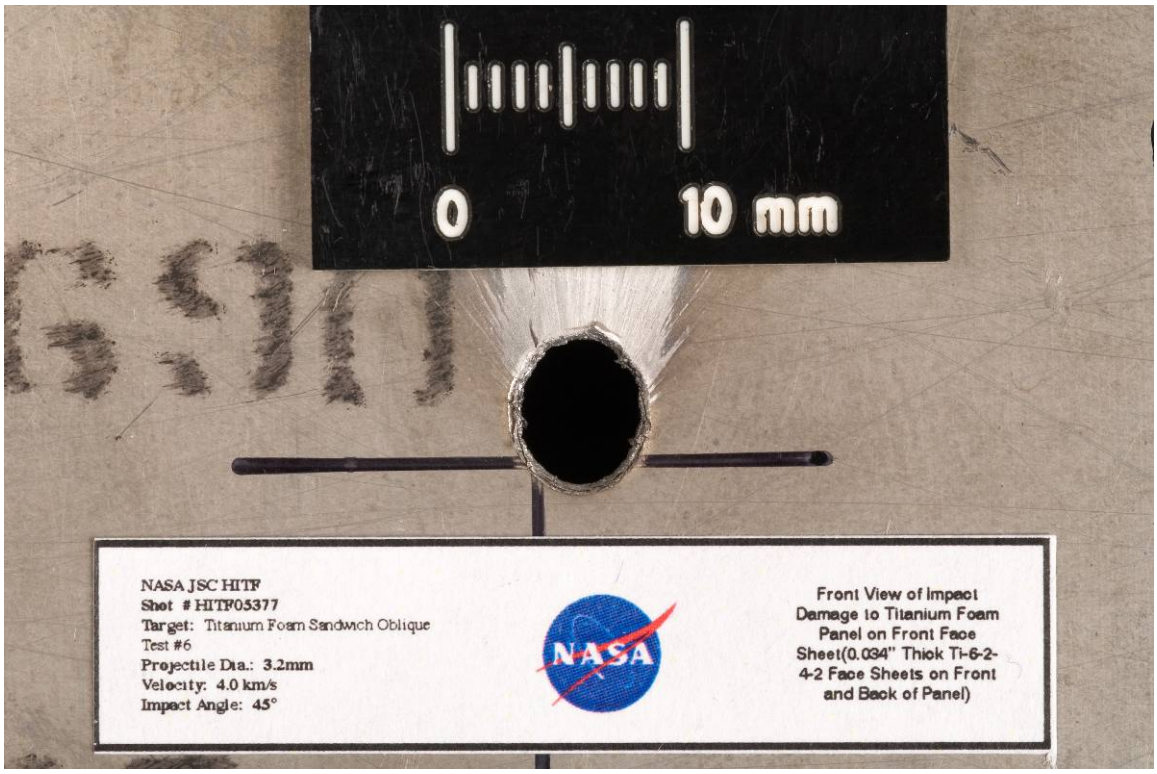

Figure A-121
Jsc2006e13239 HITF05377 Front, first facesheet

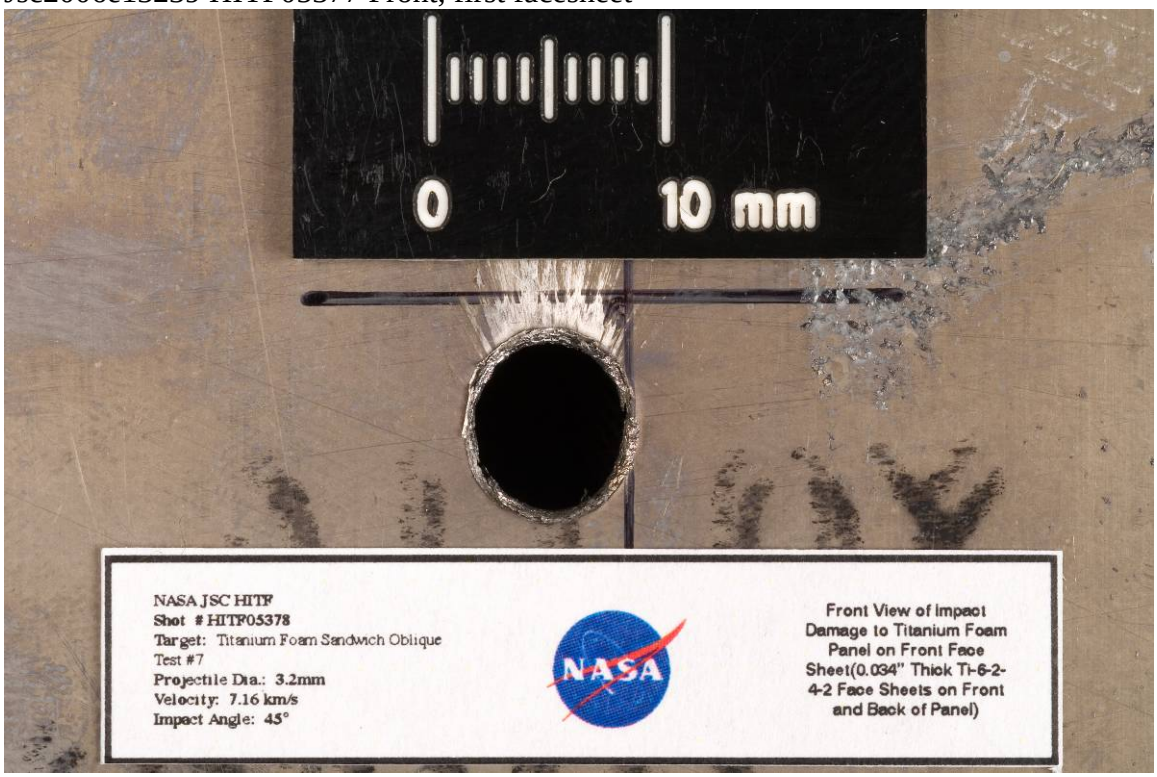

Figure A-122
Jsc2006e13240 HITF05378 Front, first facesheet

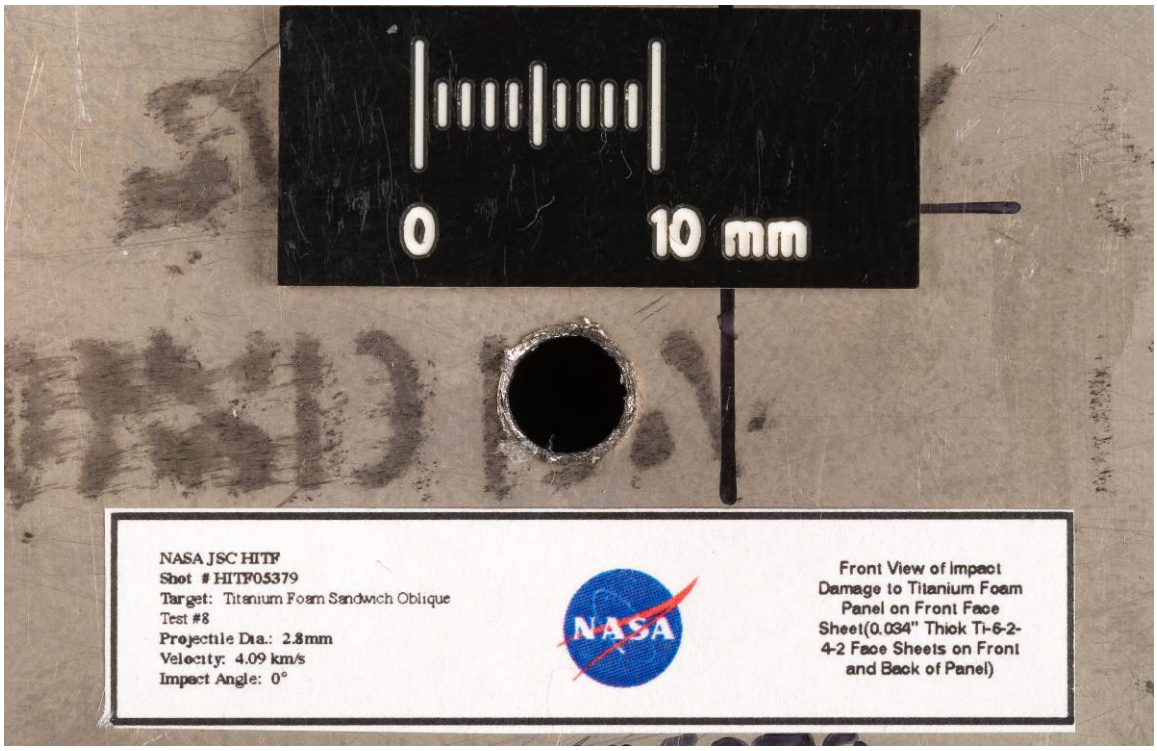

Figure A-123
Jsc2006e13241 HITF05379 Front, first facesheet

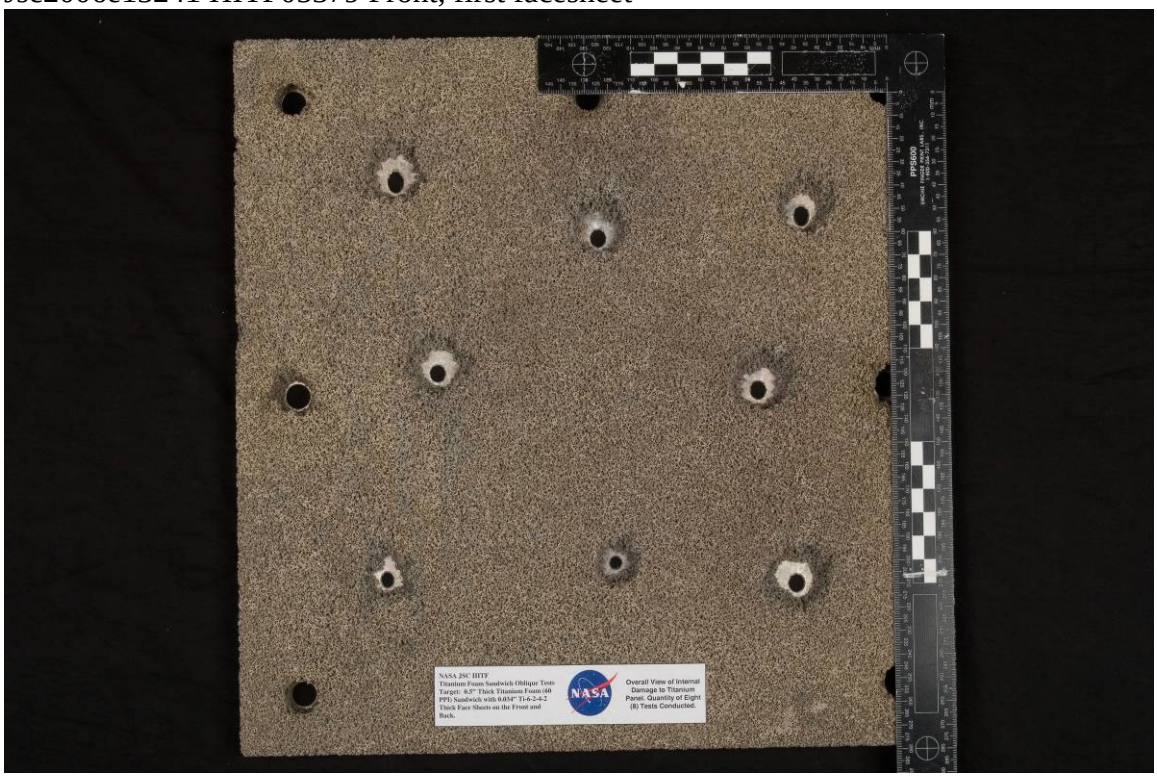

Figure A-124
Jsc2006e13230 HITF05372 – HITF05379 Rear, core

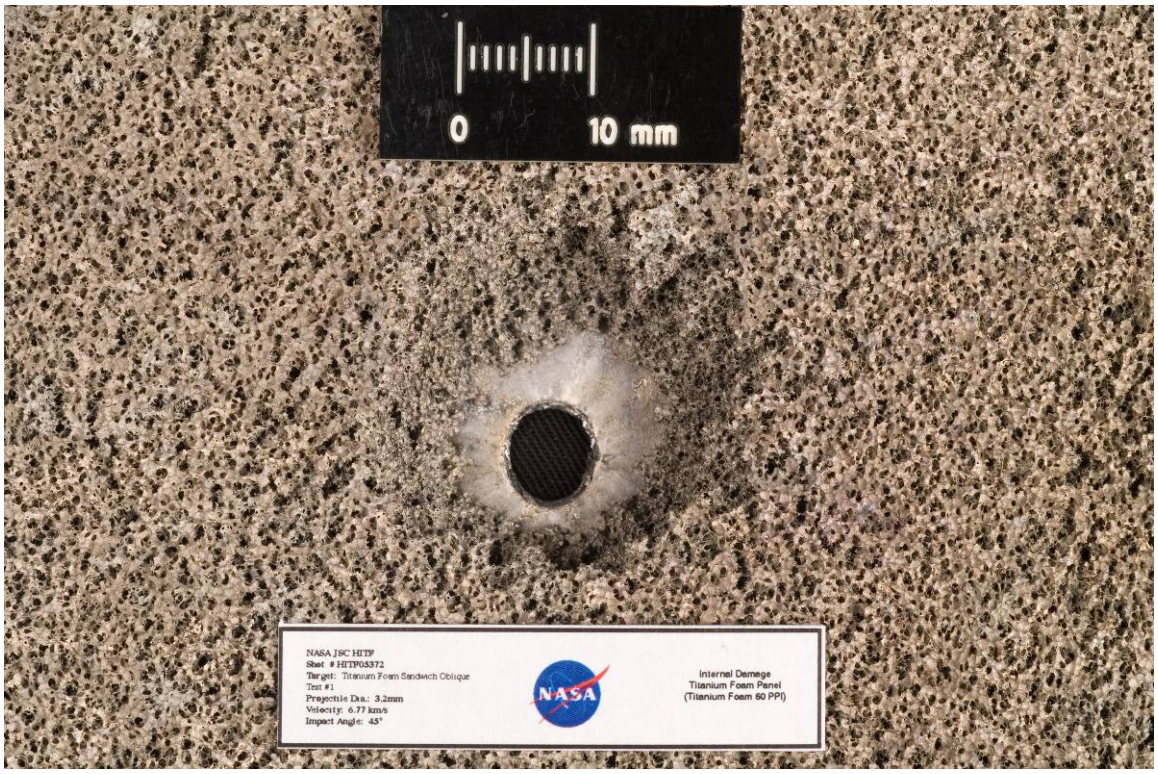

Figure A-125
Jsc2006e13242 HITF05372 Rear, core and first facesheet

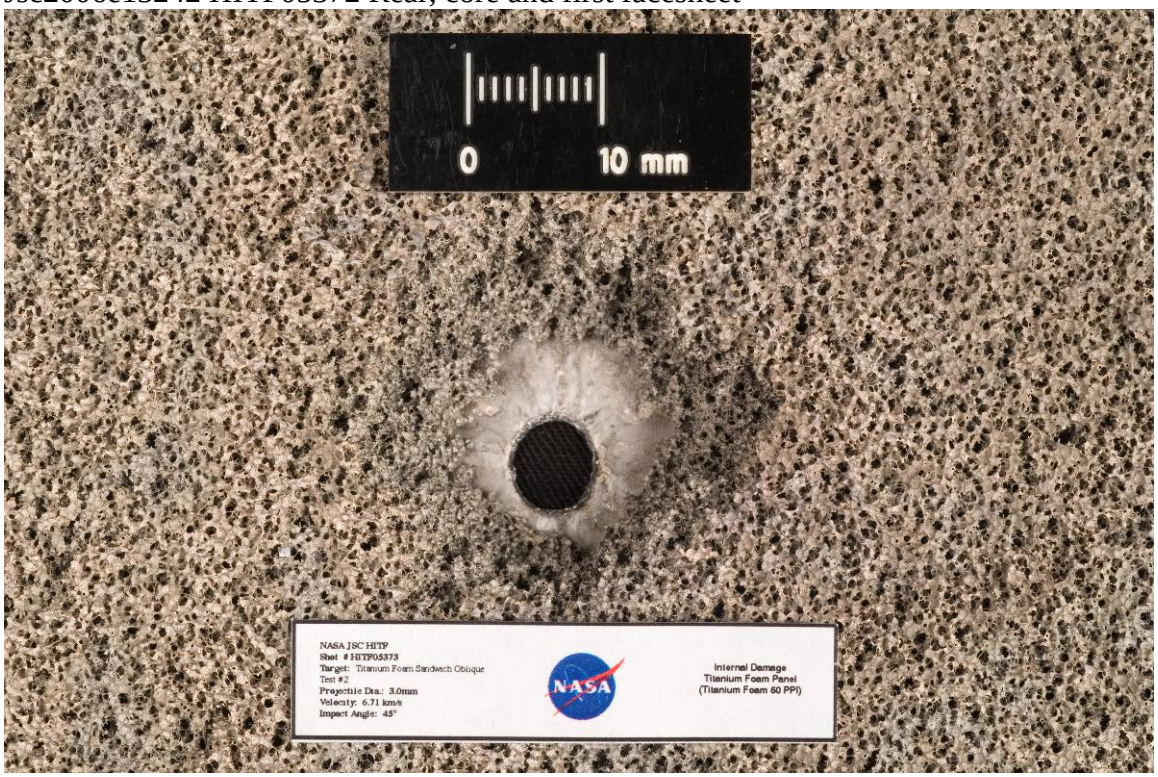

Figure A-126
Jsc2006e13243 HITF05373 Rear, core and first facesheet

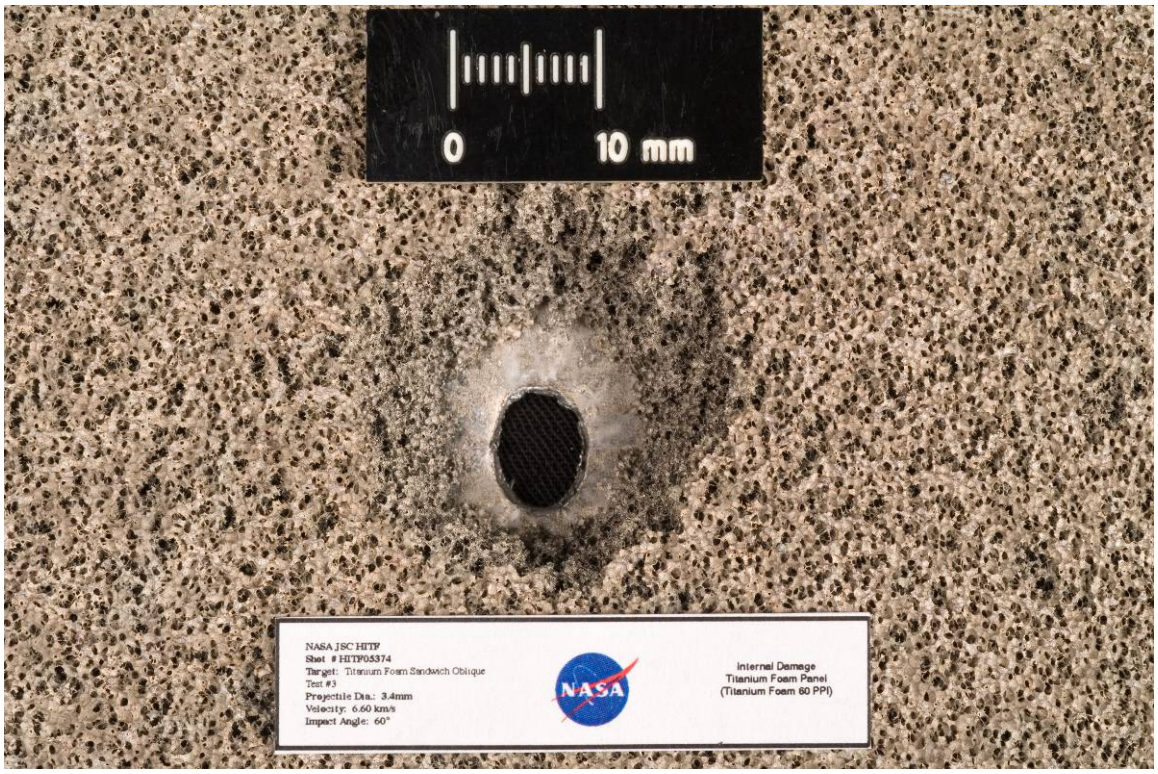

Figure A-127
Jsc2006e13244 HITF05374 Rear, core and first facesheet

Figure A-128
Jsc2006e13245 HITF05375 Rear, core and first facesheet

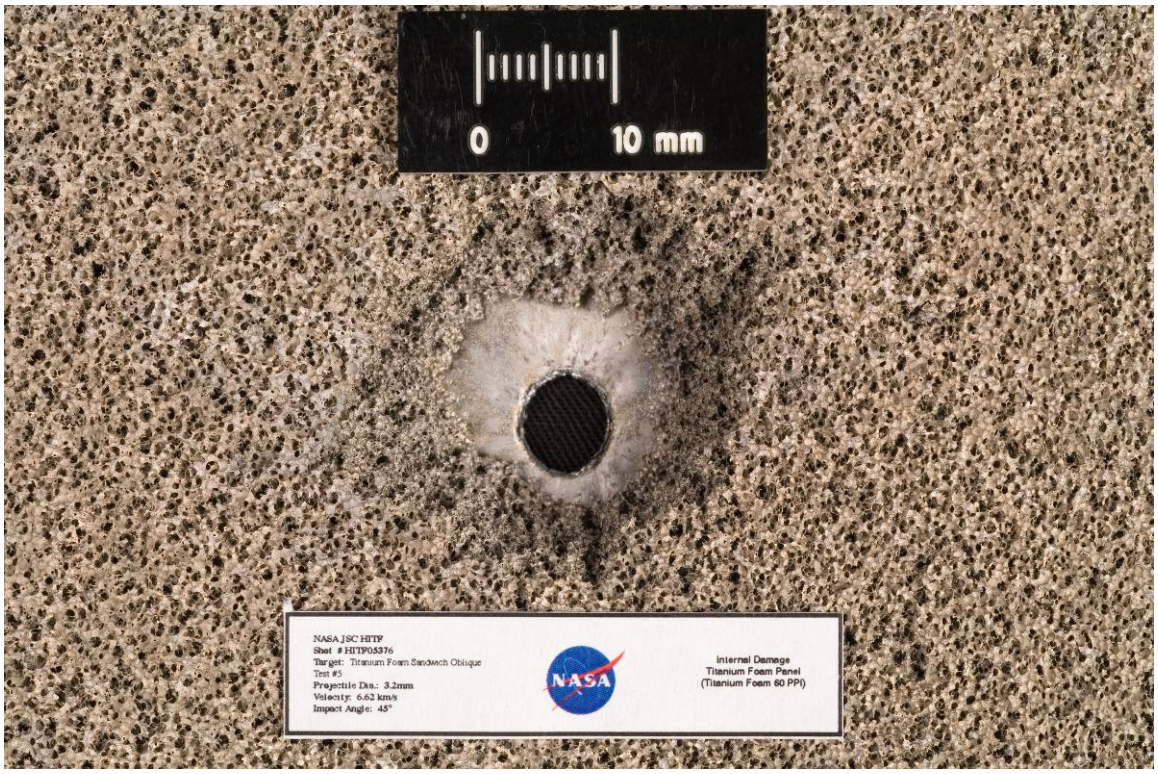

Figure A-129
Jsc2006e13246 HITF05376 Rear, core and first facesheet

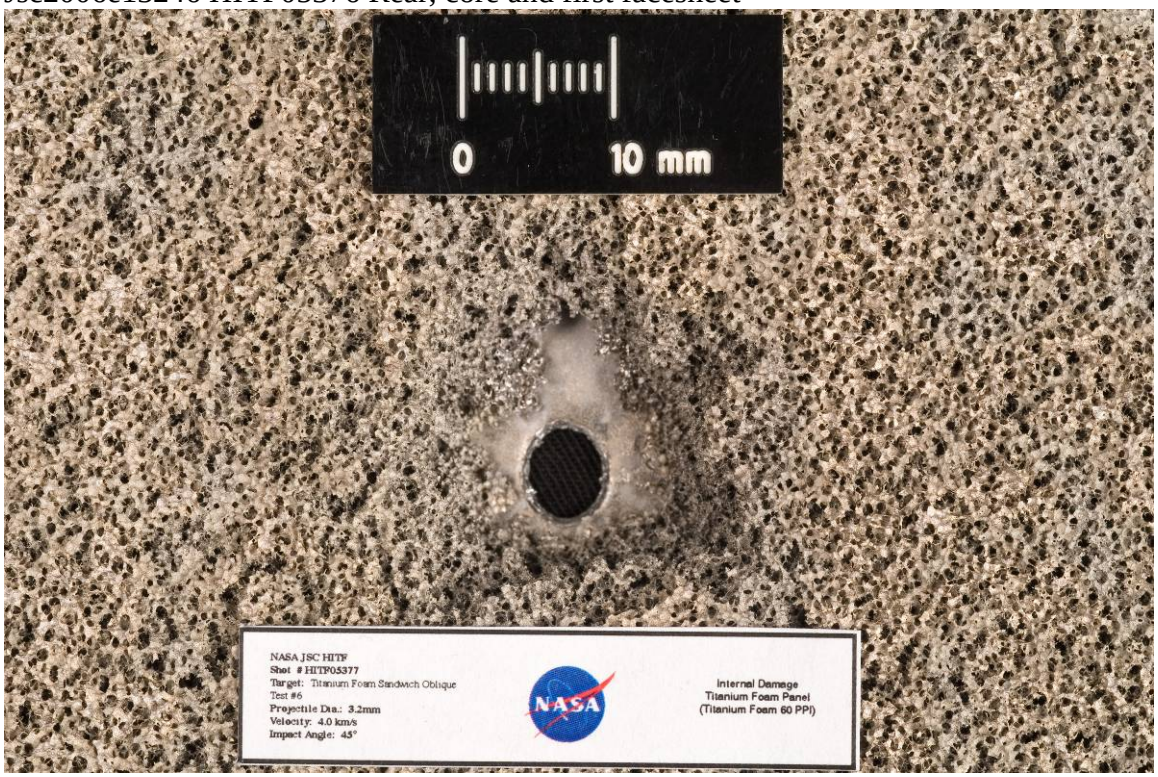

Figure A-130
Jsc2006e13247 HITF05377 Rear, core and first facesheet

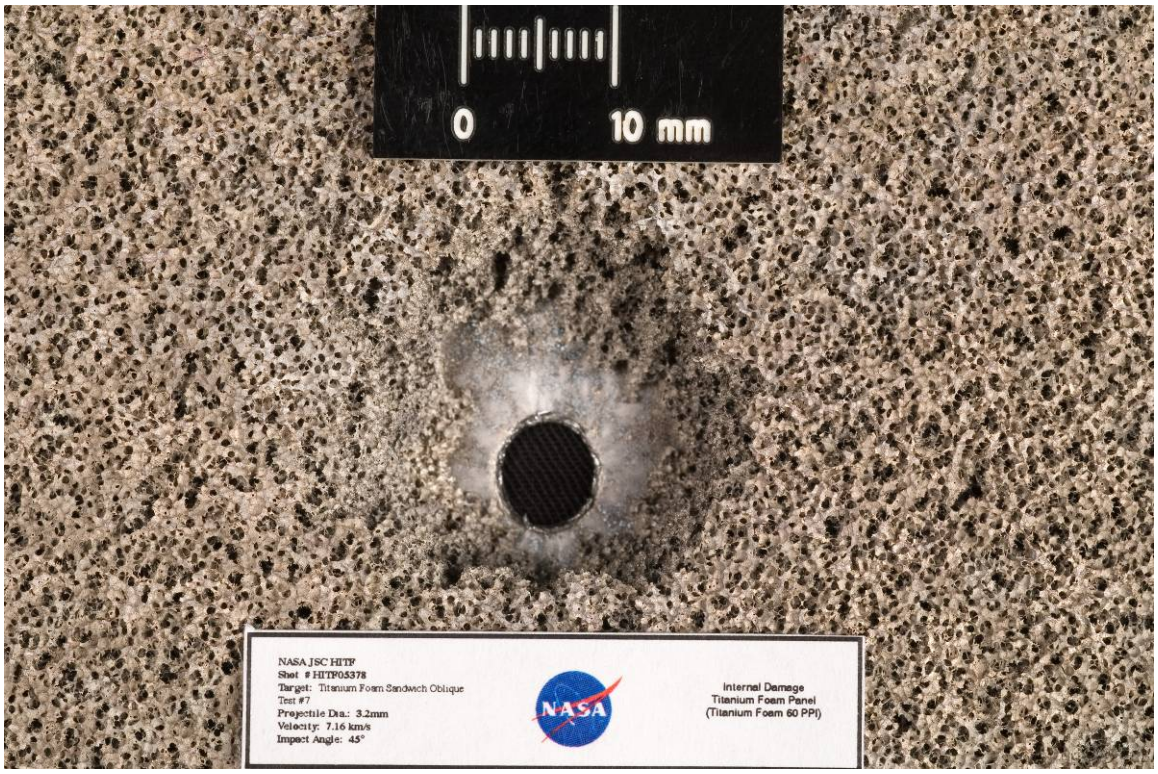

Figure A-131
Jsc2006e13248 HITF05378 Rear, core and first facesheet

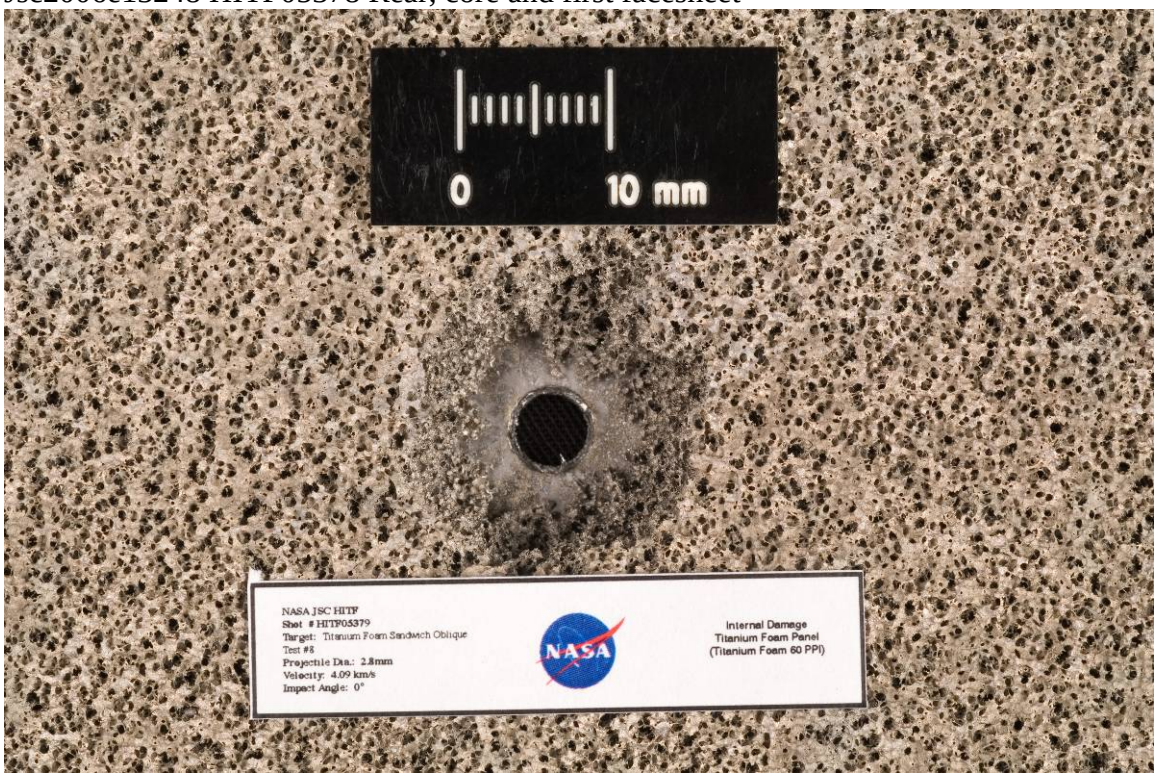

Figure A-132
Jsc2006e13249 HITF05379 Rear, core and first facesheet

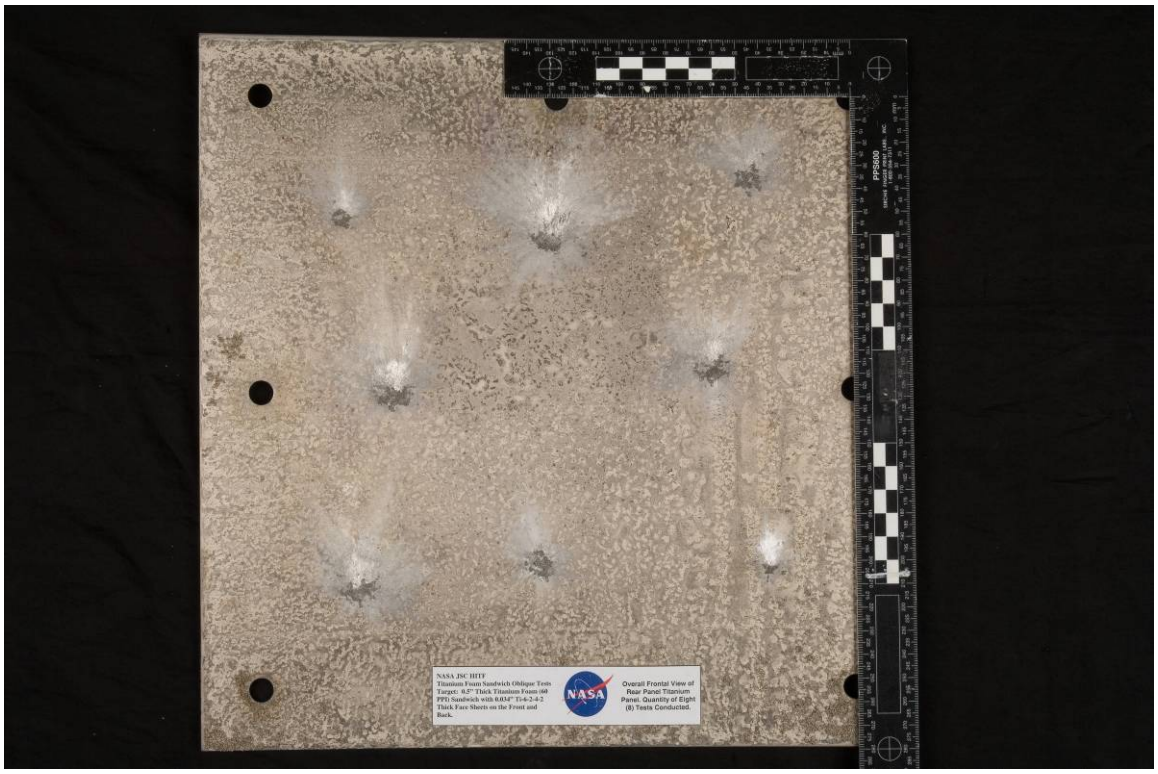

Figure A-133
Jsc2006e13231 HITF05372 – HITF05379 Front, second facesheet

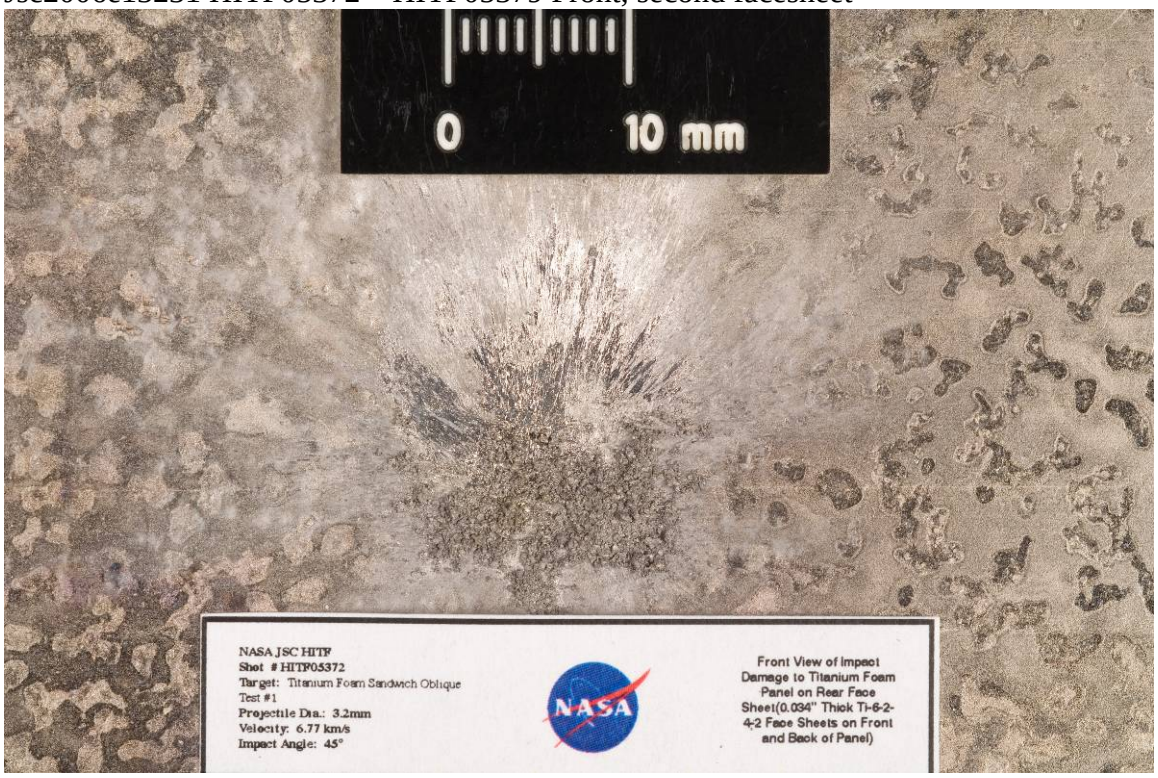

Figure A-134
Jsc2006e13250 HITF05372 Front, second facesheet

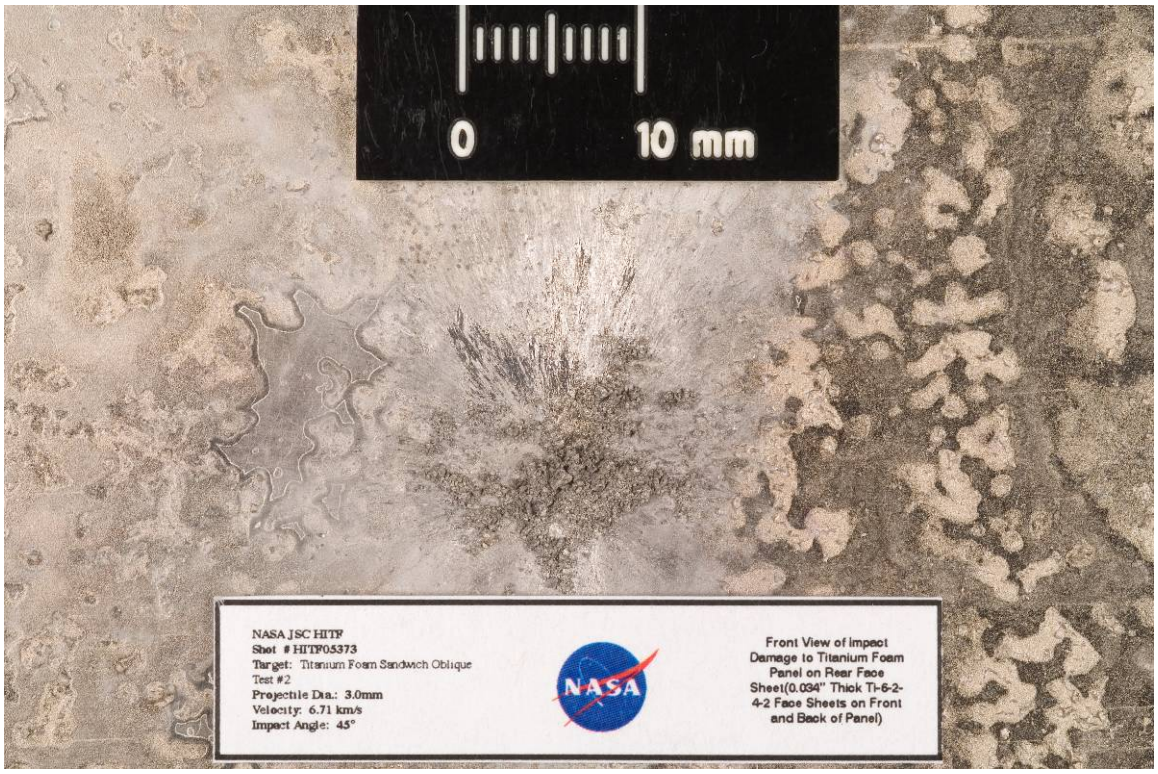

Figure A-135
Jsc2006e13251 HITF05373 Front, second facesheet

Figure A-136
Jsc2006e13252 HITF05374 Front, second facesheet

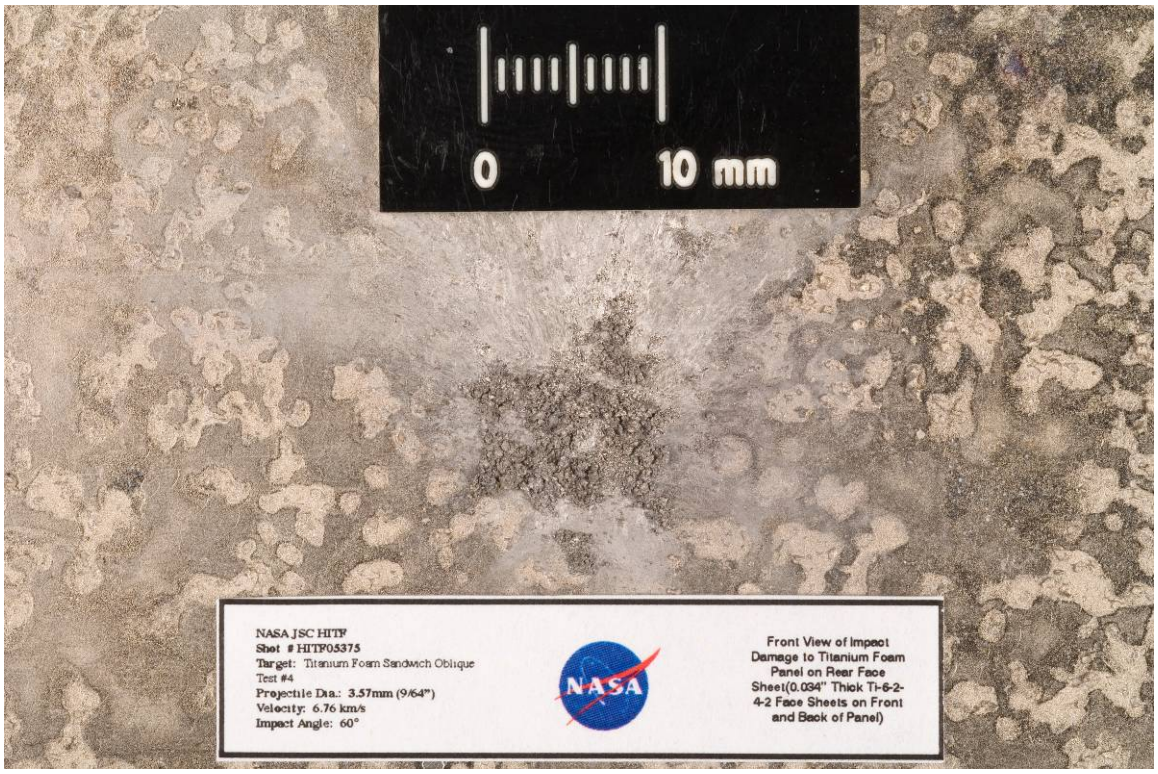

Figure A-137
Jsc2006e13253 HITF05375 Front, second facesheet

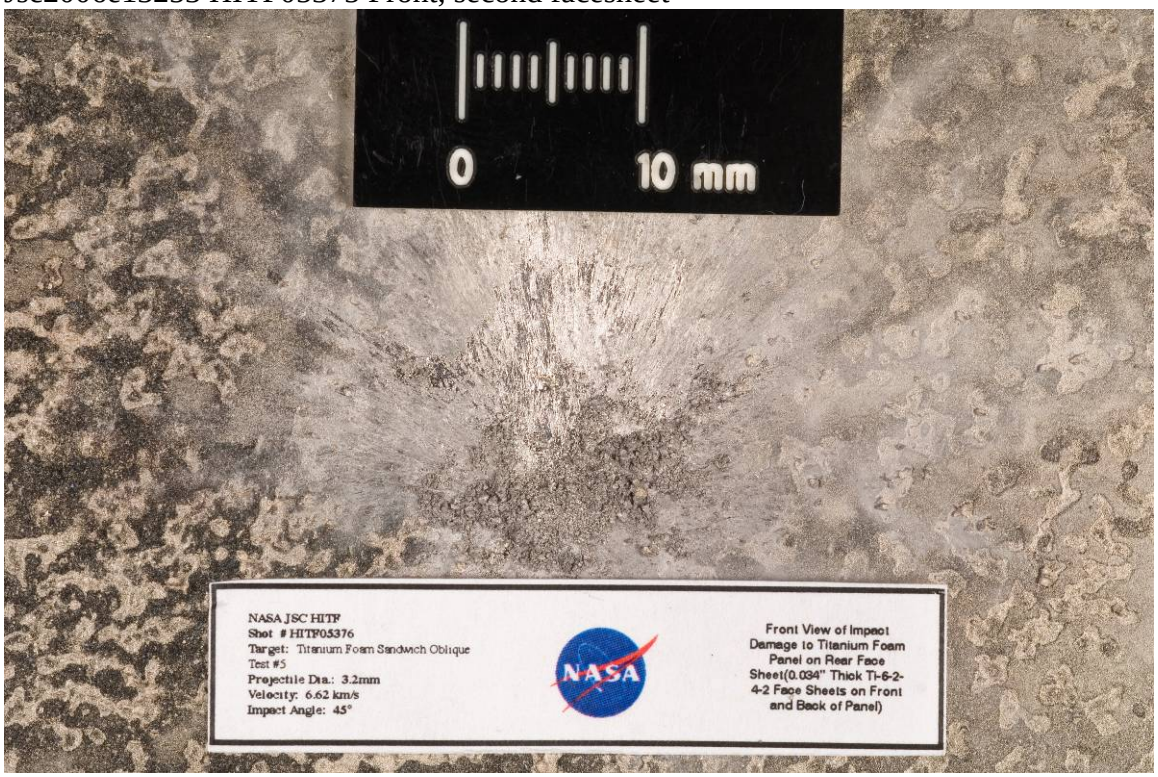

Figure A-138
Jsc2006e13254 HITF05376 Front, second facesheet

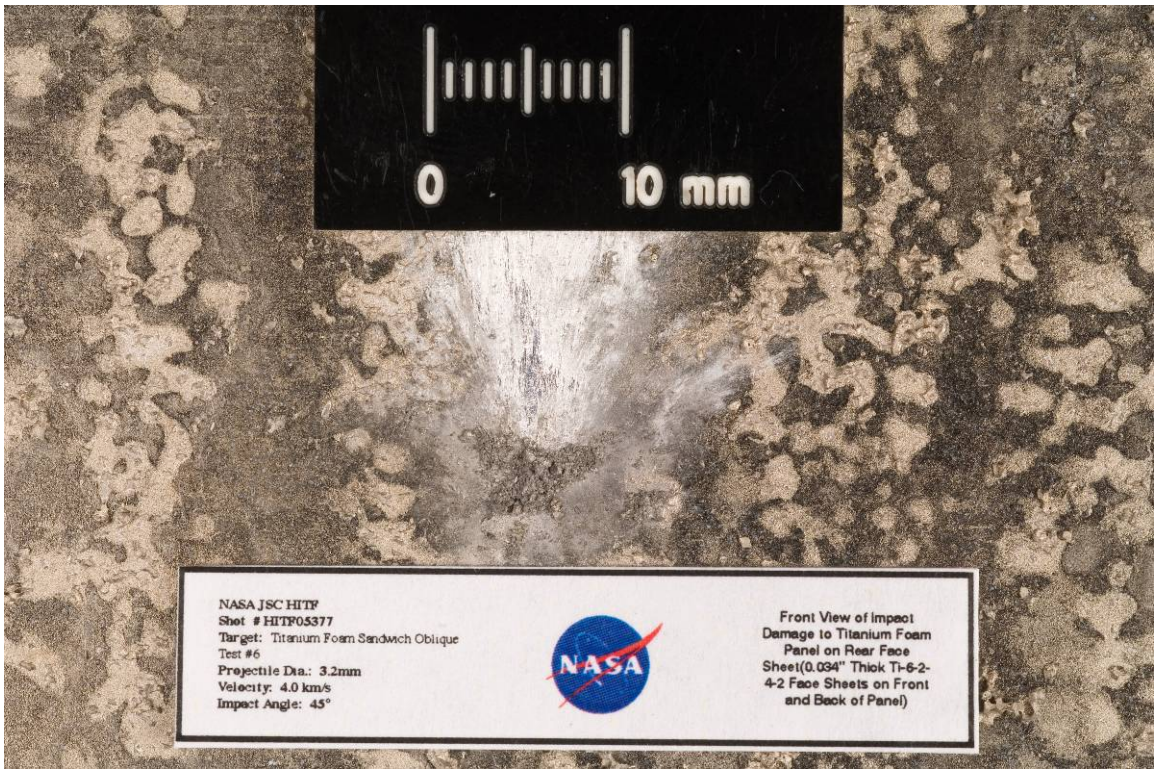

Figure A-139
Jsc2006e13255 HITF05377 Front, second facesheet

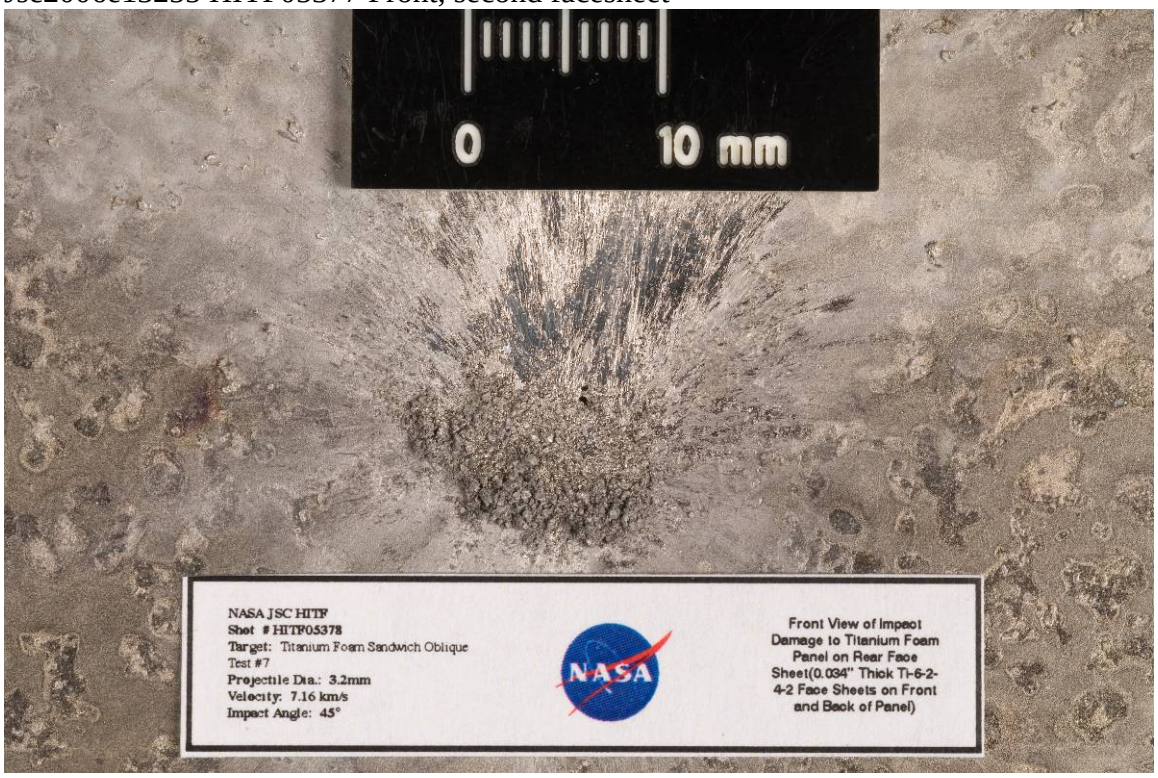

Figure A-140
Jsc2006e13256 HITF05378 Front, second facesheet

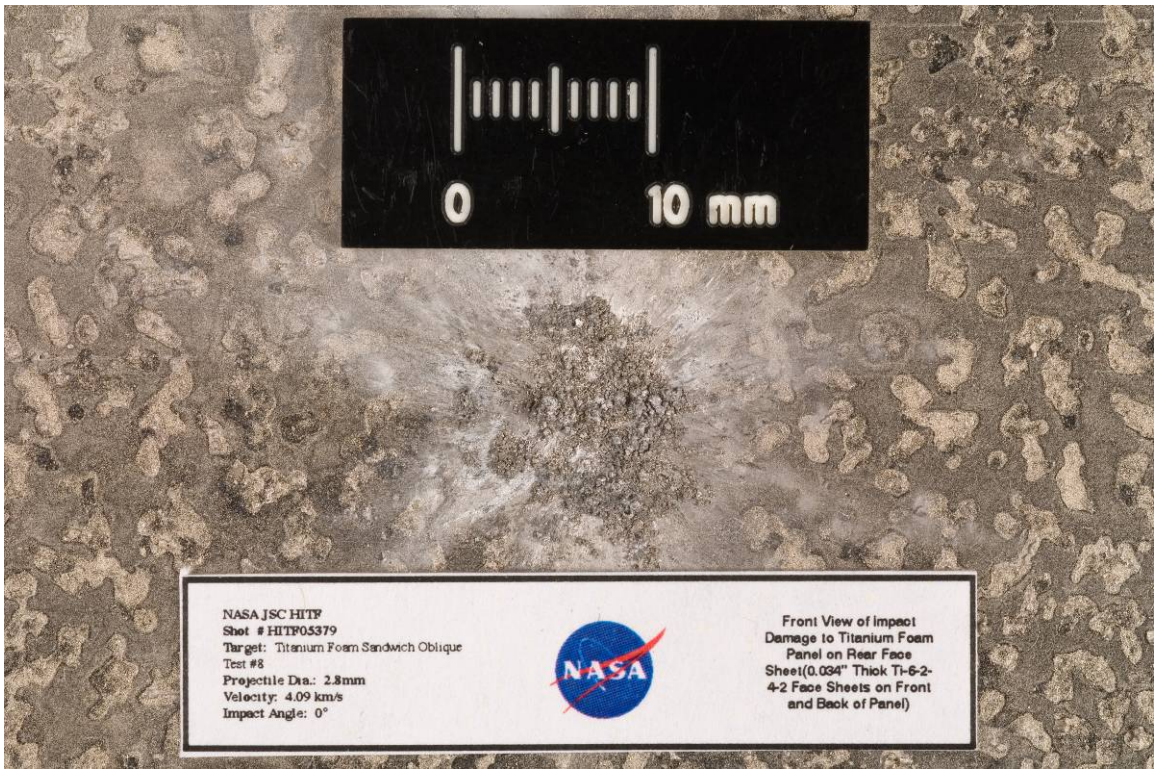

Figure A-141
Jsc2006e13257 HITF05379 Front, second facesheet

Figure A-142
Jsc2006e13232 HITF05372 – HITF05379 Rear, second facesheet

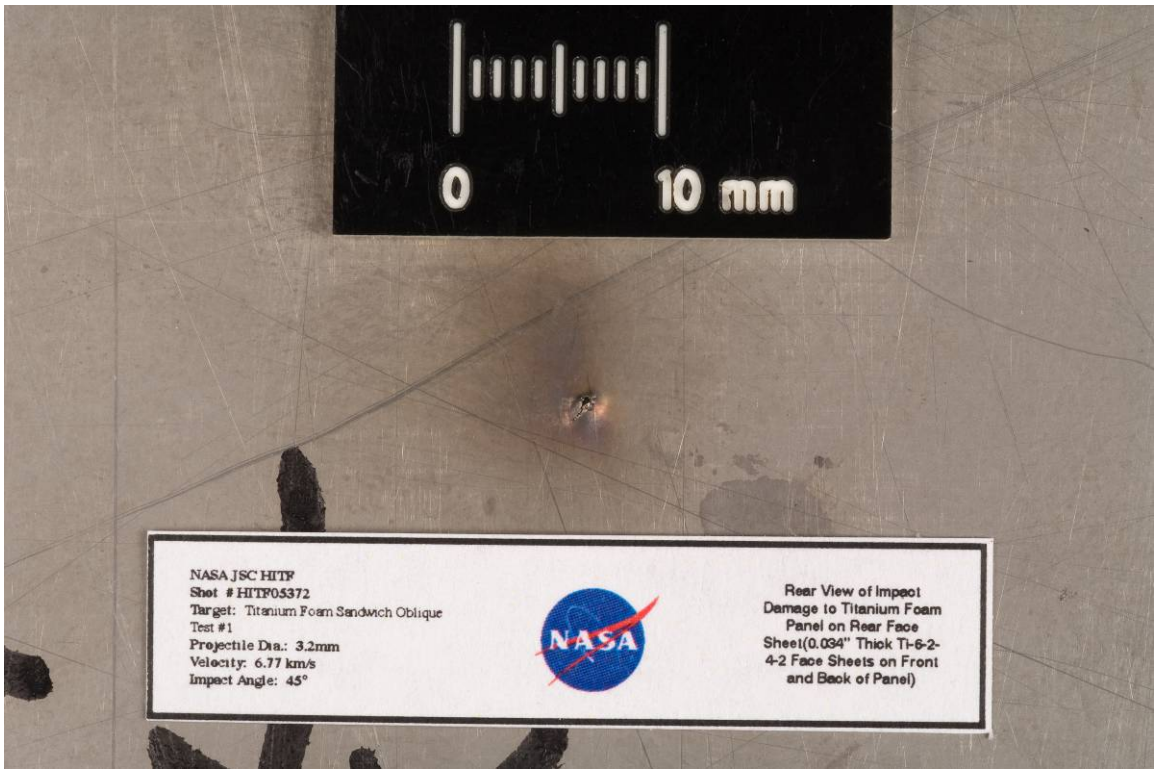

Figure A-143
Jsc2006e13258 HITF05372 Rear, second facesheet

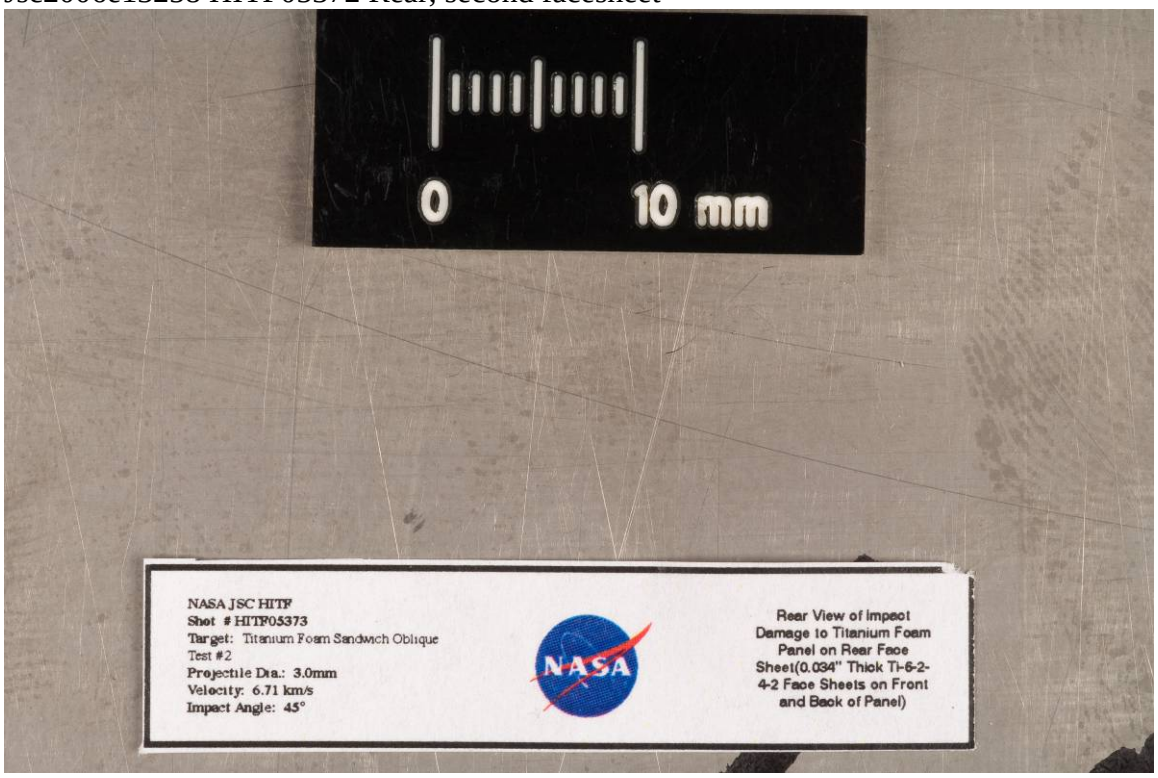

Figure A-144
Jsc2006e13259 HITF05373 Rear, second facesheet

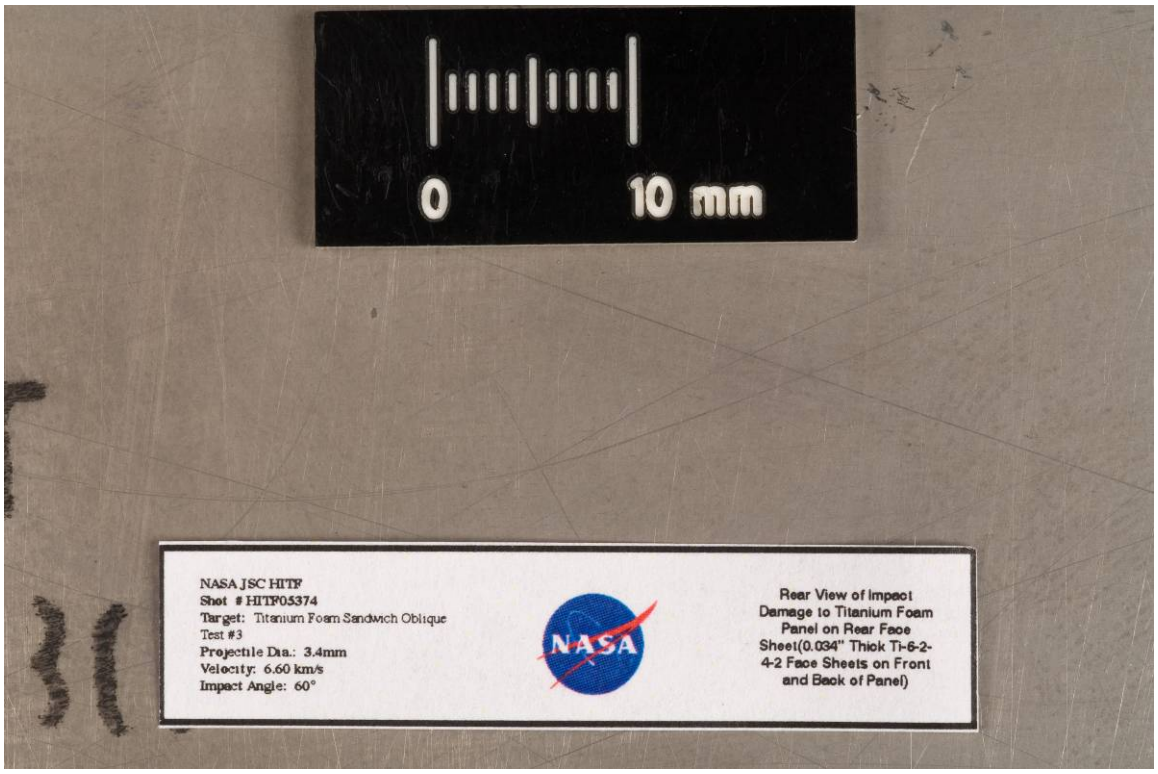

Figure A-145
Jsc2006e13260 HITF05374 Rear, second facesheet

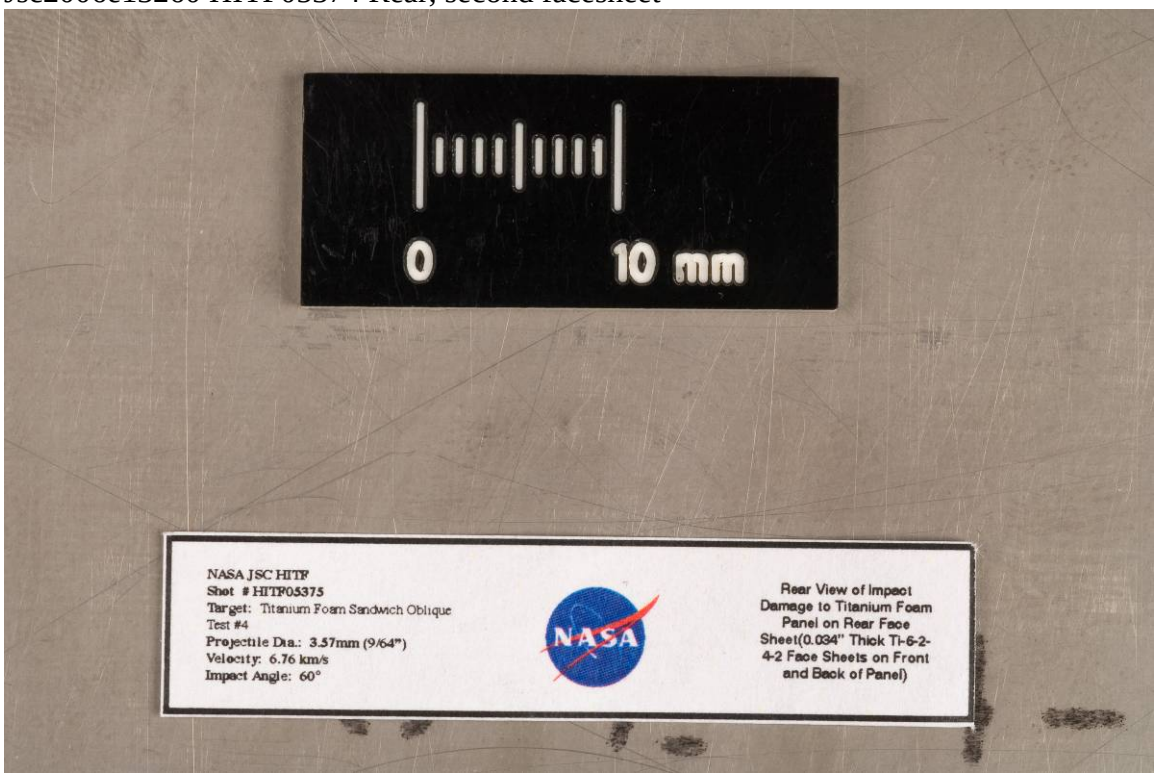

Figure A-146
Jsc2006e13261 HITF05375 Rear, second facesheet

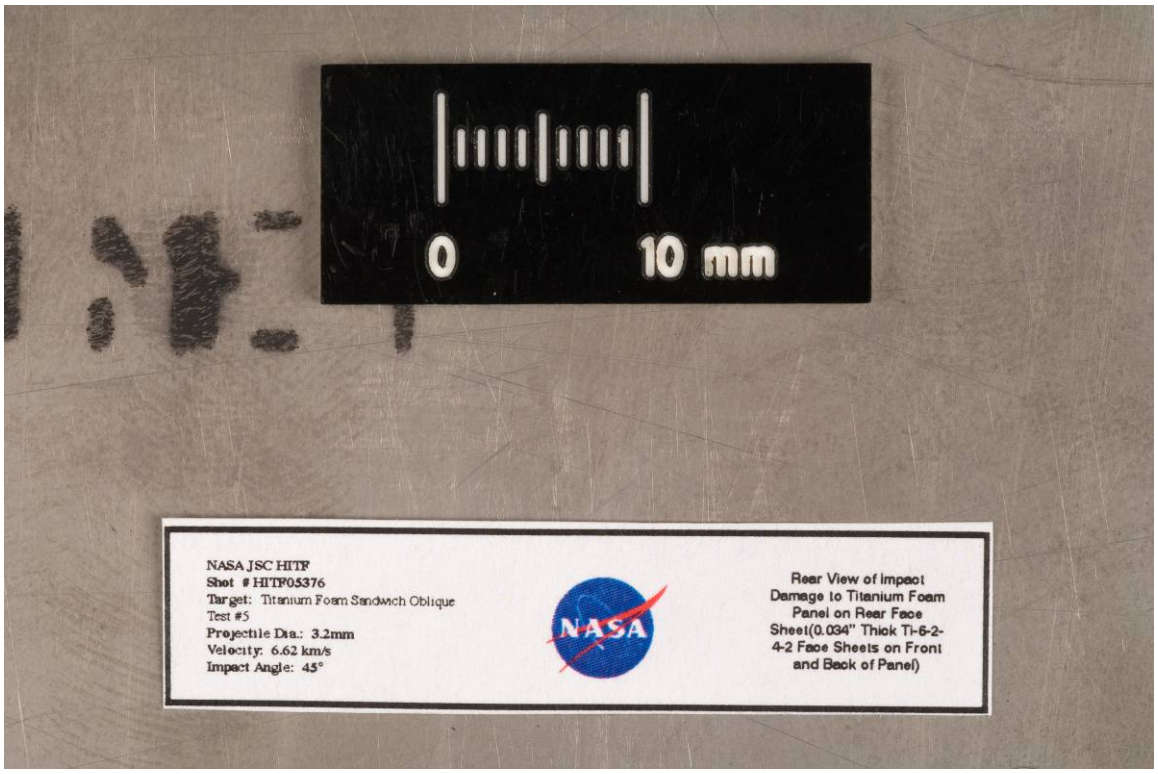

Figure A-147
Jsc2006e13262 HITF05376 Rear, second facesheet

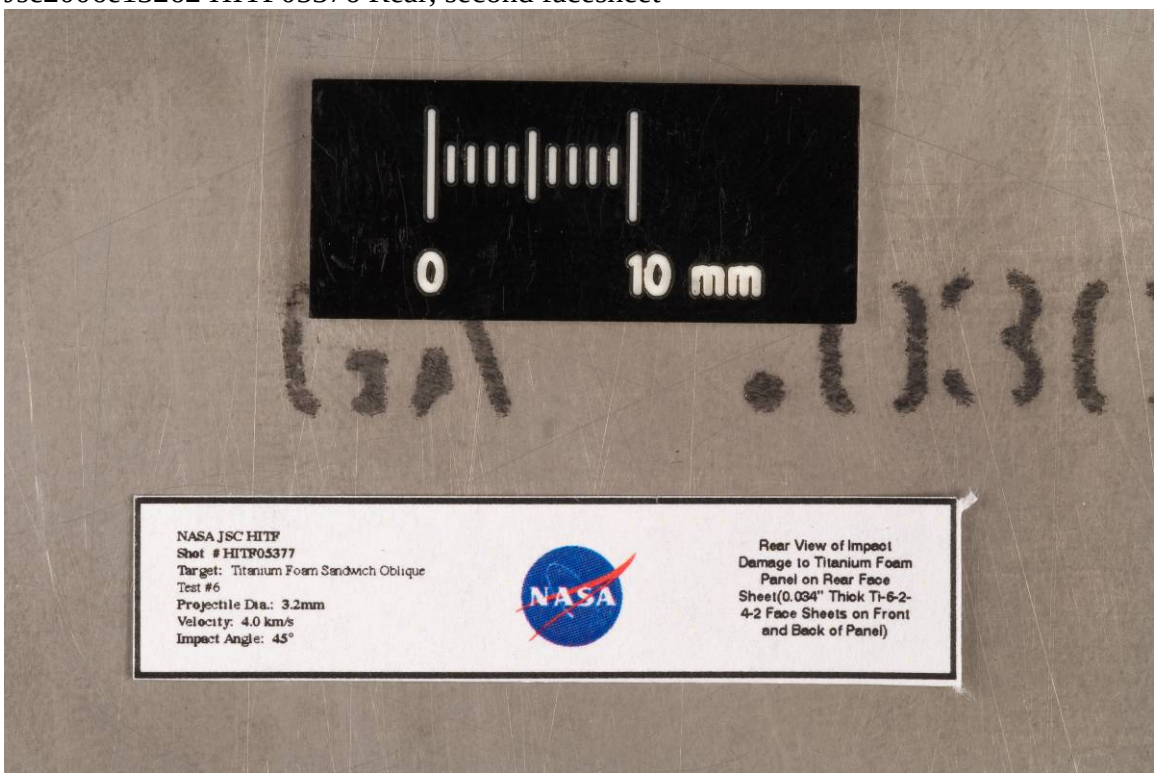

Figure A-148
Jsc2006e13263 HITF05377 Rear, second facesheet

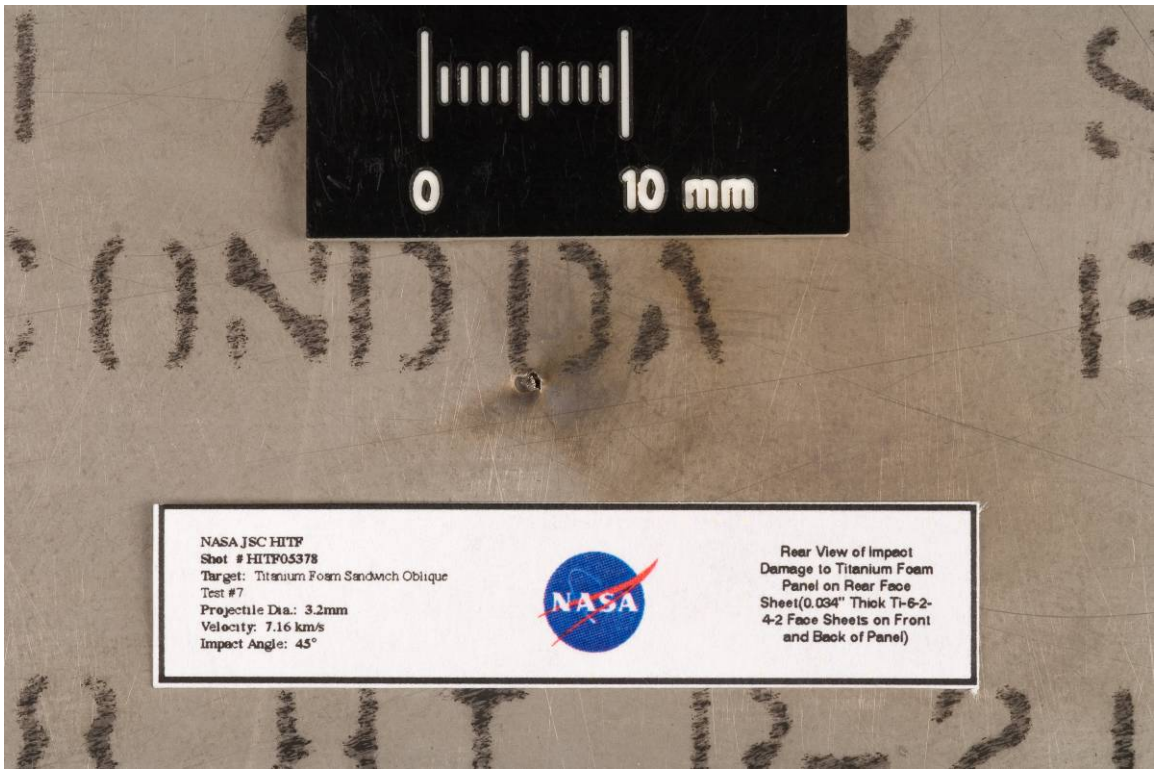

Figure A-149
Jsc2006e13264 HITF05378 Rear, second facesheet

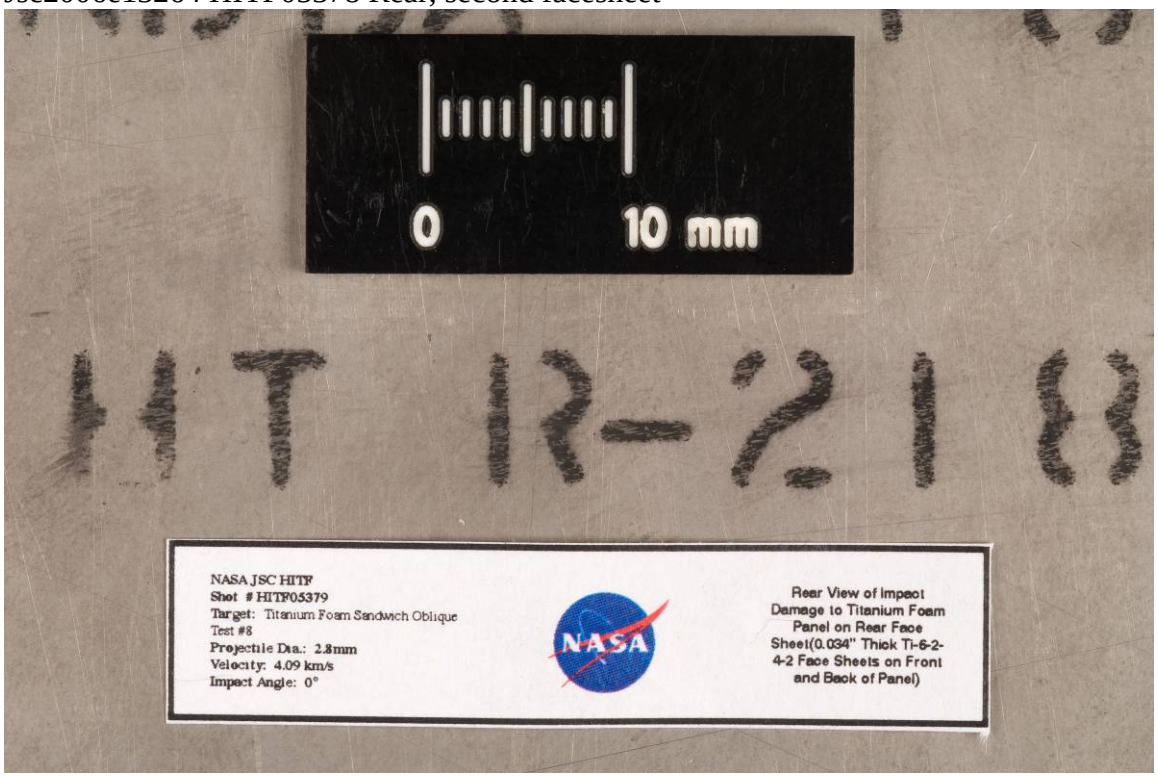

Figure A-150
Jsc2006e13265 HITF05379 Rear, second facesheet

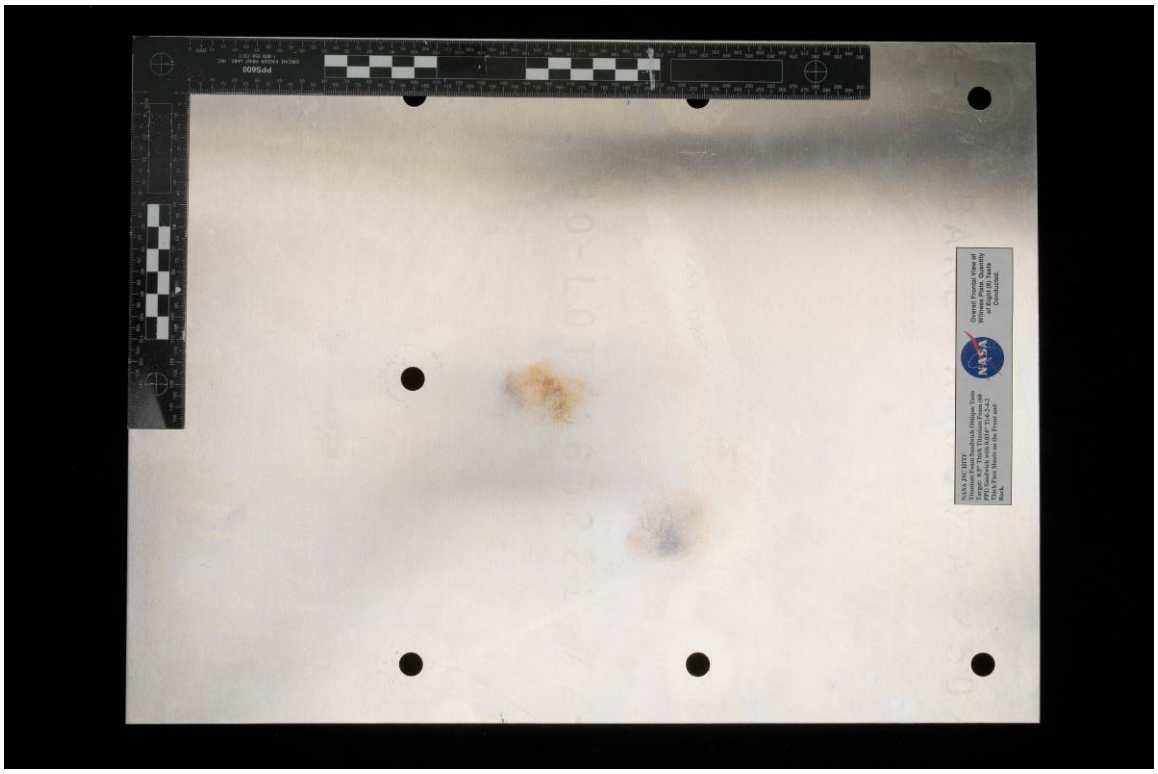

Figure A-151
Jsc2006e13233 HITF05372 – HITF05379 Front, witness plate

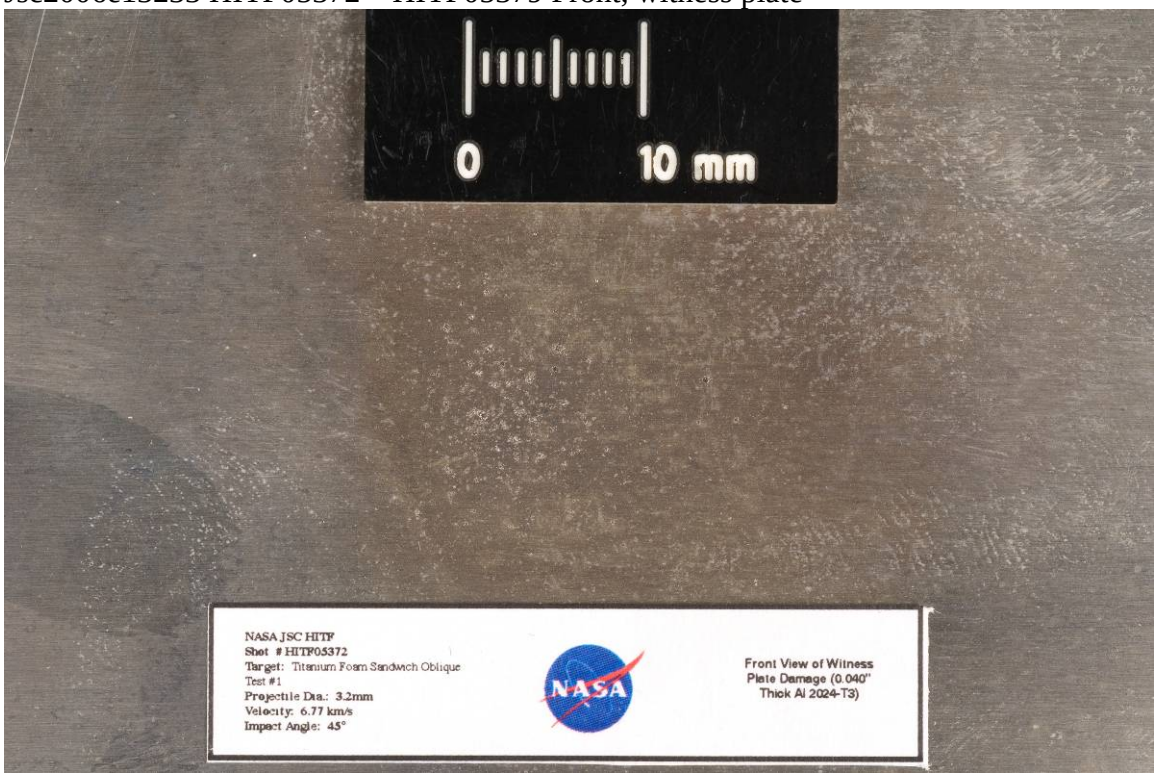

Figure A-152
Jsc2006e13266 HITF05372 Front, witness plate

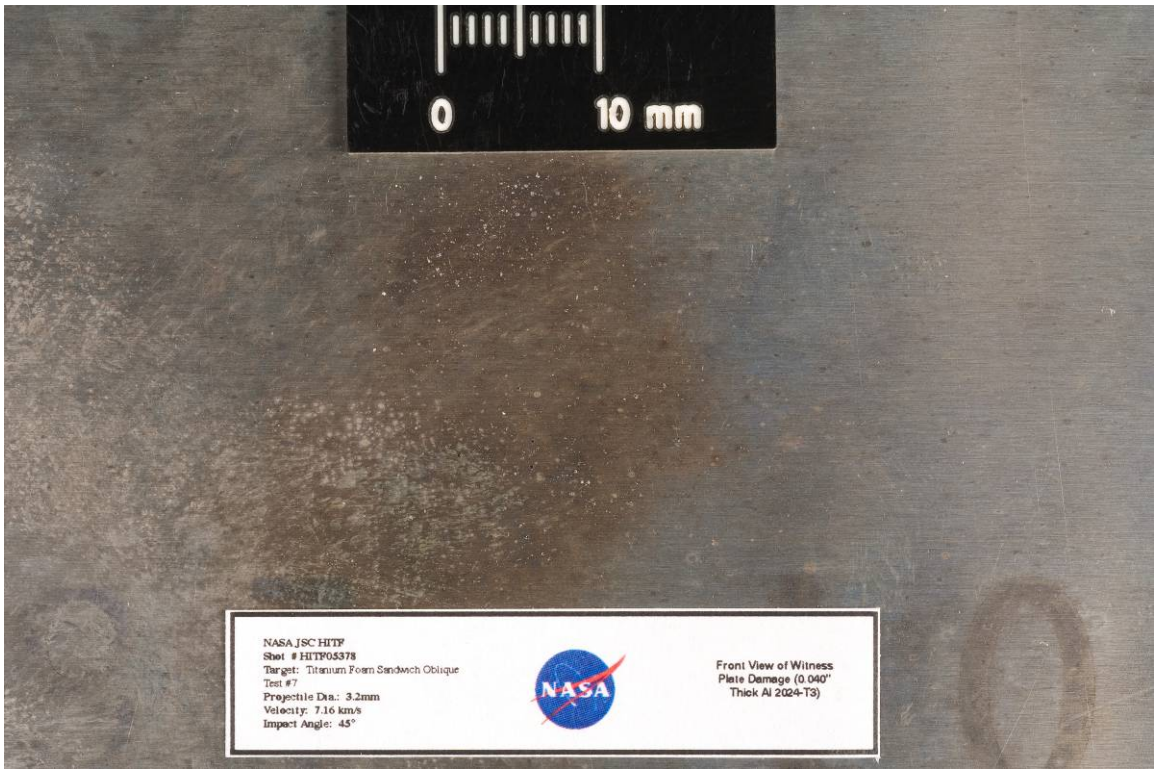

Figure A-153
Jsc2006e13267 HITF05378 Front, witness plate

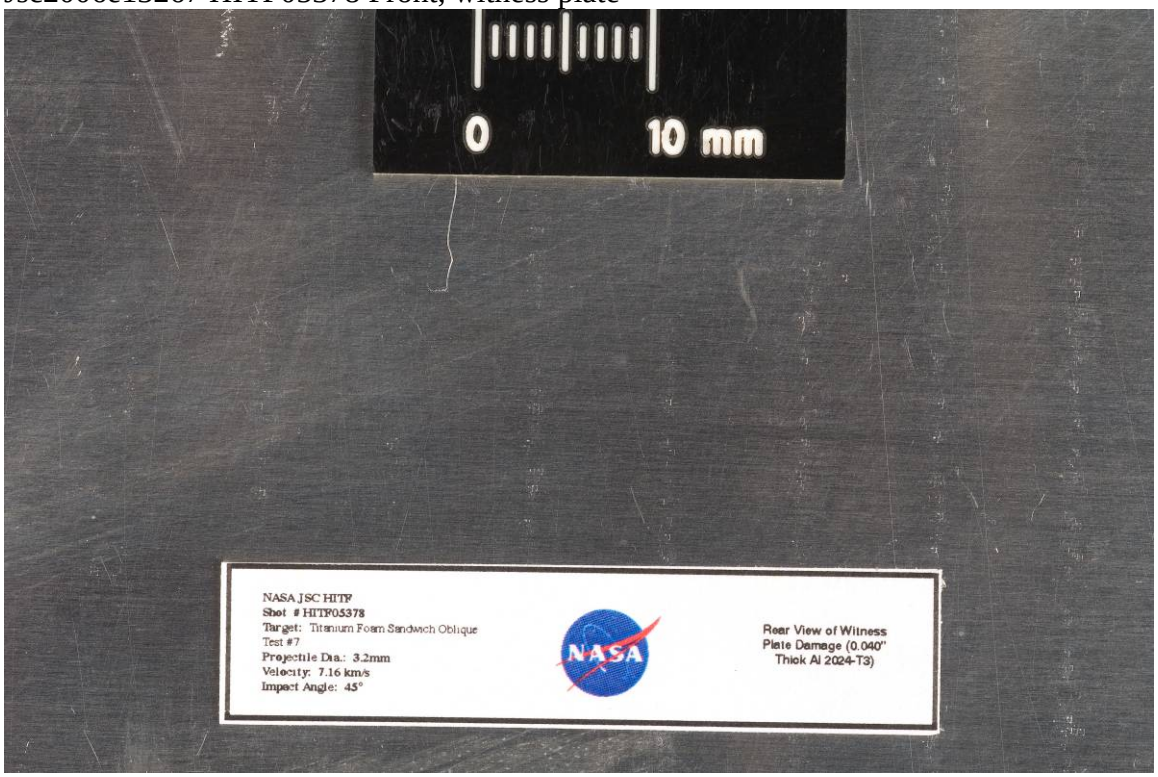

Figure A-154
Jsc2006e13268 HITF05378 Rear, witness plate

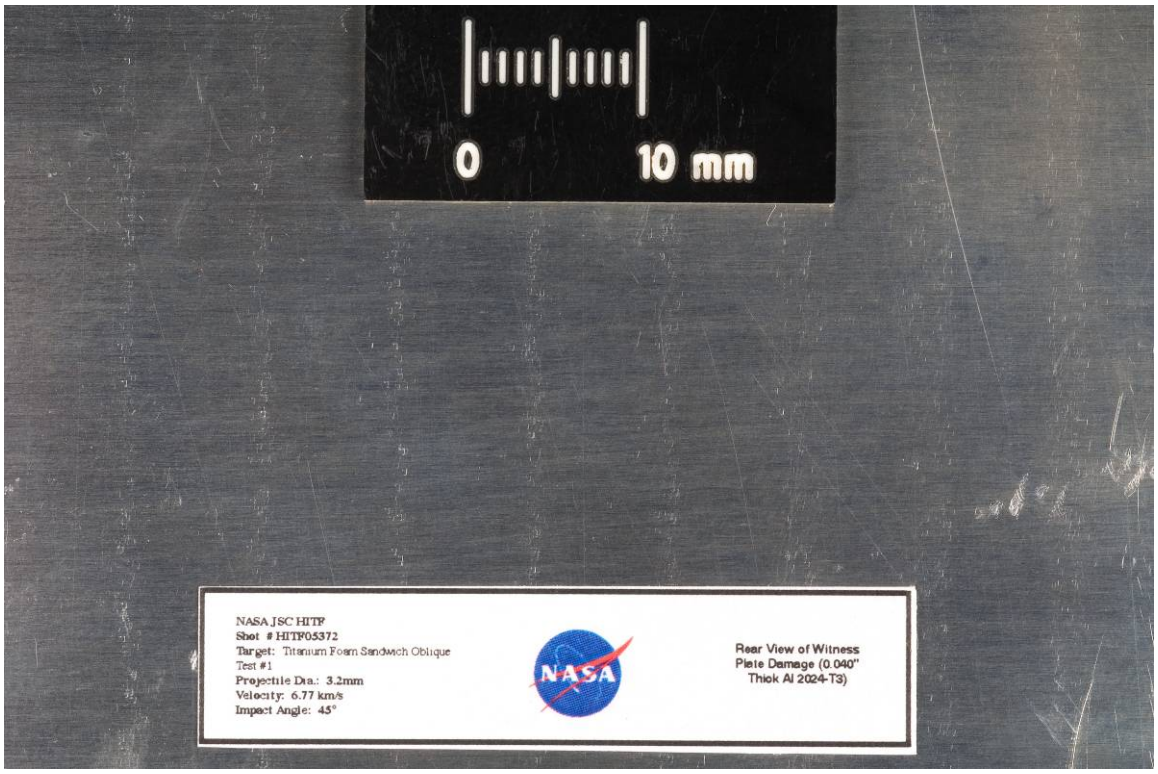

Figure A-155
Jsc2006e13269 HITF05372 Rear, witness plate

12. APPENDIX B: OTHER REPORTED DATA

In the measurements titled Max, the maximum distance across the hole was measured. The corresponding Min measurement is the measurement of the hole taken perpendicular to the Max at the midpoint of the Max measurement.

HITF Number	WSTF Number	Target Type	Panel Areal Density (g/cm^2)	Projectile Diameter (mm)	Projectile Mass (g)
HITF03147-1	WSTF03-38055	0.5" Al F10	0.51	1.0	0.0015
HITF03147-2	WSTF03-38055	0.5" Al F10	0.51	1.1	0.0022
HITF03147-3	WSTF04-38140	0.5" Al F10	0.51	1.2	0.0025
HITF03147-4	WSTF04-38140	0.5" Al F10	0.51	1.2	0.0025
HITF05036-1	WSTF05-39292	0.5" Al F40	0.49	1.0	0.0015
HITF05036-2	WSTF05-39654	0.5" Al F40	0.49	1.2	0.0025
HITF05036-3	WSTF05-39658	0.5" Al F40	0.49	1.4	0.0040
HITF05037-1	WSTF05-39293	0.5" Al F40	0.49	1.2	0.0023
HITF05037-2	WSTF05-39655	0.5" Al F40	0.49	1.4	0.0038
HITF03145-2	WSTF03-38052	0.5" Al HC	0.37	0.8	0.0008
HITF03145-1	WSTF03-38052	0.5" Al HC	0.37	1.0	0.0015
HITF05069-4	WSTF05-39414	0.5" Al HC	0.37	1.3	0.0032
HITF05293-2	WSTF05-39960	0.5" Ti F60-1	1.28	2.4	0.0197
HITF05293-4	WSTF05-39994	0.5" Ti F60-1	1.28	2.6	0.0256
HITF05293-5	WSTF05-40074	0.5" Ti F60-1	1.28	2.8	0.0321
HITF05293-6	WSTF05-40104	0.5" Ti F60-1	1.28	2.4	0.0202
HITF05379	WSTF06-40325	0.5" Ti F60-2	1.54	2.8	0.0321
HITF05373	WSTF05-40123	0.5" Ti F60-2	1.54	3.0	0.0405
HITF05372	WSTF05-40123	0.5" Ti F60-2	1.54	3.2	0.0473
HITF05376	WSTF06-40252	0.5" Ti F60-2	1.54	3.2	0.0473
HITF05377	WSTF06-40283	0.5" Ti F60-2	1.54	3.2	0.0473
HITF05378	WSTF06-40234	0.5" Ti F60-2	1.54	3.2	0.0473
HITF05374	WSTF06-40201	0.5" Ti F60-2	1.54	3.4	0.0589
HITF05375	WSTF06-40243	0.5" Ti F60-2	1.54	3.6	0.0667
HITF05292-1	WSTF05-39540	0.5" Ti HC	0.93	1.5	0.0049
HITF05292-2	WSTF05-39941	0.5" Ti HC	0.93	1.6	0.0060
HITF05292-3	WSTF05-39542	0.5" Ti HC	0.93	1.7	0.0072
HITF04151	WSTF04-38183	2" Al F10	1.25	3.6	0.0667
HITF04161	WSTF04-38186	2" Al F10	1.25	4.0	0.0928
HITF04155	WSTF04-38194	2" Al F10	1.25	4.0	0.0937
HITF04162	WSTF04-38199	2" Al F10	1.25	4.4	0.1211
HITF04152	WSTF04-38184	2" Al F40	1.18	3.6	0.0667
HITF04163	WSTF04-38187	2" Al F40	1.18	4.0	0.0937
HITF04164	WSTF04-38200	2" Al F40	1.18	4.4	0.0121
HITF05068	WSTF05-39413	2" Al F40	1.18	4.8	0.1580
HITF04159	WSTF04-38185	2" Al HC	1.59	3.2	0.0473
HITF04150	WSTF04-38174	2" Al HC	1.59	3.6	0.0667
HITF04160	WSTF04-38198	2" Al HC	1.59	3.2	0.0473
HITF04153	WSTF03-38192	2" Al HC	1.59	3.6	0.0650

HITF Number	Impact Velocity (km/s)	Impact Angle (deg)	Pass/Fail	Entry Hole Max (mm)	Entry Hole Min (mm)
HITF03147-1	6.95	0	Pass	3.4	3.4
HITF03147-2	6.89	0	Pass	3.1	2.6
HITF03147-3	6.83	0	Fail	3.6	2.9
HITF03147-4	6.87	0	Fail	3.6	2.8
HITF05036-1	6.88	0	Pass	3.1	3.0
HITF05036-2	6.90	0	Pass	2.8	2.7
HITF05036-3	6.45	0	Fail	5.2	3.4
HITF05037-1	7.05	45	Pass	4.6	3.3
HITF05037-2	6.92	45	Fail	5.0	3.2
HITF03145-2	6.75	0	Pass	2.0	2.0
HITF03145-1	6.86	0	Fail	2.3	2.3
HITF05069-4	6.99	60	Fail	3.7	2.8
HITF05293-2	3.45	0	Pass	5.0	5.0
HITF05293-4	7.00	0	Pass	6.0	5.9
HITF05293-5	6.93	0	Fail	5.7	5.7
HITF05293-6	6.80	45	Pass	6.9	5.6
HITF05379	4.09	0	Pass	5.0	4.8
HITF05373	6.71	45	Pass	6.8	5.8
HITF05372	6.77	45	Fail	7.2	6.0
HITF05376	6.62	45	Pass	7.3	6.3
HITF05377	4.00	45	Pass	6.4	5.0
HITF05378	7.16	45	Fail	7.0	6.3
HITF05374	6.60	60	Pass	7.9	5.8
HITF05375	6.76	60	Pass	8.7	6.2
HITF05292-1	6.74	0	Pass	3.8	3.8
HITF05292-2	6.79	45	Pass	3.8	3.3
HITF05292-3	6.90	60	Fail	4.1	3.3
HITF04151	6.76	0	Pass	7.9	6.0
HITF04161	6.89	0	Fail	8.7	7.4
HITF04155	6.89	45	Pass	9.5	8.7
HITF04162	6.92	45	Pass	12.0	8.9
HITF04152	6.79	0	Pass	8.5	5.4
HITF04163	6.79	0	Fail	11.0	9.1
HITF04164	6.70	45	Pass	13.2	13.0
HITF05068	6.93	45	Pass	10.2	8.2
HITF04159	6.86	0	Fail	8.0	8.0
HITF04150	6.22	0	Fail	8.1	8.1
HITF04160	6.74	45	Fail	9.1	8.0
HITF04153	6.87	45	Fail	10.3	8.6

HITF Number	Exit Hole Max (mm)	Exit Hole Min (mm)	Comments
HITF03147-1	-	-	-
HITF03147-2	-	-	-
HITF03147-3	2.2	2.1	-
HITF03147-4	2.5	2.2	Second Exit Hole, 0.3mm diameter
HITF05036-1	-	-	-
HITF05036-2	-	-	-
HITF05036-3	1.3	1.4	Crack from exit hole, Two other small exit holes
HITF05037-1	-	-	-
HITF05037-2	0.5	0.5	-
HITF03145-2	-	-	-
HITF03145-1	4.0	3.9	-
HITF05069-4	0.7	0.7	Crack from exit hole, Second exit hole 0.6mm x 0.3mm
HITF05293-2	-	-	-
HITF05293-4	-	-	-
HITF05293-5	0.9	0.9	Crack from exit hole
HITF05293-6	-	-	-
HITF05379	-	-	-
HITF05373	-	-	-
HITF05372	0.3	0.3	Crack from exit hole
HITF05376	-	-	-
HITF05377	-	-	-
HITF05378	0.9	0.1	Crack from exit hole
HITF05374	-	-	-
HITF05375	-	-	-
HITF05292-1	-	-	-
HITF05292-2	-	-	-
HITF05292-3	2.2	2.0	-
HITF04151	-	-	-
HITF04161	1.4	1.2	Second Exit Hole, 2.6mm x 0.6mm
HITF04155	-	-	Secondary Impact
HITF04162	-	-	-
HITF04152	-	-	-
HITF04163	1.1	0.2	Large bulge (~30mm)
HITF04164	-	-	Many small secondary impacts
HITF05068	-	-	-
HITF04159	5.3	4.9	-
HITF04150	7.8	4.9	Crack (7mm), Three other exit holes, 0.4mm 1.2mm 1.8mm diameters
HITF04160	3.8	2.7	-
HITF04153	4.1	3.0	Two other exit holes, 1.1mm 0.6mm diameters