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Soft Body Impacts on a Large Hopkinson Bar

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January 2026

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National Aeronautics and
Space Administration

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TABLE OF CONTENTS

SECTION	PAGE
1 - INTRODUCTION	1
2 - TEST DESCRIPTION AND INSTRUMENTATION	2
2.1 Test Range Description	2
2.2 Test Article and Test Setup Description	3
2.3 Projectile Description	5
2.4 Instrumentation	5
2.4.1 Velocity Measurement	6
2.4.2 High-Speed Photography	6
3 - TEST RESULTS	7
3.1 Impact Test Results	7
3.2 Summary and Discussion	38
APPENDIX A – Calibration Records	49

LIST OF FIGURES

FIGURE		PAGE
1	UDRI Range 5 Compress-Gas Gun	2
2	Schematic of the Strain Gage Locations on the Impacted Bar	3
3	Views of the Hopkinson Bar Test Setup	4
4	Shot 5-3325 Projectile Photographs	10
5	Shot 5-3326 Projectile Photographs	11
6	Shot 5-3327 Projectile Photographs	12
7	Shot 5-3328 Projectile Photographs	13
8	Shot 5-3329 Projectile Photographs	14
9	Shot 5-3330 Projectile Photographs	15
10	Shot 5-3331 Projectile Photographs	16
11	Shot 5-3332 Projectile Photographs	17
12	Shot 5-3333 Projectile Photographs	18
13	Shot 5-3334 Projectile Photographs	19
14	Shot 5-3368 Projectile Photographs	20
15	Shot 5-3369 Projectile Photographs	21
16	Shot 5-3370 Projectile Photographs	22
17	Shot 5-3371 Projectile Photographs	23
18	Shot 5-3372 Projectile Photographs	24
19	Shot 5-3373 Projectile Photographs	25
20	Shot 5-3374 Projectile Photographs	26
21	Shot 5-3375 Projectile Photographs	27
22	Shot 5-3376 Projectile Photographs	28
23	Shot 5-3377 Projectile Photographs	29
24	Shot 5-3378 Projectile Photographs	30
25	Shot 5-3379 Projectile Photographs	31
26	Shot 5-3380 Projectile Photographs	32
27	Shot 5-3381 Projectile Photographs	33
28	Shot 5-3382 Projectile Photographs	34
29	Shot 5-3383 Projectile Photographs	35
30	Shot 5-3384 Projectile Photographs	36

LIST OF FIGURES (Concluded)

FIGURE		PAGE
31	Shot 5-3385 Projectile Photographs	37
32	Select Front and Side View High-Speed Camera Images from Shot 5-3326	40
33	Select Front and Side View High-Speed Camera Images from Shot 5-3329	41
34	Select Front and Side View High-Speed Camera Images from Shot 5-3332	42
35	Select Front and Side View High-Speed Camera Images from Shot 5-3380	43
36	Select Front and Side View High-Speed Camera Images from Shot 5-3378	44
37	Select Front and Side View High-Speed Camera Images from Shot 5-3385	45
38	Select Front and Side View High-Speed Camera Images from Shot 5-3370	46
39	Select Front and Side View High-Speed Camera Images from Shot 5-3371	47
40	Select Front and Side View High-Speed Camera Images from Shot 5-3374	48

LIST OF TABLES

TABLE		PAGE
1	List of Impact Test Instrumentation	6
2	Impact Test Summary	7

SECTION 1
INTRODUCTION

This report documents a series of soft body impacts on a large Hopkinson bar. The impact tests were performed for NASA Glenn Research Center during the period of 3 November 2021 to 9 February 2022. The primary objective was to capture impact load data. Data collected from these tests can be compared to various soft body projectile types for potential use as a surrogate for real birds used in bird strike and bird ingestion certification tests. This test program was conducted in the Impact Physics Laboratory at the University of Dayton Research Institute (UDRI).

The tests were performed by launching soft body projectiles into a 12-inch diameter by 24 feet long Hopkinson bar at nominal velocities of 49 m/s, 110 m/s, and 304 m/s using a compressed-gas gun. The tests were conducted according to SAE Aerospace Standard AS6940 entitled, "Standard Test Method for Measuring Forces during Normal Impact of a Soft Projectile on a Rigid Flat Surface". Two types of gelatin projectiles were tested, one using a UDRI formulation and one using a German Aerospace Center (DLR) formulation. In addition to the gelatin projectiles, a set of real birds (duck carcasses and chicken carcasses) were also tested. Data recorded during the tests included bird weight, impact velocity, high-speed videos, still photographs of the projectiles, bar gage data, and digital image correlation data on the bar back face.

This work was performed under NASA-Glenn Purchase Order Number 80NSSC21P1614. Technical direction was provided by Mr. Michael Pereira of NASA. The tests were witnessed by Mr. Pereira and Mr. Duane Revilock.

University of Dayton project supervision was provided by Mr. Michael P. Bouchard, Head, Applied Mechanics Division, and Mr. Kevin L. Poormon, Impact Physics Group Leader. Mr. Poormon was also the Principal Investigator with assistance provided by Mr. Kevin Fedon and Mr. Keane Reed.

SECTION 2
TEST DESCRIPTION AND INSTRUMENTATION

2.1 TEST RANGE DESCRIPTION

This test program was conducted on Range 5, one of the University's indoor compressed-gas gun ranges located in the Impact Physics Laboratory at the University of Dayton Research Institute. A photograph of the compressed-gas gun is shown in Figure 1. The gun has a smooth bore of 7 inches and the launch tube is 30 feet long with a tapered-diameter sabot stripper attached to the muzzle of the barrel. The projectile, a 4-lb bird, was installed in a standard one-piece cast polyurethane sabot with a cavity sized to fit the projectile being launched. This package was loaded into the barrel and fired at the target using compressed air. After launch, the sabot was stopped in the sabot stripper allowing only the projectile to continue to the target. The projectile was in free flight to the target over a distance of approximately 12 feet. This free-flight distance permitted accurate measurement of the projectile velocity.



Figure 1. UDRI Range 5 Compressed-Gas Gun.

2.2 TEST ARTICLE AND TEST SETUP DESCRIPTION

The “test article” was a Hopkinson bar designed and fabricated by NASA. The Hopkinson bar was 12 inches in diameter and provided in two 12 foot sections. The bar material was 6061-T6 aluminum. The ends of each bar section were machined to a surface roughness of 0.4 – 0.8 µm (16 – 32 µin) and a perpendicularity within .025 mm [.001 in]. The two sections were supported by low friction rollers attached to a steel supporting frame. The supporting frames were clamped to T-slots embedded in the laboratory floor. The section of the bar that is impacted was instrumented with semi-conductor strain gages (KYOWA type KSPB-2-1K-E4) at two locations, 450 mm [18 in.] and 600 mm [24 in.] (1.5 and 2 diameters) from the impacted end. The two locations for instrumentation are for the purpose of making redundant measurements and assessing the accuracy of the one-dimensional wave assumption. The gages were wired in a full Wheatstone bridge configuration consisting of four gages, with two gages in the longitudinal direction and two in the circumferential direction as shown in Figure 2. The mating faces of the two bars were held in full contact with each other using an ultrasound gel coupling agent.

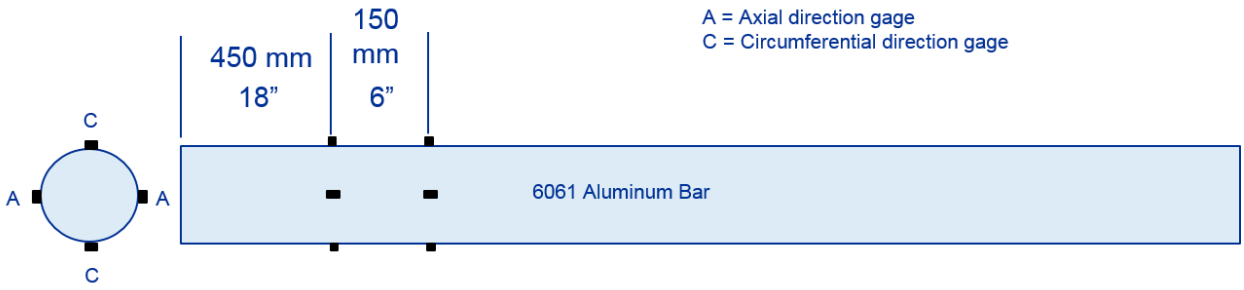


Figure 2. Schematic of the Strain Gage Locations on the Impacted Bar.

The Hopkinson bar was set up with the aim point for the impact being on the center of the bar end face. Alignment of the impact location was accomplished with the use of a laser beam that was aligned to the gun barrel centerline. The bar was set up with 0° pitch and yaw angles relative to the gun. This was verified by placing a mirror on the front face of the bar and the bar angle was adjusted until the gun alignment laser was reflected back onto itself. Figure 3 shows views of the test setup.

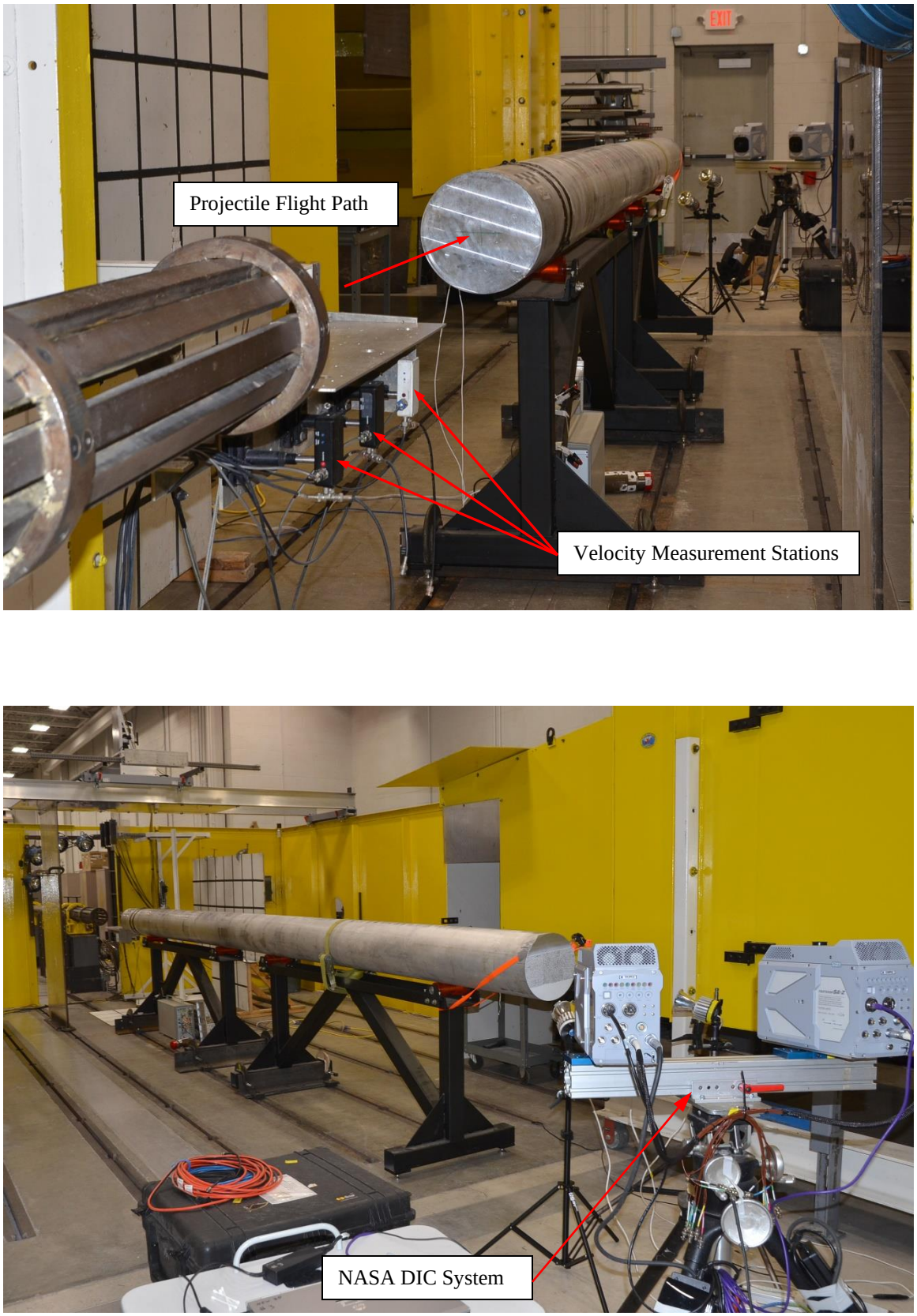


Figure 3. Views of the Hopkinson Bar Test Setup.

2.3 PROJECTILE DESCRIPTION

The soft body projectiles were cylindrical in shape with a hemispherical nose and weighed nominally 2.2-lb or 4-lb. The UDRI formulated projectiles were fabricated from a mixture of water and gelatin with the density controlled by the addition of phenolic microballoons. The density of the artificial bird was nominally 0.034 lb/in^3 (0.94 g/cc) which is about the same as that of a chicken. The 4-lb projectile had a nominal diameter of 4.2 inches and overall length of 9.2 inches. The 2.2-lb projectiles had a nominal diameter of 3.80 inches and overall length of 6.34 inches. The projectile weights were adjusted to be close to the target weight by cutting down the projectile length. Projectile weight measurements were obtained using an Ohaus balance with a resolution of 0.001 lb. The UDRI gelatin projectiles were at room temperature when launched (~67°F).

The DLR projectiles were a proprietary gelatin mixture encased in a thin 3-D printed plastic shell with internal ribbing. The DLR projectiles were patterned after the UDRI gelatin projectiles. The 4-lb DLR projectiles had a nominal diameter of 4.2 inches and a length of 9.12 inches with a hemispherical nose. The 2.2-lb DLR projectiles had a nominal diameter of 3.80 inches and an overall length of 7.6 inches with both ends being hemispherical. The 2.2-lb DLR projectiles actually weighed about 2.6 lbs. The difference in weight between the UDRI and the DLR gelatin projectiles was that the back hemispherical portion of the UDRI projectile was cut off to get the weight down to the 2.2-lb target weight. The DLR projectiles were stored in a refrigerator at 40°F and were shot cold (nominally 50°F).

The real bird projectiles were 2.2-lb Mallard ducks and 4-lb Golden Comet chicken carcasses. The chickens and ducks were received deceased and were prepared per ASTM F330-16. The original bird weight was within 10% of the final weight required by ASTM F330. The bird weight was adjusted by injecting a small amount of water into the bird if it was under weight or trimming off pieces of the wings and legs if it was overweight. The bird was sewn inside a muslin cloth bag weighing approximately 0.036-lb for the 4-lb bird and 0.029-lb for the 2.2-lb bird. The final weight (bird plus bag) was recorded and then the projectile was inserted into the sabot which was loaded into the gun barrel. After the launch, the sabot was stripped off near the muzzle of the gun and contained in the gun's sabot stripper section allowing only the projectile to travel to the target.

2.4 INSTRUMENTATION

The test data collected by UDRI included projectile weight, projectile dimensions, impact velocity, and high-speed photography. All UDRI data recording equipment are calibrated to NIST traceable standards by an ISO approved organization. The calibration status of the measurement instruments used is provided in Table 1. Calibration records are provided in Appendix A.

NASA recorded the bar strain data with their data acquisition system. NASA also set up a digital image correlation (DIC) system to measure the surface displacement of the bar rear face.

TABLE 1. LIST OF IMPACT TEST INSTRUMENTATION

Description	*Manufacturer*	*Model*	*Serial No.*	*Calibration Date*	*Calibration Due Date*
Data Acquisition Board	LDS Nicolet	BAS1M256	IDK0500406	6/2/2021	6/2/2022
High-Speed Camera	Vision Research	Phantom V2012	23224	N/A	
High-Speed Camera	Vision Research	Phantom V2012	20658	N/A	
High-Speed Camera	Vision Research	Phantom V2012	20659	N/A	
Balance	Ohaus	Solution	None	1/25/2021	1/25/2022
Steel Rule	Lufkin	62	None	9/2018	9/2023
Protractor Level	Hartzell Propeller	N/A	4781	9/26/2018	9/26/2023

2.4.1 Velocity Measurement

The projectile velocity was measured with three HeNe laser/photodetector stations spaced 12 inches apart. The last laser station was located 33.375 inches from the bar face. Each laser projected a beam that intersected the projectile trajectory normal to the trajectory and illuminated an opposing photodetector station. When the projectile interrupted the beam, the interruption time was recorded by a Genesis data acquisition system operating with a sampling rate of 1 MHz. The impact velocity was calculated by dividing the distance traveled between the laser/photodetector stations by the recorded time interval between those stations. Due to the relatively high launch acceleration loads combined with the projectile's high elasticity, the projectile contracted and expanded from its original length after it was released from the sabot. Therefore, the reported impact velocity is the average of the measured front and rear projectile velocities. Velocity measurement accuracy is better than 0.5%.

2.4.2 High-Speed Photography

Three Phantom V2012 digital high-speed cameras were used to record the impact events. The cameras recorded the 49 m/s and 110 m/s tests with a framing rate of 10,000 frames/sec. The framing rate for the 304 m/s tests was 20,000 frames/sec. These framing rates were sufficient to examine the impact and projectile fragmentation pattern during the test. One camera was positioned to view the impact from the side. A 12-inch square reference grid was placed behind the test article for reference. The side camera's sensor plane was 100.5 inches from the gun centerline and 141.0 inches to the reference grid. The second camera was positioned to view the impact from the above. A 12-inch square reference grid was placed behind the test article for reference. The top camera's sensor plane was 84 inches from the gun centerline and 129.5 inches to the reference grid. The third camera was positioned alongside the gun barrel and viewed the front face of the Hopkinson bar.

SECTION 3
TEST RESULTS

Twenty-nine impact tests were performed during this program. All tests were performed at room temperature (67° ± 1°F). Table 2 gives a summary of the impact conditions. Images of the projectiles are provided in Figures 4 to 31. Shots 5-3328, 5-3333, 5-3334, and 5-3368 to 5-3385 only used the first 12 foot bar section.

TABLE 2. IMPACT TEST SUMMARY.

Shot Number	Projectile Weight (lb)	Projectile Diameter (in)	Projectile Length (in)	Projectile Density (g/cc)	Impact Velocity (m/s)	Comments
5-3324	2.222 UD Gel. RT	3.8	6.35	0.949	52.7	Projectile flattened on impact and rebounded in one piece.
5-3325	2.222 UD Gel. RT	3.8	6.35	0.949	49.1	Projectile flattened on impact and rebounded in one piece.
5-3326	2.223 UD Gel. RT	3.8	6.35	0.949	49.4	Projectile flattened on impact and rebounded in one piece.
5-3327	2.223 UD Gel. RT	3.8	6.35	0.949	49.7	Projectile flattened on impact and rebounded in one piece.
5-3328	2.218 UD Gel. RT	3.8	6.35	0.947	49.1	Projectile flattened on impact and rebounded in one piece.
5-3329	4.017 UD Gel. RT	4.2	9.2	0.944	110.9	Projectile flattened on impact and tore into longitudinal segments spreading out radially across the bar face. Most of the segments remained attached at the back of the projectile. Projectile found lying on floor in front of bar largely in one piece.
5-3330	4.013 UD Gel. RT	4.2	9.15	0.949	110.0	Projectile flattened on impact and tore into longitudinal segments spreading out radially across the bar face. Most of the segments remained attached at the back of the projectile. Projectile found lying on floor in front of bar largely in one piece.

TABLE 2. IMPACT TEST SUMMARY (Continued).

Shot Number	Projectile Weight (lb)	Projectile Diameter (in)	Projectile Length (in)	Projectile Density (g/cc)	Impact Velocity (m/s)	Comments
5-3331	4.007 UD Gel. RT	4.2	9.37	0.923	110.6	Projectile flattened on impact and tore into longitudinal segments spreading out radially across the bar face. Most of the segments remained attached at the back of the projectile. Projectile found lying on floor in front of bar largely in one piece.
5-3332	4.010 UD Gel. RT	4.2	9.35	0.926	310.9	Projectile flattened on impact into a thin layer spreading out radially across the bar face. Projectile found fragmented into many small pieces.
5-3333	4.012 UD Gel. RT	4.2	9.1	0.954	310.3	Projectile flattened on impact into a thin layer spreading out radially across the bar face. Projectile found fragmented into many small pieces.
5-3334	4.007 UD Gel. RT	4.2	9.1	0.953	311.9	Projectile flattened on impact into a thin layer spreading out radially across the bar face. Projectile found fragmented into many small pieces.
5-3368	2.200 Duck 65.6°F	3.75 x 4	7.5	---	49.3	Bird flattened on impact and rebounded in one piece. Blood/fluid squirted out.
5-3369	2.210 Duck >60°F	3.75 x 4	7.5	---	50.2	Bird flattened on impact and rebounded in several large pieces. Blood/fluid squirted out.
5-3370	2.212 Duck 63.3°F	3.75 x 4	7.5	---	49.3	Bird flattened on impact and rebounded in 2 large pieces. Blood/fluid squirted out.
5-3371	4.004 Chicken	4.5 x 5	8.5	---	109.8	Bird flattened on impact and fragmented radially into many pieces.
5-3372	4.008 Chicken 73.4°F	4.5 x 5	8.5	---	107.5	Bird flattened on impact and fragmented radially into many pieces.
5-3373	4.003 Chicken 62.9°F	4.5 x 5	8.5	---	110.3	Bird flattened on impact and fragmented radially into many pieces.

TABLE 2. IMPACT TEST SUMMARY (Concluded).

Shot Number	Projectile Weight (lb)	Projectile Diameter (in)	Projectile Length (in)	Projectile Density (g/cc)	Impact Velocity (m/s)	Comments
5-3374	4.004 Chicken 65.8°F	4.5 x 5	8.5	---	308.9	Bird flattened on impact and fragmented radially into many small pieces.
5-3375	4.012 Chicken 78.6°F	4.5 x 5	8.5	---	309.0	Bird flattened on impact and fragmented radially into many small pieces.
5-3376	4.003 Chicken 73.2°F	4.5 x 5	8.5	---	309.6	Bird flattened on impact and fragmented radially into many small pieces.
5-3377	4.055 DLR Gel ??°F	4.19	9.12	0.967	103.3	Projectile flattened on impact and fragmented radially into many pieces.
5-3378	4.028 DLR Gel 44.6°F	4.19	9.12	0.960	117.3	Projectile flattened on impact and fragmented radially into many pieces.
5-3379	4.067 DLR Gel 48.8°F	4.19	9.12	0.969	111.2	Projectile flattened on impact and fragmented radially into many pieces.
5-3380	2.599 DLR Gel 47.6°F	3.805	7.6	0.999	50.6	Projectile flattened on impact and fragmented radially into pieces, some large.
5-3381	2.604 DLR Gel 57.6°F	3.800	7.6	1.004	48.9	Projectile flattened on impact and fragmented radially into pieces.
5-3382	2.594 DLR Gel 48.6°F	3.800	7.6	1.004	48.5	Projectile flattened on impact and fragmented radially into pieces.
5-3383	4.029 DLR Gel 54°F	4.19	9.12	0.960	299.8	Projectile flattened on impact and spread radially into paste-like consistency.
5-3384	4.005 DLR Gel 50.8°F	4.19	9.12	0.955	310.9	Projectile flattened on impact and spread radially into paste-like consistency.
5-3385	4.068 DLR Gel 50.2°F	4.19	9.12	0.970	312.3	Projectile flattened on impact and spread radially into paste-like consistency.



Pretest



Posttest

Figure 4. Shot 5-3325 Projectile Photographs.



Pretest



Posttest

Figure 5. Shot 5-3326 Projectile Photographs.



Pretest



Posttest

Figure 6. Shot 5-3327 Projectile Photographs.



Pretest



Posttest

Figure 7. Shot 5-3325 Projectile Photographs.



Pretest



Posttest

Figure 8. Shot 5-3329 Projectile Photographs.

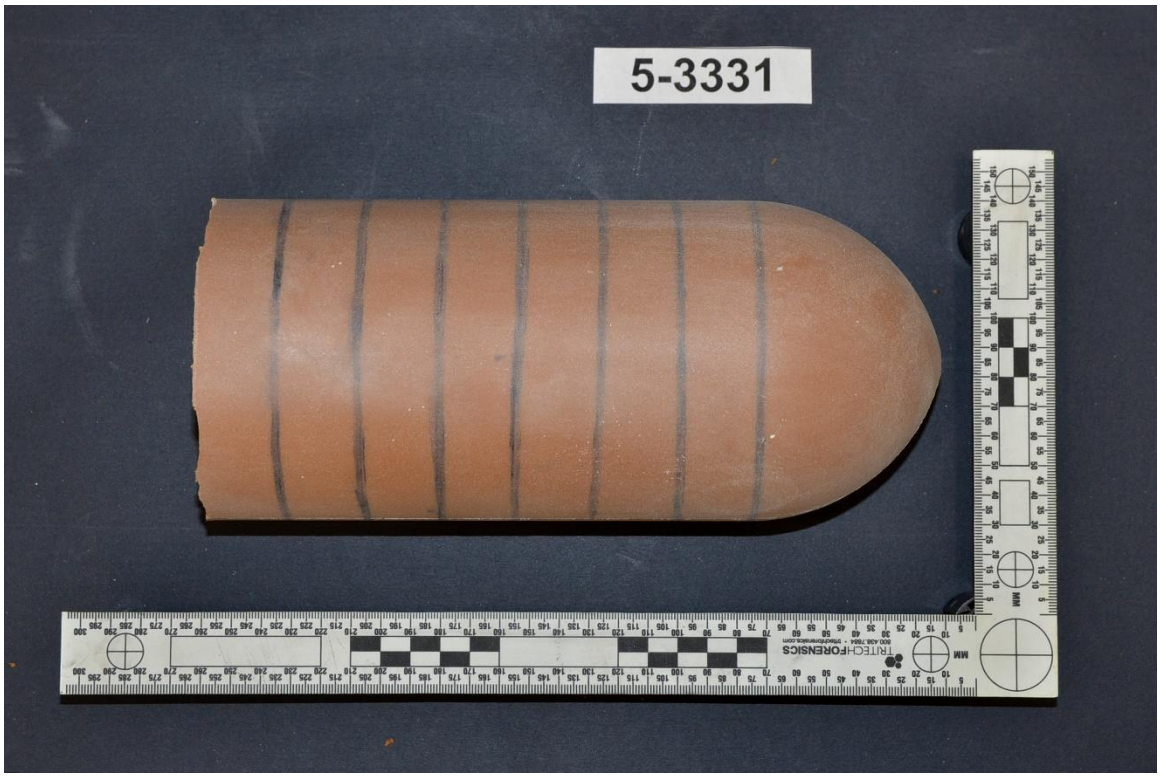


Pretest



Posttest

Figure 9. Shot 5-3330 Projectile Photographs.

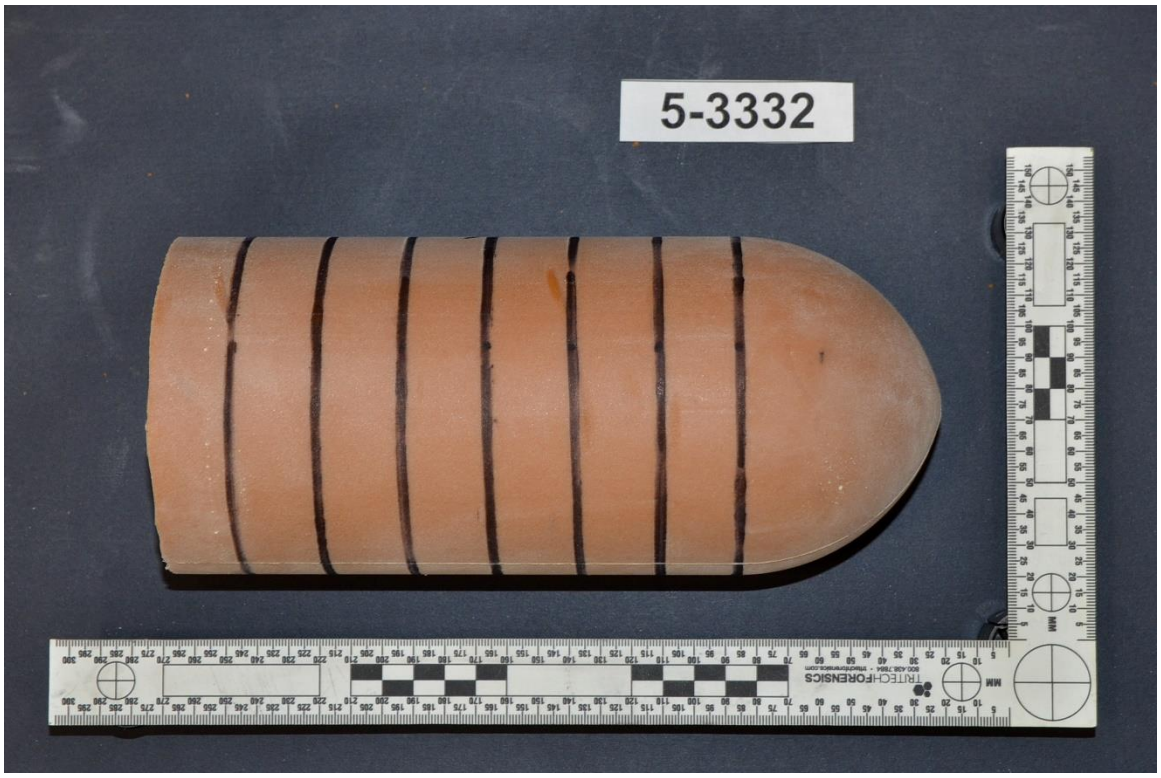


Pretest



Posttest

Figure 10. Shot 5-3331 Projectile Photographs.



Pretest



Posttest

Figure 11. Shot 5-3332 Projectile Photographs.



Pretest



Posttest

Figure 12. Shot 5-3333 Projectile Photographs.



Pretest



Posttest

Figure 13. Shot 5-3334 Projectile Photographs.



Pretest

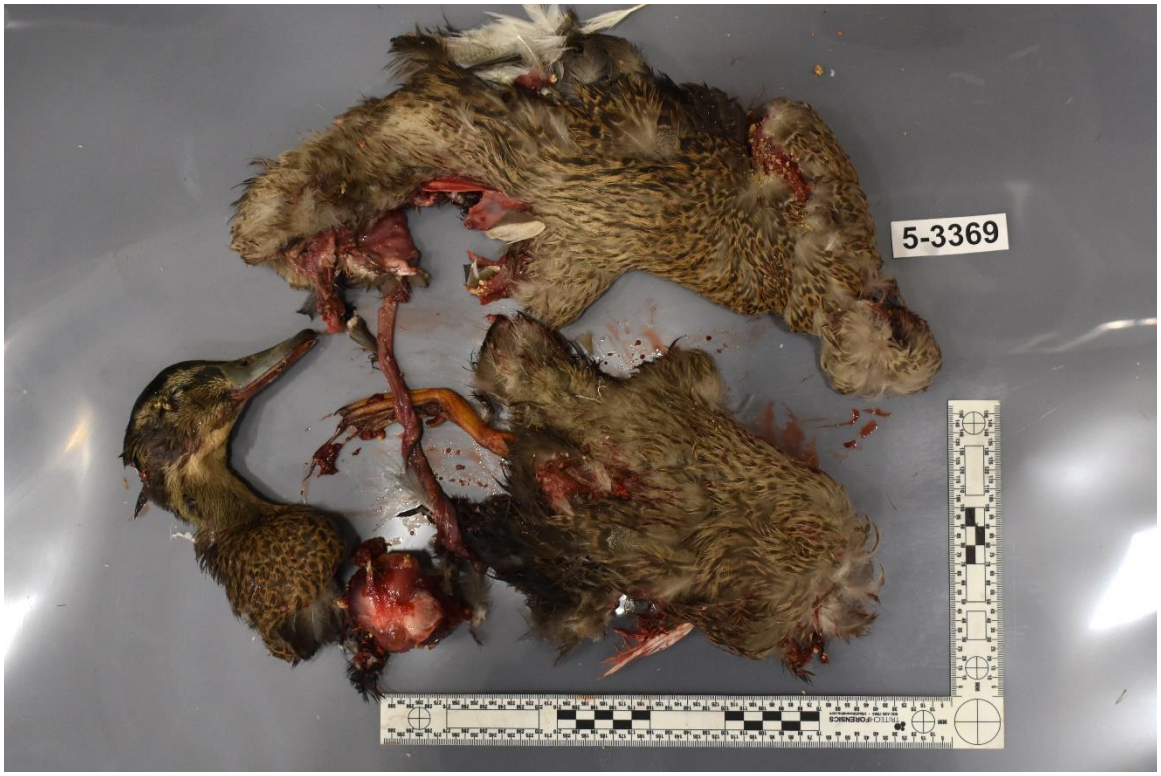


Posttest

Figure 14. Shot 5-3368 Projectile Photographs.



Pretest



Posttest

Figure 15. Shot 5-3369 Projectile Photographs.



Pretest



Posttest

Figure 16. Shot 5-3370 Projectile Photographs.



Pretest



Posttest

Figure 17. Shot 5-3371 Projectile Photographs.



Pretest



Posttest

Figure 18. Shot 5-3372 Projectile Photographs.



Pretest



Posttest

Figure 19. Shot 5-3373 Projectile Photographs.



Pretest



Posttest

Figure 20. Shot 5-3374 Projectile Photographs.



Pretest



Posttest

Figure 21. Shot 5-3375 Projectile Photographs.

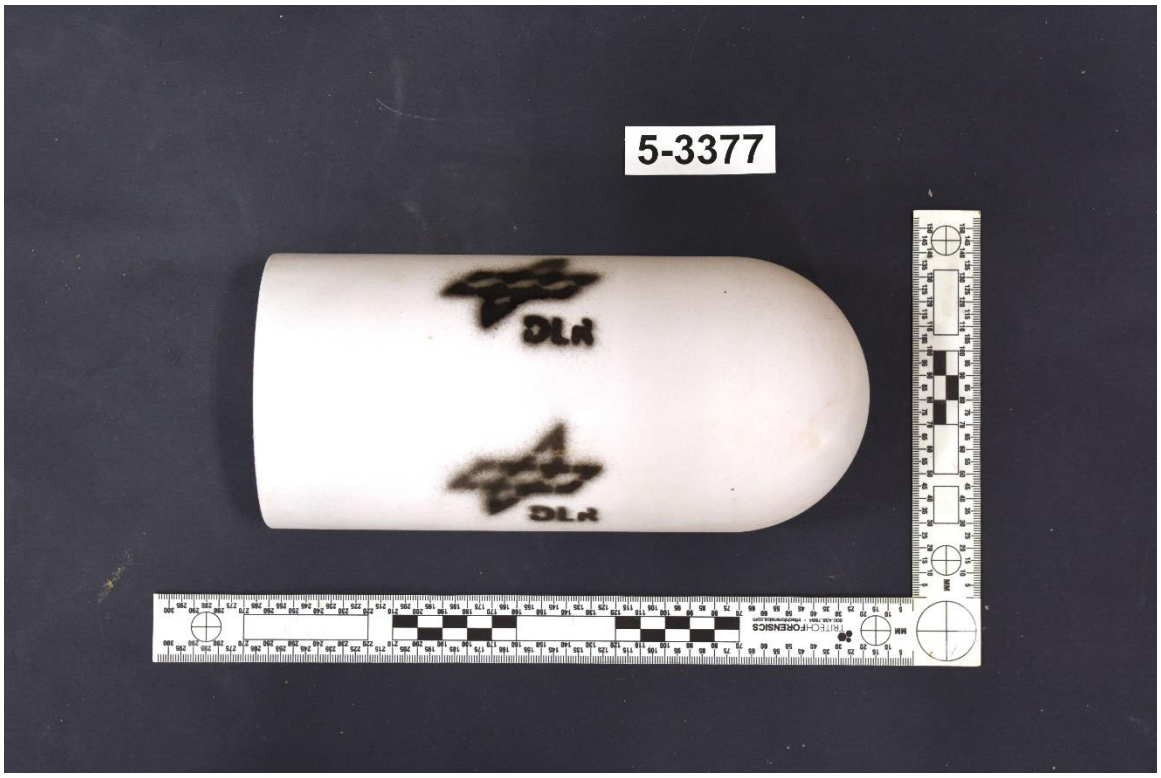


Pretest



Posttest

Figure 22. Shot 5-3376 Projectile Photographs.

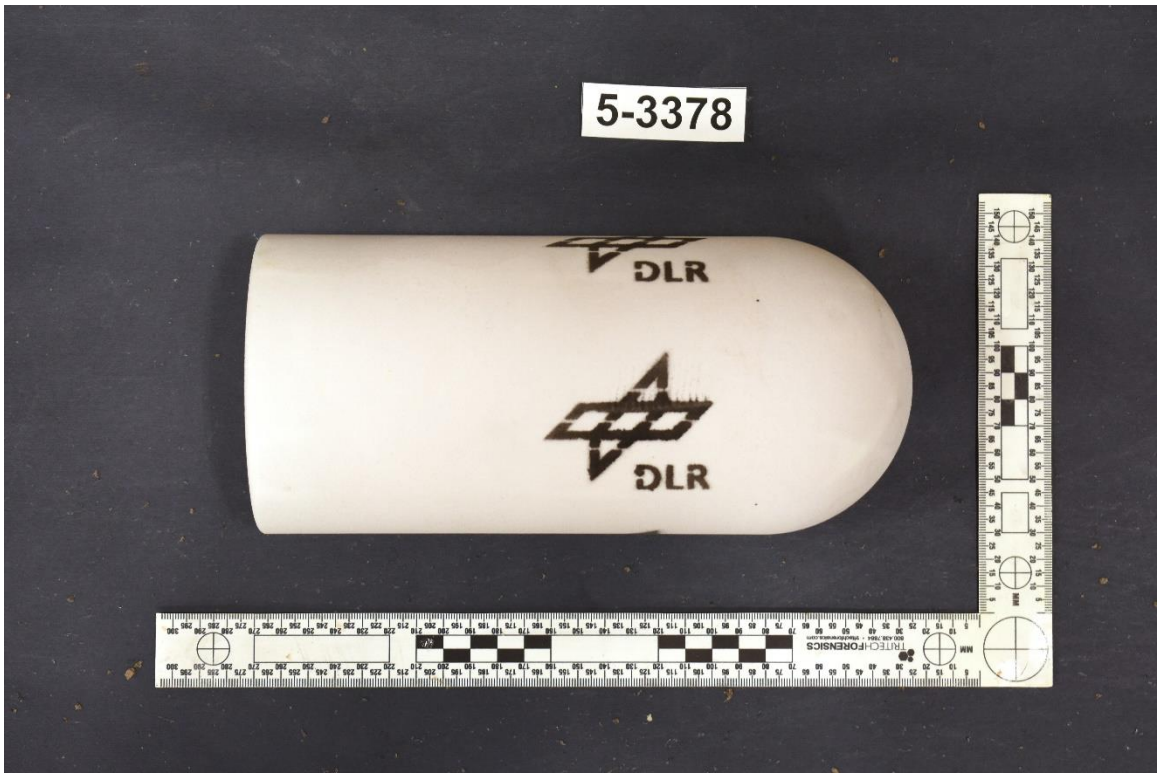


Pretest



Posttest

Figure 23. Shot 5-3377 Projectile Photographs.



Pretest



Posttest

Figure 24. Shot 5-3378 Projectile Photographs.

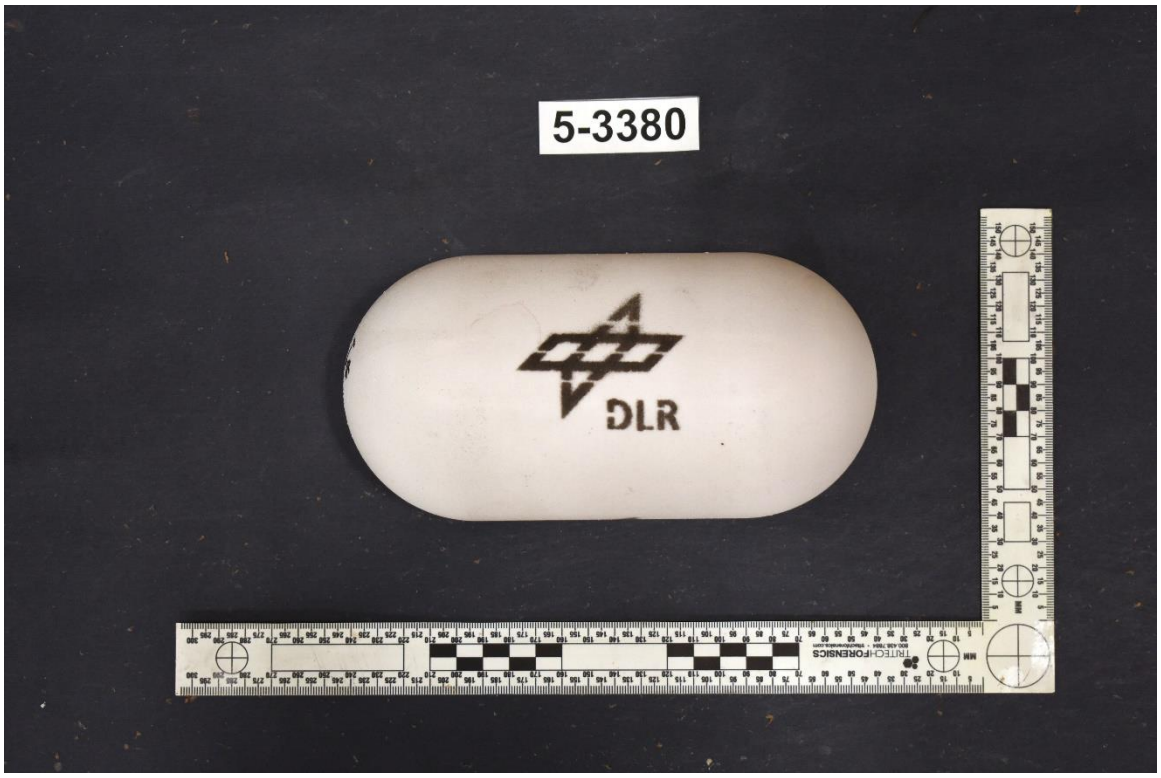


Pretest



Posttest

Figure 25. Shot 5-3379 Projectile Photographs.

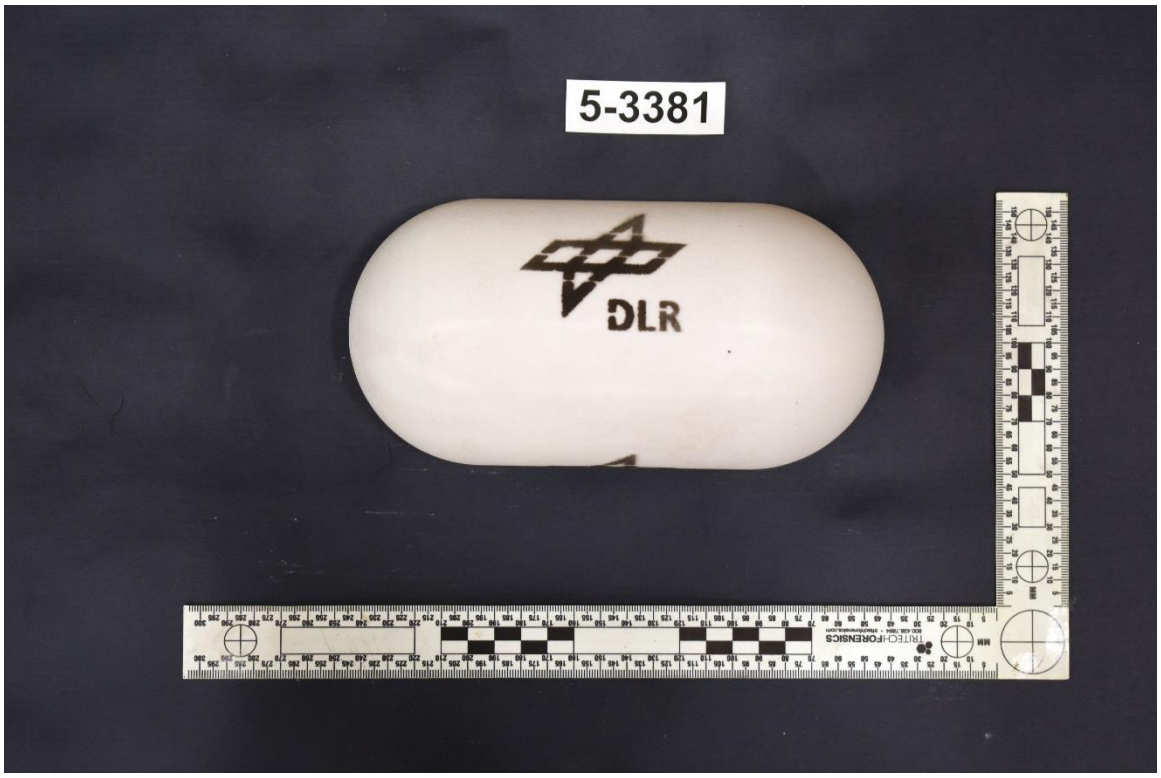


Pretest



Posttest

Figure 26. Shot 5-3380 Projectile Photographs.



Pretest



Posttest

Figure 27. Shot 5-3381 Projectile Photographs.



Pretest



Posttest

Figure 28. Shot 5-3382 Projectile Photographs.

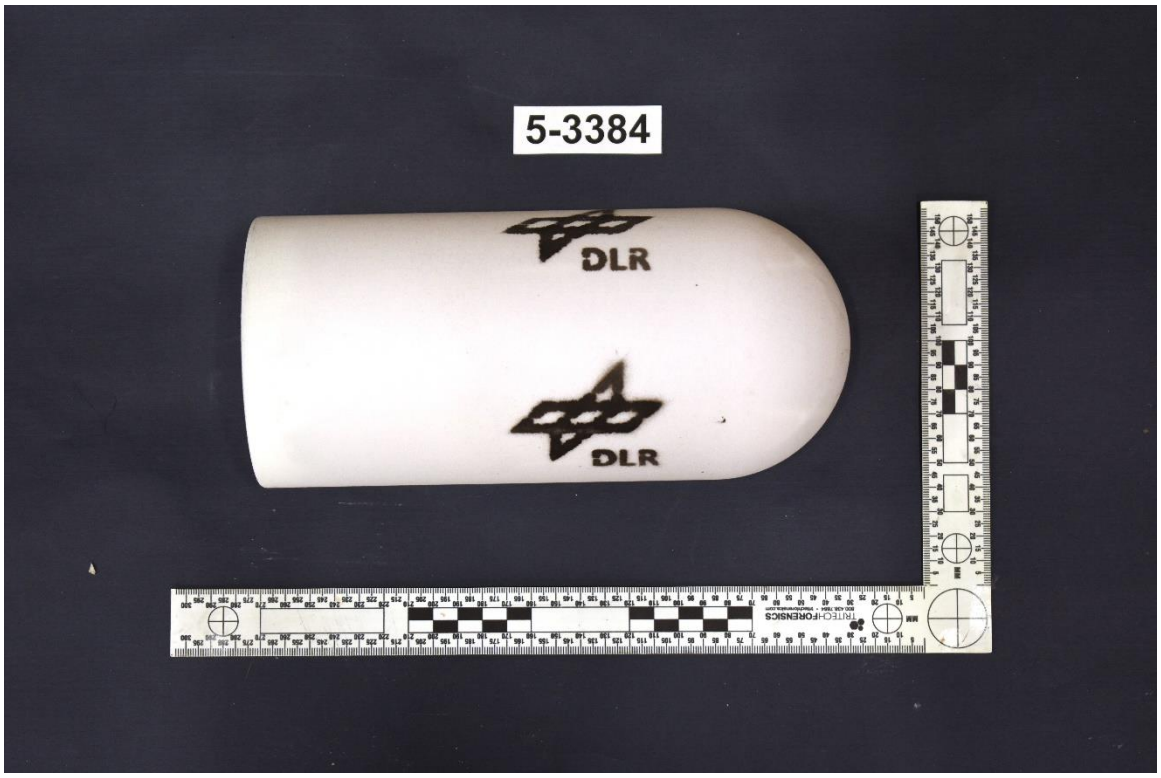


Pretest



Posttest

Figure 29. Shot 5-3383 Projectile Photographs.

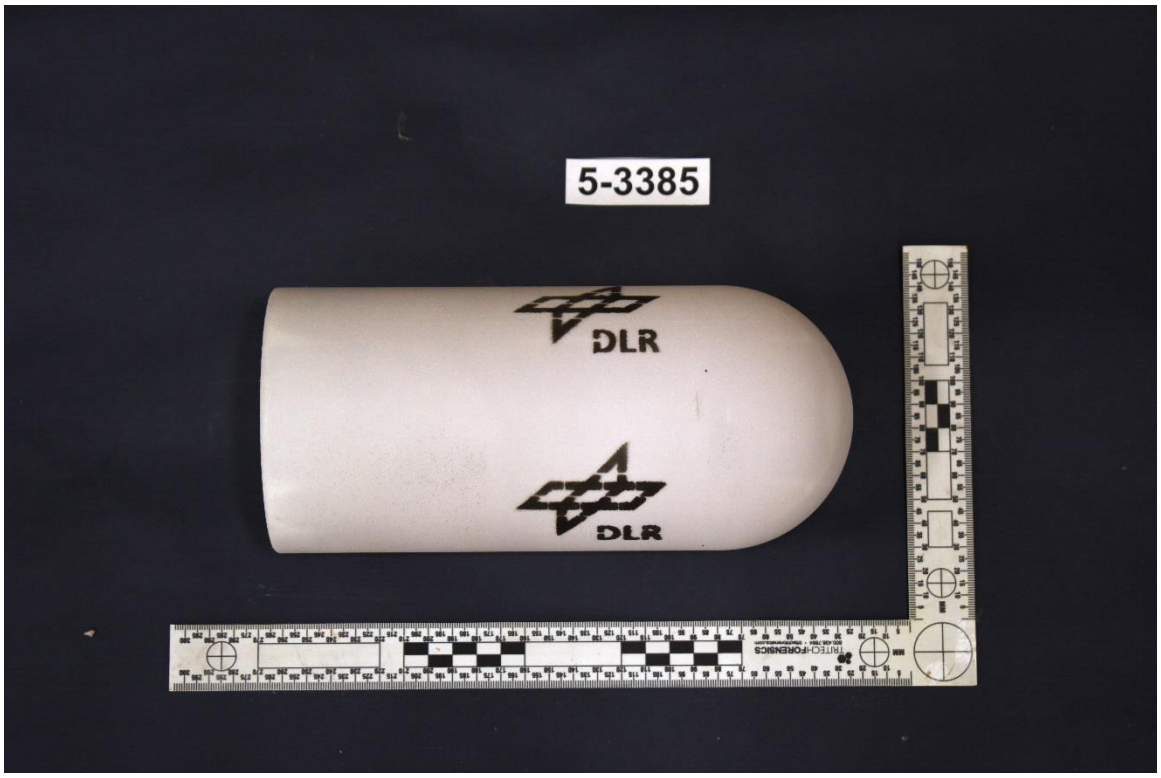


Pretest



Posttest

Figure 30. Shot 5-3384 Projectile Photographs.



Pretest



Posttest

Figure 31. Shot 5-3385 Projectile Photographs.

3.2 SUMMARY AND DISCUSSION

This report documents a series of soft body impacts on a large Hopkinson bar. The impact tests were performed for NASA Glenn Research Center during the period of 3 November 2021 to 9 February 2022. The primary objective was to capture impact load data. Data collected from these tests can be compared to various soft body projectile types for potential use as a surrogate for real birds used in bird strike and bird ingestion certification tests. This test program was conducted in the Impact Physics Laboratory at the University of Dayton Research Institute (UDRI).

The tests were performed by launching soft body projectiles into a 12-inch diameter Hopkinson bar at nominal velocities of 49 m/s, 110 m/s, and 304 m/s using a compressed-gas gun. The tests were conducted according to SAE Aerospace Standard AS6940 entitled, "Standard Test Method for Measuring Forces during Normal Impact of a Soft Projectile on a Rigid Flat Surface". Two types of gelatin projectiles were tested, one using a UDRI formulation and one using a DLR formulation. In addition to the gelatin projectiles, a set of real birds (ducks and chickens) were also tested. Data recorded during the test included bird weight, impact velocity, bar strain gage data, high-speed videos, and digital image correlation data on the bar back face.

Twenty-nine tests were successfully performed. NASA recorded the Hopkinson bar and DIC data which appeared repeatable with the impact loads proportional to the impact velocity and projectile length.

At the nominal 49 m/s impact velocity, the UDRI gelatin projectile flattened out radially on impact and then rebounded from the bar in one piece (ref. Figures 4 to 7) which would not be representative of real bird. This is due to the fact that the impact forces are not strong enough to tear through the homogeneous projectile. A real bird is non-homogeneous. Once the outer skin is ruptured, the loosely connected innards can more easily spread and tear apart. The DLR gelatin projectiles impacting at the nominal 49 m/s velocity flattened out against the bar face and spread out radially in multiple fragments (Ref. Figure 26), much more than for the real birds which were recovered in a few large pieces (Ref. Figures 14 to 16).

At the intermediate nominal impact velocity of 110 m/s, the UDRI gelatin projectile flattened out radially on impact and tore into several longitudinal sections that mostly remained attached at the base of the projectile (Ref. Figures 8 to 10). The projectile was found on the floor just ahead of the bar in one large piece with several smaller pieces. The DLR gelatin projectiles impacting at the nominal 110 m/s velocity flattened out against the bar face and spread out radially in multiple small fragments (Ref. Figure 23), much more than for the real birds which were recovered in a several pieces (Ref. Figure 17).

At the highest nominal impact velocity of 304 m/s, the projectiles behaved much more like a fluid. The UDRI gelatin projectile flattened out against the bar and flowed radially in a thin layer ultimately shredding into many small fragments (Ref. Figures 11 to 13). The DLR gelatin projectiles impacting at the nominal 304 m/s velocity flattened out against the bar face and spread out radially in thin paste-like fragments (Ref. Figures 29 to 31). The real birds at this impact velocity flattened out and spread out radially in many small fragments, the largest being primarily feathers and gelatinous tissue (Ref. Figure 20).

Figures 32 to 40, taken from select images of the high-speed cameras, illustrate the typical break up patterns as discussed above.

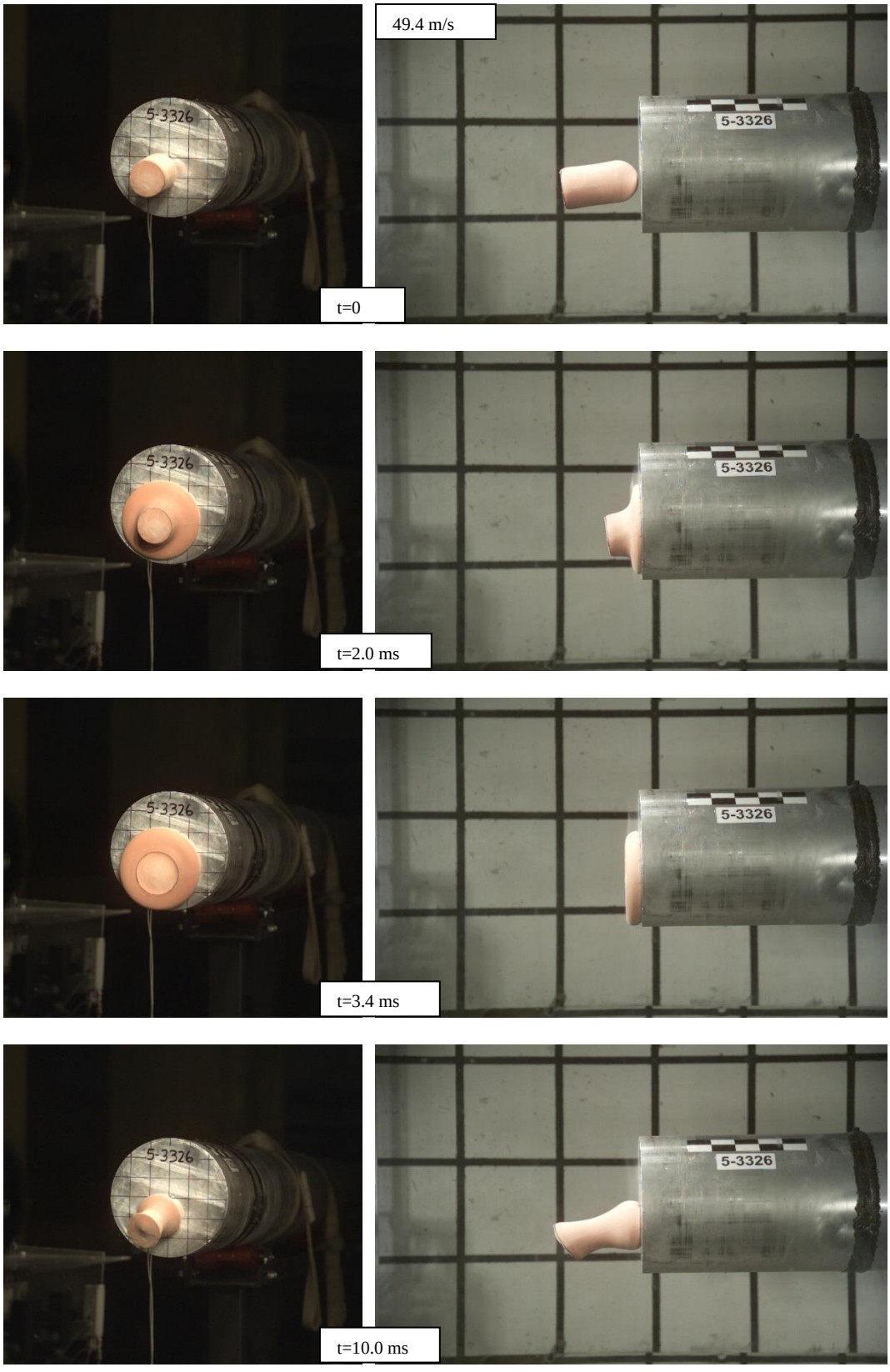


Figure 32. Select Front and Side View High-Speed Camera Images from Shot 5-3326.

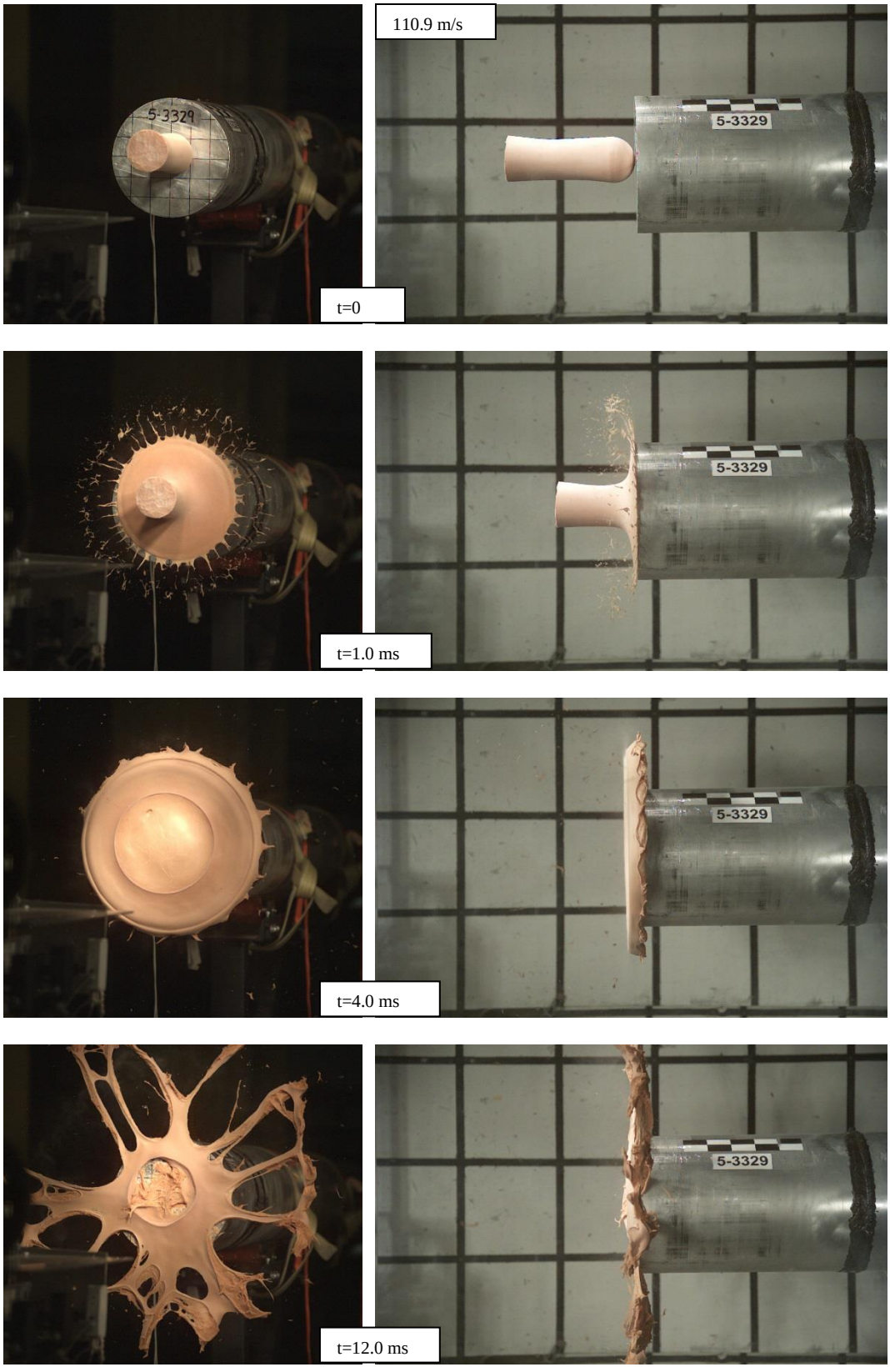


Figure 33. Select Front and Side View High-Speed Camera Images from Shot 5-3329.

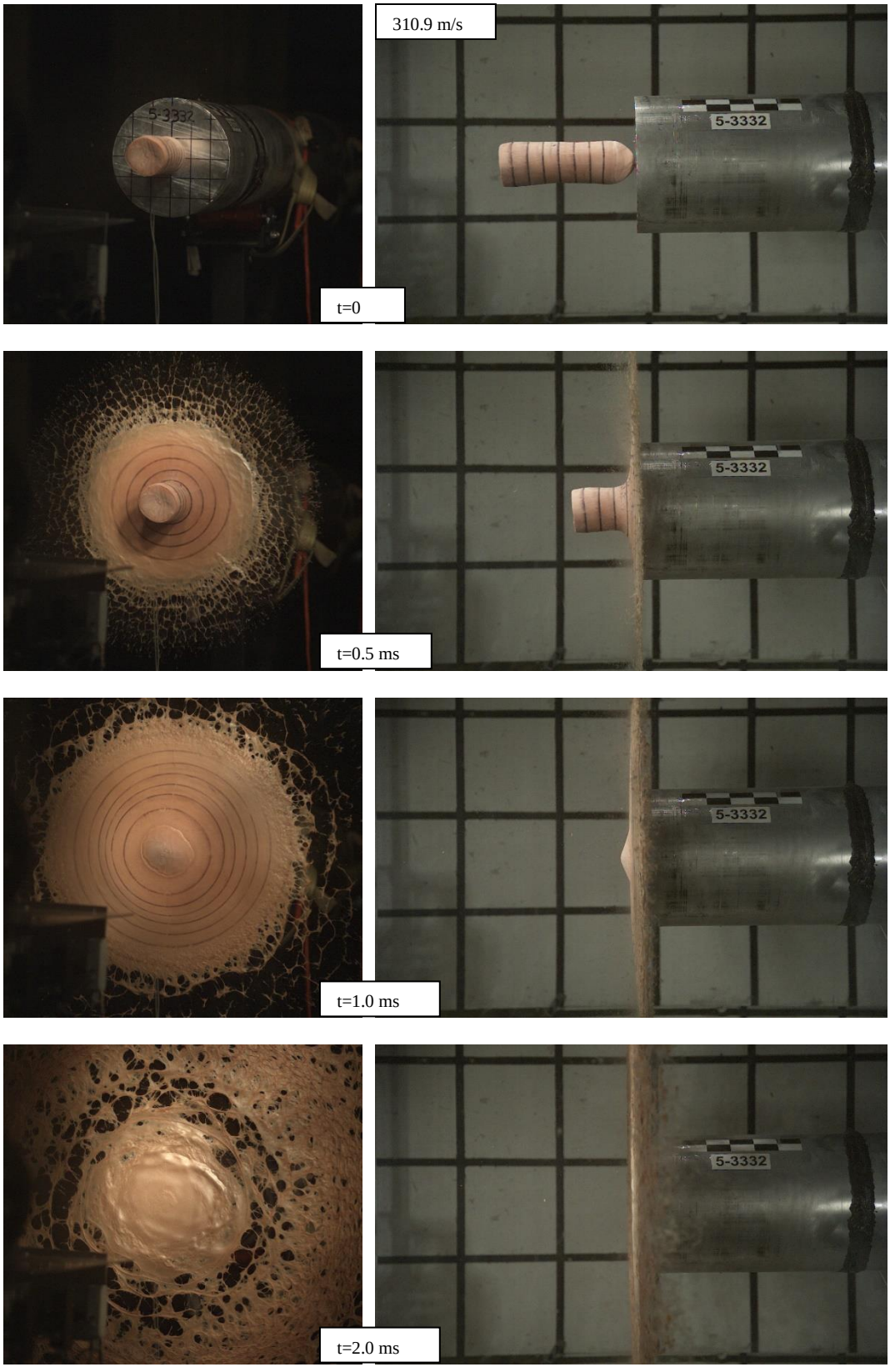


Figure 34. Select Front and Side View High-Speed Camera Images from Shot 5-3332.

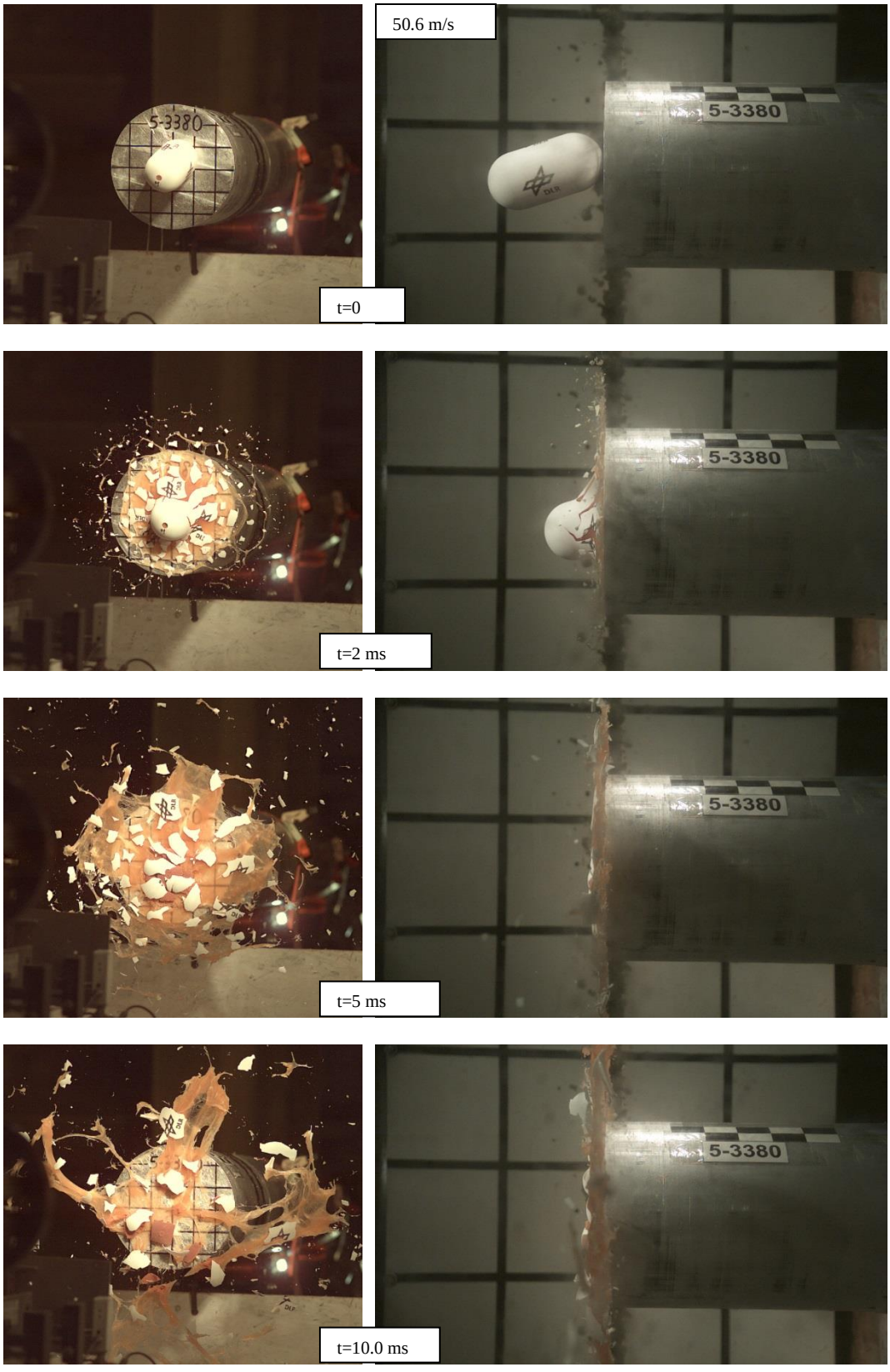


Figure 35. Select Front and Side View High-Speed Camera Images from Shot 5-3380.

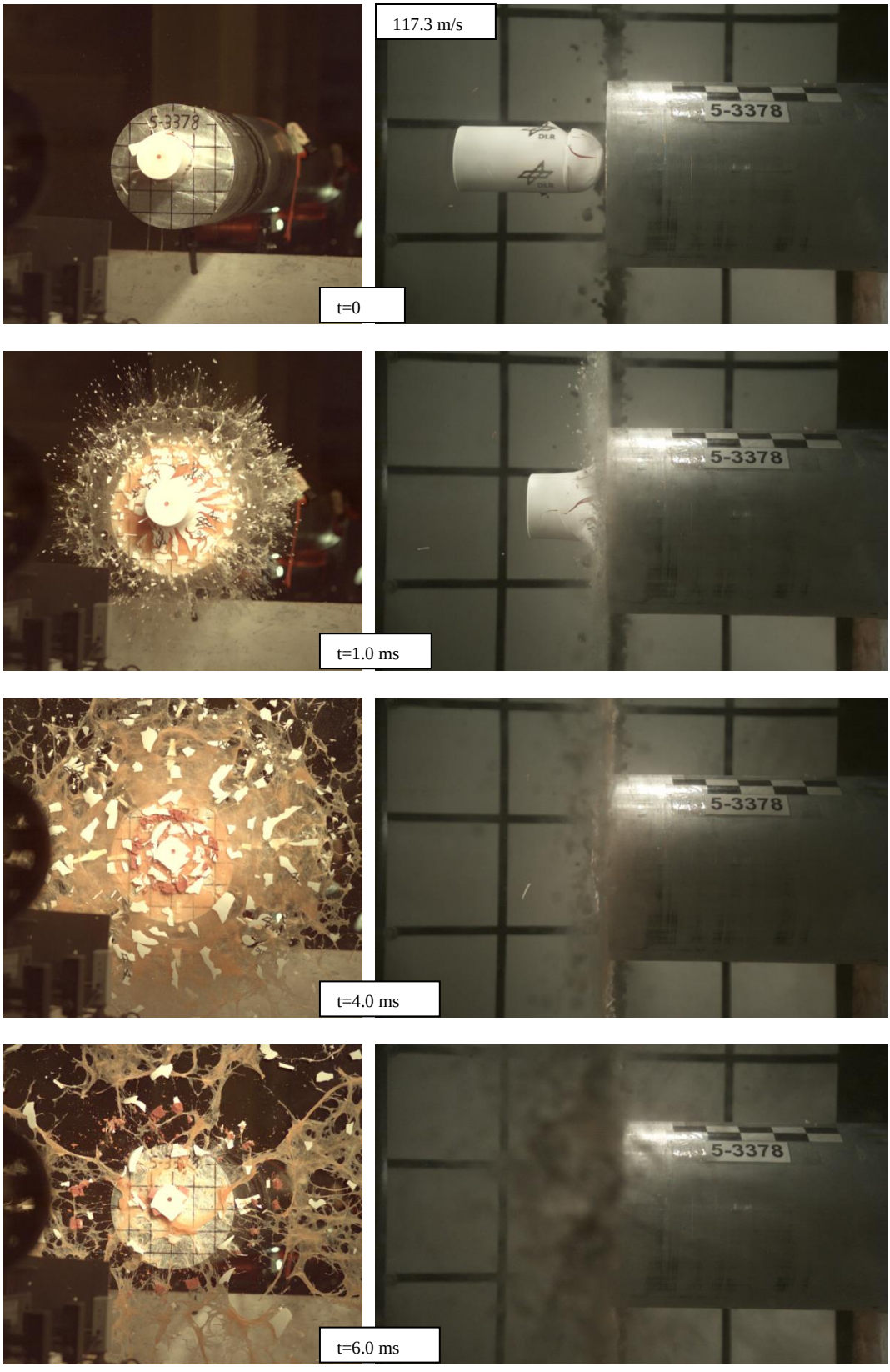


Figure 36. Select Front and Side View High-Speed Camera Images from Shot 5-3378.

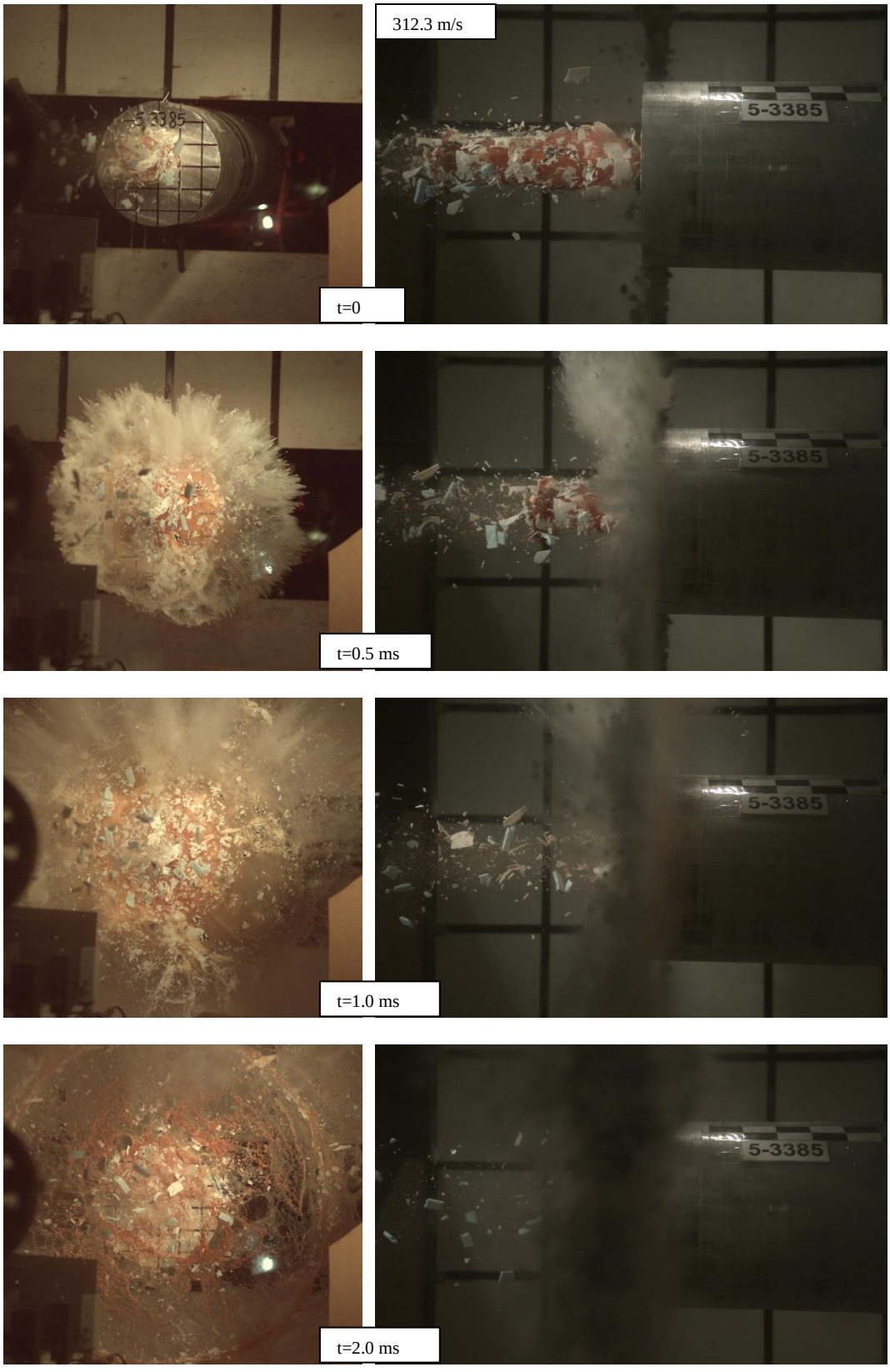


Figure 37. Select Front and Side View High-Speed Camera Images from Shot 5-3385.

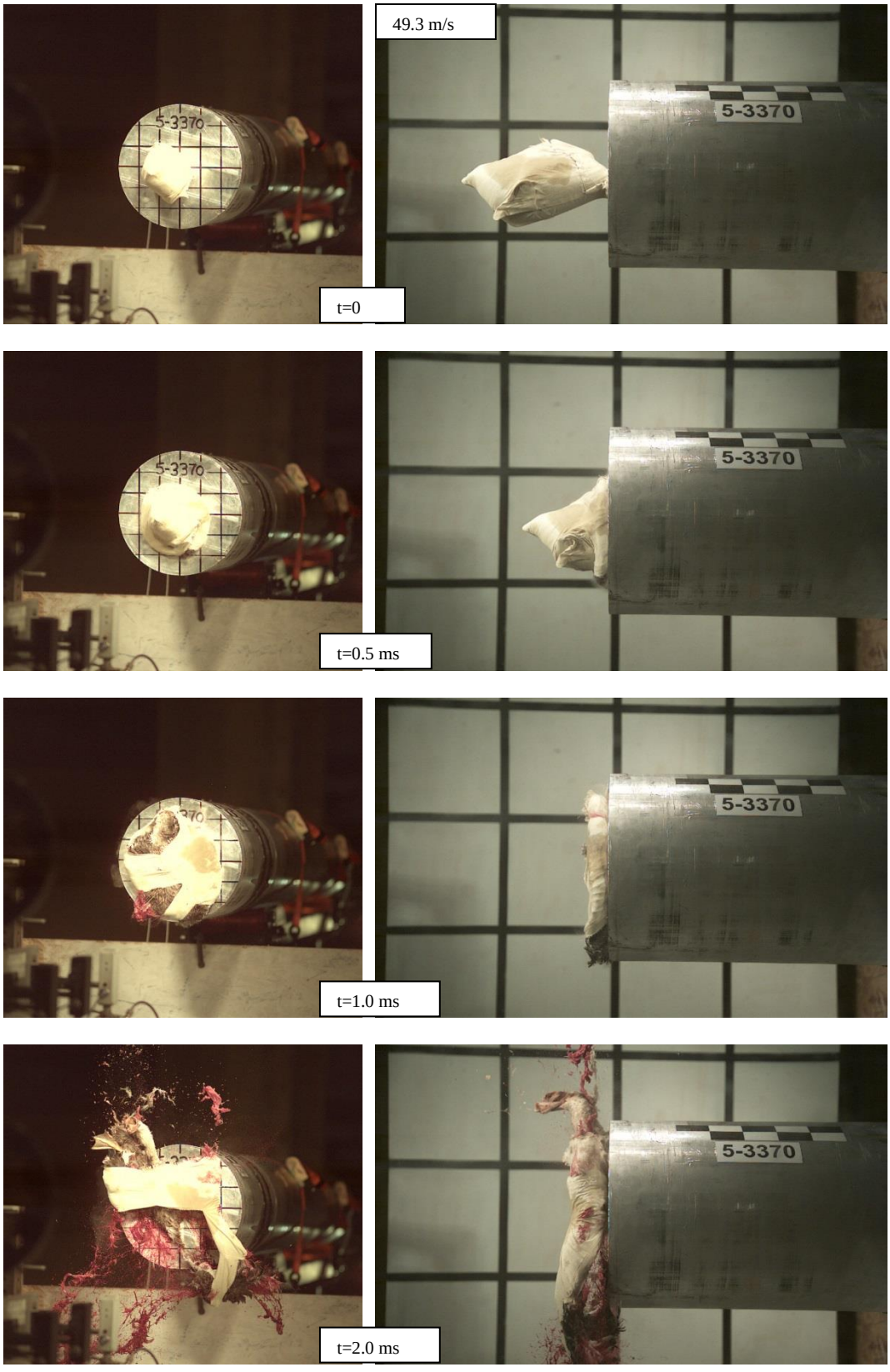


Figure 38. Select Front and Side View High-Speed Camera Images from Shot 5-3370.

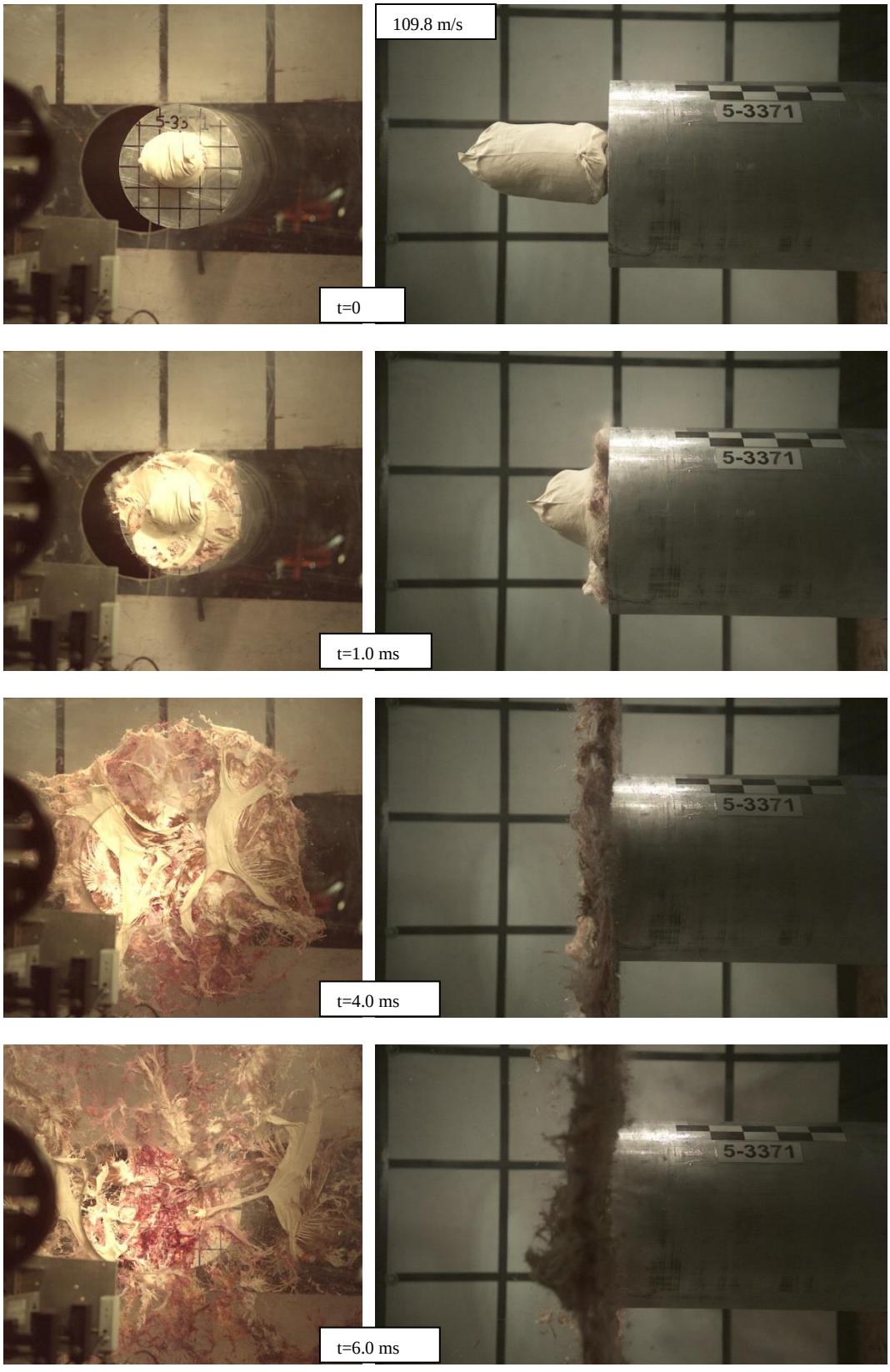


Figure 39. Select Front and Side View High-Speed Camera Images from Shot 5-3371.



Figure 40. Select Front and Side View High-Speed Camera Images from Shot 5-3374.

APPENDIX A

Calibration Records

MIDWEST METROLOGY

Certificate of Calibration

2001038696

Customer Information

On Site Calibration
University of Dayton Research Inst.
300 College Park
Dayton, OH 45469

PO #:

Account #: 159755
SO #: 2001002353

Instrument Identification

Instrument Id: **IDK0500406**
Noun: Data Aquisition Module
Mfr: Nicolet
Department: IPL
Accuracy: Mfg Specification

Model: BAS1M256
Serial #: IDK0500406

Certification Information

Reason For Service: Calibration w/Data
Type Of Calibration: Normal
As Found Condition: In Tolerance
As Left Condition: Left As Found
Procedure: MFG Manual : See Manufacturer's Manual
Remarks:

Technician: Bill Sierschula
Cal Date: 02 JUN 21
Cal Due: 02 JUN 22
Temperature: 22.0 °C
Humidity: 47.0 %

The instrument(s) listed on this certification have been calibrated against standards traceable to the National Institute of Standards and Technology (NIST), derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

Midwest Metrology's quality system complies with applicable requirements of ANSI/NCSL Z540-1 and ISO/IEC 17025.

Reported uncertainties and/or "test uncertainty ratios" (TUR's) are expressed as expanded uncertainty values at approximately the 95% confidence level using a coverage factor of K=2.

Statements of compliance, where applicable, are based on test results falling within specified limits with no reduction by the uncertainty of the measurement.

Calibration due dates appearing on the Certificate of Calibration and label are determined by the client for administrative purposes and do not imply continued conformance to specification.

All results contained herein relate only to item(s) calibrated. This certificate shall not be reproduced except in full, without the written permission of Midwest Metrology.

William Sierschula, Director of Service

Calibration History

WO#	Reason For Service	Type Of Cal	As Found Condition	As Left Condition	Cal Date	Cal Due
2001030169	Calibration w/Data	Normal	In Tolerance	Left As Found	23 May 2017	23 May 2018
2001032536	Calibration w/Data	Normal	In Tolerance	Left As Found	31 May 2018	31 May 2019
2001034644	Calibration w/Data	Normal	In Tolerance	Left As Found	03 Jun 2019	03 Jun 2020

MIDWEST METROLOGY

Certificate of Calibration

2001038696

Calibration History

WO#	Reason For Service	Type Of Cal	As Found Condition	As Left Condition	Cal Date	Cal Due
2001036917	Calibration w/Data	Normal	In Tolerance	Left As Found	12 Jun 2020	12 Jun 2021
2001038696	Calibration w/Data	Normal	In Tolerance	Left As Found	02 Jun 2021	02 Jun 2022

Calibration Data

✓ In Tolerance ✗ Out of Tolerance

Range	Nominal	As Found		As Left		Min	Max
±1 V Range Verification							
Channel 1	900.000 mV	899.076	✓	As Found		899.000	901.000
Channel 2	900.000 mV	899.277	✓	As Found		899.000	901.000
Channel 3	900.000 mV	899.307	✓	As Found		899.000	901.000
Channel 4	900.000 mV	899.165	✓	As Found		899.000	901.000
Channel 5	900.000 mV	899.415	✓	As Found		899.000	901.000
Channel 6	900.000 mV	899.332	✓	As Found		899.000	901.000
Channel 7	900.000 mV	899.091	✓	As Found		899.000	901.000
Channel 8	900.000 mV	899.227	✓	As Found		899.000	901.000
±2 V Range Verification							
Channel 1	1.900 V	1.898	✓	As Found		1.898	1.902
Channel 2	1.900 V	1.898	✓	As Found		1.898	1.902
Channel 3	1.900 V	1.898	✓	As Found		1.898	1.902
Channel 4	1.900 V	1.898	✓	As Found		1.898	1.902
Channel 5	1.900 V	1.899	✓	As Found		1.898	1.902
Channel 6	1.900 V	1.898	✓	As Found		1.898	1.902
Channel 7	1.900 V	1.898	✓	As Found		1.898	1.902
Channel 8	1.900 V	1.898	✓	As Found		1.898	1.902
±5 V Range Verification							
Channel 1	4.900 V	4.895	✓	As Found		4.895	4.905
Channel 2	4.900 V	4.895	✓	As Found		4.895	4.905
Channel 3	4.900 V	4.895	✓	As Found		4.895	4.905
Channel 4	4.900 V	4.895	✓	As Found		4.895	4.905
Channel 5	4.900 V	4.895	✓	As Found		4.895	4.905
Channel 6	4.900 V	4.895	✓	As Found		4.895	4.905
Channel 7	4.900 V	4.895	✓	As Found		4.895	4.905
Channel 8	4.900 V	4.895	✓	As Found		4.895	4.905
±10 V Range Verification							
Channel 1	9.900 V	9.891	✓	As Found		9.890	9.910
Channel 2	9.900 V	9.891	✓	As Found		9.890	9.910
Channel 3	9.900 V	9.890	✓	As Found		9.890	9.910

Visit our website at http://www.midwest-metrology.com Printed: 02 Jun 2021 01:26 PM

Midwest Metrology . 341 Smith Drive . Clayton, Ohio 45315 . Phone: (937) 832-0965 . Fax: (937) 832-0966

MIDWEST METROLOGY

Certificate of Calibration

2001038696

✓ In Tolerance ✗ Out of Tolerance

Calibration Data

Range	Nominal	As Found		As Left		Min	Max
±10 V Range Verification							
Channel 4	9.900 V	9.890	✓	As Found		9.890	9.910
Channel 5	9.900 V	9.891	✓	As Found		9.890	9.910
Channel 6	9.900 V	9.891	✓	As Found		9.890	9.910
Channel 7	9.900 V	9.891	✓	As Found		9.890	9.910
Channel 8	9.900 V	9.890	✓	As Found		9.890	9.910
±20 V Range Verification							
Channel 1	19.000 V	18.982	✓	As Found		18.980	19.020
Channel 2	19.000 V	18.981	✓	As Found		18.980	19.020
Channel 3	19.000 V	18.982	✓	As Found		18.980	19.020
Channel 4	19.000 V	18.981	✓	As Found		18.980	19.020
Channel 5	19.000 V	18.981	✓	As Found		18.980	19.020
Channel 6	19.000 V	18.980	✓	As Found		18.980	19.020
Channel 7	19.000 V	18.981	✓	As Found		18.980	19.020
Channel 8	19.000 V	18.981	✓	As Found		18.980	19.020
±50 V Range Verification							
Channel 1	49.000 V	na		na		48.950	49.050
Channel 2	49.000 V	na		na		48.950	49.050
Channel 3	49.000 V	na		na		48.950	49.050
Channel 4	49.000 V	na		na		48.950	49.050
Channel 5	49.000 V	na		na		48.950	49.050
Channel 6	49.000 V	na		na		48.950	49.050
Channel 7	49.000 V	na		na		48.950	49.050
Channel 8	49.000 V	na		na		48.950	49.050
Timing Verification							
Channel 1	2.000000 ms	2.000000	✓	As Found		1.998125	2.001875

End of Datasheet

Calibration Standards

NIST Traceable #	Instrument ID#	Description	Model	Calibration Date	Date Due
200063186	02-0104	Meter Calibrator	5500A/SC600	21 SEP 2020	21 SEP 2021

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Midwest Metrology . 341 Smith Drive . Clayton, Ohio 45315 . Phone: (937) 832-0965 . Fax: (937) 832-0966

ASSOCIATED SCALE, LLC
570 Leo Street
Dayton, Ohio 45404
(937) 275-2774
(937) 222-9337 fax
http://associatedscale.com

Calibration Report
212005-03

Date: May 3, 2021 | Issue Date: May 3, 2021 | Next Calibration: May 3, 2022

Customer: UD Impact Physics Lab
1031 Irving Ave
Dayton, OH

Contact: Kevin Poormon

Phone#: 937-229-2263

Phone:

Technician: Mark Foster

Location: C-Lab

Calibration Location: 1031 Irving Ave

Scale#	Class	Make	Model	Serial#	Division	Capacity	Decision Rule
03	III	Ohaus	Solution		0.001 Lb	40 Lb	Simple Decision

KITS

Weight	Calibration	Next Calibration
ASC-31-A	April 25, 2019	April 25, 2021
ASC-31-B		

TEST RESULTS

Procedure#: 001 | Uncertainty: 0.0043 Lb

INC/DEC LOAD

Load	UOM	± Tolerance	UOM	As Found	Errors	As Left
0.000	Lb	0.000	Lb	0.000	0.000	0.000
0.500	Lb	0.001	Lb	0.500	0.000	0.500
1.000	Lb	0.002	Lb	1.000	0.000	1.000
5.000	Lb	0.005	Lb	5.000	0.000	5.000
10.000	Lb	0.005	Lb	10.000	0.000	10.000
15.000	Lb	0.005	Lb	15.000	0.000	15.000
20.000	Lb	0.005	Lb	20.000	0.000	20.000
40.000	Lb	40.000	Lb	40.000	0.000	40.000

SHIFT

Corner	Load	As Found	As Left	Recommendations / Corrective Actions
1	10.000	10.000	10.000	Scale ok.
2	10.000	10.000	10.000	
3	10.000	10.000	10.000	
4	10.000	10.000	10.000	

SECURITY SEAL INTACT	N/A	WEATHER	N/A
SUITABLE FOR ENVIRONMENT	Yes	WIND (MPH)	N/A
BALANCE LEVEL	Yes	HUMIDITY (%)	56
SUPPORT FOR SCALE	Yes	TEMPERATURE (°F)	72
SCALE MEETS TOLERANCE AS FOUND	Yes		
SCALE MEETS TOLERANCE AS LEFT	Yes		

A2LA ACCREDITED 1585.01

Certification

☐ If this box is checked the results of this report are not covered by A2LA accreditation.

ASC-

Mark Foster — Registration# — Customer

We do certify that the above listed equipment has been correctly tested and calibrated by means of dead weights or through load applying machines utilizing a load cell transfer standard calibrated with dead weights according to HB44 or Associated Scale procedures with accuracy traceable to the National Institute of Standards and Technology (NIST) through the Calibration Laboratory to maintain compliance to 17025, Confidence Level 95% using K=2.

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University of Dayton Research Institute

Certificate of Verification

Certificate number: 2021030113

University of Dayton Research Institute
Structure and Component Characterization Group
1031 Irving Ave
Dayton OH 45419-8008

Customer Information

Impact Physics Group
Shroyer Park Center
300 College Park
Dayton, Ohio 45469

Contact: Kevin Poormon

Instrument Information

Instrument ID:	B059D	Serial # :	N/A
Equipment Type:	48" Steel Ruler	Model:	No. 62
Mfr:	Lufkin		
Location:	SPC Rm 0620		
Tolerance:	± 0.02 inch for 1/16 scale *	* Note: Accuracy between marks limited by readability - for use without a magnifier	
Range:	0 to 48 in		

Certificate Information

Reason for Service:	Verification	Cal Date:	3/31/2021
Technician:	J. Keith	Cal Due:	3/31/2026
As Found Condition:	In Tolerance	Temperature:	71.1 °F
As Left Condition:	Left as Found		
Coefficients checked:	N/A		
Procedure:	See page 2		
Type:	Verify to extend prior calibration interval and expand to full length of ruler.		
Remarks:	**LIMITED - full length of 1/16 scale on face of ruler with calibration sticker. (hole in ruler is located next to visible manufacturer label)**		

Unless otherwise detailed in a Statement of Measurement Uncertainty, reported measurement uncertainty ±U (k=2 coverage factor and approximately 95% confidence interval) is the sum of the combined standard uncertainty and the readability of the calibrated device in the procedure and conditions at the time of calibration or; is the laboratory's ISO/IEC 17025 scope calibration measurement capability when greater. In general, determination of additional factors is needed to estimate measurement uncertainty for a device in use.

Evaluation of the calibrated device to a tolerance, when reported, is determined without factoring in the effect of measurement uncertainty. A ratio of device tolerance to combined reference standard uncertainty of at least 4:1 is routinely observed unless otherwise stated.

Calibration due dates appearing on this certificate of calibration and label are determined by the client for administrative purposes and do not imply continued conformance to specification. All results contained herein relate only to item(s) calibrated.

The instruments listed on this report have been calibrated against standards traceable to the International System of Units (SI) through National Institute of Standards and Technology (NIST) or use intrinsic physical properties unless otherwise stated.
Opinions and interpretations identified with a diamond.

This report shall not be reproduced except in full without the written consent of the University of Dayton Research Institute.

Calibrated by: Justin Keith
Metrology Technician

Justin Keith
2021.03.31
15:47:13 -04'00'

Phone: (937) 229-2308
E-mail: justin.keith@udri.udayton.edu

Approved by: Daniel Drodge
MSE , Quality Manager

Daniel Drodge
2021.03.31
15:56:24 -04'00'

Phone: (937) 229-3175
E-mail: Daniel.Drodge@udri.udayton.edu

University of Dayton Research Institute

Certificate of Verification

Certificate number: 2021030113

University of Dayton Research Institute
Structure and Component Characterization Group
1031 Irving Ave
Dayton OH 45419-8008

1/16 inch scale	Readability 0.015 inch	1/50 inch scale	Readability 0.005 inch	
	DUT Inch		**STD** Inch	Error Inch
Starting location on ruler	0.00	Starting location on ruler	24.000	0.000
Intermediate point A	8.00	Intermediate point A	16.000	0.000
Intermediate point B	16.00	Intermediate point B	8.000	0.000
End location on ruler	24.00	End location on ruler	0.000	0.000
Starting location on ruler	48.00	Starting location on ruler	0.000	0.000
Intermediate point A	40.00	Intermediate point A	8.000	0.000
Intermediate point B	32.00	Intermediate point B	16.000	0.000
End location on ruler	24.00	End location on ruler	24.000	0.000

Procedure:
Locate ruler to be measured (DUT) and ruler used as standard (STD) on granite surface.
Allow rulers to thermally stabilize for minimum 30 minutes, record surface temperature.
Set up & restrain a suitable (precision-face) end-stop block on granite surface.
With DUT 1/16 scale and STD 1/50 scale faced fully against one another,
butt both rulers squarely against stop block at DUT "0" end of 1/16 scale.
Record data .
Rotate both rulers 180° placing opposite ends toward stop block.
With DUT face to calibrated and STD 1/50 scale fully against one another,
butt both rulers against stop block at DUT "48" end of 1/16 scale.
Record data.

Statement of Measurement Uncertainty:

Combined measurement uncertainty "U", k = 2, is estimated as 2x the quadrature sum of:

STD cal uncertainty divided by 2	0.0023
STD readability divided by SQRT(3)	0.003
DUT readability divided by SQRT(3)	0.009
U =	**0.02 inch**

Calibration Standards

Instrument ID#	Manufacturer	Model/Description	Calibration Date	Due Date
182-162	Mitutoyo	24" Steel Rule	NOV 2020	NOV 2022
H065XR-13	Fisher Scientific	6-662-4	3/26/2020	3/26/2022

End of Report

University of Dayton Research Institute

Certificate of Calibration

Certificate number: 2018090274

University of Dayton Research Institute
Structure and Component Characterization Group
1031 Irving Ave
Dayton OH 45419-8008

Customer Information

RI-AM-Impact Physics Group
Shroyer Park Center RM 1941
300 College Park
Dayton, Ohio 45469

Contact: Kevin Poormon

Instrument Information

Instrument ID:	B058D	Serial # :	4781
Equipment Type:	Propeller Protractor	Model:	N/A
Mfr:	Hartzell Propeller Inc.		
Location:	SPC Metrology Lab		
Tolerance:	± 0.5°		
Range:	1° to 45°		

Certificate Information

Reason for Service:	Calibration	Cal Date:	9/26/2018
Technician:	R. E. Warrick	Cal Due:	9/26/2023
As Found Condition:	In tolerance	Temperature:	70°F
As Left Condition:	As found		
Procedure:	See page 2		
Type:	Test for compliance with customer-defined tolerance		
Remarks:			

Calibration due dates appearing on this certificate of calibration and label are determined by the client for administrative purposes and do not imply continued conformance to specification. All results contained herein relate only to item(s) calibrated.

The instruments listed on this report have been calibrated against standards traceable to the International System of Units (SI) through National Institute of Standards and Technology (NIST) or use intrinsic physical properties unless otherwise stated.

This report shall not be reproduced except in full without the written consent of the University of Dayton Research Institute.

Calibrated by: R.E.Warrick
Metrology Technician

Ross E. Warrick
I have reviewed this document
2018.09.27 13:51:05 -04'00'

Phone: (937) 229-3896
E-mail: ross.warrick@udri.udayton.edu

Approved by: Steve Fuchs
MSE , Technical Manager

Steve Fuchs
approved for release
2018.10.01 09:07:19 -04'00'

SCC Group Leader
Phone: (937) 229-2718
E-mail: Steve.fuchs@udri.udayton.edu

University of Dayton Research Institute

Certificate of Calibration

Certificate number: 2018090274

University of Dayton Research Institute
Structure and Component Characterization Group
1031 Irving Ave
Dayton OH 45419-8008

Calibration Data

As Found Data

Nominal	Webber block*	CMM A023D		Hartzell Gage	Error
degree	degree	degree		degree	degree
0	0	0.0		0.0	-
1	1	1.0002		1.0	-0.0002
3	3	2.9952		3.0	0.0048
5	5	4.9902		5.0	0.0098
15	15	14.9845		15.0	0.0155
30	30	29.9855		30.0	0.0145
45	45	44.9871		45.0	0.0129
0	0	0.0		0.0	-

Procedure: Place angle block on level sine plate (check with bubble level).
Place angle gage on angle block; align and set angle to level both bubbles.
Read DUT angle.
Measure angle block with CMM.
Increments sum to exactly 360 degrees; accuracy of increments over a portion of the range is taken as verifying the device.
* Webber angle block set MR-6

Calibration Standards

NIST Traceable	Instrument ID#	Description	Calibration Date / Due Date	
CORE 114733	A023D	CMM	4/16/2018	4/16/2019
4040-8075091	H065XR-5	Fisher Scientific	10/27/2016	10/27/2018

End of Report

ilac-MRA A2LA ACCREDITED A2LA Certificate No. 1750.01 Calibration

Calibration complies with ISO/IEC 17025, ANSI/NCSL Z540-1, and 9001

Cert. No.: 4040-11934969

Traceable® Certificate of Calibration for Therm./Clock/Humidity Monitor

Manufactured for and distributed by : Fisher Scientific "300 Industry Drive,,Pittsburgh,PA,15275-1001"

B067

Instrument Identification:

Model: 06-662-4,11725843 S/N: 210087763 Manufacturer: Control Company

Standards/Equipment:

Description	Serial Number	Due Date	NIST Traceable Reference
Non-Contact Frequency Counter	26.66887	05 Jun 2021	1000455570
Digital Thermometer	221197993	14 Oct 2021	4000-11621504
Chilled Mirror Hygrometer	44654/2H3737	25 Nov 2021	17811

Certificate Information:

Technician: 353 Procedure: CAL-17 Cal Date: 05 Feb 2021 Cal Due Date: 05 Feb 2023

Test Conditions: 46.04%RH 22.15°C 1014mBar

Calibration Data: (New Instrument)

Unit(s)	Nominal	As Found	In Tol	Nominal	As Left	In Tol	Min	Max	±U	TUR
%RH	N.A.	N.A.		43.40	44	Y	38	48	0.74	>4:1
°C	N.A.	N.A.		22.99	23.1	Y	22	24	0.076	>4:1
sec/24hr	N.A.	N.A.		0.000	-0.100	Y	-8.64	8.64	0.041	>4:1

This certificate indicates Traceability to standards provided by (NIST) National Institute of Standards and Technology and/or a National Standards Laboratory.

A Test Uncertainty Ratio of at least 4:1 is maintained unless otherwise stated and is calculated using the expanded measurement uncertainty. Uncertainty evaluation includes the instrument under test and is calculated in accordance with the ISO "Guide to the Expression of Uncertainty in Measurement : (GUM). The uncertainty represents an expanded uncertainty using a coverage factor k=2 to approximate a 95% confidence level. In tolerance conditions are based on test results falling within specified limits with no reduction by the uncertainty of the measurement. The results contained herein relate only to the item calibrated. This certificate shall not be reproduced except in full, without written approval of Control Company.

Nominal=Standard's Reading; As Left=Instrument's Reading; In Tol=In Tolerance; Min/Max=Acceptance Range; ± U=Expanded Measurement Uncertainty; TUR=Test Uncertainty Ratio; Accuracy=±(Max-Min)/2; Min=As Left Nominal(Rounded) – Tolerance; Max= As Left Nominal(Rounded) + Tolerance;

Nicol Rodriguez

Nicol Rodriguez, Quality Manager

Marisa Elms

Marisa Elms, Technical Manager

Note :

Maintaining Accuracy:

In our opinion once calibrated your Therm./Clock/Humidity Monitor should maintain its accuracy. There is no exact way to determine how long calibration will be maintained. Therm./Clock/Humidity Monitor change little, if any at all, but can be affected by aging, temperature, shock, and contamination.

Recalibration:

For factory calibration and re-certification traceable to National Institute of Standards and Technology contact Control Company.

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Control Company is an ISO/IEC 17025:2017 Calibration Laboratory Accredited by (A2LA) American Association for Laboratory Accreditation, Certificate No. 1750.01.
Control Company is ISO 9001:2015 Quality Certified by DNV GL, Certificate No. CERT-01805-2006-AQ-HOU-ANAB.
International Laboratory Accreditation Cooperation - Multilateral Recognition Arrangement (ILAC-MRA).

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