ENGINEERING LAUNCH METHODS FOR NON-SPHERICAL HYPERVELOCITY PROJECTILES

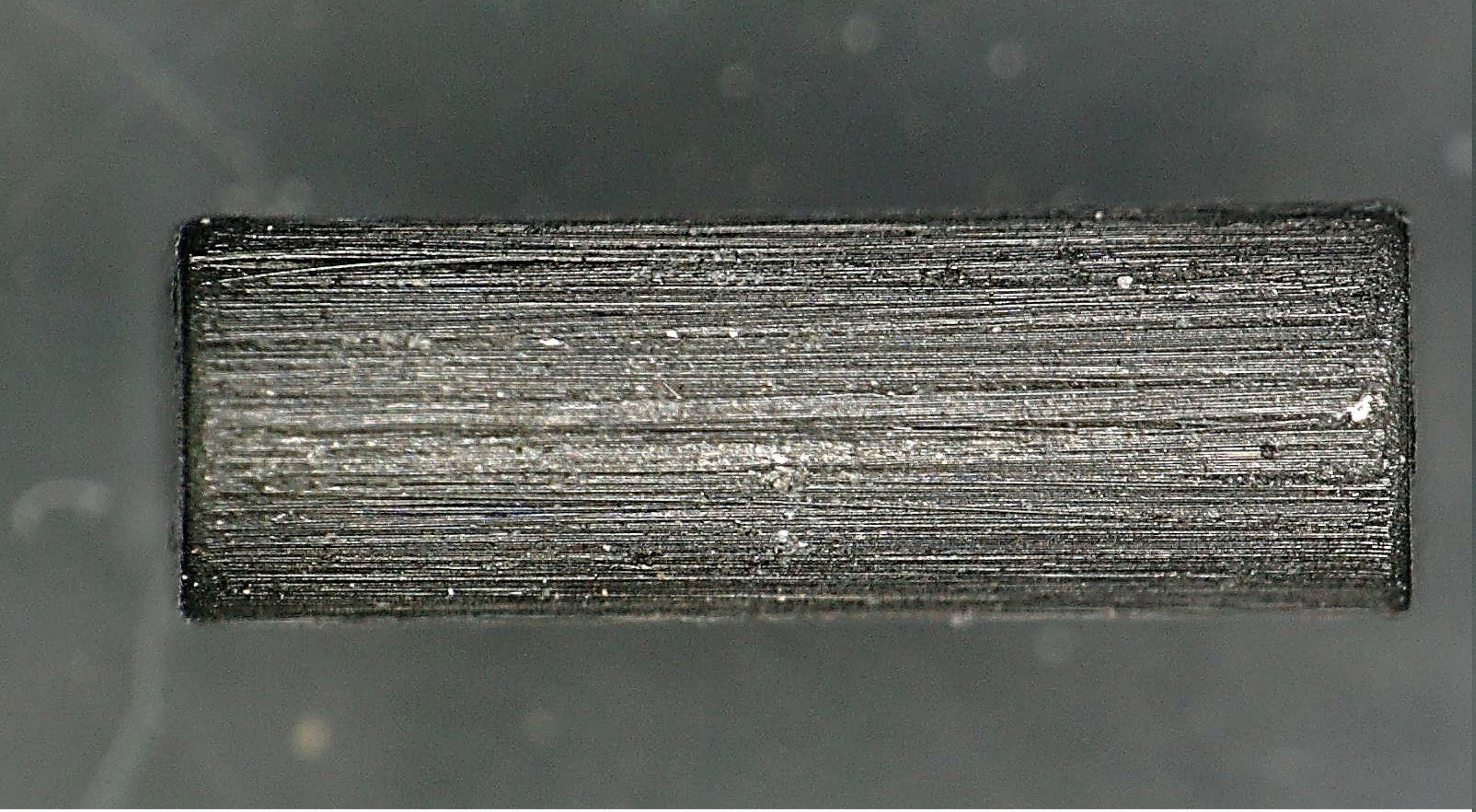
Daniel Rodriguez

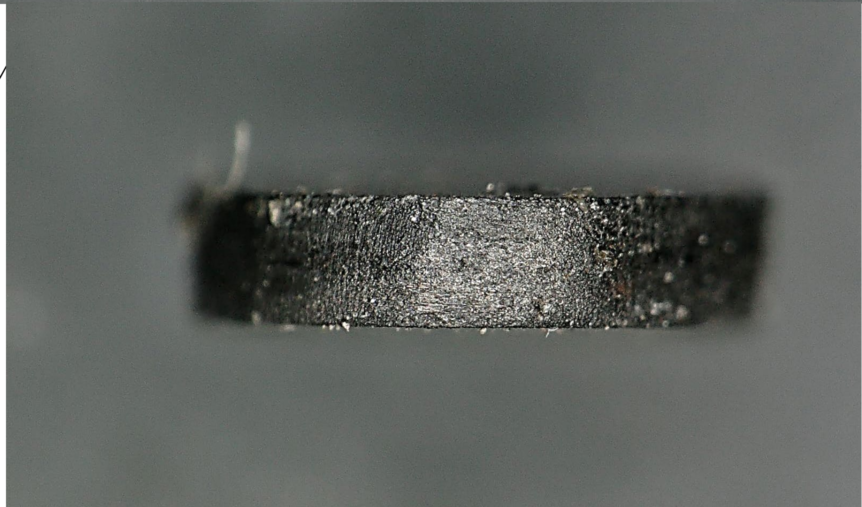
ACKNOWLEDGEMENTS

- NASA White Sands Test Facility
- NASA Johnson Space Center
- Sierra Lobo Inc.

INTRODUCTION

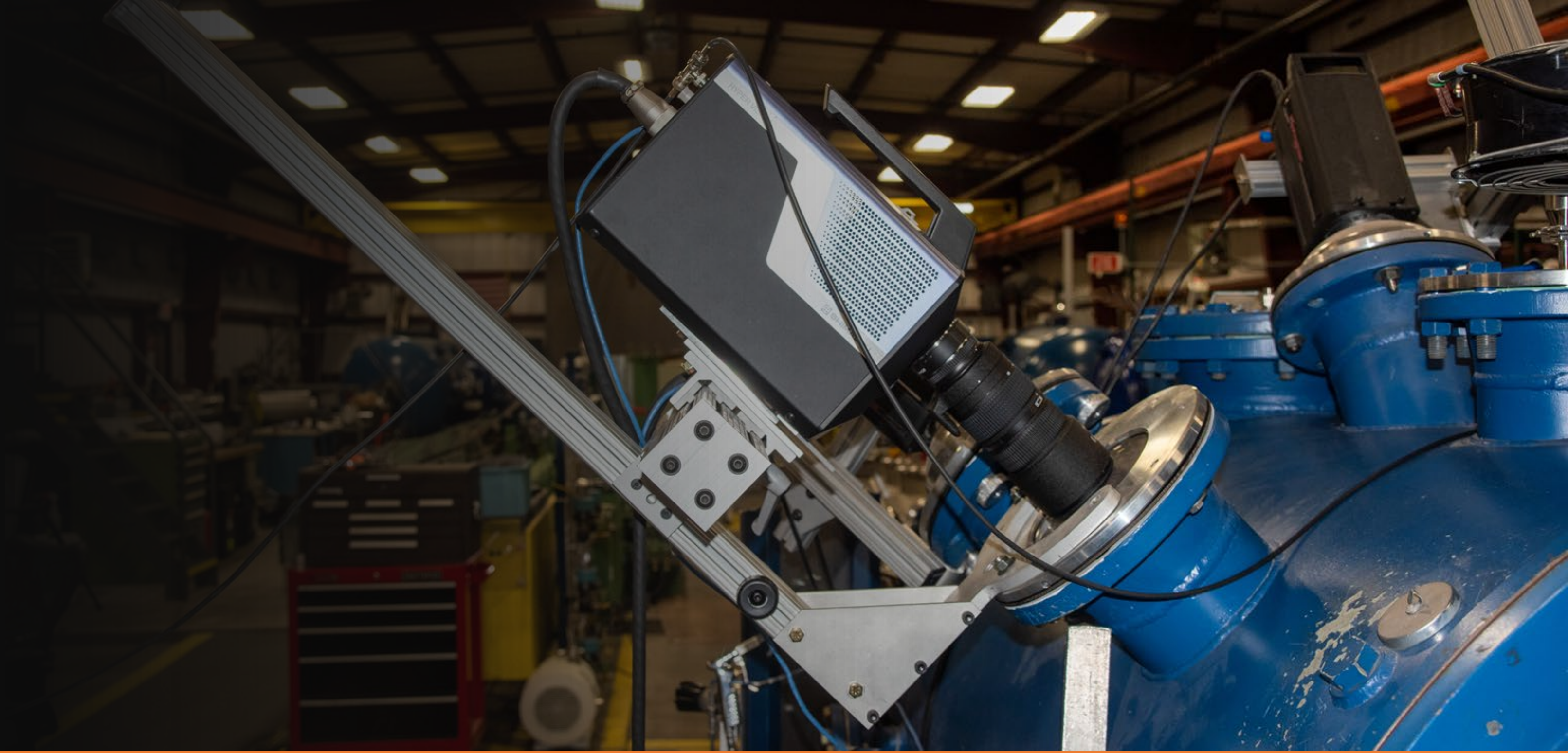
- The National Engineering Safety Center (NESC) recommended categorizing debris shapes and establishing a correlation between characteristic length and mass/shape parameters.
- An extensive dataset was gathered to characterize the shapes of a significant portion of this debris.
- It was determined that a considerable amount of this debris is primarily composed of carbon-fiber-reinforced polymer (CFRP) with length-to-diameter (L/D) ratios of approximately 1/3 (thin plate) or 3/1 (long rod).

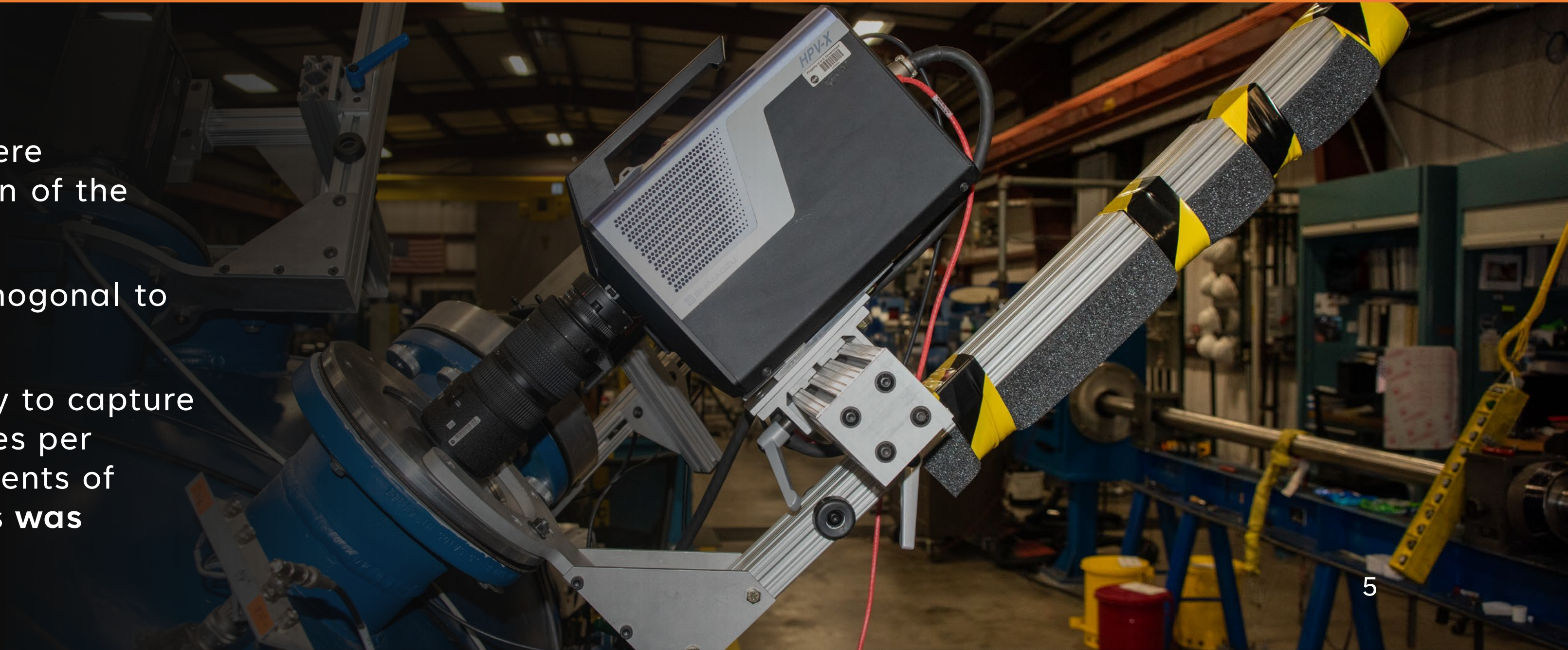




- The Remote Hypervelocity Test Laboratory (RHTL) team received a request from the Johnson Space Center (JSC) Hypervelocity Impact Technology (HVIT) group to conduct experiments involving the **launch of carbon, steel, and copper projectiles of diverse shapes**.
- The overarching objective of these experiments was to establish the capacity for the successful launch and measurement of the impact orientation of cylindrical projectiles at various L/D ratios, including 1/5 (thin plate), 2/3 (sphere equivalent mass), and 3/1 (long rod), targeting a designated shield.

HIGH-SPEED IMAGE SETUP





- Two Shimadzu™ HyperVision HPV-X cameras were employed to record both the in-flight orientation of the projectile and its post-impact damage.
- Both cameras were strategically positioned orthogonal to each other, outside the target chamber.
- These high-speed cameras possess the capacity to capture footage at frame rates of up to 10 million frames per second (fps). However, for the specific requirements of these experiments, a **frame rate of 2 million fps was deemed more suitable.**

HIGH-SPEED IMAGE SETUP (CONT.)

➢ The precision of camera alignment was ensured through the use of an alignment fixture, focusing the cameras on the anticipated flight path of the projectile while maintaining their orthogonality.

TEST SUMMARY

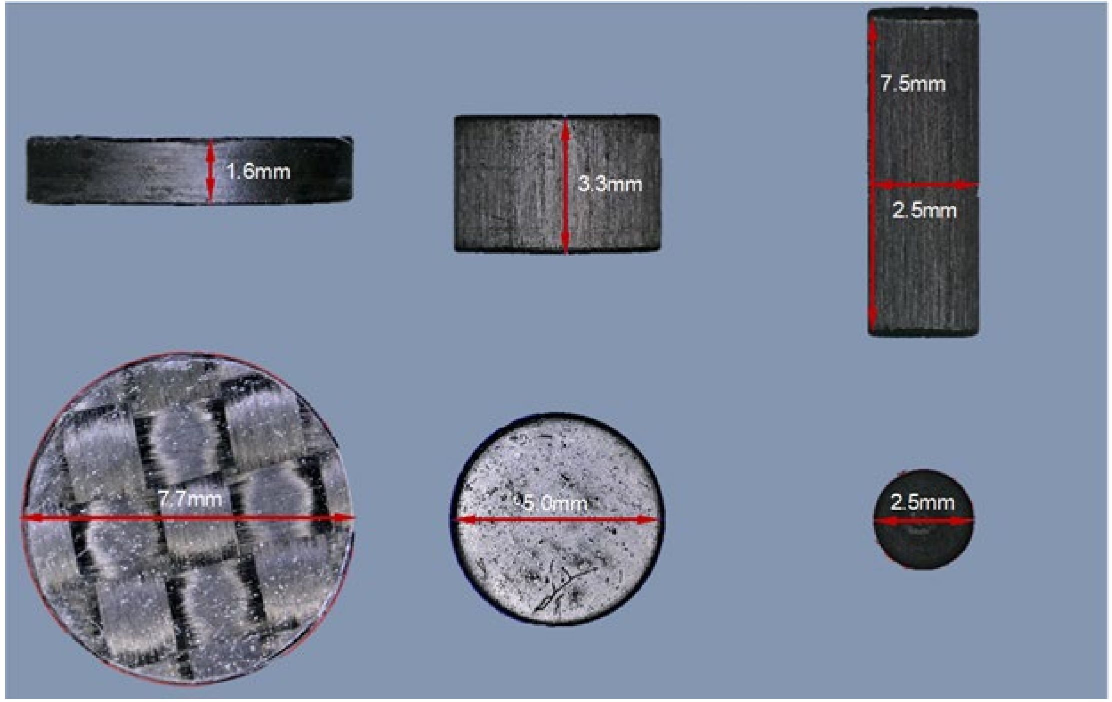
- More than 80% of the experiments employed CFRP due to its prevalence in the composition of most debris.

- The success rate achieved in this series of experiments stood at 66%, with unsuccessful attempts primarily attributed to either projectile failure or inadvertent collisions with the stripper plate.

Test #	Projectile Material	Diameter (mm)	Length (mm)	Mass (g)	Velocity (km/s)	Notes
1	CFRP	5	3.33	0.1007	6.94	Clean Test
2	CFRP	5	3.33	0.1002	6.99	Clean Test
3	CFRP	5	3.33	0.0999	6.96	Clean Test
4	CFRP	6	1.2	0.0528	6.83	Projectile Breakup
5	CFRP	2.5	7.5	0.0564	6.97	Projectile Impacted Stripper Plate
6	CFRP	2.5	7.5	0.057	6.97	Clean Test
7	CFRP	2.5	7.5	0.0572	6.99	Clean Test
8	CFRP	3.45	2.3	0.0327	6.94	Clean Test
9	CFRP	7.94	1.58	0.1163	6.95	Clean Test
10	CFRP	7.94	1.58	0.1162	6.97	Projectile Breakup
11	CFRP	7.94	1.58	0.1166	6.96	Projectile Impacted Stripper Plate
12	CFRP	1.78	5.3	0.0204	7.00	Clean Test
13	CFRP	7.94	1.58	0.1161	6.99	Projectile Breakup
14	CFRP	7.94	1.58	0.117	5.96	Clean Test
15	CFRP	7.94	1.58	0.117	6.63	Clean Test
16	CFRP	7.94	1.58	0.117	6.84	Projectile Impacted Stripper Plate
17	CFRP	7.94	1.58	0.1146	7.28	Projectile Impacted Stripper Plate
18	CFRP	4	1.58	0.0302	6.63	Clean Test
19	CFRP	6	1.58	0.0663	6.55	Impacted Stripper
20	Stainless Steel	1.2	0.8	0.0071	6.88	Clean Test
21	Stainless Steel	1.2	0.4	0.0036	6.85	Clean Test
22	Copper	0.7	2	0.0071	6.85	Clean Test
23	Copper	0.7	2	0.0069	6.83	Clean Test
24	CFRP	1.8	5.27	0.02	6.97	Clean Test

CFRP PROJECTILE DETAILS

The long CFRP cylindrical projectiles employed in this series of tests were fabricated from pultruded rods. In contrast, the disks were manufactured through turning or water jet-cutting processes from CFRP sheets.



Fiber Volume	**63%**
Tensile Strength	2.4 Gpa
Tensile Modulus	240 Gpa
Compression Strength	1.00 Gpa
Ultimate Elongation	1.10%
Glass Transition Temp.	120 C
Resin Type	Bisphenol A

SABOT DESIGN

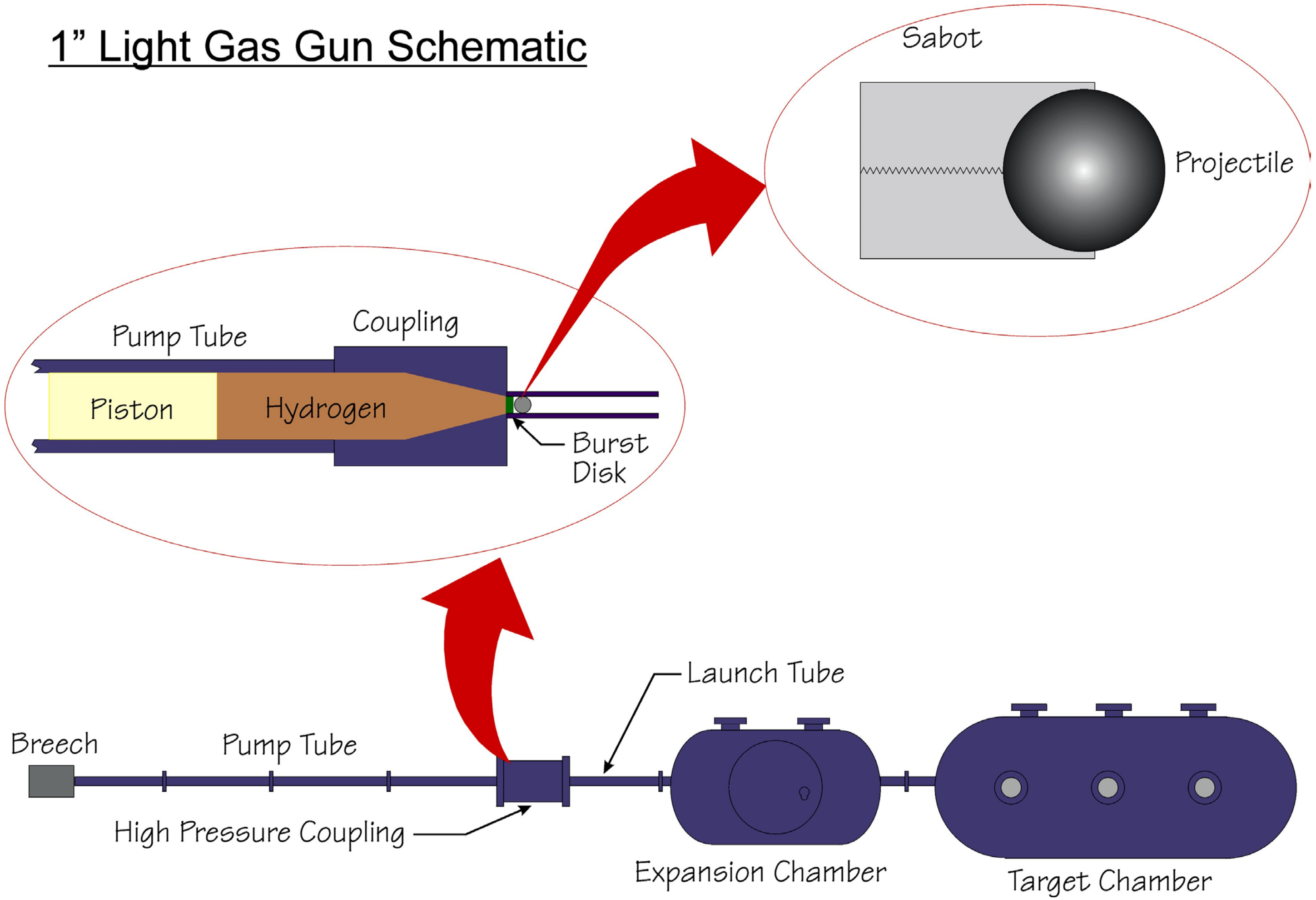
Key Optimizations:

- Minimized launch package mass.
- Minimized the Sabot Projectile's Pocket Depth.

- The launch of a flat disk presents a particularly formidable challenge. Specifically, the 1/5 (L/D) ratio.
- A redesigned pocket was developed with the primary objective of mitigating the compressive forces acting on the projectile during the launch phase.

Gun Barrel Optimization

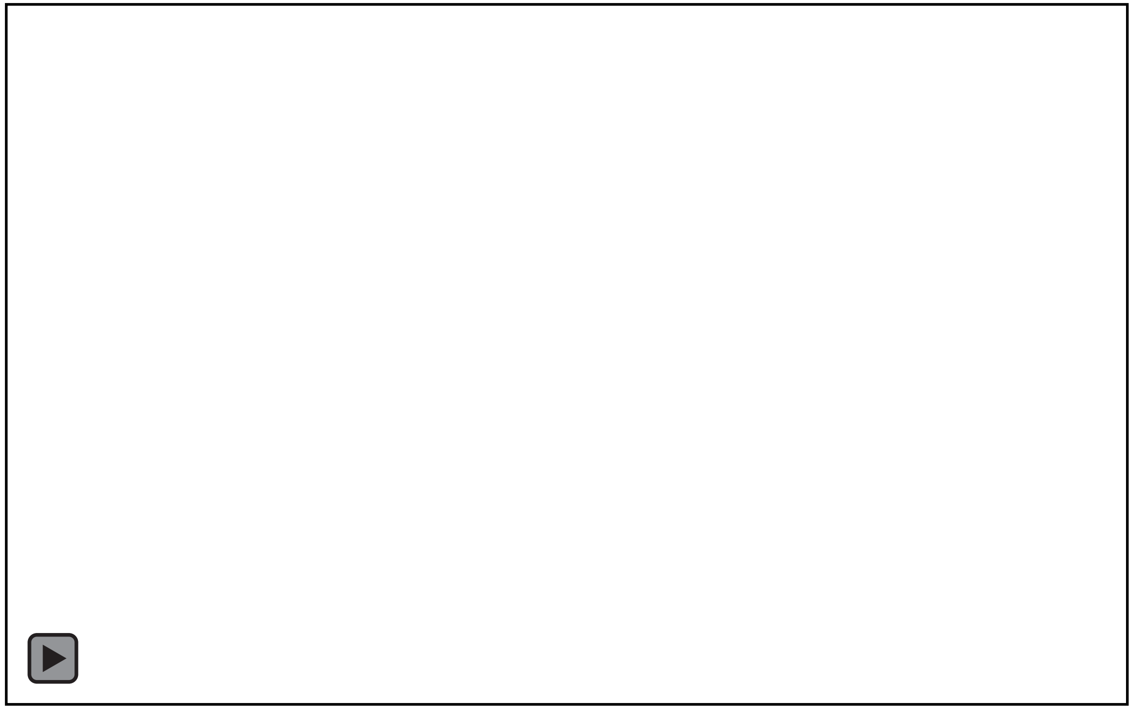
- The inclusion of a compact bore with a tapered entrance angle affords the distinct benefit of enhancing power transmission without the need for supplementary energy to compensate for losses. This judicious optimization leads to a reduction in the magnitude of applied stresses, as it necessitates a lowered upstream pressure to attain the desired projectile velocity.

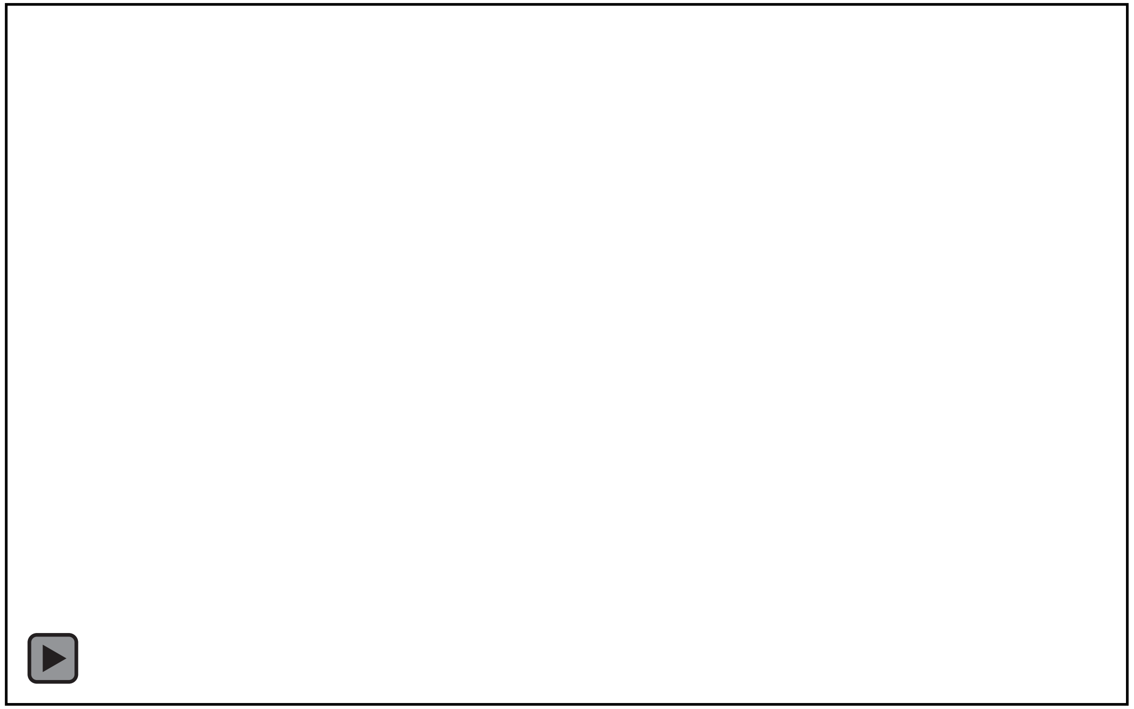


FLIGHT RANGE PRESSURE

The enhanced sabot design facilitated a deliberate reduction of flight range pressure.

This reduction played a significant role in mitigating projectile ablation during flight.





SUMMARY

- The research has successfully demonstrated the feasibility of launching shaped projectiles.
- The most challenging projectile shape to launch was the CFRP disk. Initial issues arose due to projectile compression within the sabot pocket, prompting subsequent modifications aimed at reducing applied stresses.
- The enhanced sabot design facilitated a deliberate reduction of flight range pressure by 40%. This reduction played a significant role in mitigating projectile ablation during flight.

THANK YOU