

# *Design of a High Sampling-Rate Force Measurement System for a Hypersonic Wind Tunnel*

## **Team Members:**

Asa Guldbrandsen

Maxwell Gjevre

Alexander Lee

Luke Herter

Miles Owens

## **Customer:**

Research group at the Laboratory for Laser Energetics

## **Project Overview**

The Hyper group was tasked with designing, building, and testing a prototype hypersonic wind tunnel stinger. The device was designed to resolve a shock, delivered by a pulsed laser, on a test specimen in hypersonic flow. This project aims to better understand the effect of laser shock on bodies in hypersonic flow.



## Problem Statement

A group at the University of Rochester's Laboratory for Laser Energetics (LLE) studies the effect of pulsed lasers in hypersonic flow. Currently, they do not have a direct method of measuring these effects.

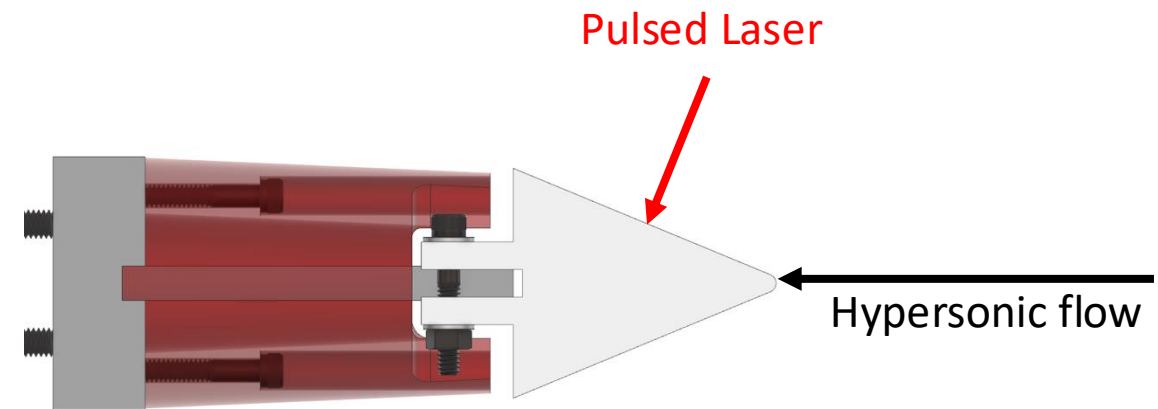
Due to the instantaneous nature of pulsed laser events, commercially available load cells do not have the necessary sampling rate or resolution to measure these effects.

This project aims to design, manufacture, and test a prototype device capable of resolving pulsed laser shock in hypersonic flow which would assist the LLE group in furthering knowledge in the field.

The findings of this project could be used in the field of defense, high speed travel, or astronomy to better understand the effects of pulsed lasers in different conditions.



CUBRC



# Deliverables, Requirements and Specifications

## Deliverables:

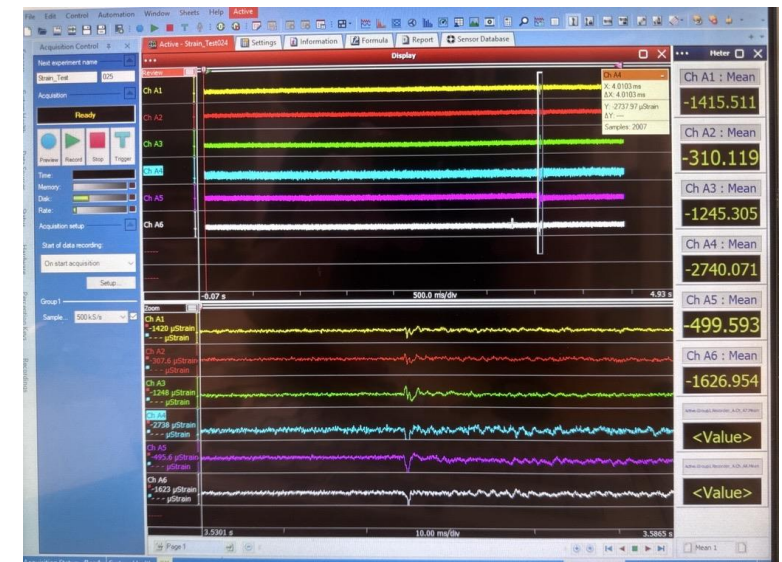
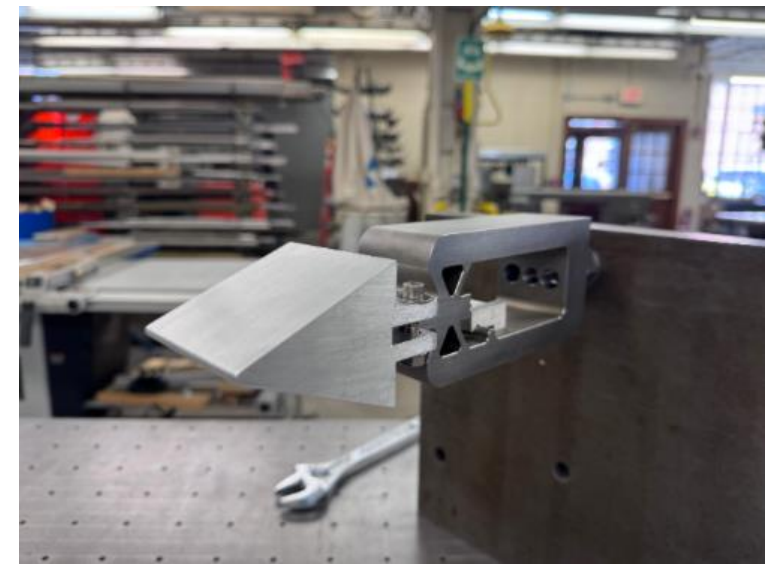
- Prototype device designed to measure forces applied by a laser in at least one degree of freedom
- Simulation data relevant to the prototype design
- Technical report outlining the design and progression between iterations

## Requirements:

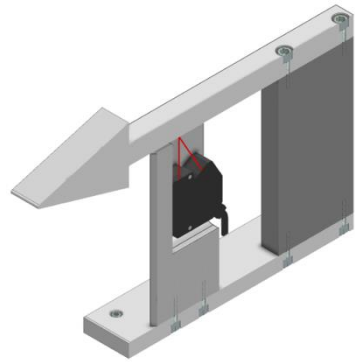
- Must not mechanically fail when subjected to hypersonic flow
- Must be compatible with diagnostics known to the LLE group
- Must be able to resolve impulse load applied via pulsed laser

## Specifications:

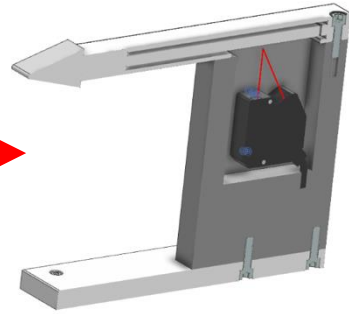
- Minimum Sampling Rate: 300 ks/s
- Minimum Data Collection Axis: 1
- Minimum Resolvable Load: 0.2 lb<sub>f</sub>
- Must not Permanently Deform Under Axial Load of: 500 lb<sub>f</sub>



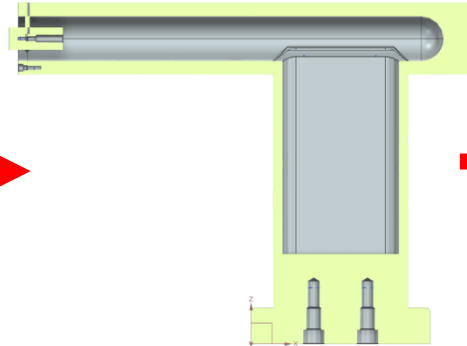
# Current Project Status – Concept Selection



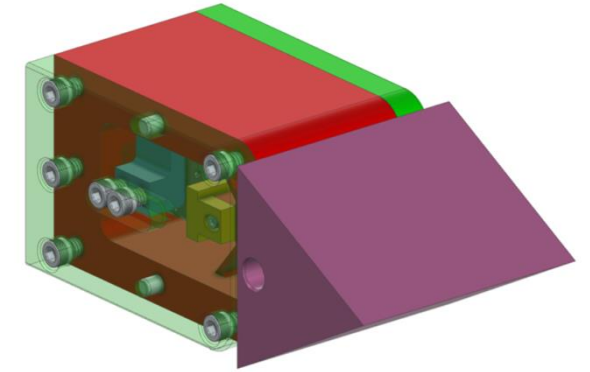
Displacement sensor



Enclosed displacement sensor

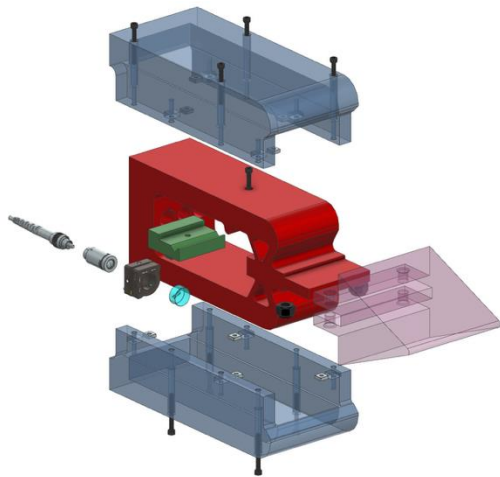


Enclosed tube

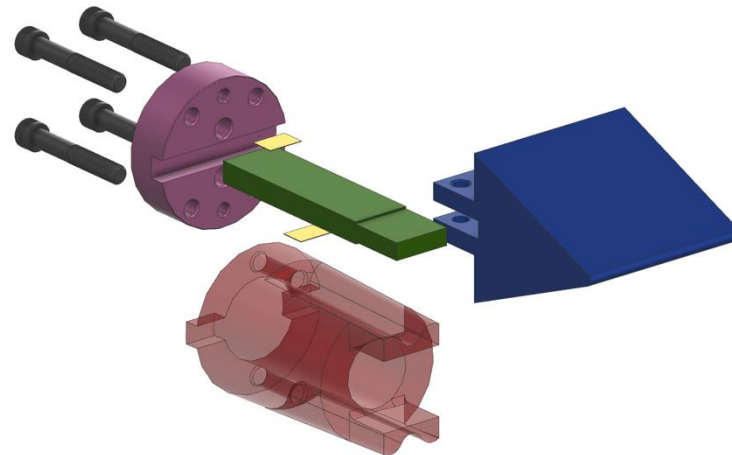


Selected concept

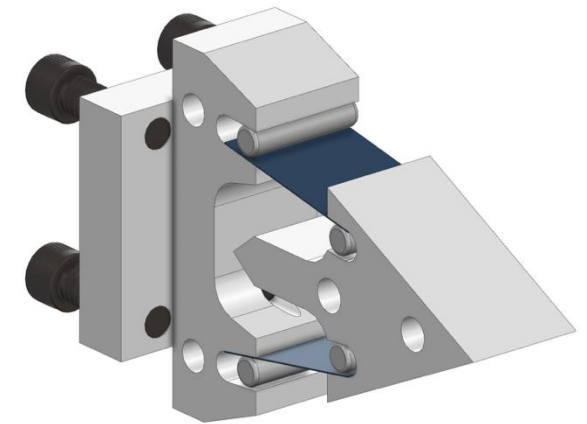
Iteration 1



Iteration 2



Iteration 3 (concept)



# Current Project Status – Data Acquisition

# Data Acquisition

## Strain Gauges

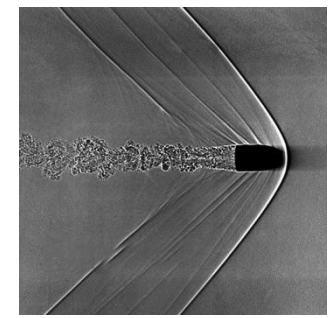
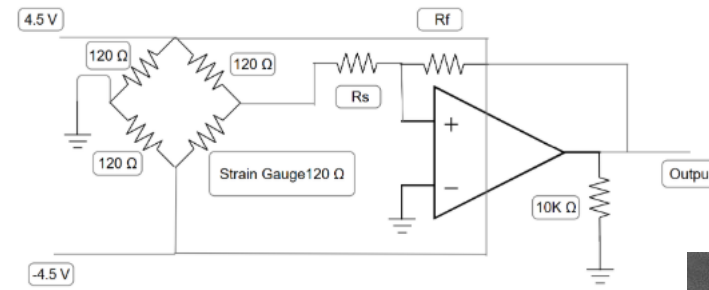
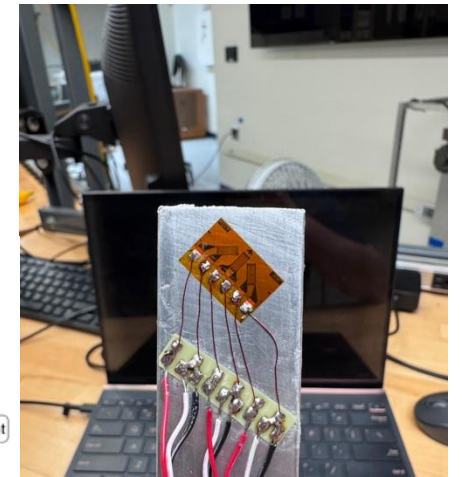
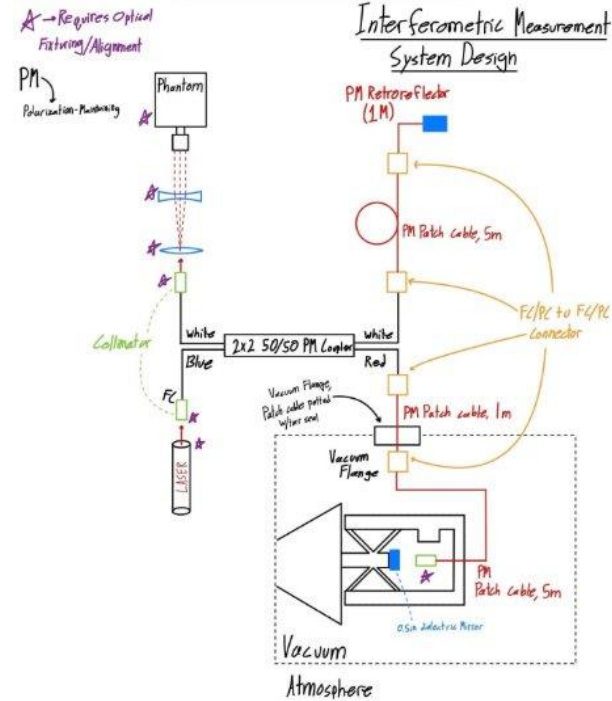
- Strain gauge locations were determined from simulations and were applied on the largest predicted strain location.
- For later iterations, multiple strain gauges were used on the cantilever step
  - Used to monitor how strain differed with the greater the distance from the applied force.
- DAQ system/Oscilloscope

## Interferometry

- A custom Michelson interferometer was designed strictly for the first iteration
- The system uses a HeNe laser on a tip tilt stage, which was shot into a collimator on a 3D stage.
- Measured the angle of deflection of the X-mechanism by examining fringes.

## Schlieren Imaging

- Phantom Camera (TMX 7510)
- 750,000 frames per second
- Used to measure the displacement of the wedge



# Current Project Status - Simulations

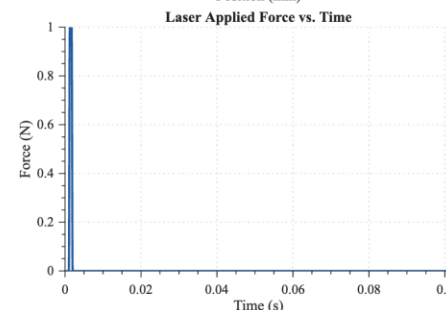
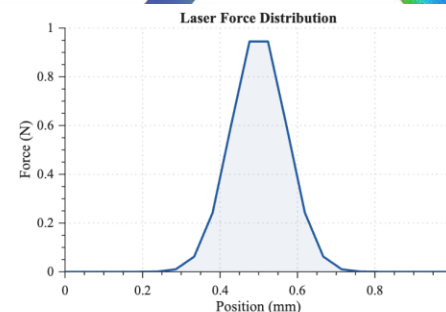
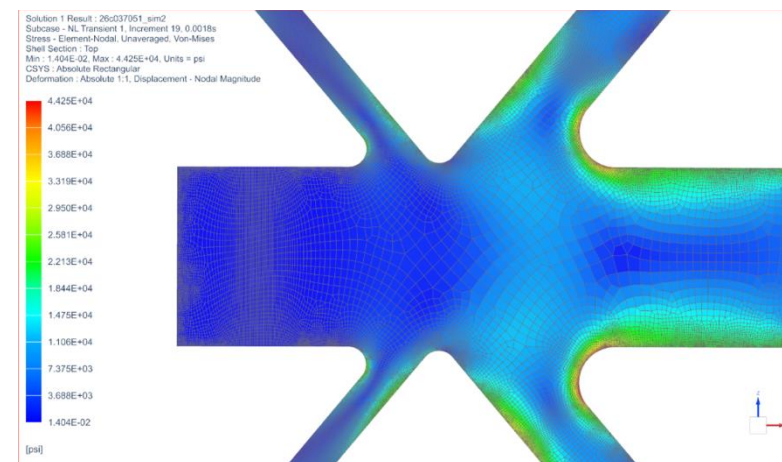
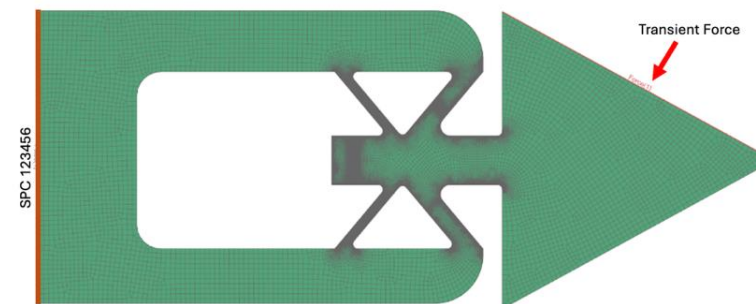
## Simulation Parameters:

- 2" shell model, 0.05" CQUAD4 mesh
- 0.025" sizing enforced on webs
- NASTRAN SOL129, time step of 1  $\mu$ s
- Transient loading (see plots), scale factor 1000 lb<sub>f</sub>

Iterated through different front/rear web thicknesses, inner web angle to reach a suitable geometry.

## Simulation results of final geometry:

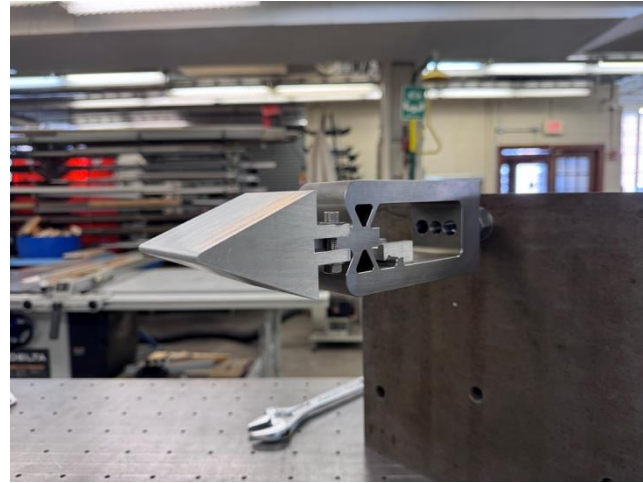
- Max. Von Mises Stress: 44.25 ksi
- Tip Displacement: 0.0187"
- Max. Mirror Tilt: 0.09°



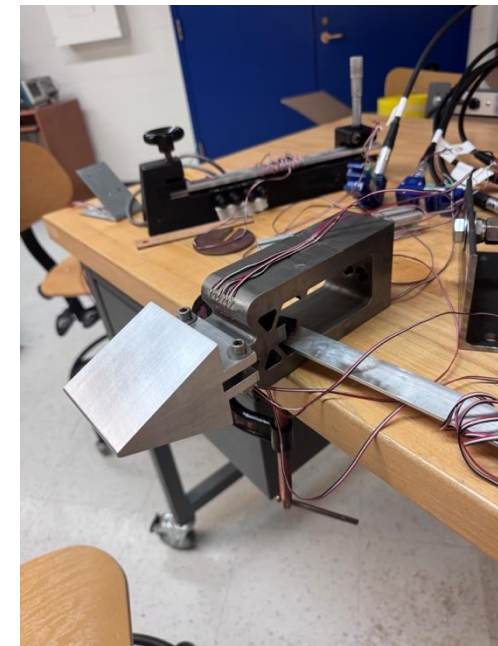
# Current Project Status - Manufacturing



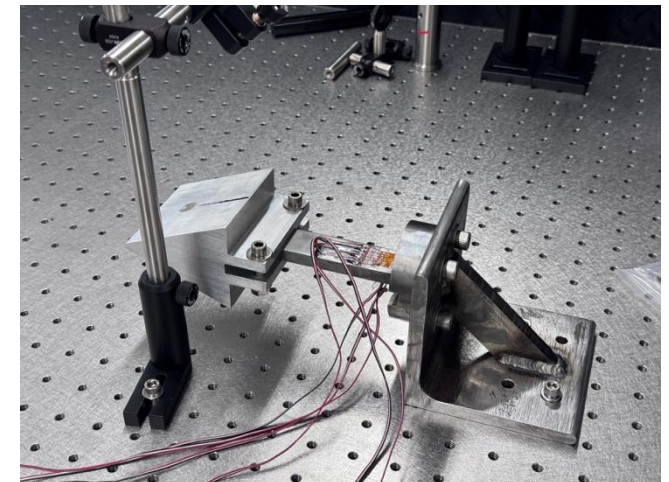
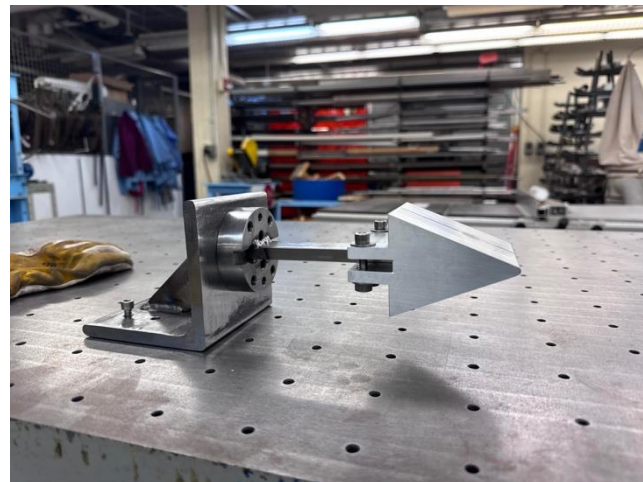
During manufacture



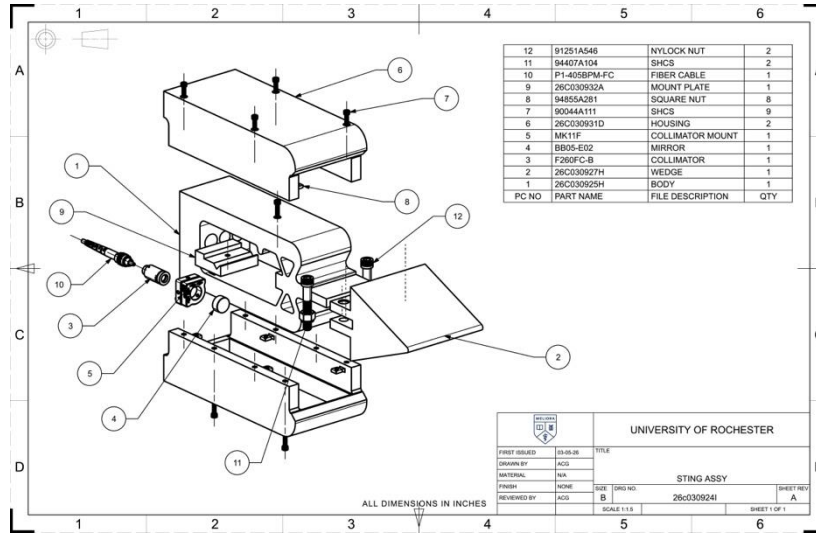
Completed prototype



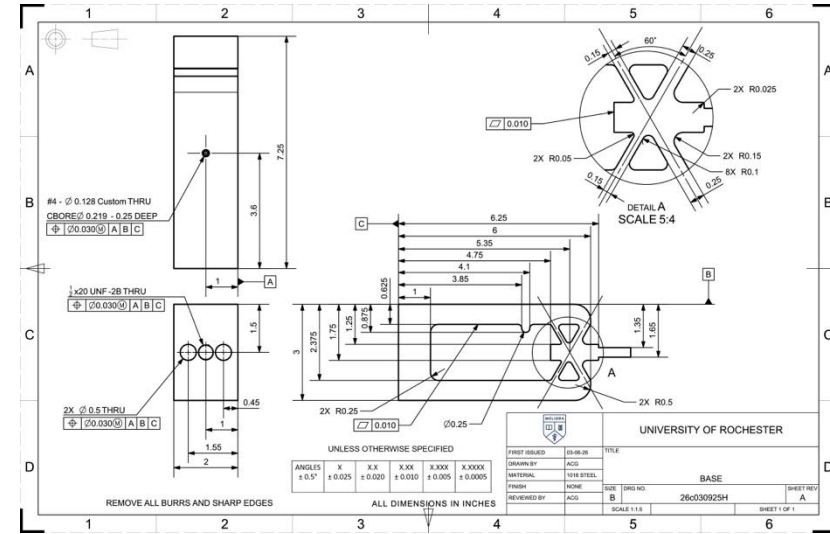
Strain gauges attached



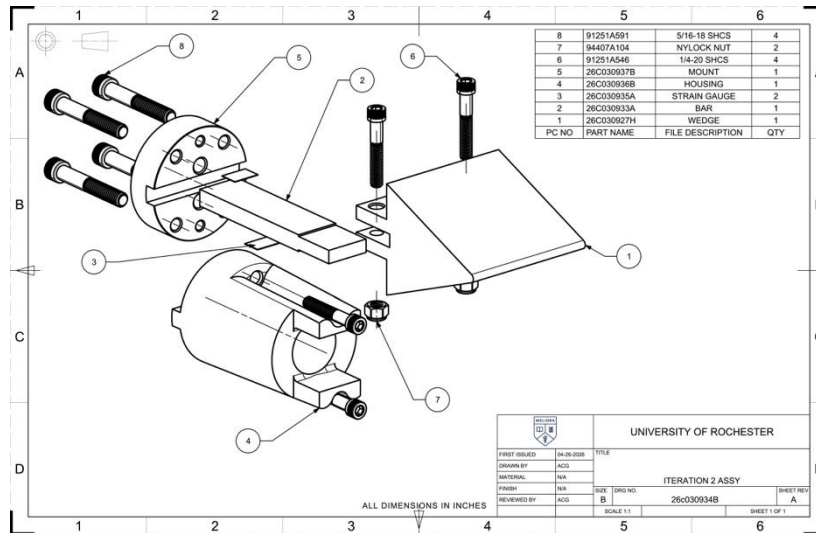
# Current Project Status - Drawings



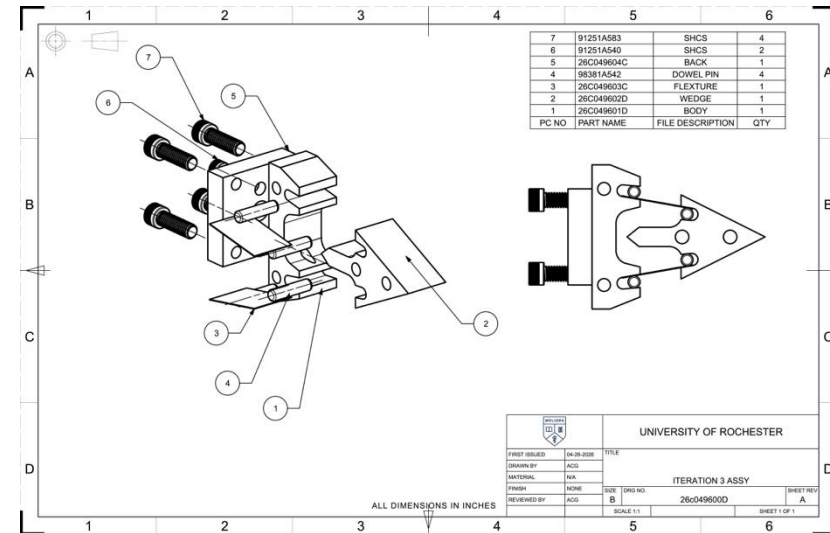
Iteration 1 assembly drawing



Iteration 1 EDM part drawing



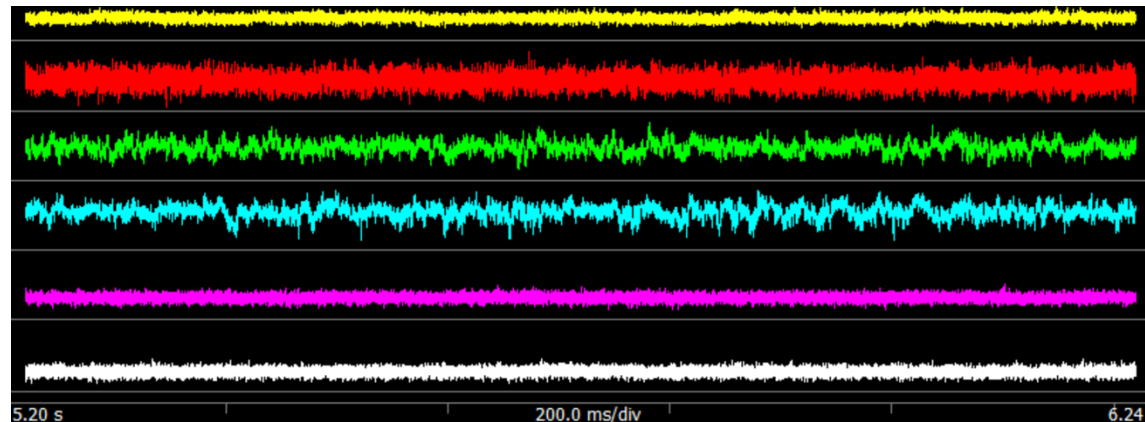
Iteration 2 assembly drawing



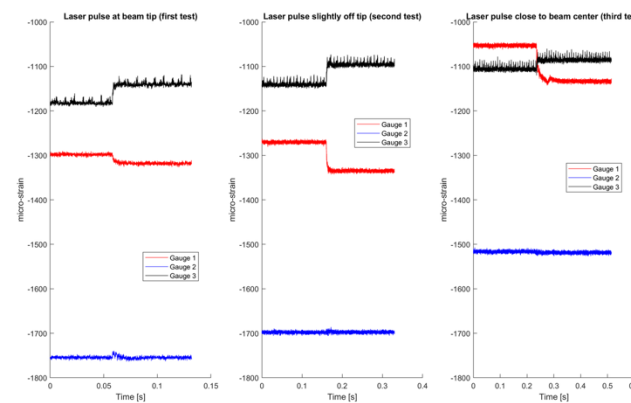
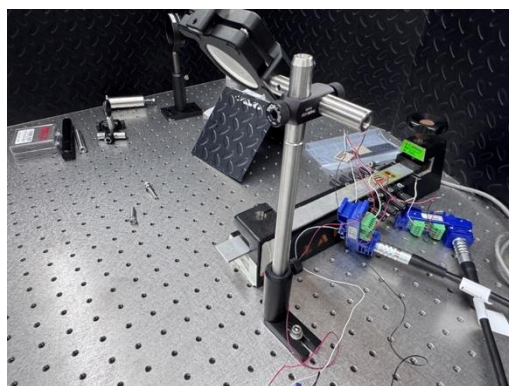
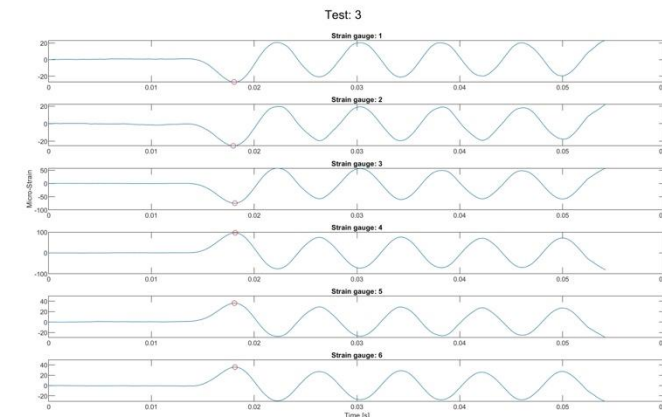
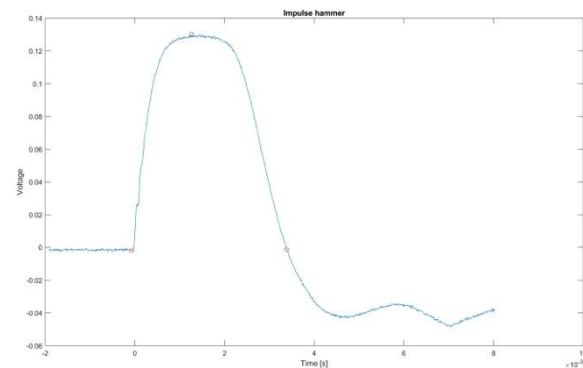
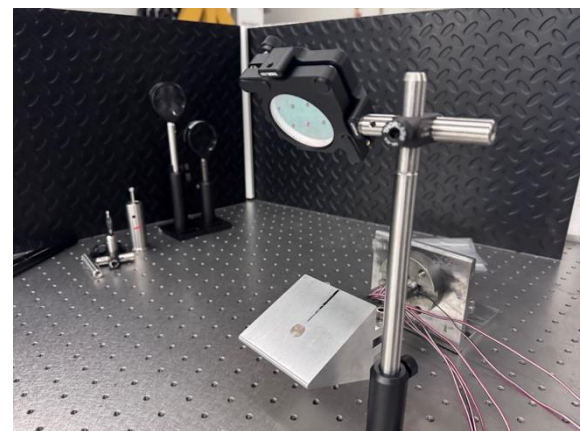
Iteration 3 concept assembly drawing



# Current Project Status - Testing



No response from pulsed laser



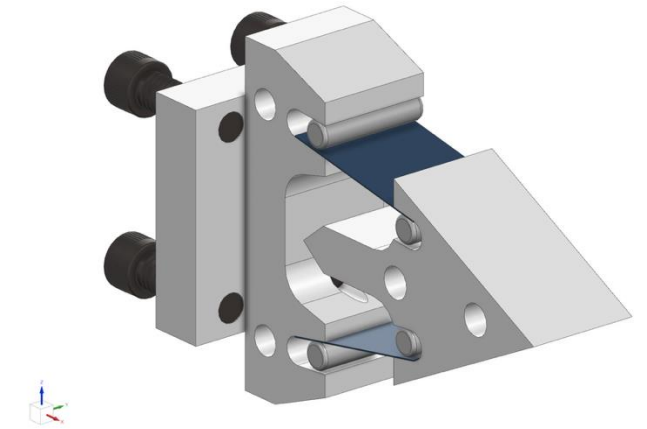
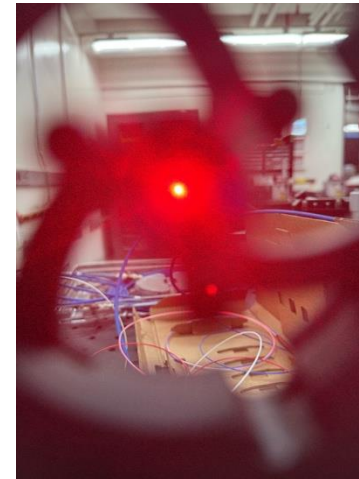
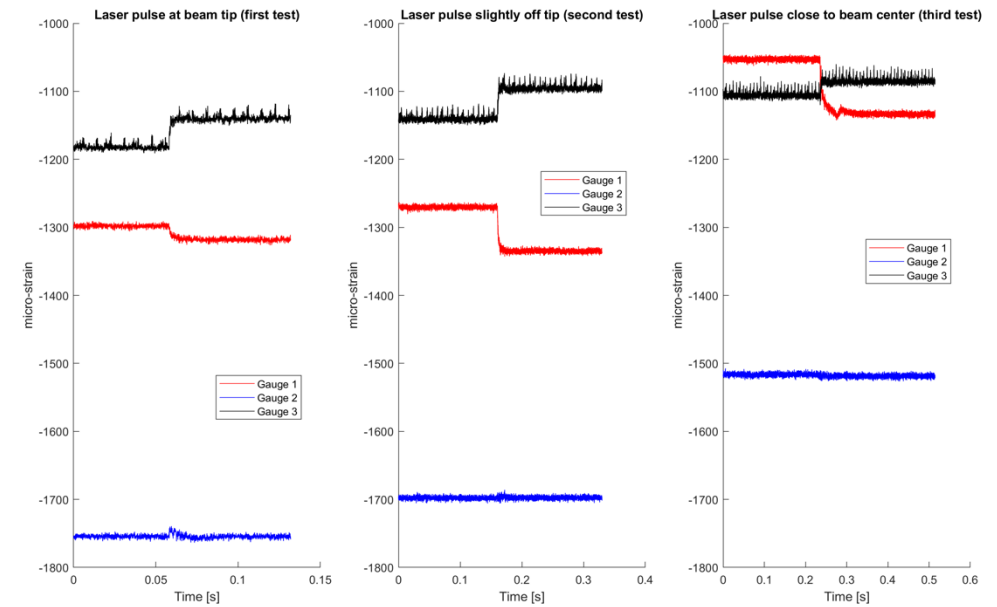
## Conclusions/Future Work

Based on this project, our group has concluded that significantly more work is required to design an independent system capable of detecting and measuring force applied by pulsed lasers in hypersonic flow.

Preliminary testing shows odd behavior/readings from strain gauges mounted to a cantilever beam. Further characterization of strain gauge's ability to resolve pulsed lasers is necessary.

Interferometric design is semi-complete limitations could include sensitivity to vibration/pressure changes. It is a promising solution that requires more time to tune, test, and postprocess.

There is room for future iterations given the current requirements. A potential design could make use of a spring steel flexure that is significantly more flexible than previous design iterations, but there is a fine balance between the stiffness of the structure and the structures resistance to movement under hypersonic flow.



The Hyper group would like to thank Chris Muir, Edward Herger, Valerie Fleischauer, Benjamin Martin, Vincent Tagliamonti, Jerry Chung, Riley Flaum, Chris Pratt, Jim Alkins, Bill Mildenberger, Samantha Kriegsman, and Hottinger Brüel & Kjær.



# Individual Contributions – Asa Guldbrandsen

## Simulation

- Simulated wedge clamping to ensure correct thickness of web

## Design

- Worked on V.1 design, drafting for lots of the parts
- Assisted with design of V.2

## Manufacturing

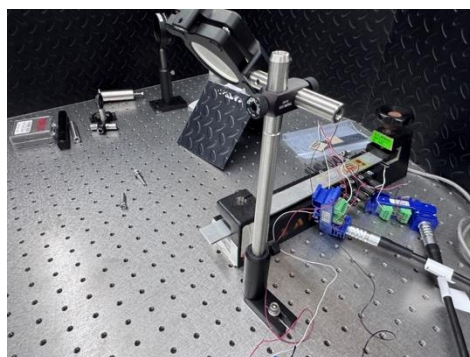
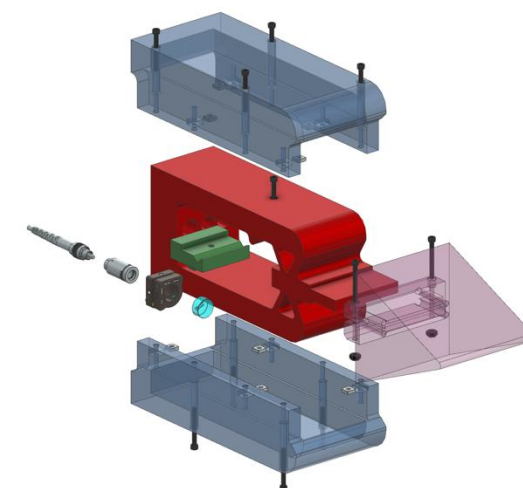
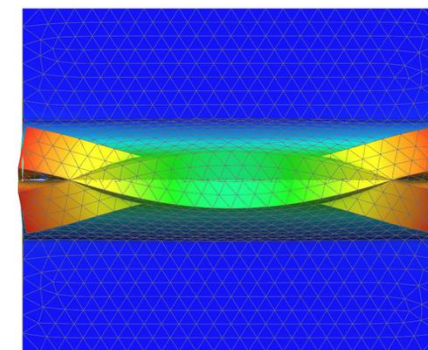
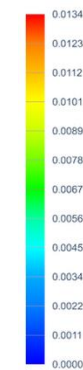
- Helped Bill with the wedge, helped with V.2 welding, and made the support brackets
- Strain gauge application

## Testing

- Performed laser testing on cantilever beam
- MATLAB analysis of calibration data



Solution 1 Result : 26c030927\_sim2  
 Subcase - Statics 1, Static Step 1  
 Displacement - Nodal Magnitude  
 Min : 0.0000, Max : 0.0134, Units = in  
 CSYS : Absolute Rectangular  
 Deformation - 10% Model, Displacement - Nodal Magnitude



4/28/2026

Projected Hours	Asa	Alex	Luke	Max	Miles		
Hours Last Week	10	12	10	10	16	Total	Cost
Total Hours	144	103	111	100.2	137.5	595.7	\$59,570.00

# Individual Contributions – Alexander Lee

## Simulation

- Simulated response to transient loading for all iterations

## Design

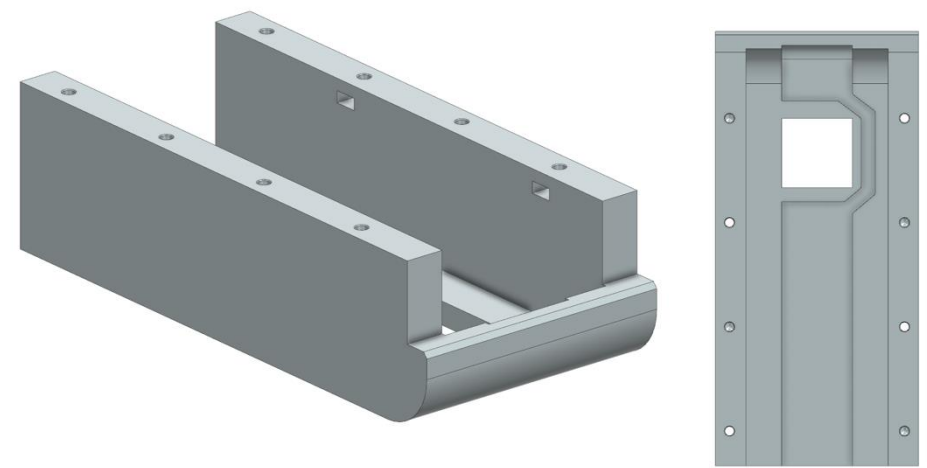
- Using simulation results, refined design of V.1, V.2, V.3 mechanisms

## Manufacturing

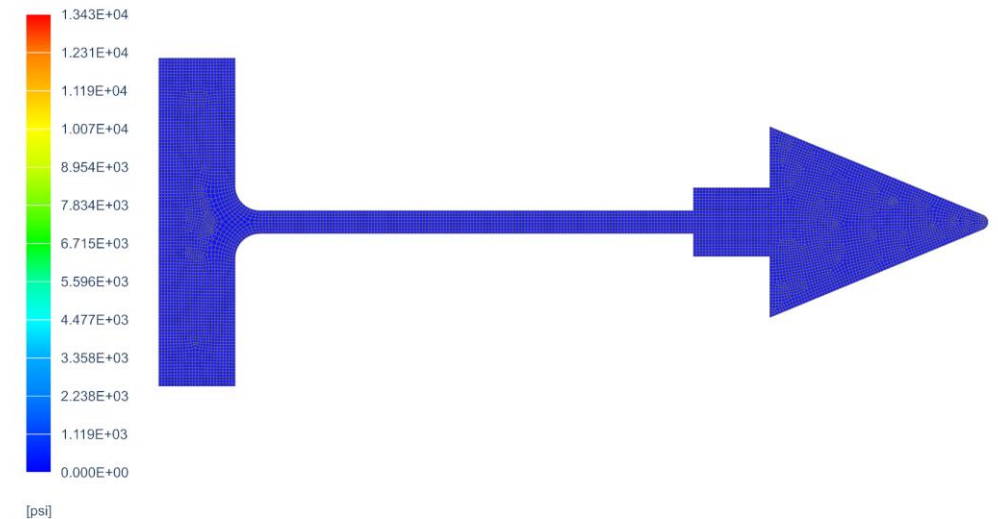
- Assisted with strain gauges, oversaw printing

## Testing

- Collected calibration and laser data for V.1 and V.2



Solution 1 Result : 26037055A\_sim1  
 Subcase - NL Transient 1, Increment 1, 0s  
 Stress - Element-Nodal, Unaveraged, Von-Mises  
 Shell Section : Top  
 Min : 0, Max : 0, Units = psi  
 CSYS : Absolute Rectangular  
 Deformation : Absolute 1:1, Displacement - Nodal Magnitude  
 Animation Frame 1 of 346



4/28/2026

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Hours Last Week	10	12	10	10	16		
<b>Total Hours</b>	144	103	111	100.2	137.5	595.7	\$59,570.00



# Individual Contributions – Luke Herter

## Simulation

- Assisted when needed

## Design

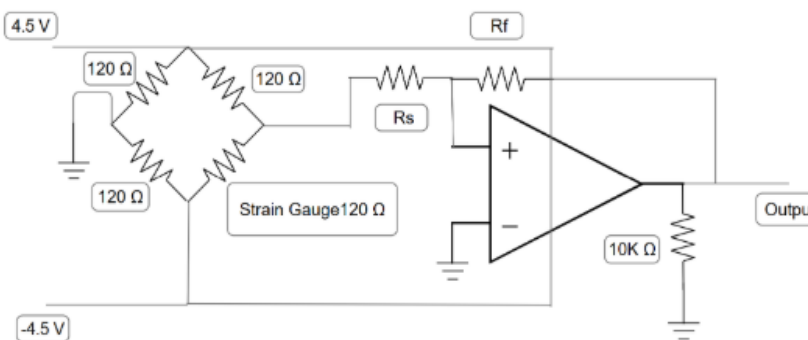
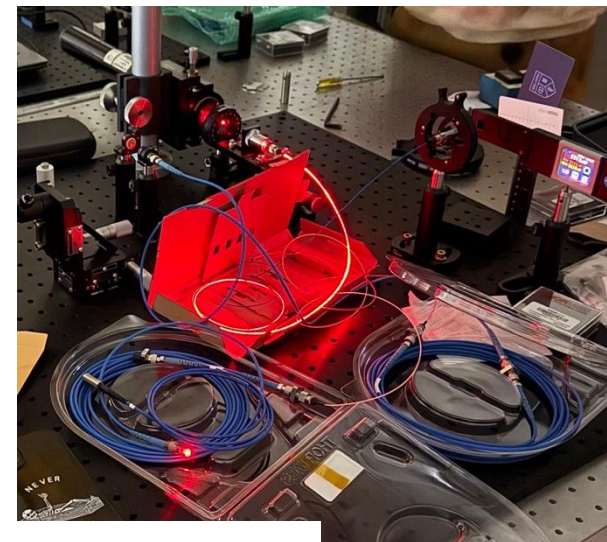
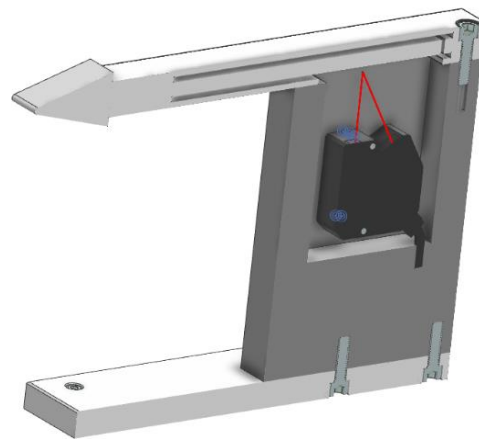
- Designed vacuum chamber concept
- Interferometry system
- Designed mount for iteration two

## Manufacturing

- Assisted with wedge manufacturing
- Manufactured mount for iteration three

## Testing

- Created amplifier for testing,
- Force hammer and laser testing at LLE



4/28/2020

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# Individual Contributions – Max Gjevre

## Simulation

- Initial modal analyses of first iteration
- Modal analysis of 12" aluminum beam

## Design

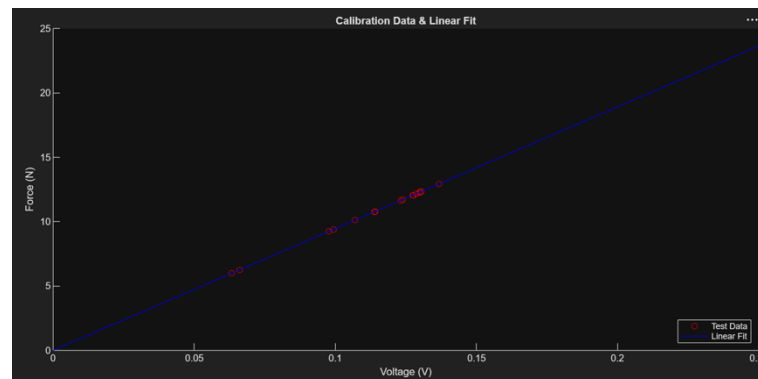
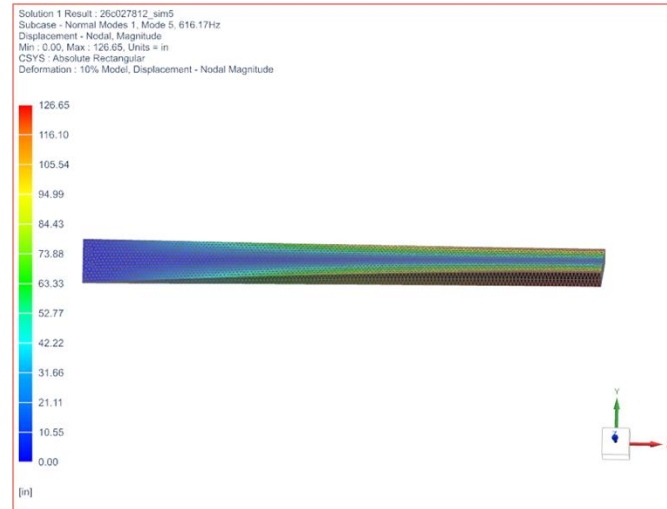
- Fiber Michelson Interferometer
- Bolt torque and fatigue calculations

## Manufacturing

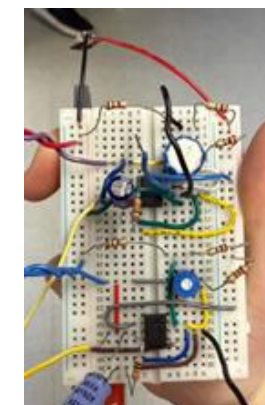
- Interferometry calibrating
- Assisted where needed

## Testing

- Strain to Force MATLAB script for HBK DAQ
- Created Op-Amps for Oscilloscope



Run #	Applied Load (N)	Gauge 1 ( $\mu\epsilon$ )	Gauge 2 ( $\mu\epsilon$ )
13	12.288	5.0274	321.17



4/28/2026

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<b>Total Hours</b>	144	103	111	100.2	137.5	595.7	\$59,570.00



# Individual Contributions – Miles Owens

## Simulation

- Modal analysis of original cantilever beam

## Design

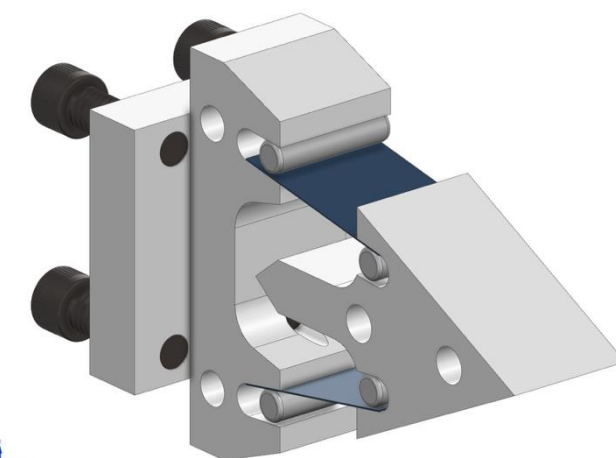
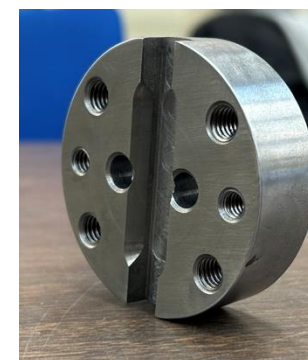
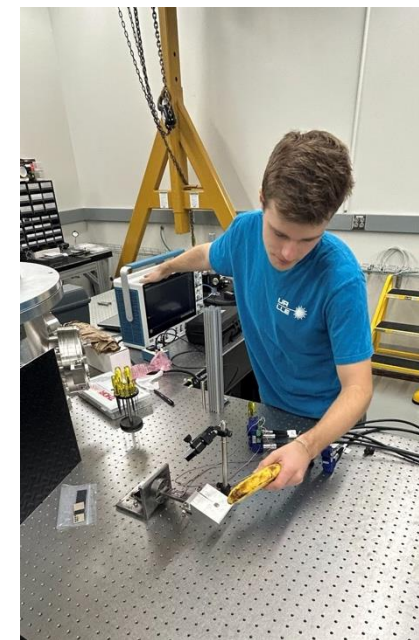
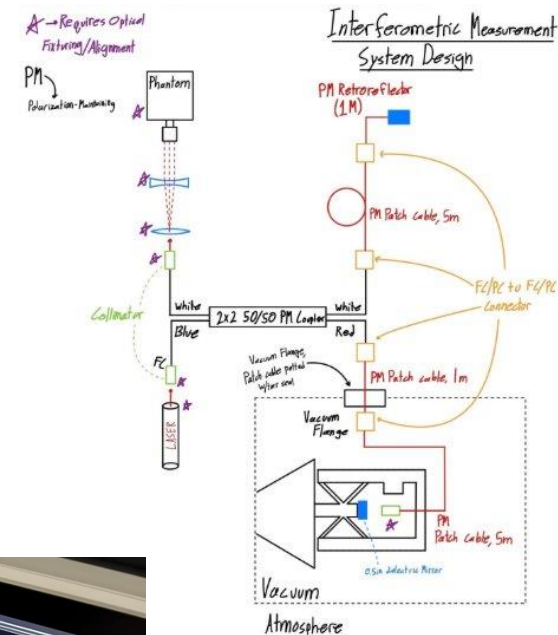
- Identified initial requirements and specifications
- Designed iteration 3
- Fiber-optic interferometer

## Manufacturing

- Interferometric system integration, interferometer testing.
- Manufactured multiple components for iterations 1 and 2

## Testing

- Force Hammer setup and usage
- Oscilloscope tuning.



4/28/2026

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