Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

WAVE Dynamics™ Final Presentation

12/04/2024
MAE-A-221

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Who Are We?

WAVE Dynamics™

Project Background

Problem Background

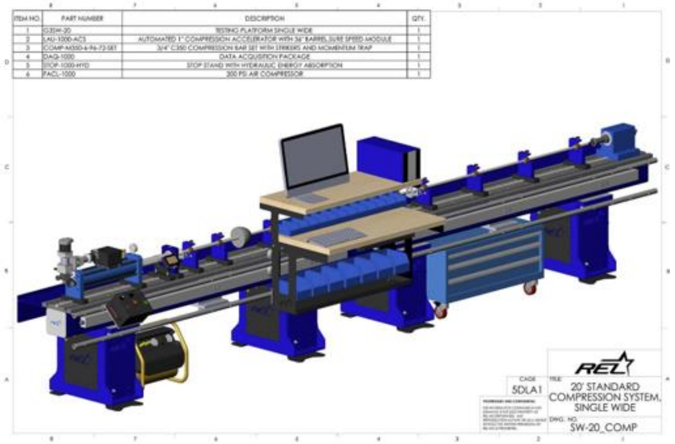


Fig. 8 Instron VHS 80/65

	SHPB	*Instron VHS*
Dimensions	52.55 x 240.358 x 72.08 in	65 x 56 x 132 in
Weight	Unknown	6393 lbs
Bar Sizes	1/8" - 3"	-
Max Speed	300 ft/sec	82 ft/s
Type of Loading	Dynamic	Quasi-static
Strain Rate Range	10^2/s - 10^4/s	< 10^3/s
Configuration	Horizontal	Vertical
Price	Unknown	~$50,000
Features		
Specimen Housing	Protective Shield	Clamp
Software	-	Advanced DAQ and Recording

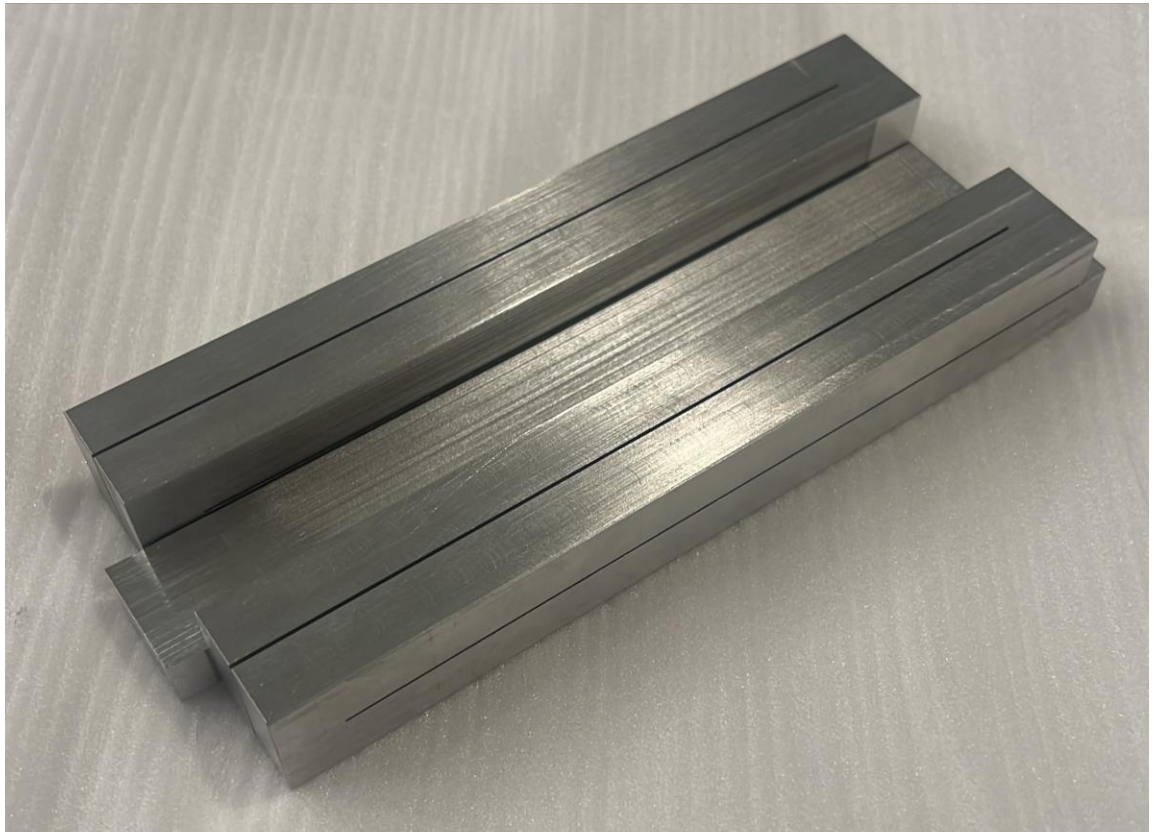
Large

Dynamic

Expensive

The Millipede Bar System

- 3 bar system
- Wave propagates through 180° bends to reach sample
- Reduces size and cost of traditional dynamic materials testing systems
  - Singular system prototype is $1,200
  - Fits within 6’x1’



Millipede Bars – Customer Needs

Newly Parameterized Needs	
The total cost for materials and fabrication to build the functional prototype must not exceed $1500 (limited by class budget).	Launcher must provide varying impact velocities in 1 m/s increments for the striker.
The total estimated cost to produce a functional bootstrap prototype (materials + labor) must not exceed $4000.	The launching mechanism must not translate or rotate on the base plate.
The prototype's parts can be made in the UF MAE Shop or outsourced to a Manufacturing On Demand company.	The striker must impact the incident millipede bar along its length axis.
System must last 5+ years with regular maintenance. Maintenance costs over 5 years cannot exceed the cost to purchase new.	The striker must generate a rectangular pulse in each of the bars with a rise time of less than 10% of the total pulse duration.
The system takes no more than 5 minutes to reset between tests. It will conduct 10 tests per day.	Generated pulses must be measured using 350-Ohm strain gages bonded on both the bars.
The prototype must have a finished, clean, and professional appearance with no free/unattached components and no visible wires.	Must measure strain rates in the regime from .1 Hz to 100 Hz.
A gap dimension of 0.2 mm is recommended, but it is not a hard upper limit.	Upon impact, both the incident and transmitted millipede bars must use appropriate features to slide smoothly on the base plate during their motion.
Impact surfaces should be flat and parallel with a bilateral tolerance of 0.12 mm.	Length to bar thickness ratio should be at least 30 to ensure pure axial motion of the bend junction on each millipede bar.
Cut surfaces should be flat and parallel with a bilateral tolerance of 0.12 mm.	Boundary conditions must extend to the rods attached to each bend to prevent their flexural deformation. Extension should be at least five times the length of the bend junction.
Critical surfaces should have a surface finish of 2 microns or less.	Must be safe to use by a technician with maximum training time of 15 minutes
The length to thickness ratio of each segment of the square cross-sectional bar must not exceed 100.	Must be easy to use by a technician with maximum training time of 15 minutes
The total length of the entire base plate including the three bars, and the launching mechanism must not exceed a 4' x 6' area	Must interface intuitively with the data acquisition system in UF's Laboratory for Dynamic Response of Advanced Materials with connection time less than 1 minute.
Launching mechanism must propel the millipede striker bar up to a velocity of 10 m/s.	

Millipede Bars – Key Customer Needs

Updated Parameterized Needs	
The total cost for materials and fabrication to build the functional prototype **must not exceed $1500** (limited by class budget).	Launching mechanism must propel the millipede striker bar **up to a velocity of 10 m/s. This may be relaxed per customer feedback.**
The striker must impact the incident millipede bar **along its length axis.**	The striker must impact the incident millipede bar **along its length axis.**
Length to bar thickness ratio **(T*) should be at least 30** to ensure pure axial motion of the bend junction on each millipede bar.	Must measure strain rates in the regime from **.1 Hz to 100 Hz.**
The total length of the entire base plate including the three bars, and the launching mechanism **must not exceed a 4' x 6' area**	Boundary conditions must extend to the rods attached to each bend to **prevent their flexural deformation**. Extension should be at least **five times the length** of the bend junction.

Key Proof of Concept: Wave propagation through 180° bend junction

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Final Design

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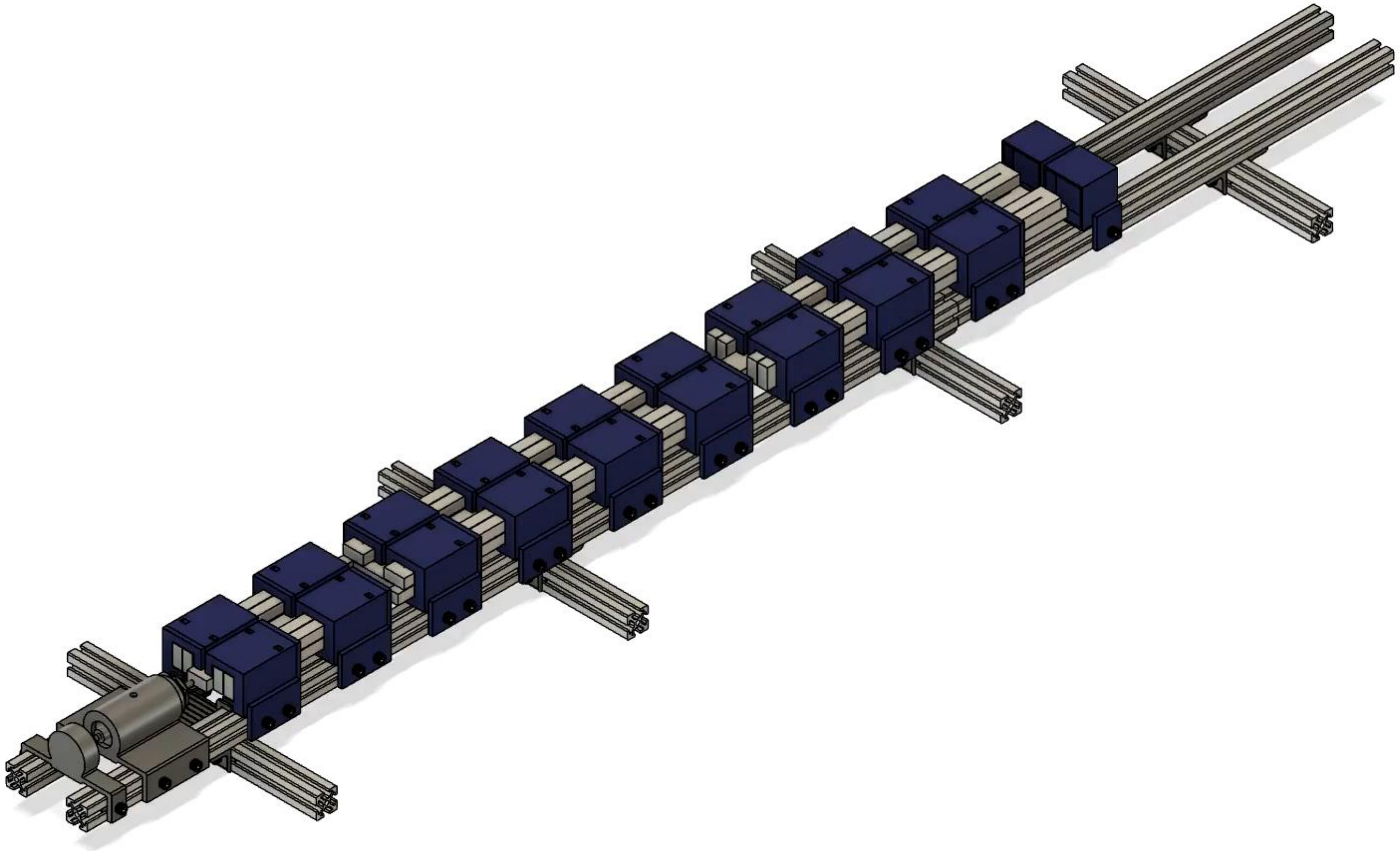
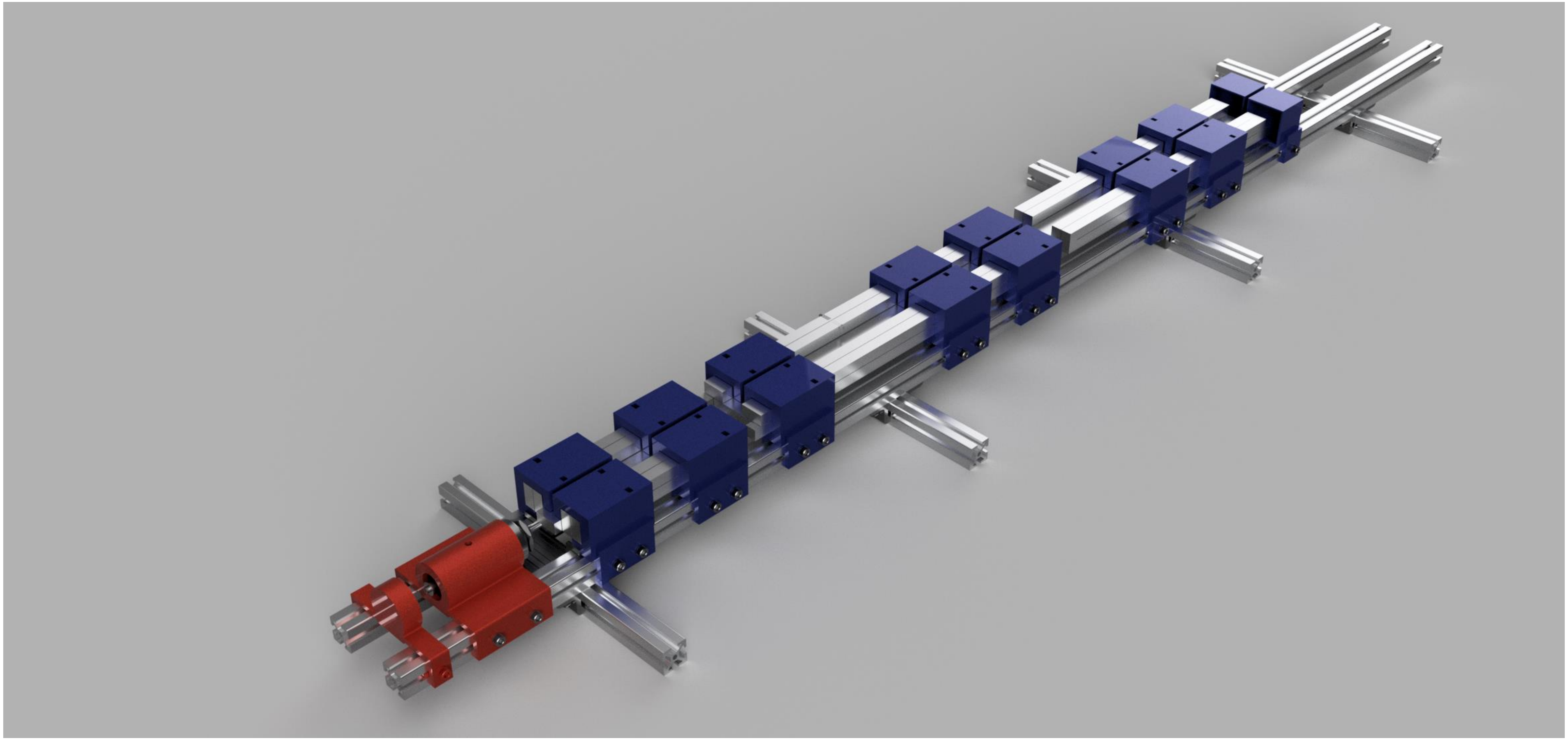
Overview of Design- Animation

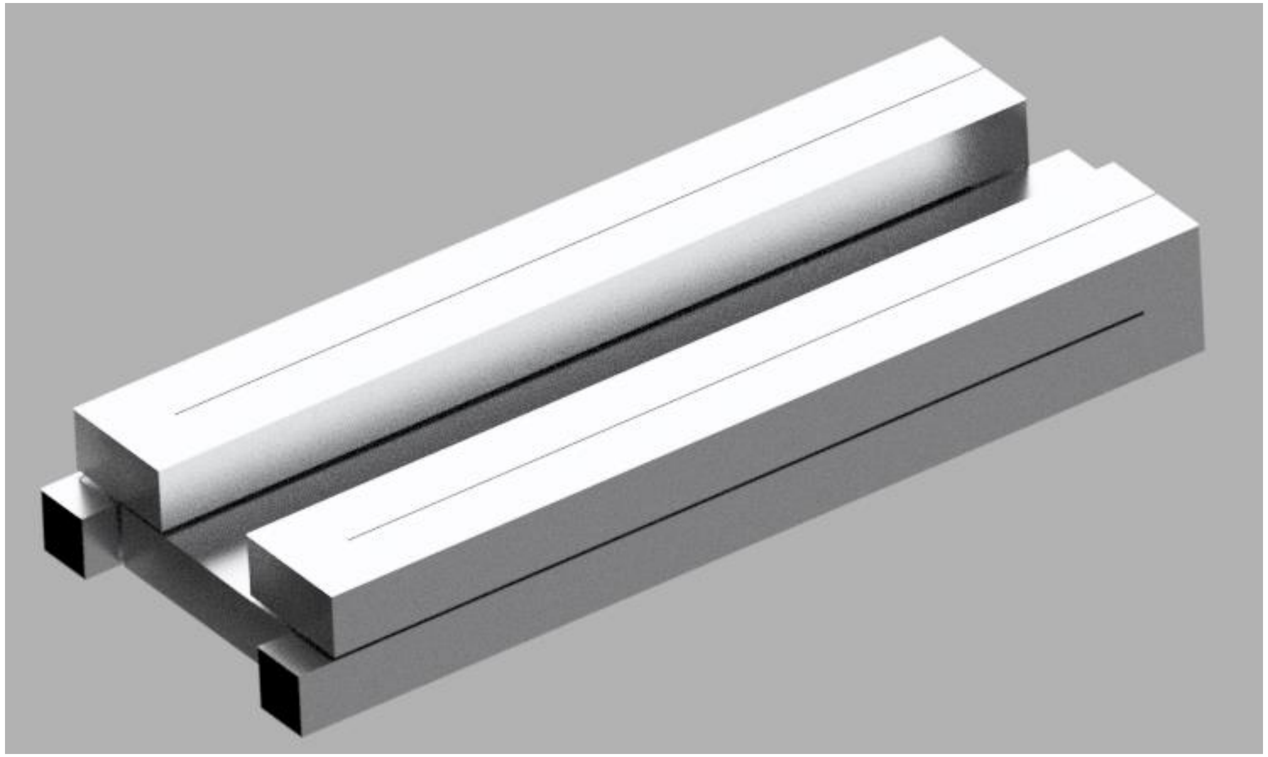


Overview of Design- 180° Bend Junction



Millipede Bars – PDR Review

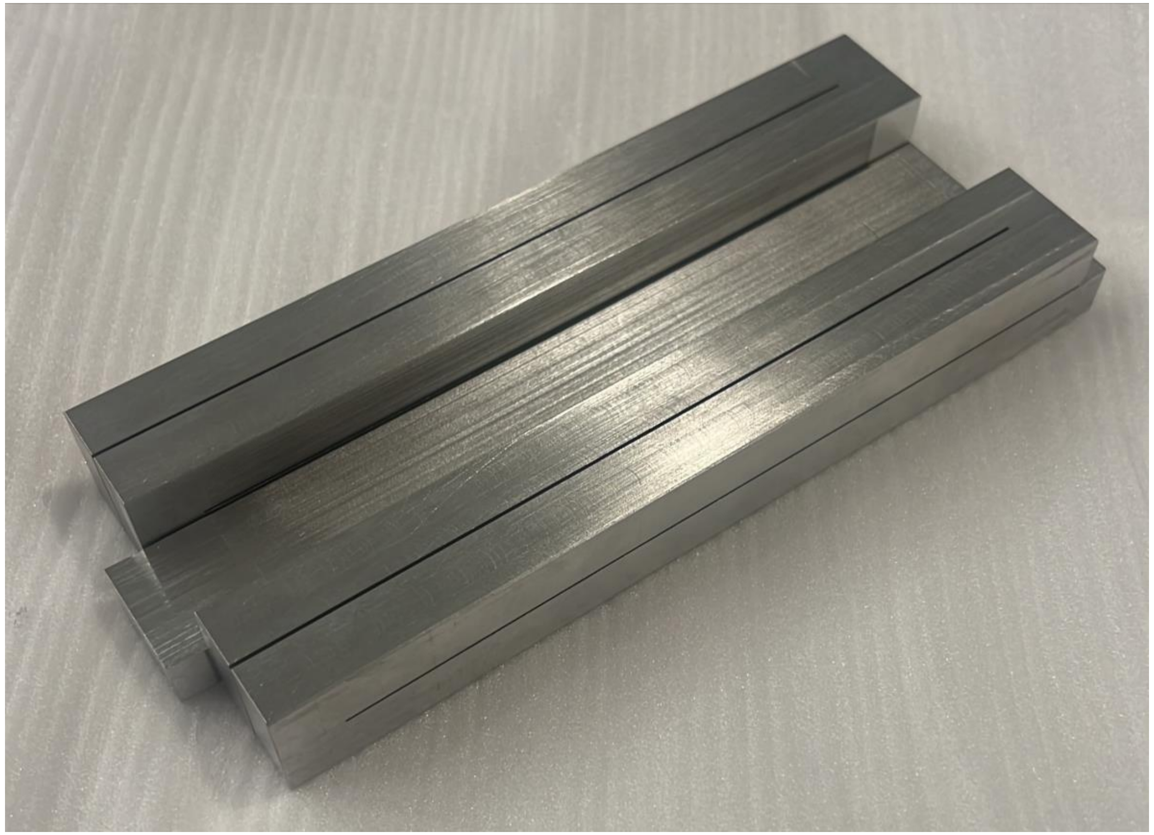
- Aluminum 6061-T6
- Used geometry of initial proposed design by Dr. Subhash but scaled by 3.6x to increase manufacturability
- Used manufacturing on-demand company Xometry



Model of striker bar

Millipede Bars – Final Artifact

- Had to loosen tolerance restrictions for completion by Xometry
- Completed bars were received 11/25
- Deformation noted in incident and transmission bar



Fabricated striker bar

Millipede Bars- Calculations

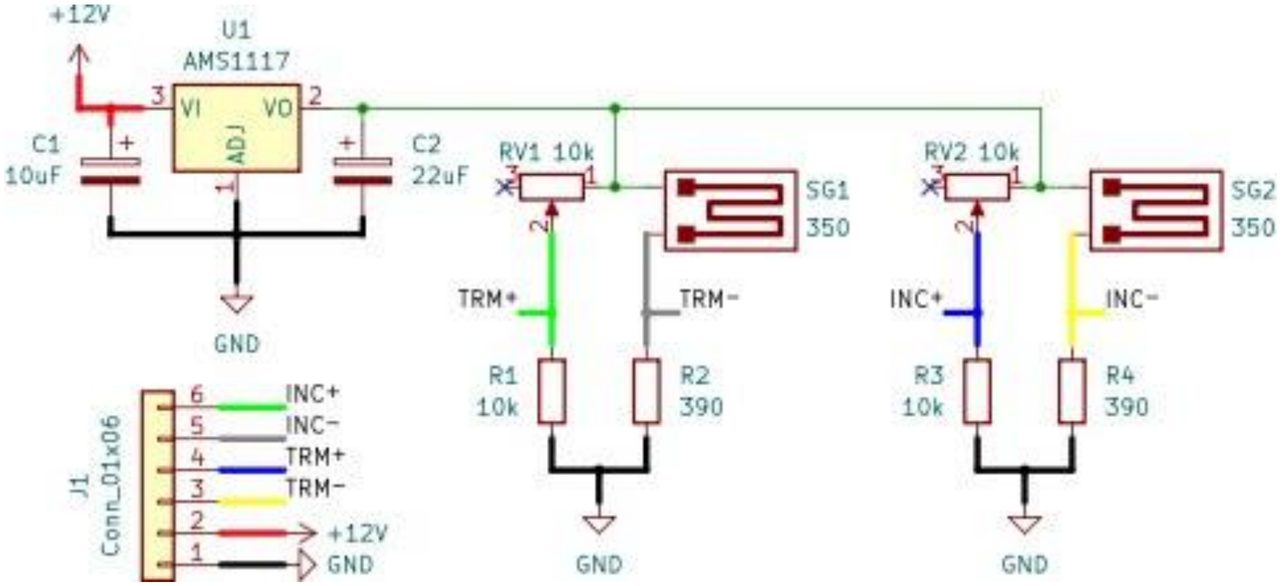
$$T^* = \frac{T_p}{T_{ch}} = \frac{cT_p}{l} = \frac{c}{l}\frac{2L_s}{c} = \frac{2L_s}{l} = \frac{2 \times 0.72\ (m)}{0.012\ (m)} = 120$$

Quantity	Symbol	Value	Unit
Elastic Modulus	E		
Density	ρ		
Wave Velocity	c	5,052	m/s
Single Segment Striker Bar Length	-	0.180	m
Number of Segments	-	4	-
“Unfolded” Striker Bar Length		0.720	m
Pulse Time		0.285	ms
Characteristic Time		0.00238	ms
Bend Time Ratio		**120**	**-**

Benchmark: Must be greater than 30

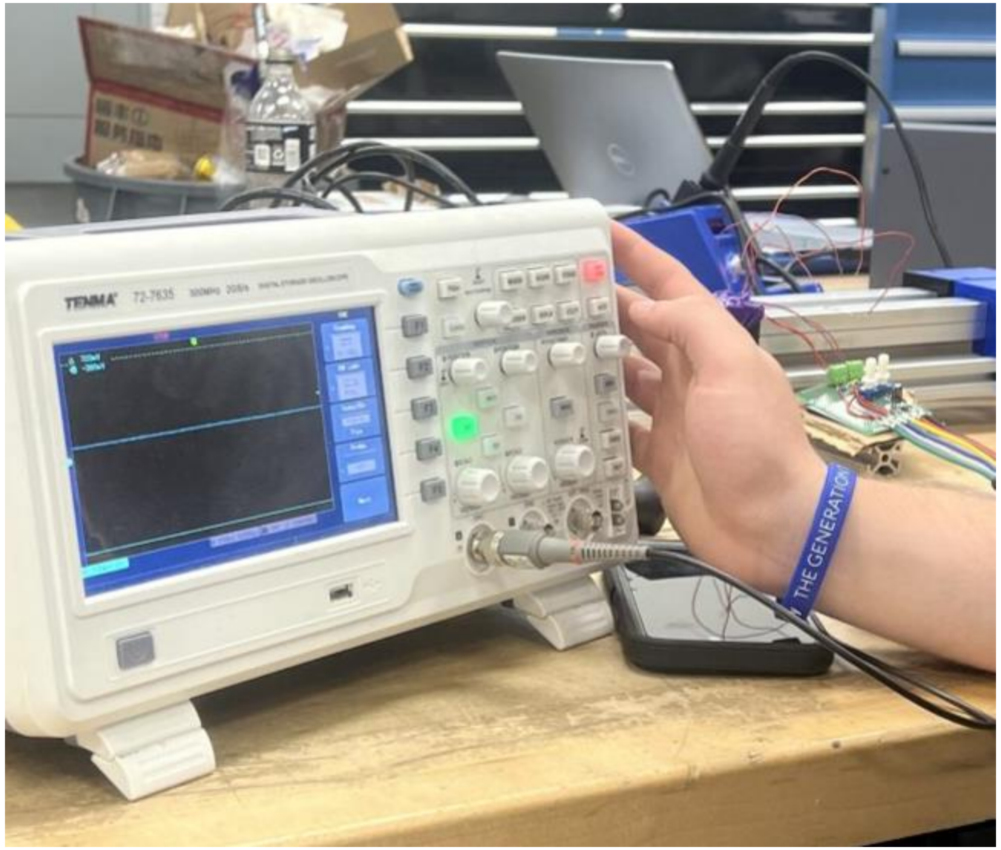
Mechanism for Measuring Strain

- Quarter Wheatstone Bridge used for strain gauge measurement.
- Strain gauge nominal resistance: 350 Ω.
- Two identical bridges: One measures incident bar, and the other measures transmitted bar.
  - Potentiometer allows bridge balancing through adjustment.
- Linear regulator chosen over switched-mode supply to minimize noise in measurements.



Millipede Bars- 180 Degree Bend Junction Proof of Concept

- 2 Gauges Instrumented to Transmission Bar
  - Wired in quarter-bridge configuration
  - Connected to oscilloscope
  - No signal after ~8 hours of testing
- Signal Amplification Attempts
  - Increased force input with a mallet
  - Wired an amplifier to the circuit

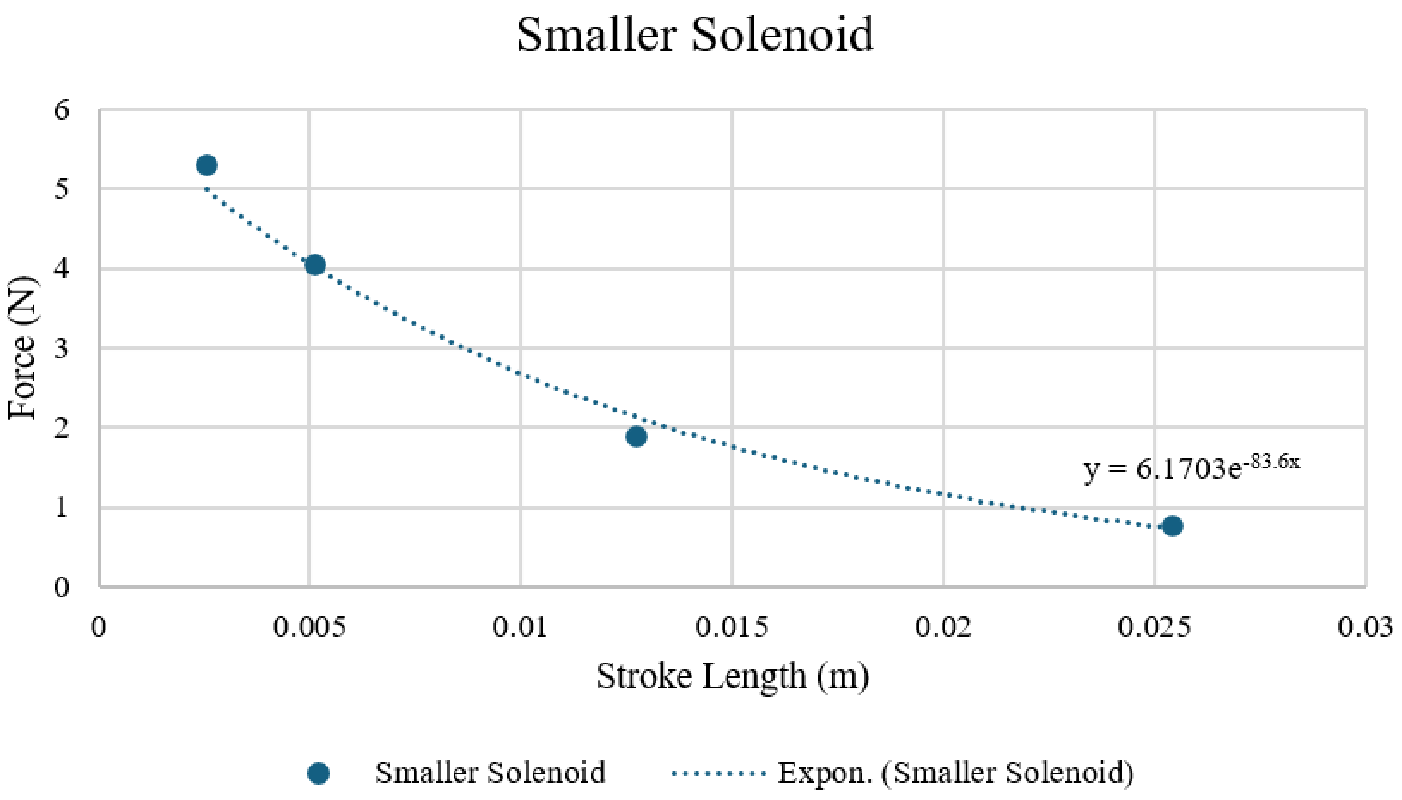


Solenoid– PDR Review

- Purchased 68 oz. solenoid from McMaster Carr with 1” stroke length
- Calculated force would not be enough to reach 10 m/s
  - Received explicit customer instruction that this requirement can be waived if other key requirements were met.

Modeling Solenoid Force

68 oz Solenoid			
Force (oz.)	**Force (N)**	**Distance (in)**	**Distance (m)**
191	5.3098	0.1	0.00254
146	4.0588	0.2	0.00508
68	1.8904	0.5	0.0127
28	0.7784	1	0.0254



Striker Bar Velocity

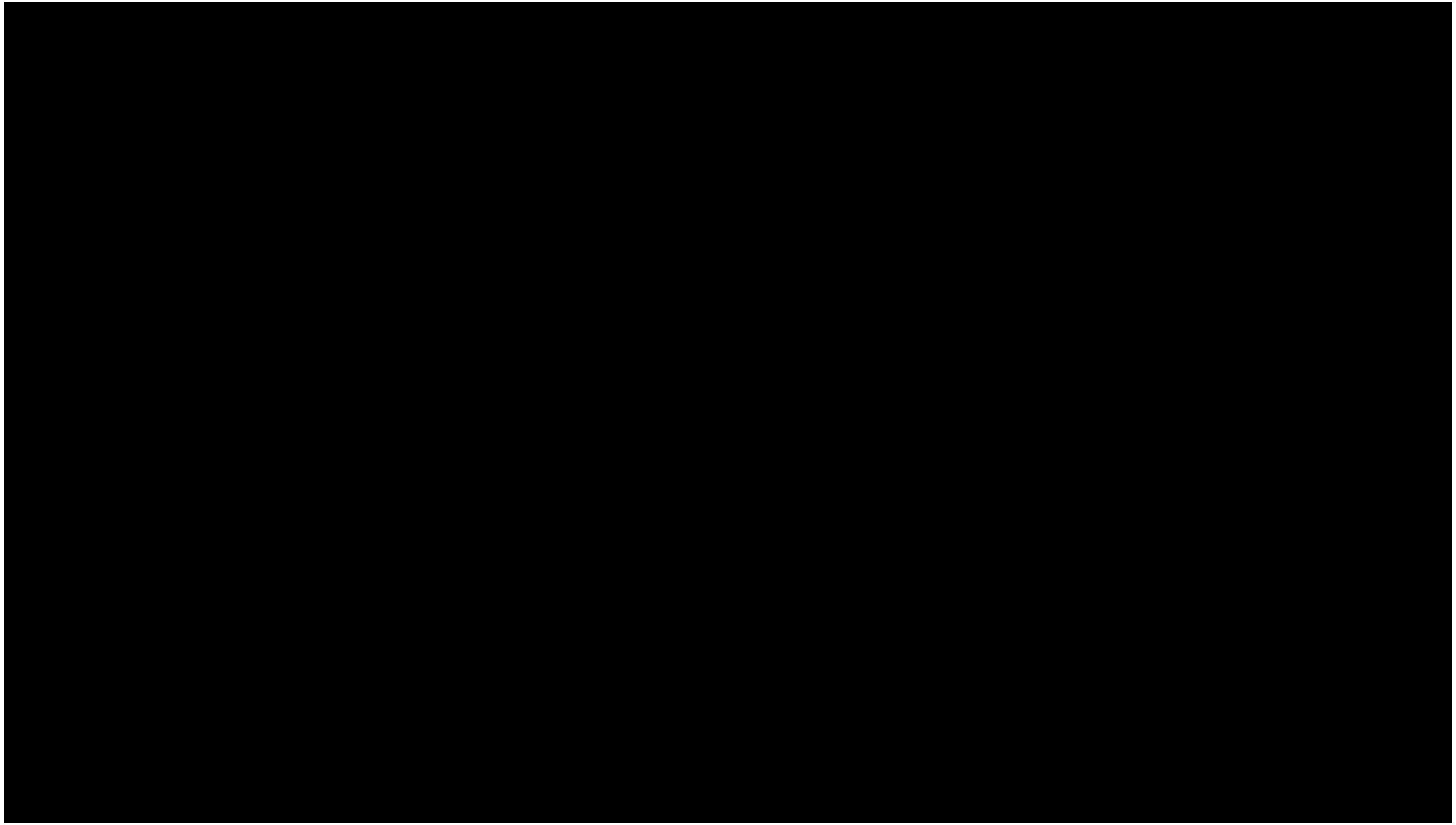
$$W = \int_0^{L_s} F_{sol} dx \qquad W = \frac{1}{2} m v_{striker}^2 \qquad v_{striker} = \sqrt{\frac{W}{\frac{1}{2} m_{striker}}}$$

Quantity	Symbol	Value	Unit
Work	W	0.065	W
Mass	m	0.715	kg
Velocity (Striker)	$\boldsymbol{v_{striker}}$	**0.427**	$\boldsymbol{\frac{m}{s}}$

Benchmark: Must achieve 10 m/s but lower velocities may be acceptable

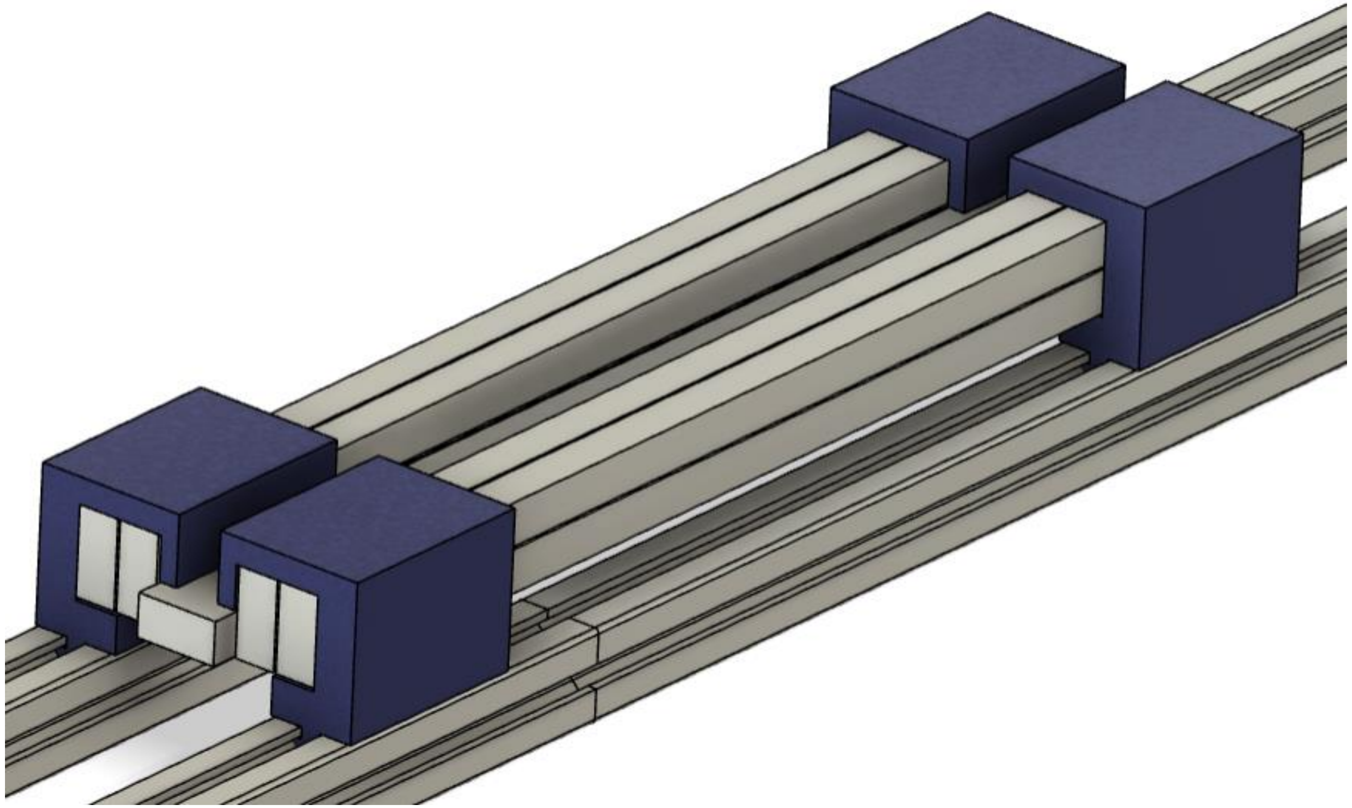
Achieved: roughly 0.25 m/s

Video of Solenoid

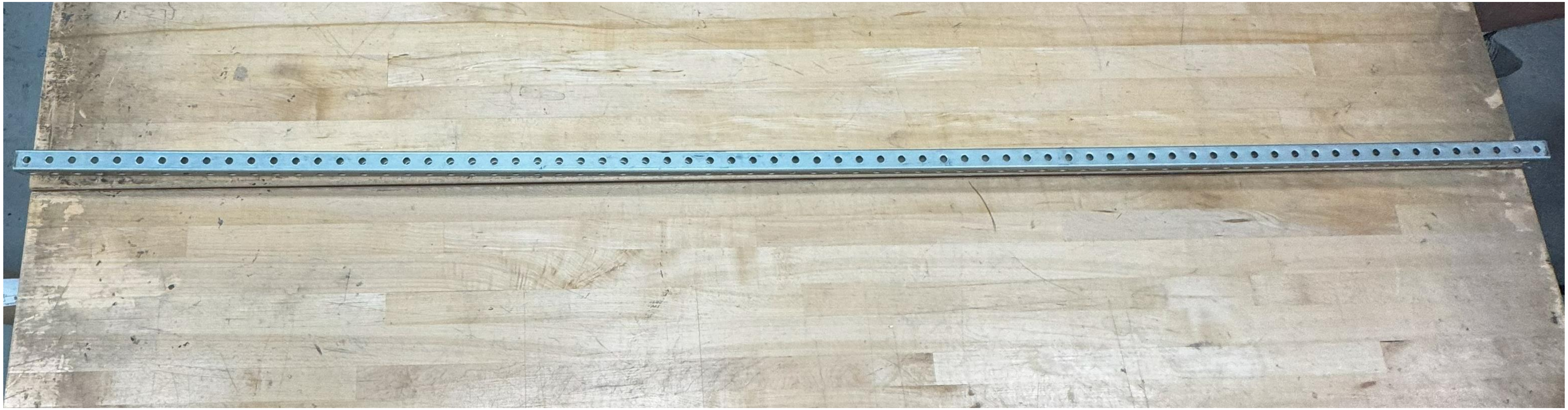


Boundary Conditions (Frame)– PDR

- Proposed 80/20 rails for easy translation and solenoid movement
  - Encouraged to explore other rail options



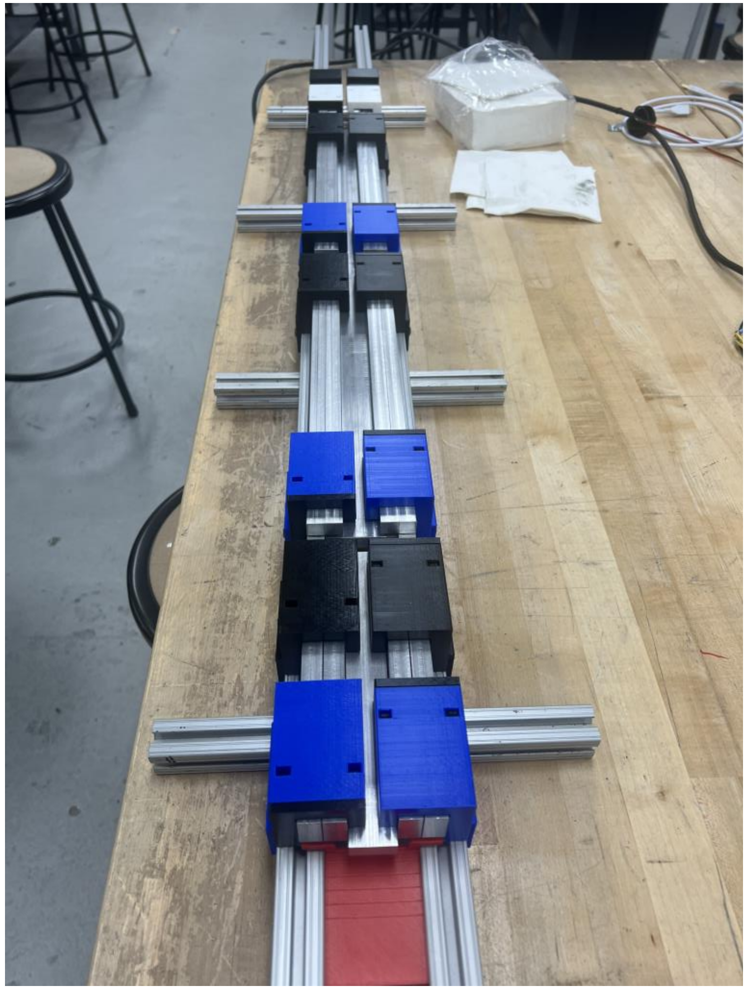
Boundary Conditions (Frame)– Intermediate Prototype



Ordered bolt rails twice and were received warped

Returned to original 80/20 design

Boundary Conditions (Frame) – Final Artifacts

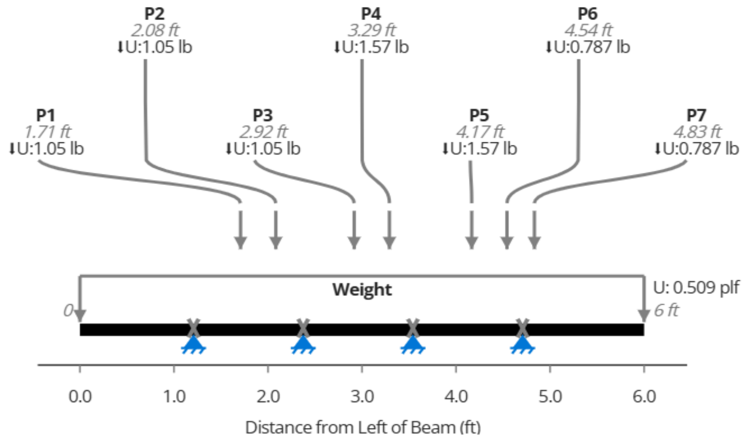


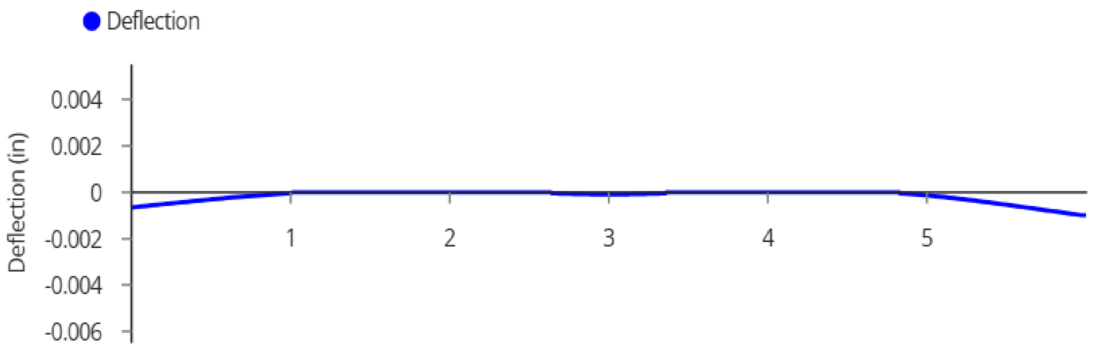
Added 4 rails underneath for stability and to prevent warping

Boundary Conditions (Frame)– Calculations

$$\sigma_{max} = \frac{M_{max} y}{I}$$

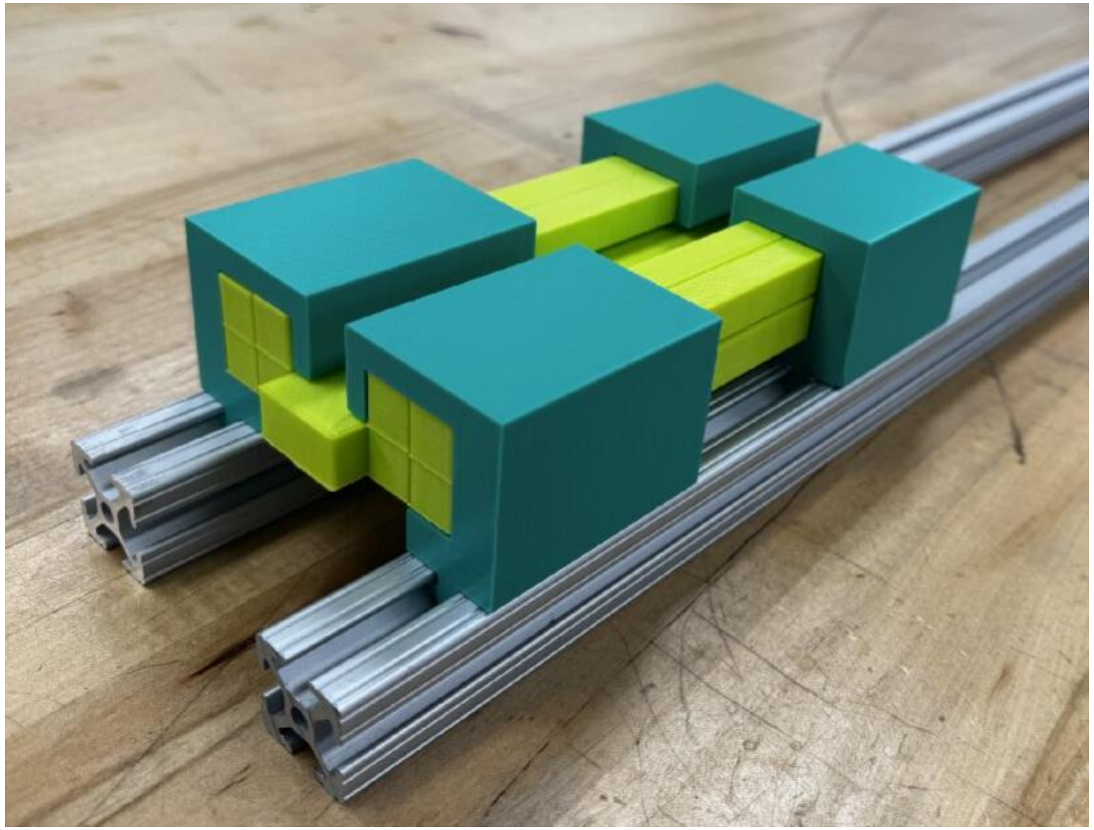
Quantity	Symbol	Value	Unit
Maximum Bending Moment	M_{max}	0.709	$N{\cdot}m$
Distance to Neutral Axis	y	0.0127	m
Moment of Inertia	I	1.840	m^4
Bending Stress	σ_{max}	**0.489**	***MPa***
Max Deformation	δ_{max}	**0.025**	**mm**
Factors of Safety		**High**	





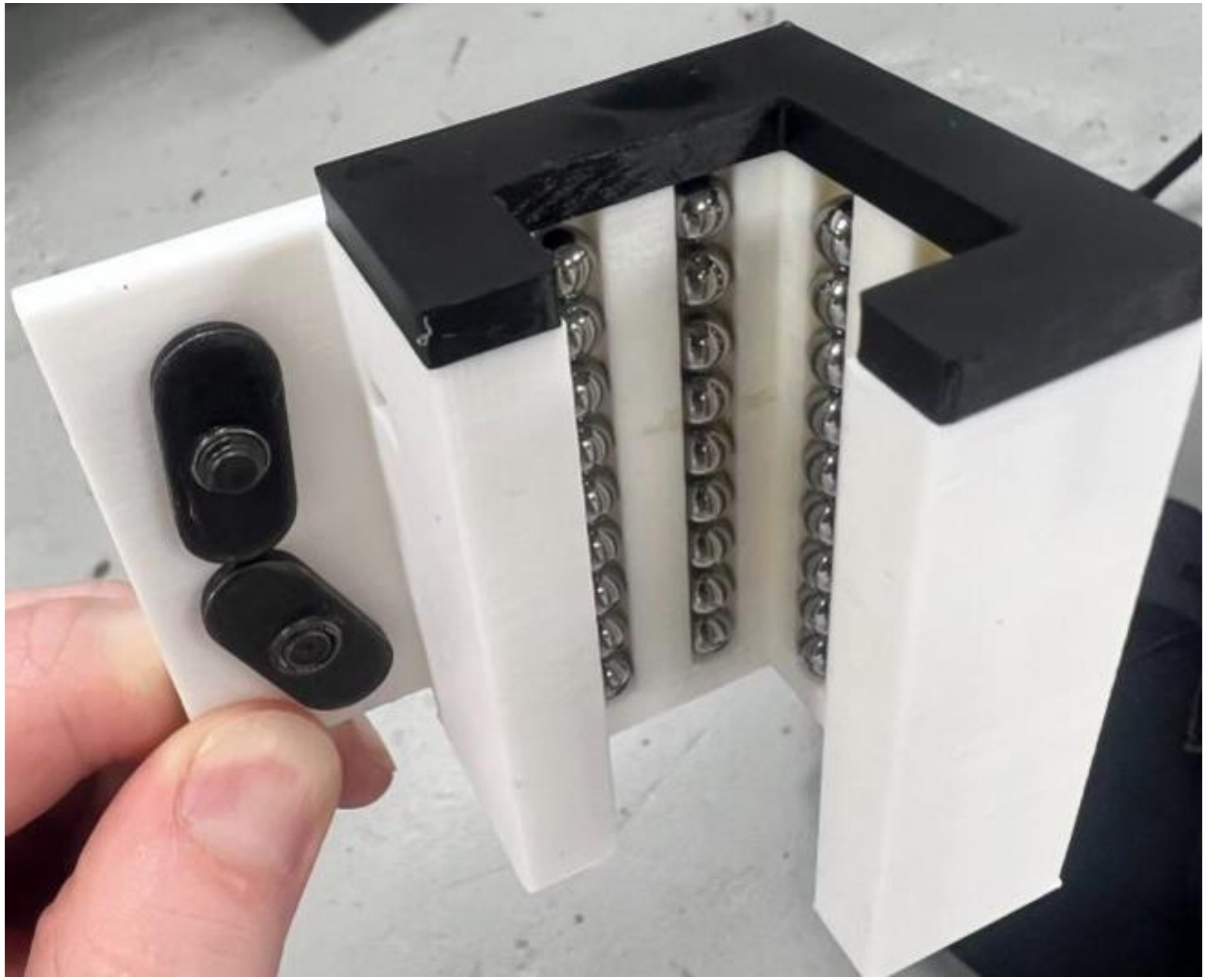
Boundary Conditions (Clamps) – PDR

- 3D printed clamps act as a collar that extends 5 times the length of the bend junctions.
  - Translate with bar along frame
- Received feedback that bars should flow through clamps
  - Encouraged to explore bearings



Boundary Conditions (Clamps) – Final Artifacts

- New design for clamps with bearings in key locations to aid in smooth translation along the frame.
- End caps are not removable to protect IP and prevent bearing loss.



Boundary Conditions (Clamps) – Calculations

$$\tau = \frac{F}{A} = \frac{4W}{\pi d^2} \qquad B_t = \frac{W}{td}$$

Quantity	Symbol	Value	Unit
Bar Weight	W	14.715	N
Bolt Diameter	d	7.94	mm
Clamp Thickness	t	5	mm
Shear Stress	τ	**0.297**	MPa
Bearing Stress	B_t	**0.371**	MPa
Factors of Safety		**High**	

Overview of Cost

Part	Units	Price/ Unit	Shipping	Total Price
Striker Bar- Xometry	1	$ 228.44	$ -	$ 228.44
Full Bar- Xometry	2	$ 274.81	$ 80.00	$ 629.62
Solenoid	1	$ 60.40	$ 2.61	$ 63.01
Bearings	13	$ 5.40	$ -	$ 70.20
Aluminum Bar- Unused	1	$ 69.41	$ -	$ 69.41
Screw Bolts- Unused	1	$ 14.88	$ -	$ 14.88
Budget				**$ 1,500.00**
Total				**$ 1,075.56**
Left to Spend				**$ 424.44**

- Spent $1075.56 overall and stayed under budget
    - Unused:
        - Bar stock for single bend prototype
        - Screw bolts for warped rail
    - Unexpected: $80 on expedited millipede bar shipping
    - Potential purchases: more powerful solenoid or alternate propulsion system

Assembly Time

Component	Total Time (s)
Clamp Assembly	5306.88
Angle Bracket Assembly	247.2
Mount Short Rails to Long Rails	169.72
Stopper Assembly	37.16
Mount Clamps and Stoppers	219.7
Mount Millipede Bars	11.85
Solenoid Assembly	59.9
Mount Solenoid Assembly	104.7
Full Assembly Time (s)	6157.11
Full Assembly Time (min.)	102.6185
Full Assembly Time (hrs.)	**1.7103**

Cost of Singular Prototype

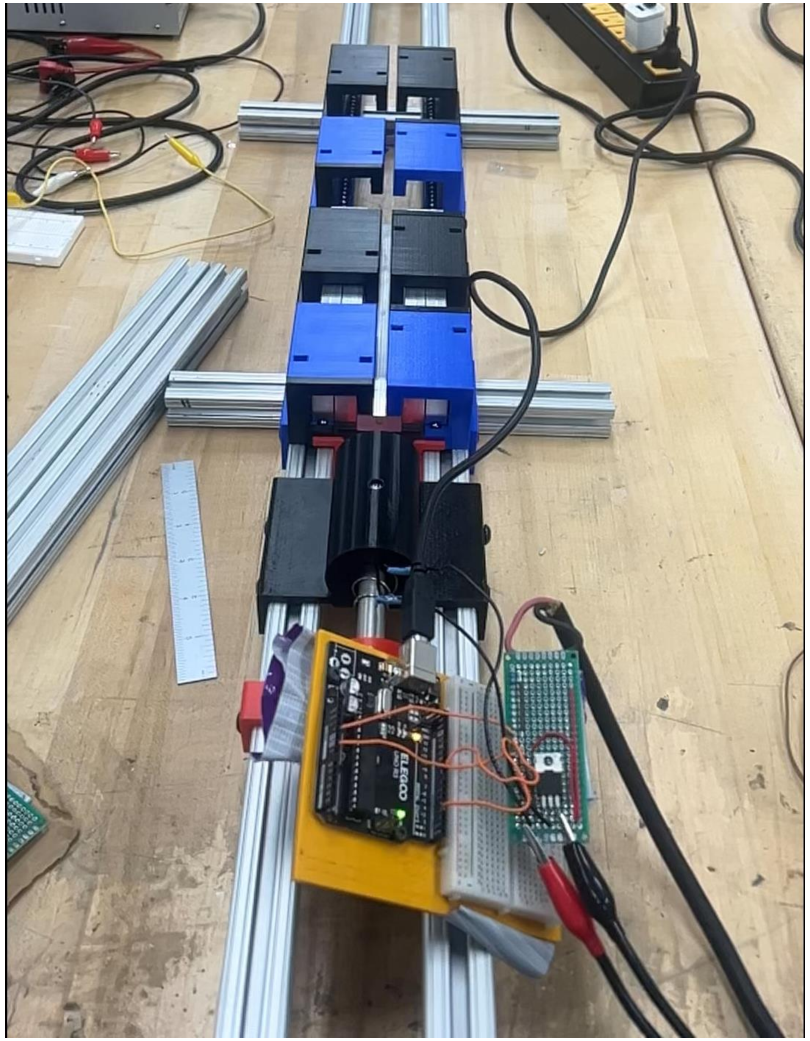
Total Costs	Price
Purchase- All Other Vendors	$ 911.05
Purchase- 80/20	$ 313.55
3D Printing	$ 2.28
Assembly	$ 32.67
Total	**$ 1,259.55**

Total Costs	Price	Price per System
Purchase- All Other Vendors	$ 2,139.71	$427.94
Purchase- 80/20	$ 921.44	$184.29
3D Printing	$ 11.40	$2.28
Assembly	$ 163.31	$32.66
Total (5 Systems)	**$ 3,235.86**	**$ 647.17**

Performance Evaluations

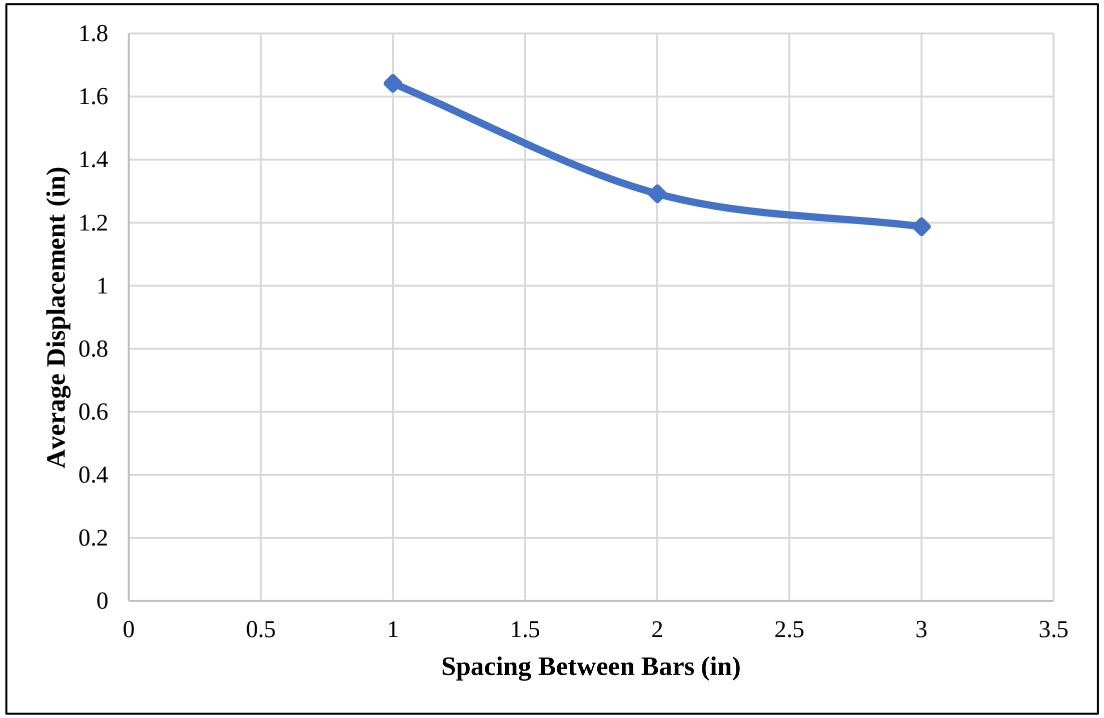
Testing Results – Performance Evaluation 1

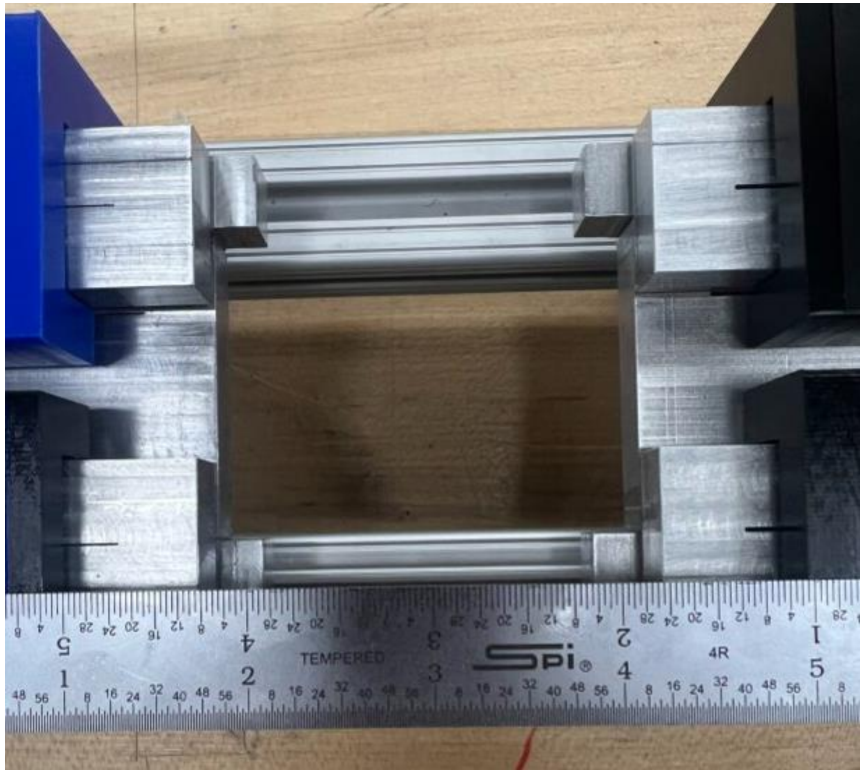
- Striker Bar Distance Test – Success
  - Solenoid force delivery is consistent
  - Striker bar max displacement = 8 in



Testing Results – Performance Evaluation 2

- Smooth Motion Test - Success
  - Solenoid force constant
  - Gap between striker/incident bar changed





Testing Results – Final Performance Evaluation

Category	3	2	1	0	Notes
Finish Quality	X				
Component Check	X				
Wiring Check		X			
Impacting Surface Finish	X				2-micron surface finish
Non-Impacting Surface Finish	X				
Striker Velocity			X		Customer relaxed this requirement
Launcher Anchoring	X				
Stress Wave				X	Strain gauge struggles
Strain Gauge Adhesion	X				
Smooth Bar Motion		X			Motion at ~10 Degree Tilt
Safety	X				
Ease/Speed of Use				X	Pending stress wave measurement
Connectivity	X				6-pin adapter was used during testing

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Customer Needs Review

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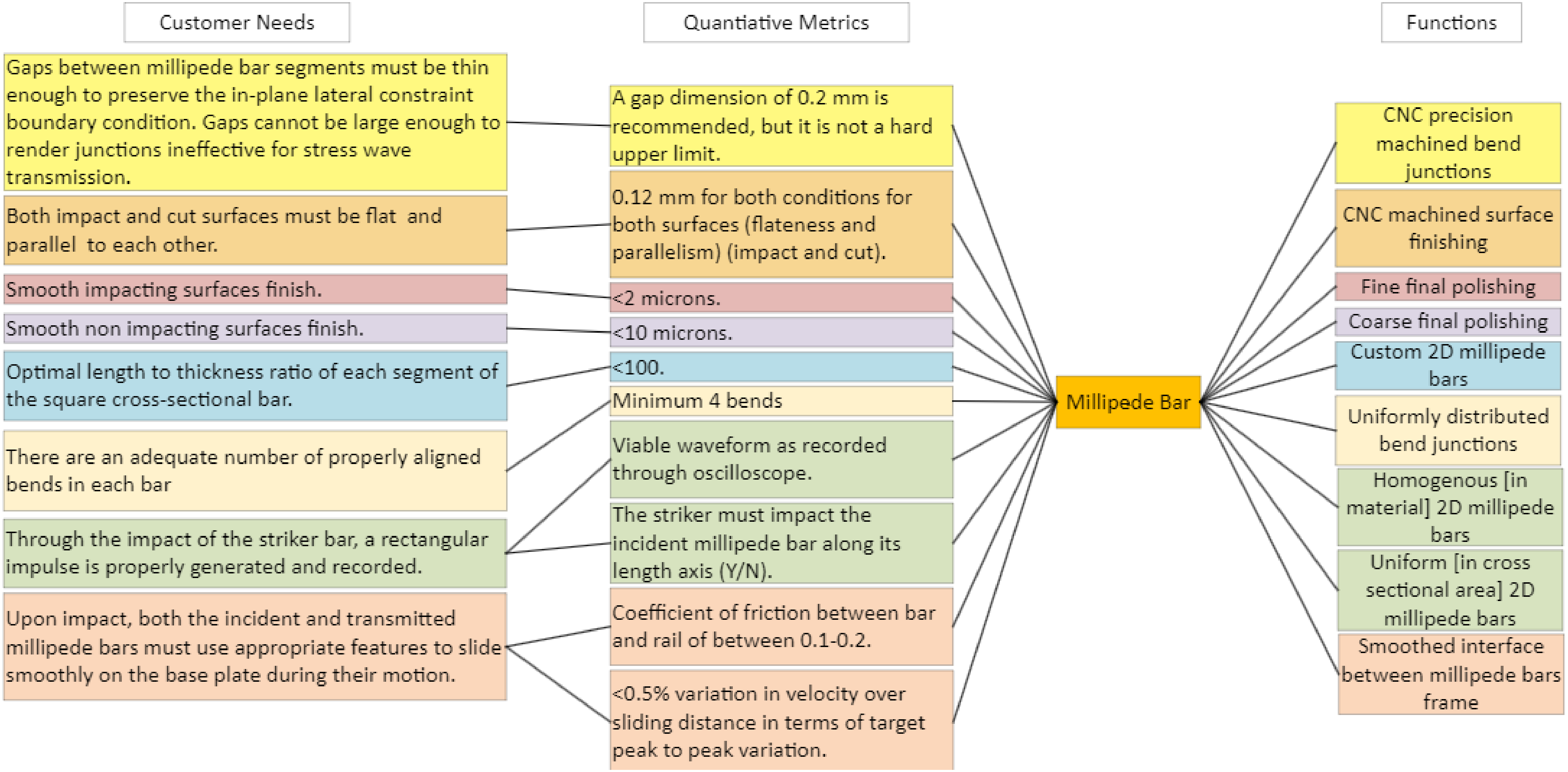
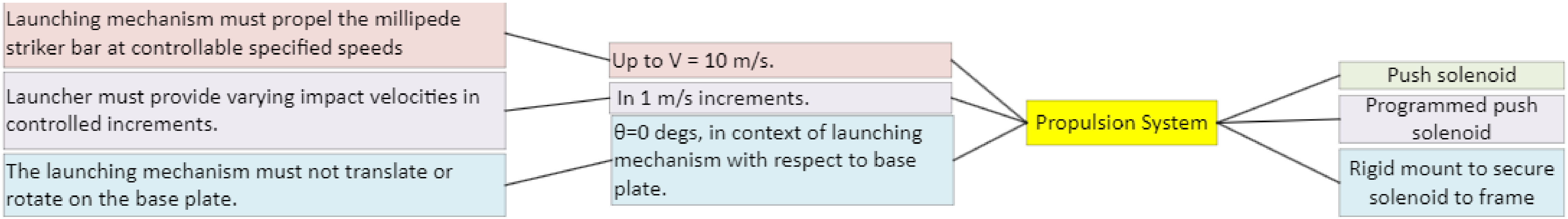
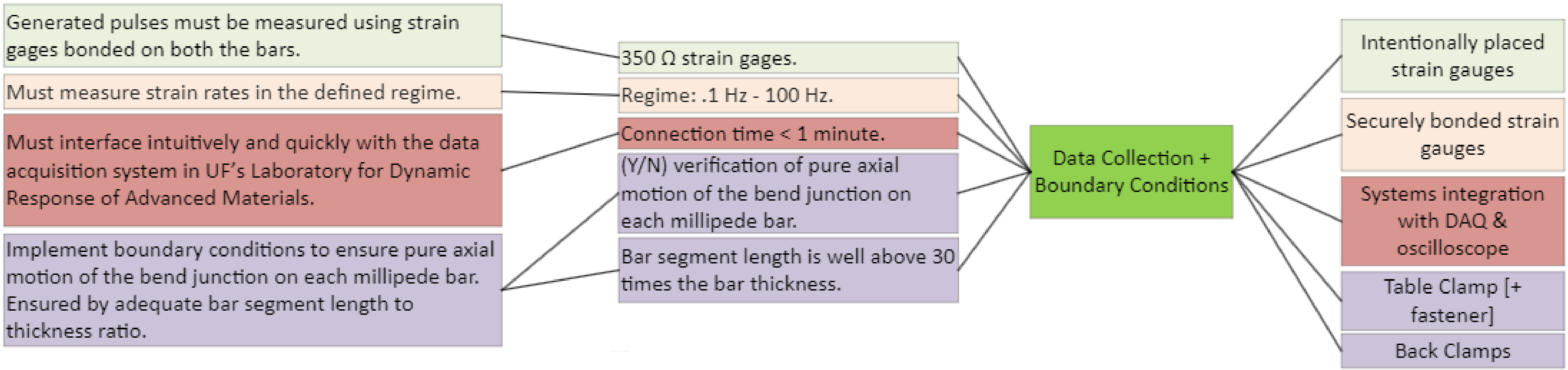
Millipede Bars – Customer Needs



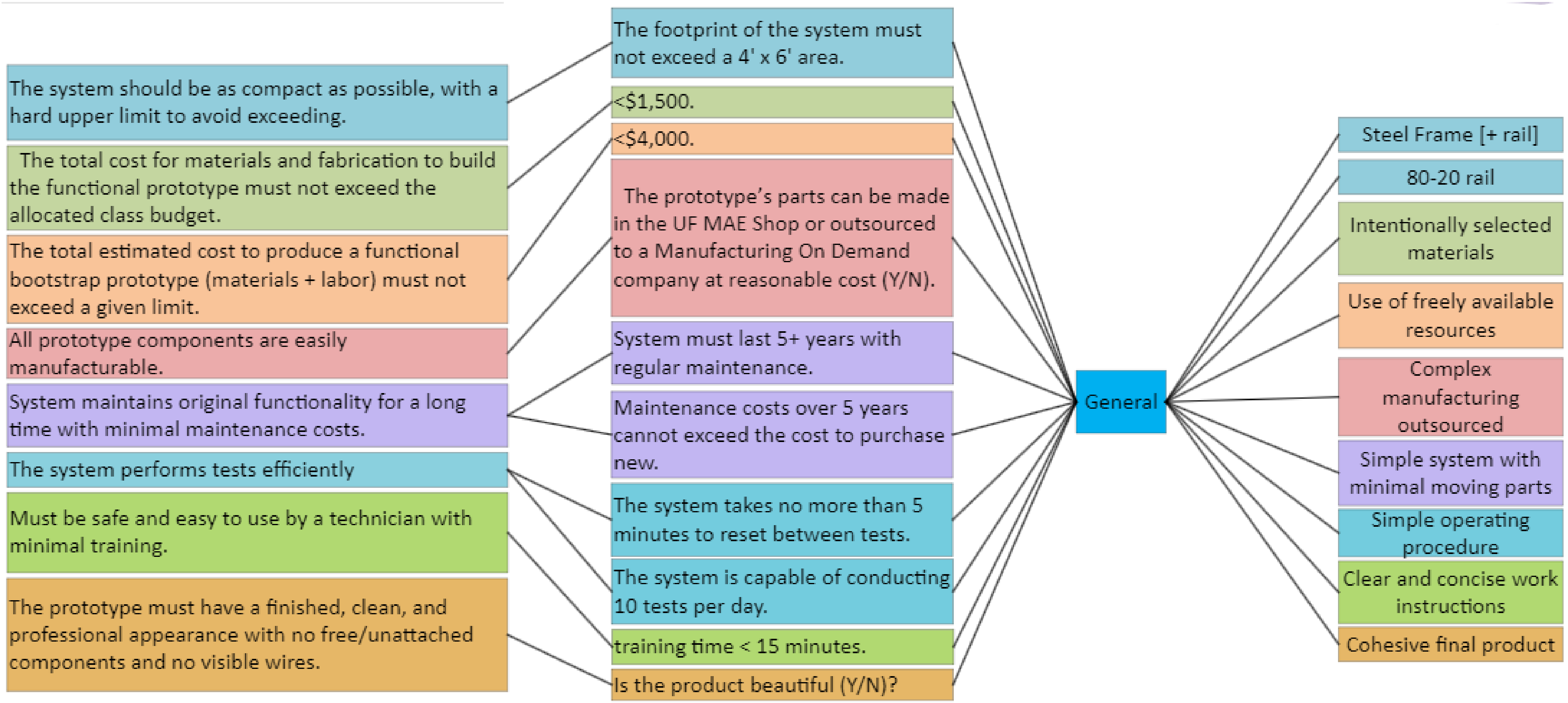
Propulsion System – Solenoid Subassembly



Data Collection and Boundary Conditions - Needs



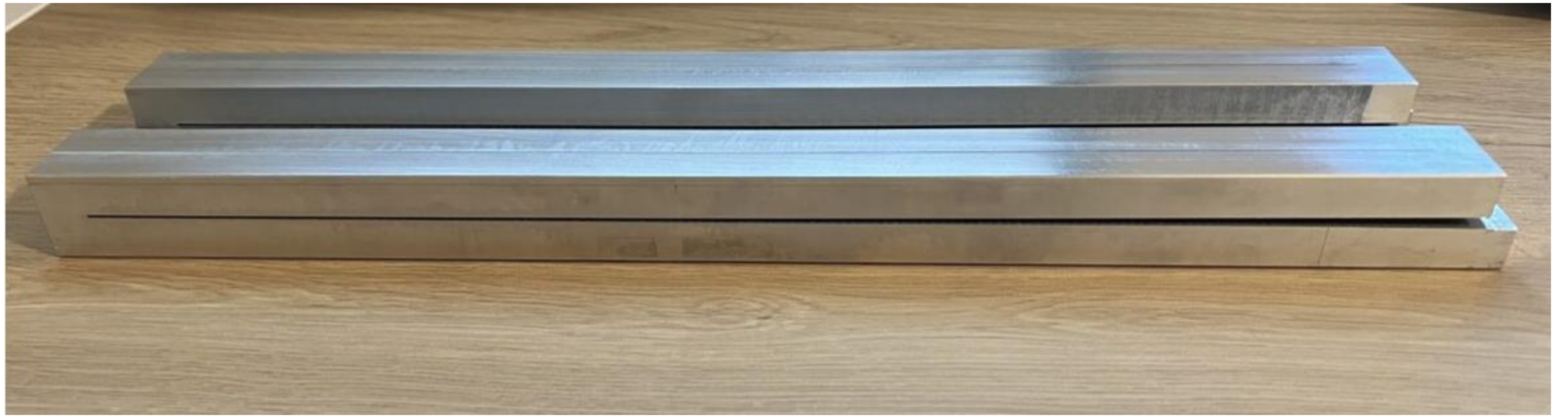
Other Customer Needs

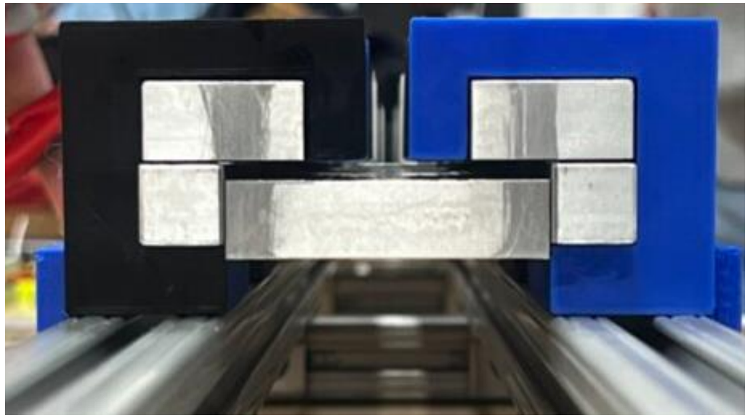


Design Improvements

Future Progress

- Stronger solenoid for increased striker bar velocity
- Incident and transmission bar design improvements
  - Decrease length to prevent deformation due to residual stresses
- Higher quality strain gauges





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FAQs

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