

**EXPO**  
engineering ▲ design



# RIFLE SCOPE MOUNT FORCE SIMULATION & DESIGN OPTIMIZATION

## TEAM: IRONSIGHT

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**SPONSOR: NIGHTFORCE**

# BACKGROUND

## WHAT IS DESIRED?

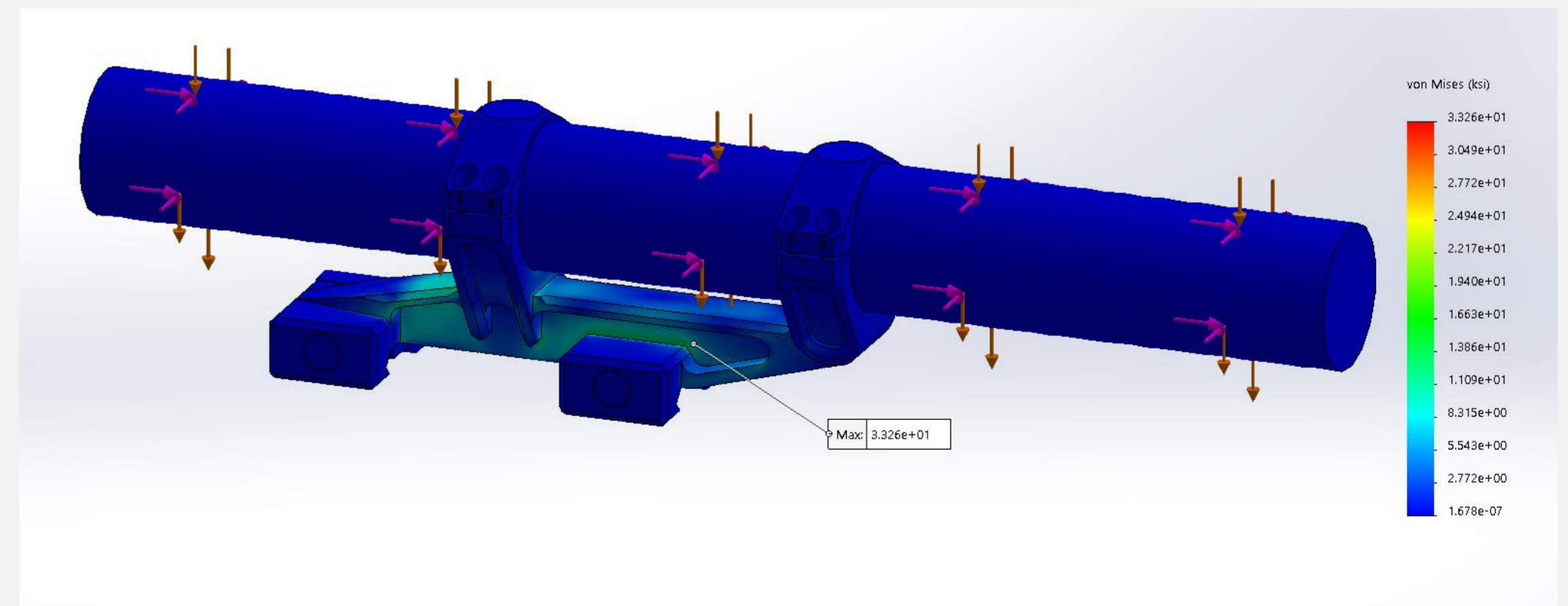
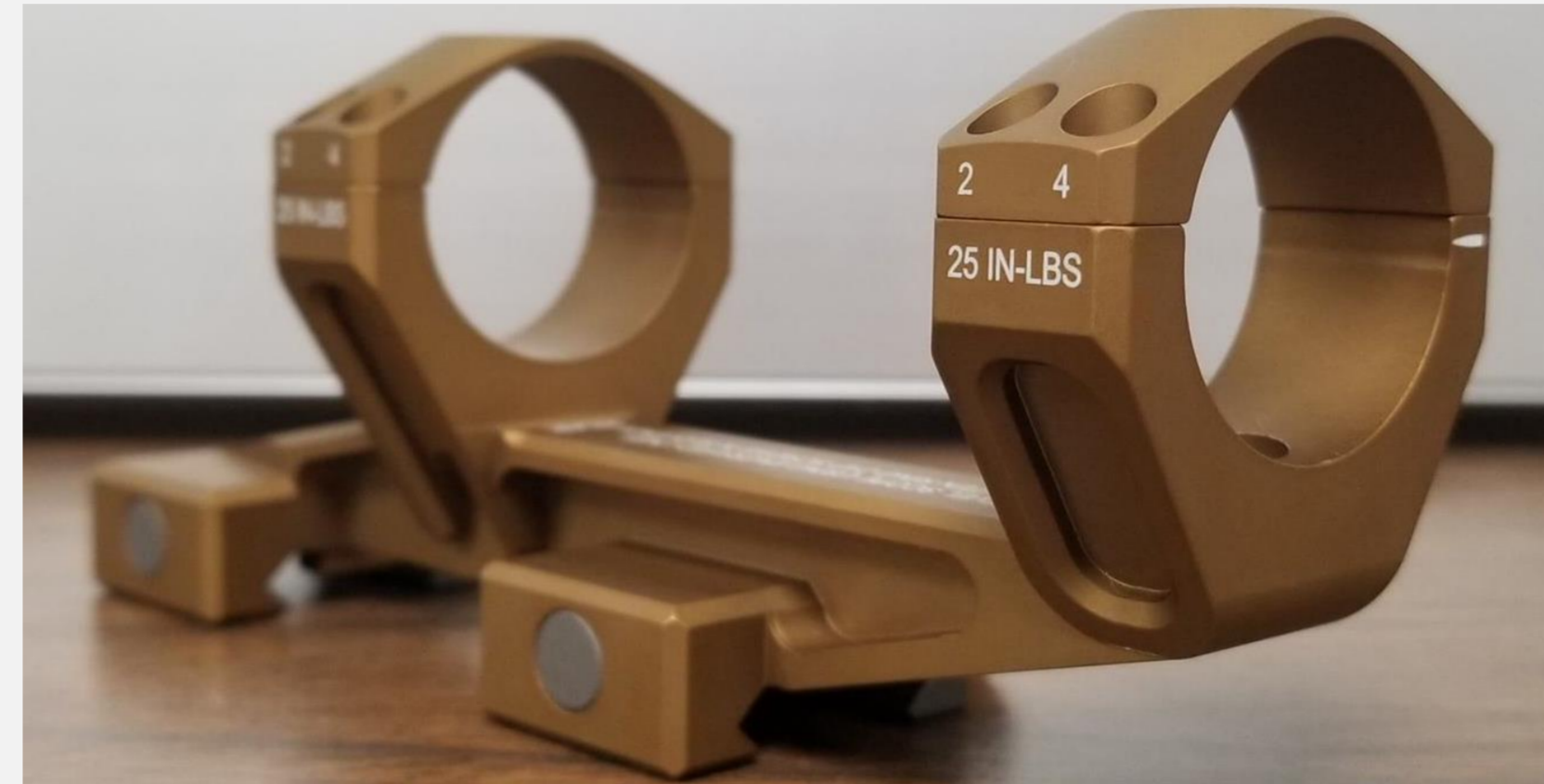


### Client Goals/Deliverables

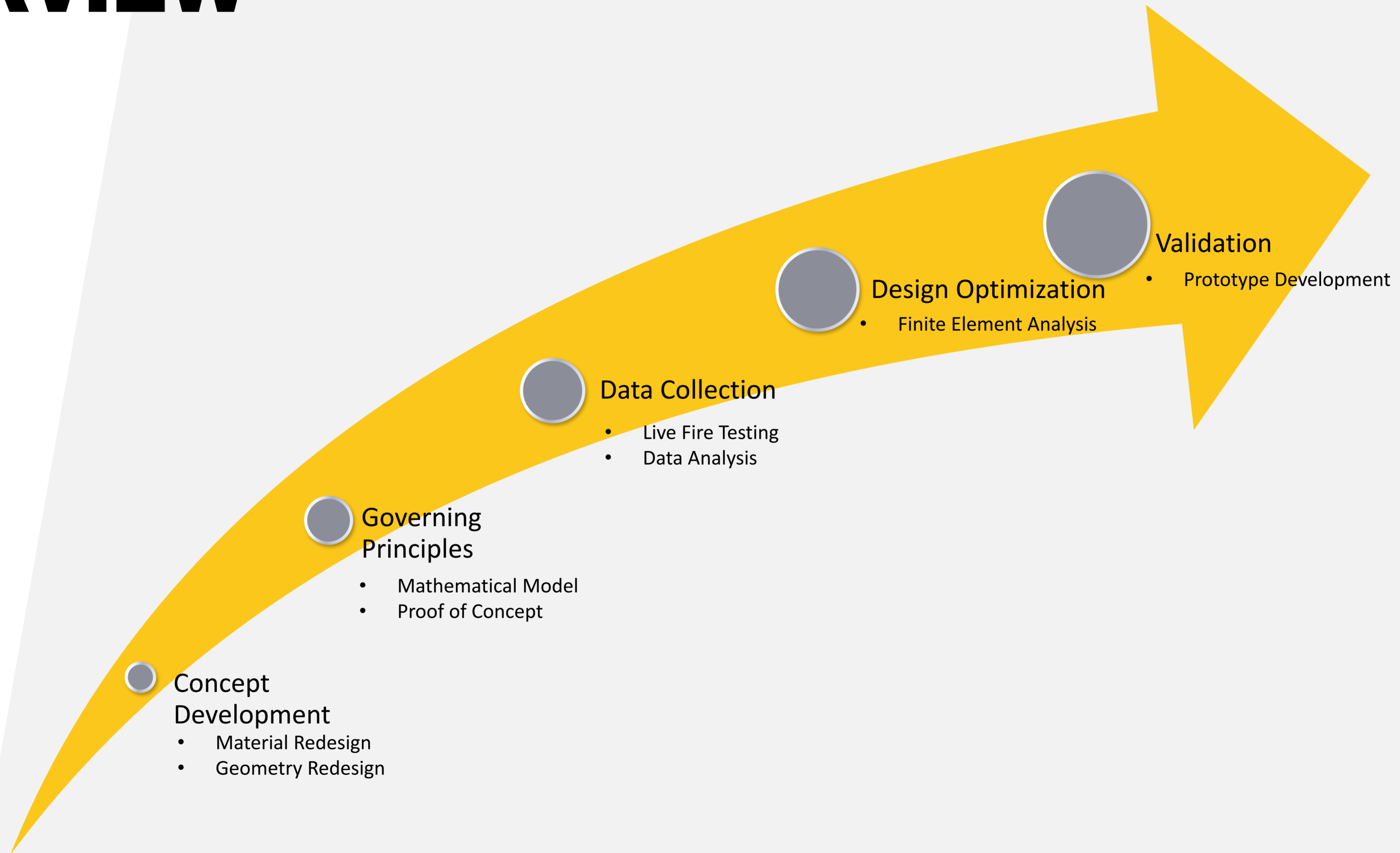
- Develop an optimized riflescope mount
  - Focus: weight reduction
- Process refinement and delivery

### Design Constraints

- Weight < 3.69 oz
- $\geq$  Strength of current design
- Cost effective



# OVERVIEW





# CONCEPT DEVELOPMENT

## MATERIAL REDESIGN IN REVIEW

### Material Indexing

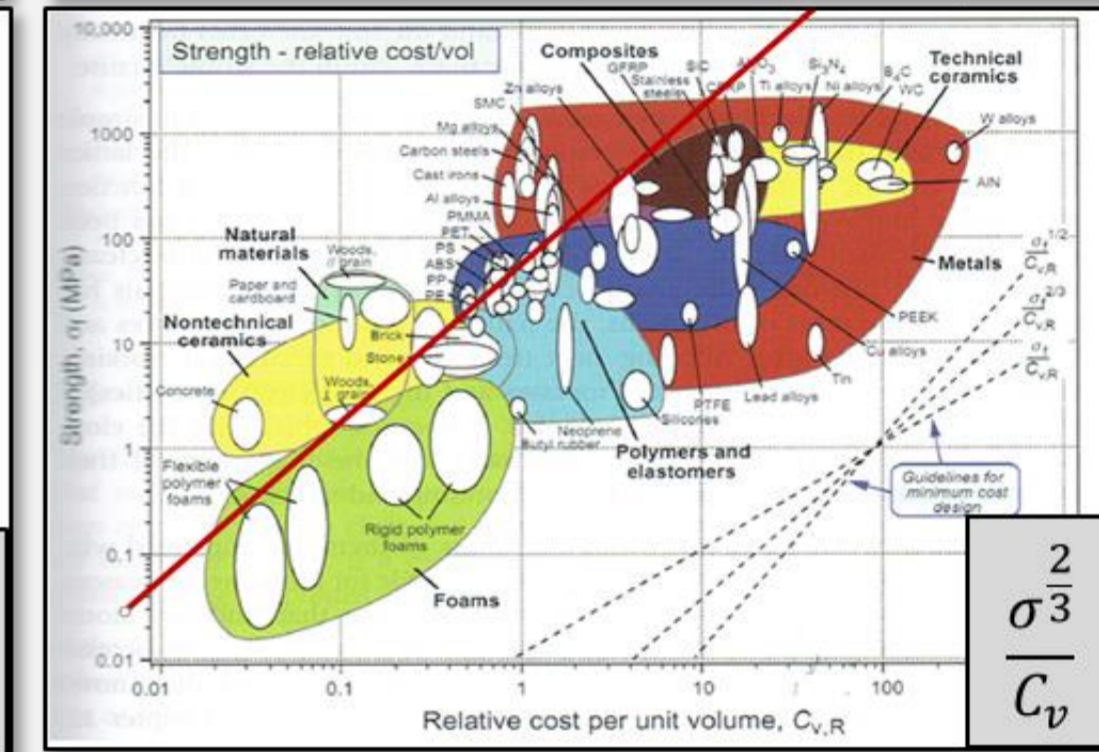
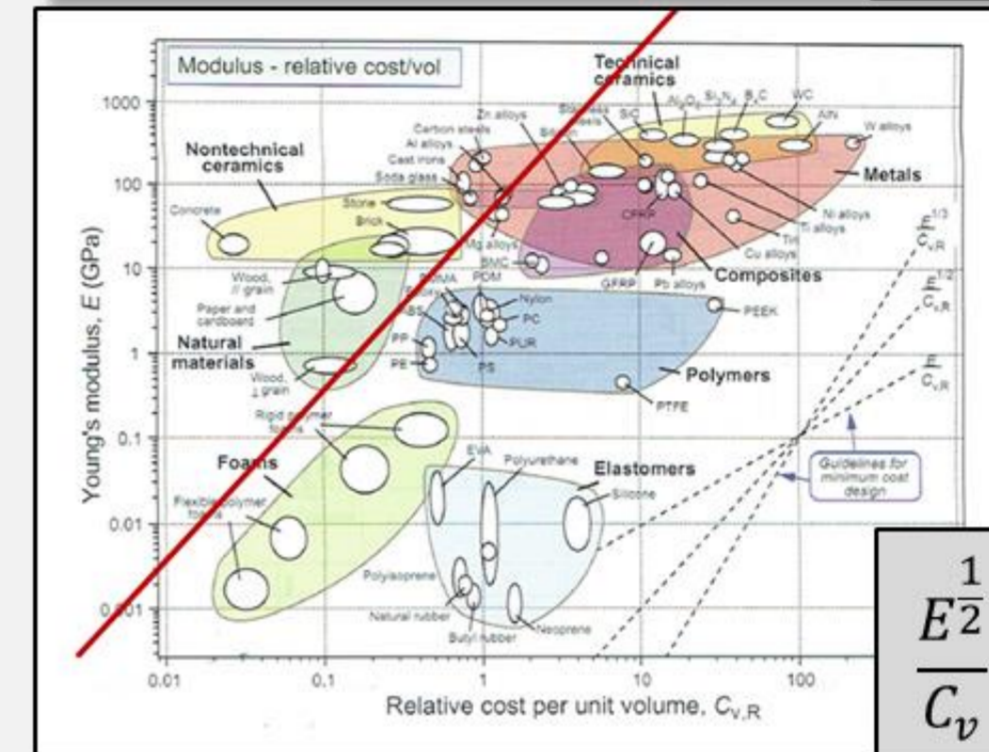
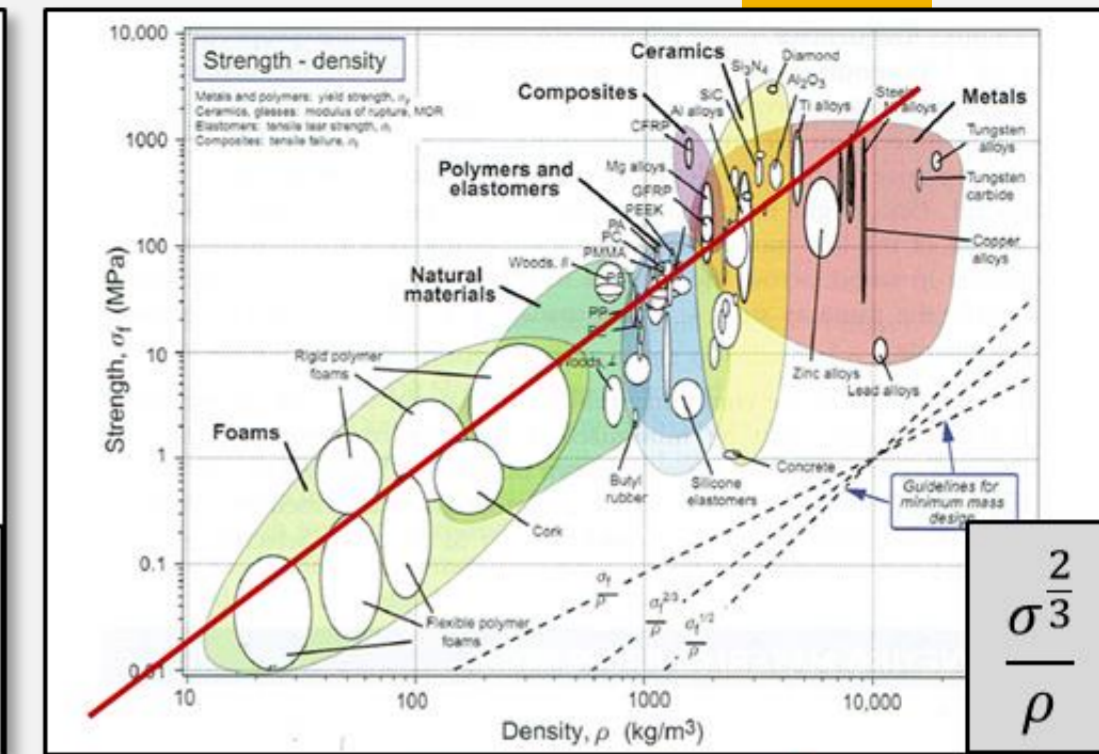
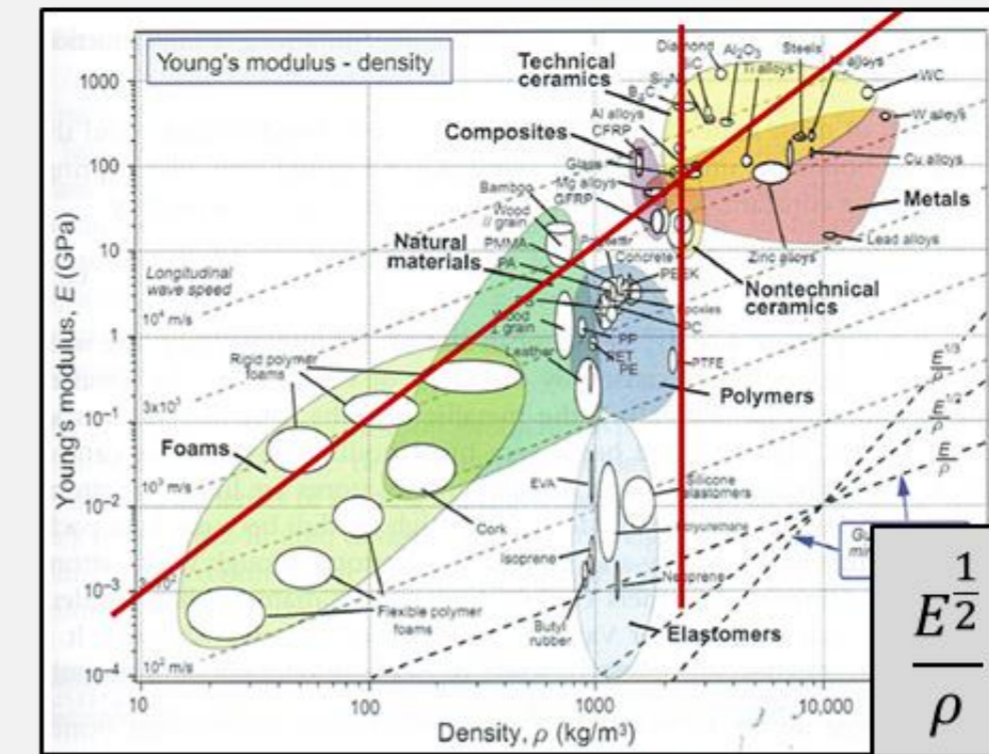
- Modulus of Elasticity (E)
- Density ( $\rho$ )
- Yield Stress ( $\sigma$ )
- Cost per Unit Volume ( $C_v$ )

### Material Compatibility

- Corrosion Study
- ASTM B117 Salt Spray Test
- Hard coating
- MIL-A 8625 Type III

### Material Pricing

- Unit and Bulk Quotation
- Purchase for Prototype



Material Indices for Four Relevant Parameters

### Candidate Material Unit and Bulk Pricing

	Al 7075	Mg AZ61A	Al 2024	Al 7068
Unit (\$/lb)	13.82	4.06-42.89	15.35-23.16	19.77
Bulk (\$/lb)	1.13	4.06-11.56	N/A	N/A

### Maximum Corrosion rate (mm/year) of treated and untreated alloys in salt spray tests

	Al-7075	Mg-AZ61A
Base Metal	0.08587 (3)	17.96 (1)
Hard Coated	0.015 (4)	0.022 (2)

### Materials Indexing Results

	Al 7075	Mg AZ61A	Al 2024	Al 7068
$\frac{E^{1/2}}{\rho}$	999.8	<u>1240.2</u>	<u>1076.5</u>	999.67
$\frac{\sigma^{2/3}}{\rho}$	171.2	159.5	139.1	<u>188.7</u>
$\frac{E^{1/2}}{C_v}$	72.3	<u>152.1</u>	<u>79.3</u>	69.1
$\frac{\sigma^{2/3}}{C_v}$	12.4	<u>19.57</u>	10.3	<u>13.0</u>

[1] Dhanapal et al., "Experimental Investigation of the Corrosion Behavior of Friction Stir Welded AZ61A Magnesium Alloy Welds under Salt Spray Corrosion Test and Galvanic Corrosion Test Using Response Surface Methodology."

[2] Sreekanth, Rameshbabu, and Venkateswarlu, "Effect of Various Additives on Morphology and Corrosion Behavior of Ceramic Coatings Developed on AZ31 Magnesium Alloy by Plasma Electrolytic Oxidation."

[3] Al-Moubaraki and Al-Ruzhud, "The Red Sea as a Corrosive Environment."

[4] P. B et al., "Effect of Anodization on the Corrosion Behavior of Aluminium Alloy in HCl Acid and NaOH."

# GOVERNING PRINCIPLES



## MATHEMATICAL MODEL

Impulse Momentum Theorem.....  $F * \Delta t = m * \Delta v$

After rearranging.....  $F = m * \frac{\Delta v}{\Delta t}$

Simplification.....  $F = m * a$

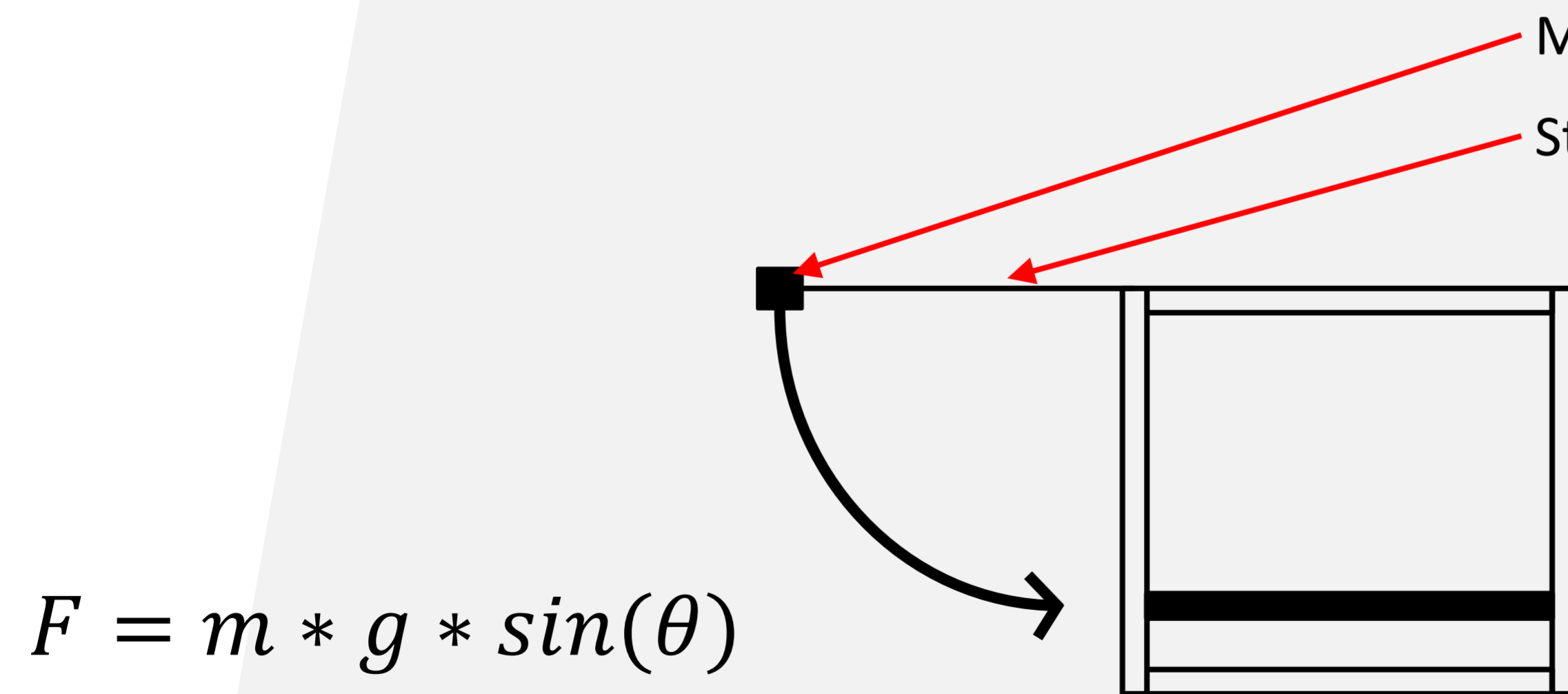


# GOVERNING PRINCIPLES

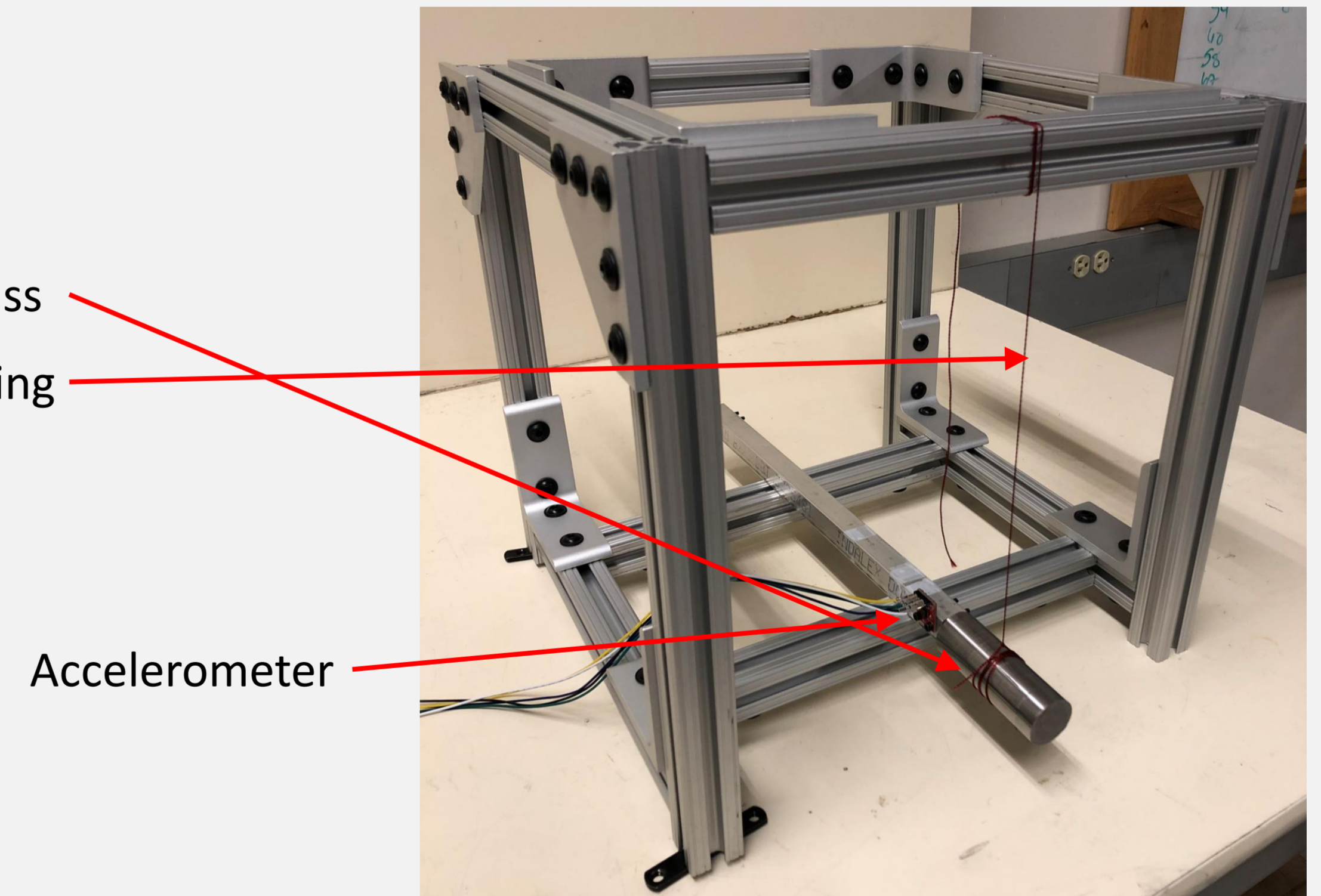


## PROOF OF CONCEPT

- Force from swinging pendulum impact force matched to acceleration in bar



Working principle behind the impact test stand



Impact test stand



# DATA COLLECTION

## LIVE FIRE TESTING

### Collection Devices

- Accelerometer Dytran 3313
- Daq Vibration Research
- Custom Accelerometer mount
- FN MK 17 Rifle

### Testing

- 80 recorded live fire tests
- Three different shooters

### Outcome

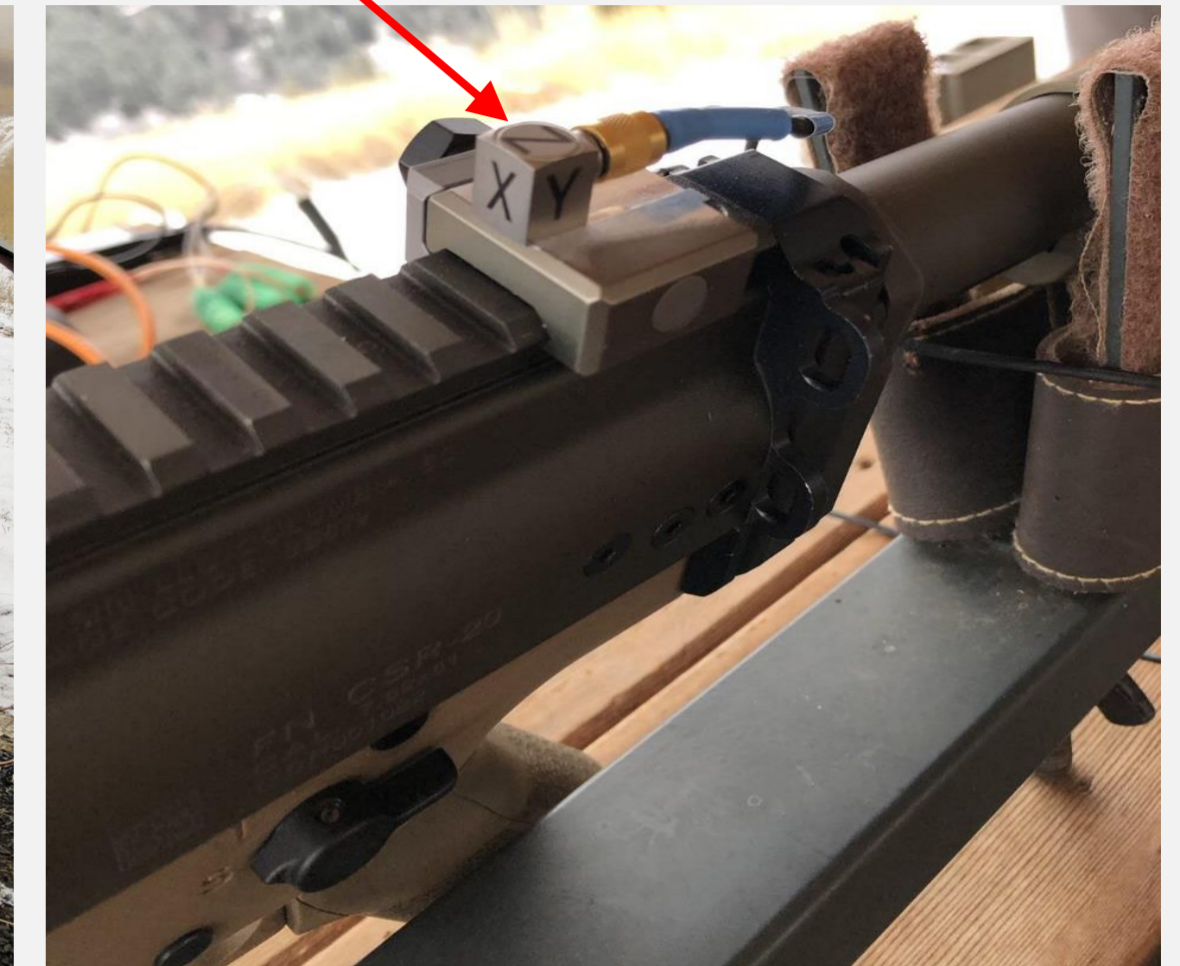
- 1.6-1.9 million points of data



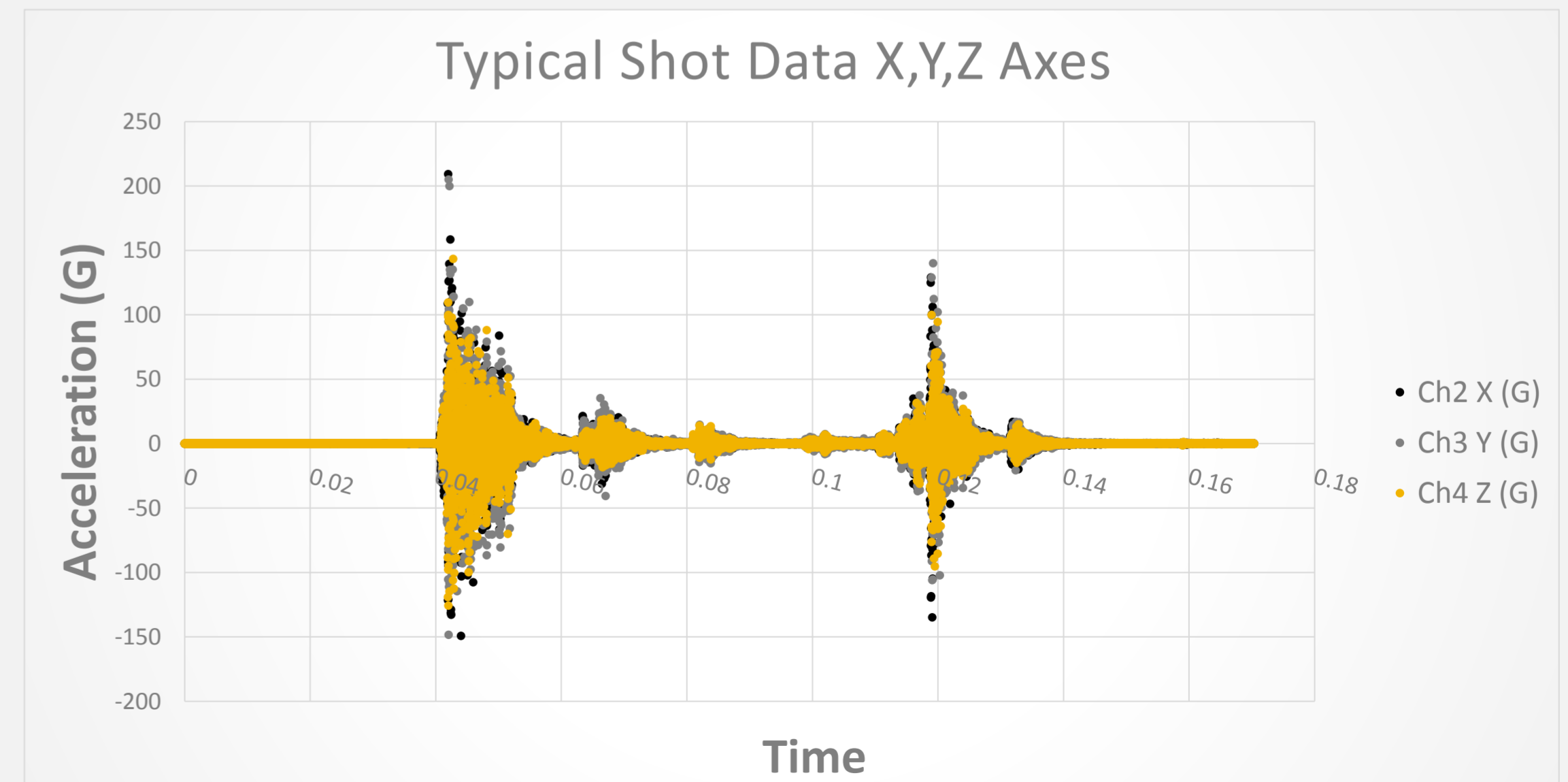
Rifle

DAQ

Mount and Accelerometer



(Left) Live fire setup for acceleration data gathering on mount. (Right) Dytran 3313





# DATA COLLECTION

## INITIAL DATA ANALYSIS

Accelerations

- Absolute Maximum
- X Axis – 209 G
- Y Axis – 213 G
- Z Axis – 187 G

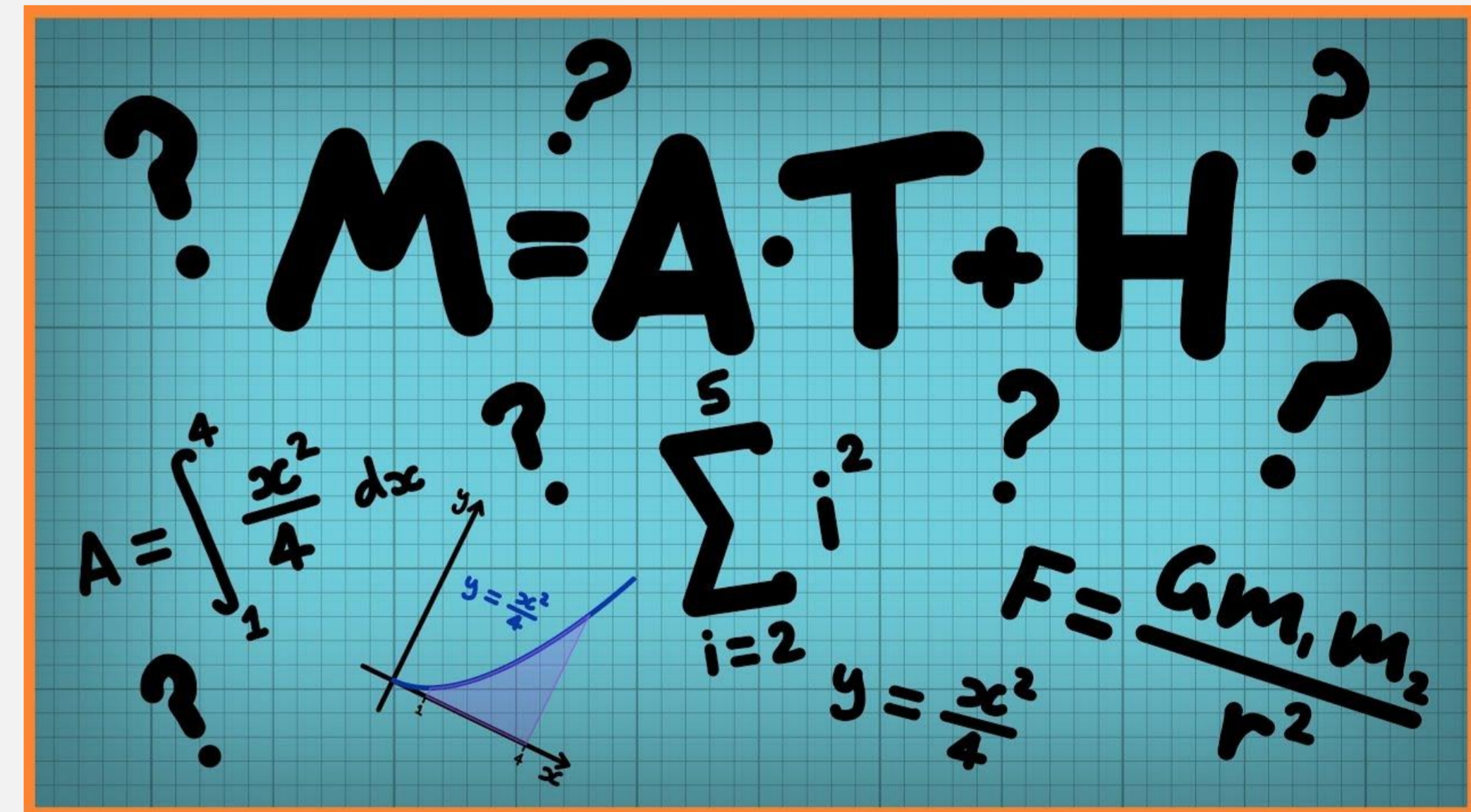


Math Model



Forces

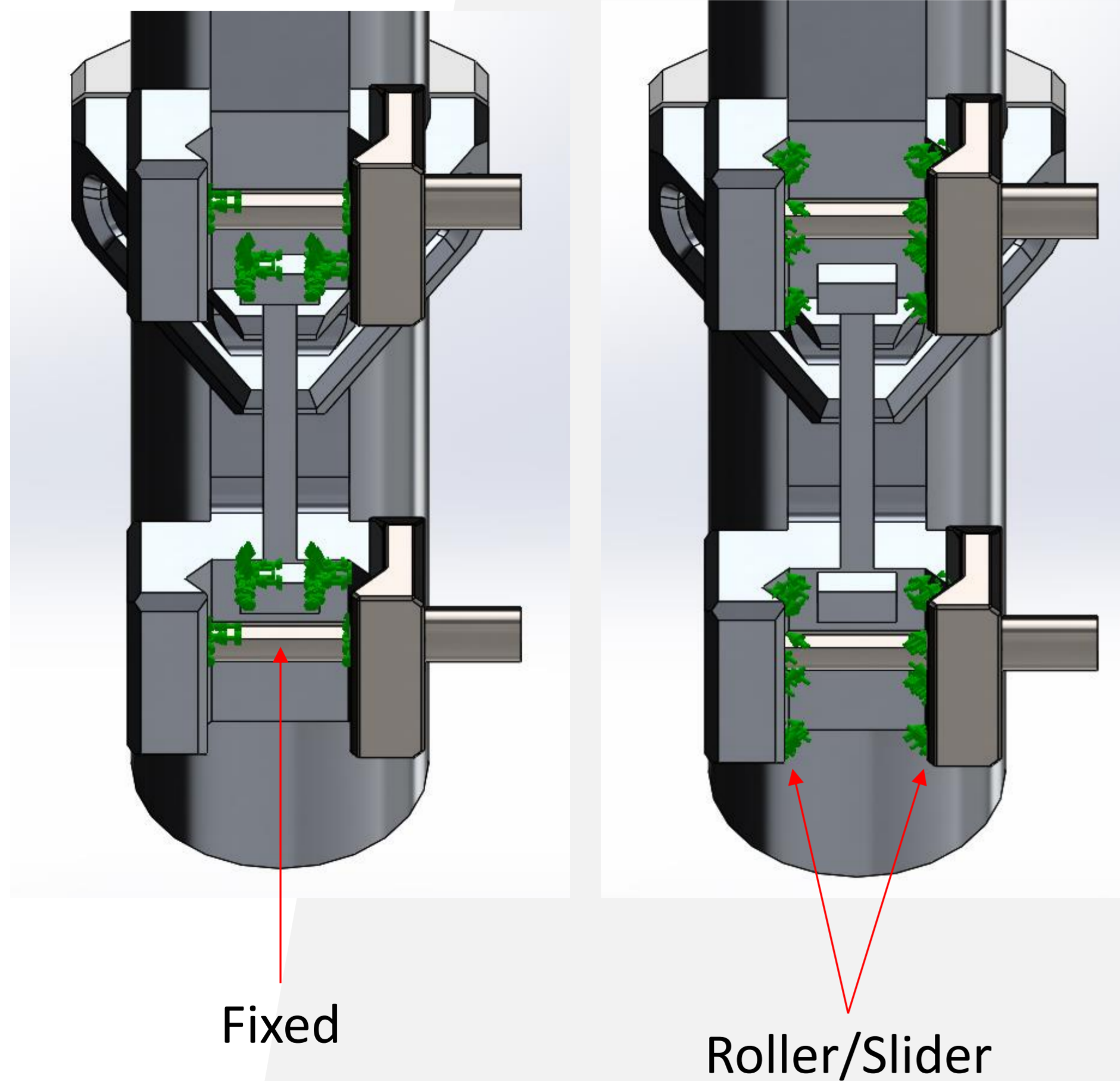
- X Axis – 726 lbf
- Y Axis – 741 lbf
- Z Axis – 652 lbf



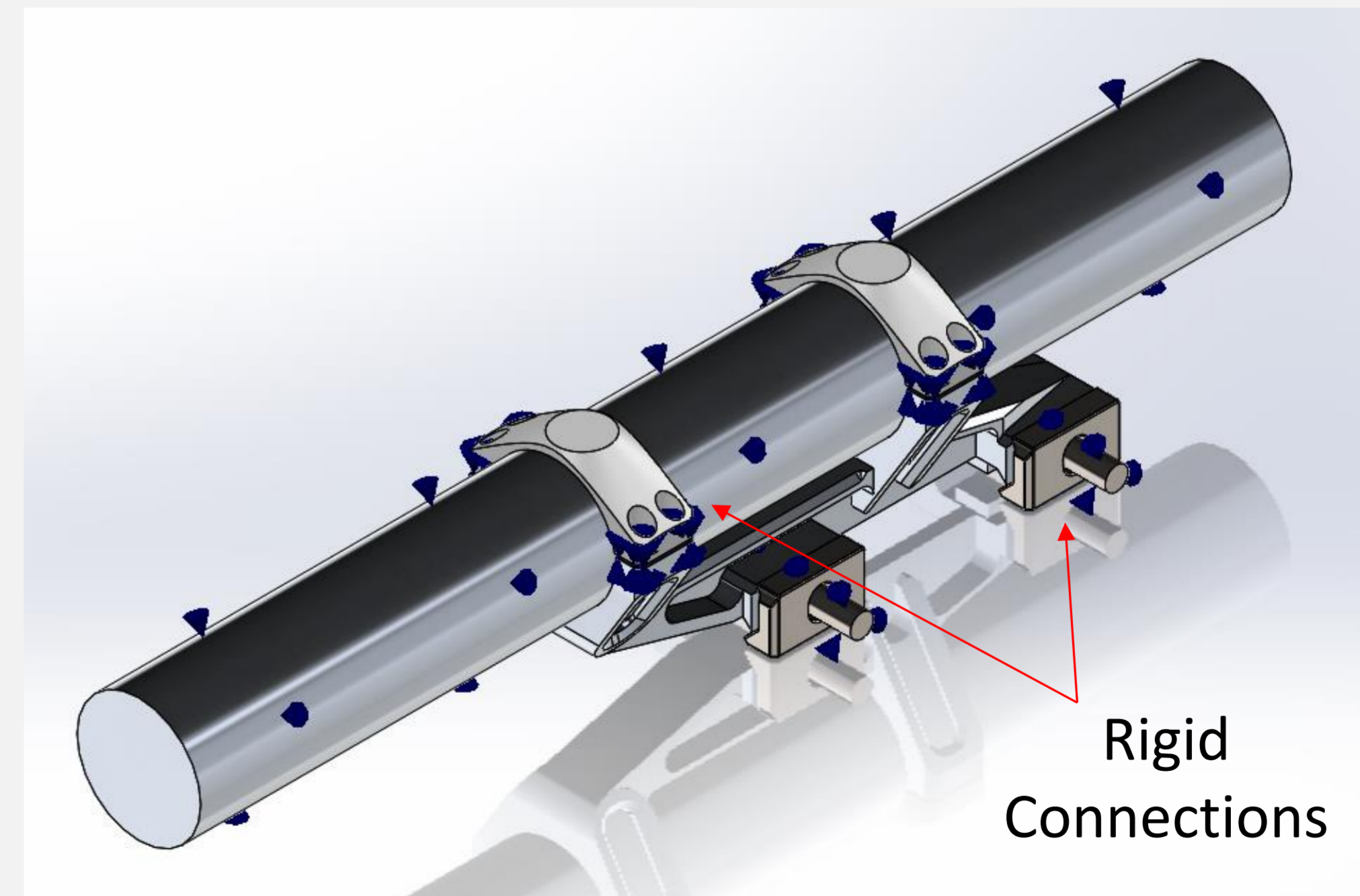


# DESIGN OPTIMIZATION

## SOLIDWORKS SIMULATION SETUP

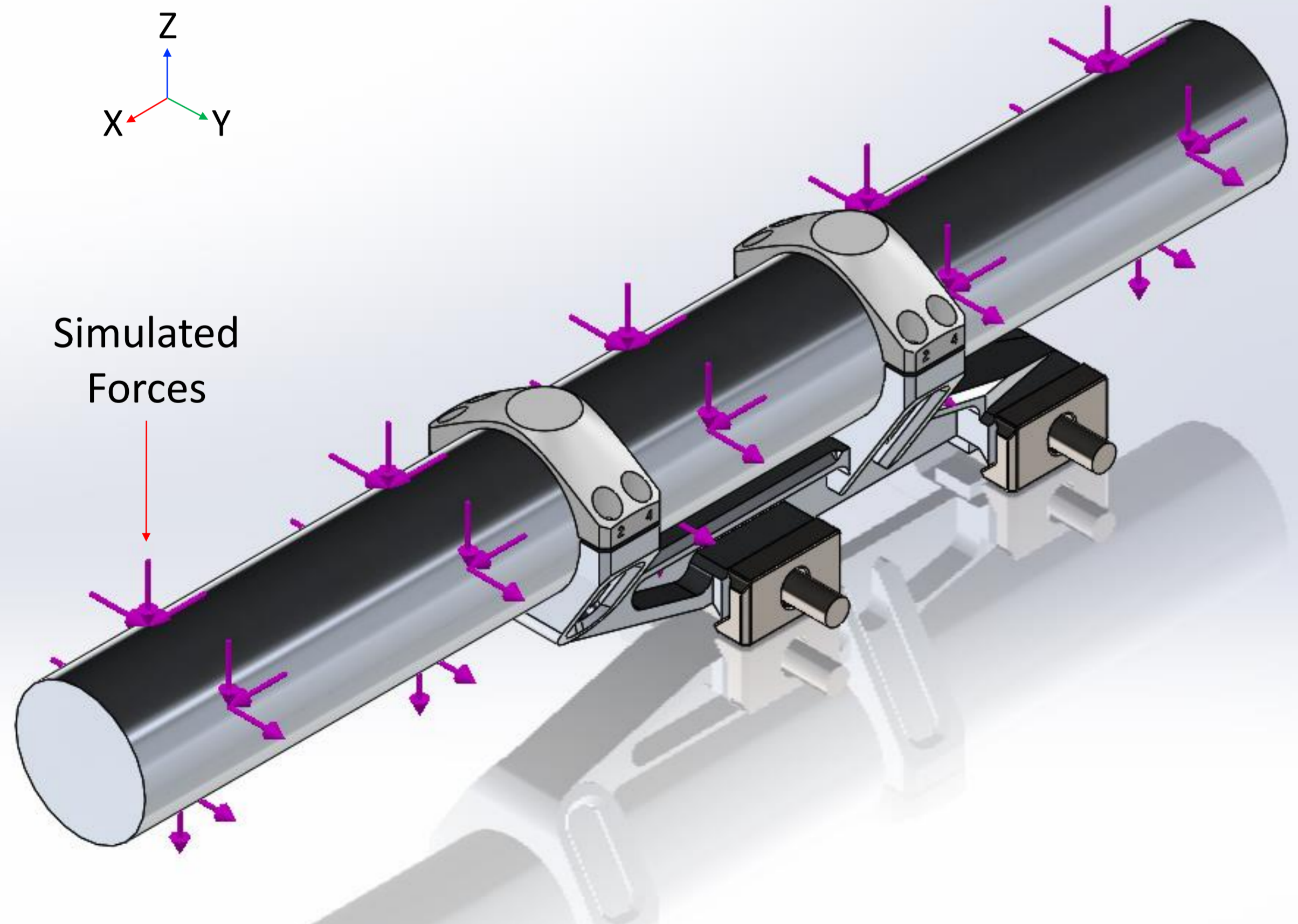


- Jaws of mount are fixed
- Hardware is estimated with rigid connections
- Scope is rigidly connected to mount base and rings



# DESIGN OPTIMIZATION

## SOLIDWORKS SIMULATION FORCES



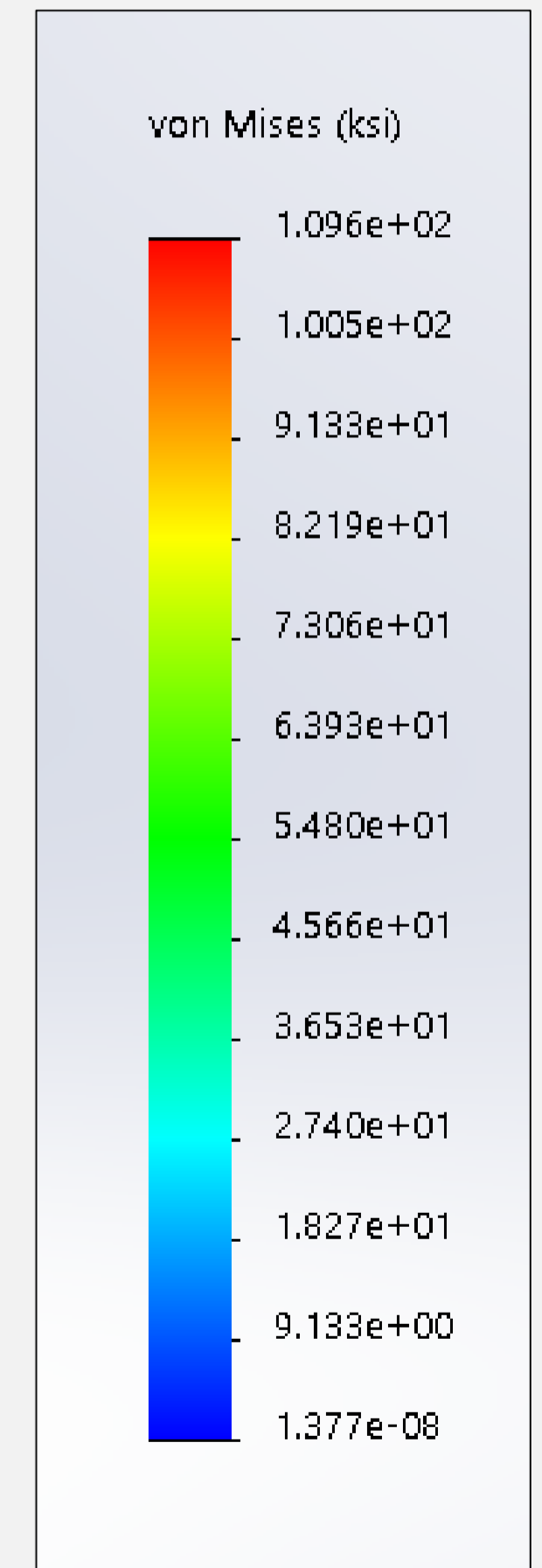
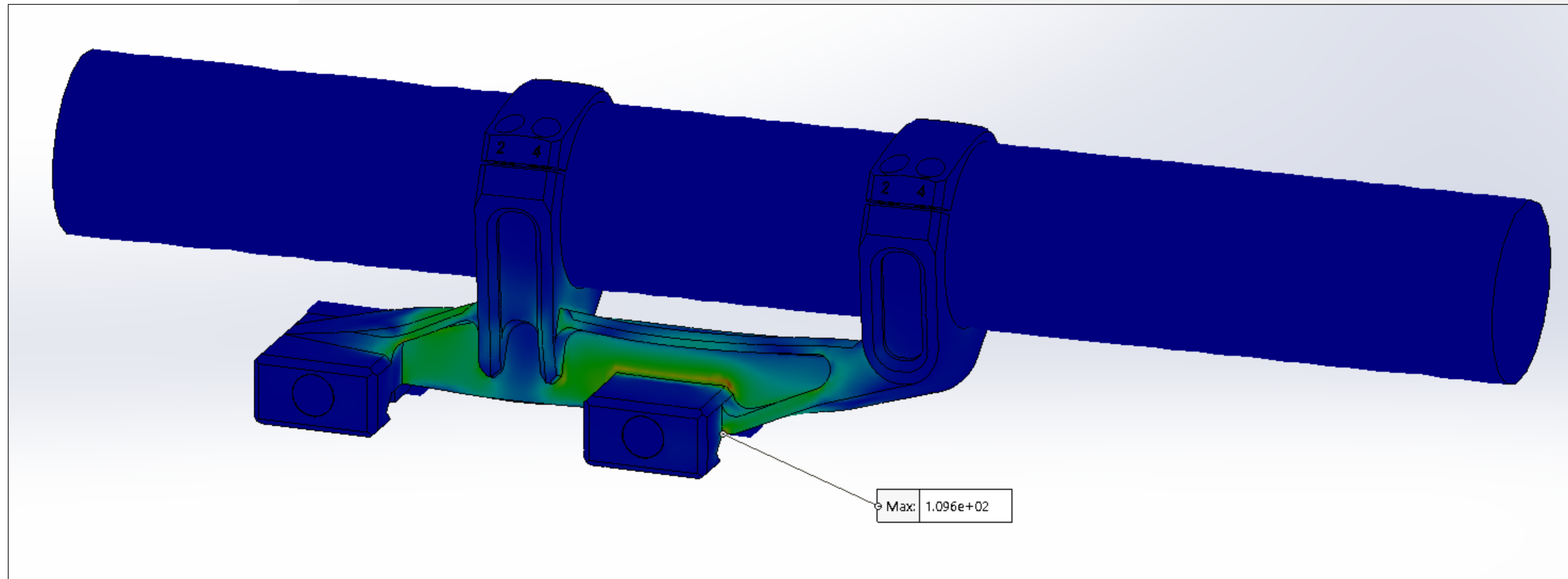
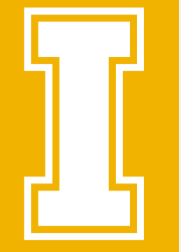
Forces are applied to the scope

- $X = 726$  lbf (Along scope)
- $Y = 741$  lbf (Across scope)
- $Z = 652$  lbf (Vertical)



# DESIGN OPTIMIZATION

## FINITE ELEMENT ANALYSIS RESULTS



# DATA COLLECTION



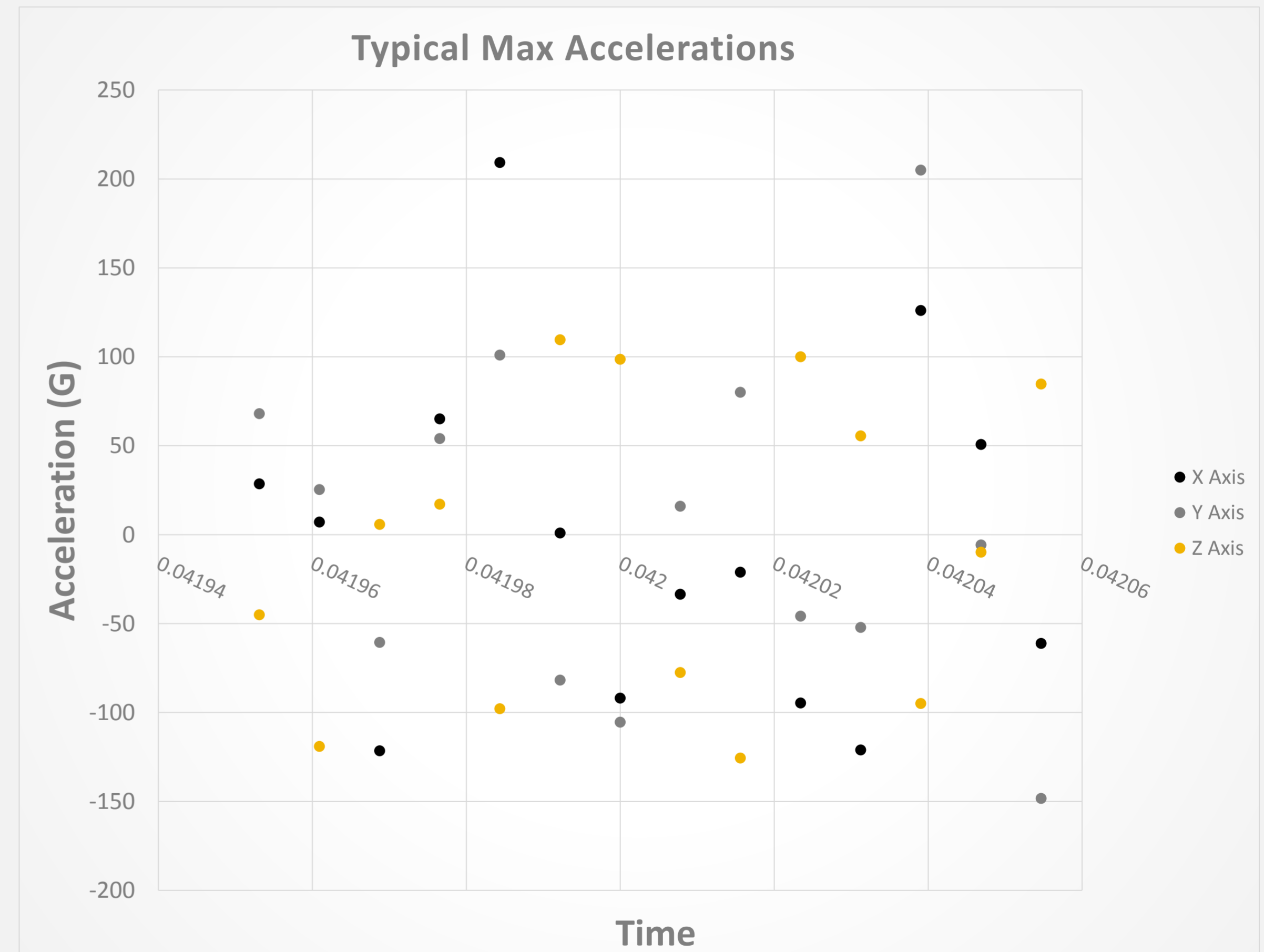
## REVISED DATA ANALYSIS

Accelerations

- Averaged Accelerations
- Strain Rate Sensitivity
- X Axis – 39 G
- Y Axis – 36 G
- Z Axis – 26 G

Forces

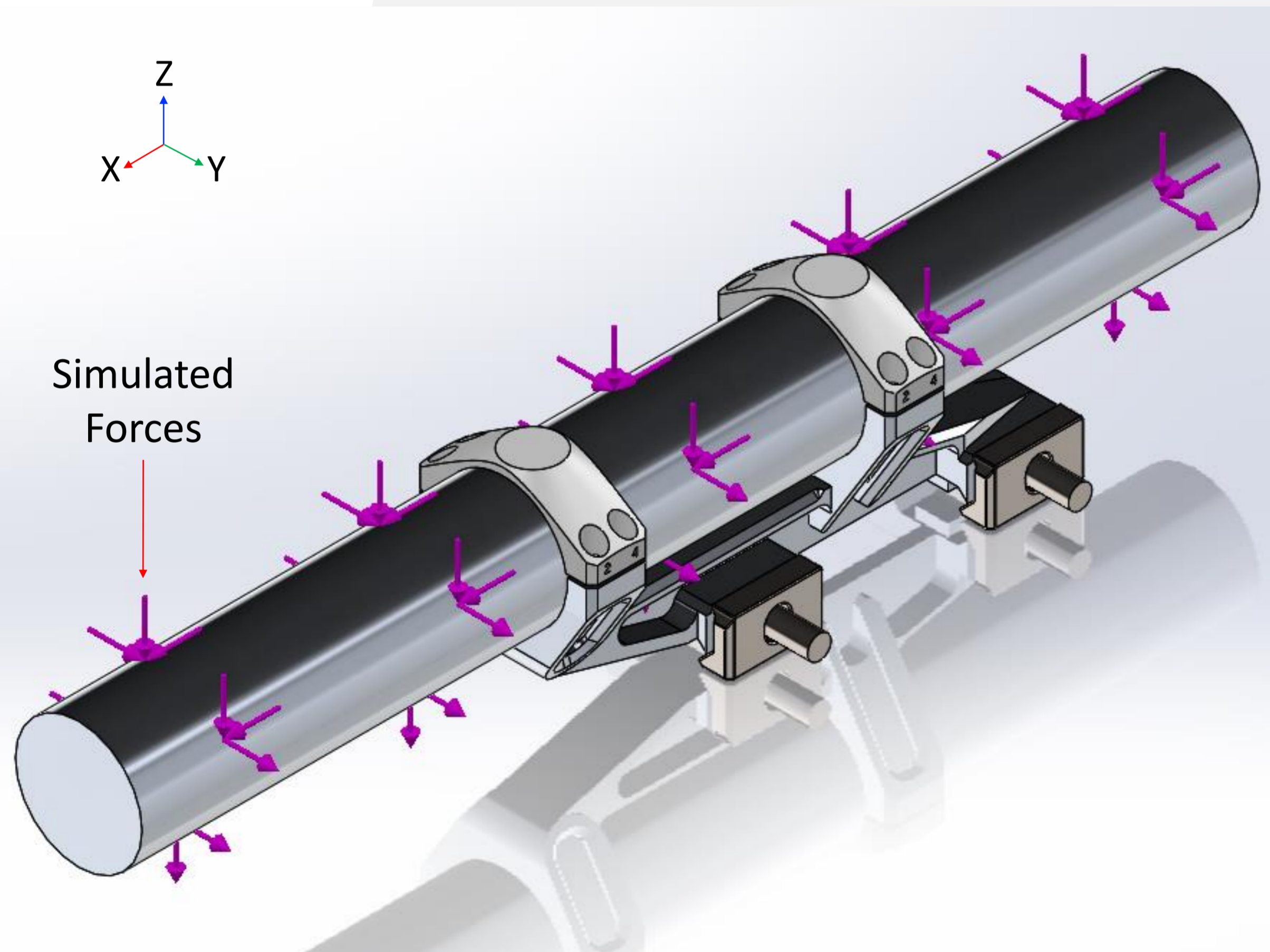
- X Axis – 137 lbf
- Y Axis – 126 lbf
- Z Axis – 93 lbf





# DESIGN OPTIMIZATION

## REVISED SOLIDWORKS SIMULATION FORCES

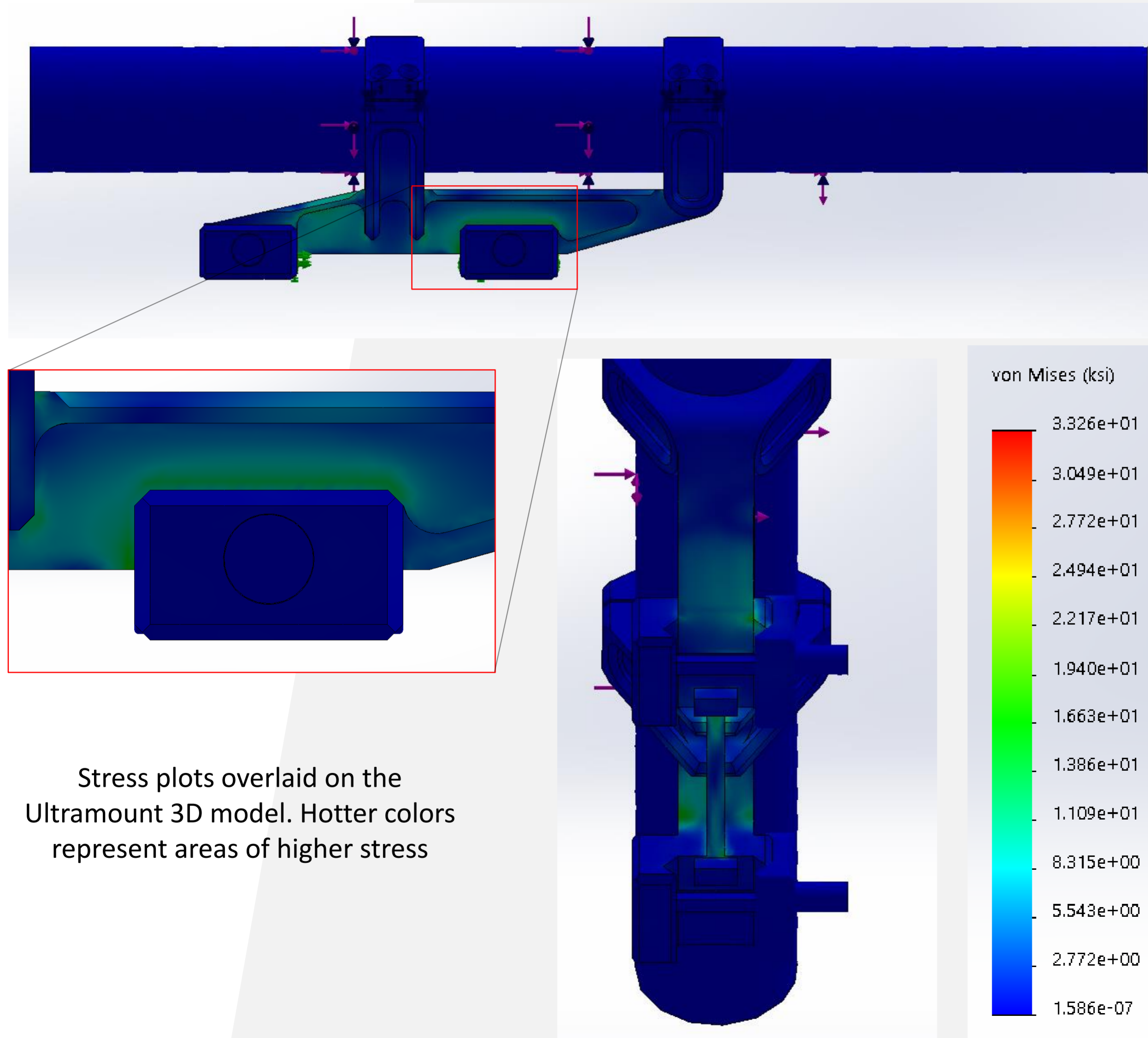


Forces are applied to the scope

- $X = 137.27$  lbf (Along scope)
- $Y = 126.04$  lbf (Across scope)
- $Z = 93.16$  lbf (Vertical)

# DESIGN OPTIMIZATION

## HIGH STRESS REGION IDENTIFICATION



Stress plots overlaid on the Ultramount 3D model. Hotter colors represent areas of higher stress

- Forces are applied to the Ultramount to locate high stress areas
- Between rear scope ring and jaws
  - Infront of front jaw toward front scope ring

High stress areas were noted as points to reinforce for future designs

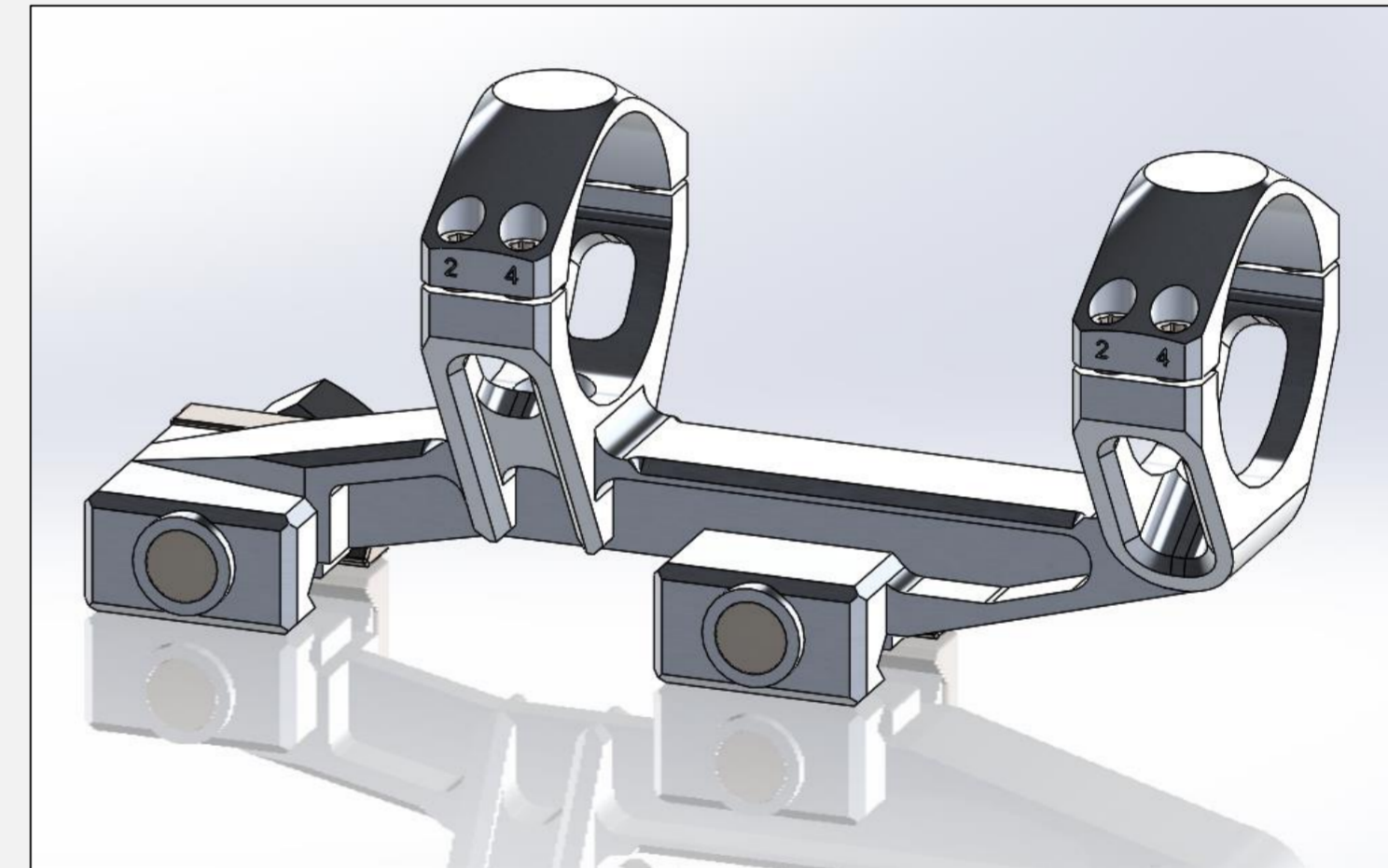
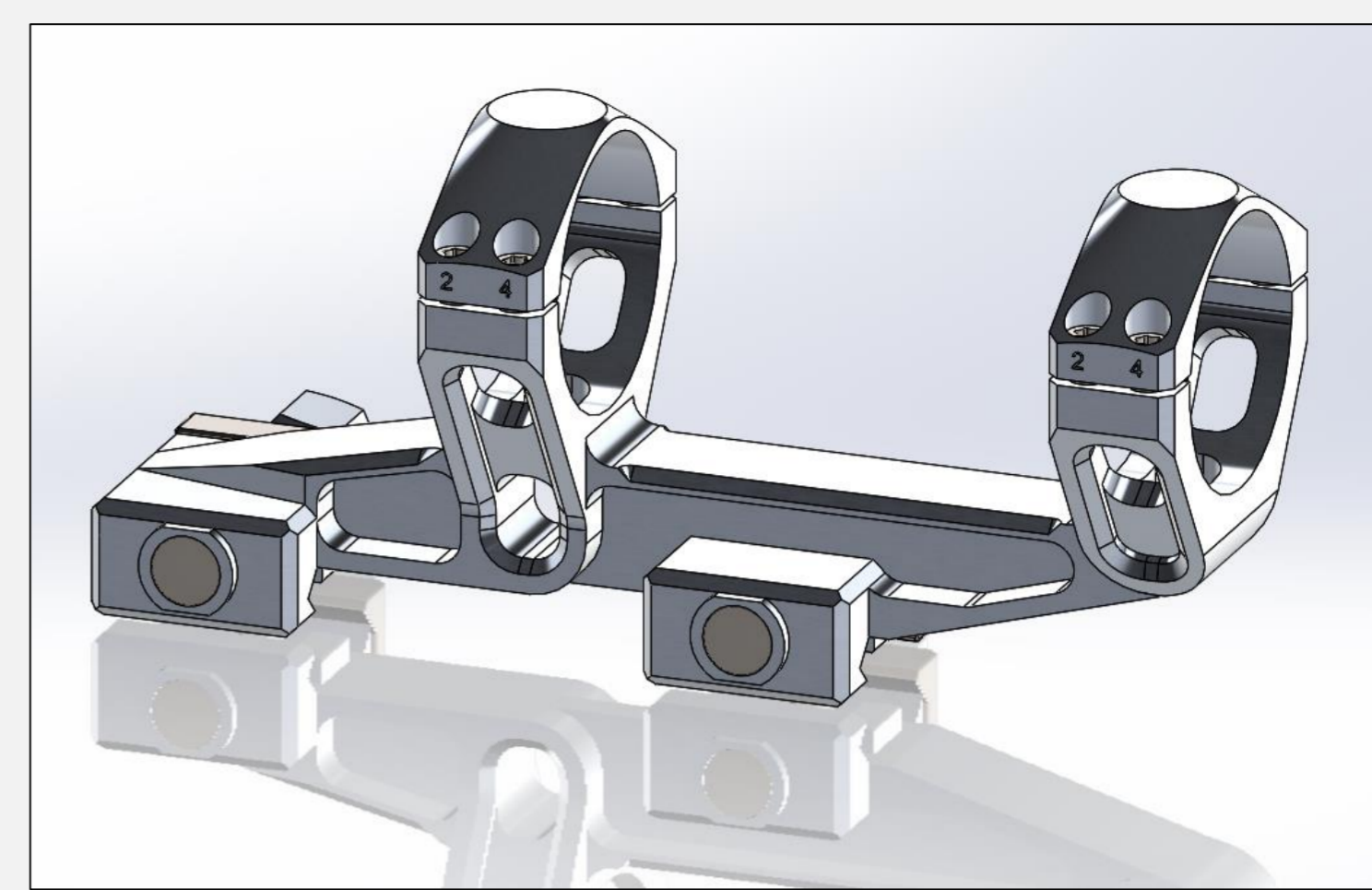


# DESIGN OPTIMIZATION

## DEVELOPMENT

3 new designs were developed over the course of this project

- Designs 1 and 2 are based on the Ultramount design
- Design 3 is a new design focused on weight reduction



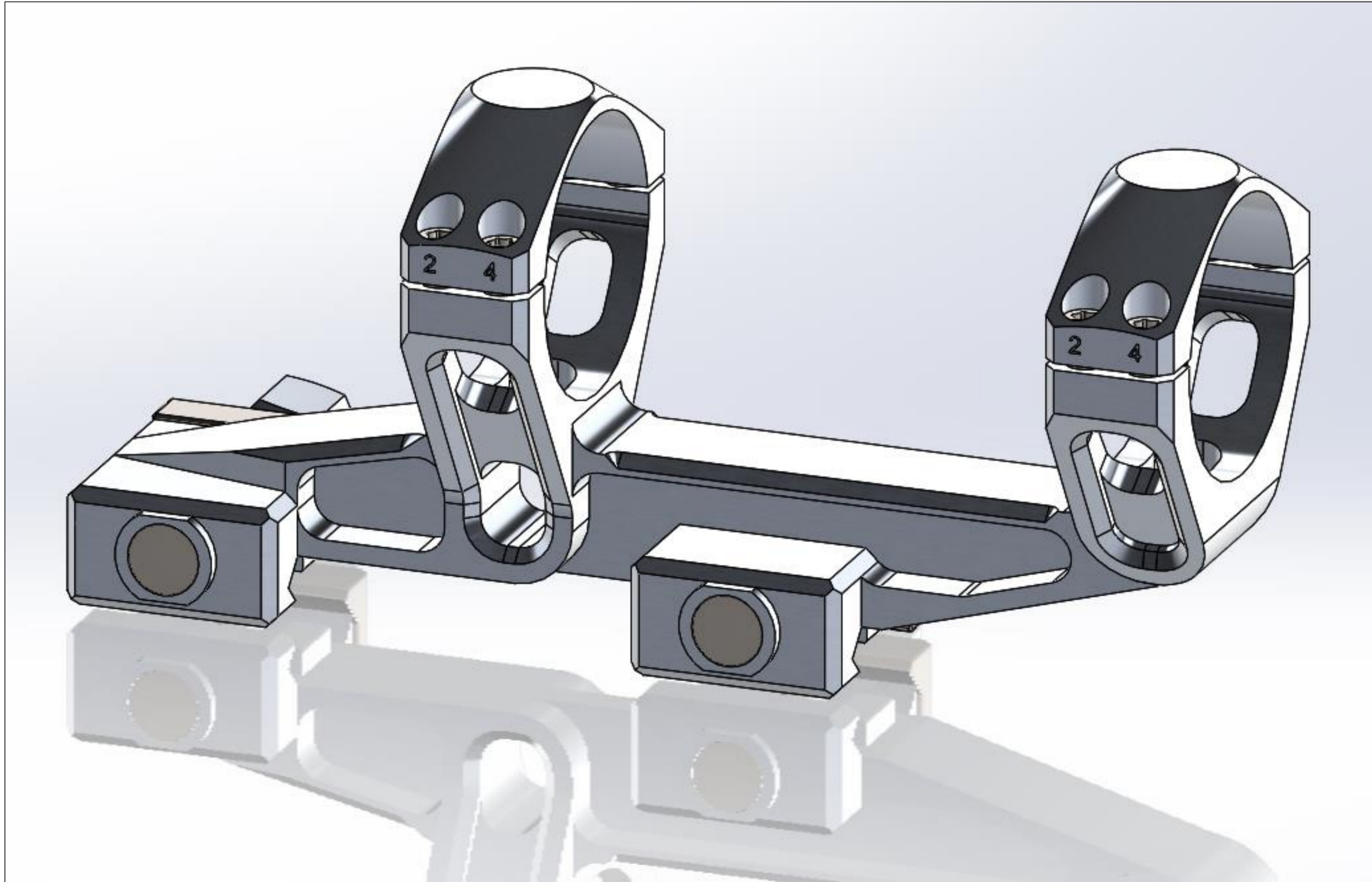


# DESIGN OPTIMIZATION



## DESIGN 1

Mass: 3.541 oz

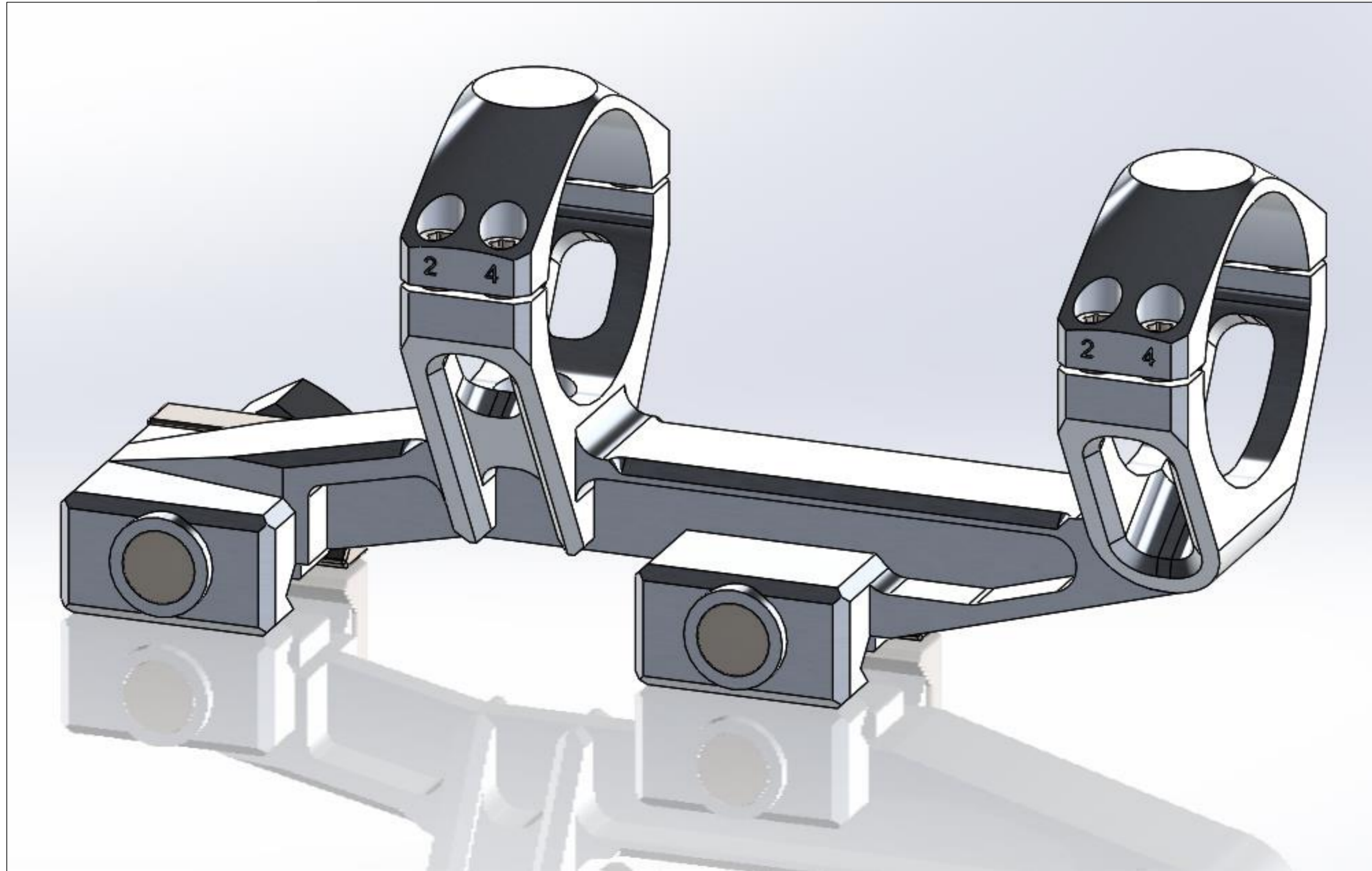




# DESIGN OPTIMIZATION



## DESIGN 2



Mass: 3.339 oz



# DESIGN OPTIMIZATION

## DESIGN 3



Mass: 2.609 oz






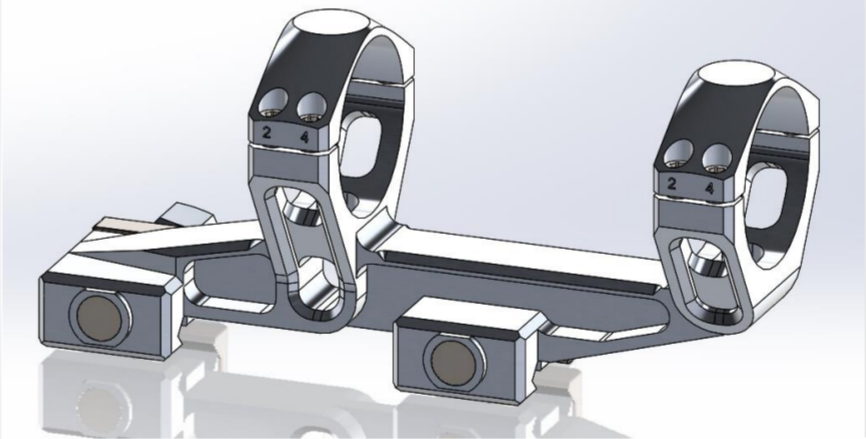
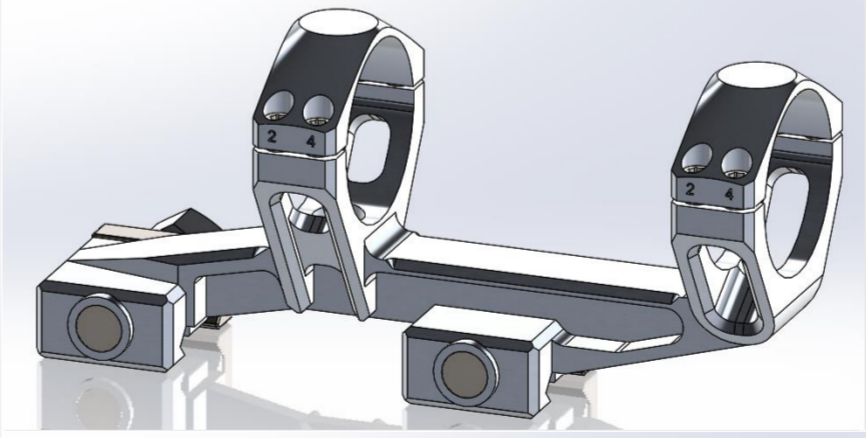
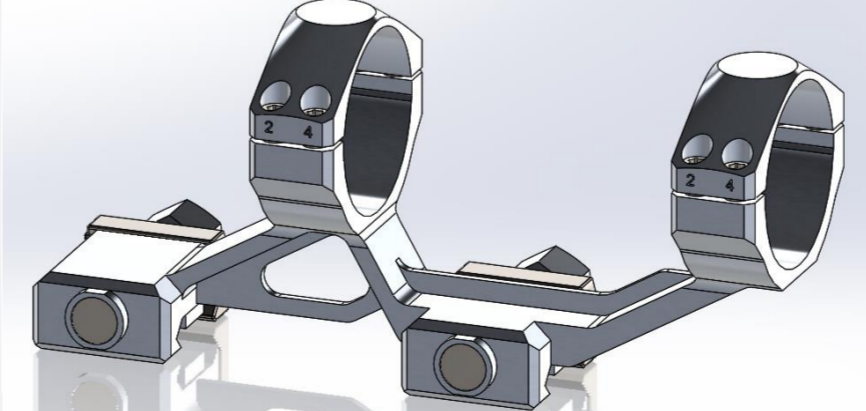
# DESIGN OPTIMIZATION



## FINITE ELEMENT ANALYSIS

The new Designs were placed under the same analysis as the Ultramount for comparison

- Designs 1 and 2 are much stronger
- Design 3 is significantly lighter but weaker than the original

Design Stats. Table			
Image	Design #	Mass (oz) / % Reduction	Peak Stress (ksi)*
	Original	3.689 / 0%	33.26
	1	3.541 / 4%	21.98
	2	3.339 / 9%	24.07
	3	2.609 / 29%	54.79



# VALIDATION

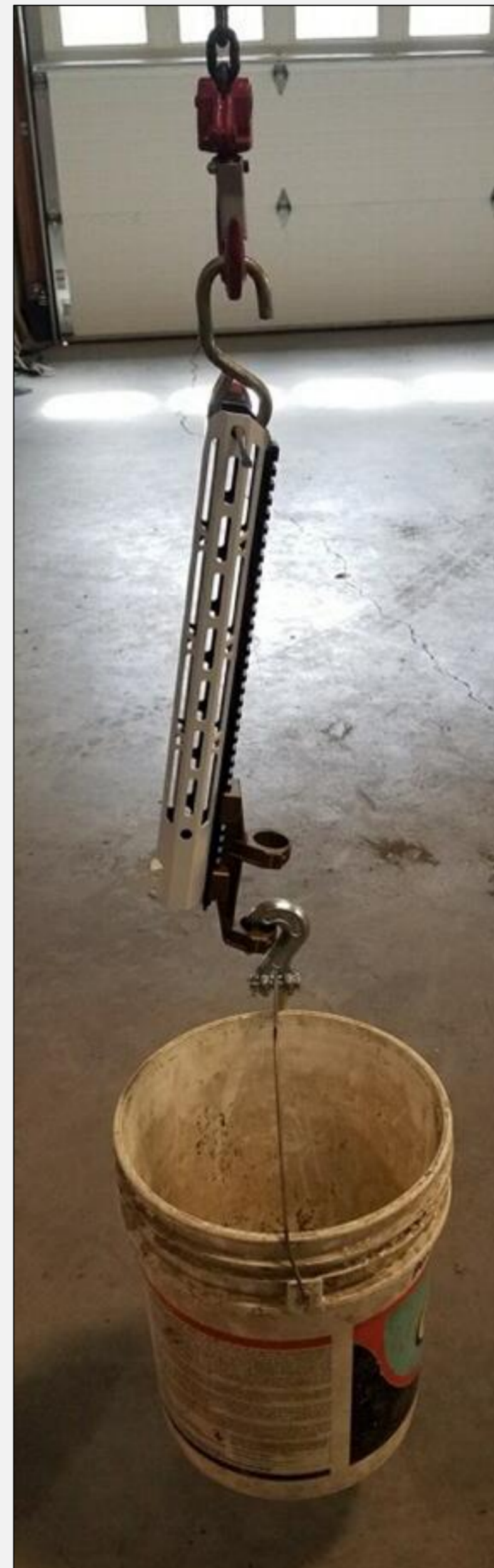
## 3D PRINTED MODELS

Models were 3D printed to validate our simulation methods

- Weights were hung from the front and back rings of the mounts
- Recorded relative displacements
- Test recreated in Solidworks



3D Printed models

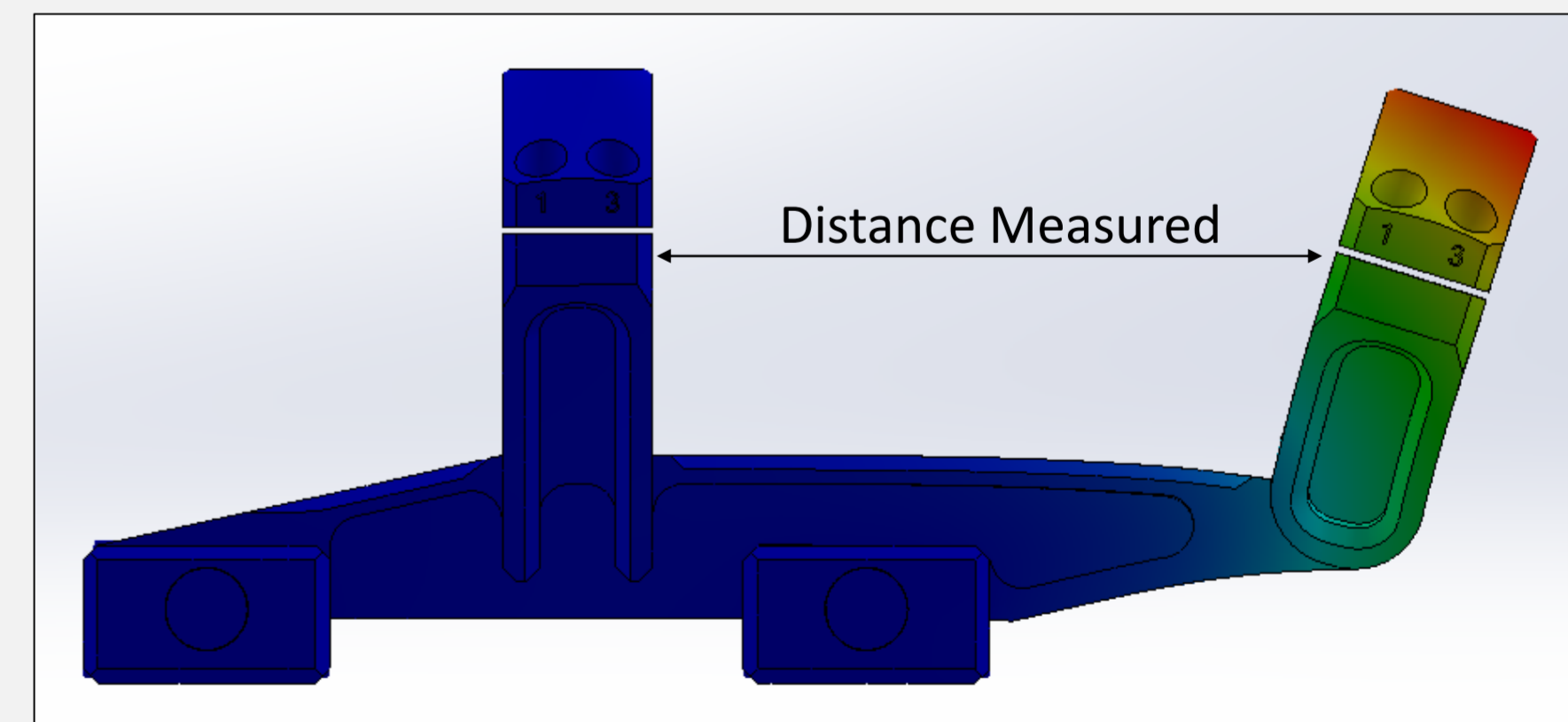


Setup for displacement testing



### 3D Printed Prototype Displacement Results

(Displacement in inches)		Ultramount	Design 1	Design 2	Design 3
Simulation	Displacement (Back Ring)	0.00584	0.007671	0.007763	0.1511
	Displacement (Front Ring)	0.02119	0.02231	0.02721	0.01378
Experimental	Displacement (Back Ring)	0.014	0.01	0.033	0.05
	Displacement (Front Ring)	0.042	0.077	0.09	0.396



Solidworks simulation for comparison



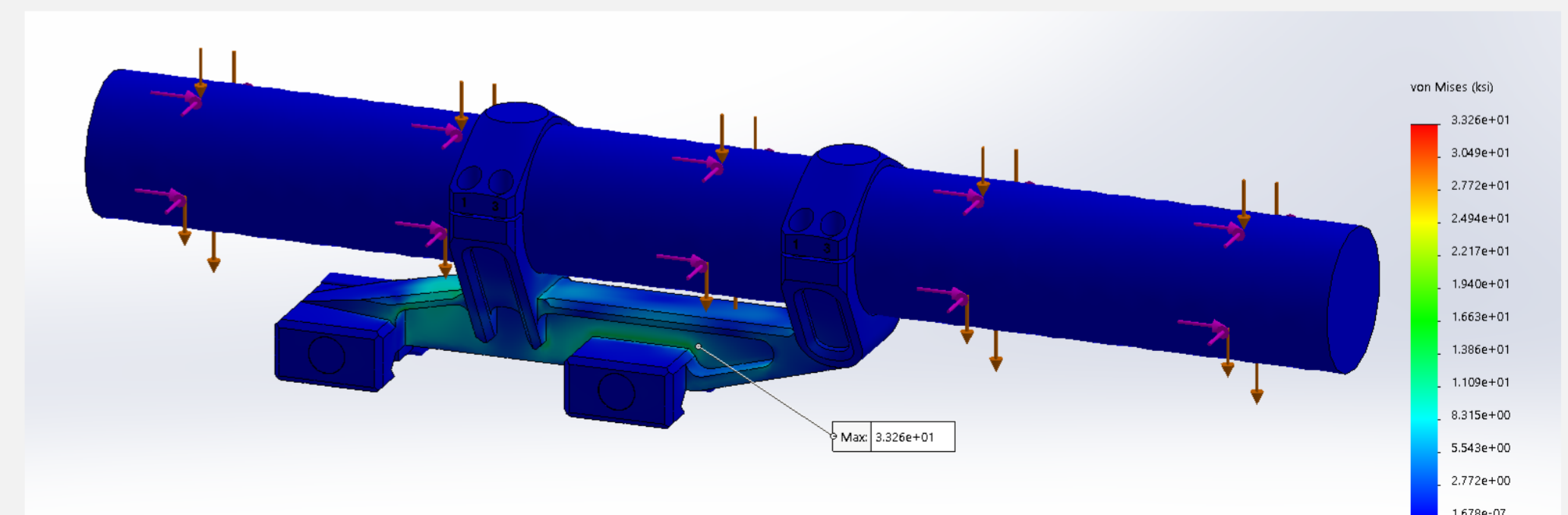
# CONCLUSIONS AND DELIVERABLES



- Three new designs furnished
  - 29% max reduction in mass (Design 3)
  - 34% max reduction in stress (Design 1)
- Three material candidates were proposed
  - Al 7068 was safest option overall
  - Mg AZ61A has highest potential for cost and mass savings with a reduction in strength
- Process developed
  - Data collection and analysis
  - Finite Element Analysis
  - Pinpointing stress & redesign

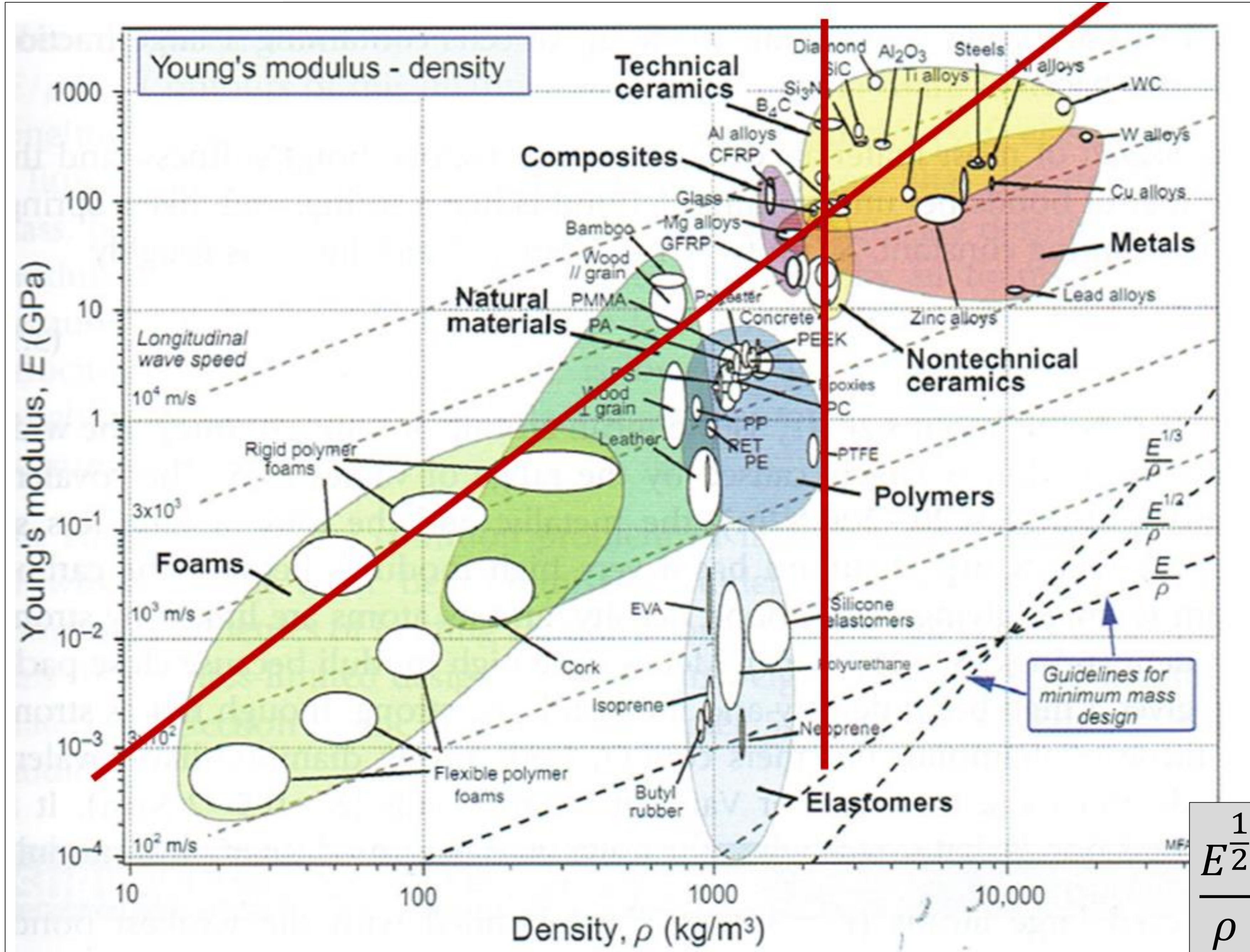
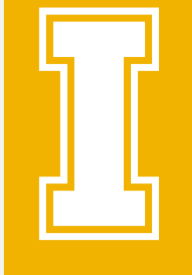


(Aluminum Suppliers)



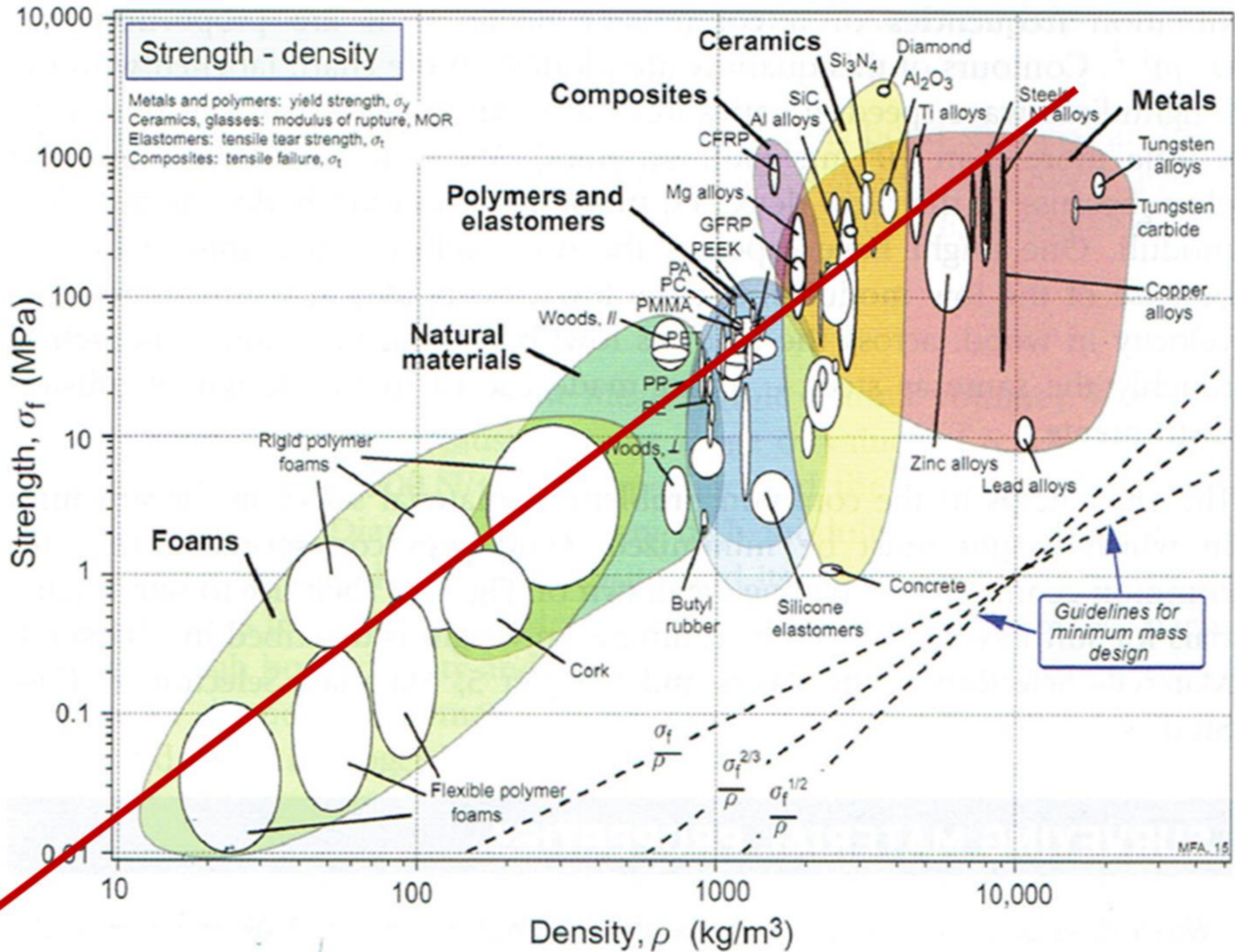
Questions?





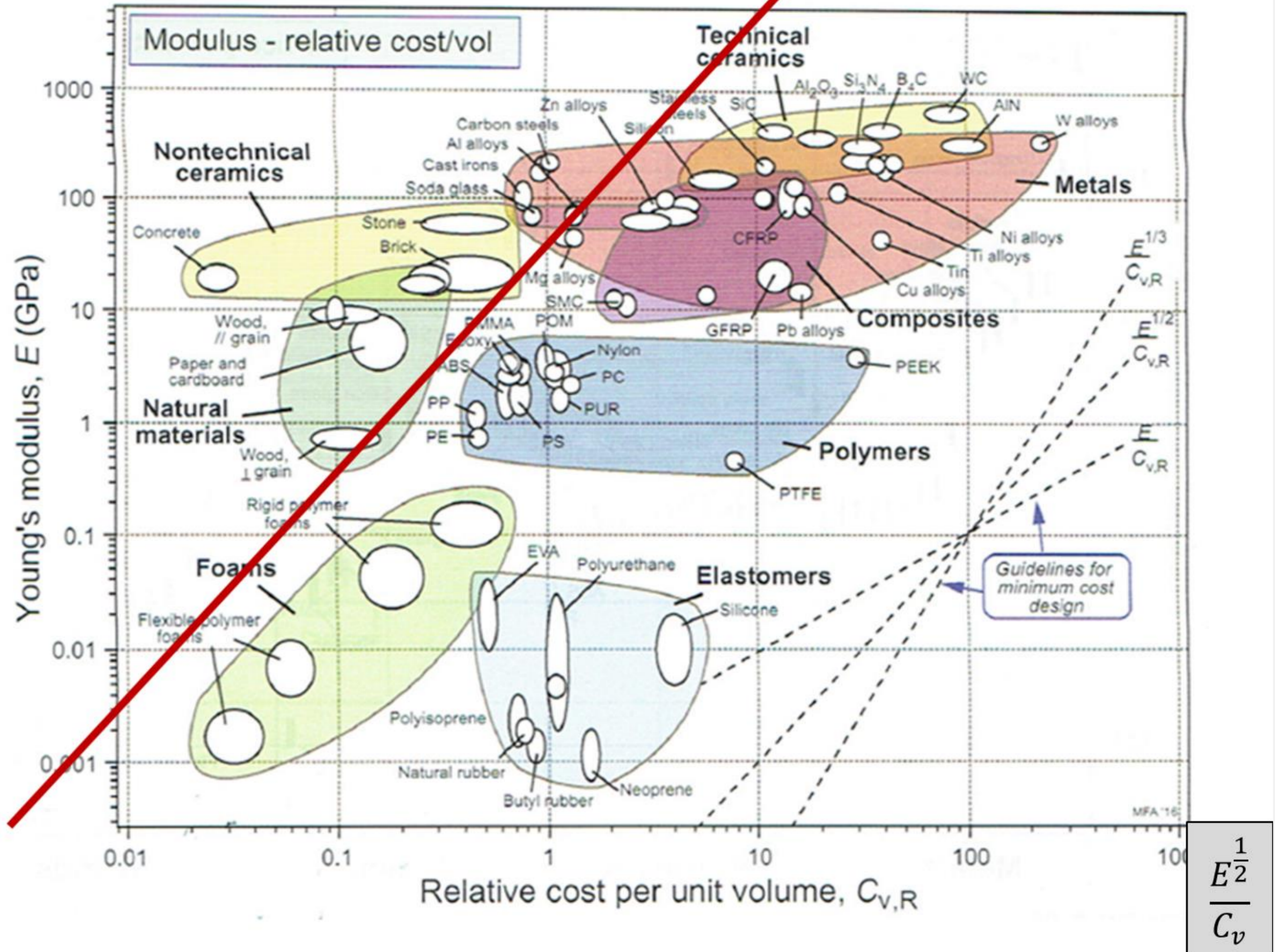
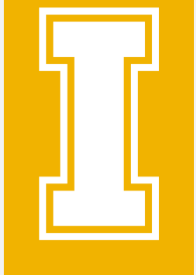
$$\frac{1}{E^2} \rho$$





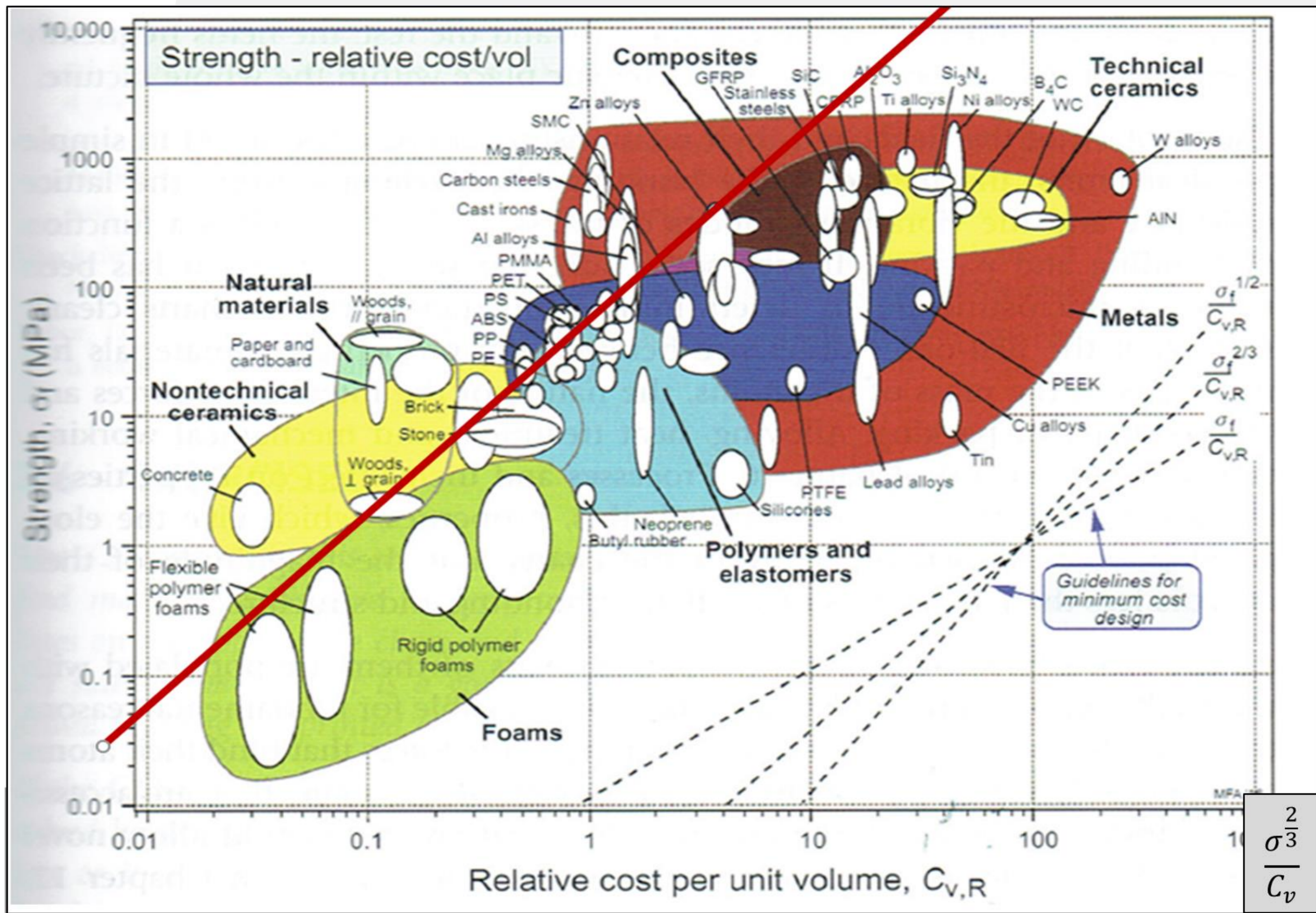
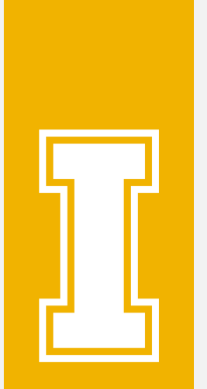
$$\frac{\sigma_f^{2/3}}{\rho}$$





$$\frac{1}{C_v} E^{\frac{1}{2}}$$





$$\frac{\sigma^2}{C_v}$$



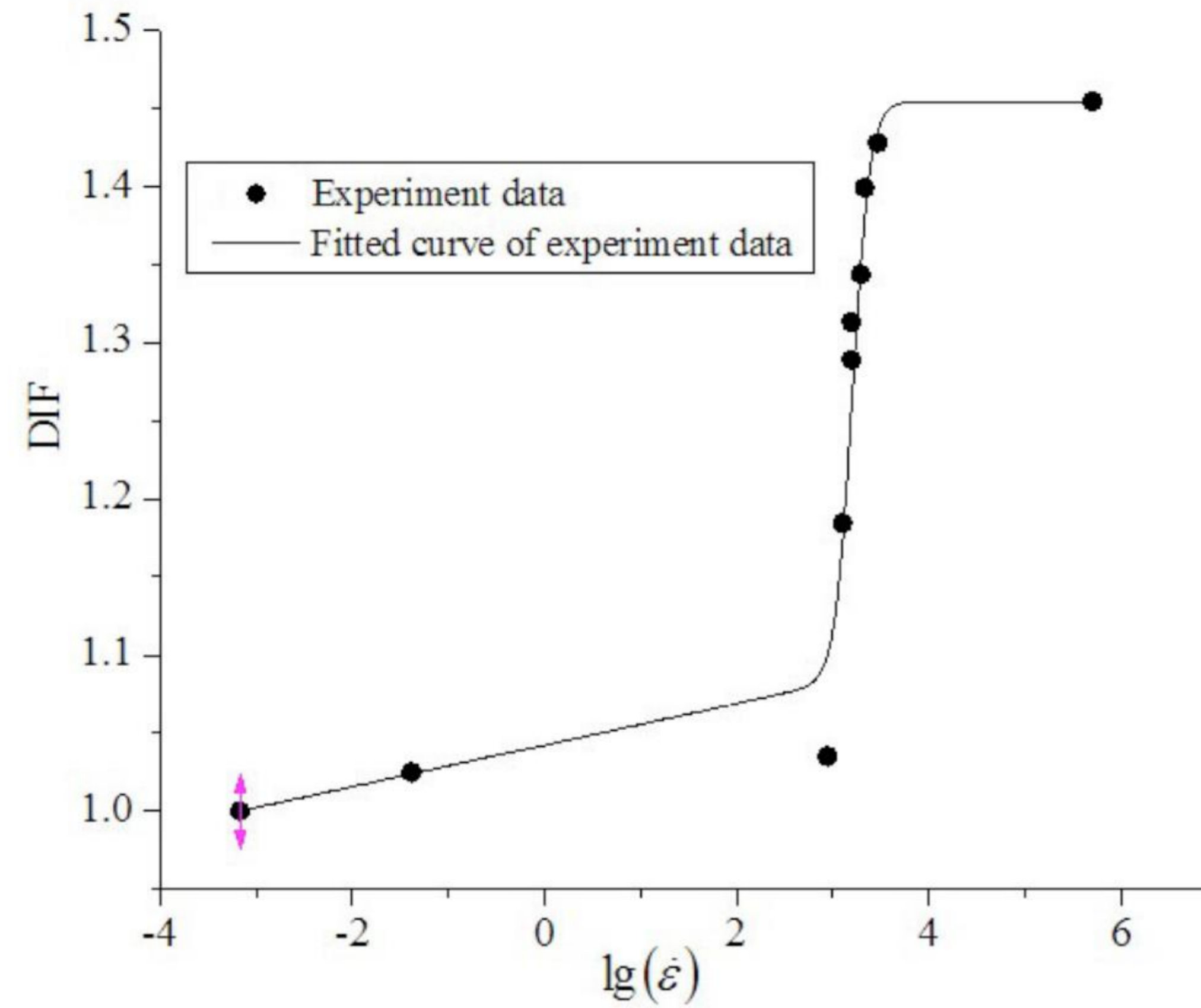


Figure 2 The relationship between DIF and common logarithmic of strain-rate for 7075 aluminum

(Strain rate effects on tensile deformation of 2024-0 and 7075-0 aluminum alloy sheet)



		Axis Maximum and Minimum Acceleration Values Live Fire Data																							
		Front of Rail						Rear of Rail						Front Scope Position						Rear Scope Position					
Shooter Size	Shot Number	$X_{max}$	$X_{min}$	$Y_{max}$	$Y_{min}$	$Z_{max}$	$Z_{min}$	$X_{max}$	$X_{min}$	$Y_{max}$	$Y_{min}$	$Z_{max}$	$Z_{min}$	$X_{max}$	$X_{min}$	$Y_{max}$	$Y_{min}$	$Z_{max}$	$Z_{min}$	$X_{max}$	$X_{min}$	$Y_{max}$	$Y_{min}$	$Z_{max}$	$Z_{min}$
Large	1	172.3	-140.7	144.8	-112.9	123.6	-101.0	111.4	-104.1	110.1	-85.9	73.6	-62.5	194.4	-148.0	156.0	-143.7	174.4	-145.5	144.6	-136.6	150.6	-126.0	121.2	-101.6
	2	161.6	-124.5	129.3	-121.5	98.4	-87.6	110.9	-105.4	96.0	-125.5	79.2	-76.1	145.3	-138.4	142.9	-124.6	146.9	-118.1	148.4	-137.6	156.1	-126.8	123.8	-126.0
	3	131.0	-144.6	182.2	-136.8	121.4	-112.0	121.6	-89.7	111.1	-104.6	75.5	-65.6	183.6	-135.5	163.4	-124.4	168.6	-127.5	209.2	-149.2	204.9	-148.4	143.4	-125.7
	4	144.8	-137.6	100.5	-107.9	98.4	-94.2	113.3	-98.6	111.8	-105.1	129.5	-81.7	132.9	-137.9	160.6	-141.6	183.0	-124.2	144.0	-132.3	149.9	-128.4	122.9	-126.3
	5	157.5	-138.7	129.1	-109.3	83.5	-89.2	122.4	-113.4	89.1	-106.5	152.8	-76.3	155.5	-143.1	167.7	-139.2	146.2	-110.5	192.3	-153.5	190.5	-154.9	133.6	-107.1
Medium	1	132.4	-126.7	90.2	-91.8	105.8	-98.5	199.5	-144.7	122.1	-126.1	97.5	-90.3	137.5	-143.8	131.4	-132.1	130.2	-127.1	126.5	-118.4	150.7	-127.3	143.2	-113.9
	2	125.9	-83.0	73.1	-103.0	85.9	-72.4	98.6	-121.0	97.7	-108.3	87.4	-78.1	186.0	-130.5	184.6	-132.2	187.9	-119.8	127.6	-146.8	178.7	-127.6	131.7	-113.4
	3	113.6	-102.8	87.2	-105.2	67.3	-77.3	72.7	-65.2	75.5	-74.7	56.7	-71.8	164.0	-152.9	181.9	-143.7	174.9	-119.6	138.1	-141.0	152.9	-123.8	119.5	-130.4
	4	122.3	-107.3	139.8	-127.0	92.2	-85.0	85.2	-76.1	69.4	-66.2	58.2	-65.6	192.7	-133.8	139.1	-129.3	166.7	-139.2	118.6	-131.4	176.8	-152.9	100.2	-116.2
	5	111.2	-129.3	135.5	-107.9	92.2	-98.3	106.3	-111.6	104.5	-110.5	62.8	-91.7	162.6	-139.8	148.3	-127.6	136.9	-119.1	172.1	-137.4	176.9	-150.5	130.2	-135.9
Small	1	98.5	-91.4	65.6	-62.2	81.8	-59.1	60.2	-83.3	67.5	-73.8	54.8	-54.0	135.1	-133.3	151.5	-129.6	124.0	-123.9	132.0	-124.9	125.9	-114.9	140.6	-91.9
	2	88.8	-73.4	100.9	-67.5	73.9	-87.5	61.6	-91.3	60.7	-77.1	62.9	-62.9	172.4	-132.9	145.2	-139.2	150.1	-143.4	174.7	-144.6	127.2	-135.5	97.6	-93.5
	3	79.4	-86.4	76.5	-79.3	90.8	-61.1	78.8	-124.2	111.1	-102.7	81.1	-57.7	172.4	-132.9	145.2	-139.2	150.1	-143.4	175.0	-131.0	178.7	-104.4	122.4	-106.9
	4	91.7	-86.0	69.3	-67.0	60.9	-54.8	61.7	-117.7	78.4	-89.2	70.0	-55.4	205.5	-141.5	199.3	-144.0	139.4	-114.9	183.9	-150.9	164.6	-140.9	139.7	-119.7
	5	112.0	-88.3	89.1	-96.9	84.1	-65.4	128.5	-122.8	110.4	-129.3	58.3	-72.8	145.8	-150.7	207.6	-143.9	142.8	-112.2	145.6	-139.3	182.2	-141.1	123.1	-129.3
Unsupported	1	120.5	-118.2	107.1	-98.4	80.8	-70.1	142.1	-124.4	112.2	-143.2	106.6	-95.0	152.6	-143.0	213.4	-152.2	162.3	-131.7	134.5	-117.2	148.6	-133.6	139.9	-148.6
	2	128.3	-136.0	116.6	-117.7	100.0	-85.7	164.7	-125.0	130.1	-130.8	104.4	-92.1	180.9	-157.3	178.2	-155.3	154.8	-149.5	169.4	-132.3	106.7	-139.0	131.8	-123.6
	3	161.4	-117.1	96.7	-131.6	92.7	-96.6	188.6	-151.9	130.8	-130.5	146.0	-132.5	135.1	-136.1	173.0	-145.9	131.8	-111.0	150.6	-140.3	178.0	-124.6	106.4	-116.0
	4	135.6	-145.2	100.9	-89.6	106.0	-94.3	165.0	-159.6	172.1	-145.2	141.6	-116.4	173.1	-150.2	192.1	-145.8	171.1	-137.3	141.8	-122.1	138.0	-129.2	110.0	-127.0
	5	123.1	-141.1	126.7	-88.6	115.7	-105.3	188.5	-126.7	153.9	-125.0	122.0	-127.6	160.4	-146.7	189.1	-149.8	155.0	-132.4	110.0	-130.4	114.6	-126.2	113.7	-133.9