FINAL DESIGN REVIEW
AIR BEARING UPGRADE FOR SHPB EXPERIMENT

Group 1

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Sponsored by Eglin Air Force Research Laboratory

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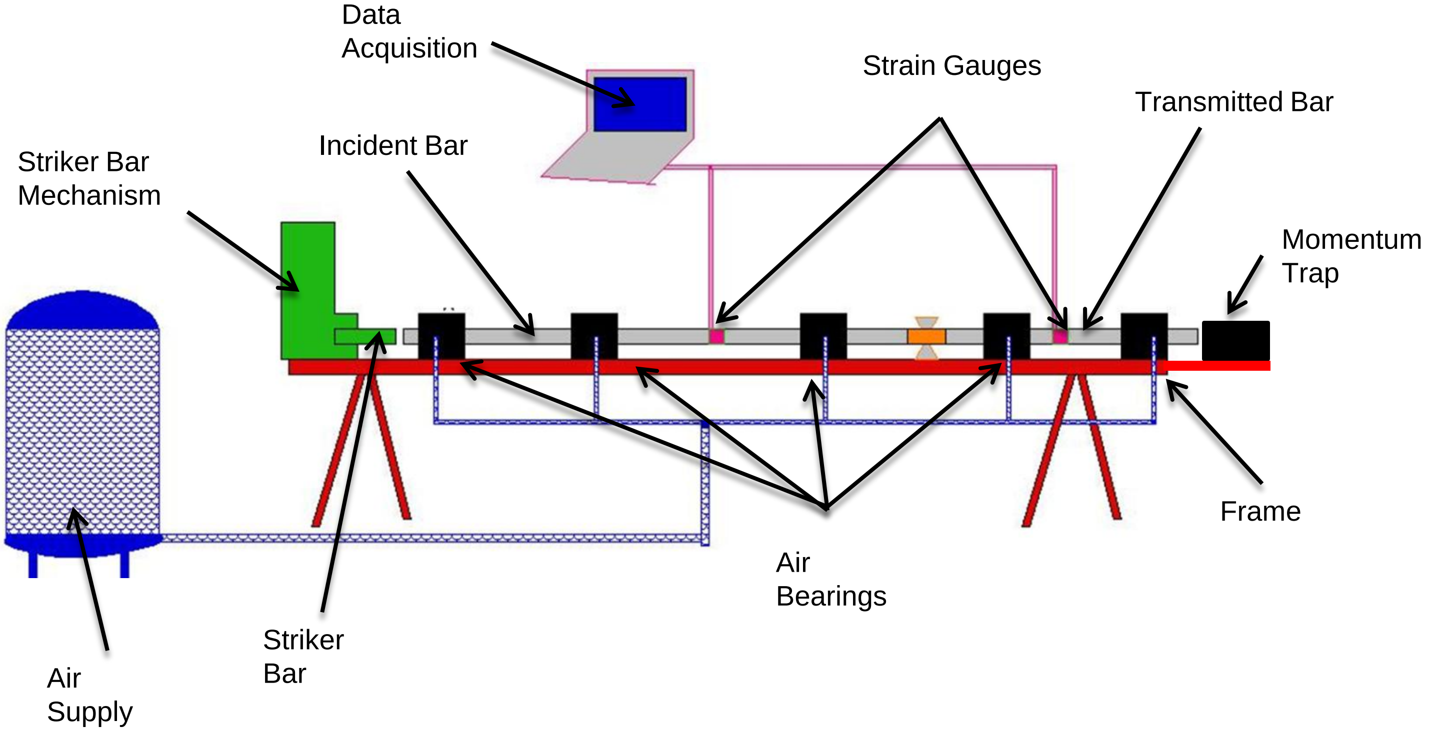
Overview

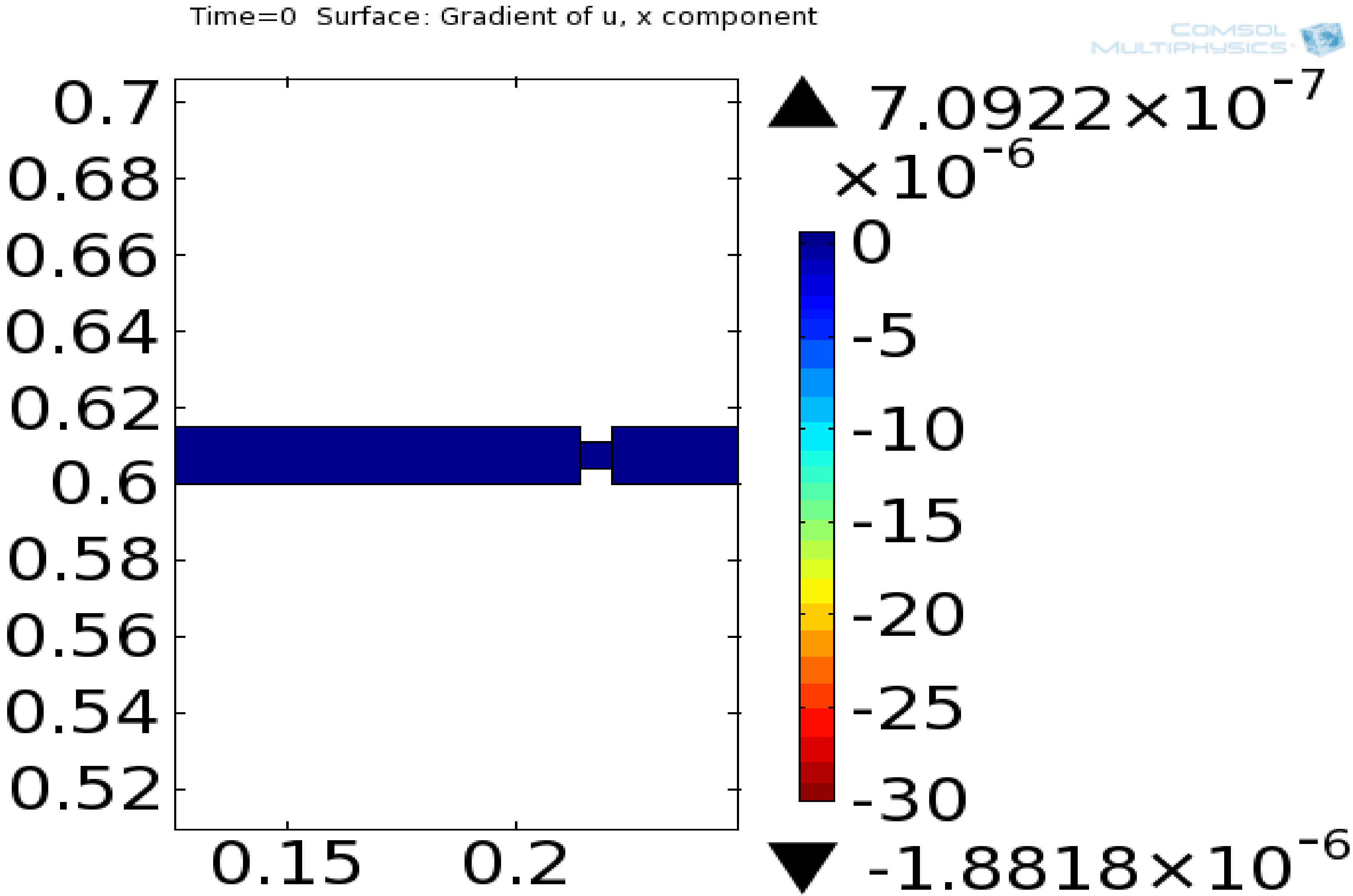
- Introduction
- Needs Assessment
- Objectives
- Design Concepts
- Decision Matrix
- Final Concept
- Cost Analysis
- System Analysis
- Environment & Safety Concerns
- Remaining Schedule
- Questions

Introduction – Overall Design

- Design small scale SHPB system



Introduction - Shock Wave



Needs Assessment

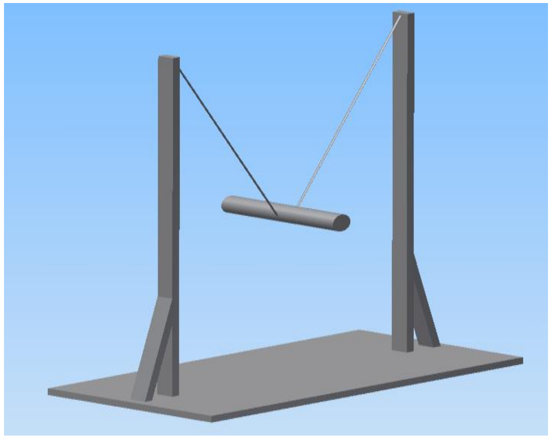
"Warhead design engineers and material scientists require mechanical property information under high deformation rates of loading on a wide variety of materials that have military significance. The most generally accepted technique for gathering such information is the SHPB experiment. The Air Force Research Laboratory's Damage Mechanisms Branch has operated such an experiment for approximately 30 years. The Damage Mechanisms Branch has a requirement to replace the current bearing system with a new air bearing design."

Objectives

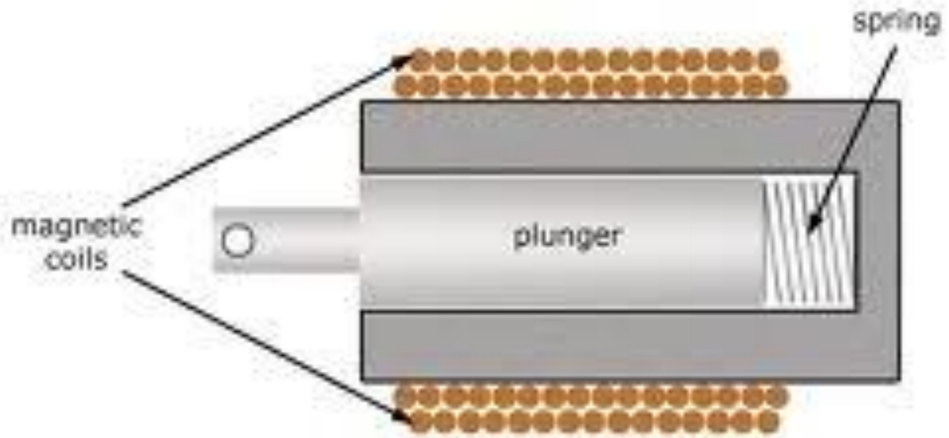
- Analyze SHPB design based on use of air bearings
- Provide analysis of:
  - Hardware cost
  - Interface requirements
  - Installation procedures
  - Impact on bar geometry
- Provide assessment of strain gauge technology
- Develop procedure to align bars
- Design a working prototype to show knowledge of system

Striker Bar Mechanism Designs

- Pendulum
  - Cost Efficient, < $50
  - Scalable
  - Easily Built



- Solenoid
  - Consistent Velocities
  - Feasible, <$100
  - Reliable Function



Incident & Transmission Bar Selection

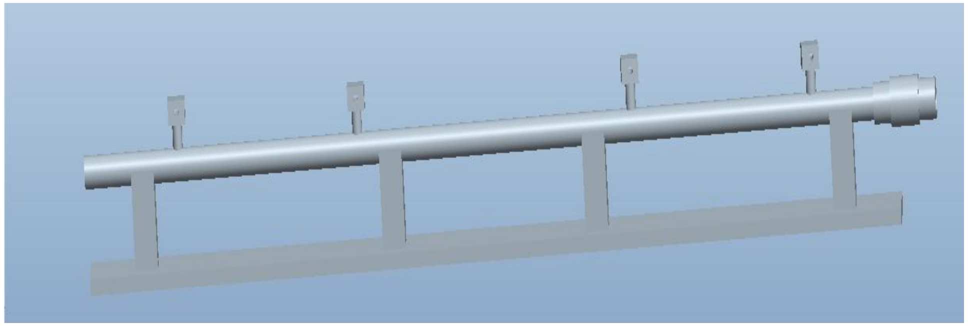
- Company: McMaster-Carr
  - 1566 Case Hardened Steel
  - 36” length
  - 0.5”diameter
    - $20.00
  - 0.75” diameter
    - $30.00
  - High Tolerances
    - Diameter: 0.0005” to -0.001”
    - Straightness: 0.002” per ft

Air Bushings Selection

- Companies
  - New Way Air Bearings
  - Nelson Air Corp.
- Sizes
  - 0.5” Bushings
    - $210.00 each (New Way)
    - $262.00 each (Nelson
  - 0.75” Bushings
    - $265.00 each (New Way)
    - $331.00 each (Nelson)

Air Supply & Manifold Design

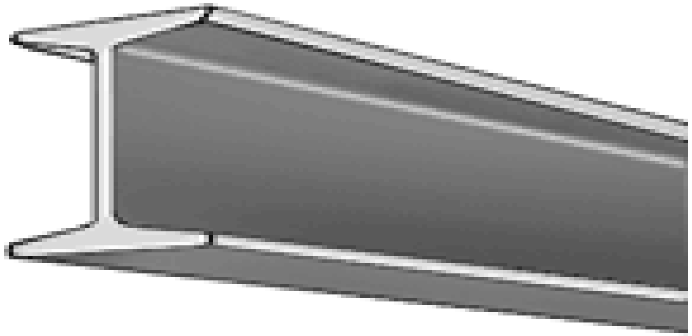
- Air Supply
  - Compressed Tank
  - Compressor

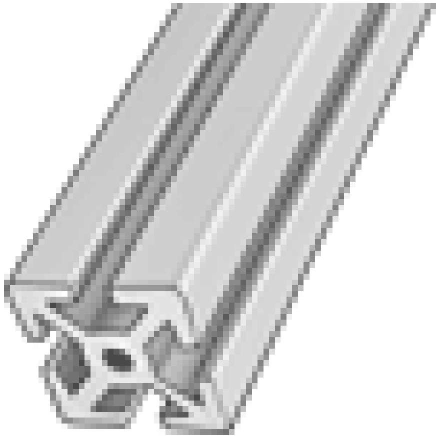


- Horizontal Manifold
  - Steel Pipe
    - < 100 psi
  - Bushing Supply
    - 4 Valves
  - System Purge
    - 1 Valve

Base Structure Selection

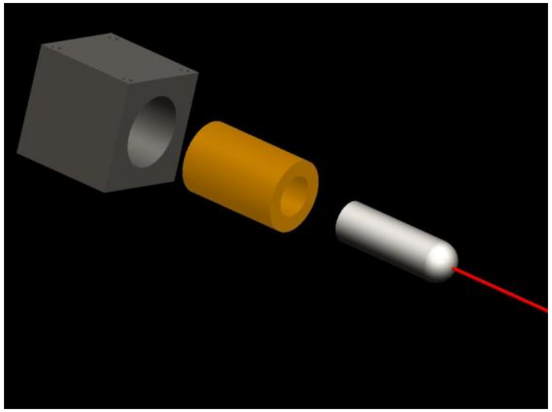
- I-Beam
  - Scalable
  - High Strength
  - Cost < $100
  - Heavy
- T-Slotted Framing
  - Scalable
  - Rigid
  - Cost < $150
  - Lightweight



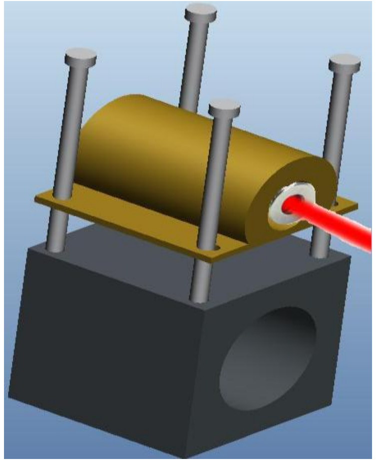


Air Bushing Alignment Method

- Center Bore Alignment
  - Simple insert and check
  - Scalable
  - Accurate

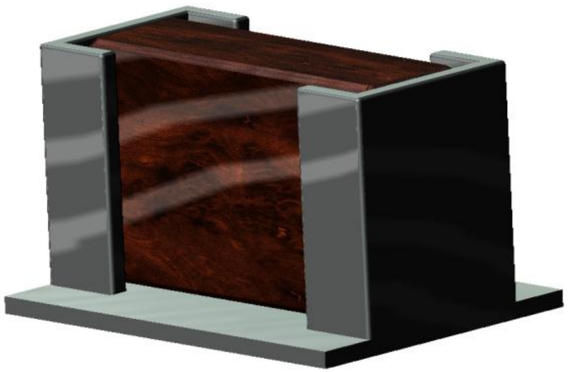


- Exterior Mount Alignment
  - Must be remounted for each bearing
  - Scalable
  - Accurate



Momentum Trap Designs

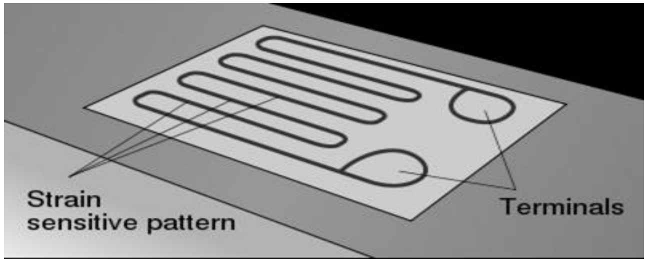
- Custom Impact Bumper
  - Simple
  - Durable
  - Cost < $30
  - Easily Scaled



- Pre-Manufactured Bumper
  - Readily Available
  - Various styles
  - $30 range
  - Less easily replaced

Strain Gage Selection

- Foil Strain Gages
  - Company : Vishay Micro-Measurements
  - Durable
  - Proven
  - Cost : $20 per 10 gages



- Semiconductor Gage
  - Company : Micron-Instruments
  - Higher Sensitivity
  - Low Durability
  - Cost: $80 to $200 for 8 gages

Data Acquisition System Selection

- Software
  - LabVIEW
    - User friendly
    - Quick setup
    - Available at COE
- Hardware
  - Expensive
    - > $500 for NI platforms
  - Solutions
    - Make use of hardware available at COE or Eglin AFB.
    - Purchase hardware.

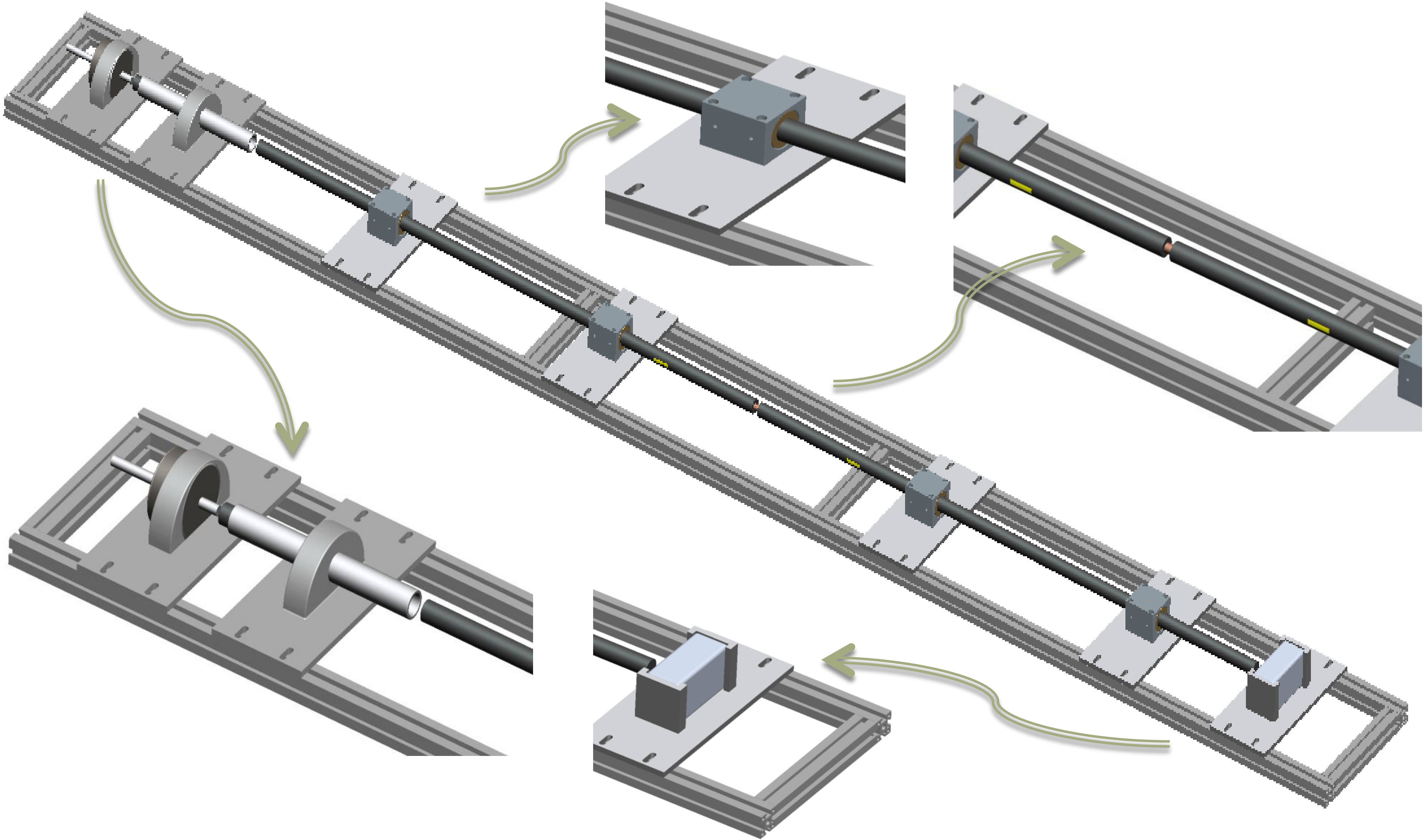
Decision Matrix

		Cost	Weight	Size	Simplicity	Durability	Portability	Scalability	Accuracy	Data Quality	Ease of Use	Score
Base	**Weight**	**0.3**	**0.2**	**N/a**	**0.2**	**N/a**	**0.3**	**N/a**	**N/a**	**N/a**	**N/a**	
	I-beam	3	2		4		4					3.3
	T-slot	5	4		4		5					4.6
Bushing	**Weight**	**0.2**	**0.2**	**0.1**	**N/a**	**0.2**	**0.1**	**N/a**	**0.2**	**N/a**	**N/a**	
	New Way	3	5	5		5	5		5			4.6
	Nelson	2	5	5		4	5		4			4
Strain Gauges	**Weight**	**0.2**	**N/a**	**0.1**	**N/a**	**0.2**	**N/a**	**N/a**	**N/a**	**0.3**	**0.2**	
	Foil	4		4		5				3	4	3.9
	Semiconductor	3		5		4				5	4	4.2
Bar *	**Weight**	**0.1**	**0.2**	**0.1**	**N/a**	**0.2**	**0.1**	**N/a**	**0.2**	**0.1**	**N/a**	
	1/2 inch	4	4	5		5	4		3	3		4
	3/4 inch	3	4	5		5	4		4	4		4.2
Striker Bar	**Weight**	**0.2**	**0.1**	**N/a**	**0.2**	**0.2**	**N/a**	**N/a**	**0.3**	**N/a**	**N/a**	
	Solenoid	3	4		3	5			5			4.1
	Pendulum	4	4		5	4			3			3.9
Air Manifold	**Weight**	**0.2**	**0.1**	**0.2**	**0.1**	**0.2**	**0.2**	**N/a**	**N/a**	**N/a**	**N/a**	
	Horizontal	3	3	3	5	4	3					3.4
	Declined	3	3	3	3	4	3					3.2
Bearing Alignmen	**Weight**	**0.2**	**N/a**	**N/a**	**0.1**	**N/a**	**N/a**	**0.2**	**0.4**	**N/a**	**0.1**	**1**
	Insert	3			2			4	5		5	4.1
	Mounted	3			4			3	4		3	3.5
Momentum Trap	**Weight**	**0.2**	**0.1**	**0.1**	**0.1**	**0.25**	**N/a**	**0.15**	**N/a**	**N/a**	**0.1**	
	Custom	4	4	3	4	4		4			4	3.9
	Prefabricated	4	3	3	4	3		3			4	3.4

Final Concept

- Base: T-Slotted Framing
- Striker Mechanism: Solenoid
- Bars: 0.75” 1566 Steel*
- Bushings: 0.75” New Way
- Bushing Alignment: Center-Bore Method
- Momentum Trap: Custom Made
- Air Manifold: Horizontal w/ Purge
- Strain Gages: Foil Type*
- DAQ: National Instruments

Final Concept Model



Cost Analysis

Budget	$2,500.00
Total Cost	$1,644.80
Remaining	$855.20

Item	Quantity	Unit Cost	Total Cost
0.75 inch Air Bushings	4	$331.00	$1,060.00
Solenoid	1	$69.94	$69.94
T-slot Framing 1 1/2 inch (96 inch length)	2	$48.15	$96.30
T-slot Framing 1 1/2 inch (4 foot length for 6 inch braces)	1	$25.15	$25.15
Incident & Transmission Bar: 1566 Steel Bar 0.75 inch (36inch length)	2	$29.42	$58.84
Air Manifold (72 inches)	1	$16.34	$16.34
T-slot Framing 1 1/2 inch (24 inch length) For stability	1	$13.98	$13.98
Striker Bar: 1566 Steel Bar 0.75 inch (12inch length)	1	$10.25	$10.25
Momentum Trap	1	$30.00	$30.00
DAQ			$0.00
Air supply			$0.00

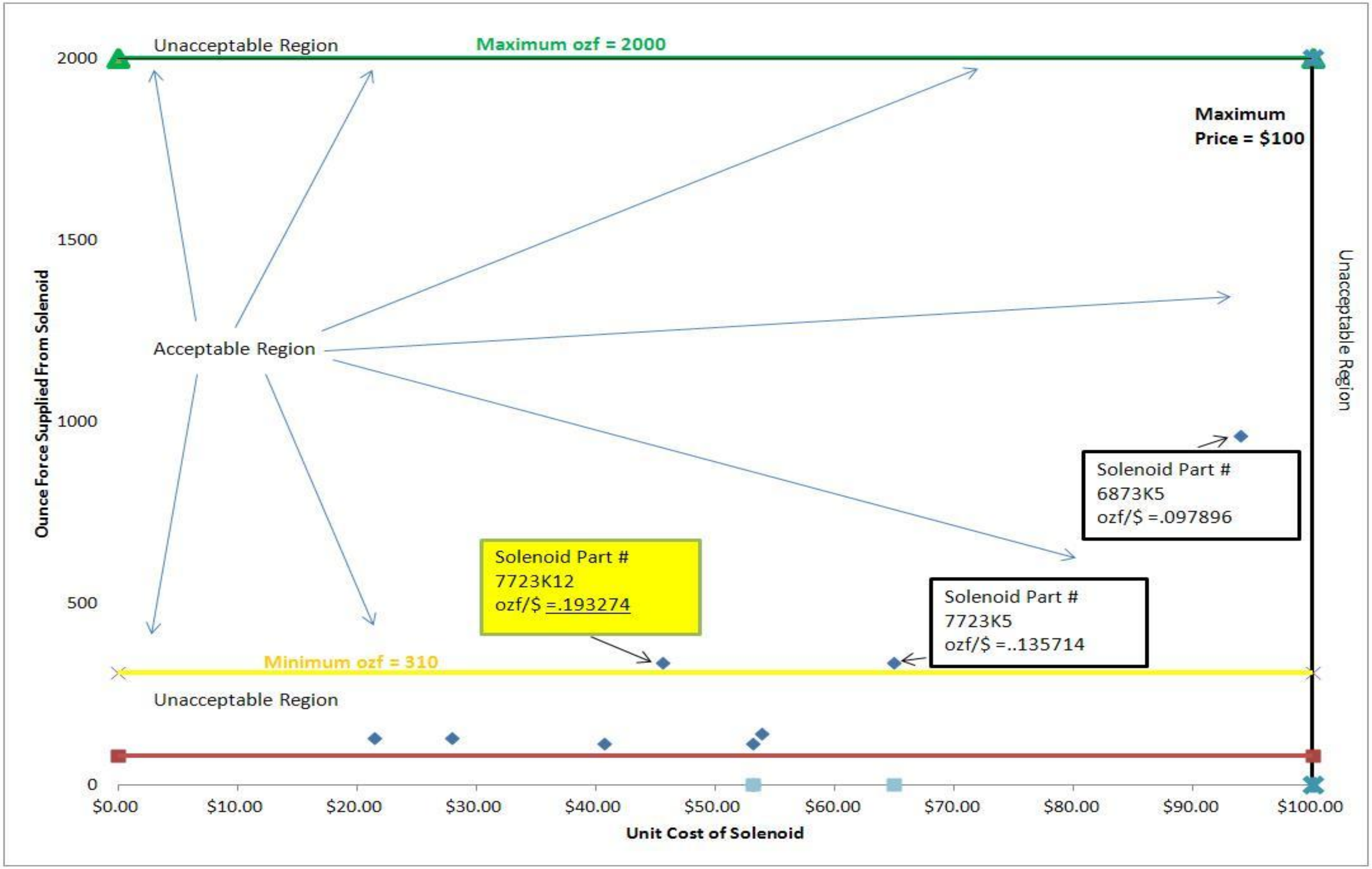
System Analysis

- Plastic deformation of copper specimen is most important factor in analysis
- Yield Stress
- Minimum Force
- Striker Bar Momentum (mass)
- Duration of Impact
- Minimum Striker Bar Velocity

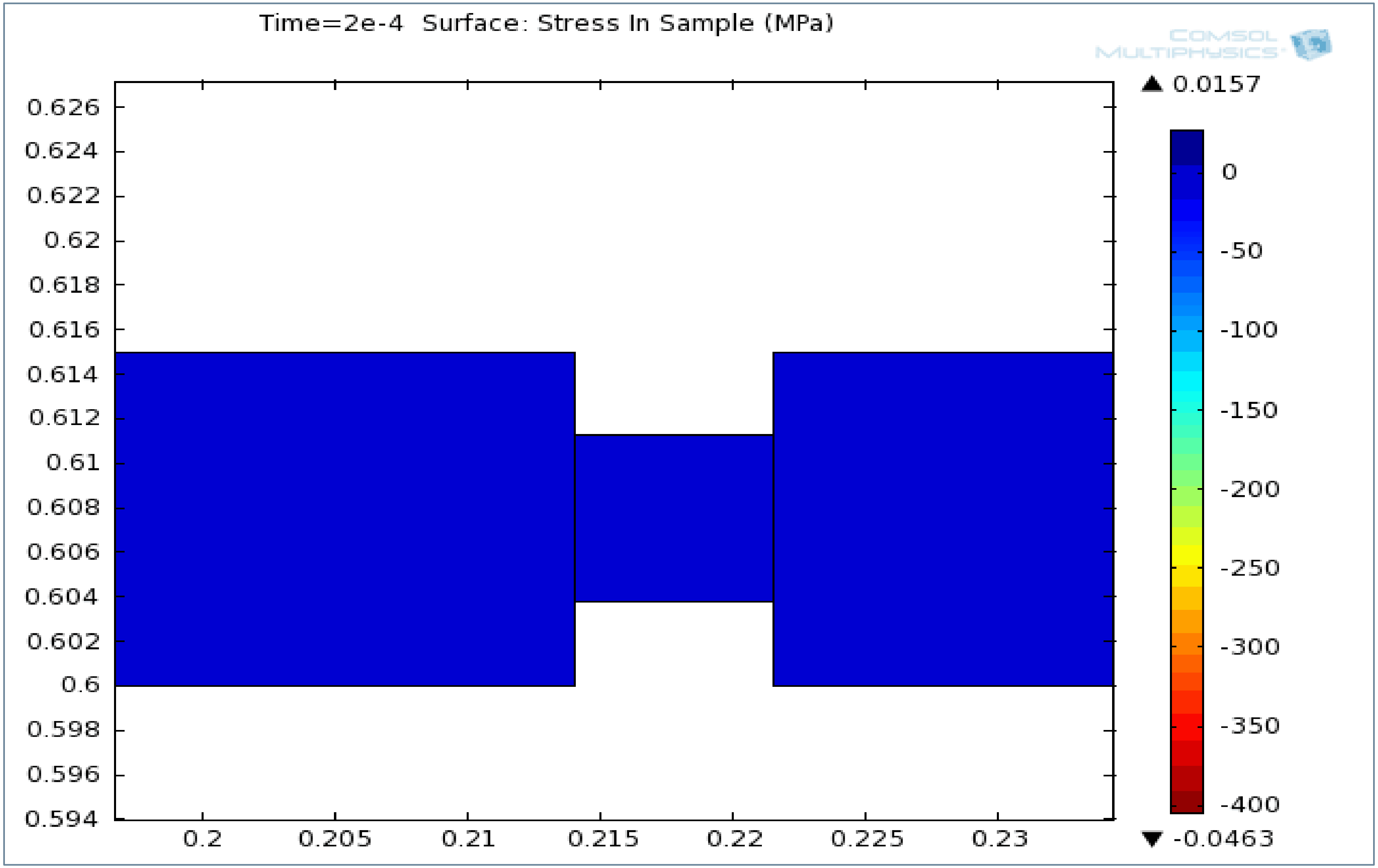
System Analysis

- Secondary Analysis Requirements:
  - Low Cost
    - Many solenoid options require the use of optimization methods
  - Elastic Deformation in Steel (Maximum Striker bar Velocity)
    - Stress concentrations require use of Finite Element Modeling

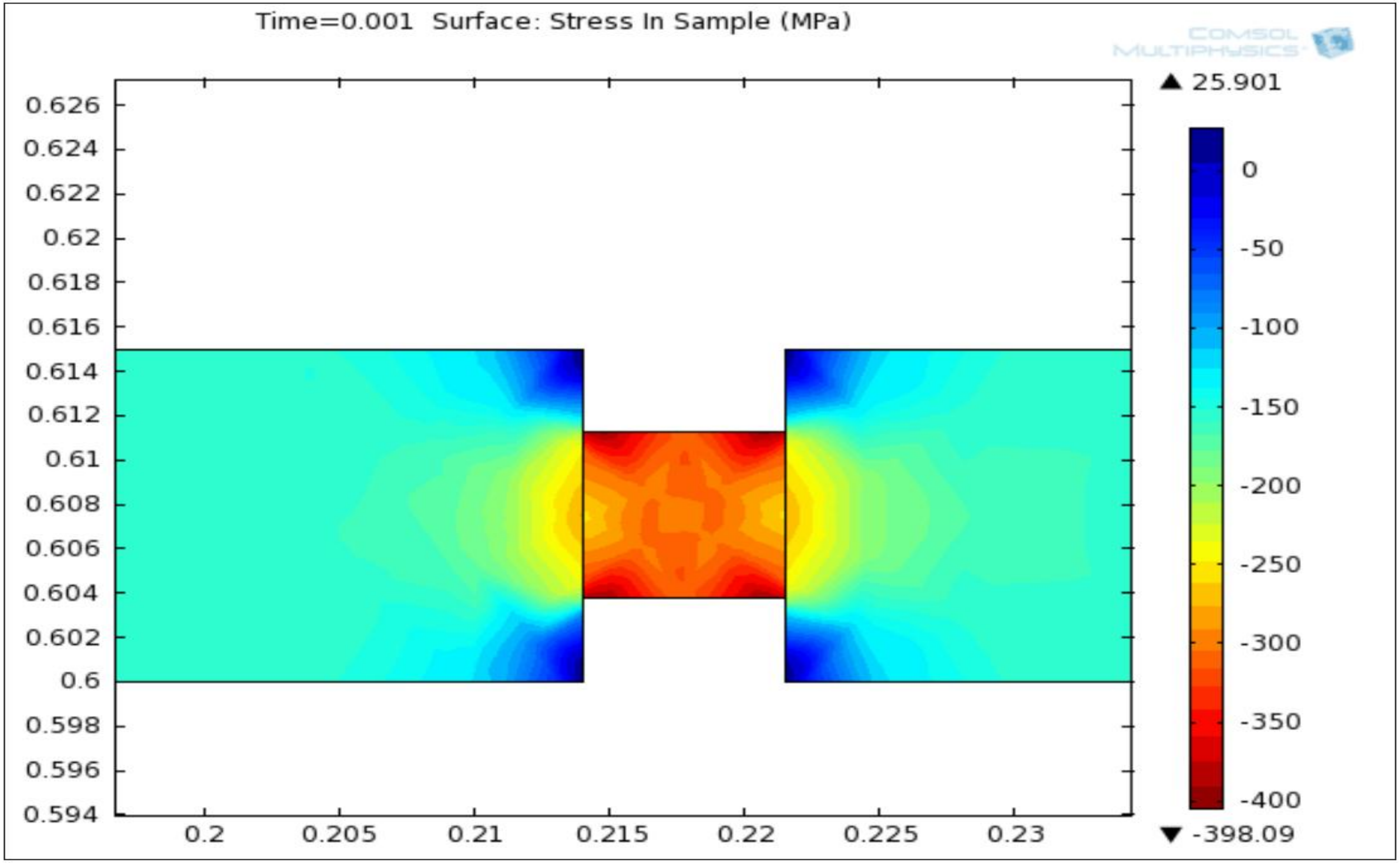
System Analysis: Solenoid Optimization



System Analysis: Stress Multiplication



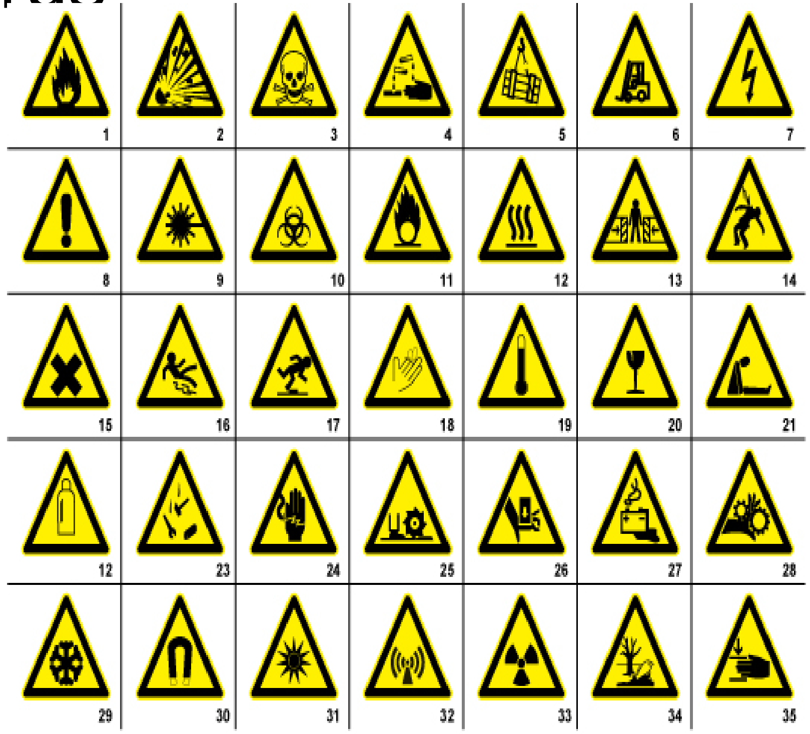
System Analysis: Maximum Stress



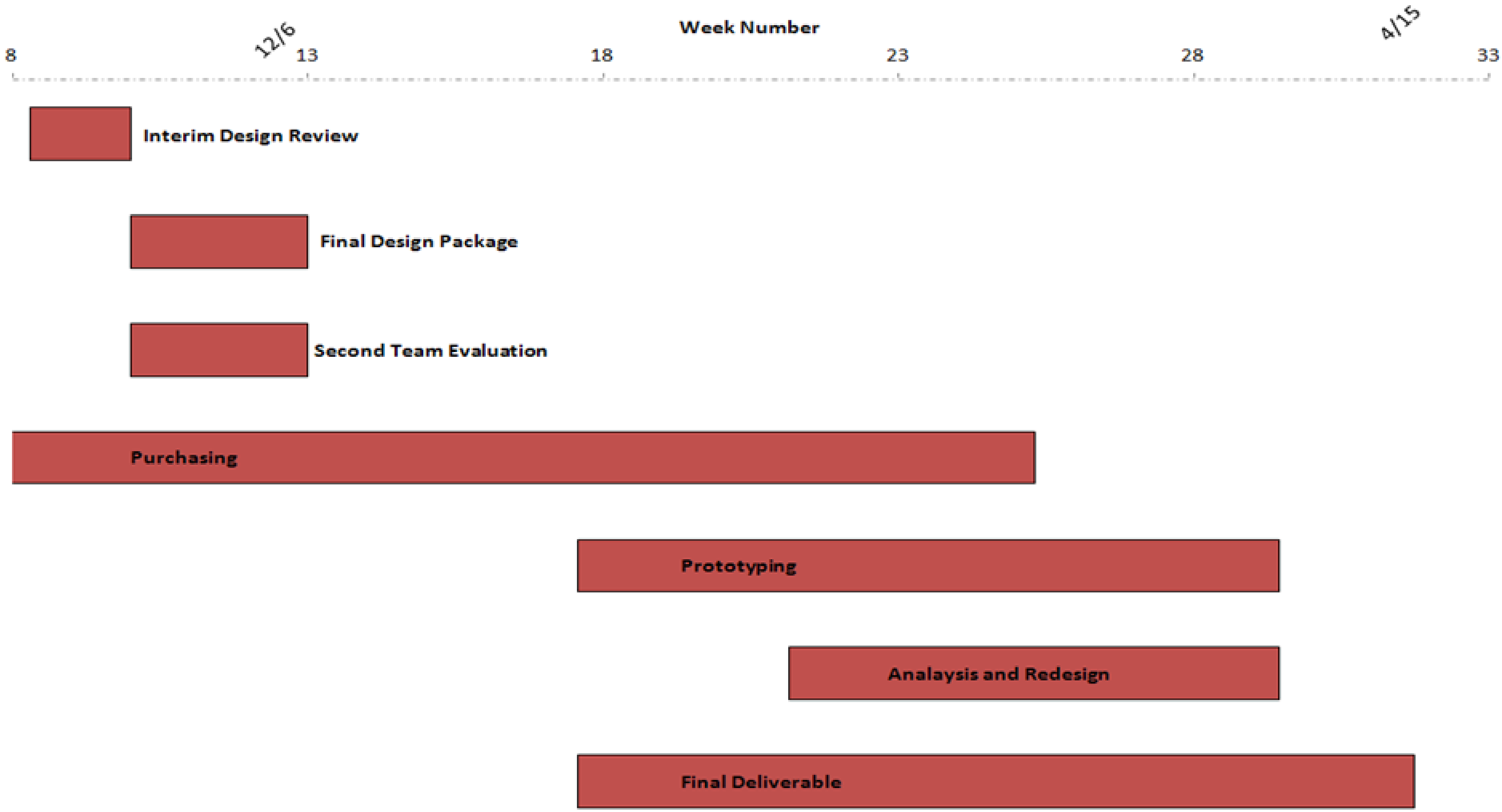
Environment & Safety Concerns

- No Environmental Hazards

- Safety Concerns
  - Pinching or crushing of fingers between bars.
  - Safety Shields



Remaining Schedule



Questions? Comments?

Our Thanks to:
Dr. House, Eglin AFRL
Dr. Hovsapian, FSU COE
Dr. Kosaraju, FSU COE

Plastic Energy Derivation

- Stress $\sigma = F/A$
- Strain $\varepsilon = (Li - Lo) / Lo$
- Gauge Factor $GF = [(Ri - Ro) / Ro] / \varepsilon$
- Data Strain $\varepsilon (Ri) = [(Ri - Ro) / Ro] / GF$

Plastic Energy Derivation

- Strain in Specimen:

$$d\varepsilon_{avg} / dt = (c_b / L_s) * (\varepsilon_{I-} - \varepsilon_R - \varepsilon_T)$$

- Integration:

$$\varepsilon_s = (C_b / L_s) * \int_0^t [(\varepsilon_{I-} - \varepsilon_R - \varepsilon_T) *dt]$$

Strain through the specimen

Plastic Energy Derivation

- Strain energy for each wave

$$\text{Kinetic energy} = 0.5 * m * v^2$$

- Initial $E_I = 0.5 * A_B * C_B * E_B * T * \varepsilon_I^2$
- Reflected $E_r = 0.5 * A_B * C_B * E_B * T * \varepsilon_R^2$
- Transmitted $E_t = 0.5 * A_B * C_B * E_B * T * \varepsilon_T^2$

Plastic Energy Derivation

- Strain energy

$$\delta S_E = E_I - E_R - E_T$$

- Plastic Energy absorbed by specimen

$$E_s = 2 * \delta S_E$$

Velocity Calculations

The velocity of the striker bar is needed
The only requirement is that the specimen plasticaly deform while the incident and transmitter bars are only loaded elasticaly
The following equations show the process

$\sigma_{yc} := 70MPa$ Yield stress of copper

$Area_c := \pi \cdot \left(\frac{.4}{2} in\right)^2 = ▮ \cdot in^2$ Area of the copper

$F := \sigma_{yc} \cdot Area_c = ▮ \cdot kN$ Force Required to reach Yield

Next the mass of the steel bar is computed

$\rho := 7.85 \frac{gm}{cm^3}$ Density of steel

$v := \pi \cdot \left(\frac{0.75}{2}\right)^2 in^2 \cdot 6in = ▮ \cdot in^3$ Volume of the 3/4 inch diameter, 6 in striker bar

$mass := v \cdot \rho = ▮$ Mass of the striker bar

Velocity Calculations

Next the amount of time the striker bar will impact the incident bar

$c := 6100 \frac{m}{s}$ — Speed of wave propogation in steel

$L := 6in$ — Length of Striker bar

$t := 2 \cdot \frac{L}{c} = \blacksquare \cdot s$ — Pressure wave propogating down the strikerbar and returning = 2 x length/speed

$t = \blacksquare \cdot \mu s$ — Duration of impact

Finaly the minimum velocity of the striker bar needed to plasticaly deform the specimen

$$V := \frac{F}{mass} \cdot t = \blacksquare$$

$V = \blacksquare \cdot \frac{mi}{hr}$ — Minimum velocity of striker bar needed to plasticaly deform the copper specimen

Velocity Calculations

$Acc := \frac{310ozf}{mass} = ▮$

Acceleration available from a chosen solenoid

$L_{sol} := 1in$

Length of piston with given force

$D = D_o + V_o \cdot t + .5A_{cc} \cdot t^2$

Generic dynamic position equation

$time_{sol} := \left(\frac{L_{sol}}{0.5 Acc}\right)^{.5} = ▮$

Derived time, from previous equation

$V_{stkr} := Acc \cdot time_{sol} = ▮ \cdot \frac{mi}{hr}$

Calculated velocity from given solenoic

$Force_{striker.sol} := \frac{V_{stkr} \cdot mass}{t} = ▮ \cdot kN$

Maximum force transfered from solenc

Weak Formulation for FEA

$$\rho \cdot A \cdot \frac{d^2}{dt^2} T - \frac{d}{dx}\left[E \cdot A \cdot \left(\frac{d}{dx} u \right) \right] - f(x,t) = 0$$

$$\int \left[w \cdot \rho \cdot A \cdot \frac{d^2}{dt^2} T - w \cdot \frac{d}{dx}\left[E \cdot A \cdot \left(\frac{d}{dx} u \right) \right] - w\, f(x,t) \right] d(x,t) = 0$$

$$\int \left[-(\rho \cdot A) \cdot \left(\frac{d}{dt} w \right) \cdot \left(\frac{d}{dt} T \right) - w\, f(x,t) \right] d(x,t) + w \cdot A \cdot \rho \cdot \left(\frac{d}{dt} T \right) = 0$$

Weak Formulation for FEA

$$[K]^*\{u\} + [C]^*\{\dot{u}\} + [M]^*\{\ddot{u}\} = \{F\}$$

$$K_{ij} = \int_{xa}^{xb} \left[a(x) \cdot \left(\frac{d}{dx}\psi_i \right) \cdot \left(\frac{d}{dx}\psi_j \right) + c(x)\,\psi_i \cdot \psi_j \right] dx$$

$$M_{ij} = \int_{xa}^{xb} c_o(x) \cdot \psi_i \cdot \psi_j \, dx$$