Shear Stress Sensor Using Cholesteric Crystals

Group #3

Group Members
Matthew Carmichael, FSU
Tyler Elsey, FSU
Luiz Paes, UNIFEI

Graduate Assistant
Matthew Worden

Sponsors
Dr. Dickinson , Eglin AFRL
Dr. Oates, FAMU & FSU COE

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eng.fsu.edu/me/senior_design/2013/team3

OVERVIEW

- Project Scope and Objectives
- Constraints
- Existing Technology
- Theory
- Concepts
- Decision Matrix
- Final Design
- Programming Needed
- Cost Analysis
- Schedule

Need Statement & Project Scope

- **Need Statement**
  - **Need in the market for a shear stress sensor that can be used outside the lab and decouple shear and normal stress**
- **Project Scope**
  - **Create Testing Apparatus**
  - **Determine if cholesteric crystals are able to measure shear stress**

Objectives

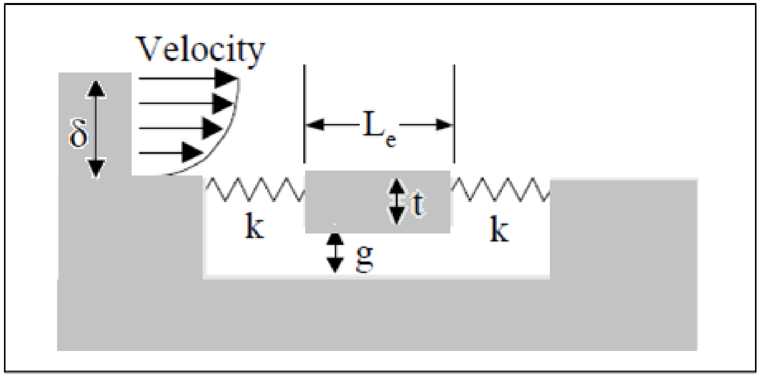
- Create a testing apparatus using given materials and setup
- Test Liquid Cholesteric Crystals
  - Possible to decouple the pressure and shear stress?
  - Determine the range of forces that can be detected
  - Determine how temperature affects the crystals
- Repeat tests with a polymerized form of cholesteric crystals

Constraints

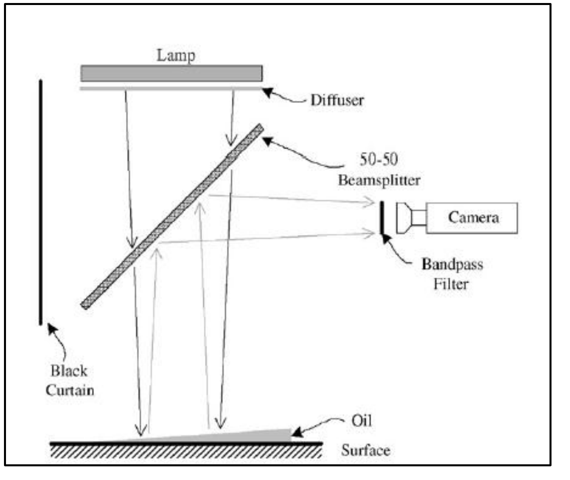
- Baseplate and mounting points have been created by a previous group
- Light source and wavelength sensor must be adjustable
- Cholesteric crystals must be independent of heat

Existing Technology

- **Microelectricalmechanical Systems (MEMS)**
  - **Devices that have been fabricated using silicon micromachining technology**
- **Thin-Oil Film**
  - **Oil thickness is measured via interferometry function of the local friction.**

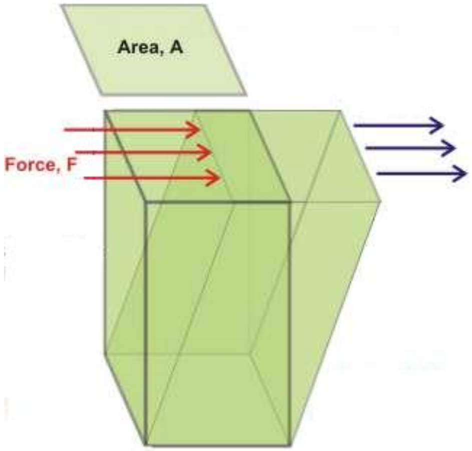


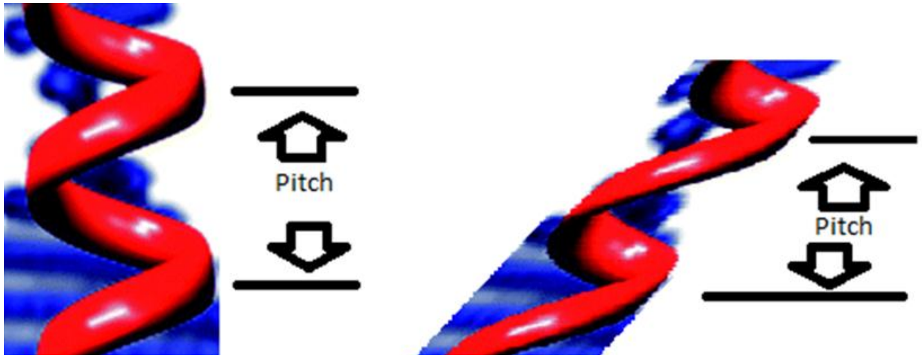
MEMS

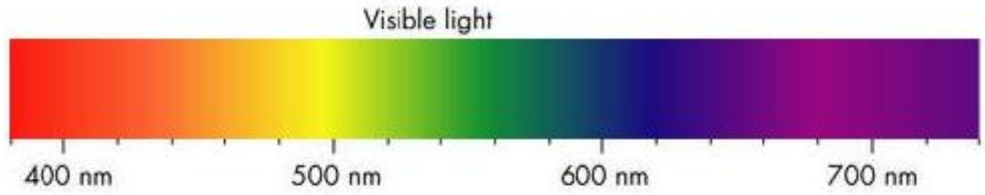


Thin-Oil Film

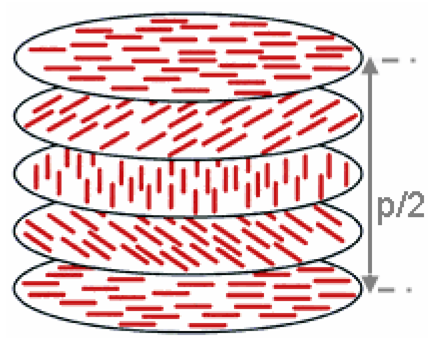
Cholesteric Crystals







- **Helical Structure**
- **Layers with no positional ordering**
- **Pitch varies with the boundary conditions**
  - **i.e. electricity or forces**



Theory

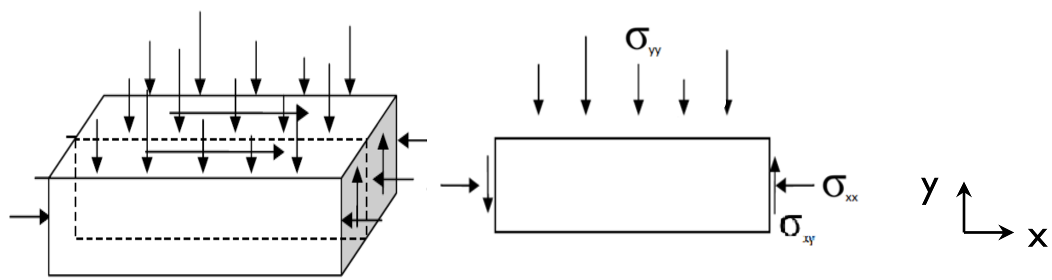
- **Plane Strain**

$$\varepsilon_{zz} = \varepsilon_{xz} = \varepsilon_{yz} = 0$$
$$\sigma_{xz} = \sigma_{yz} = 0$$

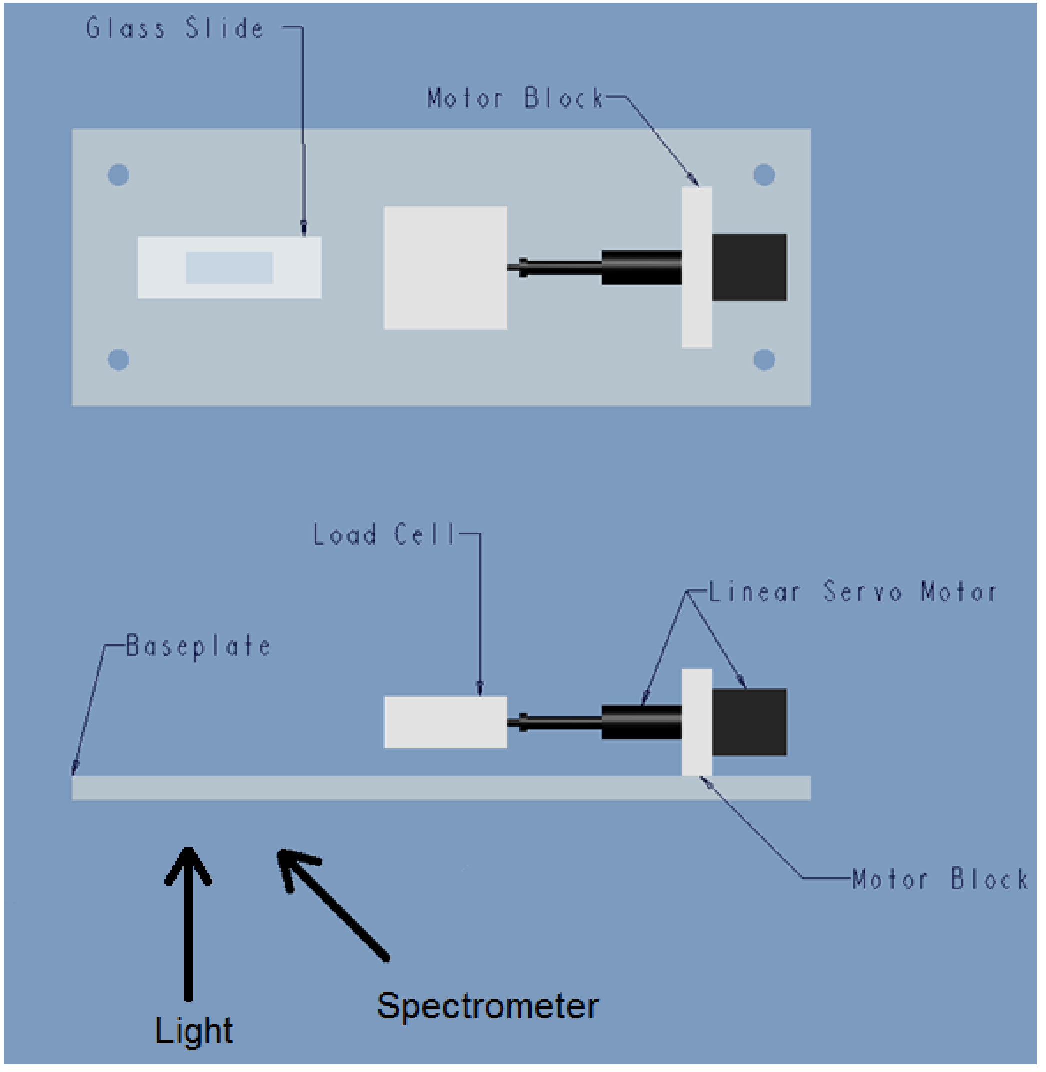
$$\begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{xy}\end{bmatrix} = \frac{E}{(1+\nu)(1-2\nu)}\begin{bmatrix}(1-\nu) & \nu & 0\\ \nu & (1-\nu) & 0\\ 0 & 0 & \left(\frac{1-2\nu}{2}\right)\end{bmatrix}\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{xy}\end{bmatrix}$$

$$\sigma_{xx} = c_{11}\varepsilon_{xx} + c_{12}\varepsilon_{yy}$$
$$\sigma_{yy} = c_{12}\varepsilon_{xx} + c_{11}\varepsilon_{yy}$$
$$\sigma_{xy} = c_{66}\varepsilon_{xy}$$

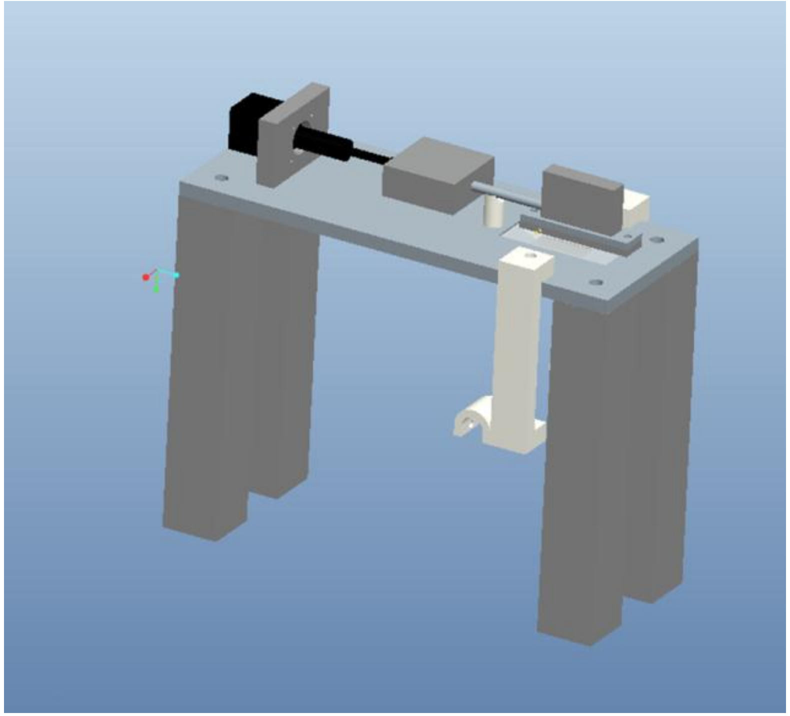
- **Material – Liquid Crystals**
- **v = 0.3   E=500MPa**

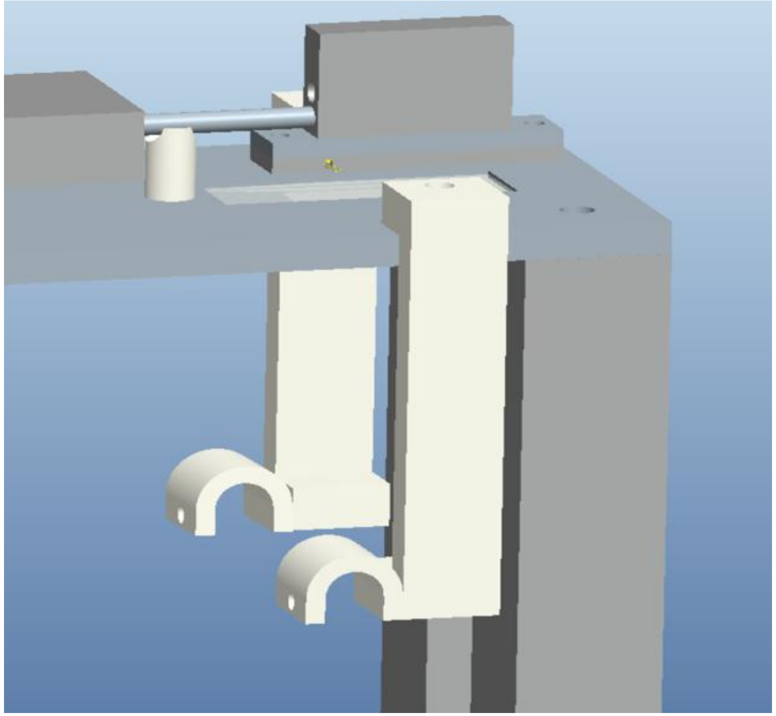


Given Parts and Design



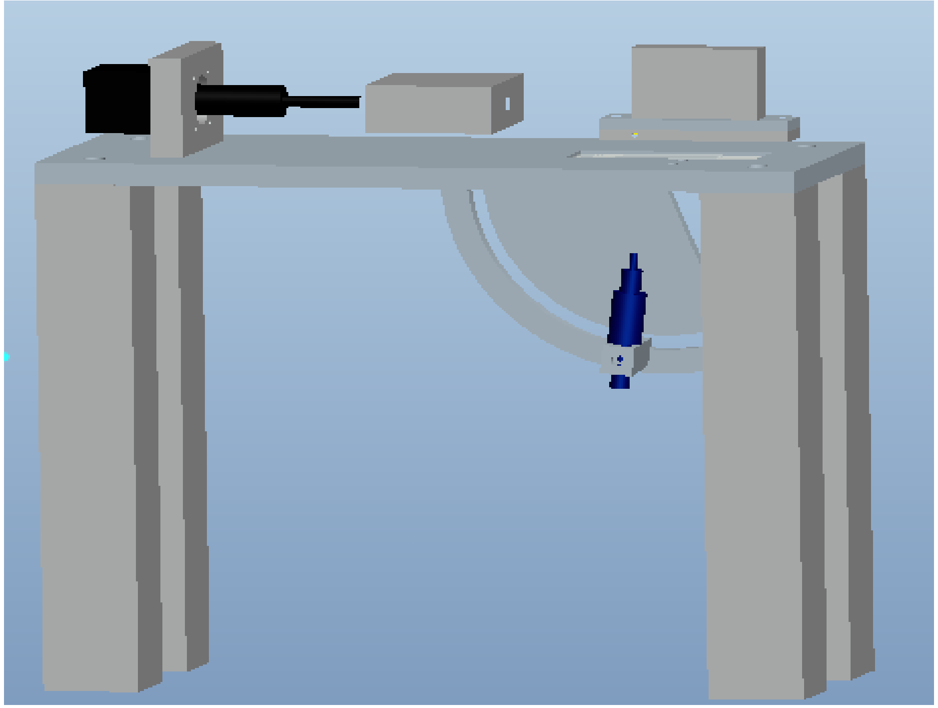
Concept 1



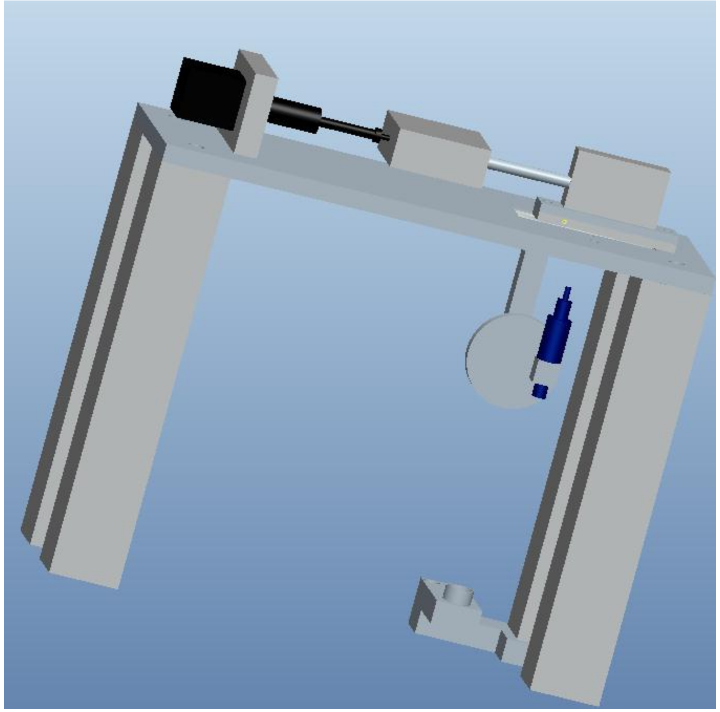


Concepts 2 & 3

Concept #2



Concept #3

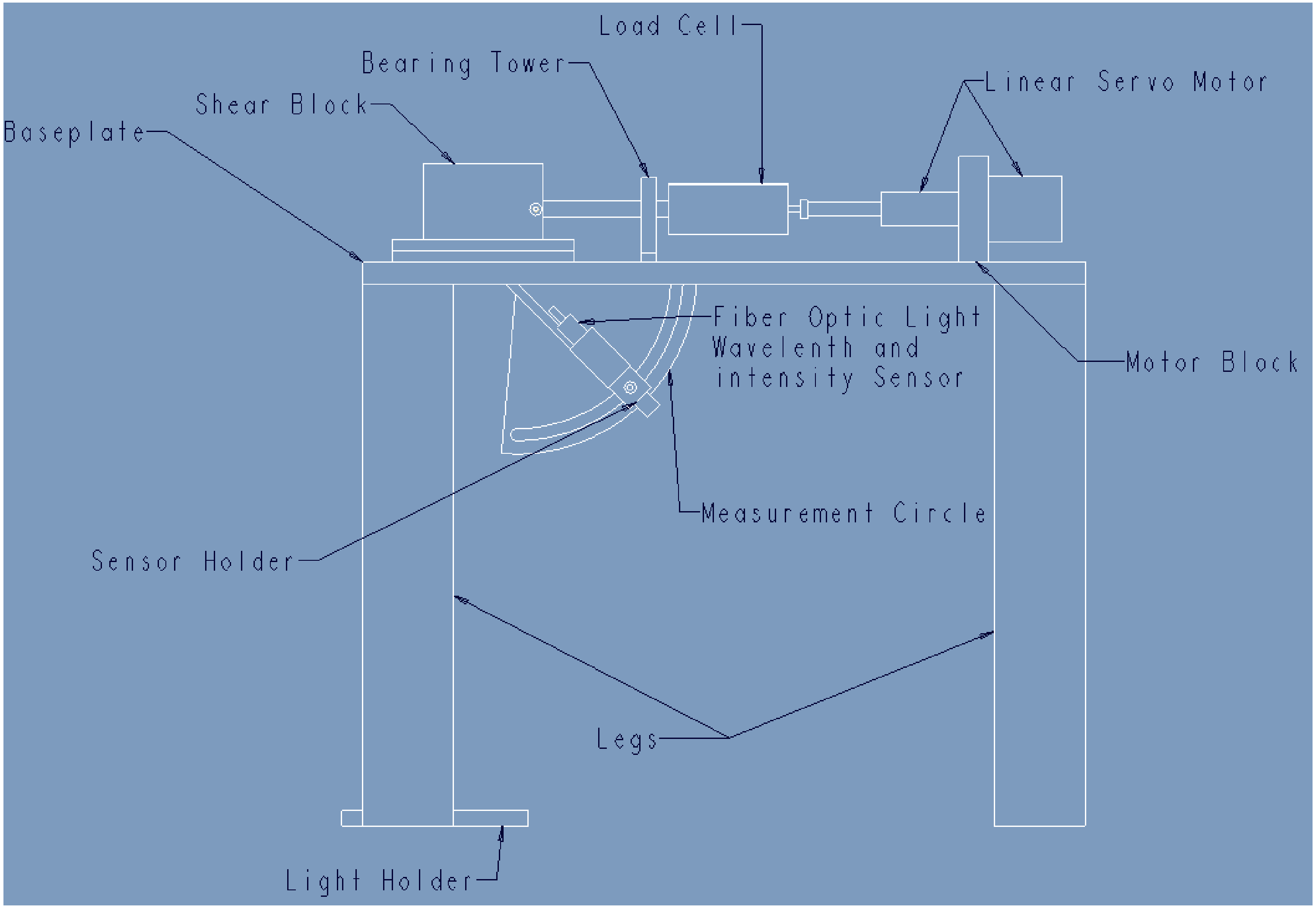


Decision Matrix

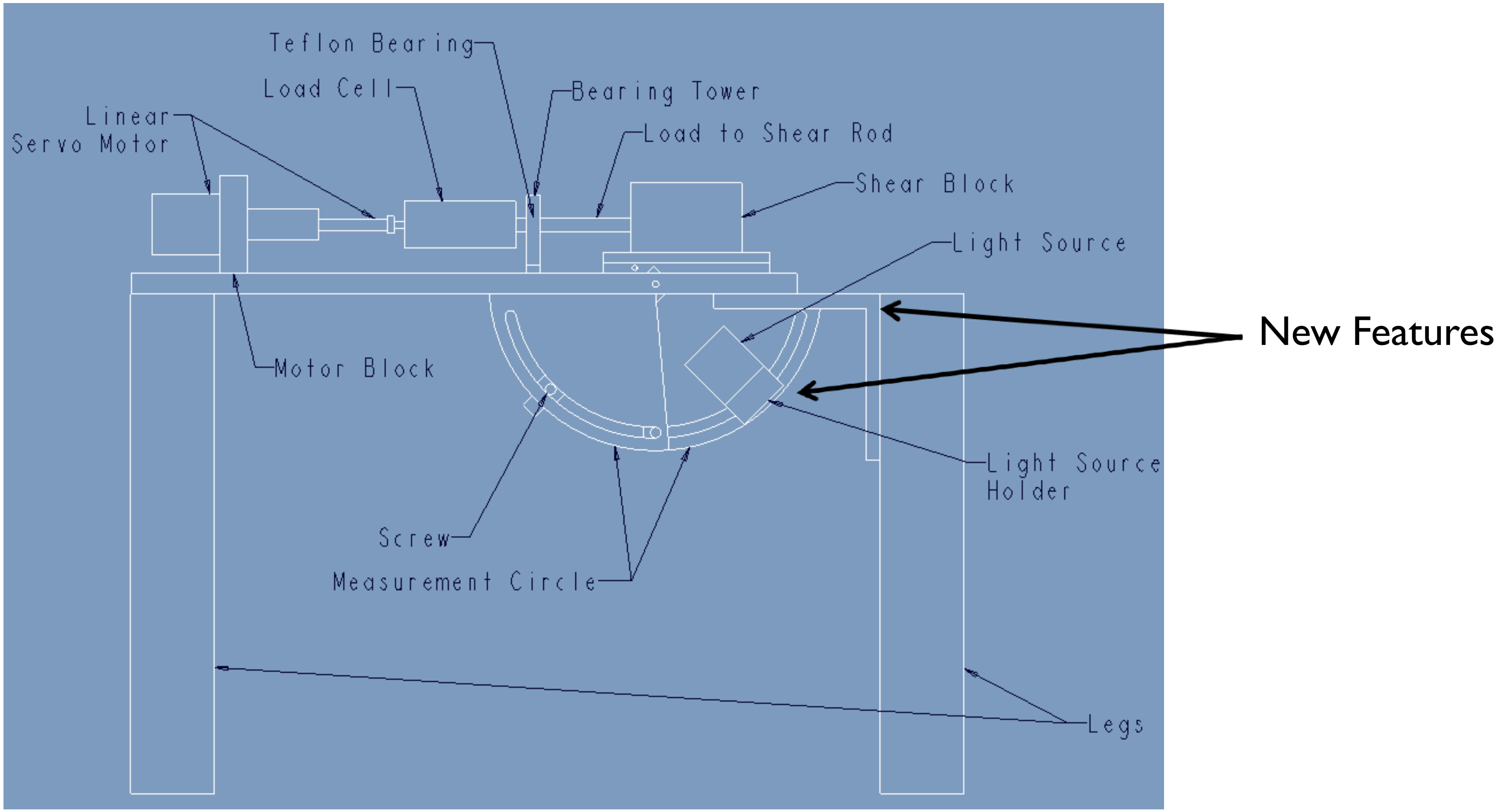
		Concept 1		Concept 2		Concept 3	
	Weight	Score	Weighted	Score	Weighted	Score	Weighted
Ease of Use	0.2	2	0.4	4	0.8	4	0.8
Reproducibility	0.3	3	0.9	5	1.5	2	0.6
Accuracy	0.3	2	0.6	4	1.2	1	0.3
Cost	0.15	3	0.45	2	0.3	3	0.45
Size	0.05	2	0.1	3	0.15	4	0.2
Total	1		2.45		3.95		2.35

- **Final Design Selection: Concept 2**

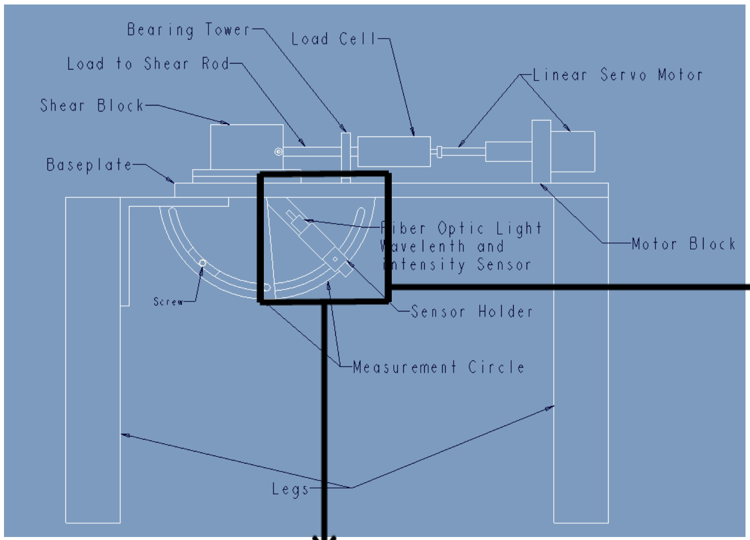
Interim Design

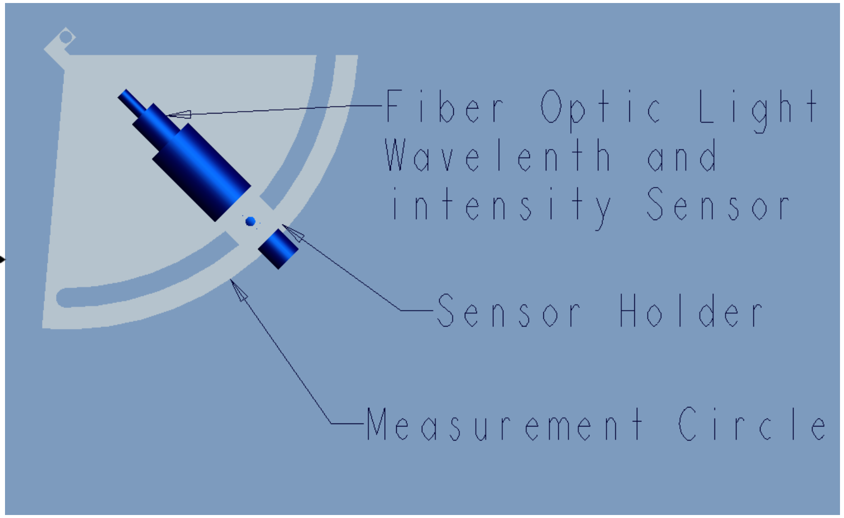


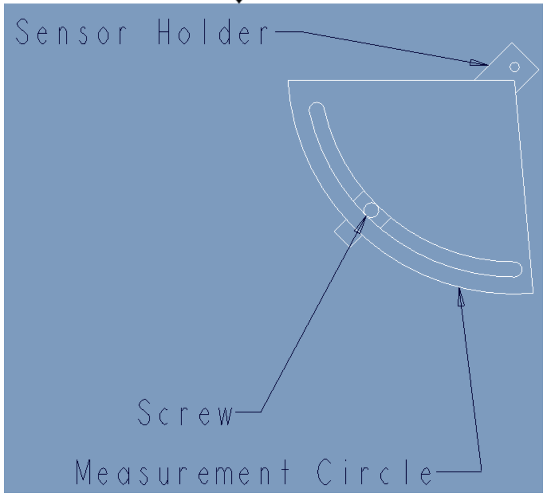
Final Design



Final Design

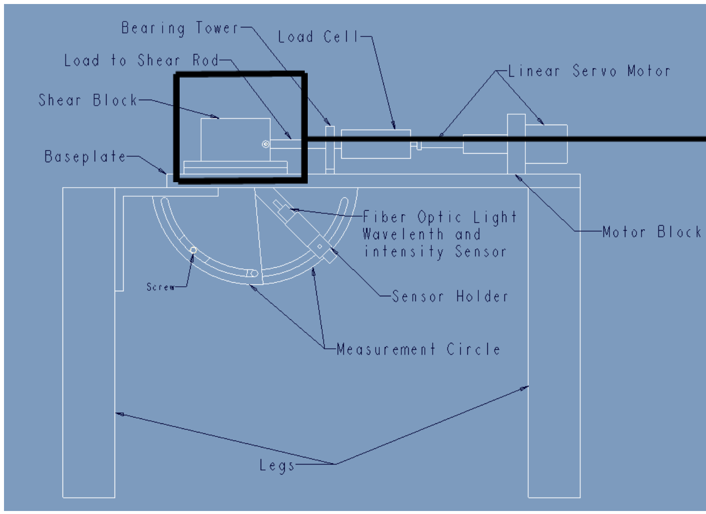


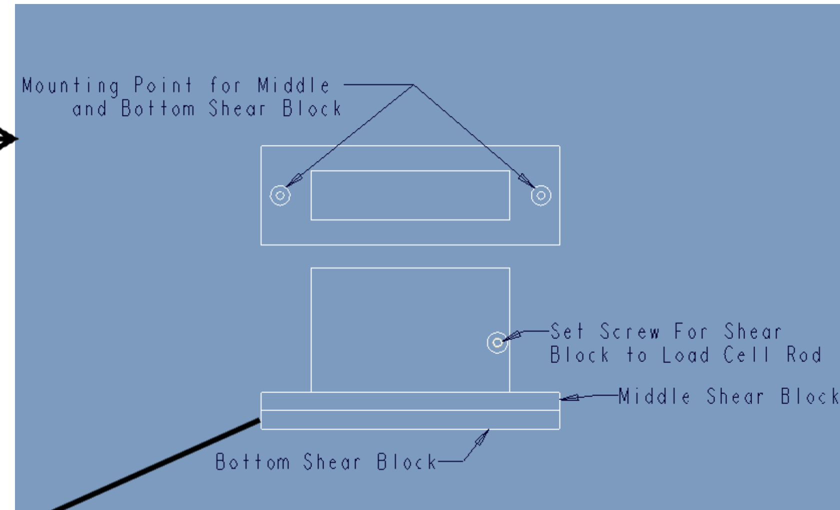


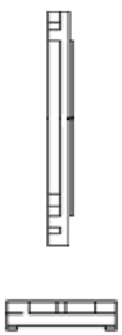


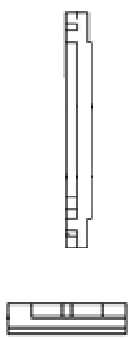
- **A fastener will be used to set the location of the sensor and LED**

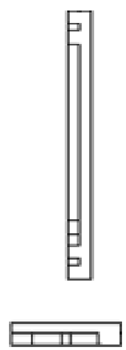
Final Design






U-Shape


Extended Shape

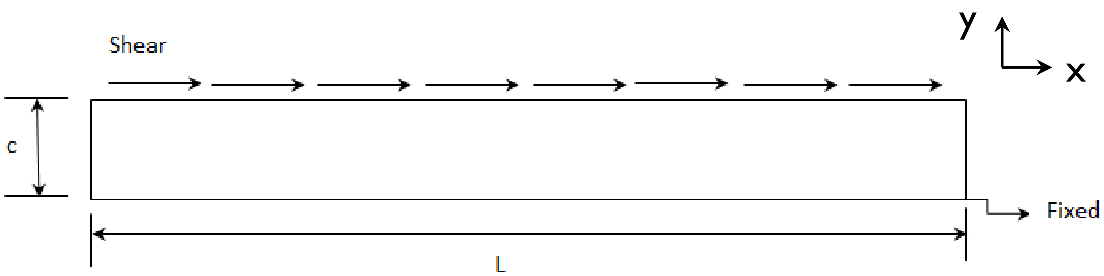

Flat-Flush Shape

- **Bottom Shear Block holds the heat pad and is modular so different block types can be tested**

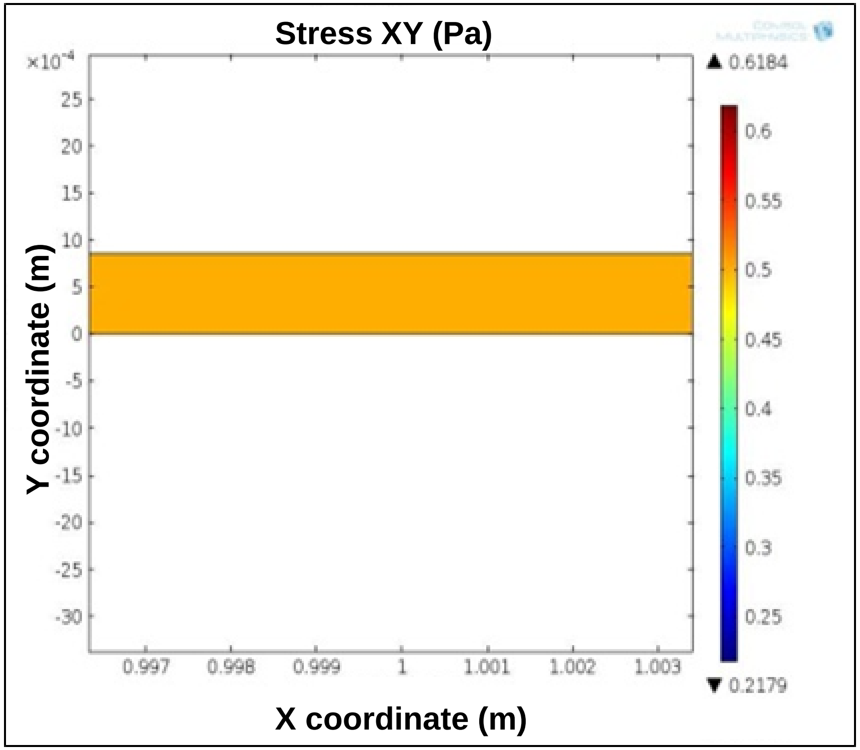
LabView

- **Correlation to shear load and voltage**
- **Load cell, servo-motor, spectrometer**
- **All need to start at the same time – record information**
- **Import data to MATLAB**

Simulation – FEM (Finite Element Method)



Constant Load 0.5Pa



Thin film - L=2000 (c)

Verification - Theory

$\sigma_{xy} = c_{66}\varepsilon_{xy}$

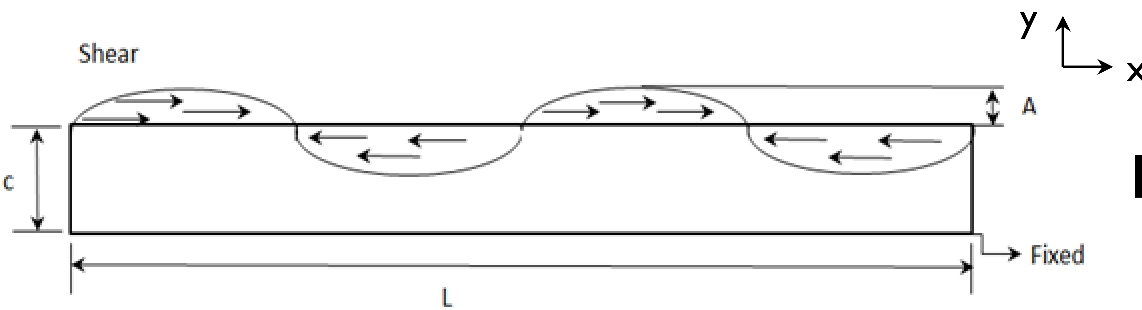
$\varepsilon_{xy\ numerical} = 26x10^{-10}$

$\sigma_{xy\ analytical} = (1.92x10^{8})(26x10^{-10}) = \mathbf{0.4992}$ **Pa**

$\sigma_{xy\ numerical} = \mathbf{0.5\ Pa}$

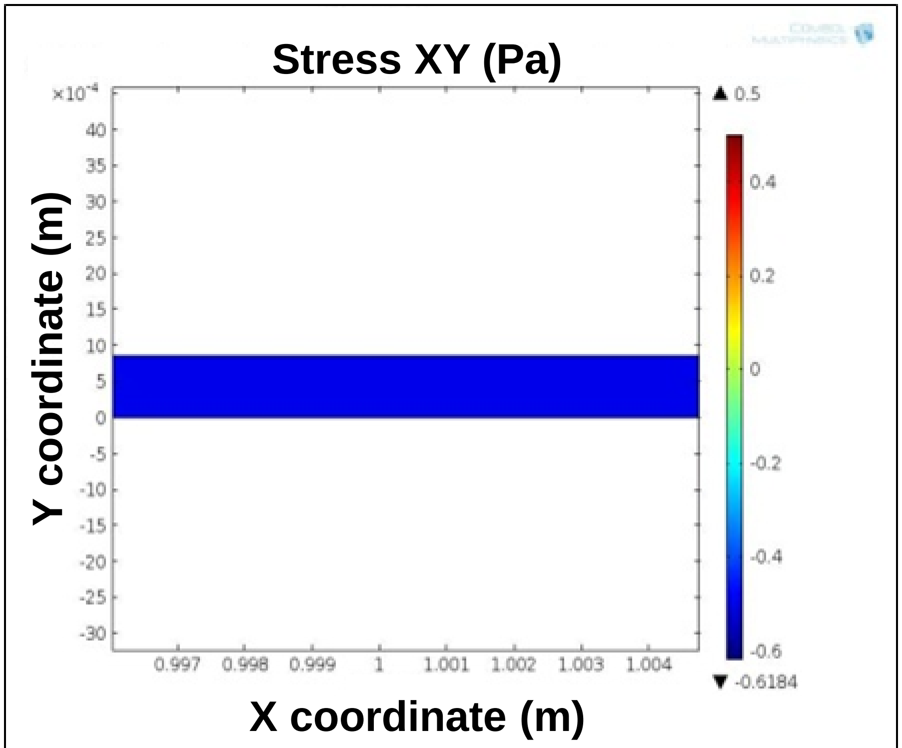
$$\boldsymbol{\sigma_{xy\ numerical} \simeq \sigma_{xy\ analytical}}$$

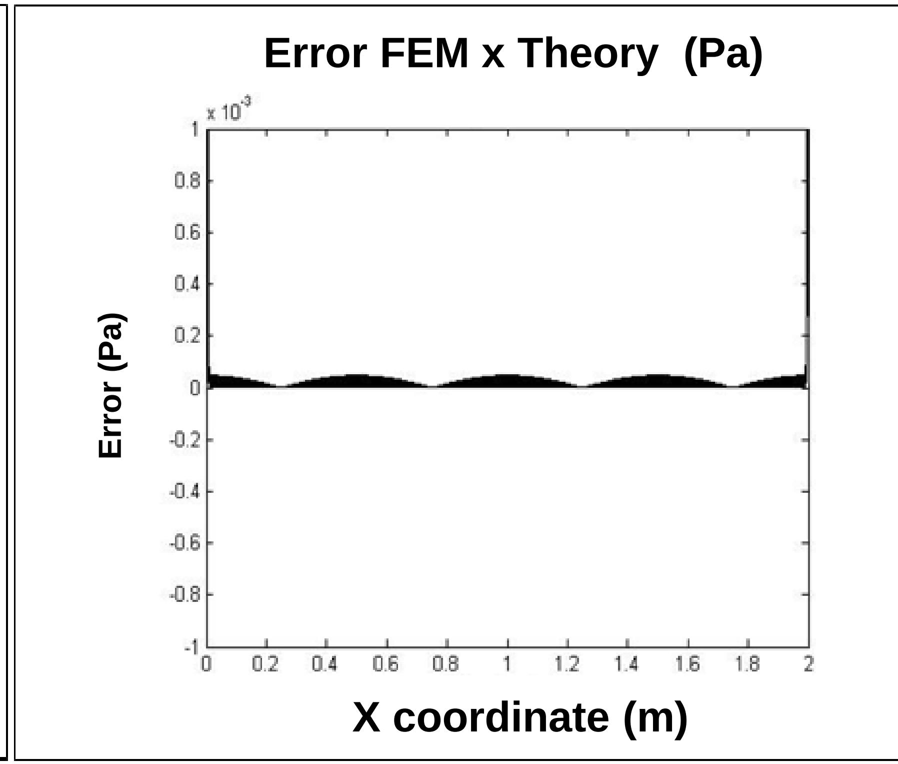
Simulation – FEM (Finite Element Method)



Cosine Load

0.5 cos ((4π/L)*x) Pa





Cost Analysis

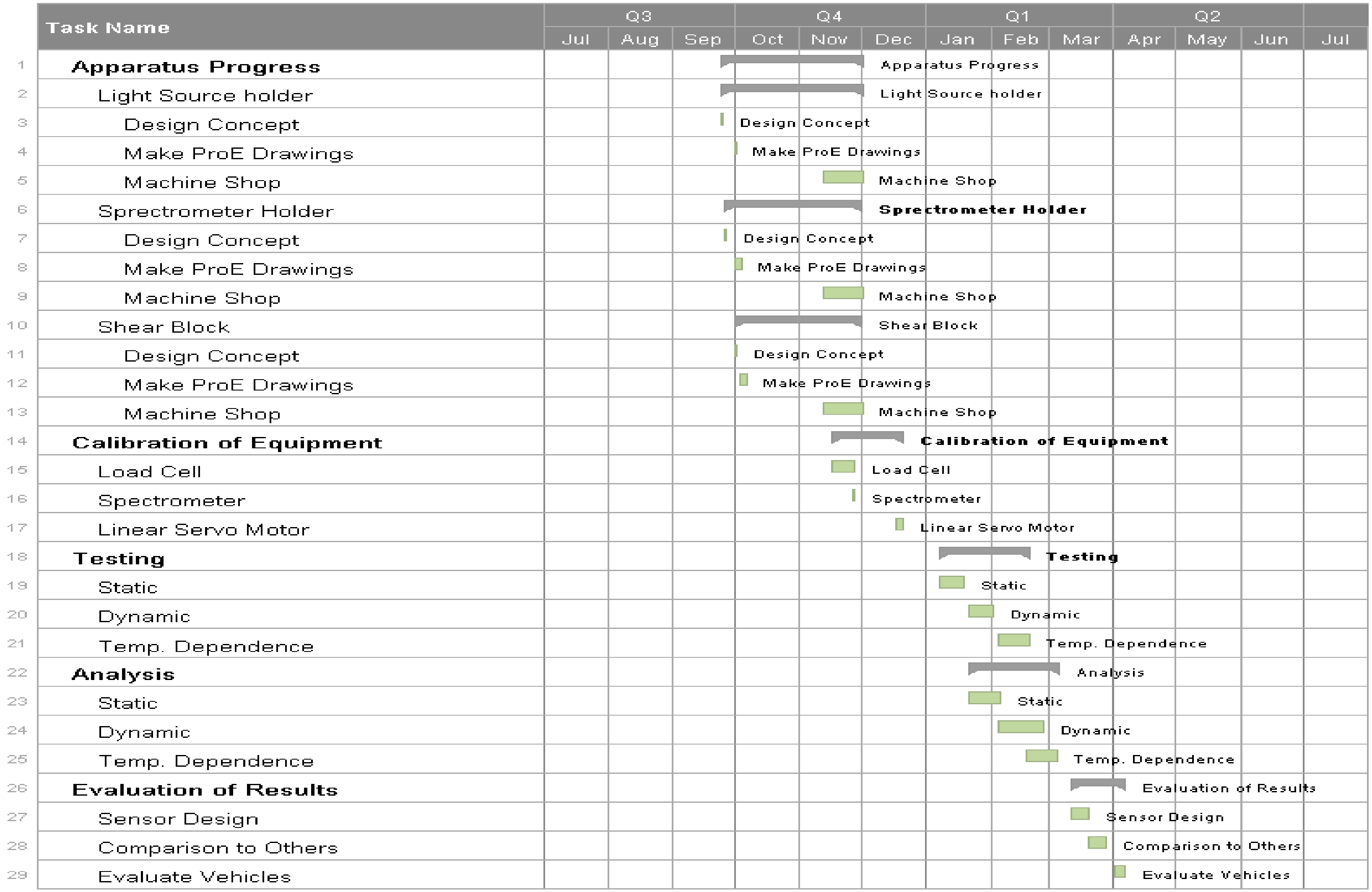
Part	Unit Price	Quantity	Price
Teflon Bearing	$3.11	1	$ 3.11
Insulation	$9.03	1	$9.03
Heat sheet	$38.90	1	$38.90
Fasteners	- -	- -	$21.84
LEDs	$23.74	3	$71.22
Liquid Crystals	$75.00	3	$225.00
		Total	$369.10

Cost Analysis

Parts Supplied

Part	Quantity	Price
Aluminum	- -	$64
Load Cell	1	$935
Fiber Optic Spectrometer	1	$2775
Linear Servo Motor	1	$75
Software	1	$60
	Total	$3909

Schedule


Task Name
Q3
Q4
Q1
Q2
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
1 Apparatus Progress
2 Light Source holder
3 Design Concept
4 Make ProE Drawings
5 Machine Shop
6 Sprectrometer Holder
7 Design Concept
8 Make ProE Drawings
9 Machine Shop
10 Shear Block
11 Design Concept
12 Make ProE Drawings
13 Machine Shop
14 Calibration of Equipment
15 Load Cell
16 Spectrometer
17 Linear Servo Motor
18 Testing
19 Static
20 Dynamic
21 Temp. Dependence
22 Analysis
23 Static
24 Dynamic
25 Temp. Dependence
26 Evaluation of Results
27 Sensor Design
28 Comparison to Others
29 Evaluate Vehicles

Questions/Comments

Purchase Order

McMaster-Carr

Part	Description	Quantity	Unit Price
Teflon Bearing	Sleeve Bearing for 1/4 ” shaft diameter, 1/4 ” length	1	$ 3.11 each
Insulation	Ultra-Thin Insulation	1	$9.03 each
Heat sheet	Ultra-Thin Heat Sheet- 10 Watts per inch^2	1	$38.90 each
M2.5x45 Screw- 3mm	18-8 SS Metric Pan Head Screw- M 2.5x45- Length 3mm (Pack of 100)	1 pack	$4.48
M2.5x45 Screw- 10mm	18-8 SS Metric Pan Head Screw- M 2.5x45- Length 10mm (Pack of 100)	1 pack	$ 5.21
M2.5x45 Screw 20mm	18-8 SS Metric Pan Head Screw- M 2.5x45- Length 20mm (Pack of 100)	1 pack	$6.55
10-24 Screw- 3/4 in.	316 SS Pan Head Screw 10-24 Thread- Length 3/4 in. (Pack of 25)	1 pack	$5.61

Purchase Order

LED Supply

Part	Description	Quantity	Unit Price
LED	Carclo 20mm Luxeon Rebel-EndorStar Optic	1	$5.99
Lens	Medium Ripple Lens and Lens holder (19° Illumination Pattern)	1	$3.00
Lens Color	Neutral- White	--	- -
Case	Aluminum LED Housing with 1/2” NPT Thread w/ 6” wire leads	1	$14.75
		Subtotal	$23.74
		Project Total	$90.08

Purchase Order

Pressure Chemical

Product	Description	Quantity	Unit Price
Liquid Crystals	Thermochromic Liquid Crystal Kit	3	$75.00
		Total	$225.00

Summary

- Apparatus design is complete
- Machine shop is machining parts
- Parts have been ordered and received
- Programming has begun this month
- Testing will commence once programming and parts are completed

Current Shear Stress Sensors

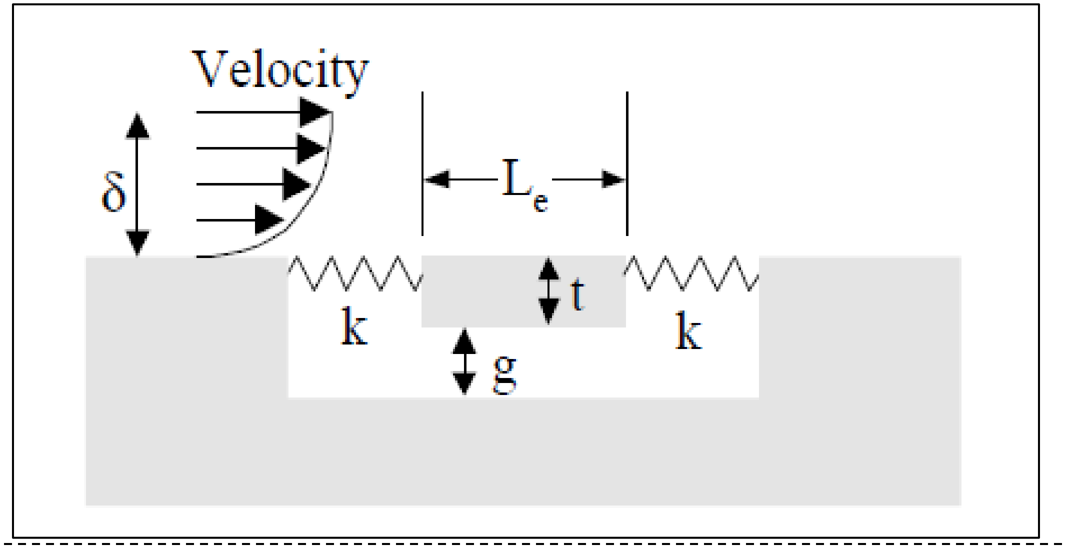
- Measurement of skin-friction
  - importance in aircraft industry
  - reduction in drag at cruise directly translates into a reduction in fuel consumption
- Techniques
  - Micro-Machined Sensors (MEMS)
  - Thin-oil-film Techniques
  - Liquid Crystal Techniques

MEMS

- Devices that have been fabricated using silicon micromachining technology
- High-resolution, time-resolved, quantitative fluctuating turbulence measurements in a controlled wind tunnel environment
- Open nature of these sensors is not well suited for dirty environments in which debris may be trapped in the sensor gaps

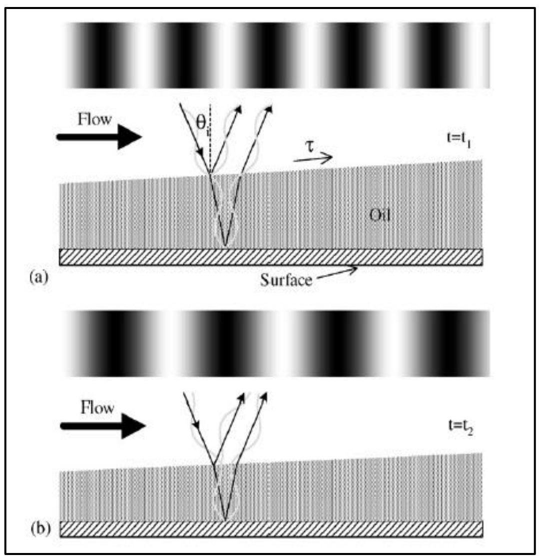
MEMS

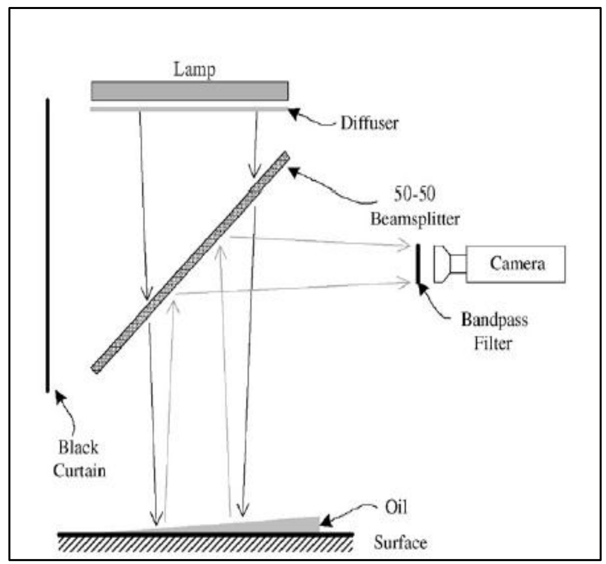
- Types – Direct sensors, thermal sensors and laser based sensors
- Direct sensors – Measure integrated force produced by the wall shear-stress on a flush movable "floating" element
- Displacement of the floating element – function of wall shear stress



Thin-Oil Film

- **Quasi direct means of measuring skin-friction**
- **The motion of oil film is sensitive to shear-stress, gravity, pressure gradients, surface curvature of the oil and surface tension**
- **Oil thickness is measured via interferometry – function of the local skin-friction**





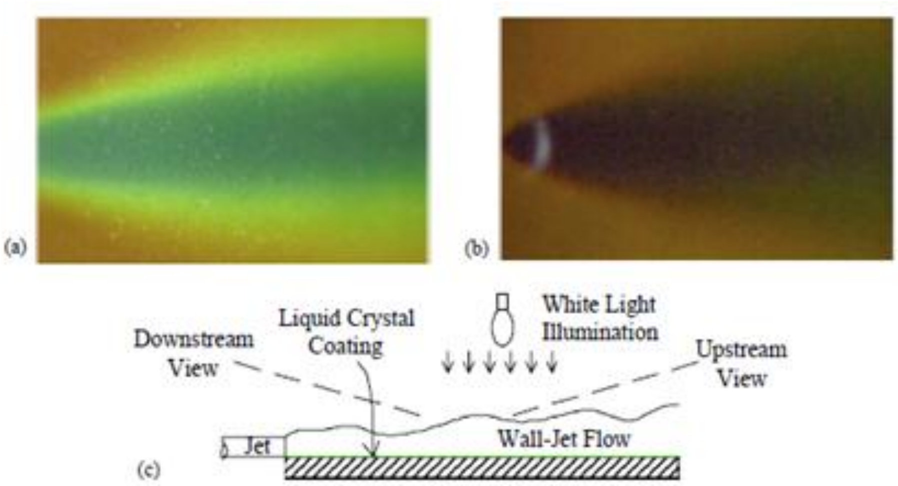
Thin-Oil Film

- Types - Single points, line and image techniques (1D and 2D)
- -Image techniques 2D analysis
- Surface imaging skin-friction - SISF
- -Advantages
- Range of 4% of uncertainty – two images during a single run
- Method is only sensitive to shear stress
- -Limitations
- It requires at least two images acquired during a test
- Complexity

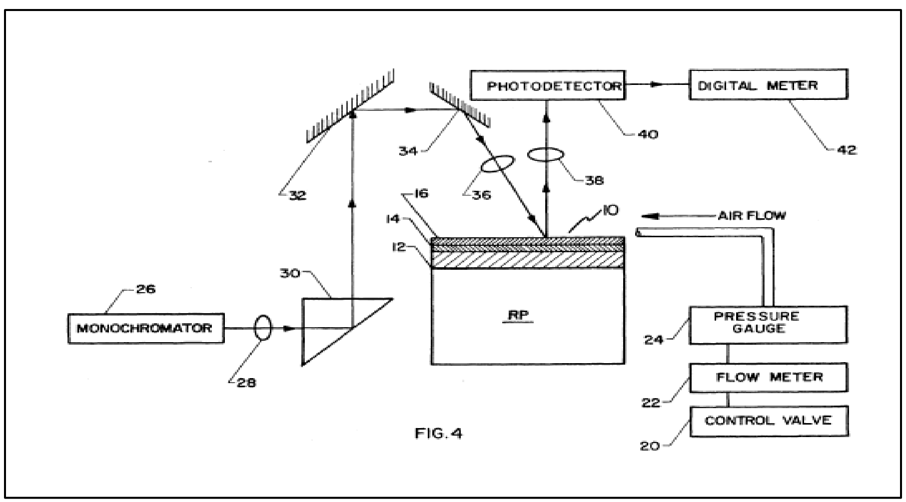
Liquid Crystal Coating

- -Advantages
- Exhibit chemical stability so that they perform well over a reasonable interval
- Can be used in dirty environments as it is not dependent on electricity
- -Limitations
- Optical access, calibration and accuracy
- The color observed is dependent on illumination and observation angles
- The coating degrades with time, and, due to the exposure of shear sensitive liquid crystals to the flow, reapplication is often necessary

Liquid Crystal Coating



- **(a) Downstream view, (b) upstream view, (c) schematic of the flow field [1]**



- **Patent Number 5223310 - The laminate structure comprises a liquid crystal polymer substrate attached to a test surface of an article [3]**