Shear Stress Sensor with Cholesteric Crystals

Group #3

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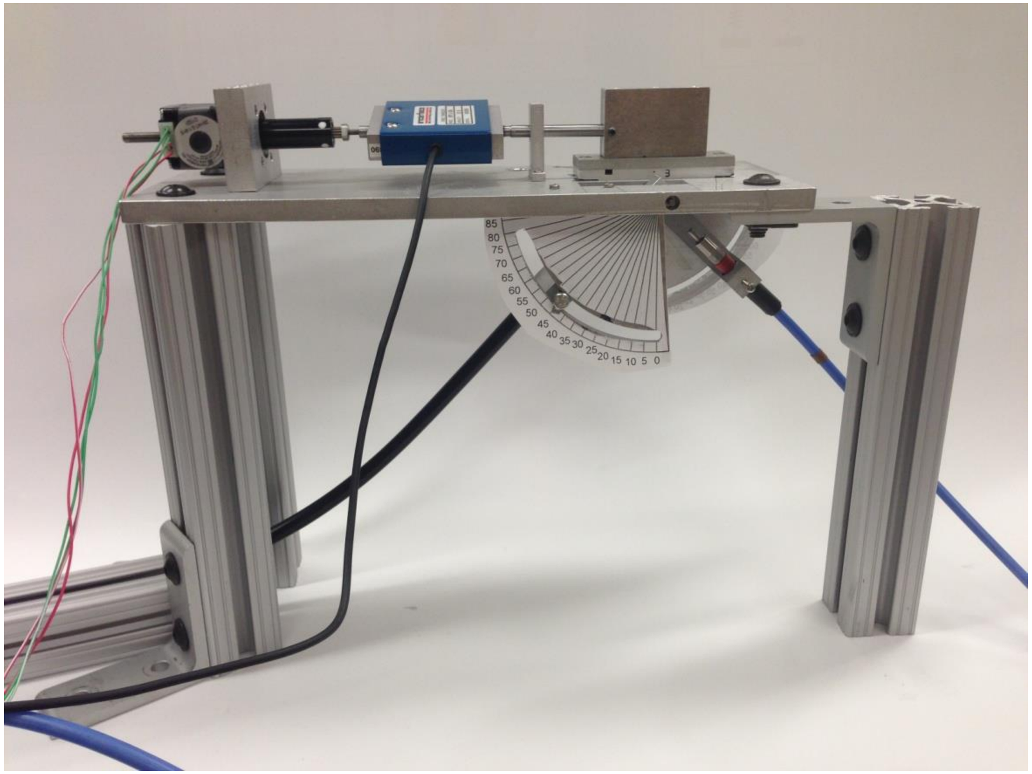
4/18/2013

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

OVERVIEW

- Project Scope
- Cholesteric Crystals
- Theory
- Final Design
- Programming
- Results
- Unit Cells



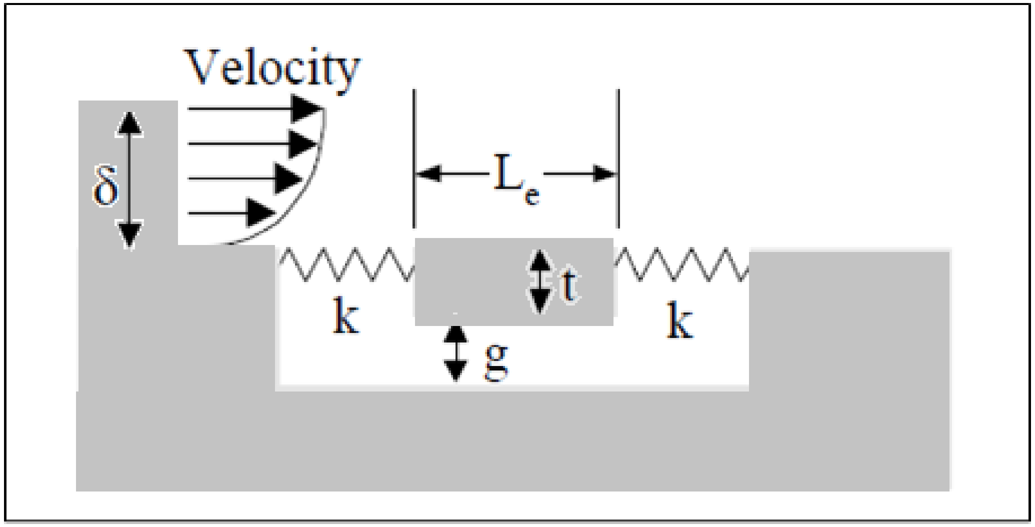
Project Scope

- Create Testing Apparatus
- Create Testing Method
- Create Data Acquisition & Analysis Software
- Characterize cholesteric crystals

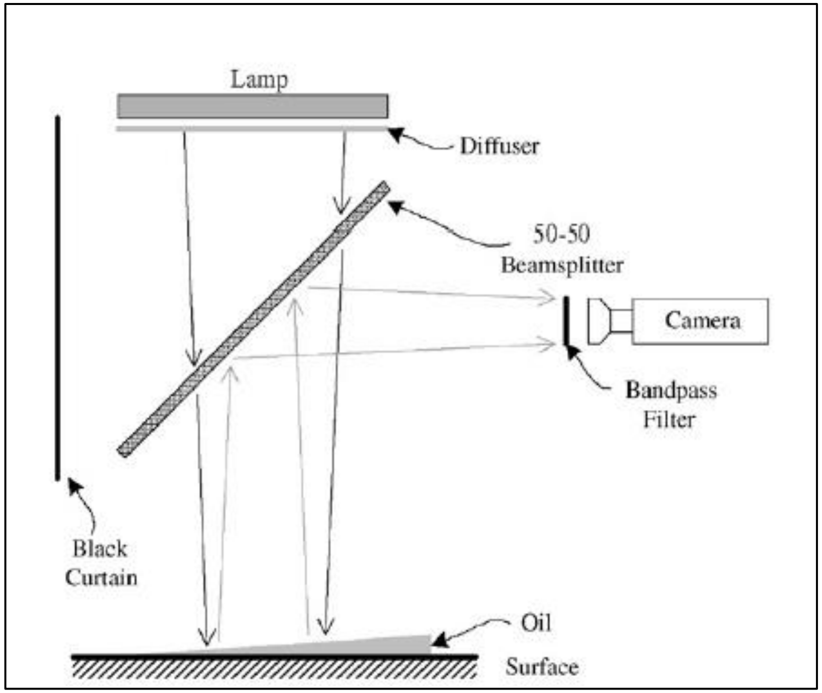
Liquid

Polymer

Existing Technology



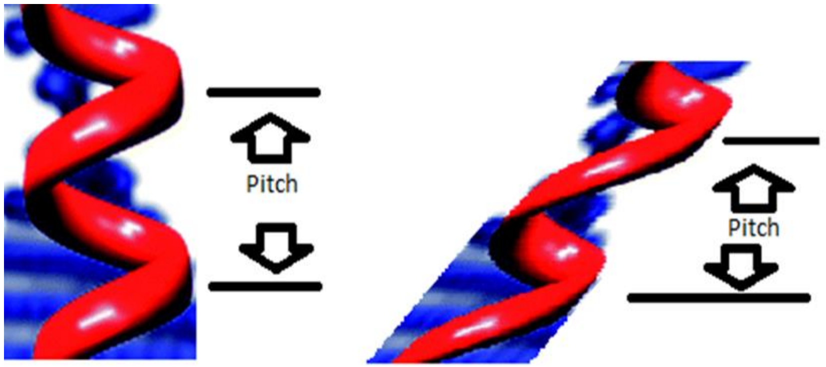
Micro-electrical-mechanical Systems (MEMS)



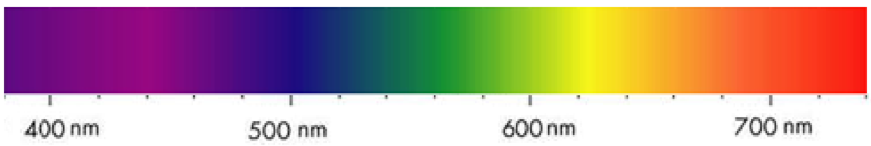
Thin-Oil Film

Cholesteric Crystals

- **Originally discovered in cholesterol**
- **Pitch varies with the boundary conditions**

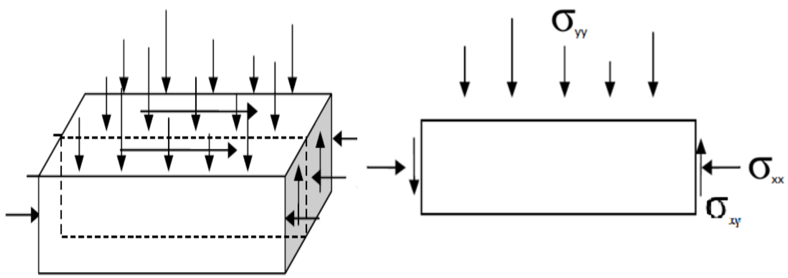


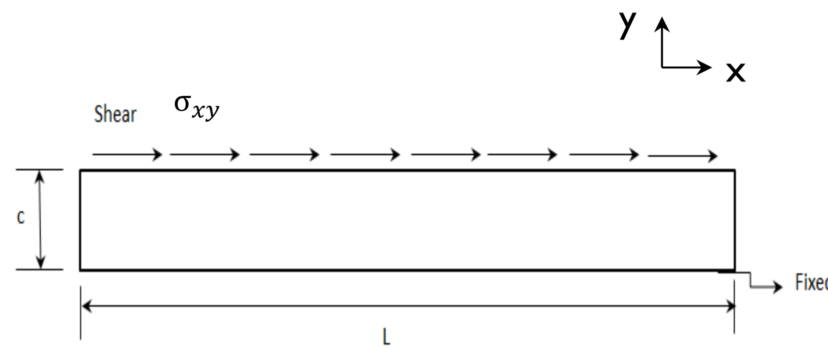
Visible Light Spectrum



Theory – Hooke's Law

-Decouple Analysis – Uniform Shear





Plane Strain

Hooke's Law

Uniform Shear

Strain

$\varepsilon_{xx} = 0$

$\varepsilon_{yy} = 0$

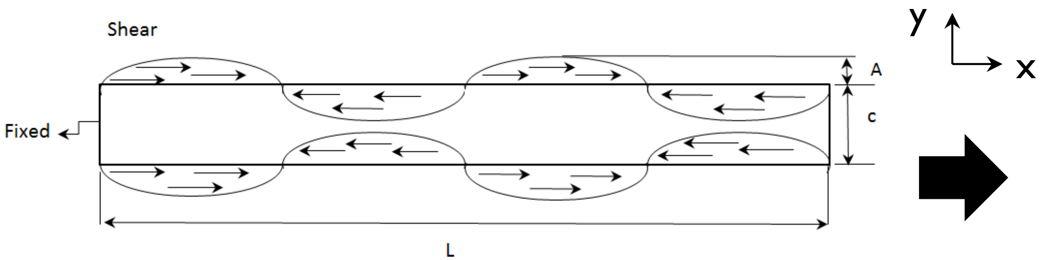
$\varepsilon_{xy} = \frac{1}{G}\sigma_{xy}$

Strain Ratio

$\frac{\varepsilon_{xy}}{\varepsilon_{xx}} \rightarrow \infty$

$\frac{\varepsilon_{xy}}{\varepsilon_{yy}} \rightarrow \infty$

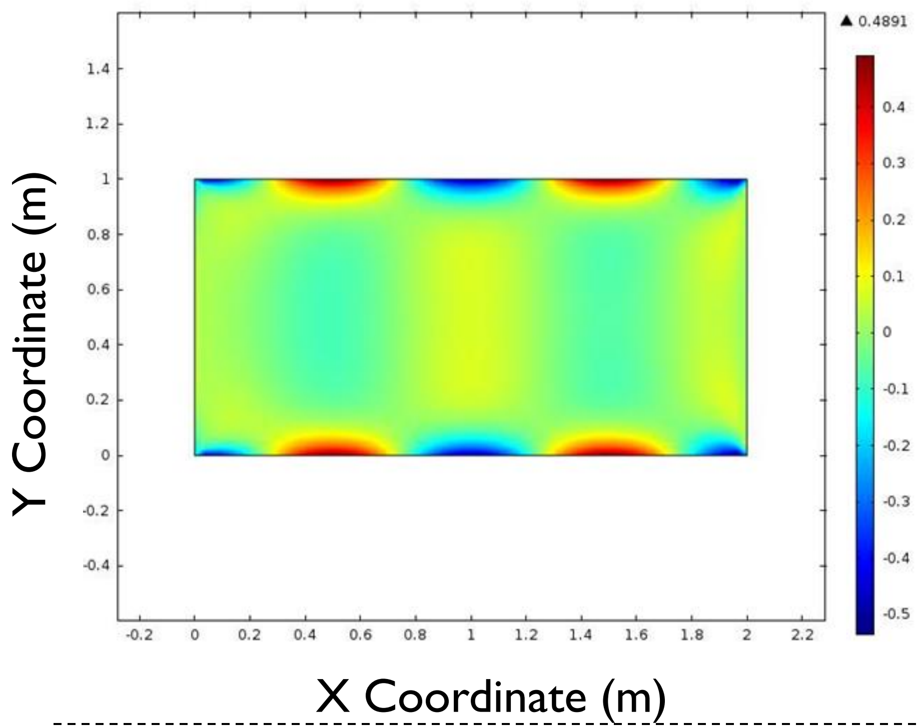
Simulation – FEM Plane Strain



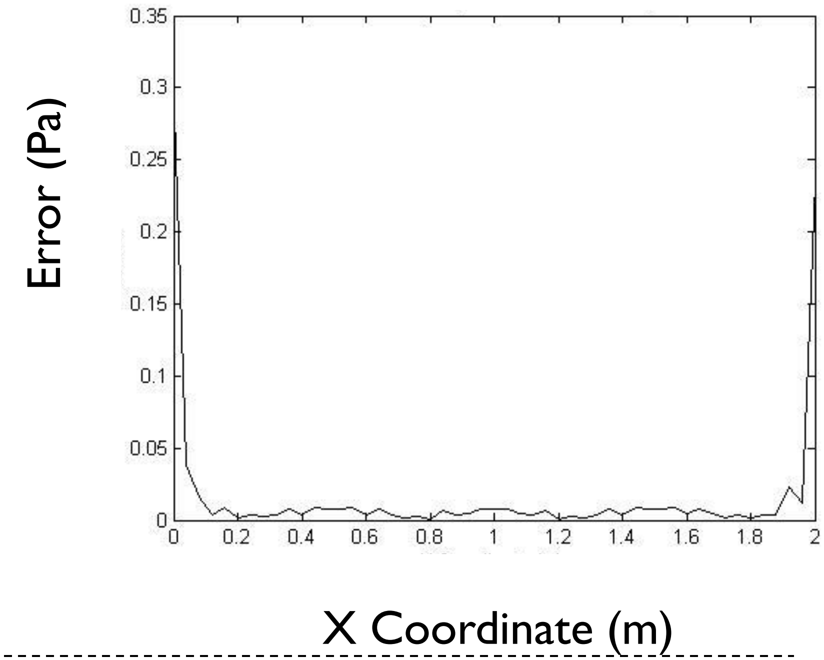
$$-\mathbf{0.5}\cos((\boldsymbol{4\pi/L}) * \boldsymbol{x})\ \boldsymbol{Pa} - \boldsymbol{top}$$

$$\mathbf{0.5}\cos((\boldsymbol{4\pi/L}) * \boldsymbol{x})\ \boldsymbol{Pa} - \boldsymbol{bottom}$$

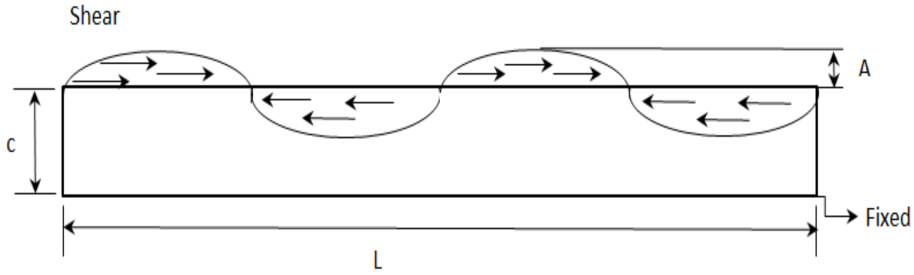
Stress XY (Pa)



Pressure Error – Sigma XY

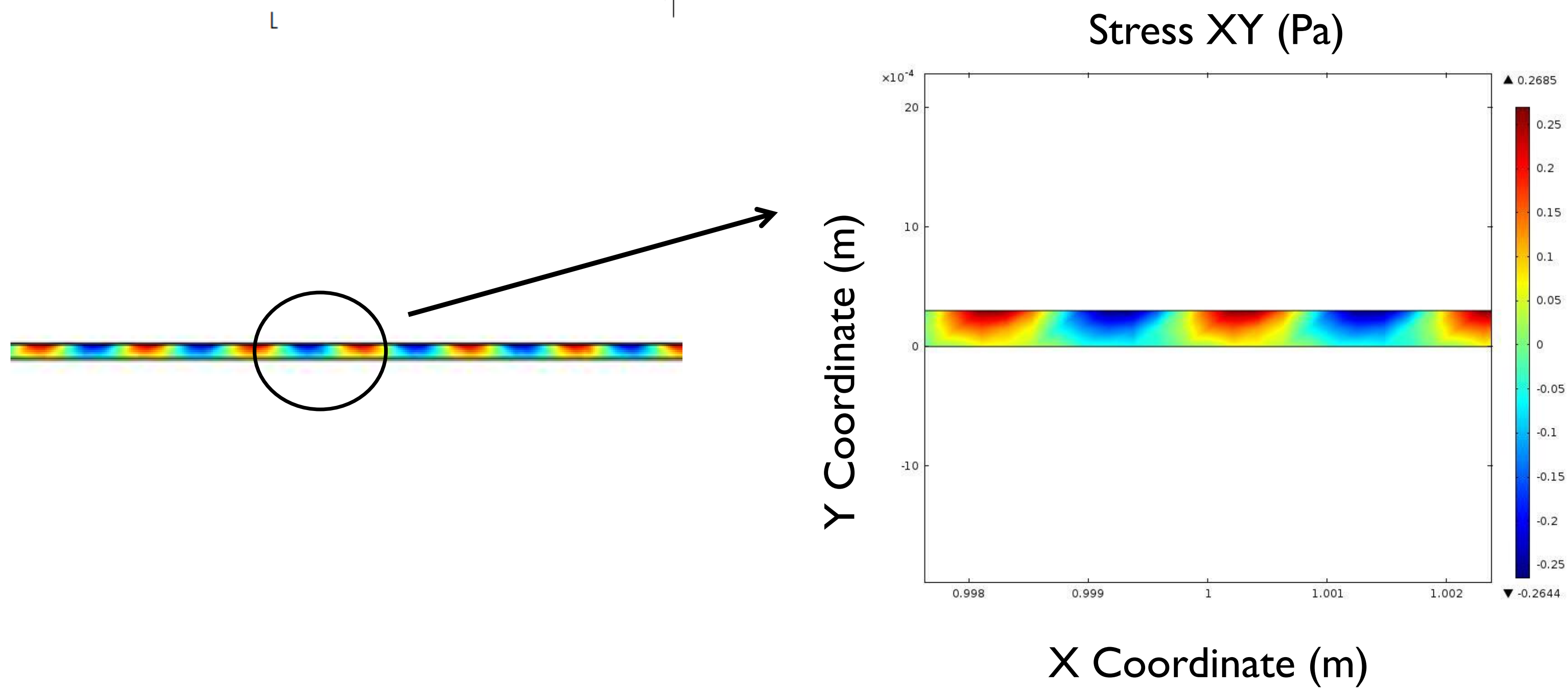


Simulation – FEM Plane Strain



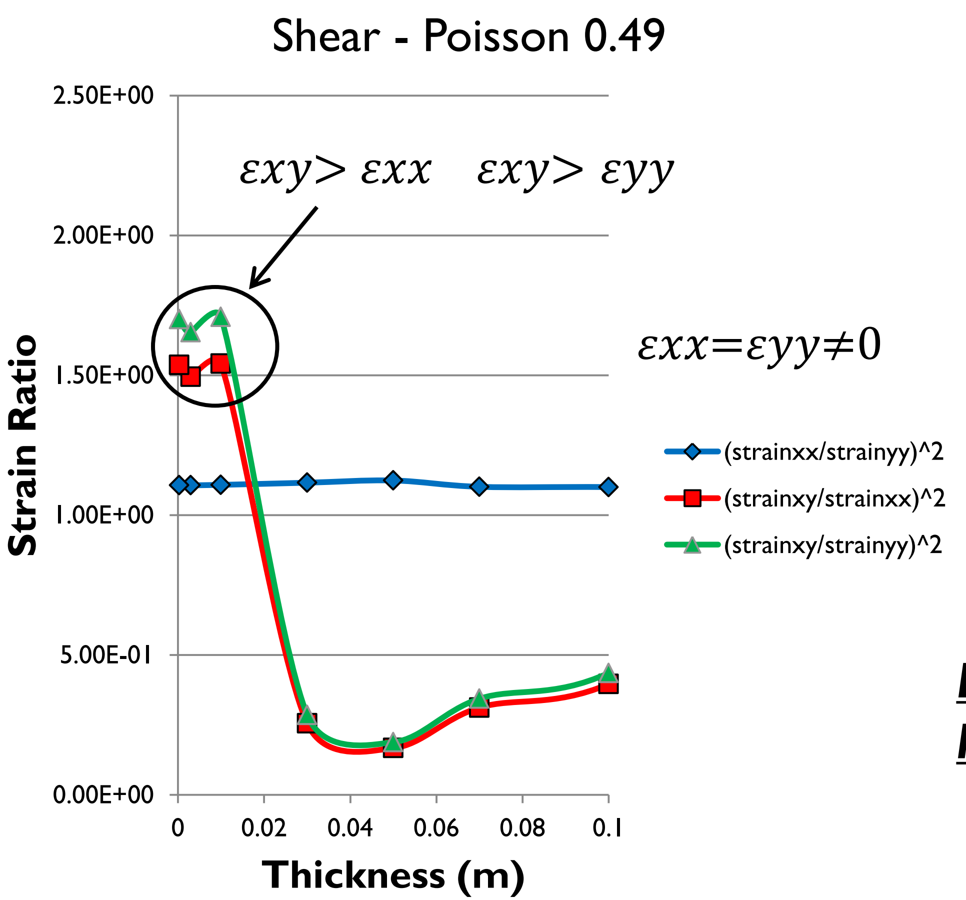
Thin film – c<<L

$$-\mathbf{0.5}\cos((\boldsymbol{4\pi/c})*\boldsymbol{x})\ \boldsymbol{Pa}\ -\ \boldsymbol{top}$$

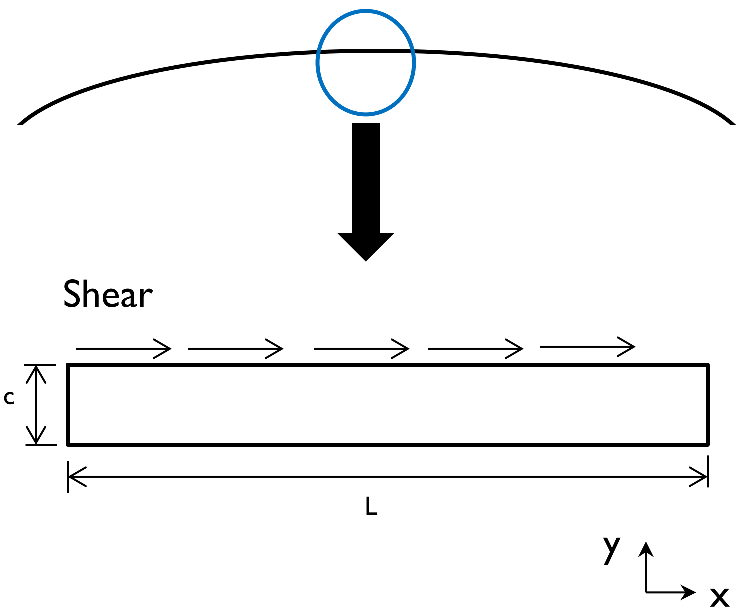


Simulation – FEM Plane Strain

-Decouple Analysis – Oscillating Shear

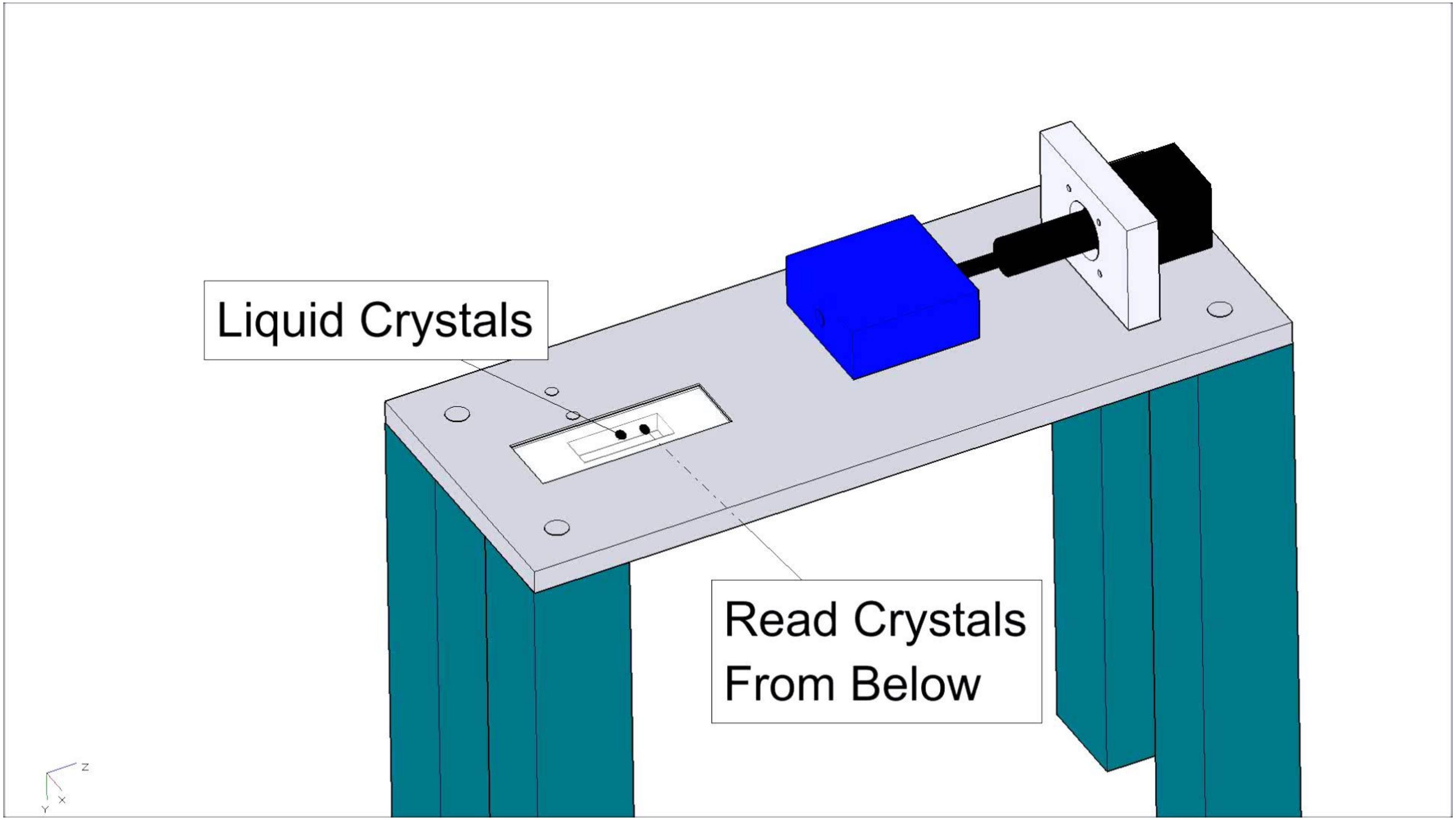


High Periods – Approximate oscillating load to a constant

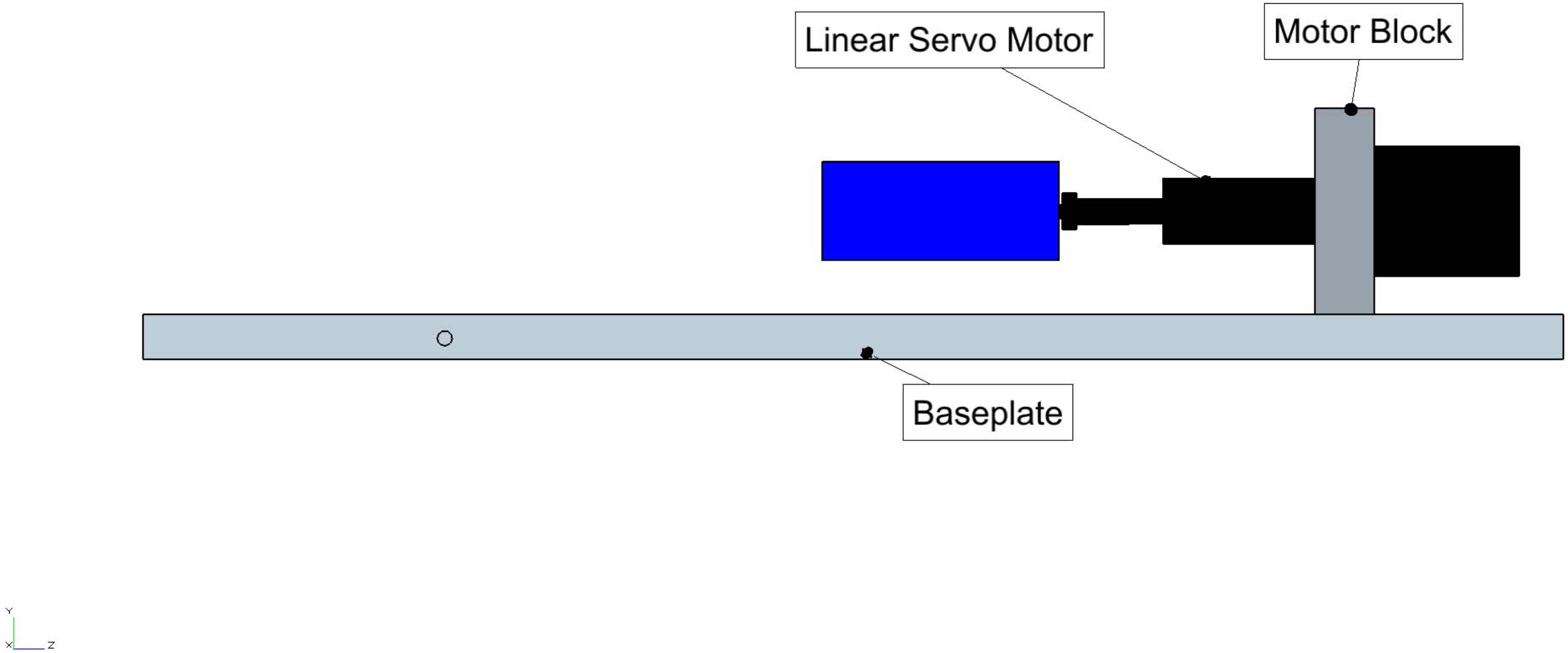


<u>Decouple is possible for constant load approximation and small c</u>

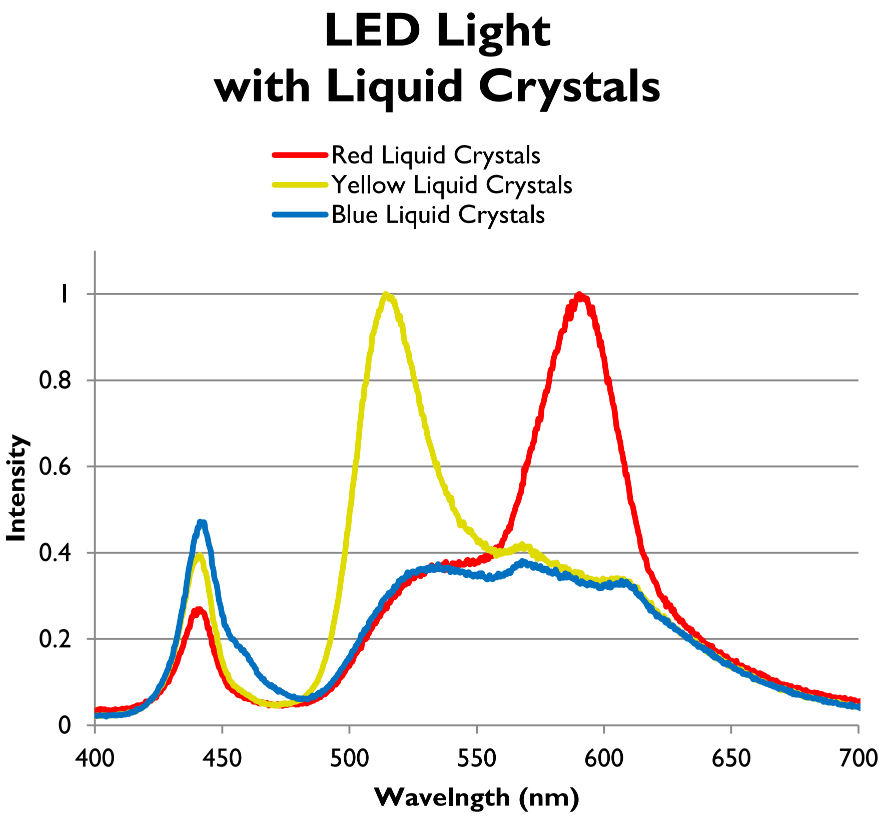
Concepts- See Videos Section

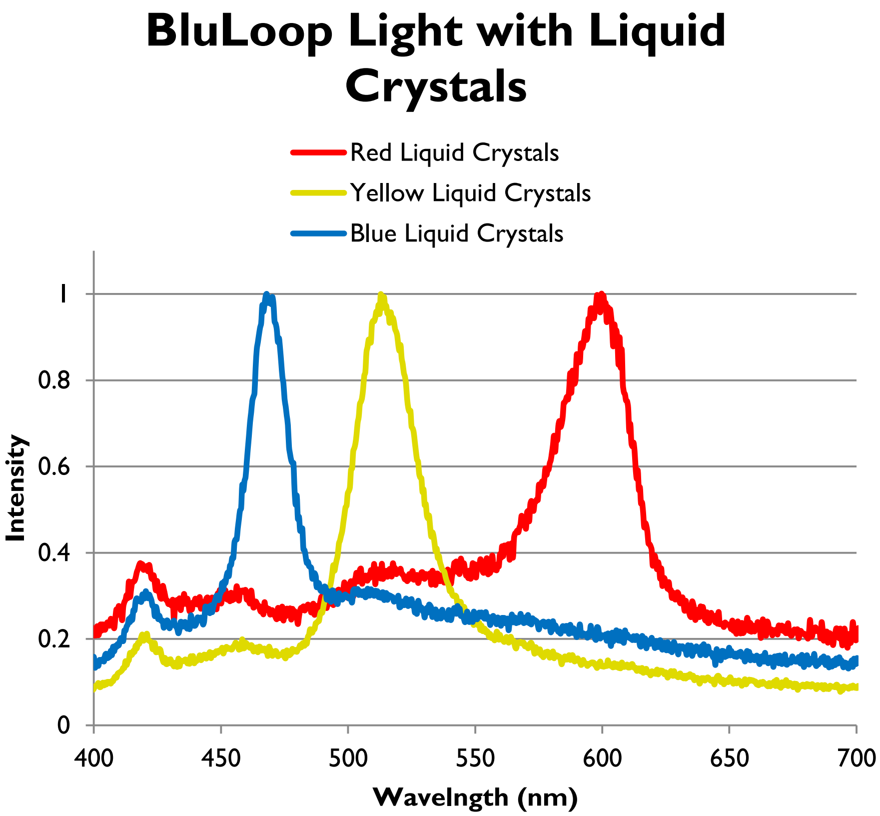


Final Design- See Videos Section



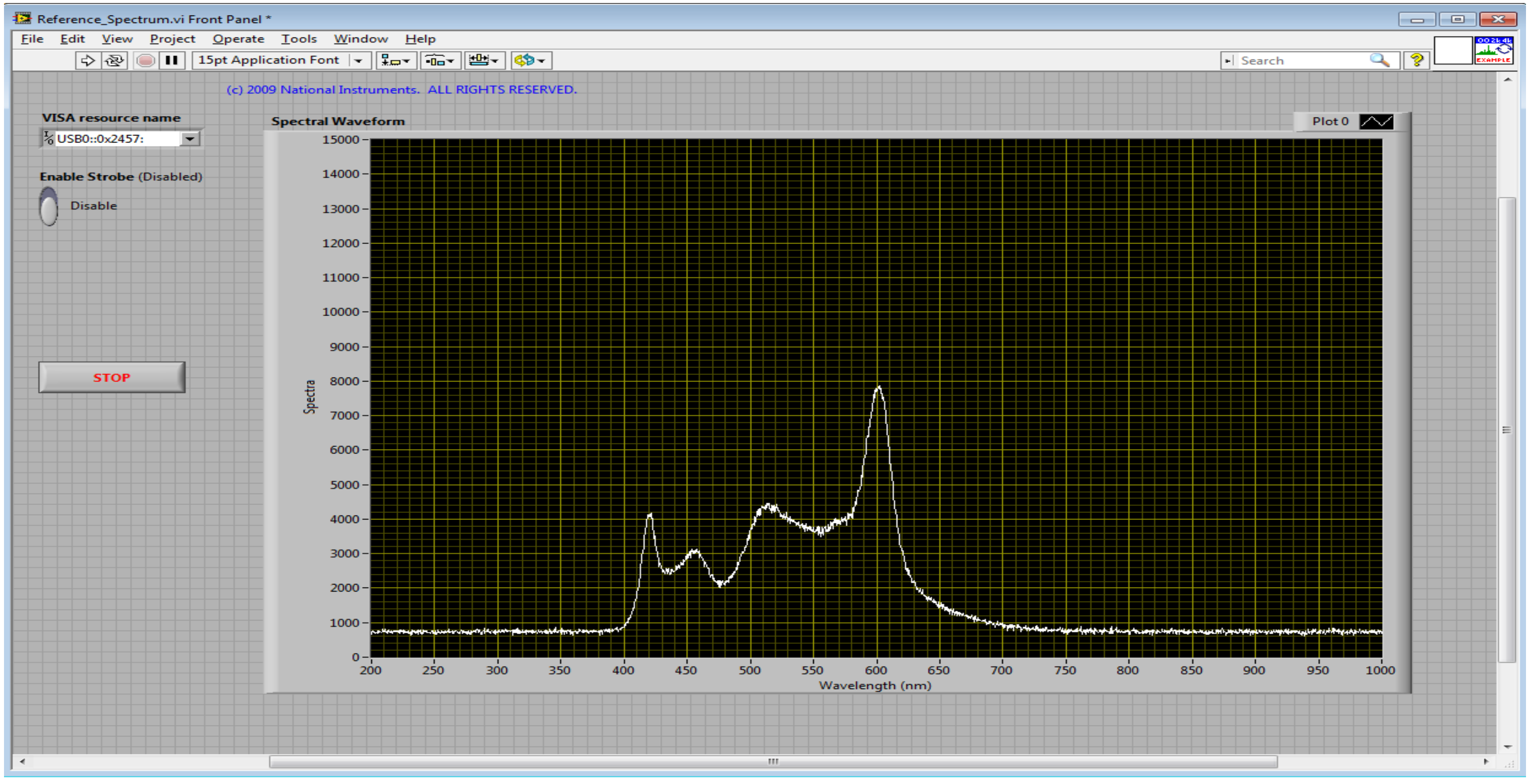
Light Sources



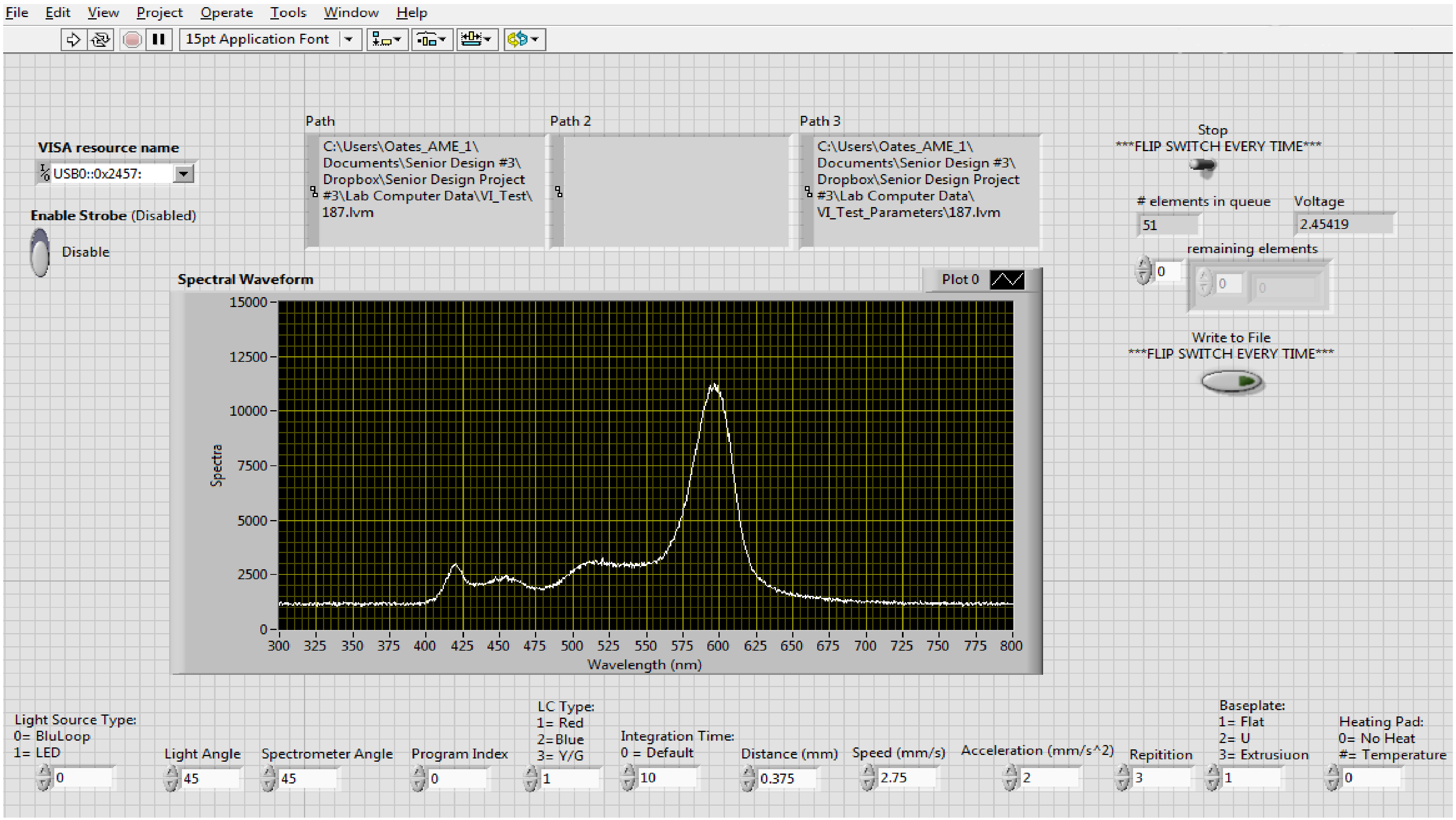


LabView

- **Record Force, Spectrum and Experiment Conditions**



LabView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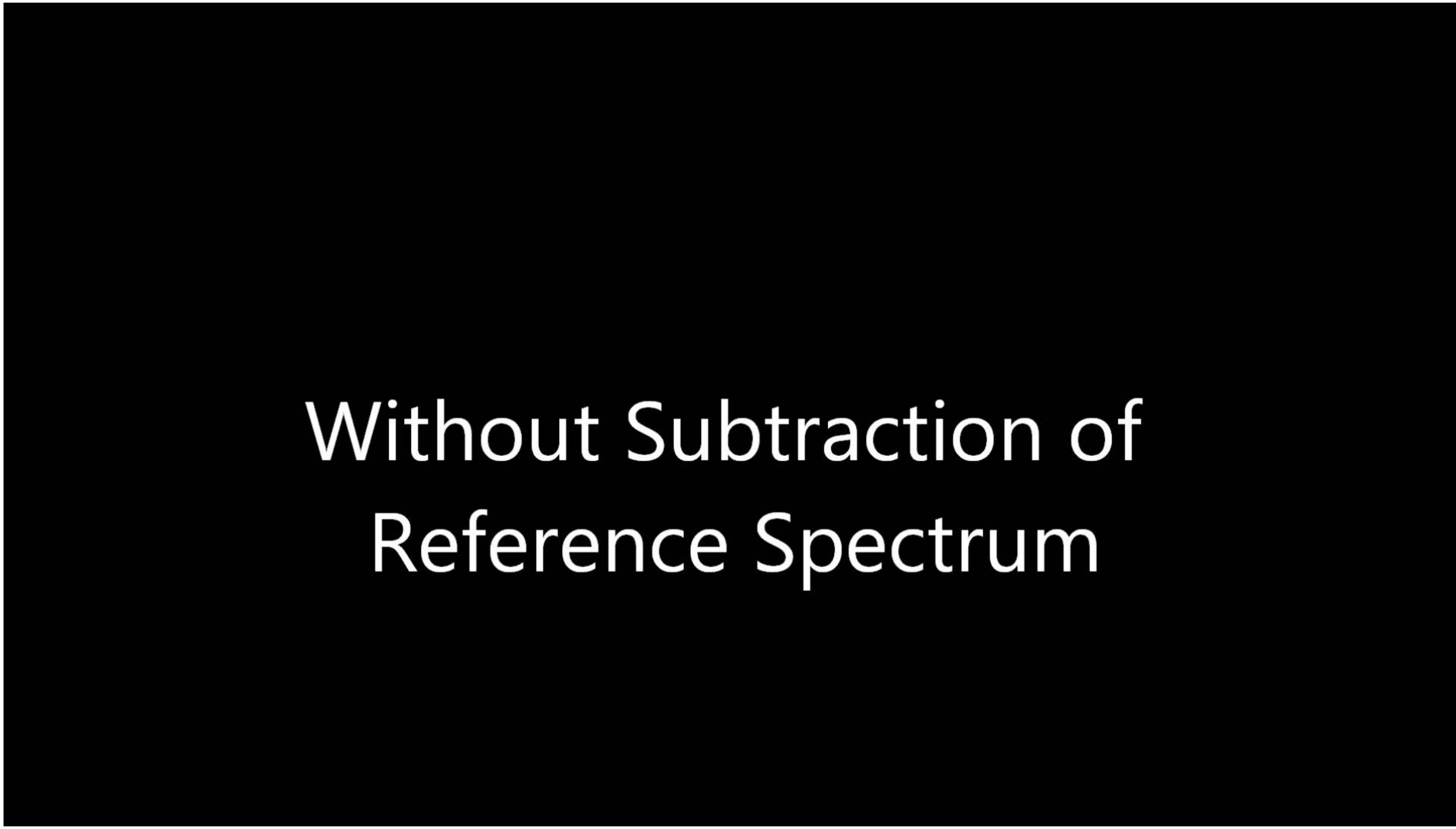
15pt Application Font
Path
C:\Users\Oates_AME_1\ Documents\Senior Design #3\ Dropbox\Senior Design Project #3\Lab Computer Data\VI_Test\ 187.lvm
Path 2
Path 3
C:\Users\Oates_AME_1\ Documents\Senior Design #3\ Dropbox\Senior Design Project #3\Lab Computer Data\ VI_Test_Parameters\187.lvm
VISA resource name
USB0::0x2457:
Enable Strobe (Disabled)
Disable
Stop
FLIP SWITCH EVERY TIME
elements in queue
51
Voltage
2.45419
remaining elements
Spectral Waveform
Plot 0
Spectra
Wavelength (nm)
Write to File
FLIP SWITCH EVERY TIME
Light Source Type:
0= BluLoop
1= LED
Light Angle
45
Spectrometer Angle
45
Program Index
0
LC Type:
1= Red
2=Blue
3= Y/G
Integration Time:
0 = Default
10
Distance (mm)
0.375
Speed (mm/s)
2.75
Acceleration (mm/s^2)
2
Repitition
3
Baseplate:
1= Flat
2= U
3= Extrusiuon
Heating Pad:
0= No Heat
#= Temperature

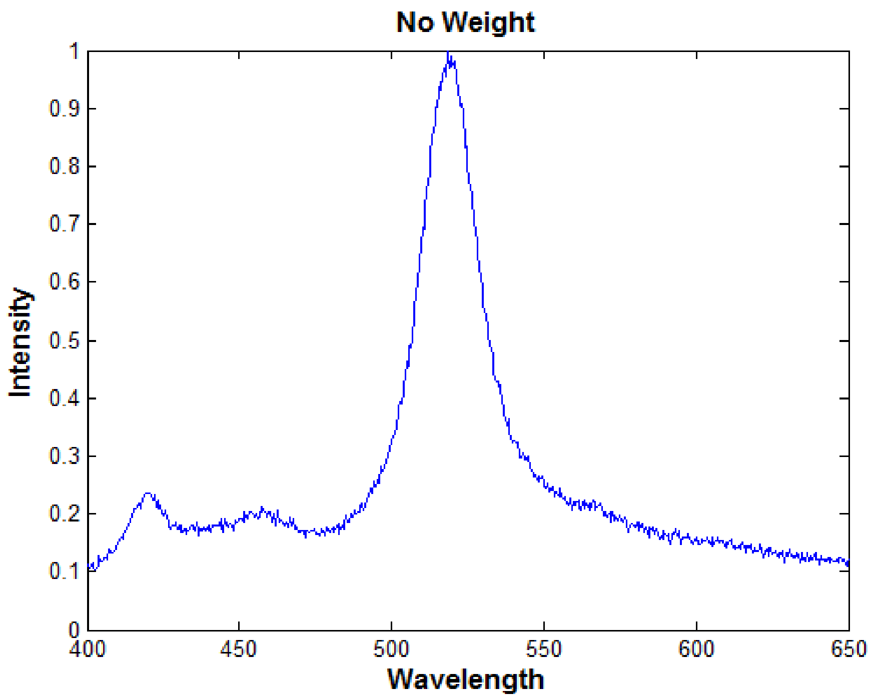
MATLAB

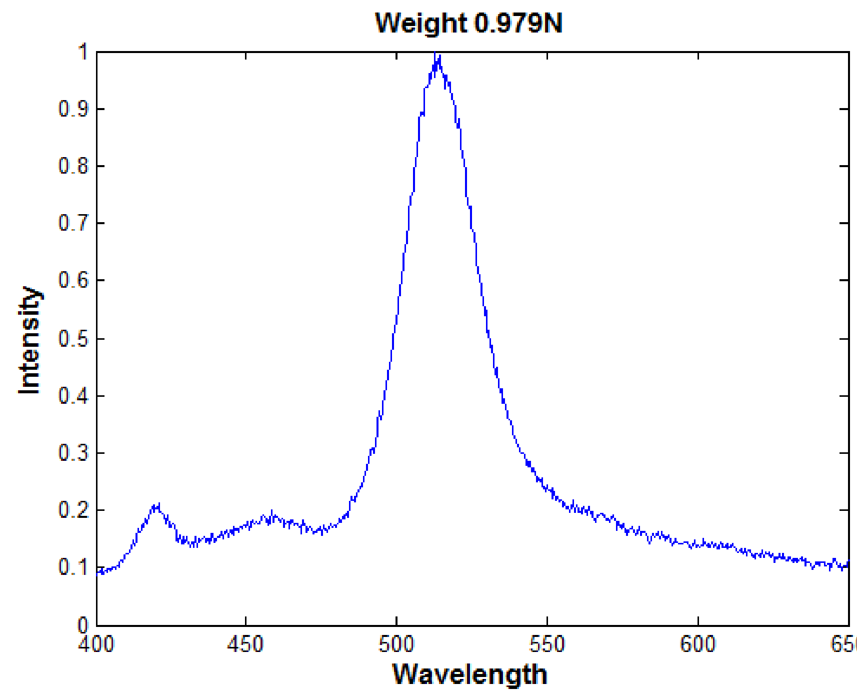
- Systematize experimental data
- Filter experiment spectrum from reference spectrum
- Analyze data set

MATLAB- See Videos Section



Results-Normal Force

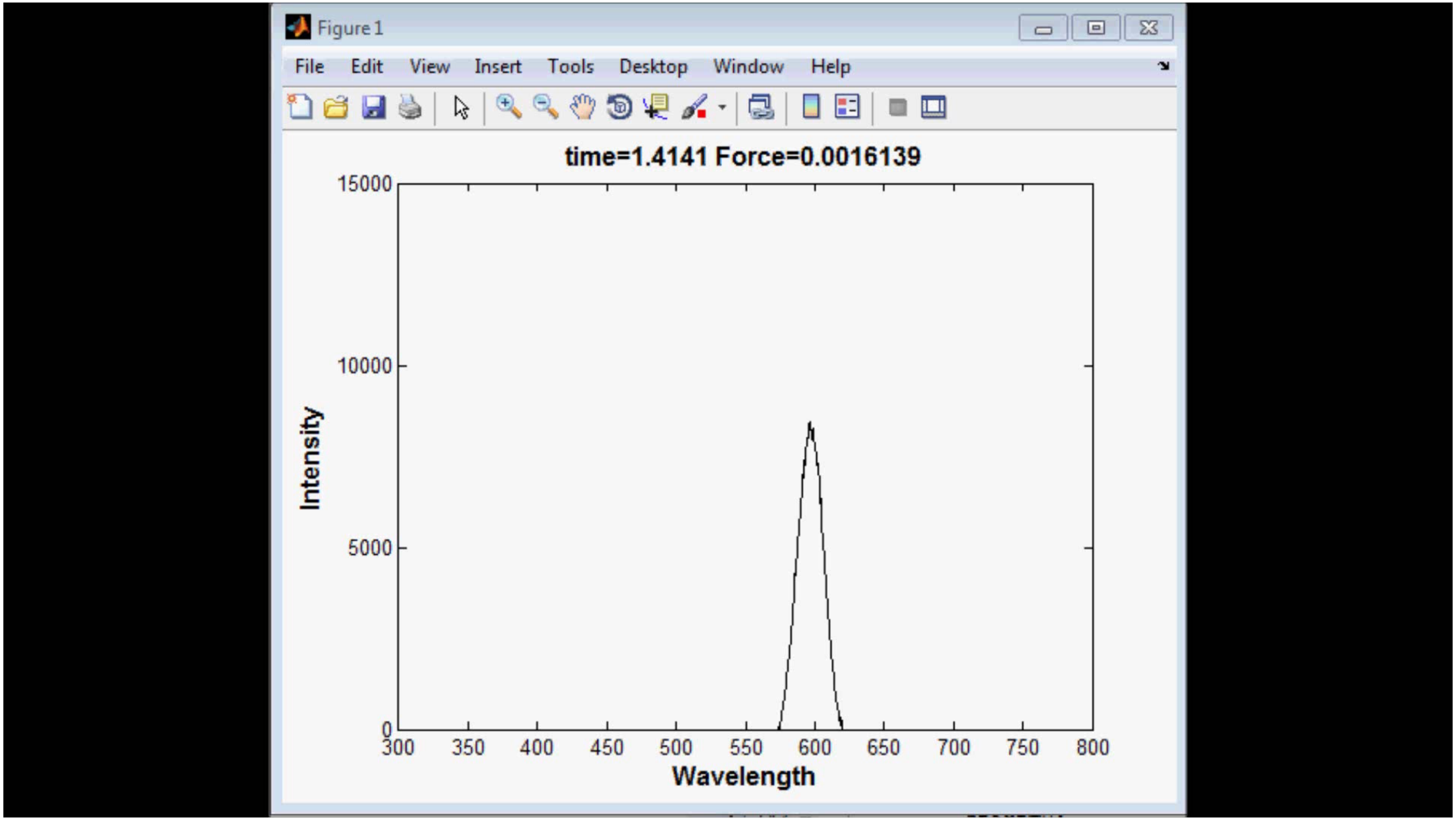




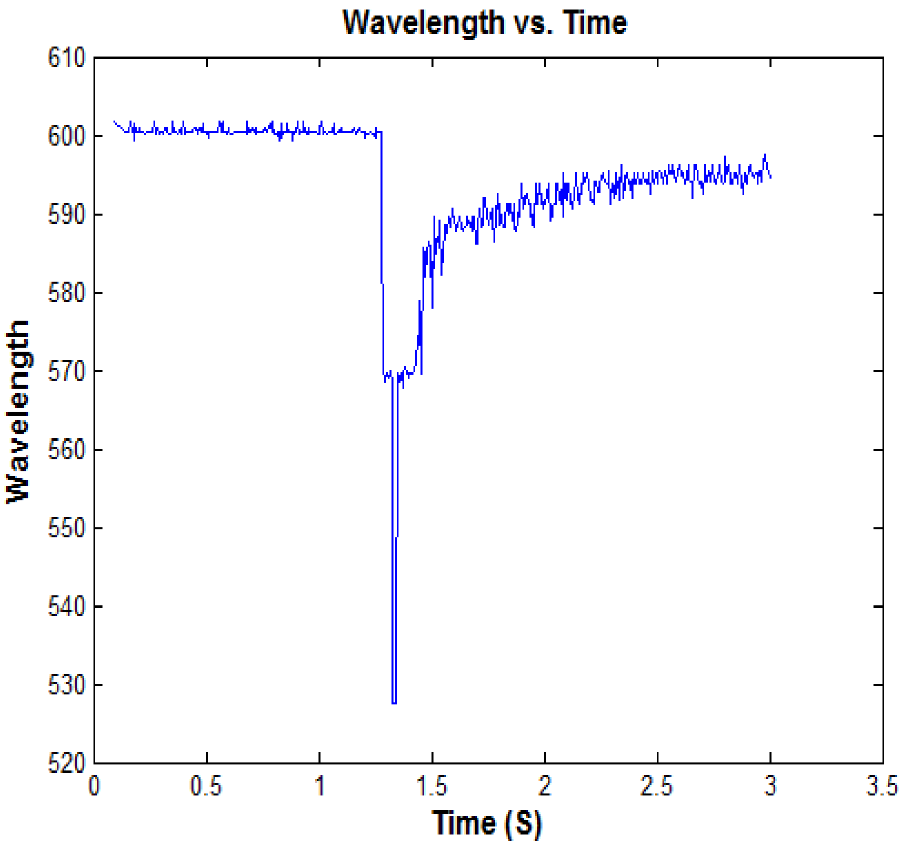
	Color						
	Red	Blue	Yellow		Red	Blue	Yellow
	No Weight				Weight (0.979 N)		
Average Wavelength (nm)	600.3	469.1	512.0	Average Wavelength (nm)	597.5	469.7	519.7

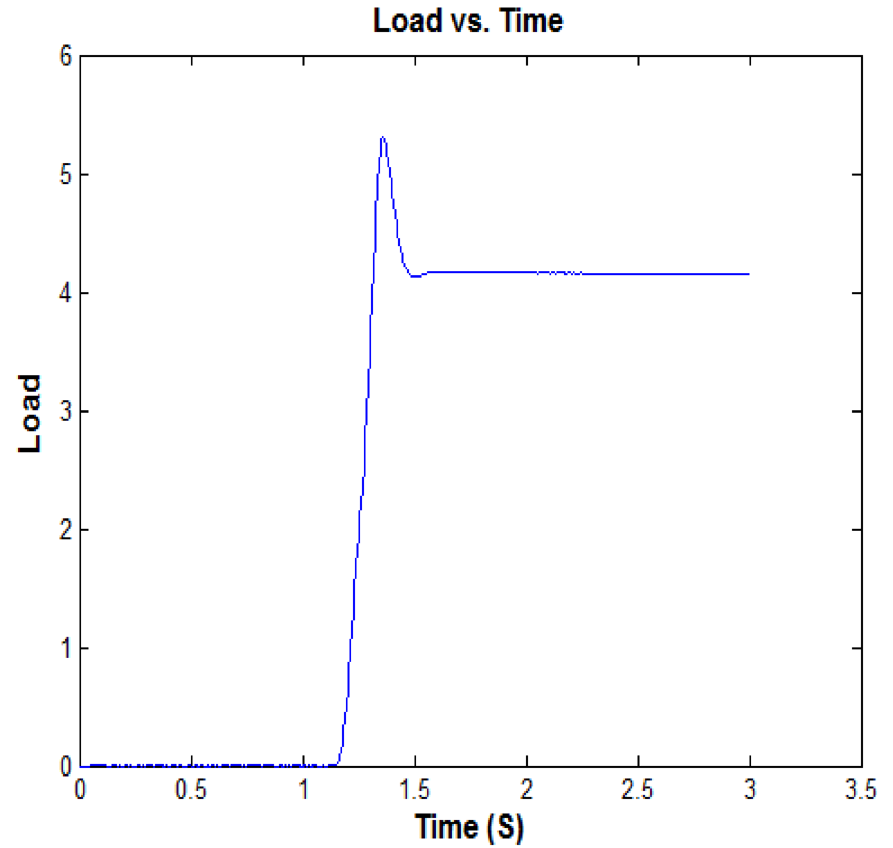
Difference	
Color	**Red**
Red	2.8
Blue	0.6
Yellow	7.7

Results- Liquid Crystals

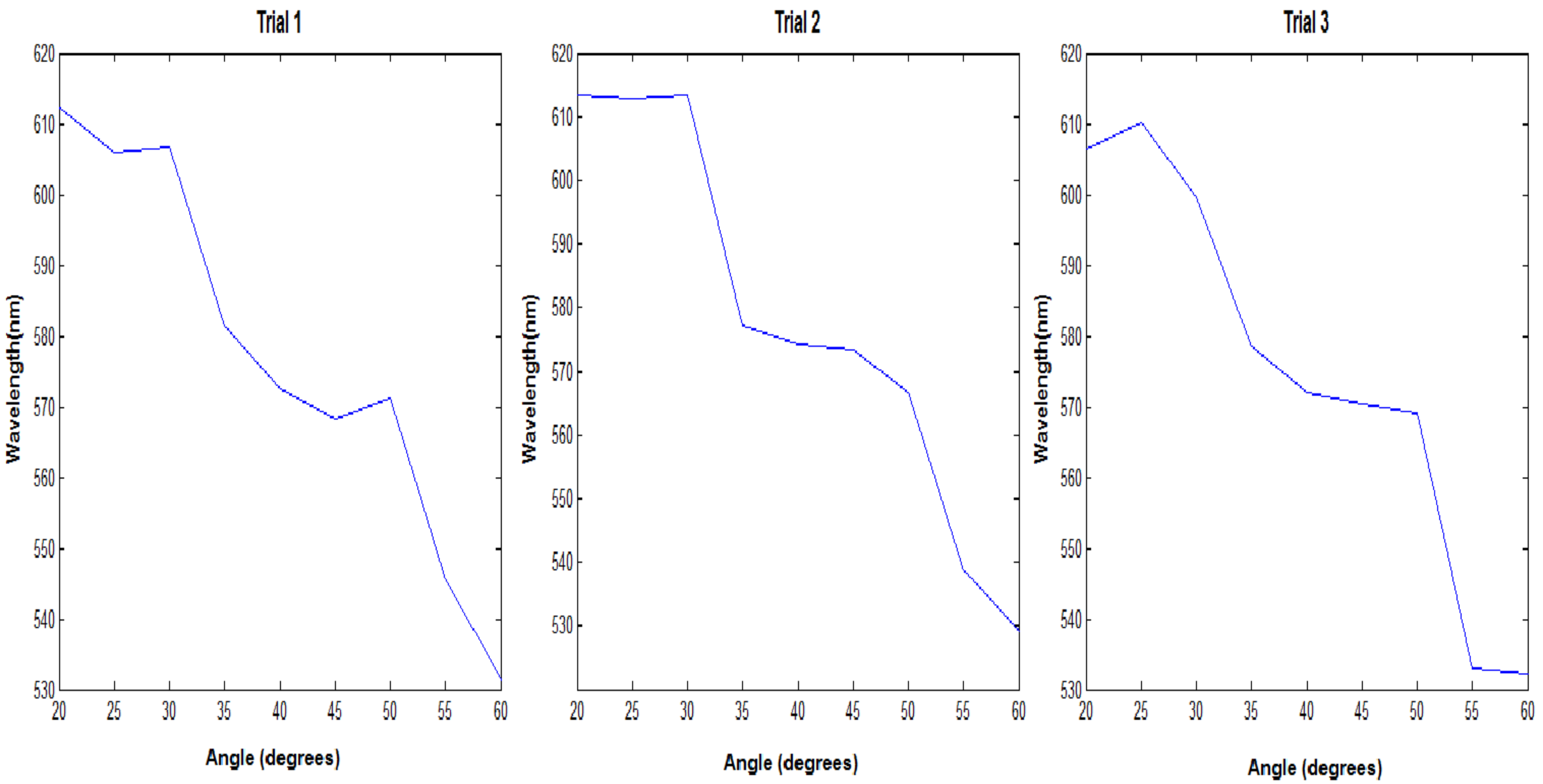


Results- Liquid Crystals





Results- Polymer crystals



Results

Variables

- Distance
- Velocity
- Acceleration
- Settling Time
- Quantity of Liquid Crystals
- Angles/Distance of Fiber Optic Cables
- Type of Light source

Unit Cells

- **Purpose is to have a manufacturable product for distribution in a sensor ready form**

VHB with Liquid Crystals

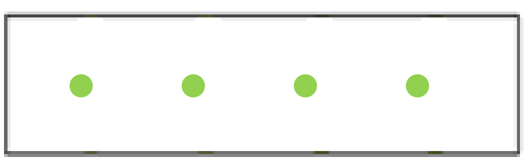
Side View

Zero Force Applied

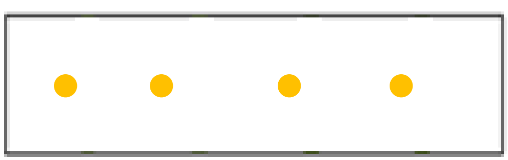
Force Applied

Top View

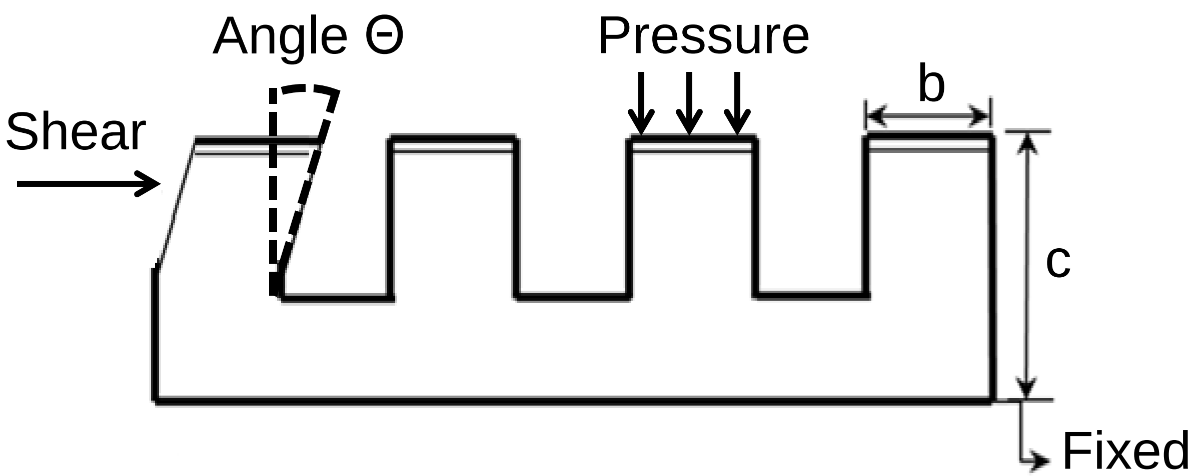
Zero Force Applied

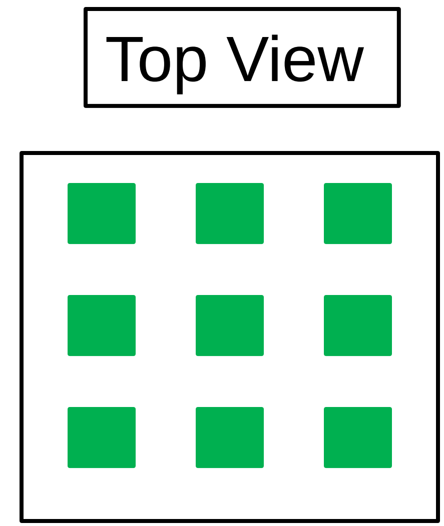


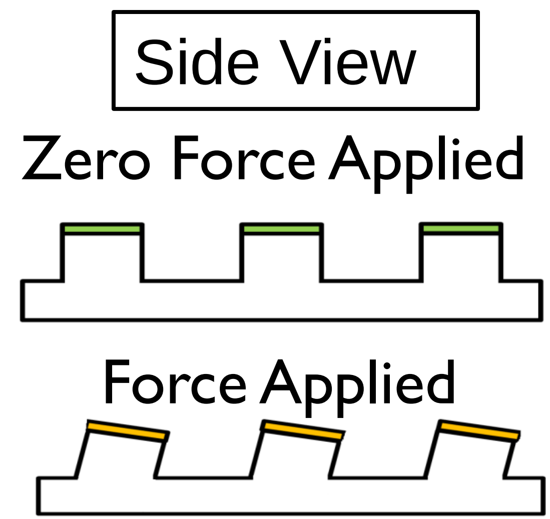
Force Applied



Unit Cells







Decouple Analysis

- Shear and Pressure

Maximize Angle θ

$$\Theta = \frac{Pc^2}{2EI} = \frac{6Pc^2}{Eb^4}$$

Cost

Part	Unit Price	Quantity	Price
Teflon Bearing	$3.11	3	$ 9
Insulation	$9.03	1	$9
Heat sheet	$38.90	1	$38
Fasteners	- -	- -	$22
LED	$23.74	1	$24
Thermocouple	$19.00	2	$38
Load Cell- 10N	$485.00	1	$485
Liquid Crystals	$75.00	3	$225
VHB Tape	$18.44	1	$19
		Total	$870

Summary

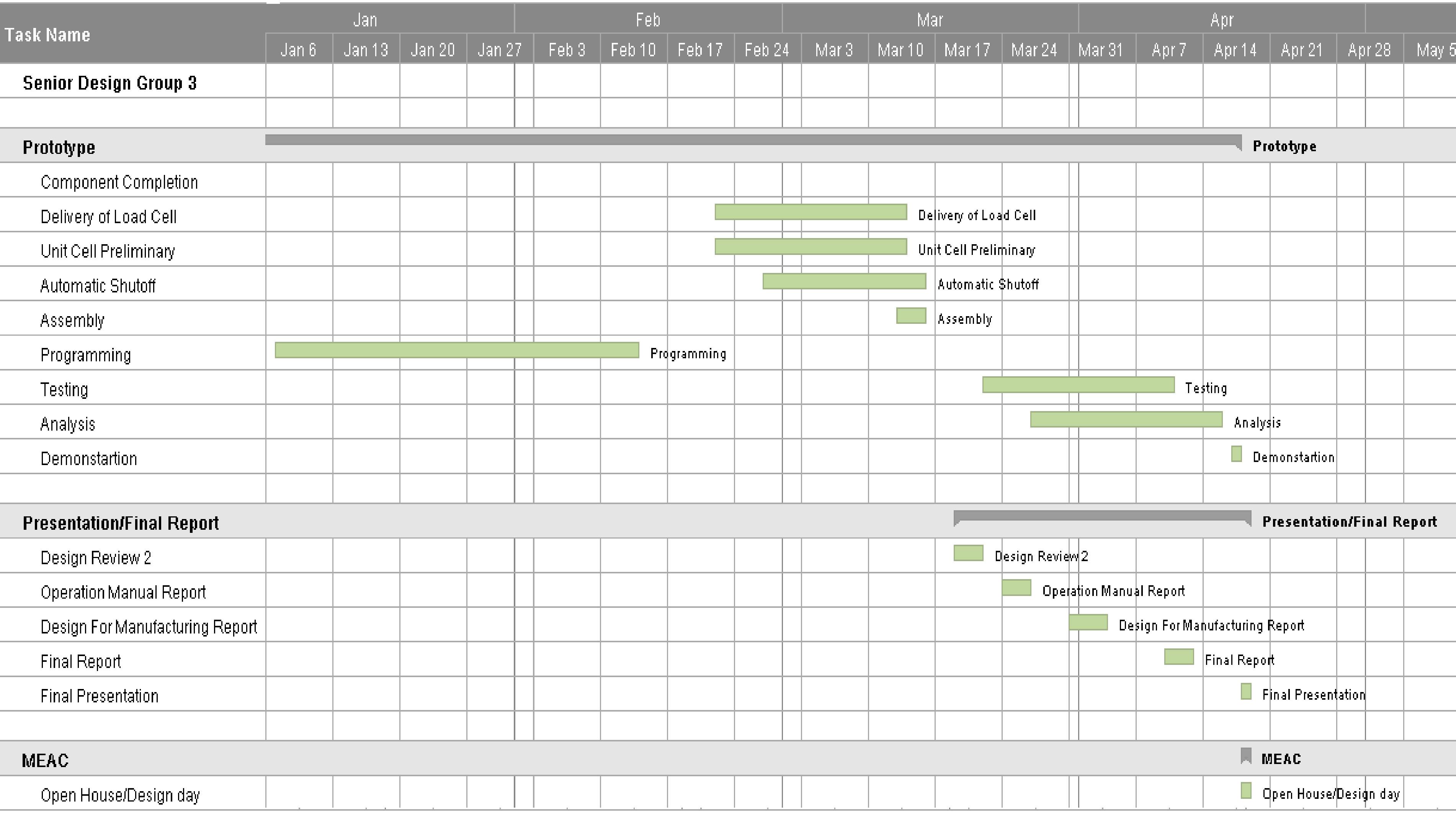
- **COMSOL analysis**
- **Designed a testing apparatus**
- **Created programs to process data**
- **Cholesteric crystals are angle dependent**
- **Basic unit cell design**

Recommendations

- **Analysis of Unit Cells**
- **More testing on Liquid Crystals**
- **Adapt apparatus for Polymer Crystals**
- **Test Polymer Concept**

Questions/Comments

Schedule


Task Name
Jan
Feb
Mar
Apr
Jan 6
Jan 13
Jan 20
Jan 27
Feb 3
Feb 10
Feb 17
Feb 24
Mar 3
Mar 10
Mar 17
Mar 24
Mar 31
Apr 7
Apr 14
Apr 21
Apr 28
May 5
Senior Design Group 3
Prototype
Component Completion
Delivery of Load Cell
Unit Cell Preliminary
Automatic Shutoff
Assembly
Programming
Testing
Analysis
Demonstartion
Presentation/Final Report
Design Review 2
Operation Manual Report
Design For Manufacturing Report
Final Report
Final Presentation
MEAC
Open House/Design day

Budget (Supplied Parts)

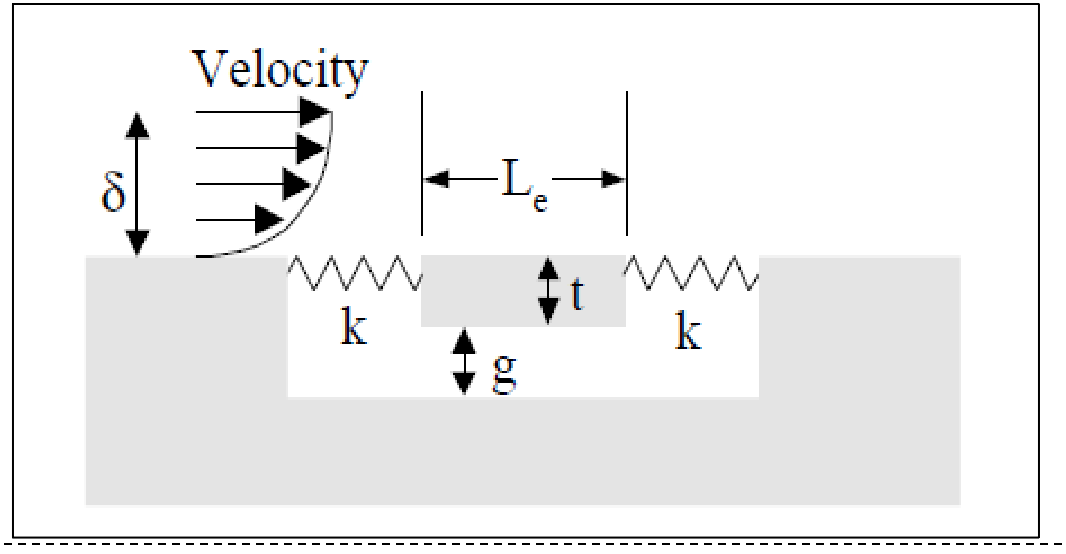
Part	Unit Price	Quantity	Price
Machine Shop	$150.00	30	$4,500.00
Aluminum	$64.00	--	$ 64.00
Fiber-Optic Spectrometer	$2,775.00	1	$2,775.00
Linear Servo Motor	$75.00	1	$75.00
BluLoop Light Source	$1,575.00	1	$1,575.00
Software	$2,669.00	--	$2,669.00
Multimeter	$15.00	1	$15.00
DAQ Board	$369.00	1	$369.00
Amplifier- SGA power signal converter	$345.00	1	$345.00
Motor Driver	$395.52	1	$395.52
Power Supply	$130	1	$130
		Total	$13,013

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

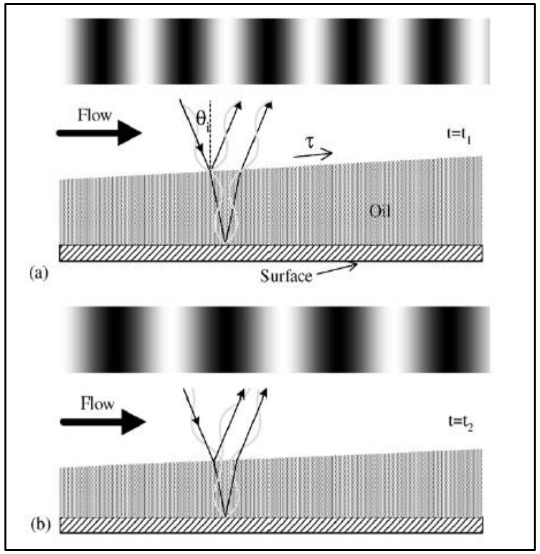
MEMS

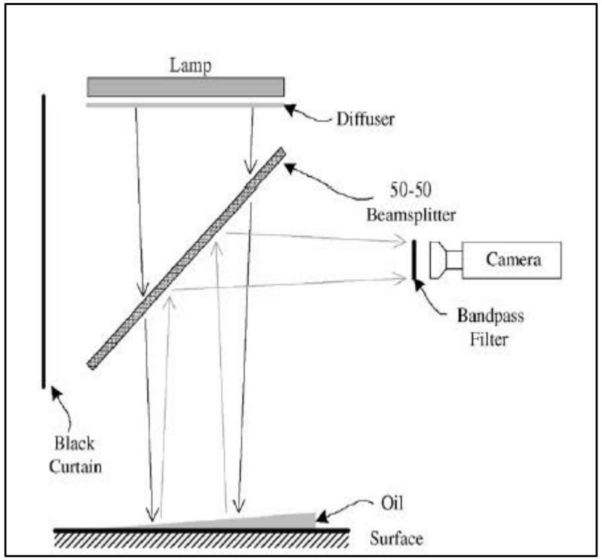
- Types – Direct sensors, thermal sensors and laser based sensors
- Direct sensors – Measure integrated force produced by the wall shear-stress on a flush movable “floating” element
- Displacement of the floating element – function of wall shear stress



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**





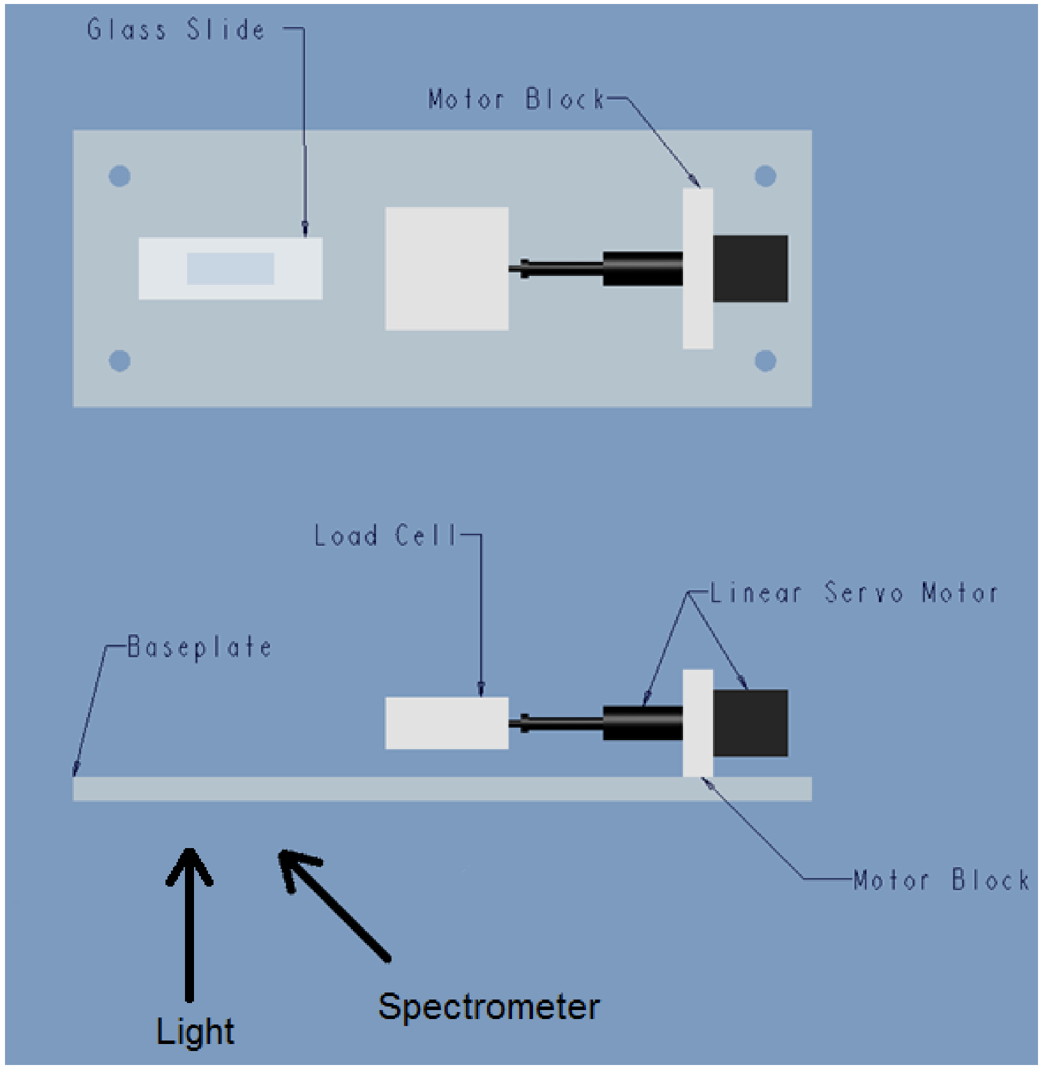
Thin-Oil Film

- 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

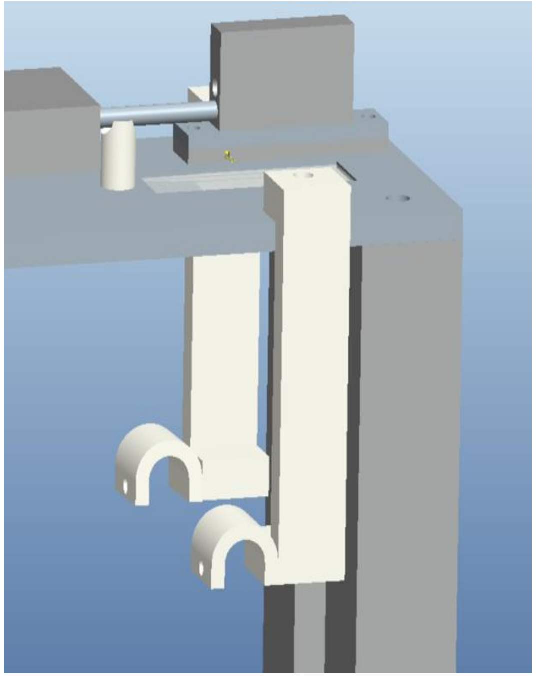
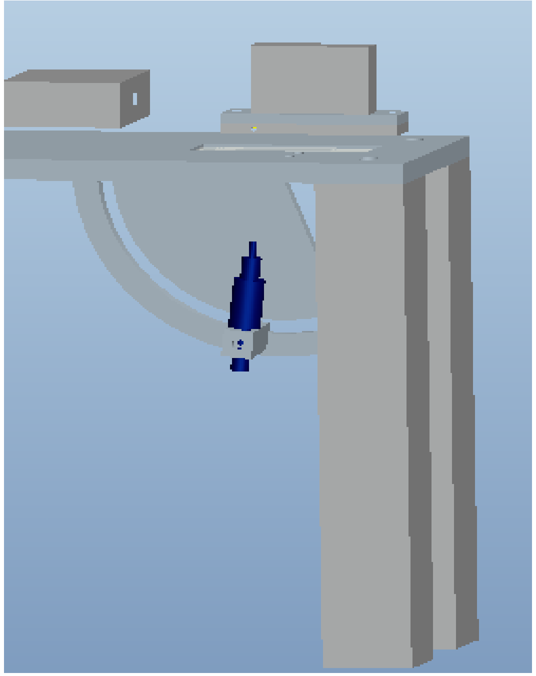
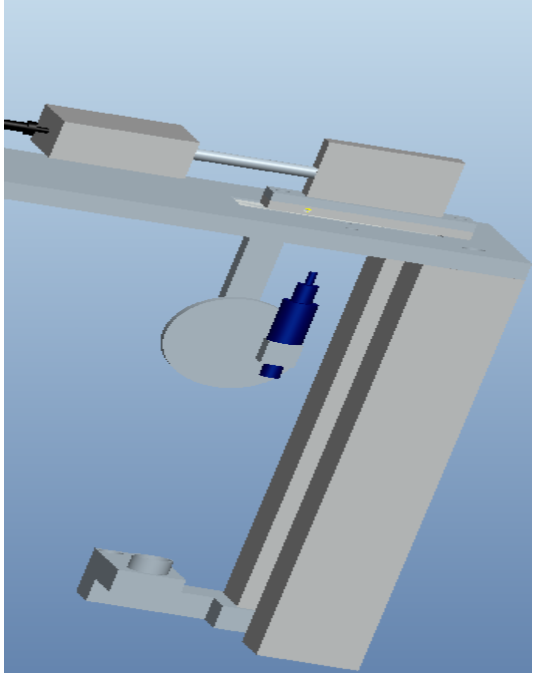
Liquid Crystal Coating

- -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

Given Parts and Design



Concepts

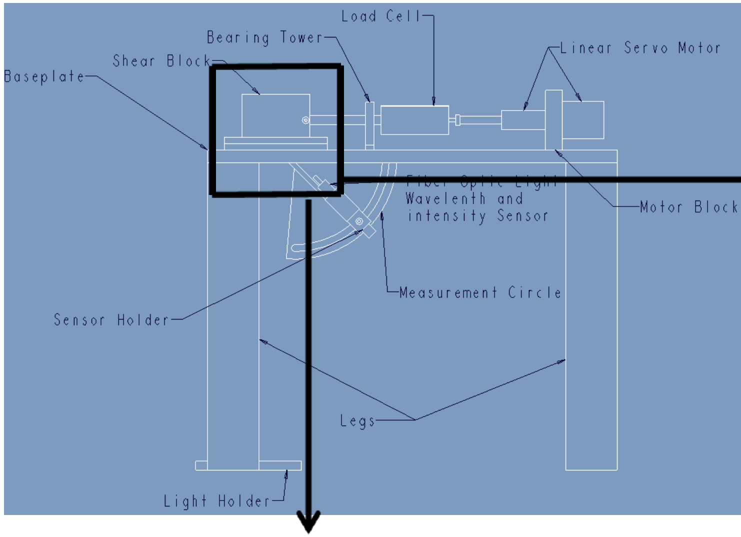
Concept #1	Concept #2	Concept #3
		

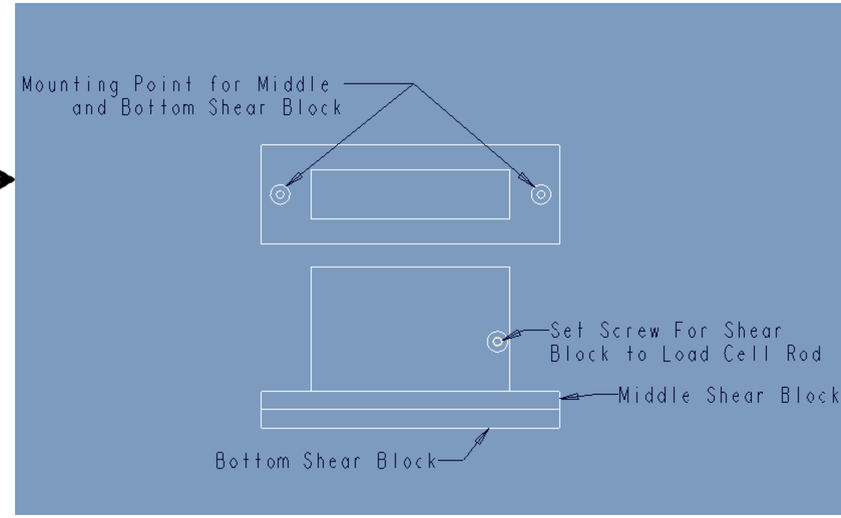
Decision Matrix

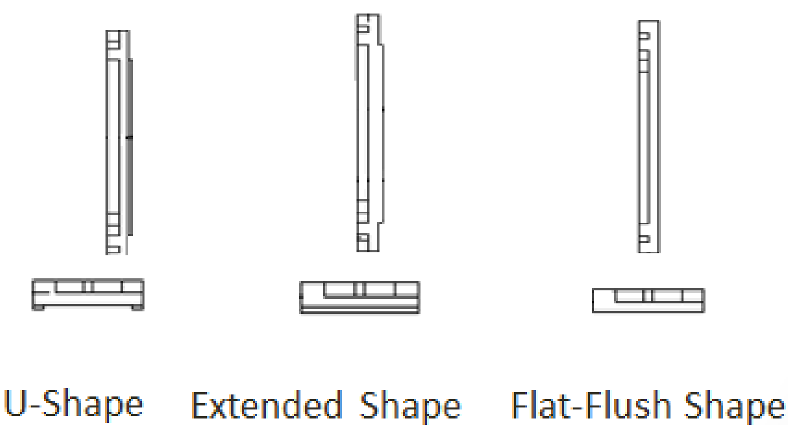
		Concept 1		Concept 2		Concept 3	
	Weight	Score	Weighted	Score	Weighted	Score	Weighted
Ease of Use	0.2	2	0.4	4	0.8	4	0.8
Reproducibility	0.3	3	0.9	5	1.5	2	0.6
Accuracy	0.3	2	0.6	4	1.2	1	0.3
Cost	0.15	3	0.45	2	0.3	3	0.45
Size	0.05	2	0.1	3	0.15	4	0.2
Total	1		2.45		3.95		2.35

- **Final Design Selection: Concept 2**

Final Design







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

Components

Load Cell

Linear Servo Motor

BluLoop Light

Spectrometer

- Polymers from Wright-Patterson AFRL

Oscillating Load

Oscillating Load – can approximate any function based on Fourier Series

Wind Speed - FAA

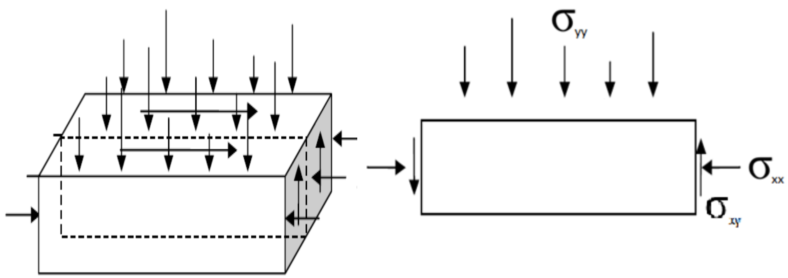
$$w = -p_1 Asin\left[\pi \frac{x-x_r}{q_1}\right] \text{ [m/s]}$$

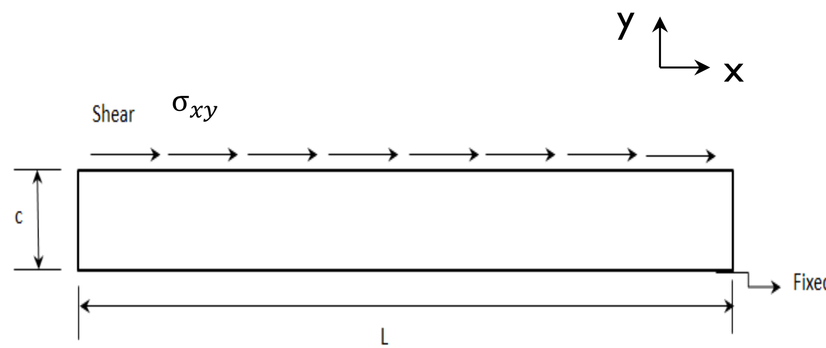
Shear - Cosine Load - Timoshenko

$$\sigma_{xy} = -0.5\cos((4\pi/c) * x)\ Pa$$

Theory – Hooke's Law

-Decouple Analysis – Uniform Shear





Plane Strain

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

→ **Uniform Shear**

$$\varepsilon_{xx} = \frac{1}{E}(\sigma_{xx} - \nu\sigma_{y})$$

$$\varepsilon_{yy} = \frac{1}{E}(\sigma_{yy} - \nu\sigma_{xx})$$

$$\varepsilon_{xy} = \frac{1}{G}\sigma_{xy}$$

Strain

$$\varepsilon_{xx} = 0$$

$$\varepsilon_{yy} = 0$$

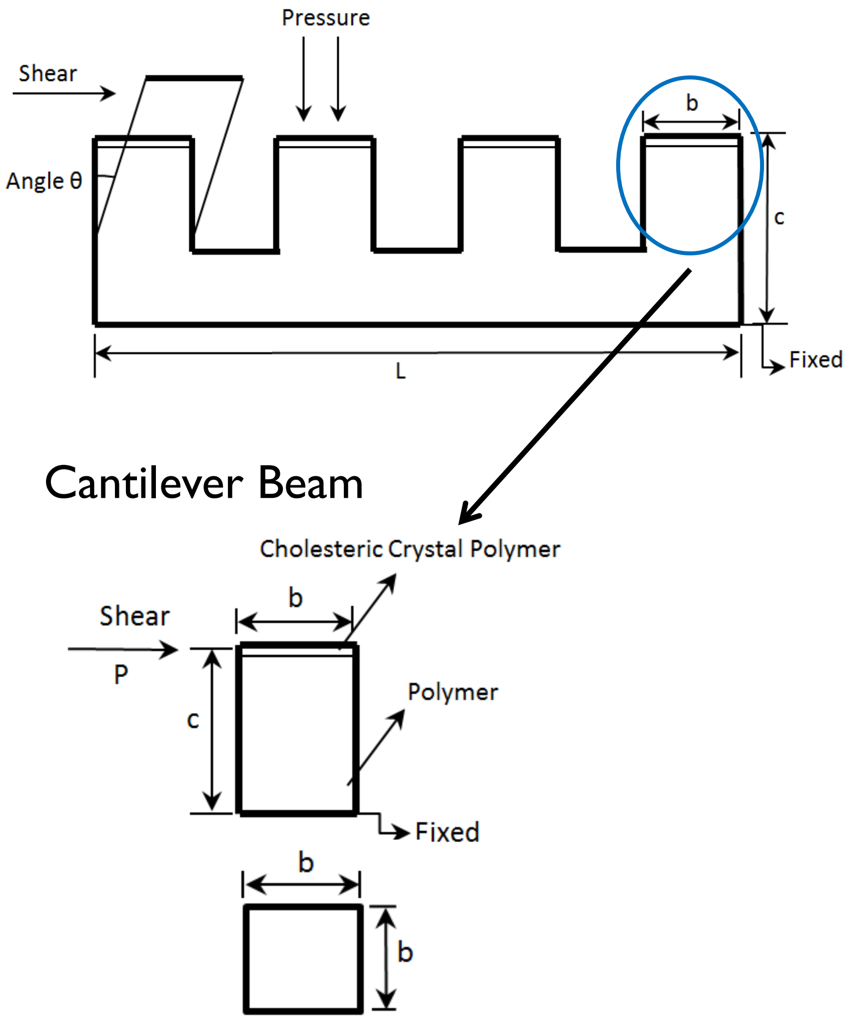
$$\varepsilon_{xy} = \frac{1}{G}\sigma_{xy}$$

Strain Ratio

$$\frac{\varepsilon_{xy}}{\varepsilon_{xx}} \to \infty$$

$$\frac{\varepsilon_{xy}}{\varepsilon_{yy}} \to \infty$$

Theory – Euler Bernoulli Beam



-Decouple Analysis

Shear – deflection θ – relate to wavelength

Pressure – No change in angle

Maximize θ

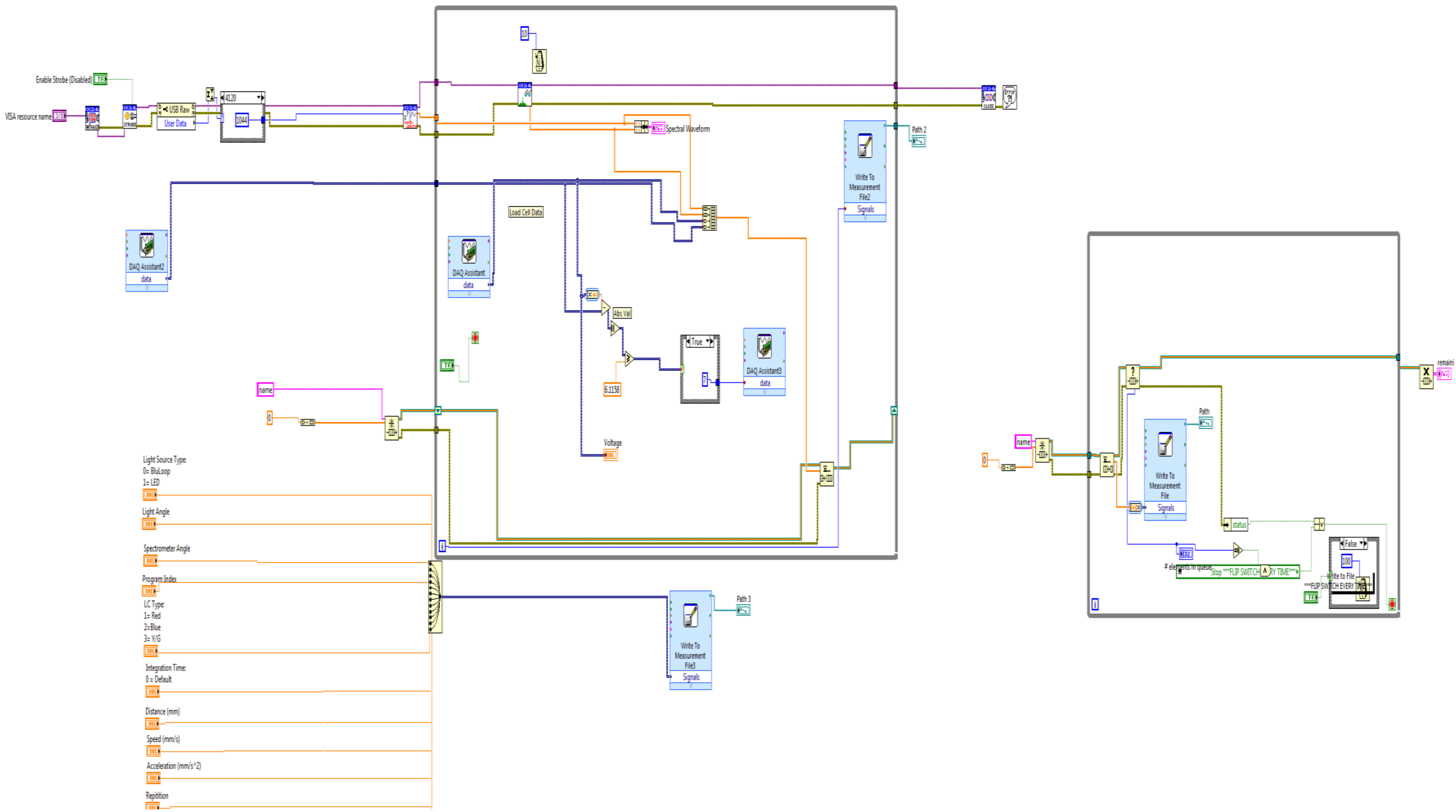
$$\Theta = \frac{Pc^2}{2EI} = \frac{6Pc^2}{Eb^4} \qquad \Theta = 6\,\frac{\sigma_{xy}\,\alpha^2}{E}$$

$$\sigma_{xy} = \frac{P}{b^2} \qquad \alpha = \frac{c^2}{b^2}$$

Sensibility α – maximize c and minimize b

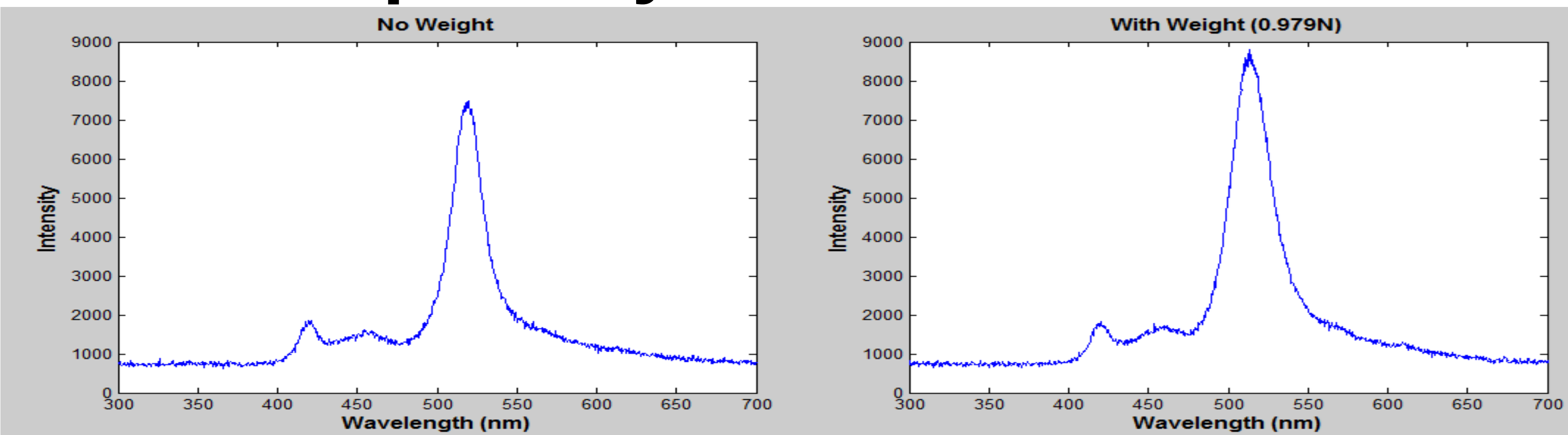
Find thickness c that satisfies both approaches

LabVIEW Block Diagram



Results-Normal Force

Yellow Liquid Crystal



- **5 Trials for each condition**

	Color						
	Red	Blue	Yellow		Red	Blue	Yellow
	No Weight				**Weight (0.979 N)**		
Range (nm)	600.3	469.1	512.0	Average Wavelength (nm)	597.5	469.7	519.7
Range (nm)	5.9	3.1	3	Range (nm)	7.2	2.2	3.1

Differences	
Color	**Red**
Red	2.8
Blue	0.6
Yellow	7.7