58:080 Final Projects

Overview of Past Projects

University of Iowa

Propose and Plan Final Projects

- **Experimental Test Plan (see textbook Chapter 1.3):** devise a plan of attack for experiments in order that the information you need is extracted.

Organized into Three Parts :

I. **Parameter Design Plan**: identify process parameters and identify a means for their control.

II. **System and Tolerance Design Plan**: select measurement technique, equipment, and procedure based on error tolerance .

III. **Data Reduction Design Plan**: determine a method of analyzing, presenting and using the experimental data

Experimental Design includes development of the experimental test plan.

Proposal for Final Projects

- See website link Part 5 Lab for an overview

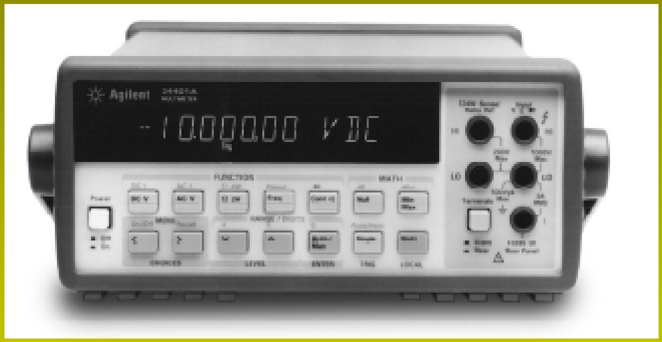
Analysis of an Electric Motor Using a Dynamometer

Equipment

- Dynamometer Kit
  - Permanent magnet DC electric motor
  - PM DC generator as load

Equipment

- Measurement Equipment
  – Digital Multimeter
  – RPM Meter



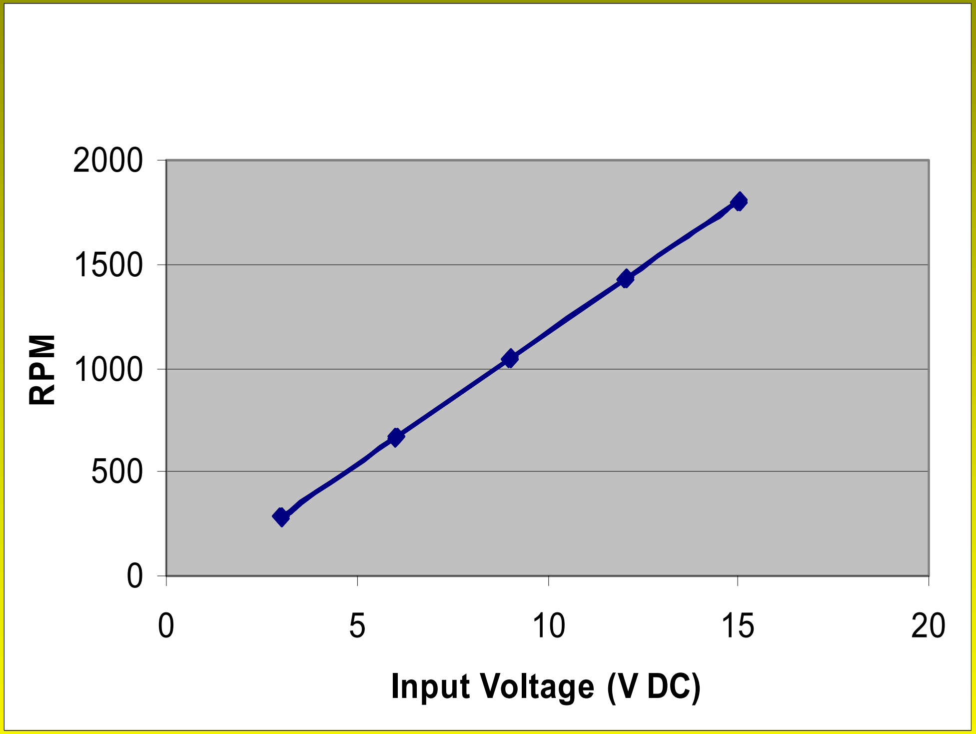
- Motor Controls
  – Voltage Power Supply
  – 50Ω Potentiometer

Set Up

- Connected Dynamometer and Electric Motor
- Used a series of four Digital Multi-Meters to measure voltage and current
- Power Source with variable voltage

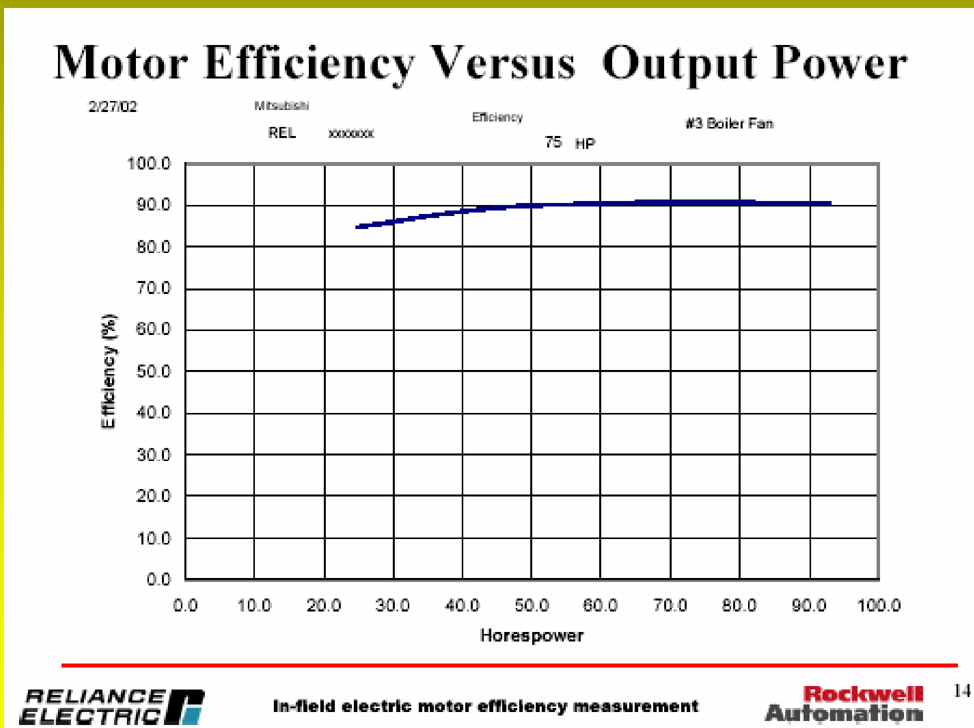
Motor Testing

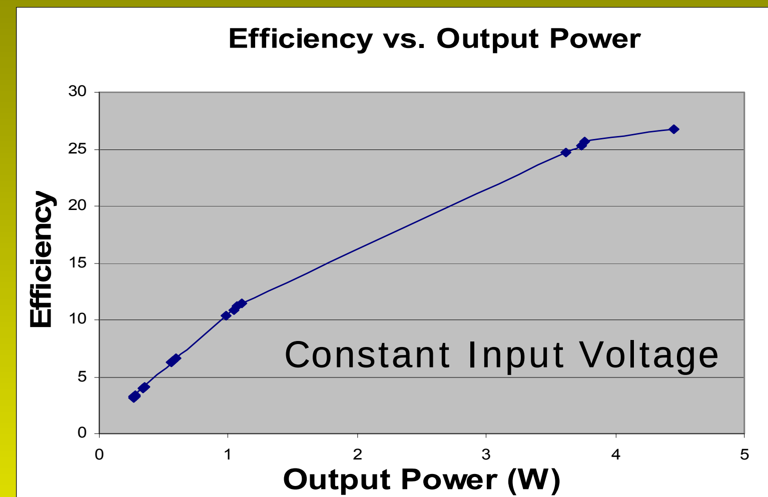
- Motor Testing
  - Input Voltage vs. RPM

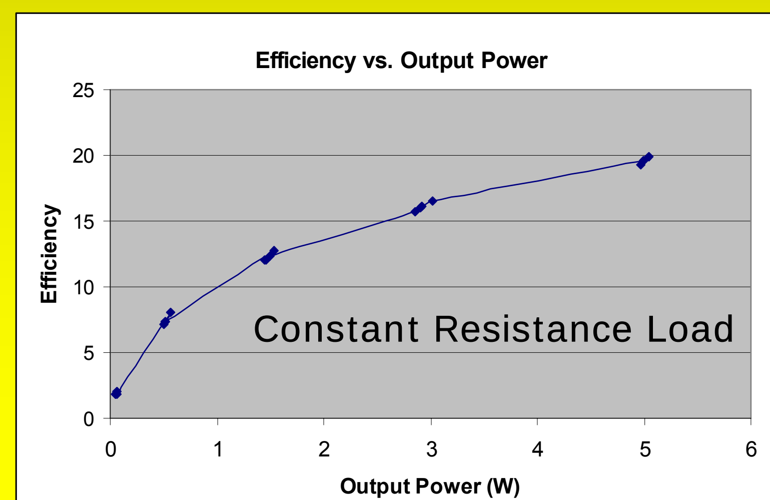


Field Data vs. Laboratory Data

- Efficiency Vs Output Power

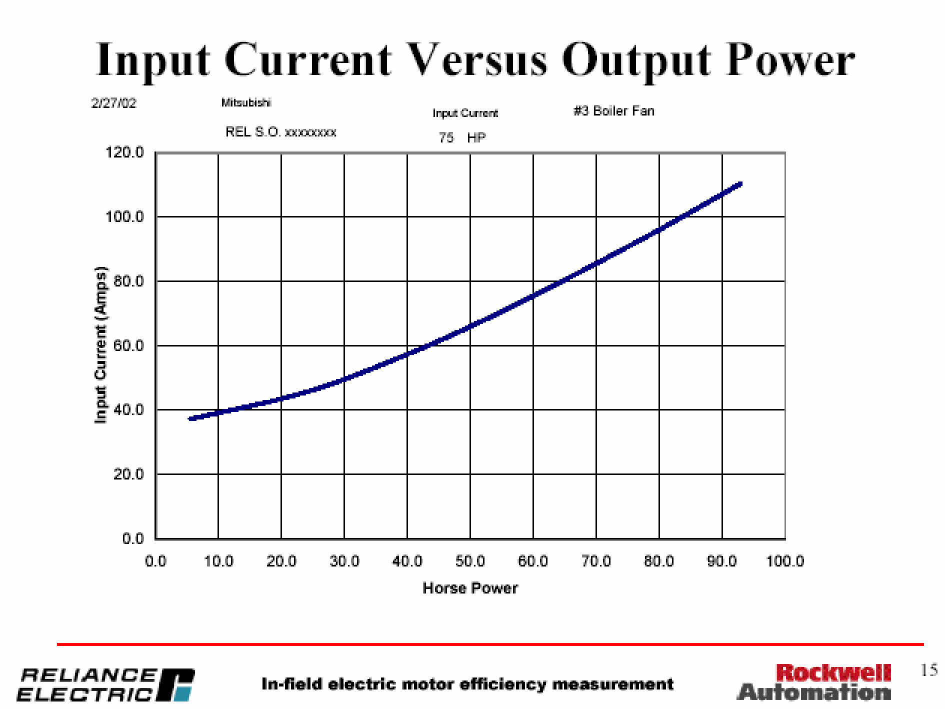


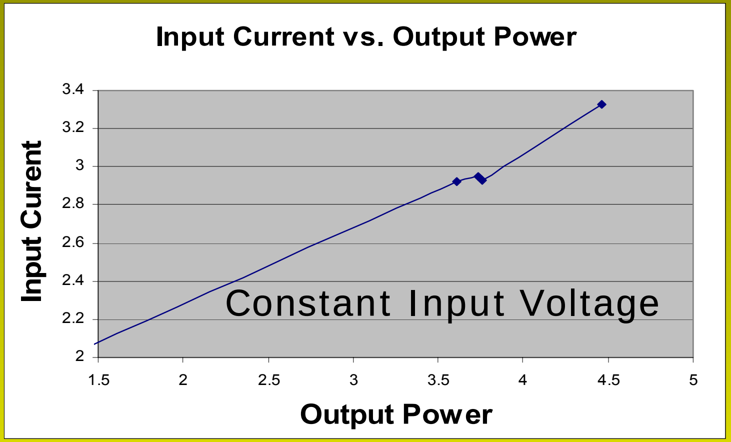


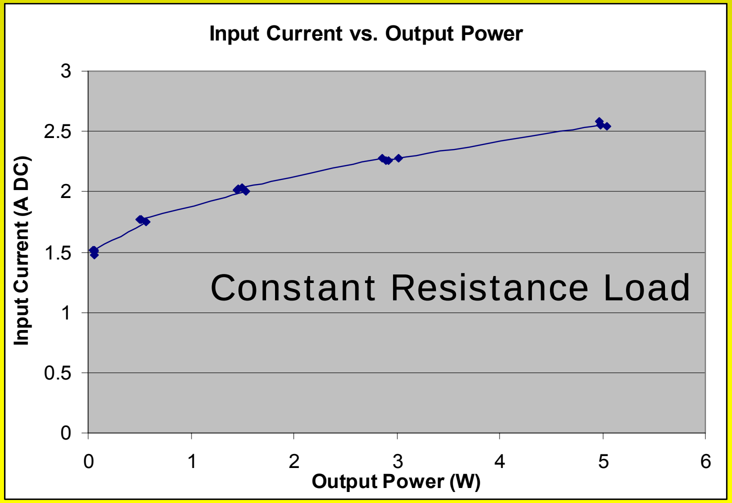


Field Data vs. Laboratory Data

- Input Current vs. Output Power







Output Power

- Output Power:

P = VI	P = (I^2)R	Difference
3.612	3.16179	0.45021
1.06797	1.0585125	0.0094575
0.59675	0.591015	0.005735
0.35035	0.3105375	0.0398125
0.273	0.24255	0.03045
0.2769	0.2495295	0.0273705
0.34532	0.2978296	0.0474904
0.56024	0.5483647	0.0118753
1.03894	1.0296125	0.0093275
3.7335	3.08898	0.64452
3.762	3.13632	0.62568

Conclusions

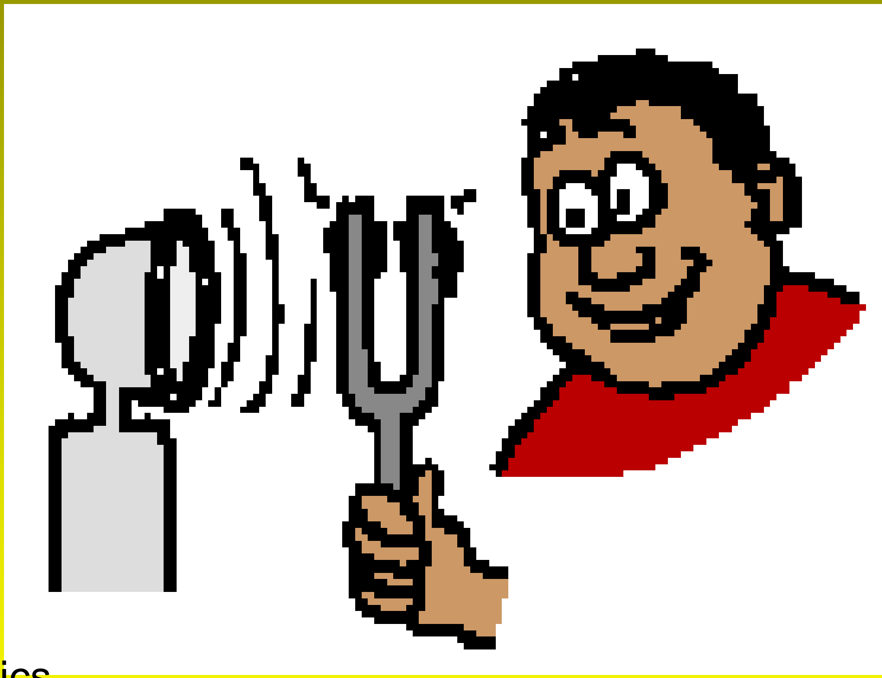
- Lab was successful / Objectives met
  - Found all desired values
  - Followed same trends as field data
- Found discrepancies in quantitative values
  - Field data motor efficiencies from 80-90%
  - Acquired data motor efficiencies from 3-30%
  - Variations in results due to losses in system and low voltage inputs

Conclusions

- Future Recommendations
  - Use a torque meter
    - Compare measured torque with values found from equations
    - Find more accurate power values from measured torque
  - Stabilize motor and dynamometer
    - Improve safety of experiment
    - Allow for higher voltage inputs
    - Reduce losses in system to noise and vibration

Comparison of Two Speed of Sound Measurement Methods

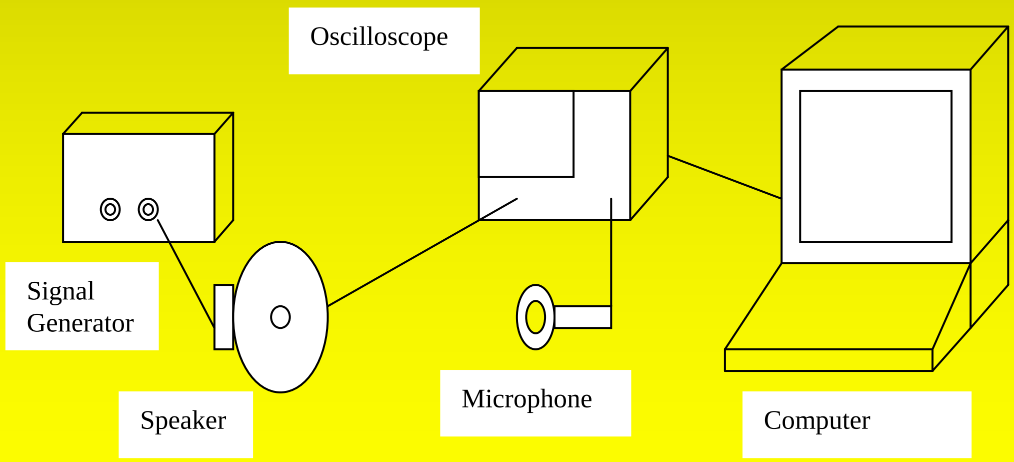
Introduction



- Objectives
  - Two separate experiments to test speed of sound
  - Balloon Experiment
  - Speaker Experiment
  - Compare to accepted values -
    - 346.22 m/s
    - Taken From http://www.measure.demon.co.uk/Acoustics_Software/speed.html
    - $T=23.3^{o}C$ and relative humidity of 60%

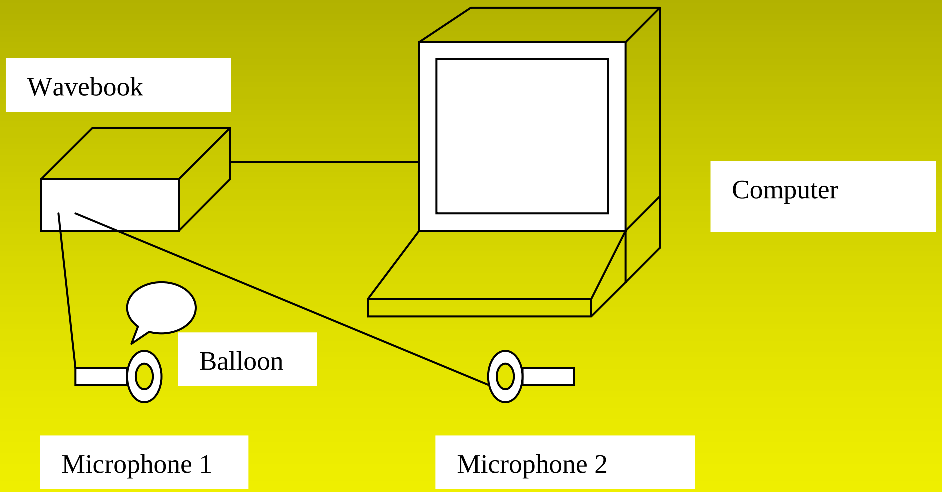
Experimental Considerations
Speaker/Microphone Method

- Calibration of Speaker/Microphone System
- Set Microphone a set distance away from speaker and set output to run into nicolet
- Run sinusoid wave through the speaker and through nicolet
- Capture the data from the nicolet for both the original sinusoid and the delayed output from microphone



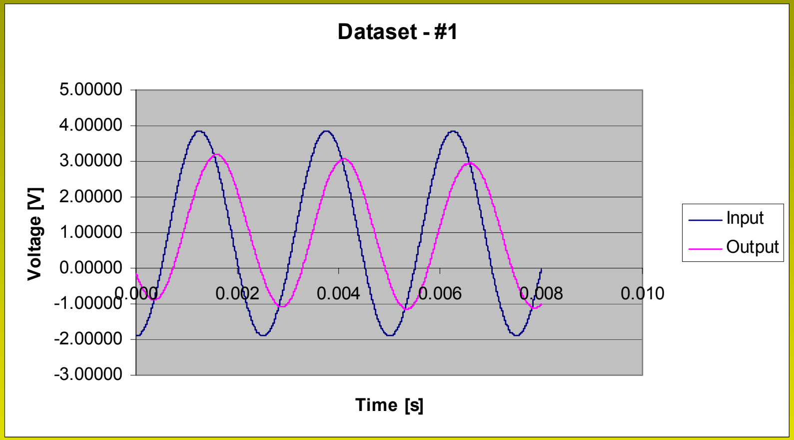
Experimental Considerations
Balloon Method

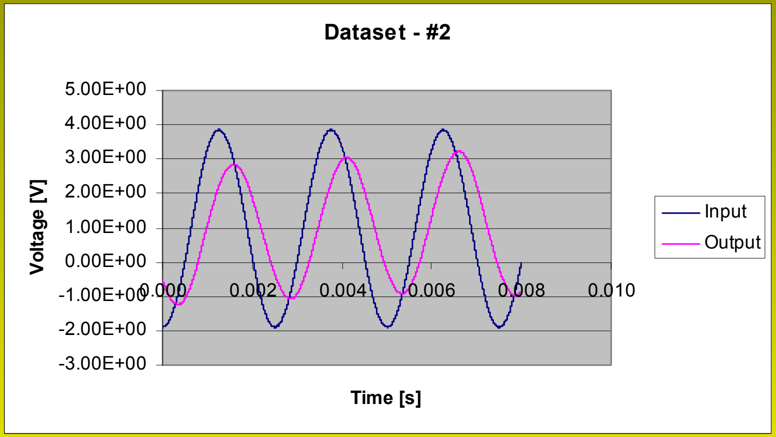
- Place two microphones a known distance apart.
- Setup microphones so that output is recorded into the wavebook data acquisition system
- pop a balloon, recording the resulting output from the microphones into the wavebook

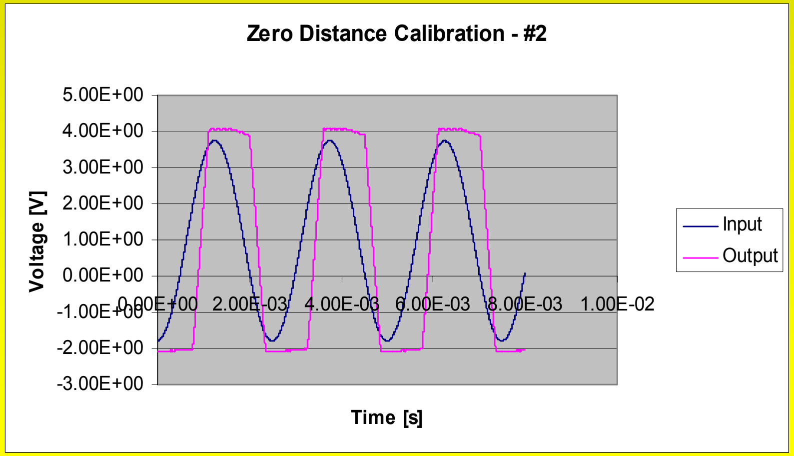


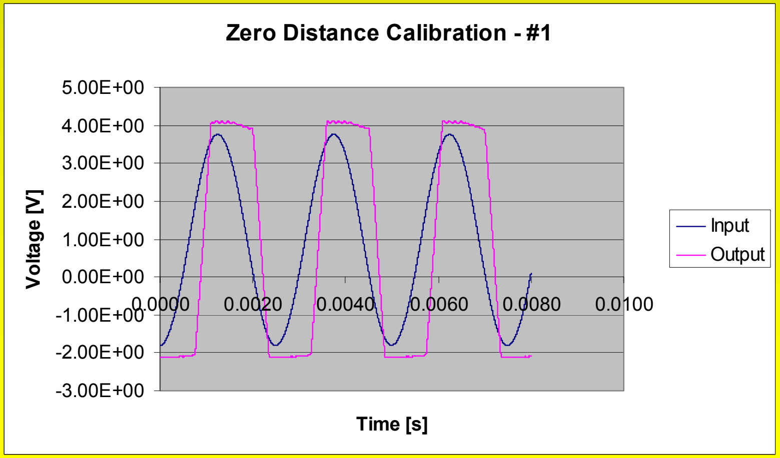
Results

Speaker/Microphone Method









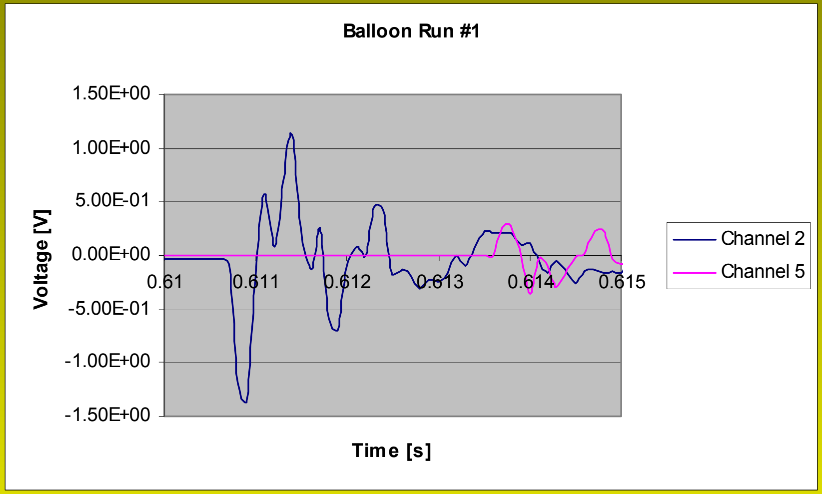
Results

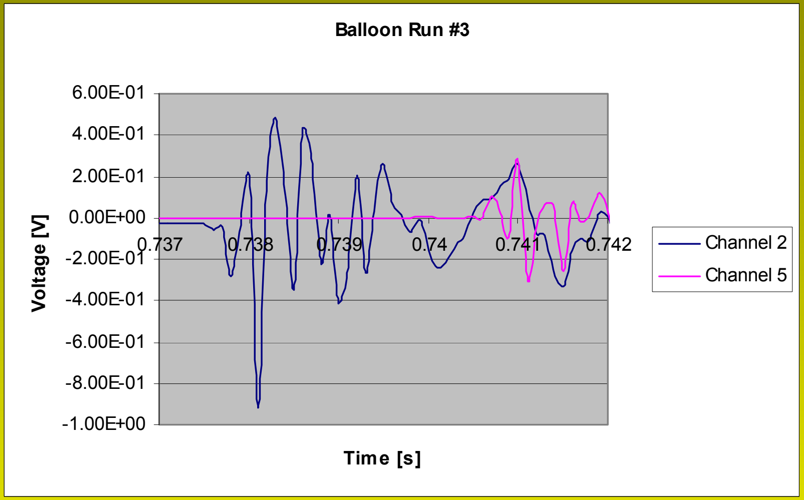
Speaker/Microphone Method (continued)

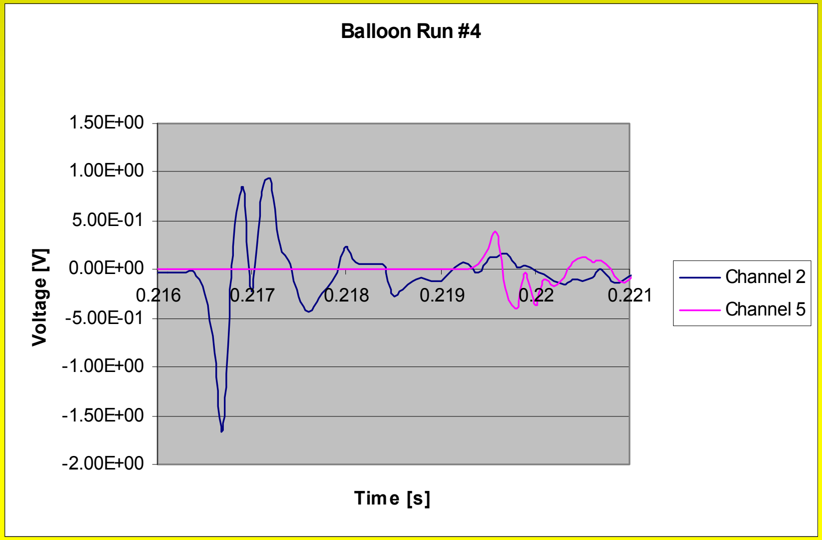
Trial	Time Between Signals [s]	Speed of Sound [m/s]
1	0.30×10^{-3}	337.33
2	0.23×10^{-3}	440
	Average	388.67 +/- 3.92

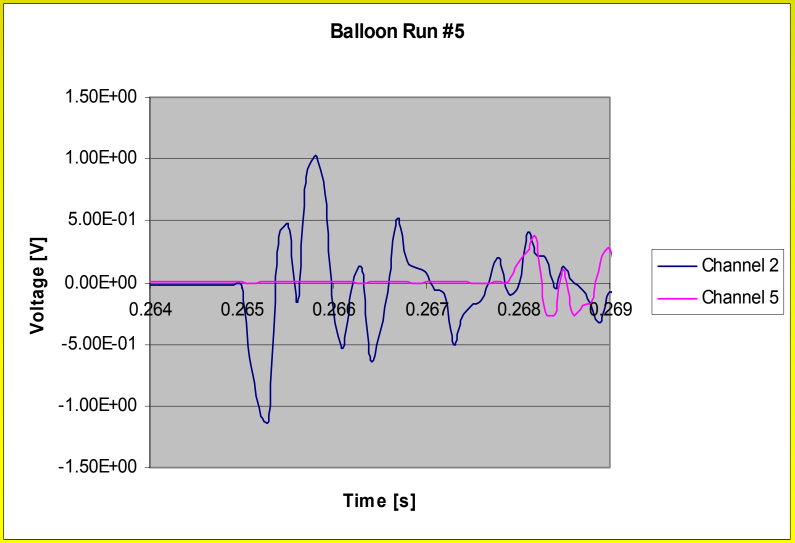
Results

Balloon Method



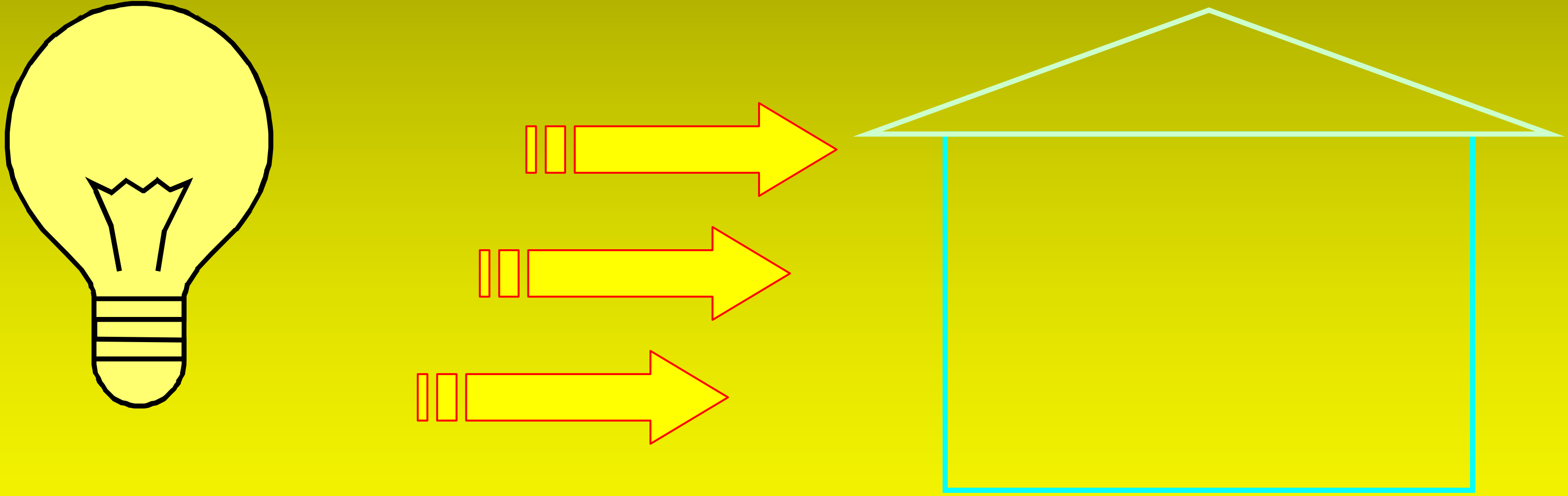






Light Fixture Heat Gain

- ❑ Lighting is a major cooling load component



- ❑ Calculation not straight forward → Estimation

Objective

- Measure the actual heat gain of common light bulbs and compare it to theoretical design values.

Experimental Procedure

- Bulbs Measured
  - 60W Incandescent
  - 75W Incandescent
  - 100W Incandescent
  - 13W Fluorescent

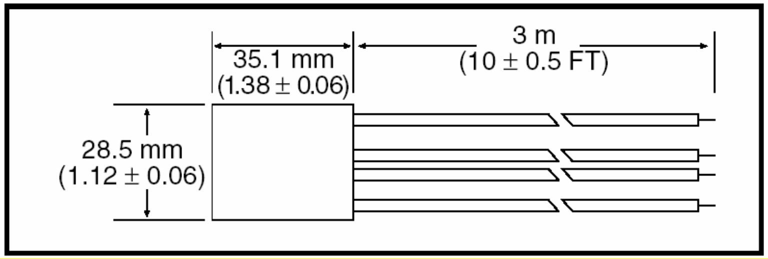
- Lightbulb surface ≤ 200ºC (400ºF)

Experimental Procedure

- Measurement Equipment
  - Omega HFS-4 Thin-Film Heat Flux Sensor

General

Upper Temperature Limit:	400°F
Number of Junctions:	40
Carrier:	Polyimide film (Kapton)
Sensor Resistance:	300Ω approximately
Lead Wires:	#30 AWG Solid Copper, Teflon insulated color coded, 10 feet long
Dimensions:	See Figure 5-1



Experimental Procedure

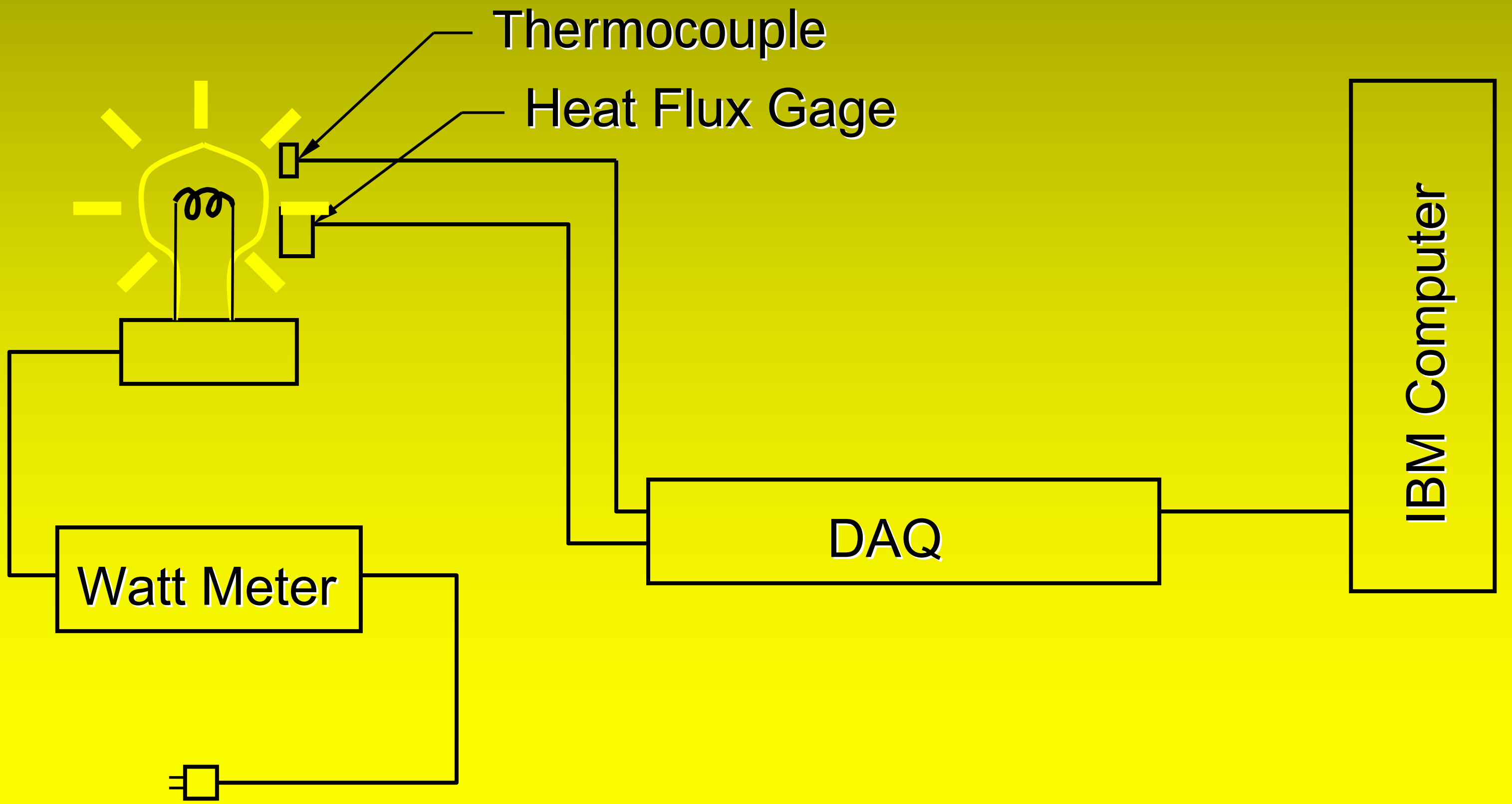
- Measurement Equipment

  - Omega T-Type Thermocouple

  - Ohio Semitronics Digital Load Monitor

Experimental Procedure

- Equipment Set-Up

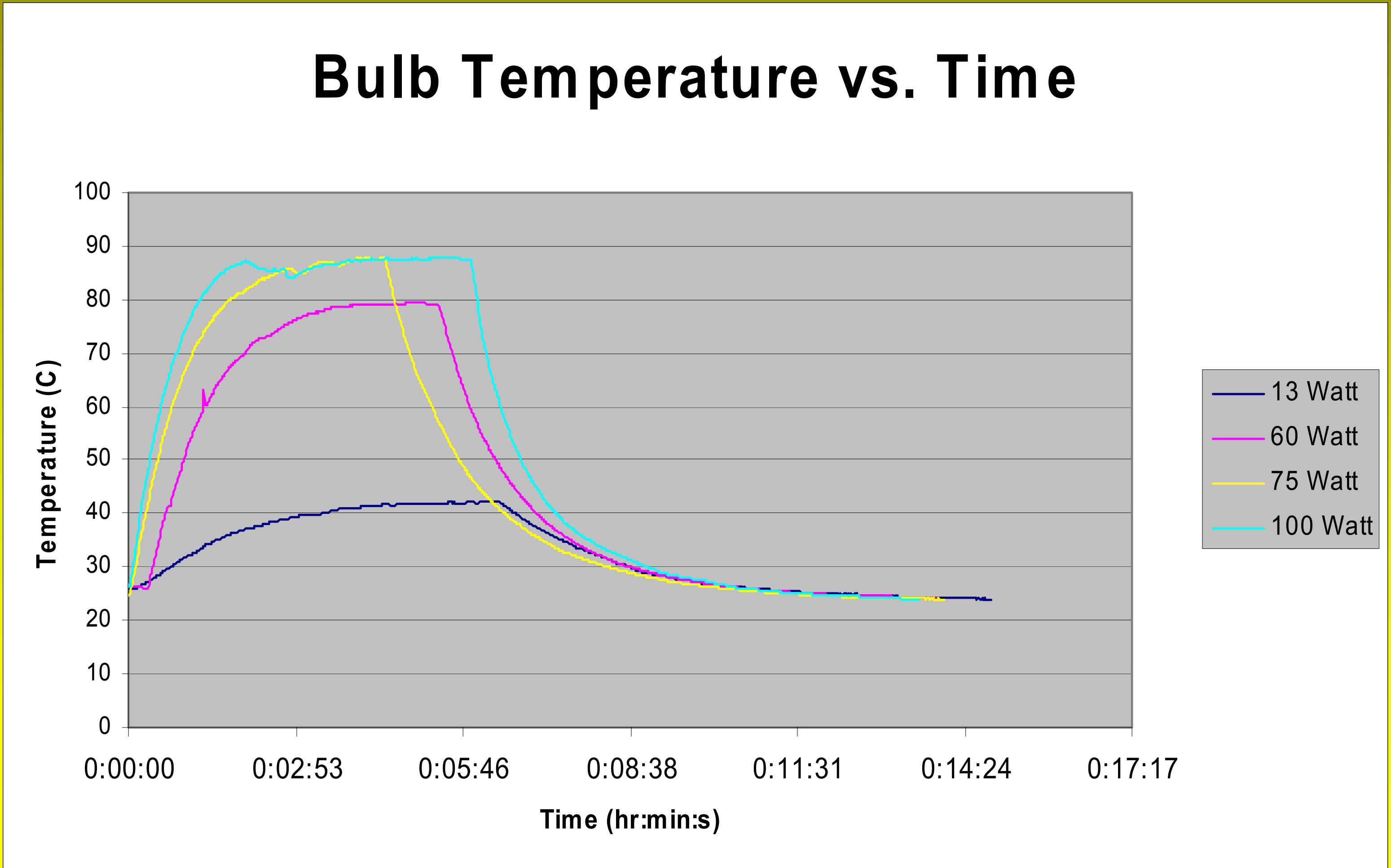


Results

- Light Bulb Surface Temperatures

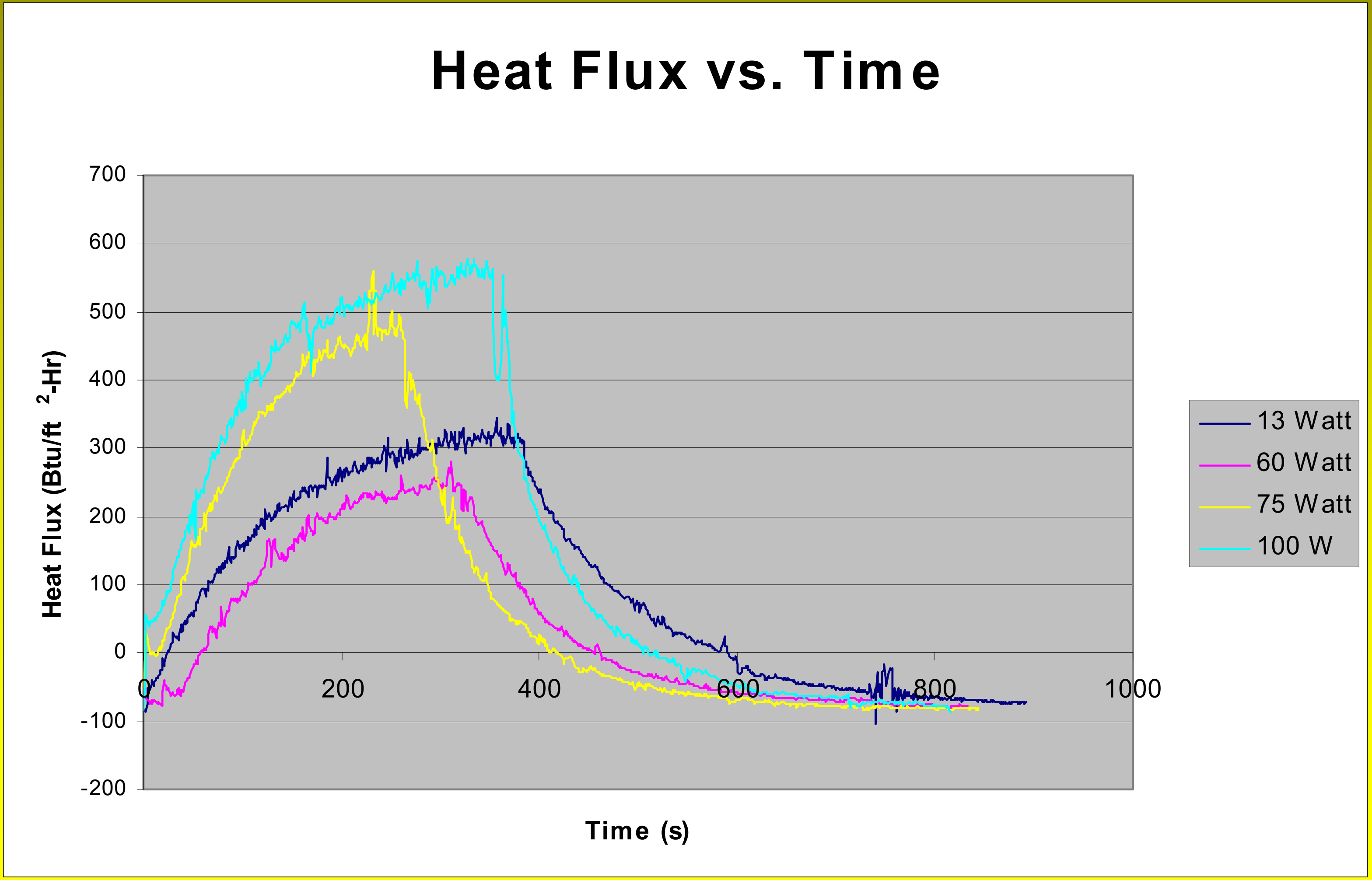
Bulb	Average W Measured	T_{max}
60W	60W	72.47ºC (162.45º F)
75W	78W	114.84ºC (238.71º F)
100W	102W	119.02ºC (246.24º F)
13W	13W	72.47ºC (138.88º F)

Results



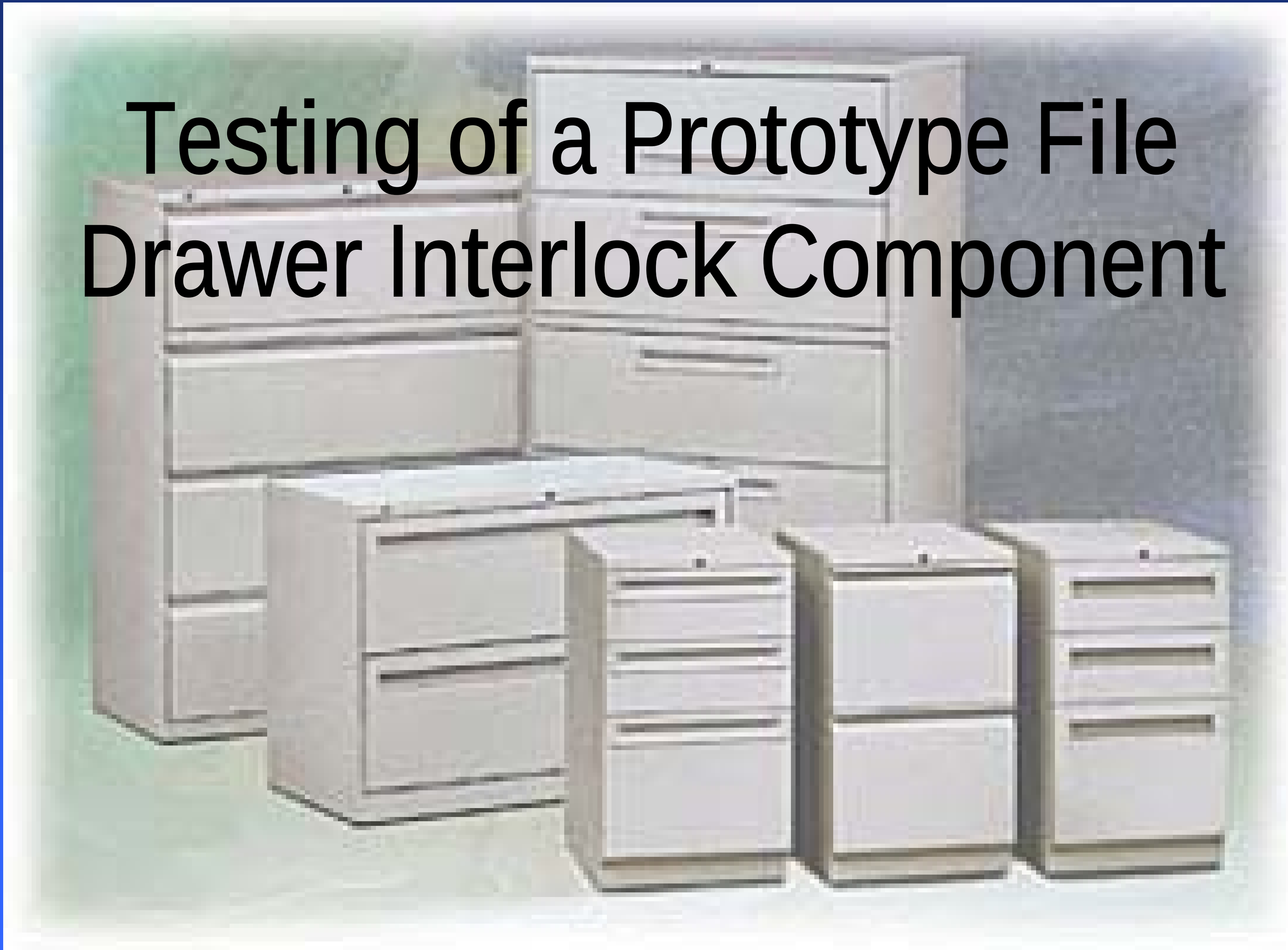
Bulb Temperature vs. Time
100
90
80
70
60
50
40
30
20
10
0
Temperature (C)
0:00:00
0:02:53
0:05:46
0:08:38
0:11:31
0:14:24
0:17:17
Time (hr:min:s)
13 Watt
60 Watt
75 Watt
100 Watt

Results



Heat Flux vs. Time
700
600
500
400
300
200
100
0
-100
-200
Heat Flux (Btu/ft²-Hr)
0
200
400
600
800
1000
Time (s)
13 Watt
60 Watt
75 Watt
100 W

Testing of a Prototype File Drawer Interlock Component



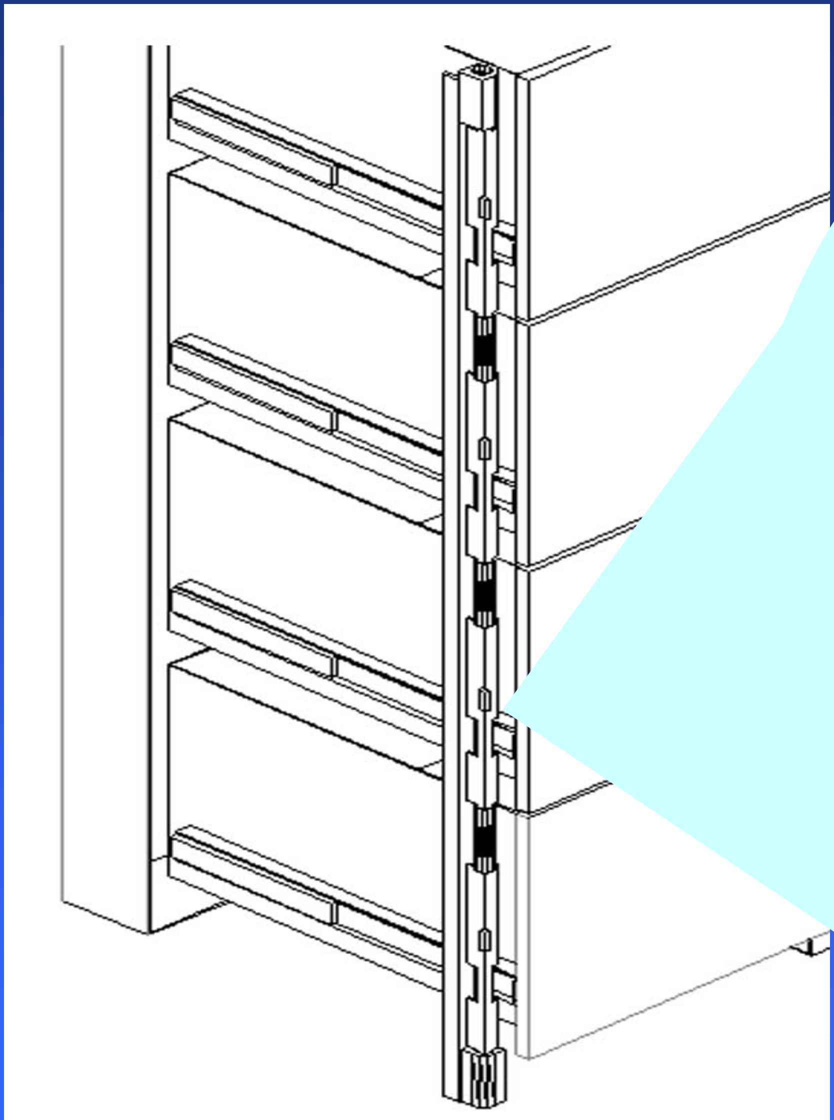
Introduction

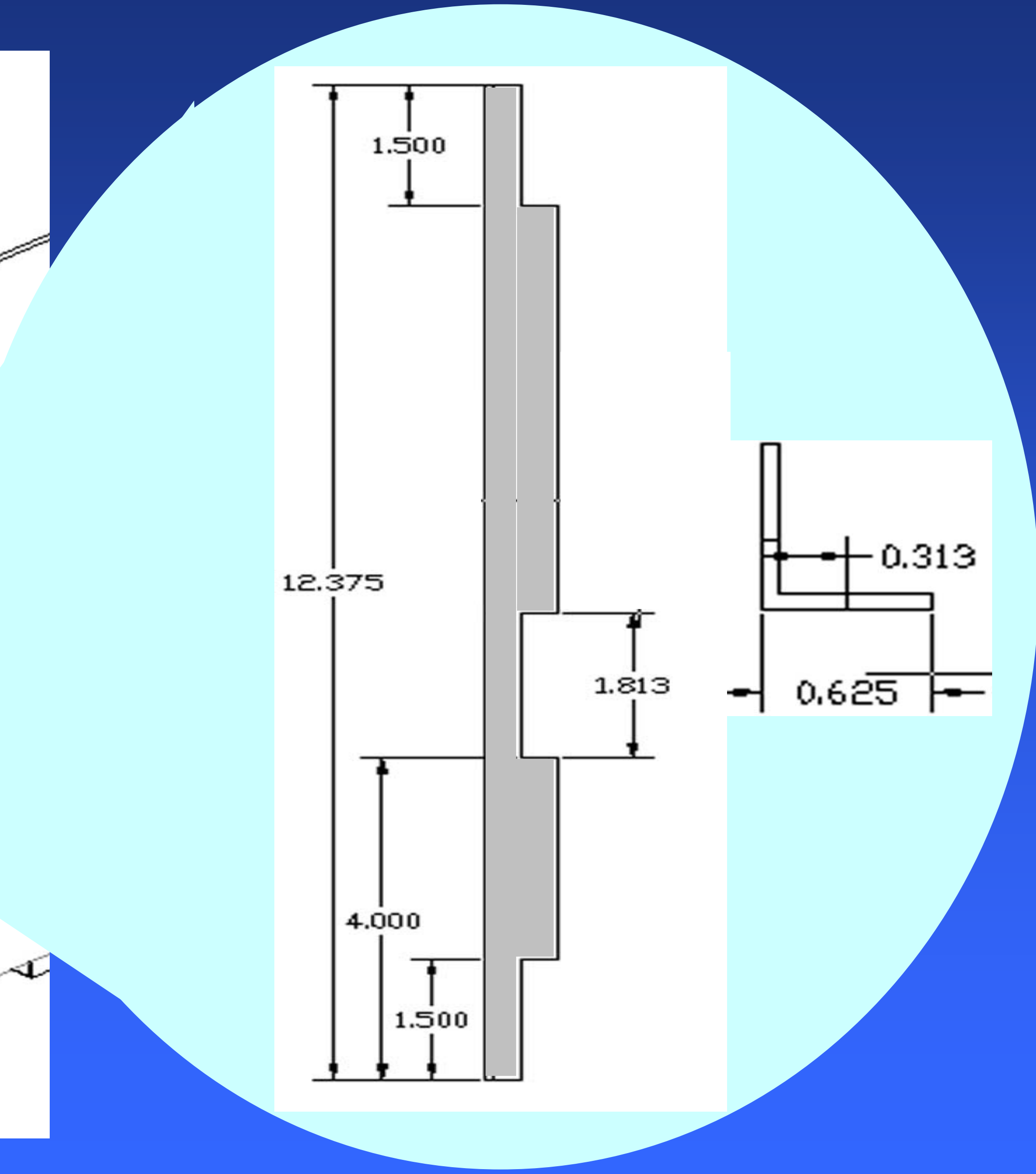
- Objective
  - To determine if a file drawer interlock component will fail under a specified load
- Motivation
  - Safety
  - New component design needs validation

Design Requirements

- ANSI/BIFMA standards
  - Drawers must interlock
  - 50 lb drawer pull
- Increased by HON (2 x)
  - 100 lb drawer pull

Rocker Component



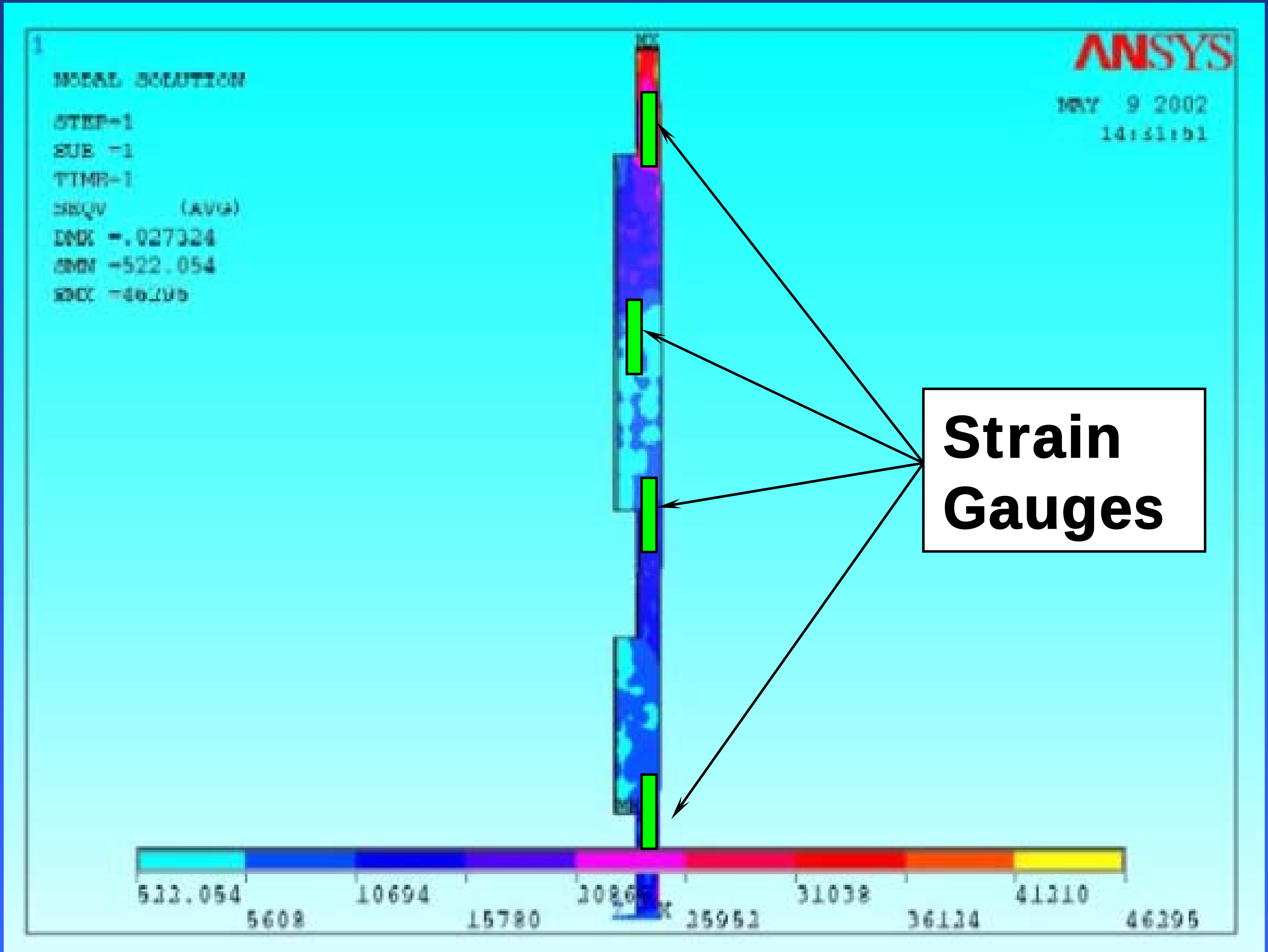


All dimensions in inches

Experimental Considerations

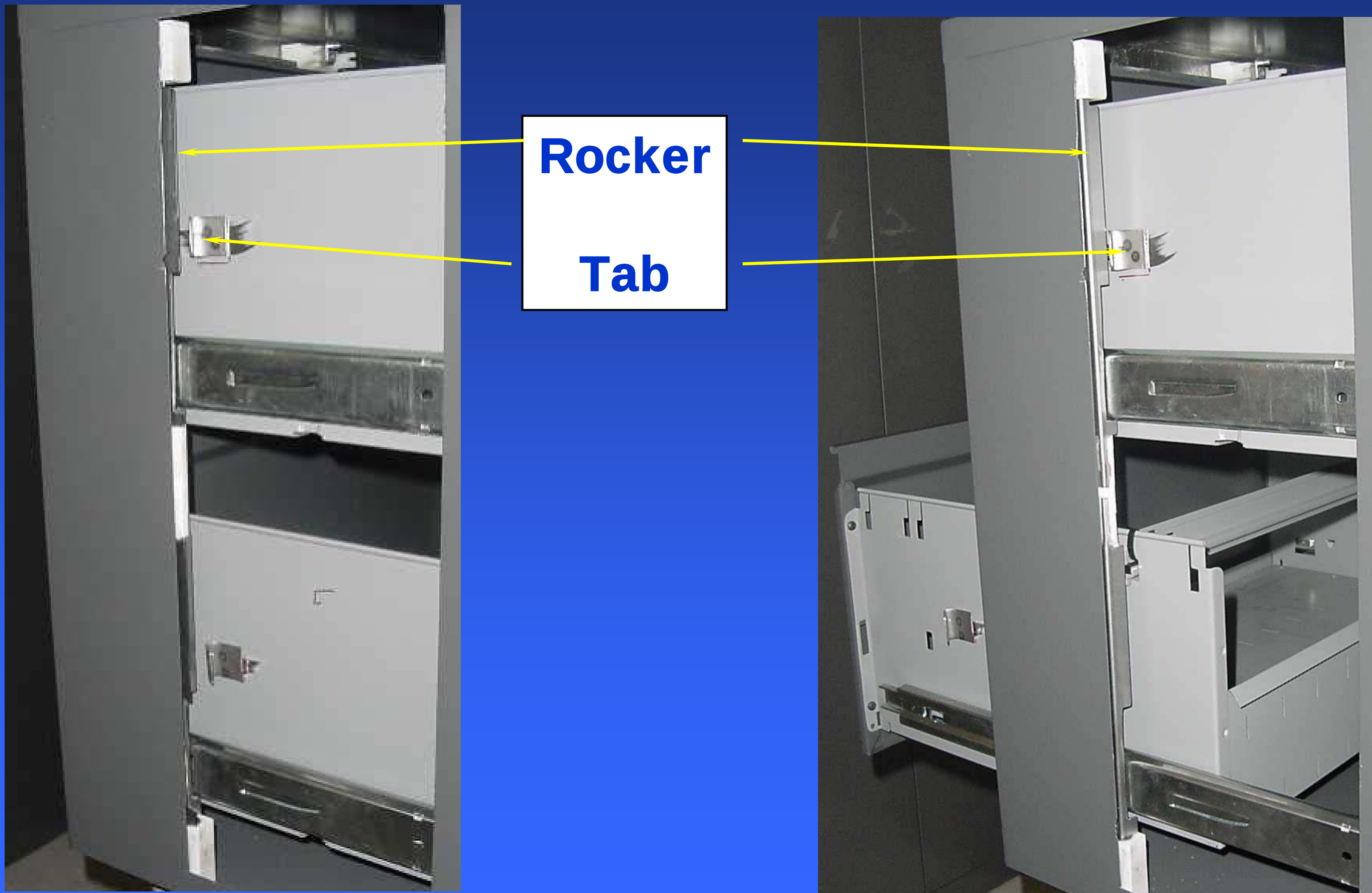
- Fabrication of prototype rocker and experimental apparatus
- Finite Element Analysis, FEA, for strain gauge placement
- Data reduction and uncertainty analysis

Finite Element Stress Result

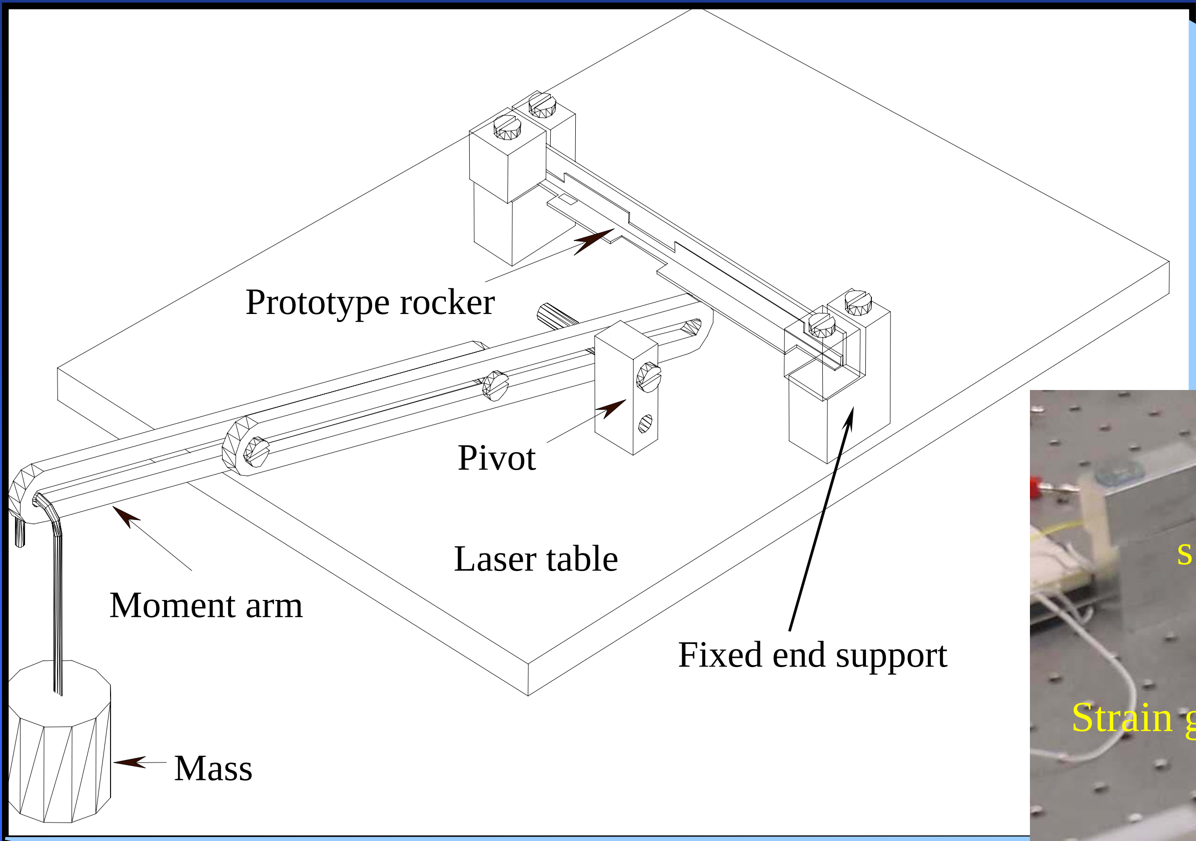


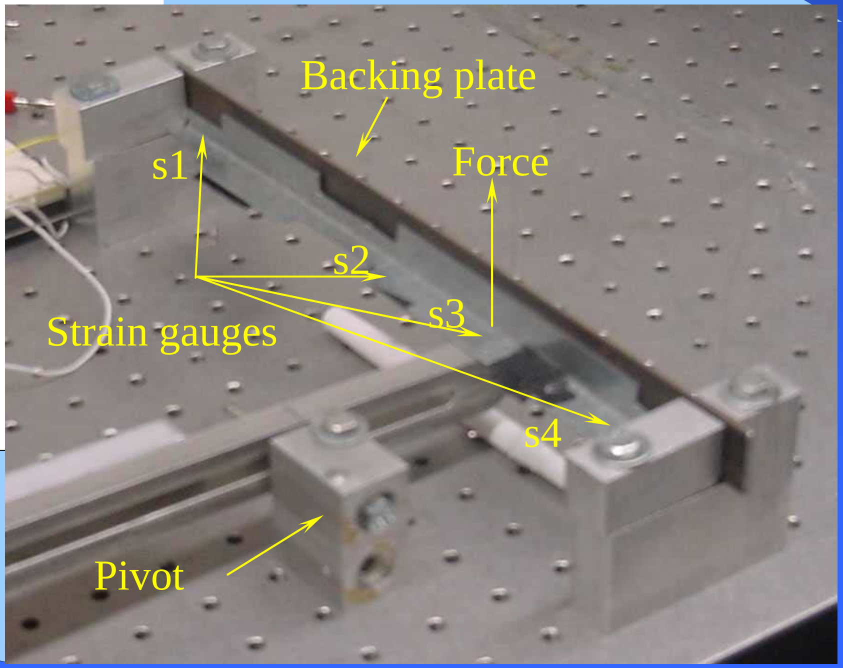
von Mises Stress Distribution

File Cabinet Prototype

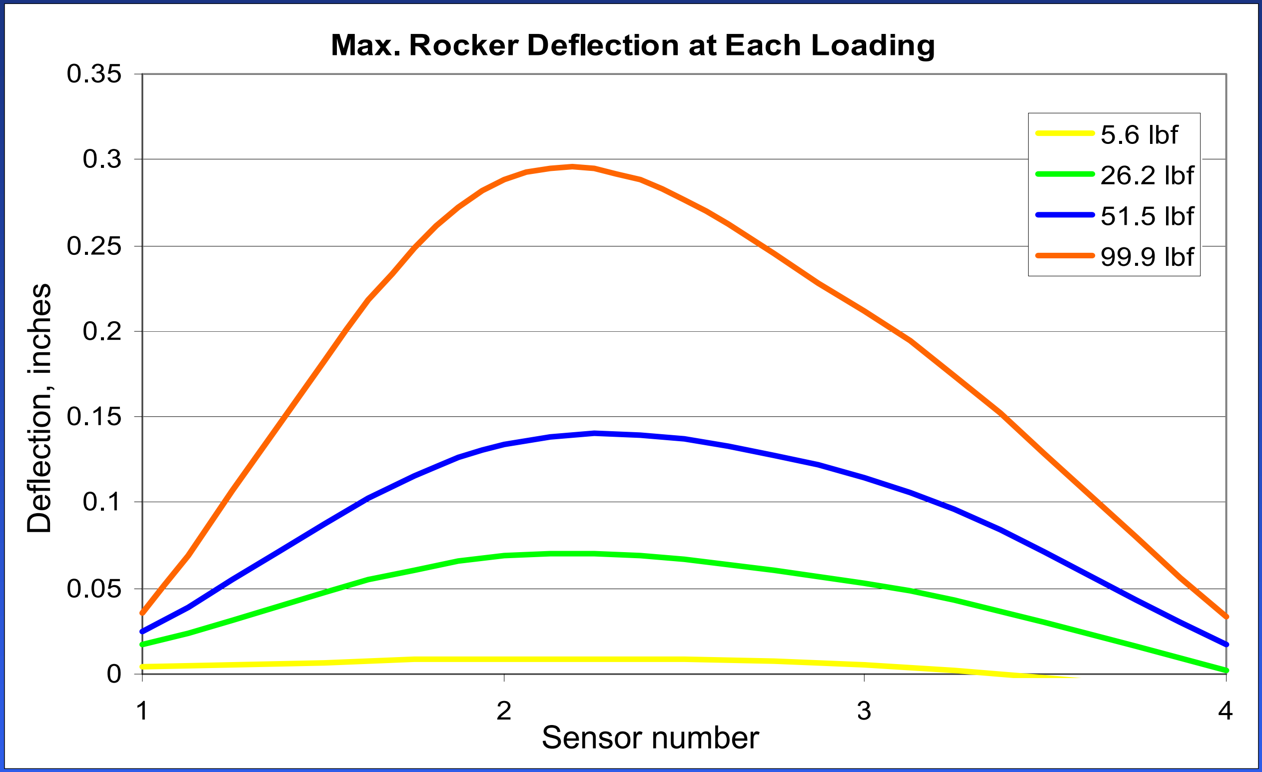


Prototype Testing





Results and Discussion



Maximum Deflection	mm	in.
Strain Gauge 1	0.9	0.0354
Strain Gauge 2	7.32	0.2882
Strain Gauge 3	5.39	0.2122
Strain Gauge 4	0.86	0.0339

Maximum Deflection at each strain gauge at maximum load

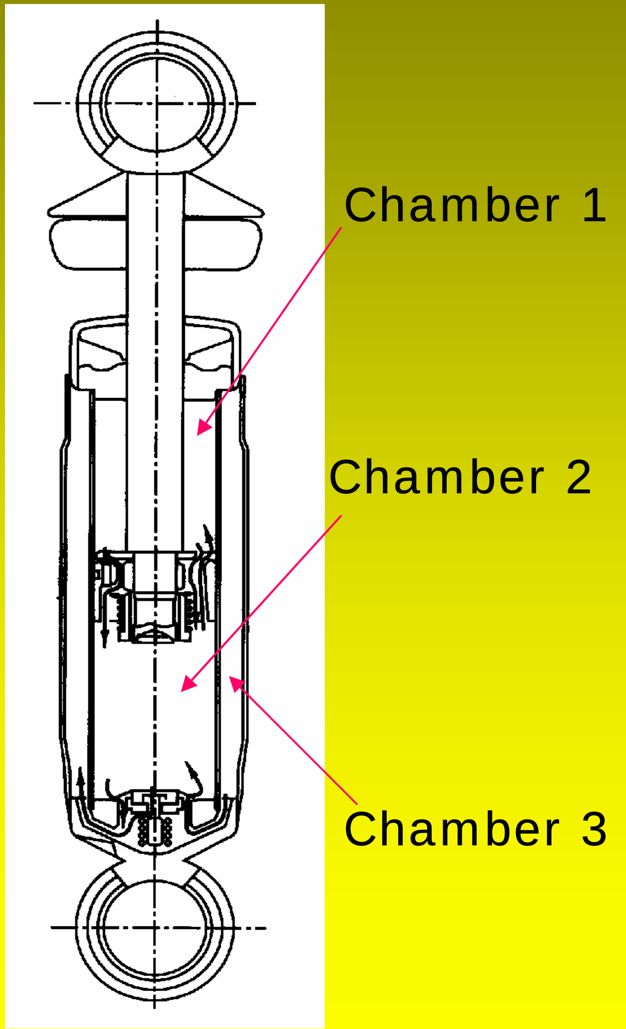
Low-Speed Dynamic Response of Shock Absorbers

Introduction

- Shock absorber uses in vehicles
  - Dampen Suspension inputs
  - Control chassis roll rate
  - Control weight transfer
- Operating Principle – Piston moving in a fluid

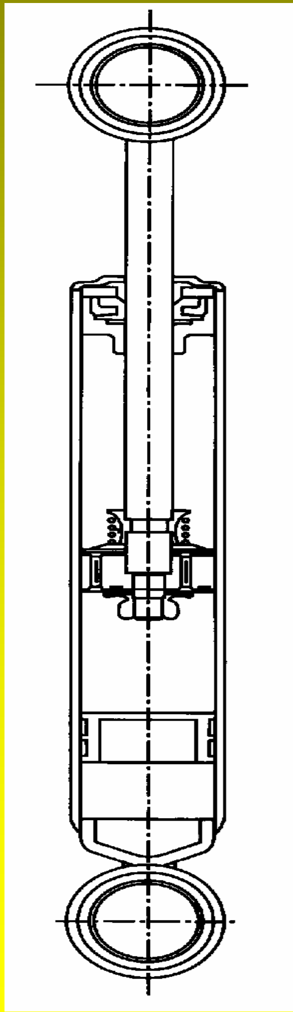
Types of Shocks

- Dual Tube
  - Tube set inside the main body of the shock
  - Piston has orifices which allow fluid to pass through as the piston moves
  - Orifices at the bottom of shock which allows fluid to pass through to the outer tube



Types of Shocks

- Monotube w/Floating Piston
  - Pressurized gas below piston becomes further compressed as the shock is compressed

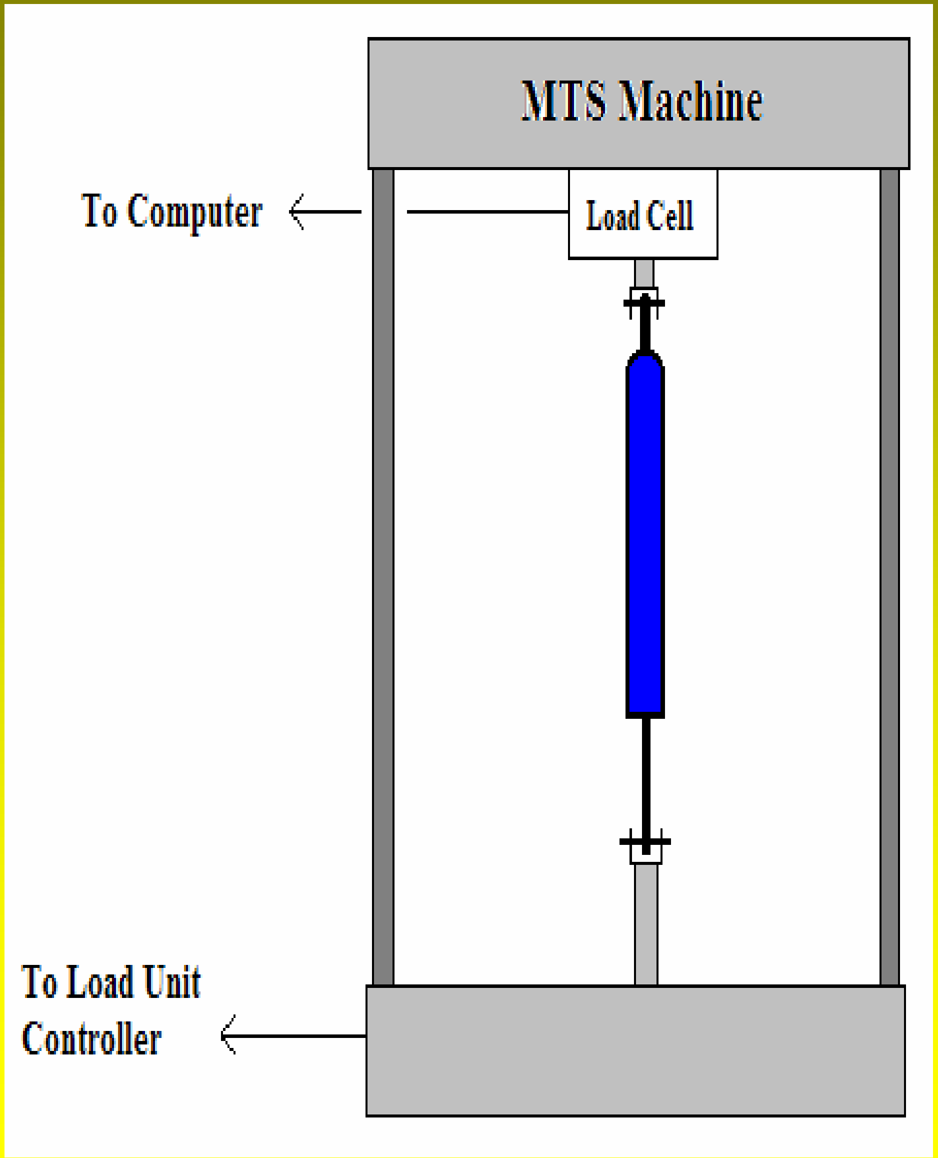


Experimental Objective

- Explore the force required to compress and extend the shock
- Calculate the damping coefficients of an adjustable shock and a non-adjustable shock at 10 mm/s and 20 mm/s

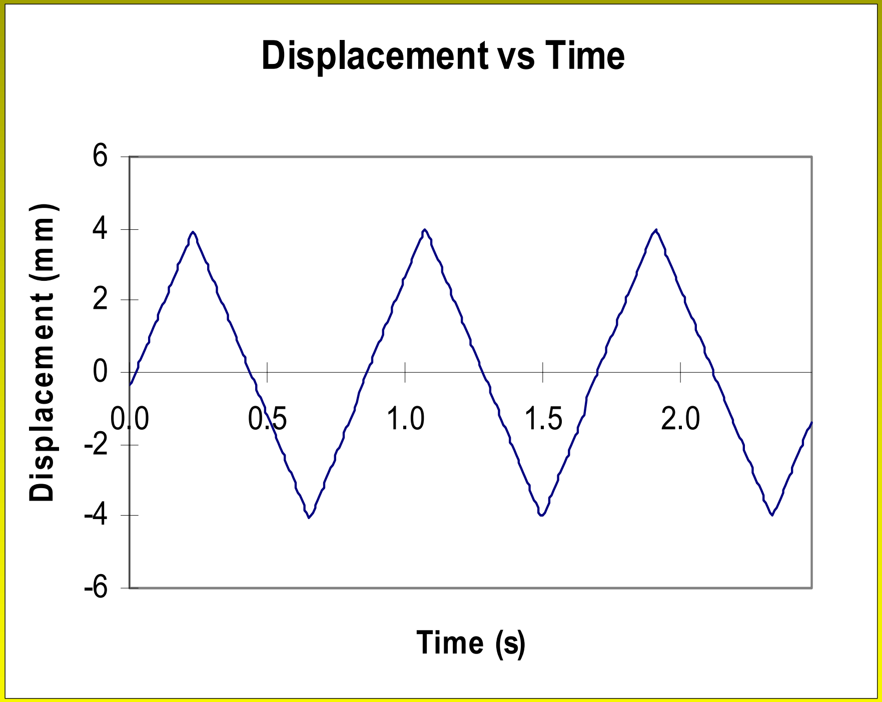
Equipment Used

- 1790 Shock (adjustable)
- 1390 Shock (nonadjustable)
- Mechanical and Testing Simulation (MTS) machine
- MTS Load Cell
- Mounting Fixtures
- TestWare



Procedure

- MTS machine created a triangle wave
- The amplitude was held at a 4mm
- For high speed velocity test, frequency was set at 1.2 Hz (20 mm/s)
- For low speed velocity test, frequency was set at 0.6 Hz (10 mm/s)

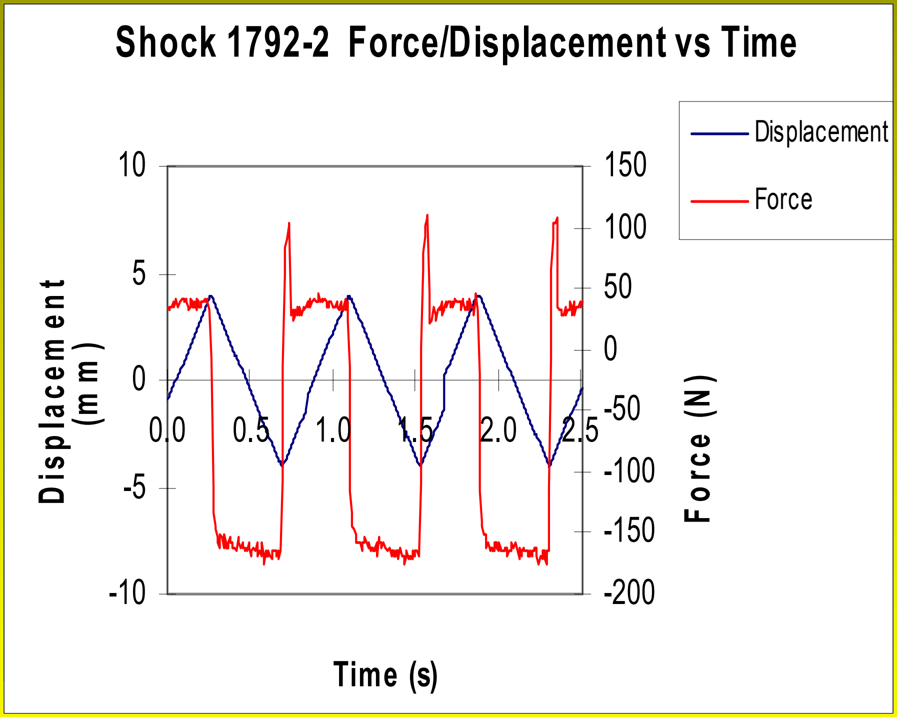


Procedure

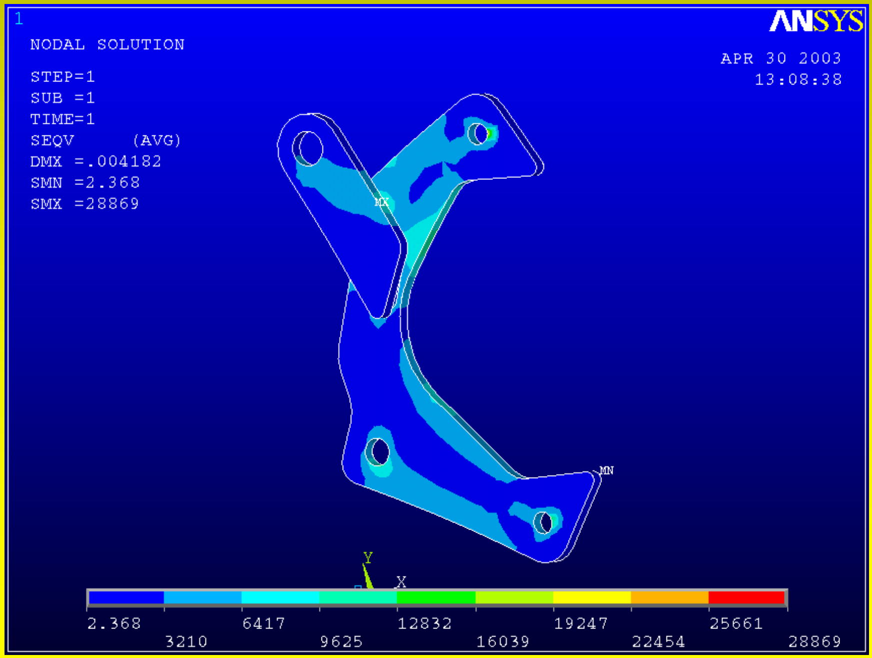
- No calibration performed
- MTS machine was “warmed up”
- Shock mounted in MTS machine
- Tests performed for each shock/shock valve setting at low and high speeds
- Data reduction with Microsoft Excel

Results and Discussion

- Force spike could reflect a pressure spike in the system
  - Observed when viscous dampening is less than 120 N.
  - Not likely stiction - does not occur at 10 mm/s
  - Pressure response through valves



Calibration of Strain Gages with a Disc Brake Conversion Bracket

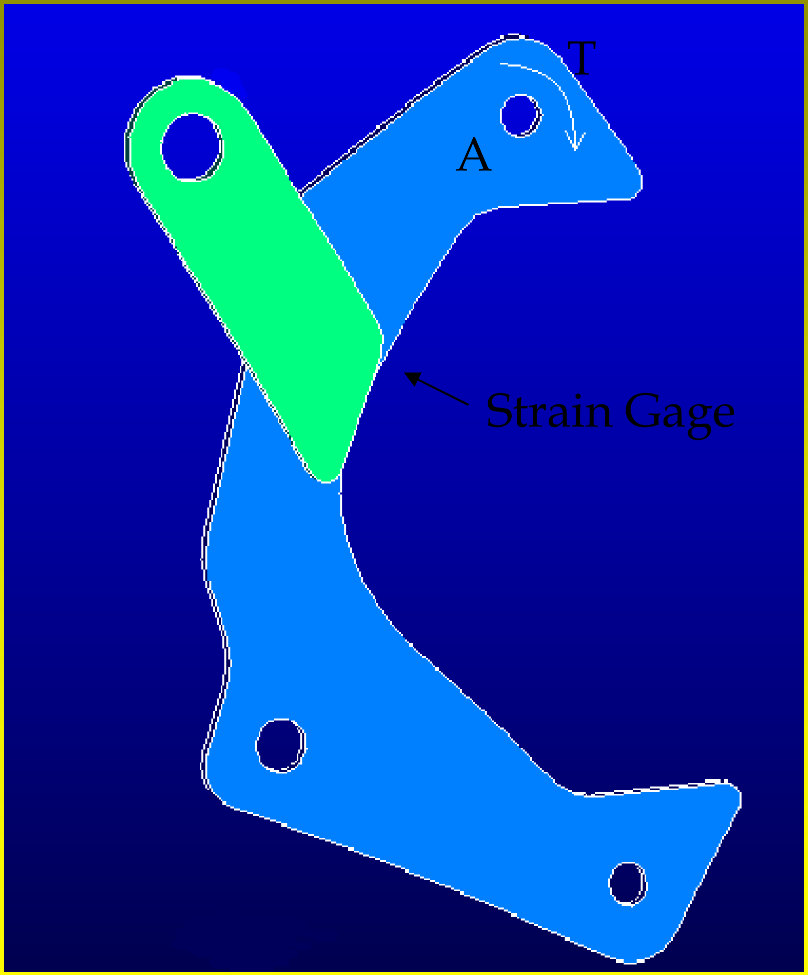


Introduction

- Objective: Calibrate strain gages in lab using torque sensor to measure applied loads
- Reduce data for 4 different loads and compare to ANSYS data at same 4 loads
- Determine uncertainty for strain gages
- Use uncertainty for assurance of accurate data with on-car testing

Experimental Considerations – The Bracket

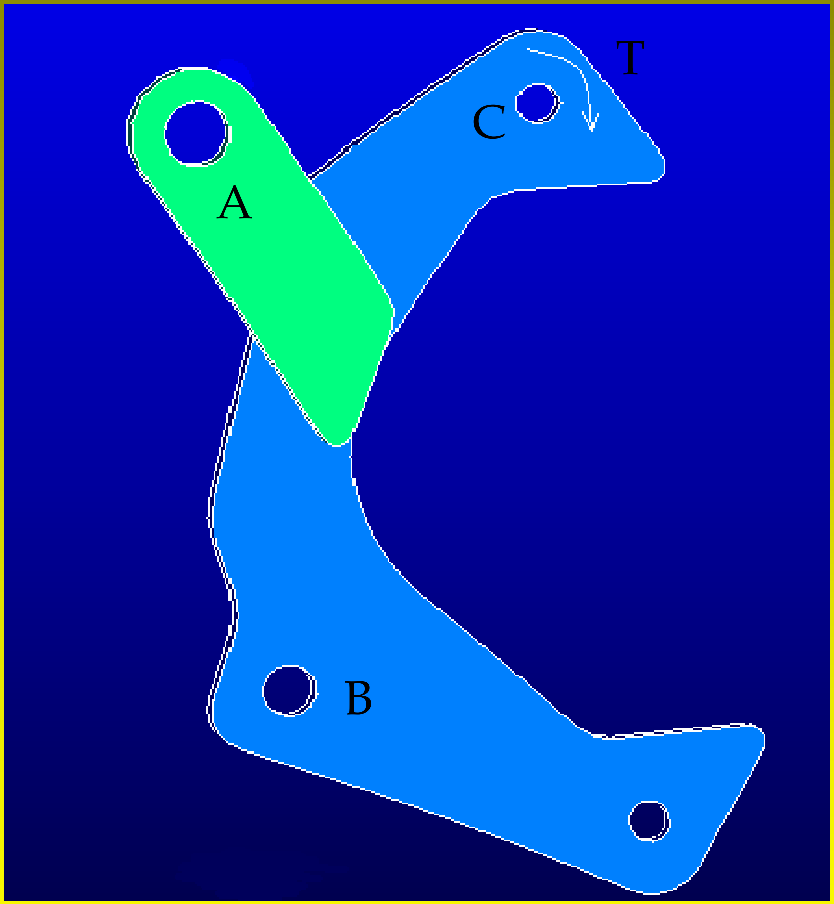
- Prototype constructed of 1/4" 1018 plate steel
  - Soft steel, easily deflected
- Could not simulate on-car type load
- Changed method of applying load



Calibration Procedure

- Bolted the bracket to the spindle
  - ensures no movement in the lateral direction
- Mounted the spindle in a vice
- Applied a torque using a breaker bar
  - Amount of torque applied is limited to durability of the threads in hole
- Recorded data using DASYLab software

Bracket and Spindle

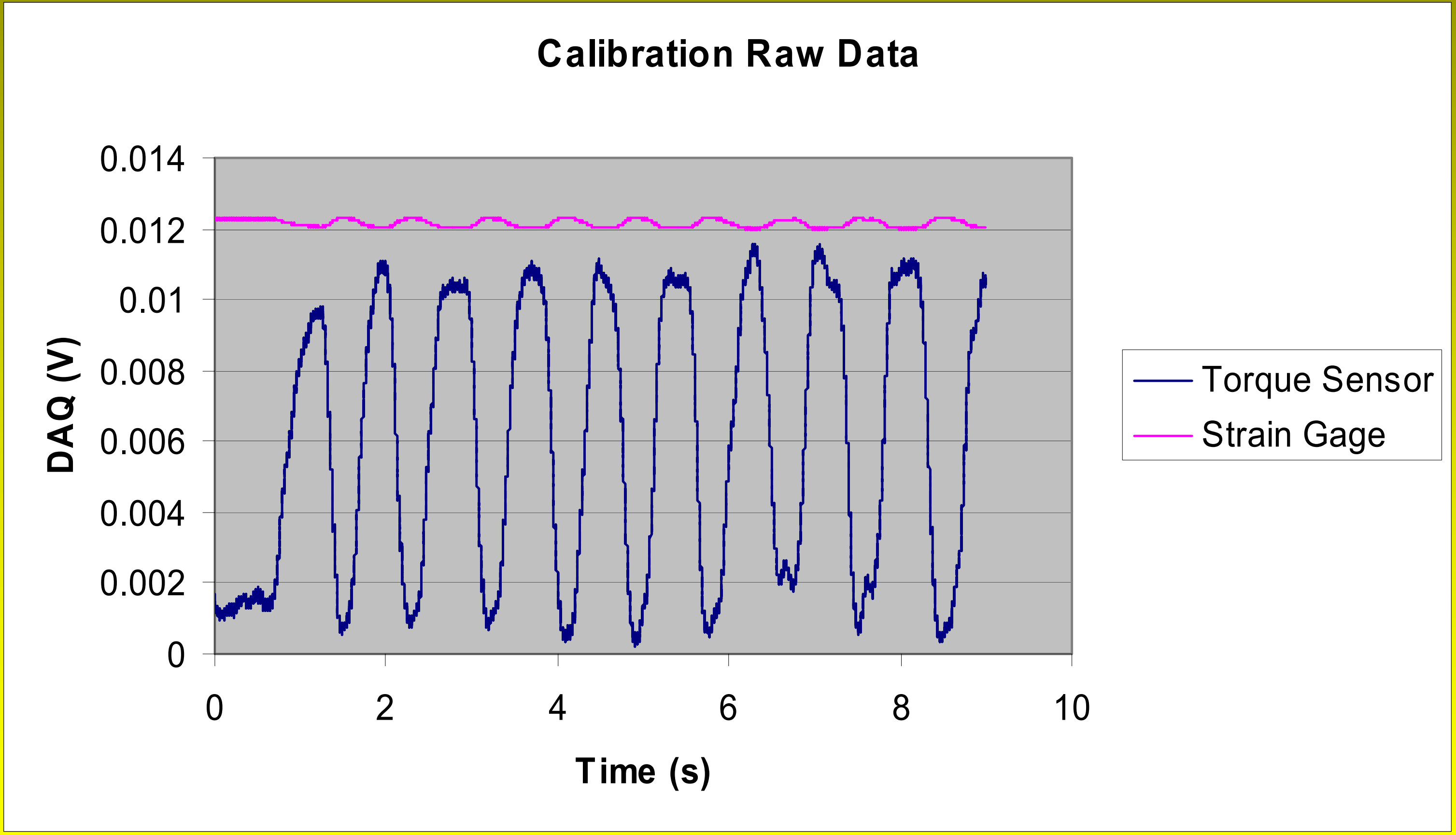


- Points A and B connect to the spindle
- Point C was location of applied torque

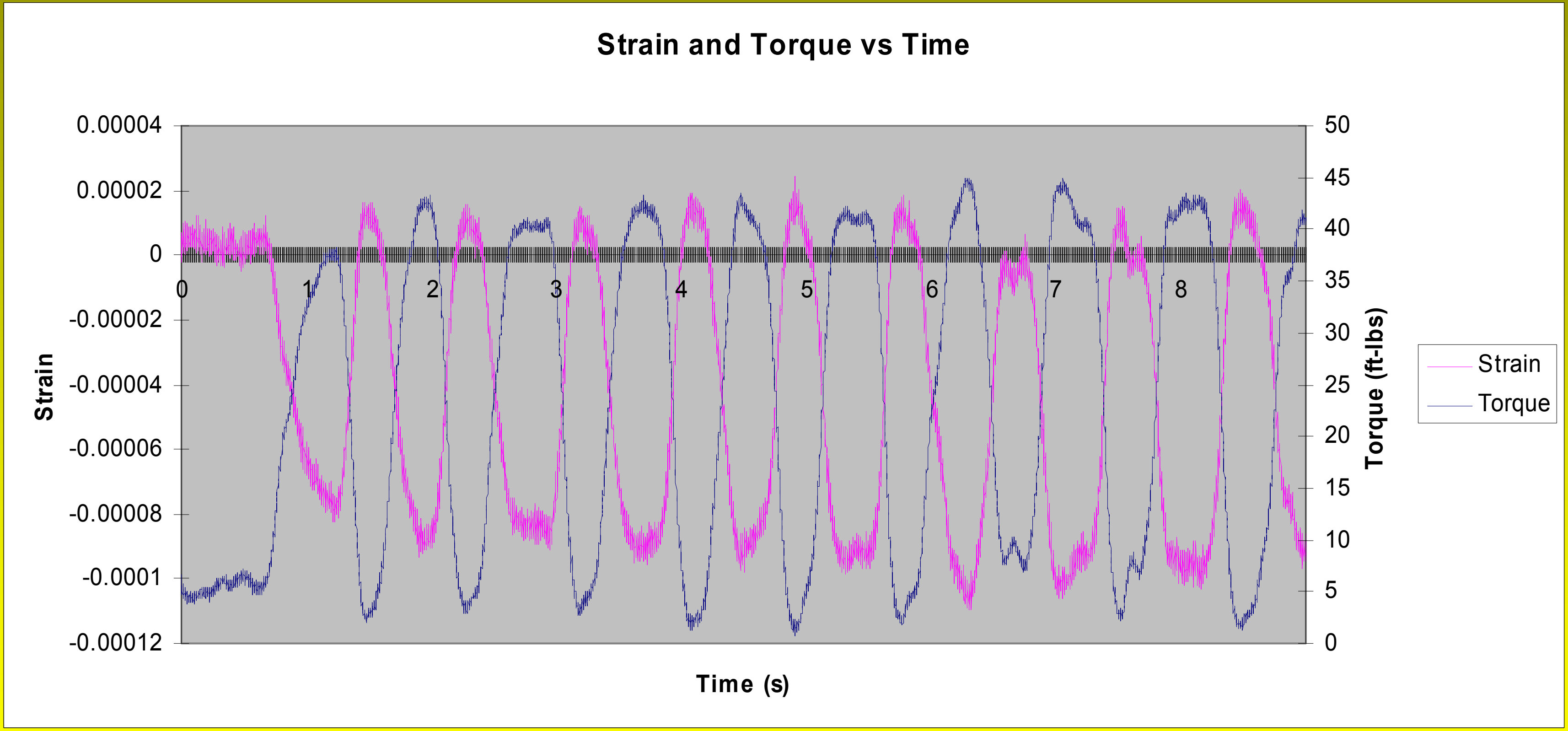
Instruments Used

- Omega Torque Indicator
  - Sensitivity:
    - 0.002141 mV / V / in-lb
- Craftsman Breaker Bar
- Omega Pre-wired Strain Gages

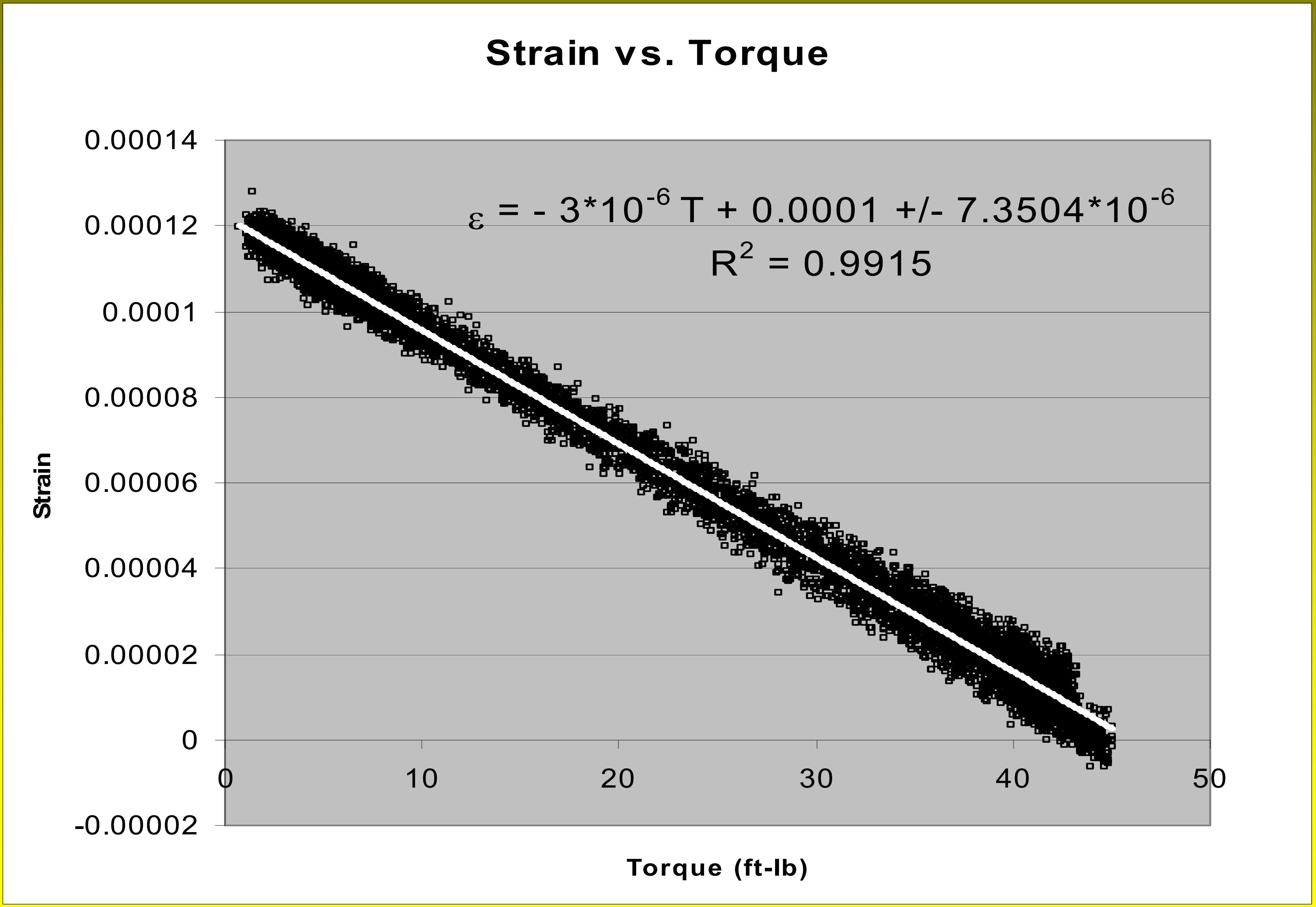
Results and Discussion



Reduced Data



Calibration Curve

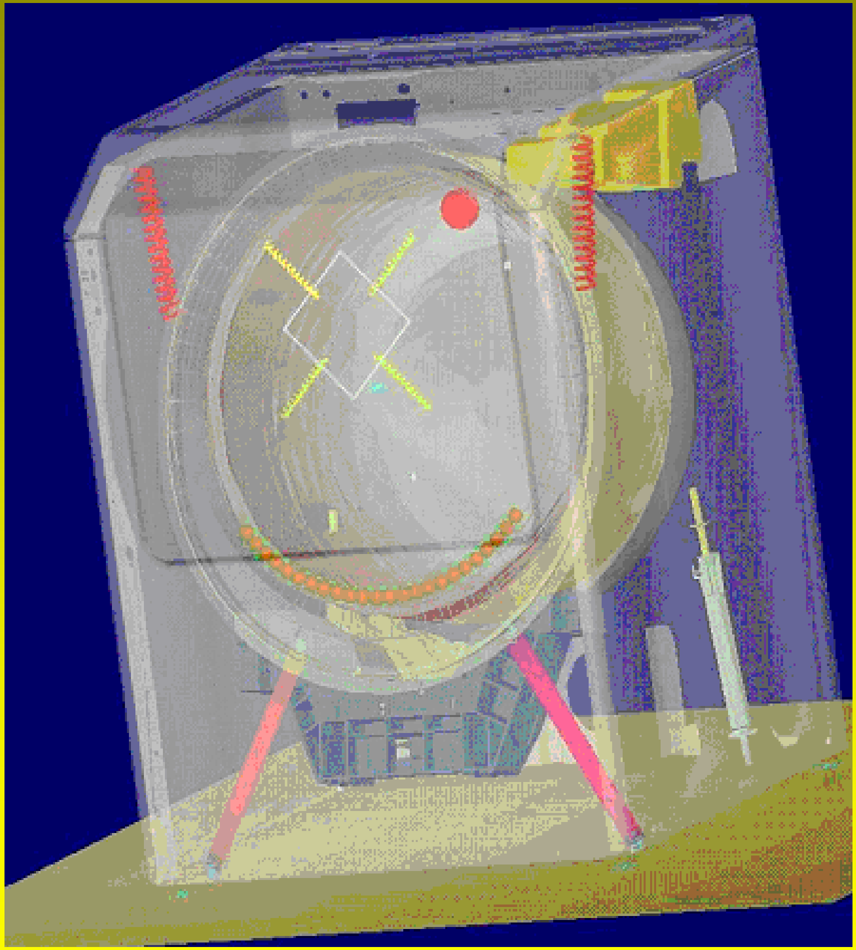


Neptune Washer Dynamics

Objectives

- Analyze the displacement characteristics of the Neptune Washer
  - Top Speed Performance
  - Transition Performance (Ramp Test)
- Compare Data with data generated from numerical analysis (DADS)

Physical vs. Dynamic



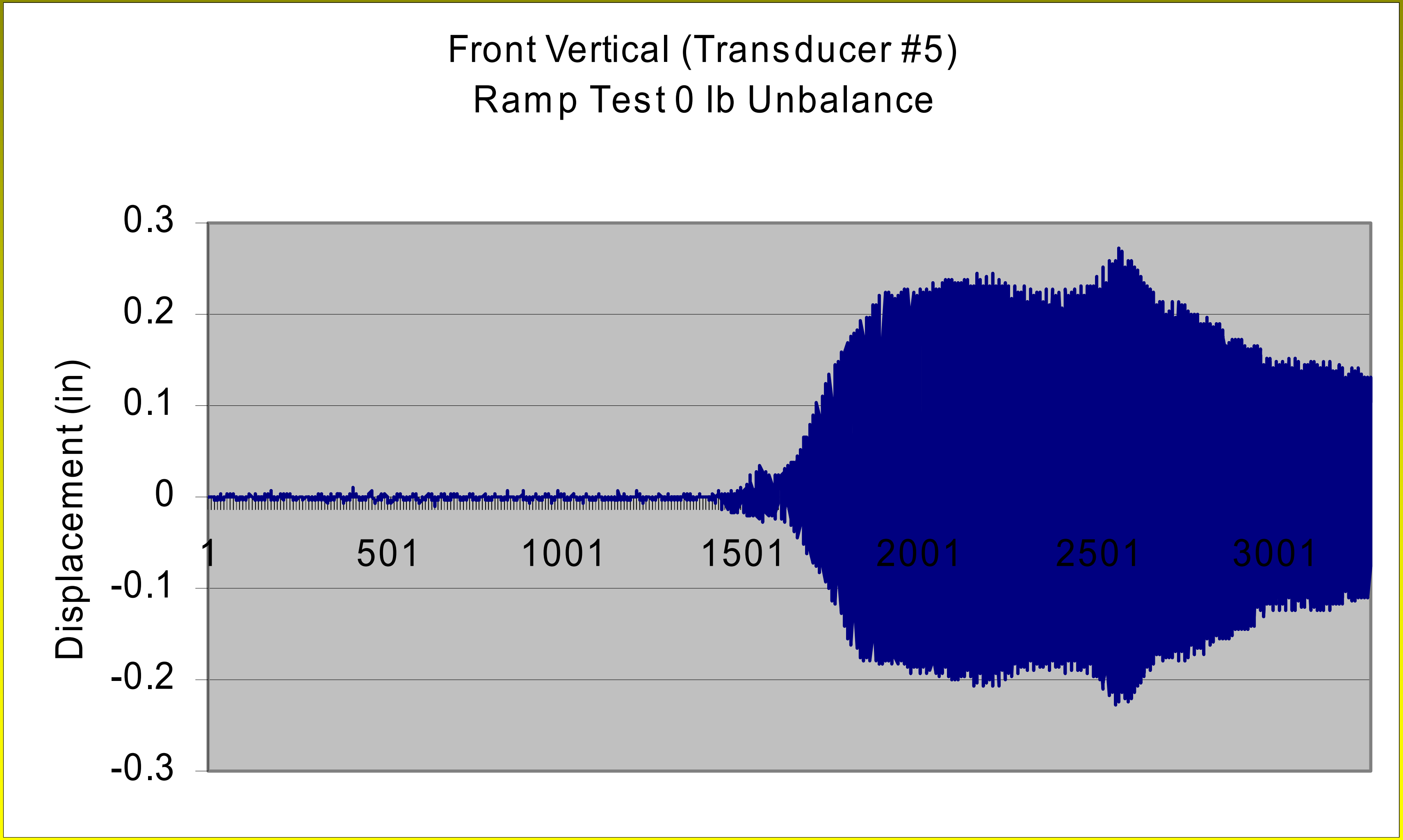
Procedure

- Calibrate Transducers
  - Four Transducers
  - 0 – 15 mm with 5 mm increments
  - Six runs
- Locate Dampers on the Tub
  - Location determined using previous analysis
- Data Collection
  - Top Speed and Ramp Test
  - No Unbalance and 1.5 lb unbalance
  - Determine Maximum Deflection Amplitudes

Data Collection

- Collected Data for 4 tub locations
- Top Speed and Ramp Tests
- No Unbalance and 1.5 lb Unbalance

Ramp Test (0 lbs)



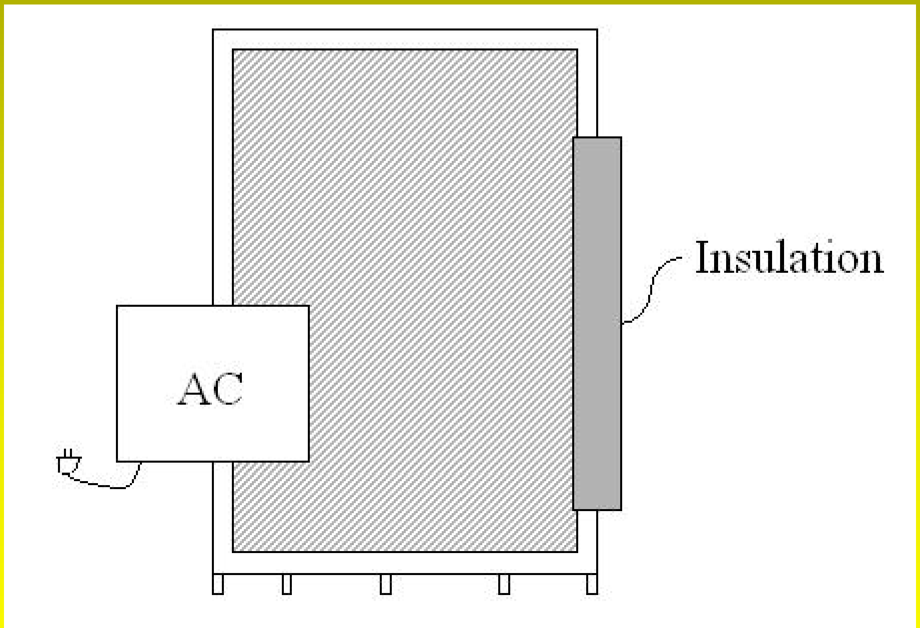
Comparison of Insulation R-Values

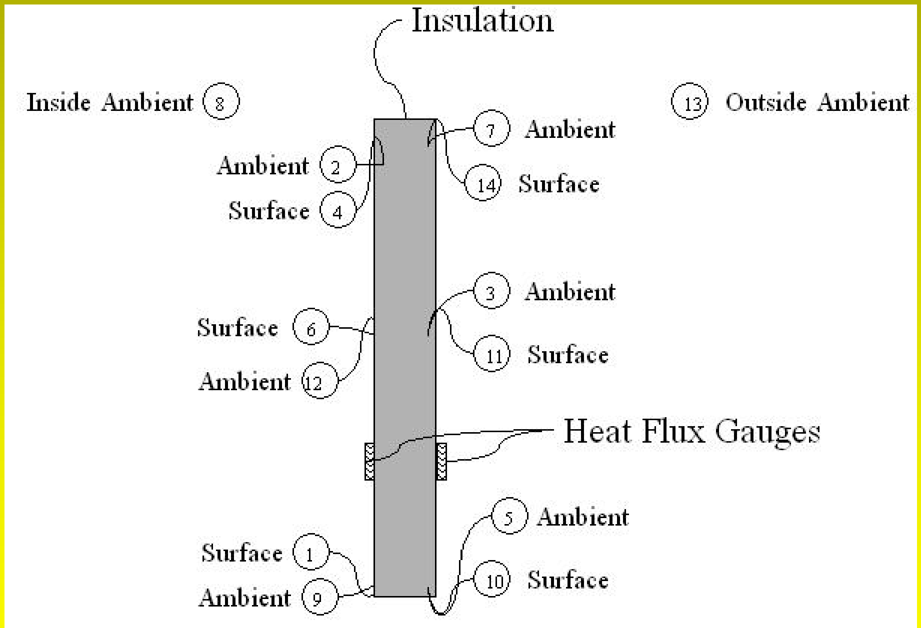
Introduction

- Objective
  - The objective of this experiment was to determine the accuracy of the specified R-value for various types of insulation.
- Motivation
  - Energy Crisis
  - Cost of Heating and Cooling Homes

Experimental Considerations

- Schematic



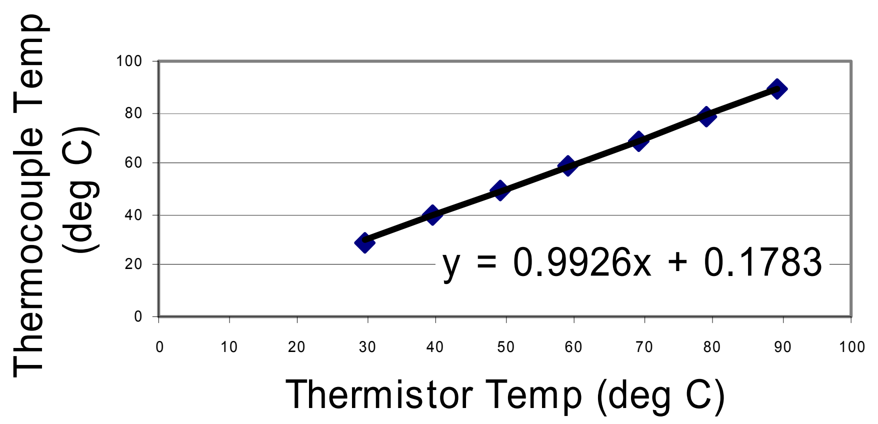


Experimental Considerations

- Insulation Types Tested
  - John’s Manville Comfort-Therm Fiberglass
    - R11
    - R11 w/ Vapor Retarder
    - R19 w/ Vapor Retarder

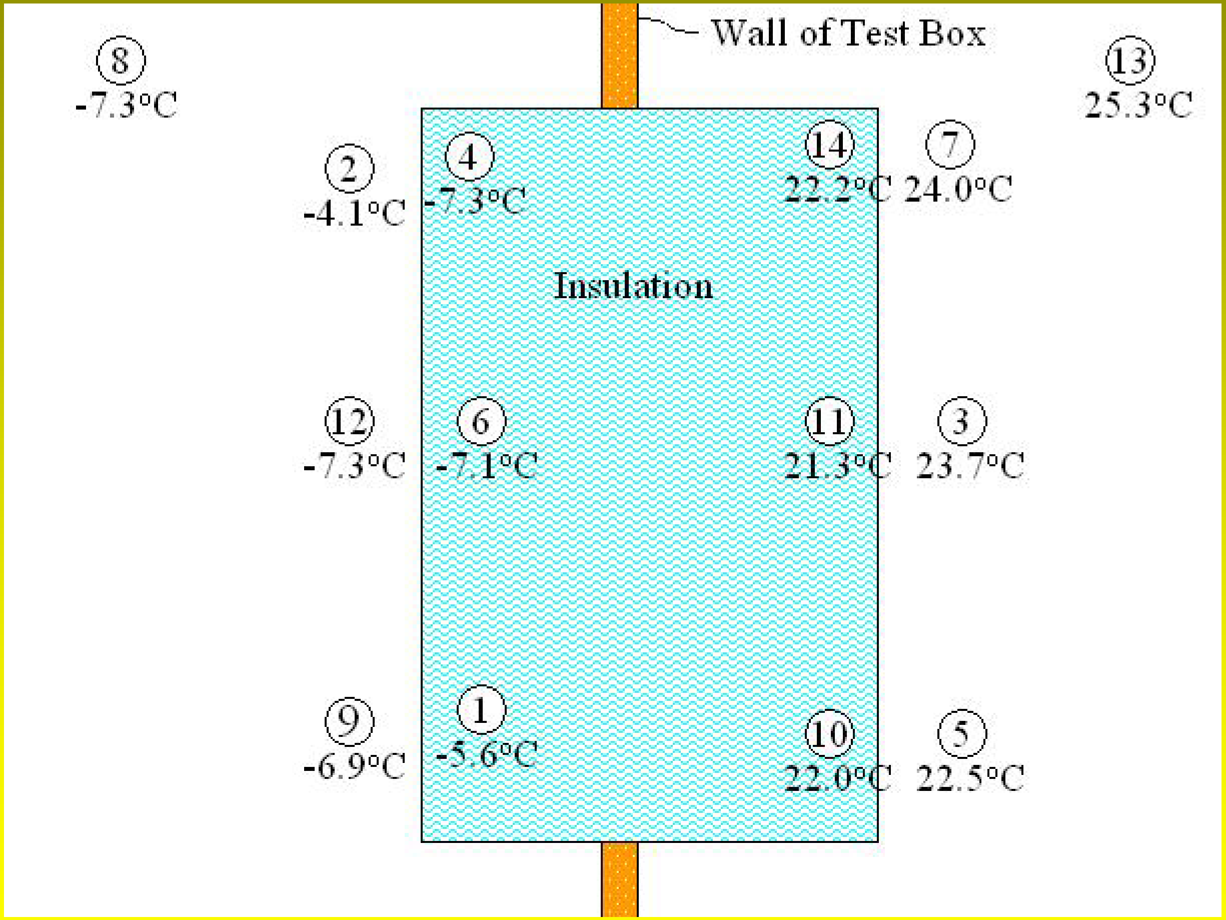
Experimental Considerations

- Calibrate T-type Thermocouples
- Calibrate Heat Flux Sensor?



Example Thermocouple Calibration Curve

Results and Discussion



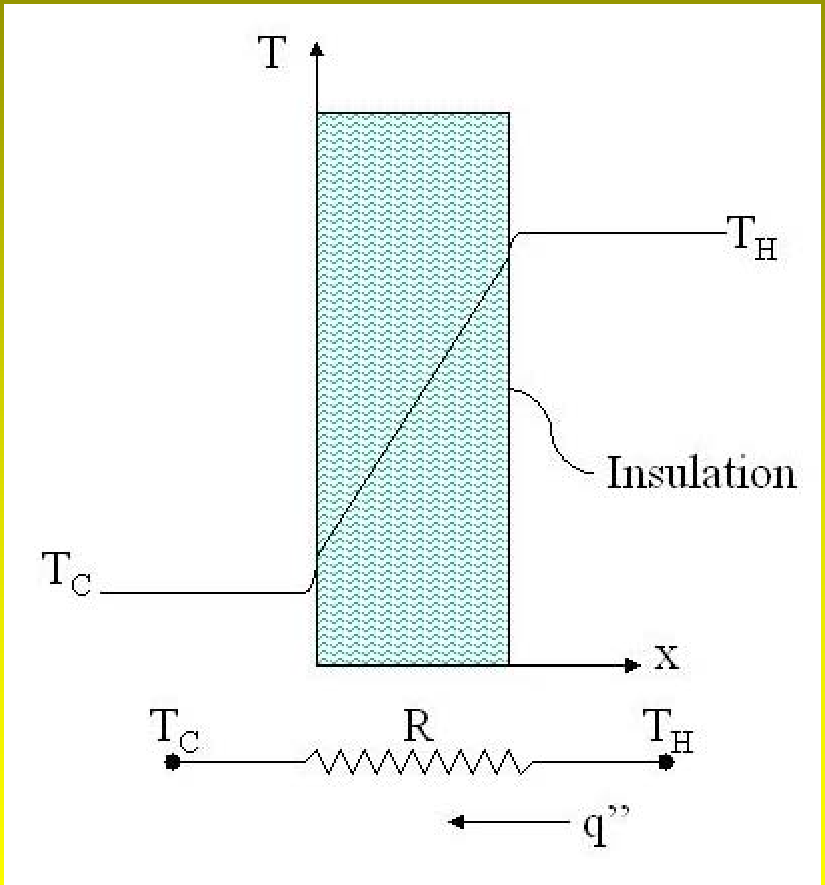
Results and Discussion

- Data Reduction
  - R-Values

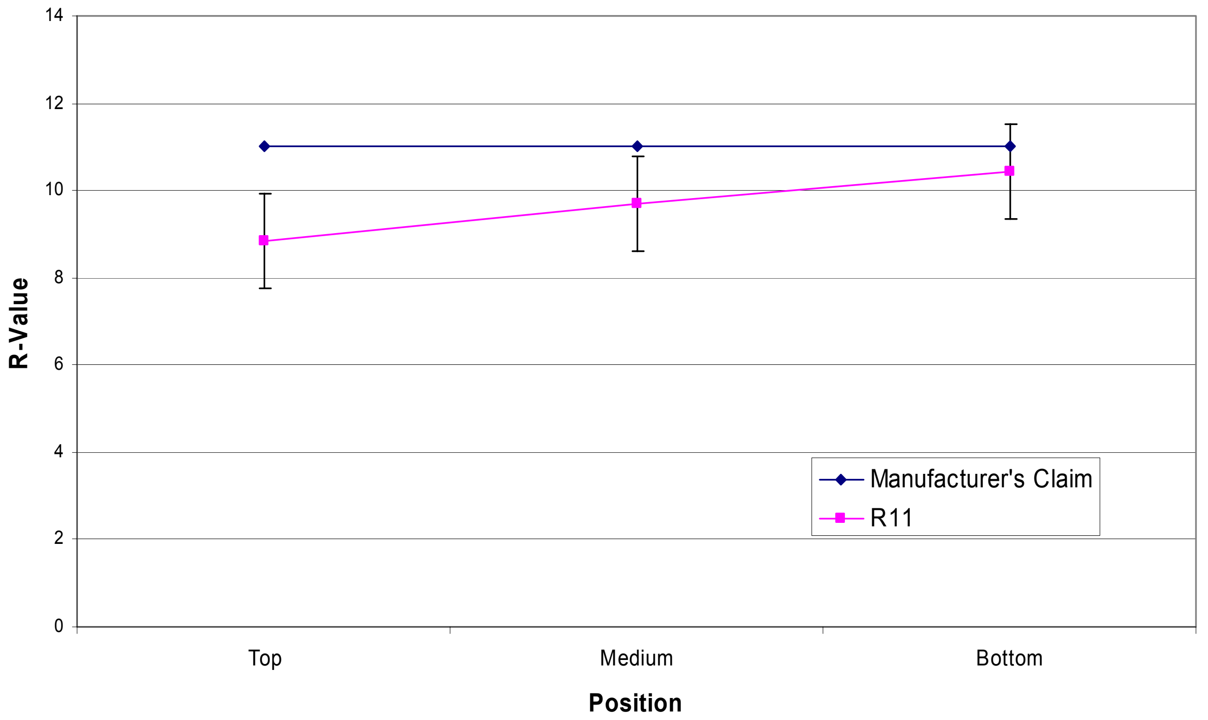
$$q = \frac{\Delta T}{R}$$

$$q = \frac{V_{heat-flux}}{0.007}$$

$$R = \frac{\Delta T}{\frac{V_{heat-flux}}{0.007}}$$

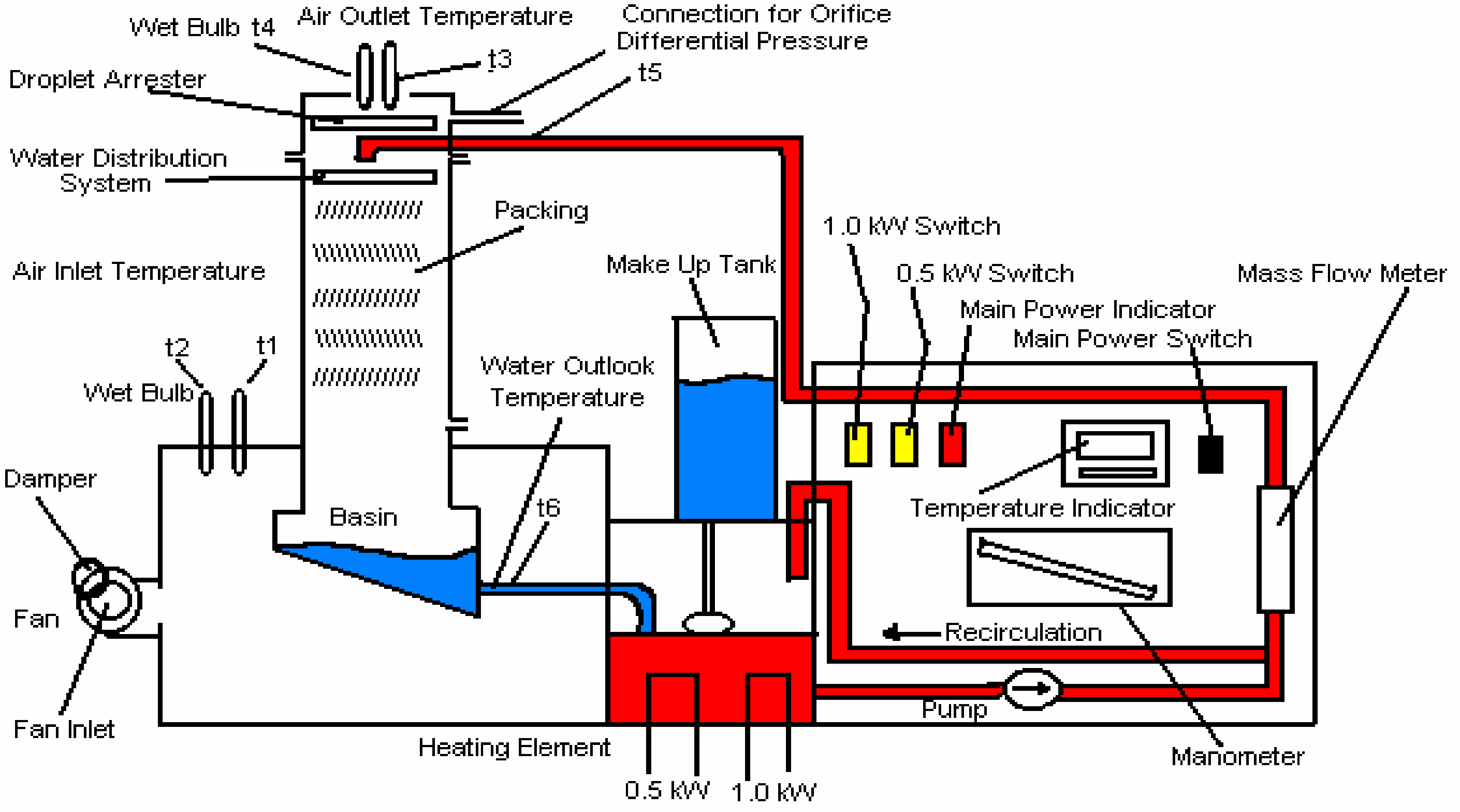


Results and Discussion



R-Values Using Outside Heat Flux Sensor and Thermocouples At Ambient Position

Cooling Tower Experiment



Experimental Setup

Procedure

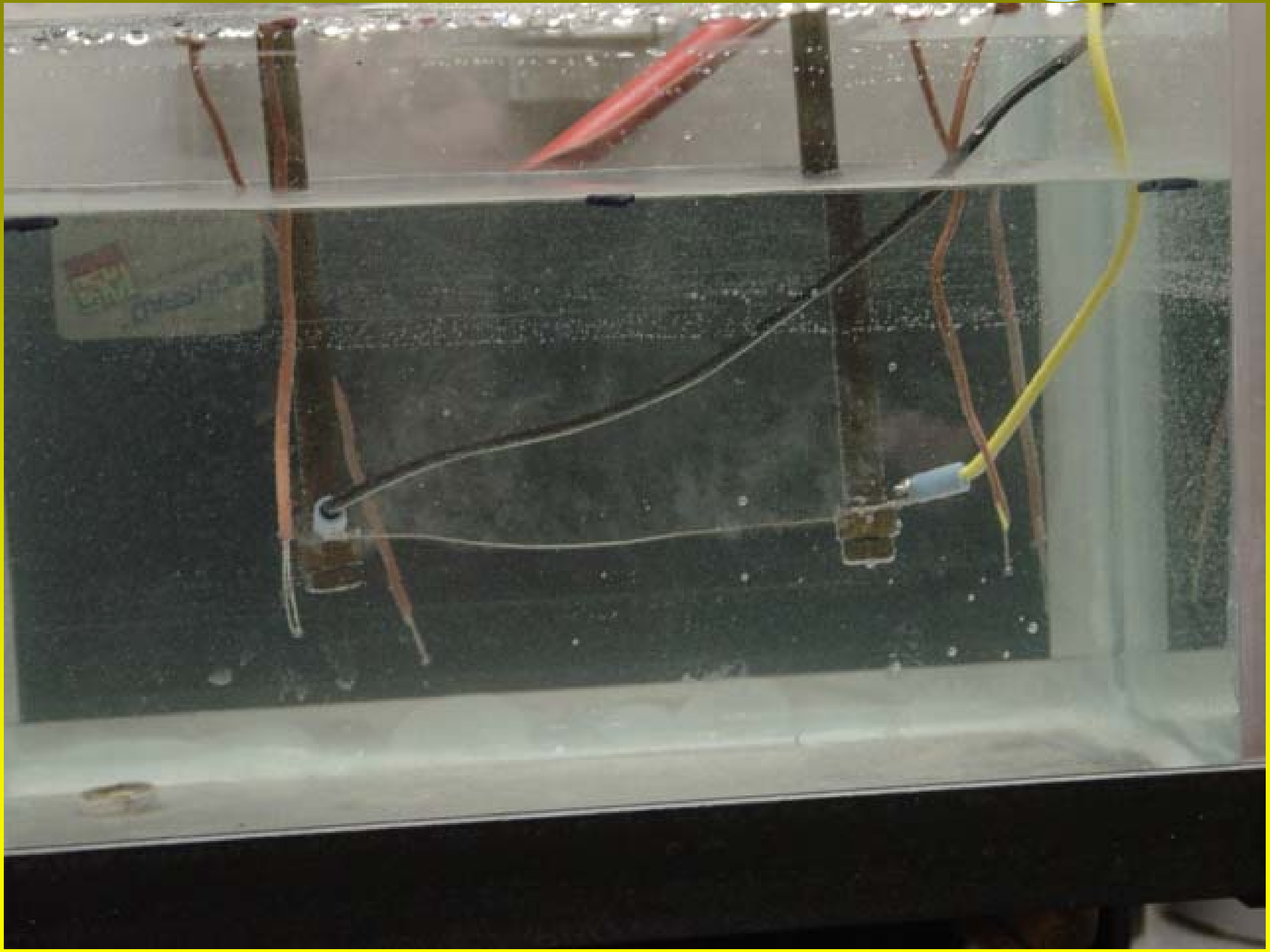
Setup

- Clean Cooling Tower Pumping System and Filter
- Install Packing Material
- Soak Wet Bulb Thermocouple Wicks
- Flow Rate > 40 gps
- Differential Air Pressure Set at 16 mmH_2O

Experiment

- Heater Set at 0.5 kW
- Reach Steady State
- Record
  - Flow Rates: Water and Air
  - Temperatures: T1 to T6
  - Input Power
- Cases
  - 1: Press Board Packing
  - 2: Corrugated Packing
  - 3: Increased Air Temperature

“Pool Boiling”

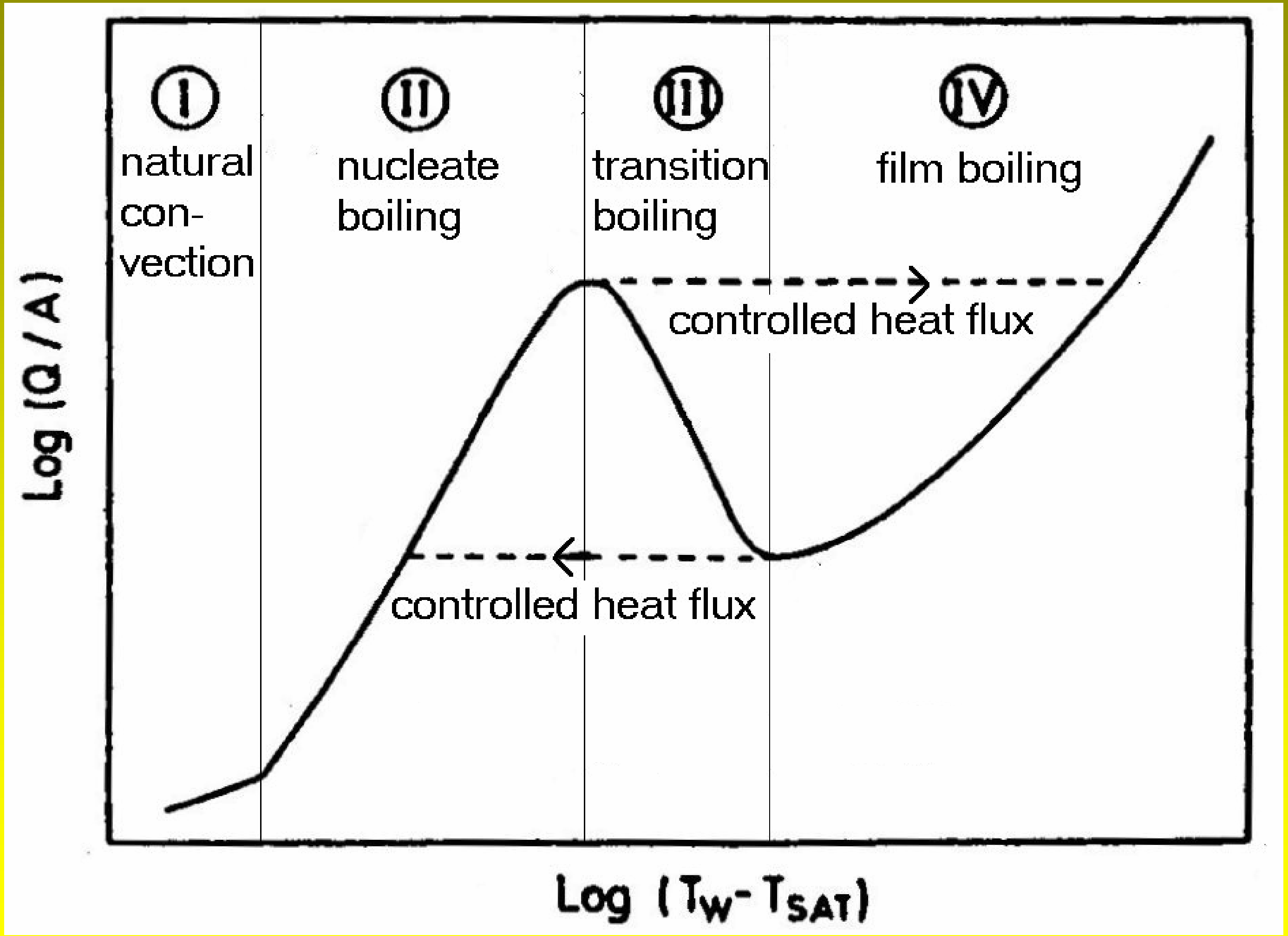


John McLaughlin Brian Elliott Aric Arneson Kim Woehrle

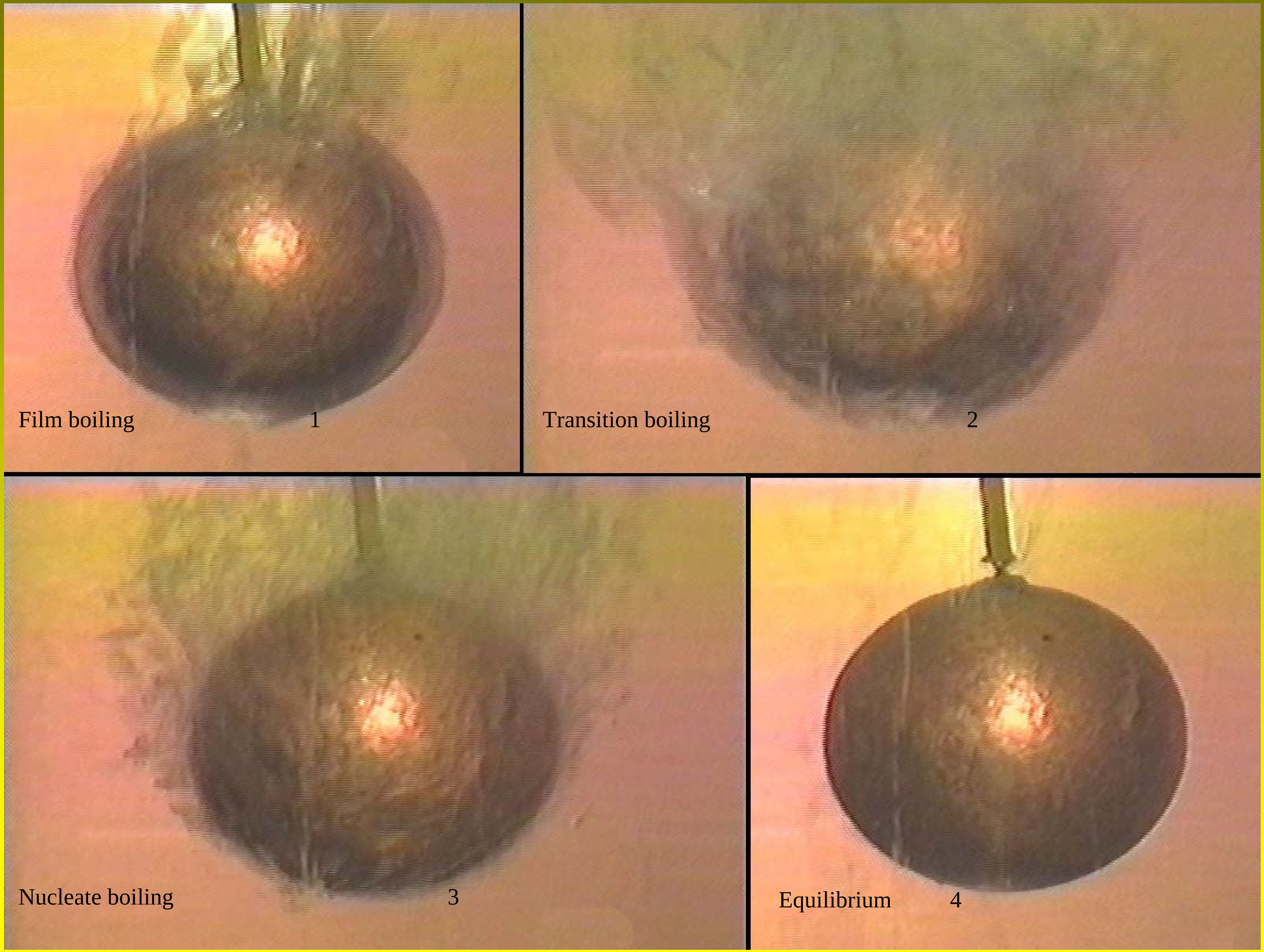
Scope of Project

- Conduct an experiment using equipment and data analysis learned from the course
- Perform data reduction analysis
- Present and Report findings

Objective



I
natural
con-
vection
II
nucleate
boiling
III
transition
boiling
IV
film boiling
controlled heat flux
controlled heat flux
Log (Q / A)
Log (T_W - T_SAT)


Film boiling
1
Transition boiling
2
Nucleate boiling
3
Equilibrium
4

Setup

Strain in the Shaft of a Golf Club

Introduction

- Motivation
  - Follow up to Mechanical Systems Design experiment
  - To investigate the effects of acceleration and club head speed on shaft strain
  - To have fun with the experiment

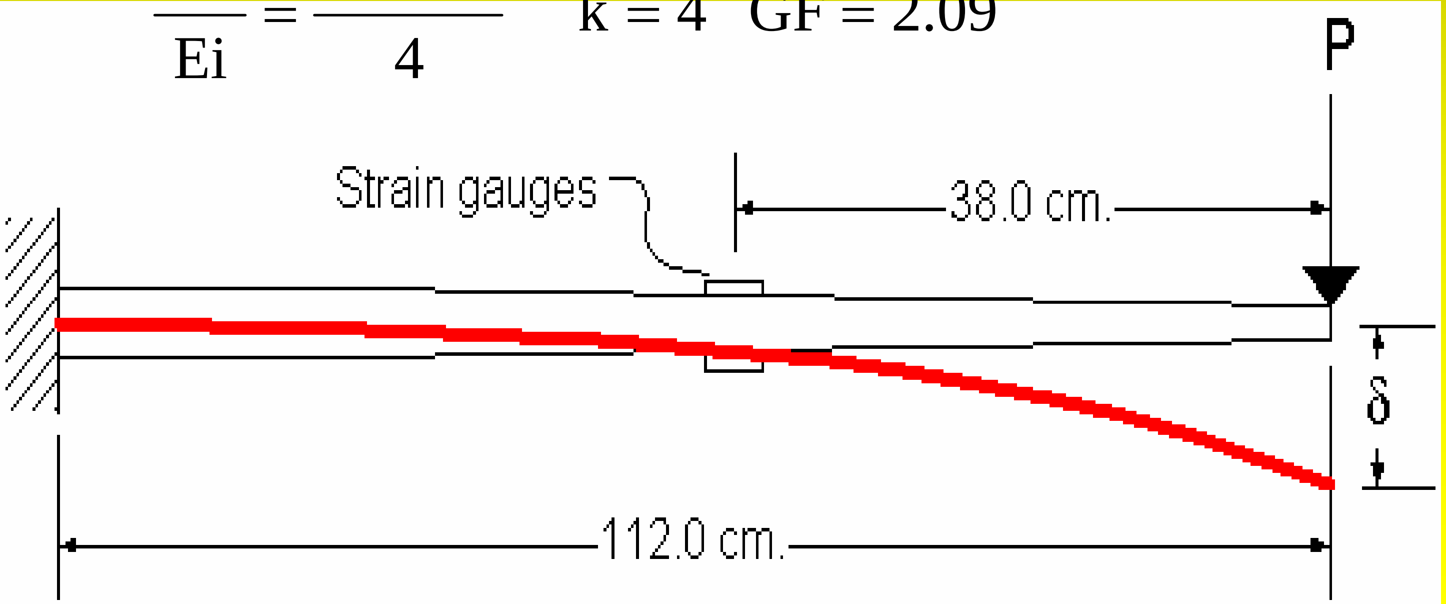
Theory

- Cantilevered beam
  - Stress/strain in beam

$$\sigma = \frac{M\,c}{I} \qquad \varepsilon = \frac{\sigma}{E} \qquad I = \frac{\pi}{64}(D^4 - d^4) \qquad M = PL$$

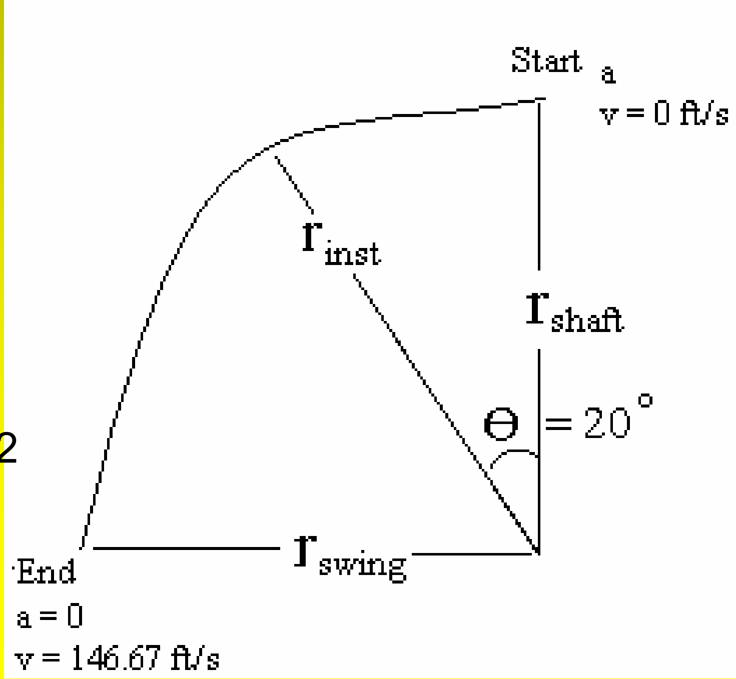
  - Strain, from strain gauge voltage

$$\frac{Eo}{Ei} = \frac{k\,GF\,\varepsilon}{4} \qquad k = 4 \quad GF = 2.09$$



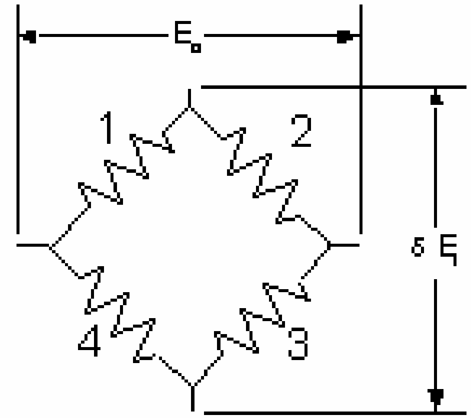
Theory

- Accelerometer selection
  - $\alpha = \partial\omega/\partial t$
  - $\alpha = (\partial\omega/\partial s)*(\partial s/\partial t)$
  - $\alpha = \omega\ (\partial\omega/\delta s)$
  - $\alpha\ \delta s = \omega\ \partial\omega$
  - $\alpha\ \delta s = \partial\omega$
  - $\alpha(s_e - s_i) = (1/2)(\omega_e^2 - \omega_i^2)$
  - With s_i and $\omega_i = 0$, the angular acceleration is $\alpha = 325\ rad/s^2$
  - $a_{max} = 1654\ ft/s^2 = 52g$
  - $a_{max} = 276\ ft/s^2 = 8.6g$

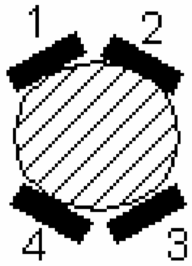


Installation and Calibration

- Strain gauge
  - Bending gauges in a full bridge configuration
  - Mounted at 33 cm. from hozzle
  - Some difficulty soldering gauge leads to strain relief and preventing leads from grounding on shaft



Nominal gauge resistance: 350+/-3% Ω



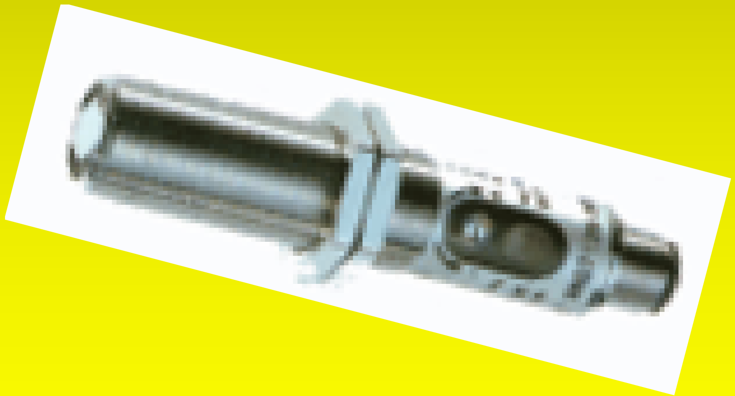
Installation and Calibration

- Strain gauge calibration
  - Used 0 - 500g mass in 100g increments to deflect shaft
  - Performed 3 up/down scale tests to check for hysteresis
  - Output voltage -> Calibration curve -> mass -> Force -> deflection -> Strain
- F = m a

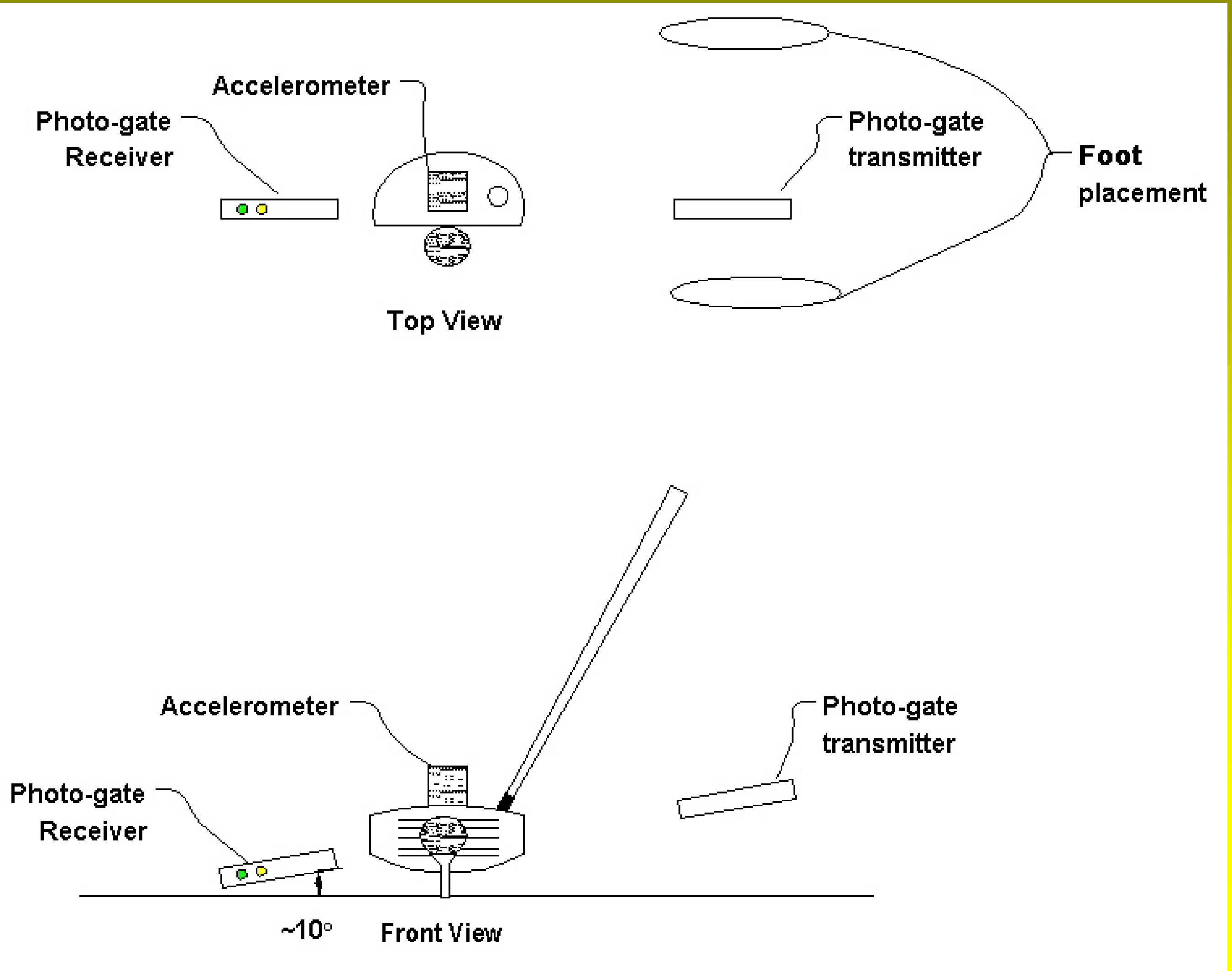
$$\delta = -\frac{F L^3}{3E I}$$

Installation and Calibration

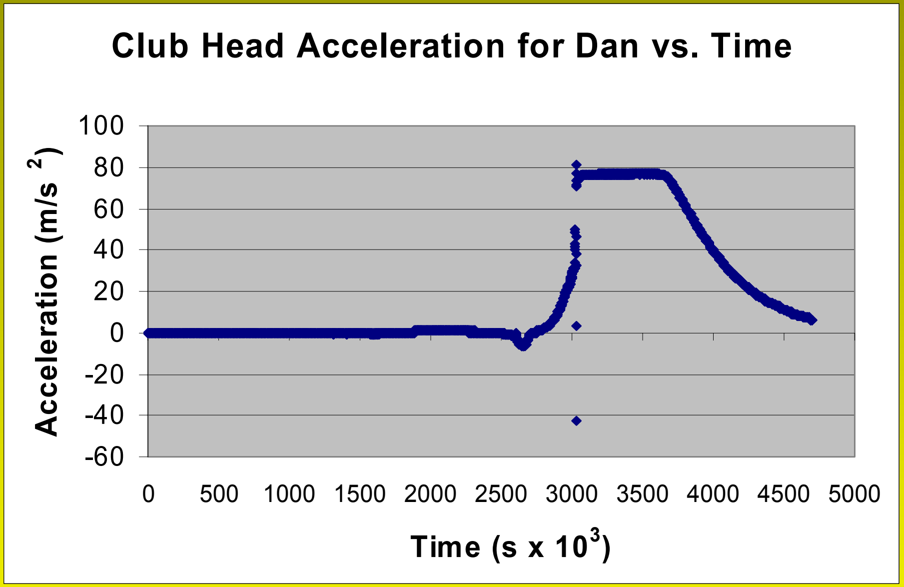
- Photo-gate
  - Used 1 set of Siemens Opto-Bero photo-gates
    - Transmitter and Receiver
  - No calibration was performed on photo-gate
    - Used in an On/Off manner

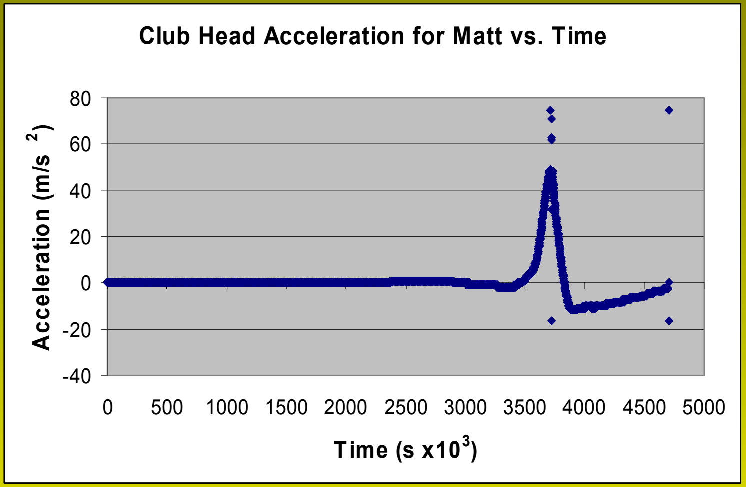


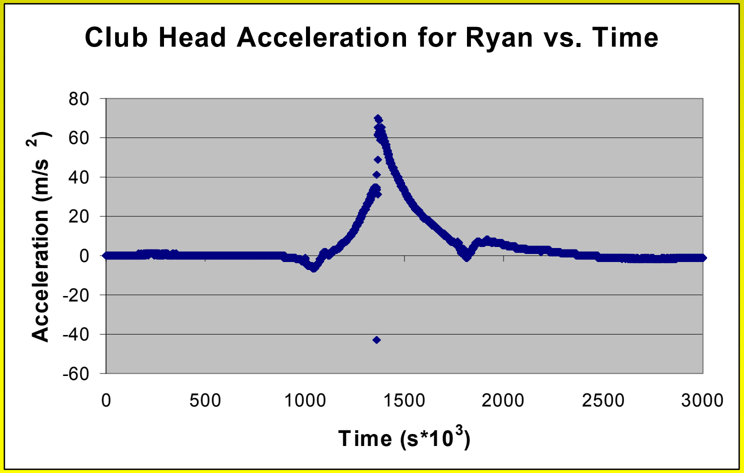
Experimental Procedure



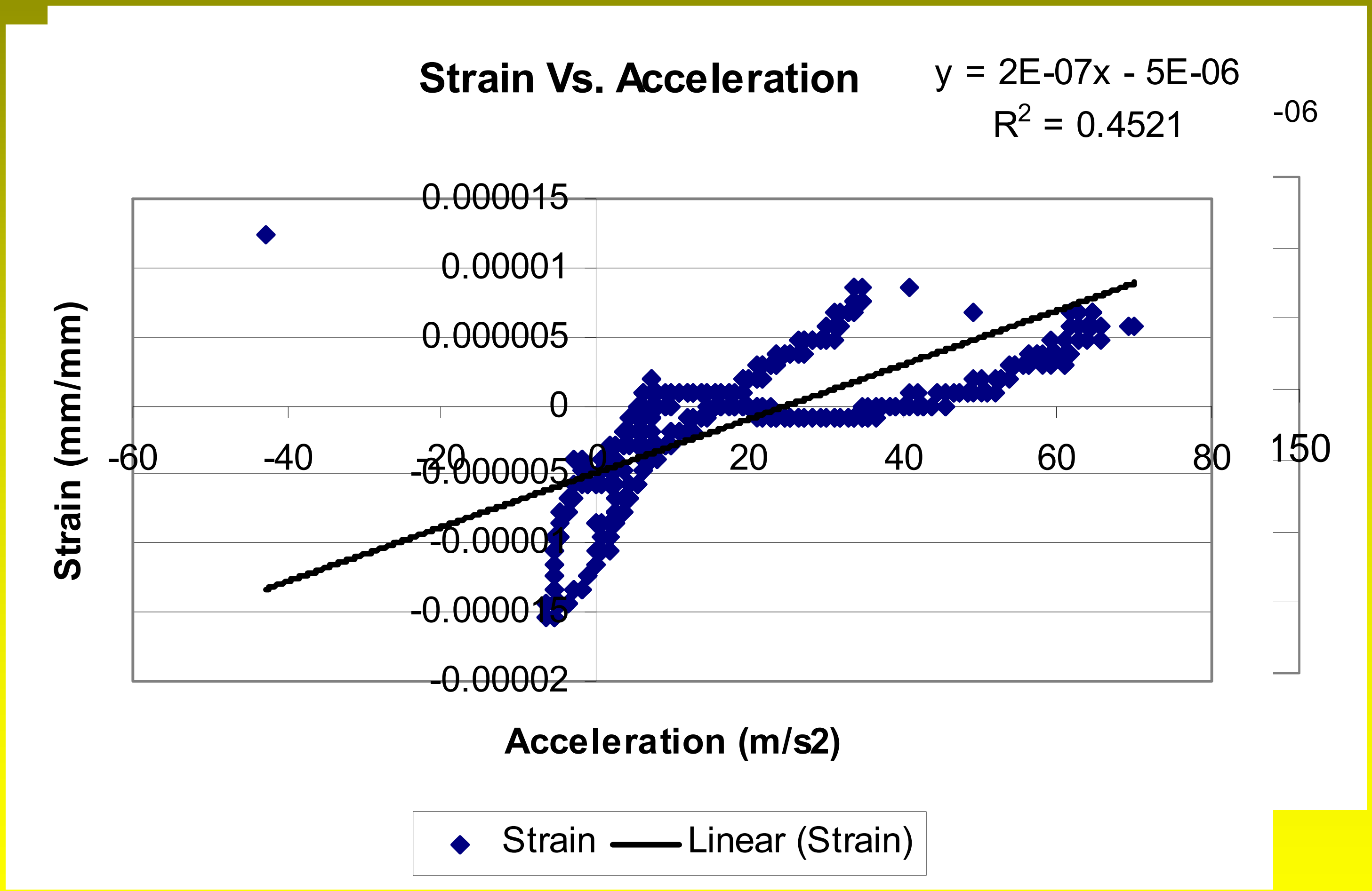
Results


Club Head Acceleration for Dan vs. Time
Acceleration (m/s 2)
100
80
60
40
20
0
-20
-40
-60
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Time (s x 10³)


Club Head Acceleration for Matt vs. Time
Acceleration (m/s 2)
80
60
40
20
0
-20
-40
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Time (s x10³)


Club Head Acceleration for Ryan vs. Time
Acceleration (m/s 2)
80
60
40
20
0
-20
-40
-60
0
500
1000
1500
2000
2500
3000
Time (s*10³)

Strain Vs. Acceleration



Thermal Resistance of a Limestone Bed

- Currently, a combination of Limestone and polystyrene insulation is used
  - Must meet building code for insulation req'ments
  - Polystyrene attracts termites
  - Limestone repels termites
- Could the polystyrene be replaced by additional limestone?
  - Yes, but…

Background & Motivation

- Thermal Conductivity of Limestone must be determined
  - This will allow building designers to meet codes concerning insulation values around the buildings foundation

- How to determine Thermal Conductivity of Limestone?

Experimental Set-up

- **Fourier's Law**

$$\boxed{Q'' = k\,\frac{\Delta T}{L}}$$

.k is what we want…can we get everything else?

Experimental Set-up

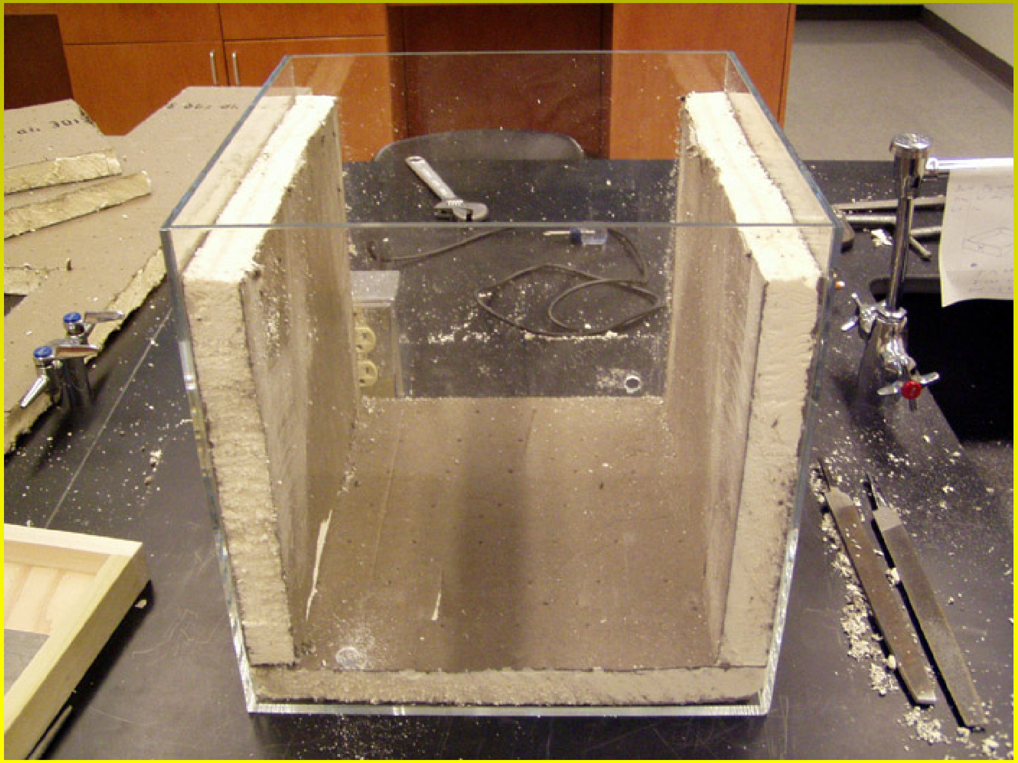
- **Yes!**
  - Thermocouples measure temperature.
    - Leads to

$$\Delta T$$

  - Ruler can measure L
  - Heat flux sensors available

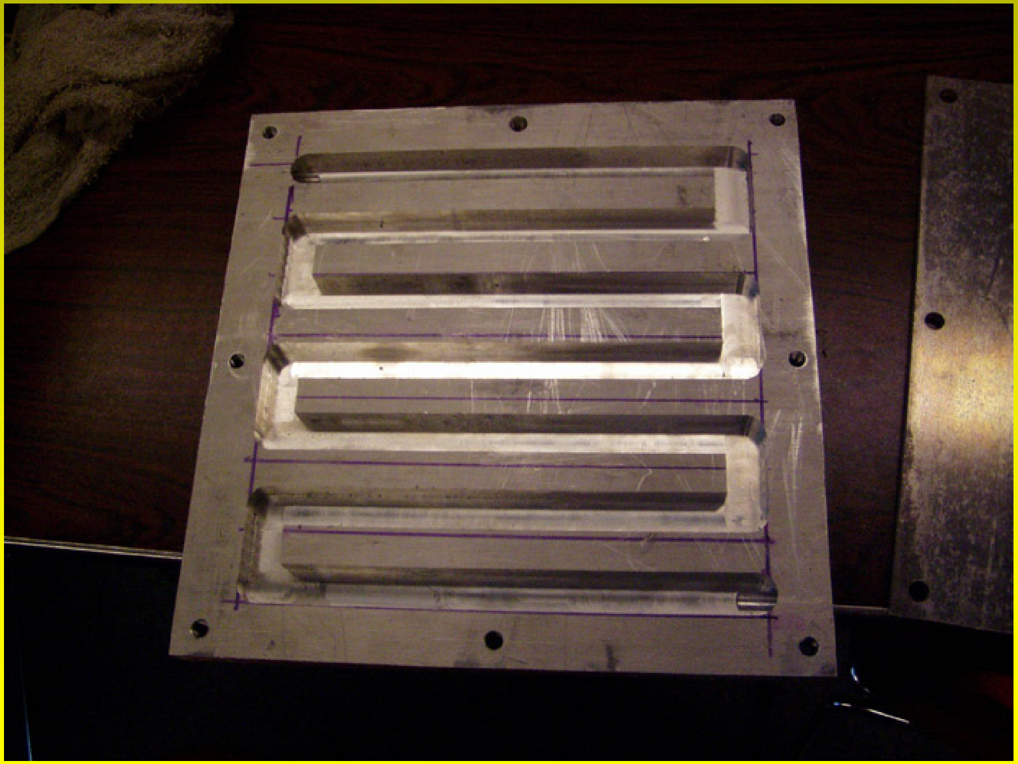
Experimental Set-up

- Insulated box was built by FSG



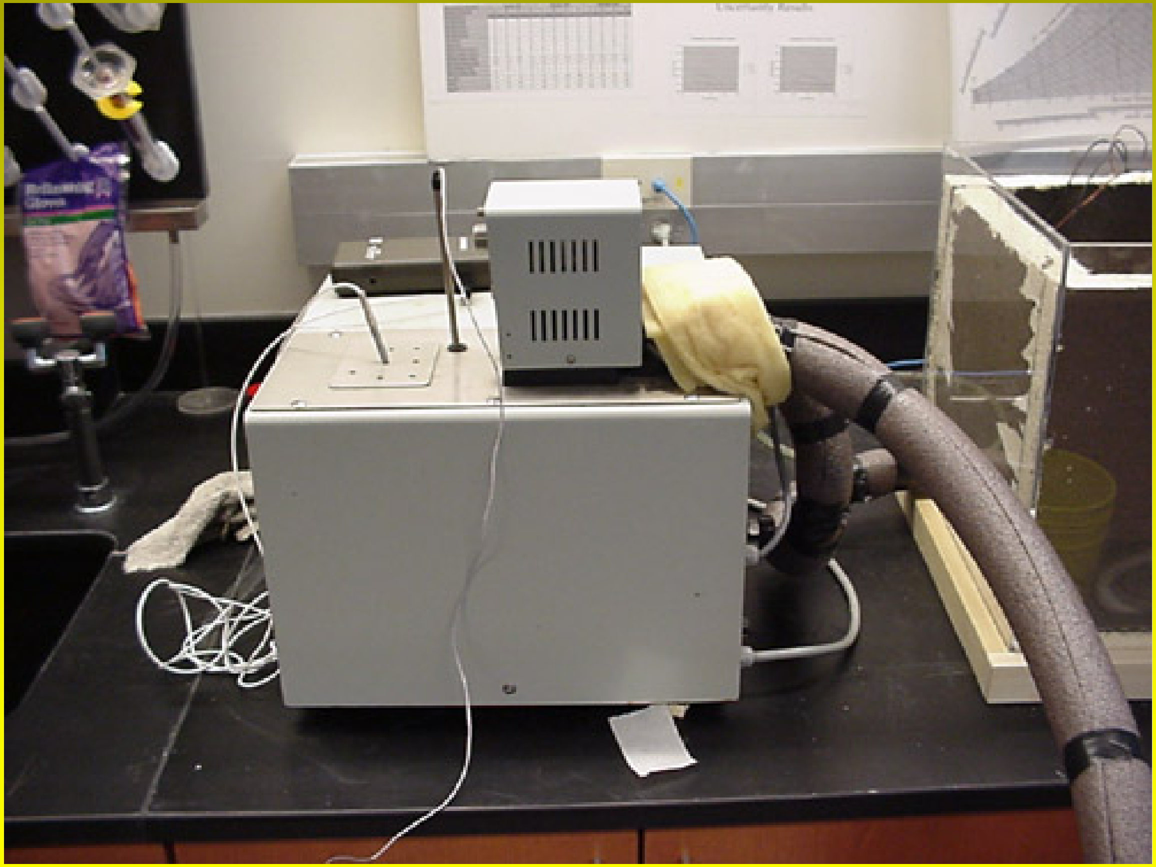
Experimental Set-up

- Built Cold/Hot plates to create a flow of heat, or heat flux across the material



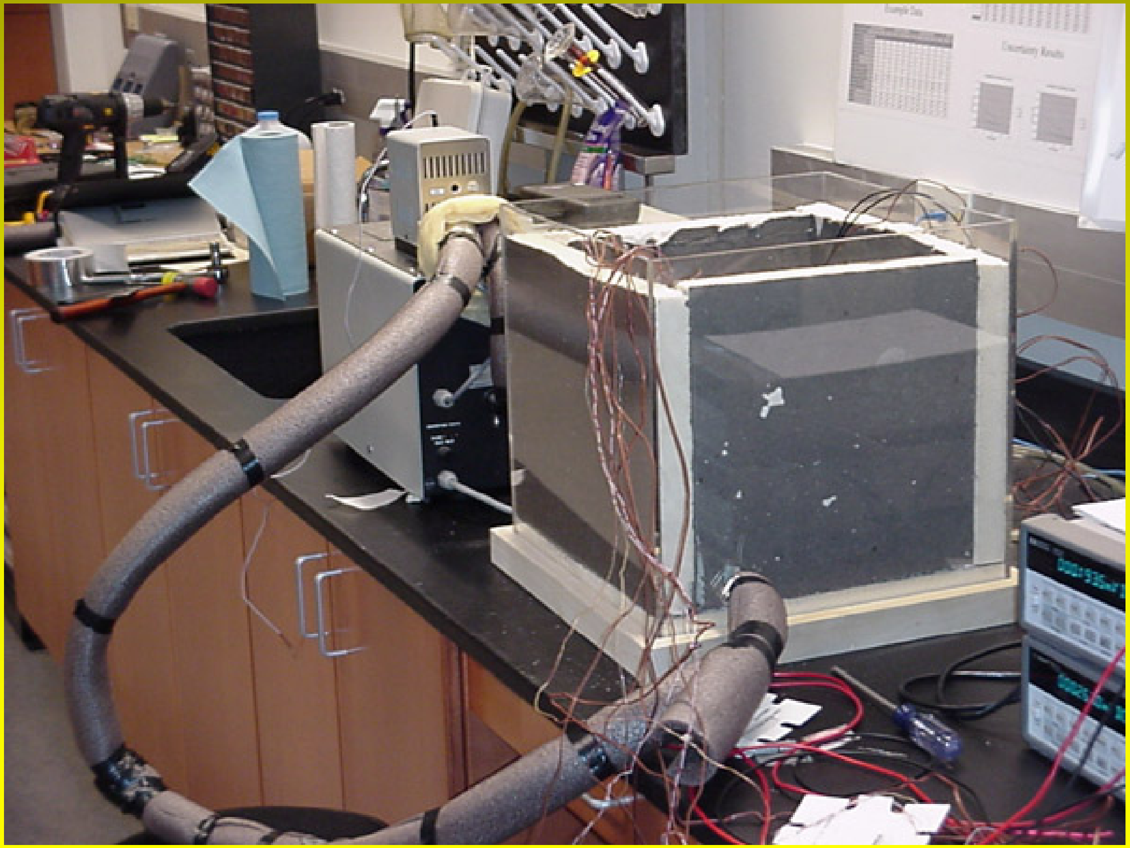
Experimental Set-up

- Assembled



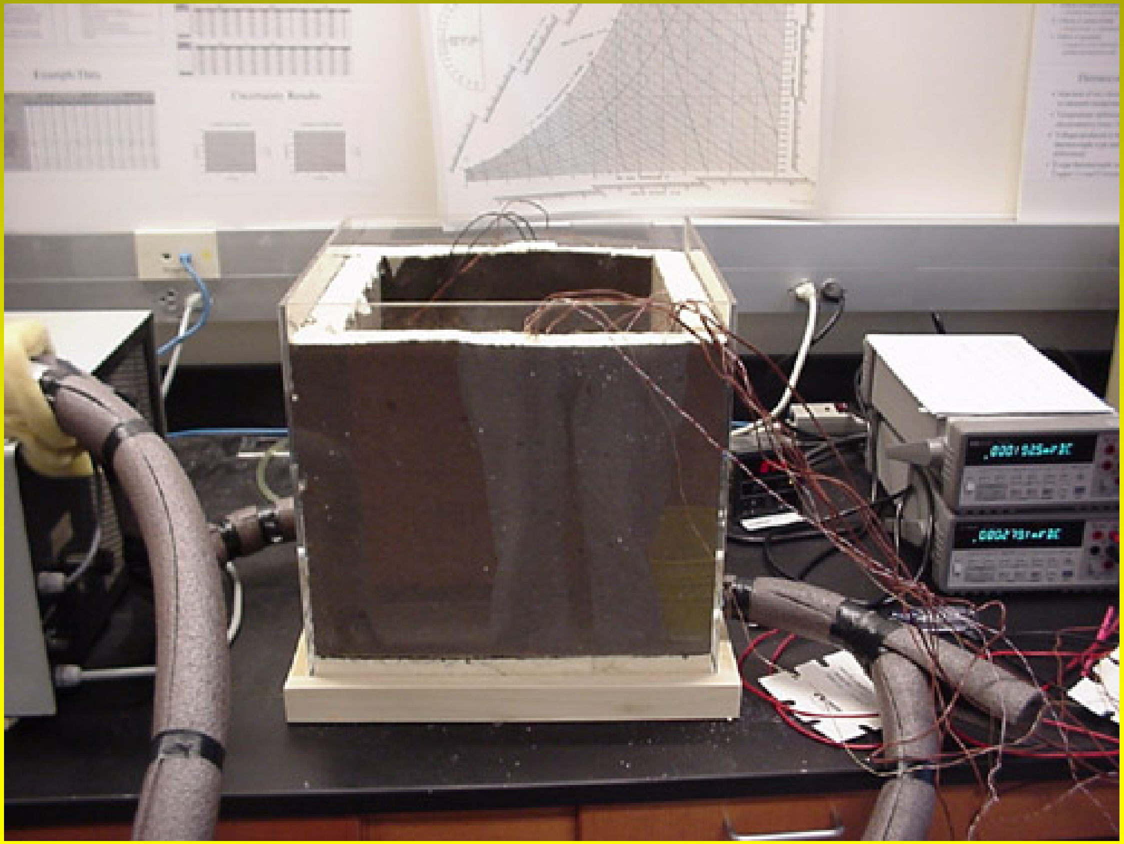
Experimental Set-up

- Assembled



Experimental Set-up

- Assembled



CALIBRATION OF TORQUE WRENCH & DEFLECTION OF PIPE

Introduction

- **Objectives**
  - Study the deflection and strain of a pipe with specified torques.
- **Motivation**
  - Tools for running the experiment were readily available.
  - The fabrication of the pipe was something the team could accomplish.
  - All team members were interested in this idea.

Experimental Considerations

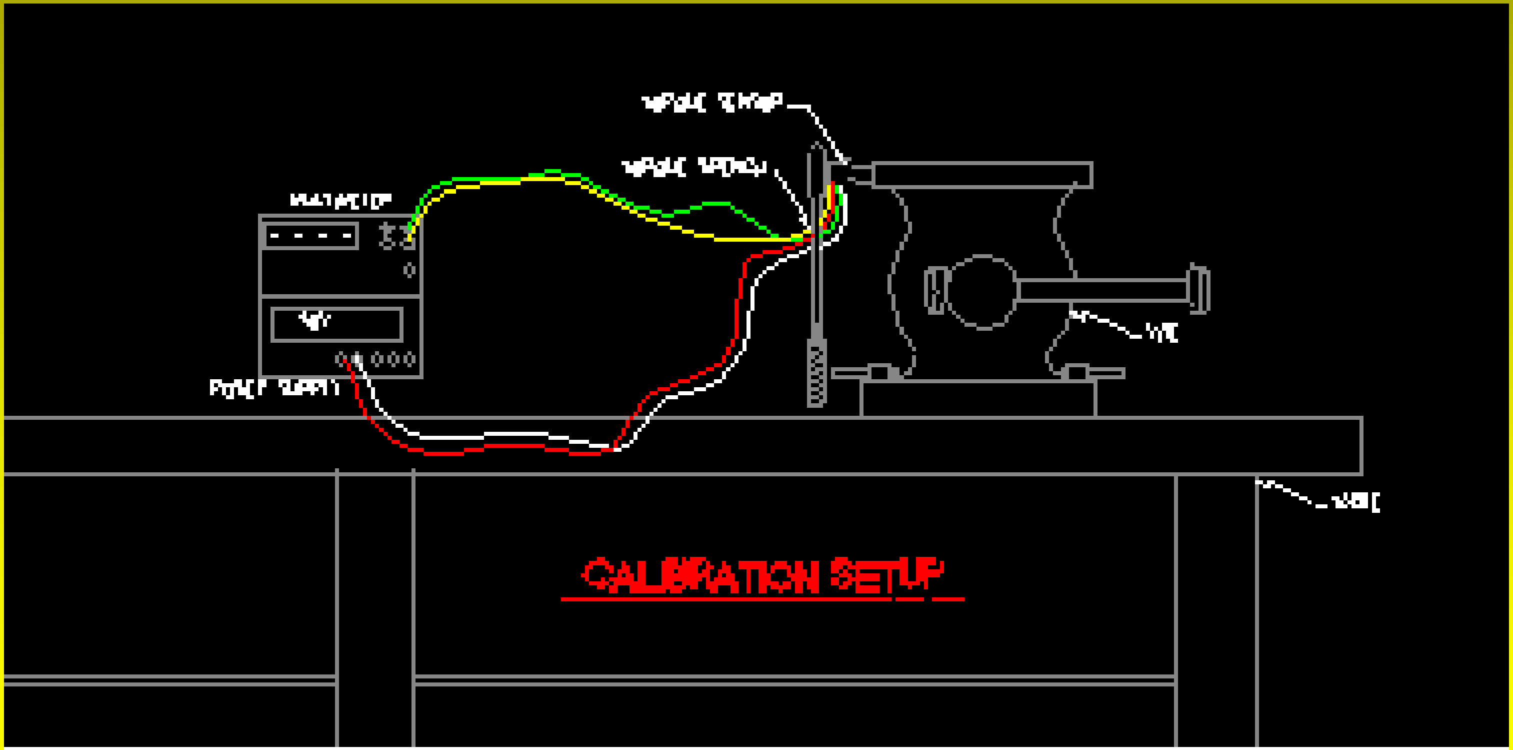
- **Design**
  - Selected two foot long, 1020 steel pipe.
  - Welded 2” x 2” x 1” block to end of pipe.
  - Welded 1-5/8” nut to opposite end.
  - Attached pipe clamp near nut end of pipe.

Table 1: Properties

Properties	Value
Inside Diameter (inches)	0.5
Outside Diameter (inches)	0.75
Length: Wrench to Vice (inches)	28.25
Length: Displacement to Vice (inches)	22.625
Modulus of Rigidity, G (lb/in^2)	11600000

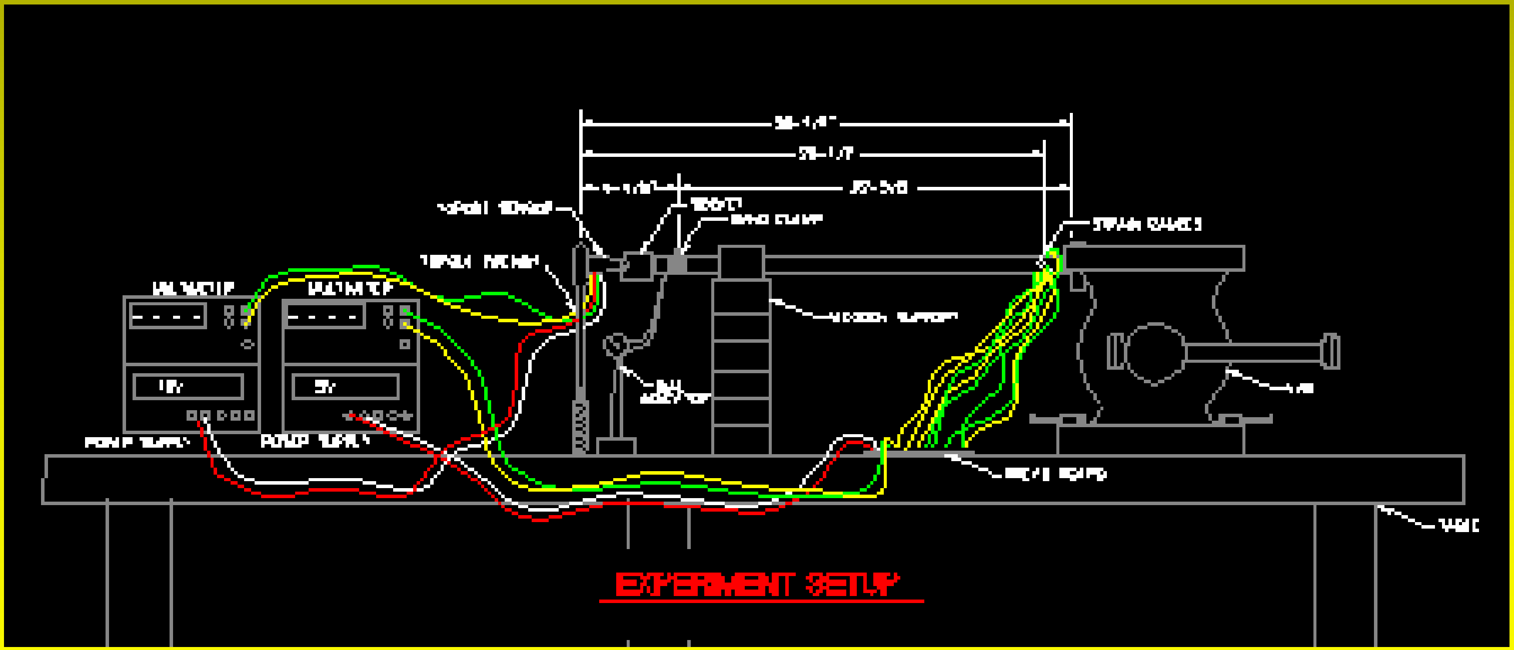
Experimental Considerations

- Calibration



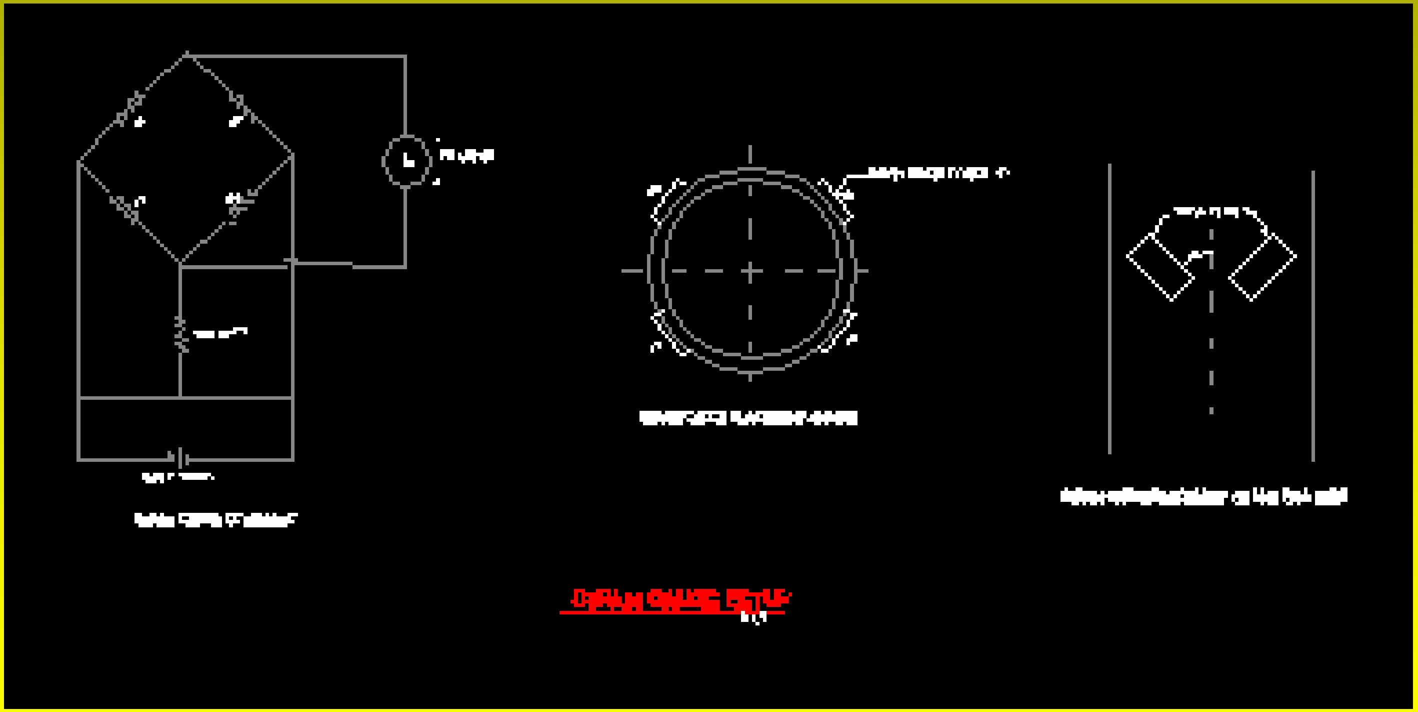
Experimental Considerations

- Experiment



Experimental Considerations

- Experiment

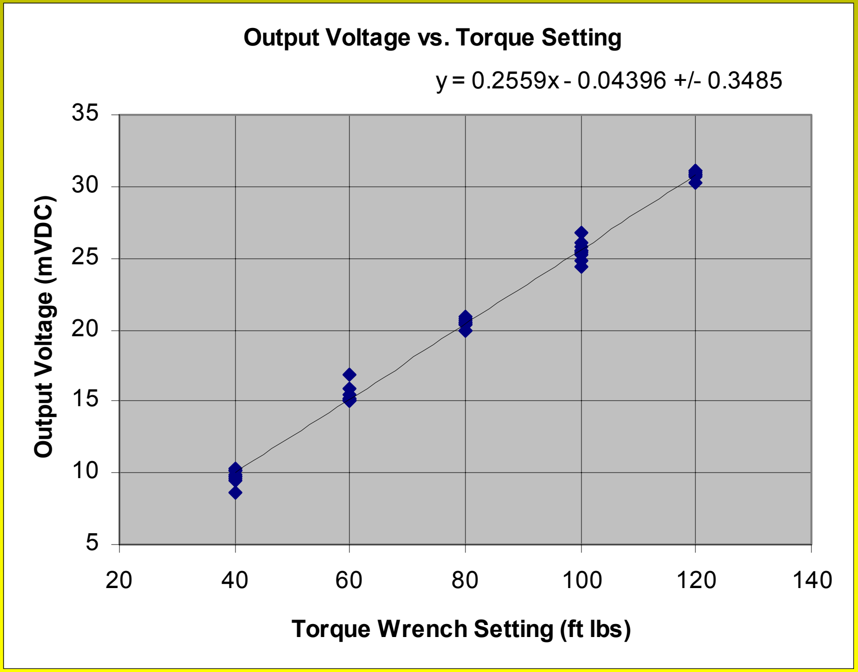


Results and Discussion

- **Uncertainty of Linear Fit**

  y = 0.2559x – 0.04396 +/- 0.3485

Table 2: Uncertainty of Linear Fit				
Torque Wrench Setting, xi (ft lbs)	Average Voltage Out, yi (mVDC)	Trend Voltage Out, yci (mVDC)	Calculation Variables	
40	9.81	10.19	Sum xi	400
60	15.42	15.31	Sum xiyi	9197.48
80	20.42	20.43	Sum xi^2	36000
100	25.49	25.55	Sum yi	101.95
120	30.82	30.67	(Sum xi)^2	160000

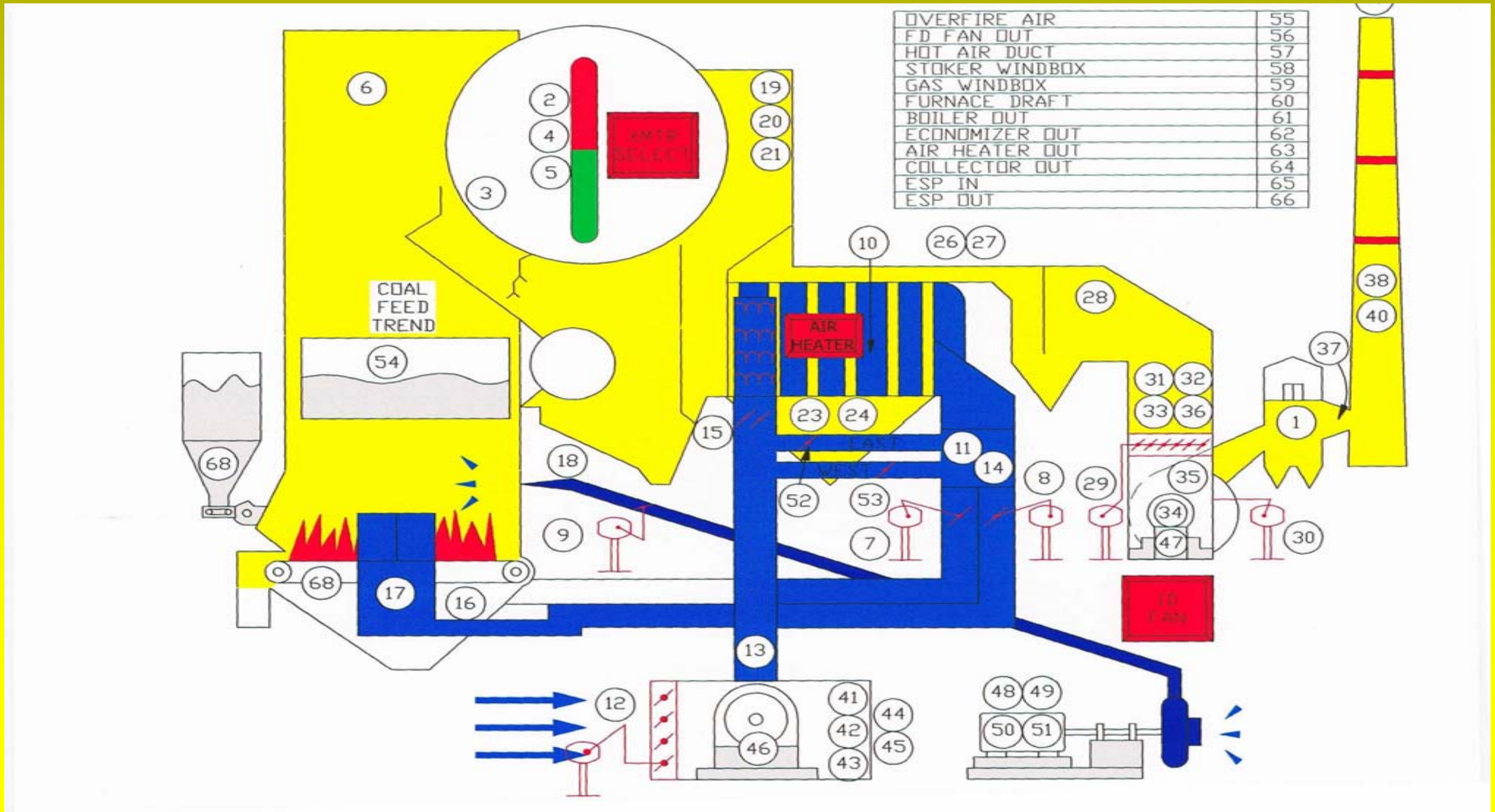


- **Hysteresis**

  Not prevalent

Determining Furnace Exit Gas Temperature

- Furnace Exit Gas Temperature (FEGT)
  - Heat Loss ($$)
  - Muscatine Power and Water Unit 7

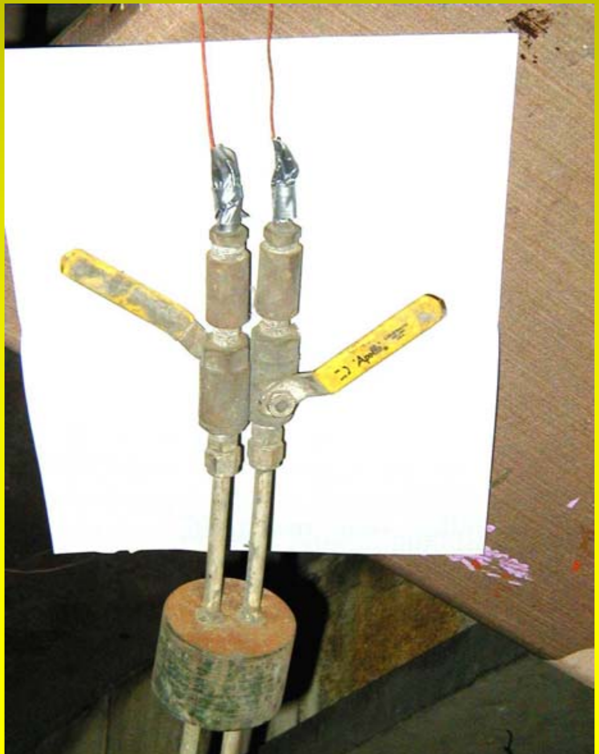


Objective

- Determine the mean temperature and its 95% confidence interval.

Experiment Objective

- Determine the mean temperature and its 95% confidence interval.
  - Final Assembly
    - Sample Probes



Experiment

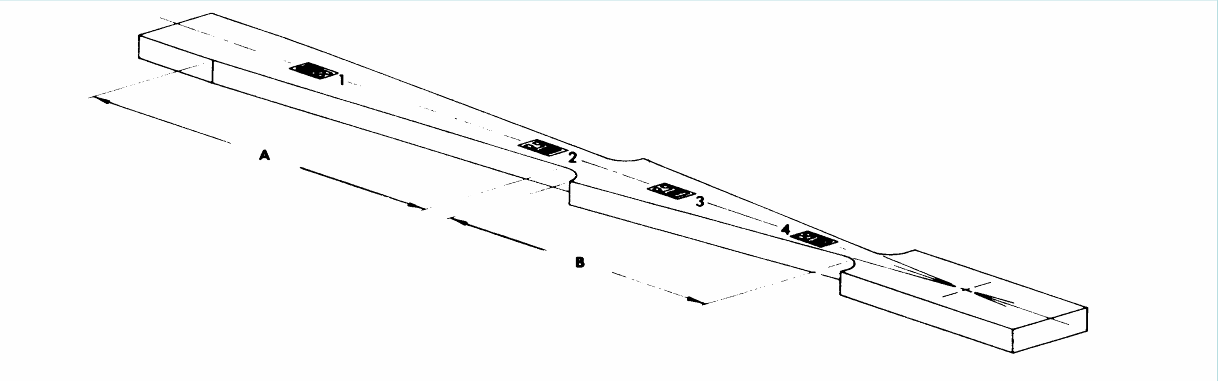
- Final Assembly

Experiment

- Final Assembly

Questions and Discussion?

Constant Stress In a Cantilever Beam



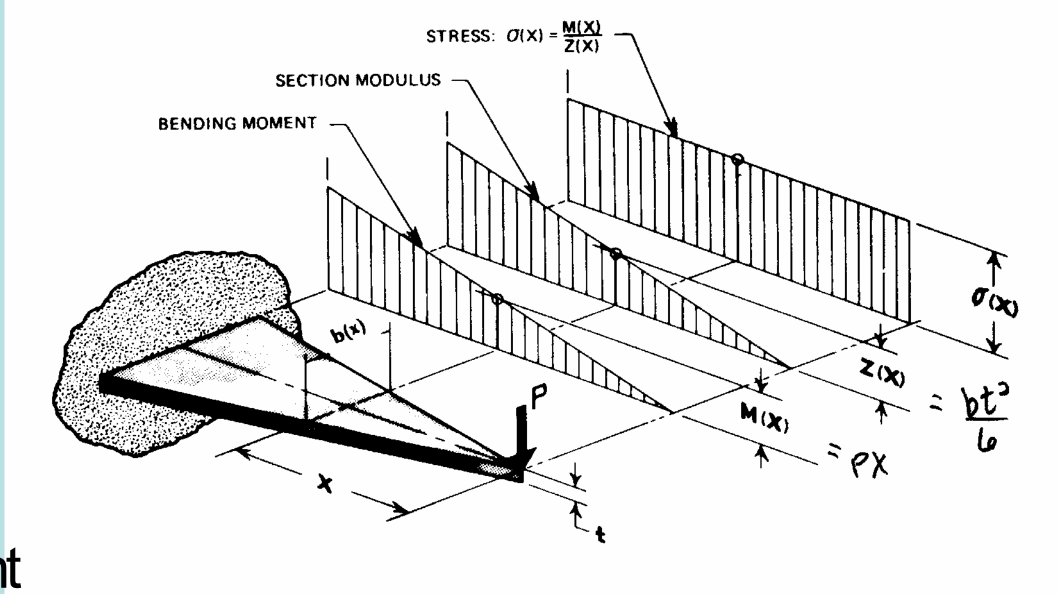
Introduction Continued...

$$\sigma(X) = \frac{M(X)\times c}{I} = \frac{6PX}{bt^2} = \frac{PX}{Z}$$

$$\frac{X}{Z(X)} = \frac{6X}{b(X)\left[t(X)\right]^2} = \text{constant}$$

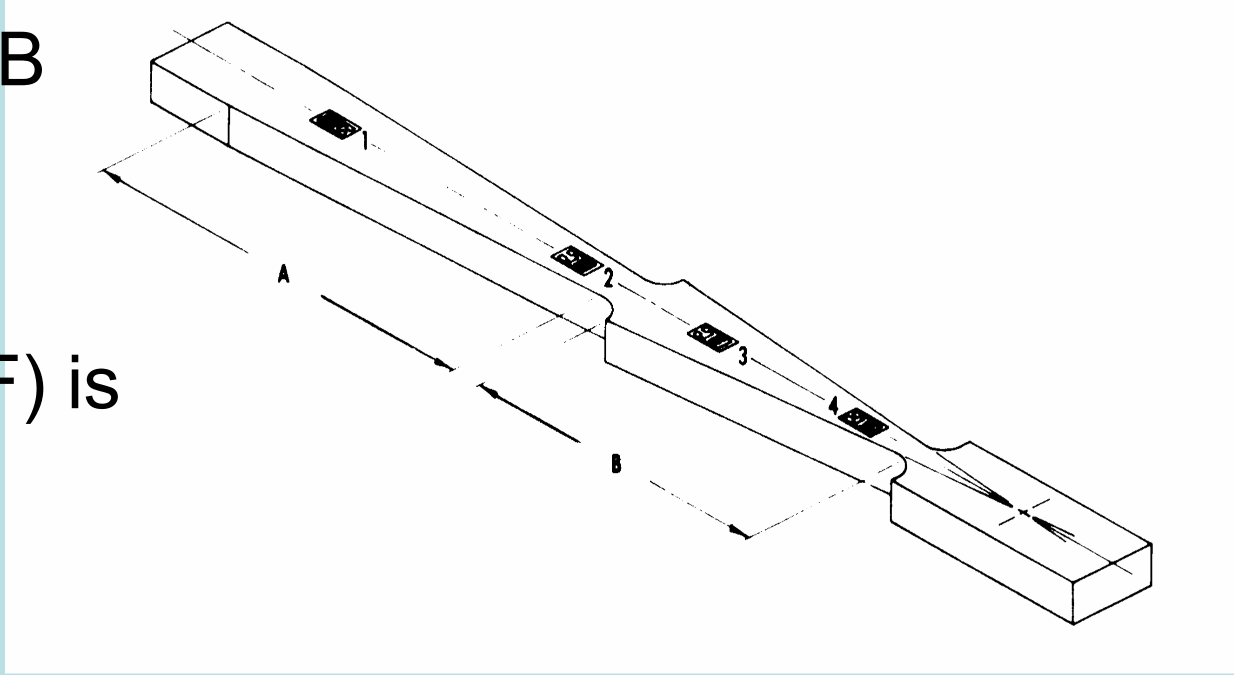
Keep thickness constant

$$\sigma(X) = \frac{6PX}{K_2 X t^2} = \frac{6P}{K_2 t^2} = \text{constant}$$



Experimental Considerations

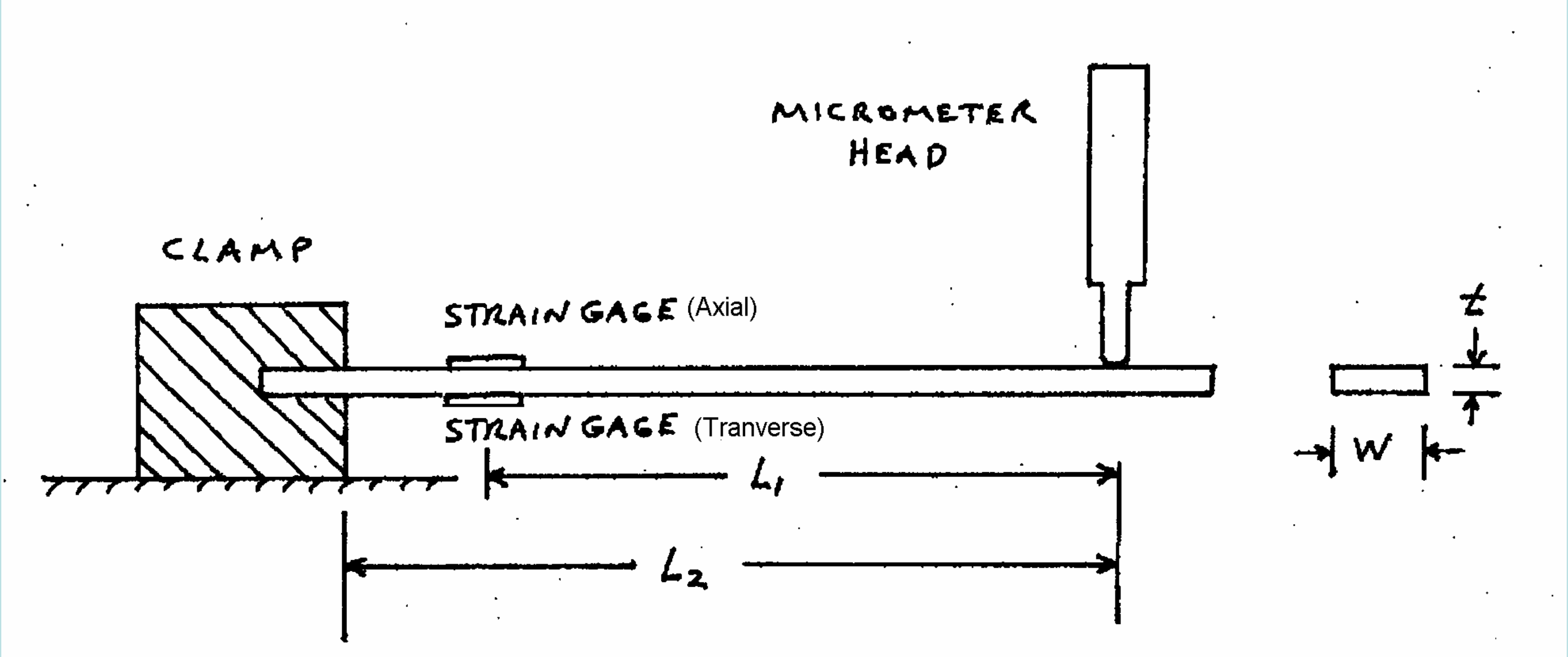
- Beam Designed so that Stress in Section A is twice in Section B



- Gage Factor (GF) is 2.085

Measurement of Poisson's Ratio in an Aluminum Beam

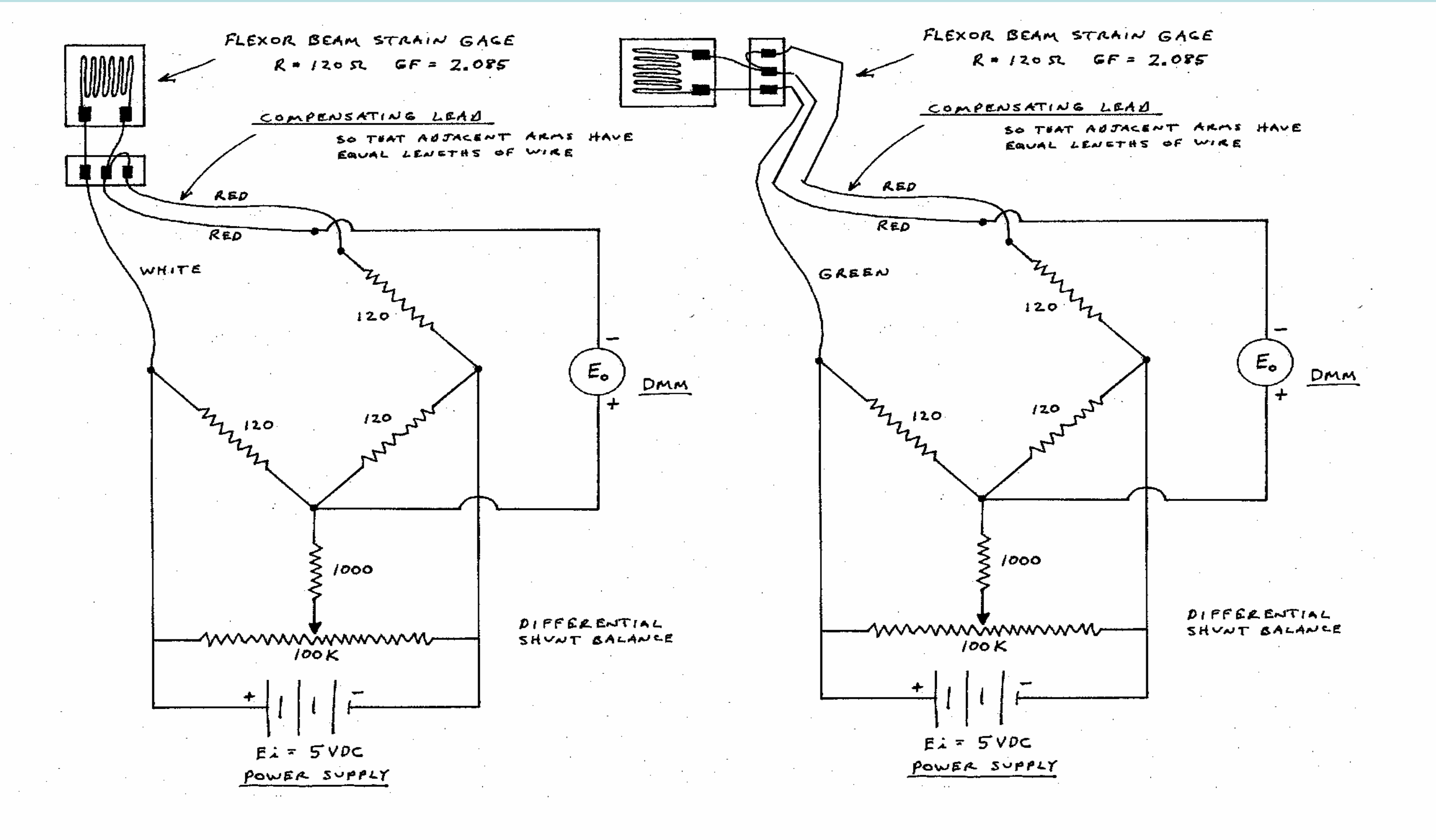
Flexor Beam Setup



Objective

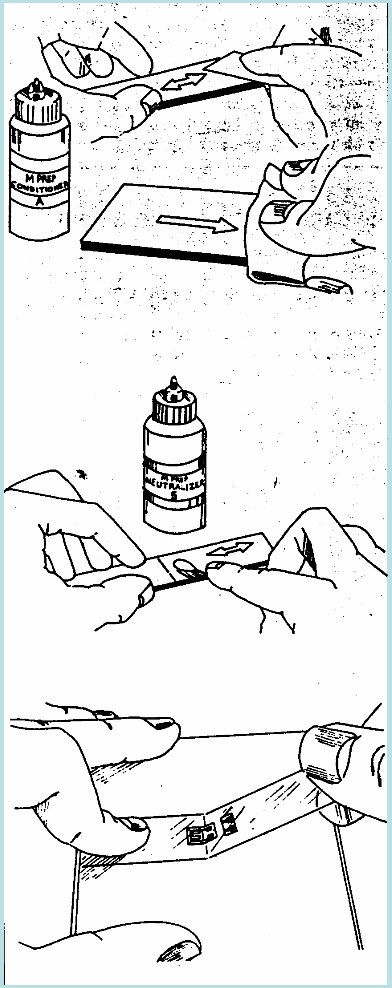
- To measure the Poisson's Ratio of an Aluminum beam by loading the beam in cantilever bending and measuring the ratio of the transverse strain to the axial strain
- Two different beam setups were used to accomplish this, one that was pre-gauged and one in which the strain gauges were applied

Wheatstone Bridge Setup



Strain Gauge Application

- Strain gauges were selected
- Application area sanded
- M-prep Conditioner applied
- M-prep Neutralizer applied
- Epoxy applied to strain gauge and surface
- Scotch tape used to apply strain gauge to surface and let to dry for 15 minutes
- Tape removed
- Connecting wires soldered to gauge terminals with tin/lead rosin core solder



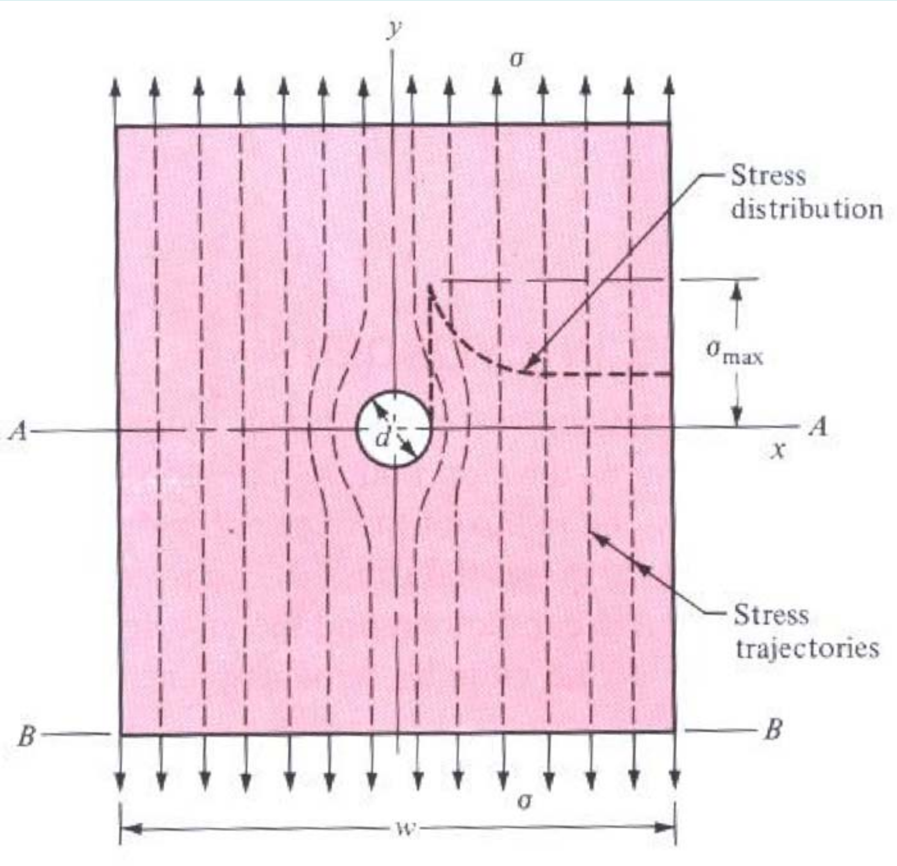
Stress and Strain in a Cantilevered Beam with a Hole

Objective of Experiment

- To demonstrate the stress and strain concentration near a hole in a cantilevered beam

Background

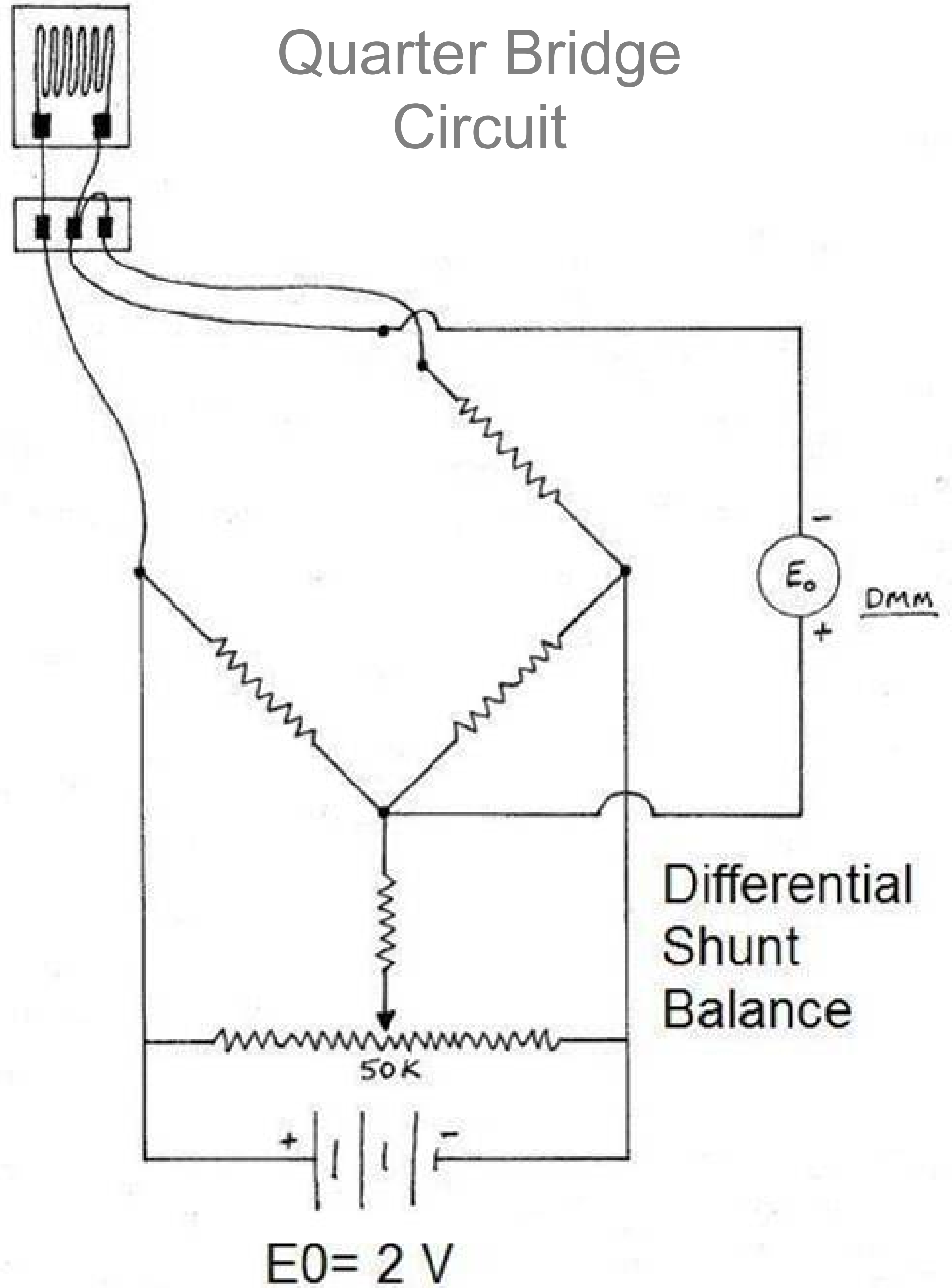
- Maximum stress occurs at edge of hole and decreases to nominal stress



Design Procedures

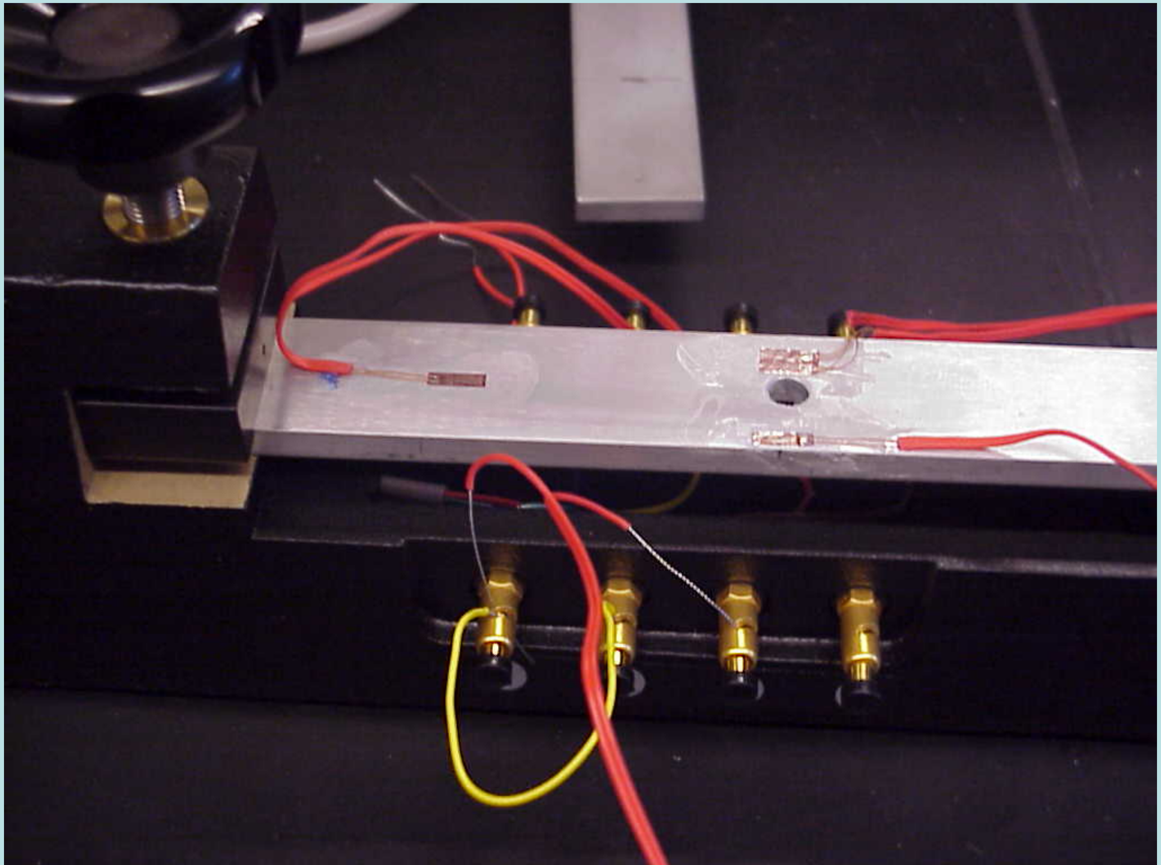
- Placed four strain gages on a cantilevered beam with a hole
  - Prepared aluminum beam for strain gauge application
  - Placed tape on the pre-wired strain gages to enable correct placement
  - Applied adhesive and catalyst to bottom side of strain gage

Design Procedures



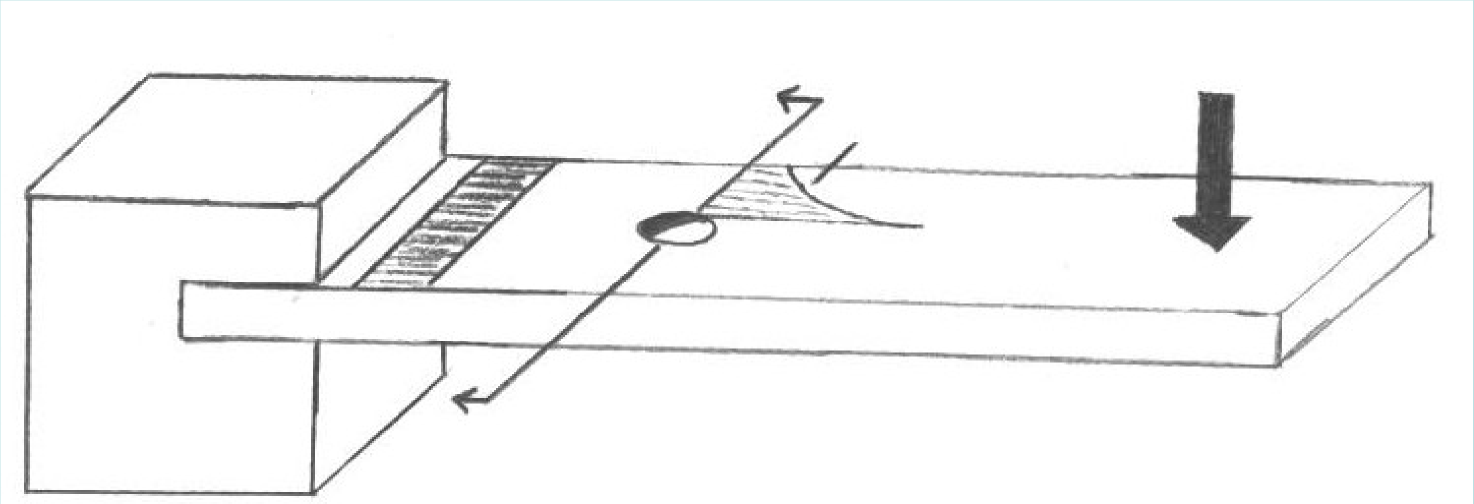
Design Procedures

– Mounted beam to flexor and Connected one strain gage at a time to flexor connection terminals



Design Procedures

- Stress/Strain Distribution and Setup



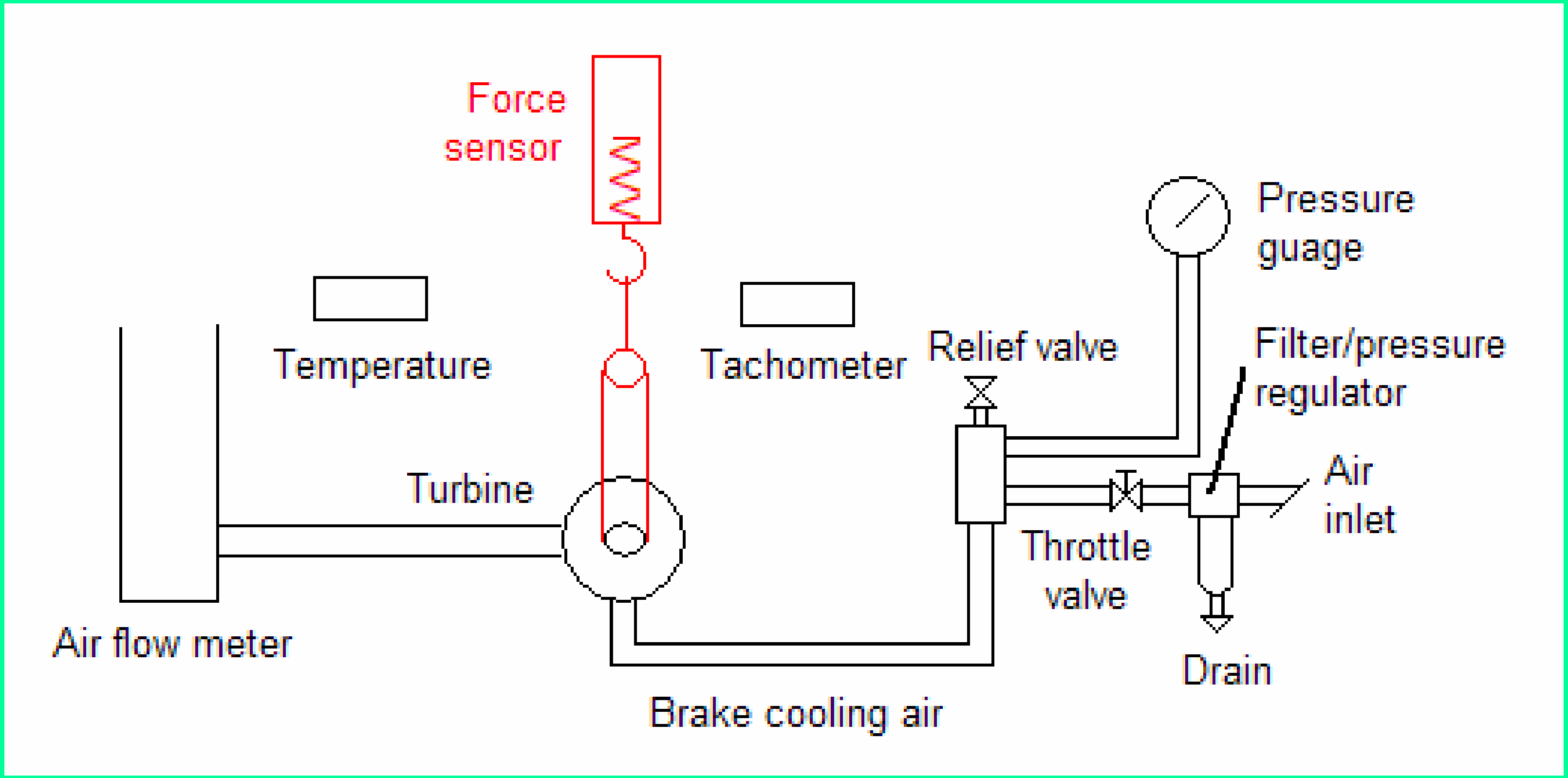
DC Generator Dynamometer for a Reaction Turbine

Introduction

- Objective:
  - Build a DC generator dynamometer to replace the existing Prony brake dynamometer
- Background:
  - Measurement of shaft power is useful in understanding the performance of turbines
- Motivation:
  - Existing Prony brake is difficult to use
  - It may be possible to reduce measurement uncertainty

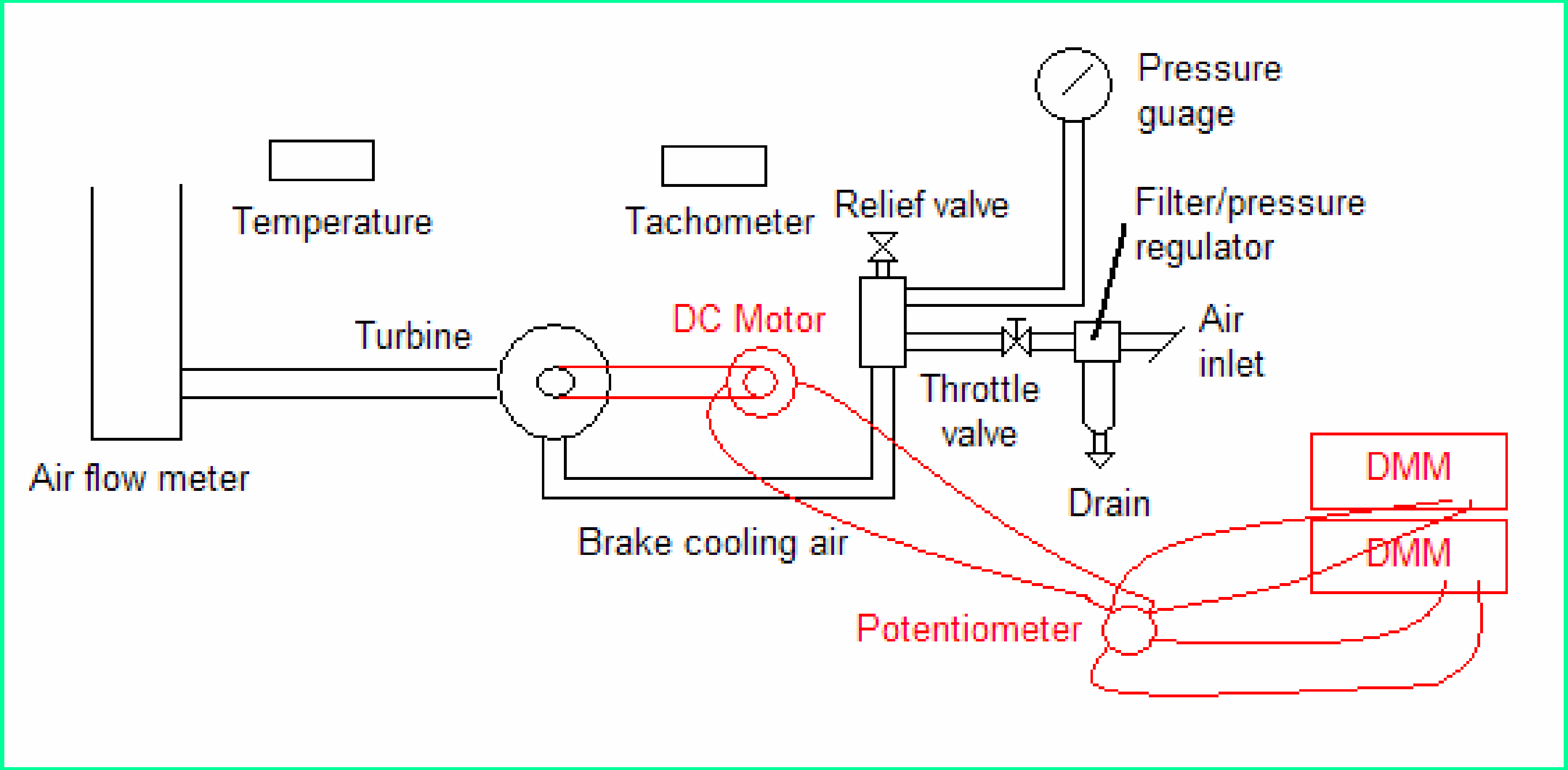
Experimental Considerations

- Prony Brake Setup



Experimental Considerations

- Proposed Setup



Experimental Considerations

- Data acquisition:
  - Record voltage and current output from DC motor at three turbine pressures (40, 60, 80 kPa).
  - RPM range: 0-20,000 RPM
    - Method 1:
      - Belt tension varied to obtain measurements across turbine RPM range.
    - Method 2:
      - Resistive load was varied to obtain measurements across the RPM range of the turbine.

Strain, Young's Modulus and Viscoelasticity

Objectives

- To determine if accurate values of Young's Modulus could be obtained for various materials
- To compare strain values obtained from the experiment to theoretical strain values
- Analyze effect of defects on strain

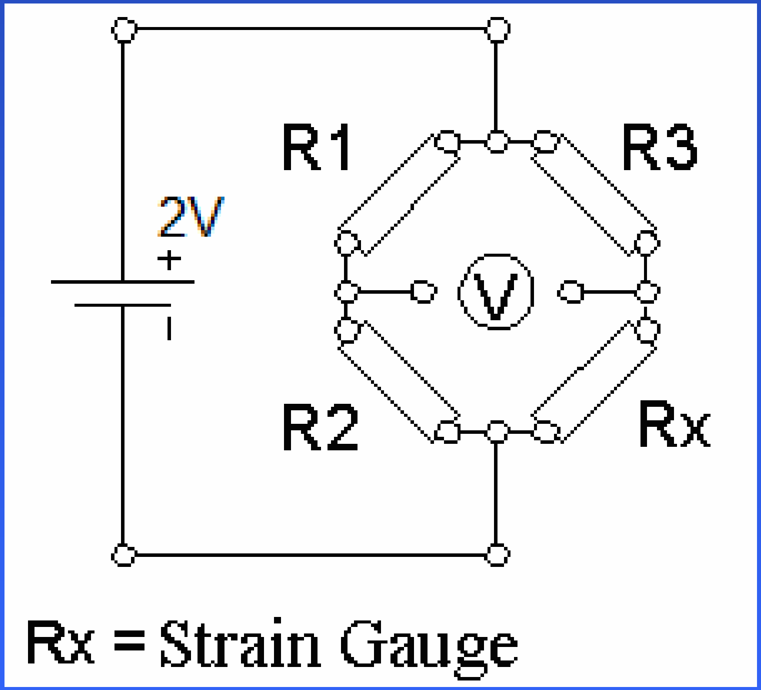
Experiment Setup

- Four Materials
  - Polyethylene (PE)
  - Polyvinyl Chloride (PVC)
  - Acrylic
  - 2024-T4 Aluminum
- Six Weights (50g, 100g, 200g, 500g, 1kg, and 2kg)

Experiment Setup

- Materials
  - Polyethylene (PE) :
    Thermoplastic Polymer
  - Polyvinyl Chloride (PVC) :
    Thermoplastic Polymer
  - Acrylic: Polymethyl Methacrylate (PMMA),
    Plexiglas
  - 2024-T4 Aluminum

Experiment Setup

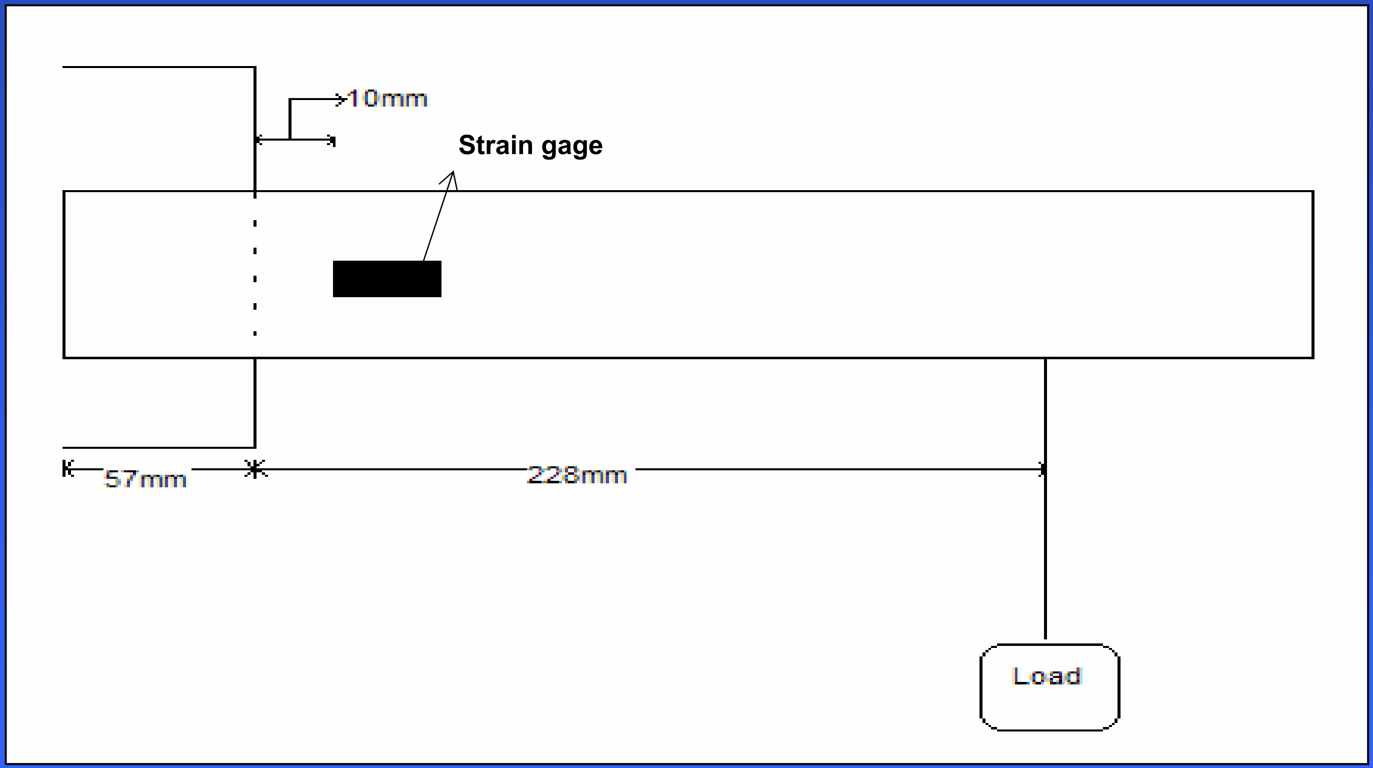


a) Quarter Wheatstone Bridge

b) Four Materials

(From left to right PVC, Acrylic, PE, Aluminum)

Experiment Setup



c) Beam Setup

Calculations

- Theoretical Calculations

$$I = \frac{1}{12} bh^3$$

$$\sigma = FL \frac{C}{I}$$

$$\varepsilon = \frac{\sigma}{E}$$

I: Moment of Inertia
b: Base
h: Height

σ: Stress
F: Force
L: Distance
C: the neutral axis to the outer edge of the beam

ε: Strain
σ: Stress
E: Modulus of Elasticity

Calculations

- Actual Calculations

$$\varepsilon = \frac{4V_o}{V_i(GF)}$$

$$E = \frac{\sigma}{\varepsilon}$$

Gage Factor (GF) : 2.11

V_o: Output Voltage

V_i : Input Voltage

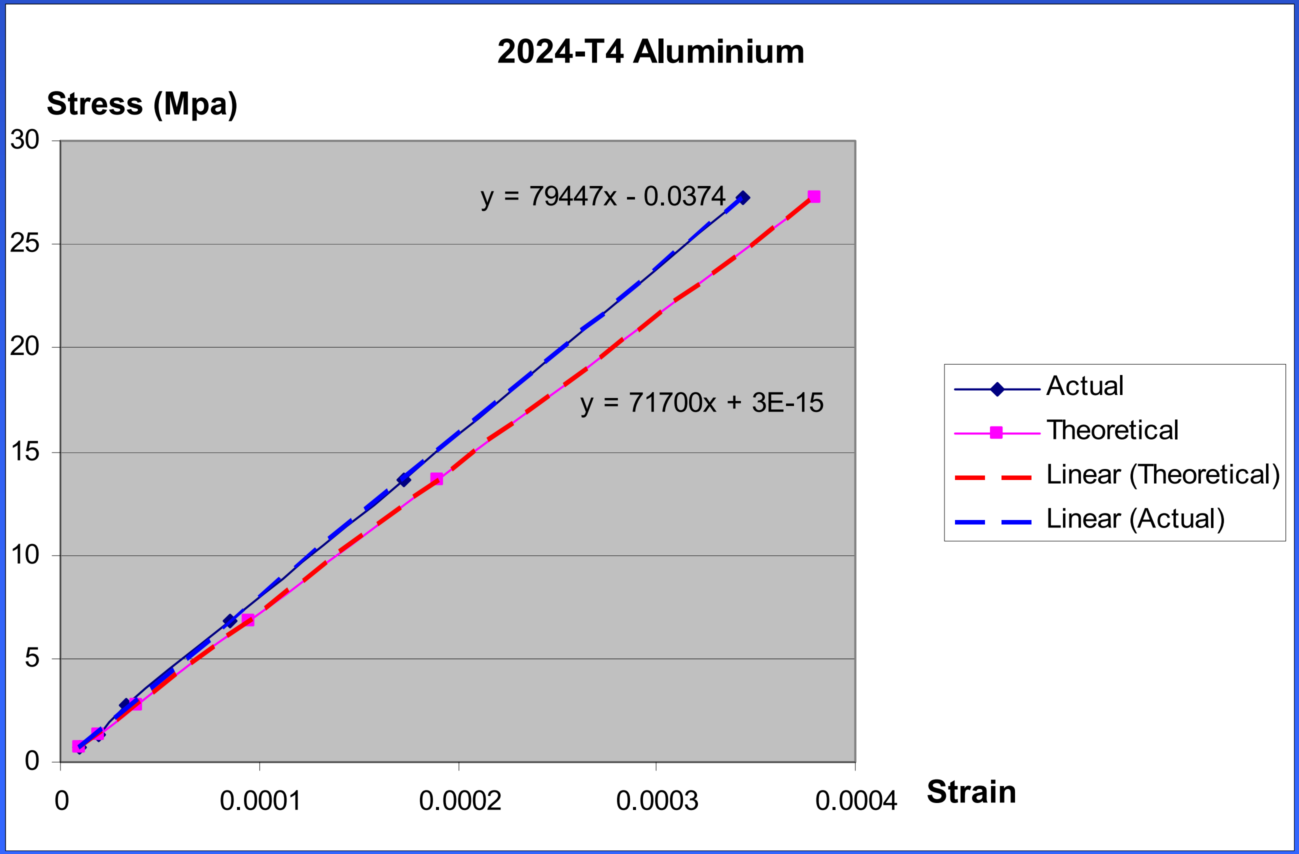
E: Modulus of Elasticity

σ: Stress

ε: Strain

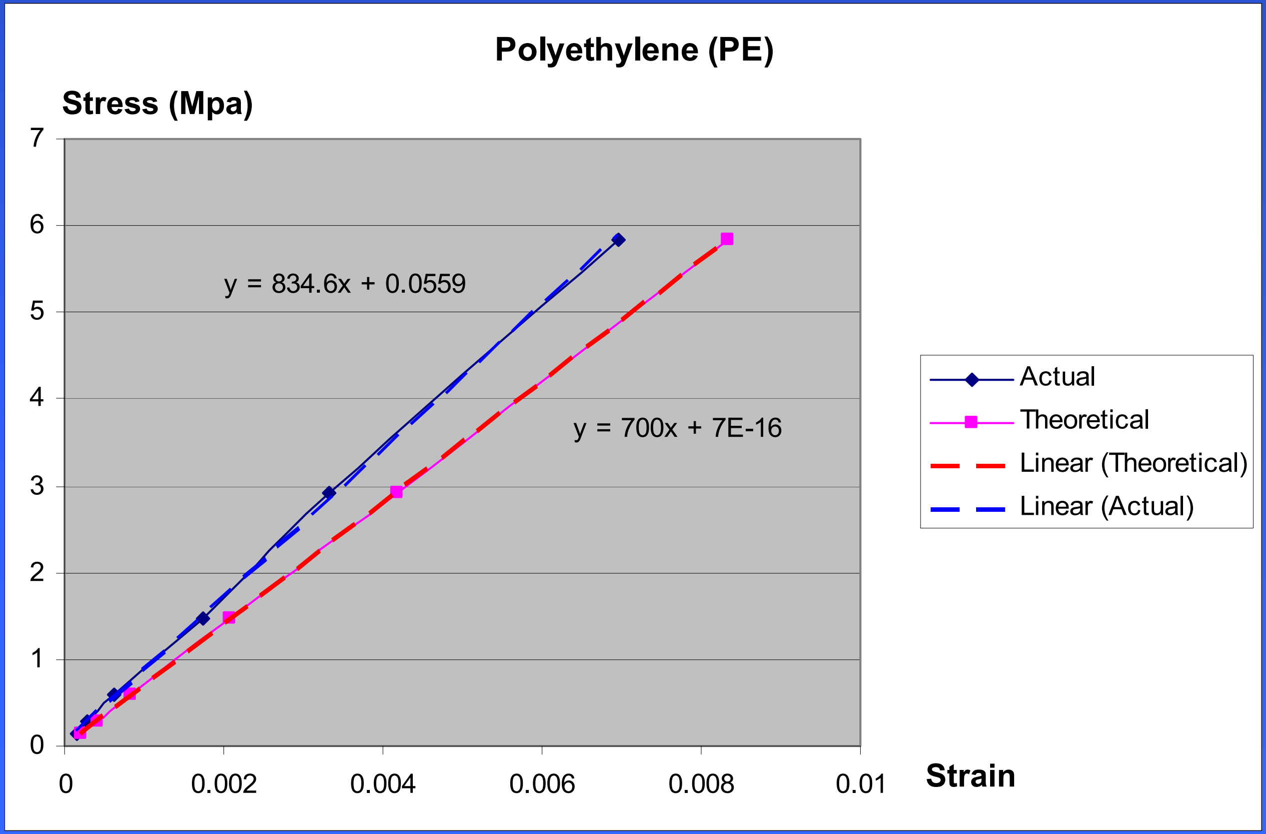
Results

Stress-Strain relationship of 2024-T4 Aluminum



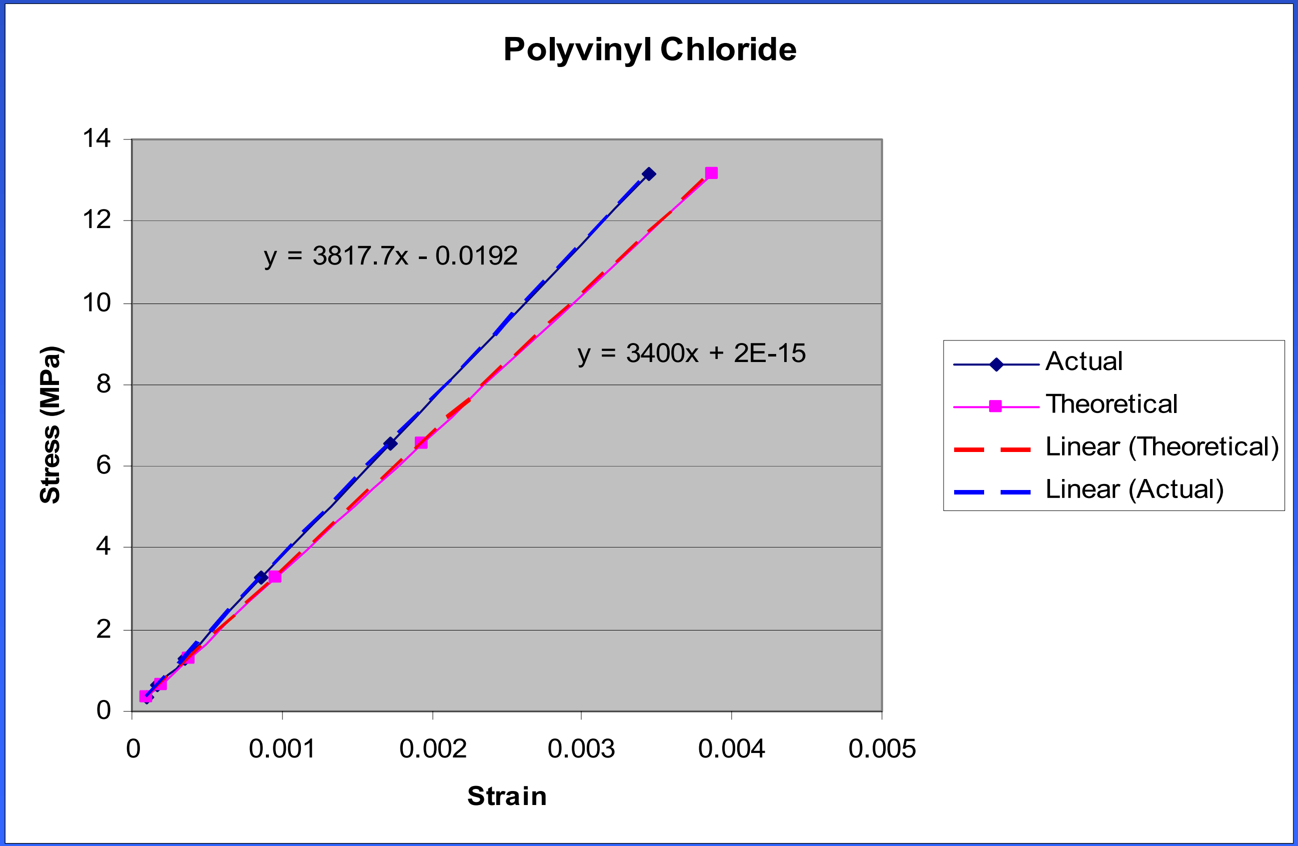
Results

Stress-Strain relationship of PE



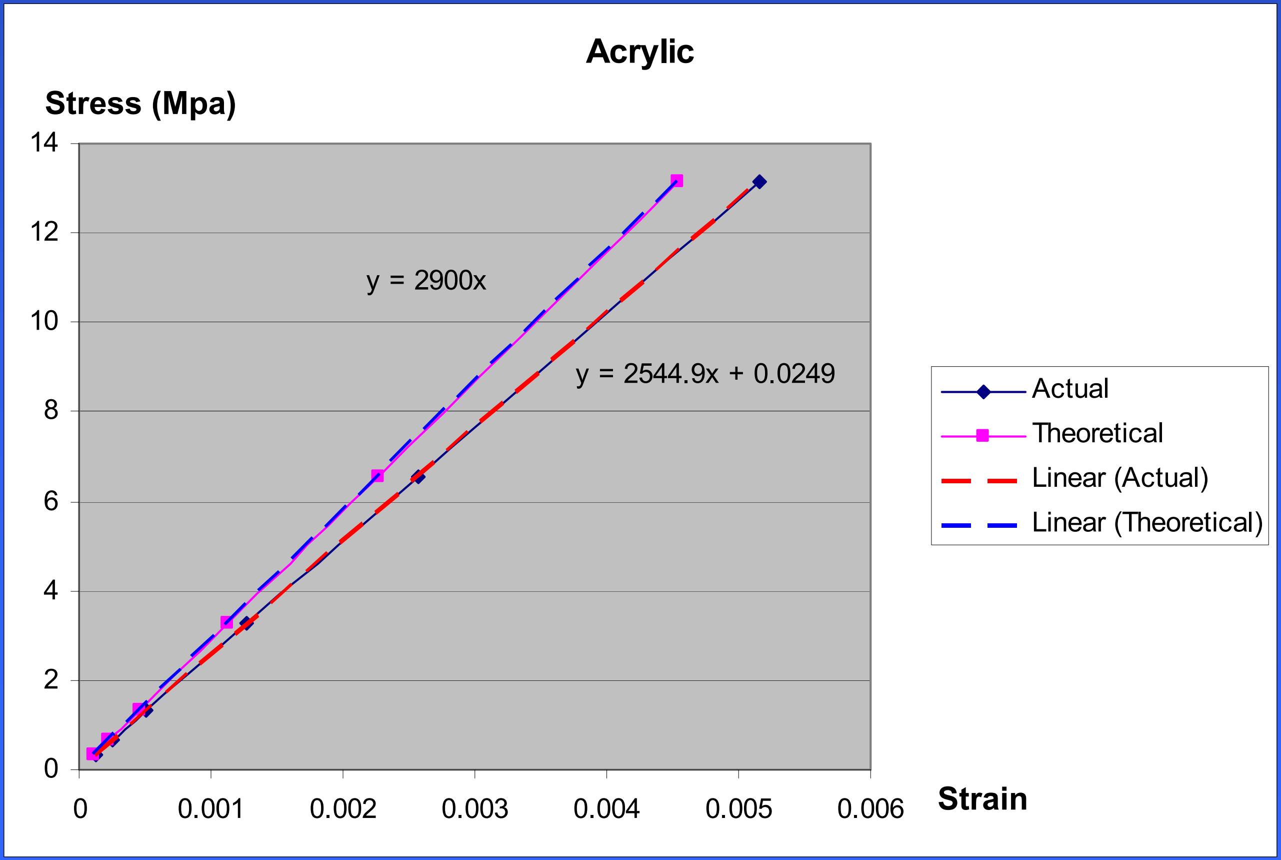
Results

Stress-Strain relationship of PVC



Results

Stress-Strain relationship of Acrylic



Results

- 2024-T4 Aluminum :
  - Measured E = 77.1 GPa (7.5% greater than empirical)
  - Actual strain was 8% smaller than theoretical.
- Polyvinyl Chloride (PVC) :
  - Measured E = 3.74 GPa (10% greater than empirical)
  - Actual Strain was 7% smaller than theoretical.

Results

- Acrylic (PMMA):
  - Measured E = 2.58 GPa (11% lower than empirical)
  - Actual strain was 10% larger than theoretical.
- Polyethylene (PE):
  - Measured E = 0.93 GPa (30% greater than empirical)
  - Actual Strain was 25% smaller than theoretical.

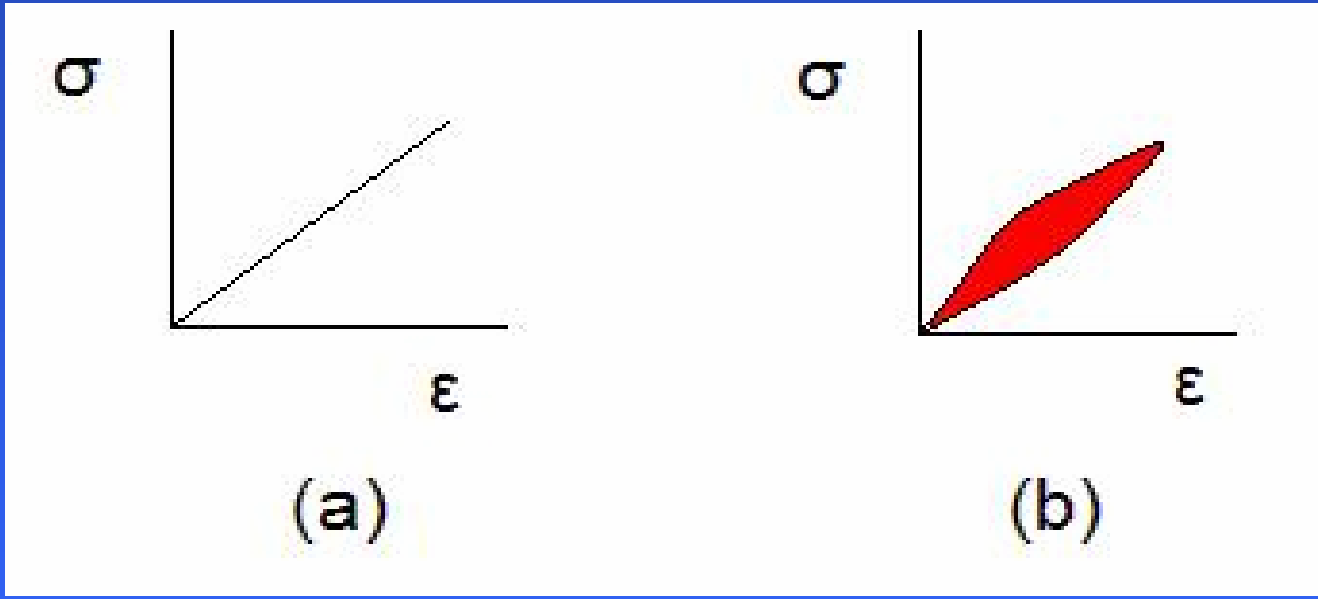
Things to Notice

- Accuracy decreased with a decrease in Young’s modulus.
- Thermoplastics: Two of them never reached theoretical strain.
- WHY???

Viscoelasticity

- Thermoplastic beams did not reach equilibrium immediately.
- Nor did the beams go back to zero strain position immediately
- Viscoelasticity : Time dependent elastic deformation

Purely Elastic Material vs Viscoelastic Material

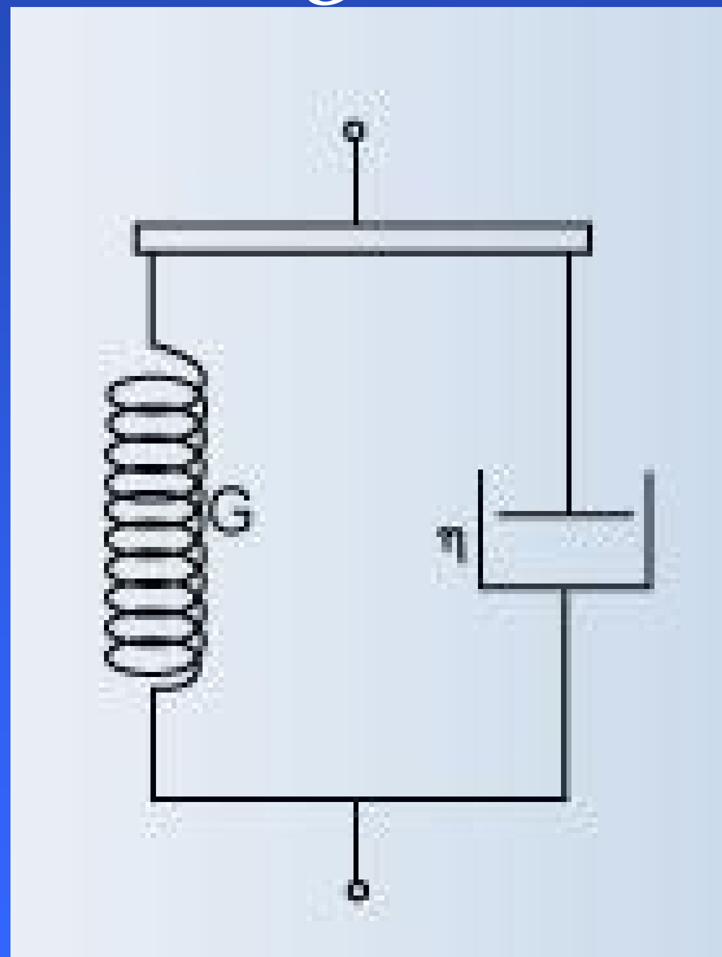


a) Purely Elastic Material

b) Viscoelastic Material

Voigt Model

σ

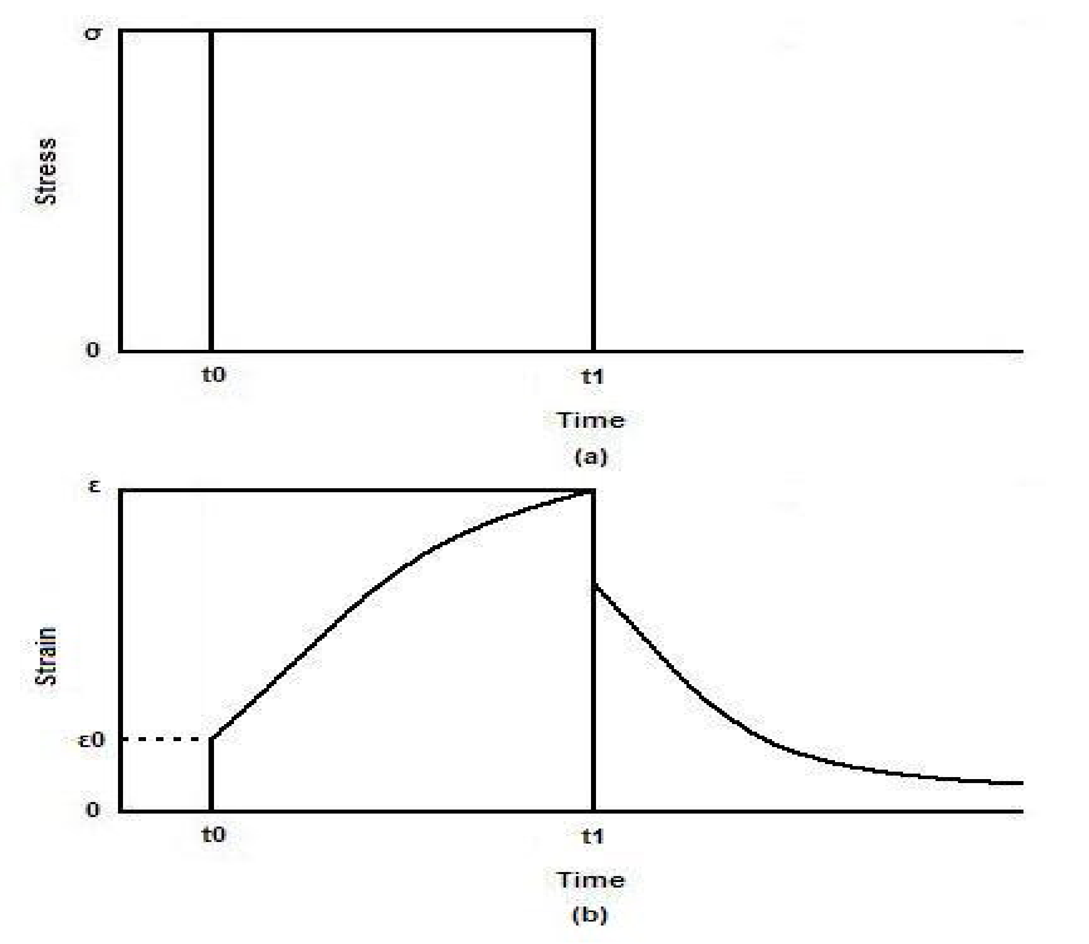


$$\sigma_{sp} = E\varepsilon$$

$$\sigma_d = 3\eta\,\dot{\varepsilon}$$

$$\sigma = \sigma_{sp} + \sigma_d$$

Viscoelasticity



Spring Stress:

$$\sigma_{sp} = E\varepsilon$$

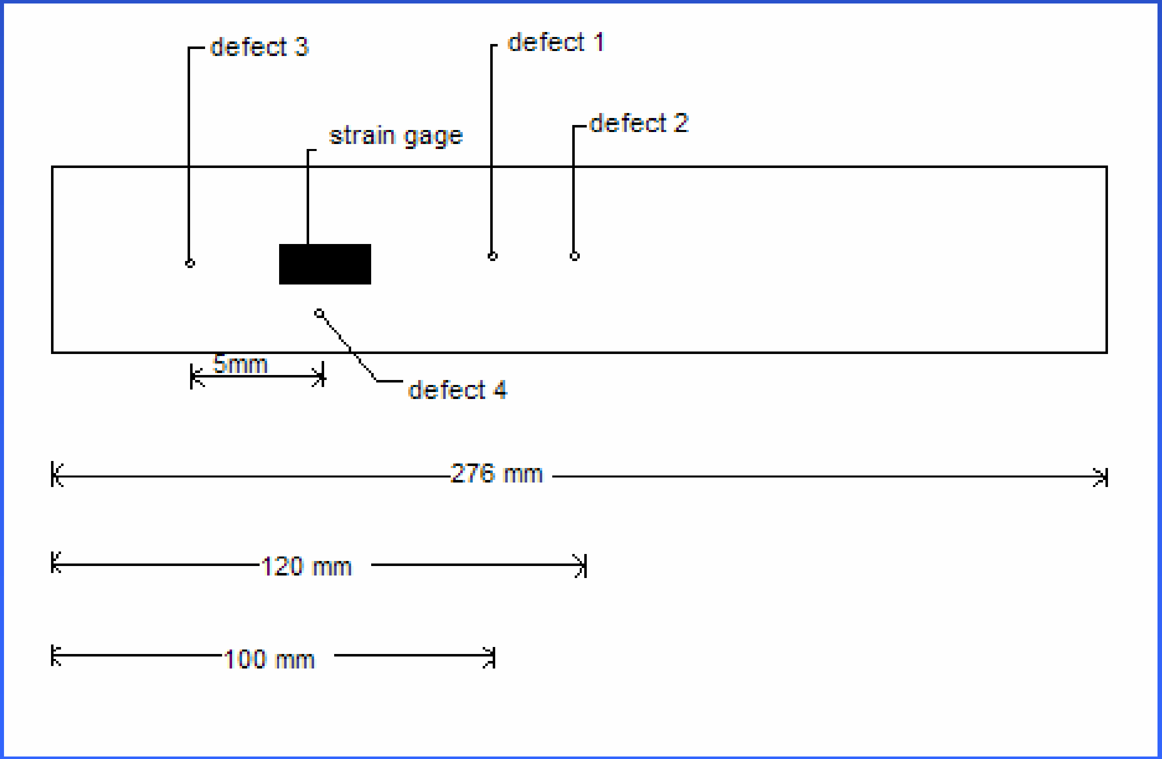
Dashpot Stress:

$$\sigma_d = 3\eta \dot{\varepsilon}$$

Applied stress (a) and induced strain (b) as functions of time for a viscoelastic material

Defect

- Four defects were applied to the PVC beam



Defect Positions on PVC Beam

Defect Effect

- Defect 1, 2, 3 :
  ~1% increase in strain each
- Defect 4 (next to the strain gage):
  ~13% increase in strain

Accuracy

- 2024-T4 Aluminum: ~87%
- Acrylic (PMMA): ~83%
- Polyethylene (PE): ~68%
- Polyvinyl Chloride (PVC): ~85%
- PVC with defects: ~78%

Conclusions

- Measured values were good approximations of theoretical values.
- Harder to get accurate results for viscoelastic materials
- Further experimentation would consider viscoelastic effects

Independent Lab: The Thermal Conductance of Various Hand Gloves

Introduction: Objectives

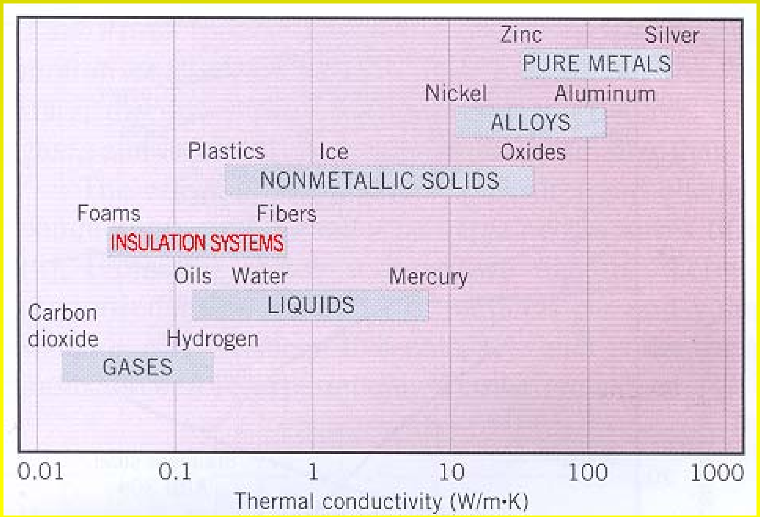
- Compare the thermal conductivity coefficient (k-value) of various hand gloves assuming steady state
- Determine which glove is best suited for use during a cold Iowa winter





Introduction: Background

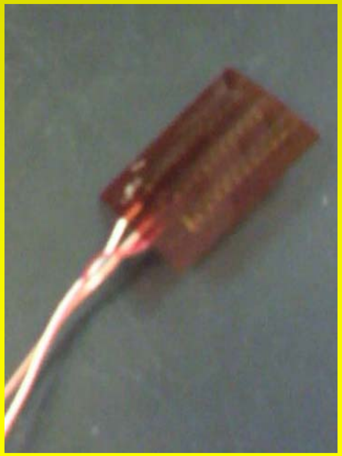
- Effective thermal conductivity
  - Material transport property that depends on the physical structure of the material
  - Indicates the rate at which heat is transferred through the material by the diffusion process (Incropera, 2002).



(Incropera, 2002)

Experimental Methods: Sensors/Instruments

- Brinkmann Cooling System
- Heat Flux Sensor
- 2 T-Type Thermocouples
- 5 Different Gloves
- DasyLab
- Heater
- Micrometer



Experimental Methods: Experimental Design

- Measured thickness of each glove
- Calibrated two thermocouples
- Attached sensors and heater to glove
- Placed glove inside insulated box
- Started data collection

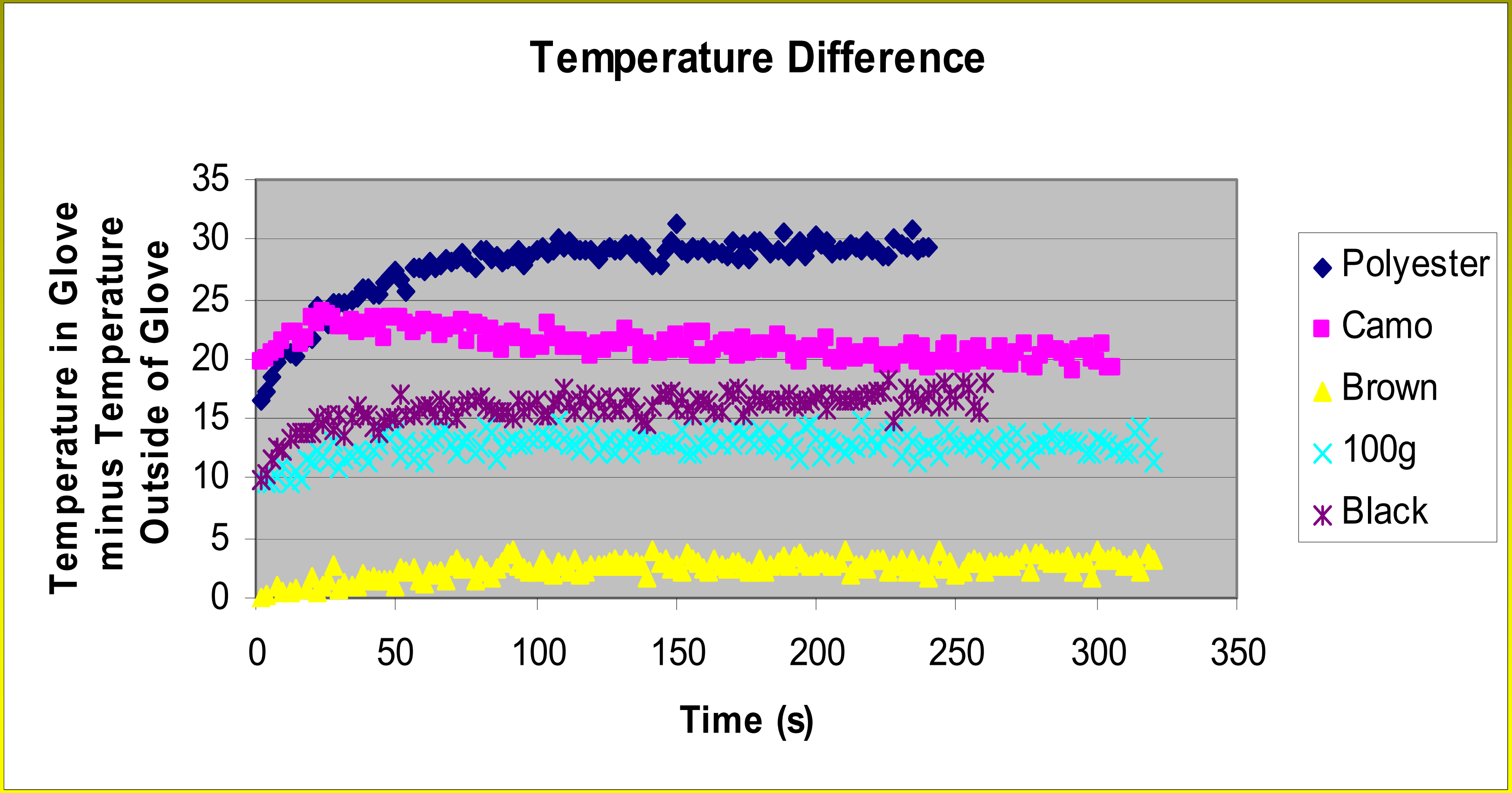
Experimental Methods: Data Reduction

- Data Analyses Equations

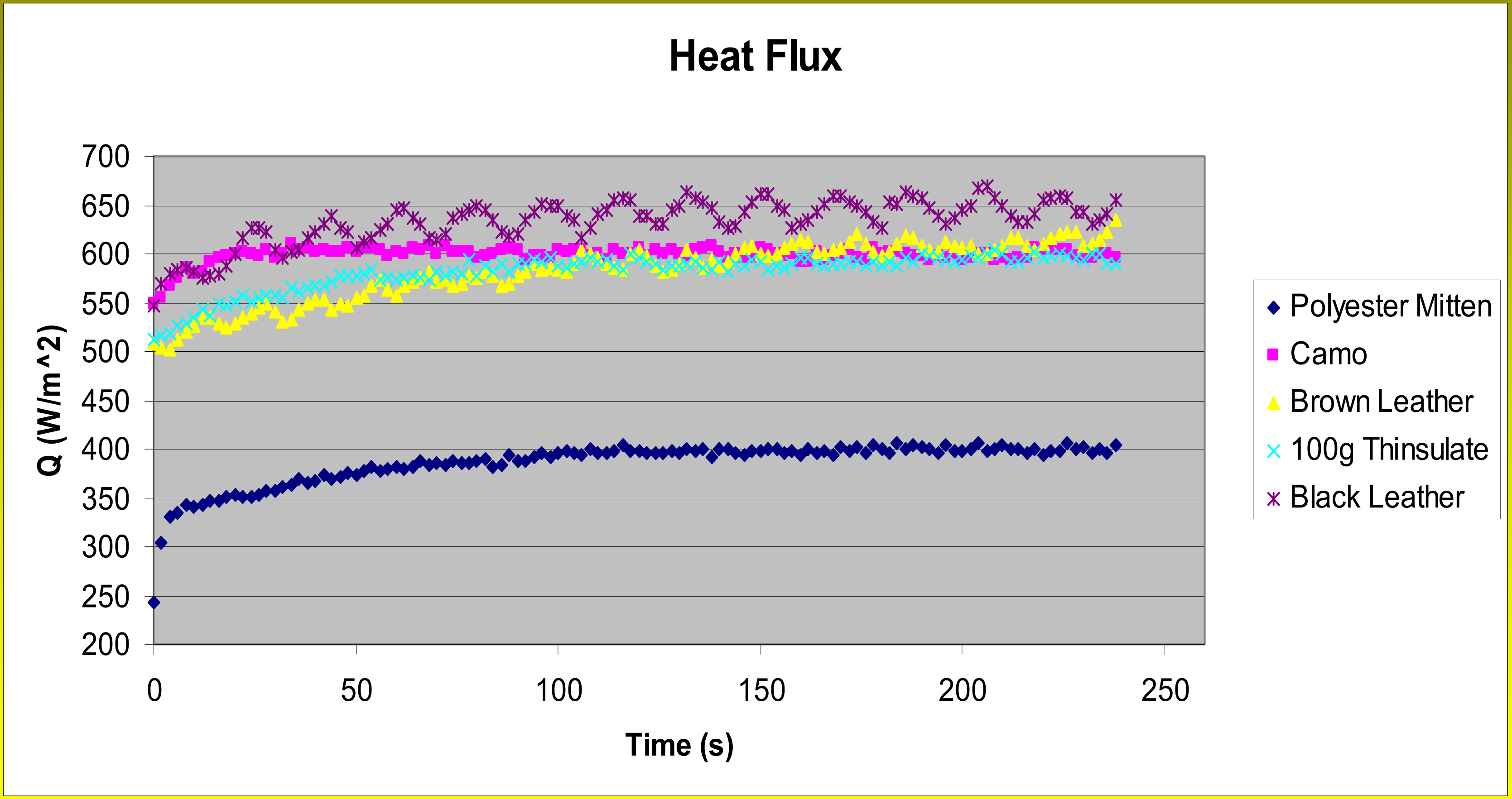
$$q = HeatFlux \div 2.22 \mu V / W / m^2$$

$$k = \frac{q * L}{(T_i - T_e)}$$

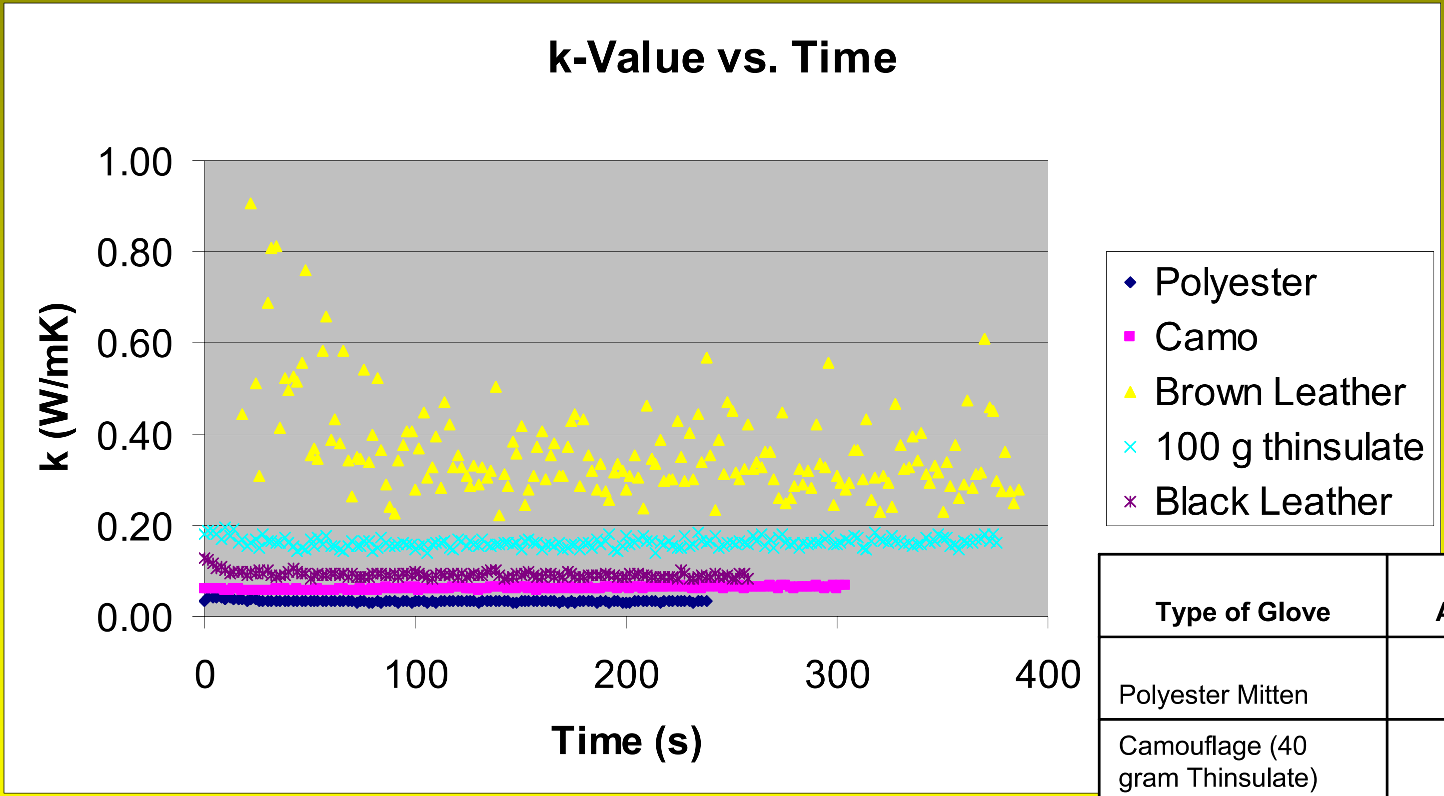
Results and Discussion: Essential Facts



Results and Discussion: Essential Facts



Results and Discussion: Data Analysis



Type of Glove	Average k	Theoretical k
Polyester Mitten	0.03317241	0.08
Camouflage (40 gram Thinsulate)	0.06138828	0.028
Brown Leather	0.37995254	0.014
100 gram Thinsulate	0.16218626	0.035
Black Leather - lined	0.09182762	n/a

Uncertainty Analysis: Bias and Precision Error

Equations for Error Analysis for Glove Measurements

$$\mathrm{B}_{\mathrm{measurement}} = \frac{1}{2}\mathrm{resolution}$$

$$P = S_{\bar{x}} = \frac{S_x}{\sqrt{N}}$$

$$u_x = \pm((B_{measurement})^2 + (t_{v,95}P)^2)^{1/2}$$

Uncertainty Analysis: Bias and Precision Error

Lightly Touching	Camo gloves (40 gram Thinsulate) (mm)	Lined Leather gloves (mm)	Leather (100 gram Thinsulate) (mm)	Polester Mitten (mm)	Leather (mm)
Average	2.167	2.282	3.489	2.371	1.523
Standard Deviation	0.0246	0.0069	0.0485	0.0887	0.0797
Student T	2.262	2.262	2.262	2.262	2.262
Bias Error	0.0005	0.0005	0.0005	0.0005	0.0005
Precision Error	0.0556	0.0156	0.1098	0.2007	0.1804
Total Error	**0.0556**	**0.0156**	**0.1098**	**0.2007**	**0.1804**

Uncertainty Analysis: Bias and Precision Error

Equations for Error Analysis of Thermocouples

$$S_{pooled} = \sqrt{\frac{\sum_{i,j=1}^{N}(x_i - x_j)^2}{N-1}}$$

$$P = \frac{S_{pooled}}{\sqrt{N}}$$

$$B_{mean} = \frac{1}{N}\sum_{i,j=1}^{N}(x_i - x_j)$$

$$u_x = \pm\left((B_{mean})^2 + (t_{v,95}P)^2\right)^{1/2}$$

Uncertainty Analysis:
Bias and Precision Error

T-Type Thermocouples			(All measurements are in degrees C)			
Calibrator -Standard	**TC1**	**(x-xi)**	**$(x-xi)^2$**	**TC2**	**(x-xi)**	**$(x-xi)^2$**
49.22	**47.43**	1.79	3.20	**48.60**	0.62	0.38
59.04	**57.94**	1.10	1.21	**58.37**	0.67	0.45
68.76	**68.46**	0.30	0.09	**68.14**	0.62	0.38
78.70	**77.34**	1.36	1.85	**78.20**	0.50	0.25
88.24	**86.84**	1.40	1.96	**87.96**	0.28	0.08
96.67	**96.43**	0.24	0.06	**97.68**	-1.01	1.02
106.82	**105.89**	0.93	0.86	**107.29**	-0.47	0.22
115.94	**115.52**	0.42	0.18	**116.98**	-1.04	1.08
124.58	**124.87**	-0.29	0.08	**126.62**	-2.04	4.16
		$\Sigma(x-xi)^2$	9.50		$\Sigma(x-xi)^2$	8.03
		S_{pooled}	0.51		S_{pooled}	0.47
		$\varepsilon_{precision}$	0.16		$\varepsilon_{precision}$	0.14
		ε_{bias_mean}	0.81		ε_{bias_mean}	-0.21
		$\varepsilon_{total\_error}$	0.82		$\varepsilon_{total\_error}$	0.25

Uncertainty Analysis: Propagation Error

Error Propagation of Thermal Conductance

$$\frac{\partial k}{\partial q} = \frac{\overline{L}}{(\overline{T_i} - \overline{T_e})} = \theta_q$$

$$\frac{\partial k}{\partial L} = \frac{\overline{q}}{(\overline{T_i} - \overline{T_e})} = \theta_L$$

$$\frac{\partial k}{\partial T_i} = \frac{-\overline{q} * \overline{L}}{(\overline{T_i} - \overline{T_e})^2} = \theta_{T_i}$$

$$\frac{\partial k}{\partial T_e} = \frac{\overline{q} * \overline{L}}{(\overline{T_i} - \overline{T_e})^2} = \theta_{Te}$$

$$P_k = [(\theta_q * P_q)^2 + (\theta_L * P_L)^2 + (\theta_{T_i} * P_{T_i})^2 + (\theta_{T_e} * P_{T_e})^2]^{1/2}$$

Uncertainty Analysis: Propagation Error

	Polyester	Camo	Brown Leather	100 g thinsulate	Black Leather
θq	8.55236E-05	0.000102346	0.000592108	0.000270465	0.036204808
θL	13.90360241	28.25803114	232.9343371	46.28563849	40.0034944
θTh	-0.001189086	-0.036442595	-0.137922335	-0.012694112	-0.091287974
θTc	0.001189086	0.036442595	0.137922335	0.012694112	0.091287974
Precision Error (L)	0.00005560	0.00001556	0.00010979	0.00020066	0.00018035
Precision Error (Th)	0.16	0.16	0.16	0.16	0.16
Precision Error (Tc)	0.14	0.14	0.14	0.14	0.14
Propagation Error (W/mK)	0.000794803	0.005675873	0.03335711	0.009494389	0.01590563

Conclusion

- Polyester fleece glove had the lowest thermal conductivity (0.03317 W/mK) – Best glove for cold Iowa winter
- Brown leather had the highest thermal conductivity (0.3799 W/mK) – Frostbite anyone?
- Thermal conductivity is the lowest for the polyester fleece glove because it traps the most air
- Obtain more accurate thermal conductivity by increasing the temperature difference