Milestone Presentation: Boat Crew

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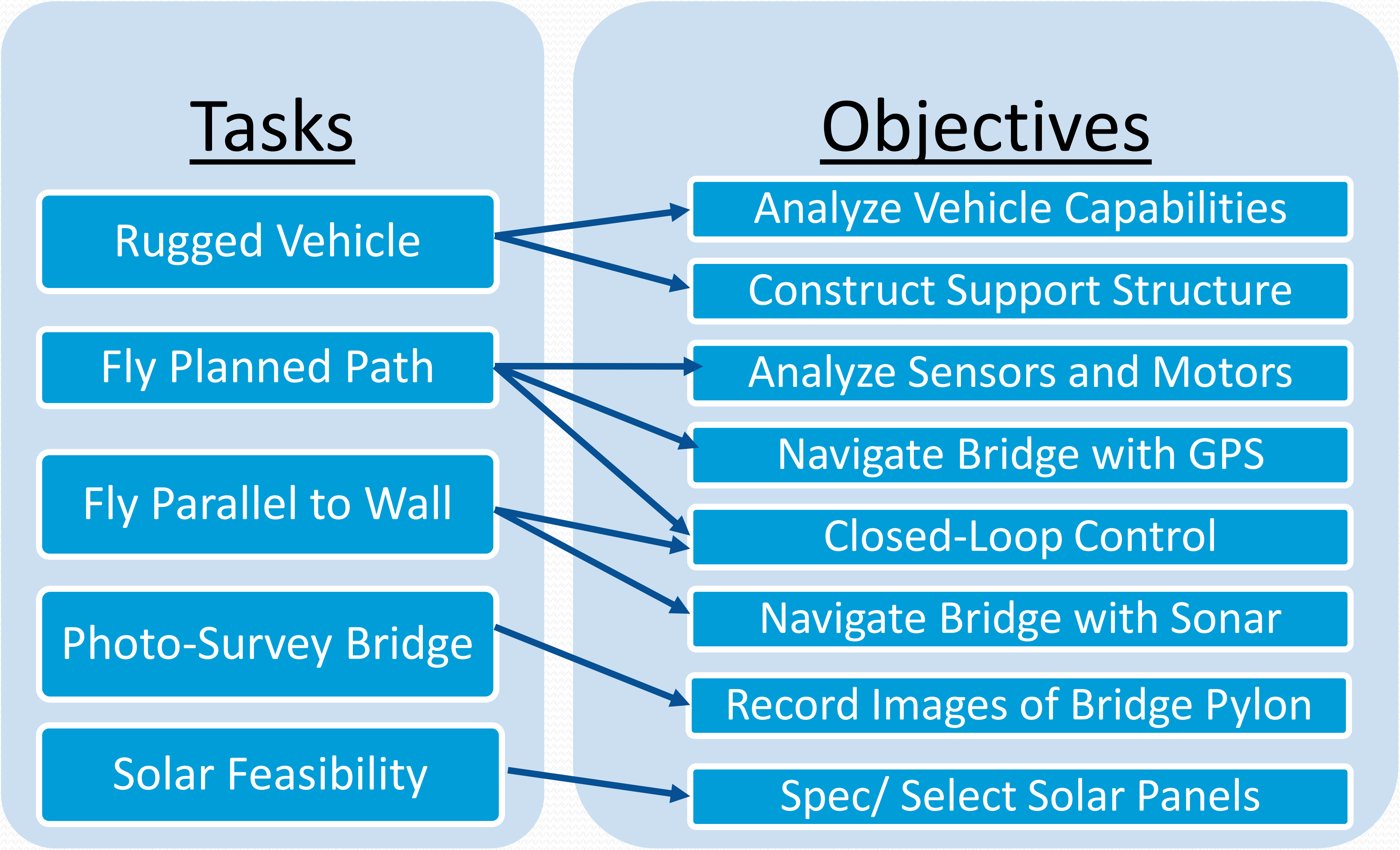
Lab Instructor: Harrison Chin

2.017 Fall 2009

November 5, 2009

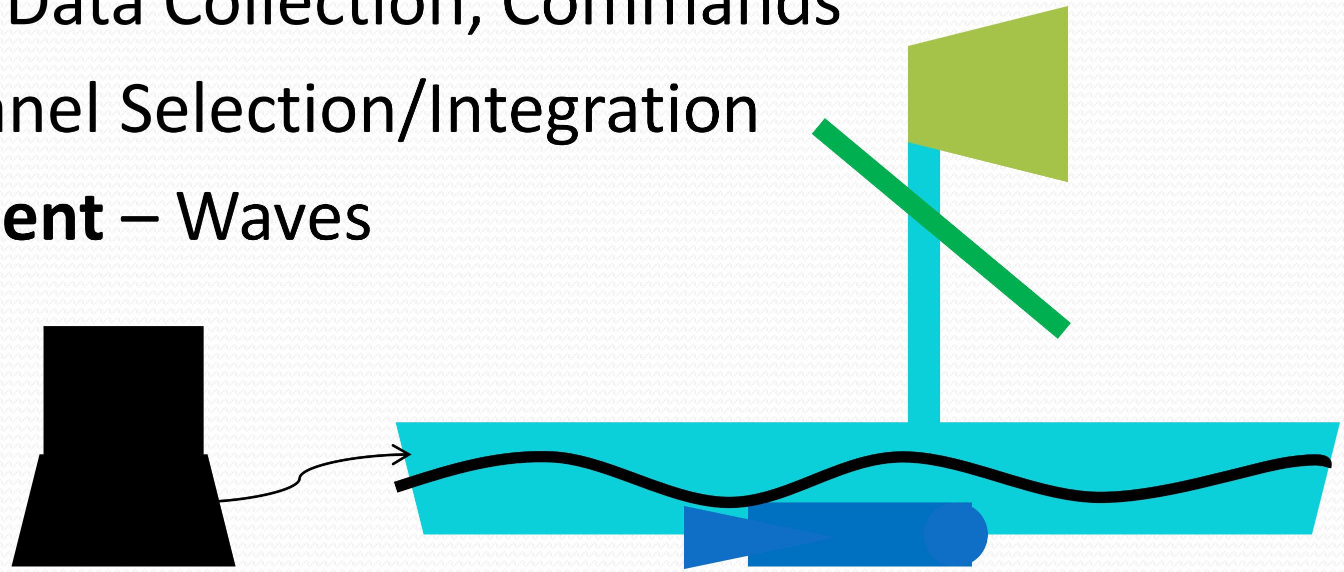
Group 2

Mission Objective Tree



Project Division

- **Vessel Structure** - Physical Components
- **Sensors** – GPS, Sonar, etc.
- **Propulsion** - Motors
- **Control** – Data Collection, Commands
- **Solar** - Panel Selection/Integration
- **Environment** – Waves

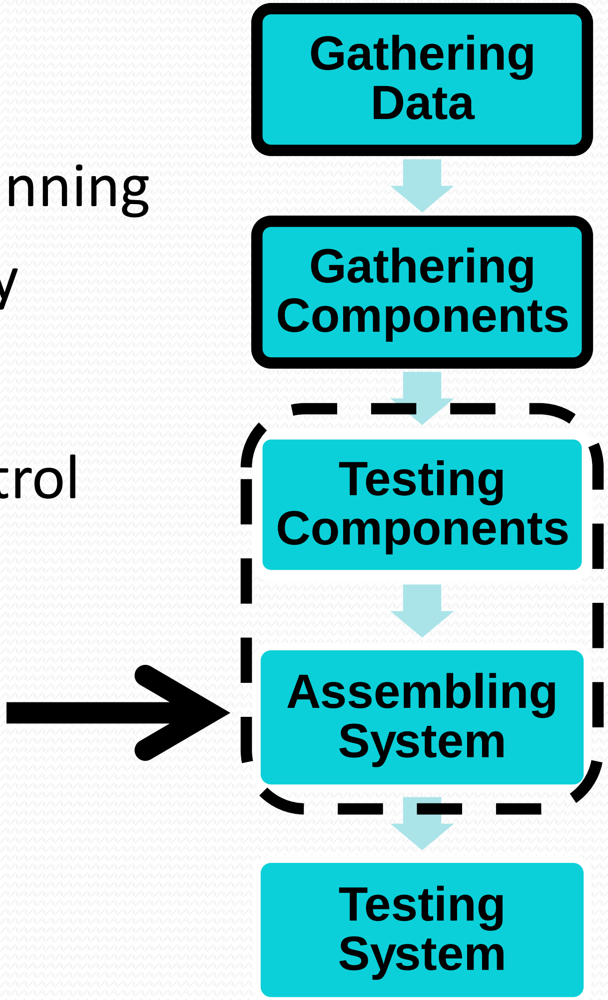


Project Status

Area	Status
Vessel Design - Student D	Design Complete Assembly Underway
Stress Analysis - Student B	Preliminary Analysis Complete
GPS and Compass - Student E	GPS Data Collected Compass Tests Complete
Sonar and Control - Student A	Sonar Testing Complete Control Designed
Motors and Control -Student C	Selected and Tested
Wave Environment - Student F	Data Collected and Analyzed
Solar Energy - Student G	Data Collected Control Protocol Designed

Upcoming Critical Milestones

- System Integration
  - Sensor components all tested and running
  - Boat components ready for assembly
- Control Software
  - Using GPS feedback for position control
  - Waypoint-triggered mode transition
- System Tests
  - Wall-following tests at tow tank
  - Yaw dynamics tests



Vessel Design

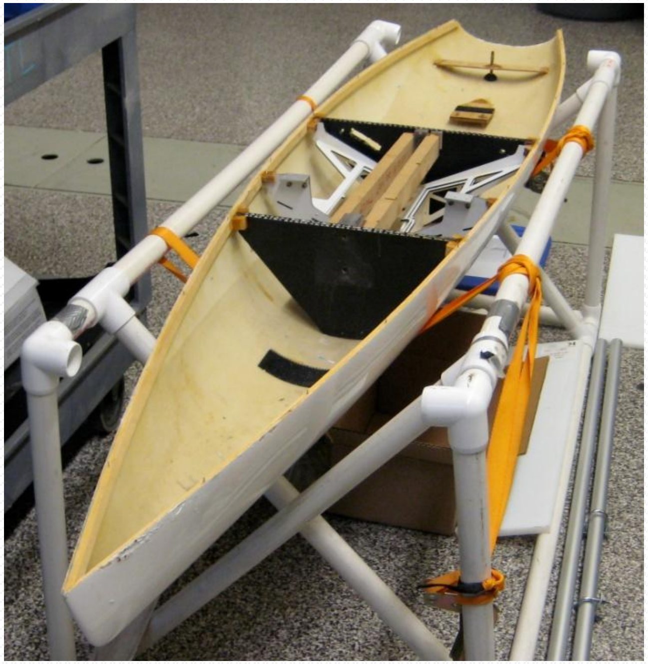
Student D

- Vessel Modifications
- Functional Requirements
- Significant Risks
- Final Design

Vessel Modifications

Motivation: needed survivable and rugged vessel

Photo of the Pro Boat Miss Elam 1/12 Brushless RTR removed due to copyright restrictions.

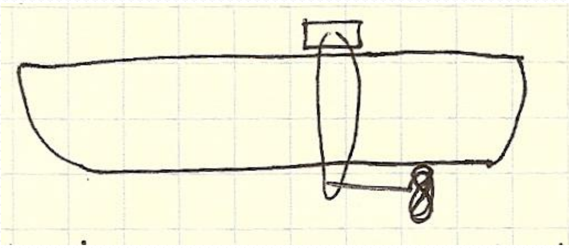
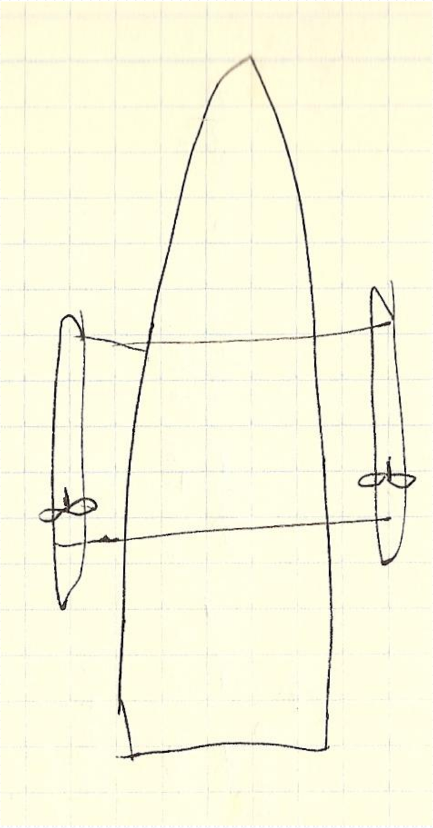
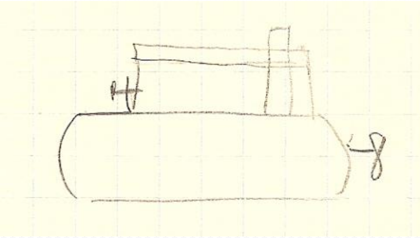
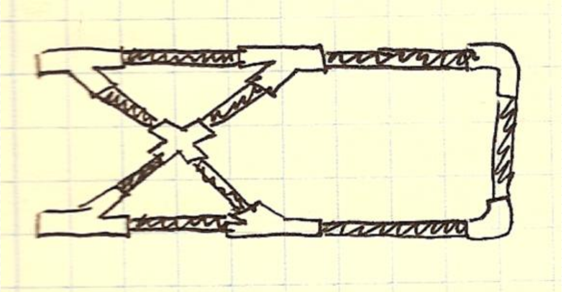
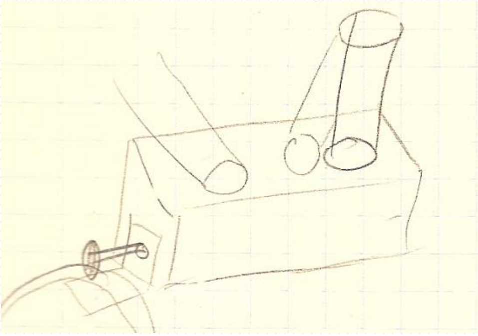
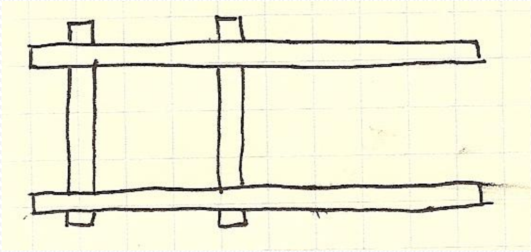


Planing hull: too small

Displacement hull: larger

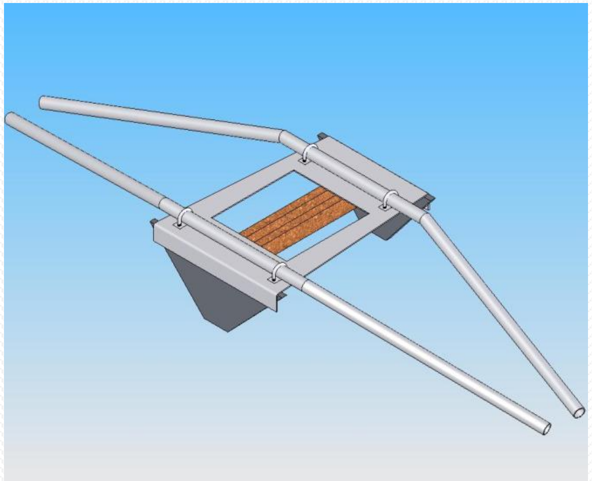
Functional Requirements

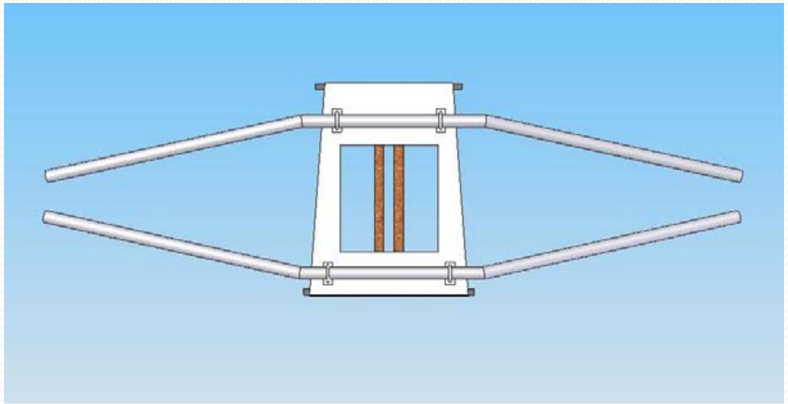
- Stable in roll and pitch
- Maneuverable
- Mounts for sensors
- Rugged design

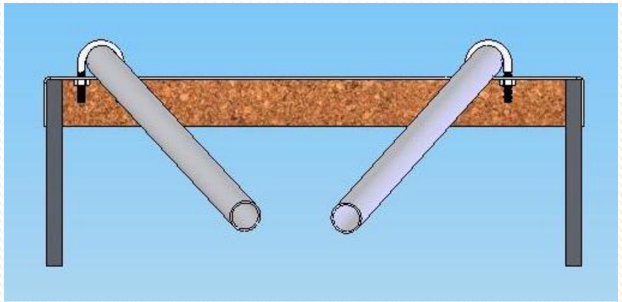







Final Design

Best Design = Motors attached to Pontoons







Risk #1: Buoyancy

$mg = F_b$

Additional weight-

Motor: 3.4 lbs
Pipes: 1.16 lbs
Bolts: 0.32 lbs
Plate: 0.80 lbs
Plastic: 0.588 lbs
Total: **6.268 lbs**
= 2.843 kg

Marine spray-in foam:
Density = 2 lbs/ft^3 = 32.03 kg/m^3

$F_b = (V_{disp}\rho_w - V_{disp}\rho_f) \bullet g = mg$

$$V_{disp} = \frac{2.843 \text{ kg}}{1025 \text{ kg/m}^3 - 32.03 \text{ kg/m}^3}$$

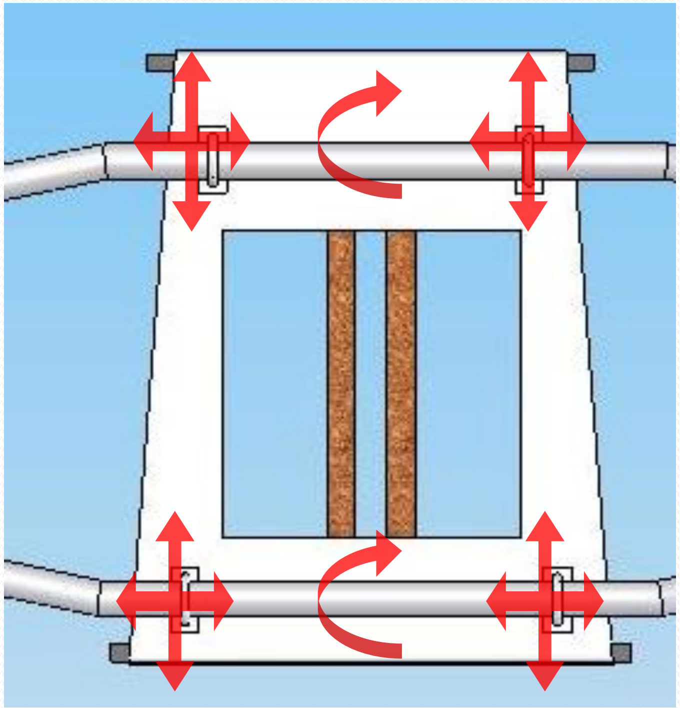
$= .00286 \text{ m}^3 = 174 \text{ in}^3$

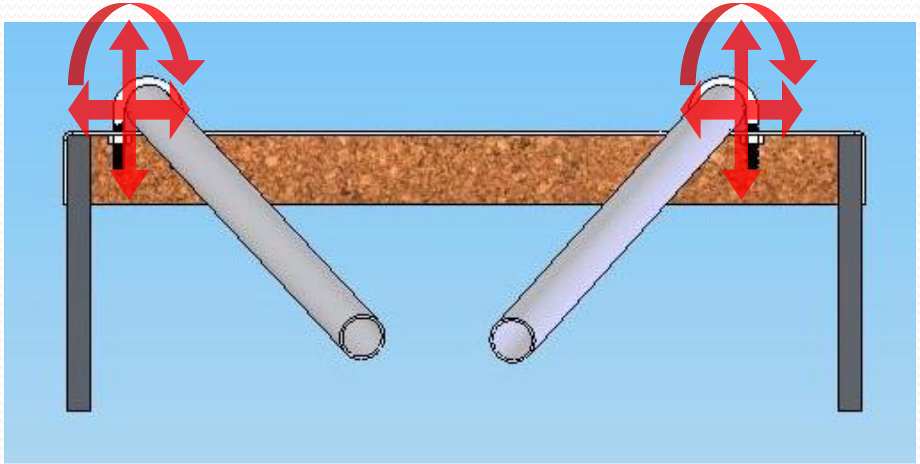
Pontoon could be 3”x3”x20”= **180 in^3**

*Will be more to provide safety factor for battery, solar panels, etc.

Risk #2: Destructive Disturbances

- Degree of Freedom constraints
  - Forces and Moments in all directions





- Stress Calculation

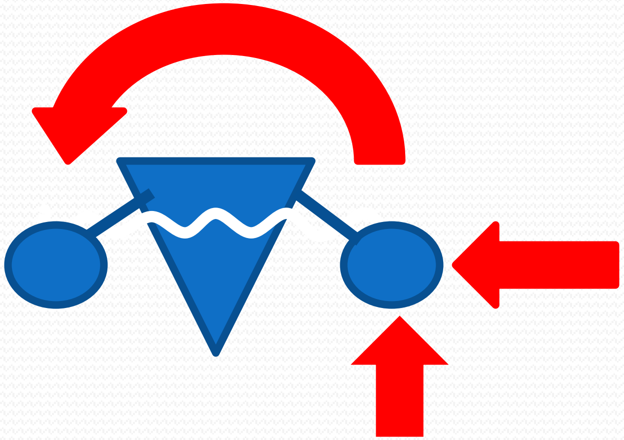
Stress Analysis

Student B

- Main Failure Modes
- Spring-Mass Model
- Wave Forcing
- Stress Calculations

Main Failure Modes

- Resonance with waves in roll



- Wave forcing on pontoons
  - Horizontal forcing
  - Vertical forcing
  - Resultant stress on structure, bolts and pipes

Resonant Frequency

- Model as single cantilever beam under point loading

- Use Euler- Bernoulli Equation

$$EI\frac{d^4u}{dx^4} = w(x)$$

$$w(x) = F\delta(x-L)$$

$$\Rightarrow \quad u = \frac{F}{3EI}L^3$$

Model as Spring-Mass System

- F = -ku, therefore:

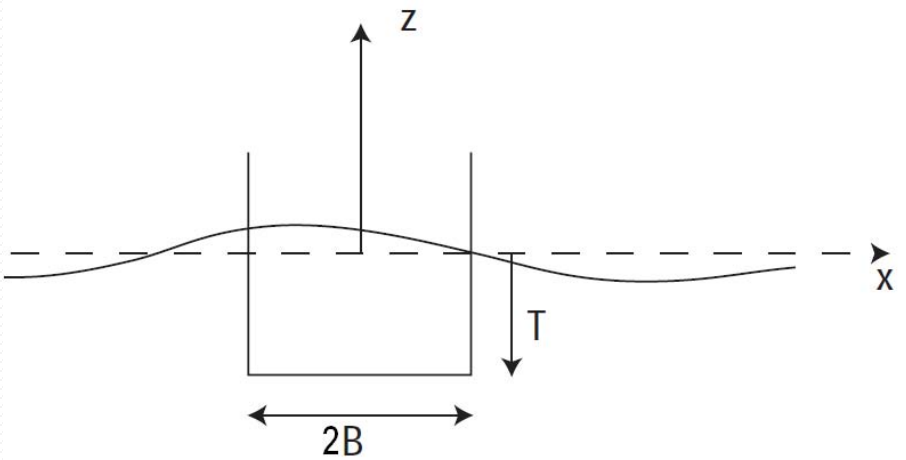
$$u = \frac{F}{3EI} L^3 \qquad k = \frac{3EI}{L^3}$$

- Find resonant frequency of system using:

$$\omega = \sqrt{\frac{k}{m}}$$

- For boat values, $\omega = 83\text{Hz}$
- $\omega_{boat} >> \omega_{waves}$

Wave Forcing on Pontoon



- B = 0.075m, T = 0.1m
- Worst-case waves :
  ω= 1Hz   A= 0.3m
- Deep water waves:

$$k = \frac{\omega^2}{m} \sim 0.1$$

- Surface pressure integration:

$$\vec{F}_{FK} = -\iint_{Sw} p\vec{n}ds$$

$$F_z = \frac{l2\rho age^{-kT}\cos(\omega t)\sin(kb)}{k}$$

$$F_{zMax} = \frac{L2\rho age^{-kT}\sin(kb)}{k} = 166N$$

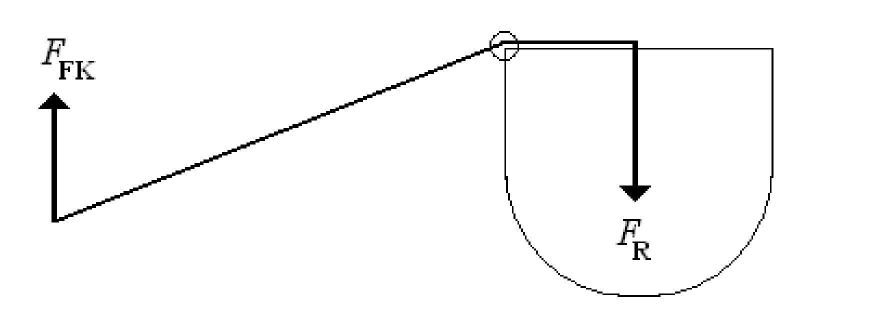
$$F_x = 2L\rho ag(1-e^{-kt})\sin(\omega t)\sin(kb)$$

$$F_{xMax} = 2L\rho ag(1-e^{-kt})\sin(kb)$$

$$F_{xMax} = 0.44N$$

Implications of wave forcing

- Horizontal force on pontoon is negligible
- Vertical force causes moment

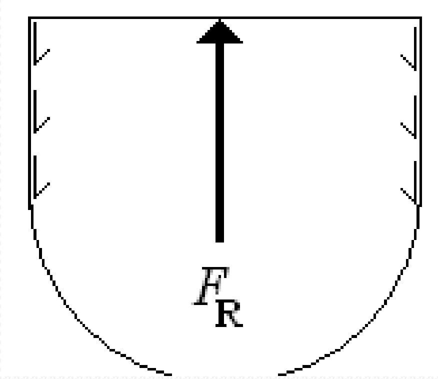


- Forcing moment: 50Nm.
- Reaction force on boat structure: 277.8N
- Could cause:
  - Failure at bend in struts
  - Bolts securing aluminum plate to damage boat structure
  - Internal structure to rip out of boat completely

Stress Calculations

- Bend in pipes
  - Stress calculated using $\sigma = \frac{MR}{I}$
  - Max stress: 8.8 x 10^6 Pa
  - Yield stress of aluminum: 4 x 10^8 Pa
- Force on bolts
  - Design distributes load over 6 bolts
  - Total force on each bolt is 46.3N
  - May be too high!
  - Requires more attachment points

Failure of Internal Structure



- Internal bracing mounted with epoxy
- Pontoon stress may be too large
- Calculate stress to ensure safety
  - Approximation: stress on epoxy in shear direction
  - Shear force per unit area of epoxy contact: 1.5×10^4 Pa
  - Shear strength of epoxy: 1.4×10^7 Pa
- Connection secure!

Note: Epoxy is much weaker in 'peel' forcing. However, hull and plate move in tandem, so peel forcing will not occur.

Next steps:

- Analyze plate design adequacy
- Modify plate design to distribute load
- Deployment load analysis
- Vessel stress analysis for true wave spectrum

GPS and Compass

Student E

- Reading GPS Data
- GPS Test Results
- Reading Sonar Data

GPS Data

- Standard Format:

GPRMC,135713.000,A,4221.4955,N,07105.5817,W,4.29,258.17,310809,,*16

- Haversine formula:
  - Computes distance between points on sphere

$$\Delta lat = lat2 - lat1$$

$$\Delta long = long2 - long1$$

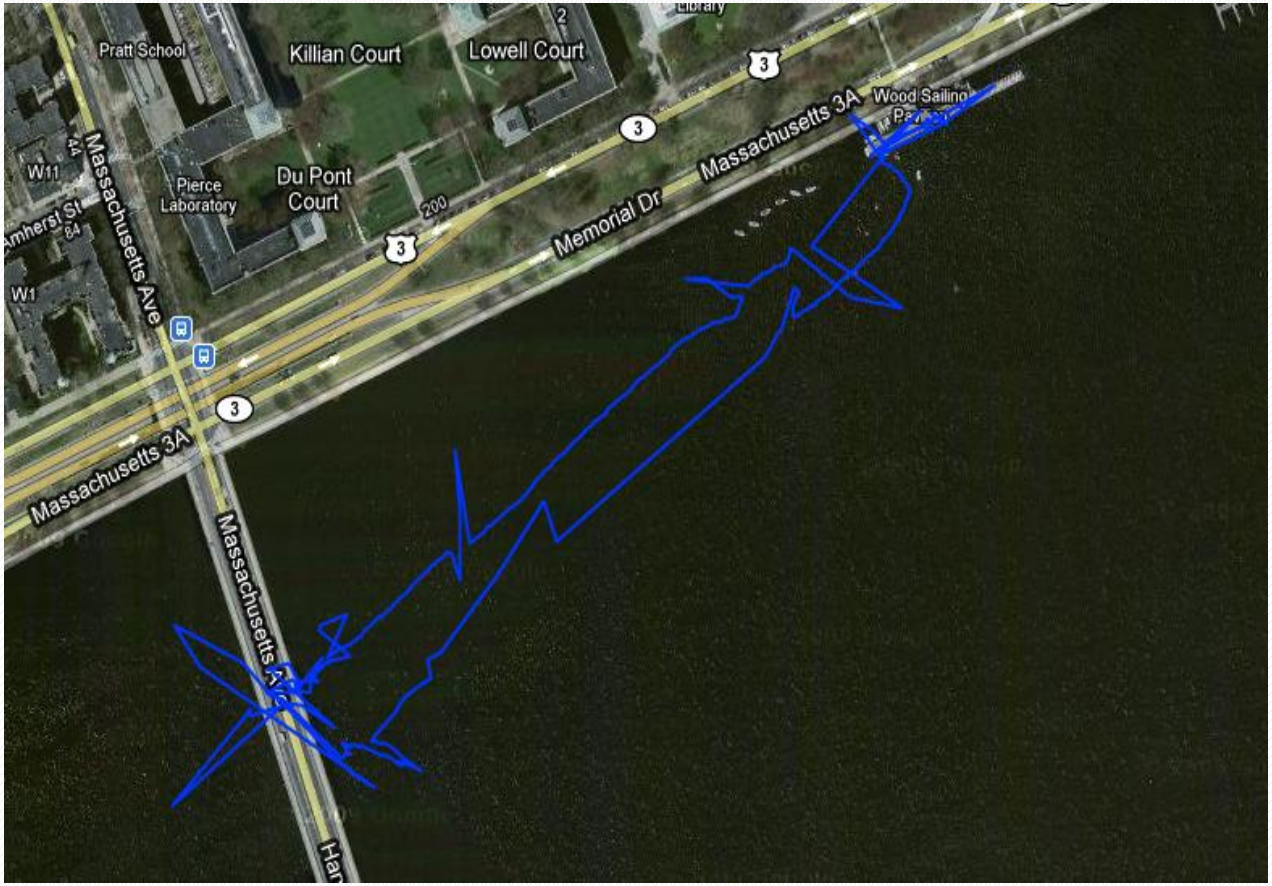
$$a = \sin^2(\Delta lat / 2) + \cos(lat1)\cos(lat2)\sin^2(\Delta long / 2)$$

$$c = a\tan 2(\sqrt{a}, \sqrt{(1-a)})$$

$$d = Rc$$

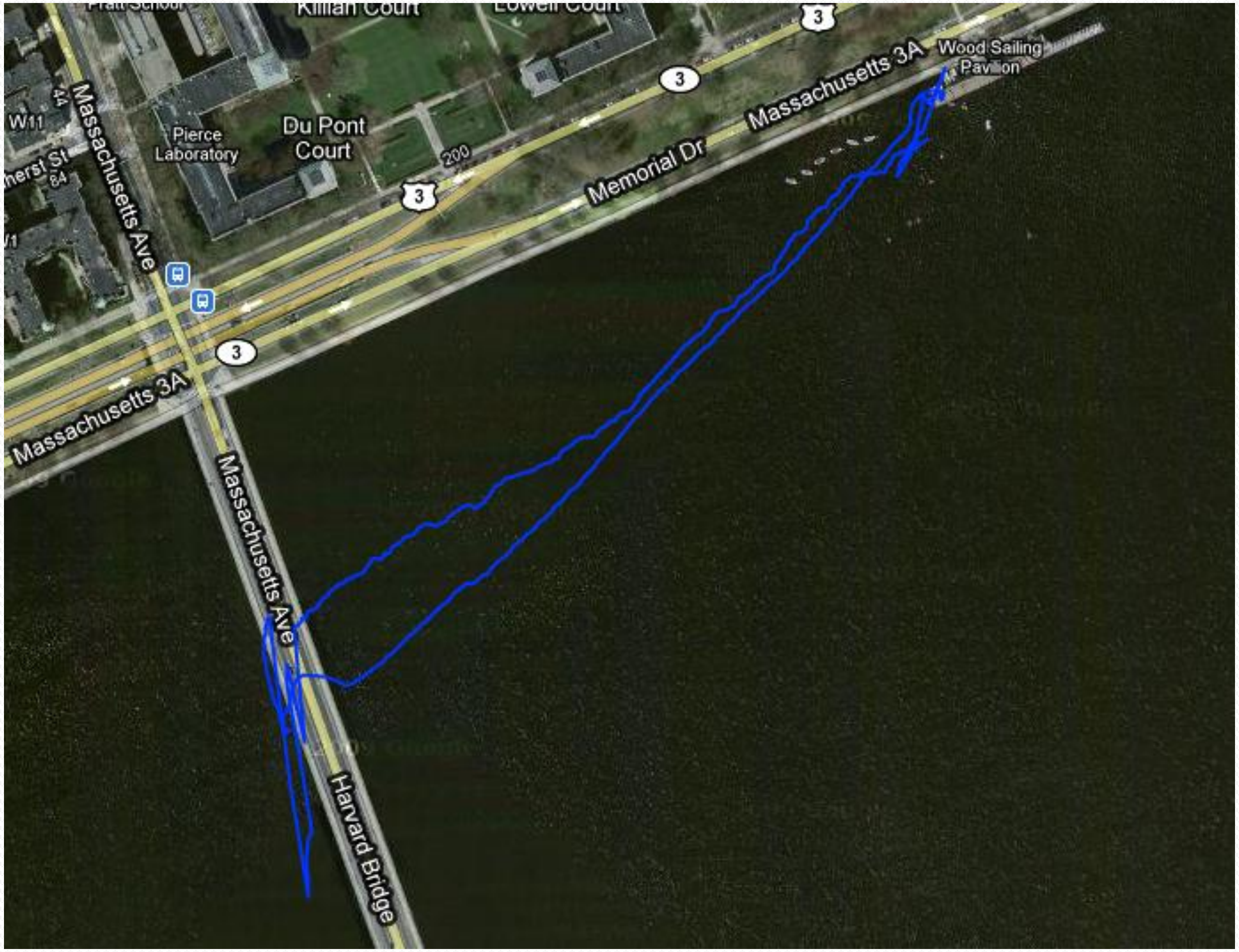
R = sphere radius

Trial 1



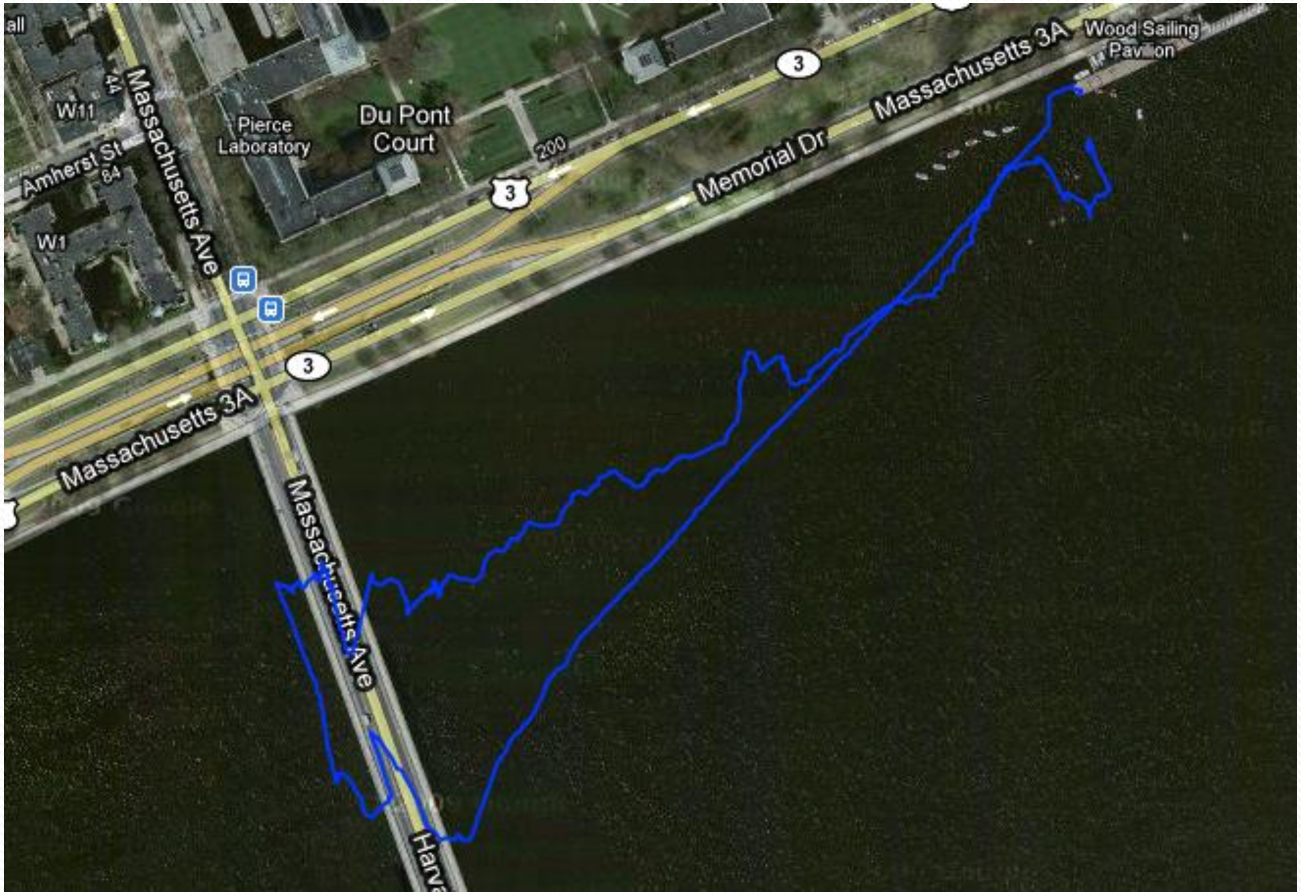
Pratt School
Killian Court
Lowell Court
Massachusetts Ave
W11
Pierce Laboratory
Du Pont Court
Amherst St
W1
Massachusetts 3A
Memorial Dr
Wood Sailing
Massachusetts Ave

TRAIL-2



Killian Court
Lowell Court
Pierce Laboratory
Du Pont Court
Massachusetts Ave
Memorial Dr
Massachusetts 3A
Wood Sailing Pavilion
Harvard Bridge

TRAIL-3



W11
Amherst St
W1
Massachusetts Ave
Pierce Laboratory
Du Pont Court
200
3
Memorial Dr
Massachusetts 3A
Wood Sailing Pavilion
Massachusetts 3A
Massachusetts Ave

Transition Point Approximation

- Pavilion = Position 1
- Cruising mode until Position 225
- @ 225: change to wall following mode
- @ 271: return to cruising mode
- @ 304: change to wall following mode
- @ 332: final transition to cruising mode
- Return to pavilion

Position 225

Positions 225-271

3-axis compass

- OS 5000 3-AXIS compass used
- Compass contains 2.5V inverting circuit
- Inverting circuit reads sensor output
- Result is data string of form:

$C..........R…………P…………T………….*1.A

Sonar and Control

Student A

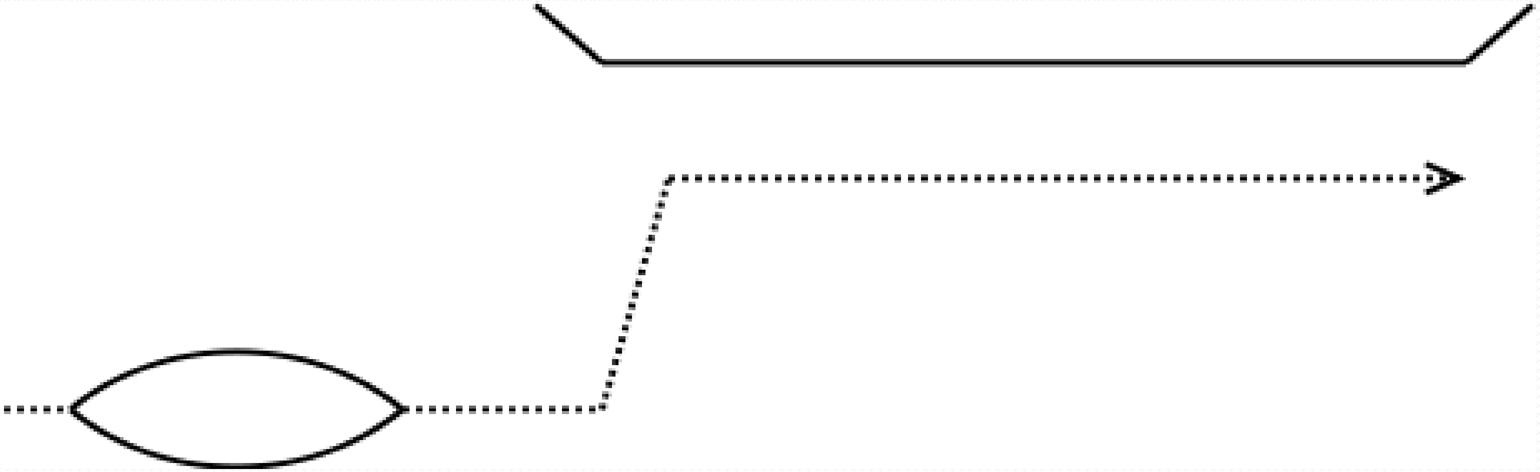
- Selected Sonar
- Wall Finding
- Wall Following
- Control Architecture

LV MaxSonar WR-1

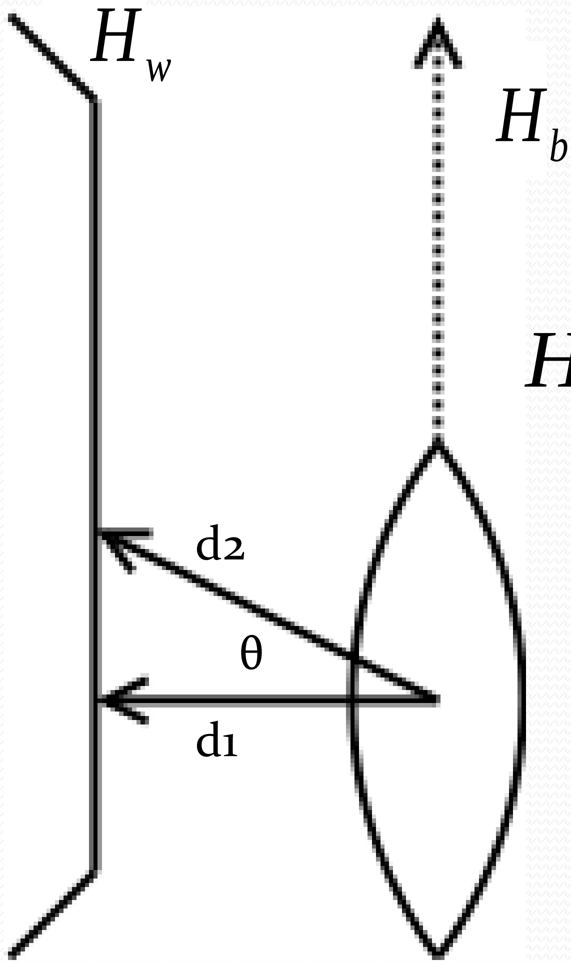
- Range 0-255 inches
- Analog and serial output
  - Analog accurate 1” of serial output
  - Maintain moving average of analog output
- Fully waterproofed
- Mounted to a servo

Wall Finding

- Run at pre-set heading until wall is detected
- Wall detection at 3.05 m, accurate reliable readings at 2.13 m
- Safety buffer of 1.52 m from wall



Wall Following

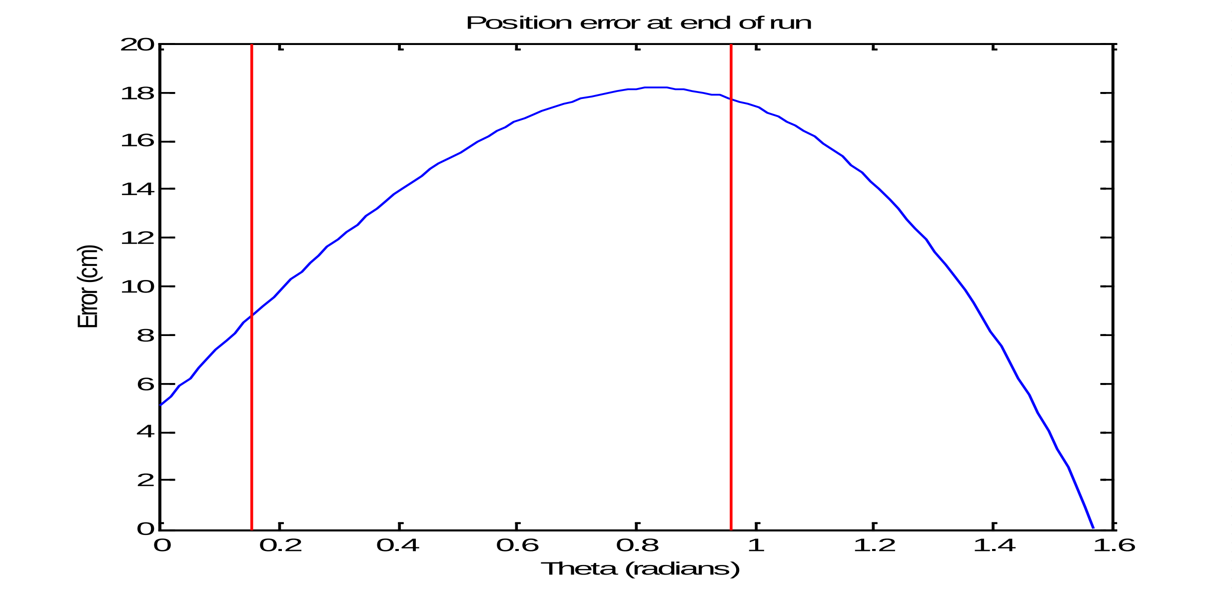


- Calculate wall heading, follow along path

$$H_w = H_b - \tan^{-1}\left(\frac{d_2\cos(\theta) - d_1}{d_2\sin(\theta)}\right)$$

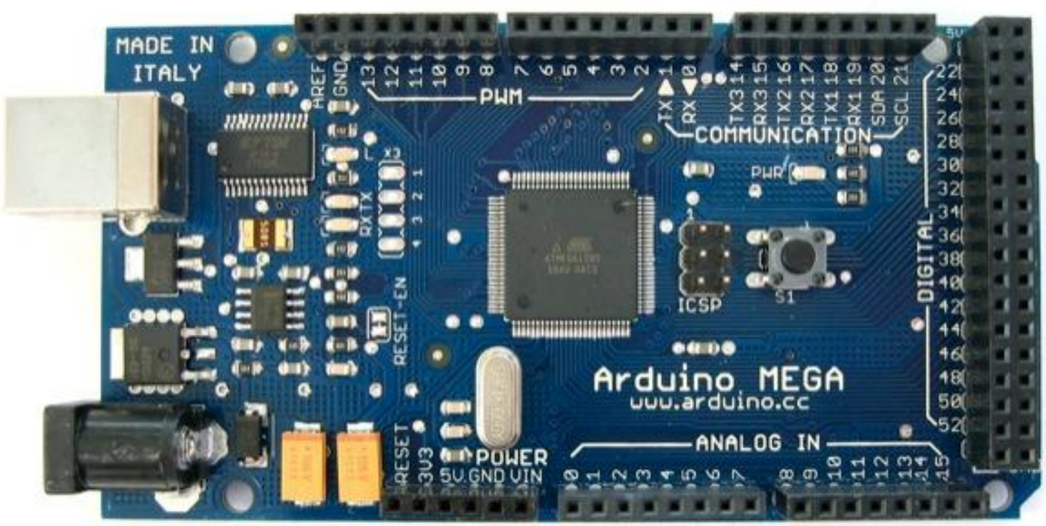
Accuracy

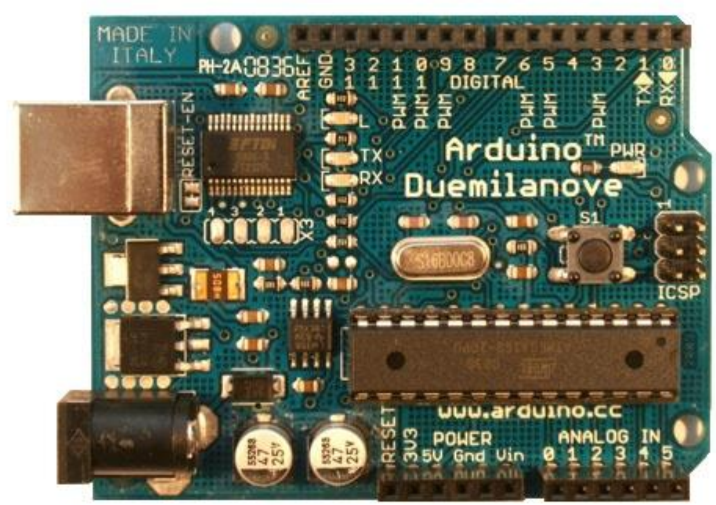
- Given sonar accuracy ± 2.54 cm
- Position error over run < 20 cm
- Optimal theta = 0.1535 radians



Control Architecture

- Mission Controller vs. Boat Controller
- Arduino Mega and Duemilanove
- Each can be tested in isolation
- Xbee communications with shore





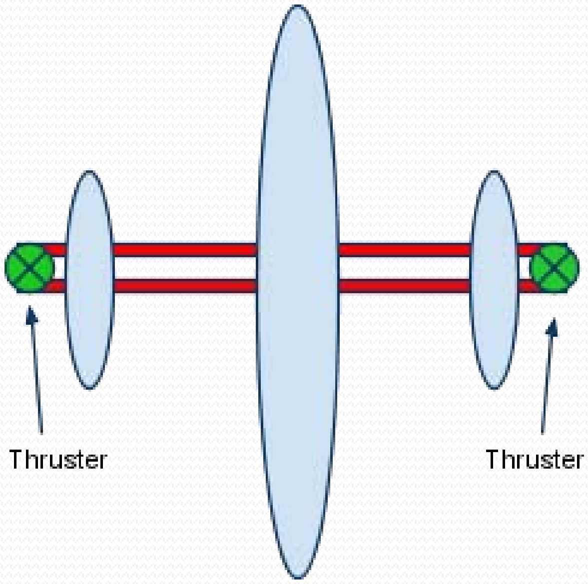
Motors and Control

Student C

- Speed Controller Tests
- Speed Controller Selection
- Thrust Tests

Propulsion System Design

- 2 Thrusters
  - 1 per outer hull
  - Differential thrust for yaw
- PWM control with Arduino and Speed Controllers
- 12V DC Trolling Motors



Speed Controller Selection

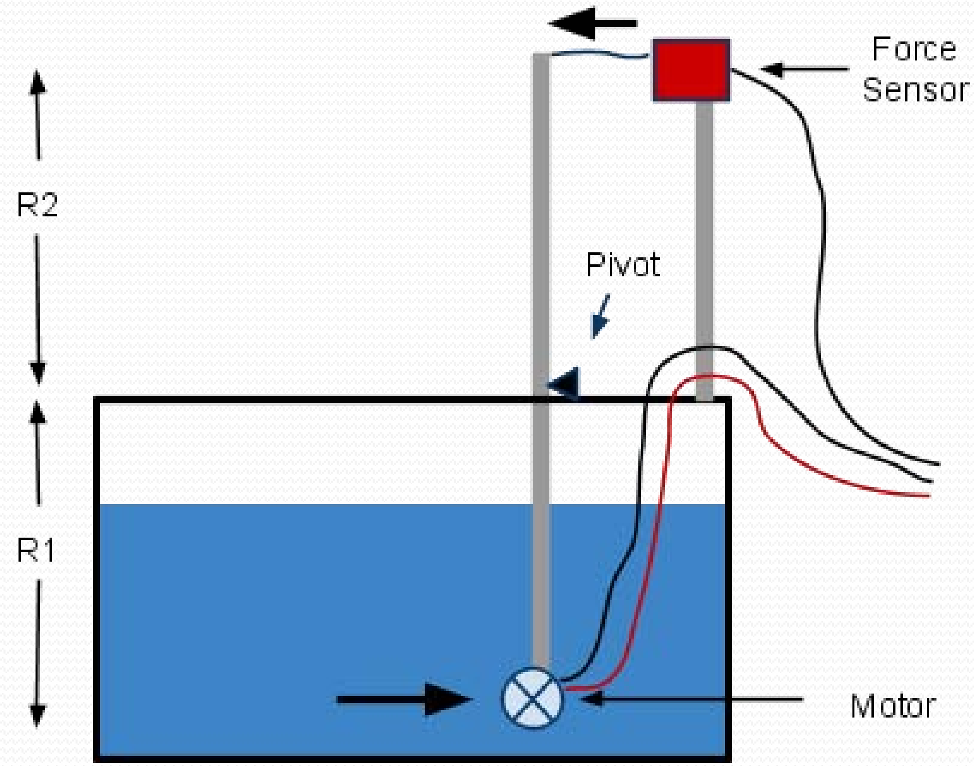
- Pro Boat 40A Waterproof ESC
  - Limited PWM frequency range
  - Incompatible with Arduino PWM
- Victor 884 ESC
  - Compatible with Arduino
  - Not Waterproof

Speed Controller Test

- Pro Boat ESC successfully driven by RC receiver
- RC PWM signal monitored on O-scope
  - PWM frequency = 55Hz
- PWM frequency not in Arduino range

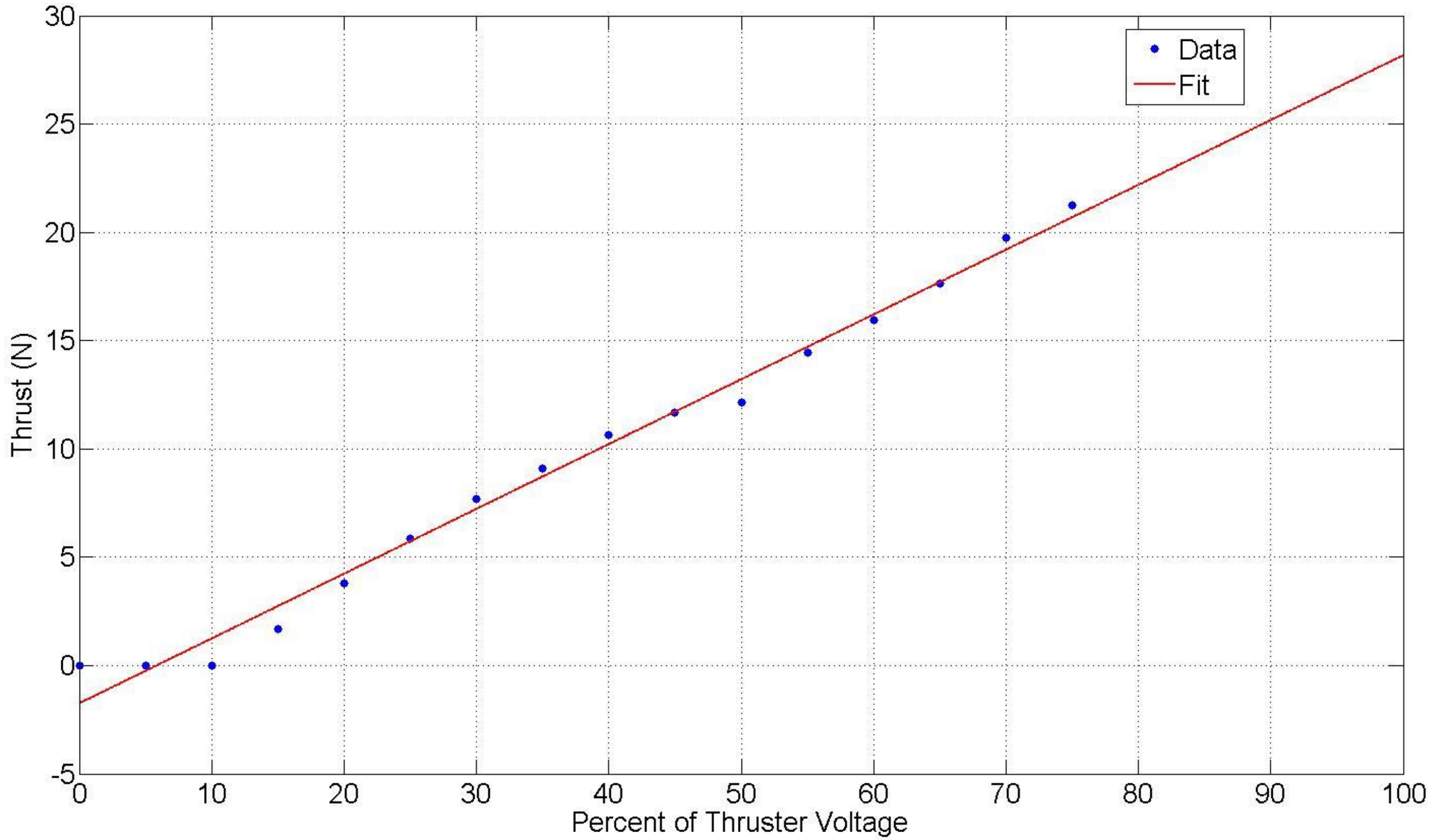
Thrust Test

- Test conducted in water tank
- Thrust was measured at different motor voltages
- Data fit to linear curve
- Maximum vehicle thrust=2X28.17N=56.3N
- Minimum voltage=1.5V



Force=Sensor Force X R2/R1

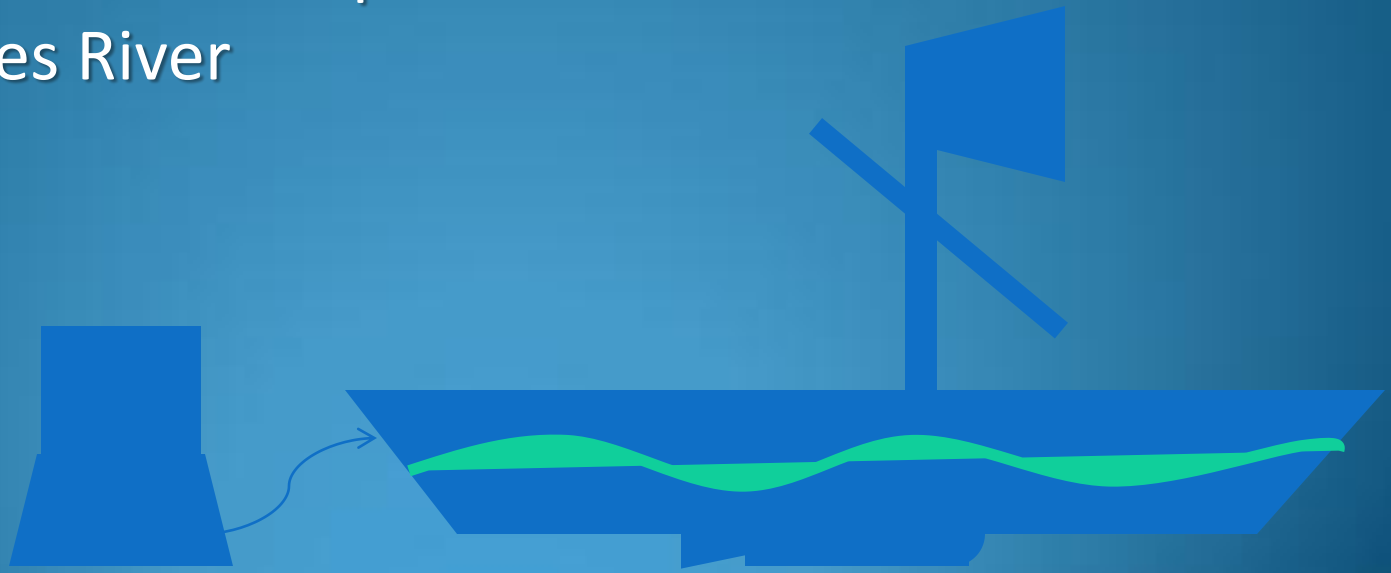
Thrust Test Data



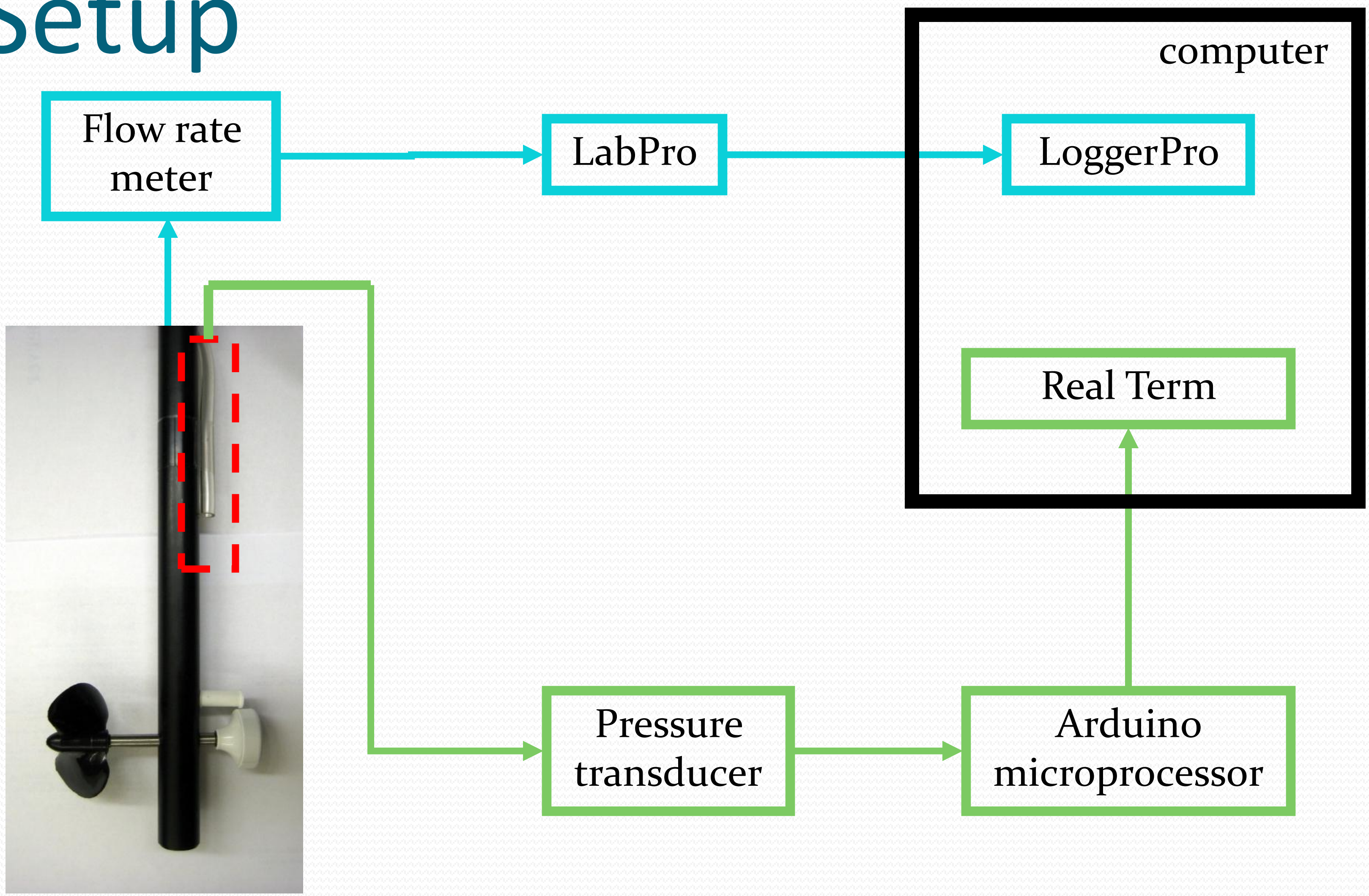
Wave Environment

Student F

Characterize wave spectrum of Charles River

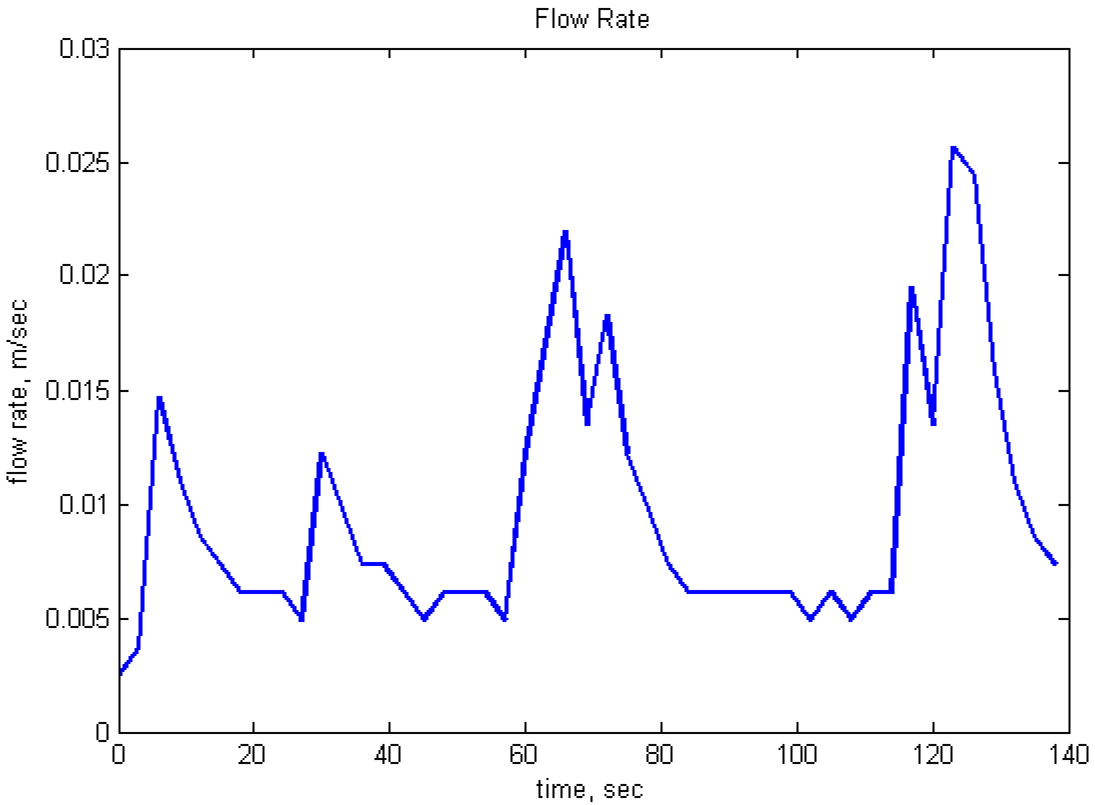


Setup



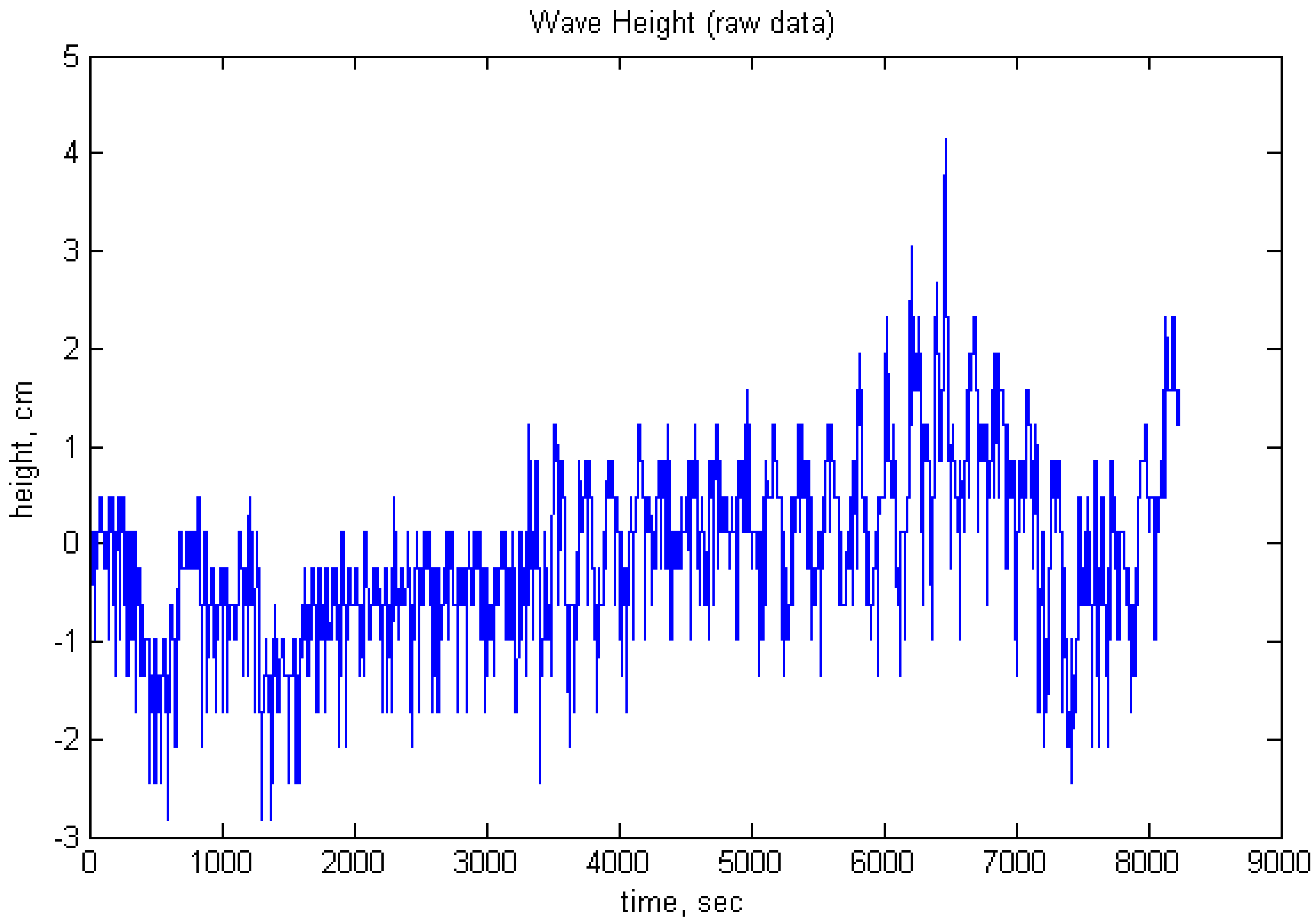
computer
Flow rate meter
LabPro
LoggerPro
Real Term
Pressure transducer
Arduino microprocessor

Flow Data



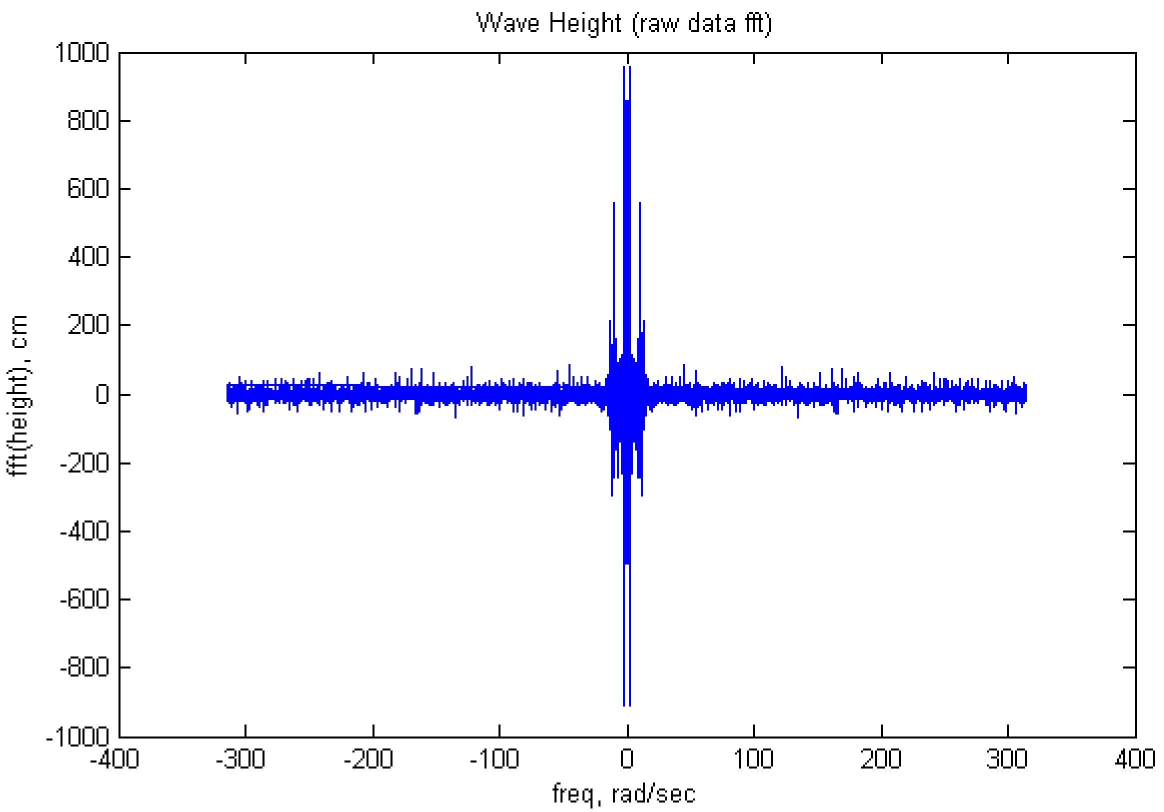
Flow Rate
0.03
0.025
0.02
0.015
0.01
0.005
0
flow rate, m/sec
0
20
40
60
80
100
120
140
time, sec

Wave Data

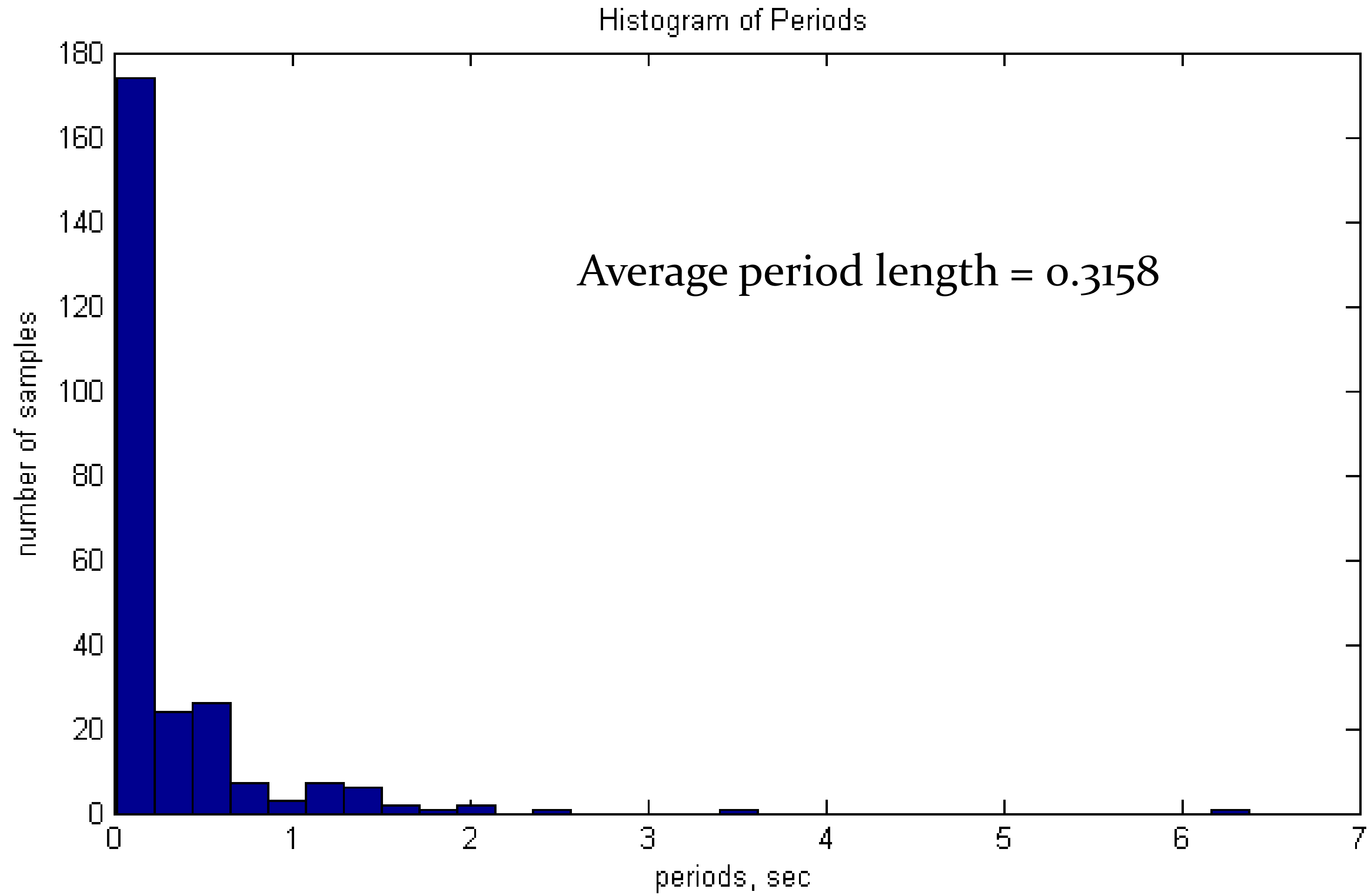


Wave Height (raw data)
height, cm
time, sec
5
4
3
2
1
0
-1
-2
-3
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

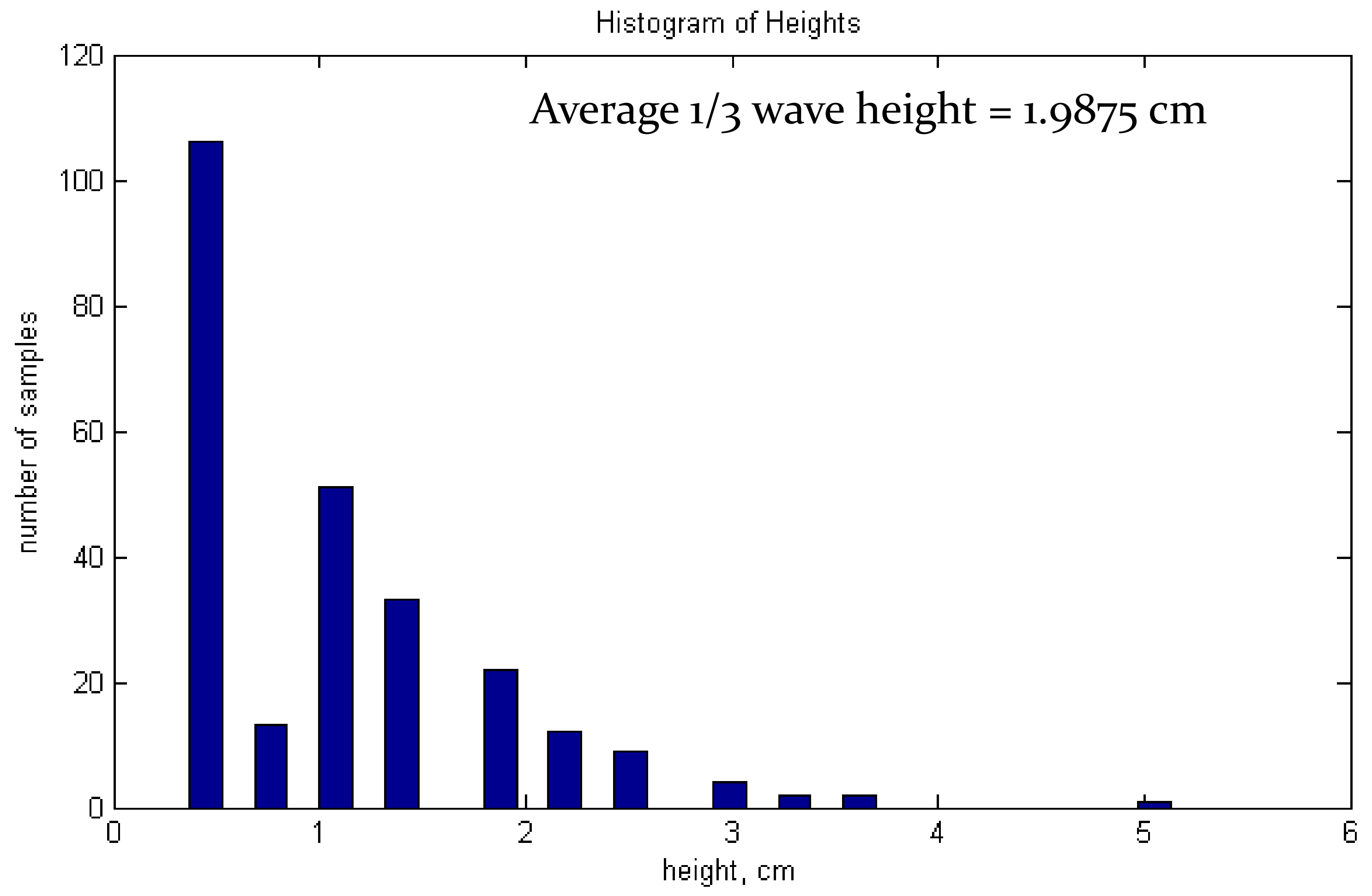
Wave Data FFT



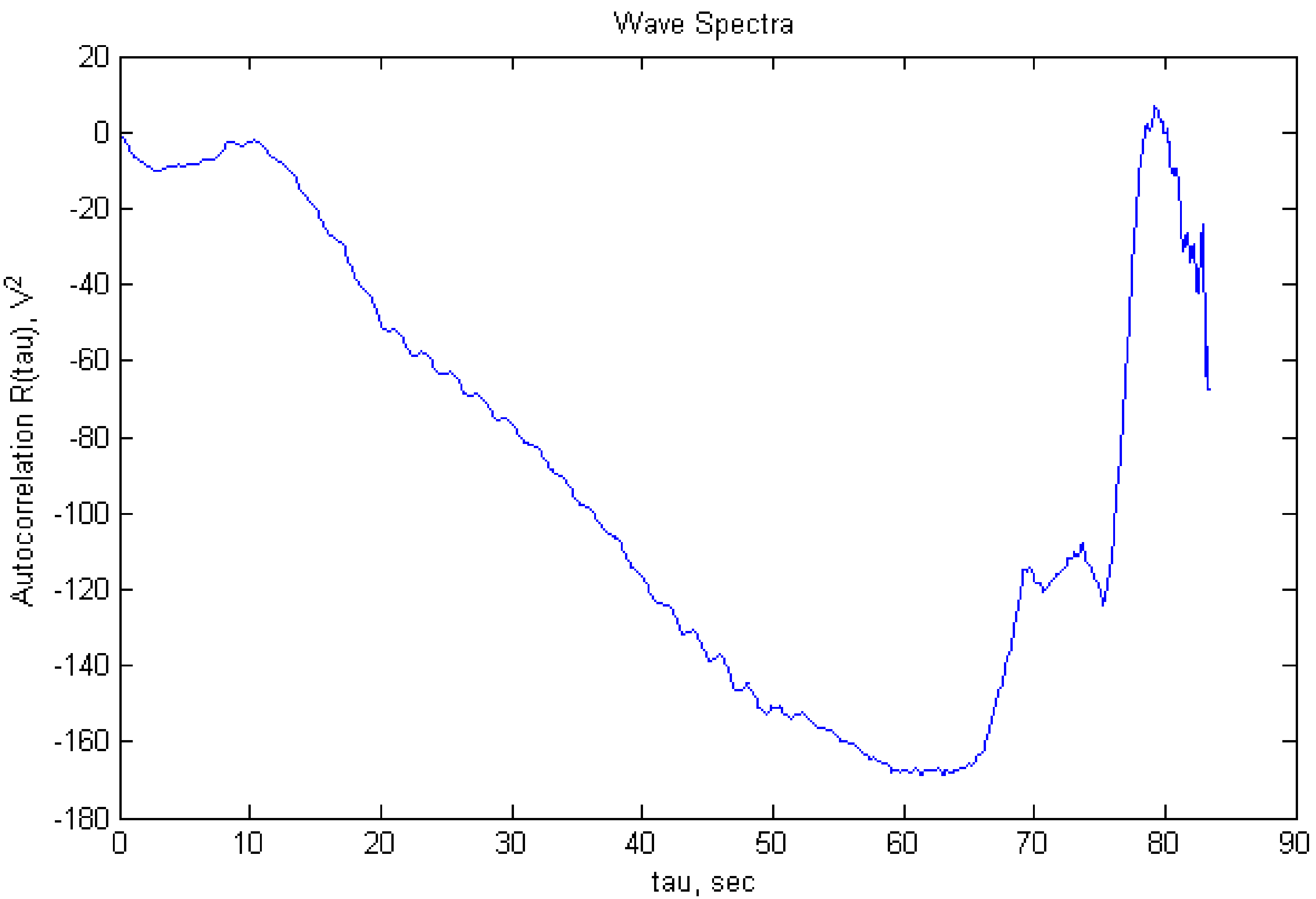
Wave Periods



Wave Heights



Autocorrelation



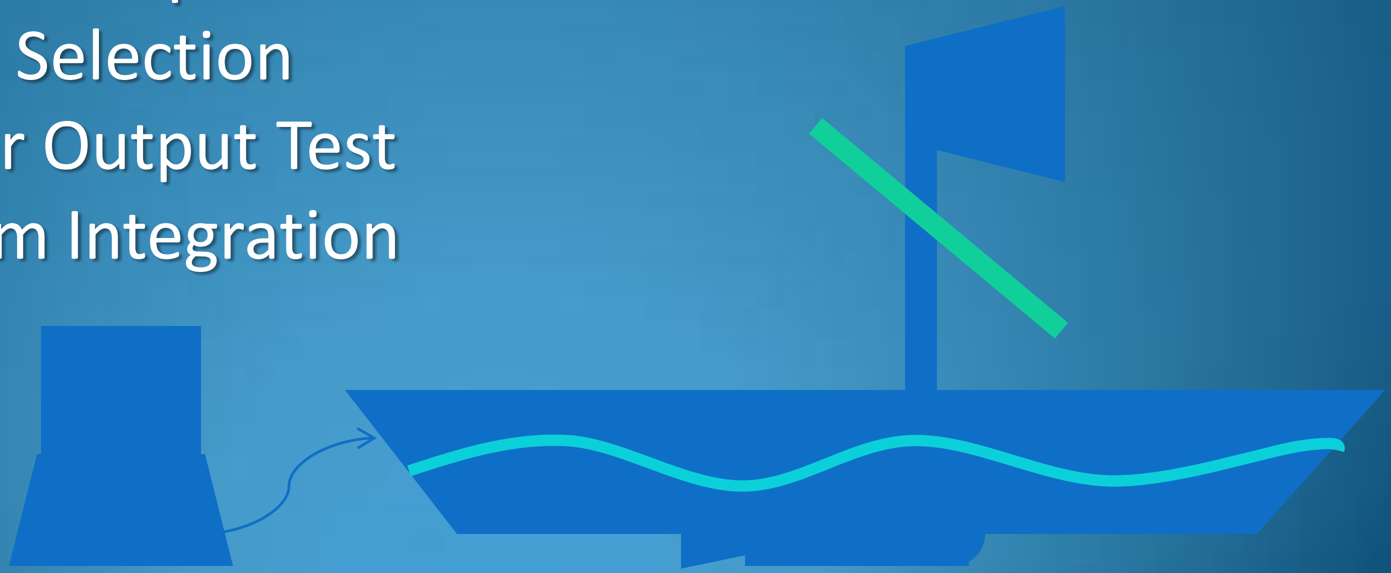
Further Work

- Collect more data
  - Differing weather conditions
- Create models
  - Heave
  - Pontoons and vessel response

Solar Energy

Student G

- Vehicle Requirements
- Panel Selection
- Power Output Test
- System Integration

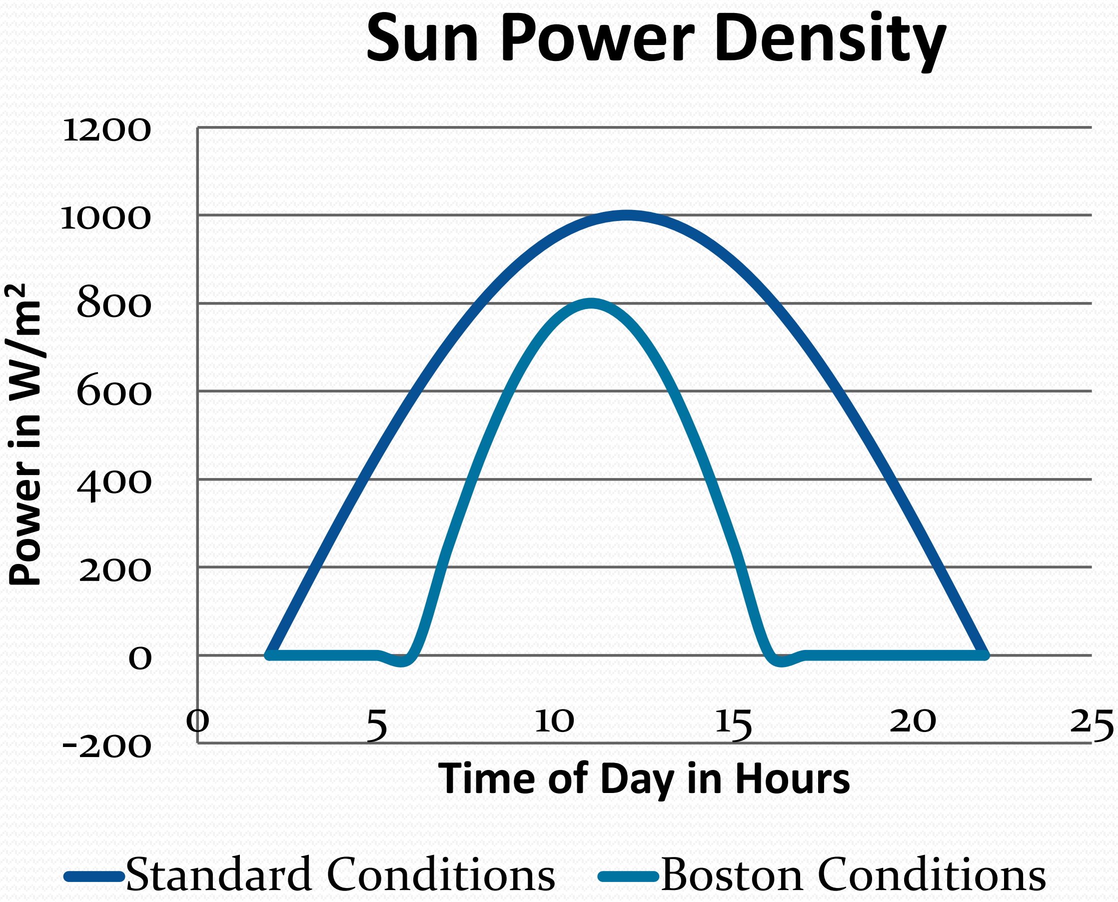


Estimating Requirements

Component	Voltage	Current	Power
Accelerometer	6V	50mA	0.300 W
Sonar	5V	50mA	0.250 W
GPS	3.3V	50mA	0.165 W
Arduino Mega	5v	50mA	0.25 W
		Electronics Total:	**0.965 W**
Motors (2) (minimum)	12V		
		Vehicle Total:	

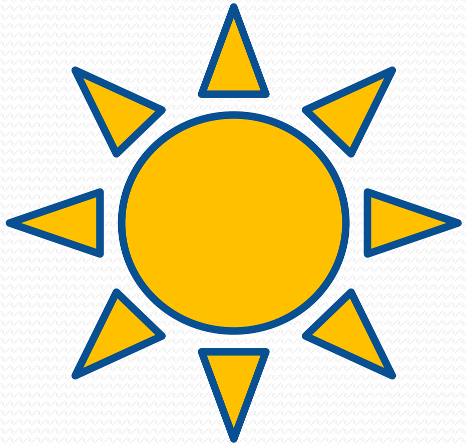
Estimating Capabilities

- Standard Rating Conditions: 1000 W/m^2
- SRCs correct for equator @noon



Correcting Specifications

- Panel output: $$P_{out} = \eta_{panel} E_{density} A_{panel}$$
- Morning deployment to minimize waves
- Ideal Mission Conditions:
  - 10am in Boston on sunny day
  - Mission $E_{density}$ = 600 W/m^2
- Non-ideal Mission Conditions:
  - 10am in Boston on cloudy day
  - Mission $E_{density}$ = 200 W/m^2

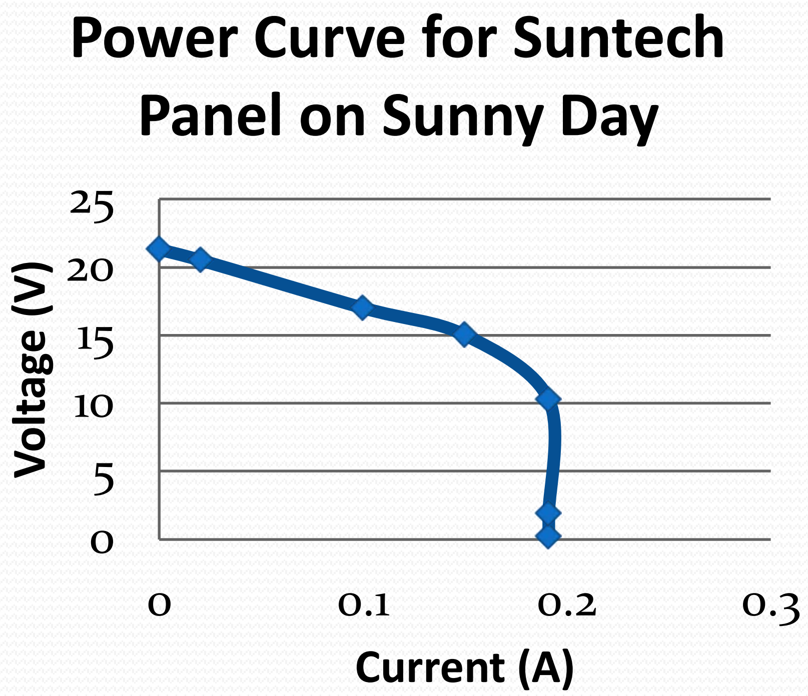


Suntech STP0055-12

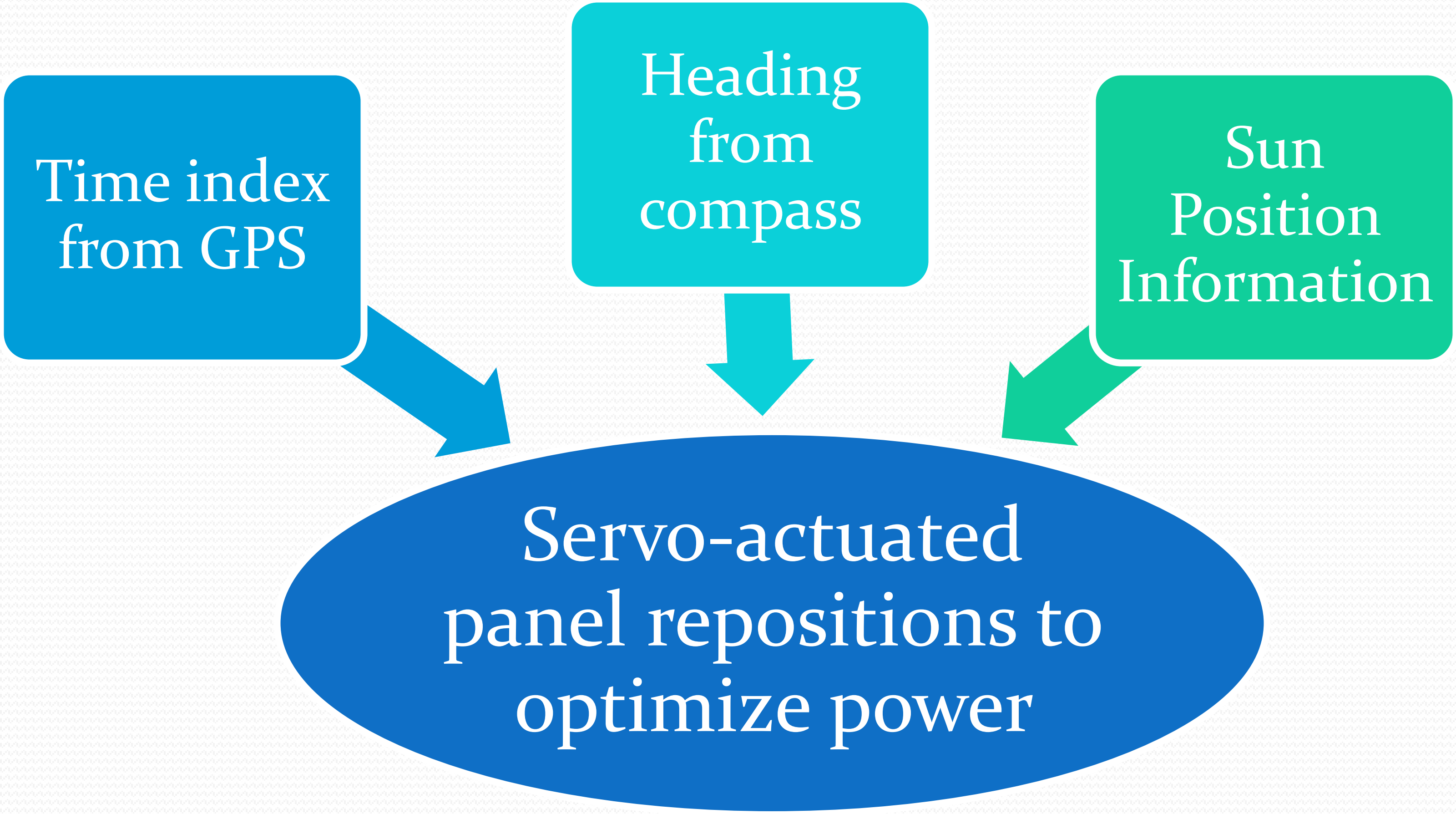
- Peak Rated Power = 5W
- Peak Power (sunny)= 3W
- Peak Power (rainy) = 1W
- Purchased 2 12”x18” panels
- Final Estimated Capability:
  - 10W max
  - 6W (sun)
  - 2W (cloudy))
- Total cost: $120.00

Testing the Panels

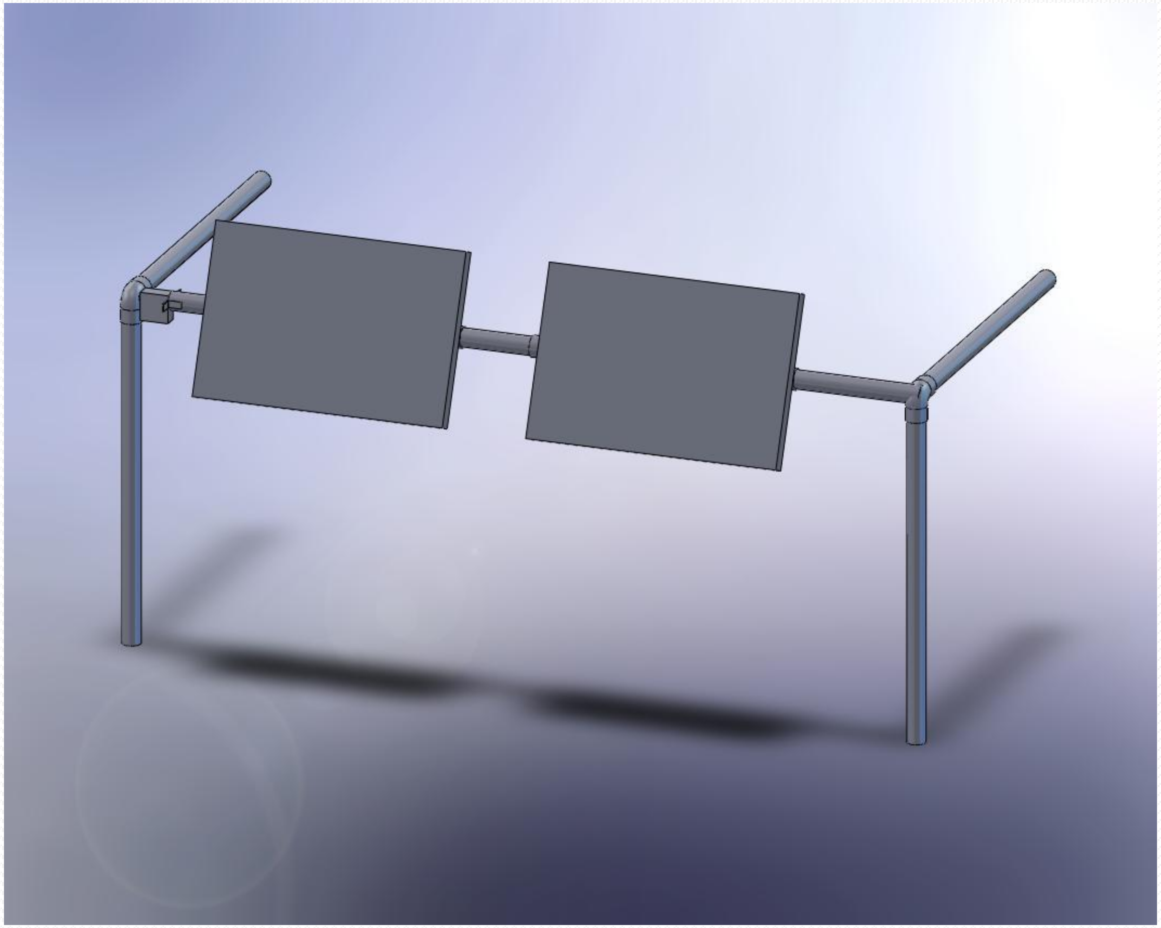
- Measured Short Circuit Current ~ 0.21 Amps
- Rated Short Circuit Current = 0.33 Amps
- Measured Power Output = 2.8 Watts



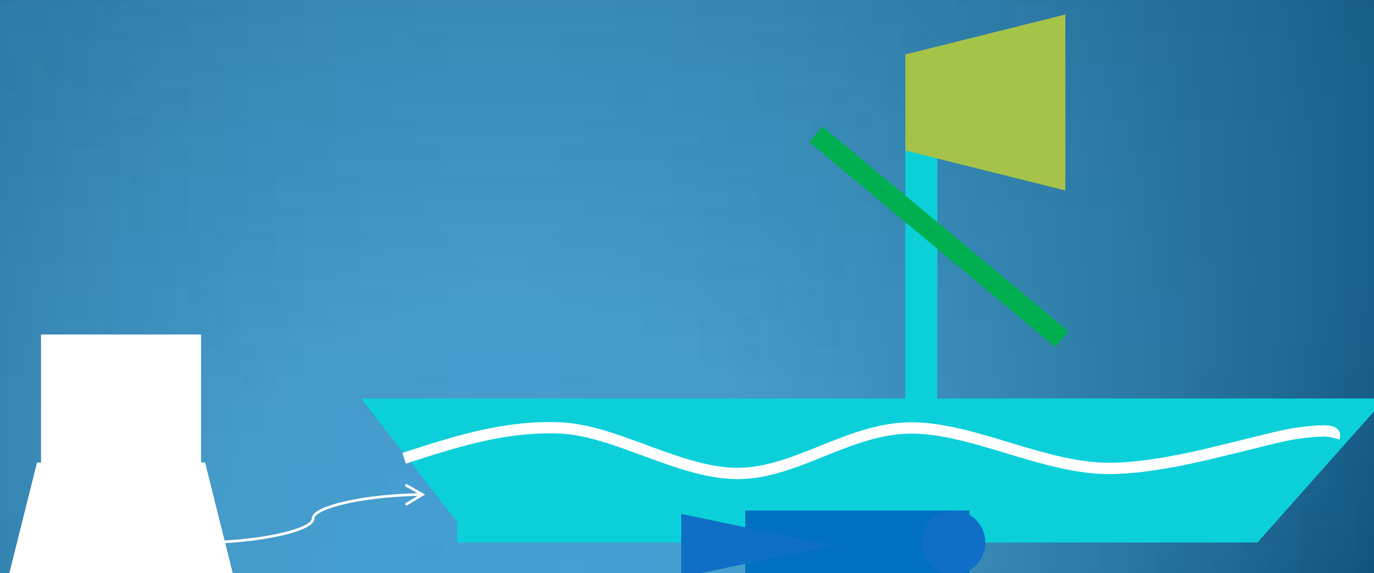
Control Architecture



System Integration



Summary and Next Steps



Significant Risks and Mitigations

- Mitigated with good planning:
  - Major construction setbacks
- Mitigated with testing and debugging:
  - Poor power management
  - Sensor Failure (GPS)
  - Data Interpretation Failure
  - Motor or Boat Controller Failure
- Uncontrollable:
  - Inclement weather

Next Steps

- Finish construction
  - Vessel: pontoons, solar panel support
  - Integrate sensors and structure
- Control System Implementation
- Testing
  - Yaw dynamic Tow Tank test
  - Wall-following Tow Tank test
- Troubleshoot
- Mission Day!

Questions?