Milestone #1:

<u>Experiment 1: Buoy Calibrator Controlled Experiment</u>

Description:

The ride identification number for this experiment was 14888. This can be used to look up the "ride session" on the Smartfin website where you can download the data for your own analysis. Oceanographers at SIO let us use the CDIP buoy calibrator, and we got a really nice-looking sine wave for this experiment.

Data was recorded at a **sampling rate of 5 Hz**, and the buoy calibrator was set to generate "waves" with a **6.25 second period, corresponding to a peak frequency at 0.16 Hz**. The **vertical displacement (or "wave height") was set to be 1.8m**.

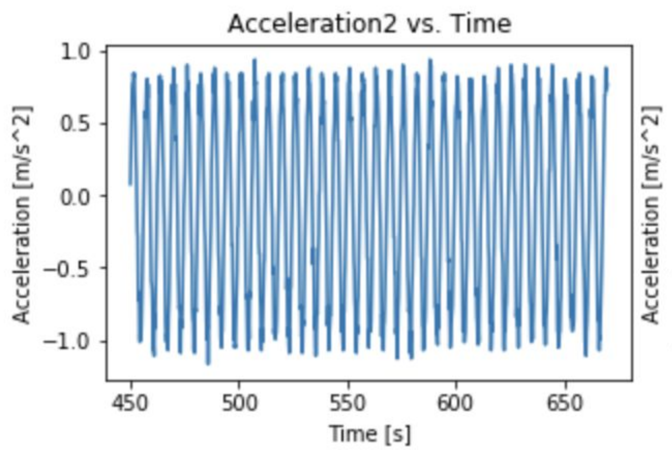


Image 1. A portion of the acceleration in the vertical direction obtained from the buoy calibrator experiment.

Spectral Analysis:

- (All included in cell 10):
    - Step 1: Detrend the data
    - Step 2: Take the FFT of acceleration
    - Step 3: Shift the FFT of acceleration
    - Step 4: Normalize the FFT of acceleration
    - Step 5: Multiply the FFT of acceleration signal by 1/w^2 where w = 2*pi*f (f is the peak frequency that we got from the FFT of acceleration, in this case it was approx 0.16)

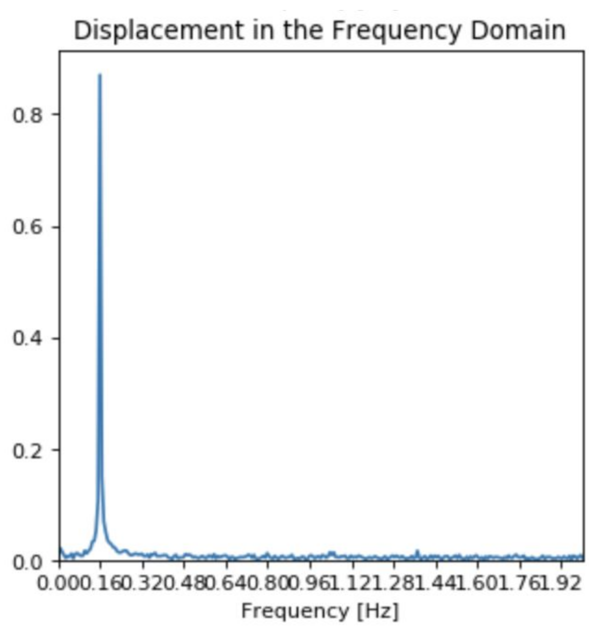


Image 2. Graph of vertical displacement in the frequency domain, produced from the buoy calibrator experiment.

Our algorithm produced the following results: a reported peak frequency of 0.159651669086 and a reported wave height of 1.74061502787. Again, the actual expected value for peak frequency was 0.16 and for wave height was 1.8m. We calculate the percent error in the table below.

Table 1. Determining Peak Frequency and Wave Height Using Spectral Analysis on IMU Data

	Peak Frequency (Hz)	Wave Height (m)
Actual	0.16	1.8
Calculated	0.159651669086	1.74061502787
Standard Error	0.00217706818	0.03299165118
% Standard Error	0.22%	3.30%

Double Integration Wave Train Analysis

Description:

We can use a method of doubly integrating our vertical acceleration data to obtain vertical displacement data. We can then use this data to determine significant wave height. Significant wave height is a statistical measurement for determining wave height from irregular waves; it is calculated as the mean of the largest one third, or 33%, of all waves.

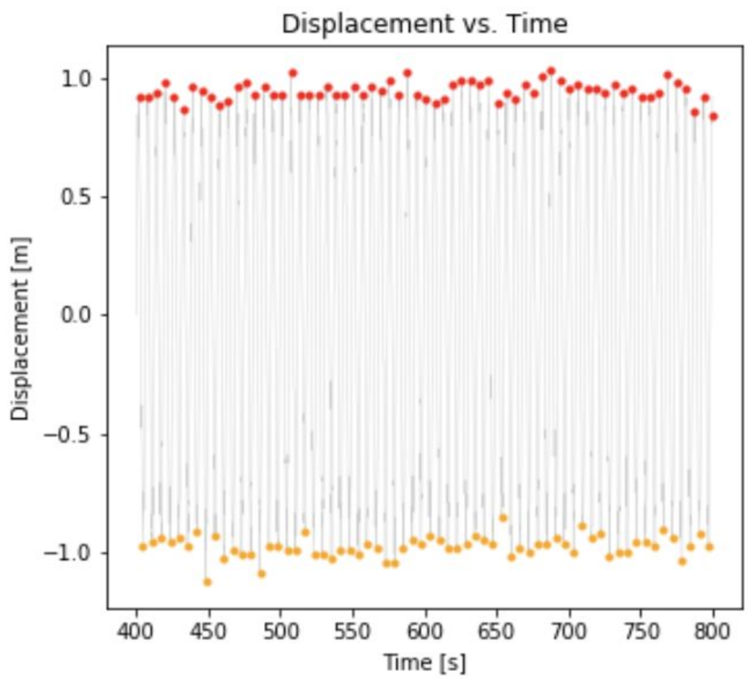


Image 4. Using a peak picking algorithm to determine the largest 1/3 of wave heights.

Table 2. Determining Significant Wave Height Using Double Integration on IMU Data

	Significant Wave Height [m]
Actual	1.8
Calculated	1.8887834075897778
Standard Error	0.04932411532
% Standard Error	4.93%

In this experiment, we see that our double integration wave analysis performs similarly to our spectral analysis when determining wave height.

Analysis of Results:

When analyzing near-perfect waves, our methodology for determining wave height and period closely matches what we expected. These experiments demonstrate that our methodologies are basically correct (<5% error) for each of these statistics in this best-case scenario. However, real world ocean data does not look exactly like the near-perfect data that we tested in this experiment, as exemplified by the image below.

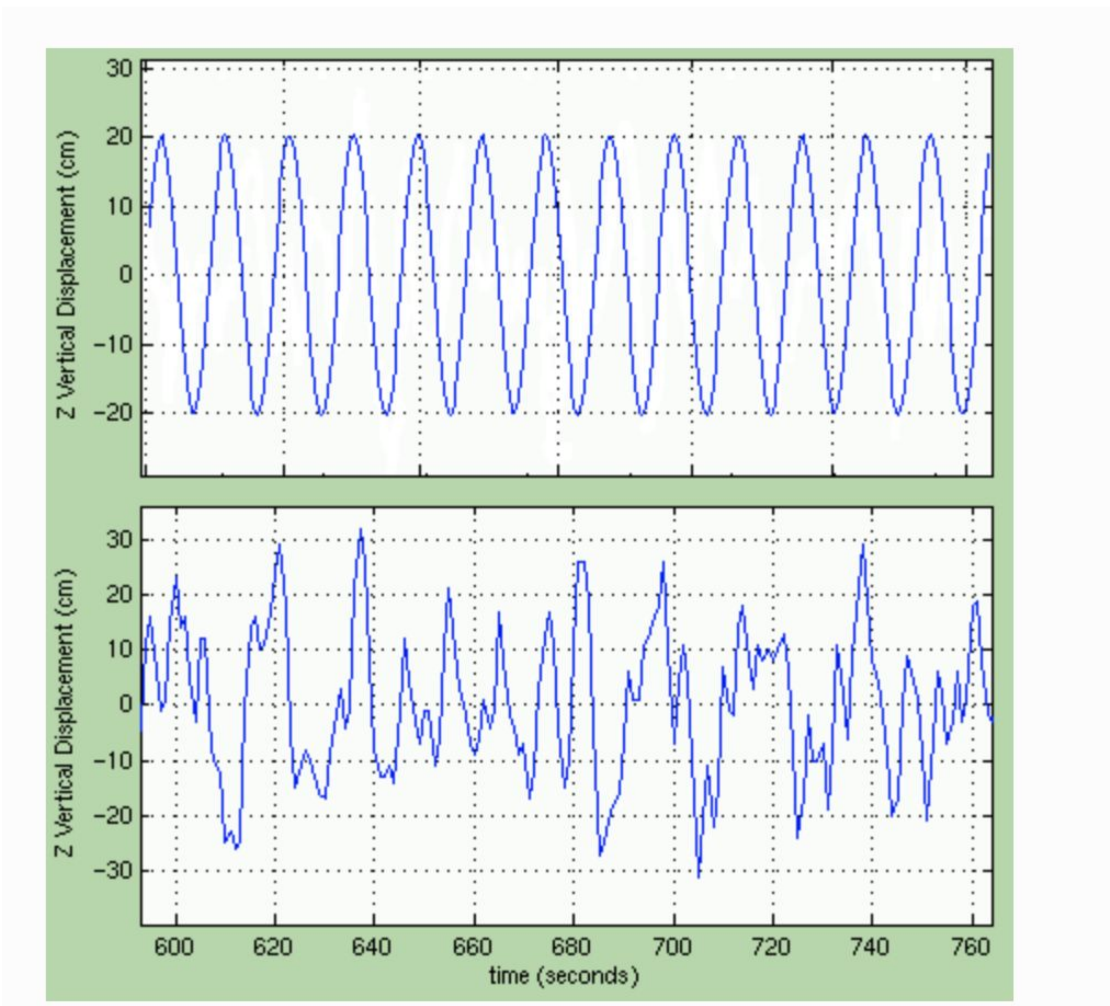


Image 3. Theoretical perfect ocean waves (pictured above) and actual irregular ocean waves (pictured below). Source: https://cdip.ucsd.edu/m/documents/wave_measurement.html

Since ocean waves will always have irregular waves due to fundamental variability on the sea surface [CDIP], we will have to calculate wave characteristics using statistical terms. For significant wave height, we will take the mean of the largest ⅓ of waves recorded during the sampling period. CDIP normally calculates these characteristics over a short-term period, for example, for one hour or less. The majority of CDIP's parameters are calculated over a 30 minute time period.

Experiment 2: Pool Displacement Controlled Experiment

Description:

The next test that we did was a controlled pool experiment in the UCSD Canyonview pool. This corresponds to ride ID number 14827 on the Smartfin website. Our experiment contained 3 sub-experiments, each with the Smartfin mounted onto a pole vertically. We simulated different wave heights by vertically displacing the Smartfin in the pool different distances and speeds. This was done to collect data in a controlled environment that more closely mirrored the type of data that we would expect to obtain from the ocean. We viewed the raw acceleration readings in a graph and then processed the data to get the resulting displacement as well as FFT. Notes for each of the sub-experiments are included below.

We **collected data at a sampling rate of 30Hz** for each experiment.

The **first controlled experiment** that we did was creating a sinusoidal wave with a t**otal vertical displacement of 1.8m (amplitude of 0.9m)** and **period of 6 seconds (corresponding to a frequency of 0.16Hz).**

The **second controlled experiment** that we did was creating a wave with a t**otal vertical displacement of 1.5m (amplitude of 0.75m)** and **period of 4 seconds (corresponding to a frequency of 0.25Hz).**

The **third controlled experiment** that we did was creating al wave with a t**otal vertical displacement of 0.9m (amplitude of 0.45m)** and **period of 2 seconds (corresponding to a frequency of 0.5Hz).**

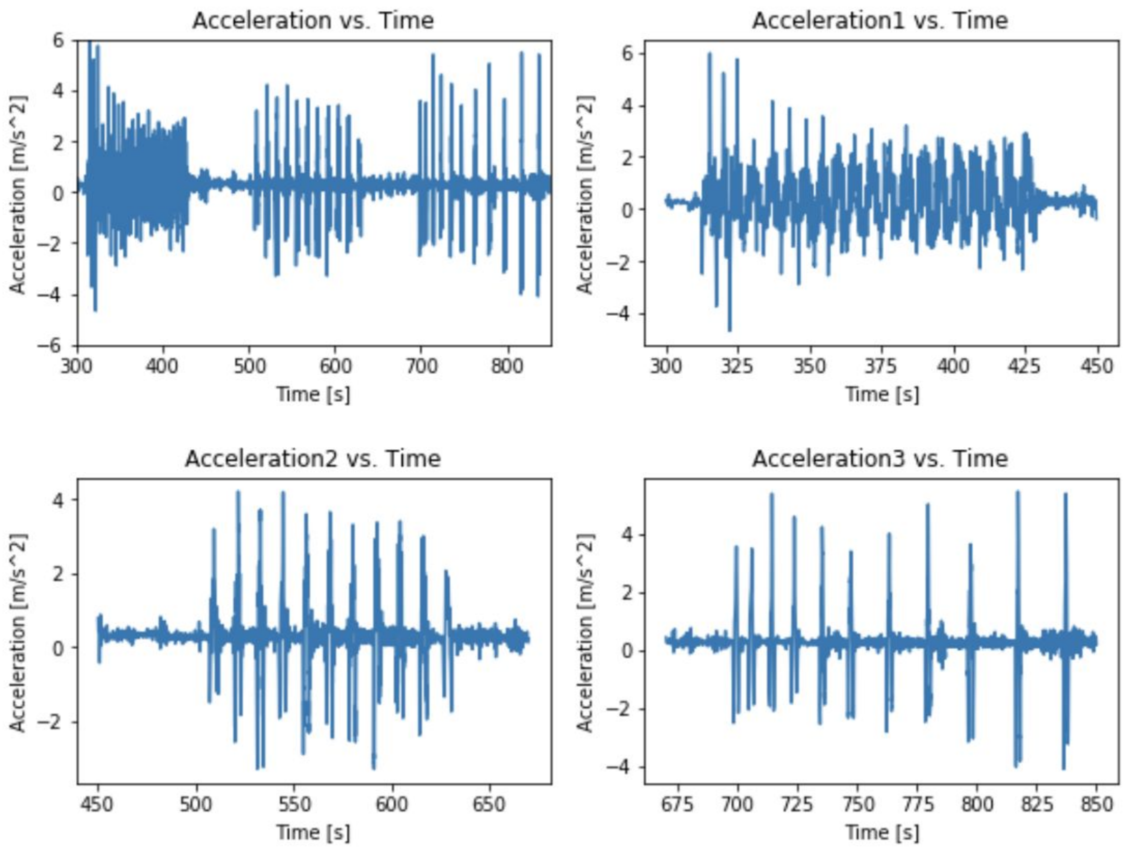
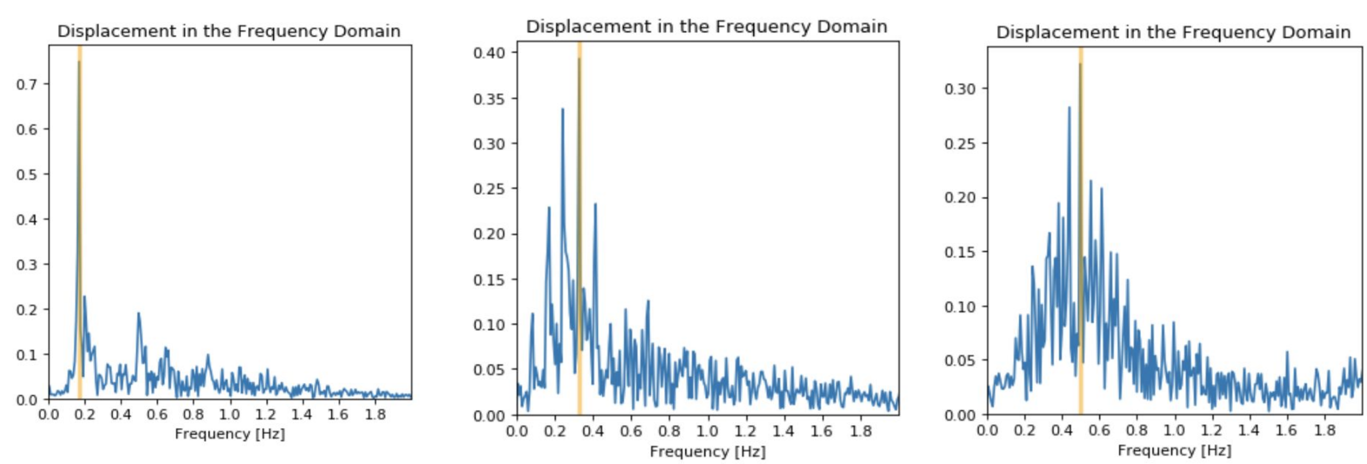


Image 4. Vertical Acceleration vs. time for each of the controlled pool sub-experiments.

Spectral Analysis:



Double Integration Wave Train Analysis

After doubly integrating, detrending, and filtering the results of each integration step, we obtain the following graphs of Vertical displacement vs. Time for each of the sub-experiments.

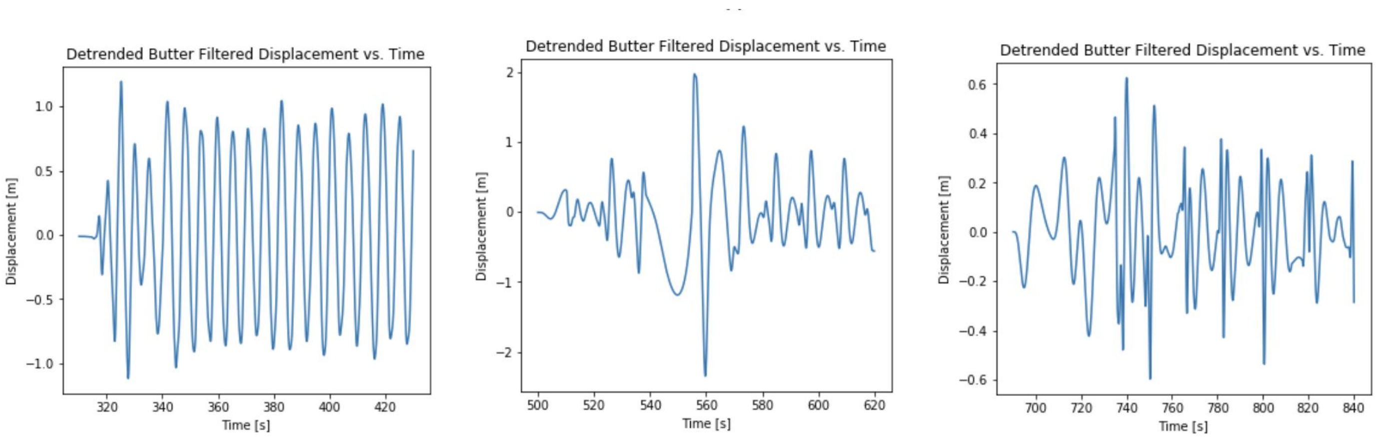


Image 5. Vertical Displacement vs. Time graphs produced from original vertical accelerations for each sub-experiment.

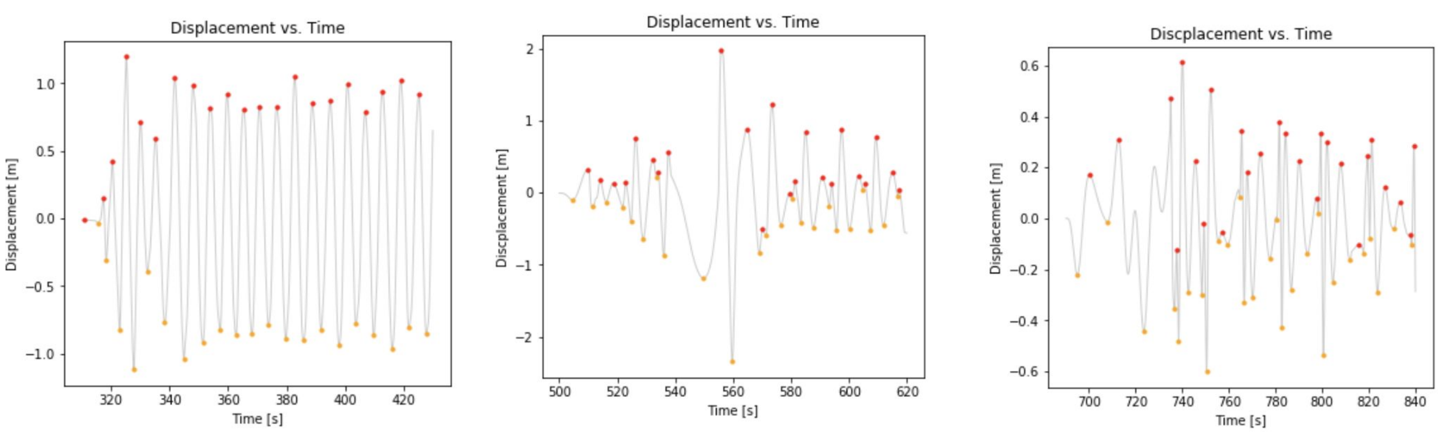


Image 6. Vertical Displacement vs. Time graphs produced from original vertical accelerations for each sub-experiment, with wave peaks highlighted in red.

Again, we can view the wave heights that were produced in order to analyze our standard error in calculating the significant wave height using each of these methods.

Table 3. Standard error calculated from significant wave height in each controlled pool experiment.

	Actual Wave Height [m]	Calculated Wave Height [m]	Standard Error	Standard Error %
Experiment #1	1.8	2.0632722103091106	0.1462633906	14.6%
Experiment #2	1.5	2.0850691485538615	0.39004609903	39.0%
Experiment #3	0.9	0.8514080931935583	0.05399100756	5.40%

Analysis of Results:

Here, we see that we often overestimate the actual wave height when computing significant wave height. However, because significant wave height is a statistical measure that takes into account only the top 33% of waves, this is to be expected. In particular, it seems like we have a great standard error for our second experiment; this is because of the unexpected large wave that we see in the middle of the graph. Because we were only sampling waves for a short period of time, this wave dominates our series. When we take more waves into consideration, for example looking at the top 50% of waves rather than the top 33% of waves (to account for errors in the manual creation of our waves), these errors drop significantly. The following table demonstrates the standard error present in this new wave height metric, which can be compared to the previous *significant* wave height metric.

Table 4. Standard error calculated from wave height in each controlled pool experiment.

	Actual Wave Height [m]	Calculated Wave Height [m]	Standard Error	Standard Error %
Experiment #1	1.8	1.9848564307387153	0.10269801707	10.3%
Experiment #2	1.5	1.619954942662752	0.07996996177	8.00%
Experiment #3	0.9	0.8514080931935583	0.05399100756	5.40%

<u>Experiment 3: Real World Ocean Experiment</u>

Description:

In order to determine how our methodology would perform in an actual real world setting, we had a surfer float in the ocean on their surfboard. We then calculated the significant wave height from that data, and attempted to compare it against CDIP data taken from the same day.