Generating Electricity from Ocean Waves

By: Arya Joshi

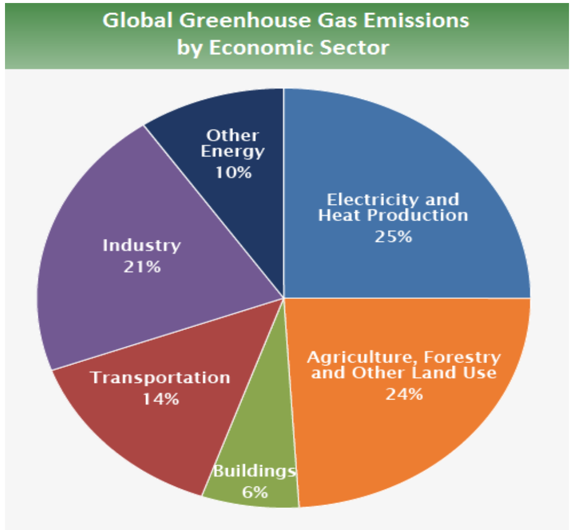
Faculty Advisor: Dr. Carlos Castro

Objective:

- Introduce method of generating power from **shoreline "swash-backwash" cycle**
  - Manufacture a miniature energy generation device
  - Design a custom unidirectional wind turbine
    - Select optimal nosecone and airfoil type
  - Test prototype power output in controlled environment

Background: Green Energy – Climate Dilemma

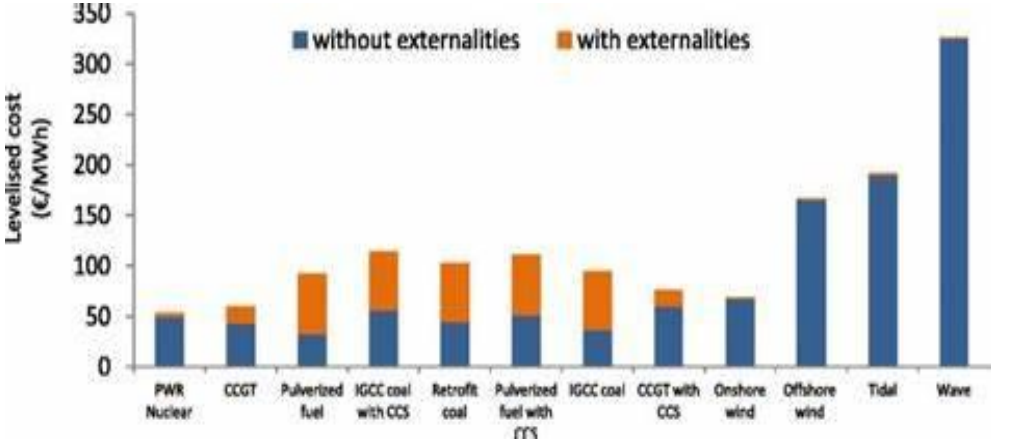
- 4 °C global temperature rise expected at current CO_2 emission rates
- 25% of CO_2 emissions from energy generation



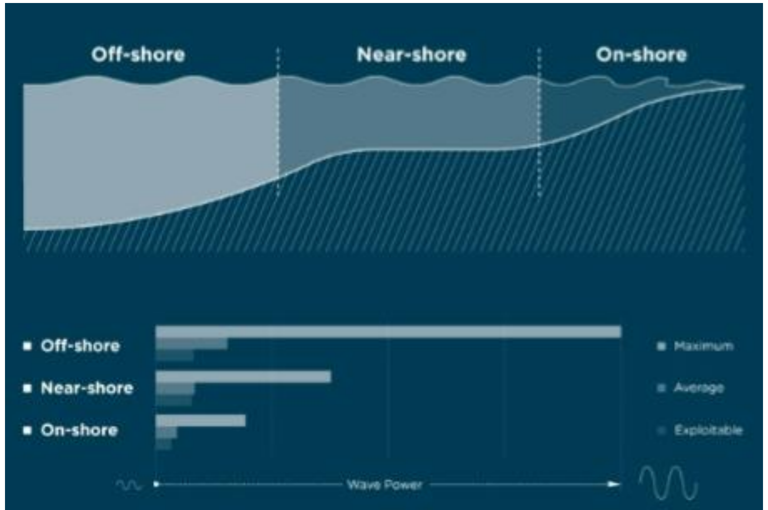
- **Renewable Energy:**
  - Major intermittency problem
    - Ex. wind speeds change, sun sets at night
  - Solution: Diversifying portfolio of <u>affordable</u> renewable energy fuels

Background: Ocean Wave Energy

- Traditional methods costly:
    - Use of strong, anticorrosive material (cement, concrete)
    - Construction in deep waters
        - Ocean depth > 0.5 x wavelength

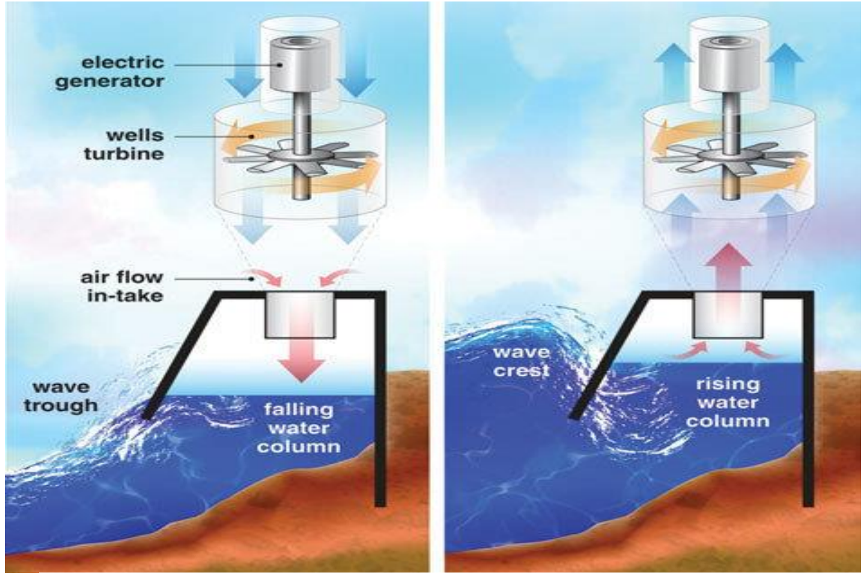


- Solution Proposal:
    - Use cheaper materials for build (ex. plastic)
    - Construction in shallow waters
    - Anticipation: **reduced cost compensates for lower power output**



Design Concept

- Stationary shoreline oscillating water column (OWC)
  - Similar to industrial OWCs



Theory:

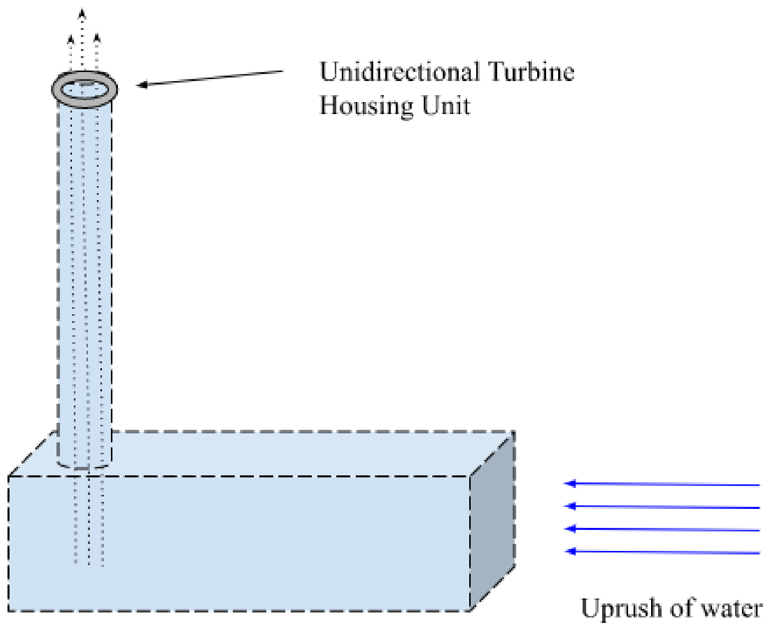
Swash

1. Water enters chamber at certain flowrate
2. Air inside chamber compressed, creating pressure gradient with open environment
3. Air flows out through pipe, spinning unidirectional turbine

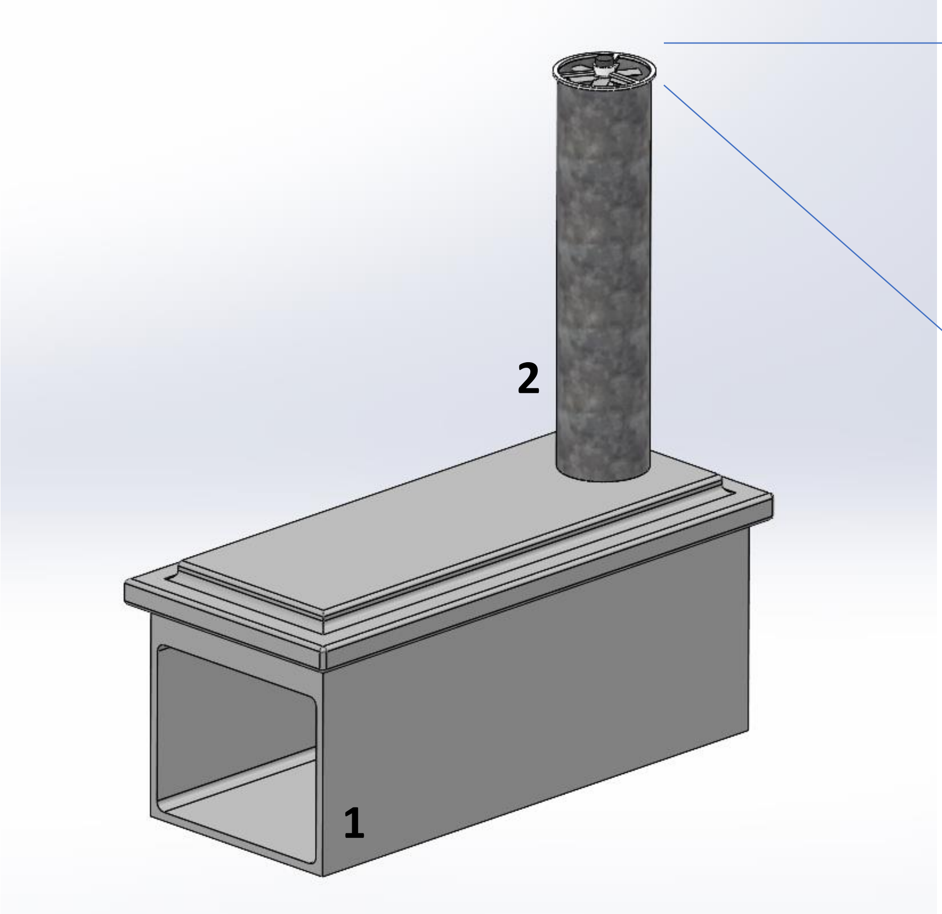
Backwash

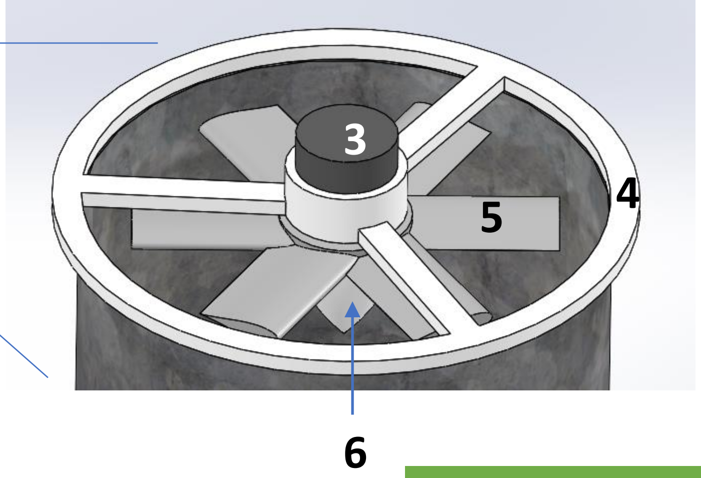
Water recedes at certain flowrate
Vacuum is created within chamber
Air flows in through pipe, spinning unidirectional turbine

Repeat



Prototype Design





No.	Product Description	Qty.
1	113 qt. Hefty Hi-Rise Clear Storage Box {16.8 in. (W) x 14.24 in. (H) x 36.04 in. (L)}	1
2	5 in. x 24 in. Galvanized Steel Round Duct Pipe	1
3	EUDAX Micro Motor Electricity Generator {Rated Speed: 6500 rpm; Rated Voltage: 12 V}	1
4	Generator Support Ring	1
5	Custom-made Joukovsky Turbine (OD: 4.10 in)	1
6	Tangent Ogive Nose Cone	1

Supporting Calculations

Theoretical Calculations:

Design Parameters:

$w := 12\ in = 0.305\ m$ Entrance Width

$D := 5\ in = 0.127\ m$ Pipe Diameter

$h := 9.5\ in = 0.241\ m$ Entrance Height

$d := 4.10\ in = 0.104\ m$ Turbine Diameter

$p_{air} := 1.225\ \frac{kg}{m^3}$ Density of Air

$C_p := 0.35$ Performance Coefficient
*Assumption based on standard Wells Turbine

A. Continuity Equation (v-in variable) - Assuming Incompressible Fluids

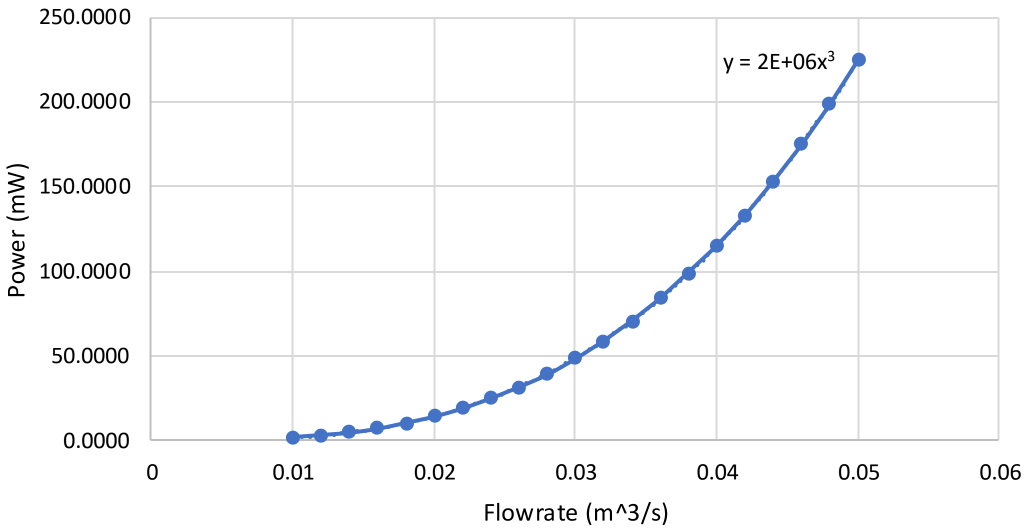
$$Q := h \cdot w \cdot v_{in}$$

$$v_{out} := 4 \cdot \frac{Q}{\pi \cdot D^2}$$ Exit Velocity

B. Power Equation

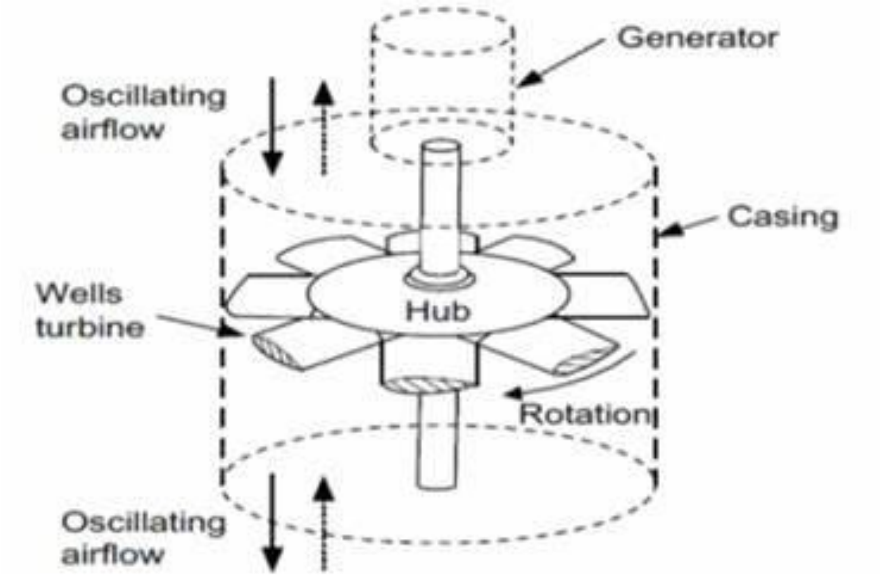
$$P_{out} := \frac{1}{2} \cdot C_p \cdot p_{air} \cdot \frac{\pi}{4}\ d^2 \cdot {v_{out}}^3$$

Figure 8: Theoretical Power Output at Various Flow Rates

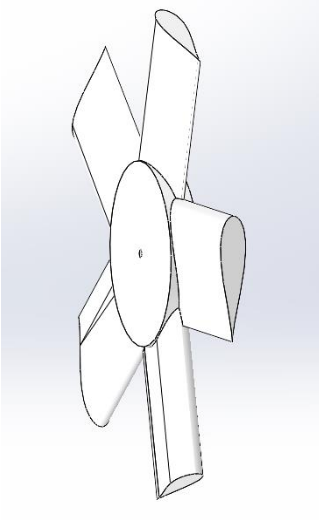


Unidirectional Turbine Design

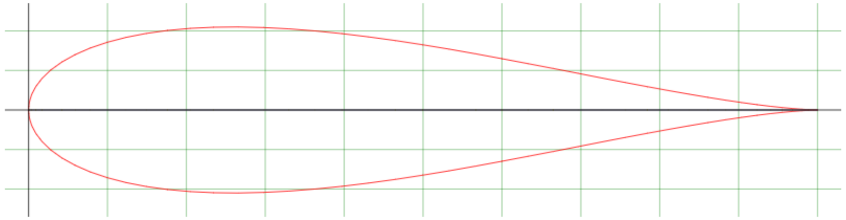
- Designed a fitting Wells Turbine (fixed pitch blades)
- Conducted comparison study of suitable airfoil types



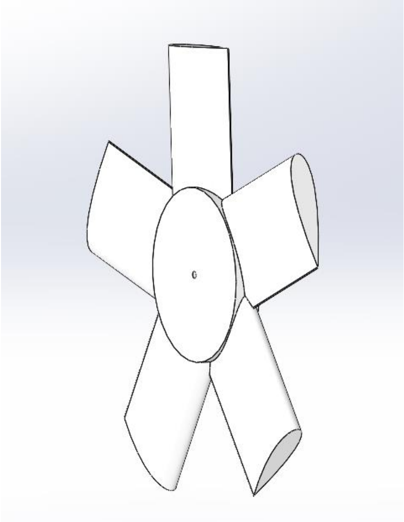
Candidate A:



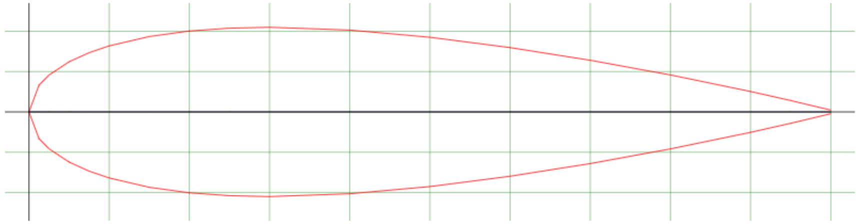
Joukovsky f=0% t=21% - Joukowski 21% symmetrical airfoil



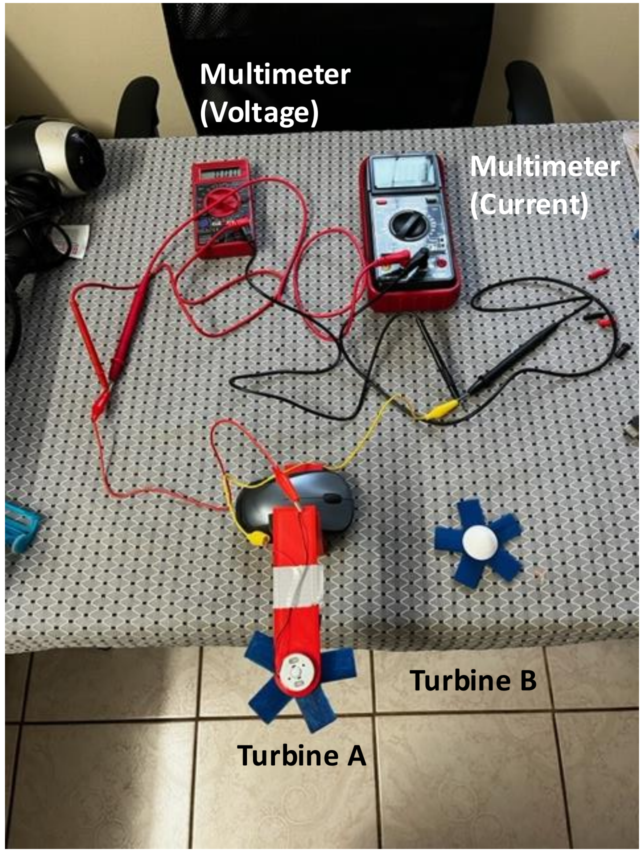
Candidate B:



NACA 0021 - NACA 0021 airfoil



Power Output Analysis w/ Varying Airfoils

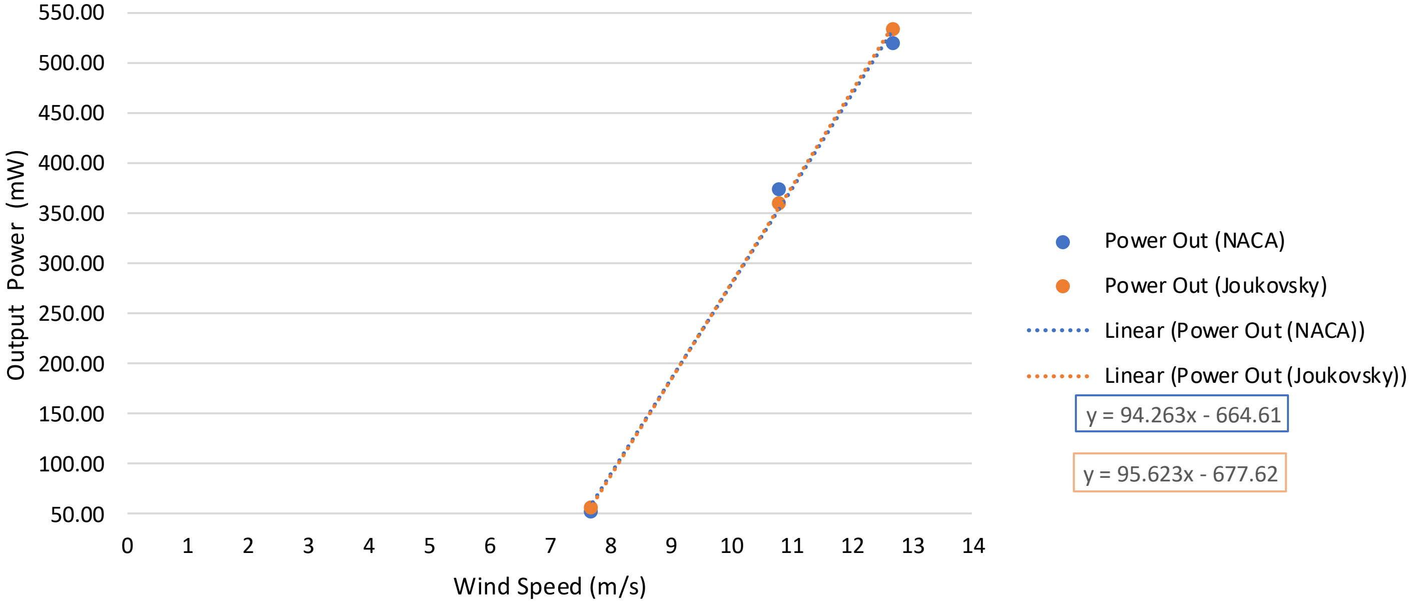


Experimental Setup

Table 1A: Correlation between Wells Turbine Airfoil Types and Power Output Components at Variable Wind Speeds

Trial	Airfoil Type	Windspeed (m/s)	Angular Velocity (RPM)	Voltage (V)	Current (mA)	Power Output (mW)
N1	NACA 0021	7.7	2519	4.33	12.30	53.26
N2	NACA 0021	10.8	4008	6.92	54.10	374.37
N3	NACA 0021	12.7	4531	7.86	66.10	519.55
J1	Joukovsky	7.7	2577	4.35	13.00	56.55
J2	Joukovsky	10.8	4028	6.78	53.20	360.70
J3	Joukovsky	12.7	4541	7.82	68.20	533.32

Graph 1B: Power Output at Various Windspeeds with Different Wells Turbine Airfoil Types

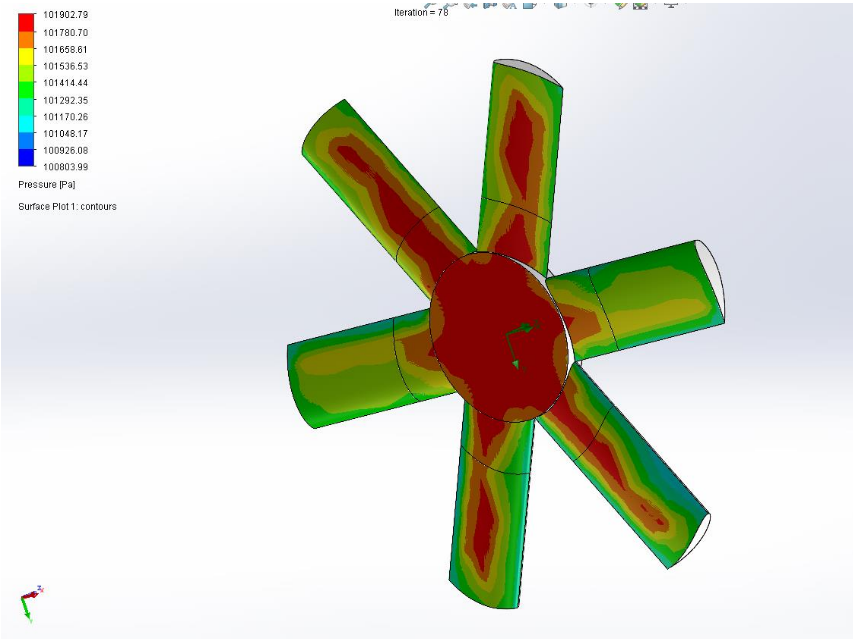


Turbine Nose Cone Static Analysis

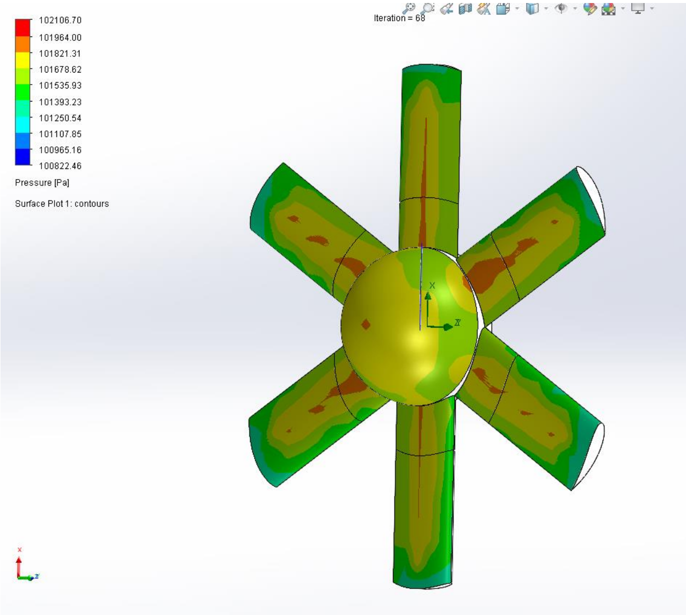
- Parameters:
  - Wind Speed: 30 m/s
  - Wind Direction: Z-axis
- Cd = 2 x Fd / (0.5 x p x A x v^2)

Drag Coefficients for Various Wells Turbine Nose Cone Geometries

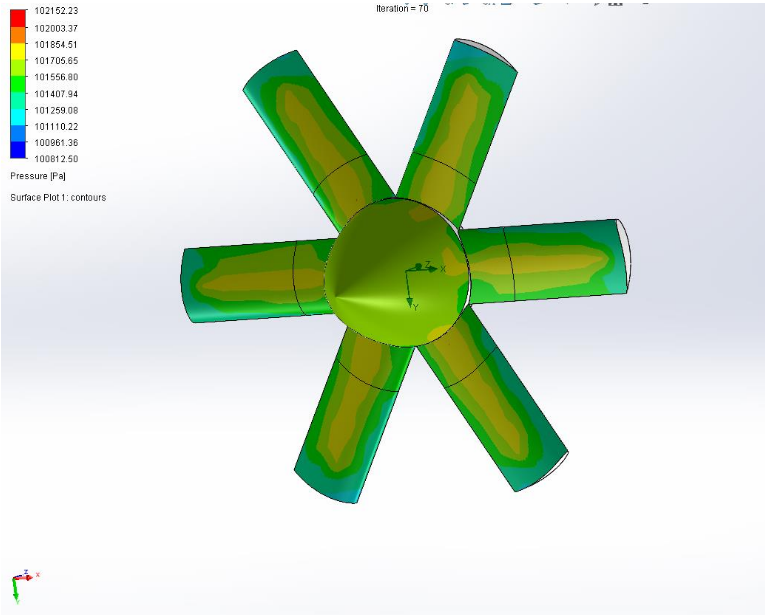
Nose Geometry	Drag Coefficient
Flat (control)	0.983
Blunt	0.685
Tangent Ogive	0.585



Flat (control)



Blunt



Tangent Ogive

Manufacturing

- Key Considerations
  - Body composition: Clear Polycarbonate
    - Lightweight, relatively cheap
    - Inert, resistive to corrosion
  - Duct Pipe composition: 5 in. (0.127 m.) Galvanized Steel
    - Corrosion resistant
    - Lightweight, relatively cheap
    - Assumed appropriate size (torque – speed balance)
  - Generator selection
    - Low starting torque
  - Custom Materials
    - 3D printed – easy manufacturability
  - Jigsaw to cut container
  - Epoxy resin as adhesive, silicone sealant for air-tightness

Beach Attempt

Testing

- Tested power output at swimming pool
  - Voltage, current data collected from multimeter
  - Flowrate measured by timing dip/rise from green line

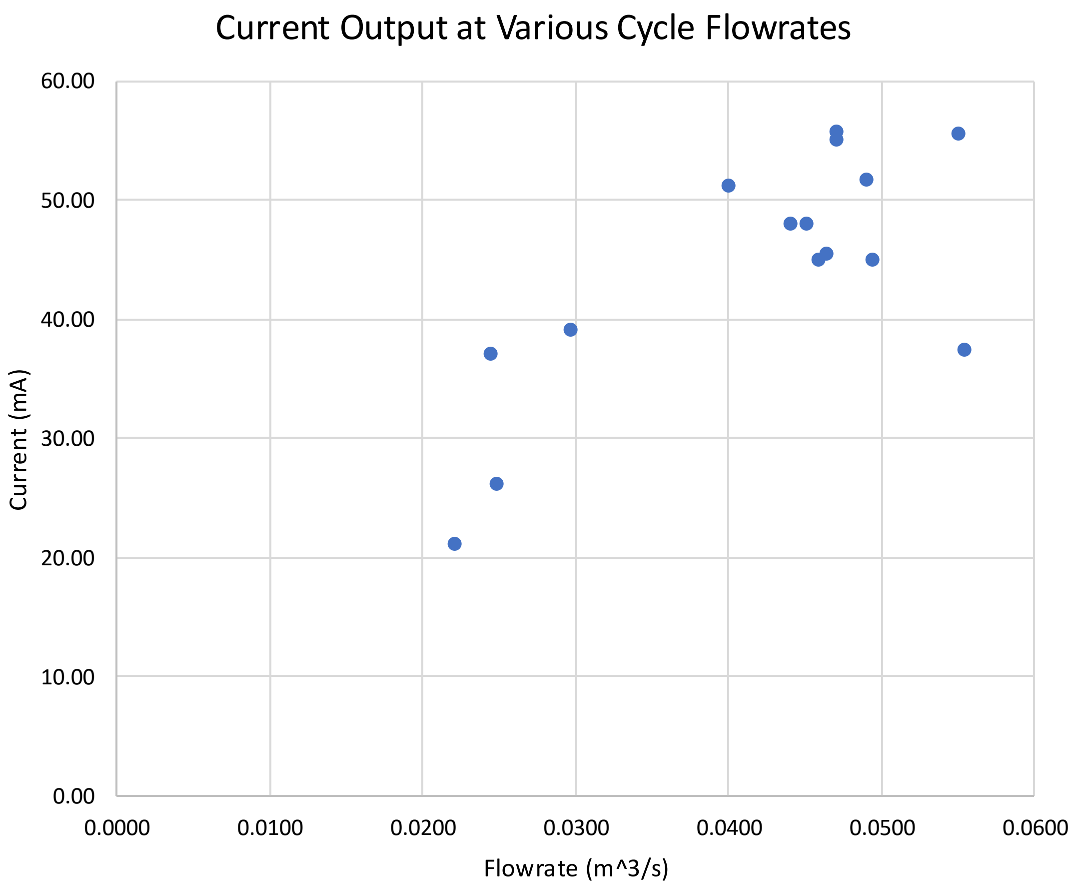
Results

- Pool Test Current Data

Full Cycle Current Output at Various Flowrates:

Trial	Cycle Time (s)	Flowrate (m^3/s)	Current (mA)
1	3.51	0.0221	21.20
2	3.13	0.0248	26.20
3	2.61	0.0297	39.20
4	3.18	0.0244	37.10
5	1.94	0.0400	51.20
6	1.58	0.0491	51.8
7	1.65	0.0470	55.1
8	1.72	0.0451	48.1
9	1.4	0.0554	37.4
10	1.41	0.0550	55.6
11	1.76	0.0440	48
12	1.65	0.0470	55.8
13	1.69	0.0459	45.1
14	1.67	0.0464	45.6
15	1.57	0.0494	45.1

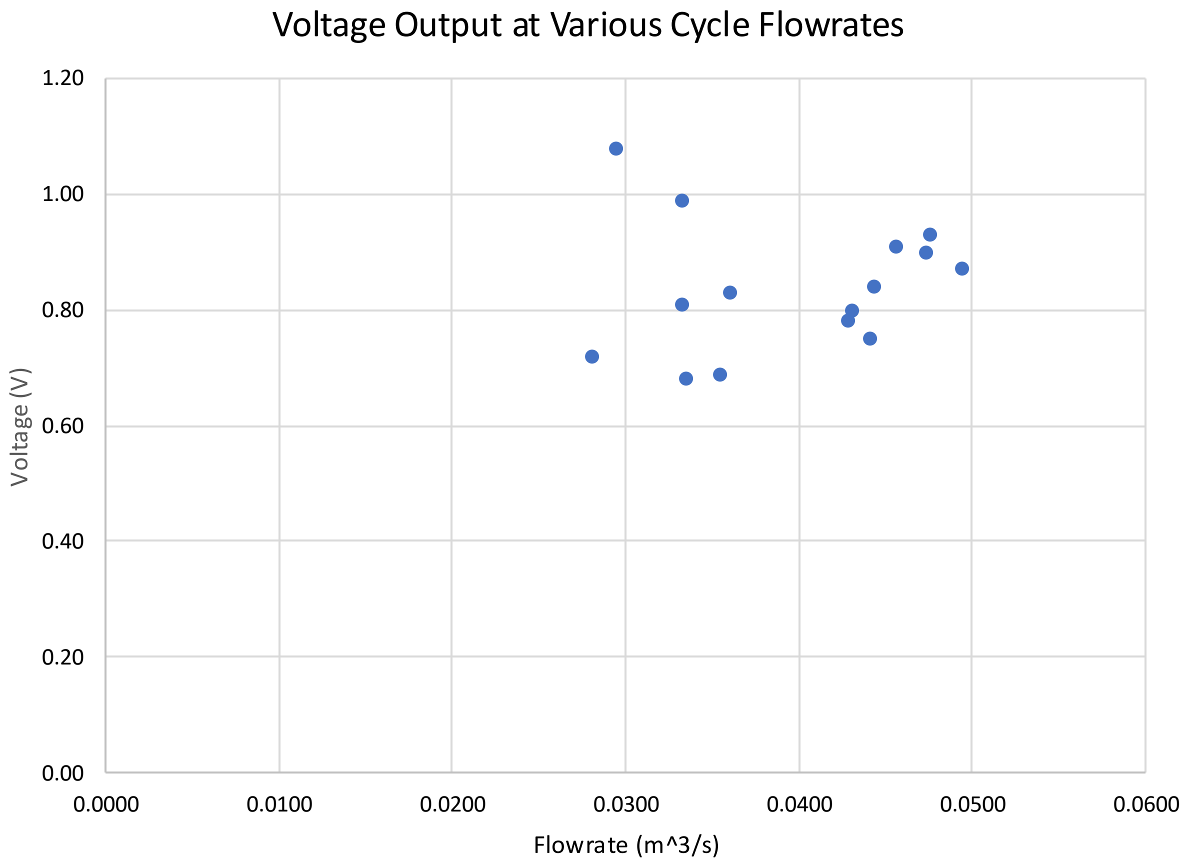
Average Flow Rate: 0.0417 m^3/s
Average Current: 44.167 mA



Results

- Pool Test Voltage Data

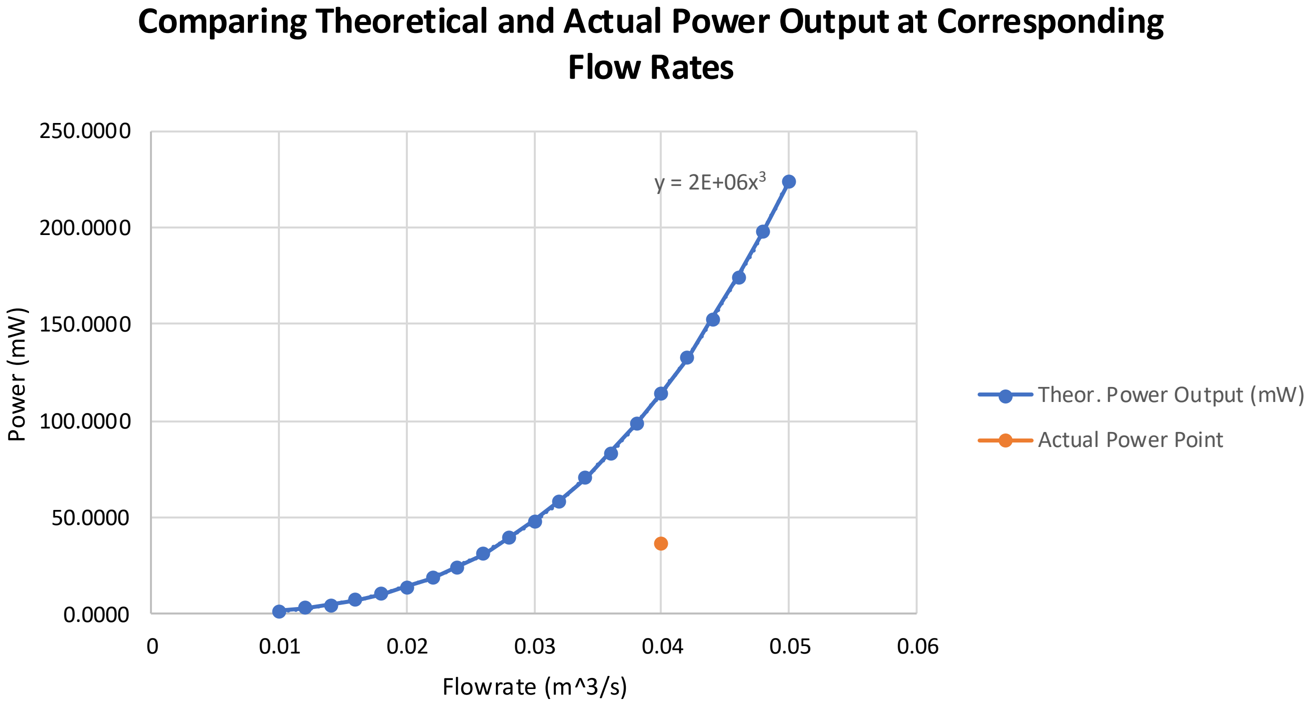
Full Cycle Voltage Output at Various Flowrates:			
Trial	Cycle Time (s)	Flowrate (m^3/s)	Voltage (V)
1	2.19	0.0354	0.69
2	2.32	0.0334	0.68
3	2.33	0.0333	0.99
4	2.63	0.0295	1.08
5	1.75	0.0443	0.84
6	2.15	0.0361	0.83
7	2.76	0.0281	0.72
8	2.33	0.0333	0.81
9	1.76	0.0440	0.75
10	1.8	0.0431	0.8
11	1.81	0.0428	0.78
12	1.57	0.0494	0.87
13	1.64	0.0473	0.9
14	1.7	0.0456	0.91
15	1.63	0.0476	0.93



Average Flow Rate: 0.3955 m^3/s
Average Current: 0.838 V

Concluding Notes

- Device able to generate power, albeit a small amount
  - Power Output: 37 mW @ ~0.04 m^3/s
  - Theoretical: 114.79 mW
    - (32.23% of theoretical)



- Causes for Low Power Output:
  - Air leaking
  - Human error when timing

Future Work

- Increase entrance width for greater flow rate
- Design for optimal turbine size (gear ratio)
- Increase prototype weight for beach application

Acknowledgements

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Pool Calculations

Pool Full Cycle Calculations:

Total Flow Rate Calculation - Sample (Trial 1, Current Data)

$w := 0.305\ m$ $h := 0.241\ m$ $l := 0.52705\ m$

$V := w \cdot h \cdot l = 0.039\ m^3$

$t_d := 2.44\ s$ Dip Time

$t_r := 1.07\ s$ Rise Time

$V_{cycle} := 2 \cdot V = 0.077\ m^3$ Total volume displacement in a given cycle

$T := t_d + t_r = 3.51\ s$ Total Cycle Time

$$Q_t := \frac{V_{cycle}}{T} = 0.022\ \frac{m^3}{s}$$