IPRO It takes a team!
INTERPROFESSIONAL PROJECTS PROGRAM

IPRO 349: Fuel Cells for Unmanned Underwater Vehicles

ILLINOIS INSTITUTE OF TECHNOLOGY

IPRO Goals

- Investigate potential use of fuel cell to power unmanned underwater vehicle (UUV)
  - o Replace the use of conventional battery power
  - o Research and design fuel cell power system
    - > Design centered on a sodium borohydride ($NaBH_4$) fuel cell
    - > Hydrogen peroxide oxidant (H_2O_2)
- Design a complete submersible package including:
  - o Dimensions
  - o Control surfaces
  - o Material requirements

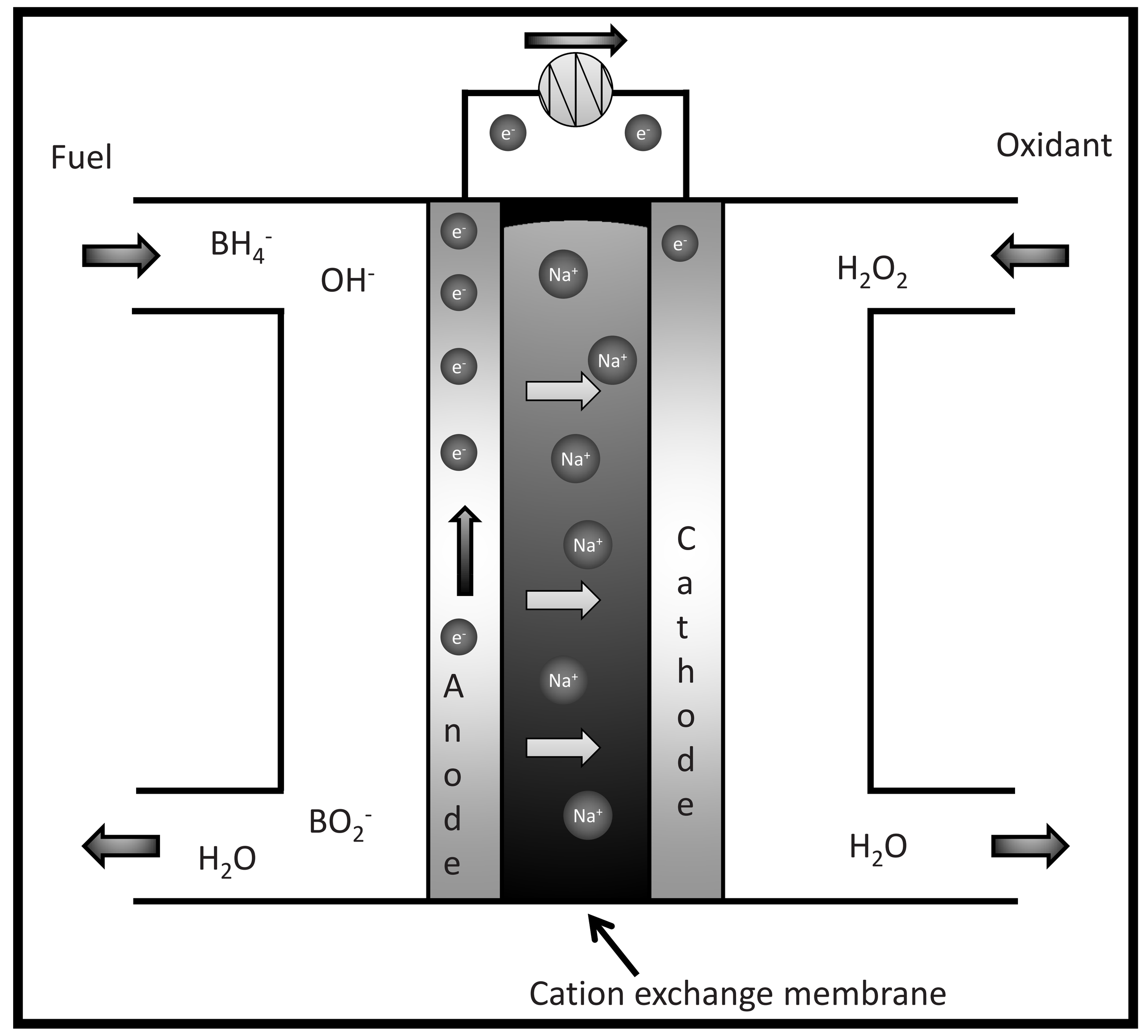
Fuel Cell Background

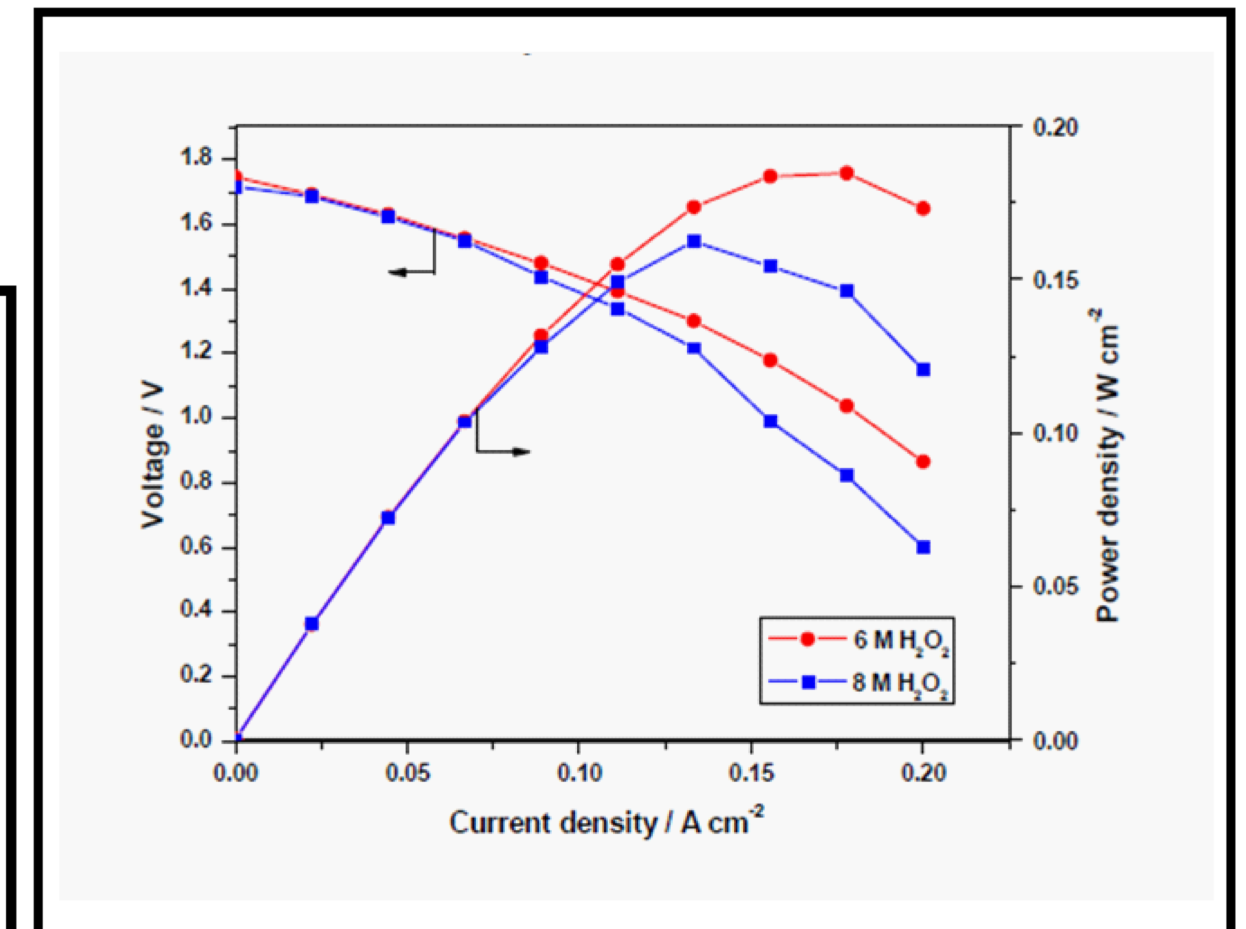
- Unmanned Underwater Vehicles (UUV) operate in conditions impossible for manned submarines
  - o Naval applications for UUV's include reconnaissance and sabotage
  - o Current UUV technology needs to improve on stealth and range
- Current fuel cell technology
  - o Hydrogen polymer electrolyte membrane fuel cells most common
  - o Research for UUV applications focus on $NaBH_4$ fuel cell
  - o Two to three times more efficient than internal combustion engines
- $NaBH_4$ fuel cell technology
  - o Relatively low environmental impact
  - o Liquid reactions produce no gases in cell

Fuel Cell

The fuel and oxidant selected for this system was a sodium borohydride fuel and hydrogen peroxide oxidant. All relevant reactions are as follows:

Anode: $BH_4^- + 8\,OH^- \rightarrow BO_2^- + 6\,H_2O + 8\,e^-$ (-1.24 V)
Cathode: $H_2O_2 + 2\,H^+ + 2\,e^- \rightarrow 2\,H_2O$ (1.77 V)
Overall: $BH_4^- + 8\,OH^- + 4\,H_2O_2 + 8\,H^+ \rightarrow BO_2^- + 14\,H_2O$ (3.01 V)



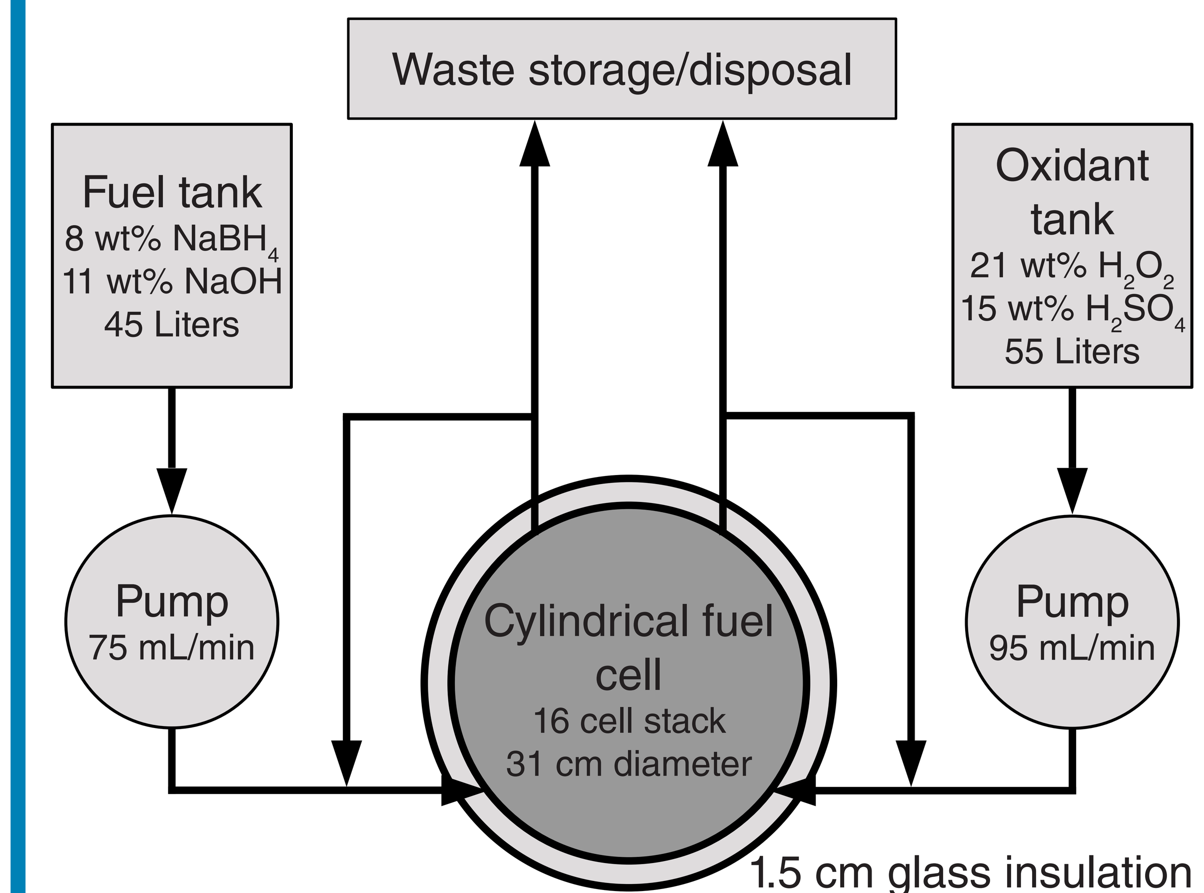


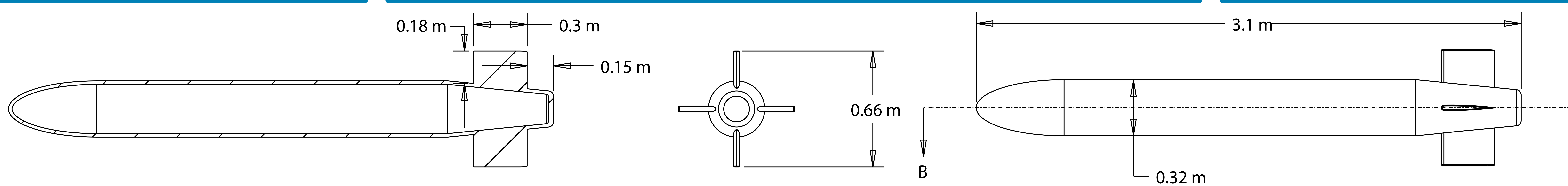
Exact system specified using:
- Chemical reaction produces no gases
- Minimal environmental impact
- Power requirements estimated by propulsion group (2 kW)
- Polarization data from literature[1] (above)
- Specific membrane selection from literature (not shown) based on:
  - > Sodium fouling resistance

Literature design overview

Fuel Cell Design Results

Number of cells	16
Cell operating voltage	1.5 V
Fuel cell length	29 cm
Fuel cell volume	23 L
Cell power output	2 kW
Cell voltage	24 V
Range	70 km



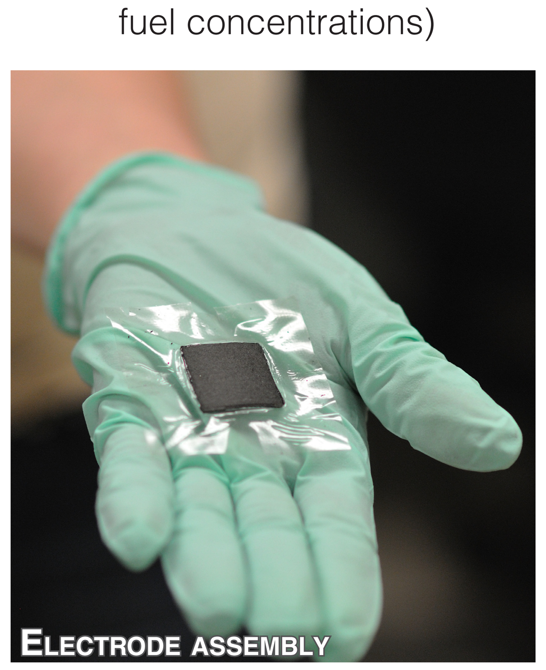


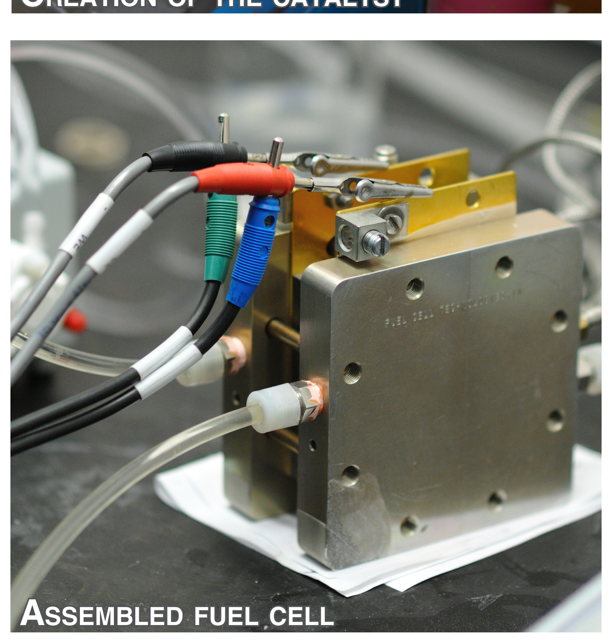
Experiments

This project also included the creation and evaluation of an actual sodium borohydride fuel cell.

- Creation of a 97% gold/3% platinum on carbon catalyst.
- Assembly of the fuel cell.
- Evaluation of the fuel cell.
  - > Polarization data (varying catalyst loading, membrane thickness and fuel concentrations)

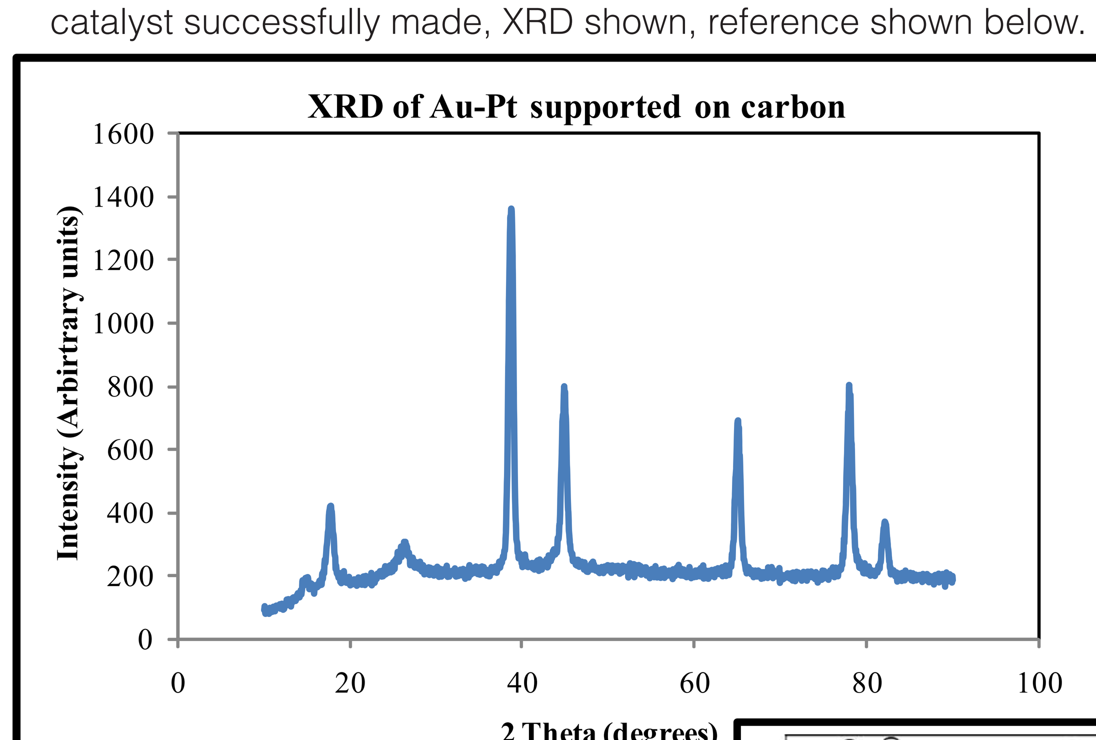

Creation of the catalyst

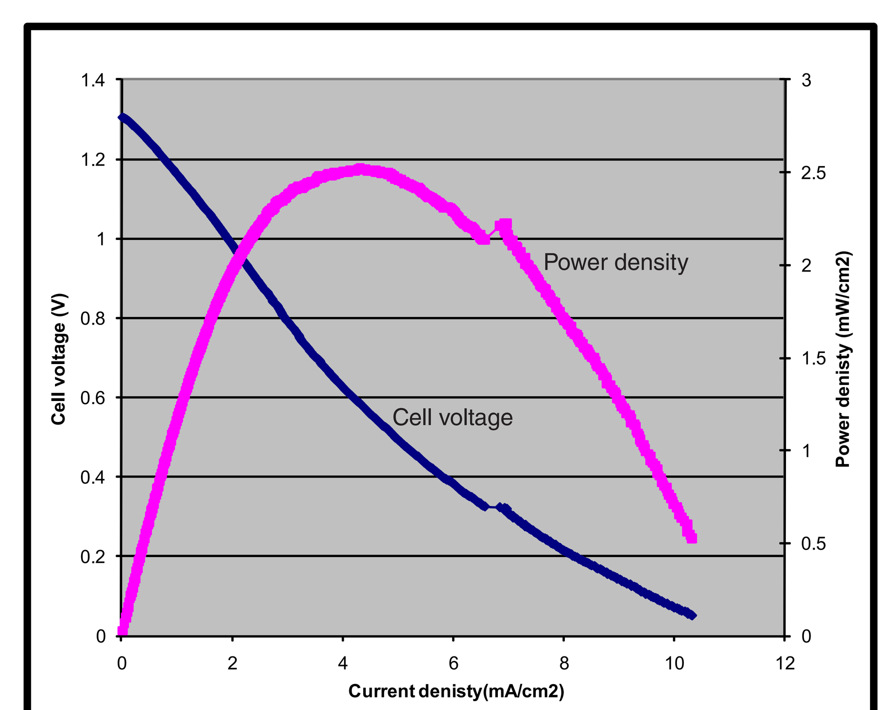

Electrode assembly


Assembled fuel cell

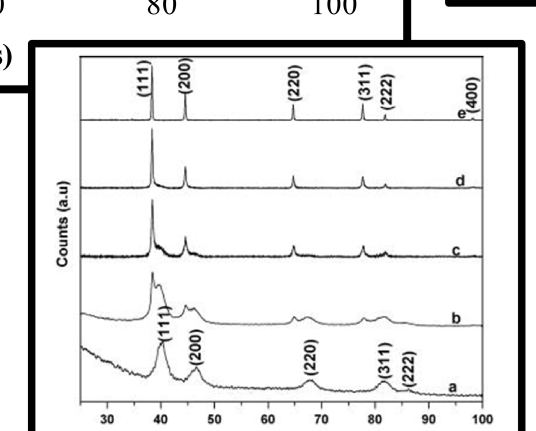
Experimental Results

- Two attempts to make catalyst, 97wt% Au, 3wt% Pt on carbon catalyst successfully made, XRD shown, reference shown below.





Reference XRD[3]
a: 100% Pt on carbon catalyst
b: 25% Au/75% Pt on carbon catalyst
c: 50% Au/50% Pt on carbon catalyst
d: 75% Au/25% Pt on carbon catalyst
e: 100% Au on carbon catalyst



- Fuel cell performance results presented above.*
  - > Performance of second fuel cell using Nafion 117
  - > Other trials used varied flow rates as well as Nafion 112
- Nafion 112 cell did not perform as well
  - > Thinner Nafion not suitable for liquids

* More detailed results will be presented at IPRO Day, Apr. 23 at IIT's main campus

Environmental Concerns

- Concentrations of BO_2^- and BH_4^- are low enough to not impact environment in the event of a spill
- Other components in reaction degrade quickly in the environment
- H_2 produced in side reactions is in low enough quantities to not adversely effect ocean at depths

Future Work

There still remains a lot of work that needs to be completed before the entire UUV can be prototyped:
- Several more iterations of the power and space requirements within the UUV
- Effective methods of defouling the membrane from sodium ions

Bibliography

[1] A Self-Supported Direct Borohydride-Hydrogen Peroxide Fuel Cell System, Shulka A.K. et al, **Energies**, 2009, 2, 190-201.

[2] A Direct Borohydride/ Hydrogen Peroxide Fuel Cell with Reduced Alkali Crossover, Raman R. K., Shulka A. K., **Fuel Cells**, 2007, 3, 225-231.

[3] **Journal of Power Sources: Volume 187, Issue 1**, Feb. 2009 page 19

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Propulsion Background

- Survey of current technology
- Design a vessel around the propulsion system
  - > Theoretical design
  - > Practical design
- Fully specify and model a practical UUV
  - > Modeled in Pro/E

Initial Modeling

- Initial specifications were based off of research

	Small UUV	Medium UUV	Large UUV
Length (m)	1.5-3	5-7.5	10-15
Diameter (m)	0.20-0.40	0.60-1.0	1-2
Energy (kWh)	2.5	5.0	10.
Endurance (at 2 knots *1.03 m/s*)	8 hours	4-6 hours	4 hours
Dry weight (kg)	100	200-300	300+

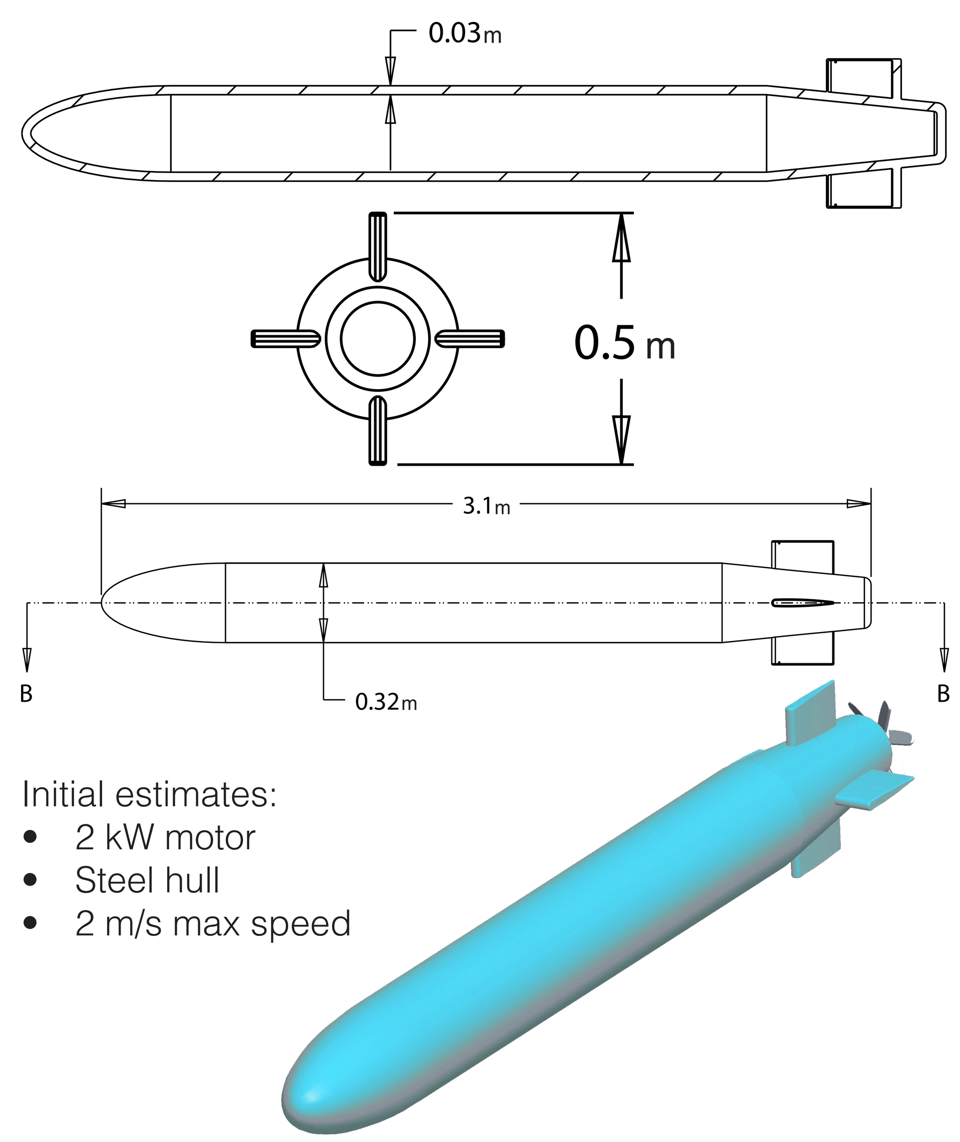
- Chose "medium" size
- Based initial dimensions off of a shortened Mk. 48 mod. 7 torpedo (current US torpedo)
  - > 5.79 m long
  - > 0.533 m diameter
  - > 1676 kg (with 295 kg warhead)
  - > Classified range ("greater than 5 miles")
  - > Classified depth ("greater than 1200 feet")
- Chose shorter length of ~3 m
- Chose narrower diameter of ~0.3 m
  - > Implied lighter weight of ~500 lbs (~225 kg)

Theoretical Design

Design criteria:

- "Medium" size (from table on the left)
- Quiet and ultra quiet operation
- Average sea water properties

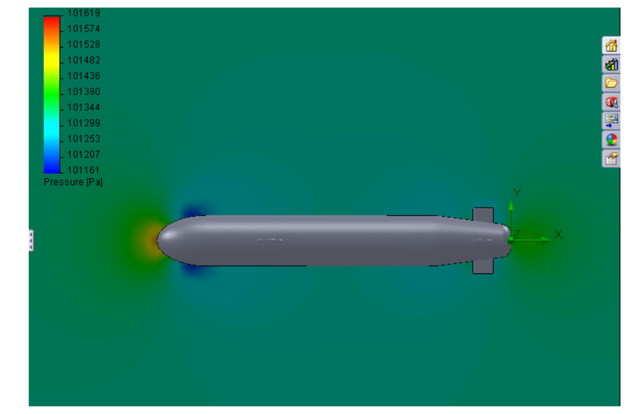
Initial sketches:



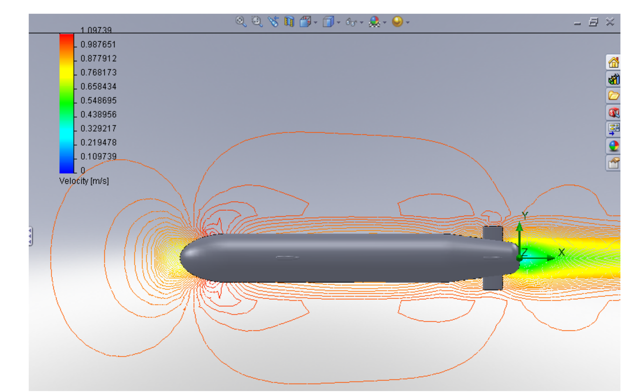
Initial estimates:

- 2 kW motor
- Steel hull
- 2 m/s max speed

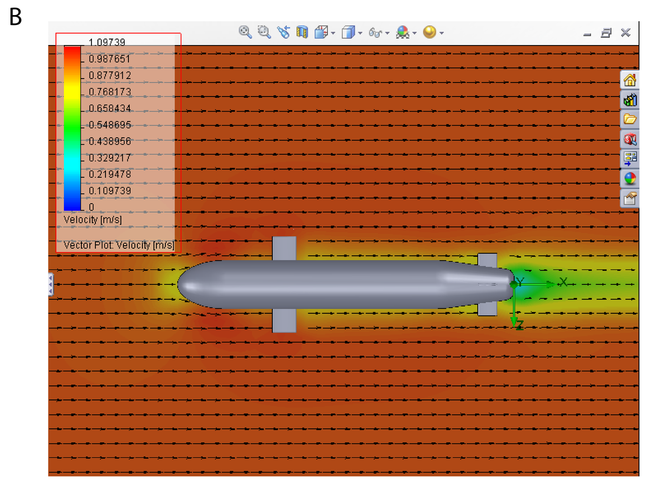
Initial computations:



- Pressure calculations on initial design (Side/Top)



- Velocity contours (Side/Top)

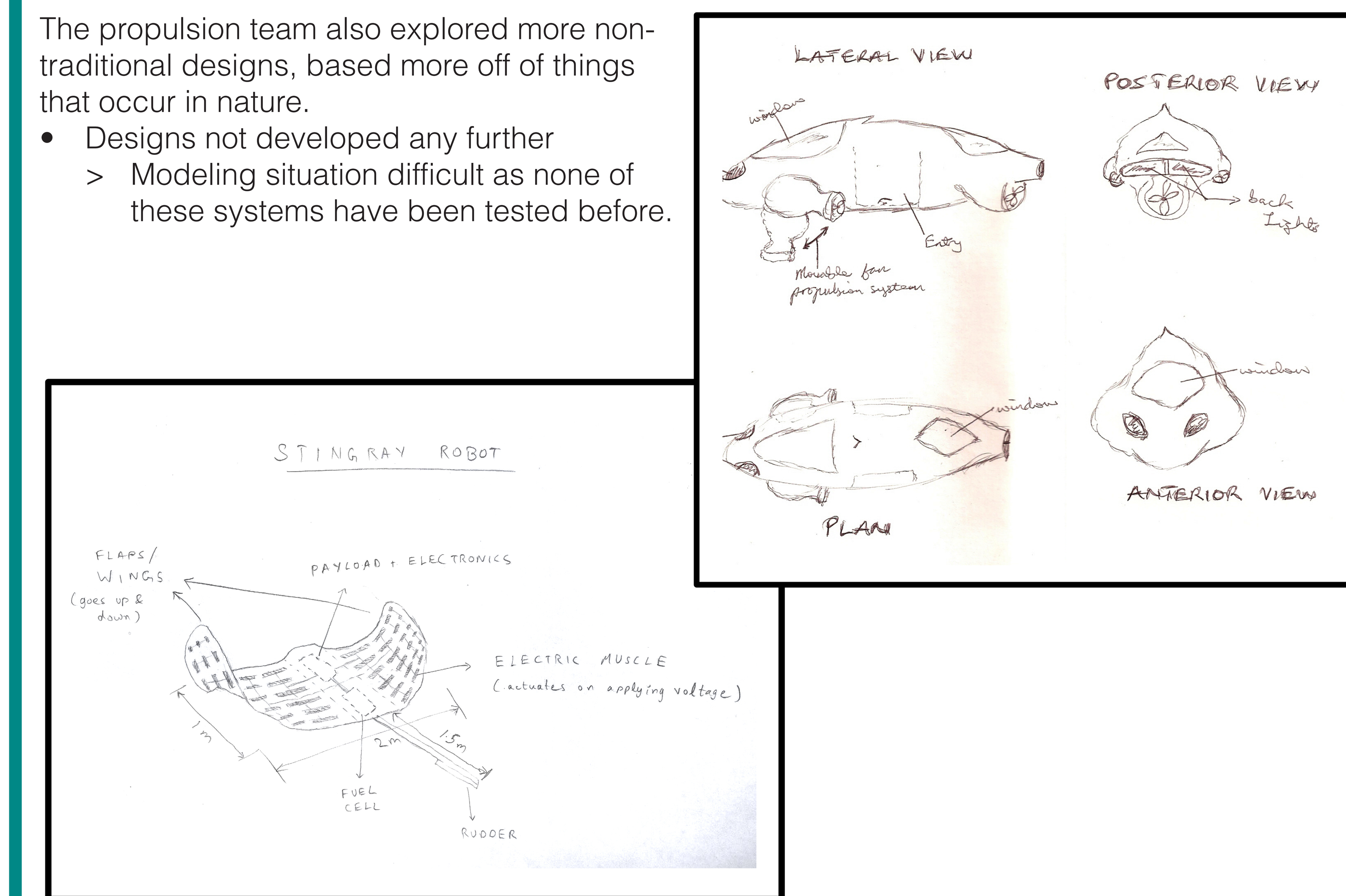


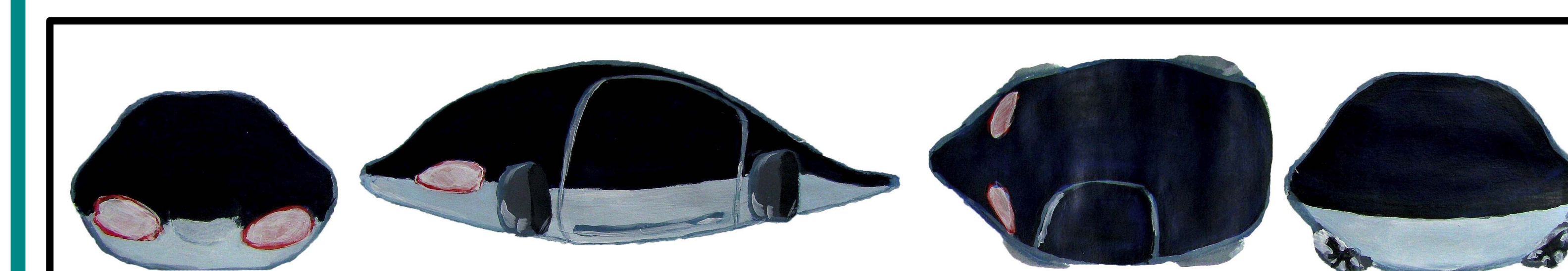
- Velocity vectors (Side/Top)

Alternate Designs

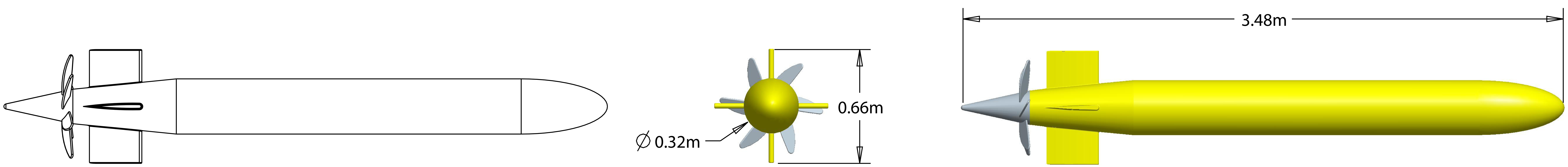
The propulsion team also explored more non-traditional designs, based more off of things that occur in nature.

- Designs not developed any further
  - > Modeling situation difficult as none of these systems have been tested before.



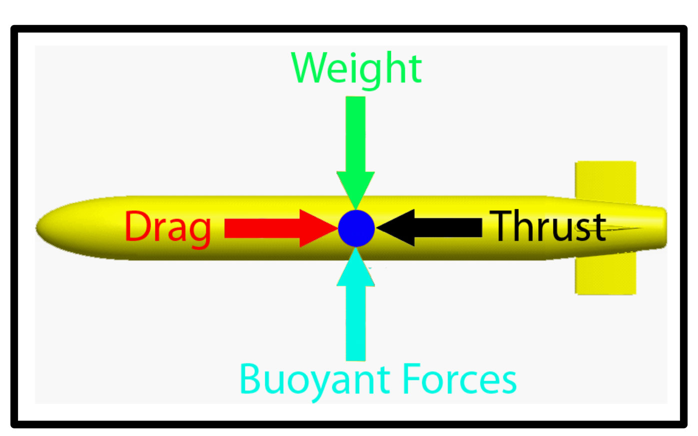


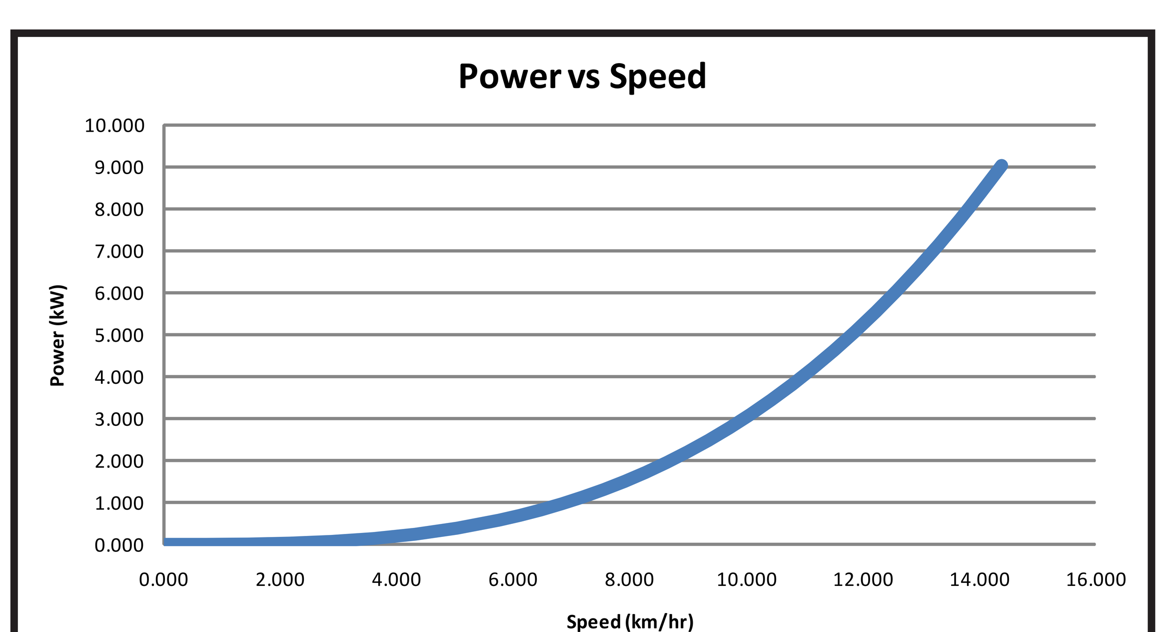
Front Left side Top Rear



Sizing

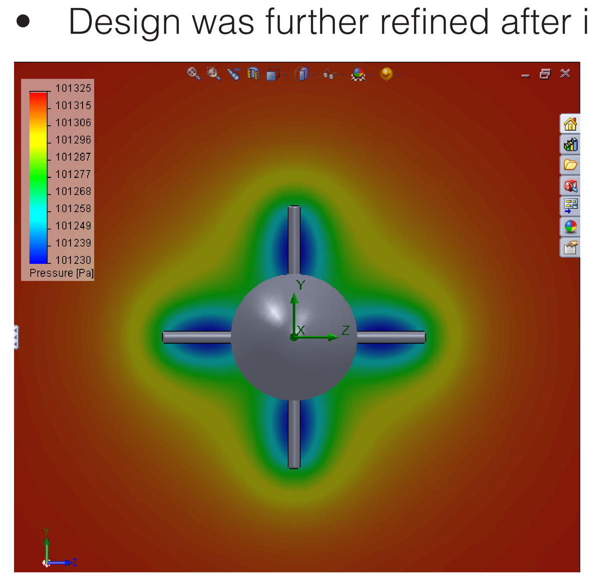
- Initial engine size requirements were needed
- Final power determined to be approximately quadratic function
  - > Based off of research numbers, ~2 m/s chosen to be approximate speed
  - > 2 kW power supply determined

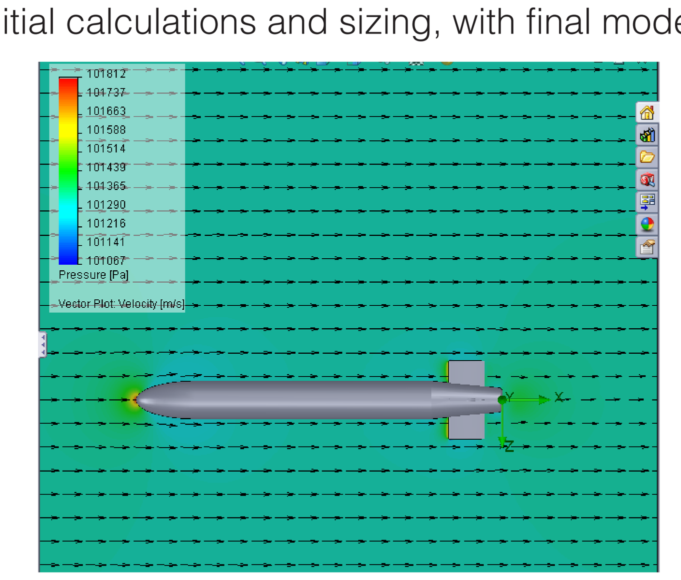




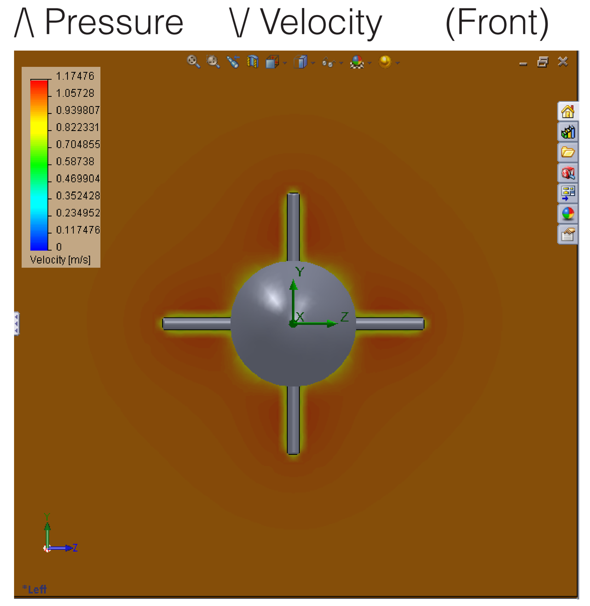
Simulations

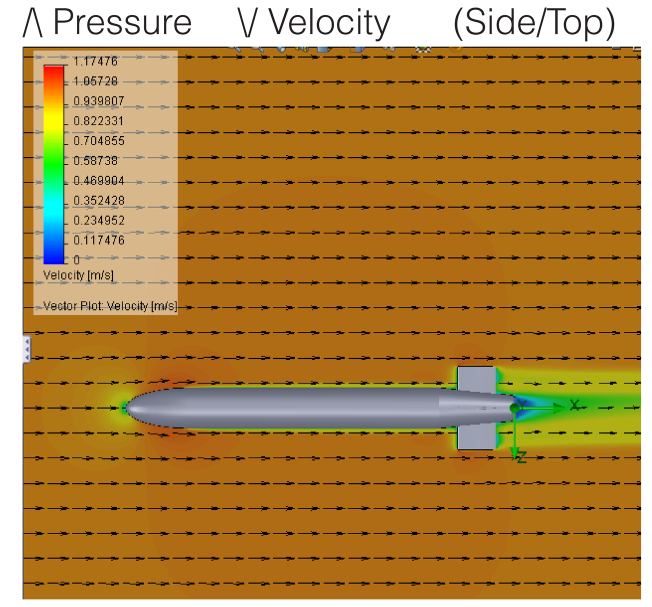
- Design was further refined after initial calculations and sizing, with final models (with proper control surfaces) shown:



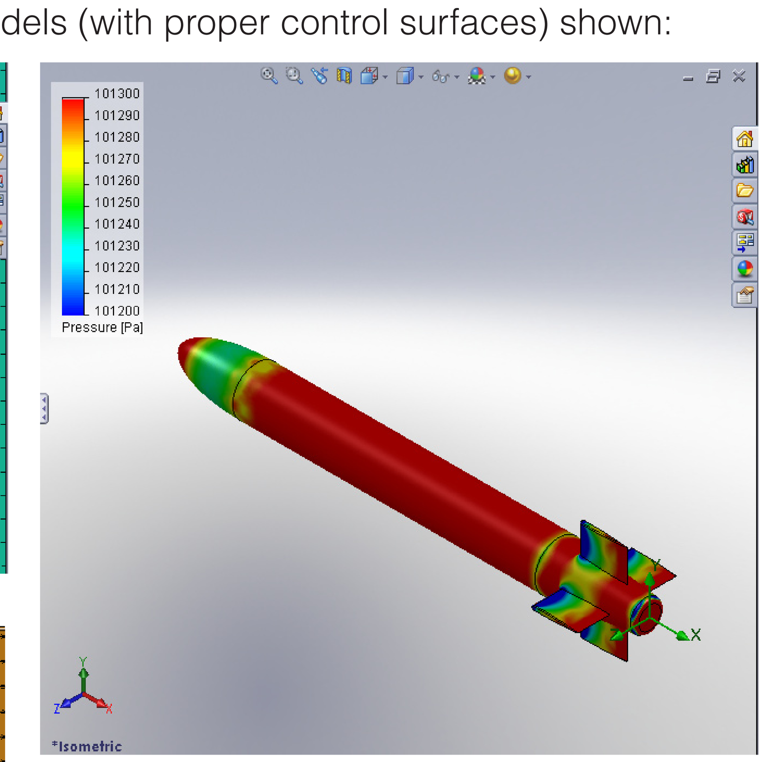


∧ Pressure ∨ Velocity (Front)

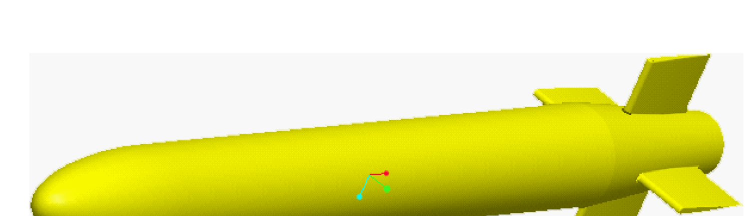




∧ Pressure ∨ Velocity (Side/Top)



∧ Surface pressure map



Future Work

- More refining on the hull shape to address stagnation issues
- More detailed drag calculations and material choices
- Detailed propeller design

Ethical Issues

- Minimal environmental impact with concentrations being used and intended environment
- Properly designing a conrol system to minimize impact to marine life
  - > Systems to avoid collisions with marine life
  - > Use of sensors that will not harm marine life
  - > Proper sealings to not impact operating environment
- No violations of current copy rights

The 349'ers

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