Hydrogen-Powered Model Submarine

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Background / Objective

The maritime industry faces a shortage of sustainable transportation solutions. Developing a clean, hydrogen-based propulsion system to generate thrust will minimize environmental impact by only producing hydrogen gas (H_2) and aluminum hydroxide ($Al(OH)_3$).

Other potential fuel sources included Mg, Zn, and Pt.
Al was chosen for its cost efficiency, light weight, and energy density.

$$Al + H_2O \rightarrow Al(OH)_3 + H_2$$

Gallium + indium eutectic permeates the Al oxide layer in order for the Al to be reactive with water.

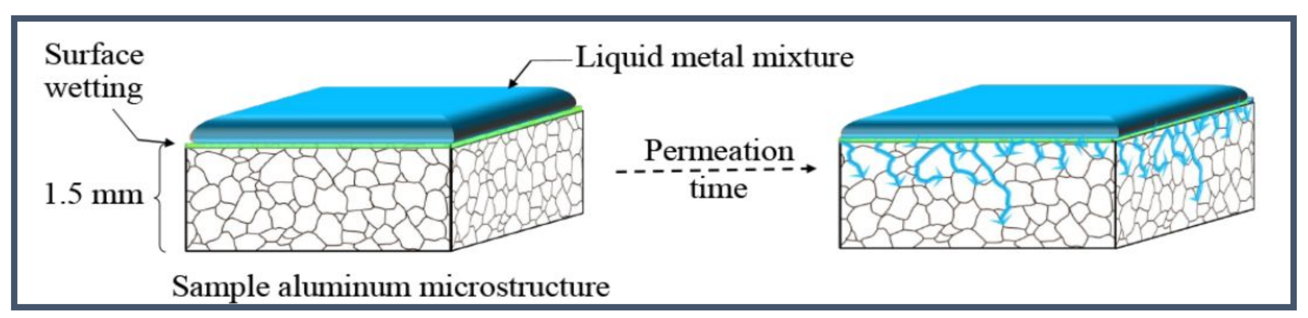


Figure 1: *Permeation of eutectic Gallium-Indium alloy to enable Aluminum for reaction with water.*[1]

Design Opportunities

- Innovative, scalable propulsion design
- Cleaner, more efficient maritime transportation
- Pioneering application of chemical-based propulsion

Design Challenges

- Reaction control
- Maintaining stability/buoyancy
- Ensuring repeatability and reliability
- First application of this reaction: lack of information

Metrics for Success

- Producing movement through water with our propulsion system
- Matching or exceeding the speed and battery life of the submarine's original electrical propulsion system
- Containing waste material and preventing leakage into water

Methods

Hydrogen Flow Rate
- Testing repeatability and rate of gas production

ANSYS Simulation
- Simulating water flow around propulsion system designs

Base Submarine Propulsion
- Driving electric submarine underwater for baseline measurements

Underwater Reaction Propulsion
- Operating fully assembled submarine propulsion system underwater

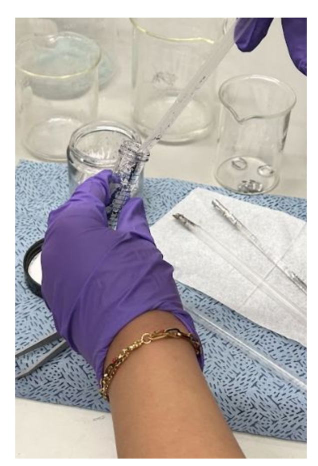
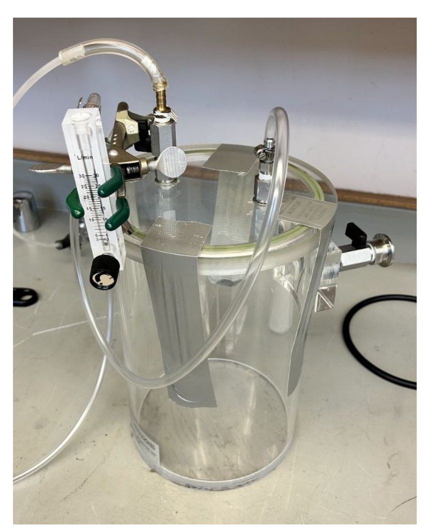


Figure 2 (left): *creating Indium-Gallium eutectic*

Figure 3 (right): *coating Al wires in eutectic*

Hydrogen Production Test Results for Coated Pellets and Wires



We reacted 3 varying aluminum pellet sizes (1 mm, 2 mm, and 6-12 mm) to observe correlation between surface area and reaction/flow rate.

Large pellets produced consistent, weak flows while 1mm pellets produced a strong "burst."

2mm pellets (later 2mm wire) yielded an ideal medium reaction.

Figure 4: *Reaction chamber used for flow meter testing*

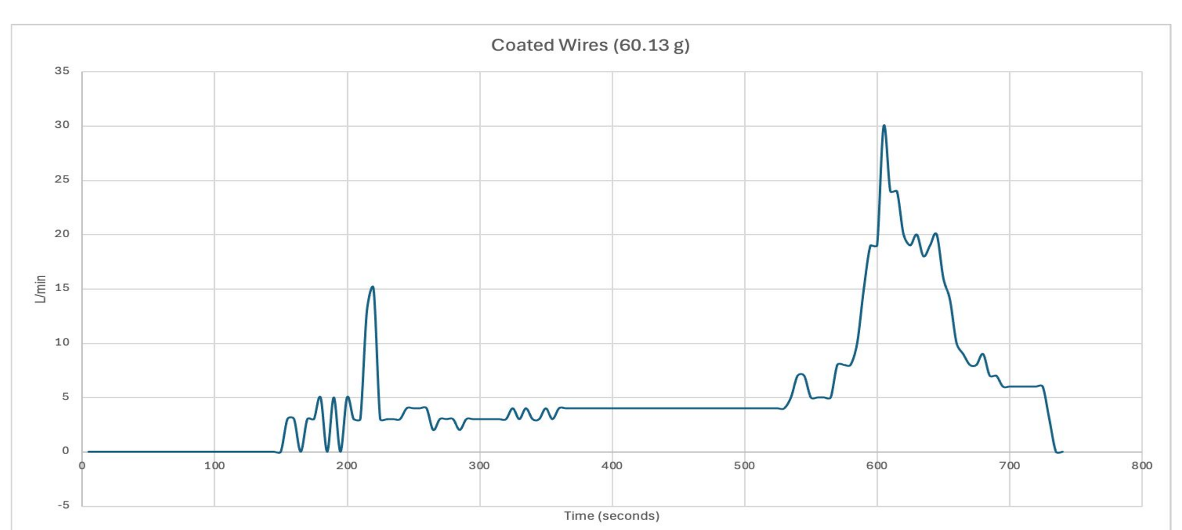


Figure 5: *Flow meter results for aluminum wires*

Propulsion design

Design 1
- Threaded attachment design
- Flow path passes through reaction chamber
- Steel mesh on inlet and outlet

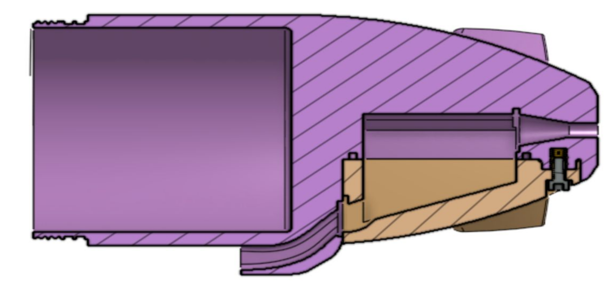


Figure 6: *Design 1*

Design 2
- Flow path passes above reaction chamber
- Mesh separating the two components to contain reactants

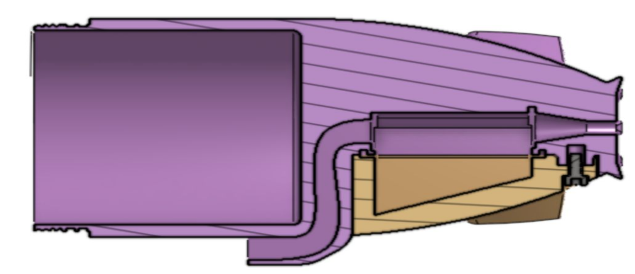


Figure 7: *Design 2*

Design 3
- Standalone submarine design
- Increased reaction chamber volume
- Improved nozzle design

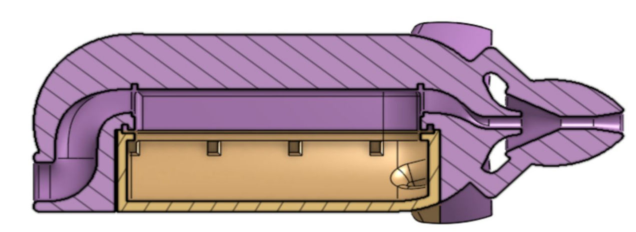


Figure 8: *Design 3 (final)*

ANSYS Simulation / Base Sub Propulsion Results

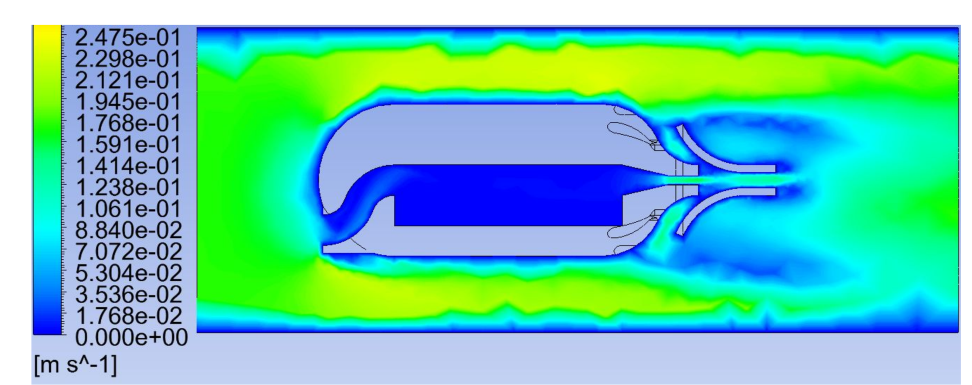


Figure 9: *Fluid simulation of final design*

ANSYS Results
- High velocity jet at outlet
- Low velocity at inlet and inside reaction chamber

Base Sub Results
- Avg. speed of electrical propulsion: 0.173 m/s
- Battery life of electrical propulsion: 1hr 54 min.

This equates to almost 1.2 km travelled per the average speed.

Water Test Results

Our final design achieved a maximum speed of 0.2 m/s for 3 seconds, and produced hydrogen for more than 30 minutes.

Pre-Test
- Final prototype 3D printed using PLA
- Reaction chamber loaded with 60g of treated aluminum

Figure 10: *The submarine before testing, with the reaction chamber open and coated aluminum wire segments inside.*

Post-Test
- Heat generated from exothermic reaction melted PLA
- Volume expansion of reactants warped and split reaction chamber open
- Combined effects caused severe leaking of reactants

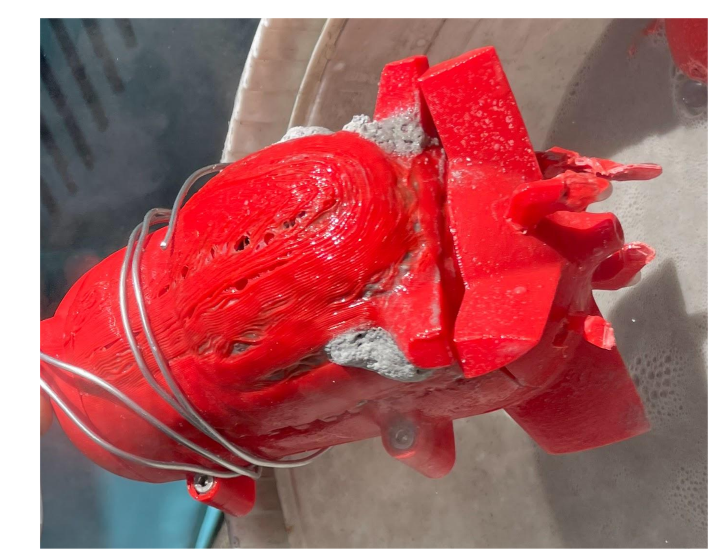


Figure 11: *The submarine after testing, showing melted PLA.*

Future Research

Flow optimization - Controlling flow of water/gas within the propulsion system during reaction.

Materials Selection- Sourcing a material that can withstand the heat produced during the exothermic reaction.

Accounting for Expansion - Produced volume of Al_2O_3 exceeds volume of Al fuel, requiring further design considerations.

Filtering Waste - Al_2O_3 is a toxic waste product that needs to be contained

Recycling Eutectic - Eutectic material showed promising recyclability as it does not mix with water or waste material.