Earth Prototype of NASA's Exploration Vehicle: Design, Performance, and Adaptations to Venus

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Super Sonic Flow Chokers

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Introduction

Problem

- NASA needs us to design and build an Earth prototype hovercraft with the ability to pick up and carry payloads across the surface of Venus
  - Pick up, carry, and deposit payloads of 10 to 50 grams
  - Have a system mass under 0.9kg
  - Store in 56 cm x 56cm x 23cm enclosure
  - Use only NASA-supplied materials

Tasks

- Design, build, test Earth prototype of Venus hovercraft
- Adapt Earth prototype for Venusian environment

Purpose

- Present design and performance for Earth prototype hovercraft
- Present adaptations for Venusian environment

Summary

Design Features of Earth Prototype

- System mass: 788 grams
- Net lift: 8.12 N
- 15.5in square shell design
- Forward mounted directional propeller
- Sweeping arm retrieval mechanism
- Meets all requirements

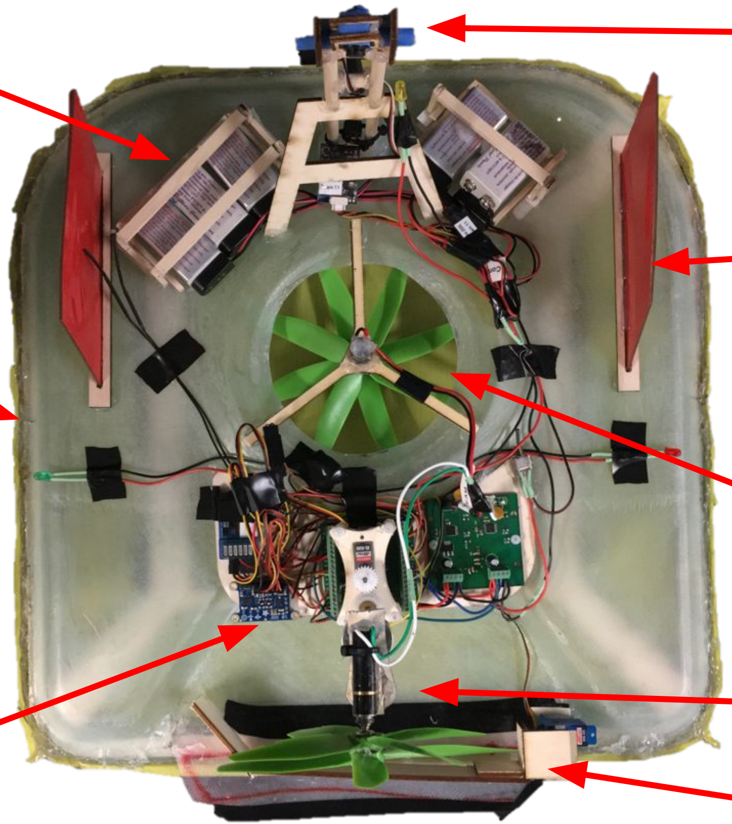
Performance and Status of Earth Prototype

- Average time for speed test: 23.7 sec
- Average time for figure-8: 147 sec
- Maximum payload mass retrieved: 260 grams

Adaptations for Venus

- Tungsten Carbide shell, Silicon Carbide electronics
- Powered by two MMRTGs to accommodate new system mass of 12.8 kg

Hovercraft System Major Components



Final Design

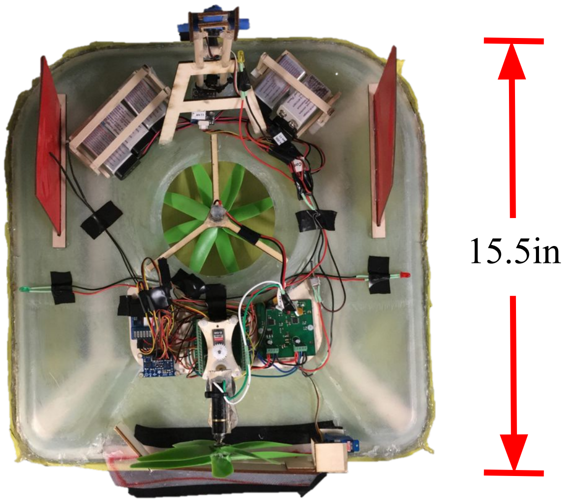
Shell

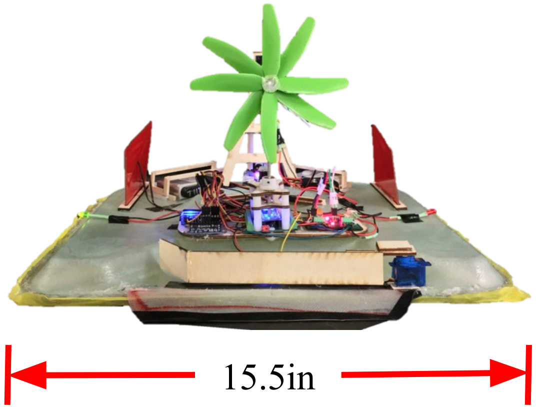
- Large 15.5in square shell
  - Shell height: 1in
  - Flight height: 1.5in
- One propeller intake for lift

Propulsion, Payload, and Control

- Forward mounted dual propellor
- 10 dof sensor
- Distribution of components for moment balance
- Sweeping arm and payload bay capable of retrieving 3 masses per run

System Mass: 788 grams

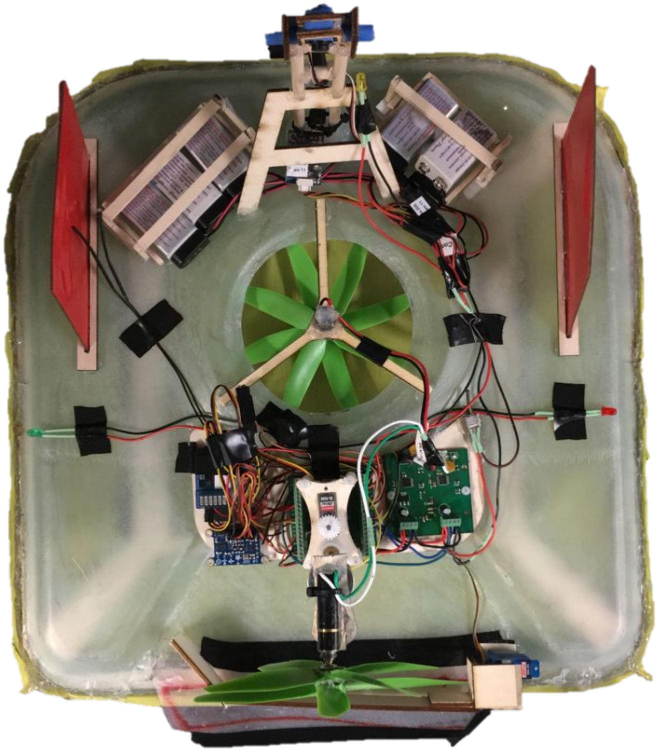




Shell and Skirt Design and Rationale

Choosing Shell and Skirt Design

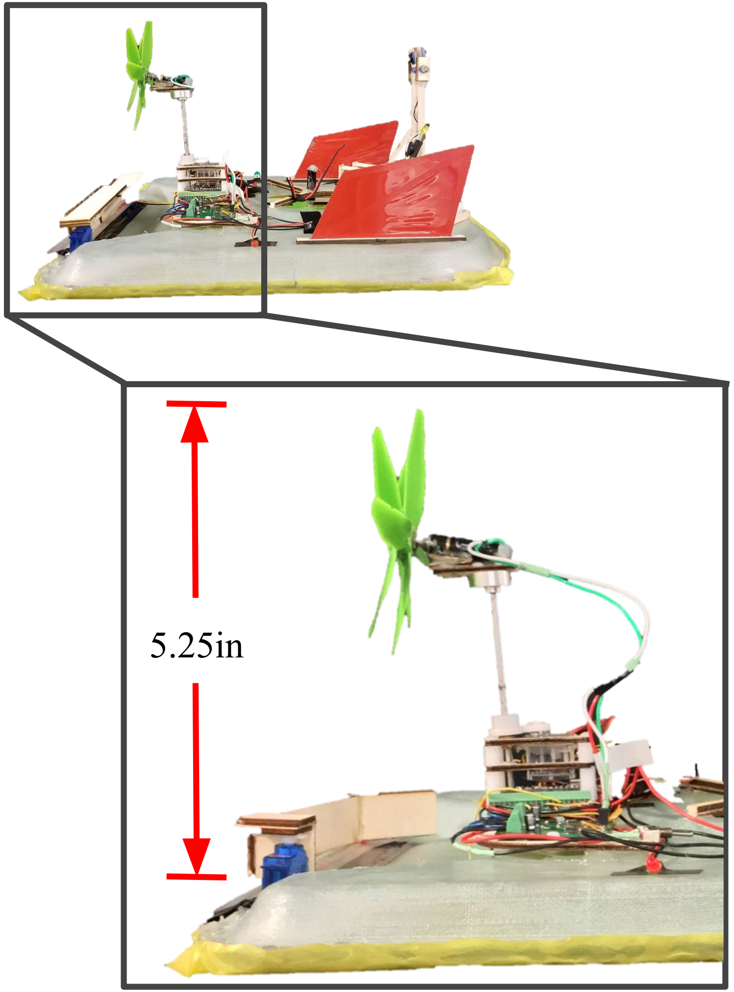
- Shell system mass: 99.08 grams
- Maximize bottom surface area
  - Wide area results in ~0.36 drag coefficient
- Measured lift
  - Total: 13.12N
  - Net: 8.12N
- One propeller intake with duct
  - Suitable amount of lift
  - Remaining propellor used for propulsion
- Pressure plate and frame to distribute flow throughout skirt



Motor Mount Design and Rationale

Choosing Propulsion Methods

- Motor mount mass: 35g
- Directional thrust
  - Chosen over rear-rudders through testing
- Pitch Angle
  - Motor pitched slightly above horizontal
  - Accounts for change of mass center with payload
- Mounted towards bow of the craft
  - Prototype with mount towards stern difficult to maneuver



Propulsion Design and Rationale

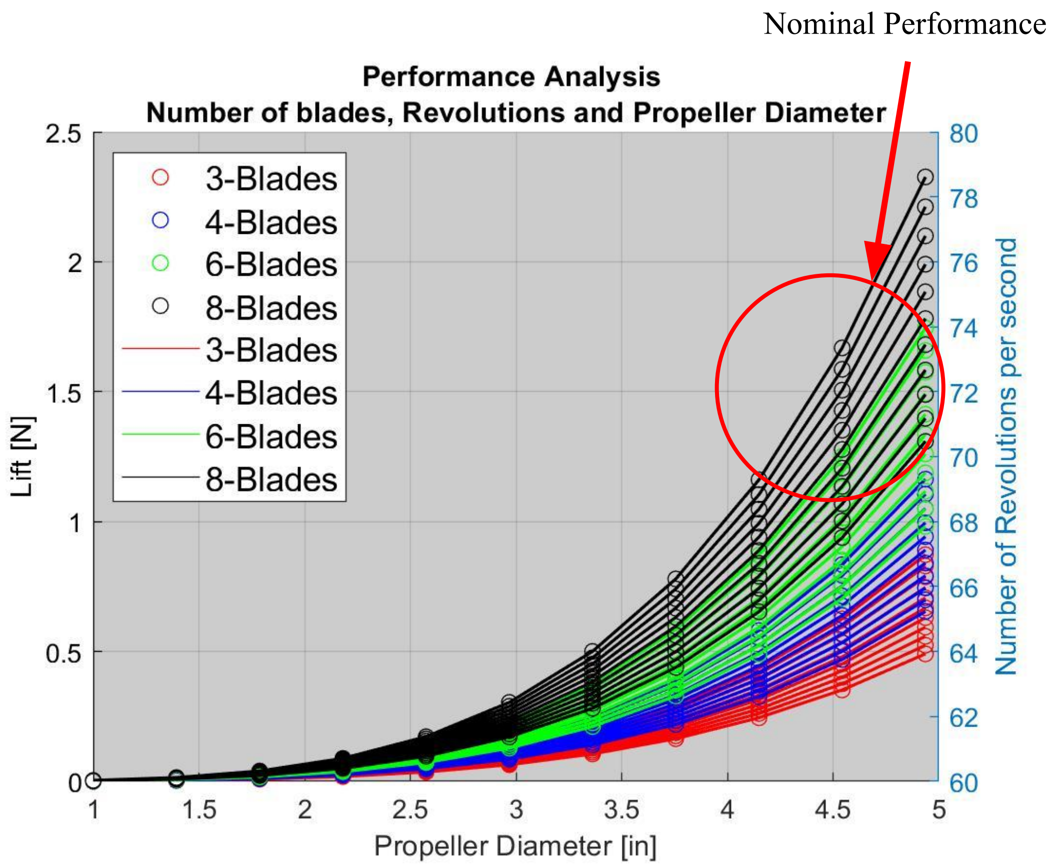
Several methods to maximize lift and thrust

- Maximize diameter
- Maximize number of revolutions per second
- Maximize number of blades

$$T = N\,\kappa_\tau n^2 D^4$$

$$\kappa_\tau = 0.15$$

Thrust coefficient approximated for both the aerodynamic and motor efficiency



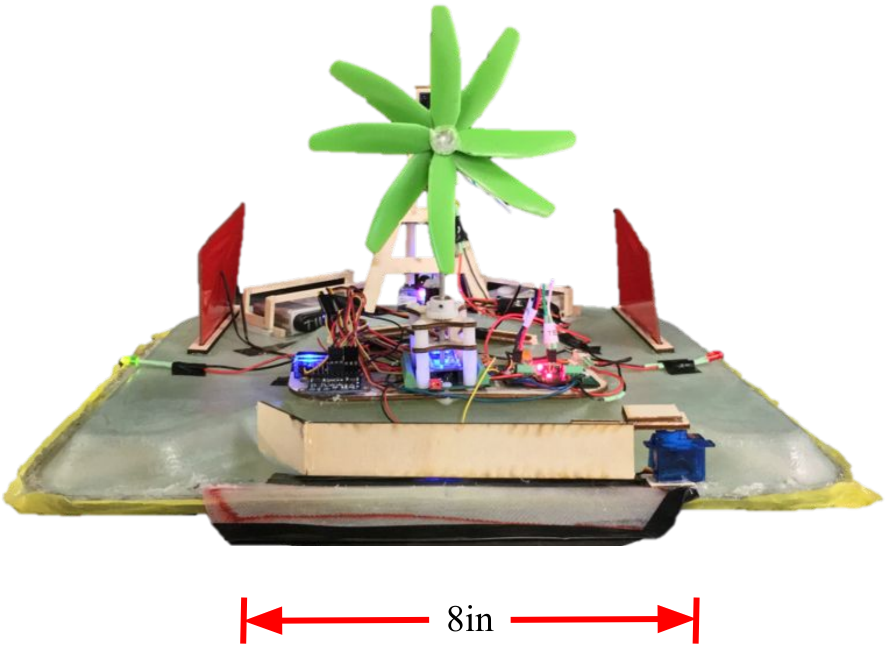
Mass Retrieval Design and Rationale

Retrieval Design

- Payload system mass: 31g
- Single sweeping arm retrieval method
  - Requires little precision
  - Servo will open arm outward
  - Hooked arm to pick up payloads more effectively

Retrieval Approach

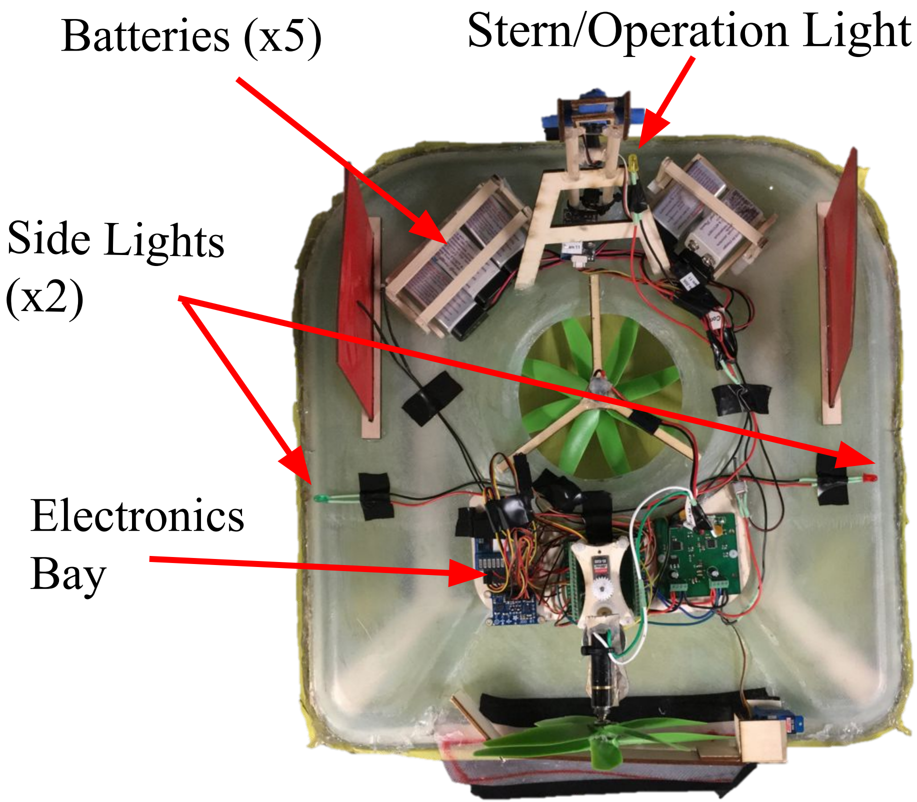
- Approach mass with open arm
- Shut off lift prop
  - Minimizes craft flight height
- Sweep arm in towards payload bay



Electronics Design and Rationale

Choosing Control Scheme

- Control servos and motors on the hovercraft by radio controller
  - 5 channels of signal
- 10 dof sensor and PID control system
  - Avoids rotation from angular momentum by the inlet propeller
  - Measures heading using the magnetometer to modify the measured value from rate gyro
- Drive assist mode with manual mode as backup



Earth Prototype Testing and Performance

Trial	Straight (sec)	Figure 8 (sec)	Mass retrieval (grams)
1	24.2	139	260
2	23.3	154	170
3	23.5	147	200
4	25.6	134	150
5	22.2	159	240

Mass Budget - Under NASA 0.9 kg Limit

Subsystem	Component	Mass (g)
Superstructure	Shell	99.3
Controllers/Sensors	Microcontroller, Motor Controller, Object Sensor, Receiver, Camera	95.0
Camera Mount		32.7
Power Source	Battery x 5	181
Avionics Components	Motor x 2, Servos x 3, Propellers x 4	101
Frame	Supports, Mounts, Payload Arm	129
Payload		**150**
Total System Mass		**788**

Power Budget

Component	Power (W)
System w/o Motor Controller, Arduino, Motor Controller, Servos	6.1
Motor x2	18.6
Camera and Receiver	3.4
Total System Power	**28.1**

Adaptations and Scaling to Venusian Environment - Materials

Empty System Mass: 12.81kg
Size: 15.5in square

Material Adaptations

- Tungsten carbide shell
  - Tensile Strength approx 6.25 times larger
  - Weight trade-off 35 times as dense
- Silicon carbide for electronics
  - Can withstand harsh temperature conditions of 737 K
  - NASA Glenn research conducted for Silicon Carbide transistors under Venusian environment [6]

Venus [3]

Adaptations and Scaling to Venusian Environment - Power

Power

- Exceeds NASA power limit
  - Request a higher power margin
- 2 MMRTG to provide power
  - Power Generated: 110 W each
  - Required 189W with 9.2 times scale factor
  - Mass: 4.4 kg

	Earth	Venus
g (m/s^2)	9.81	8.87
ρ (kg/m^3)	1.18	65
T(K)	300	737

Lift Calculations

- Star CCM+ sim. with Venusian environment
  - Estimated 564N to lift 63kg
  - 3.6m/s inlet

$$Lift = Bottom\ Pressure * Bottom\ Area$$

$$= 3070Pa * 0.182m^2 = 559N$$

$$Mass\ Lifted = {}^{Lift}/_{g_v} = \frac{559N}{8.81\frac{m}{s^2}} = 63kg$$

Conclusion

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References

1) Washabaugh, Peter. University of Michigan, Aero 205. *Hovercraft Competition.* February 2019. Accessed 1 March. 2019.

2) Williams, David R. “Venus.” *NASA*, NASA, Accessed 11 March, 2019. https://nssdc.gsfc.nasa.gov/planetary/factsheet/venusfact.html

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4) Philip G. Neudeck, Roger D. Meredith, Liangyu Chen, David J. Spry, Leah M. Nakley, and Gary W. Hunter. “Prolonged silicon carbide integrated circuit operation in venus surface atmospheric conditions”, *AIP Advances 6,* 2016

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5) “Multi-Mission Radioisotope Thermoelectric Generator (MMRTG).” Solarsystem.nasa.gov, NASA, Oct. 2013, https://mars.nasa.gov/msl/files/mep/MMRTG_FactSheet_update.pdf Accessed 11. Apr. 2019.

6) Voosen, Paul. “Armed with tough computer chips, scientists are ready to return to the hell of Venus” *Science Mag*, 22 November 2017, https://www.sciencemag.org/news/2017/11/armed-tough-computer-chips-Scientits-are-ready-return-hell-venus

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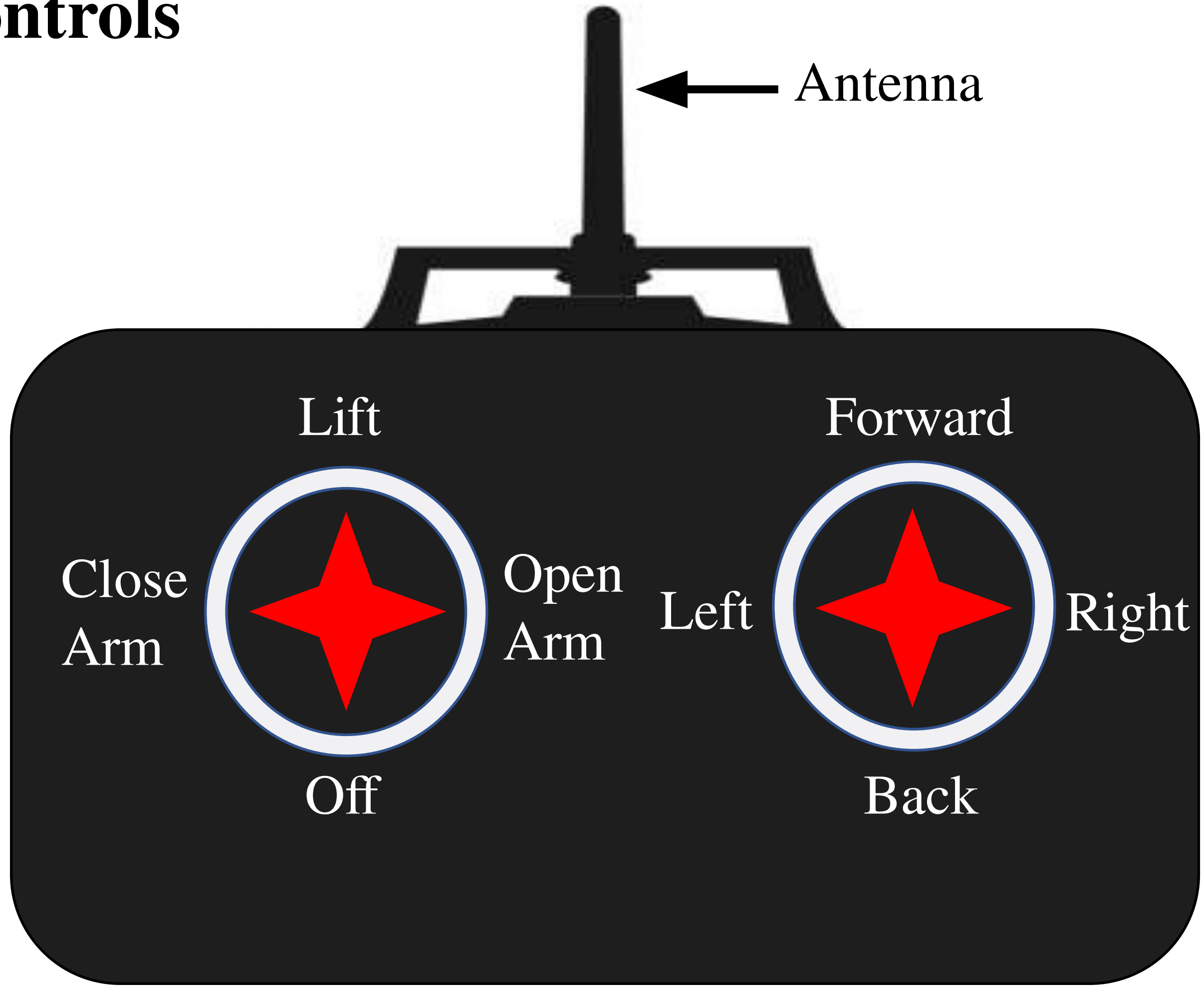
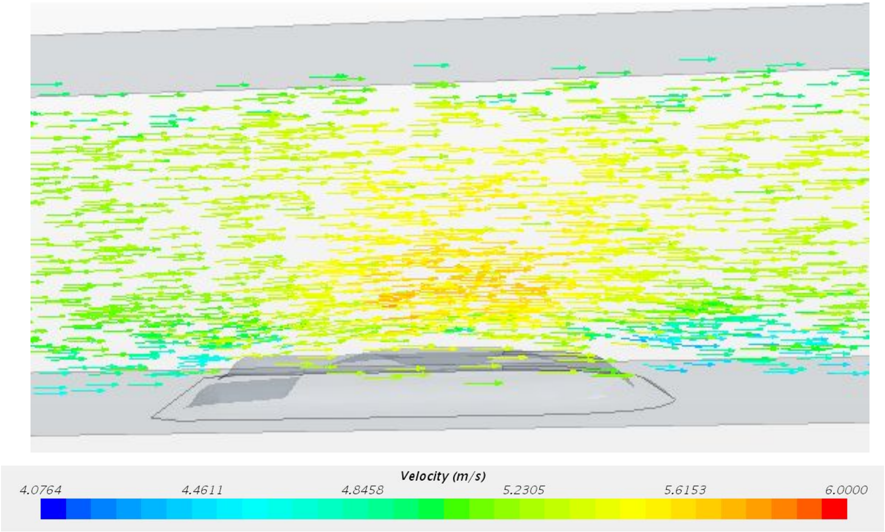
Appendix

Craft Controls

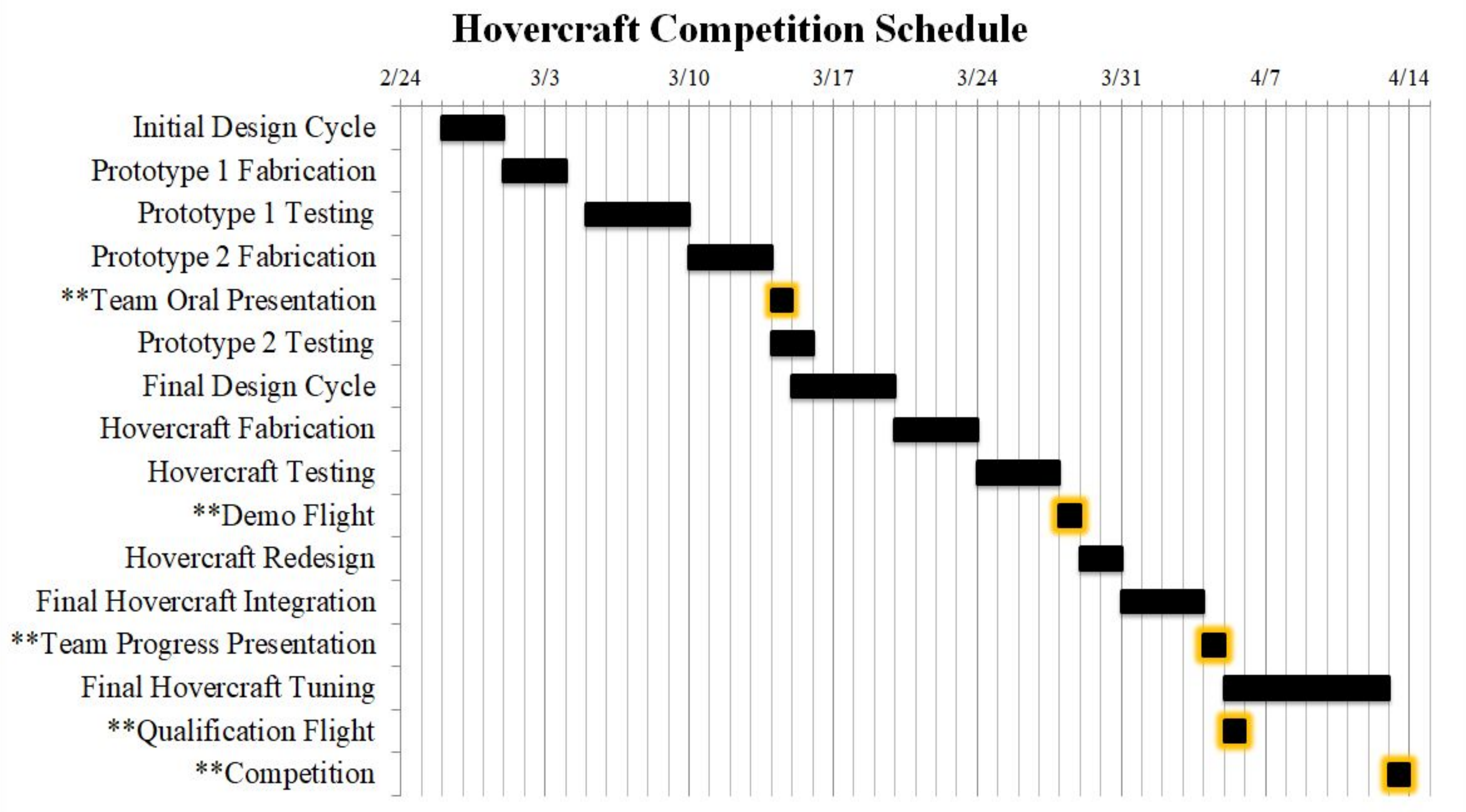


Drag Coefficient Estimation

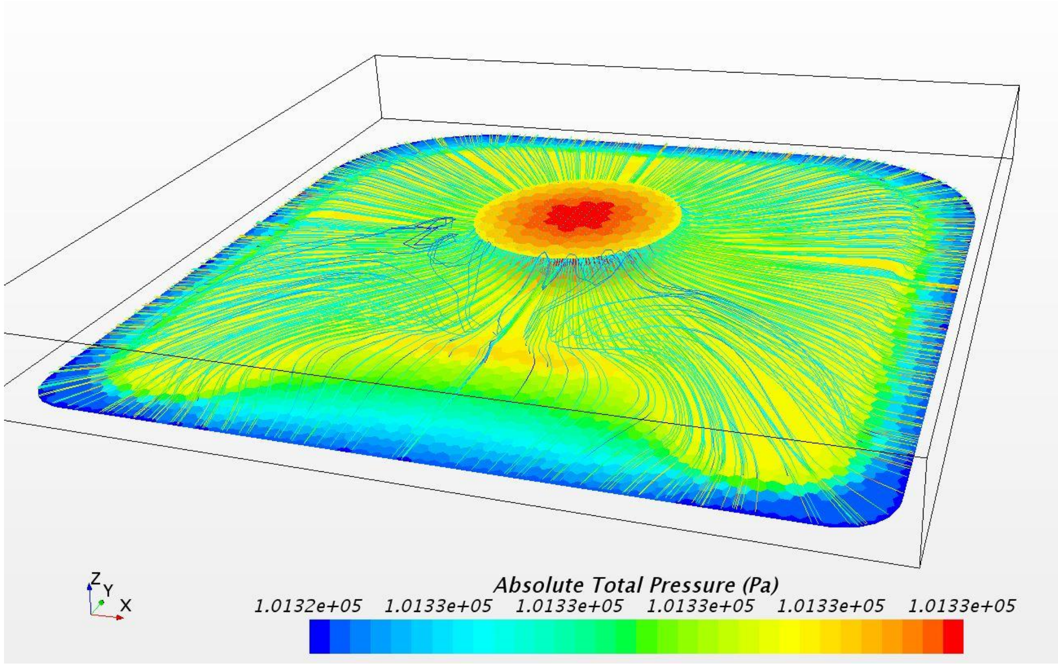
- Estimated to be 0.36
  - Calculated in Star CCM+
- Wind-tunnel simulation
  - Tunnel entrance velocity: 5m/s
  - Continuum: Air
    - $\varrho = 1.184$ kg/m^3
    - T = 300 K
  - Frontal Area = 0.01076m^2
  - Drag Force = 0.0569N



$$C_d = \frac{D}{\rho \cdot A \cdot V^2/2} = \frac{0.0569N}{1.184kg/m^3 \cdot 0.01076m^2 * 12.5m^2/s^2} = 0.36$$


Hovercraft Competition Schedule
2/24
3/3
3/10
3/17
3/24
3/31
4/7
4/14
Initial Design Cycle
Prototype 1 Fabrication
Prototype 1 Testing
Prototype 2 Fabrication
**Team Oral Presentation
Prototype 2 Testing
Final Design Cycle
Hovercraft Fabrication
Hovercraft Testing
**Demo Flight
Hovercraft Redesign
Final Hovercraft Integration
**Team Progress Presentation
Final Hovercraft Tuning
**Qualification Flight
**Competition

Inside Flow Simulation (3m/s)



Surface Average of Pressure on Volume Mesh

Part	Value (Pa)
Region: Bottom Surface	5.320918e+01
Total:	5.320918e+01

- Lift calculated is sufficient to handle system mass

$$Lift = Bottom\ Area * Bottom\ Pressure = 0.182(m^2) * 53.2(Pa) = 0.987kg$$

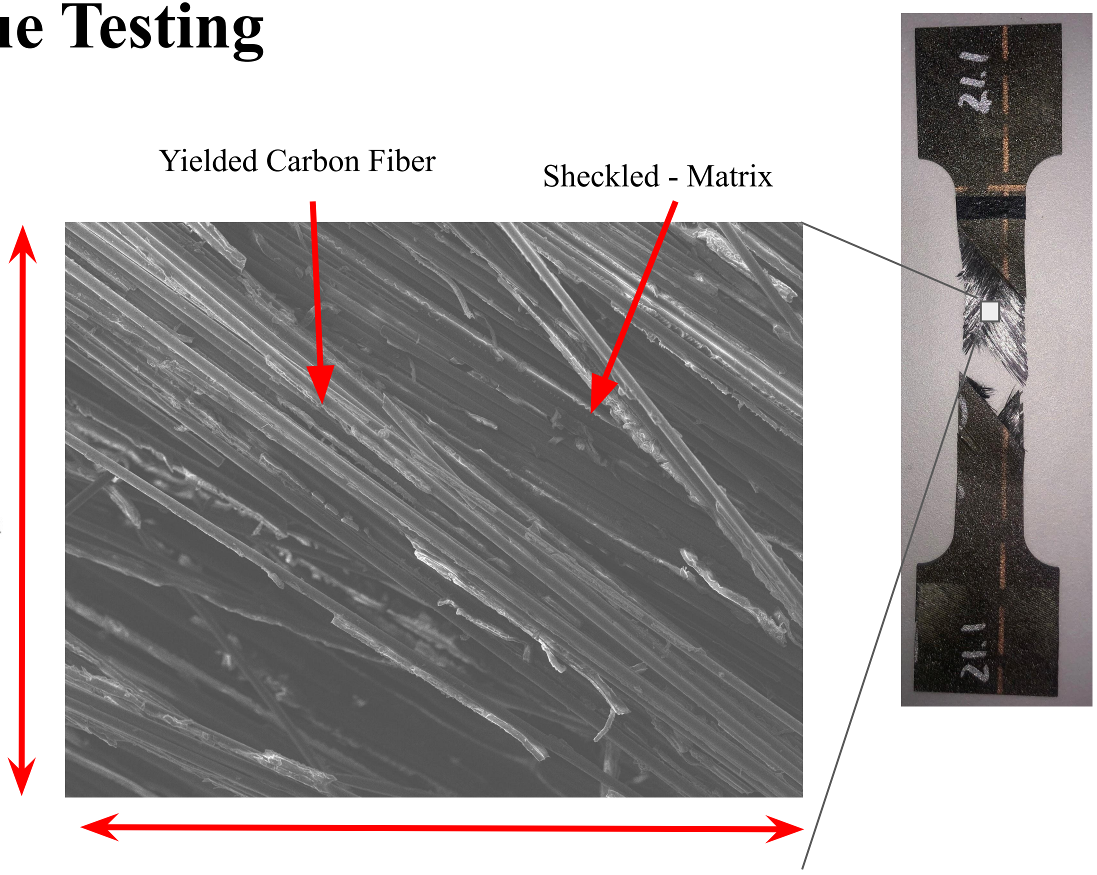
Proposal: Carbon Composite Shell

- Key Advantages
  - High strength to weight
  - High stiffness
  - High heat tolerance
  - Carbon fiber is approximately ten-times stronger and five-times lighter than aluminum
  - Manufacturing shell with woven carbon fiber dynamically re-distributes the load on the craft

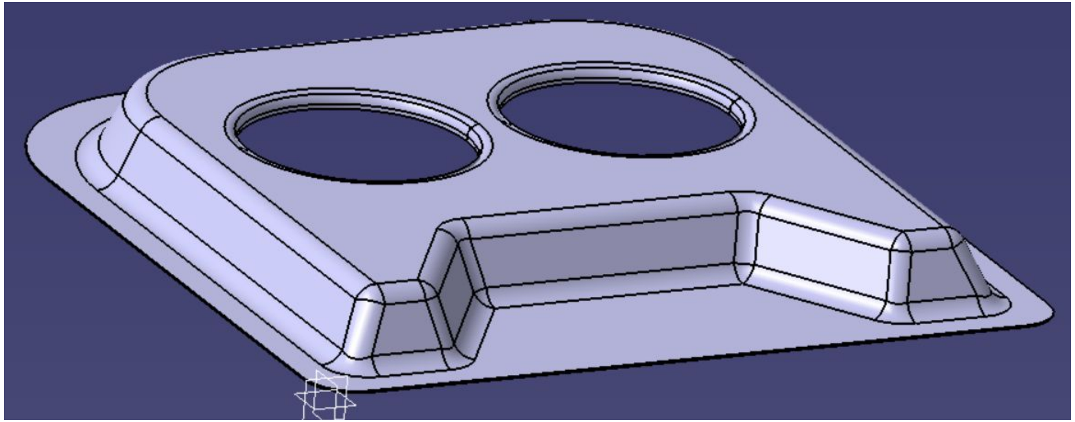
- Key Disadvantages
  - Long term sulfuric acid deteriorates the carbon fiber
  - Carbon fiber is expensive to manufacture
  - Once damaged, nearly impossible to fully repair
  - Interior micro/macro cracks make the remaining strength of the carbon composite difficult to predict
  - Slightly conductive

Carbon Composite: Fatigue Testing

- A fatigue test effectively weakens carbon fiber
  - Understand how it may act while exposed to harsh environments
- Specimen was taken to failure after fatigue test
- Within this carbon composite specimen:
  - Observed delamination about the ply’s of carbon fiber
  - Sheckling (Warping) of the binding-matrix

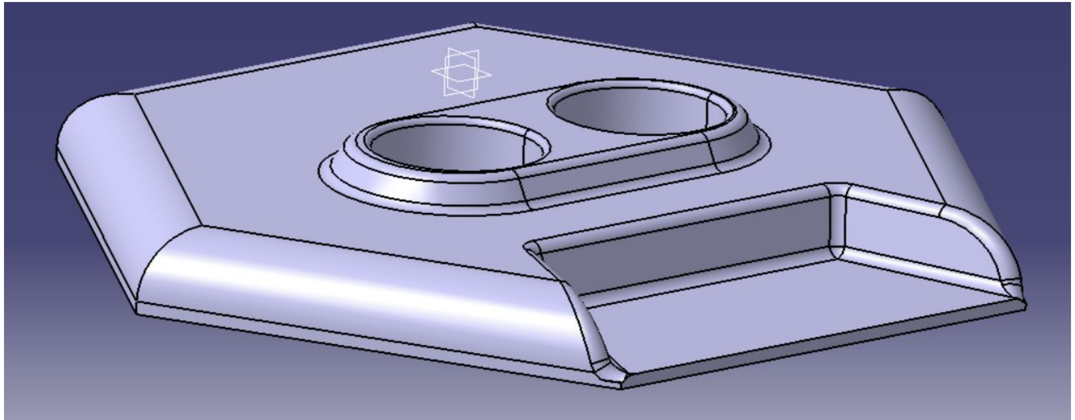


Initial Prototypes



Prototype 1

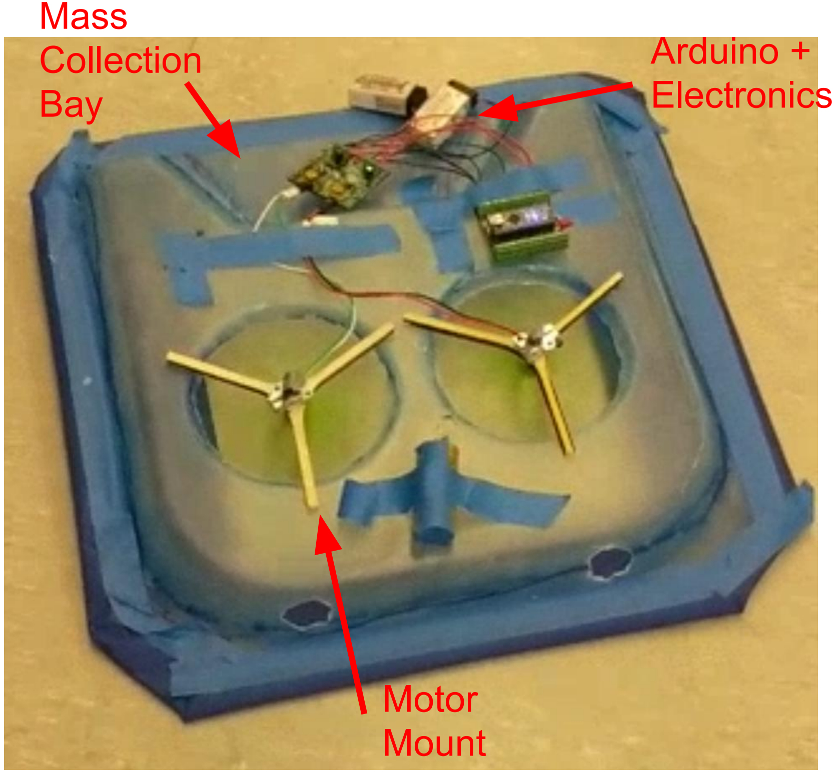
- Maximize bottom surface area (near one square meter)
- Utilize two intake lift system with propeller
- Excess pressure used to propel craft

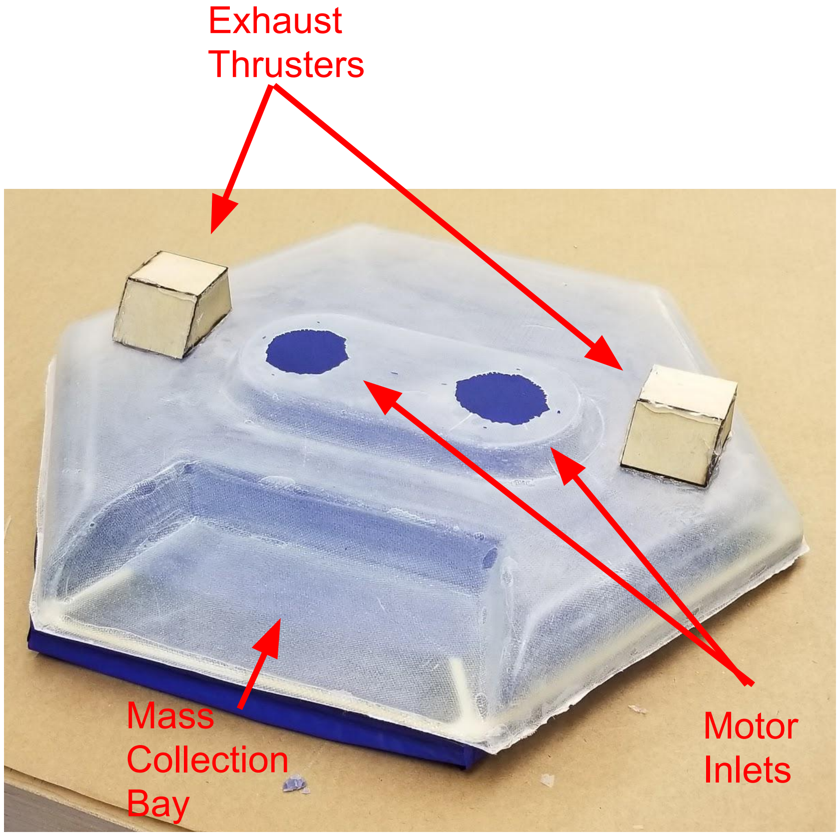


Prototype 2

- Lightweight and maneuverable
- No lip
- Utilize two intake lift system with impeller

Initial Prototypes





Team Responsibilities

Name	Construction Management	Hands on Construction	Reporting Management
Daniel	Shell	CAM, Shell fabrication	Final Presentation
Jason	Control (Lights and Camera)	Mount fabrication	Team Progress Presentation
Shigemitsu	Control (Driving)	Programming, controls testing	Rationale and Control Documentation
Alexander	Control Hardware	Servo and axle system	Team Oral Presentation
Akhil	Payload Hardware	Payload capture system	Simulations and Adaptations