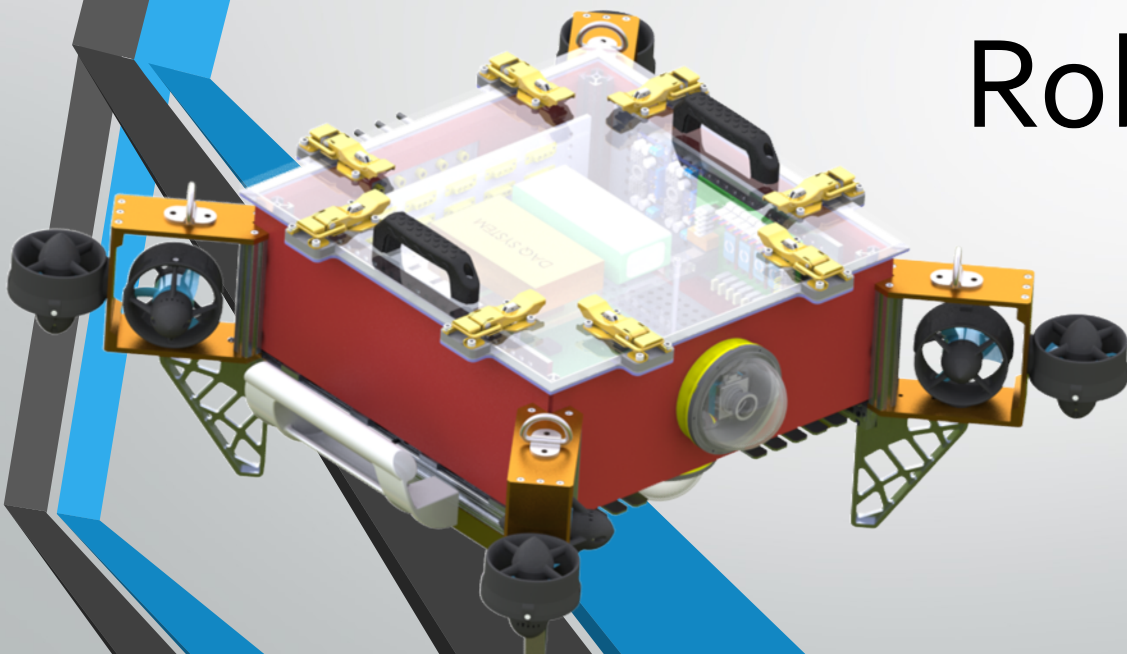
EXPO Presentation – AUV RoboSub: Lanturn

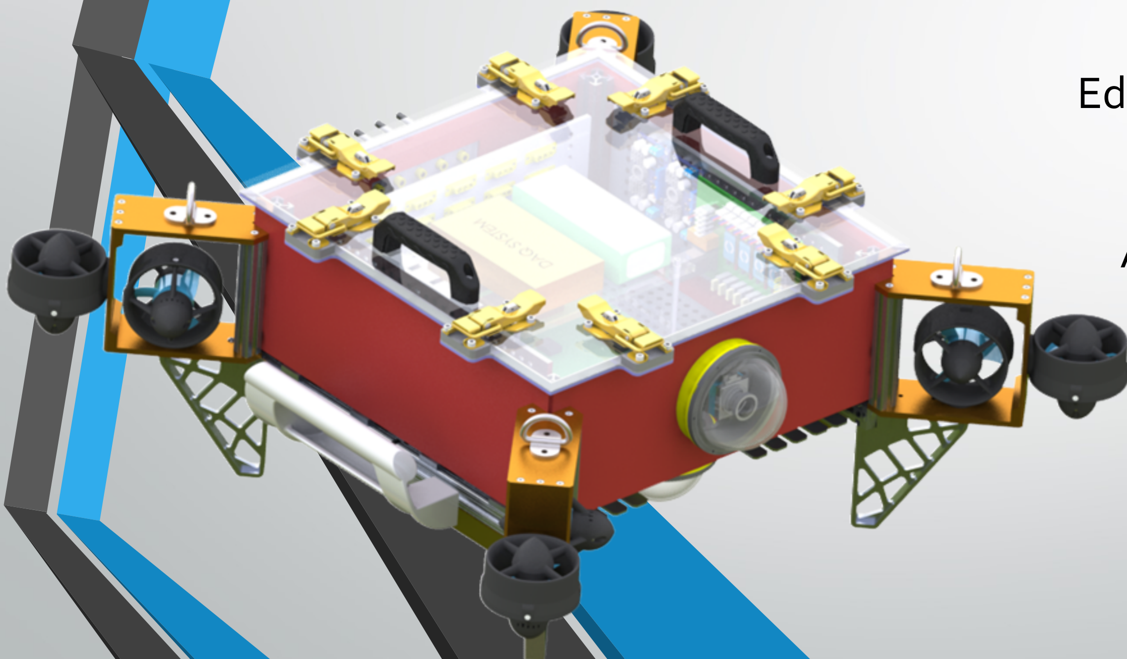


California State University – Los Angeles

ME/EE Senior Design Team 28

Year 2021

Team Members



Eddie Hernandez

Jose Barrera

Angel I. Toribio

Yongjie Li

Louis Carlin

Christopher Reza-Nakonechny

Anthony Gonzalez

Daniel Romero

Brian Sager

Charles Vidal

Advisors: Dr. He Shen
Dr. Thorburn

AGENDA

Background, Objective, Requirements

System Overview

Mechanical

Electrical

Simulation

Conclusion

AGENDA

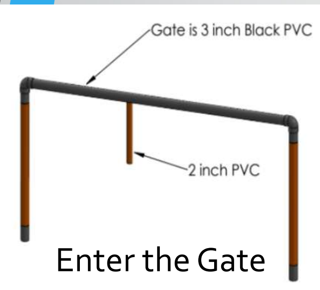
Background	Chris
Objective & Requirements	Brian

RC12

Background

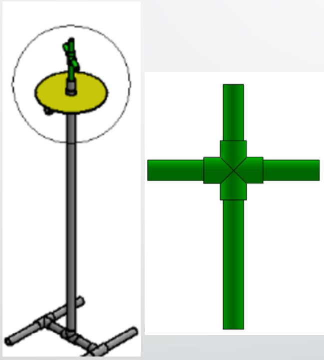
RoboSub Competition

- Yearly STEM competition
- Build Autonomous Underwater Vehicle (AUV)
    - Navigate arena
    - Complete tasks



Enter the Gate

Example waypoint



Example pickup object [1]

Image of Competition Arena, NIWCP, San Diego[1]

Example marker

Slide 5

RC12 I'll do

Reza-Nakonechny, Christopher, 4/23/2021

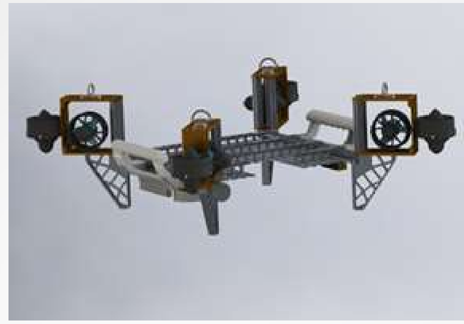
Background

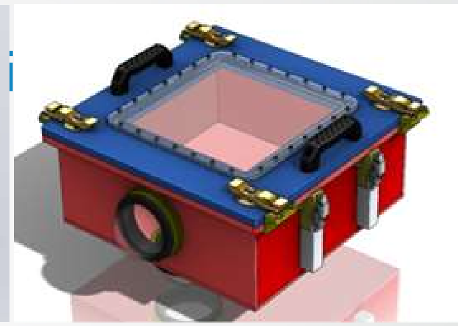
Covid-19 Restrictions

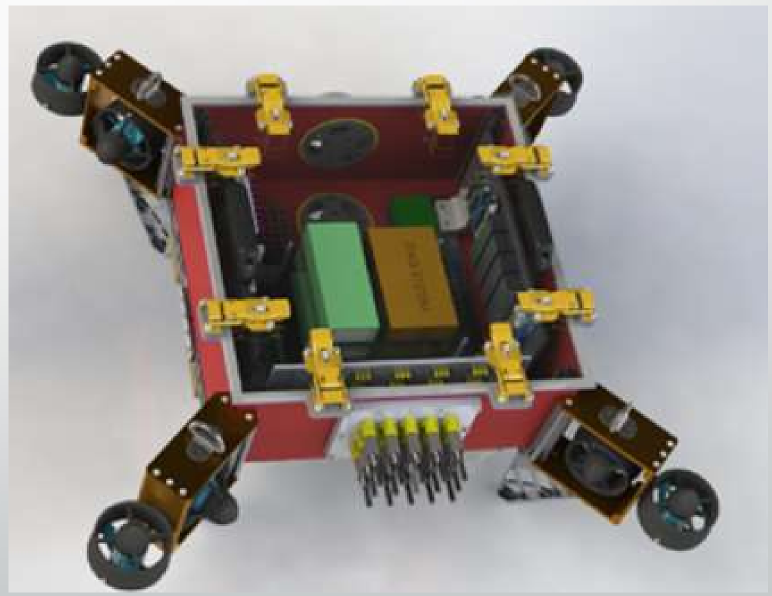
- Format of Competition changed
- Scoring:
  - Presentation
  - Technical Report
  - Website
- Virtual collaboration

Background

Lanturn

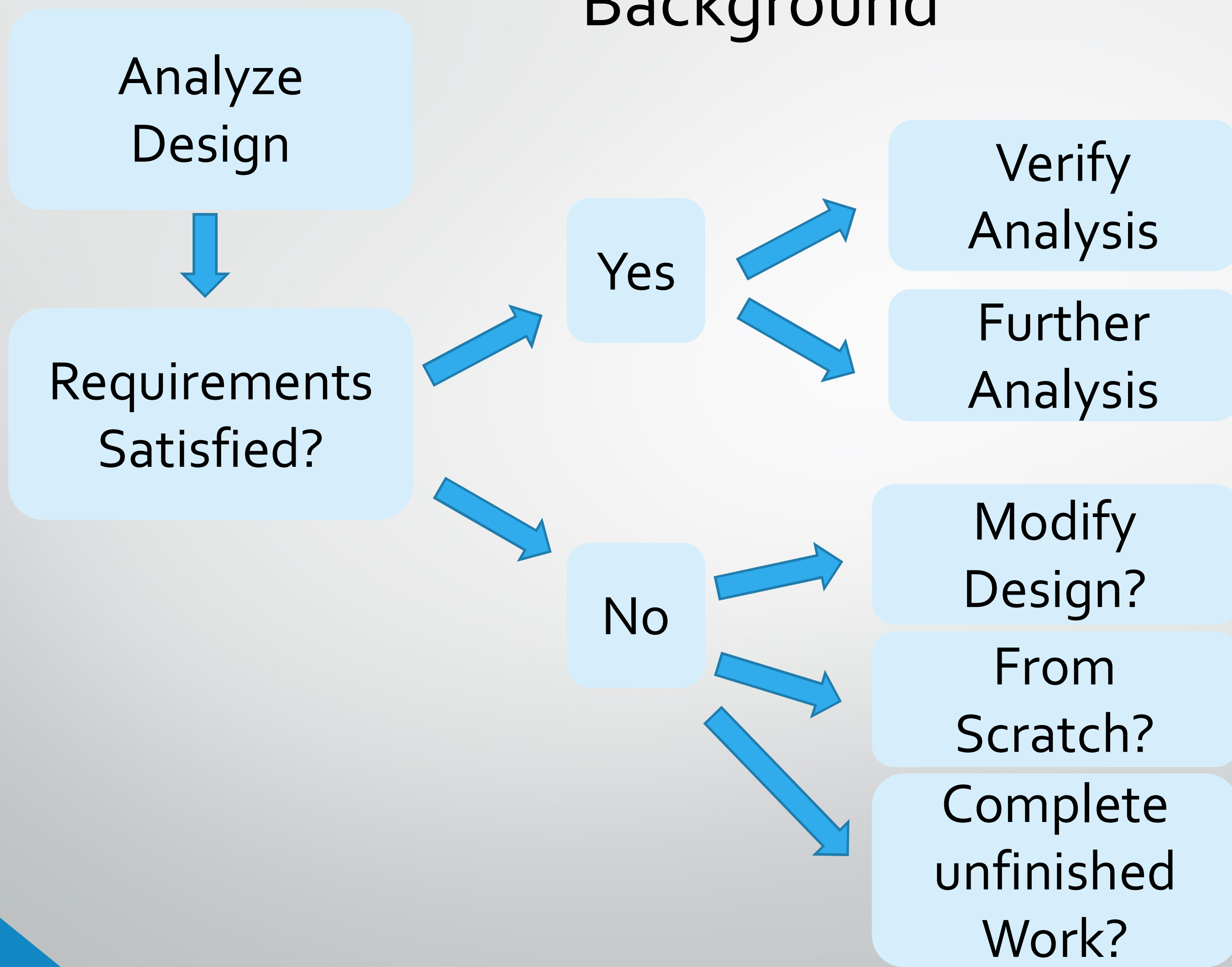






- What was inherited
- Verify it meets requirements
- Keep, modify or redesign

Background


Analyze Design
Requirements Satisfied?
Yes
No
Verify Analysis
Further Analysis
Modify Design?
From Scratch?
Complete unfinished Work?

Background

- Passing the baton
- Onboarding
- Guides

AGENDA

Background	Eddie
Objective/Requirements	Brian

Objectives

Base Project Objectives:

- Revise design of AUV to meet previous year's Robosub competition requirements
  - Functional Requirements
  - Performance requirements
- Further testing/simulation
- Refine design
- Manufacture Sub
- Compete in competition

Competition Objectives:

Competition Points Requirements revised for COVID-19 fall into

- Website
- Written Report
- Recorded Presentation

High Level Requirements

Functional

The AUV shall :

- be submergible.
- house the required electronics systems
- be able to navigate autonomously
- operate a kill switch
- operate a claw
- operate a payload system
- operate torpedo launcher

Performance

The AUV shall:

- submerge up to 10m and be under 125lb.
- contain waterproof housing for electronics with proper amount of heat dissipation
- receive information from cameras, process that information and operate thrusters to navigate through waypoints
- operate a mechanical claw to recognize, pick up and release objects
- operate a payload dropper that will house a payload and release it at a desired location
- operate a torpedo launcher to recognize a target and launch a torpedo and strike it.
- shall have an operable way to shut down, be minimum 0.5% positively buoyant when shut off through kill switch

AGENDA

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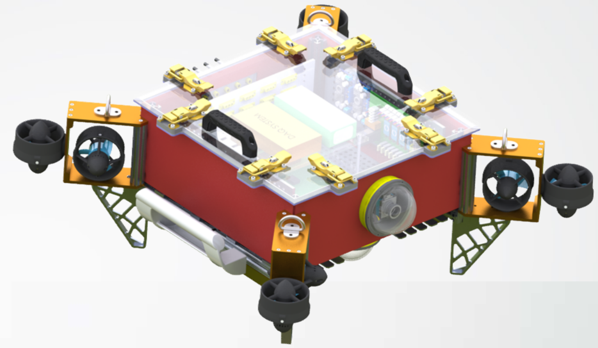
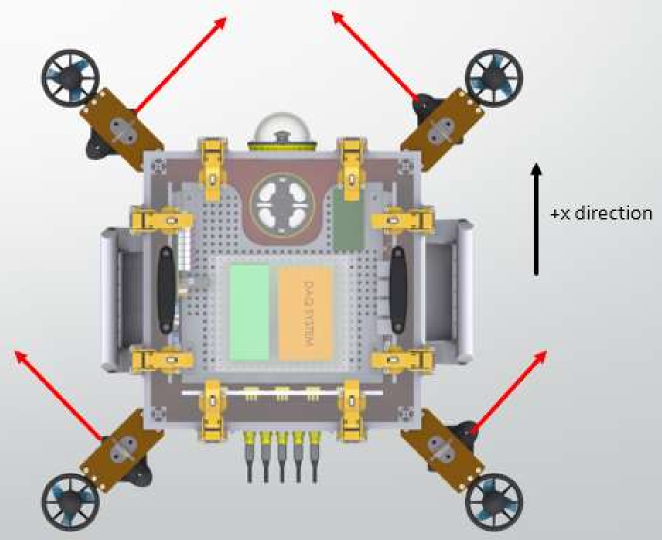
Concept Design Overview: Mechanical

- Hull includes removable electronics shelving
- Frame I- 6061 Aluminum
- Eight Thrusters
  - Four Vertical
  - Four Horizontal
- Horizontal thrusters at 45° angles

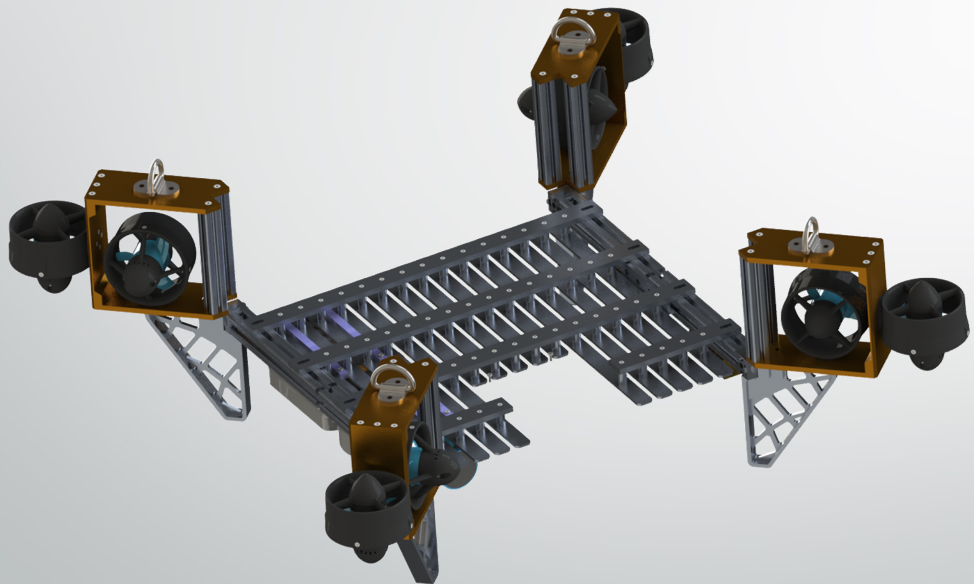




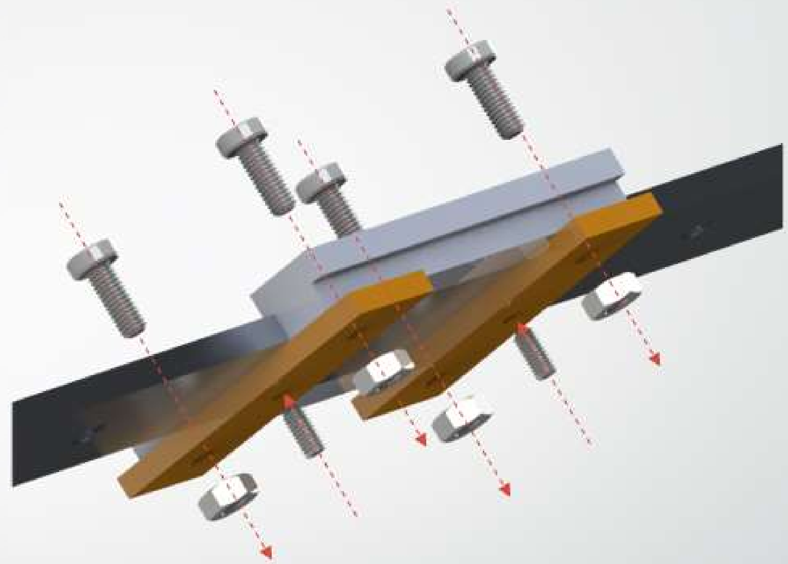
Horizontal Thruster Vectors

Concept Design Overview: Mechanical

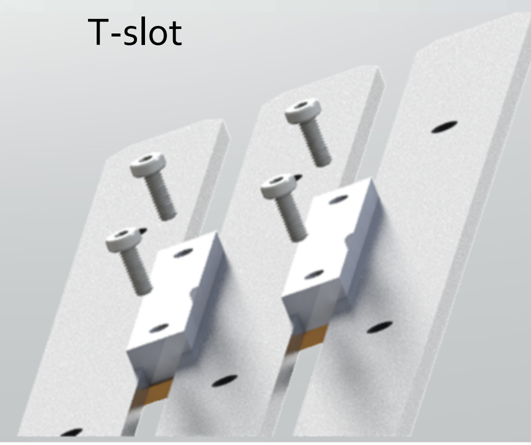
- Four Low Profile Socket Head Cap Screws
  - Connect parts to t-slot frame



Lanturn Frame and Thrusters



T-slot



Concept Design Overview: Mechanical

Buoyancy

- SolidWorks mass properties function
- Displaced volume / mass
- Mass = 26.15 kg
- Displaced volume = 0.03933 m^3
- 66.5% positively buoyant

Concept Design Overview: Mechanical

Actuated Systems

- Torpedo
- Dropper
- Grabber

Sensors

- Hydrophones
- Two Cameras
- IMU
- DVL

AGENDA

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MECHANICAL

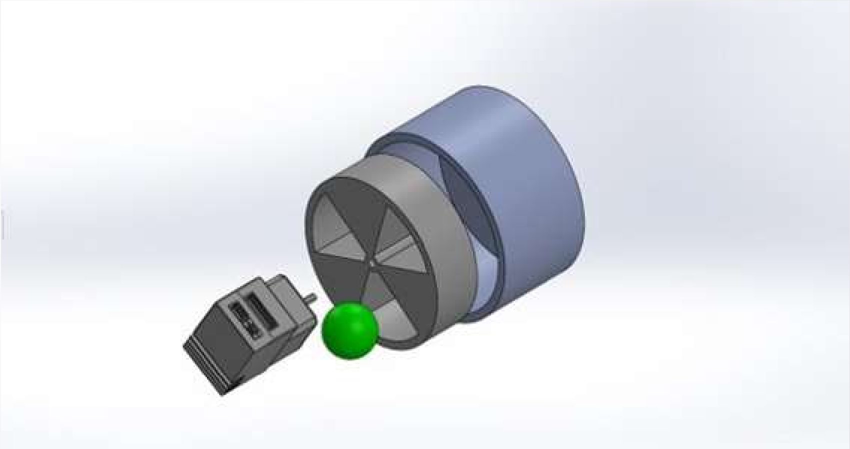
Actuated Systems	Dropper	Angel
Body	Claw	Anthony
	Torpedo	Jay
	Hull	Charles Brian
	Frame	Person

Dropper

- Simple design that will be mounted on the frame as shown

- The rotating compartment will connect to the motor's shaft therefore causing rotation of the rotating shaft

- Satisfies with the competition requirement of dropping markers of dimensions :
  - Marker dimensions: must fit within 5.1 x 5.1 x 15.2 cm box
  - Weight ≥ 2 lb.



MECHANICAL

Actuated Systems	Dropper	Angel
	Claw	Anthony
Body	Torpedo	Jay
	Hull	Charles Brian
	Frame	Angel

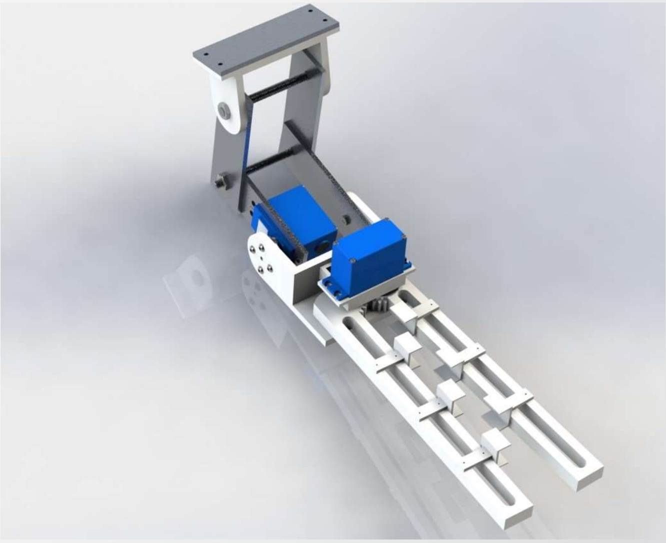
Actuated Systems – Previous Team Designs

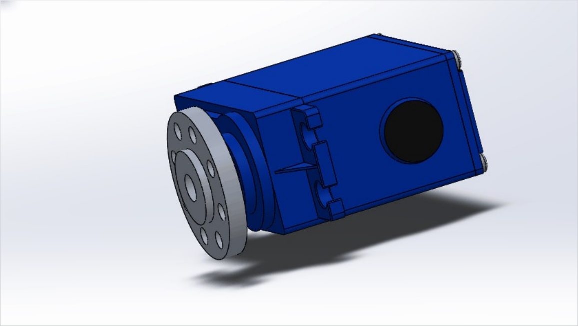
- Last year's team had two placeholder designs
- No motion capability or testing
- 1st design was created by the team
- 2nd is a design by Blue Robotics
- Currently out of stock and will no longer be for sale as a new model is being designed
- The release was unclear, so a new design needed to be made

Image from Blue Robotics [2]

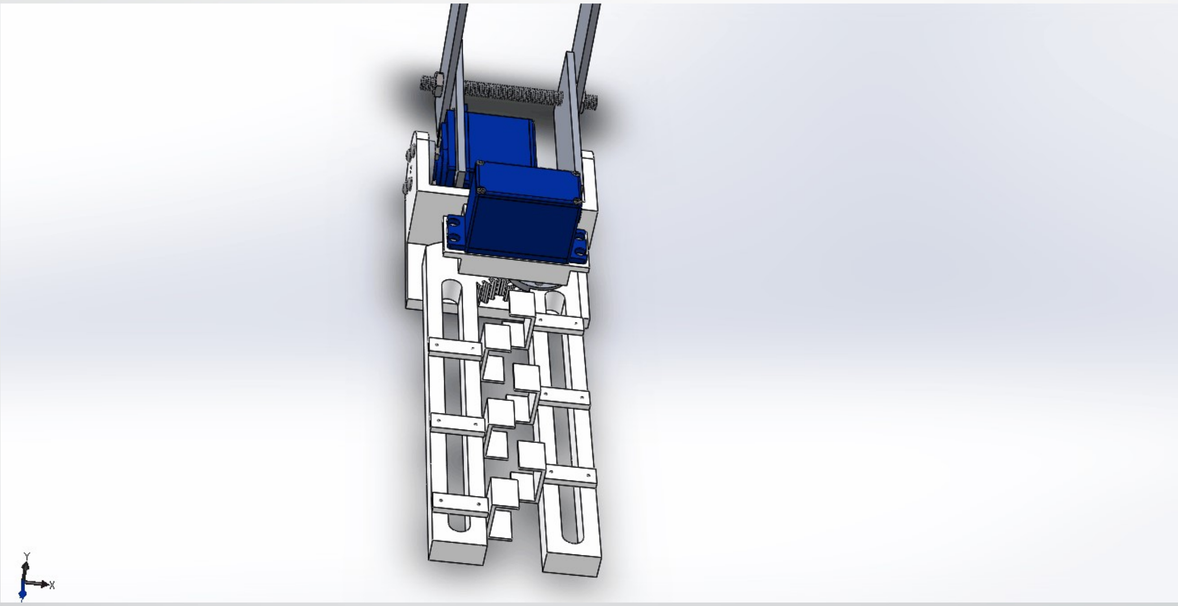
Actuated Systems – Grabber Design

- The design uses a combination of 3D parts and aluminum material
- (white = 3Dparts, gray = aluminum)
- A servo horn will be connected to the gears of the claw, as well as to the arm, to allow for motion
- Uses two HS-646WP servo motors



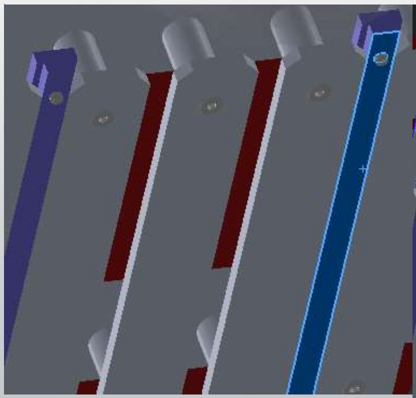


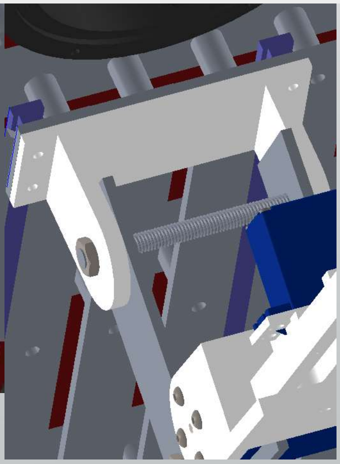
Actuated Systems – Grabber Animation



Actuated Systems – Grabber Mount

- Will be mounted to the Lanturn sub as shown in images
- This placement was unchanged to be in the view of the camera

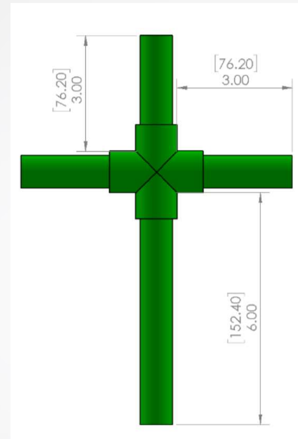


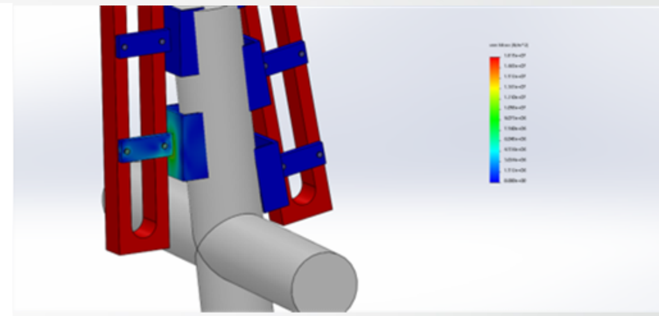


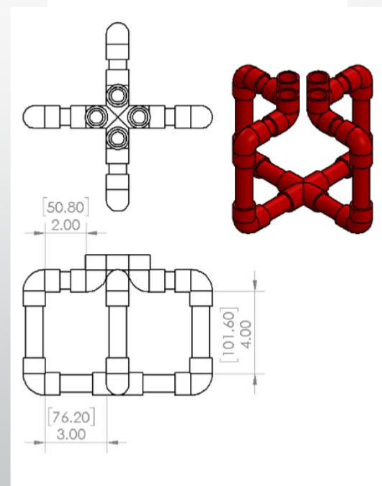
Actuated Systems – Grabber Motion Analysis

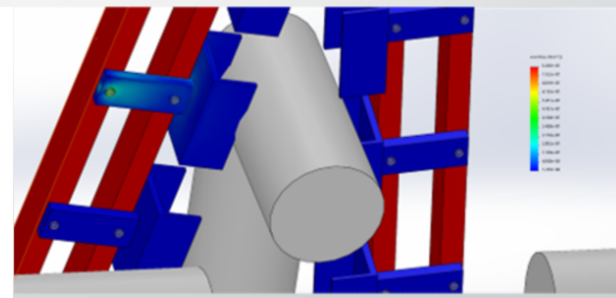
- Conducted stress analysis with crucifix prop
  - Factor of Safety is 3.3
  - Highest Stress at the holes

- Conducted stress analysis with garlic prop
  - Factor of Safety is 1.7



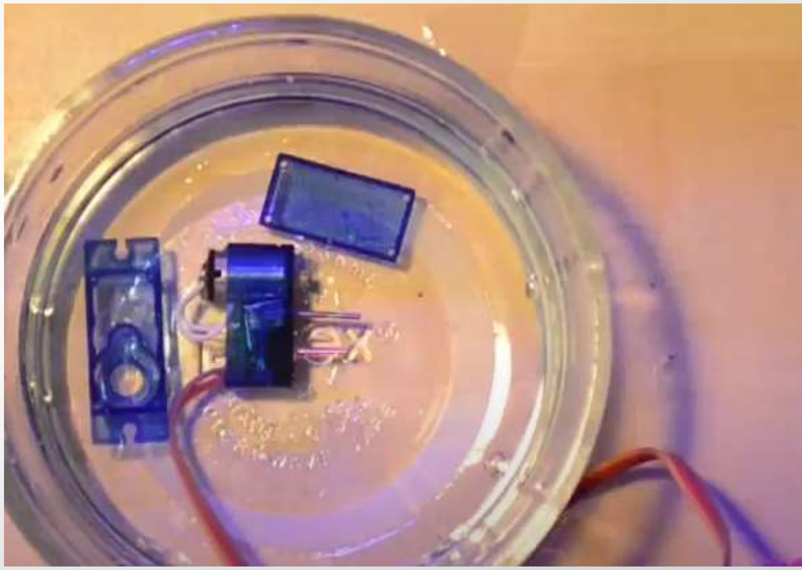






Actuated Systems – Waterproofing Servos

- Application of epoxy and mineral oil
- The epoxy and mineral oil method was tested another team
- Max depth the servo was submerged in was between 14.8ft-22ft (4.5m-6.7m)



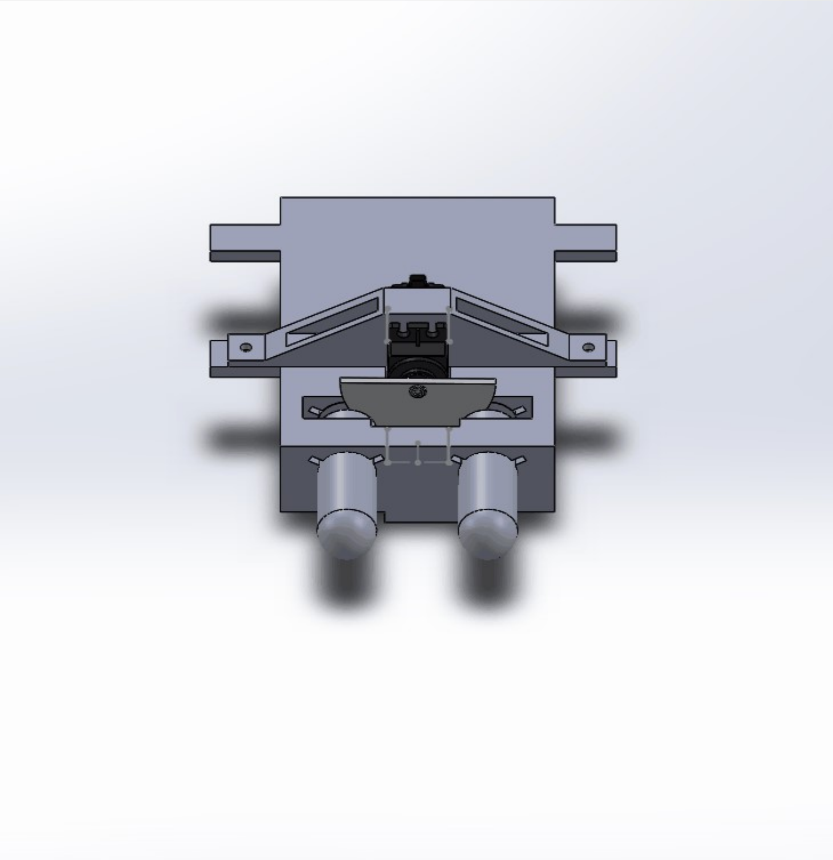
MECHANICAL

Actuated Systems	Dropper	Angel
	Claw	Anthony
	Torpedo	Jay
Body	Hull	Charles Brian
	Frame	Angel

Actuated Systems - Torpedo

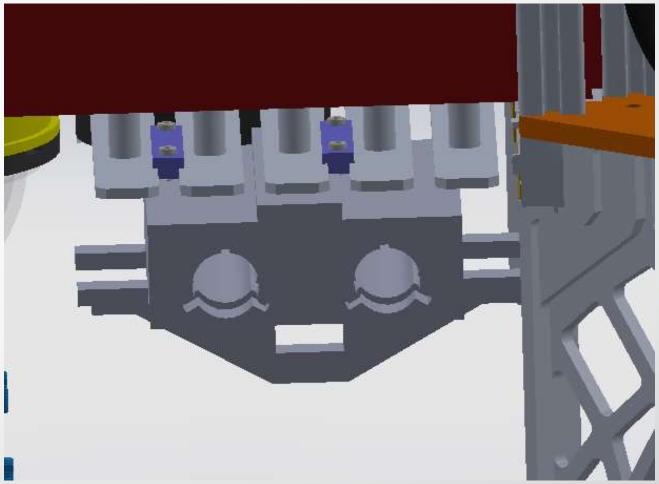
Torpedo launcher

- The design consisted of
  - 2 stainless steel compression spring
  - 3D printed housing
  - HS-5086WP waterproof servo (4.8V~6)
  - 1 Sheet metal gate
  - Aluminum rod



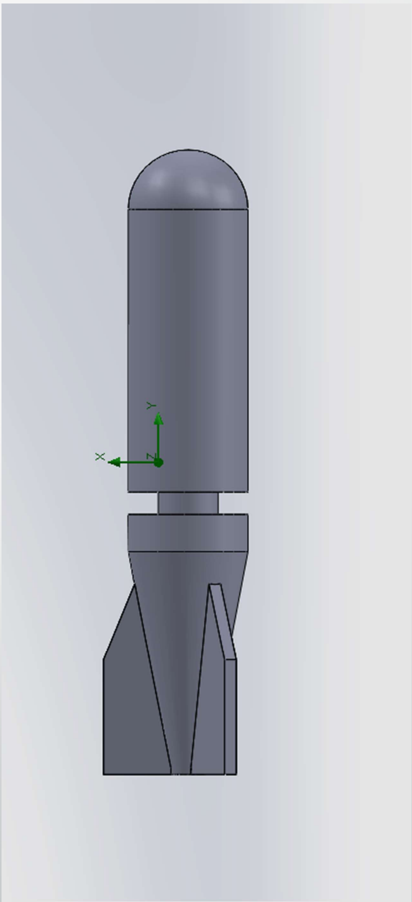
Torpedo Launcher Mount

- Launcher would be mounted with screw and bolts
- Placement would be unchanged



Mechanical Design: Torpedo

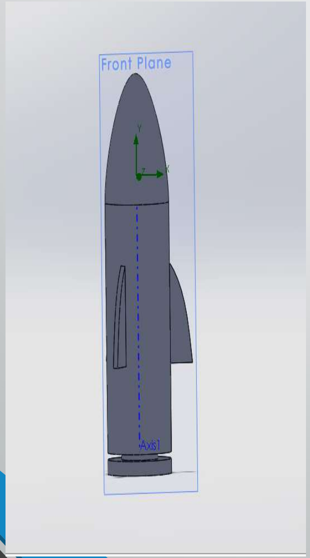
- Torpedo requirements:
    - The size limit is 5.1 x 5.1 x 15.2 cm (1)
    - Weight limit less than 2 lbs. (1)
    - Distinct Marking to identify as team's
- Identical Requirements for dropper system payload
- Fins were added onto torpedo to prevent deviation from path after being launched

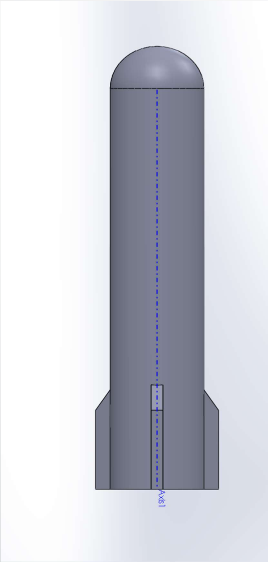


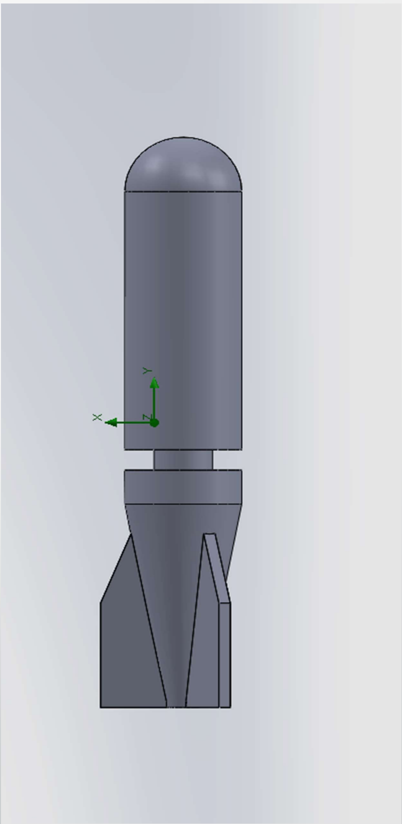
Torpedo Design

Torpedo

- 3 iterations of the prototype was made
- The first one iteration had a poor fit
- The second small fin surface area
- The last iteration was base off a real torpedo design

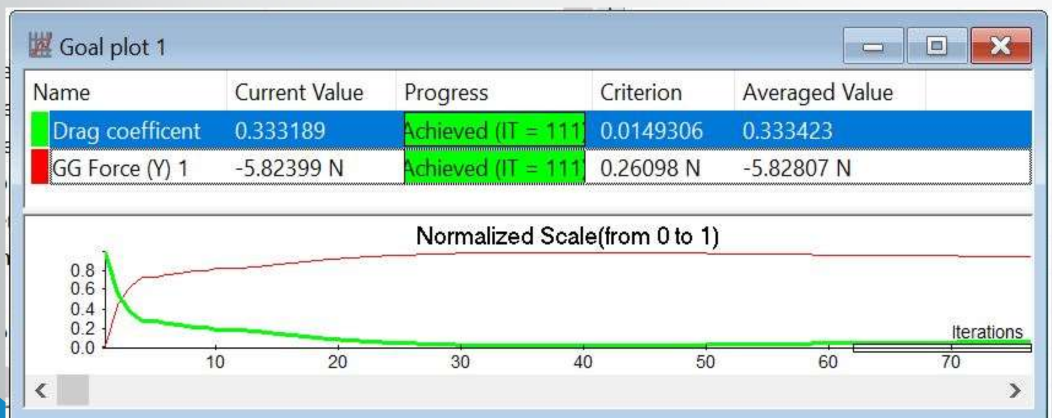




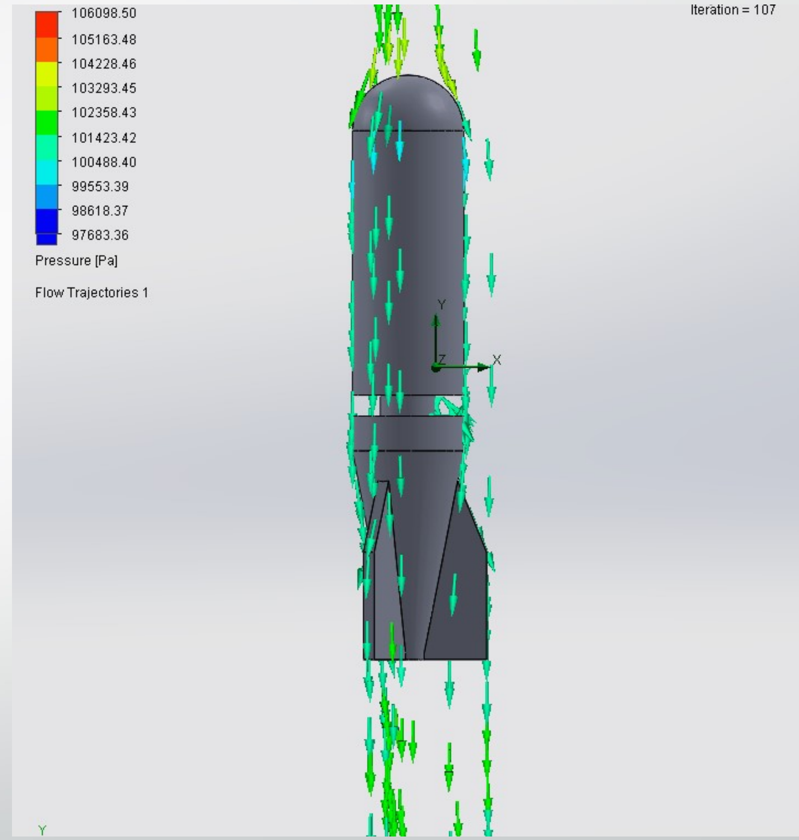


Torpedo Fluid Analysis

- Fluid Simulation performed in SolidWorks
  - Goal find drag coefficient close to 0.2
  - Obtained Cd of 0.33



Torpedo Computational Analysis



Torpedo Fluid Simulation

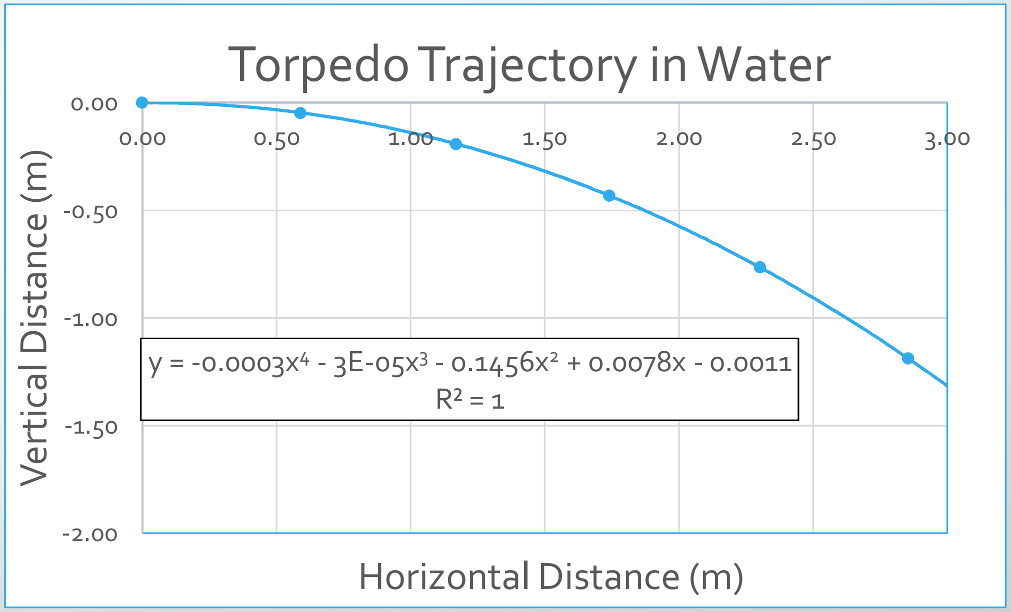
Mechanical Design: Torpedo Trajectory in Water

Simulation Inputs

- Force from Launcher
- Torpedo dimensions, drag coefficient and weight
- Camera Location Relative to Launcher

Output

- Equation of Trajectory using Cartesian Coordinates
  - Optional: Polar Coordinates



MECHANICAL

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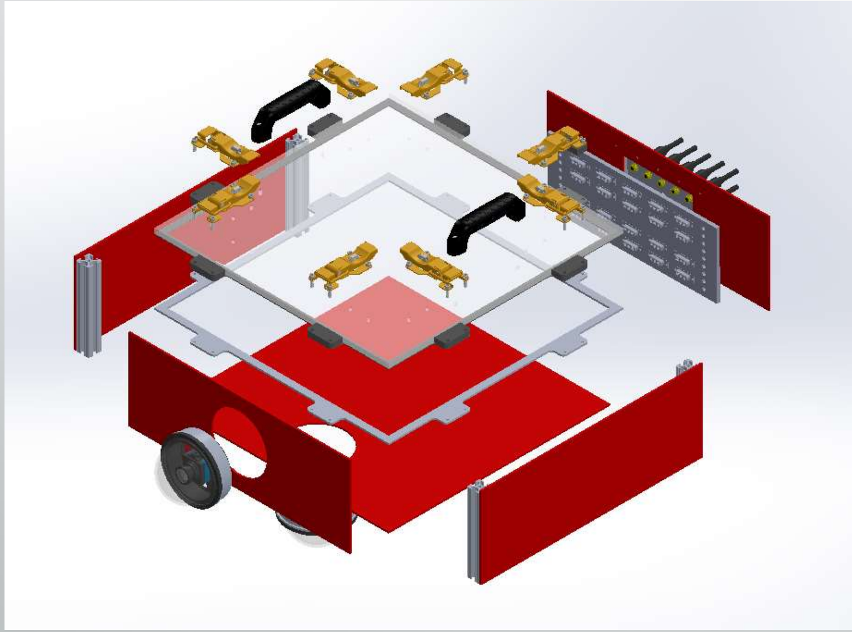
Body	Hull	Charles Brian
	Frame	Angel

Body - Hull

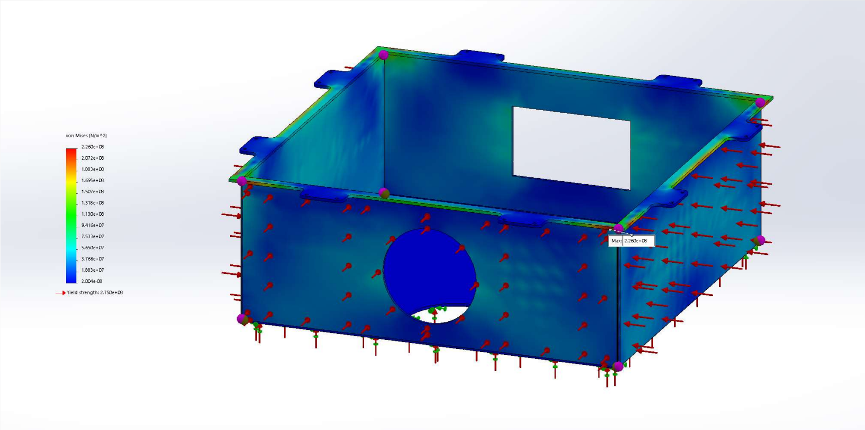


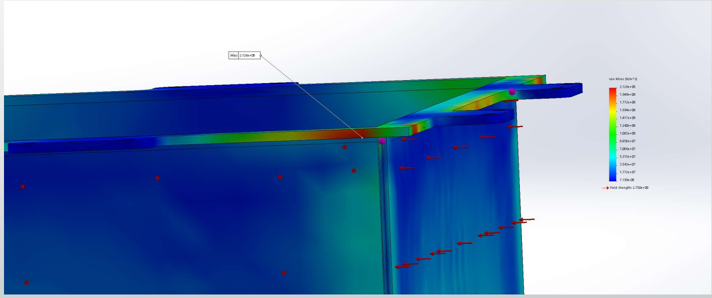
- 5 welded 1/8 in thick aluminum sheets
  - Welded to an 1/8 in aluminum sheet on top
- Designed by last year team for accessibility of electronics

Hull - Stress Analysis

A stress analysis was performed

- The max depth = 16 ft / 5m
    - Leads to a pressure of 48,000 pascals
- Factor of Safety= 1.1
    - Needed Improvement
        - Hull cannot fail
        - Max stress was found on all corners of the top sheet
        - (Adjustments will be made on this area)



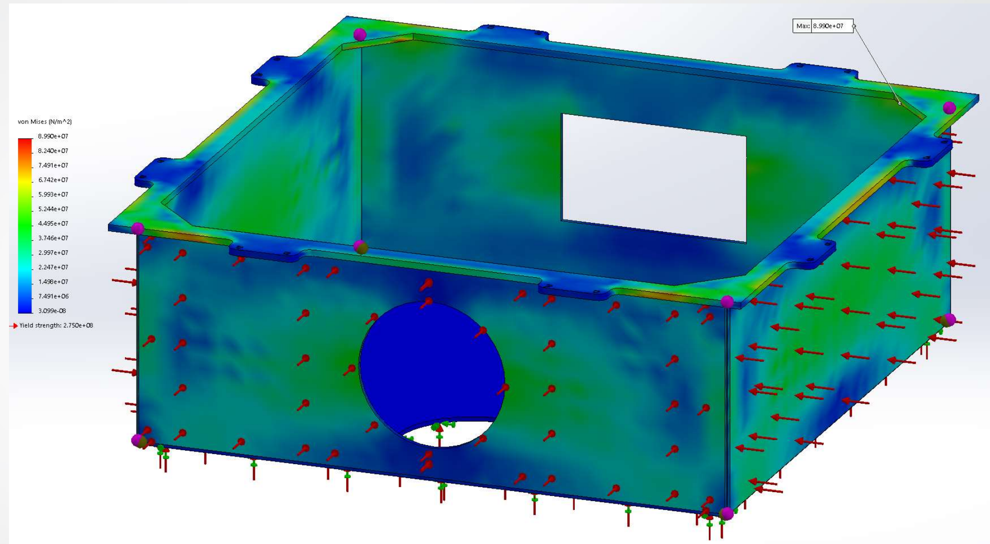


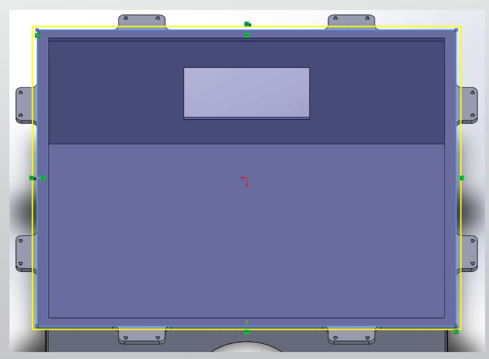
Hull - Adjustments

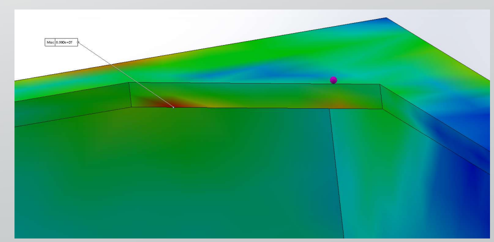
3 Adjustments

1. Increased thickness to 3/16 in
   - Factor of safety = 1.3
2. Extended top sheet by 0.2 in
   - Factor of safety = 1.9
3. Added 1.5 in chamfers to all corners
   - Factor of safety = 2.2
   - This was tested without the extended top sheet

- With both extension and chamfers
  - Factor of Safety = 3.1
  - Max stress move to beneath chamfer







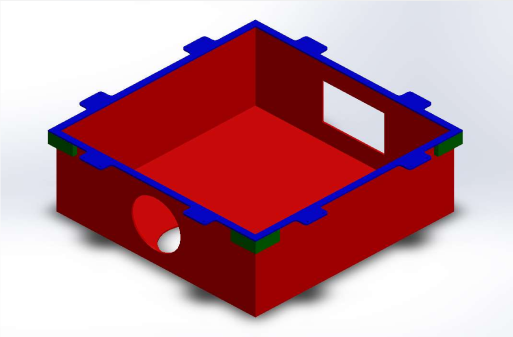
Hull - Cover and Seal

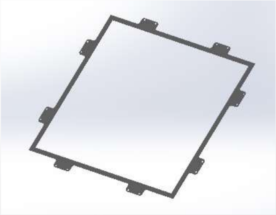
Current plan

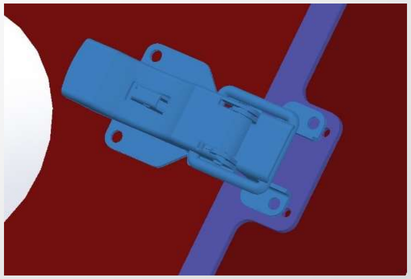
- Use a gasket shaped identical to the top surface and seal with clamps
  - Analysis of effectiveness not performed

Alternate methods explored

- Designing cover that inserts into cavity of hull and making seal inside the perimeter
  - Will require pressure release valve
- Grooved perimeter with fitted track for O-Ring
  - Reliability and replaceability concerns of O-Ring
- Using a screwing mechanism as a clamp to attach the cover over existing gasket
  - Find a torque value needed in relation to seal
  - Predicted longer durability than clamps







Hull – Electrical Housing

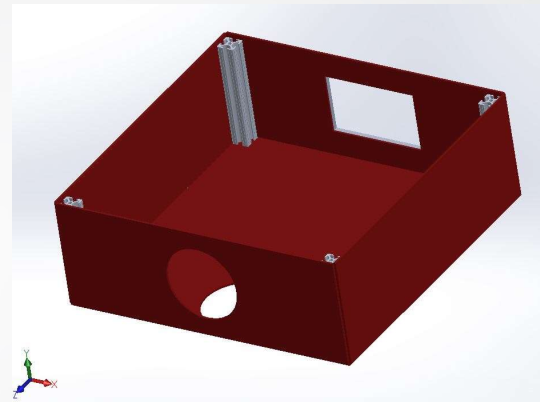
Current Plan

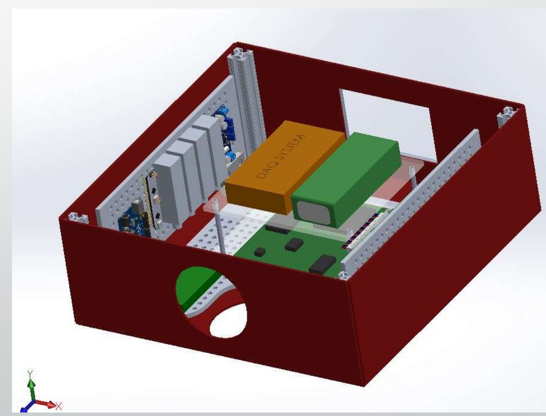
- Attaching a rail in each corner with a track to slide the separate electrical board in and out of
- Arranging a permanent plug interface in rear of hull connecting to subsystems affixed to AUV

Alternate Method

Drilling holes in floor and attaching rails to mount the electrical board

- Possibly using these holes in conjunction with mounting the frame onto hull
- More modular board installation possibilities
- However, more places to seal and could affect stress analysis and factor of safety

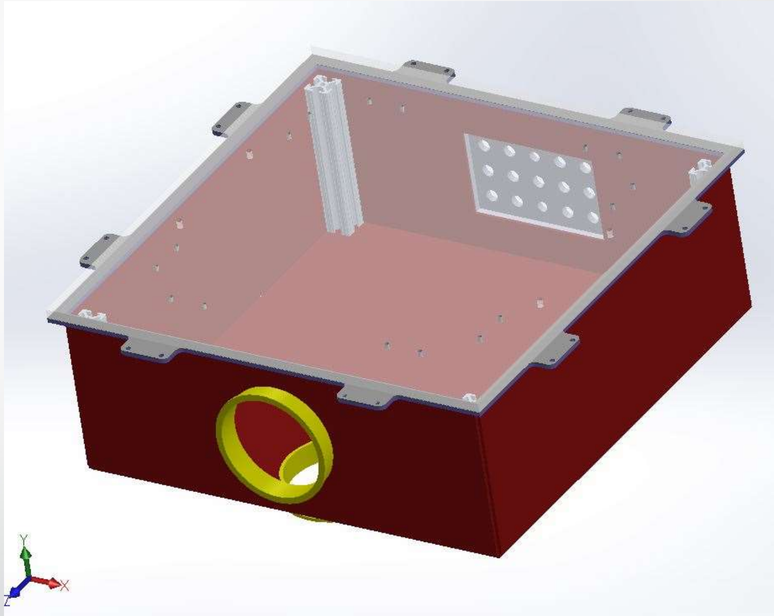




Hull – Production Status

Pending Tasks for Initial Hull Production

- Finalize sealing method of the hull with the cover.
- Finalize electrical board interface with hull
- Obtaining new materials
  - materials acquired from previous year deemed insufficient in passing stress tests
- Using a full bead welding process to ensure waterproofing
  - Finding a shop with experience to do this, unlikely student task

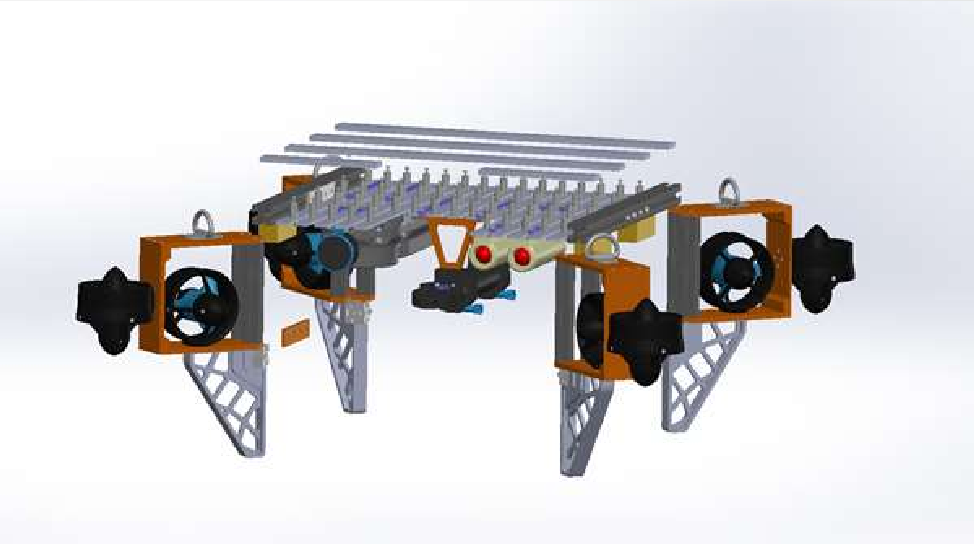


MECHANICAL

Actuated Systems	Dropper	Angel
	Claw	Anthony
	Torpedo	Jay
Body	Hull	Charles Brian
	Frame	Angel

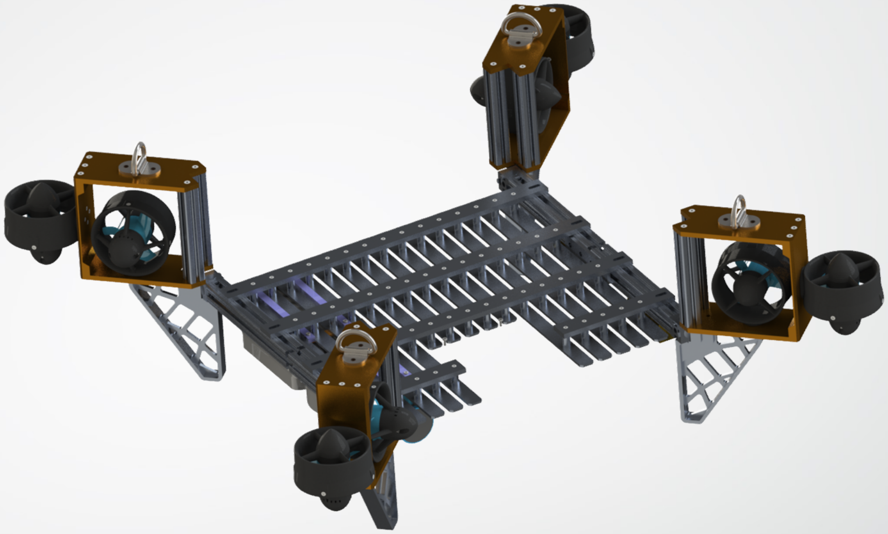
Body - Frame

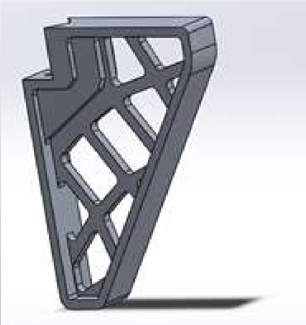
- The multiple –slot design for the frame allows easy mounting of the actuated systems.
- 8 thrusters total mounted to the corners of the frame. 2 on each corner.
- Multiple slots allows for easy add-on of numerous components to be made
  - Sensors
  - Handles
  - Mounting points to join the hull and frame

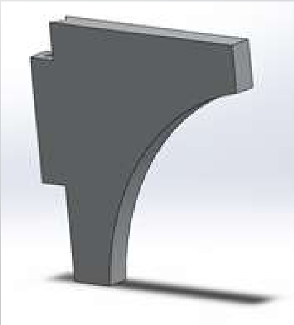


Frame

- Leg design optimized
  - Static stress analysis
  - Machine to specification (6061 Al)
- Optimization not needed
  - Weight reduction by 1.64 lb
  - Weight is of no concern
  - Production and material cost not necessary

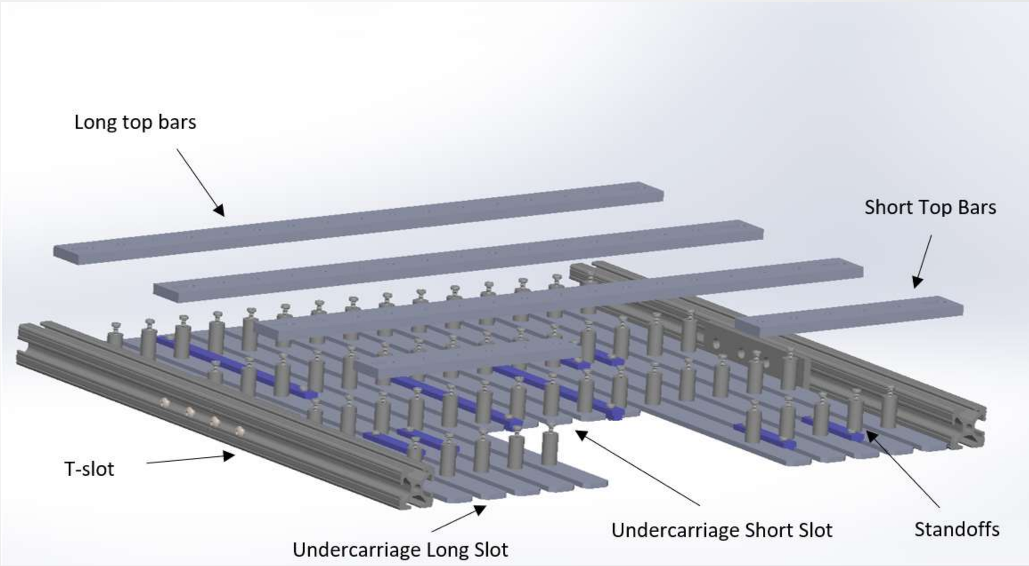






Frame

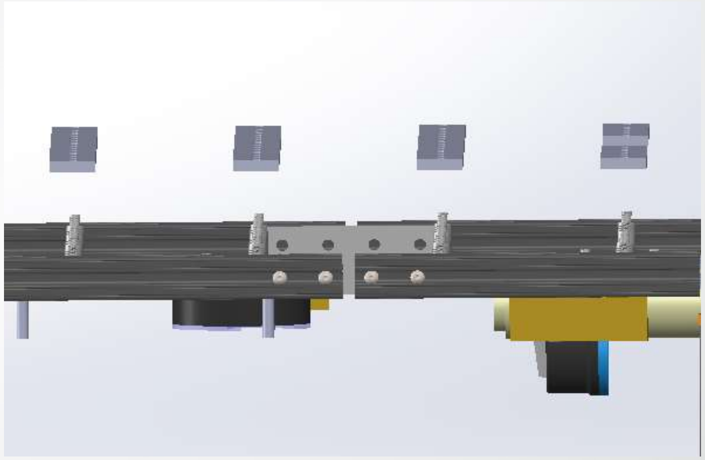
- The frame can be divided into two main sections
  - Undercarriage
  - Top Section
- The frame is composed of the numerous parts as shown in the figure
- Production
  - All bars and slots cut to appropriate dimensions
  - Assembly of cut material by using standoffs and screws to be continued
  - Legs to be produced as well as thruster's housing

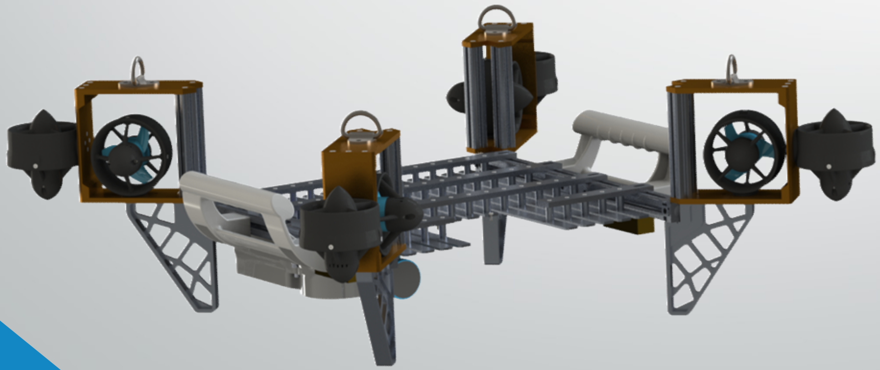


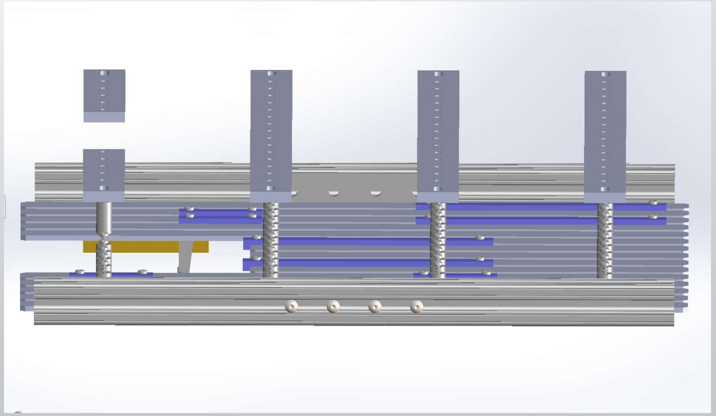
Frame

Changes from previous design

- Extruded T-bar slot to full length
- Opens mounting points for new handle location





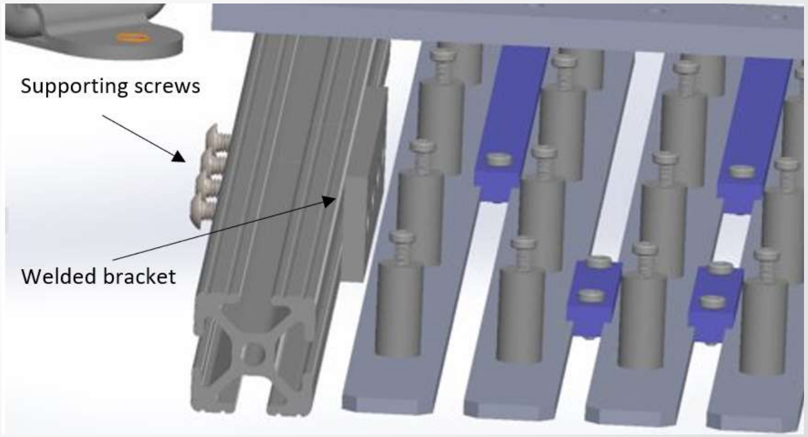


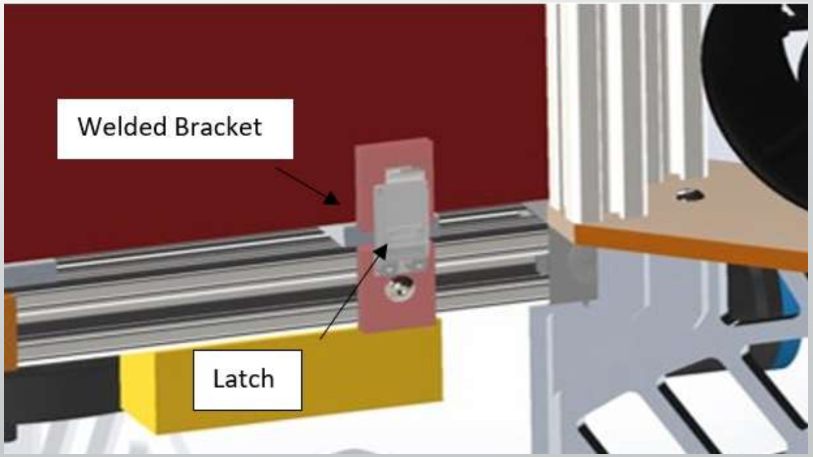
Frame

Changes from previous design

- Extruded T-bar slot to full length
- Opens mounting points for new handle location
- Welded bracket shown will join the T-slot to the bars of the frame.

- Kept from previous design
  - Welded bracket and latch to join the hull and frame





AGENDA

Background, Objective, Requirements

System Overview

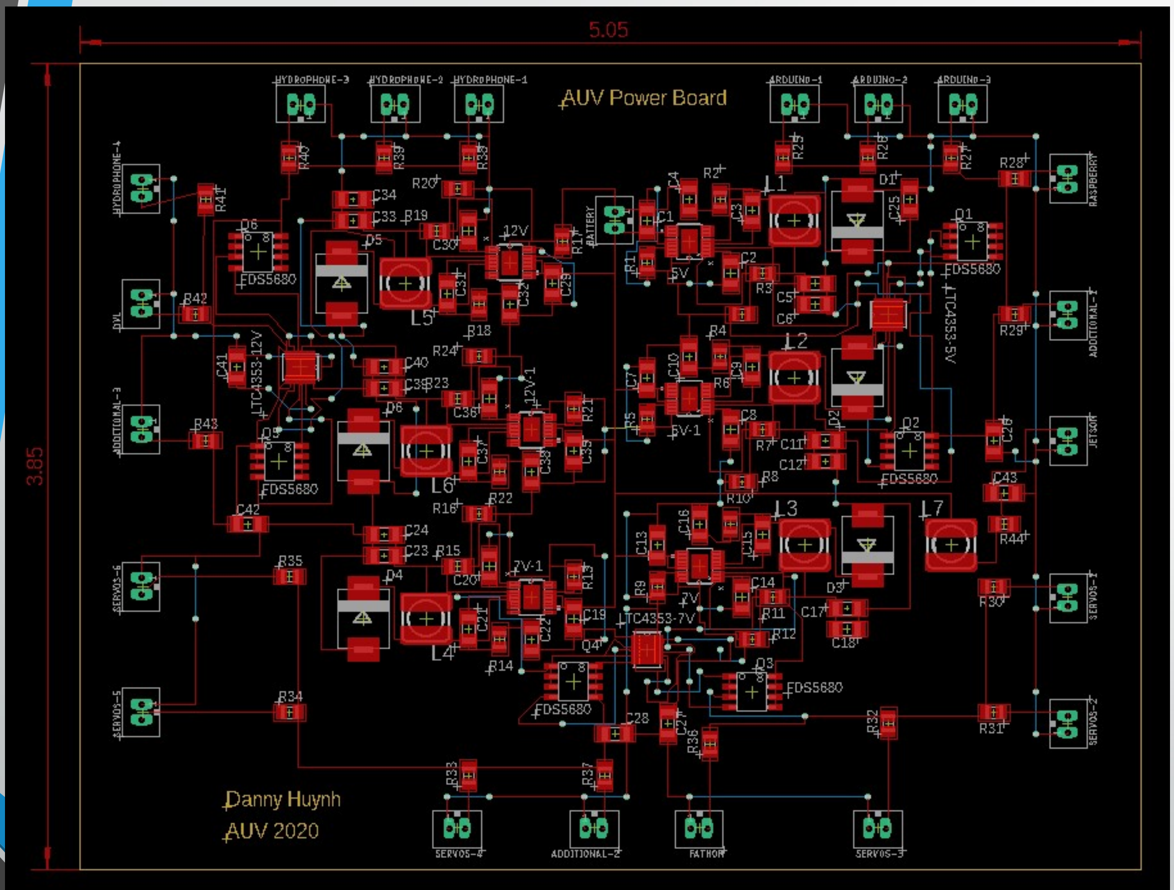
Mechanical

Electrical

Simulation

Conclusion

Electrical – Previous Version(PDB)



<u>Devices:</u>
Arduino (x3)
Servos (x6)
Fathom
Hydrophones (x4)
DVL
Jetson TX2

<u>Dimensions:</u>
97.79mm Height
128.27mm Length

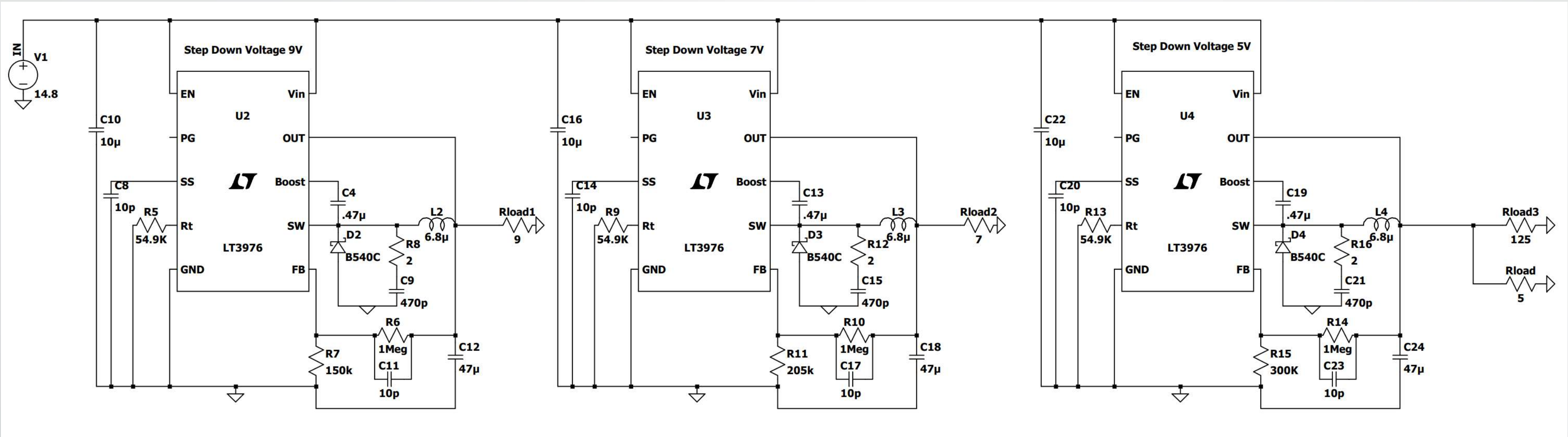
<u>Things to Note:</u>
No drill holes
Clustered surface mounted components
Board can be reduced in size
FDS5680 IC used

Electrical - Device Operation Requirements

Device	Voltage (V)	Current (A)	Power (W)
Arduino(x2)	5	1	5
IMU	5	0.04	0.2
Servos(x3)	7	1	7
Fathom	7	1	7
Hydrophones (x4)	9	1	9
DVL	14.8	4	59.2
Jetson TX2	14.8	1	15
Thruster Board	14.8	Varies	Varies
Thruster(x8)	14.8	Varies	Varies

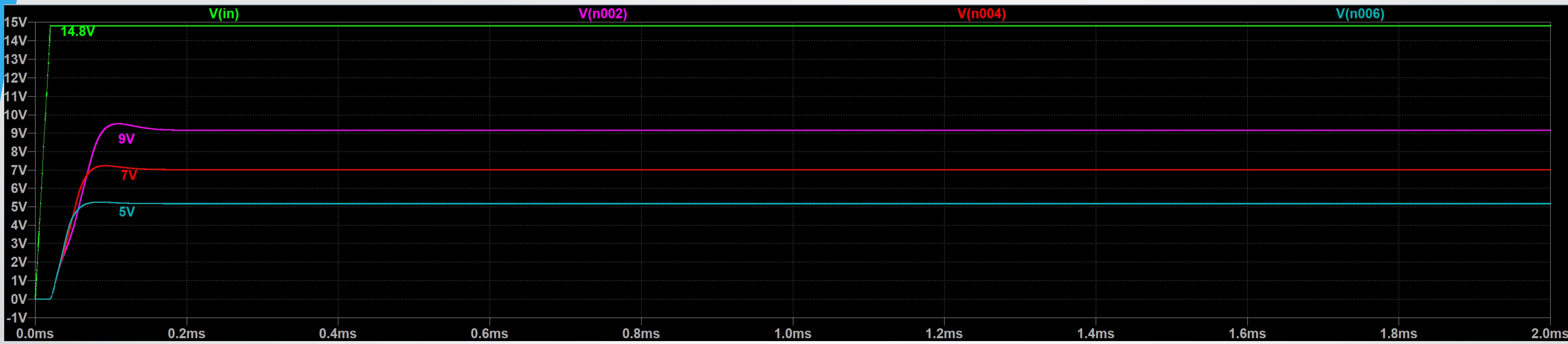
ELECTRICAL	
Power Distribution Board	Daniel Romero Jose Barrera
Simulations	Daniel Romero
Design	Jose Barrera

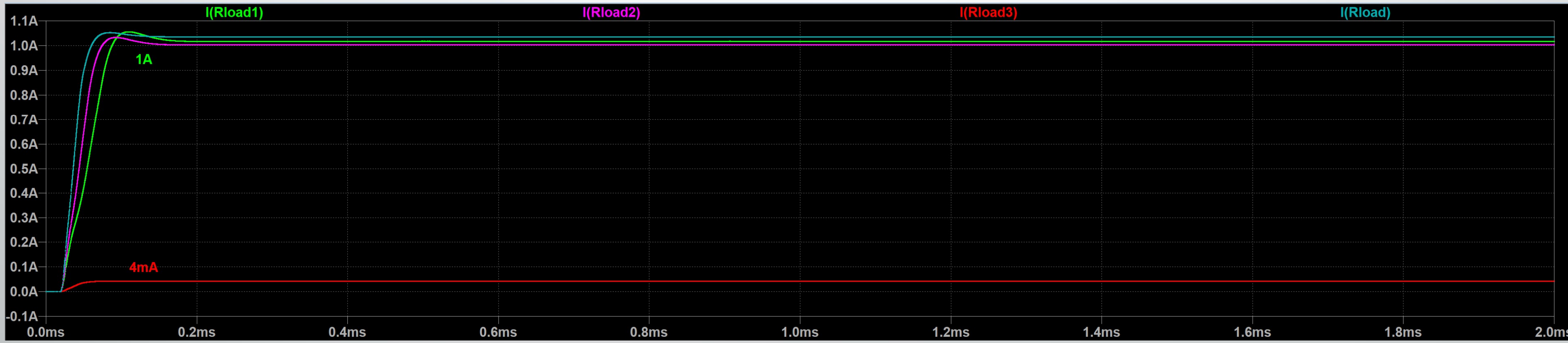
Circuit- Power Distribution Board (PDB)



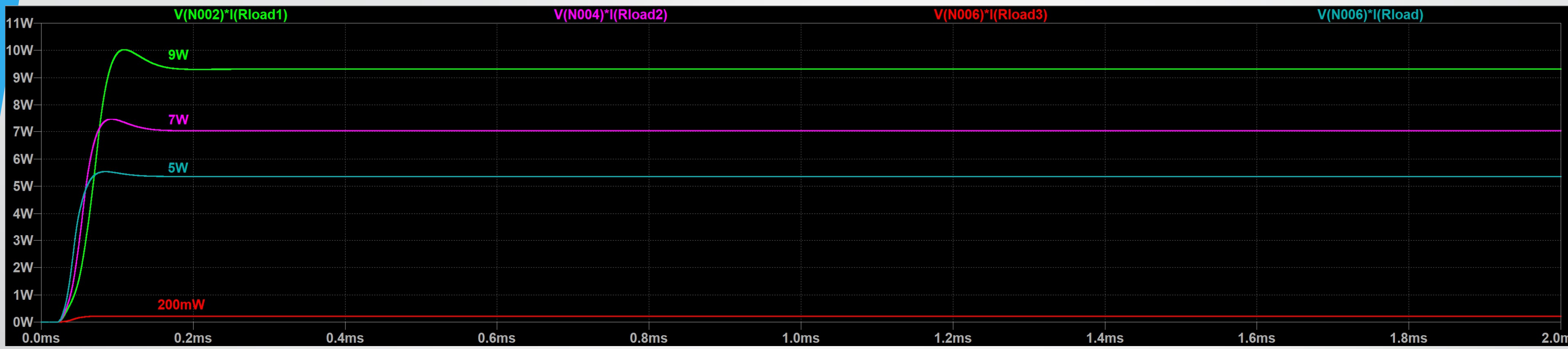
- Buck Converter: LT3976
  - Step-down voltages
  - Minimize Space on the board
  - Ideal for low current circuits
  - Input voltage range: 4.3V - 40V
  - Max current output: 5V
- Circuit made on LTspice
  - Input voltage supply: Single 14.8V LiPo battery
  - Conduct simulations for the voltage, current and power consumption

Simulations - Power Distribution Board (PDB)





Simulations - Power Distribution Board (PDB)



Efficiency: 91.7%
Input: 10.2W @ 14.8V
Output: 9.35W @ 9.17V

Efficiency: 90.9%
Input: 7.76W @ 14.8V
Output: 7.05W @ 7.03V

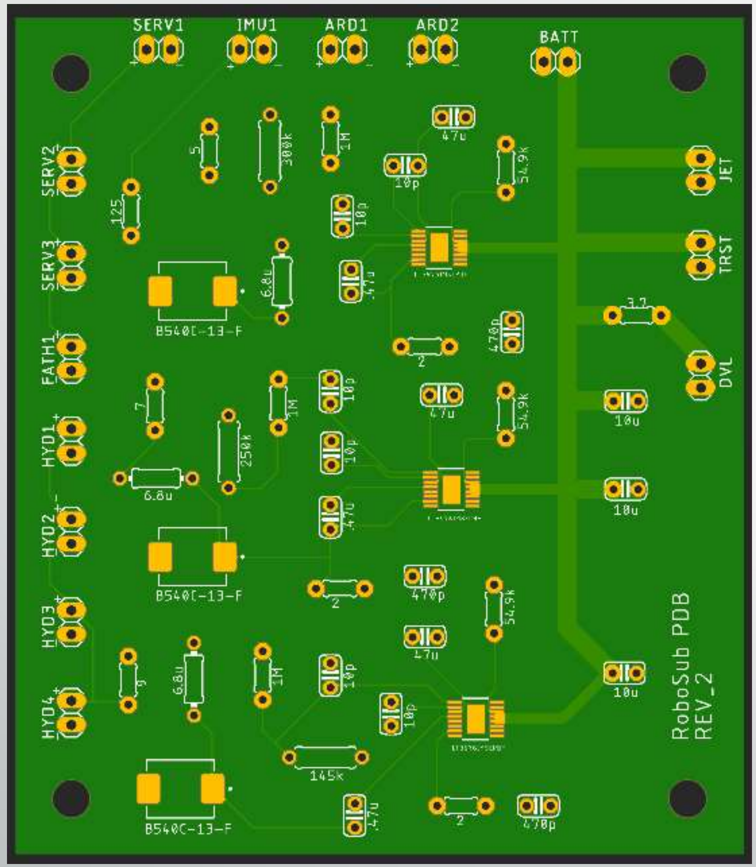
Efficiency: 76.4%
Input: 284mW @ 14.8V
Output: 217mW @ 5.21V

Efficiency: 89.4%
Input: 6W @ 14.8V
Output: 5.36W @ 5.18V

- Transient Analysis Simulations performed
  - Performance of the IC over time
  - Steady State is detected
  - Values correspond to the device operation requirements
- Efficiency Reports
  - How well the IC performs the voltage regulation
  - Values align with efficiency range on the datasheet for the IC

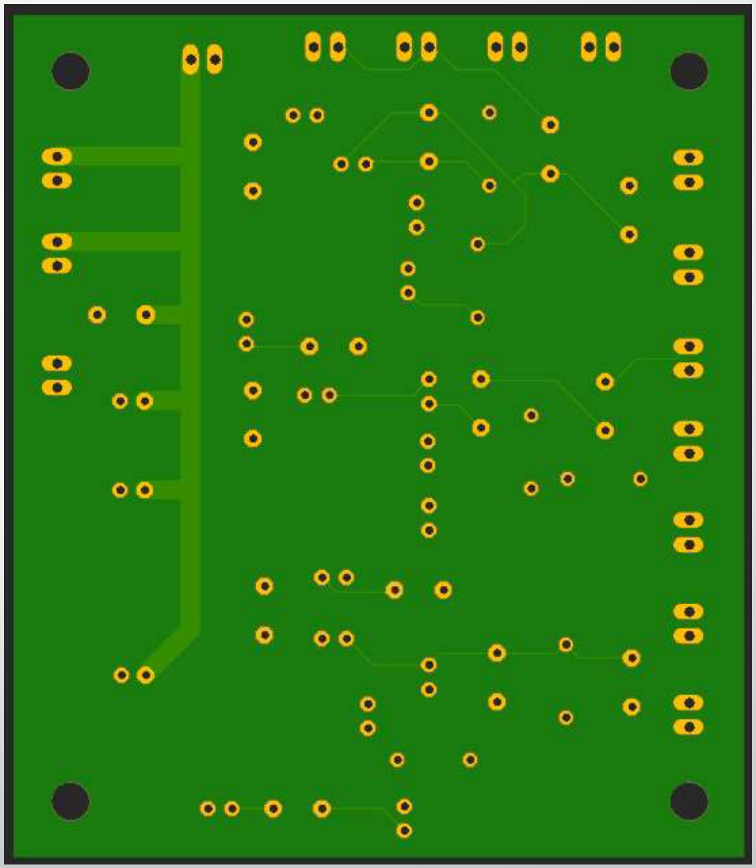
ELECTRICAL	
Power Distribution Board	Daniel Romero Jose Barrera
Simulations	Daniel Romero
Design	Jose Barrera

PDB View



--87.87mm Height

--76.33mm Length



--5.84mm Diameter Drill holes

BM7

PDB Components and Cost

Item	Value	Quantity	Cost($)	Total($)
Capacitor	10uF	3	2.58	7.74
	10pF	6	0.18	1.08
	470nF = .47uF	3	2.52	7.56
	470pF	3	0.3	0.9
	47uF	3	1.98	5.94
Resistor	54.9kΩ	3	0.12	0.36
	1MΩ	3	0.8	2.4
	2Ω	3	0.56	1.68
	300kΩ	1	0.44	0.44
	125Ω	1	1.44	1.44
	5Ω	1	0.5	0.5
	205Ω	1	0.28	0.28
	7Ω	1	3	3
	150kΩ	1	1.04	1.04
	9Ω	1	2.66	2.66
Inductor	6.8uH	3	1.1	3.3
Diode	B540C	3	0.48	1.44
IC	LT3976	3	10.04	30.12
XT90 Adapter	Male Connector	1	2.5	2.5
Male Pin Headers	2.54mm	1	7.99	7.99
TOTAL				82.37

Slide 57

BM7 All from one Website, Mouser Electronics

Barrera, Jose M, 4/22/2021

AGENDA

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SIMULATIONS

Simulink	Chris
Gazebo	Eddie
SolidWorks – Internal Thermals	Louis

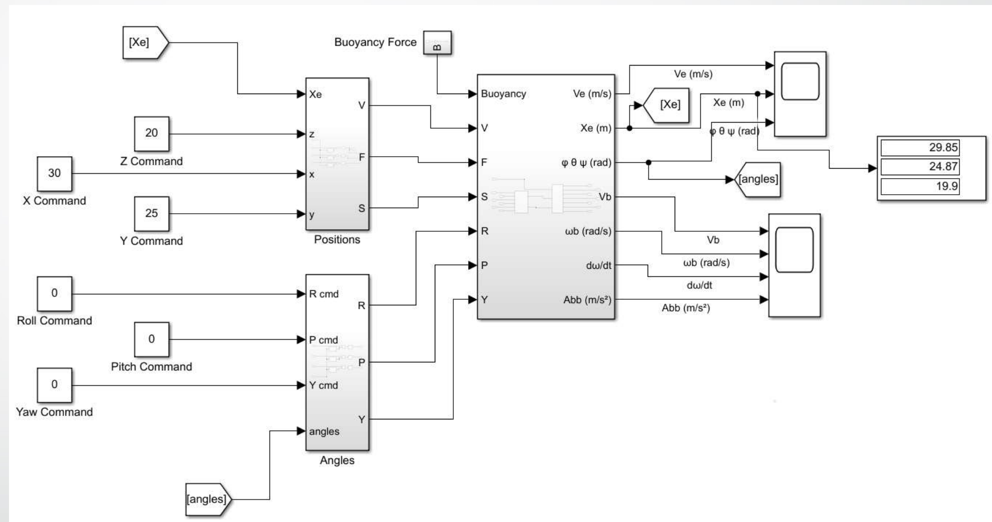
Simulation - SimuSub

Simulink

- Graphical coding language
- Simulation and modeling
- Co-simulation with Gazebo

SimuSub

- PID tuning
- Control system testing
- State System architecture

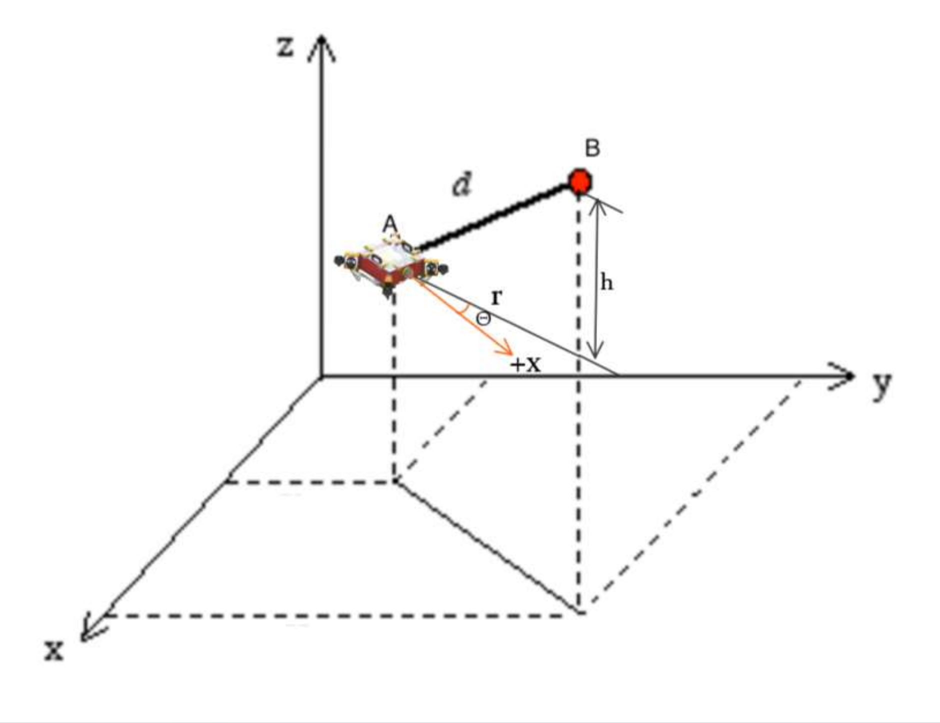


SimuSub – precision control system

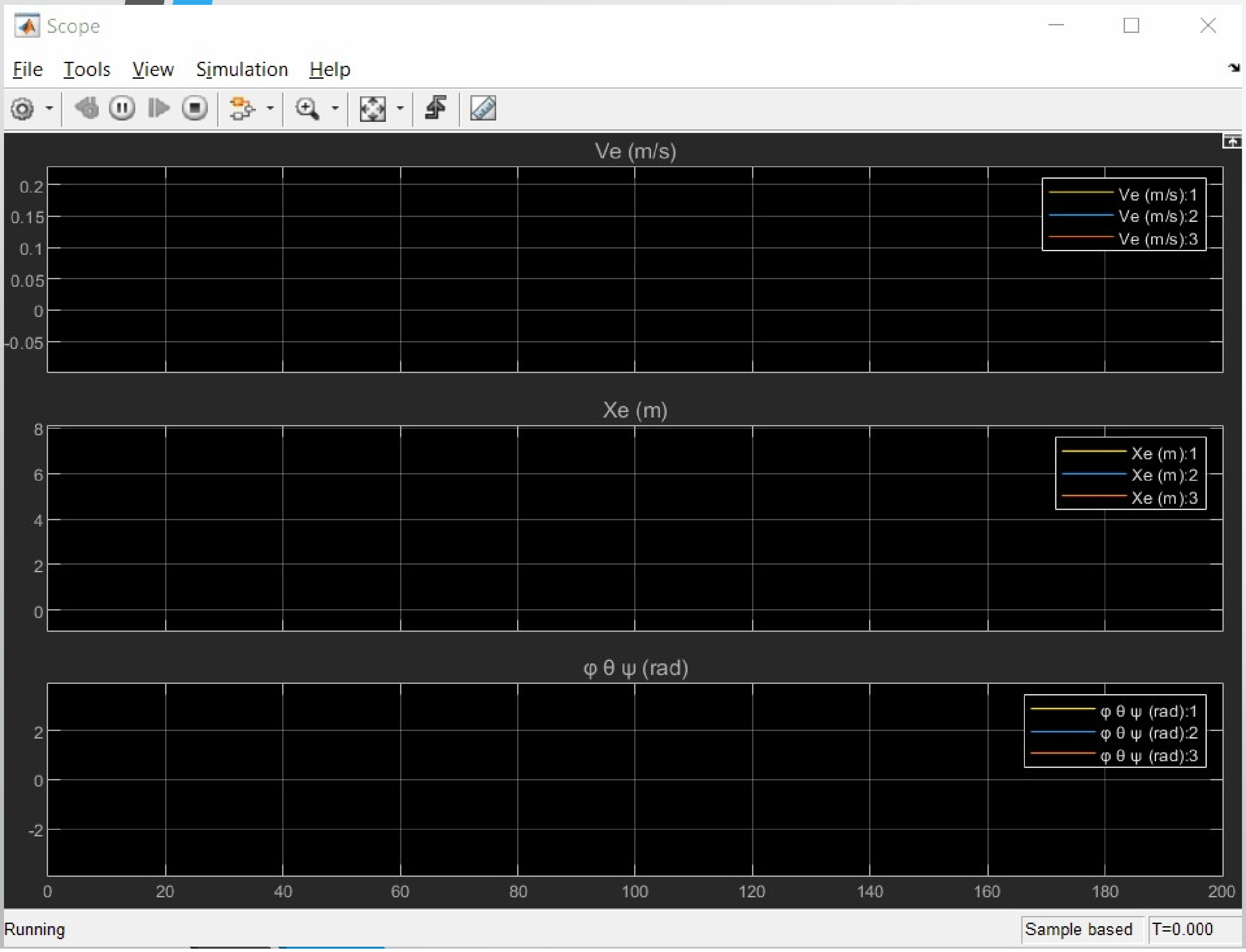
Simulation - SimuSub

Traveling Control System

- PID controlled system
- r = horizontal error
- h = elevation error
- Θ = yaw error
- Elevation either concurrent or distinct



SimuSub - Traveling

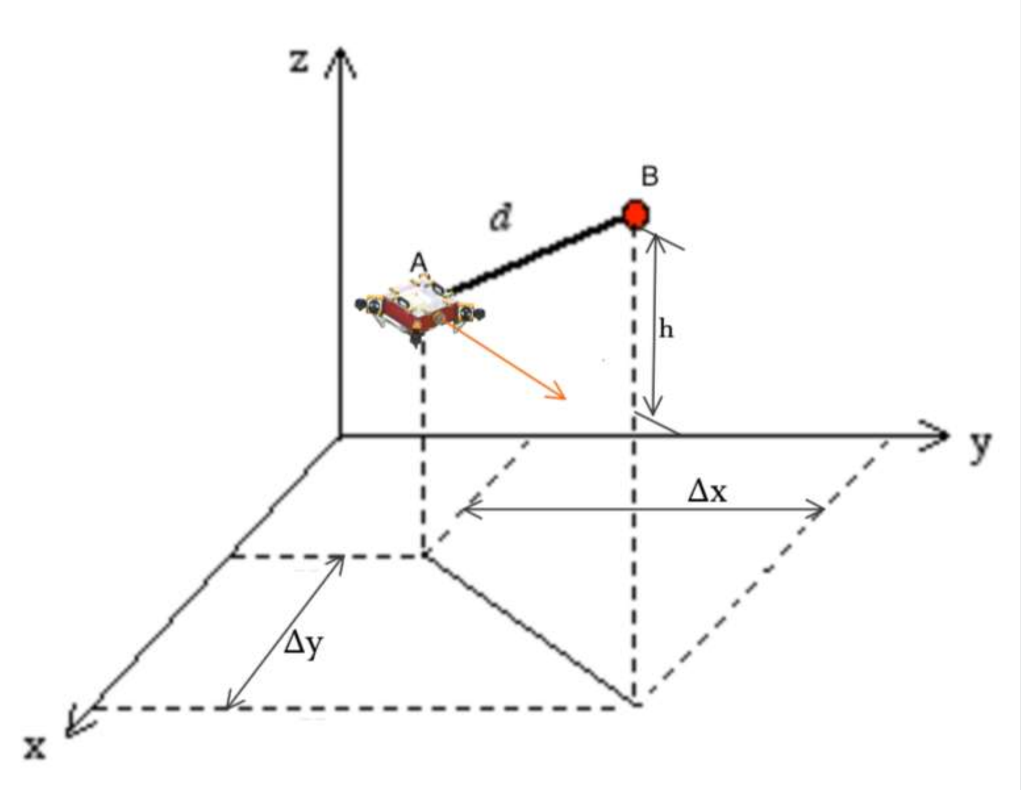


Example commands:
Cartesian; earth frame:
[5 3 0]
Euler Angles; earth frame:
N/A

Simulation - SimuSub

Precision Control System

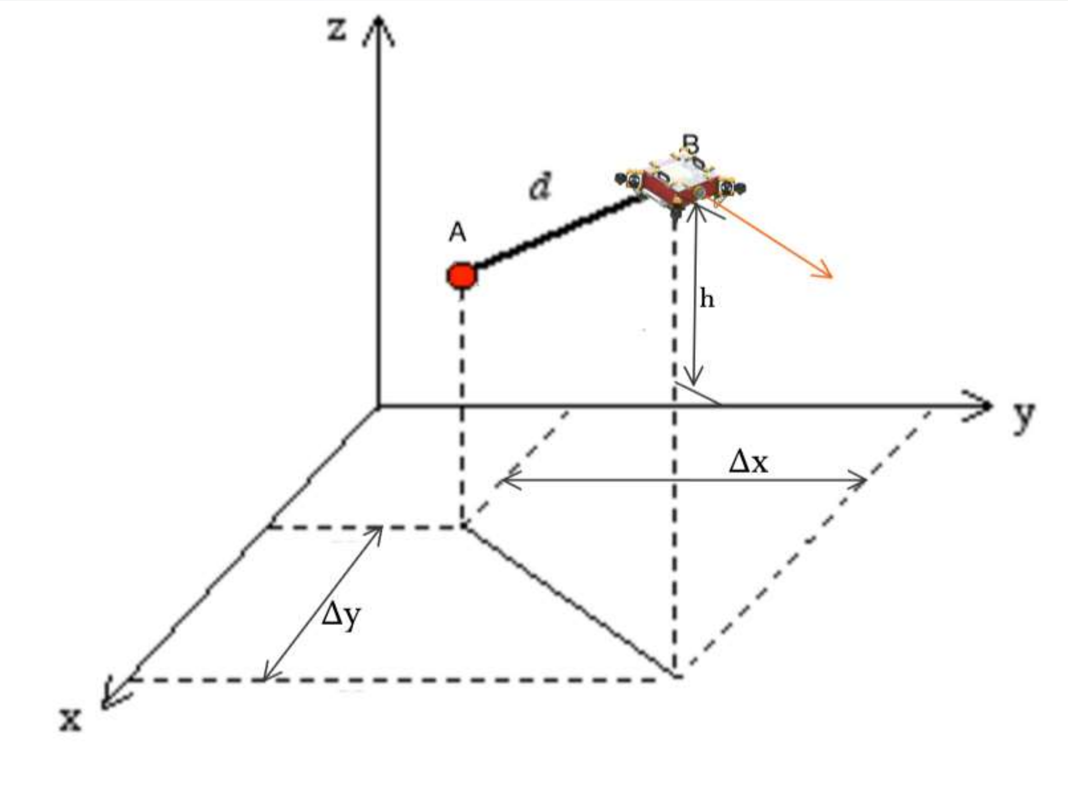
- PID controlled system
- Δx = x error
- Δy = y error
- h = elevation error
- No angular error



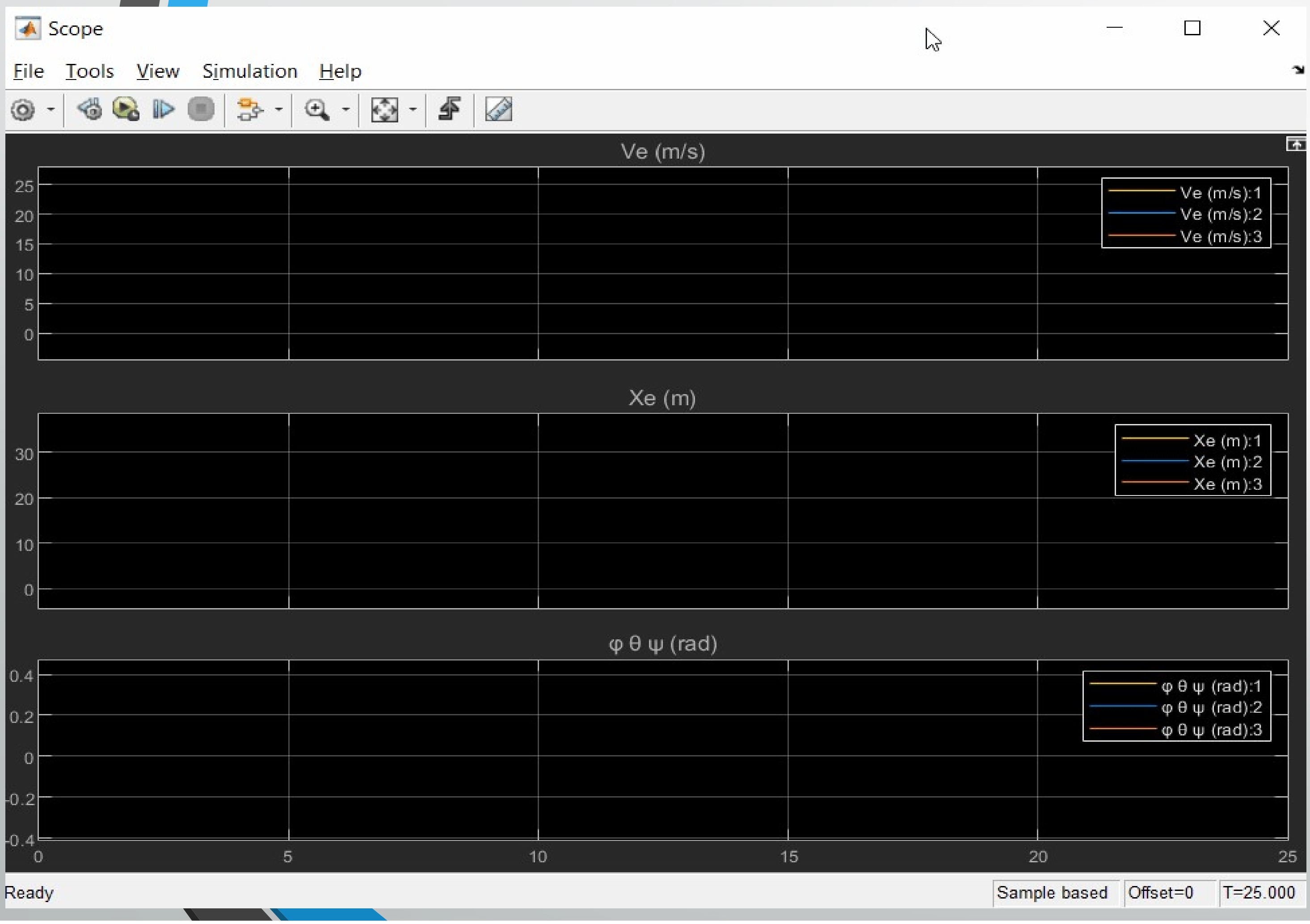
Simulation - SimuSub

Precision Control System

- PID controlled system
- Δx = x error
- Δy = y error
- h = elevation error
- No angular error



SimuSub – Precision Control System



Example commands:
Cartesian; earth frame:
[30 25 20]
Euler Angles; earth frame:
[0 0 0]

SimuSub – Future Work

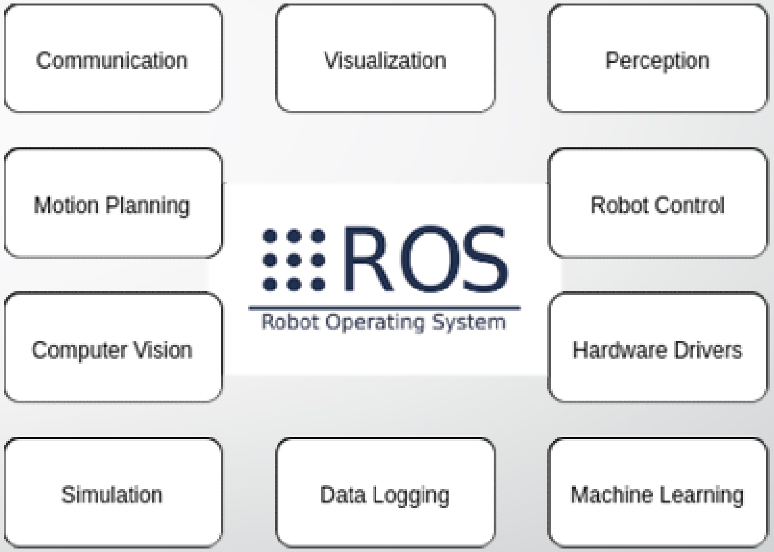
- Fixing control systems
- Mission Planning
- Navigation
- State Machine Architecture
- Co-simulation with ROS/Gazebo

SIMULATIONS	
Simulink	Chris
Gazebo	Eddie
SolidWorks – Internal Thermals	Louis

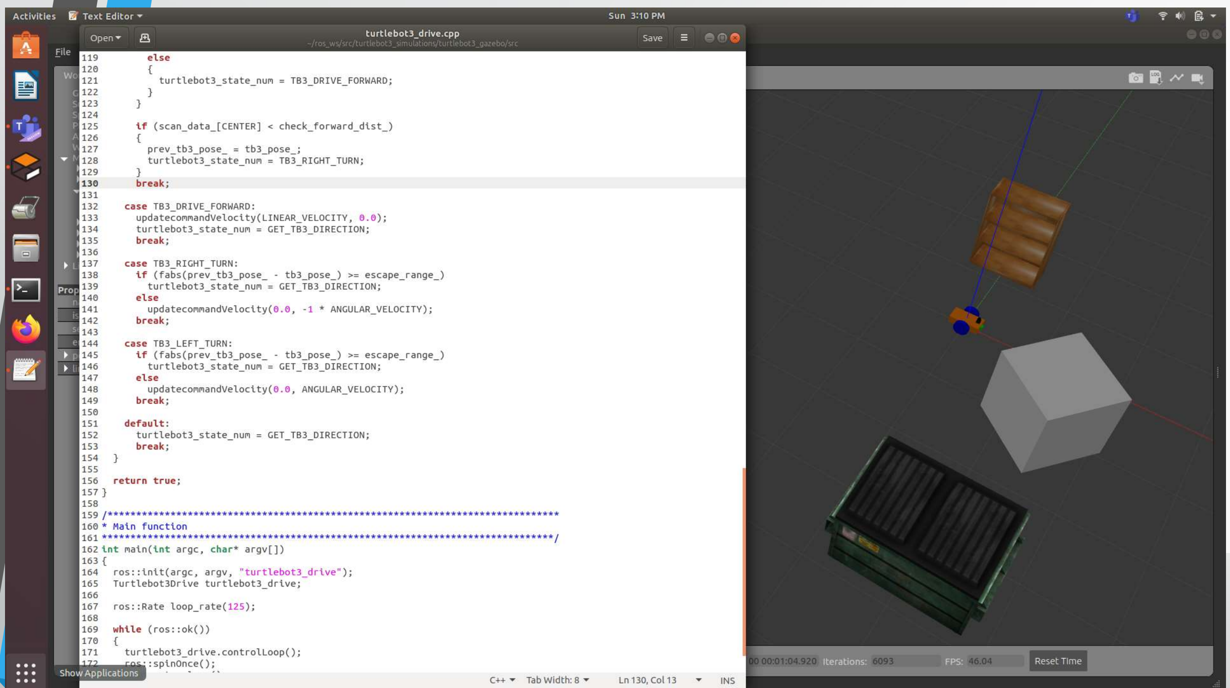
Robot Operating System (ROS)

How is this beneficial to the AUV?

- Simulation tools allows for more flexible design
  - Test data
- Thousands of packages; tools that give our AUV variety of choices that includes sensors, cameras, etc.



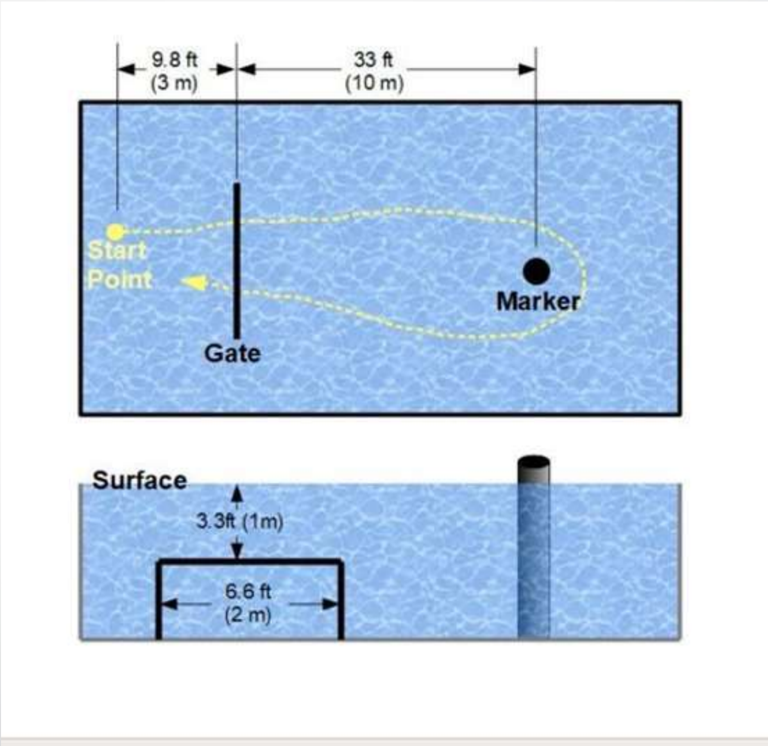
Robot Operating System (ROS) - Gazebo



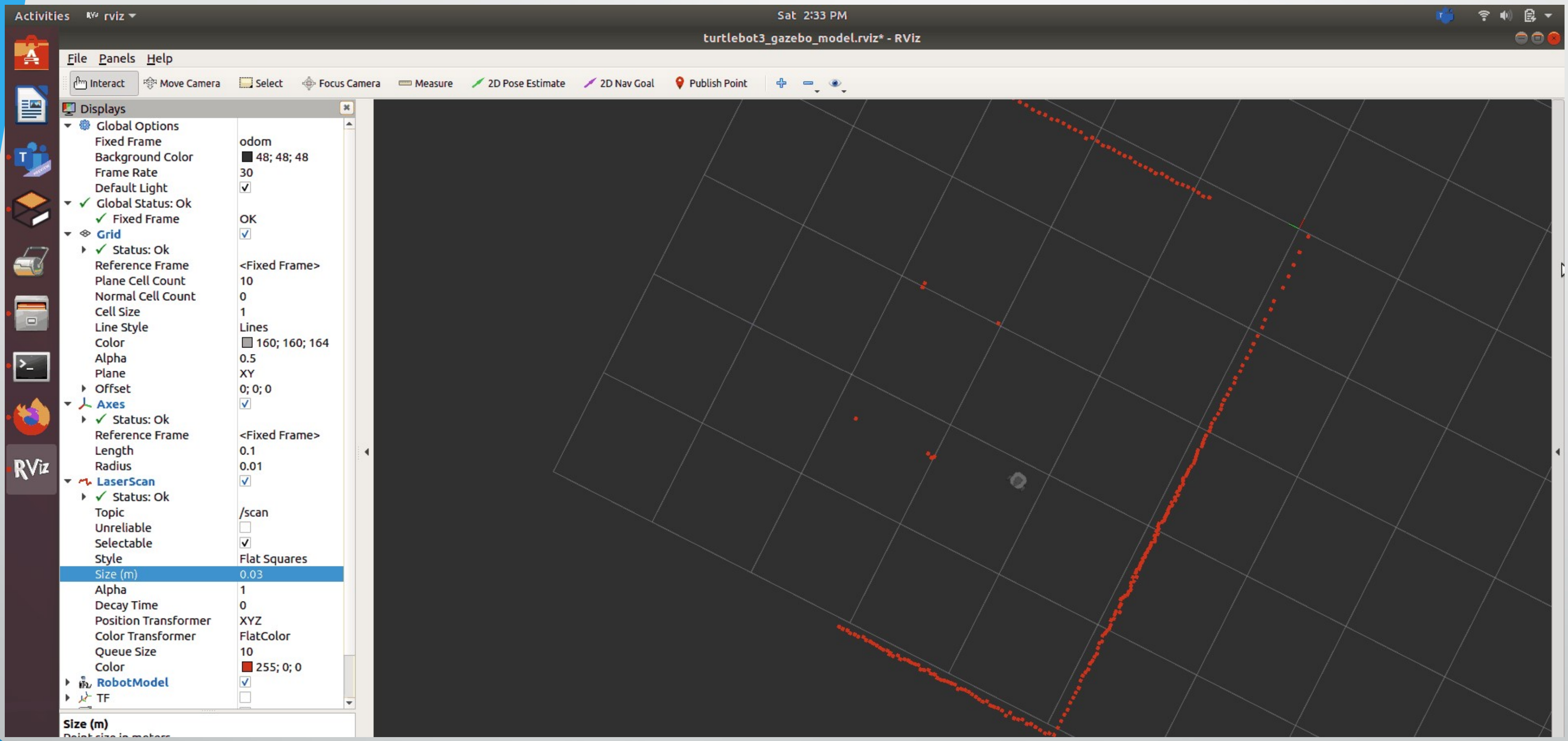
GAZEBO

Gazebo (Water Environment)

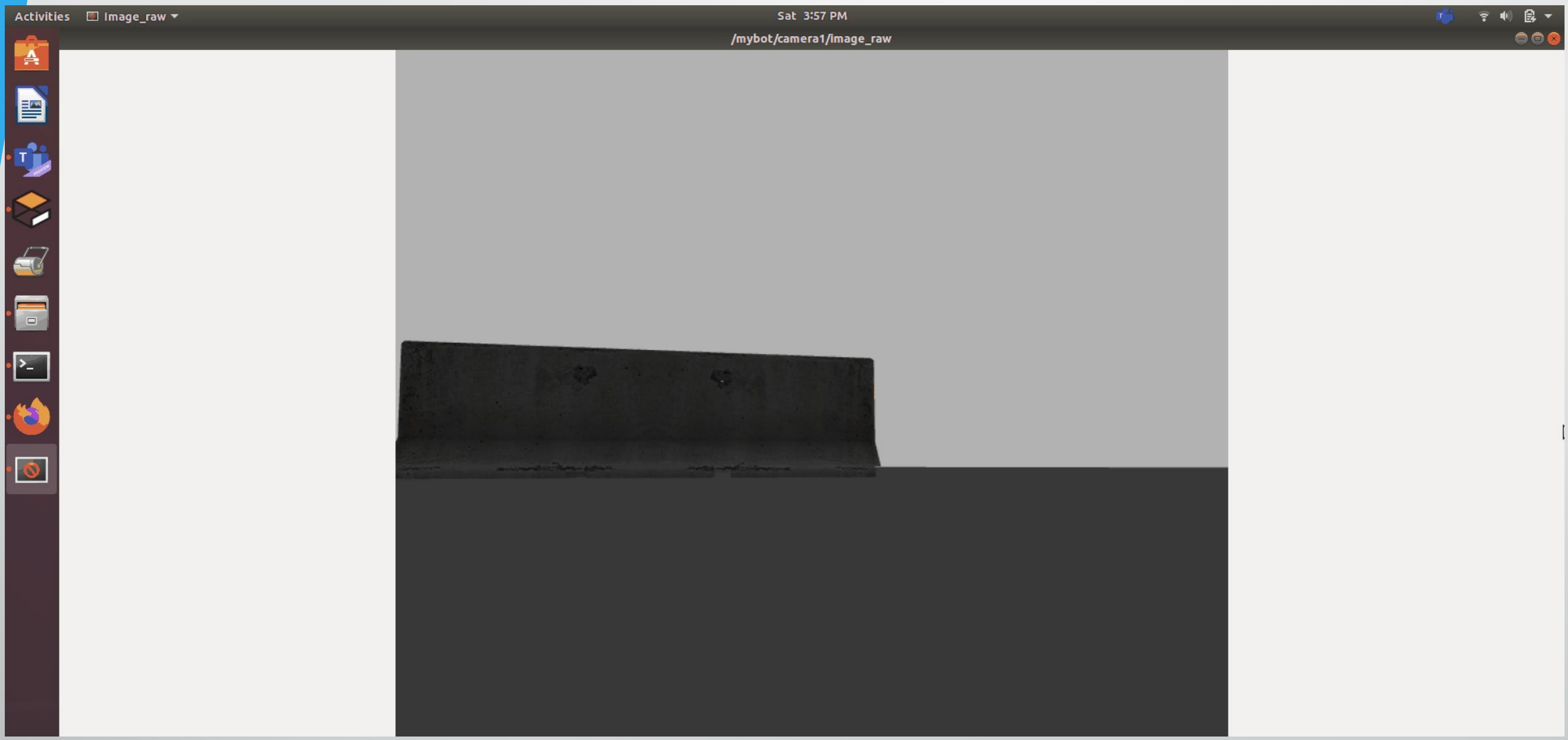
Image of Competition Arena, NIWCP, San Diego[1]



Gazebo Simulation – Laser Scan (Sensor)



Gazebo Simulation - Camera



SIMULATIONS

Simulink	Chris
Gazebo	Eddie
SolidWorks – Internal Thermals	Louis

Revisiting Internal Thermals

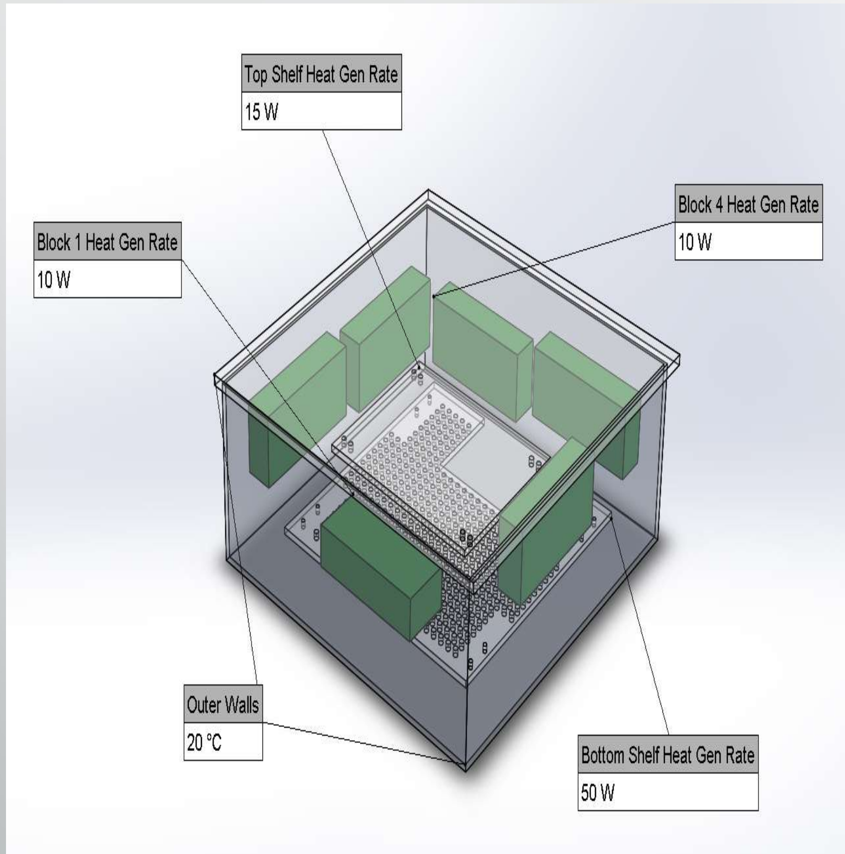
Previously

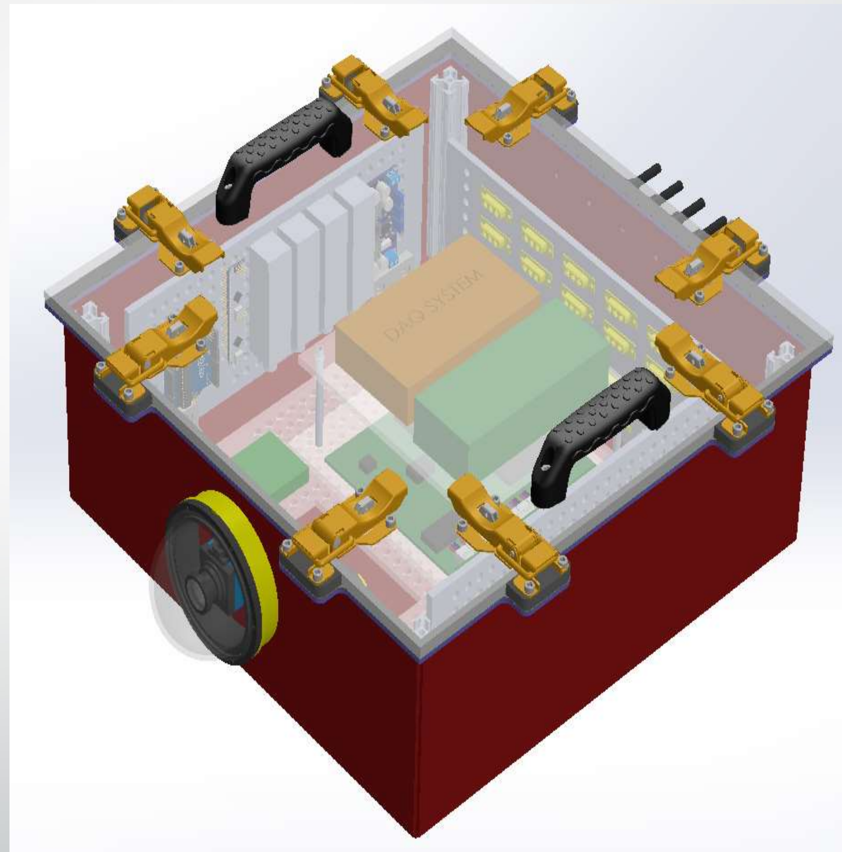
- One previous CSULA AUV would overheat
- What about current AUV: Lanturn?
  - Last semester hand calc + SolidWorks sim
  - Worst case (100 watts) – No issue, barely
- Risks and limitations
  - Additional components (Comp vision)
  - Previous simulation = steady state
    - Unknown time to reach SS
  - Simplified model used limits accuracy

The Revisit

- Attempted to use realistic internals
  - Issues: Errors + excessive calculation time
- Resolving risks and limitations
  - Simplified model
  - 125 watts heat generation
  - 1 hour of operation
- Results:
  - 37 to 43 min to hit 65 °C battery limit
  - Comp runs historically: 20 min = 1200 sec
  - Power budget available

Revisiting Internal Thermals





AGENDA

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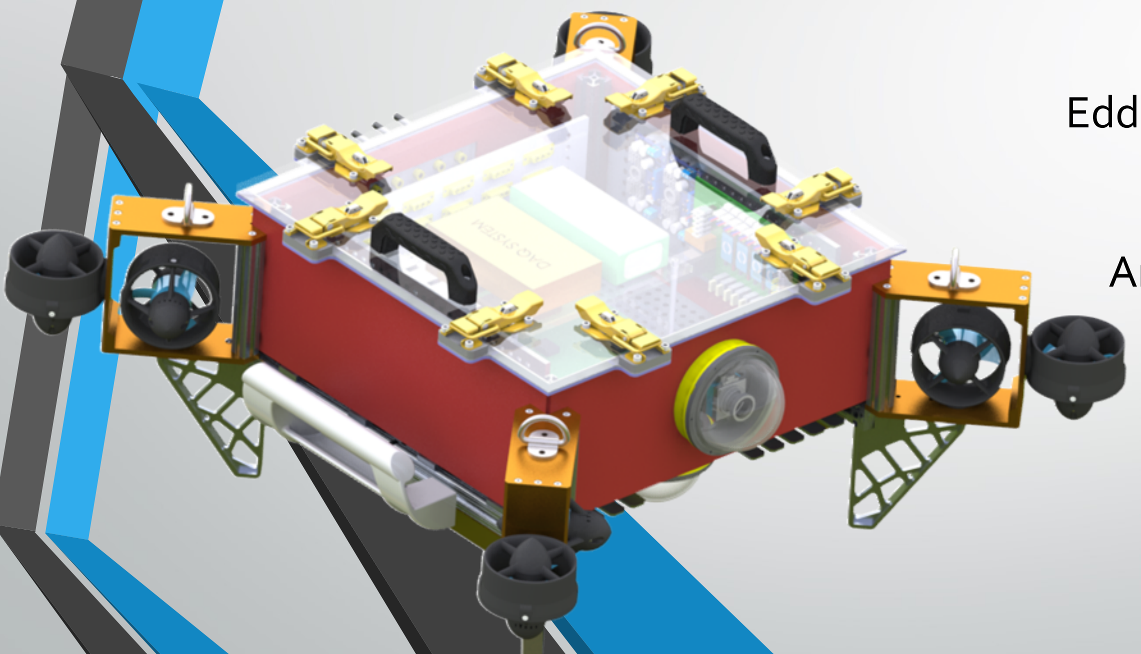
Summary

- MECHANICAL
  - Designing has been completed
  - Manufacturing incomplete
  - Testing not done
- Electrical
  - PDB design and simulation completed
  - Manufacturing incomplete
- Simulation
  - Much more work needed to be fully functional
- Passing the baton
  - Onboarding material provided to next year's team



Thank you!

Eddie Hernandez

Jose Barrera

Angel I. Toribio

Yongjie Li

Louis Carlin

Christopher Reza-Nakonechny

Anthony Gonzalez

Daniel Romero

Brian Sager

Charles Vidal

Advisors: Dr. He Shen
Dr. Thorburn

References

- [1] Robo Nation, *22ndAnnual International RoboSub Competition Mission and Scoring,* San Diego, California, 2019.

- [2] Blue Robotics, Newton Subsea Gripper, Pasadena, California, 2021.