Final Design Review

Team Speech
(Trashamaran)

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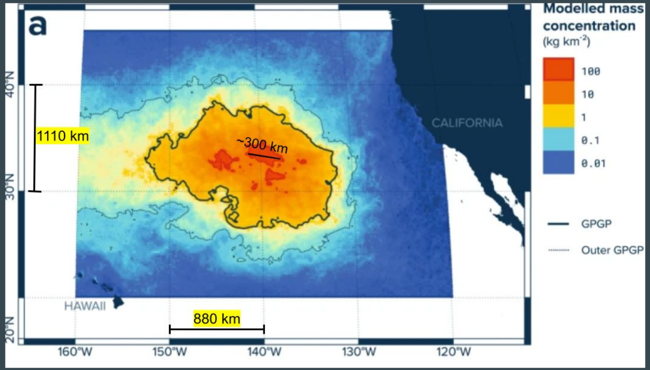
The Problem: The GPGP

- Great Pacific Garbage Patch (GPGP) is now **1.6 million square kilometers**
  - 80,000 tons of plastic debris
- Plastic waste accumulates into the food chain, laying waste to marine ecosystems
  - Ingestion, suffocation, entanglement
- Plastic waste in the ocean also affects humans
  - Of 159 samples of drinking water taken across the world, **83% contained microplastic** contamination (Kosuth, Mason & Tyree)



https://www.nature.com/articles/s41598-018-22939-w

https://earthsky.org/earth/ocean-plastic-killing-marine-turtles/

Scope

To remove all plastic from the ocean is not feasible for one contraption to do, our scope narrows to just large known plastic concentrations, e.g. the GPGP. In addition, there are a variety of plastics within the GPGP; we will be addressing the buildup of meso, macro and megaplastics (plastics greater than 0.5cm) within the GPGP during days where there is amicable weather.

In order to clean up the ocean, the GPGP must be reduced and eventually removed. The largest contributors to the GPGP by mass are macro and megaplastics; therefore the continual removal of such plastics will decrease the growing size of the GPGP.

In order to remove these plastics in a time efficient manner, an autonomous vehicle can be deployed in this area to continually collect and remove larger debris from this patch.

An efficient and continual removal of such plastics will eventually decrease the size of the GPGP, therefore removing a large source of plastic and pollution from the ocean.

We will know this problem has been satisfactorily solved when the measured size of the GPGP begins to decrease as other methods, organizations, and regulations on plastics are currently addressing mitigating the expansion of the GPGP, our solution hopes to begin minimizing it.

Design Specifications

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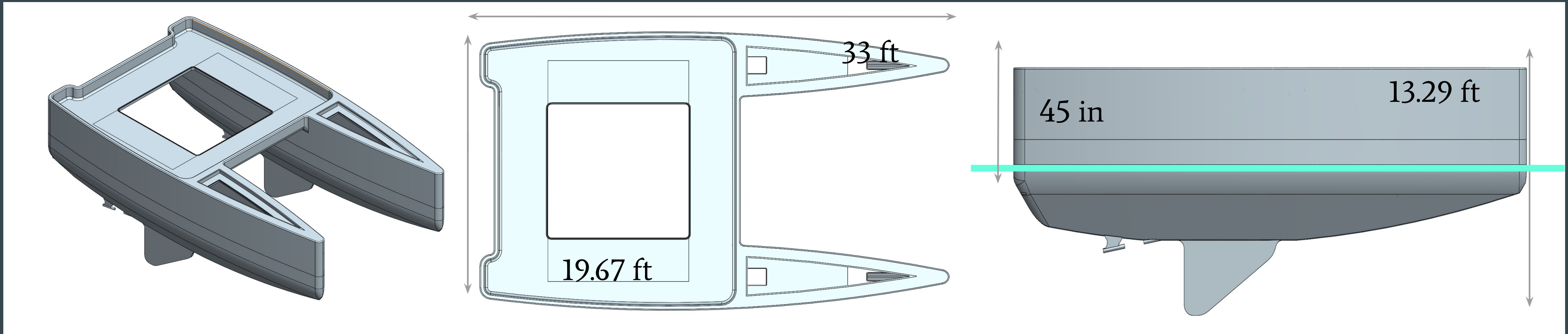
Hull Material	E Glass Fiber
Length of Boat	33 ft
Width of Boat	19.7 ft
Trip Duration	5-15 days
Product Lifetime	4 years
Maximum Load Capacity	4,043 kg
Lightweight Boat Displacement	17,249 kg
Maximum Survivable Wave Height (during operation)	2 m
Maximum Survivable Wave Height (while anchored)	4 m
Maximum Speed	10 knots
Operational Speed	0-5 knots

Powertrain type	Electric diesel dual 10 kW motor
Diesel Required per Trip	199 gallons
Trash Sensing Radius	35-70 m (size dependent)
Trash Sensing Hardware	Teledyne BlueView M900-2250-130-Mk2
Average Trash Collection Rate	23.8 kg/hr
Expected Trash Collected per Trip	4,043 kg
Expected Trash Collected over Lifetime	823,000 kg
Percentage of GPGP Collected Over Lifetime	1.03%
System Cost	\$699,161.81 initial cost, \$273,110.18 additional unit cost

System Design

Structure - E-Glass Fiber



DIMENSIONS BASED OFF CALCULATIONS AND COMMON PRACTICE

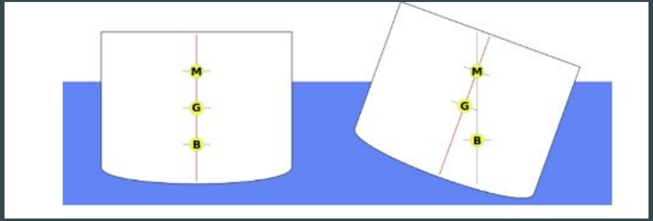
- metacentric height calculations (stability)
- buoyancy calculation
- catamaran design criteria
- design matrix
  - hull shape
  - bow shape
  - keel shape

Structure - Stability

LENGTH [m]	WIDTH [m]	HEIGHT [m]	FREEBOARD [m]	CENTER OF MASS			Iyy	Volume Imersed	METACENTER			CENTER OF BOUYANCY			V/SQRT(L) RATIO	GM	STABILITY
				x [m]	y [m]	z [m]			x [m]	y [m]	z [m]	x [m]	y [m]	z [m]			
6.096	1.524	4.572	3.048	0.762	2.286	3.048	1.798119759	46.45152	0.762	2.3247096	3.048	0.762	0.762	3.048	1.118033989	0.0387096	
6.096	2.1336	4.572	3.048	1.0668	2.286	3.048	4.934040618	65.032128	1.0668	2.361870816	3.048	1.0668	0.762	3.048	1.11803399	0.07587082	
6.096	2.7432	4.572	3.048	1.3716	2.286	3.048	10.48663443	83.612736	1.3716	2.411419104	3.048	1.3716	0.762	3.048	1.11803399	0.12541910	
7.62	3.048	5.1816	3.6576	1.524	2.5908	3.81	17.98119759	116.1288	1.524	2.7456384	3.81	1.524	0.762	3.81	1.00000000	0.15483840	
7.62	3.9624	5.1816	3.6576	1.9812	2.5908	3.81	39.5046911	150.96744	1.9812	2.852476896	3.81	1.9812	0.762	3.81	1.00000000	0.26167690	
7.62	4.572	5.1816	3.6576	2.286	2.5908	3.81	60.68654185	174.1932	2.286	2.9391864	3.81	2.286	0.762	3.81	1.00000000	0.34838640	
9.144	6.096	6.096	4.572	3.048	3.048	4.572	172.6194968	278.70912	3.048	3.6673536	4.572	3.048	0.762	4.572	0.91287093	0.61935360	
9.144	6.7056	6.096	4.572	3.3528	3.048	4.572	229.7565503	306.580032	3.3528	3.797417856	4.572	3.3528	0.762	4.572	0.91287093	0.74941786	
9.144	7.62	6.096	4.572	3.81	3.048	4.572	337.1474547	348.3864	3.81	4.01574	4.572	3.81	0.762	4.572	0.91287093	0.96774000	
10.668	8.2296	4.572	3.048	4.1148	2.286	5.334	495.4934769	438.966864	4.1148	3.414771936	5.334	4.1148	0.762	5.334	0.84515425	1.12877194	
10.668	9.144	5.1816	3.6576	4.572	2.5908	5.334	679.6892687	487.74096	4.572	3.9843456	5.334	4.572	0.762	5.334	0.84515425	1.39354560	
10.668	10.0584	5.1816	3.6576	5.0292	2.5908	5.334	904.6664167	536.515056	5.0292	4.276990176	5.334	5.0292	0.762	5.334	0.84515425	1.68619018	
12.192	10.668	2.1336	0.6096	5.334	1.0668	6.096	1233.510154	650.32128	5.334	2.9635704	6.096	5.334	0.762	6.096	0.79056942	1.89677040	
13.1064	10.0584	2.7432	1.2192	5.0292	1.3716	6.5532	1111.447312	659.1470688	5.0292	3.057790176	6.5532	5.0292	0.762	6.5532	0.76249285	1.68619018	
13.716	10.0584	3.048	1.524	5.0292	1.524	6.858	1163.142536	689.805072	5.0292	3.210190176	6.858	5.0292	0.762	6.858	0.74535599	1.68619018	
15.24	8.2296	3.048	1.524	4.1148	1.524	7.62	707.8478242	627.09552	4.1148	2.652771936	7.62	4.1148	0.762	7.62	0.70710678	1.12877194	
15.24	10.0584	3.6576	2.1336	5.0292	1.8288	7.62	1292.380595	766.45008	5.0292	3.514990176	7.62	5.0292	0.762	7.62	0.70710678	1.68619018	
18.288	10.0584	3.9624	2.4384	5.0292	1.9812	9.144	1550.856714	919.740096	5.0292	3.667390176	9.144	5.0292	0.762	9.144	0.64549722	1.68619018	
13.716	**8.2296**	**3.048**	**1.524**	**4.1148**	**1.524**	**6.858**	**637.0630418**	**564.385968**	**4.1148**	**2.652771936**	**6.858**	**4.1148**	**0.762**	**6.858**	**0.74535599**	**1.12877194**	

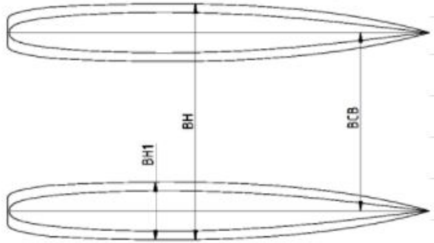
Stability as a result of maximizing the metacentric height (righting arm)

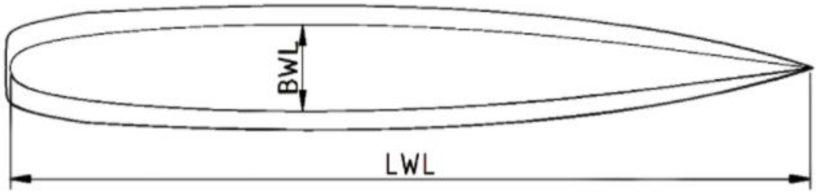
Ideal range: 0.15 - 1.5m



Structure - Catamaran Design Criteria

LH	LWL	BH	BWL	BH1	BCB	BTC	TC	LBR	LBRC
33.000	30.000	19.667	3.333	4.667	15.000	2.200	1.515	9.000	2.200





Design considerations based off of ideal ratio of length and waterline 8/10 and prismatic coefficient of 0.525 which is based on the speed/length ratio of 0.87.

- sailboats
- displacement hulls Cp range from 0.55-0.64
  - below but acceptable as we are powered

Structure - Design Matrix

Note: design criteria was weighted equally

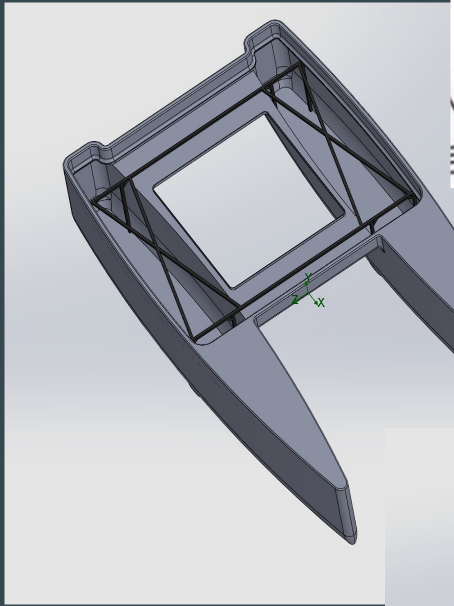
- wing vs fin

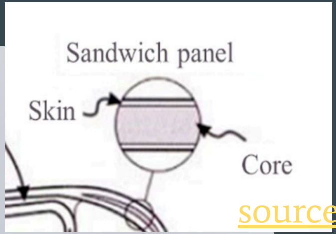
HULL SHAPE				
		DEEP V	ROUND	FLAT
	POWER	+	++	++
	HANDLING	++	+++	+
	SPEED	+++	++	++++

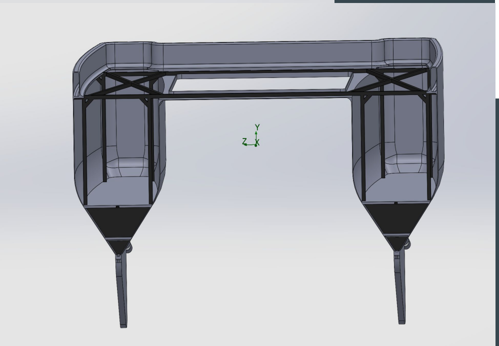
BOW SHAPE						
		STRAIGHT	RAKED	PLUMB	SPOON	AXE
	SPEED	+	+++	++++	++	+++
	STABILITY	++	+++	++	++	+++
	WAVE MAKING	+	+++	++	+	+++

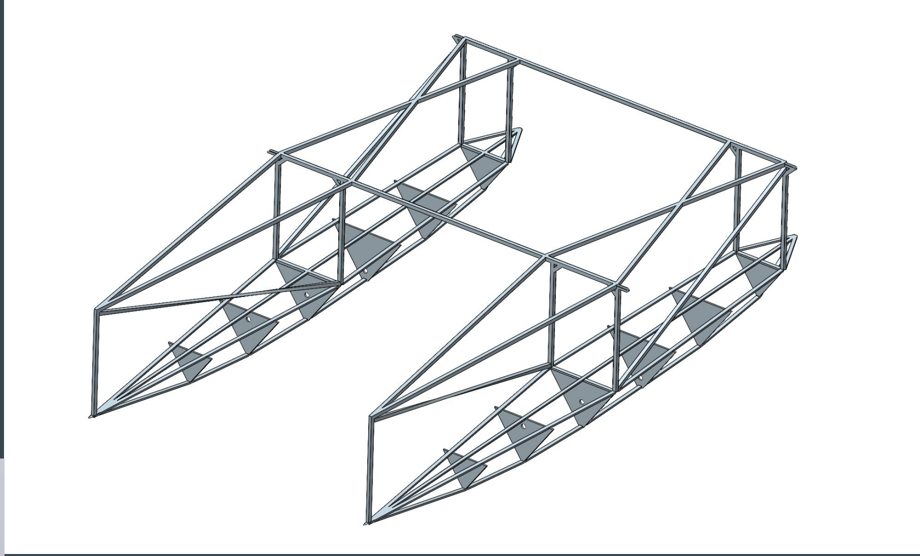
KEEL SHAPE								
		FULL	BILGE	BULB	FIN W/ SPADE RUD	FIN W/ SKEG R	WING	LIFTING
keel vs daggerboard: keel is easier matinence and build/more WSA but more added bouyancy daggerboard easier manuverbility but added control and $$$ to build	WSA (wetted surface area)	+	++	++	+++	++	+++	++
	HANDLING	+	+++	+++	+++	++	+++	++
	STABILITY	+++	++	+++	+++	+++	+++	++
	SPEED	+	+++	+++	++	++	++	++
	DURABILIITY	+++	+++	+++	++	++	++	+

Structure - Reinforcement and Space Frame







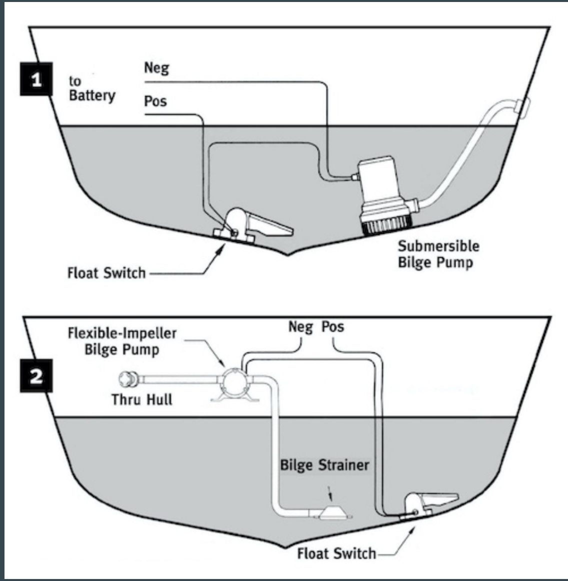


Floating Frame: Composite Beams

- E-Glass
- 10 µm weave (fiber diameter)
- PVC foam core[1]

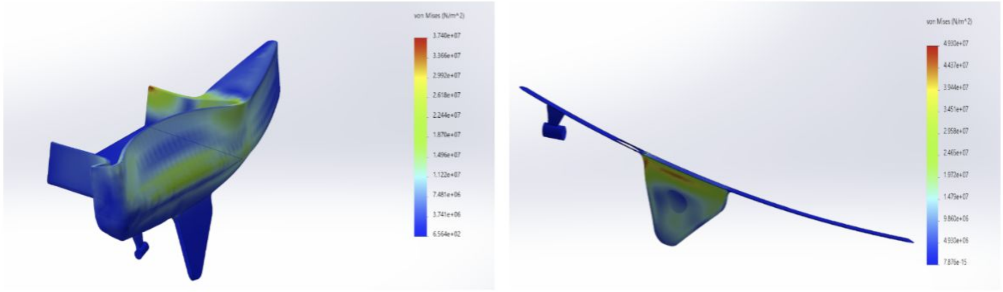
Structure - Bilge Pump

- 2x automatic centrifugal bilge pump (2x drain plug)
  - one per enclosed space
  - chosen over diaphragm as it is less prone to clogging, cheaper, and move more water
- ~24 gallons/minute
- **SELECTION:** Whale Orca Auto 1300 Electric Automatic Bilge Pump
  - Flow Rate: **1300 GPH**, Port Size: 1" - 1-1/8" Stepped
  - Select Voltage, Current Draw: 5 Amps @ 12 Volt DC
  - Built-In Automatic Sensor - Separate Bilge Switch Not Required

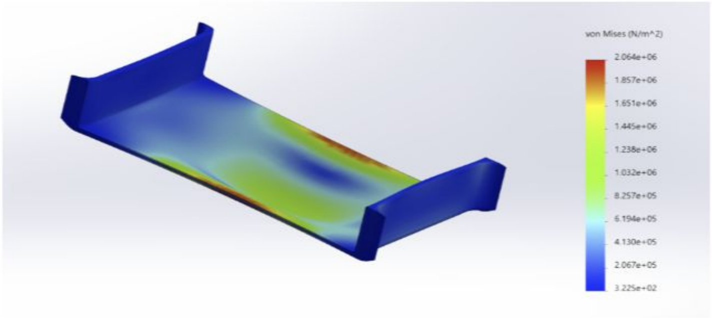


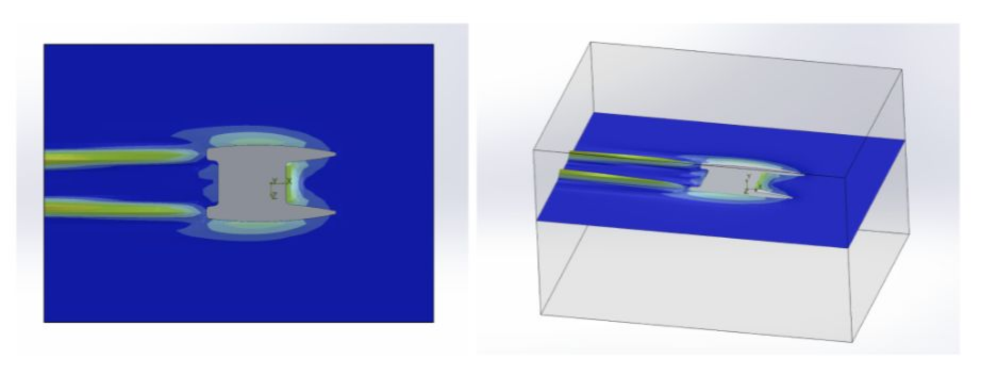
Structure - FEA and CFD

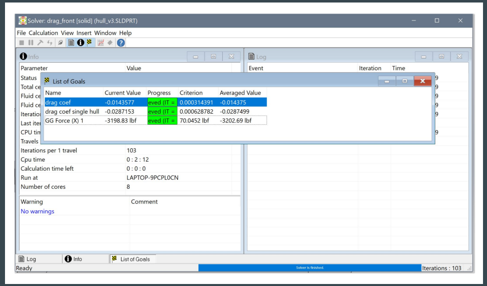
Note:
Tensile Strength of fiberglass 1950 MPa
Load of 154kn/m^2 applied from research paper for waves



(a) Hull (b) Keel and Prop Shaft Support





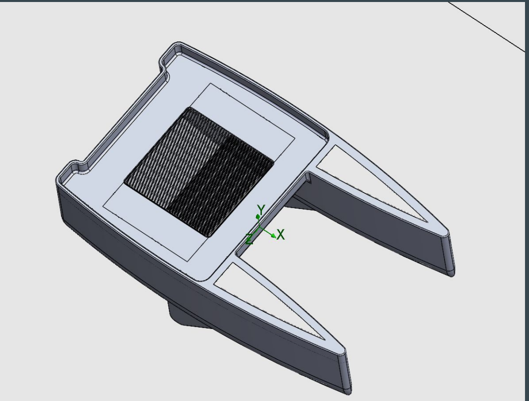


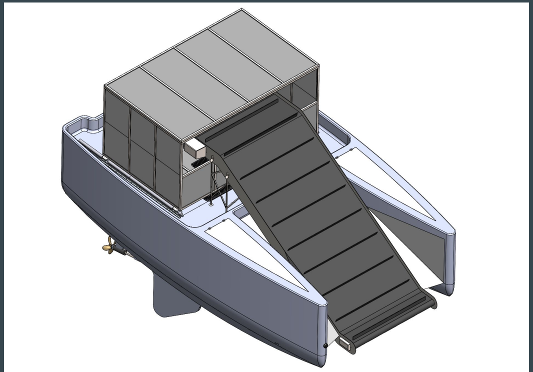
Goal Name	Unit	Value	Averaged Value	Minimum
GG Force (X) 1	[lbf]	-1785.712371	-1775.484297	-1789.7
draf coef	n/a	-0.001508187	-0.001499549068	-0.00151

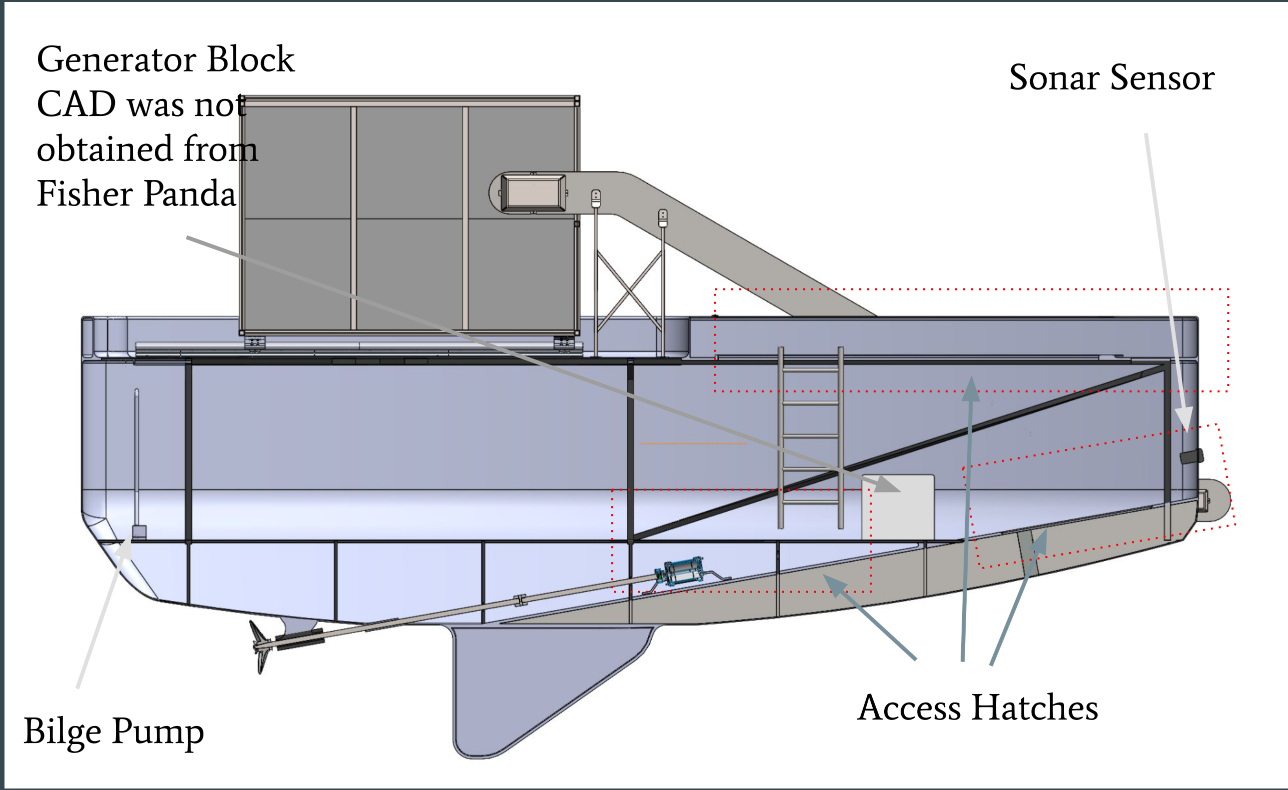
Goal Name	Unit	Value	Averaged
GG Force (X) 1	[lbf]	-3198.8347	-3202
drag coef	[ ]	-0.01435767	-0.014
drag coef single hull	[ ]	-0.02871535	-0.028

- usual drag coefficients for boats range from 0.0027 to 0.0032
  - wetted surface area vs cross sectional area

Structure - Integrated with the Assembly

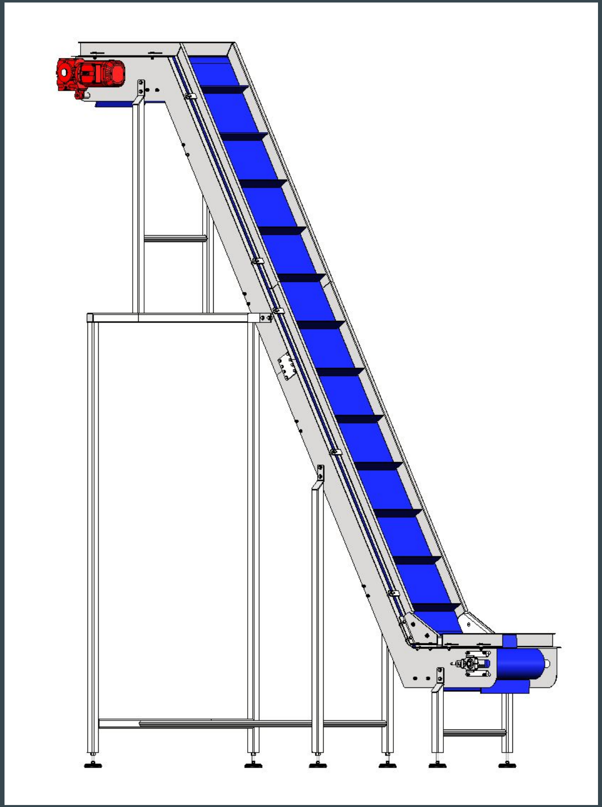






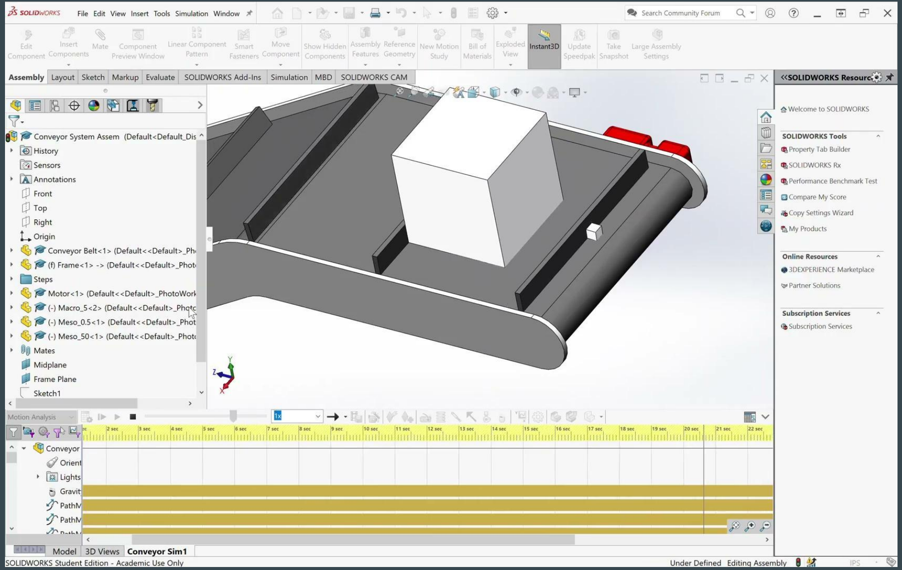
Trash Collection System

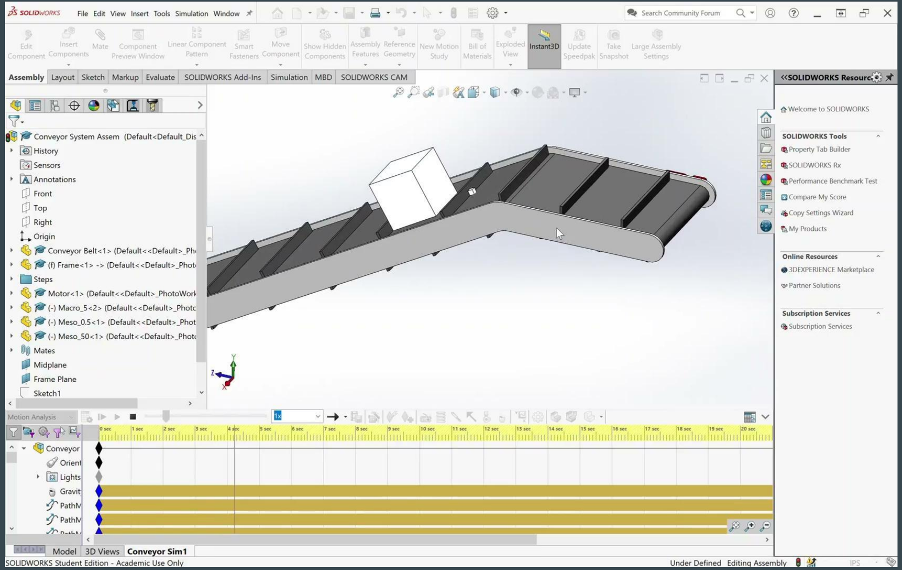
- For our trash collection mechanism, we are using a conveyor belt
- We have chosen to use the CIM-400 conveyor belt from mk North America
  - Fully customizable
  - “Ideal for wet environments”



Incline Angle Motion Analysis

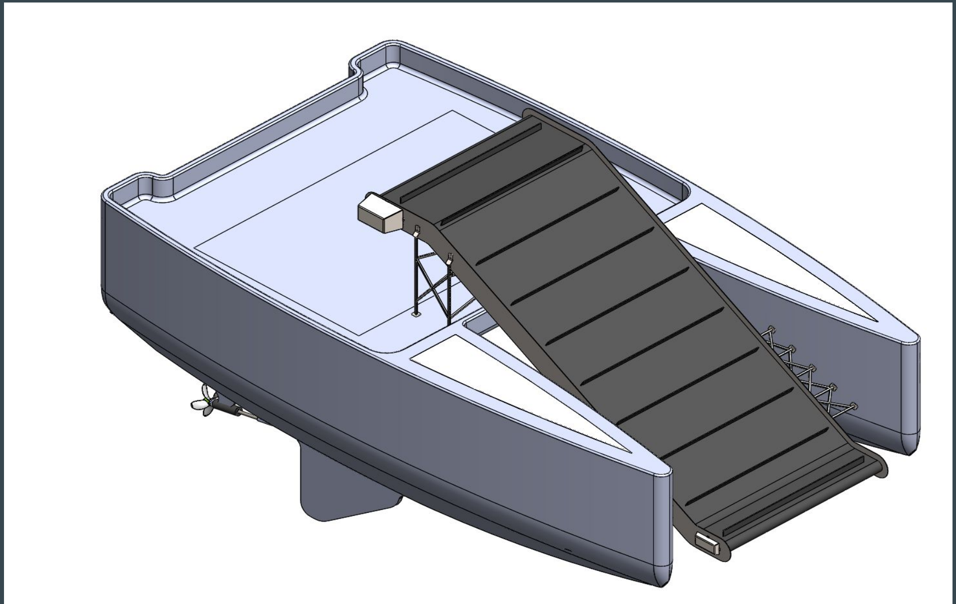
- We used SolidWorks motion analysis to determine the incline angle on the conveyor. From this, we decided upon a 30 degree incline angle.

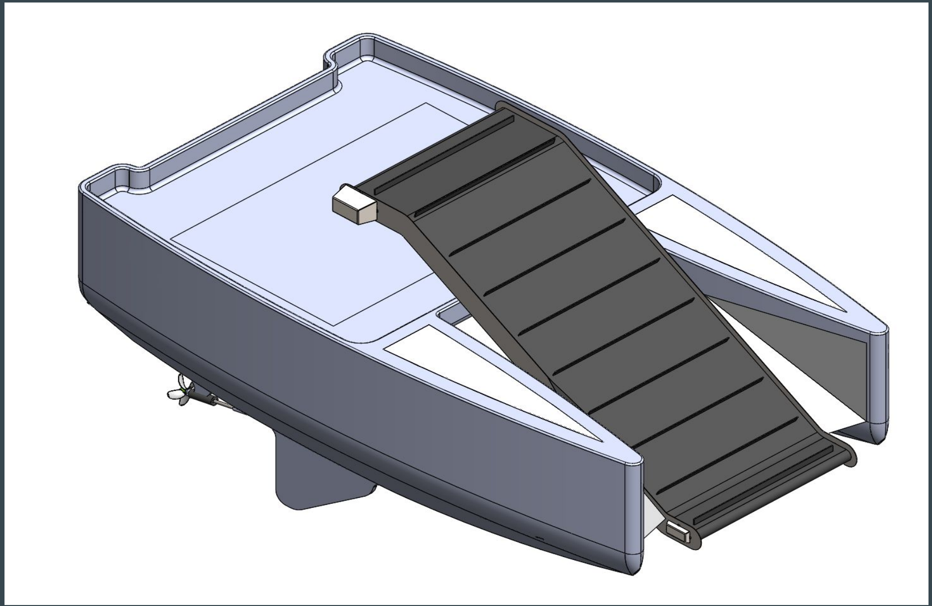




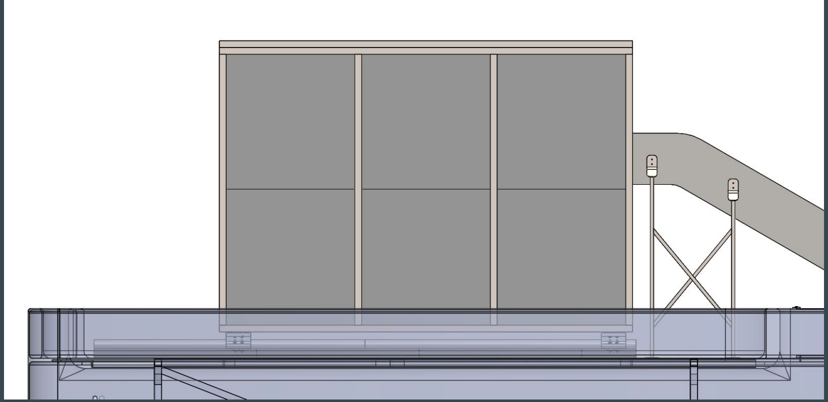
Conveyor Mounts and Funnel

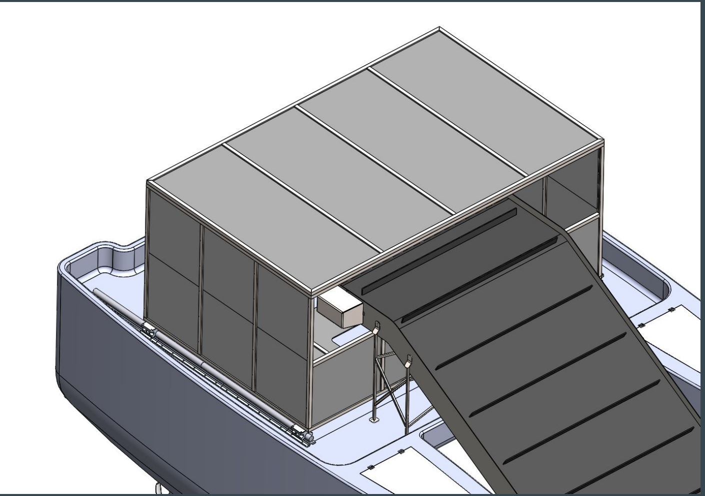
- Both the mounts and the funnels will be made of 316 stainless steel, which is the most common type of steel for marine applications

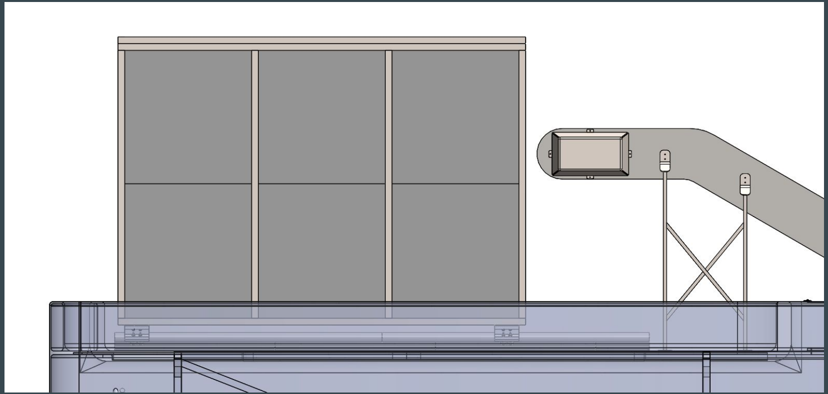


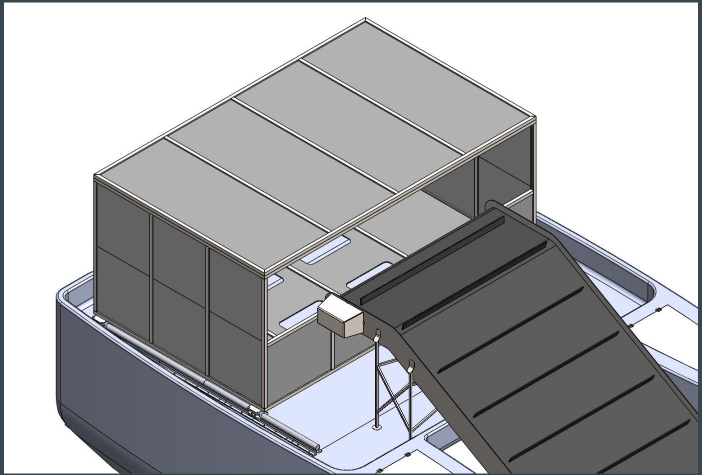


Storage Container Design

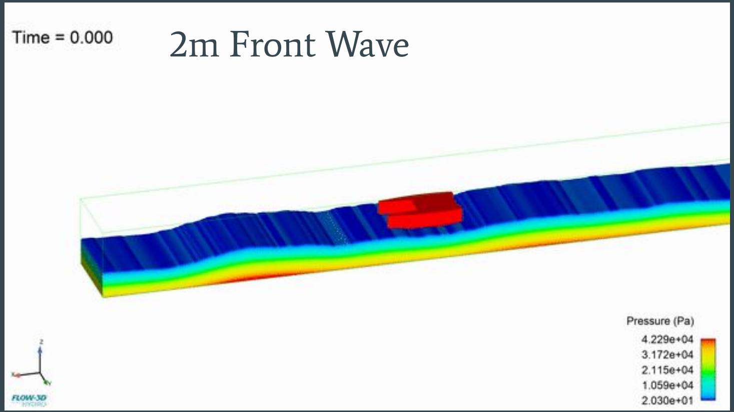


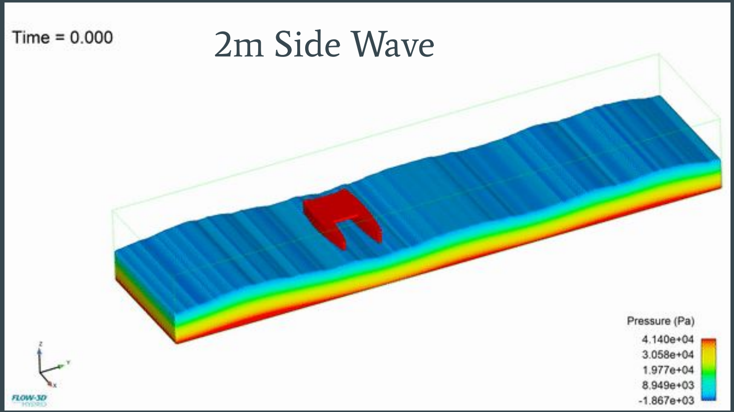


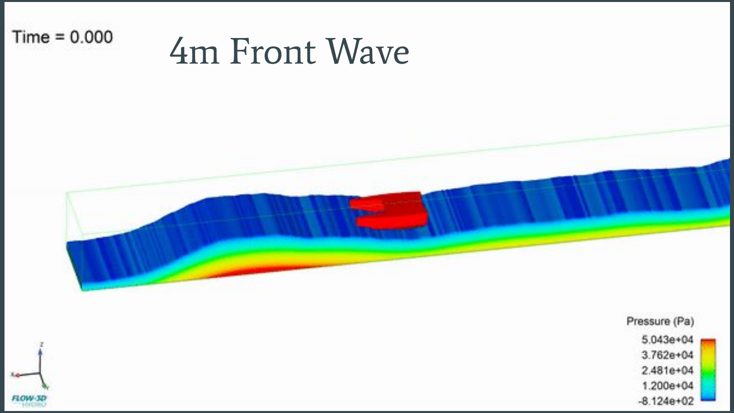


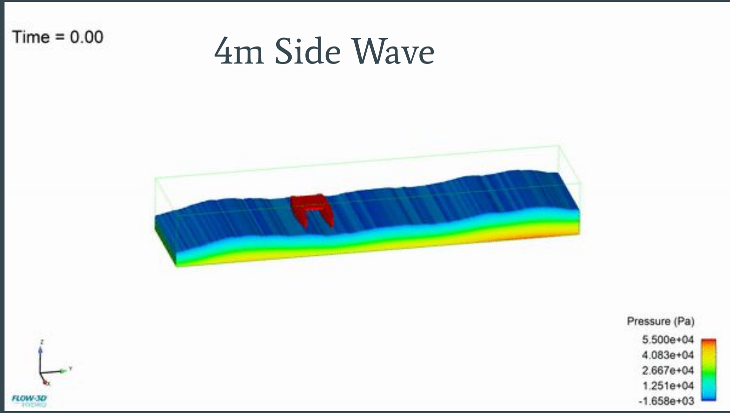


Flow3D Waves

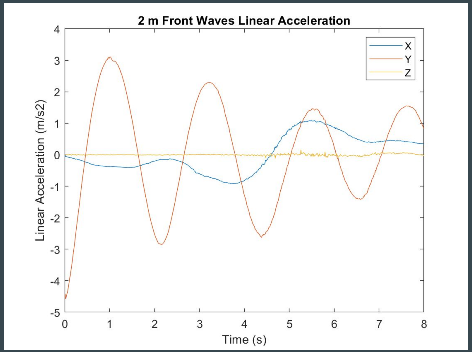


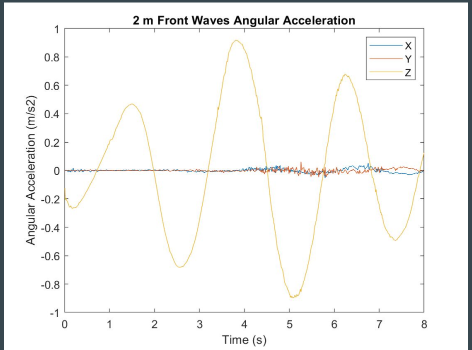


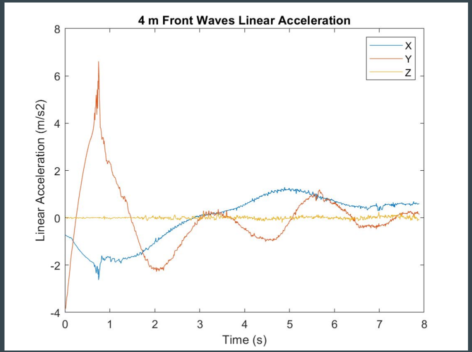


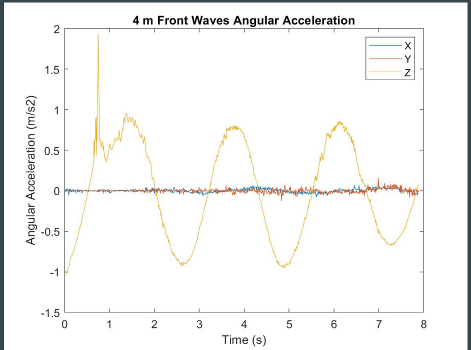


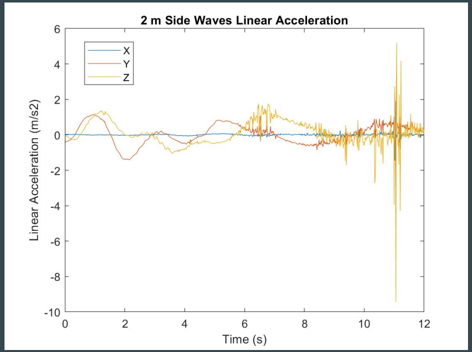
Flow3D Wave Accelerations

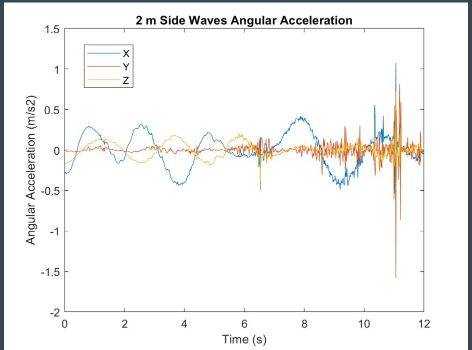


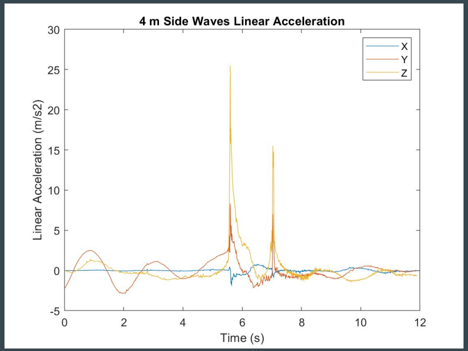


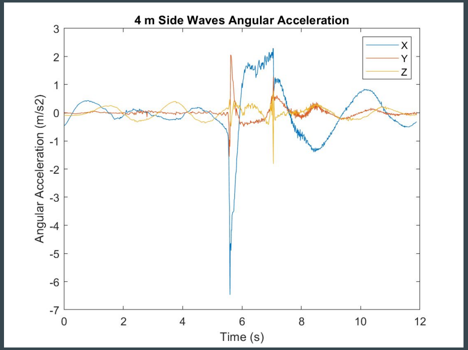






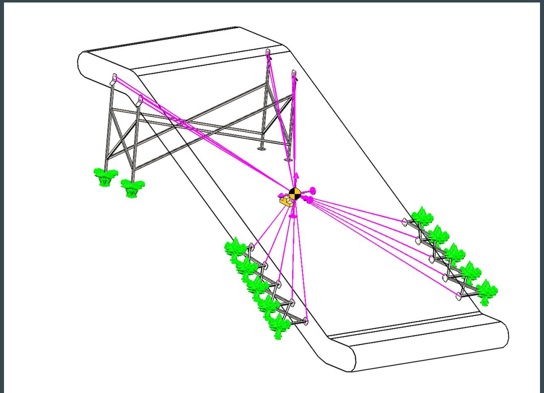


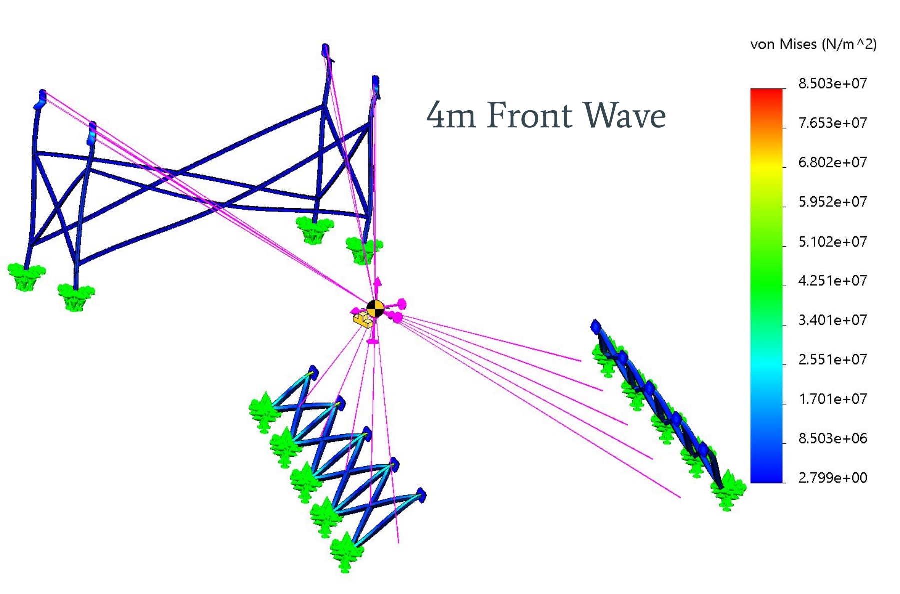


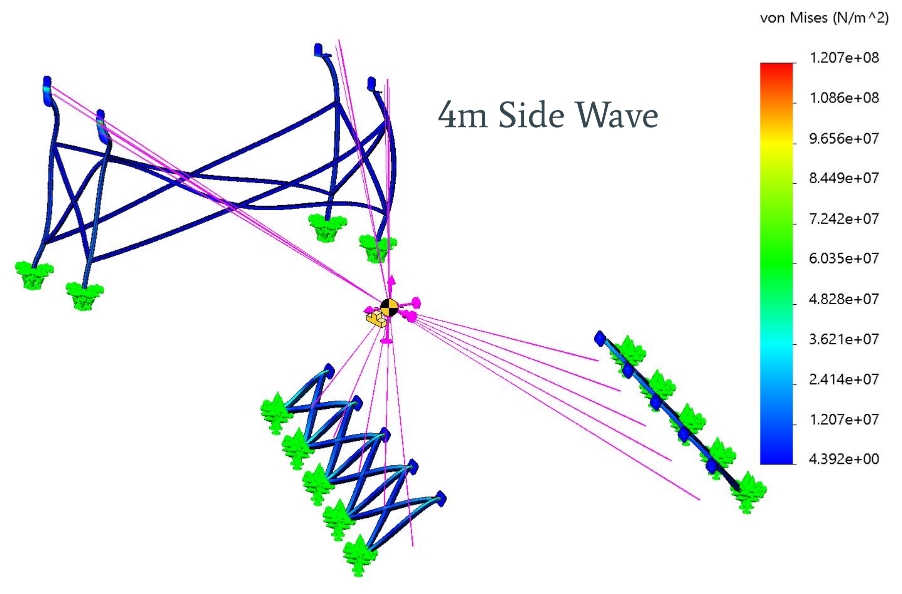


Conveyor Mount FEA (Wave Load)

- Front Wave: FOS = 6.47
- Side Wave: FOS = 4.55

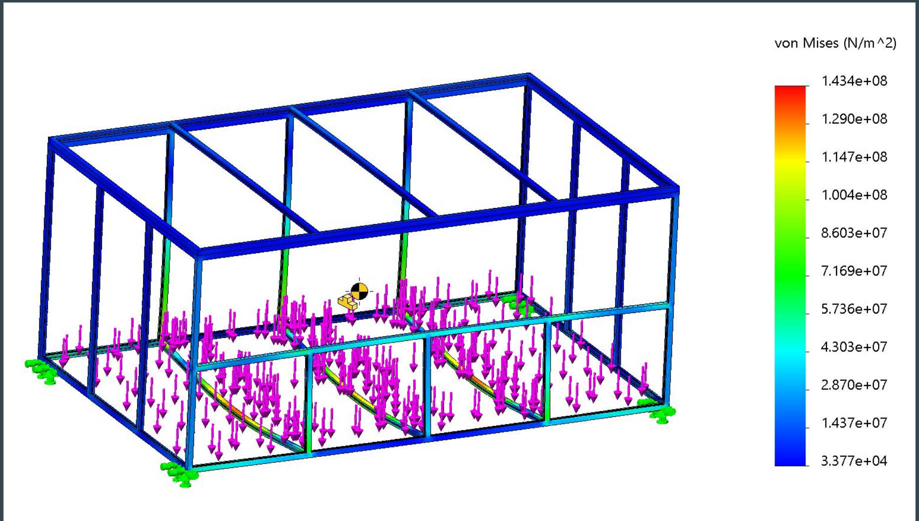


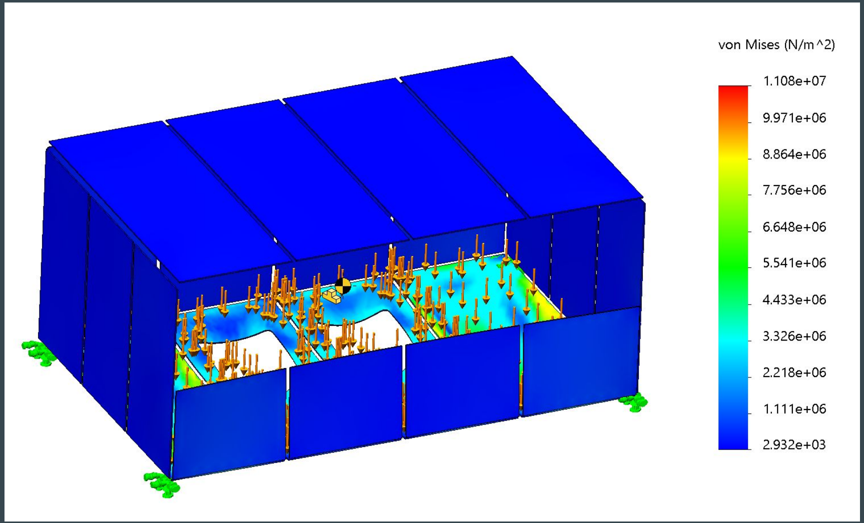




Storage Container FEA (Trash Load)

- Steel Frame: FOS = 3.84
- HDPE Panels: FOS = 1.99

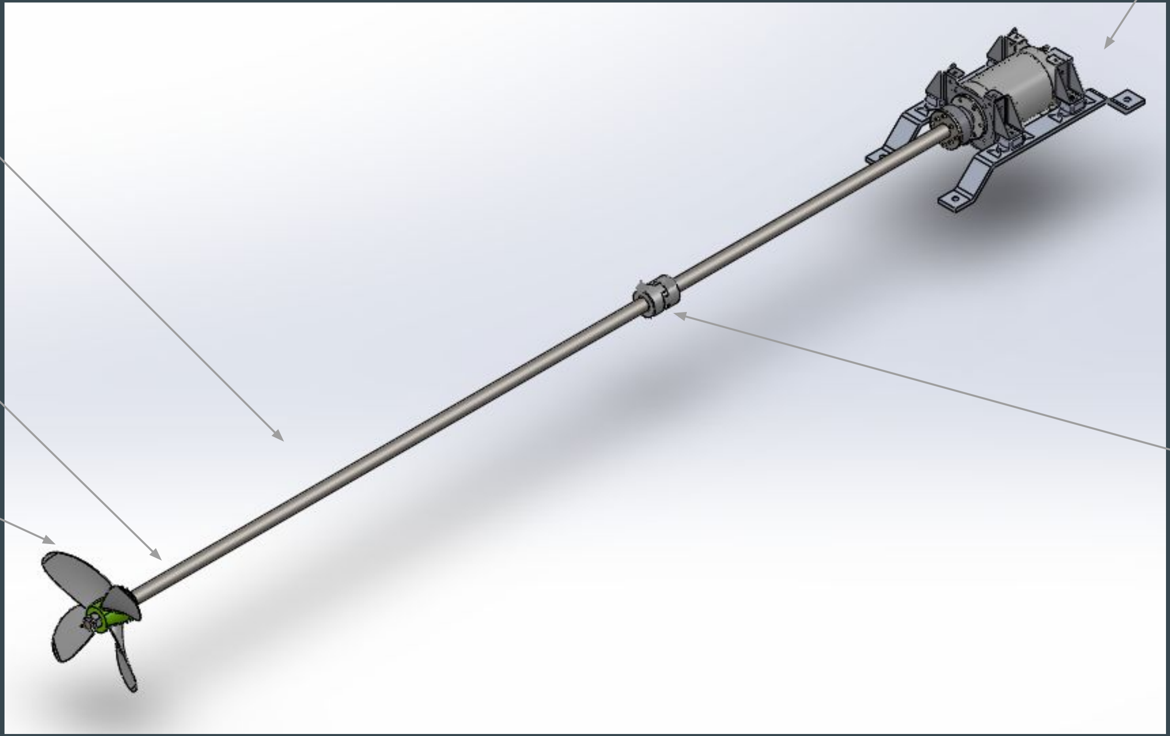




Powertrain Assembly

Motor and Motor Mounting

2 cutlass bearings to provide additional supports (not shown here)



Propeller Assembly

Flexible Shaft Coupling

Motor Selection

- Motor power requirements set based on hull resistance and maximum desired boat speed
  - Hand calculations on a generic boat geometry were used to find ballpark power value
  - Further CFD analysis on our hull was used to verify that our hand calculated values were correct
- Final hull resistance = 7952N, required shaft power to achieve 5 knots is 7.4 kW in total
- Aimed to find dual shaft motor setup that supplies 7.5 to 10 kW per motor to account for inaccuracies in our model

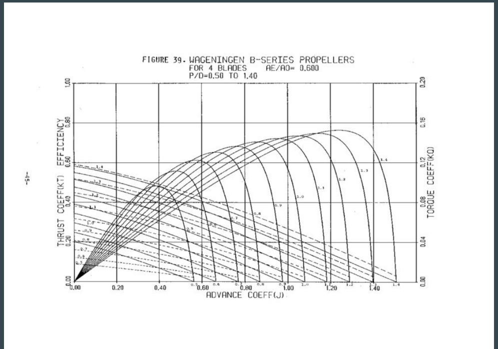
Reference for method													
Reynolds		vL/nu			Assume	No appendages for now, no steps 4 through 7 for now							
		Unit	**Notes**		Re	6.14E+07		Reynolds number					
v	5.144032922	m/s	velocity (first number in eqn corresponds to speed in knots)		C_f	0.002238871787		Friction coefficient			R	-14951.00848	N
L	13.716	m	Length		D	1.524		Average draft					
W	8.2296	m	Width		C_M	1		Midship section coefficient					
nu	1.15E-06	m^2/s	Dynamic viscosity, temperature of 16.5C, reference		C_B	3.280839895		Block coefficient					
L_wl	5	m	Waterline length		C_WP	1		Waterplane area coefficient					
B	8.2296	m	Maximum breadth		S	111.0533383	m^2	Wetted surface area					
D_FP	1.524	m	Draft at the forward perpendicular, the 1.524 number is based on guidelines from the ship stability spreadsheet		R_F	3373.776721	N	Frictional resistance					
D_AP	1.524	m	Draft at the aft perpendicular		C_P	3.280839895		Prismatic coefficient					
A_M	12.5419104	m^2	Immersed midship sectional area at L_wl/2		L_R	0				L_R	-0.9406798008		Length of run
del	564.385968	m^3	Displacement volume		D/L_WL	0.1111111111		For calculation of c_12					
A_WP	112.8771936	m^2	Waterplane area		c_12	0.6128472049							
rho	1025.6	kg/m^3	Density of fluid, temperature of 16.5C, reference is the same as nu		C_stern	0		(For normal stern hull shapes) (needs verification)					
lcb	0		Longitudinal location of center of buoyancy forward of half L_wl as a percentage of L_wl		c_13	1							
					1+k_1	-4.431534661		Form factor					
					B/L_WL	1.64592		For calculation of c_7					
					c_7	0.462027316							
					i_E	90		half angle of entrance					

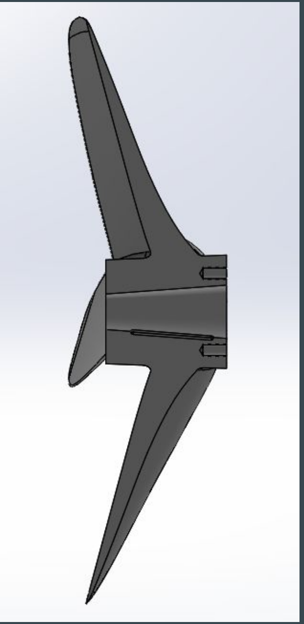
Motor Selection

- Considered multiple marine motor companies (Oceanvolt, Fischer Panda, Man Energy Solutions)
  - Went with Fischer Panda due to their motors' good fit with our drivetrain parameters set during the preliminary design review (all inboard, applications in small leisure crafts instead of large cargo tankers)
- Final motor: Fischer Panda A50-160-6-SH
  - 1200 RPM, 6 pole motor
  - 10 kW per motor
  - integratable with Fischer Panda diesel generators for hybrid powertrain setup

Propeller Design

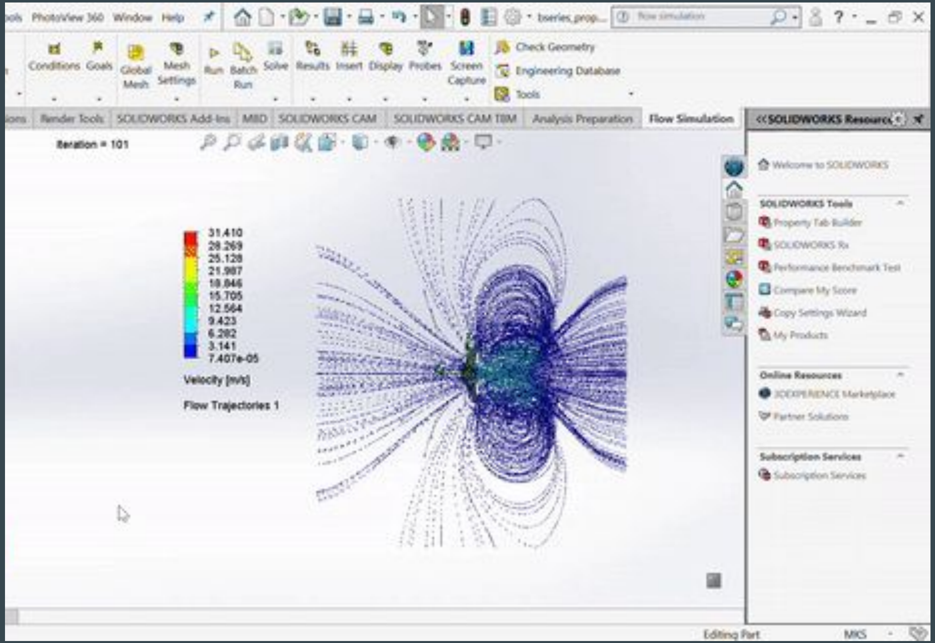
- Standard 4 bladed Wageningen B-series propeller spec was chosen to simplify propeller design process
  - B-series is also a popular propeller series → more available options on the market
- Geometry takes into account shaft power, required thrust to achieve maximum speed, and input propeller diameter
- Preliminary propeller design specs:
  - Expanded area coefficient = 0.514
  - Propeller diameter = 0.5m
  - Pitch = 0.5m
- Material: NAB alloy
- Cavitation inception speed for our sized boat is 7-10 knots, our top operating speed is below the CIS





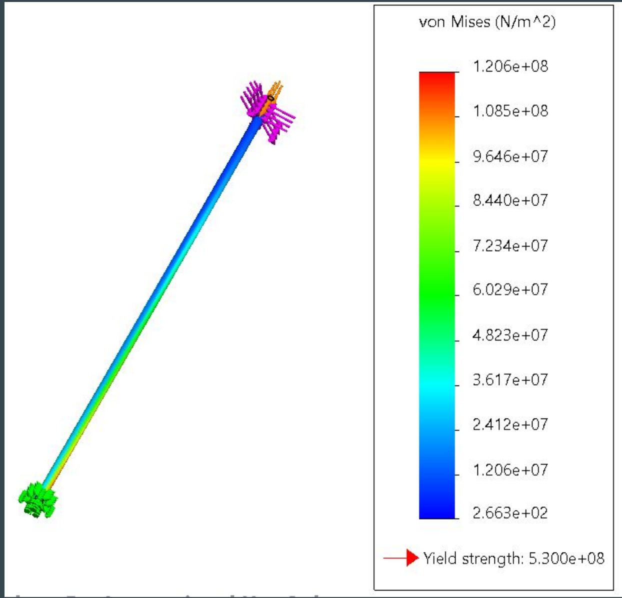
Propeller Design Verification and Propshaft Angle Study

- Used Solidworks CFD to verify that required thrust was achieved with each propeller
- Also wanted to find propeller shaft angle that allowed us to maintain thrust requirements
    - higher propeller shaft angle is beneficial for ship stability when drivetrain system is integrated with hull
- Final thrust achieved with dual propeller set up = 10734N
    - Corresponds to 1.3 thrust factor of safety
- Thrust angle set to 10 degrees



Propeller Shaft

- Basic hand calculations to determine optimum propeller length and diameter given our loading
  - bending force: 114.17N (propeller dry weight, this is conservative number)
  - torsional force: 79.5N-m (calculated from maximum RPM and shaft power)
  - axial loading: 5378N (propeller thrust)
- Propeller diameter of 0.045m was determined
- Material: Steel 1045
  - Steel 1045 is the most readily available and affordable out of common propeller material choices
- Propeller-propshaft mating features geometry determined using ISO standards (keyway, tapered mating surface, external thread)
- Hand calculations were verified using Solidworks FEA
  - Solidworks FEA show FoS of 4.4



Propeller Shaft Fatigue Calculations

- Fatigue calculations done taking a 0.4 knockdown factor for seawater caused corrosion into account
- Resultant propeller shaft lifetime: 1,157 day = 3.2 years
- Plan to use Thor-Coat Epoxy Marine Coating that is designed to last at least 5 years before inspection and can be repaired without replacing the whole shaft
    - Therefore, we believe that the propeller shaft will not be subject to as much seawater corrosion and that it will last the complete 4 year life cycle of the boat

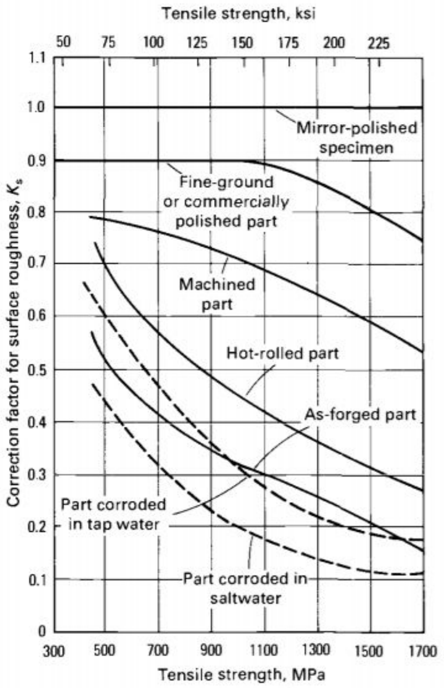
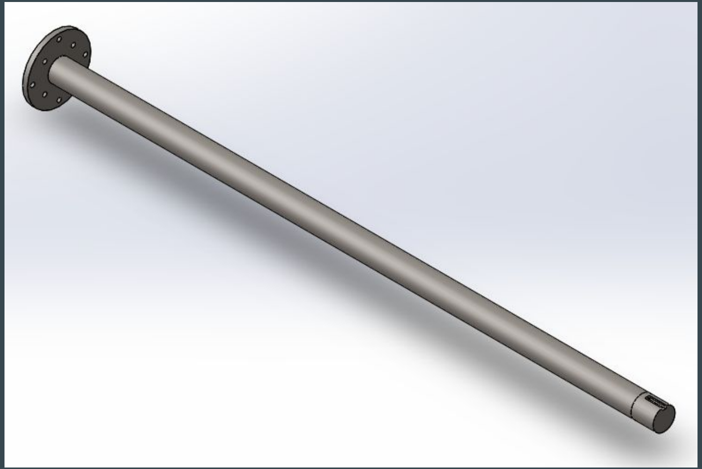
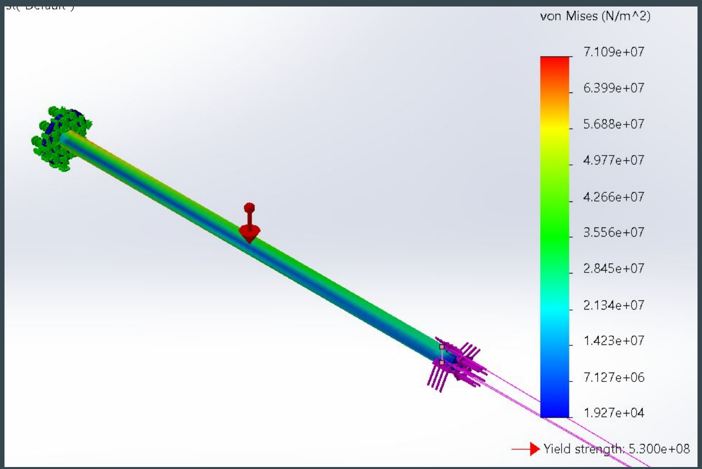


Fig. 8 Surface roughness correction factors for standard rotating-beam fatigue life testing of steel parts. See Table 1 for correction factors from part diameter and type of loading. Source: Ref 6

Thrust Shaft

- Thrust shaft added so that motor can be mounted further forward, coupled with propshaft using flexible shaft coupler
- Material: Steel 1045
- No fatigue analysis conducted on this part as it will be housed entirely inside of the boat and is subjected to less loads than the propeller shaft
- FoS: 7.5

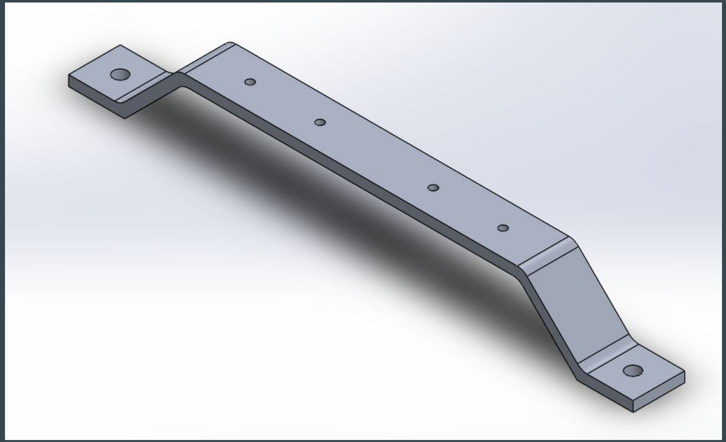


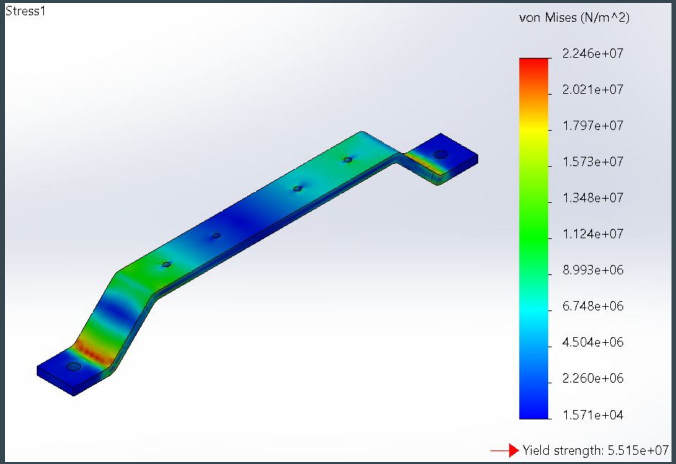


Engine Mount

Engine mount:

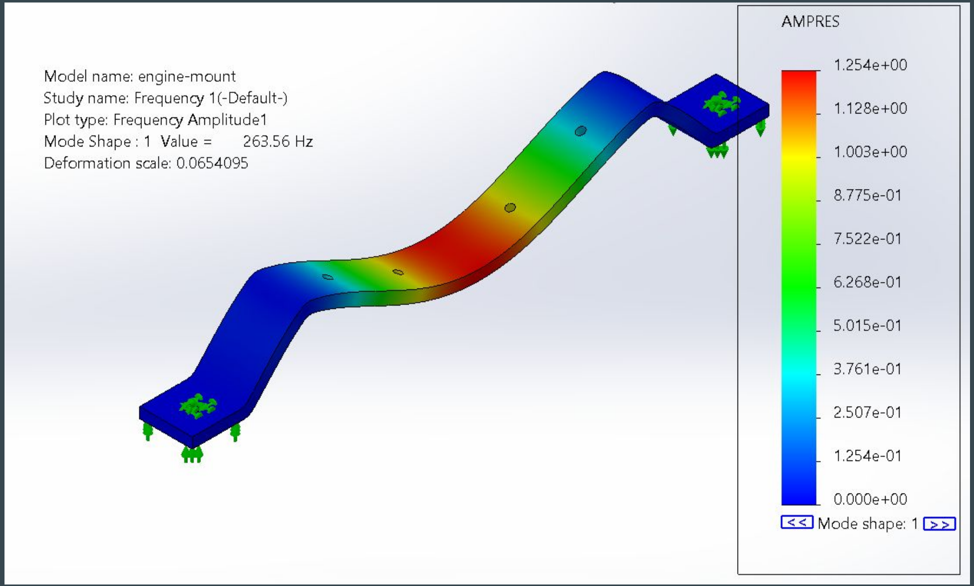
- Two pieces instead of four to improve fastener hole locational accuracy and reduce unpredicted loading on motor
- Loads:
  - 245 N acting downwards (engine weight) (flange geometry reflects contact surface area
  - 2689 N acting towards the bow of the ship (thrust from propellers)
- Achieved FoS of 2.5



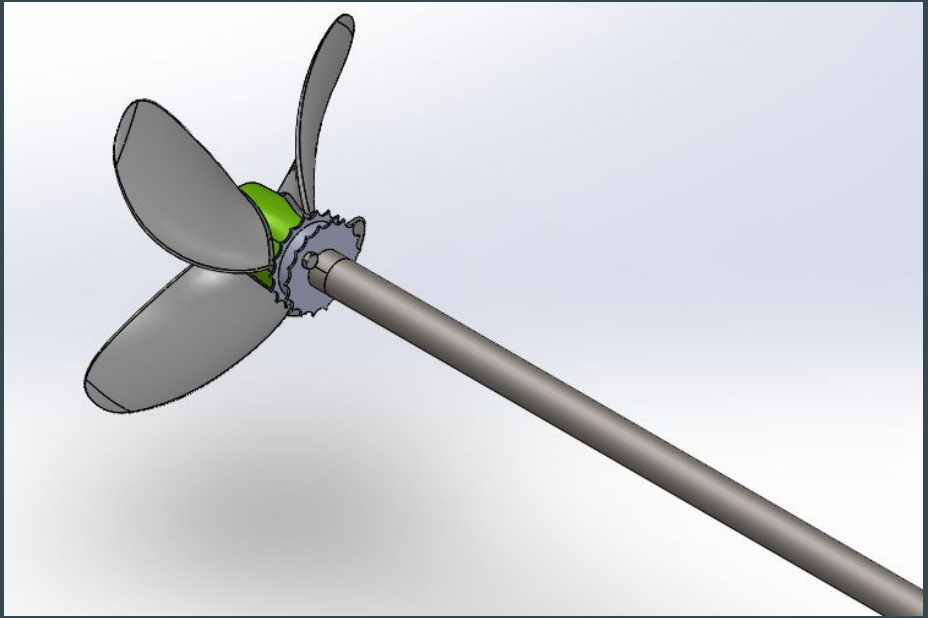


Engine Mount Vibration Analysis

- Solidworks frequency study shows first resonant mode occurs at 263.5 Hz
- Maximum motor frequency: 20Hz
- Motor has 6 poles
- Engine mount first resonant mode occurs higher than the highest motor natural frequency (120 Hz)



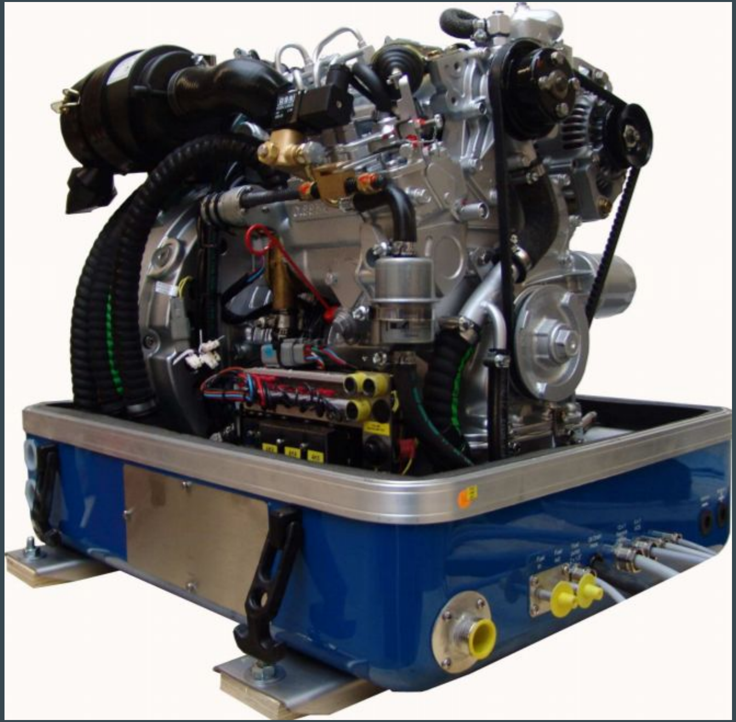
Net Entanglement



PDLC-1750 - Piranha dual line cutter

Power Requirements

- Full system motor requirements: 20870W
  - Translates to 199.8 gal diesel over a 360 hour (15 day) runtime trip
  - Fuel tank specced for a capacity of 250 gal
- Fischer Panda PMS AGT-DC 11000
- 3/0 Gauge Wire required

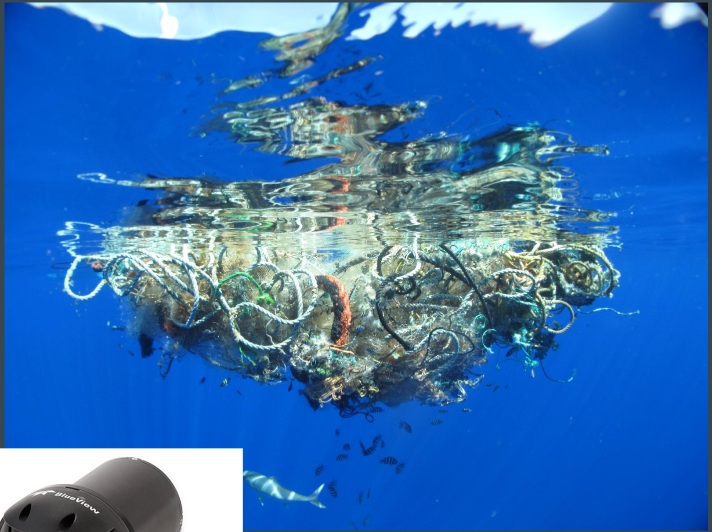


https://www.fischerpanda.de/Generator-Datasheet-AGT_11000-48V_PMS-48_DC_-_400_Hz_68.htm

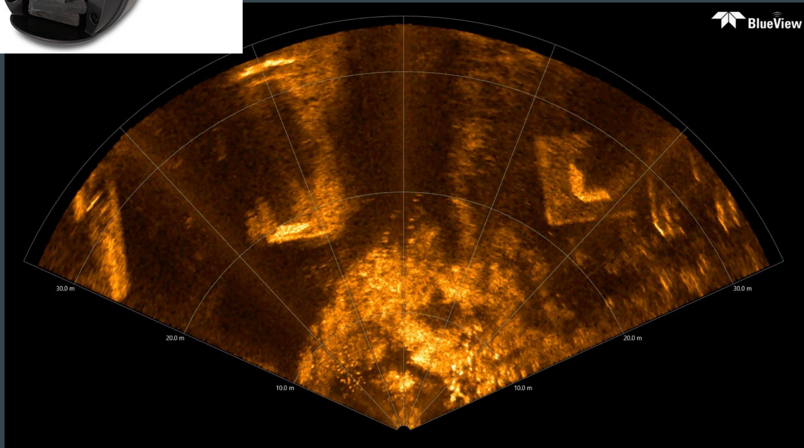
Trash Sensing - Choice of Sensor

- Goal: Go after large pieces
  - Why? Because they are massive, but sparse, and harmful to the environment.
- Plastic characteristics
  - Many are partially or completely submerged
- Sensor options:
  - FLIR (forward-looking infrared)
    - Good for above-water sensing, possible secondary sensor.
  - LiDAR
    - Also good for above-water sensing, perhaps less optimal than FLIR
  - Sonar
    - Fit for underwater sensing. Our primary sensor.
    - Specs: 2D, 130 degree FOV, 60m range for meter-sized objects, 900 kHz.

https://www.coresponsibility.com/interface-goes-beyondbau



http://www.teledynemarine.com/M900-2250-130-Mk2



Controller

- Goal: Actuate the motors to follow a waypoint path, and collect large plastics when detected.
- 4 Steps
    a. Top Level Control (logic, if-then's)
    b. Global Velocity Control
    c. Local Velocity Control
    d. Motor Desaturation

Top-Level Control

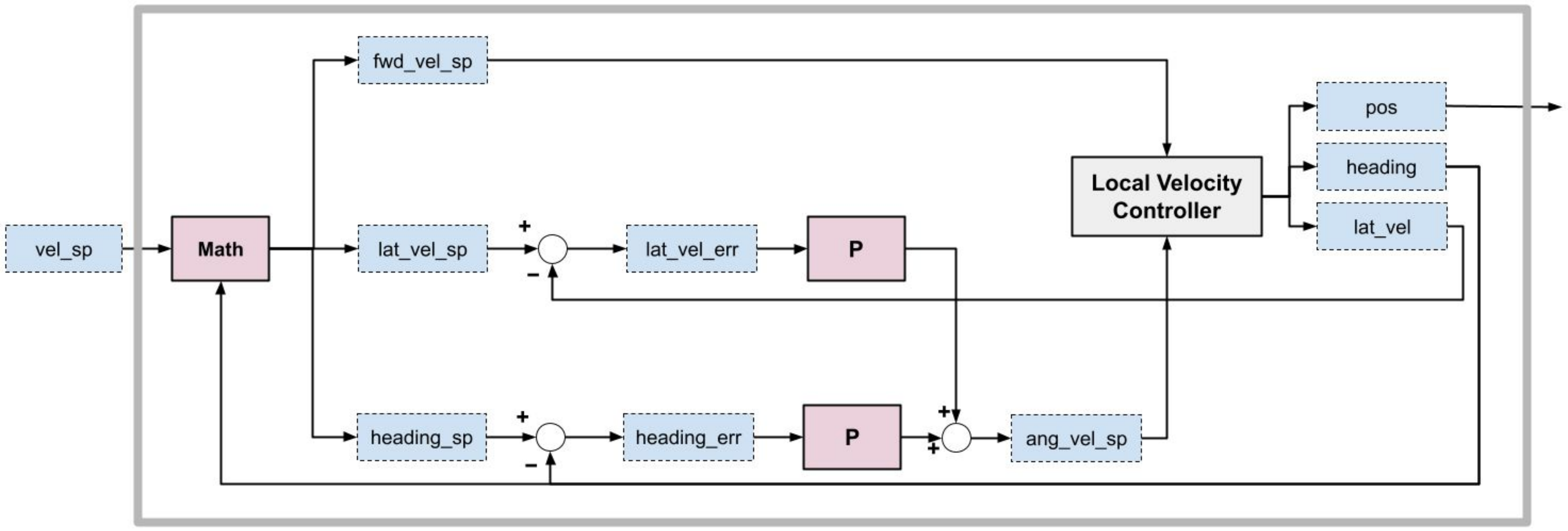
Algorithm 1: Trashamaran High-Level Control Algorithm

```
input  : A waypoint path gps_path
output: The boat follows a waypoint path and collects trash
current_gps_goal ← first waypoint in gps_path;
while True do
    boat_pos ← GetBoatPosition();
    if boat_pos is within a distance threshold to current_gps_goal and there are more waypoints left then
        current_gps_goal ← next waypoint in gps_path;
    if current_trash_goal is defined then
        if a sonar object is detected that matches current_trash_goal then
            current_trash_goal ← updated sonar object;
        else
            trash_goal_timeout ← timeout based on the distance of current_trash_goal from boat_pos;
            Set current_trash_goal to undefined;
    else
        if a sonar object meets the criteria for size, distance and azimuth then
            current_trash_goal ← detected sonar object;
    if current_trash_goal is defined then
        goal_heading ← heading of current_trash_goal relative to boat;
        vel_sp ← velocity vector at operational speed in direction of goal_heading;
        GlobalVelocityControl(vel_sp);
    else if trash_goal_timeout > 0 then
        Decrement trash_goal_timeout by the elapsed time;
        LocalVelocityControl(fwd_vel_sp = operational speed, ang_vel_sp = 0);
    else
        goal_heading ← heading of current_gps_goal relative to boat;
        vel_sp ← velocity vector at operational speed in direction of goal_heading;
        GlobalVelocityControl(vel_sp);
```

Top-Level Control Parameters

- **WAYPOINT_THRESHOLD:** 30 m
  - Distance from waypoint when it is considered reached
- **MIN_TRASH_SIZE:** 0.5 m
  - Smallest trash size to go after
- **MAX_TRASH_SIZE:** 2.0 m
  - Largest trash size to go after, based on what is safe to collect
- **AZIMUTH_OVER_DISTANCE_THRESHOLD:** (130°/2) / 30 m
  - When multiplied by the distance of a detected piece of trash, yields the max allowable azimuth in order to go after it. This avoids going after trash which cannot be collected due to limited turning radius.
- **TRASH_COLLECTION_TIMEOUT:** 2 s
  - Amount of time to continue forward after trash is expected to hit conveyor belt. This is ensures that large pieces of trash are collected.
- **OPERATIONAL_SPEED:** 1.5 m/s
  - Operational speed of the boat

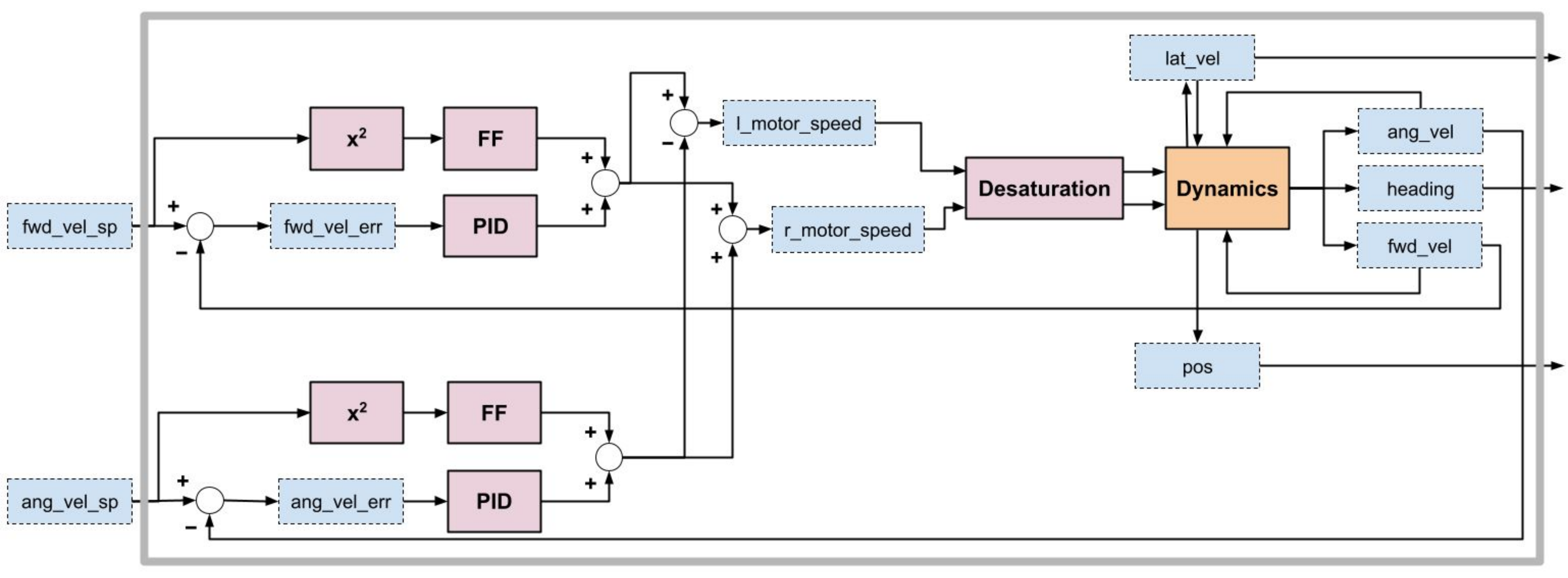
Global Velocity Control



Global Velocity Control Parameters

- **HEADING_P:** 0.25
  - Proportional gain for heading control
  - **Input**: heading_err [rad]
  - **Output**: ang_vel_sp [rad/s]
- **SIDEWAYS_VEL_P:** 0.05
  - Proportional gain for lateral/sideways velocity control
  - **Input**: sideways_vel_err [m/s]
  - **Output**: ang_vel_sp [rad/s]

Local Velocity Control

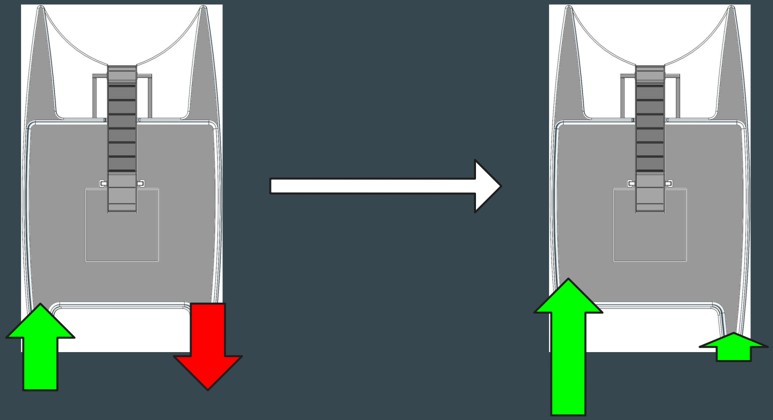


Local Velocity Control Parameters

- **FORWARD_VEL_PID:** P=40, I=0.7, D=0
  - PID gains for forward velocity control
  - **Input**: forward_vel_err [m/s]
  - **Output**: motor_speed [rad/s]
- **FORWARD_VEL_FF:** 20
  - Feedforward gain for forward velocity control
  - **Input**: forward_vel_sp^2 [(m/s)^2]
  - **Output**: motor_speed [rad/s]
- **ANG_VEL_PID:** P=2000, I=30, D=0
  - PID gains for angular velocity control
  - **Input**: ang_vel_err [rad/s]
  - **Output**: motor_speed [rad/s]
- **ANG_VEL_FF:** 1700
  - Feedforward gain for angular velocity control
  - **Input**: ang_vel_sp^2 [(rad/s)^2]
  - **Output**: motor_speed [rad/s]

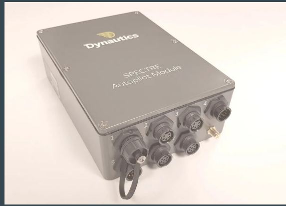
Motor Desaturation

- **Requirement**: Constrain motor speed commands to the allowable range of the motors.
- **Strategy**: Prioritize differential thrust control over collective thrust, since differential thrust is more important for maneuverability.



Control System Electronics

- Microcontroller, Gyroscope, Magnetometer
    - Dynautics E-Boat SPECTRE Autopilot
- Satellite Modem (for remote communication)
    - Dynautics Iridium RUDICS modem
- GPS
    - Garmin GA™ 38 GPS/GLONASS Antenna
- 4 Load Cells (for weighing storage container)
    - Ascell Steel Alloy 1500 kg Load Cell Shear Beam



https://www.dynautics.com/applications/platform-control-systems-electric/

https://www.dynautics.com/products-unmanned-surface-vehicle/communications-systems/iridium-rudics/

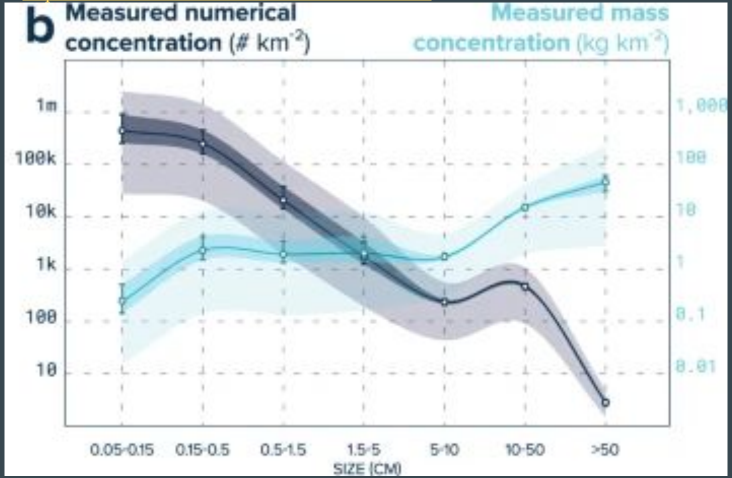
https://buy.garmin.com/en-US/US/p/133435

https://www.vetek.com/load-cell-shear-beam-1500-kg-steel-alloy-oiml-c3-cs-1500-en/article

Analysis

Simulating the Trash Distribution

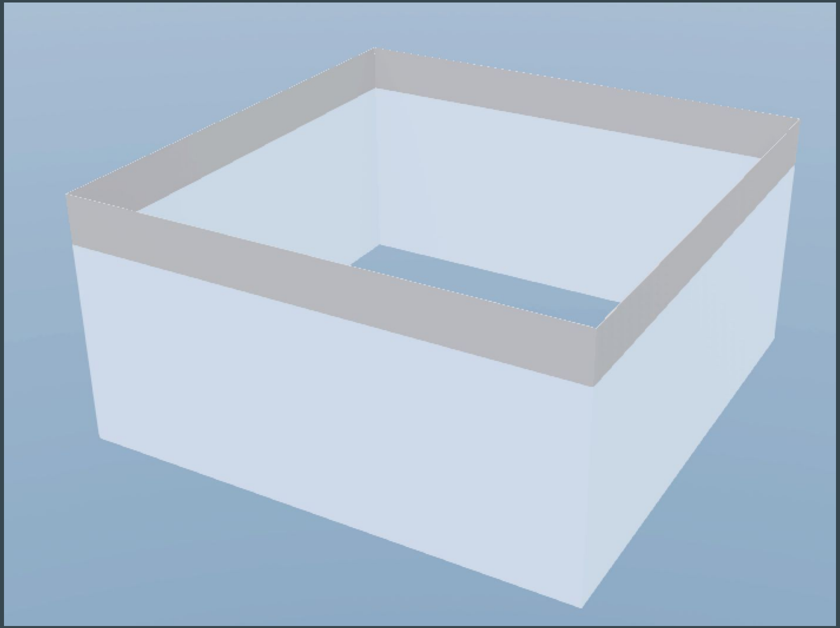
https://www.nature.com/articles/s41598-018-22939-w

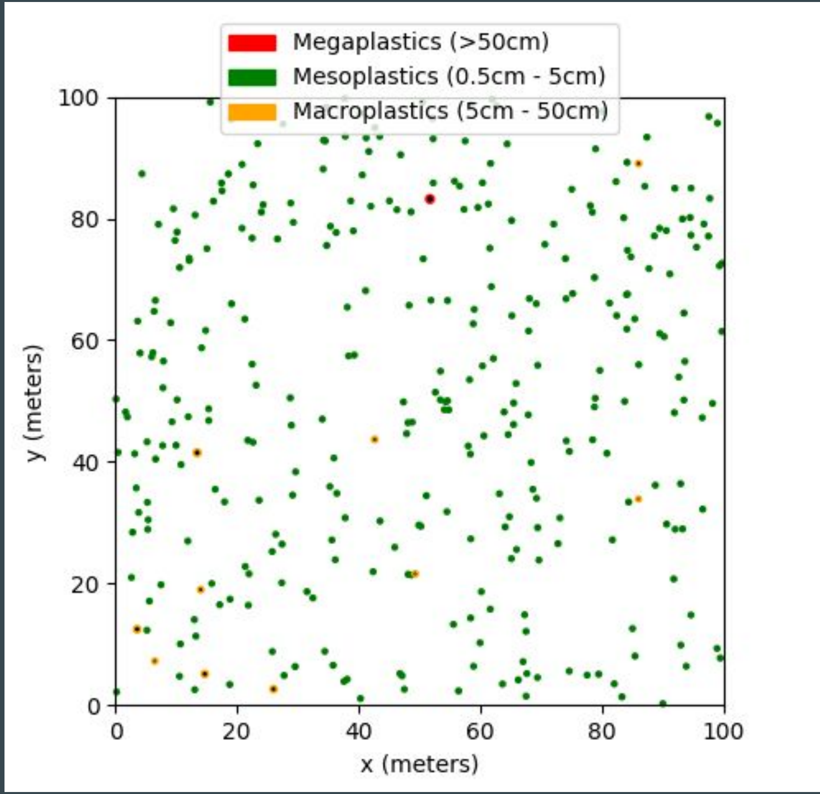


- A study conducted by The Ocean Cleanup presents the number concentration and mass concentration for different types and size classes of plastics.
- We model the most densely concentrated areas in the GPGP, and assume plastic is evenly distributed.
- To generate a trash distribution with an area:
  1. Determine the number of pieces that would appear in that area.
  2. For each, piece, choose a random position with the area (uniform random vector).
  3. For each piece, choose a random size based on a logarithmic probability distribution.
     a. This is done because size classes are broken up by order of magnitude, and there is an approximately logarithmic relationship between size and number concentration.
  4. Based on the size and type of plastic, determine the mass and density.

Simulating the Trash Distribution

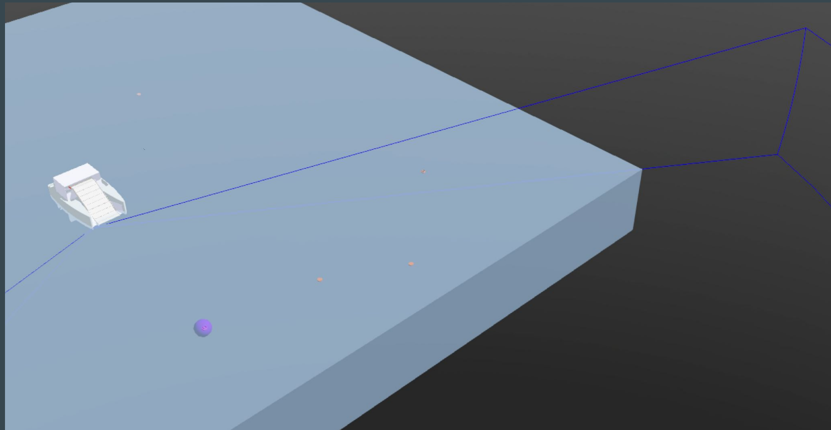
Webots:





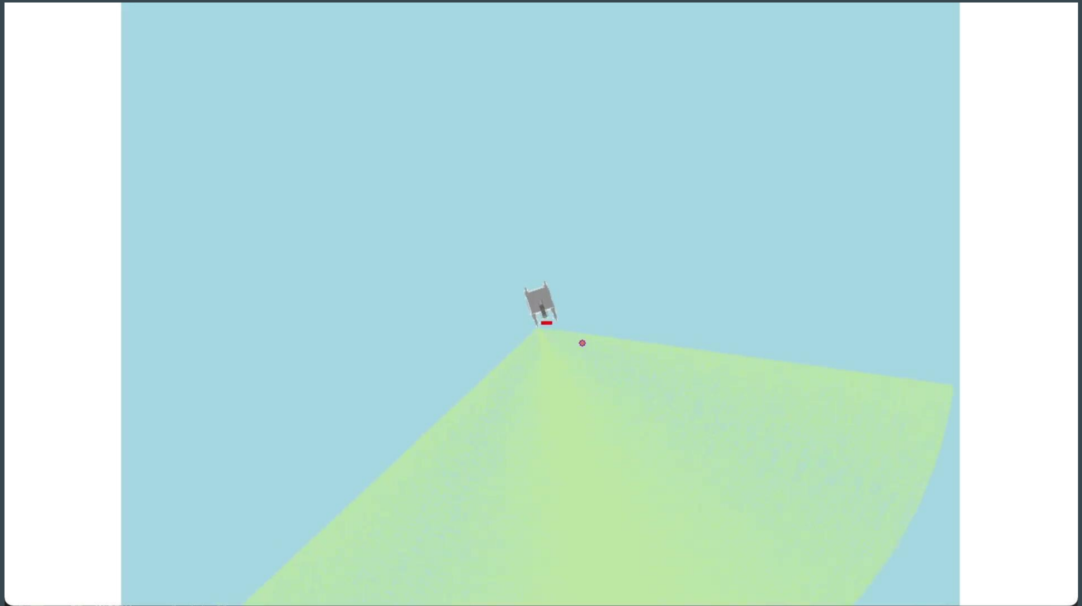
Trash Sensing - Simulation

- Assuming spherical wave propagation (outward in all directions), the minimum detectable object size (as measured by reflective area) is proportional to r^4, where r is the distance to the object.
- Limitation: Waves may not propagate out spherically near the water's surface.
- We assume the reflective area of a piece of trash to be proportional to the square of its diameter. To compensate for irregular plastic shapes and other losses, we set the reflectivity of a piece of trash to half that of a sphere with the same diameter.
- This is done similarly in both the analytical simulation and Webots.



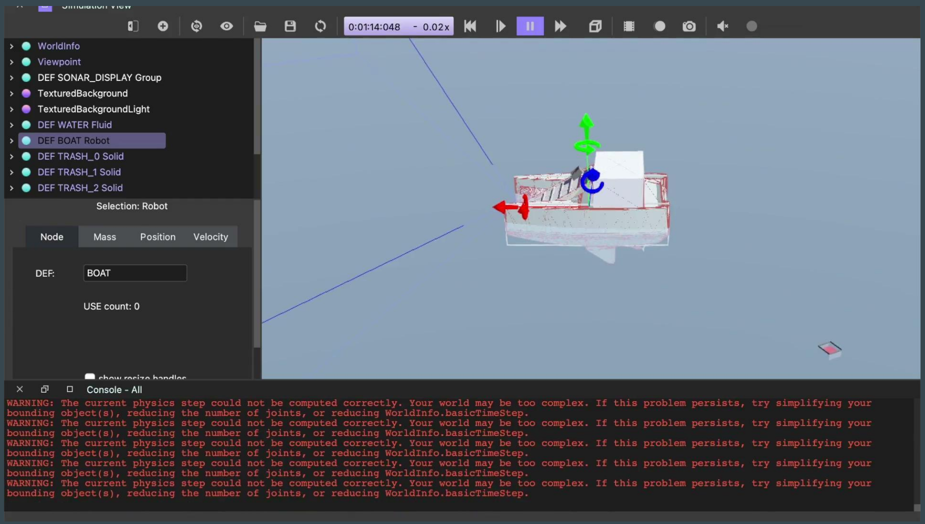
Simple Boat Dynamics and Trash Tracking

- Drag and propeller thrust are modelled
- Following trash with insufficient turning radius:
  - These trash detections are ignored in the final controller design



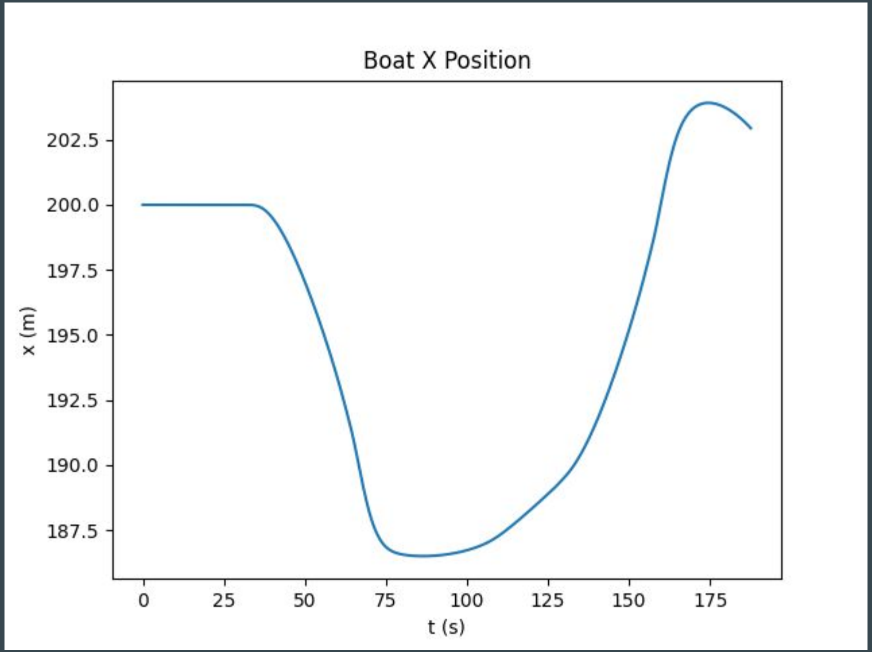
Simple Boat Dynamics and Trash Tracking - Webots vs Python

- Several pieces of trash are placed, including edge cases for the controller
- Webots and Python simulations are compared to help validate each other

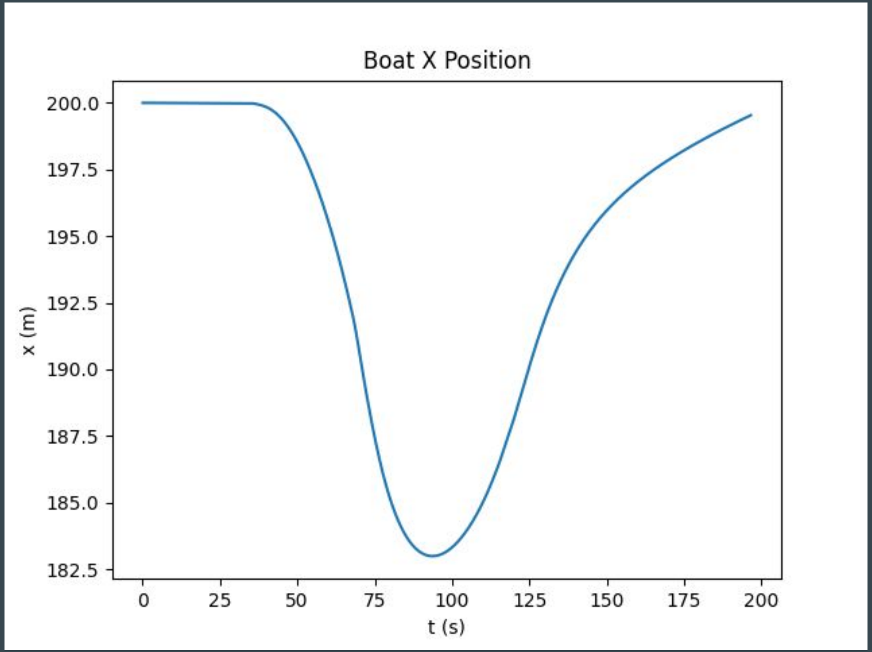


Simple Boat Dynamics and Trash Tracking - Webots vs Python

Analytical/Python

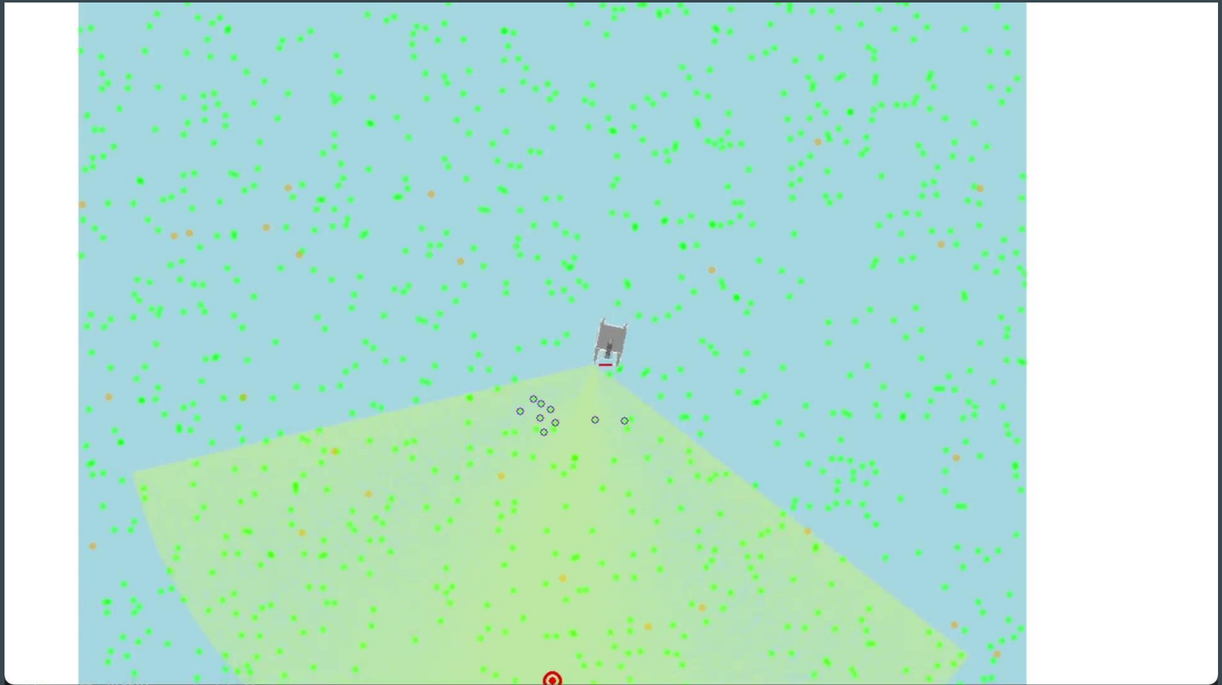


Webots

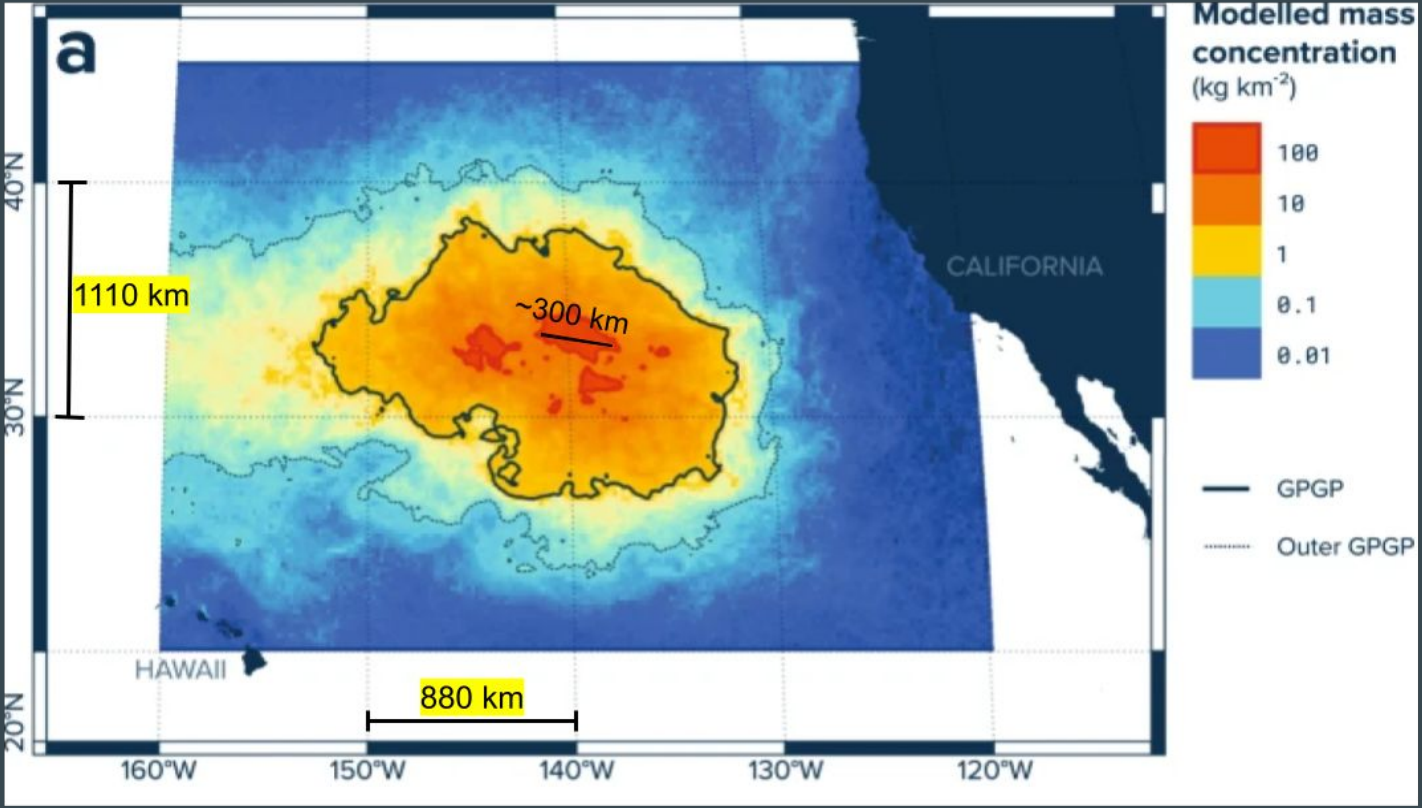


Long-Distance Mission Simulation

- Used for estimating the expected trash collection performance.
- Room for improvement - Does not include noise, waves, or other disturbances.



Long-Distance Mission Simulation: Mission Planning



Actual vs Expected Trash Collection - 25 km Simulation

	Average GPGP - Expected	Concentrated GPGP - Expected	Concentrated GPGP - 25km Simulation
Meso & macroplastic collection [kg/km]	0.0933 kg/km	0.134 kg/km	0.116 kg/km
Megaplastic collection [kg/km]	4.32 kg/km	6.21 kg/km	8.26 kg/km
Total collection [kg/km]	4.42 kg/km	6.35 kg/km	8.38 kg/km
Total collection at 1.5 m/s [kg/h]	23.8 kg/h	34.3 kg/h	45.2 kg/h

- Expected average trip length: 7 days, 900 km, based on 4,043 kg storage capacity

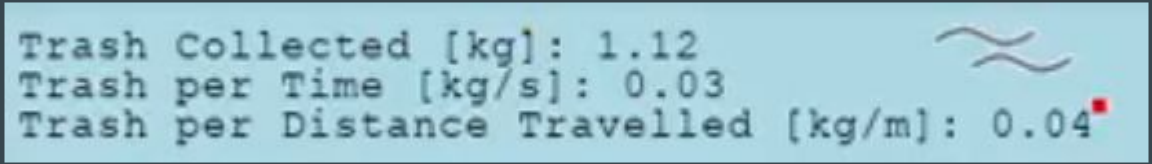
Analytical: Waves

- Weighted Random Choice made based on frequency of sea state in GPGP
- Uniform Random Choice made within associated wave height range
- Upon wave height 2m+ collision with boat, causes boat to recognize potentially unstable state
    - Occurs rarely as frequency so small in comparison to 3-4 in sea state

Wave Image	Sea State (Beaufort Scale)	Wave Height Range (m)	Frequency in GPGP
	0	0	1
	1	0.1	7
	2	0.2-0.3	118
	3	0.6-1	223
	4	1-1.5	246
	5	2-2.5	57

Analytical: Performance Metrics

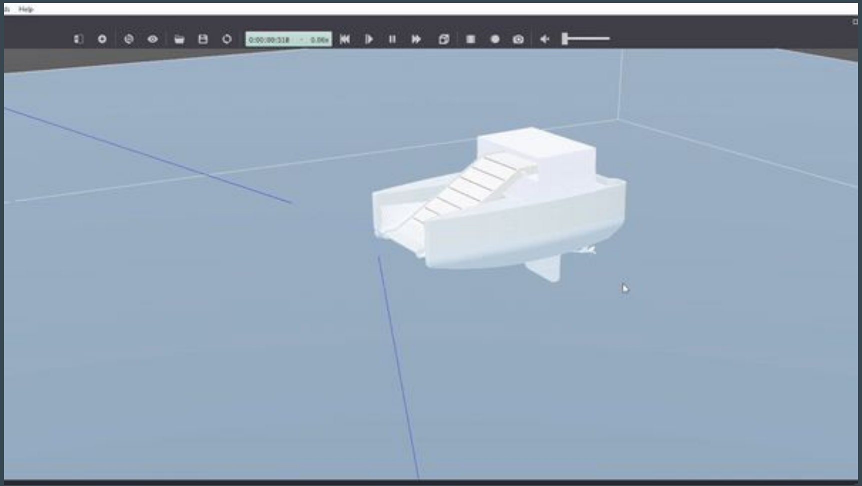
- Trash Collected
  - Upon collision with boat, trash piece's mass is added to cumulative sum and deleted
  - Current Max = 4,043 kg
  - Indicative of when to stop trash collection, remain in place until mothership pickup
- Trash per Time
  - Trash Collected [kg] / Elapsed Simulation Time [s]
- Trash per Distance Travelled
  - Trash Collected [kg] / Total Simulation Distance Travelled [m]
  - Total Simulation Distance Travelled: Euclidean distance between last and current points of simulation, each recording with every frame update



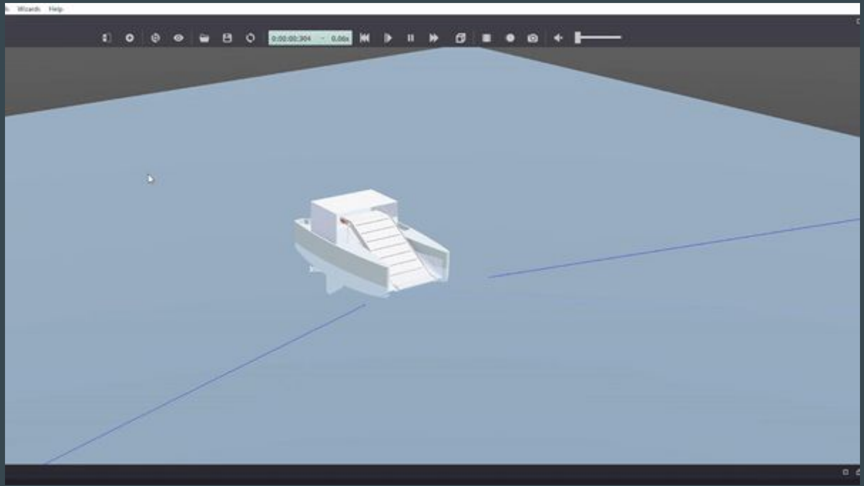
Webots Waves

- Takes FLOW-3D Wave information and applies calculated forces and torques to CoM of boat
- Tilt and movement similar to that of FLOW-3D animation, indicating stability of boat
- Repeats once reaches end of FLOW-3D data, allowing constant effect of 2m Waves

2m Front Wave

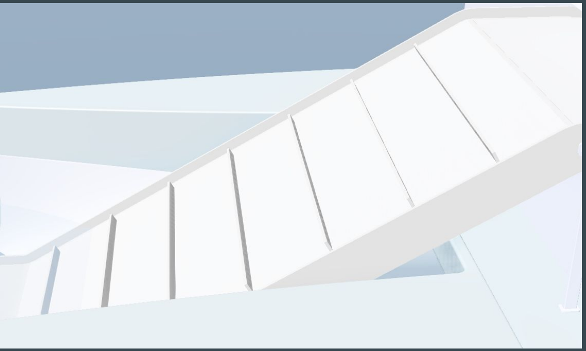


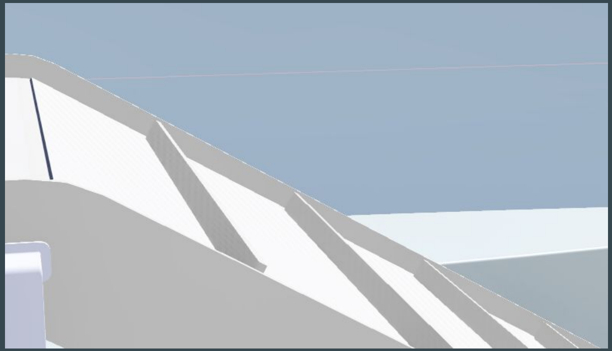
2m Side Wave

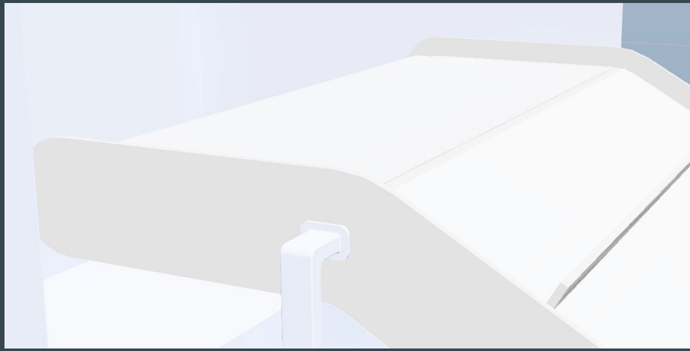


Webots Simplified Conveyor

- Cleats separate objects from conveyor
    - Individually move along one axis (same direction as diagonal portion of conveyor)
    - Using separate SliderJoint and Linear Motor for each cleat
- Diagonal and Top Portions of conveyor
    - Use Track Nodes to help objects alongside cleats
    - Move at same velocity as cleats







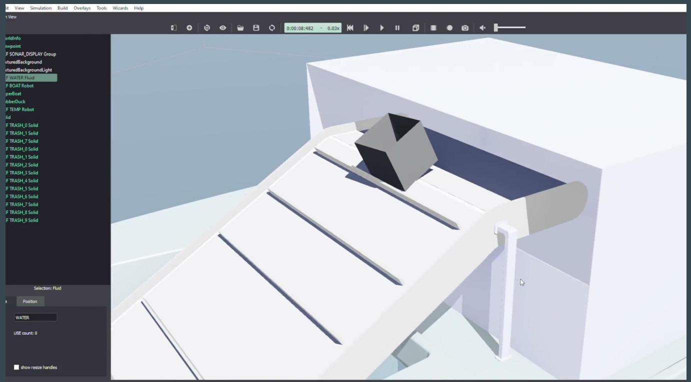
Webots Trash Collection: Basic Cubes

- Base Test to Compare w/ SolidWorks cube tests from earlier
- Generally, objects float into bottom of midsection of conveyor
  - Still able to mimic conveyor well despite not having cleats loop all the way around bottom level

Mesoplastic (5cm)

Macroplastic (25cm)

Megaplastic (50cm)

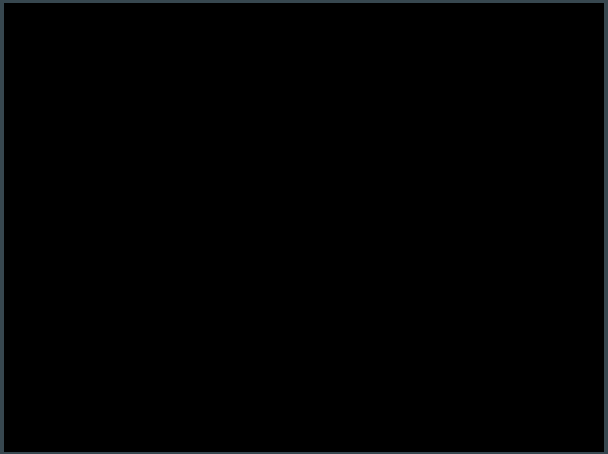


Webots Trash Collection: Odd Shapes

- Objects with Complex Curvature and Soft Bodies
  - Hooks around cleats
- Multiple Object Collection of various shapes

Duck Angle Change

Complex Curvature



Duck + Water Bottle + Paperboat

Complex Curvature + Cylinder, Multiple Object Collection

Duck Chain

Soft Bodies

Webots Trash Collection with Waves

- Object Collection succeeds in spite of constant tilt due to 2 m waves
- Object catches onto guides, rather than main conveyor, and still succeeds to move up conveyor

Collection with Side Wave Torque

Webots Example Failure Case

- Large Object, Impossible to Pick Up
  - As expected, boat unable to pick up and simply pushes along
  - Eventually, these physics complications cause boat to disappear as Webots is unable to compute the next physics step

Comparison between Performance and Requirements

- Trash collection rate: 23.8 kg/h, 571 kg/day, 800,000 kg over lifetime
- Achieved maximum trash capacity requirement: 4,043 kg (requirement was 1,000 to 5,000 kg)
- Expected average trip length: 7 days, 900 km (requirement was 5-15 days)
- Cost: $0.83/kg of trash
- Exact tactical diameter value was not obtained - acceptable because our simulation shows that we still pick up trash
- Wave survivability requirements were met: 2m operation, 4m survivable
- Trash sensing radius was met: 35-70 m (requirement was 20 m)