2019

Inflatable Vessel Design Study

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MCE Senior Capstone Design Report – Fall 2018 / Spring 2019

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Abstract

After interest was shown by the Department of Defense in the architecture and enabling technologies for a persistent, scalable, agile, open, interoperable and coordinated undersea energy, data, command, control and communications distribution network for logistics support of unmanned vehicles and sensors; the graduating class of 2019 were given the opportunity to work with sponsors NUWC and Powerdocks LLC to conduct an “Inflatable Vessel Design Study”. The study consists of a variety of designs based on parameters and objectives provided by NUWC and Powerdocks. The goal of the study was to have students design concept vessels for their numerous applications based on their specifications. Some of these objectives the sponsors were looking for included an inflatable vessel capable of navigating at sea-state 3-5 and be able to carry a load of 100 lbs. Additionally, the vessel needs to have the ability to maneuver at a 6 knot hull speed and feature puncture resistance. Other features of the vessel include ensuring optimal vessel dimensions and considerations surrounding draft to minimize overall size. Per PowerDocks, the vessel also must accommodate space for their “Black Box” (which is to act as a brain for the vessel attachments) that will be which will be placed on the vessel’s featured flat deck. The process in efforts to complete this design study began with initial research of possible related patents and any literature that may have provided ideas and concepts to provide a sound base for the study. Subsequently, concept generation was the next step in the process where each member brainstormed and provided ideas to solve the problem given. Various concepts were produced and the most feasible were chosen and used for further study. Presentations were given to the class, professor and sponsors on progress as well as proof of concept at two different intervals of the semester. Substantial engineering analysis was completed for each of the selected concepts and basic material testing has begun. Throughout the design process the progression of the team and management was collected in a Gantt chart and weekly progress reports were completed and submitted to the professors and sponsors. Two meetings with team 19’s sponsor also took place off-campus for additional information gathering, guiacance, and touring. At the beginning of the Spring Semester, the realization of the entire project took place as material testing (environmental, tensile and puncture).After tensile testing it was deduced that PVC was the most feasible material to have the vessel made from. One final model was conceptualized from the initial four designs and was altered as the semester progressed. Once the final model was complete; the final engineering analysis on the updated design was calculated. It was realized that the vessel would be approximately three times more buoyant than necessary which would be an added bonus to ensure its maneuverability in the water. Within the final model, some adjustments were made like the addition of ABS flooring to help with the rigidity of the vessel, the flat deck requirements and the inflation. Folding patterns were conceptualized as the semester ended as it was a requirement but as there was no prototype, this could not be demonstrated physically. Preparation for the build and test review commenced with three weeks

left in the second semester of the project. Sponsors NUWC and Powerdocks attended the presentation and gave great support and appreciation of the overall progress that was made with the project. Both were extremely impressed with the dedication and perseverance the entire team showed in reaching the end goal. Finally, steps were taken to ensure the project was documented in its entirety in a formal report and all engineering journals and engineering binder updated. Further work would include attempts at getting a scaled prototype manufactured to test in NUWC's wave pool facilities as well as getting quotes from companies on locally and possibly globally on manufacturing these vessels on a large scale to provide to all maring ports in the US and outside.

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List of Acronyms

NUWC - Naval Undersea Warfare Center
CAD - Computer aided Drafting
FEA - Finite Element Analysis
CFD - Computational fluid dynamics
B.O.M. - Bill of Materials
N.A.R.W.L. - Nautical Aid and Relief Waterfaring Lifeboat
IVDS - Inflatable Vessel Design Study

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1 Introduction

Naval Undersea Warfare Center Division (NUWC) and PowerDocks reached out to the University of Rhode Island and presented an inflatable vessel design study project to the students of the Mechanical Engineering class of 2019 in the Fall 2018 Engineering Capstone Design I course. NUWC is the United States Navy's research, testing, development, and engineering support for all aspects of surface, underwater, offensive and defensive weapons/vessels associated with undersea and surface warfare. PowerDocks is a quickly growing commercial marine technology company who designed and built the world's first solar electric docks.

This report is focused on performing an inflatable vessel design study to create an optimal inflatable vessel for humanitarian relief missions. This vessel will build off the foundation for PowerDocks autonomous floating microgrids. Specific design requirements were initially stated and concluded during the semester. In order to withstand the conditions of the sea, the vessel has to be puncture resistant, maneuverable at 6 knots, and capable of withstanding sea state 6 conditions. The material chosen must be capable of withstanding abrasion from seawater for prolonged periods of time. Deflated, the vessel must be packed and carried like a backpack, the carry weight must be approximately 25lbs. The payload carry weight of the vessel is 100lbs. In order to carry any payload it has been concluded that a flat deck is most suited. The Length, width, and height of the vessel are 6ft, 3ft, and 1.5ft respectively.

Previously, inflatable vessel designs have been researched by both commercial and defense industries. One major company that has been exposed to both industries is Zodiac. Zodiac started in the airship industry and then transitioned into the inflatable vessel commercial market [6]. As the demand for inflatables in the military increased, Zodiac quickly entered the military industry. The key difference between the designs conducted in this report and many inflatable vessels such as the ones offered by Zodiac is the hull. Most inflatables in military and rigorous commercial applications have rigid hulls, where this design study focuses on a completely inflatable hull so that portability is maximized.

Preliminary engineering analysis was conducted to examine buoyancy and four final designs were created using SOLIDWORKS, this was done in order to provide a proof of concept constructed within the first semester of the design study. The purpose behind the work conducted is to design the optimal inflatable vessel focusing on stability, life, and overall hull design. After the completion of both semesters one final vessel design will be achieved to be used in

PowerDocks inflatable microgrids and NUWC humanitarian relief missions. Team NARWL utilized FEA, and CFD simulations as a primary tool for testing this design, because of the completely inflatable nature of the vessel. A secondary tool for testing the inflatable was tensile testing each material. The tensile tests conducted compared the specimens left in the environmental chamber to the ones left at room temperature conditions. The environmental test chamber was used in order to mimic at sea conditions. The specimen also experienced puncture trials via drop testing a needle and a chuck, to mimic rocks and other natural projectiles. This inflatable vessel design will be the building block for many applications in commercial and defense industries for NUWC, PowerDocks, and companies beyond.

2 Reference Searches

2.1 Patent Searches

2.1.1 Jacob Chase's Patent Search

Inflatable AND rafts w/ title , title

PAT. NO.		Title
1	5,921,831	Auxiliary device for inflatable life rafts
2	4,723,929	Inflatable life rafts
3	3,995,339	Transition piece for use in inflatable life rafts

Inflatable AND boats w/ title , title

PAT. NO.		Title
1	10,071,789	Bow step and seat back for inflatable boats
2	9,745,026	Ladder for rigid inflatable boats
3	8,800,470	Dive door for rigid inflatable boats
4	8,789,486	Boats having inflatable planking
5	8,707,885	Multi-functional bench system for inflatable boats
6	8,286,573	External inflatable keel for portable inflatable boats
7	7,421,970	Access devices for inflatable and other boats
8	7,275,494	Valve structure, bladder, and hull portion for inflatable boats
9	7,240,634	Foldable rigid frame attachment system for portable inflatable pontoon boats
10	7,146,923	Valve structure, bladder, and hull portion for inflatable boats

11	5,584,260	Tube attachment device for inflatable boats
12	D350,933	Hull cap for inflatable boats
13	5,287,945	Ladder for boarding inflatable boats
14	4,991,617	Gas inlet valve assembly for inflatable boats
15	4,976,213	Securing tubes in inflatable boats
16	4,966,091	System for mounting accessories on inflatable structures such as boats
17	4,934,301	Attachment of tubes in inflatable boats
18	4,722,292	Inflatable removable keel for inflatable rubber boats
19	4,545,319	Pneumatic boats of the inflatable-deflatable type
20	4,015,622	FValve for use with inflatable articles such as pneumatic boats

Inflatable AND rafts w/ title , title

PAT. NO.		Title
1	8,640,640	Inflatable hull configuration and connection for a multihull vessel
2	7,840,387	System and method of designing a load bearing layer that interfaces to a structural pass-through of an inflatable vessel
3	7,295,884	System and method of designing a load bearing layer of an inflatable vessel
4	6,796,463	Inflatable and collapsible apparatus for dispensing fluid from a fluid vessel
5	6,547,189	Inflatable vessel and method
6	5,951,345	Vessel comprising an inflatable sealing element
7	5,819,333	Portable, inflatable, one-person vessel for recumbent, weightless, therapeutic flotation
8	5,235,931	Inflatable undersea vehicle system of special utility as a daughter vessel to a mother vessel
9	5,060,826	Container with inflatable vessel for controlling flow of liquid or viscous material
10	4,928,619	Modular rigid inflatable aquatic vessel structure
11	4,671,518	Inflatable reactor vessel stud hole plug

Referenced patents of Patent Number 4,723,929

PAT. NO.		Title
1	9,550,550	Tow rope terminal section with climb-aboard provisions
2	9,180,945	Salvage rail flotation device and method
3	9,068,670	Valve for an inflatable structure
4	7,861,663	Boarding ladder for inflatable watercraft
5	7,380,755	Frangible pneumatic latch

6	7,156,033	Inflating aircraft flotation device
7	6,941,887	Boat with perimeter float, particularly a pneumatic life raft
8	6,830,004	Inflating watercraft flotation device
9	6,817,391	Sealed O-ring connector
10	6,814,019	Inflating watercraft flotation device
11	6,802,274	Inflating watercraft flotation device
12	6,709,019	Quick connector with automatic release
13	5,975,467	Inflatable evacuation slide
14	5,320,133	Flow system disconnect and method
15	5,257,653	Ejector pull away system and apparatus
16	5,228,474	Flow system disconnect and method
17	4,989,691	Inflatable boarding ladder and rescue device

2.1.1.1 Relevant Articles

PAT. NO.	Title
4,723,929	Inflatable life rafts
8,286,573	External inflatable keel for portable inflatable boats
7,275,494	Valve structure, bladder, and hull portion for inflatable boats
7,240,634	Foldable rigid frame attachment system for portable inflatable pontoon boats
4,966,091	System for mounting accessories on inflatable structures such as boats
4,722,292	Inflatable removable keel for inflatable rubber boats
8,640,640	Inflatable hull configuration and connection for a multihull vessel
7,295,884	System and method of designing a load bearing layer of an inflatable vessel
6,547,189	Inflatable vessel and method
5,235,931	Inflatable undersea vehicle system of special utility as a daughter vessel to a mother vessel
4,928,619	Modular rigid inflatable aquatic vessel structure

Useful Patents

PAT. NO.	Title
4,723,929	Inflatable life rafts (see Appendix _)
8,640,640	Inflatable hull configuration and connection for a multihull vessel (see Appendix)

2.1.2 Steve Hafey’s Patent Search

Primary terms: Hulls, inflatable, raft

Related terms: Ships, vessels, floatation devices

Results:

10,077,537	Inflatable pollution containment rim system
10,076,641	Methods and systems for delivering substances into luminal walls
10,076,411	Perivalvular sealing for transcatheter heart valve
10,076,112	Ex vivo organ care system
10,071,792	Underwater personal submersible
10,071,789	Bow step and seat back for inflatable boats
10,071,687	Vision system for vehicle
10,070,994	Apparatuses and methods for wound therapy
10,070,980	Anchored non-piercing duodenal sleeve and delivery systems
10,066,416	Compatible storage cover
10,065,709	Cradle assembly for boats
10,064,718	Low-profile prosthetic heart valve for replacing a mitral valve
10,059,411	Quad bow paddle board
10,058,420	Flexible commissure frame
10,057,489	Vehicular multi-camera vision system
10,052,203	Prosthetic heart valve and method
10,046,092	Coating formulations for scoring or cutting balloon catheters
10,045,817	Devices and methods for forming a fistula
10,039,868	Dressing and apparatus for cleansing the wounds
10,039,637	Heart valve docking devices and implanting methods
10,035,263	System and method for inspection and maintenance of hazardous spaces
10,029,773	Submerged sailing vessel
10,029,768	Device for blocking or sealing an opening in a wall
10,029,761	Boat expanding and contracting apparatus
10,028,826	Perivalvular sealing for transcatheter heart valve
10,028,552	Two-dimensional shoe manufacturing
10,027,930	Spectral filtering for vehicular driver assistance systems
10,025,994	Vehicle vision system utilizing corner detection
10,024,307	Floating marine wind turbine
10,023,278	Pneumatic fender system for vessels
10,023,161	Braking control system for vehicle
10,021,278	Vehicle vision system with lens pollution detection

10,018,275	Sealing arrangement for an underwater mountable thruster of a marine vessel
10,011,336	Underwater vehicle design and control methods
10,011,335	Underwater vehicle design and control methods
10,011,145	Apparatus and method for inspecting flooded cavities in a floating offshore installation
10,010,417	Low-profile prosthetic heart valve for replacing a mitral valve
10,010,410	Collapsible and re-expandable prosthetic heart valve cuff designs and complementary technological applications
10,006,897	Devices for measuring parameters of water
10,005,528	Pontoon shields

Referenced Patent No.
10,011,335

1	8,679,570	Foam-like materials and methods for producing same
2	8,043,134	Human powered watercraft
3	7,556,545	Variable angle outboard motor support
4	7,013,911	Internal cross over valve
5	5,964,176	Inflatable keel
6	5,042,411	Collapsible catamaran sailboat

2.1.2.1 Relevant Articles

1)5,964,176

Inflatable keel

See appendix

This patent was useful because an inflatable keel could be used in the design of the raft to increase the stability and make it maneuverable in a seas state of 6

2) 6,634,914 Self righting water craft
See appendix

This patent was chosen because the self righting design could be useful in sea state 6 to have better stability or right itself if is capsized.

2.1.3 Alex Valisi's Patent Search

"V-shaped Bottom" AND Inflatable w/ title , title

PAT. NO.		Title
1	10,076,981	Climate comfort system for vehicle seat
2	9,776,537	Air suspended seat having auxiliary air supplies for comfort, dimensional adjustment, and personalized comfort DNA
3	9,682,640	Air bladder reclining system for a vehicle seatback
4	9,644,459	Wellbore lateral liner placement system
5	9,326,853	Retaining mechanisms for prosthetic valves
6	9,038,562	Semi-rigid craft, the buoyancy of which is adjustable
7	7,775,172	Foam stabilized watercraft with finned collar
8	6,983,709	Chambered hull boat design method and apparatus
9	6,619,224	Marine vessel
10	6,520,107	Chambered hull boat design method and apparatus
11	6,042,052	Retractable step fairing for amphibian airplane
12	5,881,665	Towable recreational watercraft having effective and convenient steering system
13	5,870,965	Foam stabilized watercraft
14	5,702,278	Towable watercraft
15	5,647,297	Foam stabilized watercraft
16	5,617,810	Compact semi-collapsible watercraft
17	5,603,277	Tack aback sailboat
18	5,282,436	Foam stabilized watercraft
19	4,993,340	Boat structure
20	4,722,292	Inflatable removable keel for inflatable rubber boats
21	4,597,355	Folding semi-rigid inflatable boat
22	4,487,151	Floating highway
23	4,351,500	Ski/float landing gear apparatus for aircraft

"V-shaped Bottom" AND Inflatable AND Ship w/ title , title

PAT. NO.		Title
1	6,983,709	Chambered hull boat design method and apparatus
2	6,619,224	Marine vessel

2.1.3.1 Relevant Articles

Patent Used

PAT. NO.		Title
1	6,983,709	Chambered hull boat design method and apparatus (See Figure 63)

The patent presented above was useful because it provided a basis on the overall shape of the inflatables presented in the proof of concept section of this report. Although the vessel is not inflatable the shape and positioning of the many compartments provided to be useful while looking into the location of the black box or "brains" of the vessel. Another component of this patent that was analyzed was the hull. Again, although the hull was rigid the shape was researched so that it could mimicked because of the ability of the hull to redirect the water in a way that provides more lift and less drag on the hull.

2.1.4 Jean-Pierre Alleyne's Patent Search

	10,059,410	Fishing kayak
2	9,873,487	Hybrid running surface boat
3	9,862,457	Rear extensions for boats
4	9,783,275	High speed surface craft and submersible craft
5	9,586,654	Monohull offshore drilling vessel
6	9,567,035	Means of water surface transport
7	9,469,384	Variable stable drilling barge for shallow water service (inland and offshore)
8	9,422,042	Cantilevered rotatable carcass carrier
9	9,394,032	Rear extensions for boats
10	9,327,811	High speed surface craft and submersible craft
11	8,136,464	C-fast system
12	7,997,220	Marine vessel module
13	7,971,550	Rigid tube buoyancy assembly for boats
14	7,950,341	Ship with a special lower level
15	7,311,053	Support vessel
16	6,666,162	Aluminum hull boat with extruded running surface
17	6,386,131	Hybrid ship hull
18	6,314,905	Boat manufactured from formable aluminum
19	6,145,466	Boat manufactured from formable aluminum
20	5,481,998	Recreational boat construction
21	5,349,917	Unitary aluminum watercraft and method of production of same
22	5,347,703	Method of coupling a module framework to a ship structure
23	5,299,520	Ship, in particular merchant ship

24 5,226,583 Module framework for larger structure, method and device for assembling module framework and coupler for module framework
25 5,170,736 Method for installing outfitting component into module frame
26 4,662,299 Method of making a ship's hull
27 4,552,085 Planking assembly and method of making same
28 4,214,332 Method of constructing welded metal skin boat hulls and hulls made thereby

2.2 Literature Searches

2.2.1 Jacob Chase's Literature Search Titles

1. RIBCRAFT USA to Introduce the 'Mitigator' -- the World's Most Advanced Rigid Inflatable Boat
2. DAKA Unveils New Motorized Inflatable 'Personal Watercraft' & Family 'Seascooter' at Super Show 2005
3. Caspian Services takes delivery of two Demaree inflatable boats
4. AMF'S new generation of rigid inflatable boats
5. Impact data for the investigation of injuries in inflatable rescue boats (IRBs)
6. Inflatable rescue boat-related injuries in Queensland surf lifesavers: the epidemiology – biomechanics interface
7. Moderate sea states do not influence the application of an AED in rigid inflatable boats
8. Ship ahoy!
9. Influence of large hull deformations on the motion response of a fast catamaran craft with varying stiffness
10. U.S. Textiles: High Performance In Every Military Environment
11. A comparison of experimental measurements of high-speed RIB motions with non-linear strip theory
12. Turbodyne Technologies Announces Marine Applications for Its TurboFlow(TM) System
13. Scorpion RIBS uses vacuum infusion process for latest boat
14. Why Rigid Inflatable Boats (RIBs) Offer Advantages Over Traditional Fiberglass Boats; Four Top Reasons From the Experts at AB Inflatables
15. United Defense, Rafael, Teaming To Sell Navy on 'Protector' Unmanned RIB
16. Development and Applications of Wave-piercing Underwater Vehicles
17. Threat Containment
18. No Crew Onboard!
19. Aquatic racing vehicle
20. NO TIME TO SPARE? GO BY AIR!

2.2.1.1 Relevant Articles

Influence of large hull deformations on the motion response of a fast catamaran craft with varying stiffness

This literature source provides so much that team 19 could potentially use for the development and testing of the inflatable device. The vessel may be different but all the analysis, testing, math, and methods are clearly defined and layed out in a way that could prove more useful than anything else found so far. The Ocean Engineering department of this respective work has accomplished a lot with this article. This source could easily be a capstone project in and of itself because of the depth and complexity that is offered. This source also offers a look into new ways that team 19 could look to optimize several designs for the design study and analyse them with similar methods to produce team version specific results.

2.2.2 Steve Hafey's Literature Search Titles

1. Numerical reconstruction of trajectory of small-size surface drifter in the Mediterranean sea

2. Simulation of Life Raft Motions on Irregular Wave - An Analysis of Situations Leading to Raft Capsizing

3. The Application of Civil Aviation Operational Techniques to Merchant Ship Operations

4. Defying Ranger Danger

5. Life raft maker pulls in deal

6. BRIEF: Two teens rescued from Lake Superior

7. Submarine life rafts to replace indicator buoys

6. WHAT'S NEW

7. US Navy Rescues 128 Med Migrants in Rough Seas

8. BRIEF: Navy ship helps rescue 128 men from distressed raft

9. The Raft

10. BRIEF: Navy ship helps rescue 128 men from distressed raft

11. Opera Software CEO saves the day for PR

12. Spain: Spain takes in 87 more migrants

13. World News: World Watch

14. Anti-roll tank at issue in fatal capsizing

15. New Survivor wearable life vest and raft

16. Lighting the Adventure

17. Ultimate Dog Pool Launches Labrador Retreat Inflatable Pool

18. Riunite wine, so nice on ice, aims for warmth, relevance via packs, ads

2.2.2.1 Relevant Articles

Submarine life rafts to replace indicator buoys

This article is a good source for the project because it gives an idea of how certain sensors can be stored and activated on the inflatable as well as how to inflate the vessel with a pressurized gas. Before it was thought there could not be enough air in a pressurized container but this article mentions how this is possible.

2.2.3 Alex Valisi's Literature Search Titles

1. Inflatable pontoon boat
2. Folding semi-rigid inflatable boat
3. Composite hull boat with rigid bottom and inflatable tubular buoyancy element
4. Collapsible boat with v-shaped pneumatic float
5. Inflatable boat with detachable hull
6. Pneumatic boat with an inflatable keel
7. Removable connection of a rigid deck and rigid keel to the covers of an inflatable boat
8. Inflatable floor, in particular for an inflatable boat
9. Inflatable boat
10. Rigid Inflatable boat

11. Intravascular radially expandable stent
12. Power boat hull
13. Construction of rigid hull inflatable boat
14. Inflatable dingy chock
15. Protective boat hull device
16. Inflatable boat with a high pressure inflatable keel
17. Water Sled
18. Rigid inflatable boat with adaptable hull
19. Collapsible surfboard or sailboat
20. New Police Vessel Launched

2.2.3.1 Relevant Articles

Inflatable boat with a high pressure inflatable keel

The literature presented offers the team extensive work done in high pressure inflatable keels. The concept was used in design 3 in the proof of concept seen in figure 25. The specific pressure of the keel or hull is still being researched and experimented due to the fact that a design requirement is a simple uniform method of inflation.

2.2.4 Jean-Pierre Alleyne's Literature Search Titles

1. Inflatable kayak
2. Inflatable boat
3. High speed marine craft motion mitigation using flexible hull design
   rigid hull inflatable boat with related U.S. application data foam insert

3 Evaluation of Competition and QFD

The initial design specifications of this project require an inflatable vessel that weighs less than 25 pounds deflated and carry a 100 pound load on a flat deck. The vessel also needs to be puncture resistant as well as 6 feet long by 3 feet wide and be able to maneuver in a sea state six. The most important parts of the design are the deflated weight, the carriable weight, and the flat deck. Most competitor inflatable vessels excel in one of these areas, but not all. Whitewater rafts are probably the best competitor option, but they are too large, heavy and no flat deck. They are capable of maneuvering in sea state 6 and are puncture resistant. For these reasons, the project design is based off of whitewater raft, but with modifications to fit the all the design specifications. The overall design specifications evolved as the project progressed. After evaluation the design of the flat deck was altered to incorporate rigid ABS flooring. The largest surface area for a design is 18784 inches^2 which is 14.5 yards^2. This value of surface are changed with the evolution of the model. The cost for a yard of Hypalon is $55.00 which brings the total of raw materials to $800.00. The competition charges $600.00 to $2000.00. These are not modified to fit the sponsor's design specifications either. NUWC and PowerDocks have a market budget range of $5000.00 to $10000.00 dollars.

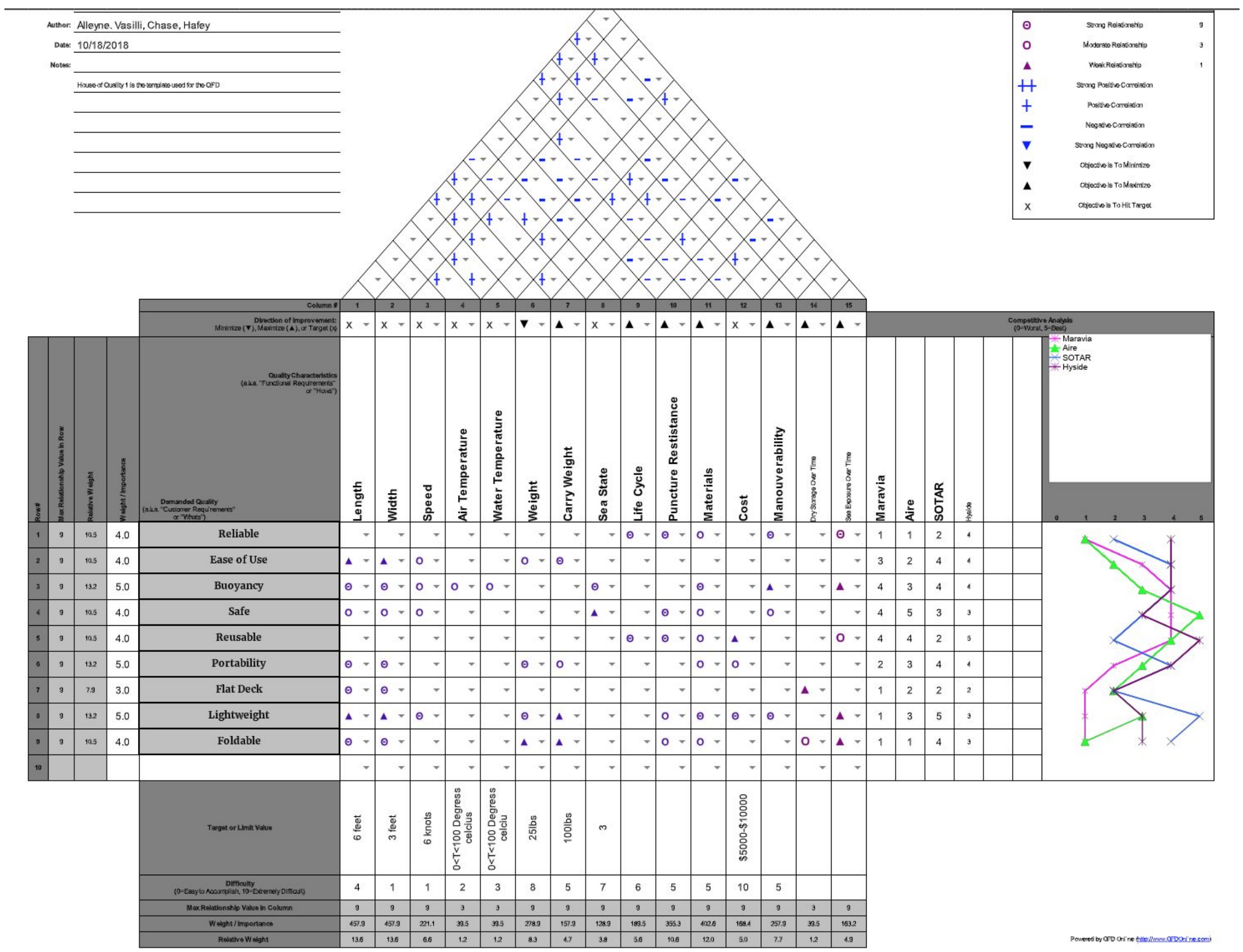


Figure (1): Figure of Quality Function Deployment (QFD)

4 Engineering Design Specifications

4.1 Evolution of Problem Definition to Design Specifications

The problem definition was clearly stated by the sponsors at the beginning of the Fall term last year. The Team was to execute a "Design Study" aimed at creating an inflatable vessel for NUWC and PowerDocks. Additionally Team 19 would develop this vessel to build off of the foundations of PowerDocks' "Autonomous Floating Microgrid". The sponsors had a bevy of open ended requirements that they wanted addressed. These requirements and specifications became the initial design specifications.

4.1.1 Initial Design Specifications

NUWC/PowerDocks were open on many aspects of the design requirements, with only a few numerical specifications. Because of the open ended nature of this "Design Study" there were both requirements as well as specifications. The sponsors required that the Design Study Vessel be waterfaring in nature, puncture resistant, reusable, and maneuverable at 6 knots. This vessel must also feature a 100 lbs payload support, a built in "flat deck", stability up to sea state 6, a weight under 25 lbs and collapsibility to fit into a backpack. Puncture resistance was never specified by the sponsors, so there was no target to aim for, and was planned for the second semester. Similarly, the flat deck and backpack storage requirements were not specified to a specific value, so once the design was finalized, those could be added. The material was not specified, as long as the weight was within the acceptable range (25 lbs) The following table outlines the numerical constraints gathered from sponsor input.

Table (1): Table of Initial Design Specifications

Customer Targets	Target Values
Target Market Price	$5,000-$10,000
Size Constraints	(L: 6 ft) x (W: 3 ft) x (H: 1.5 ft)
Unloaded Vessel Weight	25 lbs (Max.)
Load Support	100 lbs (Max.)
Buoyancy	$\rho v g \geq 25\ lbs$
Buoyancy Loaded	$\rho v g \geq 125\ lbs$

4.1.2 Progression to Current Design Specifications

As the design of the vessel continued, more specifications needed to be flushed out or updated. Values were set for the flat deck size, the needed propulsion speed, and puncture resistance. Among other things, the load support and buoyancy were updated to reflect the additional weight from the implementation of PowerDocks' electronics and propulsion. The Team designed an overly buoyant vessel, so a the material strength for support of an unexpectedly high load was later included. The size constraints were slightly tweaked to match sponsor size needs while still providing buoyancy and ample flat deck size. The materials would also need to survive at sea surface conditions, so that was added as well.

Table(2): Table of Updated Design Specifications

Customer Targets	Target Values
Target Market Price	$5,000-$10,000
Size Constraints	(L: 6.5 ft) x (W: 4 ft) x (H: 1.5 ft)
Unloaded Vessel Weight	25 lbs (Max.)
Load Support	194.6 lbs (Max.)
Buoyancy	$\rho vg \geq 25\ lbs$
Buoyancy Loaded	$\rho vg \geq 194.6\ lbs$
Speed (Propulsion)	6 Knots (to Travel 3 Knots)
Flat Deck Support	100 lbs
Flat Deck Size Rear	L: 3 ft x W: 32 in
Flat Deck Size Front	600 Square Inches
Puncture Resistance	24 Joules
"In Field" Material Survivability	$60° F,\ H \geq 50\%\ Humidity$
Durability of Vessel Material	1334.47 N Tensile loading

5 Conceptual Design

5.1 Concept Generation and Evaluation Outline

For the concept generation stage of development each member of the team was tasked with the job of conceptualizing thirty varying designs for the problem that we were given. Therefore, based on the literature research and patent research conducted, each member was able to attain this goal by using what was found from those two exercises. Listed below are the thirty designs each of the four members produced to gather ideas and a better understanding for the problem given and the various parameters that were to be considered as well. Each section is further broken down by team member designs, pugh charts, and personal evaluation. These concept designs were all in the very early stages of the design and development.

5.1.1 Jacob Chase's Concepts and Evaluations

Based on the information from the literature and patent searches, the following concepts are the best representations of the project task based on personal preference. All drawing concepts feature different inflatable vessel hulls with different shapes and respective folding designs that are constructed out of different and materials. As a simple breakdown of the concepts:

(5 Hull Designs + 5 Folding Patterns) x 3 Materials = 30 Unique Concepts

Each drawing sheet has a spot for its specific material. Material 1 is urethane, material 2 is hypalon, and material 3 is PVC. Each folding diagram has a sequential "A, B, C" listing which demonstrates how the model would break down and fold up. Each concept has been created by hand and has been respectively numbered at dated by hand as well. The hull designs are annotated to offer some more detail into how each vessel could operate or be supported. Each of these hulls also has a unique handwritten material as well.

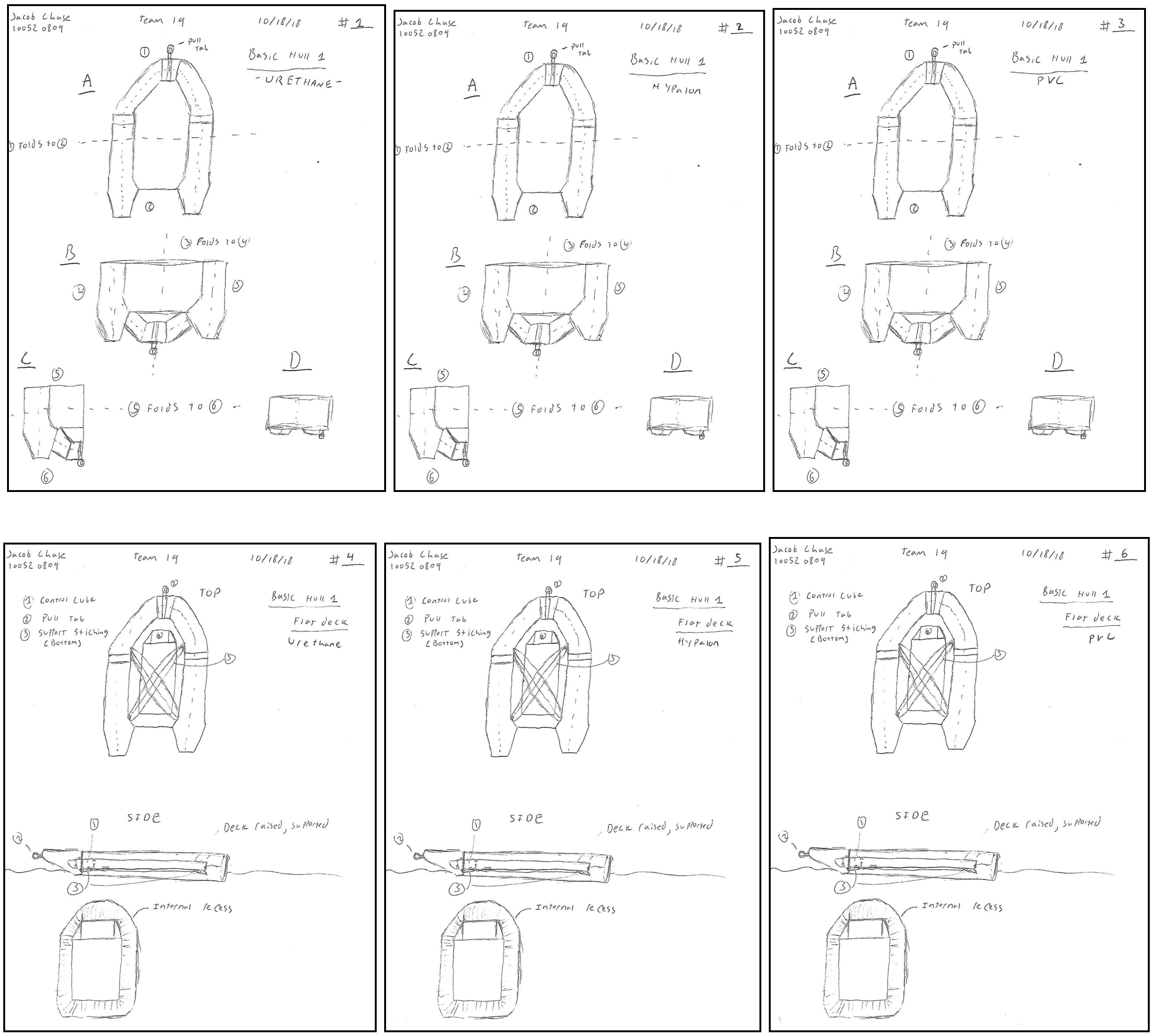
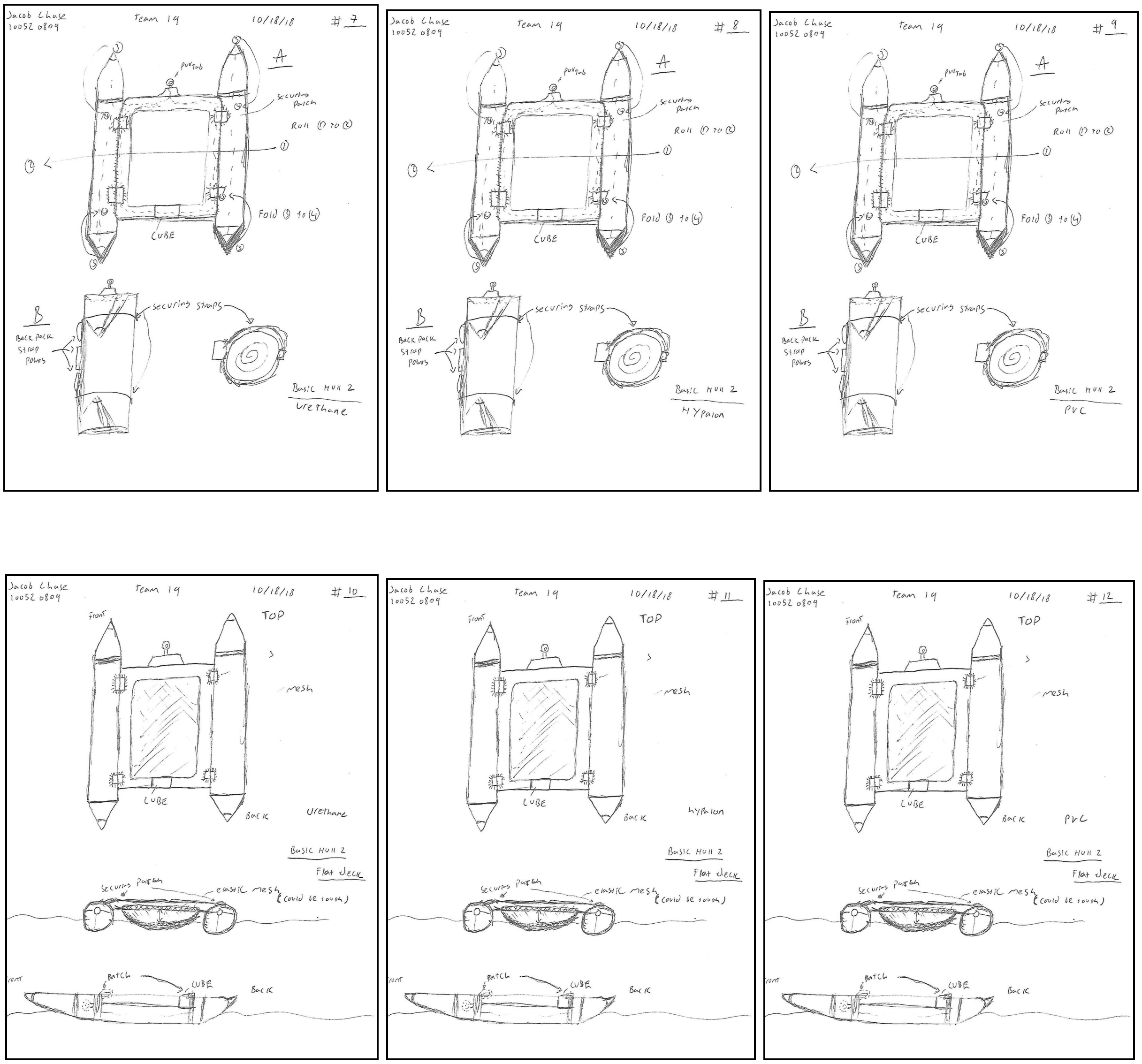


Figure (2) : Drawings 1-6 are Hull 1 and the Folding Methods for it marked with unique material



Figure(3) : Drawings 7-12 are Hull 2 and the Folding Methods for it marked with unique material

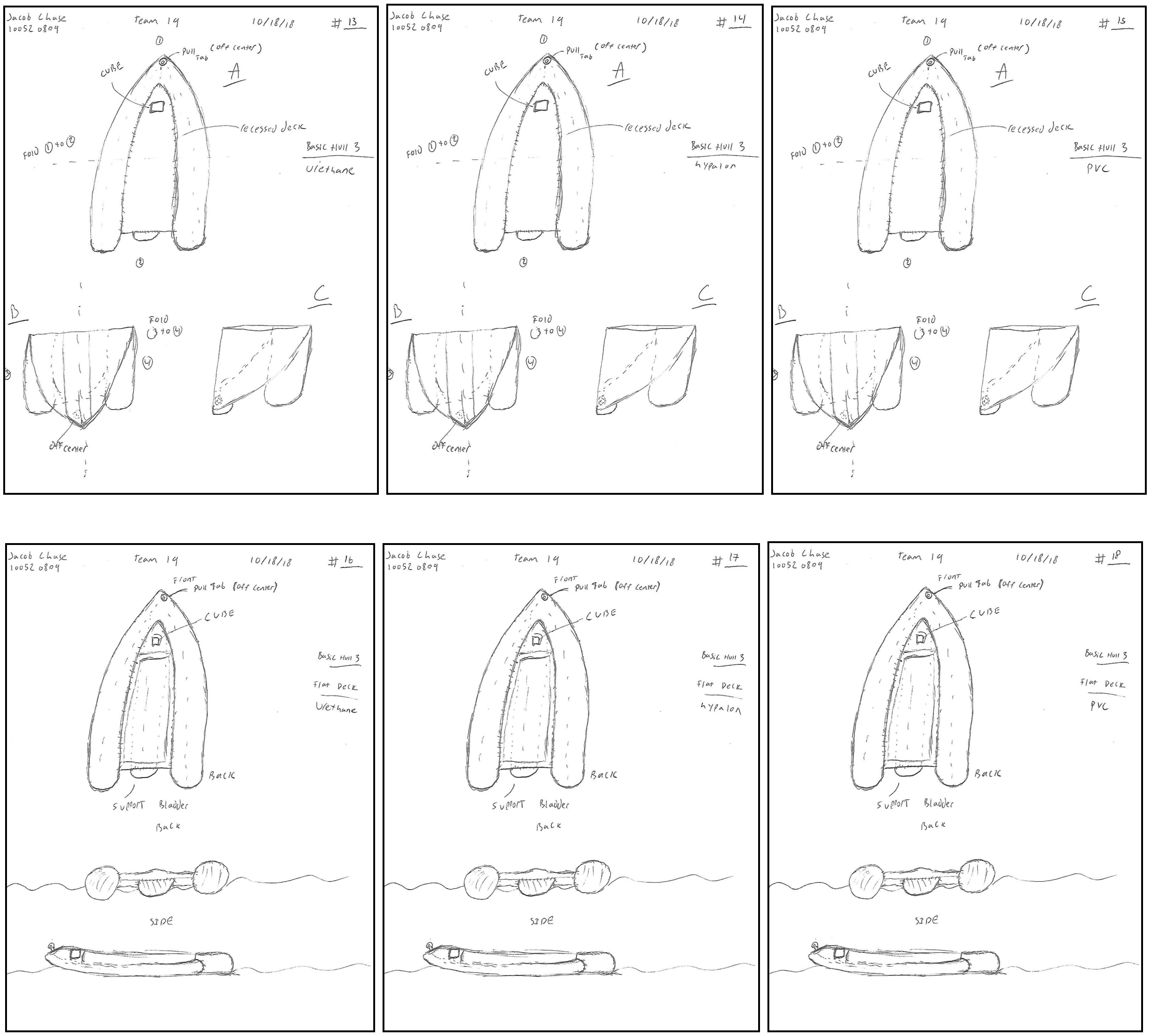


Figure (4) : Drawings 13-18 are Hull 3 and the Folding Methods for it marked with unique material

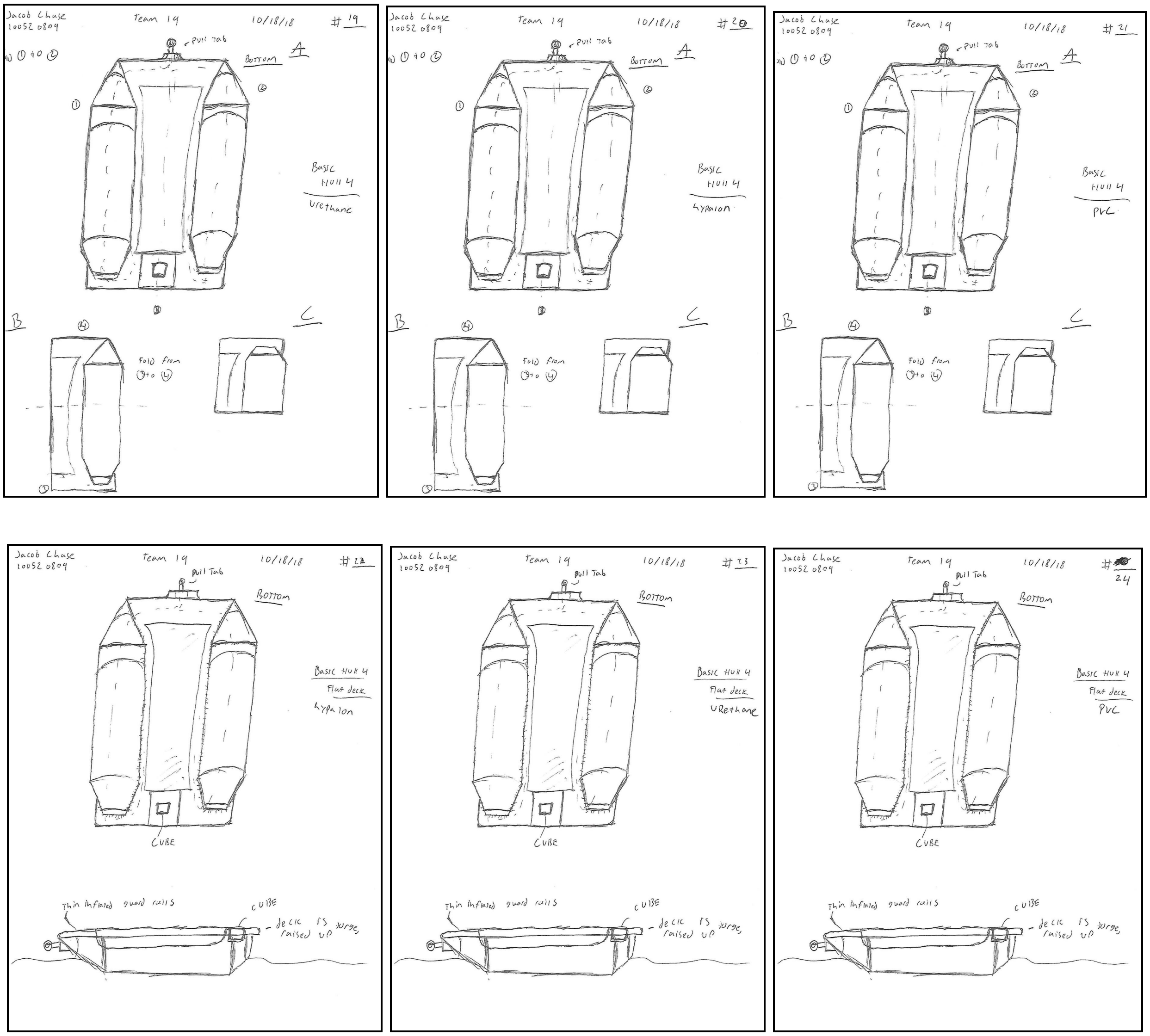


Figure (5): Drawings 18-24 are Hull 4 and the Folding Methods for it marked with unique material

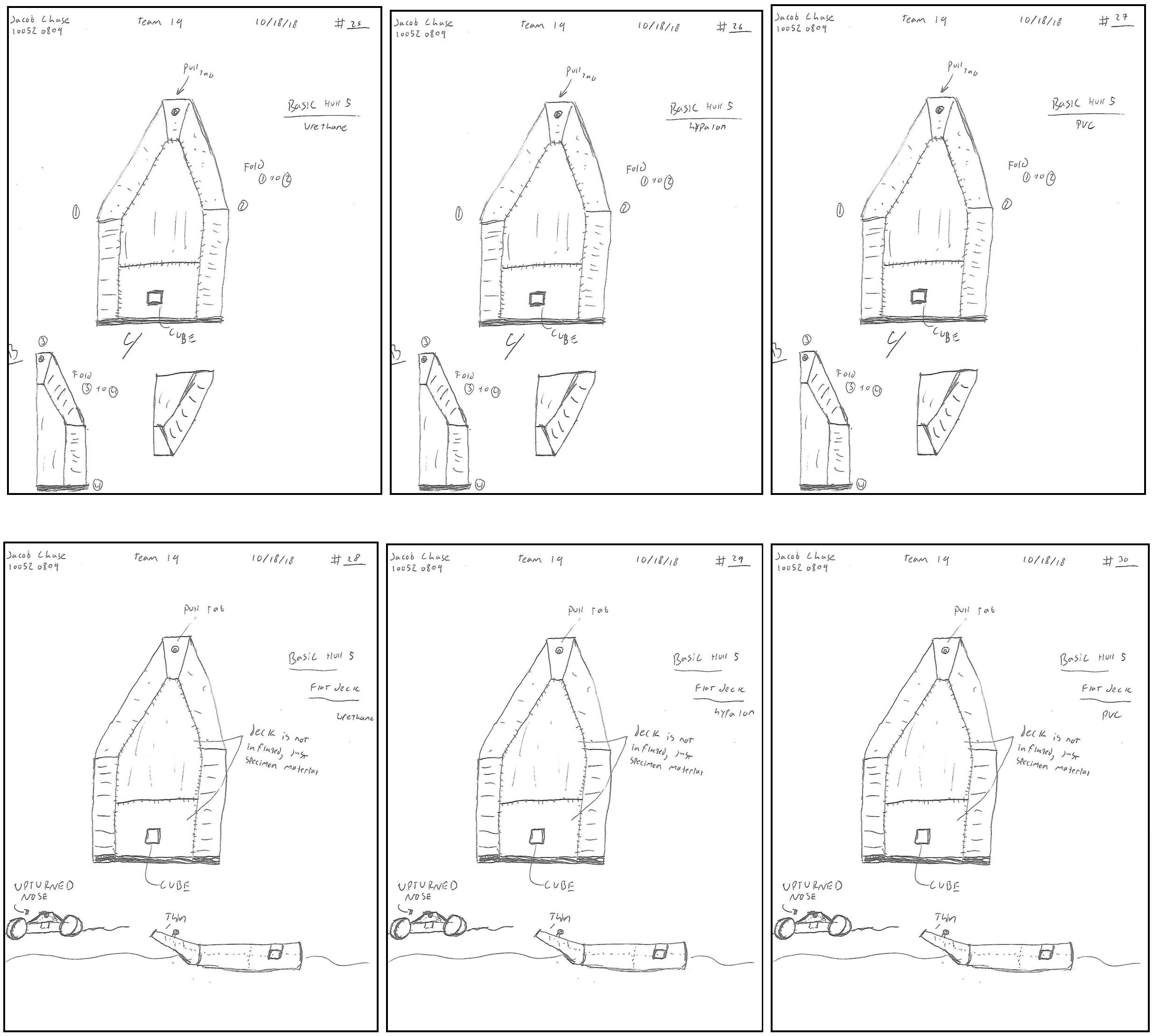


Figure (6) : Drawings 25-30 are Hull 5 and the Folding Methods for it marked with unique material

Concept Evaluation

Drawing number 13 and 16 (related design) are the best choice(s) in the created concepts. This design uses hull design 3 and its folding method, and the material chosen with these drawings (urethane). This choice came from personal preference, peer review, and the Pugh chart below which highlights the pros and cons of the concepts based on the original engineering criteria.

Table (3) : Jacob Chase's Concept Pugh Chart

		Concepts																													
Engineering Criteria	Reference Concept	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Reliable	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
Ease of Use	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Buoyancy	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Safe	+	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Reusable	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Portability	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Flat Deck	+	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-
Lightweight	+	+	+	+	+	+	+	-	-	-	-	-	-	+	+	+	+	+	-	-	-	-	-	-	+	+	+	+	+	+	+
Foldable	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
# of Plusses	78																														
# of Minuses	192																														

#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
# of +'s	6	5	5	6	5	6	5	6	6	5	5	5	8	5	6	8	7	6	6	6	4	6	6	6	5	5	5	5	6	5
# of -'s	3	4	4	3	4	3	4	3	3	4	4	4	1	4	3	1	2	3	3	3	5	3	3	3	4	4	4	4	3	4

5.1.2 Steven Hafey's Concepts and Evaluations

1. Solar panel in tow- to maximize surface area to carry supplies the solar panels which provide energy will be towed by the raft (figure A)
2. Flexible solar panels- place flexible solar panels around the tube part of the raft to maximize surface area to carry supplies (figure C)
3. Solar panels on top of the removable box which incorporates the propulsion to half ballast. (figure B)

These concepts deal with the location and type of solar panels used to make the raft self sufficient. After discussing the design specifications with the sponsors, this was decided not to be important at the moment.

4. Propeller motor which rotates to eliminate need for rudder (figure D)

5. Solar panels on both ends of the raft to allow equal balance to be able to move without supplies to distribute weight
6. Movable weight to allow even distribution of weight (figure E)
7. Chambers in inflatable to reduce damage done by puncture (figure F)
8. “T” shaped order of internal tubes to provide stiffness(figure G)
9. Collapsing rod that can be placed bow to stern to provide stiffness
10.Internal ropes to provide stiffness and shape
11. 2 pontoon inflatables with smaller inflatable tubes running perpendicular (figure H)
12.Inflatable Keel- for stability (figure I)
13.Pointed bow (figure J)
14.“V” shaped hull to cut through current (figure K)
15.Rounded bow to maximize surface area for supplies ((figure L)
16.Pointed stern to minimize surface contact to reduce drag
17.Flat deck with skid tape so supplies don’t slip
18.Flat deck with stretchable rope to hold supplies
19.Flat deck with eyelet to place bungee cords to hold supplies
20.Propeller for propulsion
21.Water jet for propulsion
22. Propulsion in back of raft to optimize mobility (figure M)
23.Sunken in flat deck using the side tubes to hold supplies

Concept Evaluation

These designs were about the shape of the hull and the propulsion. The shapes were to increase maneuverability. It was decided to go with a V shaped hull with motors that rotated on the rear.

24.Raft made out of rubber
25.Raft made out of PVC
26.Raft made of Urethane to be more maneuverable
27.Propulsion in middle for balance (figure N)
28.Double layer of material to help reduce puncture damage
29.Pontoons with removable board to provide structure
30.Drop stitch inflatable material

Concept Evaluation

These concepts deal with the material the raft is made of. Hypalon is what will be used as the main material. Drop stitch is being looked at as an internal material to keep the shape and for stability.

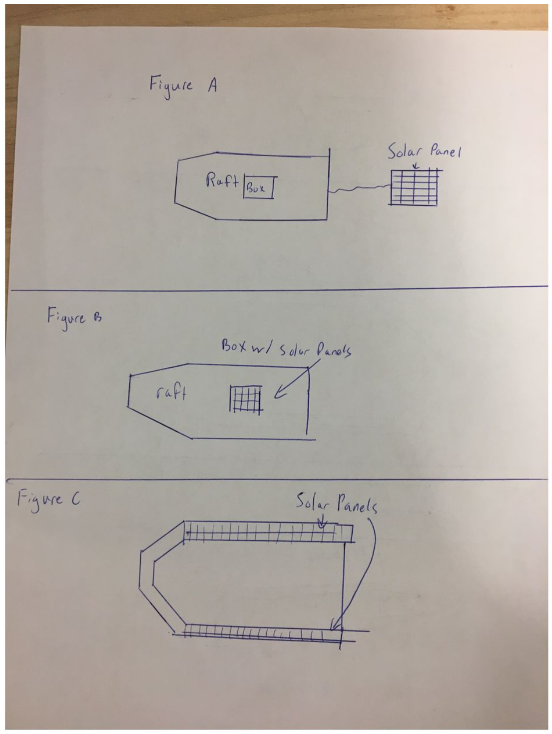


Figure (7) : Steven Hafey's Design Concepts

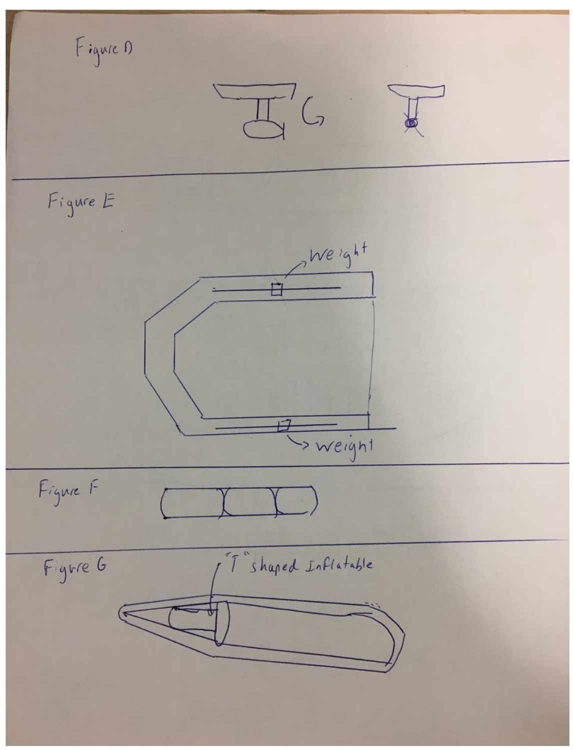


Figure (8) : Steven Hafey's Design Concepts

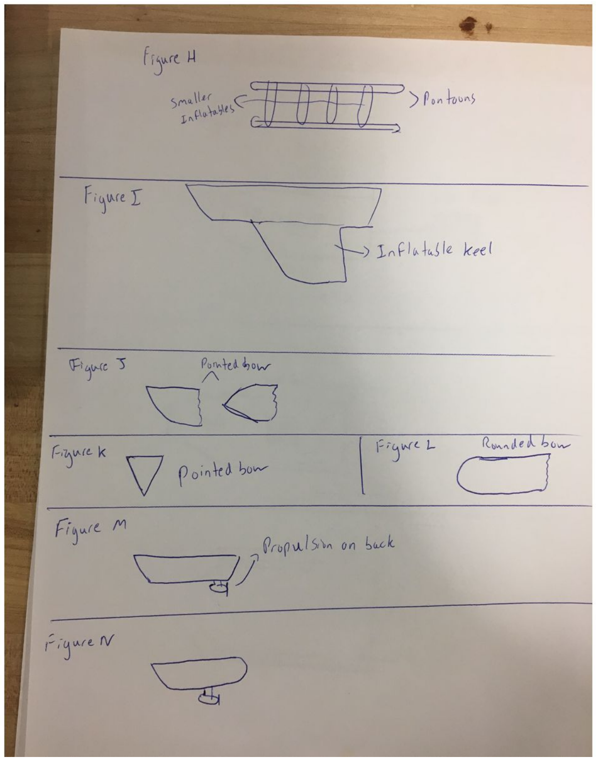


Figure (9): Steven Hafey's Design Concept

Table (4) : Steven Hafey's Pugh Chart for Concepts

		Concepts																													
Engineering Criteria	Reference Concept	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Puncture resistant		+	+	+	-	-	+	+	-	+	-	-	-	-	+	+	-	+	+	-	+	-	-	+	+	+	+	+	+	+	-
Sea state 3		+	-	+	-	-	+	+	-	+	-	+	+	-	+	+	-	+	+	-	-	-	-	-	+	+	-	+	+	-	-
3 knots		-	+	-	-	-	+	-	+	+	-	+	-	+	+	-	-	+	-	-	+	-	+	+	+	-	+	-	-	+	-
Carry 100 lbs.		+	-	+	+	-	+	-	+	+	-	+	+	-	+	-	-	-	+	-	-	+	-	-	+	+	-	+	+	-	-
Roll resistant		+	+	+	-	-	+	+	-	+	-	-	-	-	+	+	-	+	-	-	+	-	+	+	+	-	+	+	-	+	-
Easy to right		+	-	-	+	-	+	+	-	+	-	+	+	-	+	+	-	+	+	-	+	+	-	-	+	+	-	+	+	-	-
# of Plusses	95																														
# of Minuses	85																														

#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
# of +'s	5	3	4	2	0	5	4	2	6	0	4	3	1	6	4	0	4	4	0	3	2	2	3	6	4	3	5	4	3	0

# of -'s	**1**	**3**	**2**	**4**	**1**	**0**	**2**	**4**	**0**	**6**	**2**	**3**	**5**	**0**	**2**	**6**	**2**	**2**	**6**	**3**	**4**	**4**	**3**	**0**	**2**	**3**	**1**	**2**	**3**	**6**

5.1.3 Jean-Pierre Alleyne's Concepts and Evaluations

The concepts numbered 1-8 were based in the figure below.This design was also chosen based on its raft like structure which fit the description of the project. By the design specifications and parameters given to the group by our sponsors; these design were sought to be suitable based on the fact that they were fully inflatable, featured a flat deck and an optimized hull shape. Additionally, possible materials that may be used were speculated for the designs like neoprene, urethane, hypalon and PVC. Another feature to be considered and can be seen in the figure below was also two folding patterns as it was also another design requirement given.

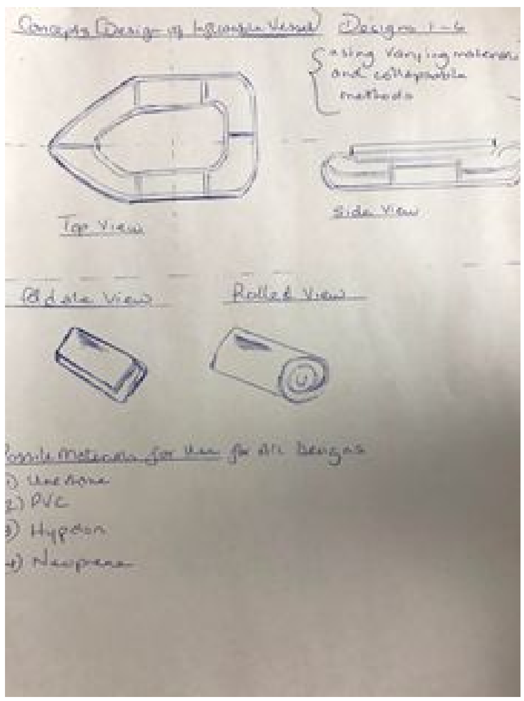


Figure (10): Drawing of Jean-Pierre Alleyne's Concept Designs 1-8

Concept 1 : Figure 12 is a speed boat like design of the inflatable vessel made out of urethane material with the rolled folding pattern. Upon further research Urethane proved to be an expensive material and hard to transport.

Concept 2: Same structural design and made of of PVC with the rolled folding pattern shown above. PVC was seen to be the least likely to be used even though it was the cheapest. Its qualities were not conducive to what was needed for our final product; since it was hard to roll and not very puncture resistant.

Concept 3: Made out of hypalon material with the rolled folding pattern. This concept was favorable as hypalon proved to be a suitable material for the inflatable vessel which its effective puncture resistance in comparison to the other materials and its ease to transport.

Concept 4: Made out of neoprene material with the same structural design as the above concepts paired with the rolled folding pattern.

Concept 5: Similar to Concept 1, concept 5 only differs in the folding pattern which is rectangular and will feature a distinct folding pattern for efficiency.

Concept 6: Same material and design as Concept 2 but with the rectangular folding pattern.

Concept 7: Similar to Concept 3, but with the rectangular folding pattern.

Concept 8: Similar to Concept 4, but with the rectangular folding pattern.

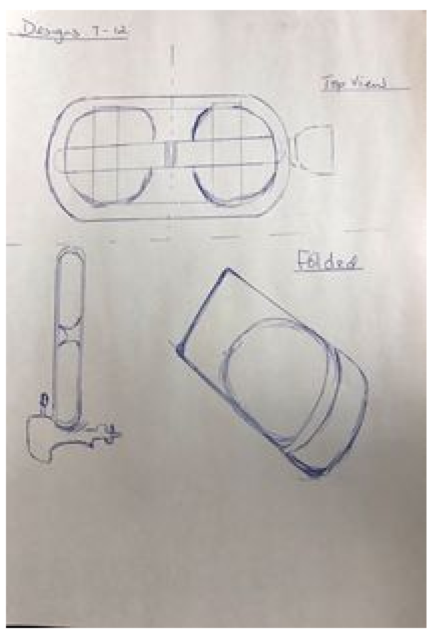


Figure (11) : Drawing of Jean-Pierre Alleyne's Design Concepts 9-12

Concept Evaluation

Concepts 9-12 are derived from the figure above and feature similar physical attributes as Concepts 1-8. However, these design concept feature a more raft like structure with a more rounded hull and rectangular body. Still fitting within the sponsors specification for the dimensions of the vessel, this shape provides a larger flat deck surface area and therefore more room to carry. However, this drawing only feature one fold and this does not allow for easy transport and possible containment into a backpack.

Concept 9: The more raft like and rounded rectangular structure seen in Figure 13 proposed to be made from urethane and folded down the middle. Urethane; again even though harder to transport features the puncture resistance characteristics needed for the vessel.

Concept 10: Same structural design as Concept 9, but made with PVC which would not be the best because of it lack of puncture resistance.

Concept 11: Differs from the other designs only by the material used which is hypalon. This is another efficient and effective choice of material for this design based on its qualities.

Concept 12: Same as the above but uses neoprene for the material.

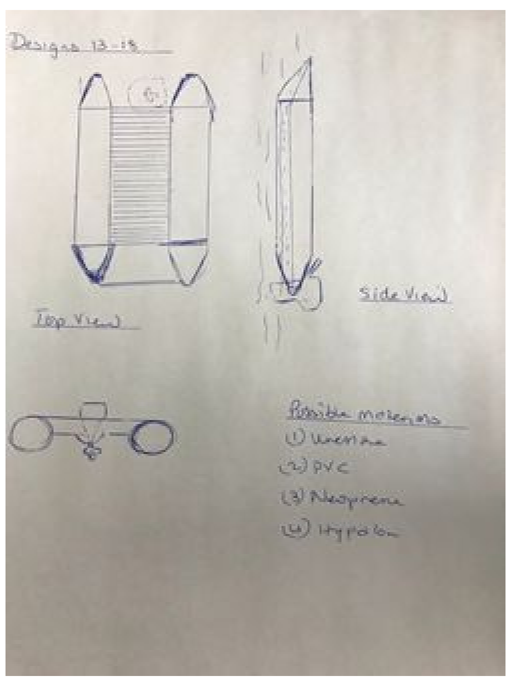


Figure (12) : Drawing of Jean-Pierre Alleyne's Design Concepts 13-20

Concept Evaluation

Concept 13-20 based on the figure above featured a flat deck with a harness like deck. Additionally, the structure of the vessel was mostly made up of two large inflatable pieces. These would provide the buoyancy and stability to the vessel needed. Again the same four materials were proposed and two folding patterns suggested. A square folding pattern and a roll folding pattern.

Concept 13: Like Figure 14 above, this design concept is reminiscent of a speed boat with raft like qualities. It still features a flat deck but of a less sturdy material being some harness type configuration. The sides of the vessel will contribute to the stability and the buoyancy as they will be filled with large amount of the selected gas. This would have been made with urethane and featured a square folding pattern when deflated.However, based on the nature of the flat deck; this was not chosen as a viable option for moving forward.

Concept 14: Similar to design 13 with the same material but differed in the folding pattern where in this design concept; when deflated the vessel will be rolled into a more compact form.

Concept 15: This design differed in the material used; hypalon. This is good material for this design based on its great qualities to be transport and folded easily. It would also aid in the square folding pattern proposed for this design.

Concept 16: Similar to concept 15, this design only differs in the folding pattern which would be of a rolling form.

Concept 17: The material used in this concept was PVC and the folding pattern was square.

Concept 18: The material remained PVC in the concept but the folding pattern was rolled.

Concept 19: Same structure as in Figure 14. But the material used was Neoprene and the folding pattern square.

Concept 20: Similar to Concept 19 but differed in the folding pattern which would be rolled when deflated.

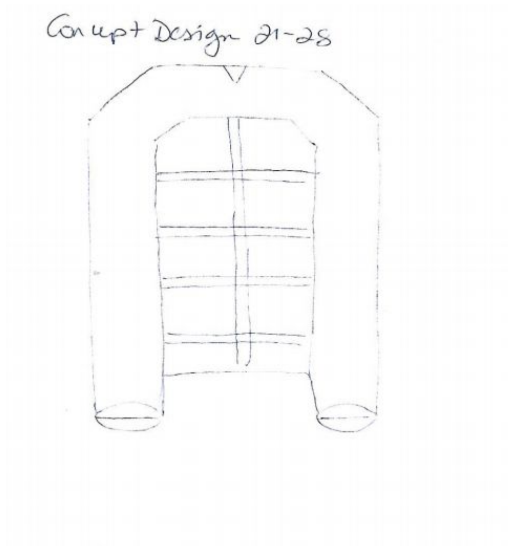


Figure (13) : Jean-Pierre Alleyne's Design Concepts 21-28

Concept Evaluation

Concepts 21-28 after evaluation were the most feasible concept designs and based on Figure 15, was one of the designs used for our final proof of concept in its many variations. In the Pugh chart in Table 3 below, it can be seen that based on the requirements for the inflatable vessel these 8 concepts are the best fit.

Concept 21: As can be seen in the figure above, Concept 21 features a flat sturdy deck and a raft- speed boat like structure. Being fully inflatable to the necessary pressure, the deck of the vessel will be able to hold the necessary loads and remain positively buoyant. The material used would be urethane and it would feature a rolled folding pattern. Additionally, the angle of the hull was optimized to be approximately 30°.

Concept 22: This design concept is similar to Concept 21 but differed in the folding pattern; featuring a square folding pattern when deflated.

Concept 23: Made from hypalon, with 30 degree angled hull and a square folding pattern.

Concept 24: Same as Concept 23 but with a rolled folding pattern.

Concept 25: Made from PVC, with a 30 degree angle hull and a square folding pattern.

Concept 26: Same as Concept 25 but with a rolled folding pattern.

Concept 27: Made from neoprene,with a 30 degree angles hull and a square folding pattern.

Concept 28: Same as Concept 27 but with the rolled folding pattern.

Table (5): Pugh Chart of Jean-Pierre Alleyne's Concepts

		Concepts																													
Engineering Criteria	Reference Concept	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Reliable		-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
Buoyant		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
Ease of Use		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
Safe		+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+		
Flat Deck		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
Reusable		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
Portability		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
Lightweight		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
Foldable		+	+	+	+	+	+	+	+	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
# of Plusses		9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	10	10	10	10	10	10	10	10		
# of Minuses		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0		

5.1.4 Alex Vasili's Concepts and Evaluations

The designs presented below are all primarily focused on the hull shape of the inflatable. It is important to note that the hull designs were focused on specific functions. For example hull designs were determined based on vessel size, hull water piercing capability, stability, speed, and lastly materials. It was later concluded that some of the hull designs presented would prove to be ineffective because the hull needed to be rigid to achieve the specific shape.

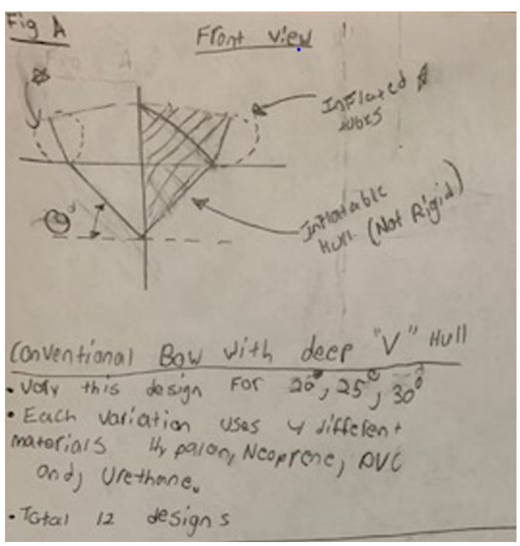


Figure (14): Alex's Design Concepts 1-12: Deep "V" Hull

Concept Evaluation

The design concepts numbered 1-8 are based on figure 16. The design is a conventional hull with a deep "V". The hull design was chosen because it is optimal for any size vessel large or small. The narrow angle of the V shaped hull pierces the water in a way that reduces resistance acting on the vessel but still offers a happy medium between stability and speed. This specific design with a hull angle of 30 degrees was chosen for proof of concept design number 3 discussed in the proof of concept section of this report.

Concept 1: Deep "V" at 20° made out of Hypalon

Concept 2: Deep "V" at 20° made out of Neoprene

Concept 3: Deep "V" at 20° made out of PVC.

Concept 4: Deep "V" at 20° made out of Urethane.

Concept 5: Deep "V" at 25° made out of Hypalon.

Concept 6: Deep "V" at 25° made out of Neoprene.

Concept 7: Deep "V" at 25° made out of PVC.

Concept 8: Deep "V" at 25° made out of Urethane.

Concept 9: Deep "V" at 30° made out of Hypalon.

Concept 10: Deep "V" at 30° made out of Neoprene.

Concept 11: Deep "V" at 30° made out of PVC.

Concept 12: Deep "V" at 30° made out of Urethane.

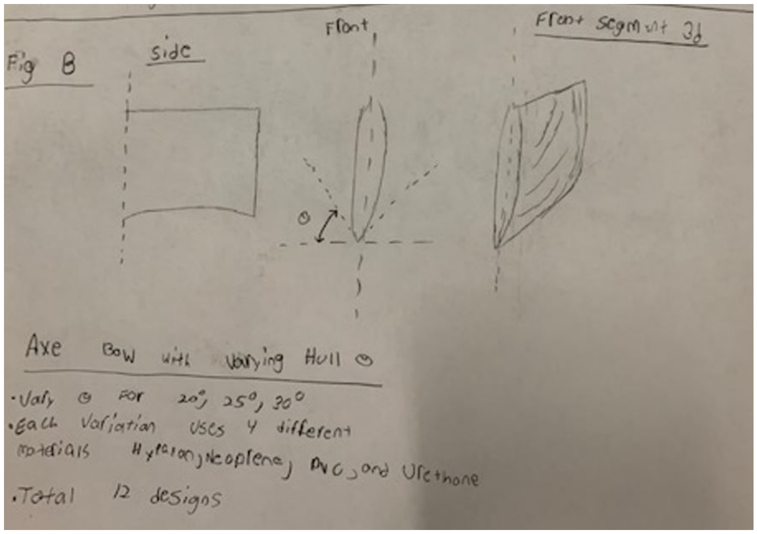


Figure (15): Alex's Design Concepts 13-24: AXE-Bow

Concept Evaluation

The design concepts numbered 13-24 are based on figure 17. The design is an AXE-Bow with varied hull angles. The hull design was chosen because it is ideal for passing through the water and cutting through waves. This means that compared to conventional bow and hull it allows for less pitching [2], which provides for a safer payload delivery. It was concluded that while this bow and hull design was beneficial for the application of our design specifications and tasks, an inflatable version of this would be difficult to mimic and reproduce.

List of Concepts Generated

Concept 13: AXE-Bow with Hull 20° made of Hypalon.

Concept 14: AXE-Bow with Hull 25° made of Hypalon.

Concept 15: AXE-Bow with Hull 30° made of Hypalon.

Concept 16: AXE-Bow with Hull 20° made of Neoprene.

Concept 17: AXE-Bow with Hull 25° made of Neoprene.

Concept 18: AXE-Bow with Hull 30° made of Neoprene.

Concept 19: AXE-Bow with Hull 20° made of PVC.

Concept 20: AXE-Bow with Hull 25° made of PVC.

Concept 21: AXE-Bow with Hull 30° made of PVC.

Concept 22: AXE-Bow with Hull 20° made of Urethane.

Concept 23: AXE-Bow with Hull 25° made of Urethane.

Concept 24: AXE-Bow with Hull 30° made of Urethane.

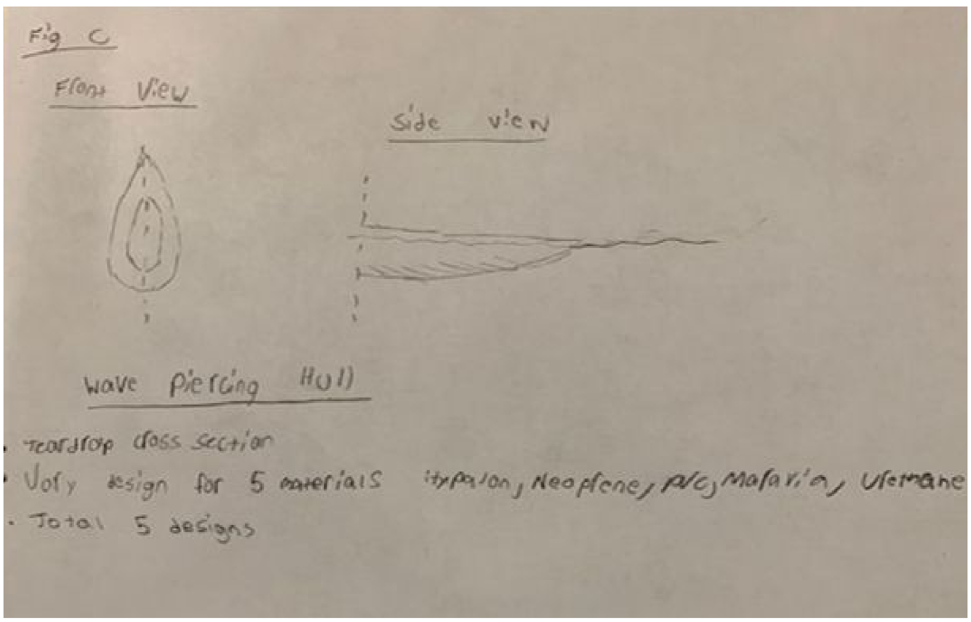


Figure (16): Alex's Design Concepts 25-30: Wave Piercing Hull

Concept Evaluation

The design concepts numbered 25-30 are based on figure 18. The design is a wave piercing or reverse hull. The hull design was chosen because it is capable of greatly reducing pitch, but it is a wetter ride [3]. This means that compared to the other designs the payload must be fashioned in a way that is capable of withstanding a saturated environment. Another benefit of the wave piercing hull is that it is capable of penetrating the water at deeper ocean levels providing a quicker deceleration if needed. Although this hull design is advantageous, It was concluded that a design that provided a dryer ride was needed. With a drier overall delivery, more emphasis could be made on other aspects of the vessel such as location of the black box electronics or "brains" of the vessel without too much concern of water damage.

List of Concepts Generated

Concept 25: Wave piercing hull made of Hypalon.

Concept 26: Wave piercing hull made of Neoprene.

Concept 27: Wave piercing hull made of PVC.

Concept 29: Wave piercing hull made of Maravia.

Concept 30: Wave piercing hull made of Urethane.

Through extensive research, engineering analysis, and financial analysis, the Deep "V" Hull design at 30 degrees composed of hypalon, and PVC was chosen to be further analyzed as a proof of concept. The Pugh chart below highlights the pros and cons of the concepts discussed above based on the original engineering criteria.

Table (6) : Alex's Design Pugh Chart

		Concepts																													
Engineering Criteria	Reference Concept	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Reliable	12	+	+	+	-	-	-	+	-	-	S	S	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Ease Of Use	12	S	S	S	S	S	S	S	S	S	S	S	R	+	+	S	+	+	S	+	+	+	+	+	+	S	S	S	S	S	S
Buoyancy	12	-	-	S	-	-	S	-	-	S	-	-	R	-	-	-	-	-	-	S	S	S	-	-	-	S	S	S	S	S	S
Safe	12	S	S	S	S	S	S	S	-	-	S	S	R	-	-	-	-	-	-	S	S	S	S	S	S	-	-	-	-	-	-
Reusable	12	S	S	S	S	S	S	S	S	S	S	S	R	S	S	S	S	S	S	S	S	S	S	s	S	S	S	S	S	S	S
Portability	12	S	S	S	S	S	S	S	S	S	S	S	R	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Flat Deck	12	S	S	S	S	S	S	S	S	S	S	S	R	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Lightweight	12	S	S	S	S	S	S	S	S	S	S	S	R	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Foldable	12	S	S	S	-	-	-	S	S	S	S	S	R	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
# of Plusses	15																														
# of Minuses	47																														

6 Design for X

6.1 Design for Manufacturability

The team's first designs did not include an external hull that would be submerged underwater. After talking to the sponsors and conducting more research, it was realized the vessel would need an external hull be to maneuverable in a sea state of six. The first hull design was very complex. The inflatable aspect made it difficult to design the hull like other commercial hulls. A design with many stitched and flat surfaces was constructed. Upon looking for quotes from companies to make a scale model, the team discovered that the hull design was not practical to manufacture. After going back to the drawing board, a new hull was designed which was only two sections with one seam stitch. After emailing some of the companies back, it was confirmed this new design could be reproduced in a factory.

6.2 Design for Cost

The inflatable vessel design study project was presented with two end goals in mind - military application and commercial sale. The final vessel would find dual applications because of its autonomous payload delivery function. Because the design needed to be be engineered to survive naval environments, but also be reasonable priced, the team worked with the price range set by PowerDocks. The vessel's inflatable material has been optimized. Even though it is about 2.5 times more buoyant than it needs to be, this was deemed necessary by the team. Higher factors of buoyancy are regularly found across common industry craft for both function and perceived safety. The vessel's body is exactly to the sponsor specifications, and there are not any inclusions of non-functioning, aesthetic components. The hull (which was required by the sponsors) was modeled in the most efficient profile according to the team's CFD analysis. Material cost could have been saved here, but the changes would drastically alter the vessel's performance while operating at any notable velocity.

The sponsors controlled many aspects of this design juxtaposed to cost. There was little wiggle room on the price related to the amount of inflatable material that would be needed. This is because the team had to design a streamline craft that was buoyant and fit inside of the defined geometry. Because of the nature of the design study, both PVC and hypalon were analysed. From a price point of view PVC is substantially cheaper. PowerDocks also insisted that they use their hefty (and pricey) black box controller, industry standard "malleable" solar panels, and easily detachable propulsion. All of these factors made sense on their end but it left little room to argue cost there.

Aside from the vessel design, the team had one other true outlet to design for cost. This presented itself in the form of the rigid floor inserts. These inserts provides the rigid shape and support the team was looking for. The inserts were chosen to be made out of ABS plastic for its rigid strength, its ease of manufacturability, its performance when exposed to water, and most important, its low cost. The floor inserts have a non-complex design for plastics and feature many thru cut holes to save weight. Saving weight also translates into saving material, and from that, saving costs.

6.3 Design for Ease of Use

In order to ease the usability of the inflatable vessel, simple setup designs were chosen. Initially the inflatable is unfolded and placed on the ground. The ABS floor inserts are inserted on the flat deck sections of the deflated vessel. The inserts lock into one another easily by a male-female interlocking hex tab and groove. The vessel is inflated around the inserts by a hand pump system. Primarily, the mid sections supports are inflated, followed by the perimeter, and finally the front section of the hull. This inflation method was chosen as it provided more support and shape during the set-up process. Once the vessel is completely inflated, the user places the black box autonomous navigation controls in the specified area. The electric motors chosen are very simple to attach and use. The motors have a pre adhered female lock fin on the underside of the vessel. The male end on the motors slides into the female end on the vessel and locks in place. The motors (ElectraFin) are provided by a company called Current Drives. The motors connecting wires are then attached to the black box. These specific motors were chosen because they are compact and feature an adhesive fin already used for other inflatables that is perfect for this application. The solar panels chosen were provided by the sponsors. They fold accordion style on one another and are included with the motors in the briefcase style package. The solar panels provided by the sponsors are then attached to the perimeter of the vessel. Specifically, on the inflatable cross sections and feature straps that buckle directly on the inflatable.

6.4 Design for Durability

For the teams' application, durability of the vessel was assessed in various methods. One of the methods was utilizing the environmental chamber. The humidity chamber was used on the Hypalon and PVC to mimic the temperature and moisture conditions at sea. Then the specimens were then loaded in tension to view the durability of them for at sea conditions. When compared to specimens that were left out of the chamber, it was found that the ones in the chamber had decreased elongation survivability. PVC withstood the most elongation after degradation and was chosen as the material used for the teams application. The materials were also drop tested to mimic rock impacts. All of the materials withstood the chuck (rock) test but failed to withstand the needle test (projectile). This test proved to us that rocks or any debris that was more pointed were dangerous for the vessel. Preventative maintenance steps were acquired to aid with this issue. After every use, the vessels underside and deck is to be rinsed off with a hose at a lower pressure to clean off any debris as well as salt that could still be attached.

7 Detailed Product Design

7.1 Product Design Outline

The design for this vessel has seen many changes over its lifetime. After some initial reworks and sponsor meetings, the 4 concepts had become 1, and featured support for the black box and a hypothetical motor. The early segments of the Product Design section will cover the basic shape and function of the vessel and related components and their evolution, where the later half of the section (B.O.M.) will discuss each part in depth. The component's function will also be discussed as well as the rationale for the specific design choices.

7.2 Early Prototype Drawings

After some revisions to the original prototypes, the following design was produced.

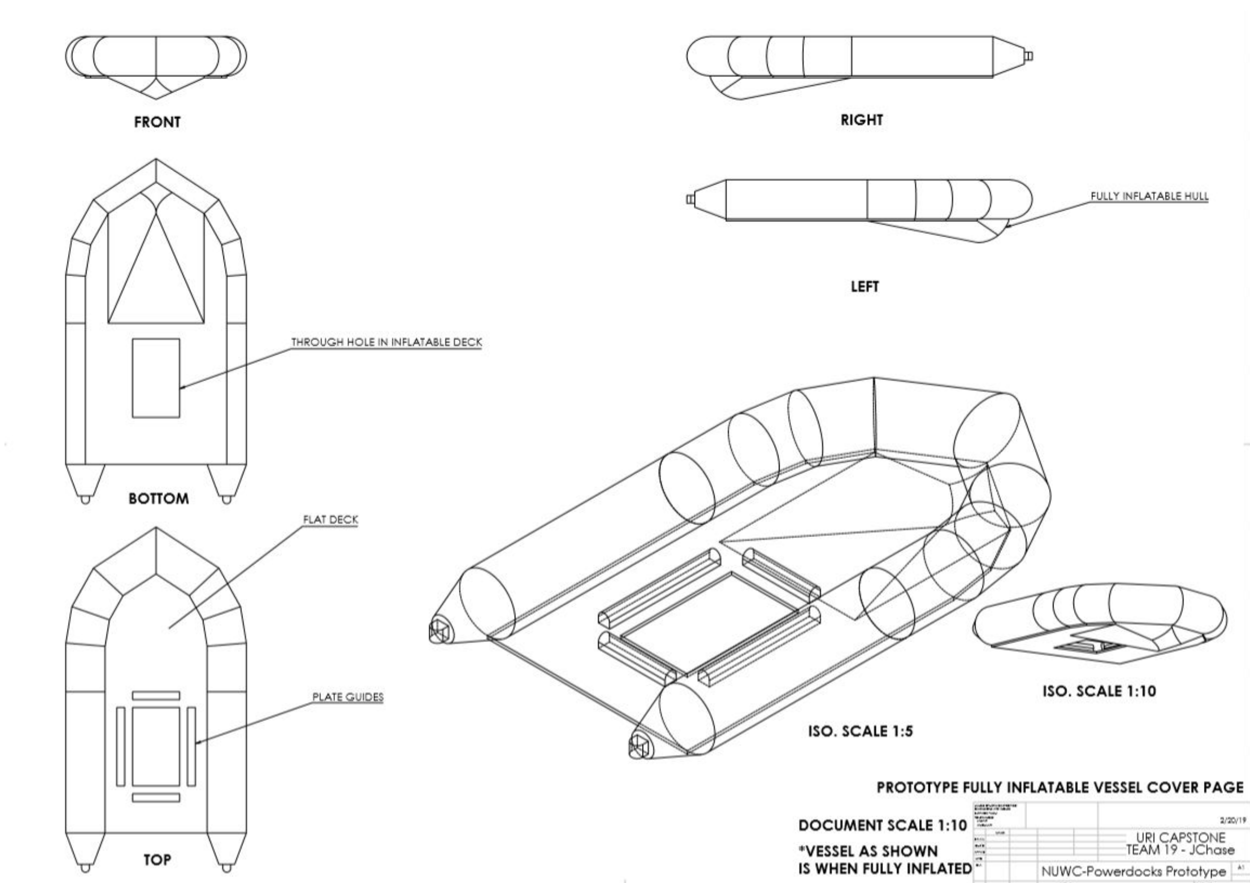


Figure (17): Image 1 of Early Prototype Drawing

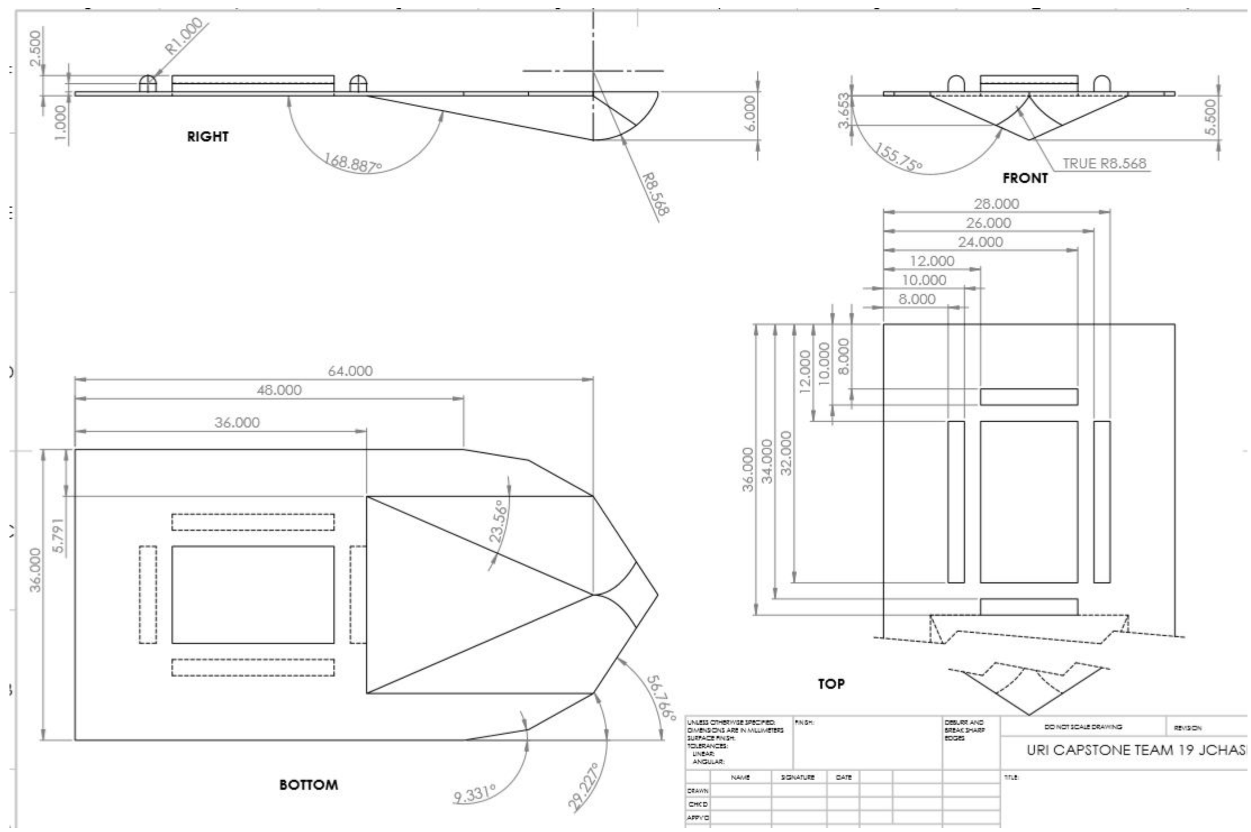


Figure (18): Image 2 of Early Prototype Drawing

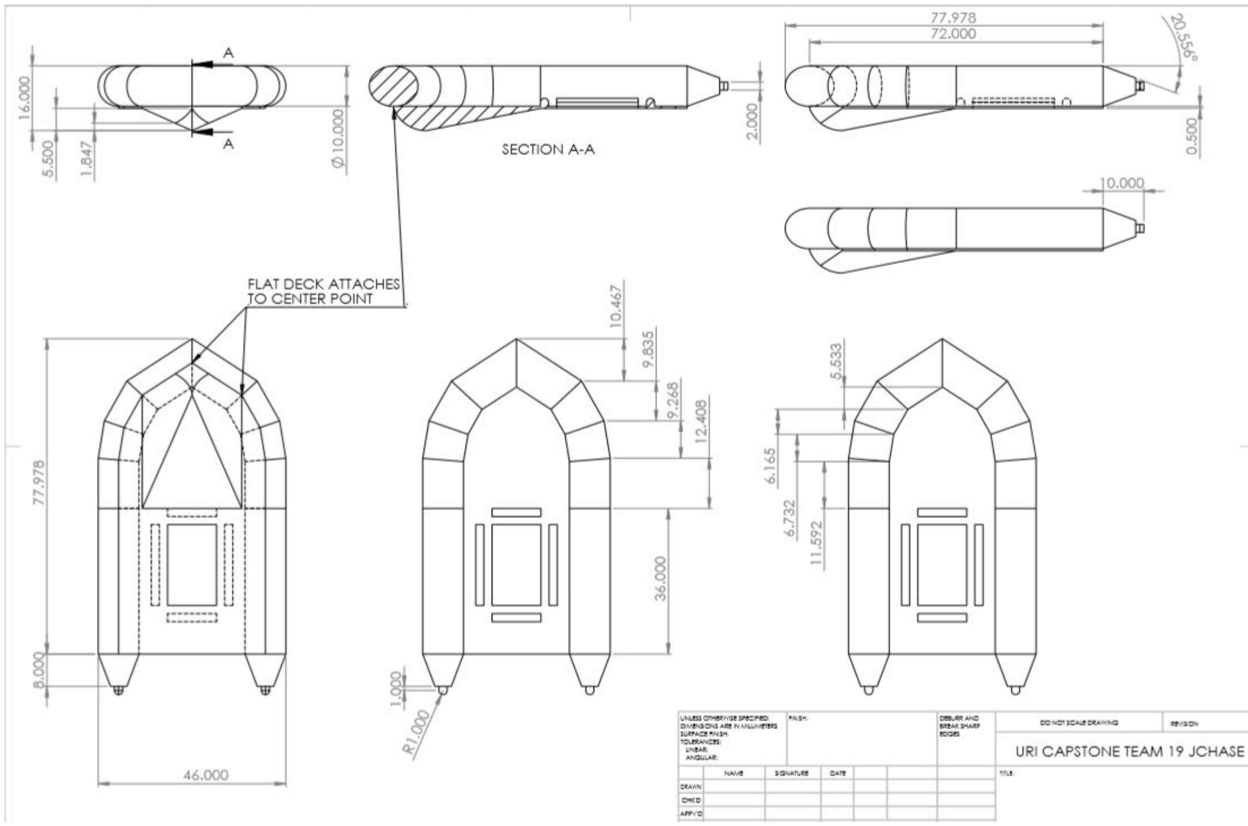


Figure (19): Image 3 of Early Prototype Drawing

This design met all of the original (non specific) design specifications. The size and properties were all adequate, but the design lacked motor and black box integration. This was a strong point of criticism that the team needed to deal with. The black box control unit was poorly fitted into the design. As the team found, the vessel also lacked horizontal stability. Additionally the newly added hull was was much too complex to be manufactured in any reasonable way.

7.2.1 Quarter Scale Model

A 3D representation was created to help illustrate the design issues to the team. Initially the model was intended to be used as a scaled size representation of all the components together. This was done to observe drastic variances with sizes, and to check manufacturing discrepancies in the floor. An unexpected outcome was that the vessel was not stable on the horizontal axis, and more design work would be needed to remedy this issue.

Figure (20): Images of Quarter Scale Model

The model actually served an additional purpose - displaying that the CAD hull the team had planned to use was far too complex for inflation purposes. Later testing would also reveal this hull design produced much more drag than necessary.

7.3 Final Prototype Drawings

The final prototype was the culmination of all the fixed issues while maintaining the original body shape, as the team found ample buoyancy in this design. Design considerations were also made into how the black box would rest and be secured in the vessel, which was a large issue the team needed to overcome. The dimensions of the vessel remained the same. The only exception to this was the new hull. The inflatable divides were added, but this was built around the existing design. An external, installable ABS floor was designed to add vessel stability and to support the black box controller prom PowerDocks.

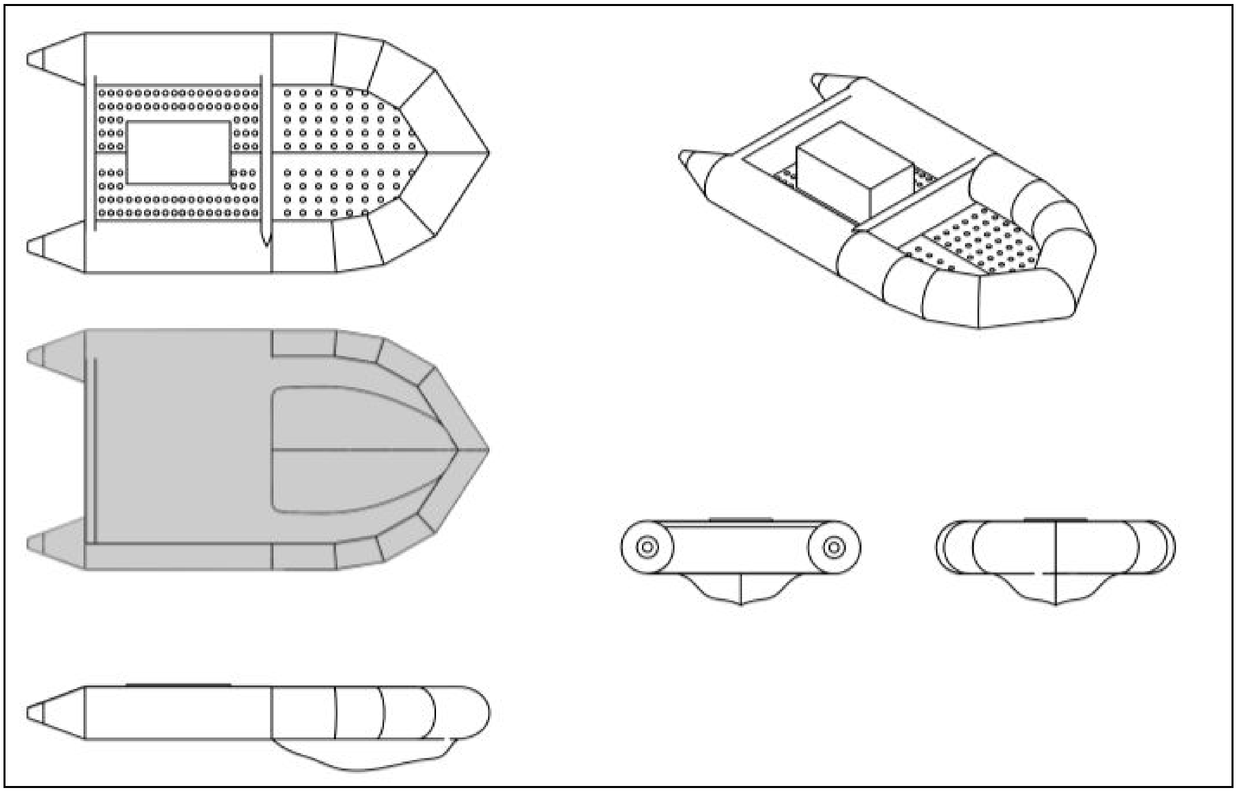


Figure (21):Image 1 of Final Prototype Drawing

The brief drawing above displays the new vessel profile, the ABS floor insert profile, the black box integration, and the new hull shape. As previously stated, the dimensions of the actual vessel and floor have remained constant. The following figure demonstrates both floor inserts in the assembled phase. A section view has also been included to help further demonstrate the interlocking nature of the floor inserts, though a more cohesive explanation of these parts can be found in the Bill of Materials section.

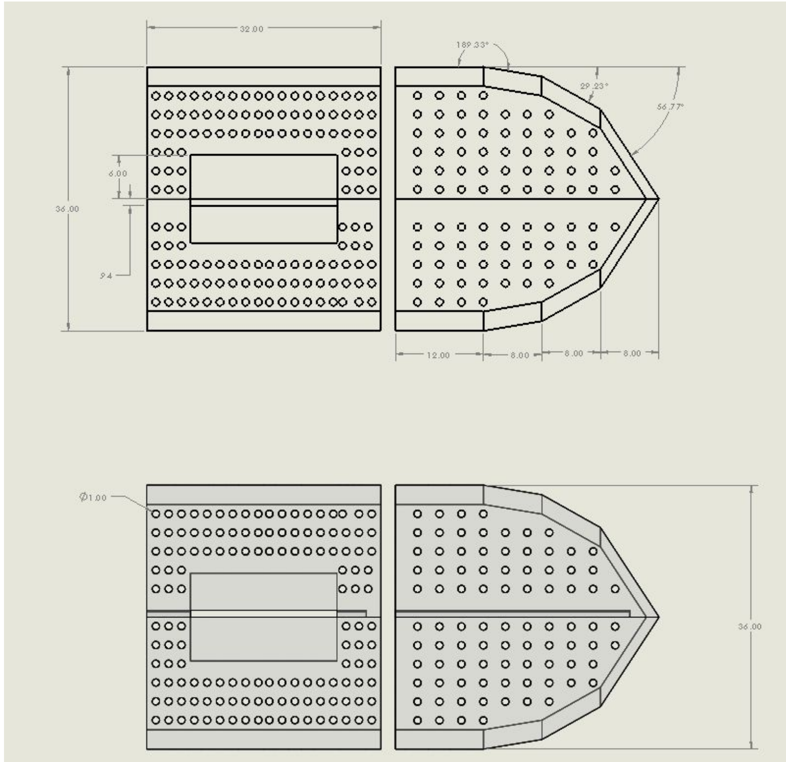


Figure (22):Image 2 of Final Prototype Drawing

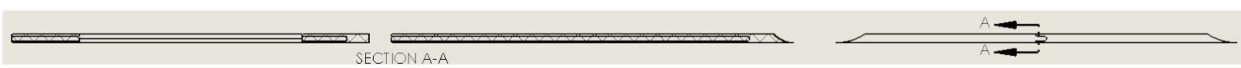


Figure (23): Image 3 of Final Prototype Drawing

Team 19 aimed to further the design guidelines provided by PowerDocks. Using both sponsor specifications, recommendations, and advisor feedback, the final prototype was created. The evolution of the design can be observed in the following two figures that show PowerDocks' vision with NUWC's guidelines.

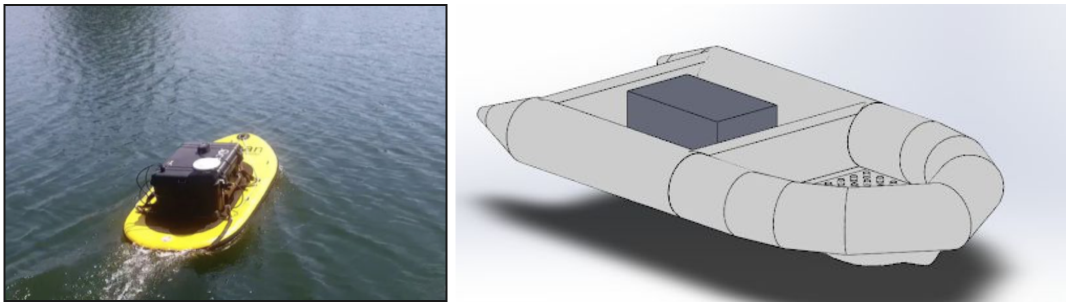


Figure (24): Comparison of Final Prototype Drawing and Powerdocks 'Calypso'

7.3.1 Description of Model Changes

The hull was updating to a simple design that could be easily manufactured, inflated, and created less drag in test environments. Inflated dividers were put in place to ensure vessel rigidity and to evenly divide load distribution. ABS floor inserts were added to the design to secure the black box and provide stability for the payload, as well as protect the interior of the vessel from any sharp edges. The flat deck was also optimized as to not protrude below the outer tubing. Detailed descriptions of each part, as well as their role in the vessel, can be found in the Bill of Materials section.

7.3.2 Folding Pattern

For the proposed rigid hull design the folding pattern will be visualized after careful deflation as follows:

- Three one foot folding wil be made from the bottom toward the front
- The inflated top of the boat will be folded inward toward the hull and down into in as the hull will also serve as the base for the backpack.
- A buckle will be passed around the entire product after fully folded and fastened for transport

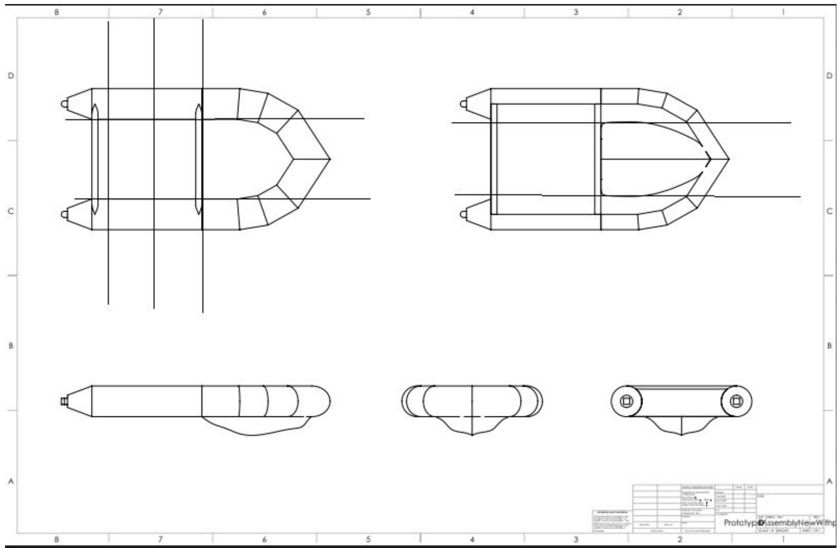


Figure (25): One of the proposed Folding patterns post deflation

For the desired fully inflatable design after careful deflation the folding pattern is visualized to be as follows:

- Lose one foot folds will be made from the top until entire boat is folded
- Subsequently, placed in a medium to slightly larger drawstring backpack.
- The inserts will be carried separately as they are rigid.

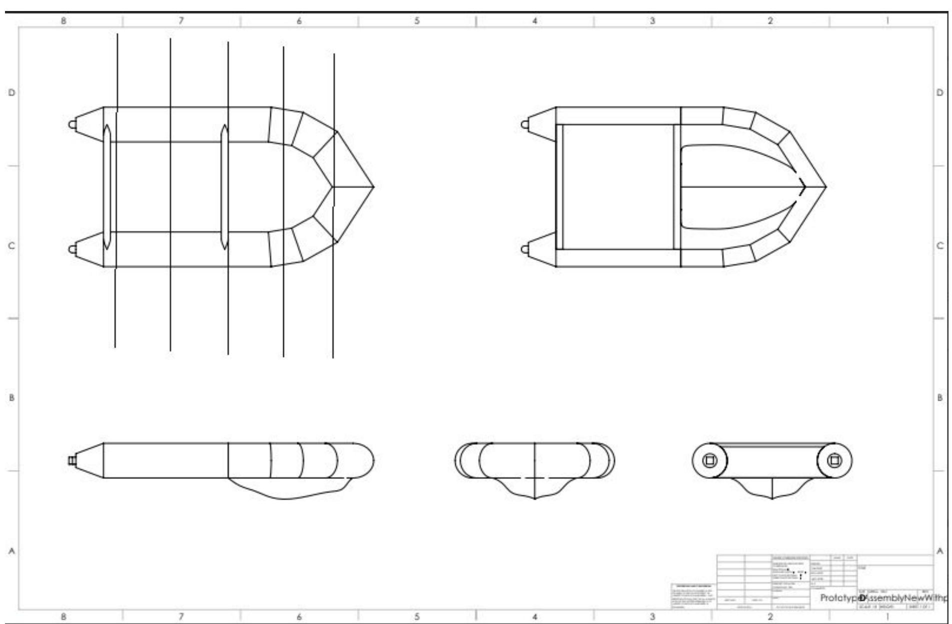


Figure (26): Folding pattern for proposed completely inflatable vessel.

7.4 Bill of Materials

The Bill of Materials section is broken down into two main categories: the first is a list of all the components that make up the vessel, the associated manufacturing details, and all related component descriptions. The second half is similar, but shorter. There is a list of all components that are to be purchases and short statement of their role and inclusion into the project.

7.4.1 Purchased Components

The main objective for team 19 was to design an inflatable vessel that would be manufactured by an expert in the inflatable raft industry and use PowerDocks black box technology to control it. There are a few items which were designed around that would be purchased from a third party. They are:

Table (7): Table of Purchased Components

Item number	Location	Part Name	Description	Quantity
10	Along the outer tube	Solar Panels	For power generation	4
11	Under the vessel in the rear	ElectraFin	Electric motor and propeller	2

7.4.1.1 Purchased Components Rundown

This section references the table from the purchased components section.
Item number 10: Renogy 160 Watt 12 Volt Extremely Flexible Monocrystalline Solar Panel

Figure (27): Image of Proposed Solar Panel Power Supply

The specific amount of power needed for all the electronics is unknown as that is information PowerDocks has not disclosed, however, waterproof solar panels are needed and these flexible ones allow them to be attached to the outer tubular section of the vessel as to not impede on payload space.

Item Number 11: ElectraFin

Figure (28): Image of Electra Fin Motor

The ElectraFin is an electronic motor with propeller that has 10 hp. It comes with a controller, battery, 2 fins and a inflatable anchoring system. This is ideal as it is lightweight, electric and is made to be fitted to inflatable paddle boards. The anchoring system allows the motor to be secured to the board without making any holes which is necessary for an inflatable. Two will be required to allow the vessel to turn as well as reach the power output needed to move the vessel and payload at 6 knots.

7.4.2 Manufactured Components

Team 19 hopes for a manufacturer to create each of the parts below and assemble them into a full deflated vessel. The Solidworks drawings and bill of materials for the components was too messy so a condensed version of that table was created. Each of the parts below has a CAD drawing associated with it, and the drawing number is to be used as a reference to the drawing with dimensions as well as the description that follows in the next section. The sizes and dimensions of the following components were set to meet the sponsor size requirements and constraints, and ultimately, to provide adequate vessel buoyancy.

Table (8): Table of Manufactured Components

Item Number	Drawing Number	Part Name	Material	Quantity
1	IVDS001	Rear Tube	Hypalon, PVC	2
2	IVDS002	Front Tube	Hypalon, PVC	1
3	IVDS003	Flat Deck	Hypalon, PVC	1
4	IVDS004	Inflated Dividers	Hypalon, PVC	2
5	IVDS005	Hull	Hypalon, PVC, Polyurethane	1
6	IVDS006	Front Floor Insert M	ABS	1
7	IVDS007	Front Floor Insert F	ABS	1
8	IVDS008	Rear Floor Insert M	ABS	1
9	IVDS009	Rear Floor Insert F	ABS	1

7.4.2.1 Manufactured Components Rundown

This section references the table from the Manufactured Components section. The purpose of this capstone design project is to fully design an inflated vessel, and as follows, each of the derivative components as well. The components have been designed to be constructed uniformly with either PVC or hypalon, both offering similar results in testing. Each component that is to be manufactured will be described in detail and is listed in numerical order.

IVDS001

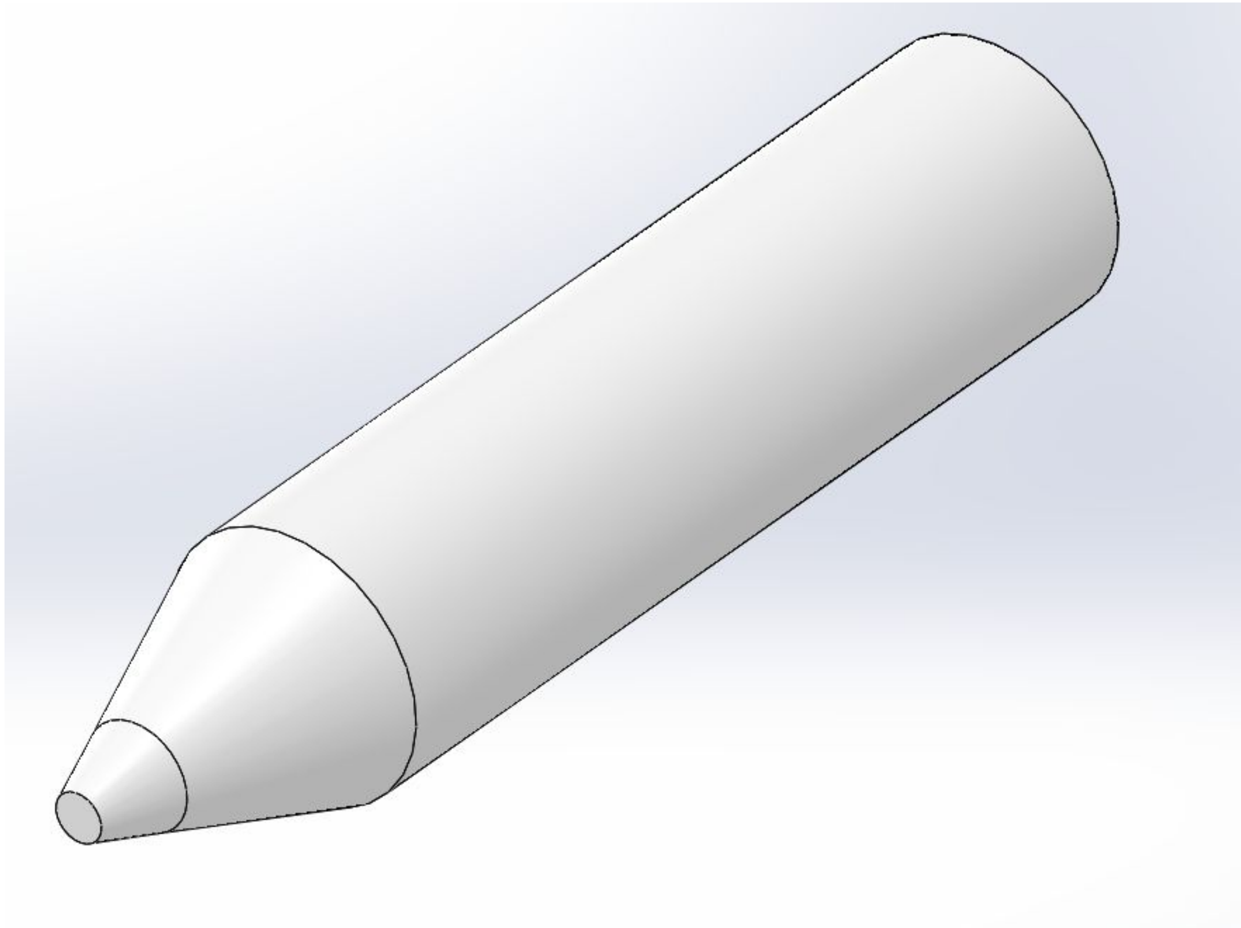


Figure (29): Image of Rear Tube of Vessel

In order to create Team 19's inflatable vessel, all of the components need to made out of inflatable material. This part is no exception. The rear tube gives the vessel about half of its overall buoyancy from its 40” long, 10” diameter tube profile. Two of these parts are to be created which form as the main sides for the vessel. In order to maintain the desired shape (diameter) upon inflation, the rears of these tubes feature stitched nose cone profile. These inflated tube structures also offer the perfect amount of needed surface area to accommodate Powerdocks' foldable solar panels they plan to use for power.

IVDS002

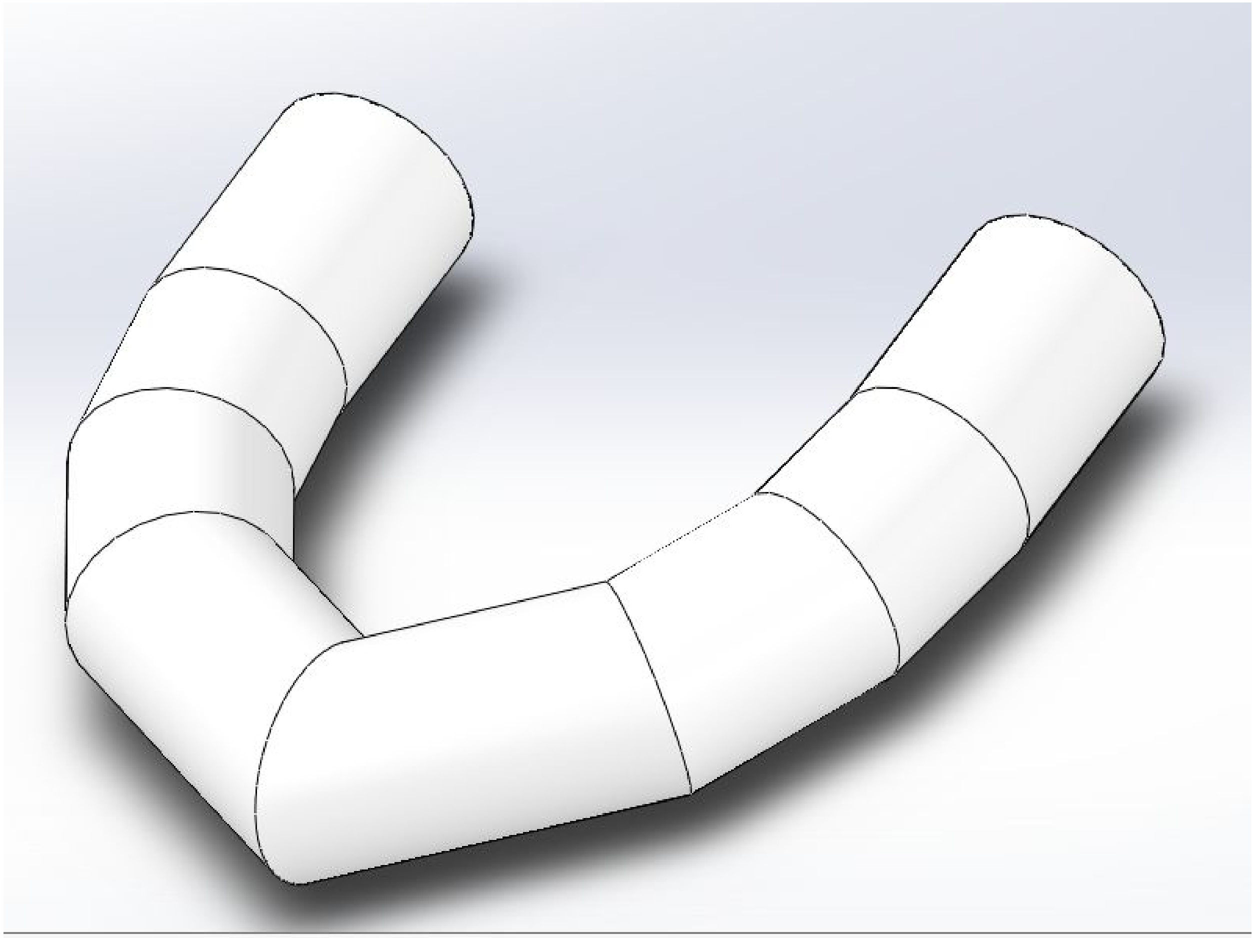


Figure (30): Image of the Front Tube of Vessel

The other large contributor for buoyancy comes from the front tube section. This section was designed to meet the width specification and to complete the length specification that was addressed in IVDS001. The component spans 46” in width by 36” long, featuring the continued 10” diameter. The first portion of the frontal tube follows a 12” horizontal length, acting as an extension of IVDS001. The remaining 24” inches are split into three equal 8” (lengthwise) sections and feature differing angles until convergence the centerline of the vessel. This style of segmented portions of the components was designed with the intentions that the manufacturer will install blow-off / sealer valve that will prevent total deflation upon potential puncture.

IVDS003

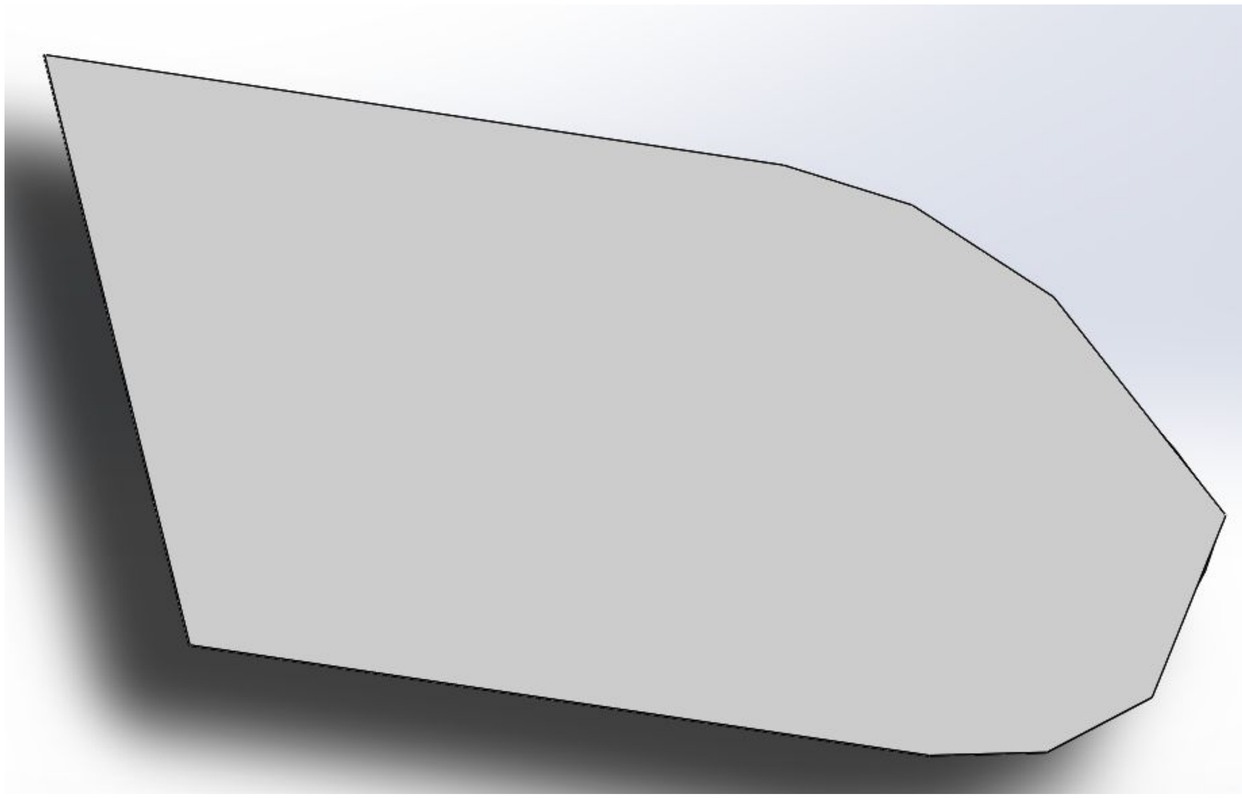


Figure (31): Image of Final Deck of Vessel

The flat deck component is crucial for the sponsors as it allows the vessel to fulfil its purpose - to deliver a payload. The flat deck was designed around having two seperate sections and utilize the floor inserts for stability and rigidity. The rear section is to support Powerdocks' electronics and propulsion, and the front section is to support the payload. The flat deck is a solid ½" thick piece of the chosen vessel material that spans 6' in length. This 6' is broken up into a 4' length section that is horizontal and features a uniform 3' in width. The other 2' of length follow the exact centerline profile of the frontal section. This is to establish a uniform "bottom floor" that meshes exactly to the vessel and does not create any protrusions that may cause drag.

IVDS004

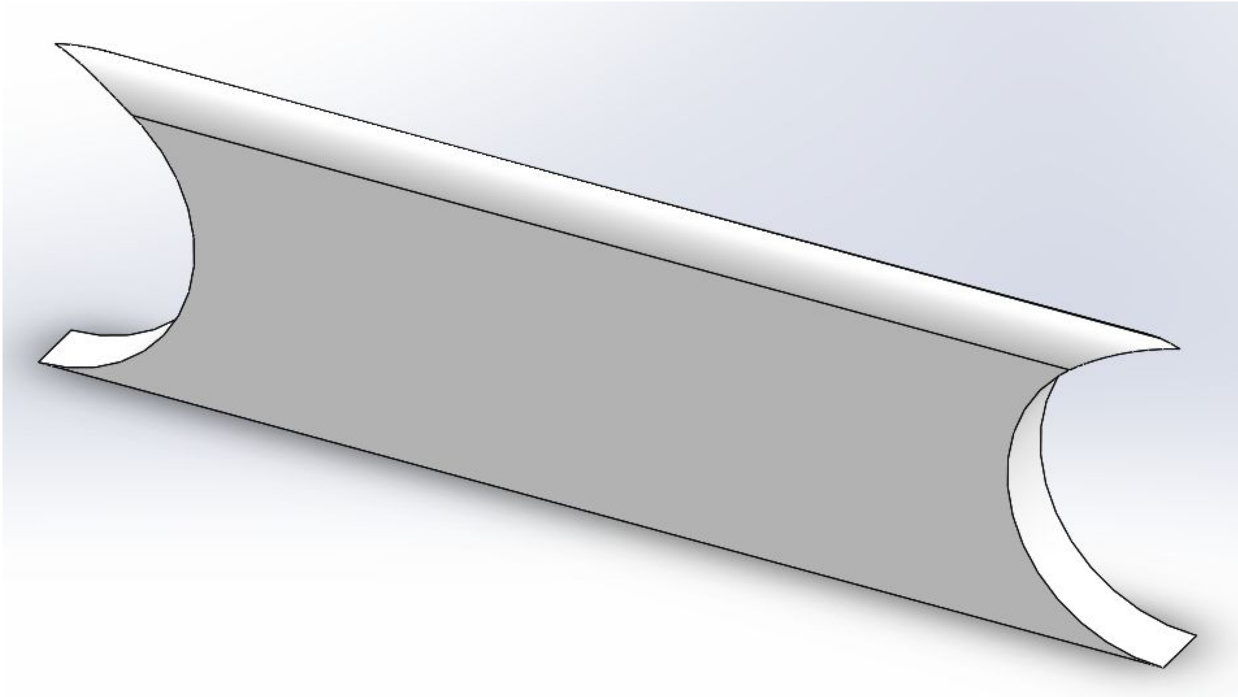


Figure (32): Image of Inflated Dividers of Vessel

As mentioned in IVDS003 the vessel's payload accommodation is broken into two sections. This is done through the inclusion of two inflatable dividers. These dividers ared 3' long and intersect the width of the vessel between the rear and 3' mark. These dividers inflate to a 1"thickness and feature a 5" radius cut into the ends to accommodate IVDS001's inflation, which is separate, though the material is still attached to the body of IVD001 on either side. These divides were included to add some additional support to the vessel to prevent a "toe-in" collapse in the events of an extreme or harsh environment.

IVDS005

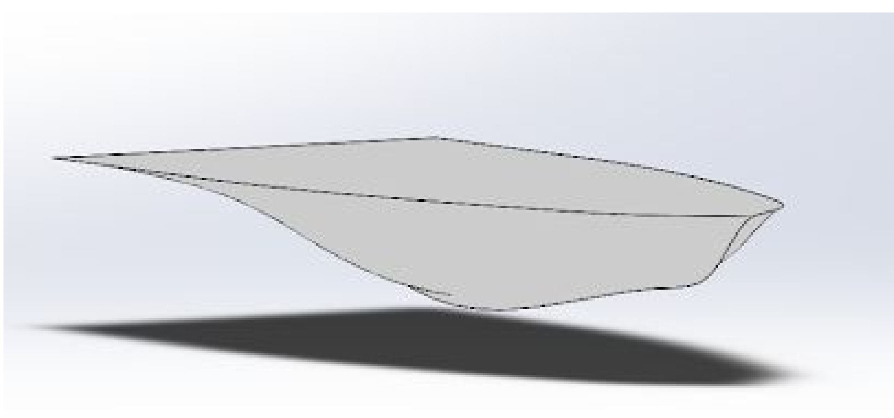


Figure (33): Image of Hull of Vessel

The hull of the vessel offers stability in moving environments. The design has been highly simplified to support inflation, but also could be constructed out of solid polyethylene to offer additional support if the sponsors so desire. The rigid design still fits in the weight restraints, and was an additional option for the sponsor, pending later changes. The hull in an inflated state follows the profile of IVDS002 and mates to IVDS003 edge line in the front. This is, again, to prevent as little grad as possible. This optimal design of the hull evolved from older designs after the research of drag and other nautical factors using CFD analysis. The hull was included later into the design process, as the sponsors decided that they wanted more vessel stability. The hull section also offers some additional buoyancy directly under the payload, which is beneficial in the instance that the payload is front heavy.

IVDS006

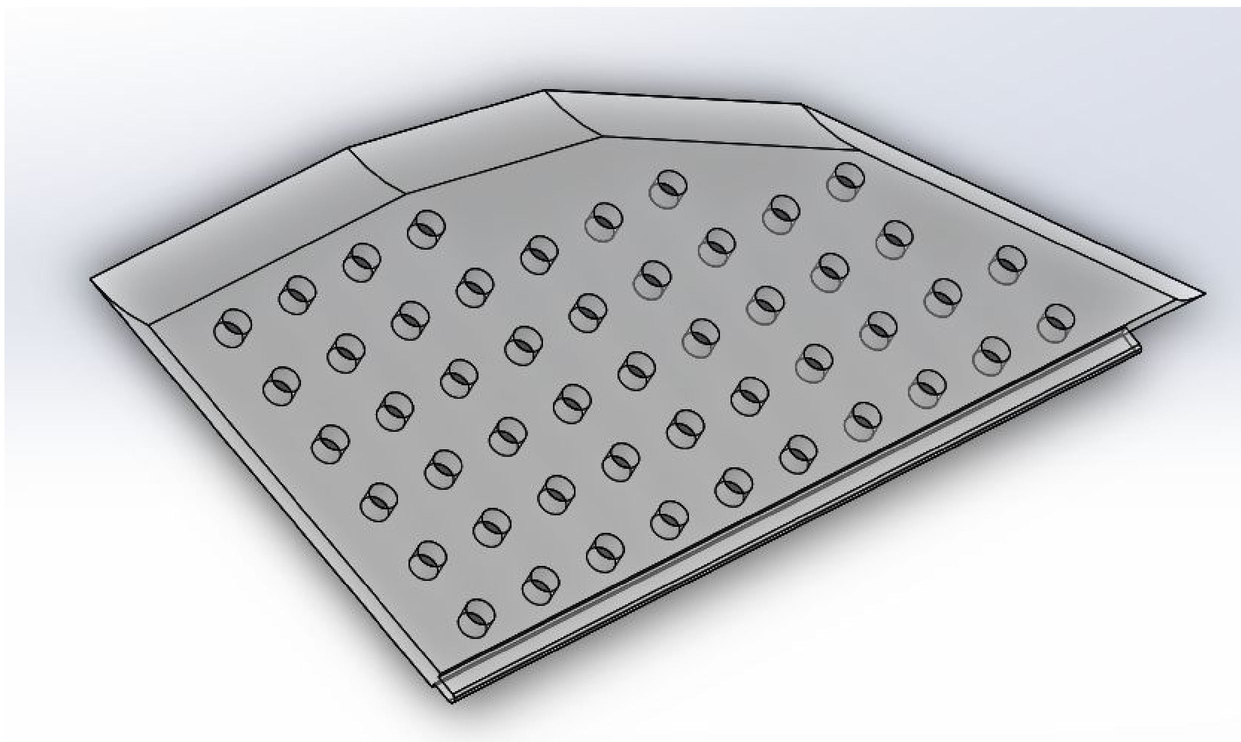


Figure (34): Image of Front Left ABS Floor Inserts

The next and final pieces of the design that need to be manufactured are all floor inserts for the vessel. The floor inserts are planned to be made from ABS. This frontal section of the floor is 3' by 3' and 0.75" thick. It offers a "hex" style tab for interlocking with a related female groove. The outer edge of the floor features a 10" D cut that follows the geometry of IVDS002. The floor is to be inserted prior to inflation and is carried separately. As the name suggests, this floor segment goes in the front section of the vessel. The front of the hex tab ends 2" before the front of the floor due to the 10” D cut. The floor also features an array of circular cut outs. This feature is primarily included to save weight, as a solid ABS floor is not necessary to offer almost identical rigidity and as it translates, vessel stability. As per the sponsor’s request, ways to optimize this piece include more holes using a different hole pattern, larger holes, and a thinner floor insert (though this may compromise the effectiveness of the interlocking hex feature).

IVDS007

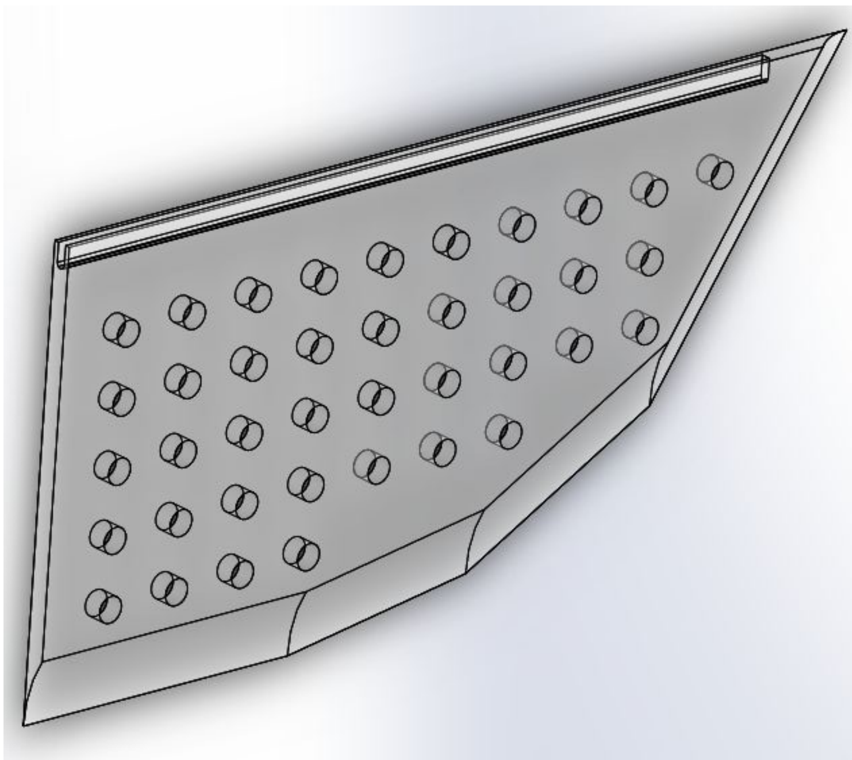


Figure (35): Image of Front Right ABS Floor Inserts

This frontal section of the floor is 3’ by 3’ and 0.75” thick. It offers a “hex” style groove for interlocking with a related male tab. The outer edge of the floor features a 10” D cut that follows the geometry of IVDS002. The floor is to be inserted prior to inflation and is carried separately. As the name suggests, this floor segment goes in the front section of the vessel. The front of the hex groove ends 2” before the front of the floor due (to match IVDS006) to the 10” D cut. The floor also features an array of circular cut outs. This feature is primarily included to save weight, as a solid ABS floor is not necessary to offer almost identical rigidity and as it translates, vessel stability. The front floor pieces combined offer a load support surface of 776.25 square inches, which is slightly larger than the design specification asks for. As per the sponsor’s request, ways to optimize this piece include more holes using a different hole pattern, larger holes, and a thinner floor insert (though this may compromise the effectiveness of the interlocking hex feature).

IVDS008

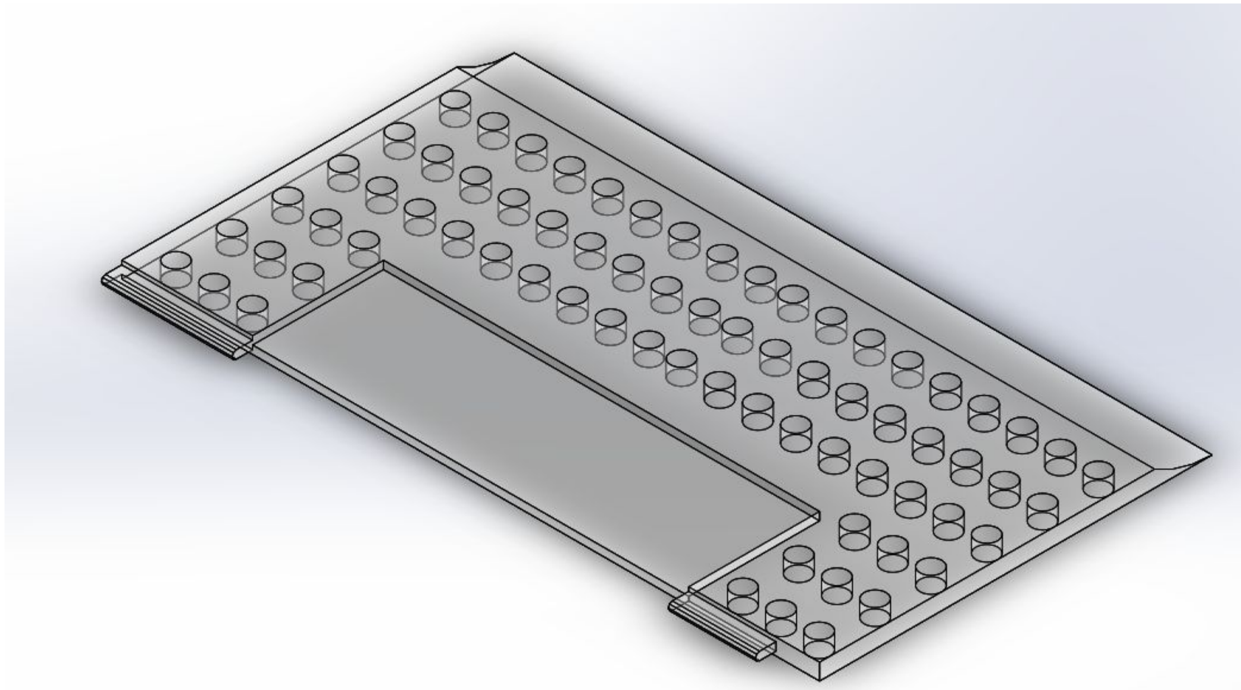


Figure (36): Image of Rear Left ABS Floor Inserts

This and the final component of the section are the corresponding male-female floor inserts for the rear. This component is the rear male floor insert. This insert fits into half of the 3' wide by 34" long available floor space in the rear. There is a 0.375" deep notch in the center of the inner wall to accommodate PowerDocks' black box control unit. The male hex tab (similar to IVDS006) is present again, but is split into two sections. This split runs the length of the length of the black box, and is necessary for assembly. The hex tab, again similar to IVDS006, stops short to prevent mistakes in assembly. The floor also features an array of circular cut outs. This feature is primarily included to save weight, as a solid ABS floor is not necessary to offer almost identical rigidity and as it translates, vessel stability. As per the sponsor's request, ways to optimize this piece include more holes using a different hole pattern, larger holes, and a thinner floor insert (though this may compromise the effectiveness of the interlocking hex feature).

IVDS009

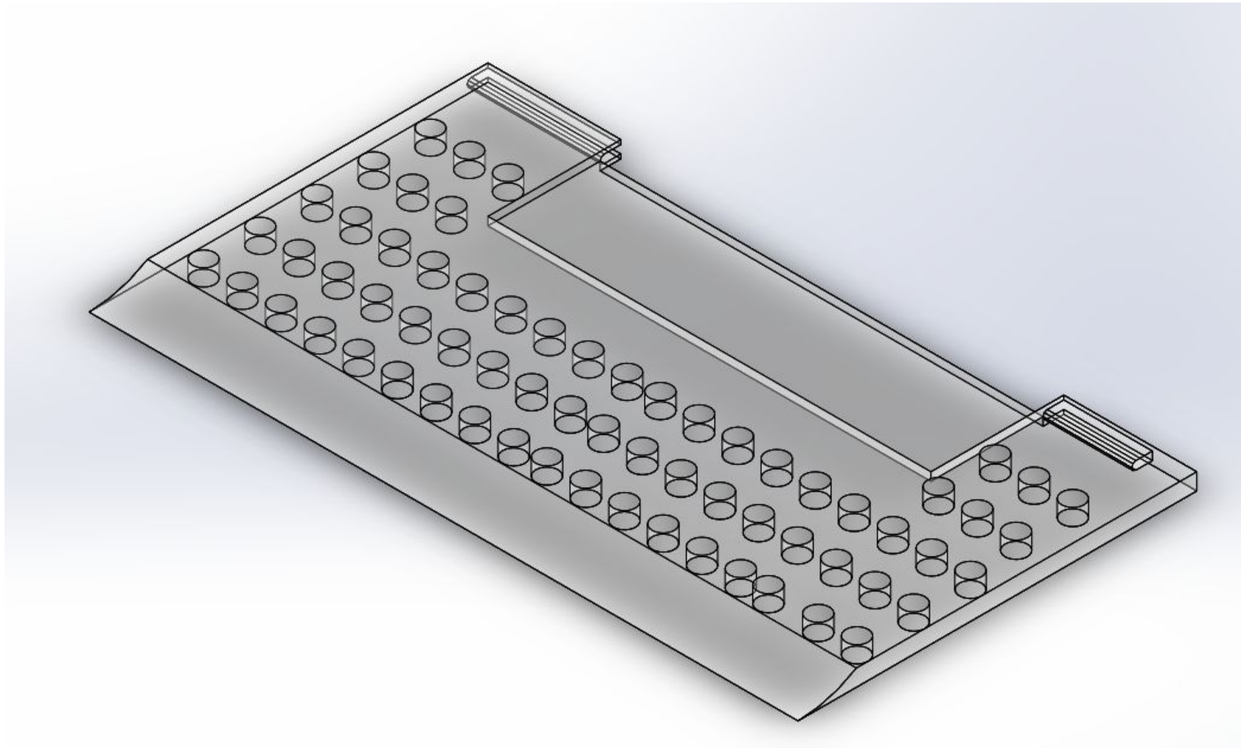


Figure (37): Image of Rear Right ABS Floor Inserts

This component is the rear female floor insert. This insert fits into the other half of the 3’ wide by 34” long available floor space in the rear. There is a 0.375” deep notch in the center of the inner wall to accommodate PowerDocks’ black box control unit. The female hex groove (similar to IVDS007) is present again, but is split into two sections. This split runs the length of the length of the black box, and is necessary for assembly. The hex groove, again similar to IVDS007, stops short to prevent mistakes in assembly. The floor also features an array of circular cut outs. This feature is primarily included to save weight, as a solid ABS floor is not necessary to offer almost identical rigidity and as it translates, vessel stability. There is one less row of holes due to the dept of the groove. As per the sponsor’s request, ways to optimize this piece include more holes using a different hole pattern, larger holes, and a thinner floor insert (though this may compromise the effectiveness of the interlocking hex feature).

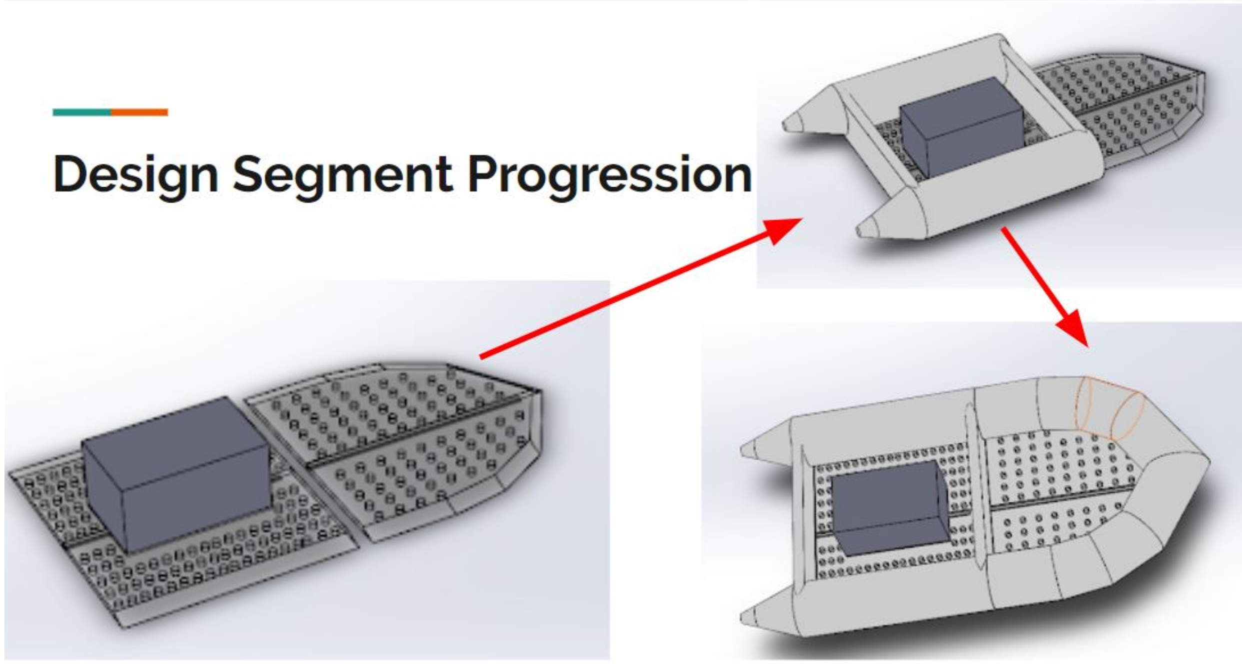


Figure (38): Image of Design Segment Progression

8 Engineering Analysis

8.1 Engineering Analysis Outline

The engineering analysis section is split into two parts. One part focuses on the theory of buoyancy, its application to Team 19's design, and the effect and design constraints of vessel size and volume. The section details calculations based on the use of different vessel materials. This section overviews and details different material optimization, buoyancy differences in different materials, and final prototype buoyancy in both water and ocean environments.

8.1.1 Buoyancy

The current focus of this section of the engineering analysis is dedicated to the math behind the calculations of buoyancy. These calculations verify if the prototype vessel will float under the assumptions that they are the maximum of 25 lbs and are not material specific. Additional consideration has been taken to analyze the vessel under fully loaded conditions. The calculations go on consider the differences in the details of the buoyant forces in both fresh and sea water. Equation (1) describes the basic principle of buoyancy.

$$F_B = F_G \quad (1)$$

Where F_B is equal to the force of buoyancy and F_G is equal to the force due to gravity. The force of buoyancy can be broken down into its components as seen in Equation (2).

$$F_B = \rho v g \quad (2)$$

Where ρ is the density of water, v is the volume of the concept vessels, and g is gravity. Next is the force due to gravity.

$$F_G = mg \quad (3)$$

Where m is the mass of the material used and g is gravity.

When analyzing if the design vessel concepts will float at maximum weight (regardless of material, equation (1) is rewritten into the following:

$$\rho v g = mg \quad (4)$$

Or in this specific case

$$\rho v g \geq 25\ lbs \quad (4.1)$$

Equation (4.1) uses the constraint of a maximum weight of 25 lbs (25 lbf) and sets a baseline for the four versions of the concepts. This equation is simplistic and does not take into consideration the used material. The following calculations and table summarize the unloaded buoyancy findings in both fresh and sea water.

$$\rho v g = mg$$

$$\rho v = m$$

$$1025\ \frac{kg}{m^3} \bullet \nu = 25 lbs = 11.34\ kg$$

$$\nu = 0.01106\ m^3 \textit{ of sea water displaced}$$

$$\rho v g = mg$$

$$\rho v = m$$

$$1000\ \frac{kg}{m^3} \bullet \nu = 25 lbs = 11.34\ kg$$

$$\nu = 0.01134\ m^3 \textit{ of fresh water displaced}$$

Table (9): Table of Buoyancy Calculations

Density of Liquid	Unloaded Max. Weight	Liquid Displaced	Vessel Volume	Findings
Sea Water 1025 $\frac{kg}{m^3}$	11.34 Kg	0.01106 m^3	0.2802 m^3	25.33x More Buoyant
Fresh Water 1000 $\frac{kg}{m^3}$	11.34 Kg	0.01134 m^3	0.2802 m^3	24.71x More Buoyant

As seen from the table, the prototype design is about 25 times more buoyant at its maximum allowed weight in both fresh and saltwater. This over buoyant design is beneficial and helps negate excess water taken on in extreme ocean environments or from excessive rainfall.

There will also have to be a second equation similar to equation (4.1) that incorporates the 100 lb load as well as the weight of the supplied electronics including: black box controller unit, ABS floor inserts, motors, and solar panels.

$$\rho vg \geq 194.6\ lbs \quad (4.2)$$

The following table and calculations are similarly executed to those directly above, but to show a fully loaded vessel in both fresh and saltwater. These calculations again do not consider vessel material, and instead assume a maximum weight of 25 lbs.

$$\rho vg = mg$$

$$\rho v = m$$

$$1025\ \frac{kg}{m^3} \bullet \nu = 194.6\ lbs = 99.7903\ kg$$

$$\nu = 0.09736\ m^3 of\ sea\ water\ displaced$$

$$\rho vg = mg$$

$$\rho v = m$$

$$1000\ \frac{kg}{m^3} \bullet \nu = 194.6\ lbs = 99.7903\ kg$$

$$\nu = 0.09979\ m^3 of\ fresh\ water\ displaced$$

Table (10): Table of Updated Buoyancy Calculations

Density of Liquid	Loaded Max. Weight	Liquid Displaced	Vessel Volume	Findings
Sea Water 1025 $\frac{kg}{m^3}$	99.7903 Kg	0.09736 m^3	0.2802 m^3	2.88x More Buoyant
Fresh Water 1000 $\frac{kg}{m^3}$	99.7903 Kg	0.09979 m^3	0.2802 m^3	2.81x More Buoyant

The findings in the above table illustrate that the vessel is still quite more buoyant than is required, which is excellent. Team 19 expects that the vessel could safely handle an additional 200-300 more pounds, depending on how the payload is distributed. The actual vessel will more bouyant, because when materials are considered, the prototype weighs under 25 lbs.

Knowing these maximum constraints will help to improve and optimization the design. Using the constraint of 25 lbs as the lead designing factor, it is possible to solve for the amount of physical material that may be used for each conceptual substance. It is know that 1 lbf = 4.4482 N, so 25 lbf = 111.205 N. Using Equation (3)

$$Weight\ (N) \ = \ mg \ = \ \frac{111.205\ N}{9.81\frac{m}{s^w}} = 11.34 \text{ kg}$$

This means that for any vessel redesign or for future updates the maximum mass that is possible to be used is 11.34 kg. Following this, for hypalon, the basic mass equation is utilized.

$$m \ = \ (Material\ Density) \ \bullet \ (Shelled\ Volume)$$

$$11.34\ kg \ = \ (1200\frac{kg}{m^3}) \ \bullet \ (Shelled\ Volume)$$

$$Maximum\ Shelled\ Volume\ must \ \leq \ 0.0094465\ m^3$$

This equation is reworked in a similar manner using the density of PVC instead, which yields the following:

$$11.34\ kg \ = \ (1467\frac{kg}{m^3}) \ \bullet \ (Shelled\ Volume)$$

$$Maximum\ Shelled\ Volume\ must \ \leq \ 0.00773001\ m^3$$

With these constraints calculated from the weight limit, the prototype model has maximum new, additional constraints that provide the framework for tweaks or future updates. The table below contains all of the actual physical model data for each component of the design.

Table (11): Table of Physical Model Data

Component	PVC Weight lb	Hypalon Weight lb	Polyethelene lb	ABS Weight lb	Shelled Volume in3	Material Thickness in	Surface Area in2
Frontal Section	5.11	5.19	X	X	108.85	0.0375	5801.8
Side Tube A	2.53	2.57	X	X	53.86	0.0375	2872.5
Side Tube B	2.53	2.57	X	X	53.86	0.0375	2872.5
Hull (Rigid)	X	X	5.04	X	57.03	0.1	3018.57
Hull (Inflated)	2.68	2.72	X	X	57.03	0.0375	3018.57
Flat Deck (Solid)	4.11	4.17	X	X	87.53	0.0375	4675.59
Divider A	1.26	1.28	X	X	26.93	0.0375	1441.53
Divider B	1.26	1.28	X	X	26.93	0.0375	1441.53
Floor Insert F.M.	X	X	X	11.93	323.8	X	1177.26
Floor Insert F.F.	X	X	X	11.37	308.51	X	1168.74
Floor Insert R.M.	X	X	X	11.24	305.08	X	1284.17
Floor Insert R.F.	X	X	X	10.87	294.96	X	1240.68

8.1.1.1 Material Effect on Buoyancy

Now that it has been confirmed that all scenarios will float under the previously stated assumptions, the next step is to analyze the prototype version when constructed out of different materials. The method for analyzing these is similar to the previous method, but is more involved. Equation (4) will be modified for the following section.

$$\rho v = m \quad (5)$$

g has been canceled from both sides as the focus is now directed more to the material properties side of things. Additionally, m is broken down into its own origin variables, creating a new equation.

$$\rho v = DV \ (5.1)$$

Where ρ is still the density of water, v is still the volume of the prototype vessel, D is the density of a chosen material , and V is the shelled volume of the prototype vessel. The shelled volumes used in the calculations bellow used to be $0.125''$, but it has been discovered that this value was much too thick and a direct contributor in the excess weight of the concept versions. The current calculations see a thickness of 0.0375". Below is an example of the design study prototype vessel calculated for use with hypalon in fresh water using equation (5.1) in SI units.

$$1000\frac{kg}{m^3} \cdot 0.2802m^3 \geq m = (Material\ Density) \cdot (Shelled\ Volume)$$

$$280.2\ kg \geq m = (1200\frac{kg}{m^3}) \cdot (0.006800m^3)$$

$280.2\ kg \geq 8.16\ kg$, which means that this vessel version will float because of the obvious difference in displacement.

Now to calculate if the material specific vessel will float under load, equation (4) must be modified again.

$$\rho vg = \Sigma mg = mg + F \quad (6)$$

It is necessary to re-incorporate gravity into this equation because of the addition of the extra weight constraint which is non-material specific.Using this equation for hypalon and finding N the following values are obtained:

$$194.6\ lbs\ (lbf) = 99.7903\ kg \cdot 9.81\ \frac{m}{s^2} = 978.943\ N$$

$$280.2\ kg \bullet 9.81 \frac{m}{s^2} \geq (8.16\ kg \bullet 9.81\ \frac{m}{s^2}) + 978.943\ N$$

$2748.762\ N \geq 1058.99\ N$, which means that while under load, this vessel version will float. As predicted above in the non-material specific calculations, the loaded vessel is ~2.8x more buoyant, this time, with the inclusion of gravity to demonstrate the respective material hypalon. This small deviation is to be expected, as the hypalon version of the design is 19.78 lbs, not 25 lbs.

Buoyancy has been successfully calculated above for the prototype vessel using hypalon in fresh water. Sea water buoyancy will behave almost the exact same (slightly more buoyant than fresh water) in the material specific calculations. The densities are extremely similar and both water types have already been solved for in the previous section. The following table summarizes the material specific finds for both PVC and hypalon, which were the two chosen materials to observe in this design study. The method for finding the data using PVC was exactly the same, except for changing material density from "1200 $\frac{kg}{m^3}$ " to "1467 $\frac{kg}{m^3}$ " . For the sake of completion (though maybe redundant) the data tables below will show both fresh and sea water.

Table (12):Table of Fresh Water Buoyancy

Material	Material Density	Vessel Weight	**Loaded** Buoyancy	Pass/Fail
Hypalon	$1200 \frac{kg}{m^3}$	8.97 Kg (19.78 lbs)	2.60x More Buoyant	Pass
PVC	$1467 \frac{kg}{m^3}$	8.84 Kg (19.48 lbs)	2.55x More Buoyant	Pass

Table (13):Table of Sea Water Buoyancy

Material	Material Density	Vessel Weight	**Loaded** Buoyancy	Pass/Fail
Hypalon	$1200\frac{kg}{m^3}$	$8.97\ Kg\ (19.78\ lbs)$	2.66x More Buoyant	Pass
PVC	$1467\frac{kg}{m^3}$	$8.84\ Kg\ (19.48\ lbs)$	2.61x More Buoyant	Pass

The buoyancy of the vessel has been proven to be successful, using either of the proposed materials, in both sea and salt water, and under a full load. This aspect of the design is an absolute success and this conclusion is proven by the data and calculations.

9 Manufacturability

9.1 Manufacturing Outline

Ideally there is a company with the experience to manufacture the vessel. The final redesign has a simplified hull which was the product of talking to some vendors and experts in the field. If the design has a rigid hull, it may be easier to replicate as it would be more in line with commercial rafts seen today. The hull is the most complicated part of the raft which is where the team believes the manufacturing process needs to begin. Once that is constructed, the rest of the raft should be built off that. The rest of the design was simplistic by nature, to keep costs down. The solar panels and ElectraFin should be placed on last as those are pieces which will use adhesive and do not have to be directly integrated into the vessel design. These are considerations that team 19 is not focused on, as they are subject to change based on sponsor needs. The Bill of Materials section can be referenced for further component descriptions and use.

9.2 Proof of Concept Focus

The Team was not able to have a physical prototype created for the proof of concept. This is because the design of the vessel was specific, and the team was not able to create a physical prototype that would reflect the care and attention to detail that they had designed. No quotes from companies came back positive, or at all. The team and sponsors decided a manufacturer would make the prototype if possible. There were additional concerns over the safety of attempting to create an inflatable and dealing with the related failure and pressure release that the team was not equipped to deal with. The proof of concept instead focused on meeting the design specifications and requirements. The focus included attributes that did not need to be tested in person, such as the flat deck surface area, the buoyancy, and the weight of the vessel.

9.3 Prototype Design Reception

Upon hearing back from a number of vendors, it was realized the hull design was non manufacturable. This led the team to go back to the drawing board and create a simpler hull shape which in turn improved simulated performance. Some companies did not think the design was cost effective as they had similar vessels but they did not meet all of the design specifications.

9.4 Final Prototype Update

The final prototype features a new V shaped hull which could be rigid or inflatable with inflatable cross sections to provide lateral support. It also includes 4 sections of ABS plastic inserts which provide the payload area with support as well as providing the whole vessel with rigidity. Solar panels can be placed on the outer tubes of the vessel and there is a place at the rear to place 2 ElectraFins under the black box to provide thrust and maneuverability.

9.4.1 Rear Tube Considerations

The rear tube sections were designed to be simple, and the implementation of the rear stability cone would be easy. These tubes were already simple by design, but no extra material or seems were added. The rear tubes should be one of the easiest parts of the vessel to manufacture.

9.4.2 Frontal Section Considerations

The frontal tube section was designed to be the connection of the rear tubes and define the front geometry of the vessel. The vessel's floor and hull also followed this profile. This design is a bit more complex than the rear tubes because of the angled bends, but the center radial line of the tube is clearly defined in the design drawings. The team would also prefer to have the inclusion of pressure release valves and close-off sections of the vessel in the event of over inflation and or puncture, but these were not pursued by the sponsors.

9.4.3 Hull Considerations

The hull was designed to be inflatable which is what NUWC and PowerDocks wants. However, to simulate the hull in water, the properties had to be that of a rigid hull. This produced the idea of a rigid hull which was shelled and acted as the backpack as well. The inflatable part of the raft would be folded into the shelled hull and the weight would still be under the 25lb requirement. Both ideas were pursued.

9.4.4 Inflated Cross Section Considerations

The inflatable cross sections (flat deck dividers) are a simple rectangle with the radius of the rear tube cut out. This combo of components is also extremely simple in nature and should not be challenging to manufacture by design. Their inclusion is required for stability and dividing the payload, and thus, were created to serve their role, in a conservative manner.

9.4.5 ABS Flooring Considerations

Aside from the hull, the flooring may be the most complex set of parts to manufacture. There are numerous holes, groves, and fillets that need addressing. Fortunately, the team chose ABS plastic for the material of these designs. ABS plastic is extremely cheap and very easy to machine. Because of this the manufacturability should be cost effective, if nothing else. No quotes were returned from any manufacturers, so there is no estimate for lead times or accurate pricing.

10 Testing

10.1 Testing Outline

Team 19 performed a variety of tests related to this design project. In accordance with the design specifications, the team pursued puncture testing, environmental chamber testing, tensile testing, CFD testing, and FEA testing. The puncture testing was aimed at addressing the sponsor concern for a puncture resistant vessel. The environmental chamber testing offered two benefits. The first results gathered were to observe material degradation at sea surface conditions using set parameters. This was done to attempt to gain material insight into durability and life expectancy. The chamber testing also provided samples to compare against untreated samples in tensile testing to observe failure. The tensile testing was done to try and gather material data on recreated loading environments, such as the material supporting a payload. The testing used fresh samples and samples treated to sea surface conditions in order to record variances. CFD testing was performed to analyze factors such as drag and other factors on the underside of the vessel in different conditions. This testing used an early hull and floor profile and was compared against the final prototype hull and floor profile. The FEA testing was completed simply in order to confirm that the ABS floor inserts could support a 100 lb payload. This was verified by the deflection value that was produced, confirming the specimen would not warp or break.

10.2 Testing Matrix

Table (14): Table of Testing Matrix

URI MCE Capstone Team 19 Testing Matrix

KEY: Y = Yes, S = Somewhat, and N = No

Testing	Execution: Relavance to Design Specification	Reasonability	Availability of Equations	Relation to Safety/Soundness	Relation to Life Expectancy	Relation to Material Properties	Relation to Faliure	Plan for Completion	Completed	Totals
Punture Testing	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y=9 S=0 N=0
Environmental Chamber Testing	Y	Y	N	Y	Y	Y	Y	Y	Y	Y=8 S=0 N=1
Tesile Testing	S	Y	Y	S	S	Y	Y	Y	Y	Y=6 S=3 N=0
CFD Testing	Y	Y	S	Y	N	N	S	Y	Y	Y=5 S=2 N=2
FEA Testing	S	Y	S	S	S	Y	Y	Y	Y	Y=5 S=4 N=0
Totals	Y=3 S=2 N=0	Y=6 S=0 N=5	Y=2 S=2 N=1	Y=3 S=2 N=0	Y=2 S=2 N=1	Y=4 S=0 N=1	Y=4 S=1 N=0	Y=5 S=0 N=0	Y=5 S=0 N=0	

The table directly above is Team 19’s test matrix. The team had a large variety of unrelated tests to complete, both simulated and in the lab. Using a conventional testing matrix proved to be much too complicated and did not help verify if the test would (or should) be attempted based on its relevance. A simplified version of the testing matrix was created to quantify the importance of any given test. The table above contains all of the testing the team sought fit to execute. Other tests were found to not be necessary based on practicality reasons. Some scrapped tests include: a wave pool test, a flow simulation against the upper hull to represent different wind conditions, and a modeled puncture test. These tests were scrapped from the above matrix after having too many negative totals, deming them unfeasible.

10.3 Materials Testing

Material testing was a large part of the project because the material of the hull was very important. There were puncture, weight and longevity requirements that needed to be fulfilled for the vessel to accomplish its goal. The first test was weighing the PVC and Hypalon to see which would be lighter. The Hypalon was lighter but both materials remained in the weight limit with our modelled raft. The next test was a puncture test. After the puncture test, a sample of the PVC and Hypalon were subjected to an environmental chamber for three weeks which was programmed to act as sea air. The samples were then subjected to a tensile along with untreated samples which were compared after.

10.3.1 Puncture Testing Scope

The puncture test was done in two parts. The first part of the test involved a needle falling onto the PVC and the Hypalon which was placed atop a styrofoam block. There was a 1 kg weight attached to the end and it was dropped from a quarter meter. Both materials failed this test. Talking to the team sponsors it was understood that the vessel would need to be puncture resistant to rocks rather than more needle like objects. It was not possible to double layer the hull as it would then exceed the weight limit of 25lbs. Another test was conducted using a screwdriver bit “chuck” which was dropped from a meter with a 1 kg weight. Neither material was pierced, thus passing the new test parameters. To be certified puncture resistant, the material needs to be able to withstand 20 joules from a pen tip object.

10.3.1.1 Related Results

Drop Testing Info

MGH = F

3x3 Samples

Needle

2kg * 9.81m/s^2 * ¼ m = 4.905 J

Chuck

2kg * 9.81m/s^2 * ¼ m = 4.905 J

Chuck v2

2kg * 9.81m/s^2 * 1.2192 m = 23.921 J

Needle Test	Drop Height	Puncture Depth	Pass/Fail
Hypalon A 1	1/4 Meter	1 cm	Fail
Hypalon A 2	1/4 Meter	1.25 cm	Fail
Hypalon A 3	1/4 Meter	1.2 cm	Fail
Hypalon B 1	1/4 Meter	1.5 cm	Fail
Hypalon B 2	1/4 Meter	2 cm	Fail
Hypalon B 3	1/4 Meter	1.5 cm	Fail
PVC 1	1/4 Meter	1.25 cm	Fail
PVC 2	1/4 Meter	1.10 cm	Fail
PVC 3	1/4 Meter	1.20 cm	Fail

Chuck Test	Drop Height	Puncture Depth	Pass/Fail
Hypalon A 1	1/4 Meter	0	Pass
Hypalon A 2	1/4 Meter	0	Pass
Hypalon A 3	1/4 Meter	0	Pass
Hypalon B 1	1/4 Meter	0	Pass
Hypalon B 2	1/4 Meter	0	Pass
Hypalon B 3	1/4 Meter	0	Pass
PVC 1	1/4 Meter	0	Pass
PVC 2	1/4 Meter	0	Pass
PVC 3	1/4 Meter	0	Pass

Chuck Test	Drop Height	Puncture Depth	Pass/Fail
Hypalon A 1	1.2192 Meters	0	Pass
Hypalon A 2	1.2192 Meters	0	Pass
Hypalon A 3	1.2192 Meters	0	Pass
Hypalon B 1	1.2192 Meters	0	Pass
Hypalon B 2	1.2192 Meters	0	Pass
Hypalon B 3	1.2192 Meters	0	Pass
PVC 1	1.2192 Meters	0	Pass
PVC 2	1.2192 Meters	0	Pass
PVC 3	1.2192 Meters	0	Pass

Figure (39): Image of Related Results of Puncture Testing

10.3.2 Environmental Chamber Testing Scope

The two materials were put into a environmental chamber set at 90% humidity and 60 degrees fahrenheit. The goal of this test was to compare it to untreated samples using a tensile test.

10.3.2.1 Related Results

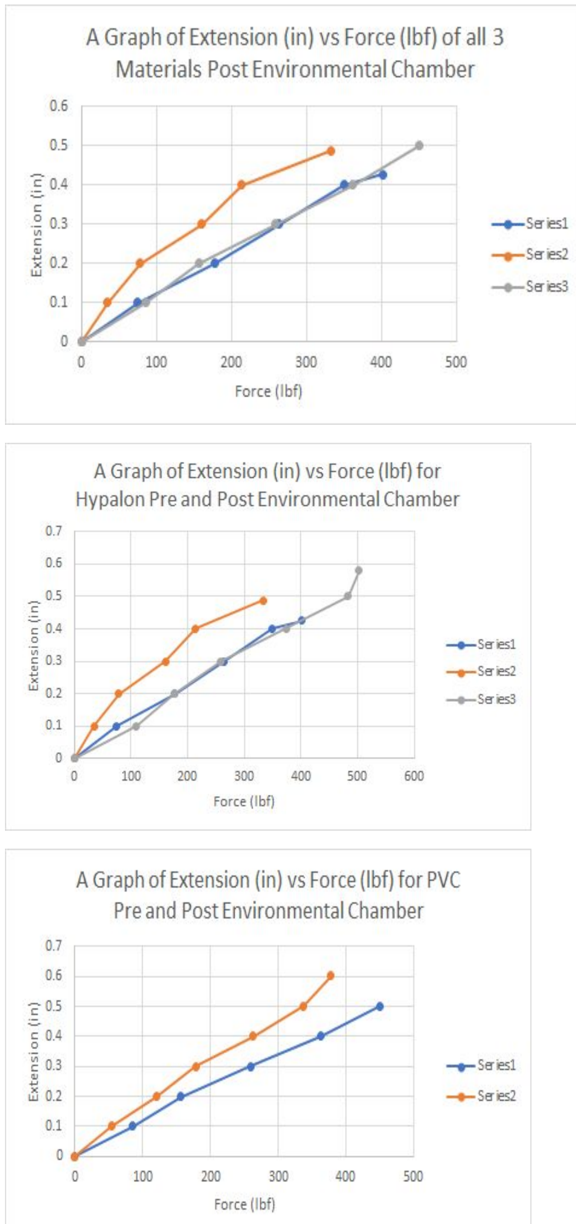


Figure (40): Image of Related Results of Environmental Testing

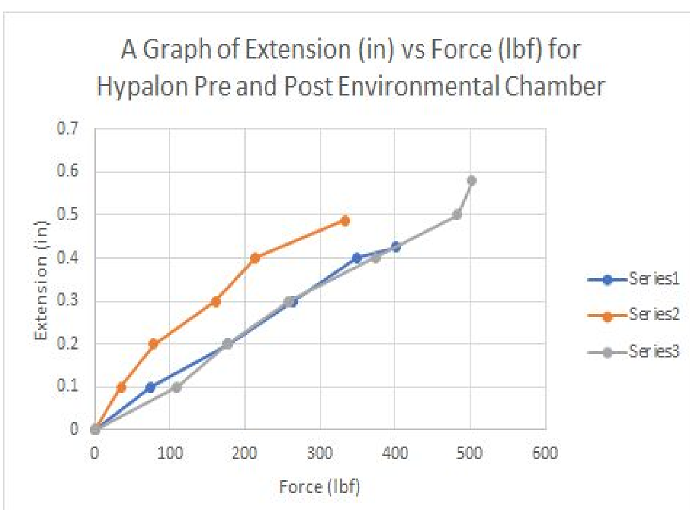
10.3.3 Tensile Testing Scope

Subsequent to the Environmental testing that was conducted on the material samples; the team decided that it would be essential to test how the tensile strength was altered after the exposure to the sea state conditions. This tensile test would be applicable when observing the vessel's survivability out at sea, especially with the loads that will be applied to the vessels deck. With the added payload and weight of the black box component, added strain and stress would be applied to the vessel and the material it is made out of has to be able to withstand that stress and strain over time. Although, the material samples were only subjected to these conditions for a mere 3-4 weeks, the team believed that this time frame would give us a good enough understanding as how the material was or was not deteriorating. The 3in by 3in exposed samples of PVC and two varying types of hypalon were tested for their tensile strength in the Instron as well as unexposed samples of the same size. Various comparisons were made to analyze the results that were found. Firstly, we compared the individual materials that were exposed to the environmental chamber against their unexposed counterparts. This was done for both PVC and Hypalon. Secondly, we compared the three materials; two types of hypalon and the PVC together to see what might be the best and most durable material after exposure. Below are the three graphs of extension in inches vs Force in pounds-force for hypalon, PVC and the comparison of the three materials respectively.

10.3.3.1 Related Results

Comparison of Tensile Strength of Hypalon Materials Pre and Post Environmental Chamber

- As expected, after the alloted time in Environmental Chamber hypalon experienced deterioration causing it to break faster than unexposed hypalon



Figure(41): Graph of Extension (in) vc Force (lbf) for Hypalon Pre and Post Environmental Chamber

Comparison of Tensile Strength oF PVC Pre and Post Environmental Chamber

- Similarly, unexposed PVC proved to have a stronger tensile strength than exposed PVC with the highest tensile strength of the three materials used.

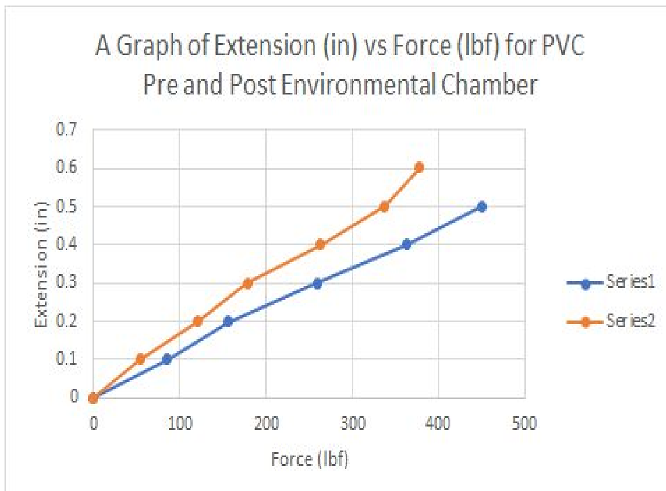


Figure (42): Graph of Extension (in) vs Force (lbf) for PVC Pre and Post Environmental Chamber

Comparison of Tensile Strength of Exposed Materials

- PVC was able to withstand the most extension and also it was seen that although the other two samples of hypalon had visible tears; the PVC did not have any visible tear although it was seen that post the tensile load was applied the material did fail.

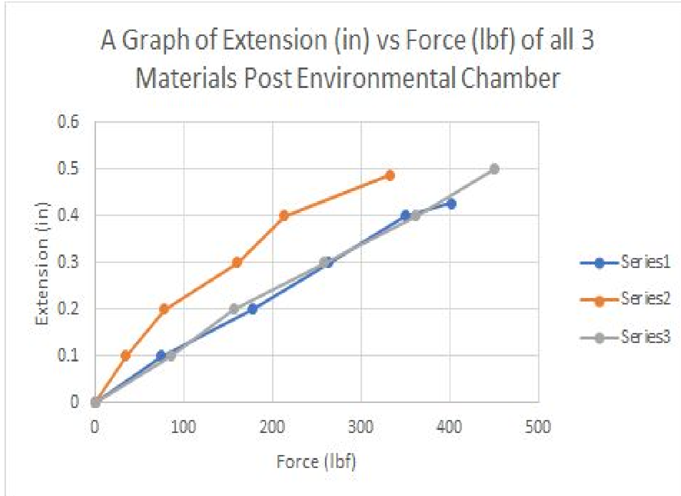


Figure (43): Graph of Extension (in) vs Force (lbf) of all three materials Post Environmental Chamber

10.3.4 CFD Testing Scope

CFD Total Drag on Two Hulls

In order to determine the hull with the least amount of frictional resistance, a comparative analysis of the CFD predictions on the two Hulls was conducted. The software used to conduct the CFD simulation was NavaSim. NavaSim is a software created by the Engineers at Navatek. Team 19 reached out to Navatek in hopes of acquiring a copy of this software. The Engineers at Navatek gave the team a copy of the software as well as many hours of support and troubleshooting tips. The team used NavaSim to conduct the simulations because of its highly accurate results as opposed SolidWorks Flow Simulator. Prior to the CFD simulations, non-dimensional parameters had to be determined, as well as several surfacing requirements. The vessel itself was modified by team 19 in a surfacing software called Rhinoceros. Specific surfacing requirements were met in order for the geometry to be read by NavaSim. The Froude number, Fn is an example of one of the most important parameters calculated. The Froude number F_n relates the speed of the vessel, gravity, and vessel length.

$$F_n = \frac{U}{\sqrt{g*L}} \quad (1)$$

Where U is the forward speed of the vessel, g is the gravitational acceleration, and L is the length at the waterline of the ship. The vessel length was 1.9458 m the gravitational acceleration is 9.81 m/s^2, and the forward speed of the vessel varied between 1.31 m/s up to 2.62 m/s.

Another important parameter that was calculated using the NavaSim software was Reynolds number, R_e. This dimensionless number is used to characterize flow by noting the ratio of internal forces to viscous forces [3] .

$$R_e = \frac{U*L}{\upsilon} \quad (2)$$

Where υ is the kinematic viscosity of salt water at 15 degrees Celsius which was calculated to be 1.19m^2/s.

The coefficient of friction is calculated using the ITTC 1957 Model-Ship Correlation Line [5] using the equation shown below.

$$C_f = \frac{0.075}{(log_{10}(R_e - 2)^2} \quad (3)$$

Where R_e is the dimensionless number described above.

The coefficient of wave making resistance is calculated using the equation for ITTC '78 [4] displayed below.

$$C_W = \frac{R_x}{0.5*S*\rho*U^2} \quad (4)$$

Where R_x is the wave resistance (-Fx) calculated by the NavaSim software, S is the wetted hull surface area of 1.66 m^2, and ρ is the density of salt water 1026.06 kg/m^3.

Now using the equations above the coefficient of total resistance or drag can be calculated. The coefficient of total resistance is a factor of both the coefficient of wave making resistance as well as the coefficient of friction.

$$C_t = C_W + (1 + k)C_f \quad (5)$$

Where k is a form scale factor used to convert the sale run to a full scale. NavaSim performs the simulation at a scaled down run to reduce computing time as well as provide less of a burden on computer processing.

10.3.4.1 Related Results

After completion of the CFD simulations the two hulls, original and evolved were compared to view the one with the most reduced drag. The Figure below depict a graphical representation of the total coefficients of resistance as the Froude number is increasing.

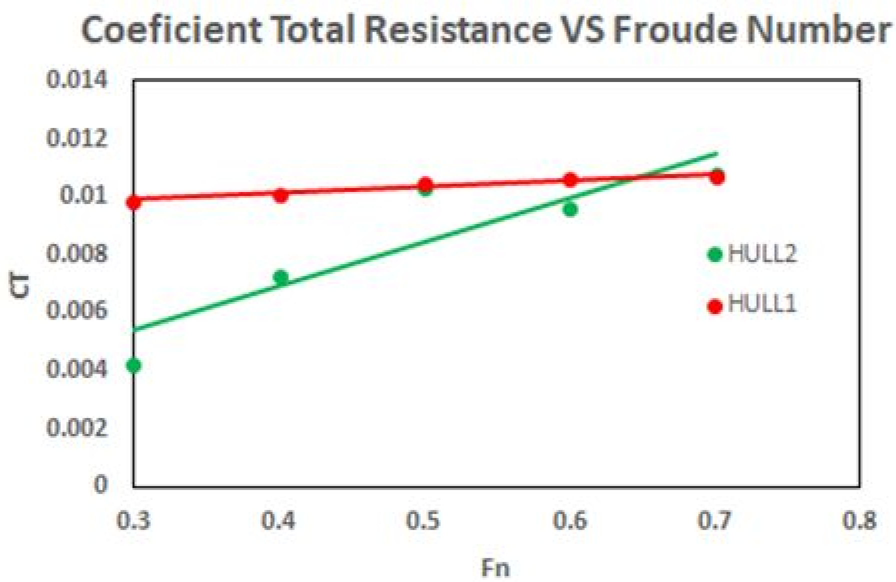


Figure (44): Coefficient of Total Resistance VS Froude Number

It is clear that the graph above shows that the evolved hull has a decreased coefficient of total resistance as the vessel is increasing in speed. The figure shows that the drag or C_T is increasing as the vessel speed is increasing. This is to be expected because of the resistance forces acted on the vessel from the waves propagated.

The Figures below shows the wave elevation of the new hull design as it travels at Froude Numbers of 0.4 and 0.5.

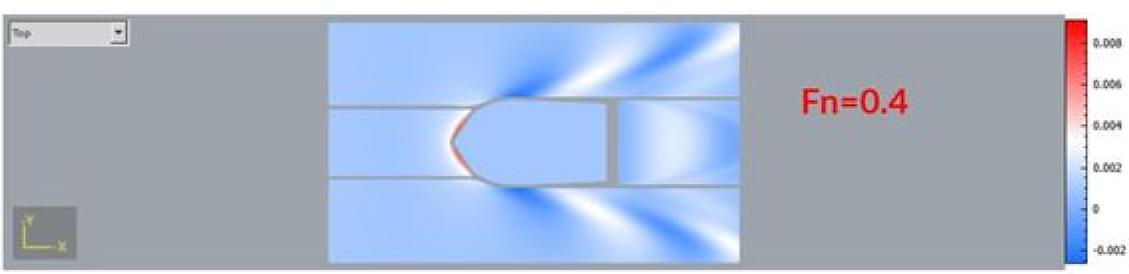


Figure (45): Hull two Wave Elevation Graphic at Fn=0.4

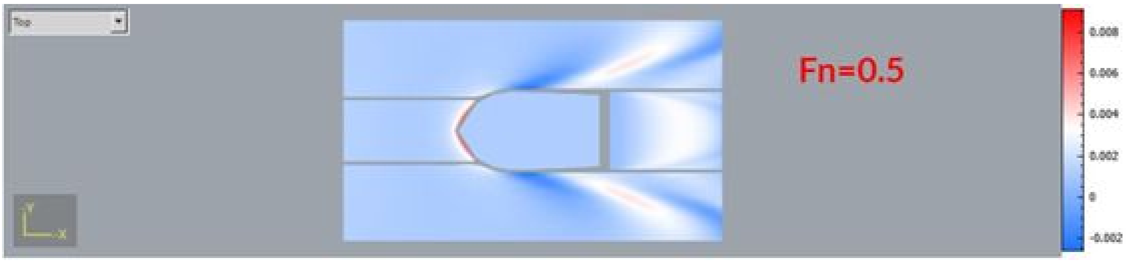


Figure (46): Hull two Wave Elevation Graphic at Fn=0.5

As shown in the graphics as the Froude number increases the wave elevation is also increasing. The maximum wave elevation zones are indicated by a red color on graphics.

10.3.5 FEA Testing Scope

Finite element analysis was performed in Solidworks on the assembly of the frontal two floor inserts. This testing was simply conducted and performed to confirm that the ABS floor inserts could support a distributed 100 lb payload. The figure below displays the specimen before subjection to a simulated load FEA load.

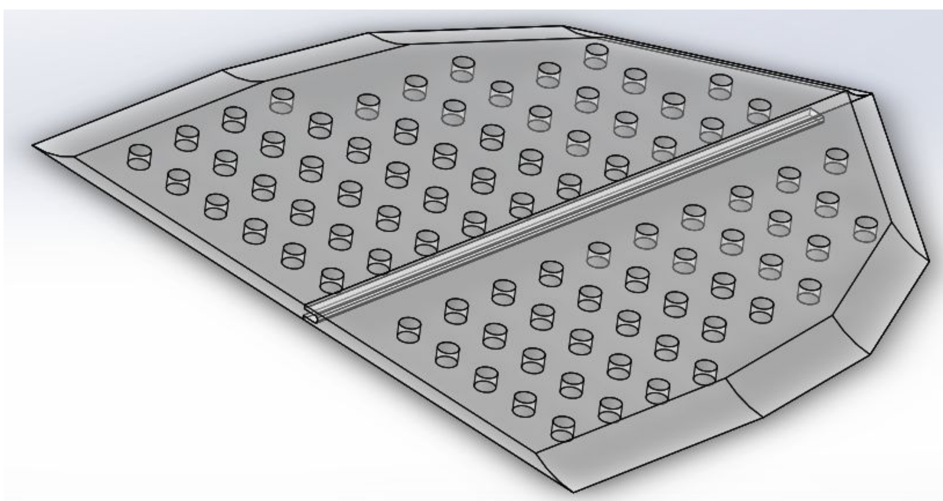


Figure (47): Image of Frontal Two Floor Inserts

Both of the top surfaces were exposed to a 100 lb (444.82 N) load and grounded appropriately. The 100 lb load was applied to both of the floor surfaces. This “doubling of the load” was done because team 19 did not have a specific sized payload, so each half was loaded with the full weight. This negated any weight distribution issues, and also aimed to prove the floors was much more sturdy than was required.

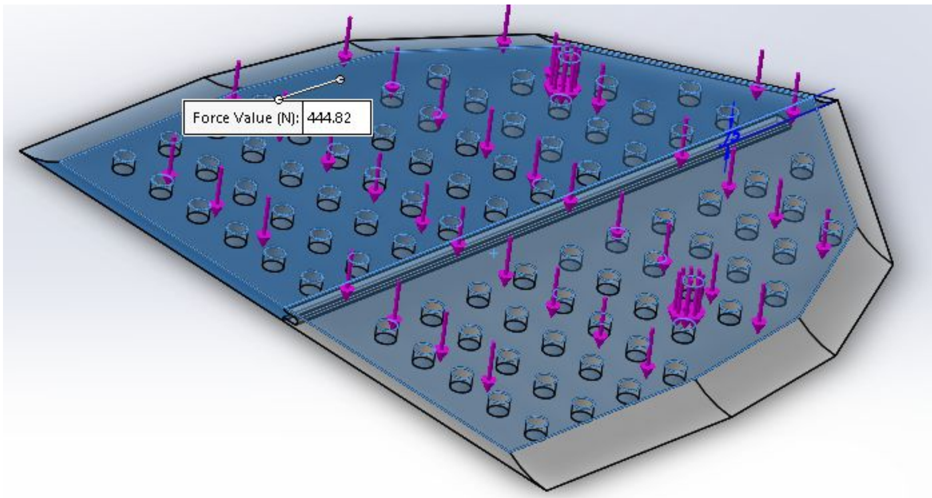


Figure (48): Image 1 of Finite Element Testing

10.3.5.1 Related Results

The following FEA results were generated using a complex mesh, the load stated in the previous section, and appropriate grounding. The Figure below highlights the range of calculated displacements.

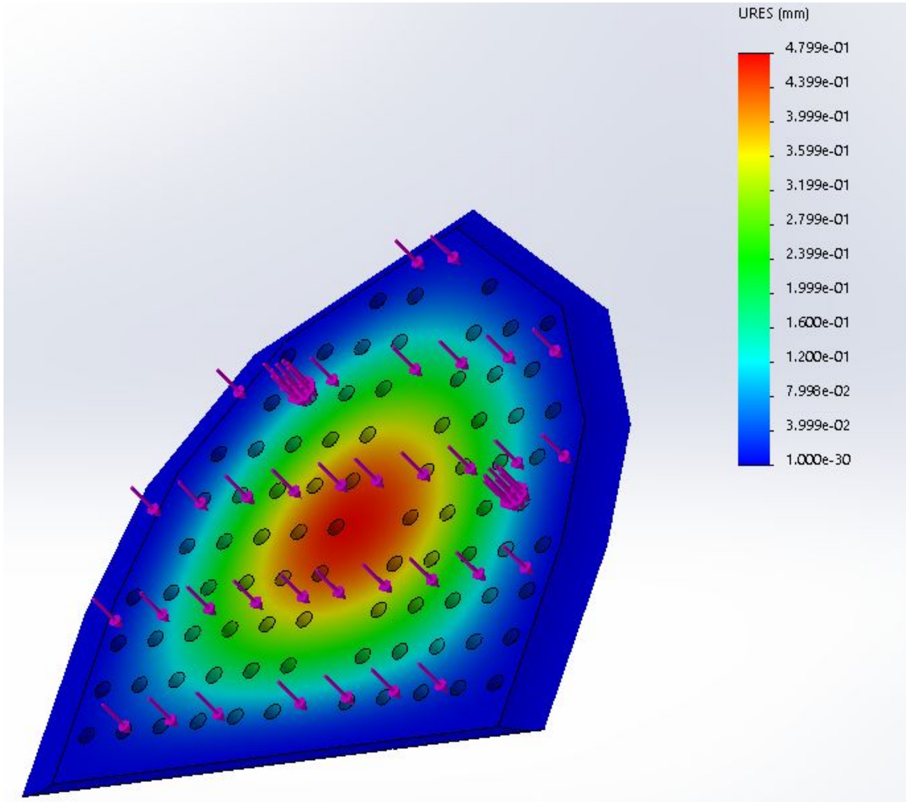


Figure (49): Image 2 of Finite Element Testing

The maximum calculated displacement 0.4799 mm. This value is extremely small, and when considering that the effective load was doubled, the strength of the floor inserts shines. This was verified by the deflection value that was produced, confirming the specimen would not warp or break in a loading environment.

11 Redesign

11.1 Redesign Outline

The product design for the inflatable vessel design study project has seen many changes, revisions and updates throughout the spring semester. Additional information regardings some specific components may be found in **7.2 Early Prototype Drawings & 7.3 Final Prototype Drawings**. The end of the fall semester saw Team 19 with 4 unique designs that all fit inside of the basic design specifications and met additional design criteria.

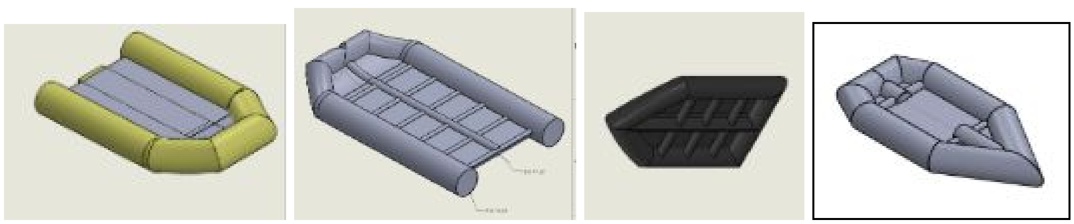


Figure (50):Image of Initial Four Designs

The designs lacked completion and realization. After a few more weeks and more sponsor meetings, Team 19 settled for one early prototype design that incorporated more and more. This design featured accommodation for a motor mount and the black box.

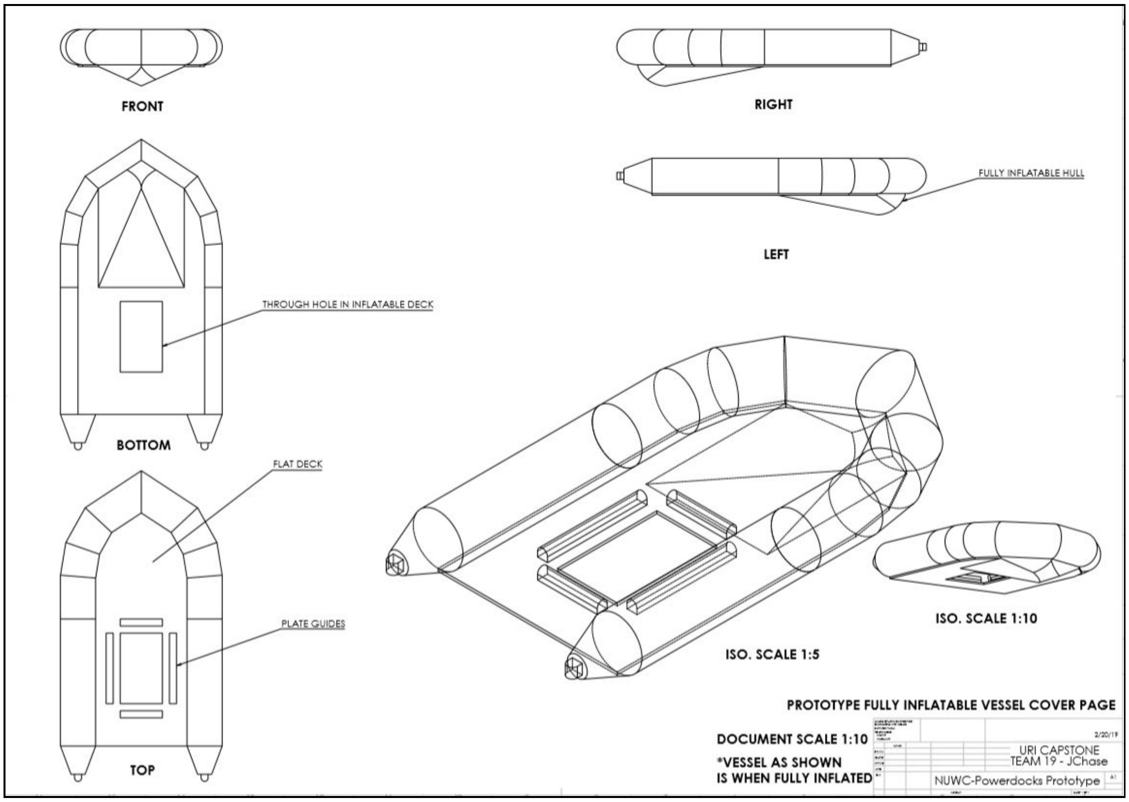


Figure (51): Image of Early Prototype Drawing

This design was aimless and lacked realization. The vessel was easily susceptible to flooding, lacked rigidity (could fail due to a "toe-in" collapse) It was clear that this vessel was in need of many updates and tweaks. The next section demonstrates the evolution of the vessel and product design over a few iterations, and discusses the changes between them.

11.2 Progressive Prototype Updates

The Team saw potential where the design had progressed to, but it was clear that there would need to be updates. The first of many revisions saw the removal of the large "black box sized" hole in the vessel. This hole was supposed to allow a black box controller to rest on a hypothetical plate that would interface with the vessel. The plate would have cut outs that matched the rectangle protrusions in the flat deck design. The controlor would then connect into a hypothetical motor plate underneath the vessel, thus sealing any water leaks. This would also provide a physical connection from motor-to-controller, as well as provide a rigid motor mount. The direction that this idea was aimed at was not completely considered before execution. The need for that much surface area exposed to water was quickly addressed.

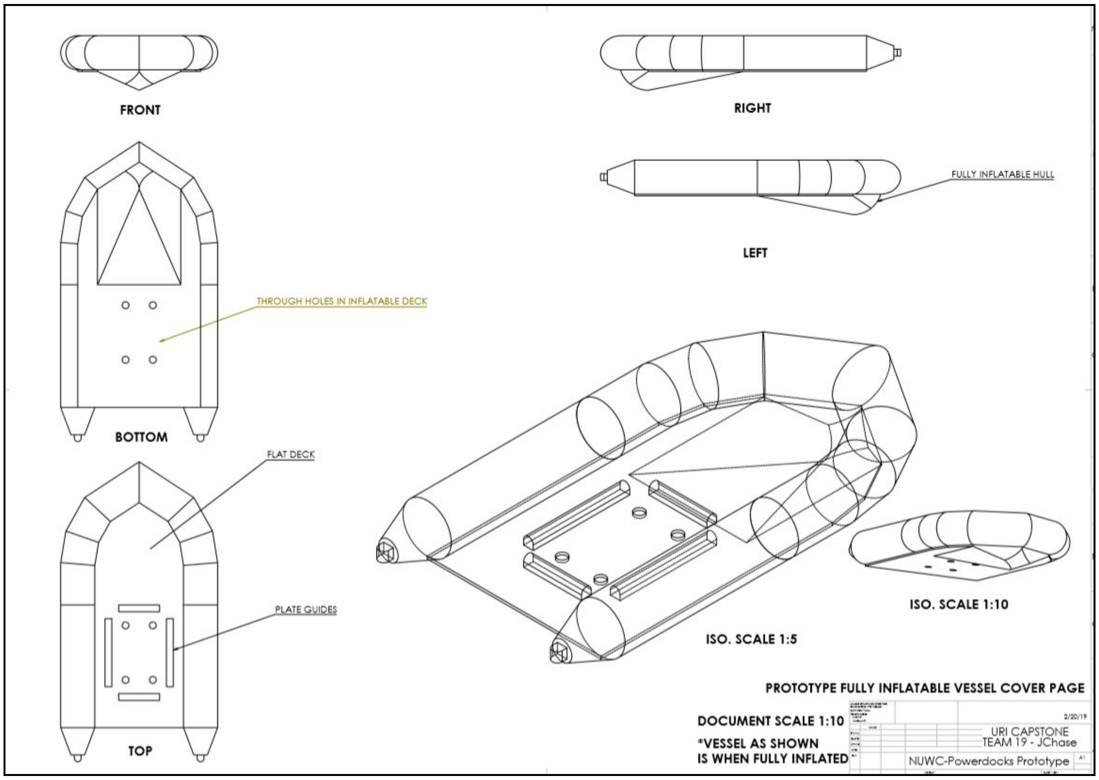


Figure (52): Image of Updated Prototype Drawing

The tweaking led to the four-hole design, as seen above. These four holes were still supposed to allow the black box to connect to a motor mount underneath. After a meeting with the sponsors, the issue of vessel stability was brought up. The team added an inflated section in the rear, adding stability and preventing immediate flooding. More discussions lead to an additional tweak, the one-hole design.

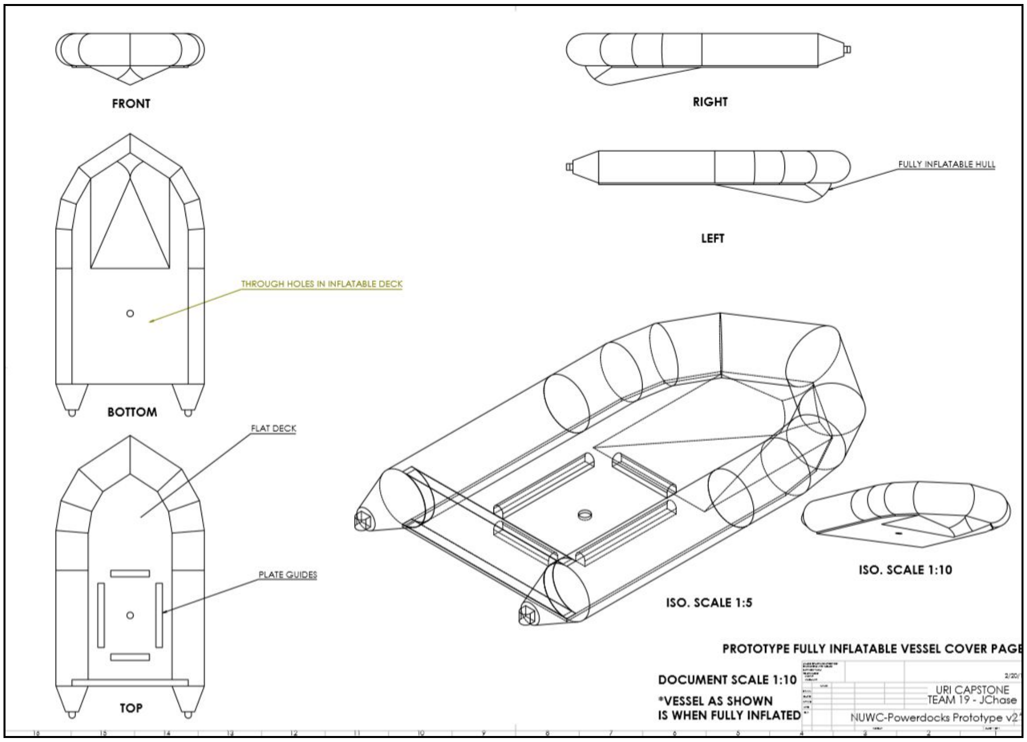


Figure (53): Image of Updated Prototype Drawing

This design saw more progress than any other model version at the time. The team moved forward with this until further review revealed the hull would need to be updated.

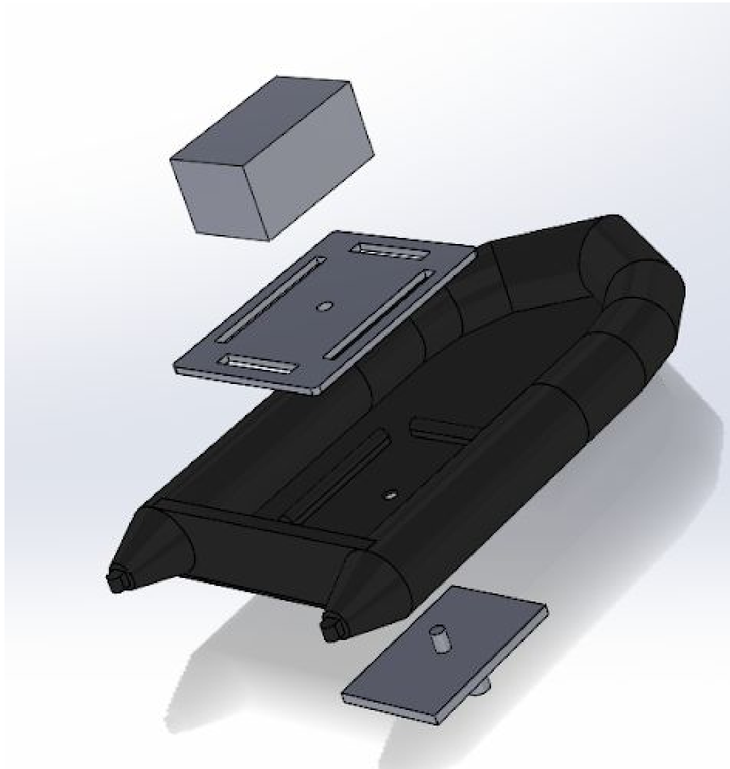


Figure (54): Image of Initial Model Assembly

The hypothetical mounting plate (to the vessels flat deck) would come to create an addition wave of problems. More forces and moments were created, almost needlessly so. The team decided, while they updated the hull profile, to scrap this aspect of the design. An opening to the water was not necessary for the sponsors. PowerDocks stated that the wiring to the motors could run externally, and that we did not need to focus on this aspect of the design. The flat deck was simplified from this point on. The team went on to add additional vessel stability and support - in the form of rigid floor inserts and another inflatable divider. The final design was realized and then used in continuing the CFD research.

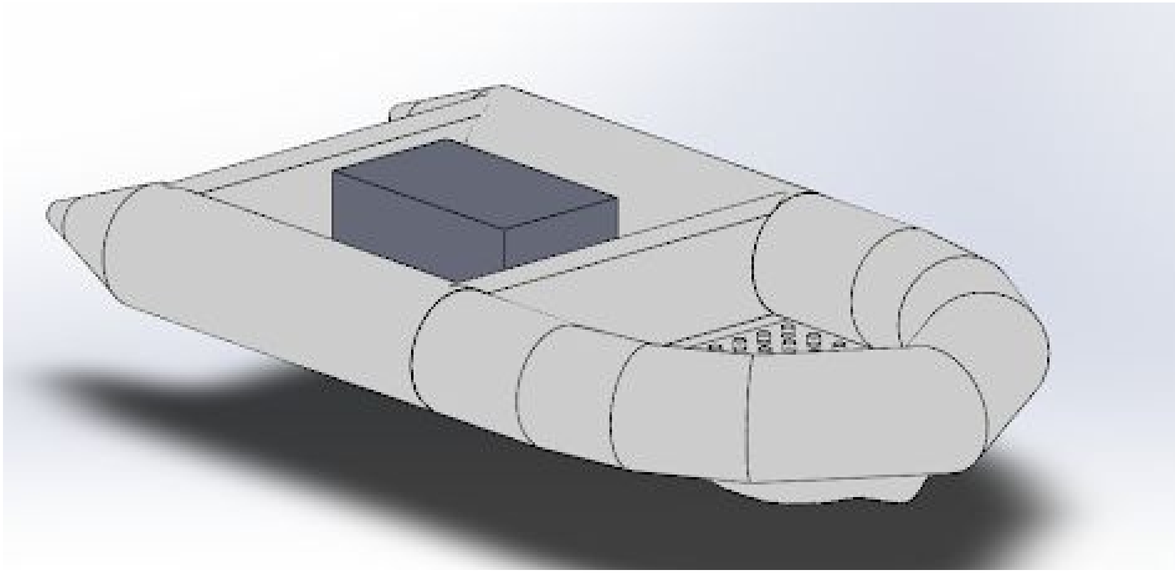


Figure (55): Image of Initial Model

11.2.1 Descriptions/Reasons for Updates

After presentations of initial vessel designs our sponsor required that the team design a hull that has more wave piercing capabilities. The first hull design was created mimicking a planning and deep V hull. Through extensive research it was found that a dead rise angle of 20 degrees was best for the team's application [1]. Due to the completely inflatable nature of the vessel, a high dead rise angle was not feasible. Manufacturing an inflatable with an increased V angle is not possible. The smallest degree dead rise angle with the smallest maximum pressure (drag) was found to be 20 degrees in [1]. This angle offered a feasible design approach while still offering decreased drag. The hull also proved to be too complex of a design for manufacturing purposes. If the original hull was to be inflated, the geometry would cause bowing-out in unintended ways. Aside from the hull, the black box integration was changed. Forcing the flat deck to support the black box and the load would cause easy stretching and tearing due to the lack of vessel rigidity. Team 19 removed any trace of an open-water opening in the vessel, and decided on an external plate insert to secure the black box as well as add vessel stability. Inflated cross sections were added to divide the vessel and provide additional security for the flat deck floor inserts. The floor inserts were necessary because there was a need for a rigid component to flush out the vessel profile as well as support the payload.

11.2.1.1 Hull Evolution

The hull design needed changes to provide a more fluid flow friendly shape. The initial design had four different sections that needed to be inflated in order to achieve the required shape. After interfacing with our sponsors/coordinator, and conducting a preliminary CFD simulation it was brought to the team's attention that the hull had high total resistance (drag) values. This was due the corners in the hull depicted below. Initially these corners were incorporated to indicate where the stitching of the hull was, in order to create its complex shape.

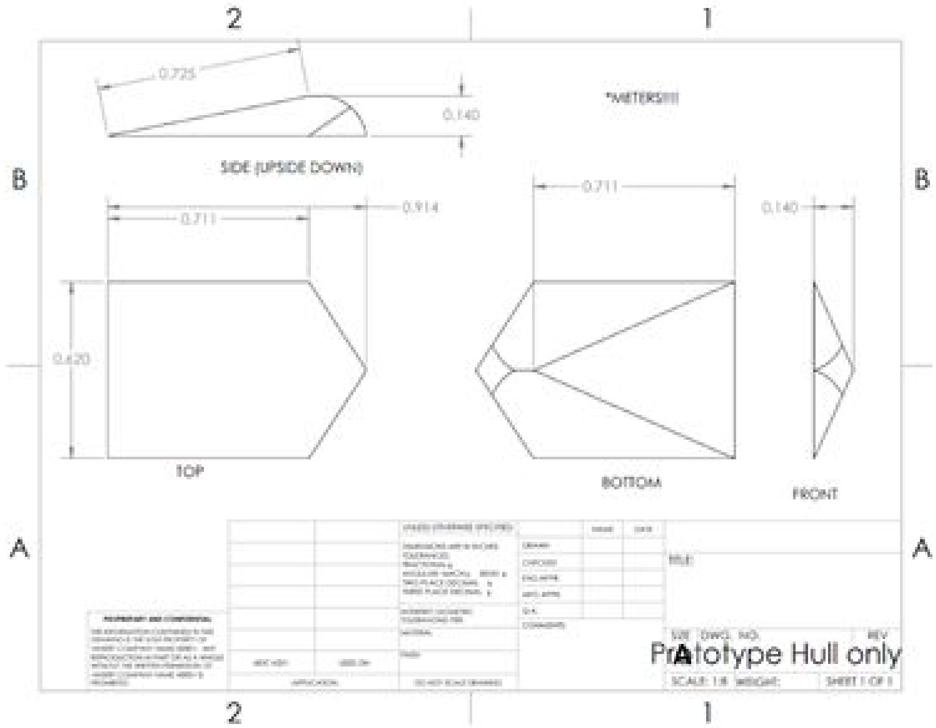


Figure (56): Initial Hull Design

The evolution approach was to minimize the amount of inflatable sections as well as providing increase flow past the Hull. The initial design called for four inflated section while the new design only called for two. Minimizing the inflation sections decreases the assembly time. The dimensions of the hull was kept the same as well as the dead rise angle. After conducting CFD drag performance predictions, It was concluded that the evolved hull provided decreased drag overall.

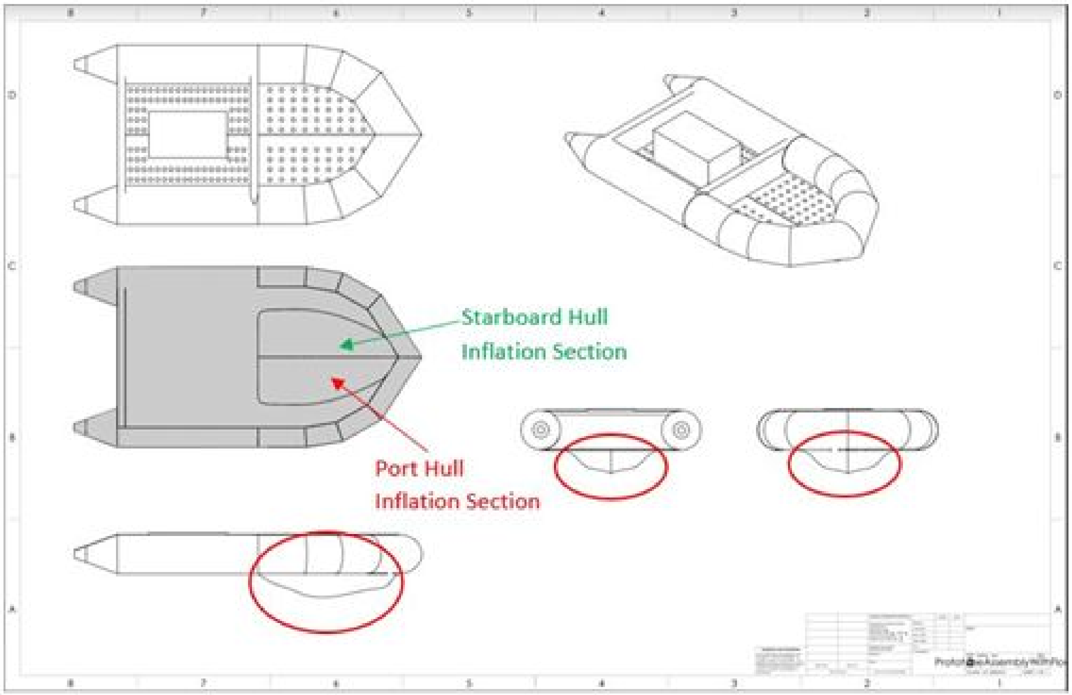


Figure (57): Evolved Hull Design

11.2.1.2 Stability Concerns

While the topic of stability has been touched upon in other sections, the concerns will be fully fleshed out and summarized here. As noted in the redesign section, a sizable effort was made into making the vessel keep its shape while being inflated. The vessel originally had a well designed outer geometry but lacked internal support to make it “rigid like” upon inflation. The rear of the vessel was easily subjected to a “toe- in” collapse. This is where the rear tube sections could be made to touch each other under the right conditions. This would be possible because of the malleability of the inflatable material and lack of a rigid skeleton . The openness of the rear also invited immediate flooding. This is because as soon as load was applied to the rear of the vessel (i.e. the black box) the rear would ever so slightly tip backwards and begin to take on water. The vessel would quickly lose buoyancy as the craft took on more and more water until the vessel would sink. One inflatable divider was added to the rear to prevent the craft from immediately taking on water. The divider also created a “rigid like’ connection between the rear of the vessel’s tubes. To further address the stability of the tubes, a second divider was added to the midsection of the vessel for more even distribution of possible opposing forces. The divider would also help to maintain the inflated vessel profile.

While these divider sections helped to give body to the vessel, the craft still needed more. The team realized the designed vessel was large in size, so a more rigid skeleton was deemed necessary. Two, two piece, interlocking floor segments were designed out of ABS plastic. These floor pieces were planned to offer in-vessel stability when exposed to seaside compression or other physical forces. The floor inserts would also provide a rigid body shape down the centerline of the vessel, furthering the focus on the maintaining vessel shape.

12 Project Planning

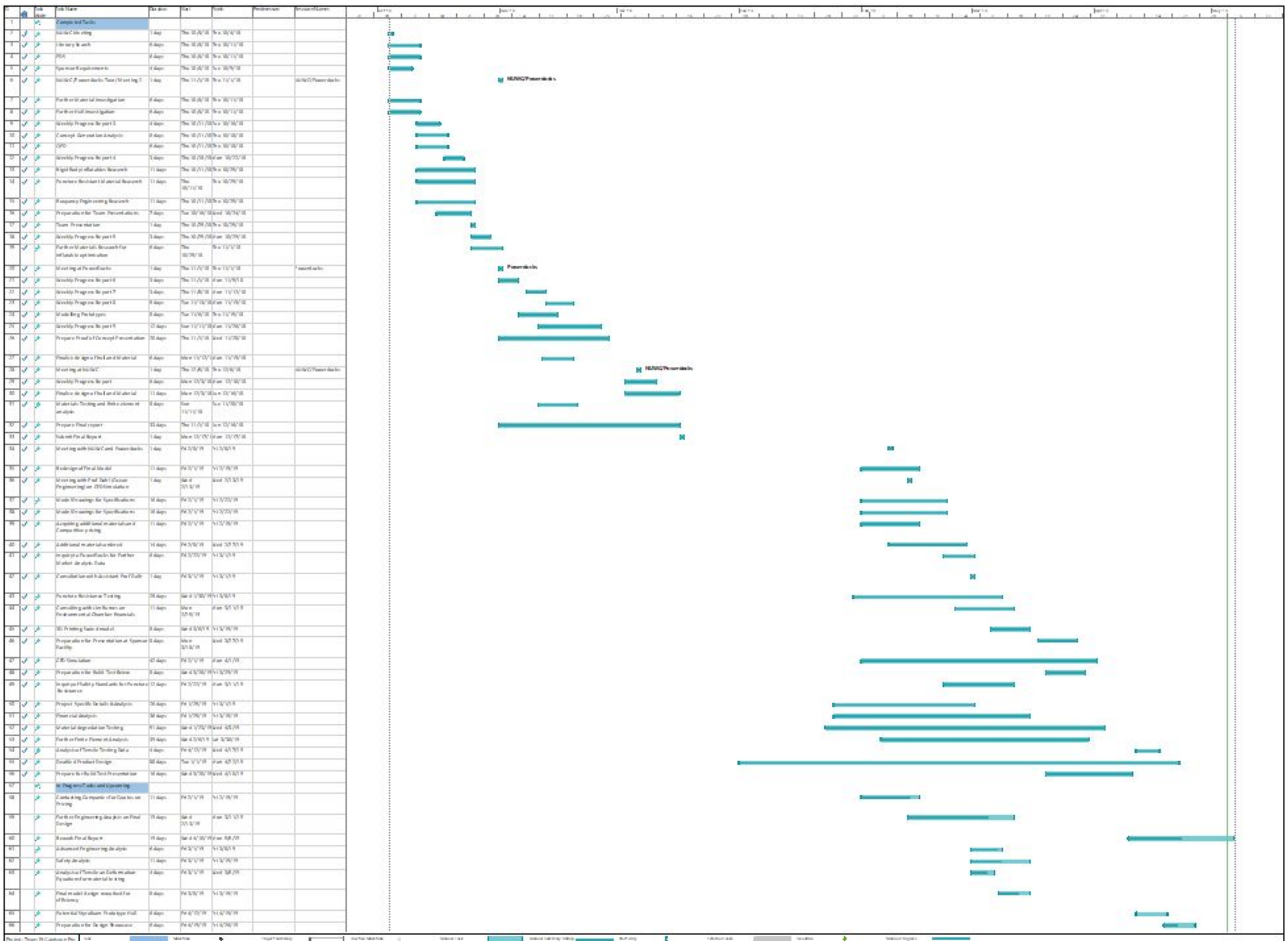


Figure (58): Gantt Chart Showing Project's Progress over Fall and Spring Semesters

12.1 Project Coordination Outline

The project presented in this design report began on Tuesday September 25, 2018. The project was divided up into two semester based on the University of Rhode Island's academic calendar. Throughout the fall semester, the team was expected to conceptualize and begin design on the product that our sponsors, NUWC and Powerdocks, had tasked us with. Along with relevant literature and patent research, the semester overall ensured that the overall scope of the project was understood where our sponsor meetings aided in this area. From this due diligence a proof of concept was constructed and the following semester would encompass its road to fruition. Therefore, spring semester more so was about the team's' ability to use the proof concept and fully design and test the product in all areas that would ensure that our sponsors design specifications were met.

Microsoft Project was used to track the progress of the project for each semester. The Gantt chart developed displayed current tasks as they were happening along with completed tasks. The tasks also increased as each semester went on based on increasingly new aspects of the project that were not known. However, as each task was completed it was marked off and moved to the completed section of the chart. On the left hand side a section for current tasks and a section for completed tasks was made and on the right hand side each tasks allotted completion time was documented using a horizontal bar chart.

12.2 Fall Semester

Fall semester tasks can be seen at the top in Figure ( ). The initial task seen in the figure is the sponsor meeting and the final task of that semester was the submission of the preliminary report. However, also it can be seen that there are numerous tasks between those two points in the semester each with its own importance to the overall completion of the project. Sponsor meetings with NUWC and Powerdocks were approximately one per month and these provided the team with feedback as we progressed along as guidance with what to do going forward. The patent and literature search conducted gave the team a better understanding of the project and its applications. As the literature and patent searches continued, the team was able to develop a PDS which was then sent to our sponsor to get detailed specifics of the vessels requirements. After, this document was returned each team member set out the conceptualize thirty possible designs for the inflatable vessel. The teams narrowed the 120 vessel design into four main designs that seemed more feasible. Additionally, as seen in Figure ( ), weekly progress reports were also submitted to show the progress of the project. Other than the progress of the project these reports also gave the issues and considerations that were coming up in the project as the semester progressed. Quality Function Development (QFD) analysis was completed to determine the critical design parameters of the vessel. The QFD is further discussed later in this report.
Research was an essential portion of the fall semester workload. The team's unfamiliarity with inflatables meant that research into this are was absolutely necessary. Puncture resistance research and buoyancy research was also conducted to gain better understanding for the material. Subsequently, presentations were given by all teams as the Critical Design Review where the final concept or concepts were displayed to the sponsors and other classmates. Feedback was received and the modelling of the final concepts commenced. The final concepts were all

modelled in Solidworks and FEA testing was conducted on these models. The finalization of the model then followed and the Preliminary report was written.

12.3 Spring Semester

At the start of the Spring Semester the customary sponsor meeting took place. The informal meeting was to touch base and gather the ideas for the upcoming and final semester of the project. Since the fall semester we had conceptualized numerous designs and narrowed them to four final designs. It was now time to put forth one final design even if it needed to be adjusted as the semester progress. In Figure ( ) we see that the Final design concept was added to the Gantt chart along with tensile testing and environmental testing. These tests took place after the acquisition of our ordered samples. These tests overall provided substantial insight into puncture resistance and material degradation as it related to the vessel and its expected conditions. Additionally, CFD consultation Dr.Dahl from the ocean engineering department and Matthew Murphy from Navatek are mentioned in the project plan because of the progression of our final design and hull model. Subsequently, preparation for the build and test review commenced. The build and test review presentation was the final presentation before the design showcase. NUWC and Powerdocks were present and we had a final meeting before the culmination of the project and semester. Finally, the deadline for this report was the last mention on the Gantt chart.

12.4 Routine Sponsor Meetings

The Sponsor meetings took place at the beginning of each month and typically served as a way for our sponsor to touch base and keep up with the progress of the overall project. As the project progressed the meetings became more in depth as we discussed design requirements and specifications that our final product should adhere to. From there the meetings also became about the steps we could possibly take to reach particular goals. Specifically in one meeting the design of the hull was discussed and one of our sponsors, Anthony Baro, aided us with the design of our hull. NUWC and Powerdocks also had access to all files and could see real time progress in our Google Drive folder.

13 Financial Analysis

13.1 Project Financial Outline

The following sections is the entire breakdown of the financials of this extensive project. Areas such as budget, cost analysis, market survey, and cost of test materials will be discussed along with several other aspects of the financials of the teams' progress with the project. Upon the commencement of the project, the team was given design specifications and within those specifications we were also given an approximate finished product cost of the vessel. This number was to be between $5000 to $10000. Additionally, based on the vessel's proposed use; our sponsors also mentioned that we should look at possibly having these vessels in all ports in the US and possibly outside of the US to aid with surveillance and security. Additionally, the vessels were also proposed to help with natural disaster relief in any US states or countries that may need that added aid to carry supplies or transport rescue personnel.

13.1.1 Budget

The overall budget of the product and related research and design of the inflatable vessel was between $5000 to $10000. However, this did not take into consideration the consulting and human allocation cost. Therefore, overall it was believe that this price point was approximately supposed to suggest the end price of the boat and what we should aim to have one unit fully manufactured for. As will be seen later in this section of the report. The entire cost of the research and design of this inflatable vessel was substantial.

13.1.2 Cost Analysis

Within the budget itself, it was essential that we considered multiple expenses such as human allocation cost, use of facilities and machinery, consulting and materials cost. As mentioned above the use of certain essential programs and facilities that contributed the project's success were analyzed and can be seen in the table below.

Table (15): Table of the Overall cost of the Necessary Computer Programs

Software	Cost per license	# of licenses required	Total cost
Solidworks 2017	$3995.00	4	$15980.00
Solidworks Simulation	$4570.00	2	$9140.00
Microsoft Office 365	$33.00	4	$132.00
Microsoft Project	$539.00	2	$1078.00
		Total Software Cost	$26330.00

Additionally, the teams overalls cost of labor was also accounted for based on the hours spent per week on the project and calculated based on the average engineer's salary of approximately

$70,000. In the tables below, the hours each teams member spent on the project over the last year; fall semester and spring semester, was calculated and totalled for an overall cost.

Table (16): Table of Overall Cost of Hour Spent by Entire team For Fall Semester

Week ending	Jacob	Jean-Pierre	Alex	Steven	Total	Payout
9/7/18	10	10	10	10	40	$1,354.17
9/14/18	10	10	10	10	40	$1,354.17
9/21/18	10	10	10	10	40	$1,354.17
9/28/18	10	10	10	10	40	$1,354.17
10/5/18	10	10	10	10	40	$1,354.17
10/12/18	10	10	10	10	40	$1,354.17
10/19/18	10	10	10	10	40	$1,354.17
10/26/18	10	10	10	10	40	$1,354.17
11/2/18	10	10	10	10	40	$1,354.17
11/9/18	10	10	10	10	40	$1,354.17
11/16/18	10	10	10	10	40	$1,354.17
11/23/18	15	15	15	15	60	$2,031.25
11/30/18	15	15	15	15	60	$2,031.25
12/7/18	15	15	15	15	60	$2,031.25
12/19/18	15	15	15	15	60	$2,031.25
12/26/18	15	15	15	15	60	$2,031.25
Term Total	185	185	185	185	740	$25,052.17

Throughout the entire year a cumulative cost of $49,427.20 was spent in relation to the team's time spent on the entire project. As can be seen in tables ( ) & ( ), as deadlines approached in each semester additional time was spent by each team member to ensure the team's success. The time spent by each team member would have be divided up into various sections such as design, research, writing, testing, analysis and group work. Overall, the project was successful because of the time each member spent and the excellent time management skills each team member displayed.

Table(17): Table of Overall Cost of Hour Spent by Entire team For Spring Semester

Week Ending	Jacob	Jean-Pierre	Alex	Steven	Total	Payout
1/25/19	10	10	10	10	40	$1,354.17
2/1/19	10	10	10	10	40	$1,354.17
2/8/19	10	10	10	10	40	$1,354.17
2/15/19	10	10	10	10	40	$1,354.17
2/22/19	10	10	10	10	40	$1,354.17
3/1/19	10	10	10	10	40	$1,354.17
3/8/19	10	10	10	10	40	$1,354.17
3/15/19	10	10	10	10	40	$1,354.17
3/22/19	10	10	10	10	40	$1,354.17
3/29/19	10	10	10	10	40	$1,354.17
4/5/19	15	15	15	15	60	$2,031.25
4/12/19	15	15	15	15	60	$2,031.25
4/19/19	15	15	15	15	60	$2,031.25
4/26/19	15	15	15	15	60	$2,031.25
5/3/19	20	20	20	20	80	$2708.33
Term Total	180	180	180	180	920	$24,375.03

The table below is a great representation of the overall cost of the time spent with consultants that was needed for the overall success of the project. This time spent was essential as there were numerous aspects of the project that were widely out of the scope of our general education. This is why the consultants were an essential element to our project. Firstly, Mr. Matthew Murphy, an engineer at Navatek was extremely helpful with the CFD simulations of our vessel along with providing us with the Navasim software to produce these simulations. Overall, from the ending of the Fall semester up until the end of the spring semester; an allotted 50 hours were spent approximately with Mr. Murphy trying to obtain accurate and useful CFD simulations.

Additionally, help was sought from Dr. Dahl, a professor on the Ocean Engineering campus of URI to also assist with the CFD and with the buoyancy of the vessel and overall design of the hull. Lastly, Dr. David Taggart, a full time engineering professor at URI, also aided us with the material selection of our vessel and was also able to steer us in the direction of obtaining samples. Overall, each contribution by these three individuals was monumental to the project especially in the areas that were unfamiliar.

Table 18: Table of Overall Cost of Time Spent with Consultants

Consultant	Time (hrs)	Rate ($/hr)	Total ($)
Mr. Matthew Murphy	50	33.85	1692.50
Dr. Dalh	25	42.31	1057.75
Dr. Taggart	15	42.31	634.65
			3384.90

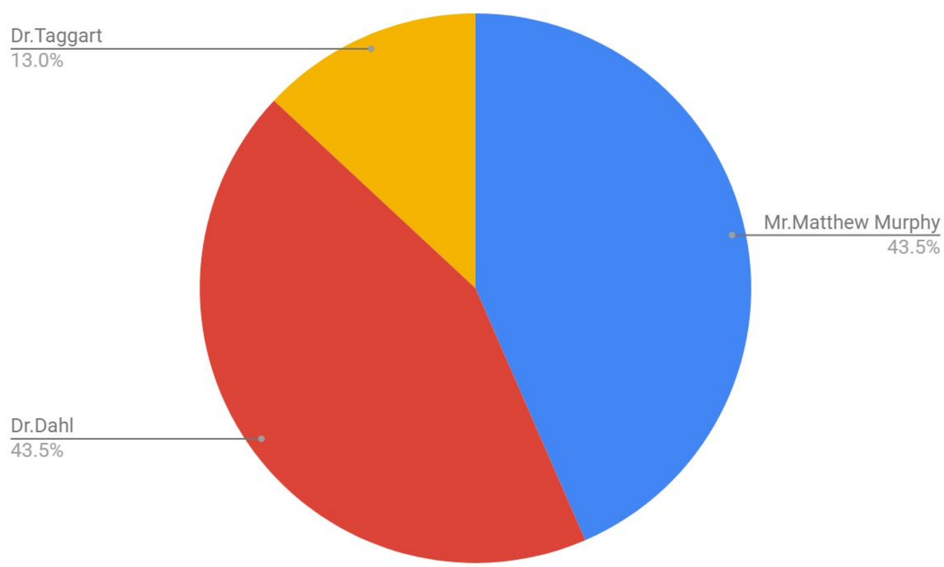


Figure (59): Figure of Overall Cost of Time Spent with Consultants

13.2 Market Survey/Extrapolations

There are a few varying markets where our product might be effectively utilized and can be in great demand. Other than its military and naval applications. The end product we are hoping to achieve can delve into other markets such as Port Security, Coastal security, dredging of marinas, construction and agriculture to name a few. Additionally, these inflatable, autonomous and solar powered vessels can also be used by entities like FEMA in natural disaster relief efforts.

Firstly, port security; globally is a multibillion dollar industry; encompassing airport and marine port security with a current value of 53.87 billion dollars and an expected growth to 110 billion in the next 6 years. However, our inflatable vessel design would delve mainly into the marine port security and has a great opportunity to be efficiently used in the industry aiding with security within the ports by means of patrol and towing supplies to and fro. Its added solar power features would also prove to be a long lasting investment at each of the ports around the world.

Coastal security, on the other hand is also another large industry and is affected on a global scale. With respect to dredging and construction it was found that steps have been taken toward having autonomous vessels outfitted with the newest technologies as can be seen in this article from www.westerndredging.org. In the tables below we can see some of the technology some of the proposed vessels would be outfitted with and another table averaging the cost to manufacture them from different entities.

Table (19): Table of the overall cost of a completely outfitted USV

Table 2. Component cost of USV.

Part Name	**Quantity**	**Cost (each)**
Lifetime, 6', 1-Man Wave, Youth Kayak	1	$85
3/4 in. x 9-1/4 in. x 8 ft. White PVC Trim (3-Pack)	1	$111.93
PERKO Extra Long Thru-Hull Connection	1	$67.55
3800 Watertight Protective Case - 16-5/16 In.	1	$39.99
2800 Watertight Protective Case - 13-3/4 In.	1	$29.99
1800 Watertight Protective Case – 9-3/16 In.	2	$14.99
ANCOR Through-Deck Wire Seals	6	$7.49
AmazonBasics 4 Port USB 3.0 Hub with 5V/2.5A power adapter	1	$16.99
Linksys AE2500 Dual-Band Wireless-N USB Adapter	1	$28.95
SmallPC custom computer	1	$5,500
PixHawk Autopilot	1	$95
DC-DC Converter 8V-40V Step Down to 12V 6A 72W Voltage Regulator Power Supply	1	$32.90
Tattu 26000mAh 22.2V 25C 6S1P Lipo Battery Pack	2	$444.60
Tattu 30000mAh 22.2V 25C 6S1P Lipo Battery Pack	2	$517.13
T200 Thruster	2	$169
25mw/200mw Hrs270t Fpv 5.8g 48ch Av Transmitter Wireless Camera Clover	1	$30.87
Mounting hardware	1	$100
FrSky Taranis X9D Plus 16-channel 2.4ghz ACCST Radio Transmitter	1	$209
Callisto Automation labor	1	$5,315
SurvTech Solutions labor	1	$8,750
Total		**$22,750**

Table (20): Table of a cost comparison for competitors of completely equipped vessels

Table 1. Cost comparison based on recent equipment quotes.

Manufacturer	Vessel Specifications	Cost
Competitor A	Includes autopilot board pc, thrusters, and battery power	$26,600
Competitor B	Catamaran style, includes autopilot board pc, thrusters, and battery power, proprietary acquisition software	$45,000
Competitor C	Includes autopilot board pc, thrusters, battery power, proprietary acquisition software	$92,000
Competitor D	Includes autopilot board pc, thrusters, and battery power	$113,000
Competitor E	Catamaran style, includes autopilot board pc, thrusters, and battery power, PTZ camera	$154,000

As can be seen in the above tables, these USV can become a costly item after all relevant and necessary equipment are added. However, with the lower end of our price point of $5000 per unit; if we were to estimate an approximate 360 marine ports within the US alone; we can approximate the market value for this version of an autonomous vessel to equal $3.6 million alone. This market value does not encompass the types of price points we seen in the tables above for the vessel and therefore the estimated 110 billion growth mark seems more attainable.

13.3 Prototype Costs

This section would encompass the overall costs of a possible prototype; however, due to the inability to get return quotes from various companies for a scaled model of our vessel we were unable to produce a prototype. However, it can be deduced that the cost to produce a scaled model for prototype purposes can range between six hundred to two thousand dollars as this is the range of the competitor prices before any equipment is attached.

13.3.1 Testing Materials

For the testing of different aspects of the vessel, an order of different types of hypalon and PVC was placed. Overall cost of testing materials was approximately $100 after purchasing three forty-five dollar tarps of hypalon, another section of coated hypalon and a small amount of PVC fabric.

13.3.2 Purchased Components

The solar panel costs $300 per panel and 4 are needed which brings the total cost of the solar panels to $1,200. The ElectraFin costs $1,800 per unit and 2 are needed so that brings the cost to $3,600 for the ElectraFins. The total cost of the purchases components are $4,800.

13.3.3 Manufactured Components

Though emails were sent out looking for quotes from inflatable raft manufacturers, no company responded with a quote. These are the prices for the raw materials.

The amount of PVC and Hypalon needed for the raft is 14.87 square yards. Hypalon by the yard costs around $60, bringing the raw cost of Hypalon to $900. PVC used for inflatables costs around $25 by the foot. About 134 feet of PVC is needed bringing the price of raw material PVC to $3,350.

13.4 Company Quotes

The team reached out to 15 vendors inside the United States as well as 2 outside of the United States once our sponsors were consulted. The vendors outside the country were emailed with a different email which left out the fact the Navy was sponsoring the project. A list of the vendors were:

Table (21): Table of List of Companies Quotes were Requested From

United States Vendors
Zodiac
SOTAR
Alpacka Raft
Aire
NRS

Cascade River Rafts
Sailski Boats
Winslow Raft
Rocky Mountain Rafts
Glacier Raft Company
ACE Raft
Durango Rafting
The Creek Company
Southern Raft Supply
Hewitt Rafts
International Companies
Qingdao Ilife Industries Co.
Weihai Hi Wobang Yacht Co.

Many of the larger companies such as Zodiac did not respond to our email asking for quotes on a scale model, 1000, 2000 and 5000 units. Some of the smaller companies responded saying they could not handle the order or capable of the design. A few commented on the complex shape of the inflatable hull, which was taken into consideration during the redesign stage. More emails were sent out with the new design but there were no responses.

13.5 Fiscal Summarization

The entire research and design of team 19's inflatable vessel with its fully inflatable hull and well supported flat deck had an overall cost encompassing human allocation cost, consulting cost, test materials cost and software costs. The end price was approximately $79,242.10. However, this amount does not include the possibility of a fully design prototype with solar panels and motor. In retrospect, not many of these costs could have been cut back based on the vast amount of research that needed to be done and the design and consulting that was clearly essential to the completion of the project. All i nall, once brought to market, the over cost of human allocation cost etc will seem miniscule as profits will be well in to the millions.

14 Operation/Assembly/Repair/Safety

14.1 Operations and "Assembly" Outline

Due to the autonomous capabilities of the vessel, not much is required to operate once it is deployed at sea. The primary focus of operation and assembly is the set up required prior to deployment. A list of materials as well as set up procedure is included with the vessel.

List of Materials

- Deflated Vessel
- Hand Pump
- Black Box Electronics Provided by the sponsor
- Foldable Accordion Solar Panels Provided by the sponsor
- Two ElectraFin Motors
- Specified Payload
- ABS Floor Inserts

Set Up Process

1. Unfold Vessel from backpack storage.

2. Layout deflated vessel.

3. Connect Floor Inserts together via hex locking mechanism.

4. Place Floor inserts on top on the deck portion of deflated vessel in order to increase stability while inflating each section.

5. Inflate middle cross member supports via hand pump mechanism.

6. Inflate perimeter cross sections of the vessel via hand pump.

7. Inflate port and starboard side of hull sections.

8. Lift the back of the inflated vessel and attach motors to the female pre adhered slot fins.

9. Place black box in designated area.

10. Attach solar panels on the inflated cross section perimeter of the vessel via clip in female straps located on vessel.

11. Connect Solar Panel wires and motor wires to Black Box.

12. Place payload on designated flat deck area.

13. Initiate Autonomous controls.

14.2 Repair Methods

Due to the completely inflatable nature of the inflatable small leaks and punctures may be repaired but holes larger than two inches in diameter require support from the manufacturer. Upon noticing a small hole in the vessel, deflate the vessel completely and dry the affected area. Cut a new piece of PVC at least 30 mm away from the hole in every direction. Apply an adhesive solvent on both sides of the patch as well as the affected area. Place the patch on the affected area from one side to another. Use a roller on the patch to ensure the adhesive sticks on to every part of the surface. If the inserts or electronics malfunction or break be sure to contact manufacturer for replacement of further steps to assess the issue.

14.3 Safety Considerations

After completing the vessel design, safety consideration had to be presented. One major consideration that was implemented was pressure relief valves for instances of over inflation. Another consideration were the various inflatable compartments. These compartments were necessary so the entire vessel wouldn't deflate during the event of a puncture. Lastly the final consideration that was thought of was the installment of GPS technology on the black box so that the vessel could always be tracked. In the event of a fatal puncture the components could be retrieved by divers. Additionally in the event of flood relief the GPS could be used to locate where crucial areas are located, such as survivors.

15 Maintenance

15.1 Maintenance Outline

The maintenance of the vessel is crucial in order to increase the life of the vessel at sea. The main components that need to be maintained are the floor inserts, and the vessel body. The electrical components as well as motors, and solar panels are to be inspected and tested after every other use. While the vessel body and floor inserts should be inspected after every use or after every three days at sea.

15.2 ABS Floor Inspection

The floor inserts should be visually inspected for cracks or debris. The inserts are to be removed from the vessel placed on the floor and high pressure washed. Due to the holes in the inserts to reduce the overall weigh, the inserts are prone to attracting debris which over time can build up and effect payload area and stability. A low pressure soap wash should also be used to remove any tough grime attracted on longer seafaring missions. The inserts should then be left to dry preferably in the sun and further inspected when dry. If the inserts still have debris or grime built up this process should be repeated until no debris is present.

15.3 Vessel Body Inspection

Once all components of the vessel are removed a 360 degree visual analysis of the vessel inflated should be conducted. The viewer should look for any asperities, this includes anything stuck to the vessel, punctures, and debris. It is important to note that any foreign objects lodged into the vessel must be removed if possible without further damaging the vessel. Once inspection is complete, the vessel is low to mid pressure washed with a soap-water mixture. The vessel is then dried and deflated. The inflation points are cleaned with solvent wipes as well as compressed air. It is important to note that build up on the inflation nozzles must be prevented. The deflated vessel is then 360 degree inspected once again for any other debris/asperity. The wash process is repeated once again using a soap-water mixture and then dried. Once the vessel is completely dry and all other electrical components are inspected the vessel is ready for re-assembly.

16 Additional Considerations

The following categories below explore additional considerations of the inflatable vessel design study. These consideration vary from economical, societal, ethical, ergonomics, and environmental.

16.1 Economical Impact

The production and distribution of these vessels could be detrimental and essential to economy. Since these boat would be autonomous the amount of job and labor for personnel accompanying vessels similar to these would be eliminated. However, on the other hand, other jobs are created for maintenance of the vessels. Profits in all areas where these vessels could be increased as the labor cost is diminished in the US and globally. As a potential product, the vessel could sea local gains for PowerDocks, and improved military operations at NUWC. This vessel will be expensive, so private use is not foreseen, but rather community ports, docks, and extended naval use.

16.2 Societal and Political Impact

This vessel can be used for humanitarian aid as well as the private sector. It can be deployed in large numbers to an area affected by floods to bring supplies to people in need. It also has some port security capabilities. This vessel is simply for payload transport, the aid it could offer (in the correct environment) change lives. Because of a military application, it could be used to further the effectiveness of related military involvement, which has obvious ties to local and national governments. The military association could make potential production across seas an issue, though this practice is not commonly an issue. Military related technologies could be regarded as negative, so the cross compatible design as a consumer good is an additional boon.

16.3 Ethical Considerations

Since this is a small vehicle controlled remotely, there is a chance it could be used for spying or other nefarious acts like with drones today. As mentioned in the societal and political impacts, military use offers a bevy of concerns and issues from the public. The autonomous nature that the vessel is planned for could be used to negatively affect other nations and peoples. While this isn't good, it is the nature of military technologies and related products. On the other hand, the vessel also has a consumer base, so the implementation of that product by the navy disconnects the moral burdens of creating a potentially unethical craft.

16.4 Health/Ergonomics/Safety Considerations

Since this vessel has humanitarian use, safety is an area of concern. Some possible hazards include puncture, propeller blades, and sinking. To counteract any threat of puncture, a materials test was conducted to prove that rocks will not puncture at 20 joules, which is the minimum requirement to be called puncture proof. The vessel also has separate internal chambers which will provide buoyancy if one section is punctured and deflates. The vessel is also designed to provide five times the buoyancy required including a 100 pound load. This would help if there was a puncture as well as providing stability in a sea state 6. If it was not this buoyant, water coming onto the vessel is this sea state could sink it.

16.5 Environmental and Sustainability Considerations

The inflatable vessel design study was conducted primarily to achieve an optimal configuration for the requirements set by NUWC and PowerDocks. The team hopes that this vessel design be used as PowerDocks building block for autonomous navigation systems. The vessel provides a sustainable design and redesign capabilities to feature an increased payload weight as well as physical vessel size. Testing was done to observe material degradation, and the team believes that the craft will survive on timely missions.

Electric propulsion provides a green energy efficient approach that does not harm ocean organisms and microorganisms. Solar panels provide the vessel with self powering capabilities, that in theory are endless in amount.

The inflatable vessel could fail and sink. The vessel in its entirety may be seen as a loss and contribute to fresh and ocean pollution. While this vessel has been design to not sink, there is always a possibility of this happening.

17 Conclusions

17.1 Conclusions

NUWC and PowerDocks approached The University Of Rhode Island and chose team 19, later known as team NARWL, to conduct an inflatable vessel design study. The vessel had specific design constraints both deflated and inflated. Inflated the vessel needed to be maneuverable at 6 knots, and capable of withstanding sea state 6 conditions. The final materials chosen for further analysis were Hypalon and PVC. The material analysis consisted of prolonged exposure to seawater as well as puncture testing. Deflated the vessel must be carried like a backpack and weigh approximately 25lbs. The vessel will be capable of carrying a 100lbs payload. For ergonomics and payload safety it has been concluded that the vessel must have a flat deck. The design parameters such as the length, width, and height are 6ft, 4ft, and 1.5ft respectively.

The final design presented by team NARWL to NUWC and PowerDocks was a combination of the previous semesters designs. It included a flat deck in the front of the vessel, inflatable cross sections to provide lateral stability and a V shaped hull. The hull design was continuously improved after getting feedback from inflatable raft vendors and consulting with Dr. Dahl of the University of Rhode Island and Navatek. The hull was designed to be inflatable but had to be tested as though it was a rigid hull. This let to the idea of a rigid hull that could be shelled to have the inflatable raft fold into. Both concepts were presented to NUWC and PowerDocks to be used at their discretion. The weight for both hull designs were under the maximum weight limit of 25lbs.

Newer features developed this semester included a solid ABS plastic floor section, inflatable cross sections, area for solar panels and possible means of propulsion. These were all developed due to the fact that the vessel was completely inflatable and had inflatable properties. Our original design had an open back which allowed water to seep into the rear of the vessel and weigh it down. This could lead to the vessel sinking. The rear tube will negate that as well as provide support and maintain the shape of the rear of the vessel. Another inflatable cross section was inserted into the middle of the vessel to maintain its shape as well as separate the payload area from the black box area. It also provides support to the black box keeping it in place. The ABS plastic floor inserts were designed to provide stiffness to the front of the vessel to support the payload area. Without these inserts, the front would start to bow. There are four sections, two for the front, two for the rear. The rear ones provide support to the black box as well as keeping the back stiff so the propulsion does not tear or deform the inflatable. Waterproof solar panels were added which are flexible so they can be installed on the sides of the vessel. It was realized the propulsion had to come from to propellers so the vessel could turn. An ideal means of propulsion would be the ElectraFin. This is an electric motor that can provide 10 hp which is more than enough to move the payload and vessel at 6 knots.

There were also some fail safes installed in the vessel. To prevent over inflation, pressure release valves could be installed. To help negate any puncture, the vessel is divided into segments so if one deflates, the others can support it. The vessel is also 25 times more buoyant than needed unloaded and 2.5 times more buoyant than needed loaded, which helps it survive in a higher sea state. Also to prevent the propeller blade from cutting the inflatable, there is a shield installed around the outside of that.

Testing was done on the hull, ABS plastic inserts and the materials. The hull was simulated through CFD. This helped the team redesign the hull and come to a final, simpler design. There was FEA done on the ABS plastic inserts to show it could support the payload. The materials were tested through a drop test to see how they handle puncture and how weather degradation affected them with a tensile test. The materials failed the first needle puncture test and passed the rock test. PVC did better than Hypalon in the tensile test.

An email probing for quotes were sent out to 17 companies. Only a few responded saying the hull design was too complicated which led to the team redesigning the hull. The new designs were sent out with even fewer responses. Most of those companies were smaller that could just not handle the requests. Further testing could be performed once the team has a scaled model.

Team NARWL presented its final designs to NUWC and PowerDocks which met all the design specifications. It was within the weight and dimension requirements, although some extra features may go over the weight limit. It should be able to survive a collision with a rock and be able to move a 100lb payload at 6 knots. The survivability in sea state 6 is the next step as it is difficult to simulate, so a scaled model is needed. This vessel will provide NUWC and PowerDocks with a backpack portable raft which can be used to help in disasters as well as port security or other commercial needs.

17.2 Further Work

The next step in this design project would be a final round of tweaking once a vendor responds to the request for a quote, making any adjustments to the design to make it manufacturable. Once that is complete, further research into the implementation on thrust's effect based on the motor placements may prove useful. Maximum power needs could be further pursued, if provided by

PowerDocks to fit certain applications. This may prove helpful to find cheaper alternatives to the ElectraFin or lessen the amount of solar panels needed. More tests could also be performed with a scaled model in the URI wave pool to see how it reacts to different sea states and how stable and maneuverable it is in practice.

17.3 Recommendations

It is recommended that the hull be constructed of rigid material to help with manufacturability as well as performance and mobility. It is easier to simulate the rigid hull design and having an inflatable hull may have different properties than predicted, i.e bowing out. Additionally the team recommends some amendments to the initial design specifications. IF the sponsors have a specific payload in mind, or a more defined payload size, the flat deck aspect could be custom tailored to the vessel utilization.

18 Acknowledgments

This project was proposed in collaboration with NUWC and PowerDocks LLC. Special thanks to the University of Rhode Island College of Engineering for providing the software and opportunity to conduct this assignment. Also, thank are extended to Professor Bahram Nassersharif, Professor David Taggart, Dr. Jason Dahl, Dr. Peter Hardro, and Mr. Anthony Baro, Matthew Murphy and all others involved for their coordination, assistance, and knowledge shared in order to make this senior project possible.

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20 Appendices

US 7,159,529 B2

1

INFLATABLE BOAT WITH A HIGH PRESSURE INFLATABLE KEEL

CROSS REFERENCE TO RELATED APPLICATION

This application claims priority to French Patent Application No. 04 06372 filed on Jun. 11, 2004, the contents of which are incorporated by reference herein.

FIELD OF THE INVENTION

The present invention relates generally to the field of inflatable boats, and it relates more specifically to improvements made to inflatable boats of the type comprising: a float that is generally U-shaped and open at the stern, and that is made up of at least one pneumatically inflatable tube whose aft ends are braced by a transom; a floor that is rigid at least transversely and that is disposed inside the space defined by the float, and a V-shaped keel formed of a flexible canvas sheet fastened to the float and to the transom and tensioned by a longitudinal inflatable keel-forming spacer interposed between said floor and said canvas sheet.

BACKGROUND OF THE INVENTION

Boats arranged in this way are already known, in particular from documents FR 1 155 376, FR 2 510 064, FR 2 734 234, and FR 2 795 040.

The well known advantage of inflatable keel-forming spacers compared with rigid keel-forming spacers, e.g. keel-forming spacers that are made of wood, lies in their light weight, and in the ease with which the boat as deflated and folded can be stored and carried.

Unfortunately, such inflatable keel-forming spacers suffer from a drawback that lies in the narrowness of the zone in which they are in contact with the floor. If the floor is insufficiently rigid, it can, over time, end up curving significantly in its central longitudinal region. Such a drawback might remain relatively insignificant with a floor made of wood or of a lightweight metal, regardless of whether it is made up of juxtaposed slats or of juxtaposed panels. However, the problem can arise more significantly with inflatable floors, i.e. floors formed by a flat chamber braced internally by ties and inflated under a relative high pressure.

Although the floor deforming to some extent does not jeopardize the capacities of the boat as regards both handling and safety, it does however appear highly desirable to prevent such deformation, or at least to minimize it so that it is no longer perceptible.

OBJECT AND SUMMARY OF THE INVENTION

Essentially, the object of the invention is to propose an original and inexpensive solution for solving the problem posed, without that also resulting in a significant modification to the general structure of the boat.

To these ends, in an inflatable boat as mentioned in the introduction above and as arranged in accordance with the invention, the inflatable keel-forming spacer is formed by at least two elongate chambers, each of which is defined by two substantially plane and parallel main walls that are braced by a multitude of flexible ties, each chamber being inflated under a relatively high pressure, and the two chambers are disposed with their respective bottom longitudinal edges touching and with their respective top longitudinal

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edges spaced apart from each other so that the keel-forming spacer is generally V-shaped in cross-section.

By means of these provisions, the composite keel-forming spacer of the invention continues to perform its function under the same conditions as a single inflatable keel-forming spacer, and in particular as an inflatable keel-forming spacer inflated under a relatively high pressure like the keel-forming spacer of Document FR 2 795 040. However, unlike a single keel-forming spacer, and in particular unlike the relatively high-pressure inflatable keel-forming spacer of Document FR 2 795 040 which bears against the floor over a narrow region only and which is thus characteristic of keel-forming spacers of the state of the art and suffers from the above-mentioned drawbacks thereof, the composite keel-forming spacer of the invention bears against the floor at two locations that are spaced apart from each other: thus the two component chambers of the keel-forming spacer of the invention define a wide bearing surface in the central longitudinal region of the floor, thereby tending to avoid or at least to reduce curvature thereof.

The arrangement of the invention can lead to multiple variant embodiments.

In particular, it is possible to make provision for the keel-forming spacer to comprise two chambers that are independent from each other.

It is also possible to make provision for the keel-forming spacer to comprise a single pouch that is flat in general shape and that is folded to form said two chambers that are inclined relative to each other in a V-shaped configuration. In which case it is advantageous for the single pouch that is flat in general shape to have at least one longitudinal constriction defining two communicating chambers situated on either side of said constriction, and for said pouch to be folded along said constriction to form said two chambers that are inclined relative to each other in a V-shaped configuration.

Commonly, the touching bottom edges of the inflatable chambers are curvilinear. In which case, it is desirable for the height of the chambers to increase very rapidly from the forward end to define a bow portion, and then to decrease gradually sternwards, and for the maximum height of the chambers in the vicinity of the forward end to be relatively large in order to impart to the tensioned canvas sheet the shape of a sharp bow portion that forms a relatively closed V-shape.

In a preferred embodiment, the floor is an inflatable floor formed of a flat pouch defined by two approximately parallel main walls that are braced by a multitude of flexible ties, said pouch being inflated under a relatively high pressure, and the inflatable chambers forming the keel-forming spacer are secured longitudinally and axially to the bottom face of said inflatable floor so as to form a single piece. It is then possible to make provision for a pneumatic communication link to be established between firstly the inflatable floor and secondly the inflatable chambers forming the keel-forming spacer, and for the single piece to be equipped with a single valve for simultaneously inflating the floor and the chambers forming the keel-forming spacer. It is then possible to consider making provision for the keel-forming spacer to be formed of two pouches, each of which has a longitudinal constriction which defines two communicating chambers situated on either side of said constriction, for each pouch to be folded along its constriction, and for two base-forming side chambers to be secured to the bottom face of the inflatable floor so that the central other two chambers are inclined relative to each other in a V-shaped configuration. In which case, permanent communication link may be

Figure(60): Inflatable Boat With High Pressure Inflatable Keel Article Page 1

established between the inflatable floor and, for each pouch, said base-forming chamber secured to said floor.

A variant embodiment of the above-described structure consists in that the keel-forming spacer comprises a pouch having three longitudinal constrictions which define four communicating chambers, in that the pouch is folded along its constrictions, and in that two base-forming side chambers are secured to the bottom face of the inflatable floor so that the central other two chambers are inclined relative to each other in a V-shaped configuration. A single piece is thus obtained that is easy to install and that is inflatable in a single operation.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood on reading the following detailed description of certain particular embodiments which are given merely by way of non-limiting example. In the description, reference is made to the accompanying drawings, in which:

FIGS. **1** and **2** are diagrammatic views respectively from above and from the side, showing the whole of an inflatable boat equipped with a keel-forming spacer of the invention;

FIG. **3** is a very diagrammatic cross-section view of the boat shown in FIGS. **1** and **2**;

FIG. **4** is a diagrammatic side view showing, on its own, the inflatable keel-forming spacer of the boat of FIGS. **1** to **3**;

FIG. **5** is a diagrammatic cross-section view of a chamber constituting the inflatable keel of FIG. **3**;

FIG. **6** is a very diagrammatic cross-section view of a preferred variant arrangement of an inflatable dingy equipped with an inflatable floor and with an inflatable keel-forming spacer of the invention;

FIG. **7** is a very diagrammatic cross-section view showing a preferred example of an arrangement of the inflatable floor and of the inflatable keel-forming spacer of the dingy of FIG. **6** in the form of a single T-shaped piece;

FIG. **8** is a view in perspective of the single piece of FIG. **7**, shown upside down (keel-forming spacer upwards);

FIG. **9** shows an advantageous embodiment of the inflatable keel-forming spacer implemented in the arrangement of FIG. **7**;

FIG. **10** shows a variant embodiment of the inflatable keel-forming spacer of FIG. **9**;

FIG. **11** shows yet another variant embodiment of an inflatable keel-forming spacer of the invention; and

FIG. **12** shows an advantageous variant embodiment of the inflatable keel-forming spacer of FIG. **11**.

DETAILED DESCRIPTION OF THE INVENTION

With reference firstly to FIGS. **1** to **3**, the inflatable boat, designated by overall numerical reference **1**, comprises a float **2** that is generally U-shaped, that is open at the stern, and that is constituted by a least one pneumatically inflatable tube whose branches **3** and **4** are substantially parallel. Said branches are, at their aft ends, braced by a transom **5**.

Inside the space defined by the U-shaped float **2** and by the transom **5**, there extends a floor **6** that is fastened to the float and to the transom, and that is rigid, at least transversely.

In the example shown in FIGS. **1** to **3**, the rigid floor is made up of slats or panels extending transversely to the branches **3**, **4** of the tube, said slats or panels, in particular made of wood or of metal, being hinged together.

Finally a bottom sheet constituting a V-shaped keel is formed of a flexible canvas sheet that is fastened to the float **2** and to the transom **5** and that is tensioned by an elongate inflatable keel-forming spacer **8** disposed axially between the rigid floor **6** and the flexible canvas sheet **7**.

The general arrangement of this type of boat is known, for example, from Document FR 1 155 376, with a keel-forming spacer formed of a chamber inflated under the same relatively low inflation pressure as the float **2**.

In the invention, the inflatable keel-forming spacer **8** is formed by at least two elongate chambers **8***a*, **8***b*, each of which is defined by two main walls **9** that are substantially plane and approximately parallel main walls **9** that extend longitudinally and that are braced by a multitude of flexible ties **10** which, with the chamber being inflated under a relatively high pressure (to give some idea: e.g. about 10^5 pascals (Pa), while the float is inflated under a significantly lower pressure, e.g. about 0.2×10^5 Pa to about 0.3×10^5 Pa), hold the main walls in a predetermined relative position, in particular approximately plane and parallel to each other as shown in FIGS. **3** and **5**. In addition, the two chambers **8***a*, **8***b* are disposed with their respective bottom longitudinal edges touching each other, and with their respective top edges spaced apart from each other, so as to present a generally V-shaped cross-section.

The arrangement of each chamber **8***a*, **8***b* of the inflatable keel-forming spacer **8** is shown on a larger scale in FIG. **5**. The walls **9** can advantageously be made in multi-layer form and the ties **10** can be formed by wires anchored in the thickness of the walls **9**, using a technique that is well known to the person skilled in the art.

By means of this structure, it is possible to give the inflatable keel-forming spacer **8** any desirable shape firstly by using a shape that differs from the tubular shape that is currently used and that gives rise to a rounded bow portion which is insufficiently sharp and which limits the handling characteristics of the dingy, and secondly by giving the keel-forming spacer a wider area via which it bears against the bottom face of the floor.

In the context of the invention, it is possible to impart to each chamber **8***a*, **8***b* of the keel-forming spacer **8** a flat sheet-like shape whose thickness is considerably smaller than its height and than its length, as can be seen more particularly in FIGS. **3**, **4**, and **5**. In addition, it is possible to adapt the angle of mutual inclination of the two chambers **8***a*, **8***b* as a function of needs, and it is possible, optionally, to have an angle that varies longitudinally. It is thus possible to make the bow portion **11** very sharp, enabling it to part the water better.

In addition, it is possible to impart to the inflatable keel-forming spacer **8** any desirable shape. In particular, the bottom edge **12** of the keel-forming spacer can be curved with its height being at its maximum at the bow portion **13** and decreasing gradually sternwards, as can be seen more clearly in FIGS. **2** and **4**.

It is thus possible to impart to the keel-forming spacer a general shape that is analogous to the shape of a rigid keel (e.g. a wooden keel), with, at the bow portion **13**, a height that is considerably greater than the height of a conventional tubular inflatable keel-forming spacer. This large height procures a very pronounced bow portion imparting more stable course-holding to the boat.

In addition, the fact that the two chambers **8***a*, **8***b* are inflated under a relatively high pressure makes the keel-forming spacer **8** very rigid, and almost as rigid as a conventional rigid keel. The drawback of the relative lon-

Figure (61) : Inflatable Boat With High Pressure Inflatable Keel Article Page 2

gitudinal deformability of conventional inflatable keel-forming spacers that are inflatable under low pressures is thus avoided.

The combination of the rigidity, of the sharpness, and of the large height at the bow portion of the keel-forming spacer of the invention makes it possible to impart optimum characteristics to the bow portion that significantly improve the performance of the boat.

FIG. **6** is a very simplified cross-section view showing an arrangement of a boat in which the floor is constituted, in a manner known per se, in the form of a flat pouch **14** defined by two approximately parallel main walls braced by a multitude of flexible ties, the pouch being inflated under a relatively high pressure, using a technique analogous to the technique for constituting the keel-forming spacer of the invention. Inflatable boats equipped with such inflatable floors are commonly commercially available.

Combining, in the same boat, a floor and a keel-forming spacer, both of which are constituted analogously and are inflatable under a relatively high pressure, makes the boat very rigid and makes it entirely deflatable and foldable, without voluminous rigid elements that are awkward to carry and to stow.

It is more precisely in the context of such an inflatable floor that the keel-forming spacer having at least two chambers in a V-shaped configuration offers a definite advantage, so that the resulting keel-forming spacer bears against the bottom face of the inflatable floor over a wider region so as to avoid, or at least to reduce, curving of the floor in the presence of the tension force due to the tensioned canvas forming the bottom **7**.

As shown in FIG. **7**, it is possible to consider constituting the inflatable floor **14** and the inflatable keel-forming spacer **8** in the form of a single piece **18** that is generally T-shaped in cross-section. To this end, the floor **14** and the keel-forming spacer **8** can be made using the same technique in the form of two independent elements that are then secured together, e.g. by adhesive bonding or by sealing, with reinforcing and holding brackets **15** being affixed. In order to simplify implementation of the two pouches that are of the same design and that are inflatable under the same pressure, it is possible to provide a pneumatic link between them (e.g. a link tube **16**), while only one of them (e.g. the inflatable floor **14** that is easier to access from the inside of the boat) is equipped with a common inflation valve **17**.

FIG. **8** is a perspective view of the single piece **18** shown upside-down, with the keel-forming spacer **8** upwards, and as inflated.

Admittedly, the keel-forming spacer **8** can be formed by two chambers **8***a*, **8***b* that are independent from each other and that are assembled together and to the floor **14** by means of brackets. However, such an arrangement requires assembly at a multitude of points, and also suitable pneumatic links between the floor and each of the chambers **8***a*, **8***b*.

However, making the single piece **18** is facilitated if the keel-forming spacer **8** is itself constituted by a single pouch folded in a V-shaped configuration to define the two chambers **8***a*, **8***b*.

An embodiment that is preferred because of the simplicity it procures for manufacturing the component parts is shown in FIGS. **7** and **9**.

Firstly, a flat pouch **20** (FIG. **9**) is made from the above-indicated material, and a constriction **21** is formed in its central region. The constriction **21** extends longitudinally and allows one or more passageways to remain for enabling the inflation air to pass between the communicating chambers **8***a* and **8***b* that are situated on either side. The longitudinal constriction **21** constitutes a fold score line enabling the two chambers **8***a*, **8***b* to be disposed in the required mutually inclined configuration, in their inflated state, as shown in FIG. **7**.

By way of a variant, the single pouch **20** can be held in the folded position by means of stiffeners interposed between the two chambers **8***a*, **8***b* defined in this way, as shown in FIG. **10**. For example, the stiffener means can consist of a continuous strip of woven fabric, or else of a plurality of strip segments **22** (as shown in FIG. **10**) secured (bonded by adhesive or by sealing) to the respective end edges of the two chambers **8***a*, **8***b*. The resulting keel-forming spacer **8** can be secured to the bottom face of the floor **14** by means of brackets **15**, as indicated above, but it is also possible, by way of a variant, to consider securing said stiffener means, in particular the strip segments **22**, to said face in order to secure the keel-forming spacer thereto.

Also by way of a variant, the single pouch **20** can be mounted significantly differently to the manner indicated above. In this context, as shown in FIG. **11**, two pouches **20***a*, **20***b* are implemented, each of which comprises two communicating chambers **23***a*, **8***a*; **23***b*, **8***b* respectively, separated by a constriction **21**. The two pouches **20***a*, **20***b* are secured, parallel to each other, to the bottom face of the inflatable floor **14** via one of their respective chambers **23***a*, **23***b* which are spaced apart from each other at a distance smaller than the sum of the widths of the two juxtaposed chambers **8***a*, **8***b*: as a result, since the two chambers **8***a*, **8***b* cannot bear against the floor **14**, they are positioned in a V-shaped configuration. Advantageously, passageways **24** (in the form of holes) can be established through the juxtaposed walls of the floor **14** and of the respective ones of the chambers **23***a*, **23***b* so as to procure a direct pneumatic link between the floor **14** and the chambers **23***a*, **23***b*, and thus the chambers **8***a*, **8***b*, thereby enabling the inflatable structure as a whole to be inflated directly under a relatively high pressure.

Optionally, the touching edges of the two chambers **8***a*, **8***b* can be assembled together and reinforced by means of brackets **15**. In order to improve overall stiffness, it is also possible to provide strip segments **22** (shown in chain-dotted lines) dimensioned to hold the two chambers **8***a*, **8***b* in a relative position having the desired angle of mutual inclination.

An advantageous variant embodiment of the above-described assembly consists, as shown in FIG. **12**, in that the pouches **20***a*, **20***b* are made in one-piece form, as a single pouch **25** provided with three longitudinal constrictions **21** that are spaced apart from one another and mutually parallel, and that define between them the above-mentioned communicating chambers **8***a*, **23***a*, **23***b*, and **8***b*. A single passageway **24** allows the assembly to be inflated in one operation. Optionally, the rigidity of the assembly can be improved by providing strip segments **22** under the same conditions as above.

The two embodiments of FIGS. **11** and **12** make it possible to constitute a single inflatable piece **18** that is suitable for being installed rapidly and that is inflatable under a relatively high pressure in a single operation by means of a single inflation valve **17**.

What is claimed is:

1. An inflatable boat defining a bow, a stern, a midsection intermediate the bow and the stern, and a longitudinally-central plane and comprising: a float that is generally U-shaped and open at the stern, and that is made up of at least one pneumatically inflatable tube whose aft ends are braced by a transom; a floor that is rigid at least transversely

Figure (62) : Inflatable Boat With High Pressure Inflatable Keel Article Page 3

US 7,159,529 B2

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and that is disposed inside the space defined by the float, and a V-shaped hull formed of a flexible canvas sheet fastened to the float and to the transom and tensioned by a longitudinal inflatable keel-forming spacer interposed between said rigid floor and said canvas sheet;

wherein the inflatable keel-forming spacer is formed by at least two elongate, substantially flat inflatable chambers which extend between said rigid floor and said canvas sheet and which have respective lower edges joined together and resting against said canvas sheet and respective upper edges spaced apart transversely and resting against said rigid floor at locations symmetric with respect to the longitudinally-central plane of the boat and, at least in the midsection of the boat, at locations laterally remote from the tube, with said two chambers being together disposed in a substantially V-shaped configuration in cross-section; and

wherein said two chambers are each defined by two substantially plane and parallel main walls that are braced by a multitude of flexible ties, said at least two chambers being inflated under a relatively high pressure.

2. A boat according to claim **1**, wherein the keel-forming spacer comprises two chambers that are independent from each other.

3. A boat according to claim **1**, wherein the keel-forming spacer comprises a single pouch that is flat in general shape and that is folded to form said two chambers that are inclined relative to each other in a V-shaped configuration.

4. A boat according to claim **3**, wherein the single pouch that is flat in general shape has at least one longitudinal constriction defining two communicating chambers situated on either side of said constriction, and wherein said pouch is folded along said constriction to form said two chambers that are inclined relative to each other in a V-shaped configuration.

5. A boat according to claim **1**, wherein the joined together lower edges of the inflatable chambers are curved.

6. An inflatable boat according to claim **5**, wherein the height of the chambers increases very rapidly from the forward end to define a bow portion, and then decreases gradually sternwards, and wherein the maximum height of the chambers in the vicinity of the forward end is relatively large in order to impart to the tensioned canvas sheet the shape of a sharp bow portion that forms a relatively closed V-shape.

7. An inflatable boat according to claim **1**, wherein the floor is an inflatable floor formed of a flat pouch defined by two approximately parallel main walls that are braced by a multitude of flexible ties, said pouch being inflated under a relatively high pressure, and wherein the inflatable chambers forming the keel-forming spacer are secured longitudinally and axially to the bottom face of said inflatable floor so as to form a single piece.

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8. An inflatable boat according to claim **7**, wherein a pneumatic communication link is established between firstly the inflatable floor and secondly the inflatable chambers forming the keel-forming spacer, and wherein the single piece is equipped with a single valve for simultaneously inflating the floor and the chambers forming the keel-forming spacer.

9. An inflatable boat according to claim **7**, wherein the keel-forming spacer comprises two pouches each of which has a longitudinal construction which defines two communicating chambers situated on either side of said constriction;

wherein each pouch is folded along its constriction; and

wherein two base-forming side chambers are secured to the bottom face of the inflatable floor so that the central other two chambers are inclined relative to each other in a V-shaped configuration.

10. A boat according to claim **9**, wherein a permanent communication link is established between the inflatable floor and, for each pouch, said base-forming chamber secured to said floor.

11. A boat according to claim **7**, wherein the keel-forming spacer comprises a pouch having three longitudinal constrictions which define four communicating chambers;

wherein the pouch is folded along its constrictions; and

wherein two base-forming side chambers are secured to the bottom face of the inflatable floor so that the central other two chambers are inclined relative to each other in a V-shaped configuration.

12. An inflatable boat comprising: a float that is generally U-shaped and open at the stem, and that is made up of at least one pneumatically inflatable tube whose aft ends are braced by a transom; a floor that is rigid at least transversely and that is disposed inside the space defined by the float, and a V-shaped hull formed of a flexible canvas sheet fastened to the float and to the transom and tensioned by a longitudinal inflatable keel-forming spacer placed between said floor and said canvas sheet;

wherein the inflatable keel-forming spacer is formed by at least two elongate chambers, each of which is defined by two substantially plane and parallel main walls that are braced by a multitude of flexible ties, each chamber being inflated under a relatively high pressure; and

wherein the two chambers are disposed with their respective bottom longitudinal edges touching and resting against the canvas sheet and with their respective top longitudinal edges resting against the floor and spaced apart from each other so that the two chambers together disposed are generally V-shaped in cross-section.

* * * * *

Figure (63) : Inflatable Boat With High Pressure Inflatable Keel Article Page 4

US006634914B2

(12) **United States Patent**
Vancil

(10) **Patent No.: US 6,634,914 B2**
(45) **Date of Patent: Oct. 21, 2003**

(54) **SELF-RIGHTING WHITEWATER RAFT**

(76) Inventor: **Darren Vancil**, 284 Holley La., Grand Junction, CO (US) 81503

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/865,985**

(22) Filed: **May 25, 2001**

(65) **Prior Publication Data**

US 2001/0046820 A1 Nov. 29, 2001

Related U.S. Application Data

(60) Provisional application No. 60/207,491, filed on May 26, 2000.

(51) **Int. Cl.**[7] **B63B 35/58**
(52) **U.S. Cl.** **441/40**; 441/38
(58) **Field of Search** 114/345, 362, 114/61.1, 61.11, 61.22, 61.24, 61.25; 441/35, 38, 40

(56) **References Cited**

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5,013,270 A * 5/1991 Walls 441/45
5,921,831 A * 7/1999 Schulze 441/38

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Primary Examiner—Ed Swinehart
(74) *Attorney, Agent, or Firm*—Christie, Parker & Hale, LLP

(57) **ABSTRACT**

An inflatable raft has an inflatable hull of catamaran type. The hull has parallel spaced fore-and-aft pontoons centrally of its length between elevated transverse bridges at the ends of the hull. The pontoons and bridges are connected by inclined connecting sections. Along a vertical longitudinal centerplane of the hull there is an inflatable righting structure. The righting structure is of inverted V configuration having legs connected at an arm peak above the hull. Lower ends of the legs are connected to the bridges so that the arm extends between the bridges. Inflatable righting sponsons can extend laterally from the arm at its peak area.

36 Claims, 5 Drawing Sheets

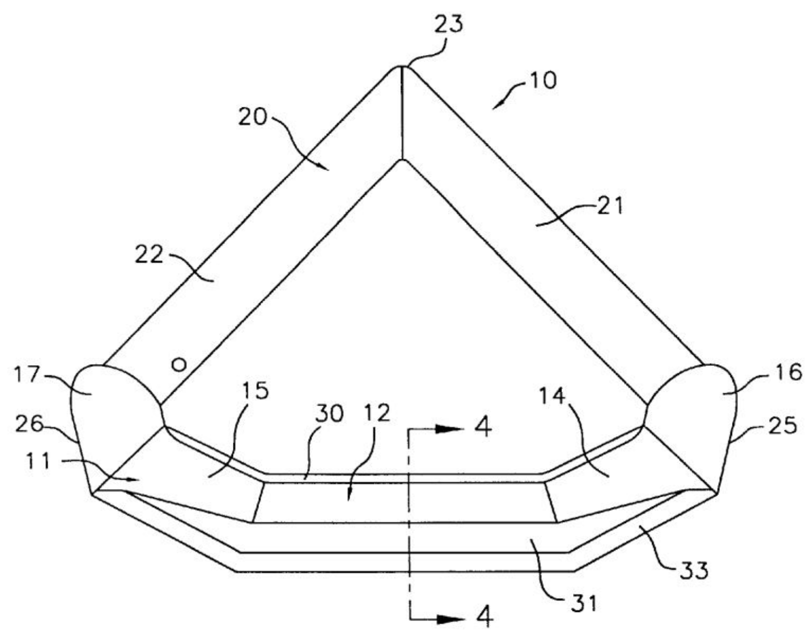

Figure (64):Steve Hafey's Patents

Appendix 2

United States Patent	**5,964,176**
Grunau , et al.	**October 12, 1999**

Inflatable keel

Abstract

Methods and devices are provided for a water craft, for use on a body of water, having a bottom, and an inflatable keel, coupled to the bottom, wherein the keel contacts the surface of the water during operation of the craft, the keel comprising an inflatable bladder wherein inflating the bladder results in the keel at least partially transitioning from a collapsed state to an inflated state.

Inventors:	**Grunau; William C.** (Yorba Linda, CA)**, Batson; Douglas A. R.** (Norco, CA)
Assignee:	**WETCO, L.L.C.** (Yorba Linda, CA)
Family ID:	**21915766**
Appl. No.:	**09/041,288**
Filed:	**March 12, 1998**

Current U.S. Class:	**114/345**; 114/140
Current CPC Class:	B63B 7/085 (20130101); B63B 3/38 (20130101)
Current International Class:	B63B 7/08 (20060101); B63B 7/00 (20060101); B63B 3/00 (20060101); B63B 3/38 (20060101); B63B 007/00 ()
Field of Search:	;114/345,253,140 ;441/40,80

References Cited [Referenced By]

U.S. Patent Documents

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4603651	August 1986	Harding
4640217	February 1987	Ferronniere
4722292	February 1988	Marino et al.
5354222	October 1994	Elias

Primary Examiner: Avila; Stephen
Attorney, Agent or Firm: Fish; Robert D. Crockett & Fish

FIELD OF THE INVENTION

The field of the invention is water craft.

BACKGROUND OF THE INVENTION

Water craft of various types have been used for centuries. For some types of watercraft, such as inflatable boats and rafts, portability and ease of storage are primary factors to be considered when designing the craft. One way of improving portability and ease of storage is to reduce the overall size and weight of the craft. Reduction of the overall size and weight can generally be accomplished by reduction in the size and weight of the various components or members of the craft.

One member which is common to many boats is a keel. For many water craft the purpose of the keel is to act as a primary structural support. Another purpose, in many craft, is to provide stability by making it more difficult for the craft to be pushed "sideways" to the line of travel, thus making it easier to propel the craft in a straight line, and to provide a countering force. Additionally, the keel in many craft is used to shift the center of gravity downward to increase the probability that the craft will remain upright. Thus, keels are frequently designed to be rigid, heavy, or both rigid and heavy. Providing a craft with a keel which is rigid or heavy tends to make it less portable and more difficult to store.

When designing water craft, it is generally desirable to reduce drag so that less energy is required to accelerate the craft to some velocity, and to maintain that velocity once it has been reached. ***Inflatable rafts*** frequently have flat bottoms to reduce drag at lower speeds and to permit hydroplaning at higher speeds. If the raft is self-propelled, hydroplaning at higher speeds is generally desirable. However, if the raft is being towed, the tendency to hydroplane is less desirable as it frequently results in instability with the raft bouncing about and wandering back and forth in the wake of the craft which is towing the raft.

Inflatable craft are frequently designed to be both portable and easily storable. As such, it is generally undesirable to provide such a craft with a rigid or heavy keel. As a result, various alternatives have been tried.

One such alternative is the use of fins, center boards, dagger board, and outriggers (see U.S. Pat. Nos. 3,577,576 to Lobb (May 4, 1971), 4,249,276 to Snyderman (Feb. 10, 1981), and 4,735,163 to Filshie (Apr. 5, 1988)). However, such devices are not completely satisfactory as their use requires providing a means for mounting them to the craft, thus increasing the cost of the craft, and increasing the time required for setting up the craft. Additionally, being rigid and having more weight than the inflatable portions of the craft, they tend to decrease portability and ease of storage. Portability and ease of storage is also decreased because of the increased number of parts.

Another alternative to providing a rigid and heavy keel is to modify the bottom or hull of the craft into a `V` shape. This alternative is generally used with craft having substantially rigid bottoms. As an example, U.S. Pat. No. 3,694,836 discusses a collapsible boat having a substantially rigid buoyant bottom. However, because of the substantially rigid bottom, the craft, even when collapsed, occupies at least as much space as the bottom. Another example having a similar problem is U.S. Pat. No. 4,858,550 which discusses the use of a hard shell shaped to cover the bottom of an inflatable craft and made from various contoured staves or segments joined together. Although there is less of a problem in regard to size as the segments can be separated, the individual segments are still of a size and weight to limit portability and ease of storage. Also, as with the use of devices such as dagger boards, there are more items to maintain, increased cost, and increased setup time.

For craft having a bottom comprising a hard, flat, and rigid surface covered by a more watertight, flexible material, hull shape modification can be accomplished using a cylindrical, inflatable member between the rigid bottom and the flexible sheet. U.S. Pat. Nos. 4,640,217 to Ferronmiere (Feb. 3, 1987) and 4,603,651 to Harding (Aug. 5, 1986) discuss craft having such members. Two of the primary problems with these designs are that (1) the `V` shape of the hull tends to be relatively flat and to have a rounded bottom, thus decreasing the ability to cut into the surface of the water and prevent hydroplaning, and (2) a hard, flat, and rigid bottom is required to provide the support required for the hull to maintain its shape. The shaped ***hulls*** of Ferronmiere '217 and Harding '651 don't comprise an "inflatable keel" as the term is used herein in that the ***hulls*** themselves are not inflatable, the inflatable members used to modify the shape of the ***hulls*** don't contact the water, and a

Appendix 3

United States Patent	**6,634,914**
Vancil	**October 21, 2003**

Self-righting whitewater raft

Abstract

An ***inflatable raft*** has an inflatable hull of catamaran type. The hull has parallel spaced fore-and-aft pontoons centrally of its length between elevated transverse bridges at the ends of the hull. The pontoons and bridges are connected by inclined connecting sections. Along a vertical longitudinal centerplane of the hull there is an inflatable righting structure. The righting structure is of inverted V configuration having legs connected at an arm peak above the hull. Lower ends of the legs are connected to the bridges so that the arm extends between the bridges. Inflatable righting sponsons can extend laterally from the arm at its peak area.

Inventors:	**Vancil; Darren** (Grand Junction, CO)
Family ID:	**26902285**
Appl. No.:	**09/865,985**
Filed:	**May 25, 2001**

Current U.S. Class:	**441/40**; 441/38
Current CPC Class:	B63B 35/613 (20130101); B63B 1/10 (20130101); B63B 7/08 (20130101)
Current International Class:	B63B 35/58 (20060101); B63B 35/613 (20060101); B63B 035/58 ()
Field of Search:	;114/345,362,61.1,61.11,61.22,61.24,61.25 ;441/35,38,40

Appendix 4

Submarine life rafts to replace indicator buoys

Containerised system improves crew safety, promises Babcock

BABCOCK Intec has developed a containerised life raft system, which has been installed and commissioned on Walrus submarines within the Royal Netherlands Navy.

The submarines were originally fitted with indicator beacons that transmit a distress signal to trigger rescue operations.

But to improve crew safety, these indicator buoys are being replaced with the new life raft containers.

Each contains the inflatable raft, an automatically activated GPS search-and-rescue emergency beacon, and supplies.

The system is designed for deployment either sub-surface, from inside the pressure hull, or on the surface from outside the pressure hull with an external release mechanism.

The rafts are contained within a GRP pressure vessel stored in a cradle between the pressure hull and casing – one under the forward casing and one under the aft casing.

When released from a submerged submarine the container rises to the surface, where the life raft self-inflates, an action triggered by a pressure sensor. Inflation is automatic and immediate when released on the surface.

The need for absolute reliability of this safety system posed technical challenges for Babcock's engineers. They had to deal with the restricted space available beneath the submarine casing, a complex problem that made the design task more onerous.

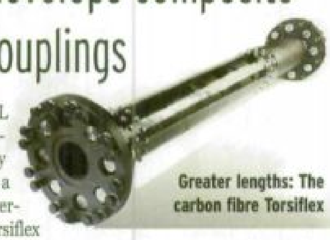
Additionally, the materials had to withstand operational requirements, the hostile marine environment, and ensure reliable operation, as the system will remain static for long periods but must activate immediately on demand.

Babcock Intec project manager Paul Moxham said: "Many submarines have no life rafts and crew members have to rely on individual survival gear.

"This system can be customised for retrofit into existing submarine platforms, or incorporated into new-build programmes, and a number of potential customers have expressed interest."

Blow-up: The self-inflating raft, which contains GPS and supplies, can be deployed inside the pressure hull or topside

Bibby develops composite shaft couplings



Greater lengths: The carbon fibre Torsiflex

MECHANICAL power transmission firm Bibby has developed a carbon fibre version of its Torsiflex shaft couplings for use on equipment such as cooling tower fans, vertical pumps, marine drives, test beds and engine dynamometers.

The composite couplings can operate over 30 metres in one application. Bibby says their low-mass, high-strength characteristics make them more suited to operating over longer lengths than equivalent metal type couplings.

They do not require support bearings or lubrication, and are essentially maintenance-free, says the firm.

The Turboflex tubes are filament wound on mandrels, and are cured while in position. This results in high tube dimensions accuracy, roundness and straightness, it says.

Purpose-developed software enables Bibby to offer tubes with fibre windings at angles adjusted to give the optimum performance for specific torque and torsional stiffness requirements.

'Waggle' wings cut mid-flight resistance

WINGS that redirect air to "waggle" sideways could cut airline fuel bills by a fifth, researchers have found.

The discovery, which promises to dramatically reduce mid-flight drag, uses tiny air-powered jets to redirect the air.

The jets work by the Helmholtz resonance principle – when air is forced into a cavity the pressure increases, which forces air out and sucks it back in again, causing an oscillation – the same phenomenon that happens when blowing over a bottle.

Dr Duncan Lockerby of the University of Warwick's school of engineering, who is leading the project, said: "This has come as a bit of a surprise to all of us in the aerodynamics community. It was discovered, essentially, by waggling a piece of wing from side to side in a wind tunnel.

"We're not exactly sure why this reduces drag but with the pressure of climate change we can't afford to wait around to find out. We are pushing ahead with prototypes and have a separate three-year project to look more carefully at the physics behind it."

IF THE CAP FITS...

North Yorkshire-based Micro Metalsmiths has developed and manufactured a fuel cap for luxury car manufacturer Spyker in under eight weeks.

The aluminium fuel cap, which features Spyker's distinctive company emblem, an aircraft propeller and a wire wheel, was produced as an investment casting and will feature on all production cars. Micro Metalsmiths has previously developed air vents for the Dutch car maker.

Appendix (_)

4,723,929 Inflatable life rafts:

United States Patent [19]
Parish

[11] **Patent Number:** **4,723,929**
[45] **Date of Patent:** **Feb. 9, 1988**

[54] **INFLATABLE LIFE RAFTS**

[75] Inventor: **James M. Parish,** Wadsworth, Ohio

[73] Assignee: **The B. F. Goodrich Company,** Akron, Ohio

[21] Appl. No.: **50,610**

[22] Filed: **May 18, 1987**

[51] **Int. Cl.**[4] **B63B 35/58**

[52] **U.S. Cl.** **441/39;** 114/362; 141/382; 182/48; 244/905

[58] **Field of Search** .... 114/345, 362; 441/30, 441/31, 39, 40, 41; 52/2 R, 2 H; 141/382; 182/48; 193/25 B; 244/905

[56] **References Cited**

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4,678,443	7/1987	Edwards et al.	441/40

FOREIGN PATENT DOCUMENTS

1538084	1/1979	United Kingdom	244/905

Primary Examiner—Sherman D. Basinger
Assistant Examiner—Thomas J. Brahan
Attorney, Agent, or Firm—Joseph Januszkiewicz

[57] **ABSTRACT**

An improved life raft with inflatable tubes having a boarding ramp attached to such raft wherein the raft is inflated by a hose interconnected by a coupling means and via a second hose to the raft such that the pressurized life raft chamber inflates the boarding ramp. The coupling means is a quick disconnect coupling means which in a connected condition is operative to main a flow connection between hoses and chambers but in a disconnected condition is operative to block the flow connection from both hoses and their respective chambers. A tension member is used to interconnect the quick disconnect coupling means to the raft and provides the means for disconnecting the coupling means when sufficient tension is provided as extending the distance between the coupling means and the raft. Such coupling means with the tension member can also be installed between the main inflating cylinder and the raft.

11 Claims, 5 Drawing Figures

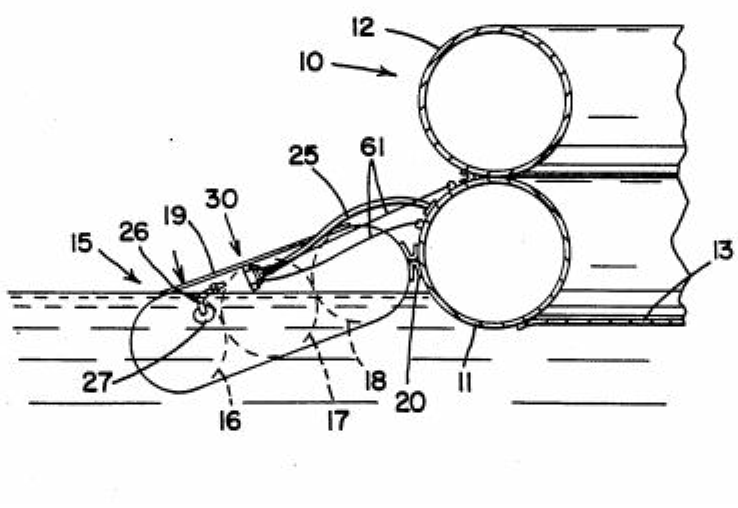

Figure (65):Steve Hafey's Patents

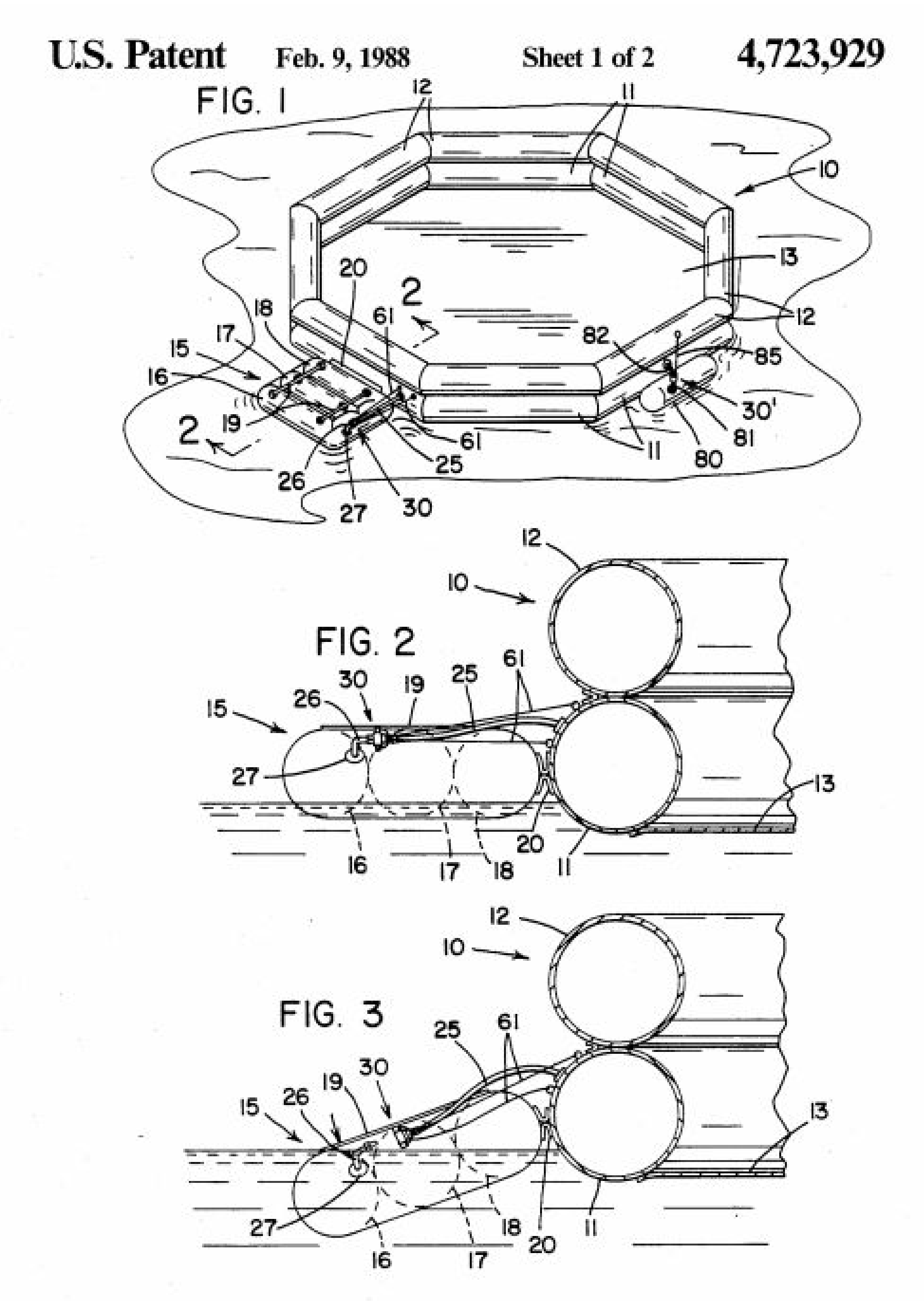

Figure (66): Steve Hafey's Patents

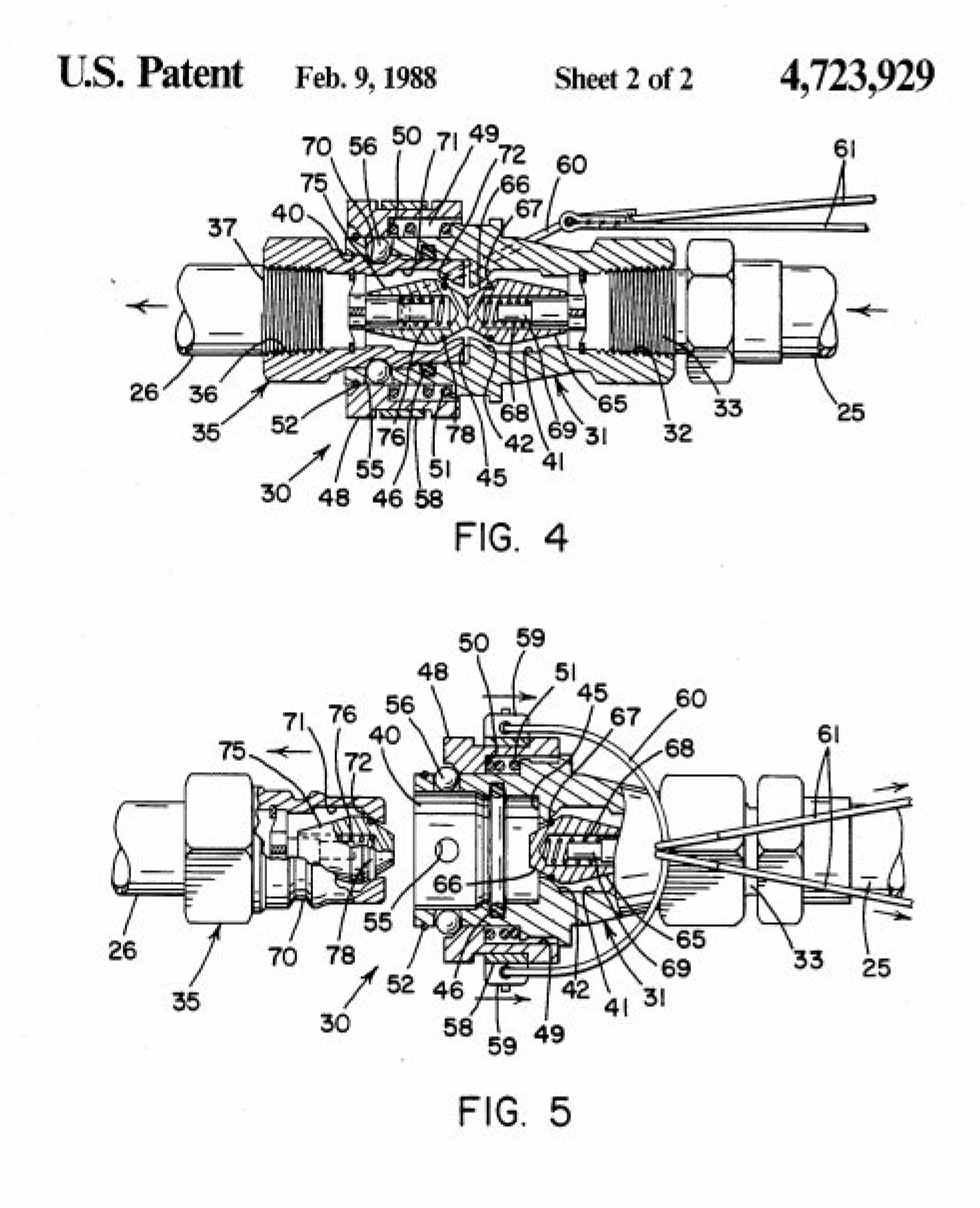

Figure (67): Steve Hafey's Patents

4,723,929

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INFLATABLE LIFE RAFTS

BACKGROUND OF THE INVENTION

This invention relates to inflatable life rafts and more particularly to a new and improved life raft with an inflatable boarding ramp with a connector therebetween.

Inflatable life rafts are generally compulsory equipment on certain sea-going vessels as well as aircraft because of their unique advantage that they can be stowed in an exceedingly small space and then deployed in a matter of seconds under adverse condition. It is important in the deployment of these inflatable rafts that means be provided to facilitate their boarding and accessibility by personnel from the waters which is not necessarily done under ideal conditions. To accommodate such boarding, life rafts have employed ramps that are attached to the inflatable raft but at a lower level than the side walls of the raft. In the process of inflating such rafts, which are generally composed of a plurality of circular tubes stacked and suitably connected together, the tube chambers are generally connected to a common gas source or charged cylinder to facilitate their inflating. With the placement or attachment of the ramp to the raft, it has been necessary to inflate the ramp from the chamber of the raft tube or tubes since the ramp chamber is generally of a much lesser volume. When the raft is in use, the connection between the raft tubes and the ramp was considered permanent or non-detachable. As the raft in rough sea conditions could undergo unusual stresses, a tube in the boarding ramp could be punctured and the boarding ramp and the chamber (lower set of tubes in the raft) supplying air to such ramp would deflate leaving the raft with only half of its buoyancy or load carrying capacity. The present invention provides the new concept of interconnecting the ramp chambers with the raft chambers that supply the air inflating means for the ramp with a disconnect coupling therebetween which closes off the respective chambers to prevent deflation of the air supplying chamber from the raft without jeopardizing its integrity or reducing its full carrying capacity. Such action disconnects or isolates the raft chambers from the ramp chamber before any failure occurs, thus pressure will be maintained in one chamber (for example the lower tube or tubes of the raft) if the other chamber (ramp tubes) is punctured. The present invention utilizes standard available hardware which makes the assembly unique in that it can be readily made, repaired and maintained.

SUMMARY OF THE INVENTION

The present invention contemplates a life raft composed of inflatable tubes that make up the sides of the raft that are cooperative with a floor to define a boat-like structure. An inflatable boarding ramp attached to the raft has their chambers interconnected by hoses via a quick disconnect coupling means which in its connected condition is operative to maintain the hoses and chambers interconnected for the flow of pressurized gas but in the unconnected or disconnected condition is operative to maintain the hoses blocked so that the chambers cannot lose pressurized gas via their hoses. A tension member is used to interconnect the quick disconnect coupling means to the raft and provides the means for disconnecting the quick disconnect coupling means when sufficient tension is provided thereon as extending the distance between the coupling means and

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the raft beyond a predetermined distance. Such quick disconnect coupling means can also be installed between the pressurizing cylinder for the raft chamber and the raft chamber, with the tension member operative in the same manner as between the boarding ramp and raft.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective diagrammatic view of a life raft and boarding ramp;

FIG. 2 is a cross sectional view of the raft and boarding ramp taken on line 2—2 of FIG. 1;

FIG. 3 is a cross sectional view of the raft and boarding ramp similar to FIG. 2 but showing the boarding ramp under a load on its forwardly disposed portion;

FIG. 4 is a cross sectional view of a quick disconnect coupling means in an operative and engaged condition;

FIG. 5 is a cross sectional view of the quick disconnect coupling means of FIG. 4 in a disconnect and inoperative condition.

DETAILED DESCRIPTION

Referring now to the drawings, wherein like reference numerals designate like or corresponding parts throughout the several views, there is shown in FIGS. 1 and 2 an inflatable life raft 10 comprising a lower set of inflatable tubes 11 suitably bonded to an upper set of inflatable tubes 12 and holding them apart in a circumferential loop when inflated. The respective upper set of tubes 12 and lower set of tubes 11 communicate with one another through a common gas source so that all tubes of the assembly or life raft can be inflated simultaneously when the life raft 10 is required to be projected from its stowage in an emergency. The life raft 10 has a lower panel member 13 that has its entire periphery suitably bonded to the lower or bottom surface of the lower set of tubes 11 to form the bottom surface of the life raft 10.

A suitable source of pressurized air or gas as a container or bottle of compressed gas is mounted on the side or underside of the raft which in turn is connected via suitable conduits and valve means to inflate the upper and lower tubes 11 and 12 in a manner old and well known in the art.

To facilitate the boarding of the raft 10 from the water by those to be rescued, an inflatable boarding ramp 15 consisting of three inflatable tubes 16, 17 and 18 are connected as by patches 20 bonded to the respective sides of tube 18 and an adjacent lower tube 11 as seen in FIG. 2.

The tubes 16, 17 and 18 of ramp 15 are of smaller diameter than raft tubes 11 or 12 to accommodate their use as a boarding device to the adjacent vertically stacked tubes 11 and 12.

Boarding ramp 15 consisting of such tubes 16, 17 and 18 may have such tubes as separate distinct tubes, all intercommunicating with each other to define in effect a single inflatable chamber for the ramp or may have such plural tubes made from a pair of panels bonded along the intersection of tubes 16 and 17 and bonded along tubes 17 and 18 as by using tapes. The tubes 16, 17 and 18 are suitably reinforced along the periphery of the panels or tubes.

Two webbing straps 19 as shown in FIG. 1 may be bonded to the respective sides of the ramp to help maintain the integrity of the boarding ramp unit and can be used as handles during boarding.

Figure (68): Steve Hafey's Patents

A hose **25** via a fitting on one end is connected to the upper portion of one of the tubes **11** adjacent to the boarding ramp **15**.

Tube **16** of boarding ramp **15** has a flexible hose or a rigid elbow-shaped hose **26** connected to it via a hose attachment fitting **27**. A quick disconnect shut-off coupling **30** interconnects the respective hpses **25** and **26**.

Coupling **30** is composed of a socket **31** connected via an internally threaded end portion **32** to a threaded end **33** of hose **25**. Coupling **30** also has a plug **35** connected via an internally threaded end portion **36** to a threaded end **37** of hose **26**. As seen in FIG. **5** the respective plug **35** and socket **31** of coupling **30** are shown disconnected whereas FIG. **4** shows the plug **35** engaged with socket **31**.

Socket **31** has a stepped bore with an enlarged opening or bore portion **40**, a reduced portion **41** with an intermediate frusto-conical bore **42** that tapers from bore portion **41** radially inwardly towards the axis of such bore **41** defining a valve seat **42**. The enlarged opening or bore portion **40** has a shoulder **45** that terminates at the radially innermost reduced portion of frusto-conical bore **42**. Enlarged bore portion **40** has a recessed ring that receives an O-ring **46**. A sleeve **48** with a recessed portion **49** is slidably received by the socket **31**. Socket **31** has an annular shoulder **50** against which a spiral spring **51** is seated. The spring **51** biases the sleeve **48** axially away from the hose **25**. The external body of socket **31** adjacent to the forwardmost portion thereof is recessed to receive an annular seal **52**, which as seen in FIG. **4** limits the axial movement of sleeve **48** as biased by spring **51**. Such forward body portion of socket **31** has a plurality of circumferentially spaced bores **55**, receiving stainless steel balls **56** suitably hardened to operate as a locking mechanism. The intermediate external socket **31** has an annular recess to receive a circular ring **58** which in turn has a pair of spaced lugs **59** receiving an arcuate clip **60** connected by tension lines or cords **61**—**61** to loop patches on tube **11**.

Located within bore **41** is a valve **65** having a frusto-conical forward portion **66** with an annular sealing ring **67** seated on the valve seat **42**. The valve **65** has a central recess receiving a spring **68** suitably seated on a stem **69** to bias valve **65** in a leftward direction as viewed in FIG. **5** to seat sealing ring **67** on the valve seat **42** and prevent any pressurized fluid from hose **25** flowing past valve **65** into central bore **40**.

Plug **35** has a cylindrical outer surface with an annular groove **70** which is adapted to receive steel backing balls **56** as depicted by FIG. **4**. Plug **35** stepped internal bore **71** communicating with hose **26**. The forward portion of bore **71** has a radially inwardly tapering frusto-conical bore portion **72**, defining a valve seat **72**, that is adapted to receive a valve **75** biased by a spring **76** into sealing engagement with valve seat **72**. Such valve **75** has an annular seal **78** that insures a sealing engagement of such valve on valve seat **72** to stop the flow of any pressurized fluid from hose **26**. Thus as viewed in FIG. **5**, the respective valves **75** and **65** seal the respective hoses **26** and **25** to prevent the escape of pressurized fluid.

In engaging plug **35** with the socket **31**, sleeve **48** is moved rightwardly as viewed in FIG. **5** while plug **35** is moved into enlarged bore portion **40** until the balls **56** enter the annular groove **70** such that release of sleeve **48** moves over the balls **56** and maintained thereover by the biasing action of spring **51**. During this action, the respective valves **75** and **65** engage each other and com-

press their respective springs **76** and **68** such that the respective valves unseat from valve seats **72** and **42** respectively to allow the flow of pressurized air from hose **25** to the hose **26** which in effect allows the pressurization of ramp **15** from the chambers as defined by tubes **11**. By selecting the correct length of lines **61**—**61**, the flow of air between tubes **11** and the chamber of ramp **15** can be interrupted after the chamber of ramp **15** has filled out as when the ramp **15** is pulled downward as when boarding as depicted by FIG. **3** by the pulling of sleeve **58** towards the raft by lines **61** which unlocks the socket from the plug **35** and they assume the position as depicted by FIG. **5**. This action insures that respective ramp chamber and the chamber of raft tube **11** remain distinct and independent thereafter.

By shortening the tension lines or cords **61**—**61** in the example described above, the coupling **30** will disconnect when the ramp **15** is completely filled out by inflation or when the fabric of the ramp is stretched due to inflation pressure causing the ramp **15** to move further away from the raft **10** which causes the tension member or tension cords **61**—**61** to slide back the sleeve **58** and thus disconnect coupling **30**. The hose **25** should be in a slack condition or slightly longer than the tensioning member so as not to carry any of the tension.

Once the raft chamber has inflated the ramp chamber, there is no reason to keep them connected because a failure in one can result in the other losing pressure. The above described structures isolates the respective raft chamber from the tube chamber at a predetermined time so failure in one eliminates loss of pressure in the other.

A modification of the above described invention is to have a quick disconnect coupling **30'** interconnecting a container or bottle of compressed gas **80** via hose **81** to a hose **82**, which hose **72** is in turn connected to one of the inflatable tubes **12**. As in the first described embodiment, a tension member or tension line **85** interconnects the quick disconnect coupling **30'** to the raft to provide sufficient tension under inflation such that the tension member **85** will be operative to separate the bottle of compressed gas from the raft tube **12** in rough sea conditions. Under these conditions the quick disconnect coupling **30'** would separate hoses **81** and **82** before the relatively heavy bottle tore any attachment fittings of hose **82** out of the tube **12**, the main buoyancy chambers, thus retaining the raft in a fully inflated condition.

Various modifications are contemplated and may obviously be resorted to by those skilled in the art without departing from the described invention, as hereinafter defined by the appended claims as only a preferred embodiment thereof has been disclosed.

I claim:

1. An inflatable life raft comprising a plurality of inflatable tubes forming the sides of a boat like structure upon inflation, said tubes defining a first inflatable chamber, a flexible impermeable floor united to said inflatable tubes for cooperation with said inflatable tubes to form a boat like structure, an inflatable ramp attached to said tubes to accommodate the ingress into said boat like structure from water surrounding said raft, said ramp defining a second chamber, a first hose attached to one of said tubes for communicating with said first chamber, a second hose having one end attached to said ramp for communicating with said second chamber, quick disconnect shut-off means interconnecting said first hose to said second hose for intercommunicating said first chamber to said second chamber, a

Figure (69): Steve Hafey's Patents

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tension member interconnected between said raft and said quick disconnect shut-off means and being operative to actuate said disconnect shut-off means to isolate said chambers to prevent flow of pressurized air between said chambers through their respective hoses in response to a preset distance between said quick disconnect means and said raft being exceeded.

2. An inflatable life raft as set forth in claim 1 wherein said quick disconnect means includes a plug on said second hose and a socket on said first hose, said socket being operative to receive said plug to intercommunicate said hose and said chambers in a connected condition, and said plug spaced from said socket to define a disconnected condition and being operative to isolate said chambers.

3. An inflatable life raft as set forth in claim 2 wherein said plug and said socket each have a valve member operative to abut each other upon being in said connected condition to provide intercommunication between said chambers.

4. An inflatable life raft as set forth in claim 3 wherein said valve members are operative to block the flow of any pressurized air from the respective chambers upon said plug and said socket being in a disconnected condition.

5. An inflatable life raft as set forth in claim 4 wherein said tension member is a flexible line having one end attached to said quick disconnect means and having the other end attached to said raft.

6. An inflatable life raft as set forth in claim 5 wherein said quick disconnect means has a locking mechanism for maintaining said plug and said socket in engaged and connected condition, a sleeve member on said quick disconnect means being biased to retain said locking mechanism engaged, and said tension member having said one end attached to said sleeve to bias said sleeve to release said locking mechanism which releases said plug from said socket to make said valve members operative to block the flow of pressurized air from said respective chambers.

7. An inflatable life raft comprising a plurality of inflatable tubes forming the sides of a boat like structure, a floor member having its periphery connected to said inflatable tubes to form a boat like structure, said tubes defining a first chamber, an inflatable ramp connected to said tubes to provide ingress onto said raft, said inflatable ramp defining a second chamber, a hose connected to each of said chambers, a quick disconnect means interconnecting said hoses, said quick disconnect means having valve means operative in its connected condition to maintain an unobstructed passageway between said chambers, said valve means of said quick disconnect means operative in a disconnected condition to completely obstruct and block the passageway in each of said hoses to prevent deflation of chambers connected thereto, a tension member interconnected

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between said quick disconnect means and said raft, and said tension member operative in an untensioned condition to maintain said valve means of said quick disconnect means in said connected condition while operative in a predetermined tensioned condition to place said valve means of said quick disconnect means in a disconnected condition and thereby place said chambers in an uncommunicated condition.

8. An inflatable life raft as set forth in claim 7 wherein said valve means includes a coupling having a socket member and a plug member wherein said socket member is operative to receive said plug member in an operative condition to maintain said passageway unobstructed and having said socket member disconnected from said plug member in a disconnected condition to completely obstruct and block said passageway in each of said hoses.

9. An inflatable life raft comprising a plurality of inflatable tubes forming the sides of a boat like structure upon inflation, said tubes defining a first inflatable chamber, a flexible impermeable floor united to said inflatable tubes for cooperation with said inflatable tubes to form a boat-like structure, a cylinder attached to said tubes, said cylinder having pressurized gasses therein defining a second chamber, a first hose attached to one of said tubes for communicating with said first chamber, a second hose having one end attached to said cylinder for communicating with said second chamber, quick disconnect shut-off means interconnecting said first hose to said second hose for intercommunicating said first chamber to said second chamber, a tension member interconnected between said raft and said quick disconnect shut-off means and being operative to actuate said disconnect shut-off means to isolate said chambers to prevent flow of pressurized air between said chambers through their respective hoses in response to a preset distance between said quick disconnect means and said raft being exceeded.

10. An inflatable life raft as set forth in claim 9 wherein said quick disconnect means includes a plug on said second hose and a socket on said first hose, said socket being operative to receive said plug to intercommunicate said hose and said chambers in a connected condition, and said plug spaced from said socket to define a disconnected condition and being operative to isolate said chambers.

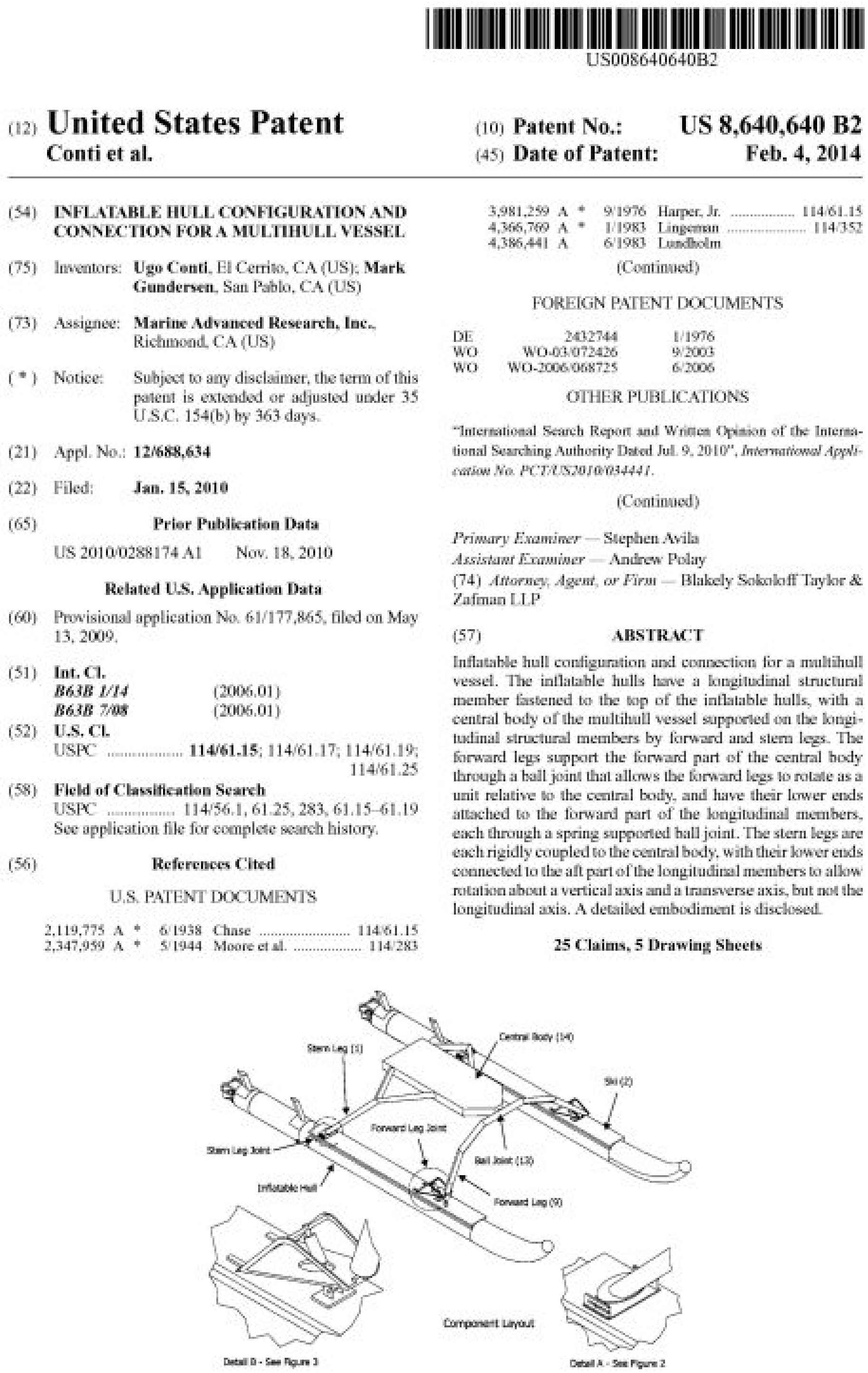
11. An inflatable life raft as set forth in claim 9 wherein said plug and said socket each have a valve member operative to abut each other upon being in said connected condition to provide intercommunication between said chambers, and operative to block the flow of any pressurized air from the respective chambers upon said plug and said socket being in a disconnected condition.

* * * * * *

Figure (70): Steve Hafey's Patents

Appendix (_)

8,640,640 Inflatable hull configuration and connection for a multihull vessel:



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(12) **United States Patent**
Conti et al.

(10) **Patent No.: US 8,640,640 B2**
(45) **Date of Patent: Feb. 4, 2014**

(54) **INFLATABLE HULL CONFIGURATION AND CONNECTION FOR A MULTIHULL VESSEL**

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(73) Assignee: **Marine Advanced Research, Inc.**, Richmond, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 363 days.

(21) Appl. No.: **12/688,634**

(22) Filed: **Jan. 15, 2010**

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(51) **Int. Cl.**

B63B 1/14	(2006.01)
B63B 7/08	(2006.01)

(52) **U.S. Cl.**
USPC **114/61.15**; 114/61.17; 114/61.19; 114/61.25

(58) **Field of Classification Search**
USPC 114/56.1, 61.25, 283, 61.15–61.19
See application file for complete search history.

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Assistant Examiner — Andrew Polay
(74) *Attorney, Agent, or Firm* — Blakely Sokoloff Taylor & Zafman LLP

(57) **ABSTRACT**

Inflatable hull configuration and connection for a multihull vessel. The inflatable hulls have a longitudinal structural member fastened to the top of the inflatable hulls, with a central body of the multihull vessel supported on the longitudinal structural members by forward and stern legs. The forward legs support the forward part of the central body through a ball joint that allows the forward legs to rotate as a unit relative to the central body, and have their lower ends attached to the forward part of the longitudinal members, each through a spring supported ball joint. The stern legs are each rigidly coupled to the central body, with their lower ends connected to the aft part of the longitudinal members to allow rotation about a vertical axis and a transverse axis, but not the longitudinal axis. A detailed embodiment is disclosed.

25 Claims, 5 Drawing Sheets

Figure (71): Steve Hafey's Patents

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Figure (72): Jacob Chase's Patents

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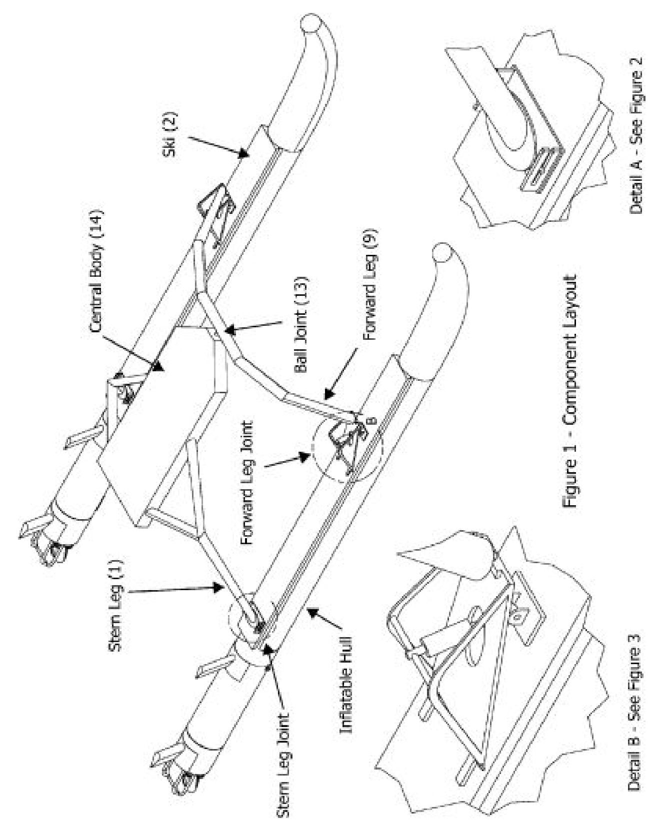

Figure (73): Jacob Chase's Patents

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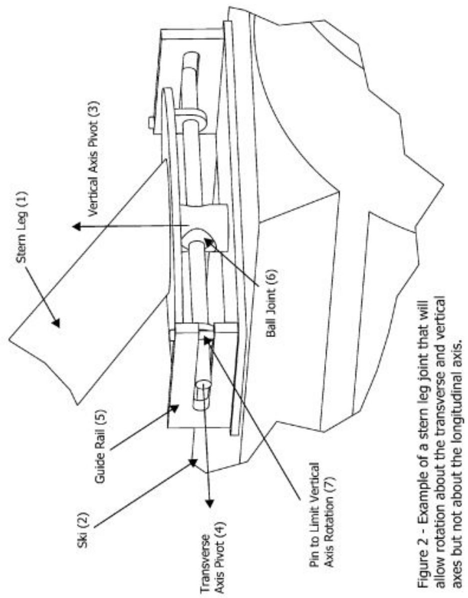

Figure (74): Jacob Chase's Patents

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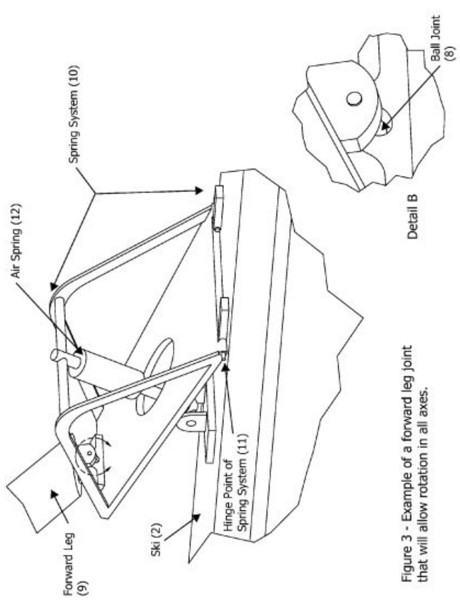

Figure (75):Jacob Chase's Patents

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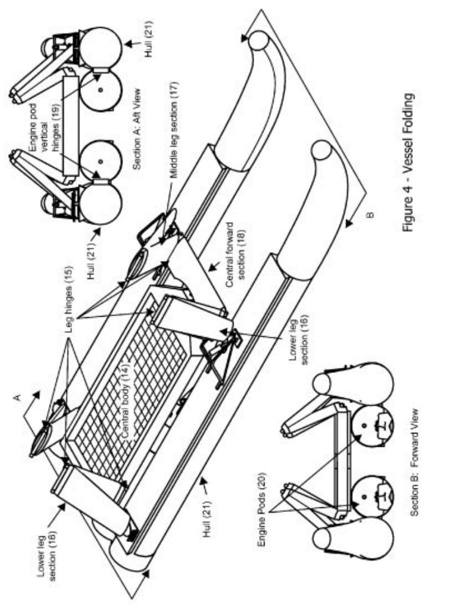

Figure (76):Jacob Chase's Patents

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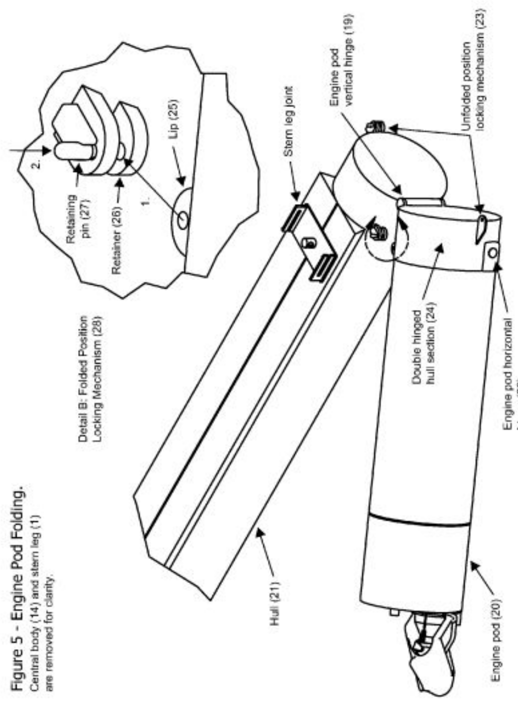

Figure (77):Jacob Chase's Patents

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INFLATABLE HULL CONFIGURATION AND CONNECTION FOR A MULTIHULL VESSEL

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application No. 61/177,865 filed May 13, 2009.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the field of watercraft, and in particular, inflatable craft.

2. Prior Art

U.S. Pat. Nos. 6,874,439 and 7,562,633 describe technologies for boats with inflatable hulls connected by a jointed structure so that such hulls adapt to the surface of the sea.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates the component layout of one embodiment of the present invention.

FIG. **2** illustrates details of a stern leg joint in accordance with one embodiment of the present invention.

FIG. **3** illustrates details of a forward leg joint in accordance with one embodiment of the present invention.

FIG. **4** illustrates one embodiment of leg and hull folding in accordance with one embodiment of the present invention.

FIG. **5** illustrates further details of the embodiment of leg and hull folding of FIG. **4**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This invention provides elements of improvement over the previous designs for wave adaptive modular vessels (WAM-V®) of the type described in the foregoing issued patents. One improvement is the addition on top of the inflatable hulls of a longitudinal structural member on each hull that can be rigid or semi-rigid according to the type of boat and its intended use. The degree of rigidity becomes a design parameter that is available to the engineer to be chosen according to boat size, payload weight, speed, expected sea states, etc.

This longitudinal member (the ski) of each hull could be considered the equivalent of the rim in an automotive wheel: it connects with the inflated part of the hulls—that is now an independent structure—just as a tire is independent and removable from the rim of a wheel (see ski (**2**) in FIG. **1**).

The advantages of this method of hull construction are:

1. The rigidity of the ski can be defined at the design stage.
2. The ski (**2**) connects through the spring system (**10**) (FIG. **3**) with the rest of the boat structure in a fixed manner that does not depend on the pressure of the inflatable hull.
3. The pressure of the inflated part of the hulls can now be set within a broader range than before. This allows the pressure to be controlled to accommodate for sea state and maximum efficiency of motion through the water. For example, in a choppy sea with short waves, a low inflation pressure allows the inflated hulls to absorb the wave impact before it reaches the payload and the rest of the boat structure.

Another improvement to the design of a WAM-V® is an improved method of connecting the two hulls with the rest of the structure in such a way that allows the hulls to move semi-independently while following the water surface.

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FIG. **1** illustrates such a structure connecting two hulls, each having a ski (**2**) on top of the inflated hull. The structure is comprised of forward legs (**9**) and stern legs (**1**) connected by a central body (**14**). The two forward legs form the forward arch that is connected with the central body (**14**) by a ball joint (**13**) so as to be able to rotate as a unit with respect to the central body. In general, the ball joints described herein allow at least limited rotation about at least two axes, and usually about all three axes thereof. The ball joints described with respect to the preferred embodiment actually incorporate balls, though the phrase ball joint is used herein and in the claims in a more general sense to describe or suggest the characteristics of the joint, and not to limit the actual structure thereof. The stern legs are preferably rigidly connected to the central body (**14**), though may be somewhat flexible as desired.

The ends (feet) of the four legs are connected with joints and springs to the hulls skis. The stern leg joints (A, also see FIG. **2**) are composed of a transversal pivot (**4**) and a vertical pivot (**3**), the vertical pivot (**3**) being facilitated by the slots in guide rails (**5**). The housing of the ball joint (**6**) is fastened at its bottom to the plate on which it rests and thus indirectly to the ski (**2**). There is some clearance between the top of the housing of the ball joint (**6**) and the plate on which the stern leg (**1**) is fastened, so that the plate and the stern leg may rotate about the transverse axis pivot (**4**), and the stern leg and plate may rotate about the vertical axis pivot (**3**). The plate is captured between the guide rails, and thus prevents linear motion along the transverse axis.

Thus the transversal pivot (**4**) allows the stern leg (**1**) to rotate about the vertical axis, but holds the hull transversally. The ball joint (**6**) allows motion in the vertical and transverse axis but is prevented from rotating about the longitudinal axis of the hull by the guide rails (**5**). The guide rails (**5**) also limit the rotation around the vertical axis (**3**), by means of pins (**7**), to allow for a small angle of movement necessary to avoid unwanted torsional stresses transmitted to the structure when the hulls move independently from each other.

The forward legs (**9**) connection to the skis (**2**) (FIG. **3**) are ball joints (**8**) that allow rotation in all axis. This eliminates torsional stresses and implements the maximum number of degrees of motion freedom. The ball joint (**8**) connects the forward leg (**9**) to a spring system (**10**) that in FIG. **3** is implemented, as an example, with an air spring (**12**). The spring system is connected to the ski (**2**) by a hinge (**11**).

The forward legs joint systems (detail B) do not prevent the hull systems from twisting around the transversal axis. This rotation is prevented solely by the stern legs joint systems (A).

The modifications to the joints as described above increase the degrees of freedom for the WAM-V® technology described in U.S. Pat. No. 6,874,439, thereby minimizing stresses due to relative hull motions. Each and all improvements described above will result in increased shock mitigation and provide a smoother ride.

Another aspect of the present invention may be seen in FIGS. **4** and **5**. In these Figures, the leg connections to the skis may be the same as for the embodiment of FIG. **1**. The WAM-V® watercraft is a very versatile watercraft, and when configured as shown in FIGS. **4** and **5**, has still additional advantages. In particular, the basic watercraft is very stable, high speed, shallow draft, and depending on the power plants used, may be beachable. As such, it has many applications wherein transportability by aircraft or over roads is highly desirable. For this purpose the central body (**14**) shown schematically in these Figures may be lowered by use of leg hinges (**15**) between the lower leg section (**16**) and the middle leg sections (**17**) so that the central forward section (**18**),

Figure (78): Jacob Chase's Patents

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connected to the central body (**14**) by a ball joint as in FIG. **1**, is approximately even with the top of the skis. At the same time, the hulls (**21**) may be moved closer together to reduce the width of the watercraft for transportation. Prior to doing so, however, in accordance with this aspect of the invention, the engine pods (**20**) are rotated about vertical hinges (**19**) 180 degrees so as to lie adjacent the hulls (**21**) between the hulls as shown in section A of FIG. **4**. This substantially shortens the overall length of the watercraft for transport purposes, yet has substantially no effect on the ability to move the hulls (**21**) closer together for watercraft width reduction.

Further details of the hinging of the engine pods (**20**) may be seen in FIG. **5**. Engine pod vertical hinge (**19**) allows the engine pod (**20**) to be rotated as shown and locked in the rotated position by the lip and retainer assembly shown on an expanded scale in detail B of FIG. **5**. In particular, the lip (**25**) fits between retaining members (**26**) on a rigid portion of the hull with a pin (**27**) passing through the holes in retainer (**26**) and lip (**25**) to lock the engine pod (**20**) in position. A similar unfolded position locking mechanism (**23**) is used to lock the engine pods (**20**) in the unfolded position for normal use of the watercraft.

Particularly as shown in FIG. **5**, the engine pod vertical hinge (**19**) is preferably positioned somewhat forward of the double hinged hull section (**24**). That is the hull section which also includes the horizontal hinge characteristic of the WAM-V® type watercraft. Further details of the horizontal hinge mechanism and its function may be found in U.S. Pat. Nos. 6,874,439 and 7,562,633 and U.S. Patent Application Publication No. US-2009-0178602-A1, the disclosures of which are hereby incorporated by reference. Alternatively, of course, the vertical hinge (**19**) could be aft of the horizontal hinge of the WAM-V® type watercraft, though this is not preferred.

Thus the present invention has a number of aspects, which aspects may be practiced alone or in various combinations or sub-combinations, as desired. While a preferred embodiment of the present invention has been disclosed and described herein for purposes of illustration and not for purposes of limitation, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the full breadth of the following claims.

What is claimed is:

1. In a watercraft having first and second spaced apart and parallel inflatable hulls supporting a central body on legs there between and above the inflatable hulls, the improvement comprising:

each inflatable hull having a longitudinal structural member extending over the top of the inflatable hull and fastened thereto;

the body being supported with respect to each inflatable hull by a stern leg and a forward leg;

the forward legs being coupled to the central body to allow at least a limited rotation of the forward legs as a unit with respect the central body;

a lower end of each forward leg being coupled to a forward part of a respective longitudinal structural member through a spring mounted ball joint;

an upper end of each stern leg being rigidly coupled to the central body;

a lower end of each stern leg being coupled to a rear part of a respective longitudinal structural member through a joint that allows at least limited rotation about a vertical axis and about a horizontal axis perpendicular to a length of a respective longitudinal structural member, but not about an axis parallel to the length of the respective longitudinal structural member;

wherein the stern legs are each coupled to a rear part of a respective longitudinal structural member through a ball joint assembly that allows at least limited rotation about a vertical axis and about a horizontal axis perpendicular to the length of a respective longitudinal structural member, the ball joint assembly including apparatus preventing rotation about an axis parallel to the length of the respective longitudinal structural member.

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2. The watercraft of claim **1** wherein the forward legs are coupled together and to the central body through a ball joint.

3. The watercraft of claim **1** wherein the inflatable hulls each have an engine pod coupled to an aft end thereof by a horizontal hinge having a horizontal hinge axis perpendicular to a length of a respective longitudinal structural member.

4. The watercraft of claim **3** wherein the engine pods are also coupled to an aft end of the inflatable hulls by a vertical hinge allowing the engine pods to rotate about the vertical hinge axes 180 degrees so as to lie adjacent and between the inflatable hulls.

5. The watercraft of claim **4** wherein the vertical hinge is forward of the horizontal hinge.

6. The watercraft of claim **4** wherein the vertical hinge is aft of the horizontal hinge.

7. The watercraft of claim **4** further including a lock to lock the engine pods in the unrotated position, each with respect to its respective inflatable hull.

8. The watercraft of claim **4** wherein each forward leg and each stem leg is hinged to be foldable to allow the central body to lower with respect to the inflatable hulls and the inflatable hulls to move closer together.

9. In a watercraft having first and second spaced apart and parallel inflatable hulls supporting a central body on legs there between and above the inflatable hulls, the improvement comprising:

each inflatable hull having a longitudinal structural member extending over the top of the inflatable hull and fastened thereto, and having an engine pod coupled to an aft end thereof by a horizontal hinge having a horizontal hinge axis perpendicular to a length of a respective longitudinal structural member;

the body being supported with respect to each inflatable hull by a stern leg and a forward leg;

the forward legs being coupled together and to the central body through a ball joint to allow at least a limited rotation of the forward legs as a unit with respect the central body;

a lower end of each forward leg being coupled to a forward part of a respective longitudinal structural member through a spring mounted ball joint;

an upper end of each stern leg being rigidly coupled to the central body;

a lower end of each stern leg being coupled to a rear part of a respective longitudinal structural member through a joint that allows at least limited rotation about a vertical axis and about a horizontal axis perpendicular to a length of a respective longitudinal structural member, but not about an axis parallel to the length of the respective longitudinal structural member;

wherein the stern legs are each coupled to a rear part of a respective longitudinal structural member through a ball joint assembly that allows at least limited rotation about a vertical axis and about a horizontal axis perpendicular to the length of a respective longitudinal structural member, the ball joint assembly including apparatus prevent-

Figure (79):Jacob Chase's Patents

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ing rotation about an axis parallel to the length of the respective longitudinal structural member.

10. The watercraft of claim **9** wherein the engine pods are also coupled to an aft end of the inflatable hulls by a vertical hinge allowing the engine pods to rotate about the vertical hinge axes 180 degrees so as to lie adjacent and between the inflatable hulls.

11. The watercraft of claim **10** wherein the vertical hinge is forward of the horizontal hinge.

12. The watercraft of claim **10** wherein the vertical hinge is aft of the horizontal hinge.

13. The watercraft of claim **10** further including a lock to lock the engine pods in the unrotated position, each with respect to its respective inflatable hull.

14. The watercraft of claim **10** wherein each forward leg and each stern leg is hinged to be foldable to allow the central body to lower with respect to the inflatable hulls and the inflatable hulls to move closer together.

15. In a watercraft having first and second spaced apart and parallel inflatable hulls supporting a central body on legs there between and above the inflatable hulls, the improvement comprising:

each inflatable hull having a longitudinal structural member extending over the top of the inflatable hull and fastened thereto;

the body being supported with respect to each inflatable hull by a stern leg and a forward leg;

the forward legs being coupled to the central body to allow at least a limited rotation of the forward legs as a unit with respect the central body;

a lower end of each forward leg being coupled to a forward part of a respective longitudinal structural member through a spring mounted ball joint;

an upper end of each stern leg being rigidly coupled to the central body;

a lower end of each stern leg being coupled to a rear part of a respective longitudinal structural member through a joint that allows at least limited rotation about a vertical axis and about a horizontal axis perpendicular to a length of a respective longitudinal structural member, but not about an axis parallel to the length of the respective longitudinal structural member,

wherein the inflatable hulls each have an engine pod coupled to an aft end thereof by a horizontal hinge having a horizontal hinge axis perpendicular to a length of a respective longitudinal structural member and a vertical hinge allowing the engine pods to rotate about the vertical hinge axes 180 degrees so as to lie adjacent and between the inflatable hulls;

wherein the stern legs are each coupled to a rear part of a respective longitudinal structural member through a ball joint assembly that allows at least limited rotation about a vertical axis and about a horizontal axis perpendicular to the length of a respective longitudinal structural member, the ball joint assembly including apparatus preventing rotation about an axis parallel to the length of the respective longitudinal structural member.

16. The watercraft of claim **15** wherein the forward legs are coupled together and to the central body through a ball joint.

17. The watercraft of claim **15** wherein the vertical hinge is forward of the horizontal hinge.

18. The watercraft of claim **15** wherein the vertical hinge is aft of the horizontal hinge.

19. The watercraft of claim **15** further including a lock to lock the engine pods in the unrotated position, each with respect to its respective inflatable hull.

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20. The watercraft of claim **15** wherein each forward leg and each stern leg is hinged to be foldable to allow the central body to lower with respect to the inflatable hulls and the inflatable hulls to move closer together.

21. In a watercraft having first and second spaced apart and parallel inflatable hulls supporting a central body on legs there between and above the inflatable hulls, the improvement comprising:

each inflatable hull having a longitudinal structural member extending over the top of the inflatable hull and fastened thereto, and having an engine pod coupled to an aft end thereof by a horizontal hinge having a horizontal hinge axis perpendicular to a length of a respective longitudinal structural member and a vertical hinge allowing the engine pods to rotate about the vertical hinge axes 180 degrees so as to lie adjacent and between the inflatable hulls;

the body being supported with respect to each inflatable hull by a stern leg and a forward leg;

the forward legs being coupled together and to the central body through a ball joint to allow at least a limited rotation of the forward legs as a unit with respect the central body;

a lower end of each forward leg being coupled to a forward part of a respective longitudinal structural member through a spring mounted ball joint;

an upper end of each stern leg being rigidly coupled to the central body;

a lower end of each stern leg being coupled to a rear part of a respective longitudinal structural member through a joint that allows at least limited rotation about a vertical axis and about a horizontal axis perpendicular to a length of a respective longitudinal structural member, but not about an axis parallel to the length of the respective longitudinal structural member

wherein the stern legs are each coupled to a rear part of a respective longitudinal structural member through a ball joint assembly that allows at least limited rotation about a vertical axis and about a horizontal axis perpendicular to the length of a respective longitudinal structural member, the ball joint assembly including apparatus preventing rotation about an axis parallel to the length of the respective longitudinal structural member.

22. The watercraft of claim **21** wherein the engine pods are also coupled to an aft end of the inflatable hulls by a vertical hinge allowing the engine pods to rotate about the vertical hinge axes 180 degrees so as to lie adjacent and between the inflatable hulls, and wherein the vertical hinge is forward of the horizontal hinge.

23. The watercraft of claim **21** wherein the engine pods are also coupled to an aft end of the inflatable hulls by a vertical hinge allowing the engine pods to rotate about the vertical hinge axes 180 degrees so as to lie adjacent and between the inflatable hulls, and wherein the vertical hinge is aft of the horizontal hinge.

24. The watercraft of claim **21** further including a lock to lock the engine pods in the unrotated position, each with respect to its respective inflatable hull.

25. The watercraft of claim **21** wherein each forward leg and each stern leg is hinged to be foldable to allow the central body to lower with respect to the inflatable hulls and the inflatable hulls to move closer together.

* * * * *

Figure (80): Jacob Chase's Patents

US006983709B2

(12) **United States Patent**
Hickok

(10) **Patent No.: US 6,983,709 B2**
(45) **Date of Patent: Jan. 10, 2006**

(54) **CHAMBERED HULL BOAT DESIGN METHOD AND APPARATUS**

(75) Inventor: **William L. Hickok**, Bellingham, WA (US)

(73) Assignee: **ACB's Aluminum Chambered Boats**, Bellingham, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/723,402**

(22) Filed: **Nov. 26, 2003**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation of application No. 10/350,843, filed on Jan. 24, 2003, now abandoned, which is a continuation of application No. 09/642,113, filed on Aug. 18, 2000, now Pat. No. 6,520,107.

(60) Provisional application No. 60/149,957, filed on Aug. 19, 1999.

(51) **Int. Cl.**
B63B 43/14 (2006.01)

(52) **U.S. Cl.** **114/123**; 114/356; 441/40

(58) **Field of Classification Search** 114/355, 114/356, 123; 441/35, 40
See application file for complete search history.

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(74) *Attorney, Agent, or Firm*—Michael F. Hughes; Hughes Law Firm, PLLC

(57) **ABSTRACT**

A multichambered boat that is constructed upside-down on stationary platforms where flotation chambers are located in the perimeter portion of the multichambered boat. The perimeter chambers have a laterally downward sloping exterior surface that directs fluid downwardly and provides lift to the multichambered boat which creates a smoother ride. A fuel input line that passes through the flotation chamber to the fuel storage tank to provide convenient access for refueling the multichambered boat.

4 Claims, 6 Drawing Sheets

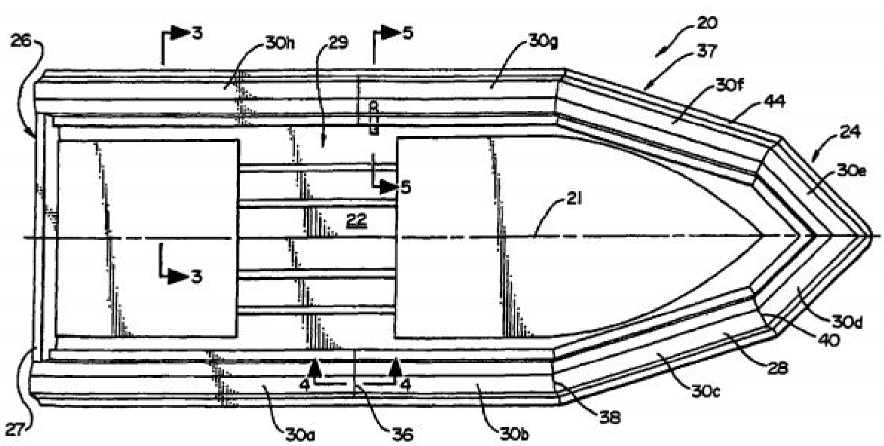

Figure (81): Chambered Hull Boat Design Patent

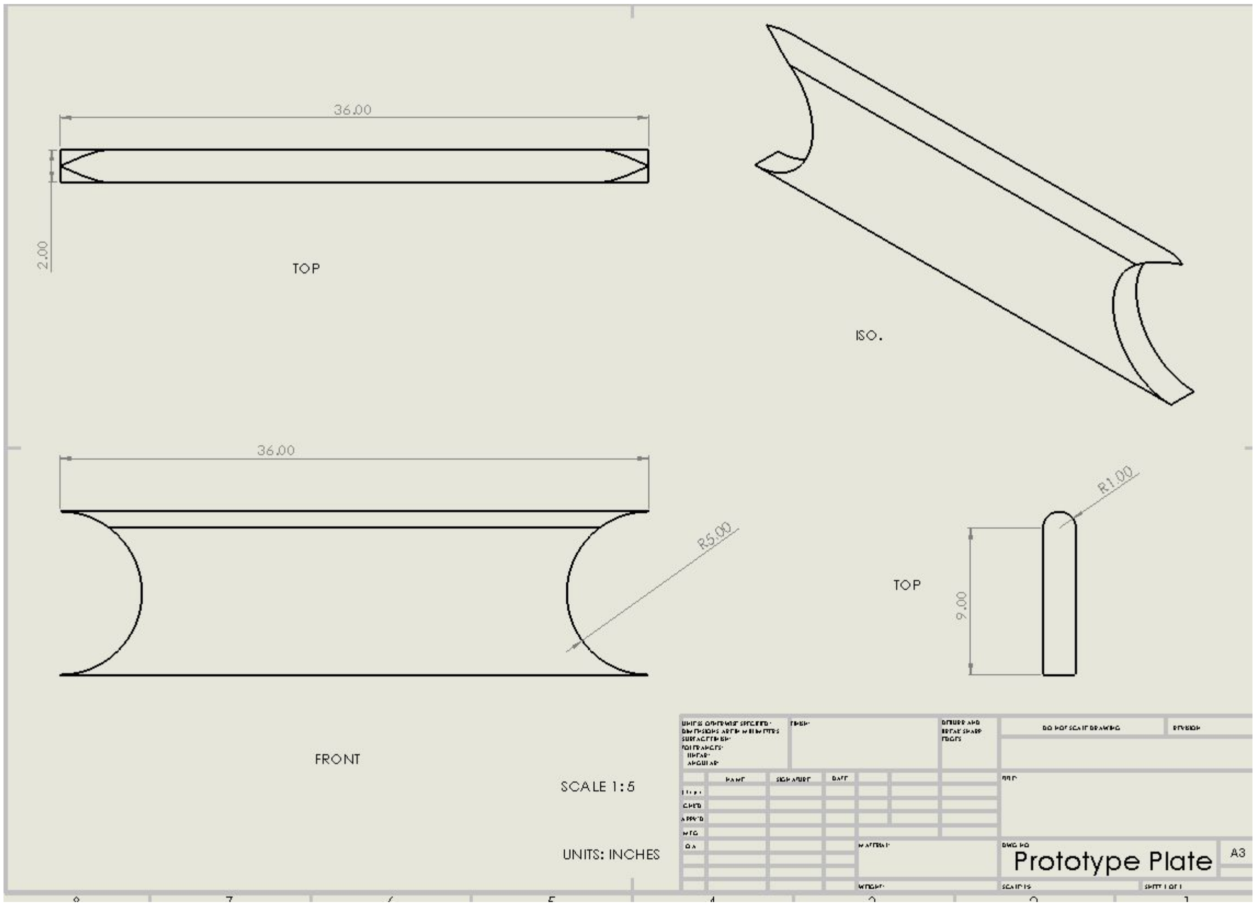

Figure 82: Inflated Section Drawing

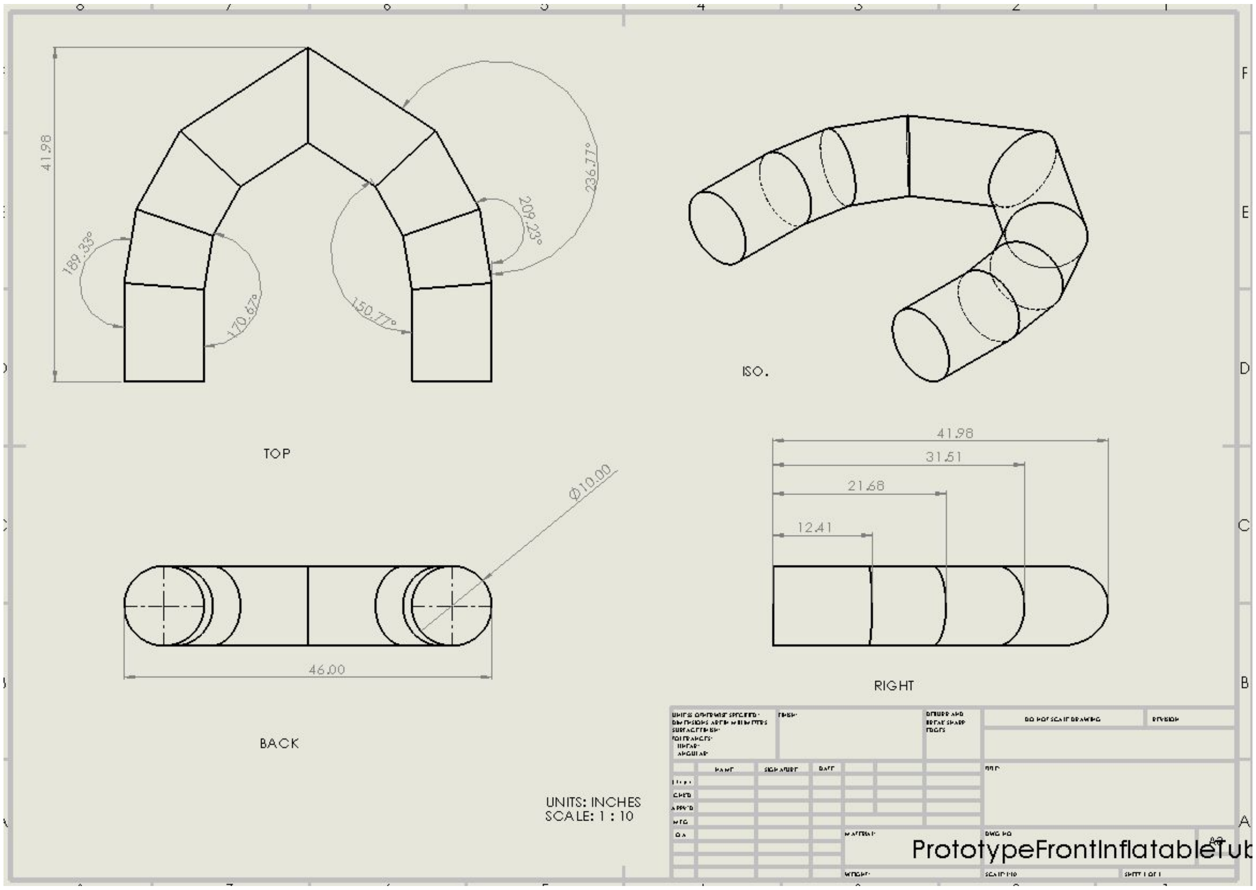

Figure 83: Frontal Inflated Section Drawing

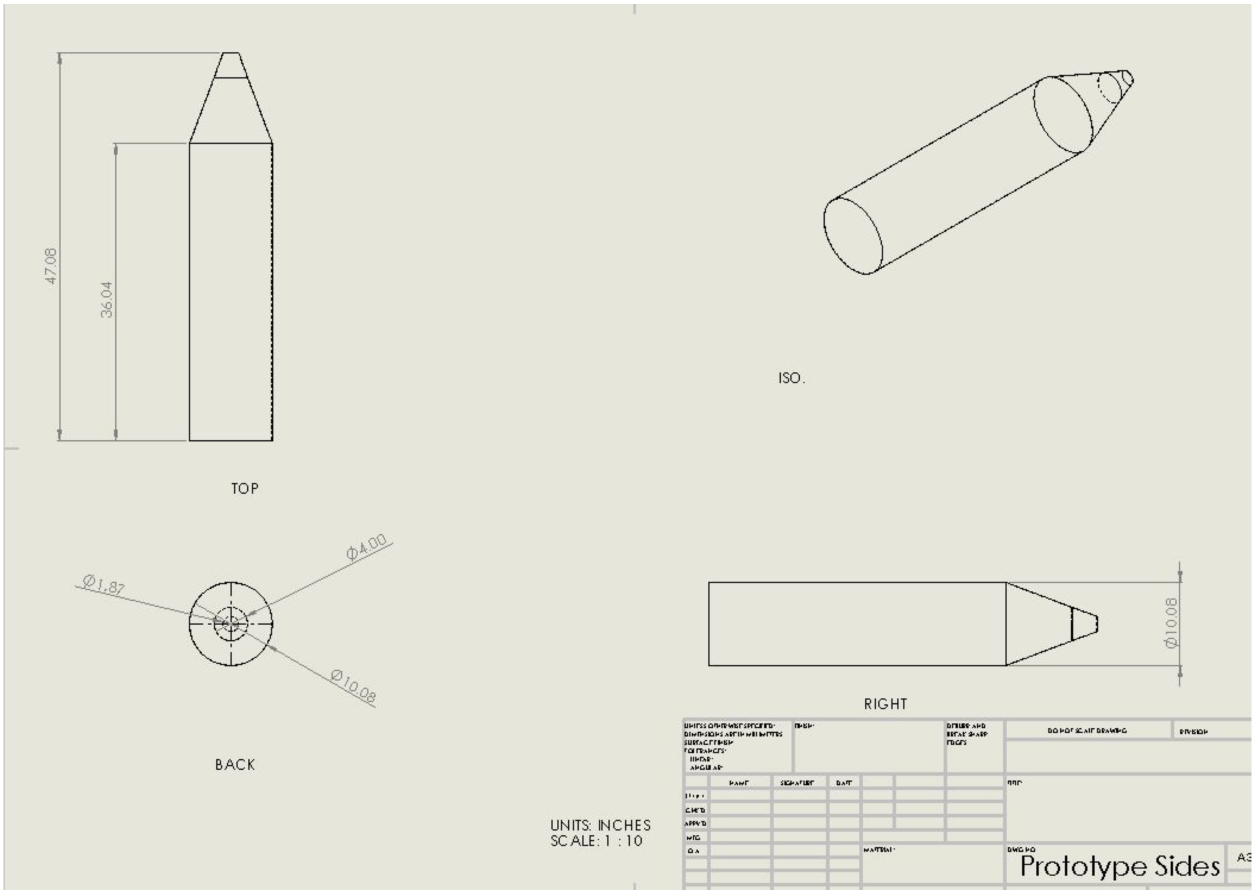

Figure 84: Rear Tube Drawing Section

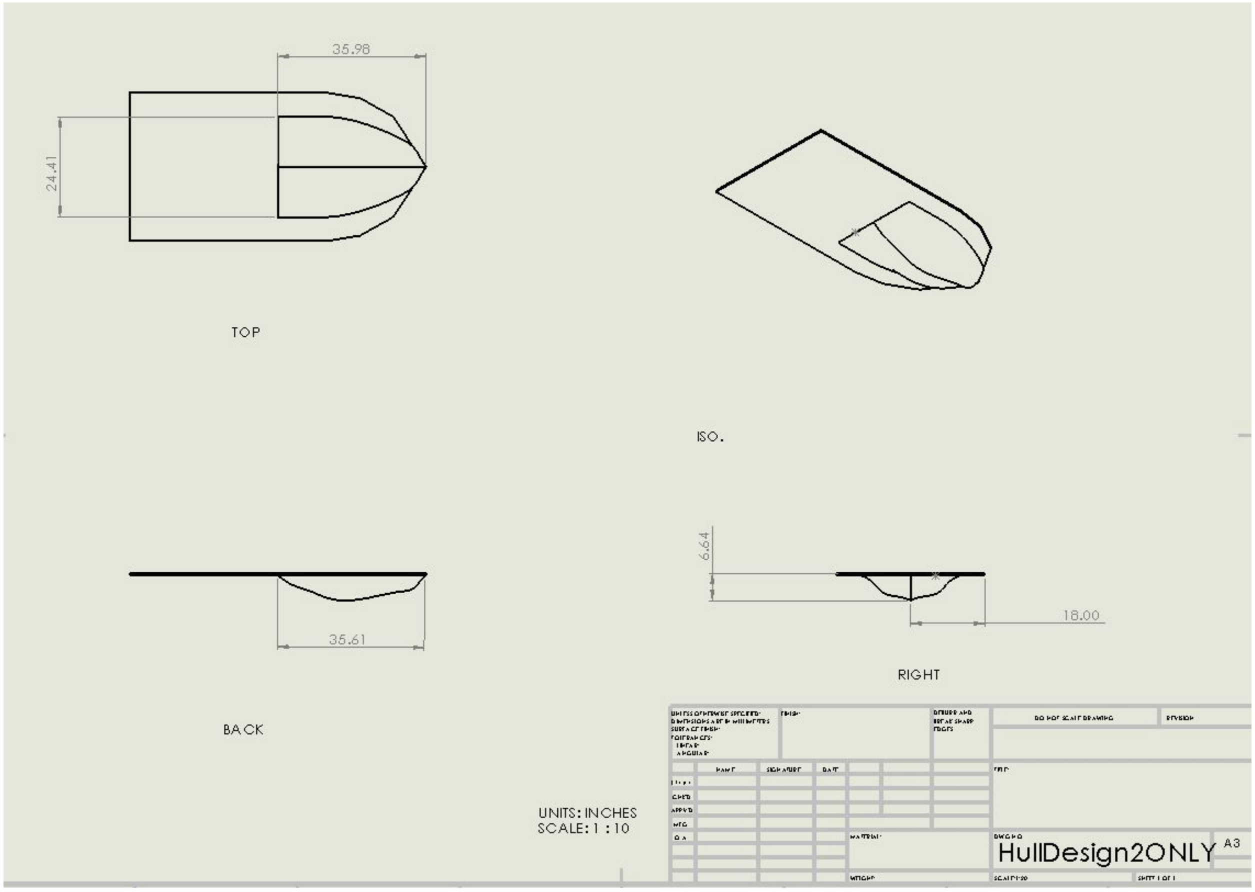

Figure 85: Inflatable Hull Drawing