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Human-Centric Environment for Saturation Divers

Industrial Design Thesis Report 2020

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Human-Centric Environment for Saturation Divers

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Abstract

Saturation diving is a demanding profession that requires endurance, mental strength and motivation to withstand its challenges. Saturation divers are required to reside in a pressurized environment for up to 28 days to reduce the risk of decompression sickness while working underwater. The claustrophobic and isolated environment means that divers are vulnerable to various physical and psychological stresses. This industry reveals limited innovational progress towards improving the health of the primary user. Methods of qualitative and quantitative research, as well as the ergonomic evaluation of full-scale models, were used to understand the direct challenges that divers are experiencing in saturation diving today. The data collected provided a platform to develop an interior to exterior system that enhances quality of life, improves comfort and flow of their environment, offering a safer work experience for every diver. The concept was developed to explore an unfocused area of saturation diving by means to inspire innovative and improved solutions.

Acknowledgments

This is to the ID graduating class of 2020 and my fellow classmates who were always able to be a positive influence and inspiration to me. It is so great to see so much talent in a small group of future designers. I want to thank the friends that were brought into my life from the start of this program, who encouraged me to work harder, believe in my abilities and always make me laugh.

Thank you to our professors who were able to provide us with amazing design opportunities, supported and worked hard in order to see the students succeed.

I would like to thank my advisors for taking time out of their busy schedules to educate me about the complicated and astonishing industry that is saturation diving, as well as share their honesty and kindness in order to guide me through this thesis.

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CHAPTER 1 – PROBLEM DEFINITION

1.1 Problem Definition

Saturation divers are required to reside in a pressurized environment to reduce the risk of decompression sickness. Divers are trained to endure work in underwater environments for a duration of up to 28 days. The divers carry out basic activities such as sleeping, eating, and necessary ablution within the saturation system until returning to their 8-hour shift (Banbury, 2018). Saturation diving is a demanding profession that requires endurance, mental strength and motivation to withstand its challenges. The claustrophobic and isolated environment means that divers may be vulnerable to physical and psychological stress such as joint pain, loss of muscle strength, spatial disorientation and anxiety (Campbell, 2019). Overall, there is the opportunity to enhance the quality of life for the individual diver; ergonomic improvements that can elevate comfort and safety (capable of exploring at least three major body part areas), enhancing the flow of claustrophobic and isolated work environments, and material adjustments for sustainability considerations. The goal is to ensure divers are comfortable; in a proper state of mind and in good physical condition to ensure that they will perform their job safely.

1.2 Investigation Approach

Qualitative and quantitative research will be conducted in order to gather in-depth insights into the saturation diving industry, on aspects that have not been well understood. This will provide a better comprehension of health/safety, comfort and ergonomic challenges faced by the primary user. Various methods such as interviews, surveys, discussions, image and video analysis will be conducted. The researcher will observe the diver and their interaction within their situated environment. Any physical difficulties such as uncomfortable reach or fit, safety concerns, ergonomic issues, and environment aesthetics will be noted. In order to better understand the users' psychological challenges, facial expressions and body language will be analyzed and rated in accordance to their comfort level versus the executed activity. Reaching these objectives will guide the question as to how we can improve safety and comfort in Saturation diving.

Key Questions

1. How can we improve the safety and comfort of saturation diving?
2. How can we mitigate the psychological and physical stress of saturation divers?
3. How can we improve spatial awareness between the diver and his/her environment?
4. What innovative concepts from existing designs/systems can be used as inspiration?
5. What design aspects should be avoided, from existing systems?
6. What are the primary needs of the divers?
7. How can we increase the efficiency of the diver on the job?

Table 1. Displays an overview of the methods/approach taken throughout the duration of the project.

General Design Methods	**Specific for Thesis Development**
RESEARCH	User Research -user profile -User observation -Interviews -Ergonomic study -Activity mapping Product Research -literature review -benchmarking
ANALYSIS	-User demographics -function of existing systems -competitive/frequency analysis -health and safety -aesthetics/materials

IDEATION	Rapid sketching, Mind mapping, Final sketches
CONCEPT DEVELOPMENT	Ergonomic/sketch model development
CONCEPT REFINEMENT	Detail development, Cad development
MODEL DEVELOPMENT	Cad model, hard model
COMPLETED DESIGN	Formal Presentation

Table 1

1.3 Background

Saturation diving is a profession that requires years of specialized training and takes an individual with determination to be able to withstand the challenges that come along with it. The intensity and dangers of SAT diving and the expense of diving programs (tuition can come up to $20,000 U.S per year (cDiver, 2016)) means that there are very few individuals who become offshore/saturation divers. Less than 1% of those are female (ADAS, 2017). Since the start of commercial diving, introduced by Jacques Cousteau around the 1950s (The Cousteau Society, n.d.) there have been technological advancements, but very little research regarding the individual health of the diver or ergonomic improvements within the saturation diving profession. The systems and technologies that are involved within the industry are sensitive and specifically engineered (Chamber Oceanics, 2008) which makes it difficult to be innovative without altering the safety of the system. Thesis design development will be guided through the most recently improved and modernized saturation systems such as “Divex” by JFD, a subsea operations and manufacturing company (JFD, 2019). Safety rules and regulations, technical specifications, user-oriented design features and workflow of divers will be analyzed from this existing system.

Through various online discussions with qualified saturation divers, it was clarified that the importance of “unionization” was considered a priority. Divers changing locations and working for various companies means that the the pros and cons of their experiences can be compared. The difference between working in a unionized industry such as Australia (versus parts of Asia) means that they can rely on the safety standards that are to be expected (cDiver, 2016); Proper food, alternating shifts between divers, the required number of divers needed for a dive, the proper supervisors to ensure communication is engaged for safety purposes, clean and organized living chambers, and thought-out mission plans. This can be compared to an industry that takes time/money as a priority over safety. Here, jobs are rushed, there may be an insufficient number of divers, and equipment/system is outdated. This takes a toll on the mental and physical stress of the diver (M. Aidney, personal communication, Oct. 11, 2019). Using this information will help guide the priorities that saturation divers expect to see within their work. These aspects provide a base in which will then be developed further into innovative and revolutionary design concepts. If an individual goes into a SAT dive with a negative mindset, it will affect the efficiency and safety of their work due to increased anxieties, risk of a panic attack, and loss of focus to complete their task at hand. The goal of the thesis is to reduce these challenges by providing the diver with increased comfort and safety within the final design.

CHAPTER 2 - RESEARCH

This chapter will provide an organized arrangement of data regarding an in-depth outline of user demographics by dissecting relevant information through image and video analysis and primary user interviews. This will be followed by benchmarking in order to identify strengths, weaknesses and technical information of current products on the market. All information is applied to guide the development of this thesis submission.

2.1 User Research

2.1.1 User Profile

This section presents qualitative and quantitative research data regarding the profession of saturation diving. This report will review a targeted demographic by collecting information on age, gender, location, education, family status, occupation, ethnic background, as well as analyzing user behaviour by collecting data regarding the motivations, income level, user activity, and cognitive aspects of divers. This will be based on image, literature searches and interview analysis. The result is a research informed persona that will be used to clarify a user profile.

Demographics

Data is collected from images and tables shown in Appendix B

Primary Users:

These divers are responsible for completing the job or missions. Individuals are most involved in underwater construction, repairs, maintenance of infrastructure and sometimes marine research. There are three main users in SAT diving, the closed bell diver who acts as a stand by and is responsible for the divers on site, the other two are submerged underwater.

Secondary Users:

This includes supervisors that stay in the control room chamber to ensure that everything is stabilized in a pressurized environment. This individual is also a trained diver. They are responsible for the organization of each mission for a duration of 28 days. They keep in contact with the bell diver in case of emergencies. There are Life support technicians on site to provide immediate medical aid.

Tertiary Users:

These individuals can be considered the instructors or teachers who are responsible for properly training the SAT divers.

Age & Gender: Divers who become certified offshore divers are predominately male, age 30 – 60.

Education: Required to have completed secondary education to be qualified to study and practice commercial diving

Income: Divers earn an average of $60,000 US (ranging from 40k to 100k annually). The wage increases with their experience level. Tuition for diving school cost approximately $20,000 US a year indicating the need for prior income due to this expense (Best Welding Supply, n.d.)

Ethnicity: Divers can come from a broad range of backgrounds such as Caucasian, Asian, South American varying on their diving location. Majority of divers are Caucasian.

User Persona

Name: Pierre Martin
Age: 31
Sex: M
Job: Saturation diver of 10 years
Education: Commercial Diving Institute of Canada
Family: Recently Engaged
Location: Vancouver, BC
Social: Has grown close with his saturation team, when out of SAT he likes to spend his spare time with his work crew
Activities: Traveling with friends or fiancee, biking, maintains physical shape and good health
Income: 40k-150k annualy

Image of commercial diver from Canadian Diving Institute.

User Behaviour

Pierre is a 31 year old Caucasian male who grew up in Vancouver British Columbia. He spent a year off after high school backpacking around Europe with his friends. It was during his adventures in Italy where he learned that he had an interest in diving. His interest brought him to start his career path at CDI, the commercial diving institute of Canada. He was able to accomplish his first saturation dive about a year and a half after starting his training. John has been a saturation diver for 10 years. His last dive took place off the coast of New Zealand where he and his dive partner, Alex, had to repair construction of an oil rig that was 300m below the waters surface. He spends his time in a pressurized environment for 28 days with 6 other SAT divers. On his free time, he enjoys spending time with his fiancée and friends. Often, they go biking through forest trails.

2.1.2 Current User Practice

Duration & Frequency: SAT divers spend up to 28 days in their chambers and up to 8 hours on the seabed per day, with alternating shifts to complete their task. Since the industry fluctuates; work may be abundant with great working conditions and high wages or there may be phases of downturns, leading to minimum wages and unemployment for certain periods of time. Divers can expect to work more or less than 100 days per year.

Social/solitary: Every diver is required to have a partner and supervisor in case of an emergency. This indicates that saturation diving is a group activity where they live, eat, sleep and carry out other basic activities in the same vicinity. Working on a dive job requires only two individuals where communication is limited creating a solitary and isolated experience for the individual. Due to the small living space and limited privacy, the divers are forced to spend time together and is important that they get along for the time they are in the chambers to ensure efficiency in their work.

Locus of control and self efficiency: Since saturation diving involves many challenges and lots of training to be certified, it takes an immense amount of motivation or passion for the industry. If an individual goes into a SAT dive with a negative mindset, it will affect the efficiency and safety of their work due to increased anxieties, risk of panic attack, and loss of focus to complete their task at hand.

Location: Saturation divers work across the globe. Common locations include Australia, Malaysia, and Northern coastal areas.

Lifestyle: From thorough reviews of online user blog profiles of qualified saturation divers, it is evident that they share common interests. These individuals have a clear passion for the diving related industry.

Prior to their career as a saturation diver include activities related to travel/exploration of seas, aquaculture, harvesting, a desire for adventure and challenge. On their spare time after their 28-day cycle, the primary user spends time travelling with or visiting friends and family.

2.1.3 Activity Mapping

This section examines user interaction and behaviour based off a selected video analysis. The objective of this user observation is to analyze the challenges a saturation diver may face within their industry. In more specific terms, the researcher will observe the primary user (diver) in their situated environment through various videos and any physical difficulties such as uncomfortable reach or fit. Environment aesthetics and structure such as colour and space, will also be observed and taken note of. In order to better understand the user's psychological challenges, facial expression and body language will be analyzed to rate their comfort levels in reference to the activities they carry out. Reaching these objectives will guide the question as to how we can improve safety and comfort in Saturation diving.

Video Analysis

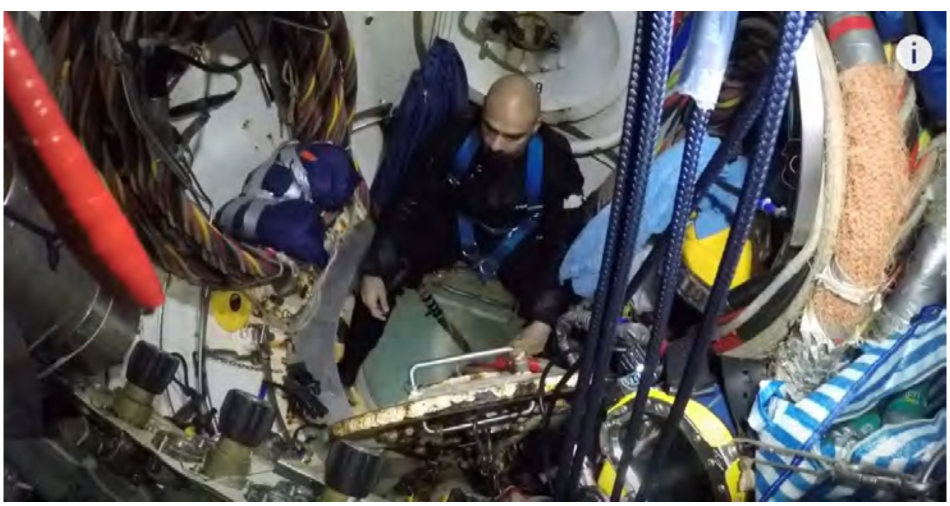


Figure 1 – Diver in Dive Bell

Title: Saturation Diving

Source: Youtube, June 12 2019, Username: DiverDariusD

Duration: 2:10 Minutes

The key activities to be carried out will be to analyze various videos/documentaries from platforms such as YouTube, and break down sections of the media. Through the dissection, the videos will be rated on a scale of "pain to pleasure" from one to five. This can provide insight on how to improve negative experiences. This data will then be plotted on a user experience map showing the details of a specific moment where a user may have a negative/neutral/positive experience. Throughout these activities, visual demographics will be noted.

Video source: https://www.youtube.com/watch?v=kwjmWQ3xNto						
Task: Shows environment of a saturation system and preparing to dive.						
Step #	**Description**	**Gradient Scale of Pain – Pleasure Points** Negative = 1; Neutral = 3; Positive = 5 **1**	**2**	**3**	**4**	**5**
01	Diver maneuvering through chamber to chamber (through doors/ports)	X	O	O	O	O
02	Sleeping area (special analysis)	O	X	O	O	O
03	Putting on equipment	O	O	X	O	O
04	Divers during past time/eating	O	O	X	O	O

05	waiting to enter the diving bell	O	X	O	O	O
06	Preparing gear for diver 2 to enter water	O	X	O	O	O
07	Diver 1 remains in bell (supervising)	X	O	O	O	O
08	Diver 2 resurfaces (both divers are in bell removing equipment)	X	O	O	O	O
09	Diver 1 washes up	O	O	X	O	O
10	Diver 1 exercises (push-ups and sit-ups)	O	O	O	X	O
11	Diver 1 has leisure time goes on computer	X	O	O	O	O

Table 2

Key activity 1: Residing in Saturation System

- Carrying out basic daily activities such as sleeping, eating, personal hygiene
- Retrieve items from delivery portal
- Ensure that pressurization is stable
- Bending, reaching and minimal exercise

Key activity 2: Preparing personal equipment for dive in diving bell

- checking and adjusting pressure

- assisting other diver with equipment, helmets, and ensuring umbilical cords and oxygen tanks are working correctly
- connection with members on ship above for emergency situations
- dive supervisor in charge of getting diver 2 and 3 into the water safely

Key activity 3: Underwater Work

- divers are now submerged under water
- they are responsible for completing their task; repairs and maintenance of underwater infrastructure/systems
- extremely low visibility and cold environment b/c of depth up to 300m
- divers submerge back into bell and begin the assist each other in removing gear

User Experience Map

The following diagram organizes the chronological information in *Table 2* into a line graph. The **orange line** represents the **current experience**.

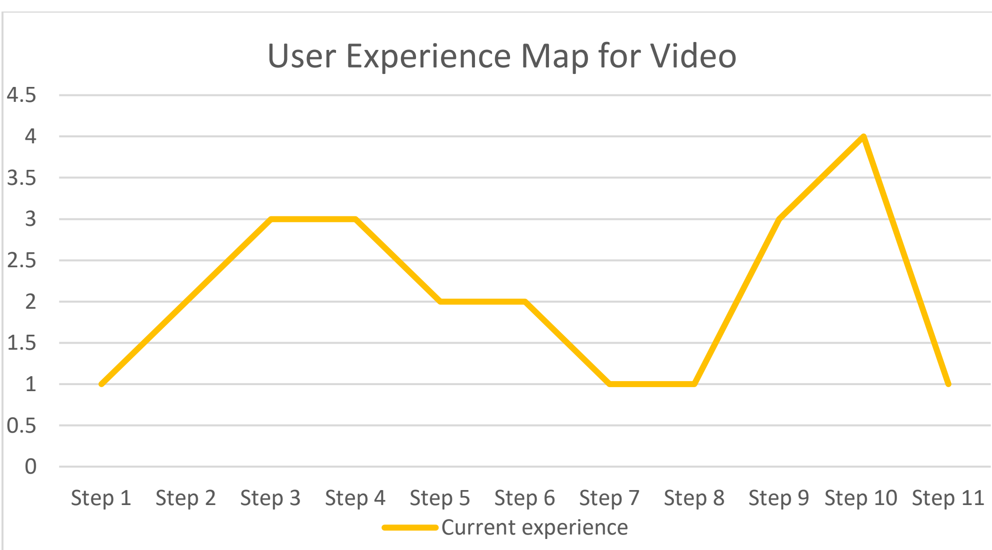


Table 3 – User Experience Map

Current experience

- Poor ergonomic considerations, poor posture, crouching too low, bending spine too often
- Extremely limited space, individuals are very close together which allows limited privacy, disorganization and clutter
- System is predominately made of metal which may mean that sound carries easily
- Users find their own space to exercise wherever they can and if willing
- Safety features are not clearly identified or accessible
- Visibility is extremely poor underwater

2.1.4 Ergonomic Research

The interior dimensions of the saturation chamber and diving bell are analyzed. This provides a visual presentation of human-environment interaction. 5th percentile female and 95th percentile male is used for the focus of ergonomic research. Measurements are based on existing benchmarked systems.

Literature Review

Anthropometric measurements were primarily obtained from Henry Dreyfuss's *Measure of Man* (Tilley, 2002). Secondary references were used to verify and compare certain ergonomic measurements from, *Health Facility Guidelines* document (Tahpi, 2015). This data was used to validate dimensions in reference to certain parts of the system, such as standard heights and widths, as well as incorporating ergonomic measurements of the smallest female and the largest male to ensure both individuals are capable of efficiently interacting throughout and with the system.

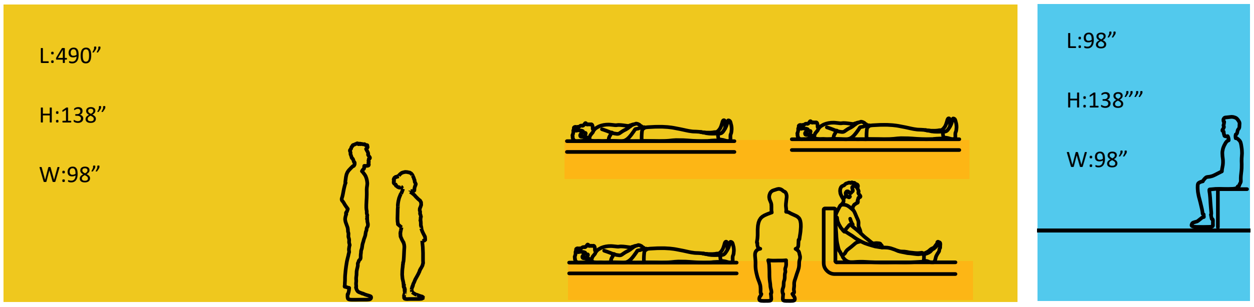
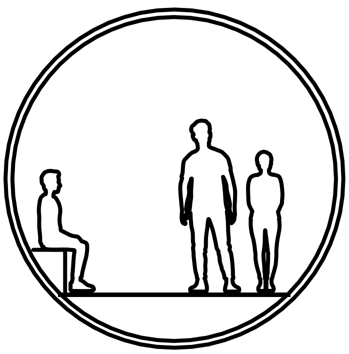


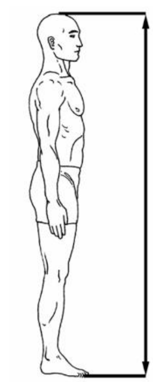
Figure 2

Main Chamber in orange

Diving Bell in blue

Ø138”





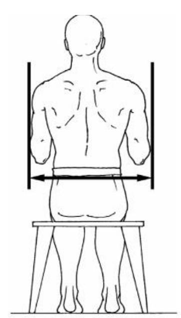
Stature height

5% female: 60”

95% male: 74”

Seat height: 18”

(Gordon, 1989)



Forearm Breadth

5% female: 16”

95% male: 24”

2.1.5 Health and Safety Research

There are many factors involved in standards and regulations for safety within general, deep, and Submersible Compression Chambers (SCC) and Lock-Out Submersibles (LOS) that are relevant for the requirements of the final thesis design and development. The following points are obtained from *workers Compensation Act.* (Workers Compensation Act, 2019)

OCCUPATIONAL HEALTH AND SAFETY REGULATION

Part 24 — Diving, Fishing and Other Marine Operations

Key safety considerations

- all divers must be trained in CPR, oxygen therapy and diving accident management
- dive site must be provided with list of facilitates, with hyperbaric chambers capable of providing emergency treatment
- a first aid kit and oxygen therapy unit with enough capacity to reach emergency medical services
- divers must be equipped with bailout bottle containing minimum of 1.4 m^3 (50 ft^3) of breathing medium
- a chamber operator must be available on the surface at the dive site or hyperbaric chamber
- if necessary, to transport a diver suffering a diving ailment by air, provision must be made to furnish the patient with oxygen and flight altitude must be prescribes by diving supervisor
- hyperbaric chambers must conform to standards by means of extinguishing fire, oxygen monitoring device, oxygen delivery system with built in breathing system, adequate supply of air, emergency reserve supply to complete any decompression and treatment procedures
- diving supervisor must have a means of monitoring depth of divers and the SCC, controlling the pressures of the breathing mixtures
- rest period of at least 24 hours, in any 24 hour period, there is a rest period of at least 12 continuous hours after the applicable time limits in paragraphs (a) and (b) have been reached.
- Each SCC and LOD must be equipped to permit transfer of persons under pressure and into and from a surface compression chamber, must have doors and hatches that act as pressure seals, and may be opened from either side
- Heating lighting equipment backup illumination
- Standby divers' umbilical bundle must be 3m longer that umbilical bundle

- Design must allow divers to enter and exit without difficulty, allows at least two divers, equipped and dressed for diving operation to be seated within, in case of emergency allow diver to disconnect the primary lifting cable and umbilical bundle

2.1.6 Interview Results

This section analyzes feedback and data collection through various online sources. Through survey platforms and blog communities, a series of 10 open ended questions were provided to be answered by SAT divers from various locations. The data collected from each interviewee were reflected upon and summarized into key points related to the primary user. Online discussions were dissected and analyzed, gathering the most important information relative to the thesis subject. Full Interviews and discussion can be viewed in Appendix C

Key Points from combined interviews relevant to the user

- Various qualifications are involved in becoming a SAT diver such as medical and Non-destructive testing (NDT certification)
- The industry fluctuates; work may be abundant with great working conditions and high wages or there may be phases of downturns, leading to minimum wages and unemployment
- Unionized industries provide much better working conditions, safety regulations, such as Australia. This can be compared to Asia and the Middle East where conditions are poor.
- Divers are at the underwater jobsite for at least 6 hours, there are three men signed to each mission/job.

- Working with individuals who one may not get along with can make a stressful situation in an isolated environment.
- Job will last for 7.5 hours and the next team will continue with the same routines, in teams of three. The job can last for 18-28 days.
- Regimented shift system is a major improvement for morale, sleep patterns and efficiency (instead of ratcheting shifts) maximum of 28 days, and ensured breaks.

2.2 Product Research

2.2.1 Current Products Profile

The aim of this section is to investigate benchmarking and gather a database of existing products and take note of their features, compare and organize the information using a variety of methods such as x-y graphs and frequency charts. Taking important information and analyzing the pros and cons will be taken into consideration. Through benchmarking, important aspects are integrated into the final thesis such as safety rules and regulations, ergonomic considerations, maximum comfort, modularity and aesthetics.

Benchmarked Products

Table 4. below compares the similarities and differences between each system. Certain specifications such as the depth the system can withstand, will be noted for technical application within the thesis. The dimensions and capacity ratio are useful to understand a realistic proportion as to what a certain space can fit ergonomically. This information will have to be taken as an approximate measurement since some of these systems are currently not “space-efficient”, giving divers little space

and privacy to be comfortable. The table also provides safety equipment and technologies that are necessary for improved user experience.

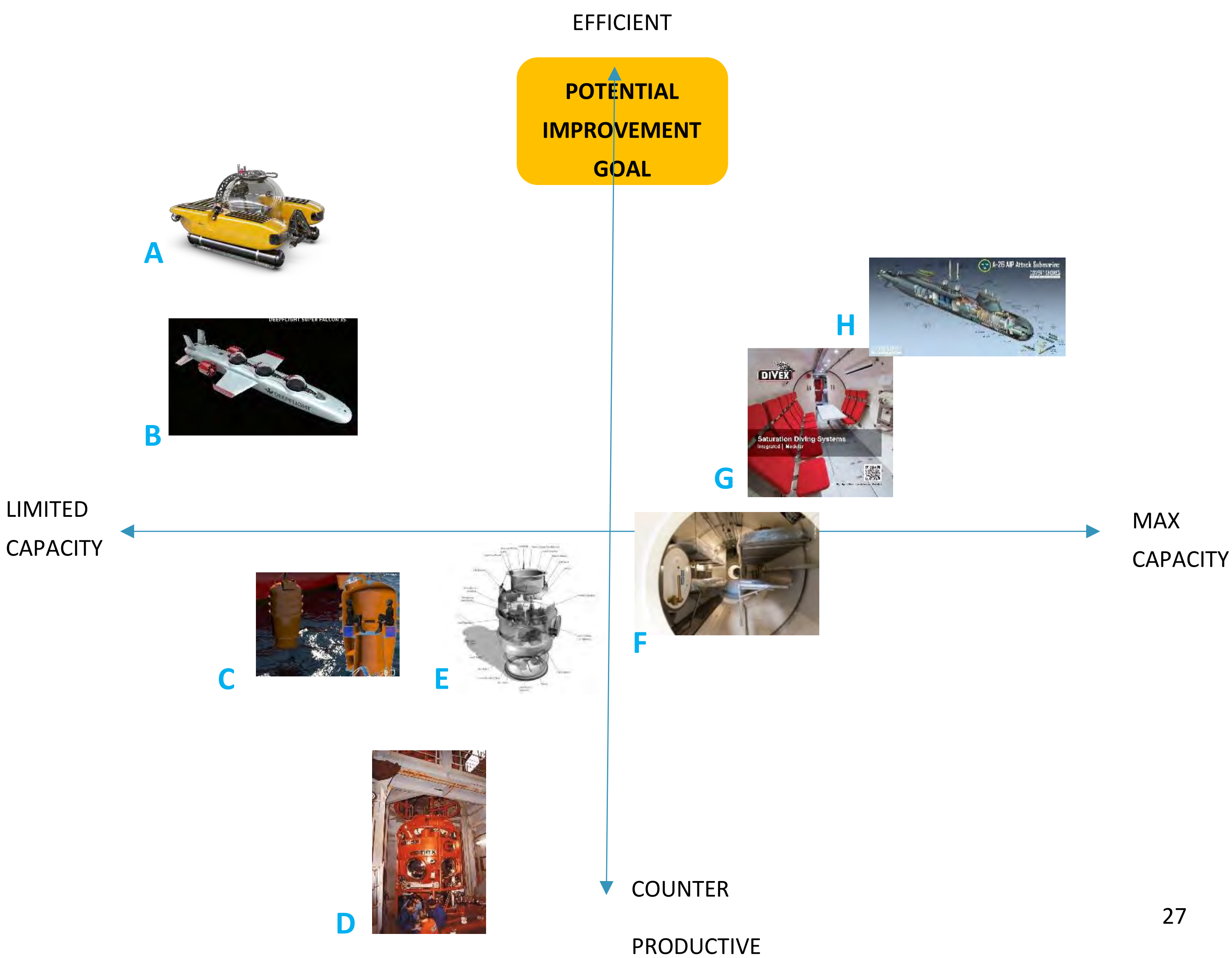
PRODUCT	CAPACITY	DIMENSIONS	TECHNOLOGY	SAFETY ASPECTS	DEPTH OF TRAVEL
G.DIVEX SATURATION SYSTEM	12, 12 or 24 persons	Ø: 2.5m -Client specified	-Automated control rooms utilising touch-screen technology. -Air-condition -Dimmable lights -Modular/integrated	- design-approved and classified by Lloyds Register and DNV - life support machinery, gas recovery system	300msw
E. JFD RESCUE BELL	-6 rescues, 1 operator	Length – 2500mm Width- 2500mm height – 3500mm	associated equipment (winch and umbilical) can be rapidly mobilised by land and air.	rapidly mobilised by air or land, ready in hours	up to 300msw
C. DRASS SUBMARINE RESCUE	9 DISSUB 2 operators	N/A	-hydraulic winch -three independent sub-systems:	N/A	300msw
B. DEEPFLIGHT SUPER FALCON SUBMARINE	2 persons	LxWxH: 5.9m x 2.7m x 1.6m	Auto return to surface 3-axis flight control Fly by wire tech	Low voltage=safe to use around sealife/swimmers	100m 8 hour endurance
A. TRITON SUBMERSIBLE	2 persons	L: 3.2m W:2.5m H1.85m	Lead acid (lifepo4 battery) 3-axis flight control - transparent pressure hull.	- open the hatch while on the surface. - single lift point - Manual overrides -Direct air injection to ballast tanks emergency battery power 96 hours.	305m 10-12 hour endurance
D. COMEX DIVING BELL	3 persons	N/A	Ballast release systems Bell Heaters	-Emergency battery -Emergency respiratory units -Fire extinguisher	300msw
F. RANA CALYPSO SAT SYSTEM	15 persons	L:12200 W:2440mm H:2890mm	Modular and transportable	Emergency generator life support equipment	300msw

H. SAAB SUBMARINE	26 persons ~ 8 persons [multi mission portal only]	L:62m ~ L:6m [multi mission portal only] Ø: 1.5m	-Propulsion system -weapon systems -modular system -Multi-mission	-leisure time -"hot bunk" -emergency air blowing system -double shut off valves -rescue at 180m	-200m -45 day endurance

Table 4 – Benchmarked Product

x-y Graph

It is important to understand the efficiency of each system. The graph below compares the benchmarked systems. "Max and limited capacity" measures the number of persons able to fit in the system from low to high. "Efficient/counterproductive" measures various capacities for safety, ergonomics and endurance of the system



In order to compare the 8 products listed in reference to "safety and comfort" was to place the data onto an x-y graph, measuring efficiency and capacity. This is shown in the diagram above. "Potential improvement goal" represents the ideal circumstances for the final result.

Benefits and Features

Below are the key benefits and features listed in order of highest frequency appearance. The information was generated through a further detailed chart shown in the Appendix E.

BENEFITS	Frequency Benefits	FEATURES	Frequency Features
Comfort	**7**	Technology	**5**
Efficiency	**5**	Modular/Transportable	**9**
Safety	**10**	Rescue	**11**
Spacious	**1**	Ergonomics	**1**
Privacy	**1**	Endurance	**6**

Table 5

Key Benefits	Key Features
1. Safety	1. Rescue
2. Comfort	2. Modular/transportable
3. Efficiently	3. Endurance
4. Privacy	4. Technology
5. Spacious	5. Ergonomics

This frequency table provides a platform to analyze the most basic and necessary needs that are involved throughout the 8 systems, some more significant than others. The number one occurring feature and benefit both relate to the safety of the individual. The least occurring, only listed once within the descriptions include privacy, space and ergonomics. Of course, the safety of the individual is the most essential aspect that is considered within the development of this thesis.

2.2.2 Benchmarking – Functionality

Benchmarked products share common features. This includes the number of individuals that can be withheld in the system, technical specifications involving dimension and depth of travel of the system, as well as technological and safety aspects. The function of the benchmarked system varies from recreational purposes to professional or commercial. Smaller submersibles target a capacity of up to two individuals and are used for leisure and adventure, allowing the user to experience the underwater world on an intimate level. These systems run on a lower endurance level meaning they are limited to traveling depths over 100m and last for up to 10 hours max of travel time. The features of these small submersibles tend to include a system that is more intuitive and easier to use for the user. The individual who owns or operates these submersibles are intended to use it with no or little training.

The larger systems, containing 8 or more individuals, namely the benchmarked saturation chambers, dive bells and submarines are focused on the efficiency of work. The priority of these systems is to ensure a safe pressurized environment capable of holding the needed number of crew members for rescue or job duties. These systems involve complex controls and specific procedures that could require years of training to operate. Endurance exceeds depth greater than 100m and has the capacity to endure greater amounts of wear and tear because of its size, durability and technical advantages (such as a stronger energy source). An important feature that many of these designs incorporate is modularity. They are capable of fitting and disassembling parts in order to allow transportation to alternate locations in less time and with less complexity.

Safety aspects are similar throughout the systems. Backup generator or batteries, emergency exits/kits, and the ability to be mobilized by air and return to surface in emergency situations, are integrated. The newer systems such as Divex, Super Falcon and Titan provide an improved user-oriented experience because they integrate touchscreen technology, mood lighting and simple maneuverability and even consider comfort of environment through air conditioning and anti-humidity.

2.2.3 Benchmarking – Aesthetics and Semantic Profile

x-y Graph of Aesthetic Profiles

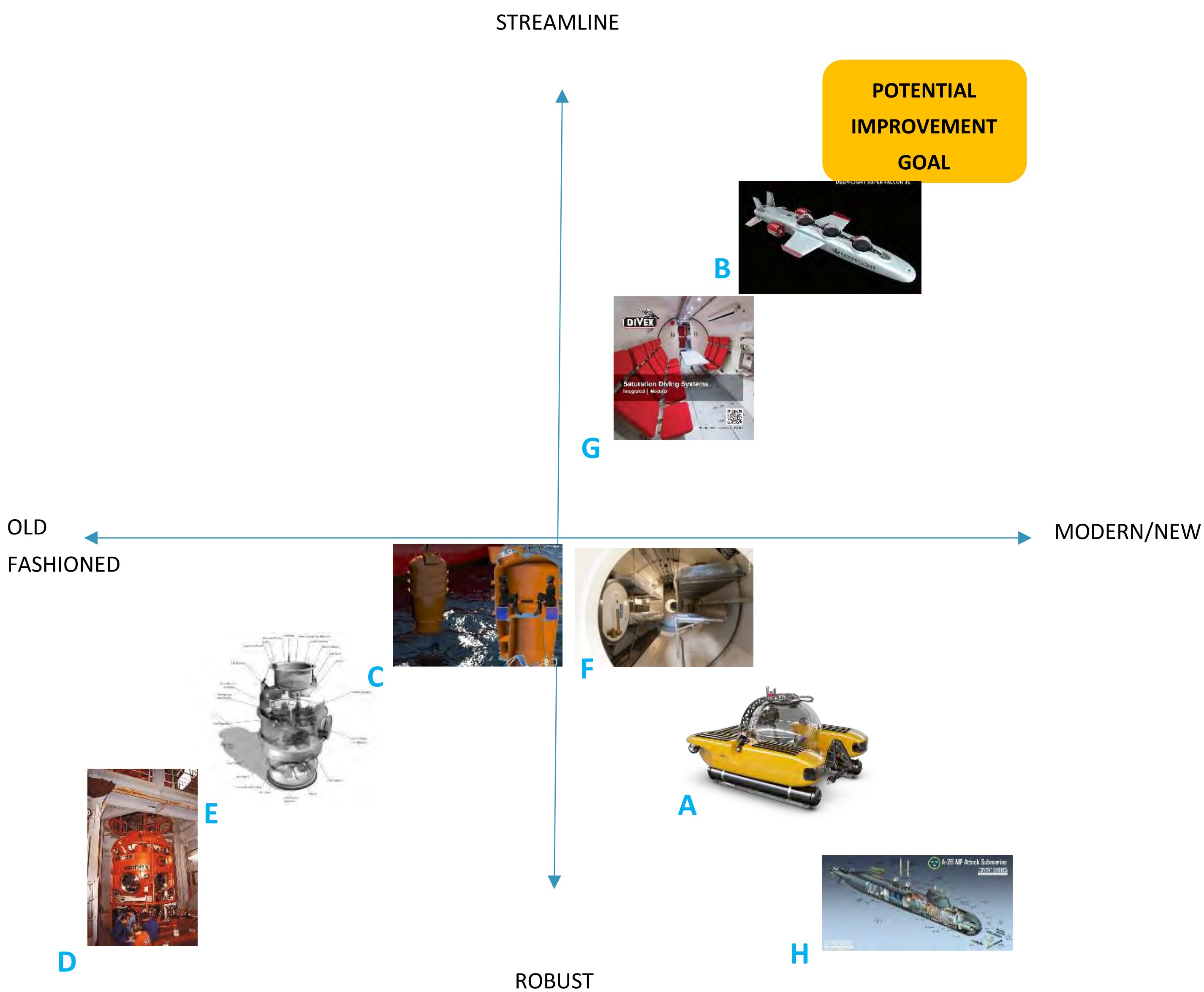


Figure 3 *DeepFlight Super Falcon Submersible*

Figure 4 *Divex Integrated saturation system*

The newer systems, Divex and The Super Falcon (see figure 3 and 4) show slim and aerodynamic design by using cylindrical interior/exterior bodies and smooth surfacing. Depending on the need for visibility will alter the colour of the design. A warfare submarine such as letter “H”, shown in the x-y graph above, that relies on its function to be discrete/invisible will intentionally be a dark hue. The Triton submersible, on the other hand is a bright yellow for it to remain more visible. It is not stated specifically within the spec sheet, but it can be assumed that brighter use of colour can make it easier to locate the system in perhaps, an emergency.

All systems have a general look of “robustness” due to the fact that they need to be durable. With the evolution of design, the use of lighter and thinner materials and modular aspects allows a more streamlined design. Rescue systems are also shown in a bright vibrant colour, orange, indicating the need for it to be easily located. The interior of system “F” versus system “G” shown in the x-y graph above, displays a differentiation in aesthetics. The updated design shows a contrast of colours, white and red, which can stimulate a positive user experience when residing in a space for a length of time, compared an interior that solely consists of metal. This can make the environment feel cold, uncomfortable or unwelcoming. It is also important to consider that certain individuals may have different reactions to certain colours. It is possible that not every user will have a positive experience to the colour red, for example. This psychology of colour will be analyzed in greater depth within chapter 3.

2.2.4 Benchmarking – Materials and Manufacturing

A collection of materials and manufacturing methods can be gathered through reviewing various benchmarked products. The use of composite materials offers the benefit of weight reduction and durability, necessary to withstand harsh underwater environments and signifies technological advancements. Plastics such as acrylic and metals including aluminum and titanium alloys that are used in the production of submersibles.

Acrylic glass: used for hemispherical viewports. Bag moulded, centrifugal-casted and contact-moulded manufacturing processes. PLEXIGLAS® offers a technology for a larger viewport and can withstand immense tons of water pressure. (PEXIGLASS, 2019)

Gasket: Fills space between mating surfaces to prevent leakage. A Material manufactured by Globe Composite, specifically developed a thermoset elastomer named *"Brandonite".* This is a high strength, flexible and high elasticity material. Provides: resistance to abrasion and tear, energy absorption, low creep and compression set properties, high resistance to seawater, oils, UV and chemical degradation (Delaforce, 2011)

Metals: Titanium and carbon fibre offers the lightest weight and cost-efficient material for extremely deep ocean depths, simple to replace parts of hull construction (Oceangate, 2019)

Manufacturing of the submersible hull involves assembly of steel plates. Parts are welded together and are divided between an inner and outer portion along with many other sub compartments to ensure watertight components. Welding seams are grinded by highspeed grinding wheels to smooth out the surface which also allows less friction during travel. A protective “anti corrosion” coating is applied to all surfaces.

2.2.5 Benchmarking – Sustainability

There is limited information on sustainability or environmental concerns with regard to the benchmarked systems. The Super Falcon submersible lists one of its features that concerns the environment. The design uses a “high efficiency DC drivetrain” and an underwater “Lithium iron phosphate battery” that allows it to run fast, clean and quiet. Its low voltage system allows it to be operated safety around sea life or other divers, reducing environmental disturbance (DeepFlight, 2019). The Swedish manufacturing company, SAAB, mentions sustainability initiations within their annual report of 2016. Their considerations include; to reduce greenhouse gases emissions by 20% by 2020, to phase out the use of hazardous chemicals (replace hexavalent chromium) and have been lead free as of 2007 (SAAB, 2016).

2.2.6 Interview Results

This section analyzes feedback and data collection through various online sources. Through survey platforms and blog communities, a series of 10 open ended questions were provided to be answered by SAT divers from various locations. The data collected from each interviewee reflected upon and summarized into key points related to the product/system. Online discussions were dissected and analyzed, gathering the most important information relative to the thesis subject. Full Interviews and discussion can be viewed in Appendix C.

Key Points from combined interviews relevant to the product

- The vessel conditions differ depending on the part of the world you are assigned a job. North Sea has high quality diving systems and good food vs Asia/Africa.
- Lowering to depth from in the diving bell usually takes around 15- 20mins
- The balance between chamber size, weight, cost of very expensive helium to pressurize them, helium reclaim capacity, emergency management due to pressure loss and atmosphere contamination all interact.
- Size of diving bells have a delicate balance because they must be able to float by dropping emergency weights while being able to withstand the internal and external hydrostatic pressures at the design depth and carry mandated emergency gas supplies.
- Geometry of the living spaces must follow pressure vessel design constraints – flat sides are impossible beyond small viewports.
- Material selection must be tested so they don’t outgas toxic chemicals in the closed environment at 30-50 atmospheres of pressure.
- Must have low combustibility due to pressurized oxygen concentrations.
- Seafoam green was the best colour inside confined spaces for extended periods, white being the most stress inducing (according to NASA)
- Ability to disinfect surfaces in chambers, skin and ear infections are common due to divers spending time in wet suits and heat/humidity
- Improvements: systems with a chamber per team, no top bunks, phones, WIFI and mood lighting.
- Floor to lower and raise instead of ladder

CHAPTER 3 - ANALYSIS

The following chapter analyzes the information presented in chapter two and further organizes the needs of the primary user. Chapter three will identify and establish how these needs may be met by the proposed design solution. A variety of research methods are used to analyze the data. This includes user and activity observation, ergonomic analysis, material and sustainability research. Over all, the data will aid and guide the thesis towards an improved user-oriented experience within saturation diving.

3.1 Needs Analysis

Current benchmarked products are predominately geared towards safety, an important aspect when it comes to the diving industry. The systems focus on completing specific activities, whether that be recreational or professional. In most cases this may lead to a lack of focus on treating the ergonomic and psychological needs of the primary user. Divers are accustomed to the work their job entails. In their mind they do what they are trained to do. With the intensity of their profession and the toll it can take on their mental and physical health, it is necessary that improvements are to be made. There are many opportunities to improve the comfort of their work environment in order to ease stress on the mind and body, allowing them to preform their work with maximum safety and efficiency. There is a separation between existing products. There are systems meant for leisure/recreation and there are systems meant for professional purposes. It is rare to see a blend of both systems that may benefit the user. Taking assets from both systems and integrating into one can provide the emphasis of comfort as well as the important element of safety, leading to an improved user experience.

3.1.1 NEEDS AND BENEFITS

Existing systems focus on the ability of the diver and his/her ability to complete the assigned task. There are complex and sensitive procedures that are involved within the workflow of the primary user to ensure safety due to the pressurized environment. This tends to leave less innovation towards the efficiency of workflow, lack of dynamic space and privacy, poor ergonomic considerations, and absence of relief towards psychological stress. There is insufficient research regarding the differentiable needs of females within this predominately male industry, an area which can be explored and improved on as well. The table Below presents potential improvement regarding the saturation diving industry and its workflow.

NEEDS	BENEFITS
Comfort	• less stress on the body • Improved positions for rest or leisure • Simplicity and ease of workflow • Limit feelings of isolation
Safety/health	• Retention of muscle mass • Simplicity of emergency procedures • Ease of medical/emergency access • Increase mental acuity and morale • Improved environmental temperature (reduce humidity) to ease skin Irritation
Productivity	• Increased productivity: more work done in less time • Increase number of workers for task • Improved workspace and flow for productivity
Privacy	• Option for privacy when needed, improving space for both sexes

Table 6 – Needs and Benefits

3.1.2 LATENT NEEDS

The proposed design can be connected to Maslow's Hierarchy of needs, which presents the need for human fulfilment in five categories. The needs are: physiological and safety (basic needs), belonging/love and esteem (psychological), and lastly self-actualization (self fulfillment).

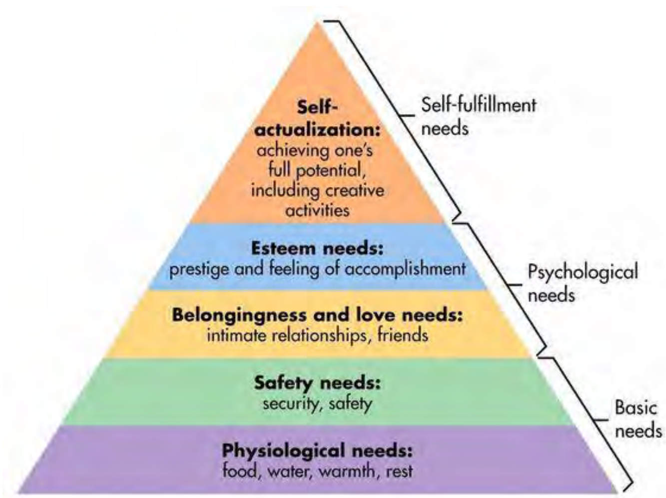


Figure 5 – Maslow's Hierarchy of Needs

Benefit	Fundamental Human needs	Relationship with Benefit
Comfort	Physiological, love & belonging,	Strong
Health & safety	Safety, physiological, love & belonging	Strong
efficiency	Safety, self-actualization	Moderate-strong
Aesthetics	Esteem	Moderate

Table 7 - The following chart displays the relation of the benefits between the proposed thesis design and fundamental human needs.

Comfort:

Determines the “physiological” and “belonging” needs of the primary user. These are basic aspects required for human survival. Divers should feel that their needs are met through the design of the system since they are spending a lengthy period within such an isolated environment for proper bodily function and ability to communicate with friends and family.

Health and Safety:

Determines the “physiological, safety and belonging needs” of the primary user. The basic needs should be fulfilled regarding accessibility to food, water, and ability to breath in extreme environments, and even politically (regarding unionized industries vs ununionized.) It is important for the psychological health of the individual, to feel a sense of love and belonging from interpersonal relationships between team-mates or others on the surface.

Efficiency:

This can be connected to “safety and self-actualization”, furthermore, the ability to achieve ones’ full potential. The ease of flow and movement throughout the system is important for productivity, ensuring the assigned task is completed thoroughly with maximum safety. The diver can feel a desire for adventure and problem solving within the industry of saturation diving. This is part of what keeps them motivated to continue their work.

Aesthetics

Aesthetics can play a role in phycological aspects to fulfill the needs of the primary user. The proper use of the elements and principles of design can have an influence on the way a user feels in his or her environment. For example, the use of colour, how does red versus blue, differentiate the mood of a human. This is to be considered throughout the design of the thesis proposal.

3.1.3 CATEGORIZATION OF NEEDS

The design will focus on enhancing the user experience, integrating a better workflow, improving ergonomics and considering the users psychological health in order to establish a safer experience for every saturation diver. These needs were determined through in-depth literature reviews, user observation and direct interviews.

Wishes/Wants

- Noise reduction (absorption)
- Clean and organized environment
- Adventure and travel

Immediate Needs

- Ergonomic Modularity and adjustability
- Improving psychological and physical strength of diver
- Privacy in a shared space
- Improved accessibility to safety features.

Latent Needs

- Modernized aesthetic – trust in the equipment
- gender oriented design (or neutral)

3.1.4 NEEDS ANALYSIS DIAGRAM

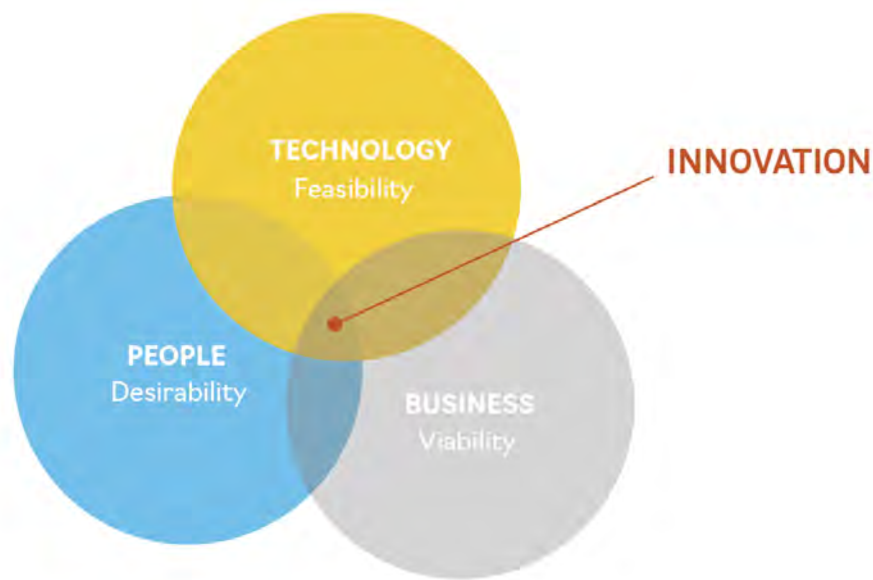


Figure 6 – Needs Analysis Diagram

Desirability:

There are many aspects that can be improved in the industry. With new systems such as “Divex” there is evidence that companies are beginning to realize the importance of comfort for the individual diver. Through discussions with qualified saturation divers, it is evident that living such a lifestyle begins to put stress on their bodies and mind. Therefore, there is a desire to improve the diver’s user experience.

Feasibility:

The systems involved in saturation diving are extremely complex and require precision and training for proper function. The challenge is ensuring the design alterations within the proposed thesis will enable the system to function safely. The exterior structure or design [still to be determined] will be difficult because of the lack of existing technologies that could prove if it would work or not.

Viability:

The commercial diving industry is necessary for the survival of many business. There will always be a need for this trade. It is an extremely expensive industry, a large portion of it is being controlled by billion-dollar oil industries. Interior solutions are viable as parts plastics and metals can be mass produced.

There needs to be a reason behind the design, not just something "cool" but something that will offer differentiation, progression and will mirror the diver's culture. Aiming to step out of the box and innovate instead of "playing it safe". Lining up aesthetics with function will ensure that nothing is arbitrary. Finally, it is important to consider the sustainability of materials for longevity in an environment where its use is extremely harsh.

3.2 Functionality

Safety, space to work/rest/play, and ergonomics are aspects that will allow to diver to use minimal effort when interacting with the product or system. Having the capacity situated at a neutral amount means that there should be only enough people to provide a space comfortable enough to share in comparison to its size. Approximately 6 people are needed for the divers to carry out alternating shifts, (three on-site then switch.) too many people for one job can be overwhelming posing potential safety hazards. Overall, the efficiency of the smaller recreational submersibles and their ability to maneuver, travel distance and depth, ease of control/use and aesthetics will be taken into consideration.

3.2.1 ACTIVITY/WORKFLOW MAPPING

Through concluding chapter 2, analyzing benchmarked products and understanding user activity generated a platform for observation. These points are generalized into thematic areas that are considered for the development of the final system. Observations are gathered from literature reviews, interviews and discussions with qualified SAT divers.

Observation 1

Efficiency and capacity were analyzed in order to better understand the interior to exterior design and how the user may be situated in those environments. There must be a balance of space to person “ratio” in order to have an efficient system. The individuals must have enough space to be productive while at the same time maximizing the use of the space, not wasting any part of its function. The final thesis development must involve a system that can provide required safety rules and regulations, ergonomic considerations, maximum comfort, modularity and streamlined aesthetics. The goal is to provide a solution that will allow better productivity and comfort on the job, which will hence let them perform their job in a safe manner, enhancing the user experience.

Observation 2

The primary users in their observed environment are spending a lengthy time in a restricted environment. This leaves no space an important component of human health, exercise, something that seems to be ignored in the designs. It was observed that divers are currently making their own space for exercise, using infrastructure as pull-up bars, (which is not their indented purpose) or any flat surface they can find to do push ups or etc. Providing features for exercise, which is essential for a human physical and phycological health is necessary. A common issue found among saturation divers is the loss of muscle mass because they reside in such a restricted environment. Providing an element of fitness will, improve energy levels, self esteem, reduce stress and anxiety and keep the individual fit and strong, improving the quality of life of the SAT diver. **(cDiver, 2016)**

The images in the chart below are referenced from a YouTube video done in user observation chapter 2, section 2.1.1

Steps	**Image**	**Workflow**
1 Entering saturation chamber/decompression		Diver maneuvering through chamber to chamber (through doors/ports)
2 Preparing for dive inside chamber		Putting on equipment -Safety checks, Bending, reaching and minimal exercise
4 Dive Bell	-	-3 Safety checks -checking and adjusting pressure -dive supervisor in charge of getting divers into the water safely

		
5 Lowering to depth		Diver 1 remains in bell (supervising) - Ensure that pressurization is stable - Supervisor waits for diver's shift to end (up to 8 hours)
6 Resurfacing		Diver 2 resurfaces (both divers are in bell removing equipment)
7 Leisure time within chamber		-Washing up -Exercise - Carrying out basic daily activities such as sleeping, eating,

	 	personal hygiene
8. Wake up repeat		Shifts rotate between divers

Table 8 – Activity Mapping

3.2.2 ACTIVITY EXPERIENCE MAP

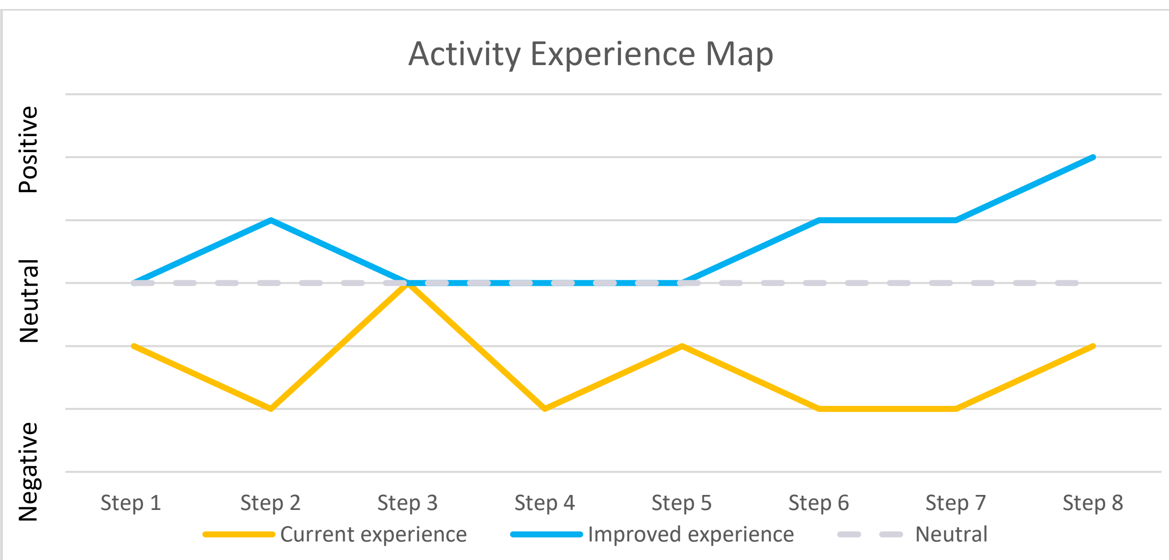


Table 9

The following information summarizes what is displayed in table 8; the key activities carried out within saturation diving. These key activities are further categorized into current experience and the potential improved experience.

Key activity 1: Residing in Saturation System

- Carrying out basic daily activities such as sleeping, eating, personal hygiene
- Retrieve items from delivery portal
- Ensure that pressurization is stable
- Bending, reaching and minimal exercise

Key activity 2: Preparing personal equipment for dive in diving bell

- checking and adjusting pressure
- assisting other diver with equipment, helmets, and ensuring umbilical cords and oxygen tanks are working correctly
- connection with members on ship above for emergency situations
- dive supervisor in charge of getting diver 2 and 3 into the water safely

Key activity 3: Underwater Work

- divers are now submerged under water
- here they are responsible for completing their task; repairs and maintenance of underwater infrastructure/systems
- extremely low visibility and cold environment b/c of depth up to 300m
- divers submerge back into bell and begin the assist each other in taking gear off

Key activities	**Current experience**	**Improved experience**
1. **Residing in Saturation System**	• poor ergonomic considerations, poor posture, crouching too low, bending spine too often • users find their own space to exercise wherever they can and if willing	• Improve spatial area providing more room creating a safer and more comfortable environment • Providing space for exercise which is extremely important for human health and maintains a healthy mindset in isolated environment • Providing ergonomic angles for sleeping and sitting and carrying out basic activities such as writing, reading or using the computer • Implementing privacy in a shared environment between divers, this can

		encourage a better environment for women who share space with men
2. **Preparing personal equipment for dive in diving bell**	• system is predominately made of metal which mean sound carries easily • safety features are not clearly identified or accessible • extremely limited space, individuals are very close together which allows limited privacy, disorganized and cluttered	• To improve accessibility to emergency kits and passage ways avoiding cluttered or cramped space • Limiting extended reach, crouching, bending to avoid injuries and strain to muscles
3. **Underwater Work**	• visibility is extremely poor underwater • tools are large and not easily accessible.	• Using the exterior of the system to aid in visibility • Providing a platform for easier handling of tools and equipment

Table 10

3.3 Usability (ergonomics Report)

The following section observes human - environment interaction of the 5th percentile female and 95th percentile male. The focus of analysis involves the work flow of the individual and the efficiency of movement within an interior system. The aim is to improve the workspace providing a productive workstation for the divers on their regimented work shifts, as well as improving an overall system to reduce hostility through organized placement of sub systems and providing a space that can be comfortably used for both male and female users. More specifically, this report will consider ingress/egress flow through portal doors and a modular workspace that allows productivity while at the same time, considers its surroundings and maximizes efficient use of space. It Is observed that saturation divers are forced to adapt to the discomforts of a claustrophobic and isolated system. Through design innovation and understanding the impact of effective/proper use of ergonomics will provide an enhanced user experience for a range of percentiles.

Methodology

Two aspects of the system were developed and tested with participants, the first component being a “productivity workspace”. This explores the function of a modular “sit-stand” workstation that allows the divers to be seated or stand while using a provided surface to accomplish off duty tasks. This can include the use of a laptop, reading writing or eating, offering a space for rest and optional interaction with other individual. The second component involves a simple yet necessary adjustment to the handle above the hatch door that can allow an easier exit/entrance through the system.

Objectives

The purpose of the following ergonomic full-scale mock-up (1:1) is to determine and validate whether these components and its interaction with the primary users will function suitably within the vessels limited space. It also determines whether the configuration will in fact provide a more spacious environment that will increase the user’s productivity and workflow throughout the system. This ergonomic evaluation outlines the methods used to achieve a successful design that will meet the requirements of a full-bodied human interaction design (capable of evaluating three major body part areas). This includes hands, head, back and overall posture. The improvements within the proposed designs are aimed to eliminate physical challenges and reduce the possibility of psychological stress.

Decisions to Be Made

The following interactions relevant to three specific major body part areas (Kappen et al., 2018) were investigated to provide an improved user experience.

1. Entering/exiting through the system easily through circular hatch doors, this considers hand positions on handles
2. Workspace productivity: This considers a sit-stand modular workspace, comfortable positions and angles, over-all body posture considering wrists, head and vision angle
3. The combination of two divers sharing a workspace and their need to communicate versus their need for solitude and determining a layout that will provide the least amount of disturbance between individuals

Description of Users Targeted by Product

The target demographic consists primarily of the male user however, will also examine the female demographic which is not commonly researched or observed within the saturation diving industry.

Valid research regarding the primary user includes:

- Divers who become certified offshore divers are predominately male, age 30 – 60.
- Required to have completed secondary education to be qualified to study and practice commercial diving
- Divers earn an average of $60,000 US (ranging from 40k to 100k annually). The wage increases with their experience level. (cDiver, 2016)
- Divers come from a broad range of backgrounds such as Caucasian, Asian, South American varying on their diving location. Majority of divers are Caucasian.

Ergonomic Measurments

The ergonomic analysis was further detailed with the use of vector diagrams. The resutls display the information and measurements conducted in the previous section. ***All measurements are represented in inches.***

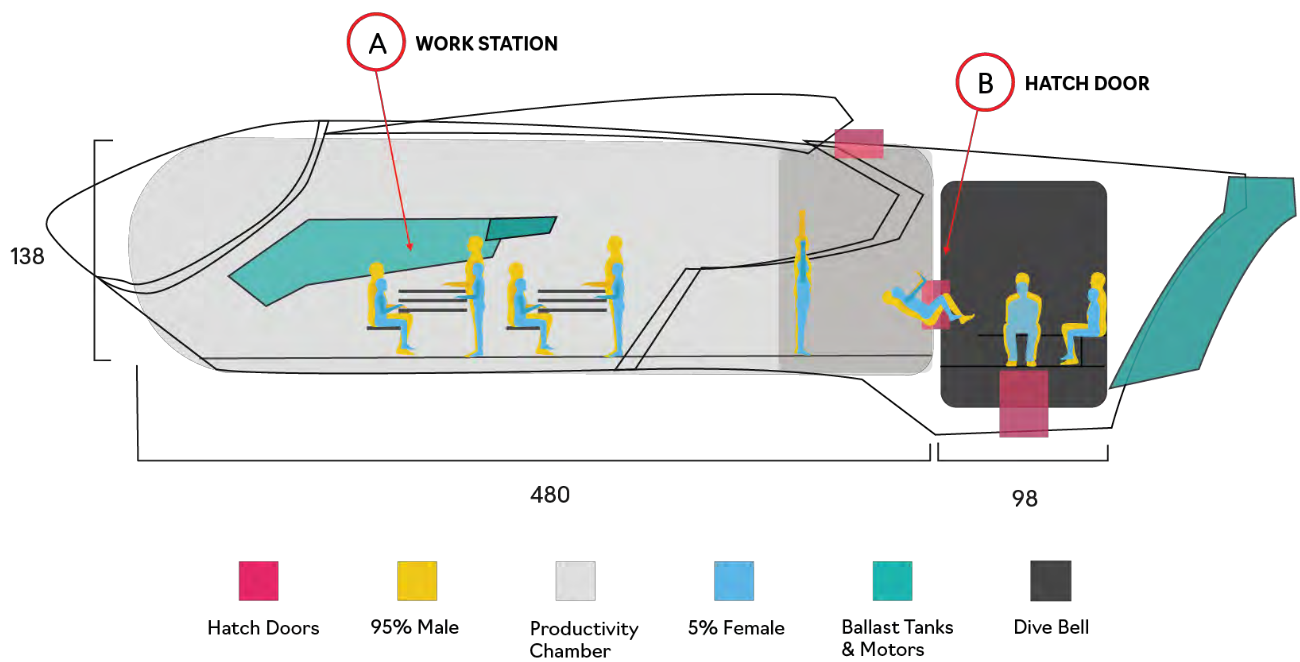


Figure 1 – Configuration Diagram displays the interaction between the vessel interior and divers, legend and vessel dimensions. A: Work Station and B: Hatch Door are the two interior components that were analyzed for this ergonomic report.

OBSERVATION 1 – VECTOR DIAGRAM

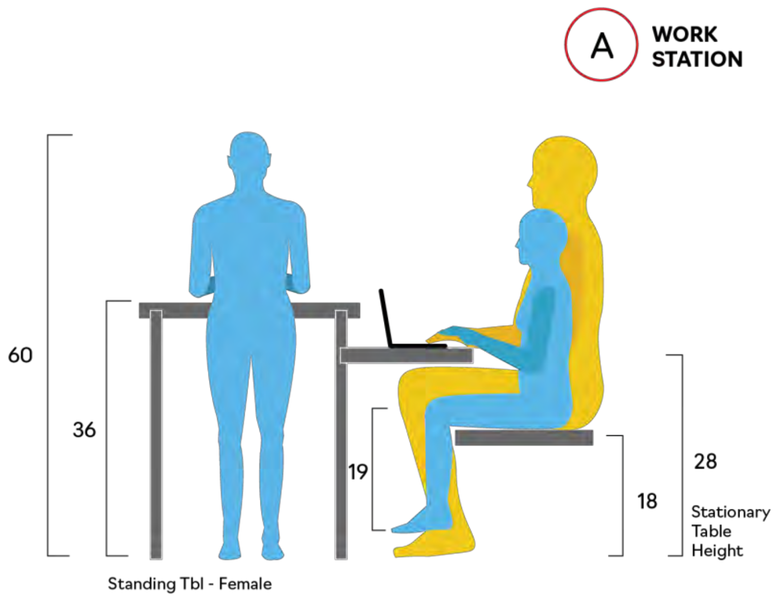


Figure 2 – Workstation at adjusted standing height for 5th percentile female with stationary seat height and Knee height.

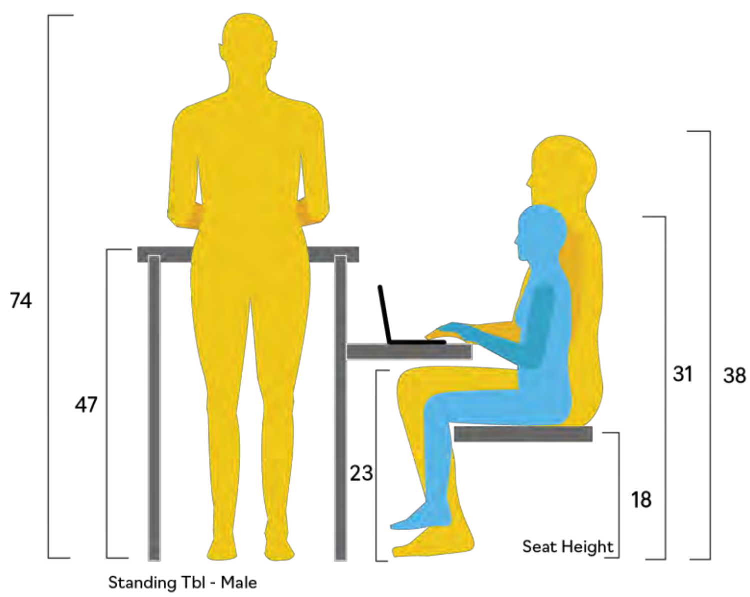


Figure 3 - Workstation at adjusted standing height for 95th percentile male with stationary percentile seated height and knee height.

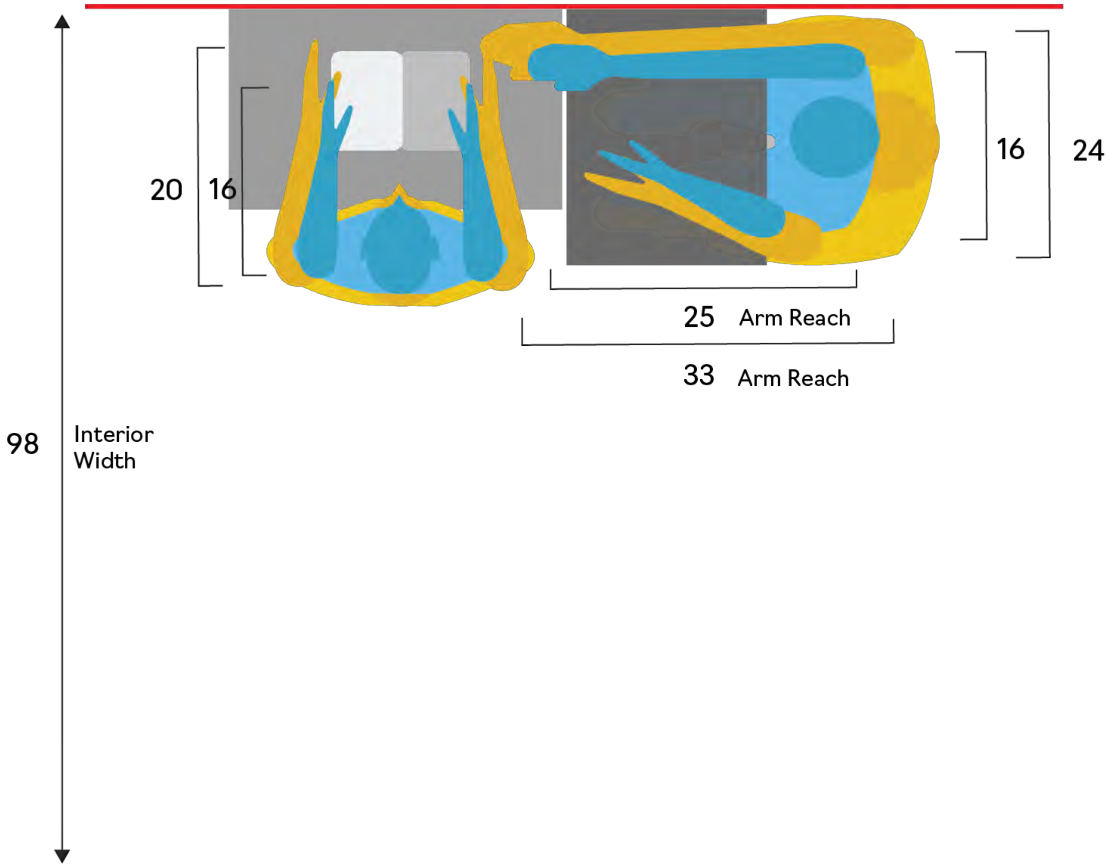


Figure 4 – Top view of workstation displaying arm reach, forearm length, and breadth of shoulder for both percentiles

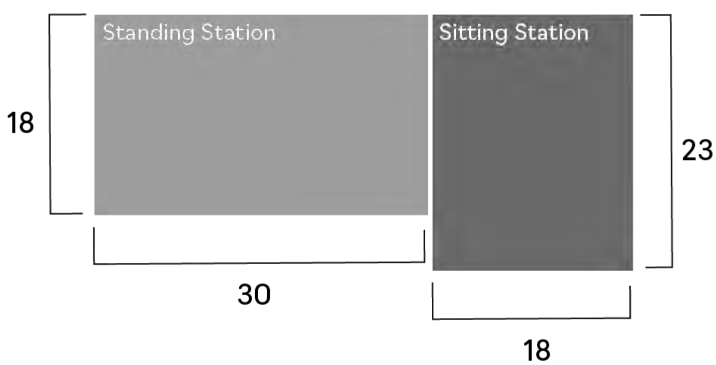


Figure 5 – Dimensions of workstation

OBSERVATION 2 – VECTOR DIAGRAM

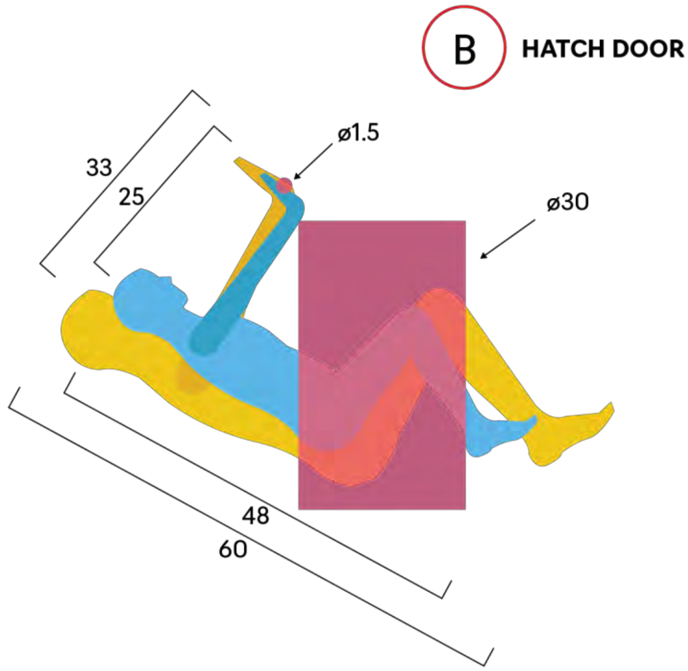


Figure 5 – Egress/ingress position through hatch doors

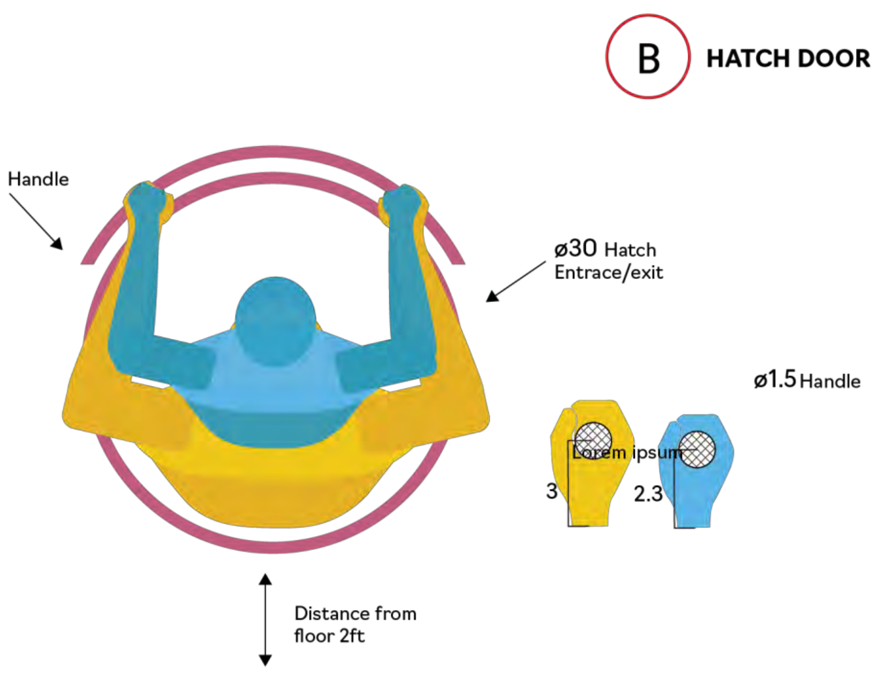


Figure 6 – Hand position placement and diameter of handle for both percentiles.

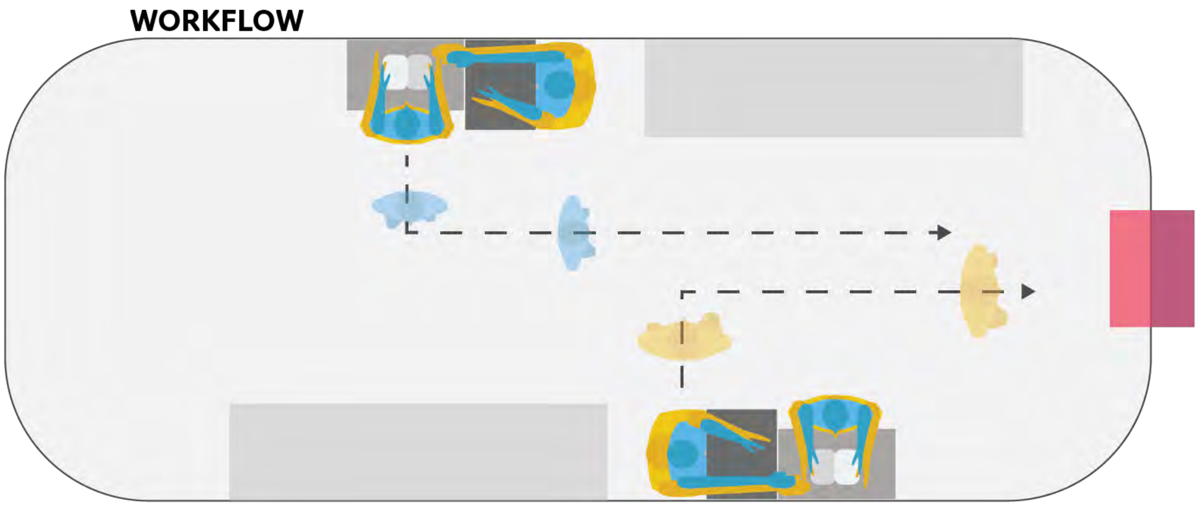


Figure 7 – Displays the workflow of both percentiles through the vessel interior, specifically when leaving the workstation.

Conclusion

The seating area of the workstation remains at a height of 28”. This allows enough room for a comfortable sitting position for both individuals with proper posture in order to continuously work. This provides them the option to be seated to conduct their preffered extra curricular acitiviy when they are off the job. The seat remains at an 18” height from the ground. The workstation also provides a standing option. This is adjustable to suit the needs of both percentiles. The 5th percentile female height is stationed at 36” and the 95th percentile male height is stationed at 47”. The table width provides reliable space for elbow distance at 30” and depth at 18”. This gives suitable distance for the arm and hand to reach the keyboard and for writing use. This individual is seated to allow an optimal viewing zone of a maximum 60 degrees from the viewing line, which provides the user with “a viewing range without stress” (Tilley, 2002). See Figure 8 below.

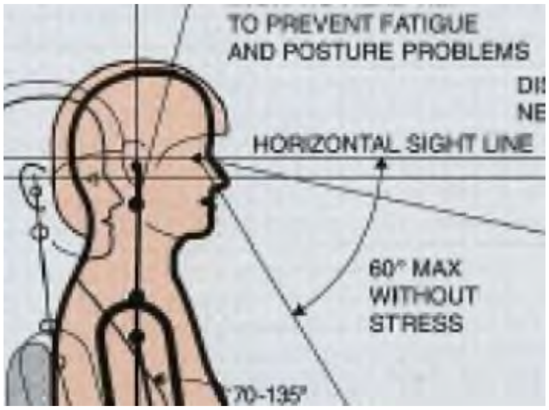


Figure 8 – optimal viewing range according to Henry Dreyfuss

Evaluation process

The evaluation process consisted of designing a full scale (1:1) ergonomic buck. components of the transportation vessel are limited within the space of the chamber. Critical observation includes the following:

1. Observing how the user enters and exits through the vessel
2. Observing how the user can perform tasks in midst of other individuals and surroundings at proposed workspace
3. Observing how the individual departs from his/her seated position in order to proceed to another location without disrupting the flow or rest of other divers (limiting obstacles)
4. Identifying areas of desired interaction between divers versus the opportunity of solitude

Description of User Observation Environment Used in this Study

This study was used to analyze individuals of the 5th percentile female and 95th percentile male, their interaction with a “productivity work station” and their egress and ingress between chambers of the system. Due to the size of the proposed design and the limitations of space provided at the research location, only two sections of the system were considered involving critical elements.

Location and Timeframe

Date of Observation(s): December 20th 2019 time 5:00pm

Location of Observation(s): Home of Researcher

Results

The results below display a combination of photos that present relevant ergonomic measurements in regards to the primary user. Basic materials such as foam core, cardboard, and painters’ tape were used to construct the overall form of the workplace and entrance/exit flow models. Ergonomic measurements were referenced from reliable sources (listed in literature review). Observations were split into two categories – *Observation 1: Productivity Workstation* and *Observation 2: Hatch Door exit/entrance.*

Primary user interaction

For full in depth user study see *appendix IX*

OBSERVATION 1 – Productivity Work station

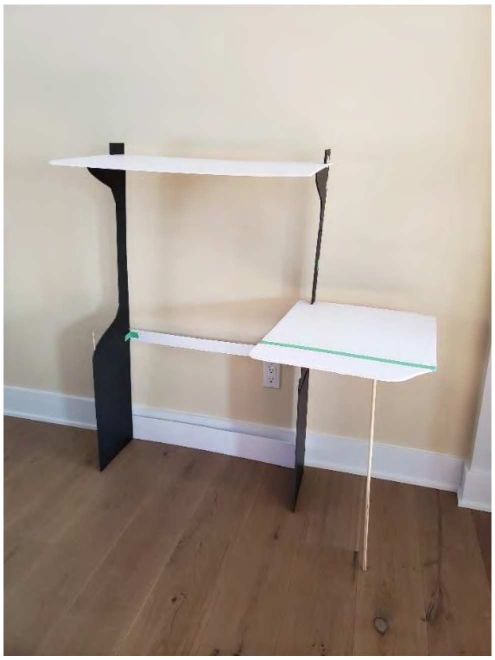


Figure 8 – Workstation at 95% Male

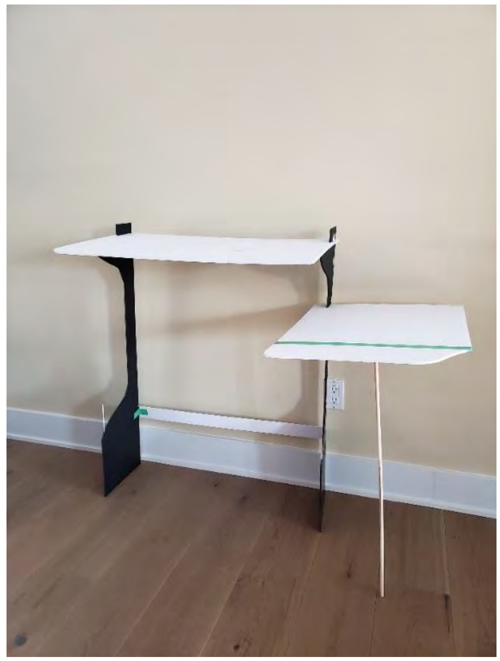


Figure 9 – Workstation at 5% female

Figure 10 - Participants carry out extra curricular tasks, Laptop use and writing

Figure 11 - Participants carry out extra curricular tasks, laptop use and writing

Figure 12 – Participants take time away from individual activity to interact and converse comfortably.

OBSERVATION 2 – hatch door exit/entrance

Figure 13 - Hatch door rests 24” off the ground

Figure 14 – 95% male places hands on handle above hatch to assist entrance

Image 15- 5% female places hands on handle above hatch

Image 16– 95% Male places hands on handle above hatch

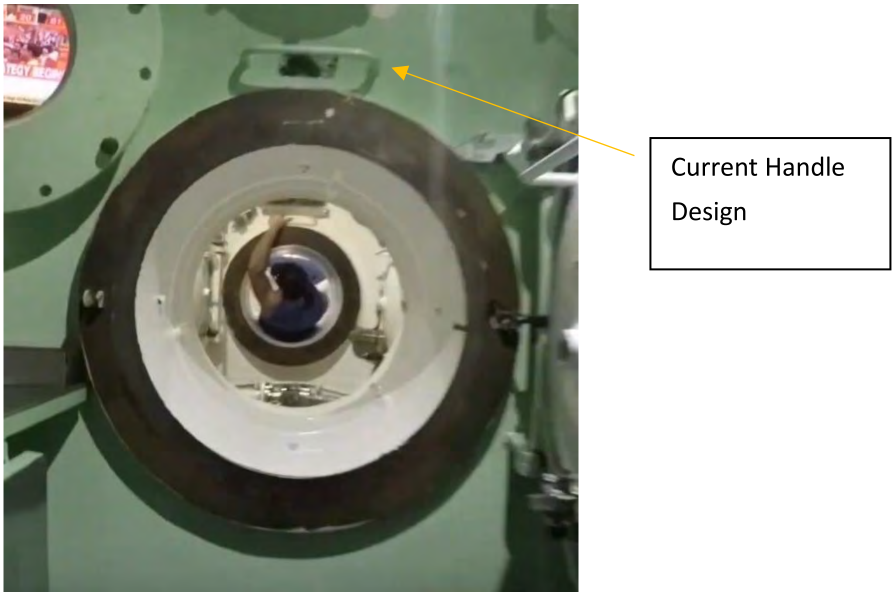


Image 7 – Handle above hatch represents current design in SAT systems

Analysis

The proposed design solution and the interaction between 5th percentile female and 95th percentile male has shown usable features that can be carried on into the final design and further developed. The purpose of this ergonomic analysis and observation allows the opportunity to witness a product in its environment in full 1:1 scale, and with real life participants. With this, features that need to be improved on or those that work efficiently can be recognized. This allows the opportunity to further understand the physical challenges of the primary user in the provided setting. The ergonomic buck was continuously modified throughout the process of creating the ergonomic sketch model. Areas that were short of reach, seemed crowded or unnecessary were adjusted to meet the needs of the primary user.

The original goals for an improved system (physically) include; privacy, the opportunity to be productive and improved workflow. These are factors that were constantly taken into consideration during the construction process. For cost effective purposes and space efficiency it was considered that certain components consist of manual features rather than a solely automatic option. The seating in the productivity workstation area remains stationary to reduce the complexity of it.

Due to the limited space and lack of exercise/movement that divers face within a saturation system, a standing desk option is proposed. According to *Health Line* (Leech, 2017), Standing while working can provide many benefits especially when seated for lengths of time. This negates the harmful effects of sitting for too long. Having the option to stand and continue to work can reduce back and neck pain, and improve energy levels. 87% of those using standing desks reported increased vigor and energy throughout the day (Pronk, Katz, Lowry, & Payfer, 2012). This is important to consider when a diver prepares for his/her shift, it can help the mind and body to be stimulated and alert.

The individual in the <u>seated</u> position faces along "x-axis" where the <u>standing</u> individual faces forward (shown in Figure 12). Since the individuals are integrated at their work station in this specific way allows them to choose the option of interaction versus none. A slight turn of the head will allow them to comfortably converse if needed, while at the same time, through this observation, users felt that their "working" position gave them a feeling of being at different workstations all together. This workstation positioning also allows a free flow of exit, where the standing individual can walk by the seated individual without disruption and vice versa. This was considered since traditional chambers have very little room to stand without interfering with the space of other divers. The seating area remains open and minimal to provide spaciousness.

The hatch door handle can be compared to current system where it is placed as a small integrated component directly above the port, shown in image 17. The improved semi circle handle design seems to provide the opportunity for "natural placement", where the individuals automatically feels comfortable grasping the handle in a specific position. Even with both individuals being drastically different sizes, the area in which they gripped the bar is the same. This is displayed in Figure 15/16 and in figure 6. The hatch door handle has a diameter of 1.5” which, according to *The Measure of Man*, is the suitable thickness for proper grip for both percentiles and the proper strength for the diver to lift their body through the hatch door. (Tilley, 2002)

The transportation device is estimated to fit up to 6 saturation divers. Once at an appropriate level of metres sea water, the dive bell section will allow 4 divers to exit into the water to preform their underwater duties while the other two remain in the system to supervise and keep communication with those in the main vessel above. Individuals carry their own portable devices for use while off their regimented work shift.

Limitations and Conclusions

Limitation to the study include:

- The space used was limited in length which did not allow enough area to analyze the full flow of the system and being able to perform a full “walk through” and interaction within the interior space
- While two participants were analyzed, the total number of divers would be 6.
- Due to the lack of similar equipment and number of participants, the proposed space provided, to remove and apply equipment with several individuals occupying the same space was not analyzed.
- The environment of observation was not pressurized, or isolated which gives a casual approach for interaction where in an actual scenario, divers are under physical, psychological and physiological stress. This may alter the individual’s desires and actions in that moment, differentiating from the participant observation.

- Material consideration that needs to be researched in depth, may limit the opportunities for modularity or technology in the system as well as strict safety rules determined by government laws, rules and regulations.

Overall, the participant observation was successful in validating referenced ergonomic dimensions that were built into the ergonomic model. Building the physical model allowed the researcher to alter dimensions that would be more suitable for the use of both percentiles.

Ergonomic issues that are still not yet resolved

The entire system integrates other components that have not been thoroughly analyzed through ergonomic models due to limited space and time. Other components that will be further explored into the proposed design system include the dive bell, or "mission area" where the divers can exit the vessel underwater, as well as the remaining space within the interior that may include safety systems, ablution, control and privacy/rest areas. Modularity of the workstation is not yet resolved. With further development of style ideations, research, mechanical/functional aspects and manufacturing methods will establish limitations for the final design.

Alternate Possibilities for the Future

Alternate possibilities for the future include finding a more open/large space to conduct a thorough research analysis, and more participants. Creating an ergonomic model that is made up of more durable materials and able to represent similar function of proposed technologies or mechanical components for part to move, fold, or adjust in certain ways, instead of solely a stationary work station that represent the user of different heights. As well as adding a 1.5" diameter shape for the hatch door handle to give the participants the full effect of its use. Lastly, to explore other components of the system that include access to safety and emergency features.

3.4 Aesthetics

Aesthetics of existing saturation systems are constricted because of the technicalities of the engineered system. Many components cannot be changed aesthetically due to safety precautions and ensuring proper function of these engineered parts. For example, a pressurized system must have a cylindrical shape for the distribution of pressure to be equalized to the environment correctly. These limitations though, provides an outline of materials and methods that are essential for a functioning system. Considering the most important feature, safety and how it comes into play with the designs. The materials that are used for durability and stability, and its connection to cost.

Design Approach

Visually, pressurized systems present a hostile environment. The interior and exterior structure is made up of metals, components are typically unorganized and there is a lack of colour. Material use and fabric should be easy to clean and repel humidity to maintain a hygienic environment. In order to differentiate certain features, such as safety valves versus water release, can be colour coordinated to provide simplified interaction. The aesthetic language of the design should introduce a robust yet modernized look. When improving the efficiency of space, integrating modular components that can be used for multiple purposes or put away easily when not needed can manifest a sleek design approach.

Design Language

(If the final proposed design was to incorporate an element of travel, away from the main vessel such as the diving bell) it should consider the use of colour. At depths of 300m underwater, visibility is extremely low, and colour becomes dull since there is no light reaching certain areas. The vessel should contain bright neon colours such as orange or yellow, in order to be easily recognized in emergency rescue situations. General Colour use of interiors should consist of ones that ease the mind of the user, reduce stress and anxieties. Studies show that red hues induce stress or adrenaline where as blue keeps may reduce nerves. (Wise & Wise, 1988).

3.5 Sustainability – Safety, Health & Environment

Safety:

There are many safety concerns throughout the industry. An important and essential part of ensuring one's safety is communication and efficient access to the those who oversee emergency situations, evacuations and rescue. This communication is key to maintain. The environment should allow emergency exits that allows easy access and smooth flow and quick reach to emergency kits, back up generators and oxygen. Politically, safety must be prioritized, which can sometimes be lost in money making industries (such as oil). In order to promote the saturation diving profession, its reputation must uphold the fact that they will be able to provide the safest environment for divers, mitigating their fears that include death, injury, loss of oxygen or disconnected from main vessel. Ensuring safety will make the industry desirable for those interested in the profession, sustaining employment for the future, and allowing the saturation diving industry to be more invested in.

Health:

Exploring materials in relation to the diver's health and long-term survival of the design. using modular components with durable materials provides an efficient way of use, reducing the number of parts that may be manufactured. Reusability of systems that, instead of being thrown away, can be upcycled or reused and can be updated or integrated into something else. Similar to how some systems are made today, they are meant to last and use recyclable metals such as steel and aluminum, but they are not built to be recycled, they are built to last forever (Since the industry is extremely slow to change, and a lot of money is put into it.) Design can incorporate components that will be beneficial to the diver's health as well as cause less harm for the environment regarding the way its produced, use materials or supporting manufactures that have a small carbon footprint.

Environment

It is difficult to encourage environmental safety within saturation, because a large portion of it is targeted towards the oil industry, something that causes environmental degradation, especially in our oceans. Since this thesis proposal is aimed for the "future", when there will be further technological advancements, the target area could possibly direct and emphasize other industries instead of oil, such as marine research. Using saturation diving as a beneficial addition to the study of our deep-sea environment and unexplored areas can further research development regarding the health of the earth's underwater environment and develop a better understanding of its health and status.

Business

Sustainability in business addresses categories such as equality. Expanding the target market can also improve sustainable aspects of business, for example, promoting woman in the industry just as much as men. This now becomes an industry that can stabilize inequality that is found in saturation diving.

3.6 Commercial Viability

This section will investigate the viability of cost, materials and manufacturing

3.6.1 MATERIALS AND MANUFACTURING

The following section summarizes the use of sustainable materials and sustainable motives used throughout the design of ZESU490

Metals

The support structure of the designed system will be made up of recycled aluminum and titanium. Both materials can provide a lightweight frame and strong support structure while incorporating long lasting and durable features (Natori Manufacturing Co., 2008). Titanium and aluminum are resistant to rust and corrosion allowing the materials to last for decades when exposed to environmental elements. This is especially important within a slow changing industry. The metals' lightweight features allow easy transportation, without the use of extreme equipment, reducing costs. The recycling process of aluminum does not reduce the quality of its physical properties, also uses only 5% of the energy it takes to make primary aluminum (Plastics Industry Association, 2020). These metals provide the strength, formability and lifespan needed for an underwater vessel.

Plastics

Fibre reinforced plastic (FRP) is used for various advanced engineering structural purposes. They can be seen used in spacecraft, ships automobiles and civil infrastructure. Its use is for the ability of forming complex and beautiful shapes/forms. FRP is used for the overall interior structure including storage compartments, seating and other surfaces. Plastics provide a sustainable advantage due to its durability and corrosion resistant qualities, allowing for long lasting applications. They provide insulation from heat or cold and even sound, reducing echoes from the outer metal structure. Plastics are lightweight and easily transportable reducing the need for heavy equipment. FRP is recyclable or can be used for "Energy Recovery Technologies", recycling plastic in a way that can be used for fuel or electricity

(Plastics Industry Association, 2020) . These plastic surfaces are easy to clean and maintain making them last long in harsh environments. (Englesmann & Spalding, 2010), (Plastics Europe, 2012)

Figure 8 - Chanel Mobile Art Pavilion made of FRP or GRP (glass Reinforced plastic) exterior and interior structure by Architect Zaha Hadid.

Fabrics

The use of fabrics must consist of materials that provide anti-mildew and fire-resistant qualities. Nylons and polyesters can provide fabrics that are easy to clean and resistant to abrasion and wrinkling. These are suitable for humid environments that the vessel may withhold. These qualities make the fabrics long lasting and durable for extended length of use. Unfortunately, the manufacturing process of these materials release green house gases and harmful chemicals and are not biodegradable for its end of life disposal (Alberto, 2013). The safety of the saturation diving environment must be prioritized in this case.

Figure 9 – DROTEX – "FRCOTTON" material

Drotex Cotton material can meet the safety requirements of what is needed to be used in the set environment. It has permanent flame retardant qualities, is eco-friendly and *Okeo Tex-100* certified, withholds permeability. This fabric is commonly used in oil and gas, welding, and petrochemical industries. (Drotex, 2019)

3.6.2 COST

Saturation diving is a billion-dollar industry that is government funded. Existing manufacturing and labour costs relevant to the construction of submarines include a variety of funding categories. It is estimated that up to $100 million can be spent on depot overhaul, $30mil for support of crew and consumables, $60mil for science support and another $30mil for maintenance. This is not an accurate estimate for ZESU490, but it will consist of the same measures and production methods when it comes to developing and investing in the design. more specifically, the interior can be broken-down into areas for funding. This includes metal, plastic and fabric. The support structure that is primarily made up of aluminium panels are prices at $1755 per metric ton (Terifs, 2019)]. Fire retardant DROTEX fabrics are priced at $10,500 for 3000 metres or $3.50/metre [Alibaba, 2020], lastly Fibre Reinforced Plastics or carbon fibres are priced ranges at approximately $10-35 per square metre [Alibaba, 2020]. Zesu is also powered by multiple Lithium Ion phosphate batteries which is prices at $175 per kWh (Rathi Akshat, 2019)

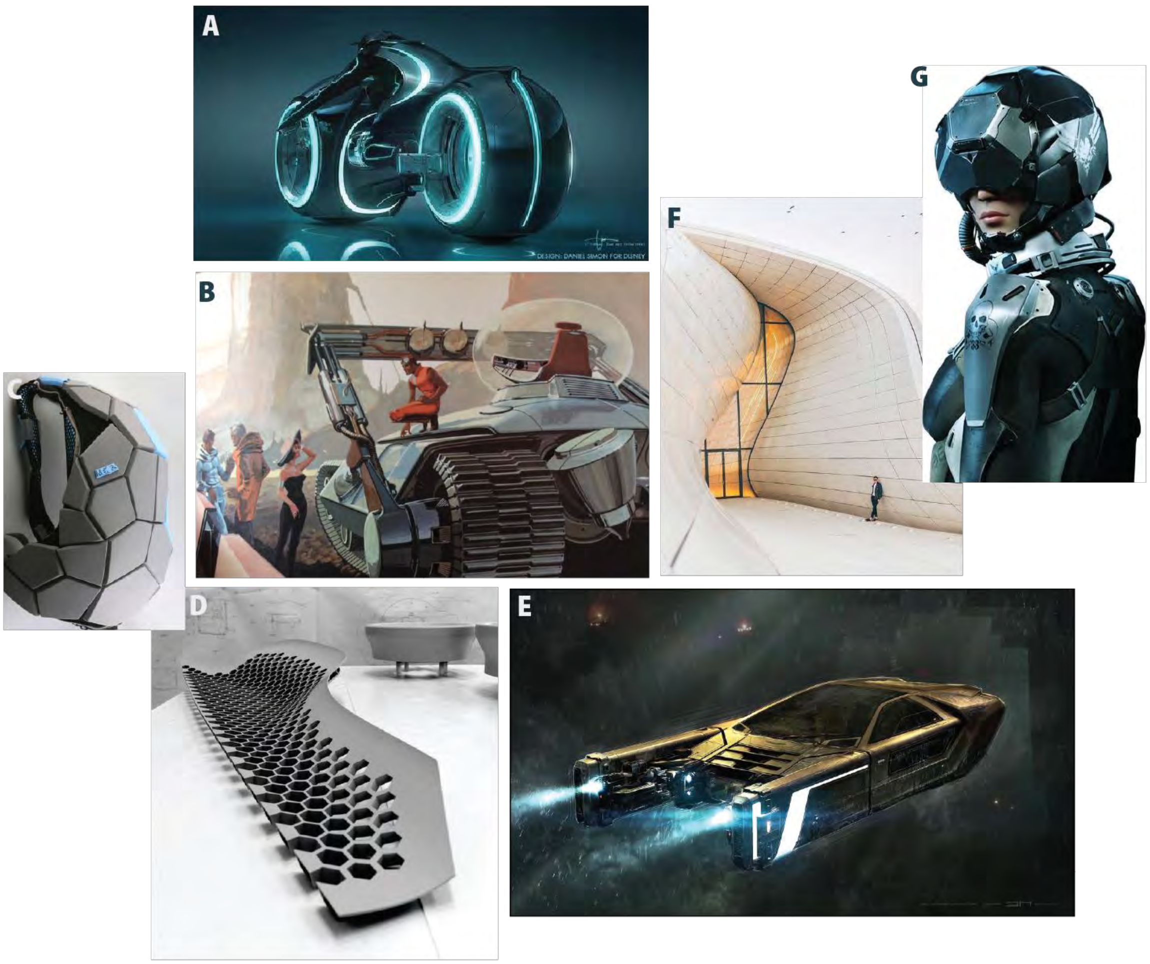
3.7 Design Brief

The goal of this thesis is to better the lifestyle and meet the physical and psychological needs of saturation divers who reside in an isolated environment for up to 28 days.

- To improve accessibility to emergency kits and passage ways avoiding cluttered or cramped space
- Limiting extended reach, crouching, bending to avoid injuries and strain to muscles
- Improve spatial area providing more room creating a safer and more comfortable environment
- Implementing privacy in a shared environment between divers, this can encourage a better environment for women who share space with men
- Improving material use for comfort, safety and sustainability; for potentially for cleaner surfaces, cushioned for seating, textiles that provide a sense of warmth and "at home" feeling. As well as materials that keep the environment dry
- Providing ergonomic angles for sleeping and sitting and carrying out basic activities such as writing, reading or using the computer
- Providing space for exercise which is extremely important for human health and maintains a healthy mindset in isolated environment
- Using aspects of colour to better the user experience
- Incorporating sustainable and modular aspects within the system or design.

CHAPTER 4 – DESIGN DEVELOPMENT

This chapter will illustrate the development of the design process for the proposed *Transportation Vessel for Saturation Divers*. Initial concept exploration, refinements and resolutions will be exemplified through images, leading to the final design.



4.1 Ideation

Images Cites:
A: Aufloria55.ru, Tron Legacy motorcycle concept ideas
B: Sydmead.com, concept art by Syd Mead
C: Designboom.com, Meiosis Backpack by David Gilad
D: Motivezine.com, Renault R.S 2027 Vision Concept
E: Ghull.com – Concept art by George Hull
F: Archdaily.com – Architecture by Zaha Hadid
G: Tumblr.com, User: Headlesssamurai

Figure 10 Mood-board and Inspiration

Visual Inspiration for this thesis project is derived from various concept artists (such as Syd Mead and George Hull), and from artistically designed and futuristic movies such as Blade Runner. The overall aesthetic quality that is aimed for the final design follows this sort of futuristic dystopia and streamlined appeal. Inspiration from unique materials, patterns, various design details, and forms found within architecture are integrated into the final design.

Ideation Sketches

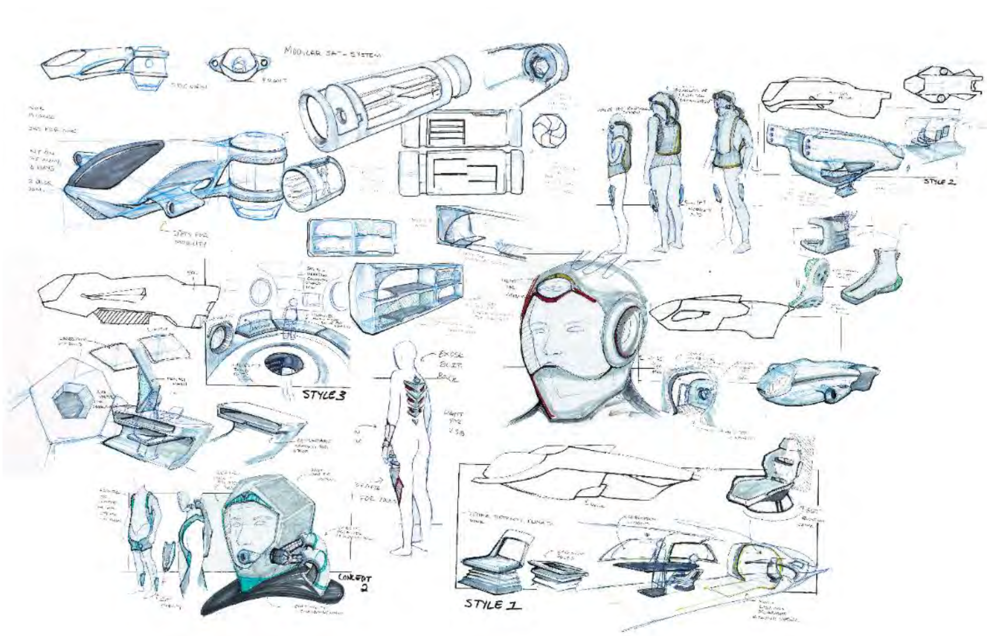


Figure 11 – Ideation Sketches

Ideation development through the early weeks explored a range of concepts. Exterior shapes and interior configurations were considered as well as wearable solutions. Specifically, preliminary concepts consisted of modular sleeping chambers, portable dive bells and advanced-tech dive suits.

4.2 Preliminary Concept Exploration

The following section goes into further detail of two concepts that were presented to be considered for the final chosen design. Each concept focused on different areas of saturation diving based on the research and studies conducted previously.

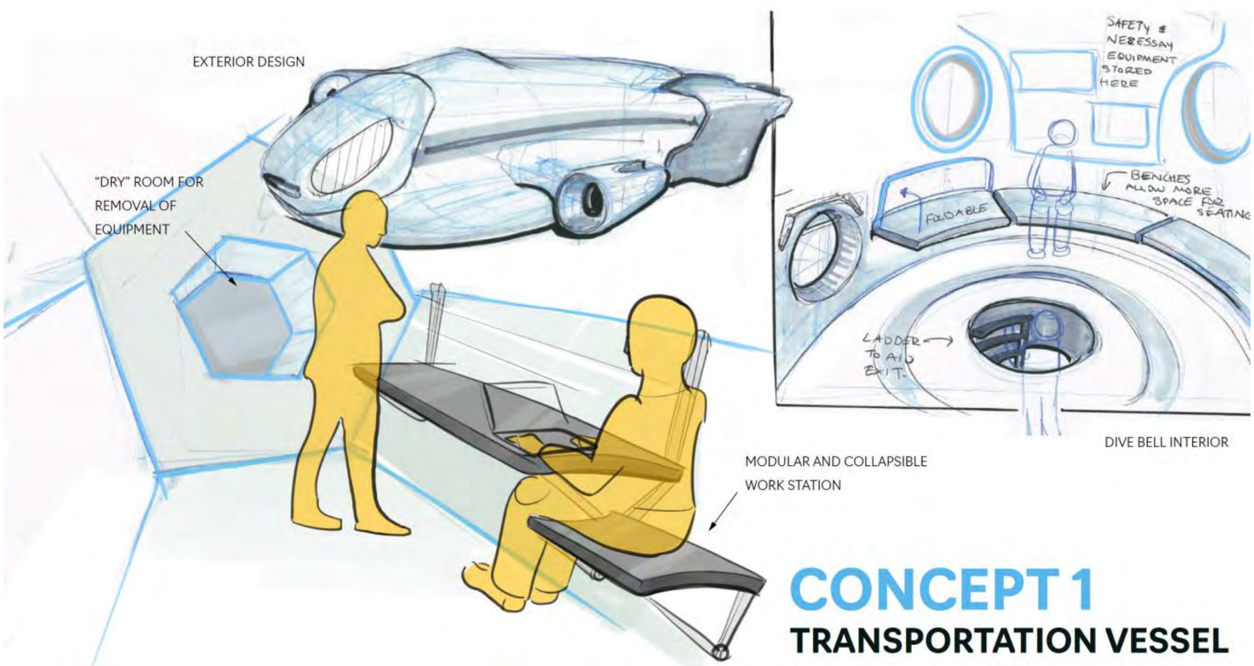


Figure 12 – Concept 1

Concept 1

The “transportation vessel” intended to provide a system that could give the divers more freedom of travel when targeting work underwater as well as increase the number of divers of the job to provide a more efficient and productive work experience. The illustration above shows a possible exterior design, and an interior area in which individuals can comfortably carry out activities, as well as modular seating within the dive bell interior.

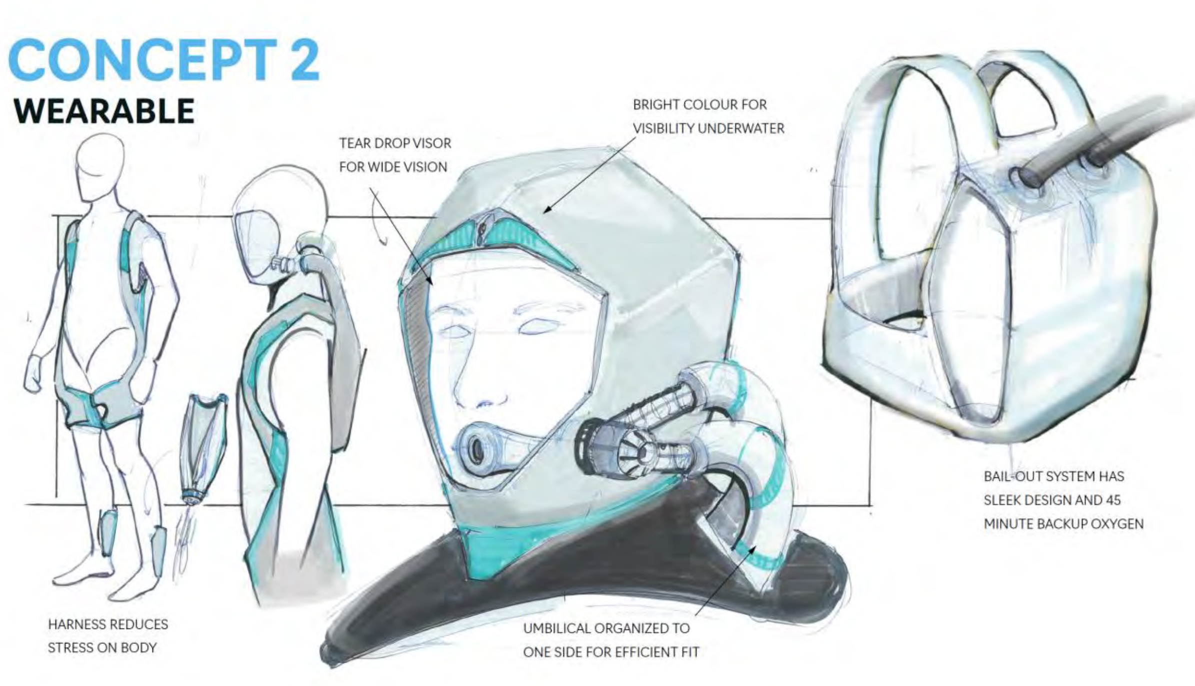


Figure 13 – Concept 2

Concept 2

The “wearable” concept was intended to provide divers with a more comfortable working solution with increased safety while on the job. The illustration below shows a reconfigured emergency rebreather for quick access, a harness to reduce stress on body, increased visibility through lighting and increased mobility through jet propulsion.

4.3 Concept Refinement

Concept 1 was chosen to move forward with. Concept 1 provided a more complex, in depth platform for innovation and research and the opportunity for immense improvement of comfort and safety within the saturation diving industry. Each subsection of the interior system was refined and examined in further detail.

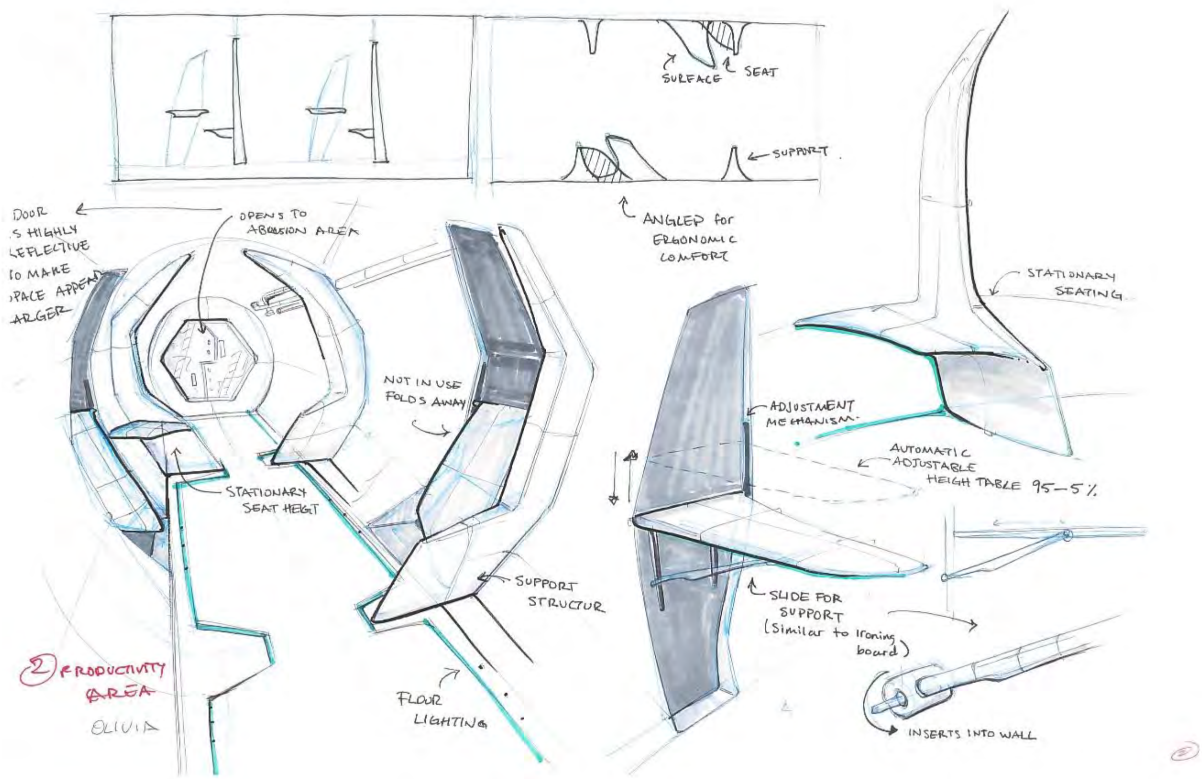


Figure 14 – Productivity Area

The illustration above presents the first part of the modular interior system which is reffered to as a productivity area. This is where divers, while off their regimented sift, can have a comfortable space to relax, read or work on their personal assignments.

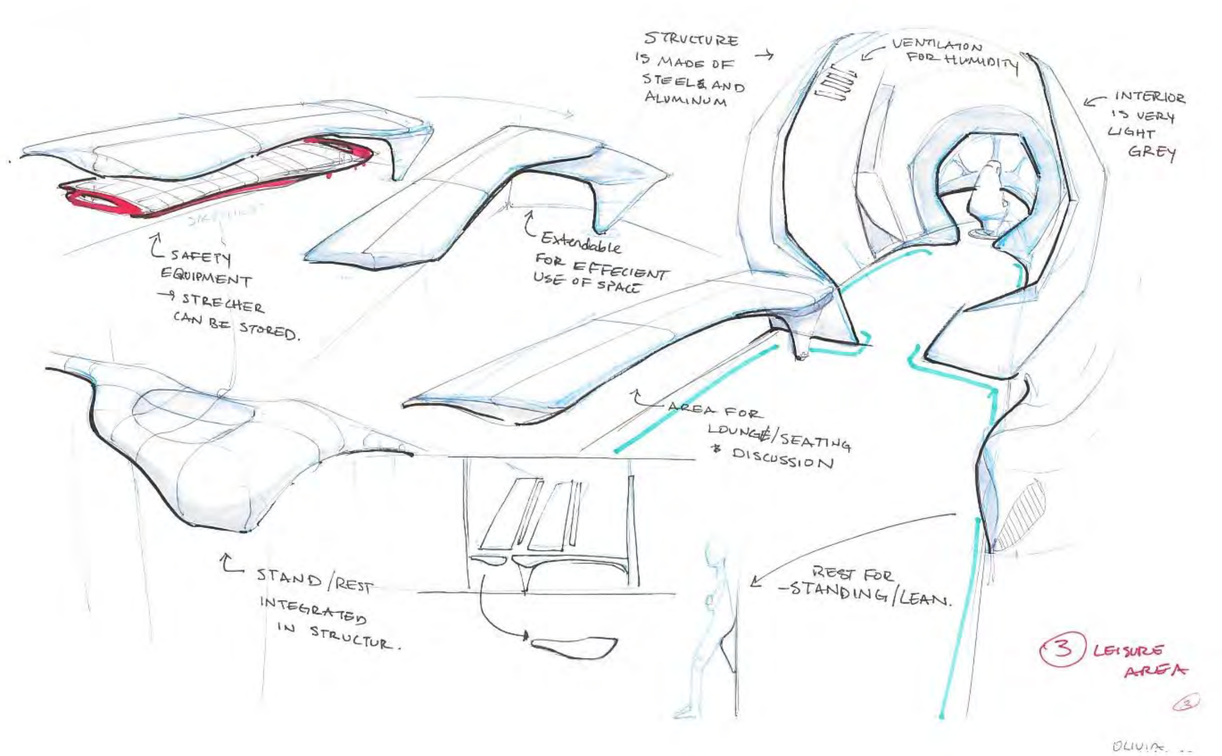


Figure 15 – Productivity Area Continued

The second part of the productivity area includes a simple seating area where the team can meet, discuss and arrange protocalls for their upcoming work shift.

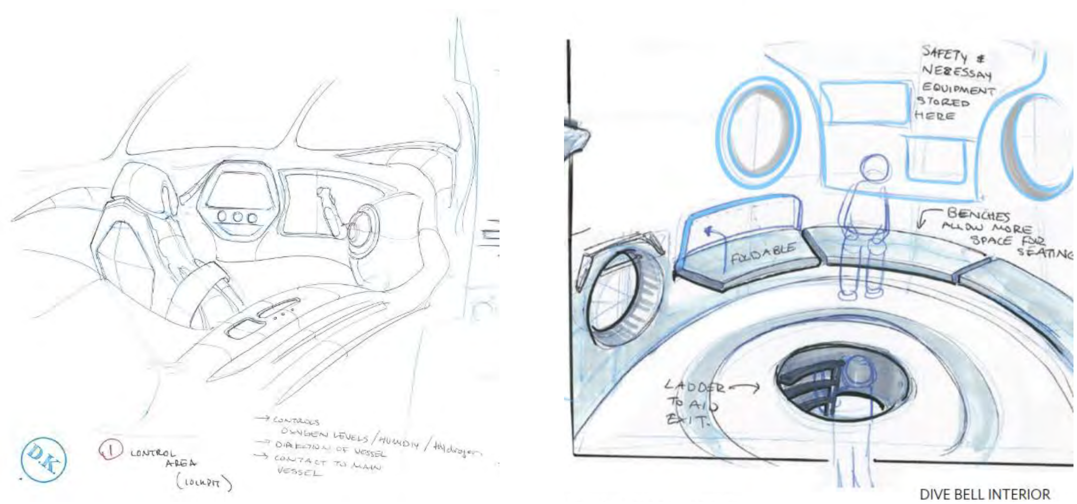


Figure 16 – Control Area and Dive bell

Figure 17 – Dive Bell

The control area will allow one individual to control direction and speed of the vessel, this is where pressure controls, heating and oxygen to the divers underwater will be distrubuted and controlled. connection to the team on land is managed here. The illustration above shows the dive bell which can now hold more divers and seating because the controls are instead, located in the control area.

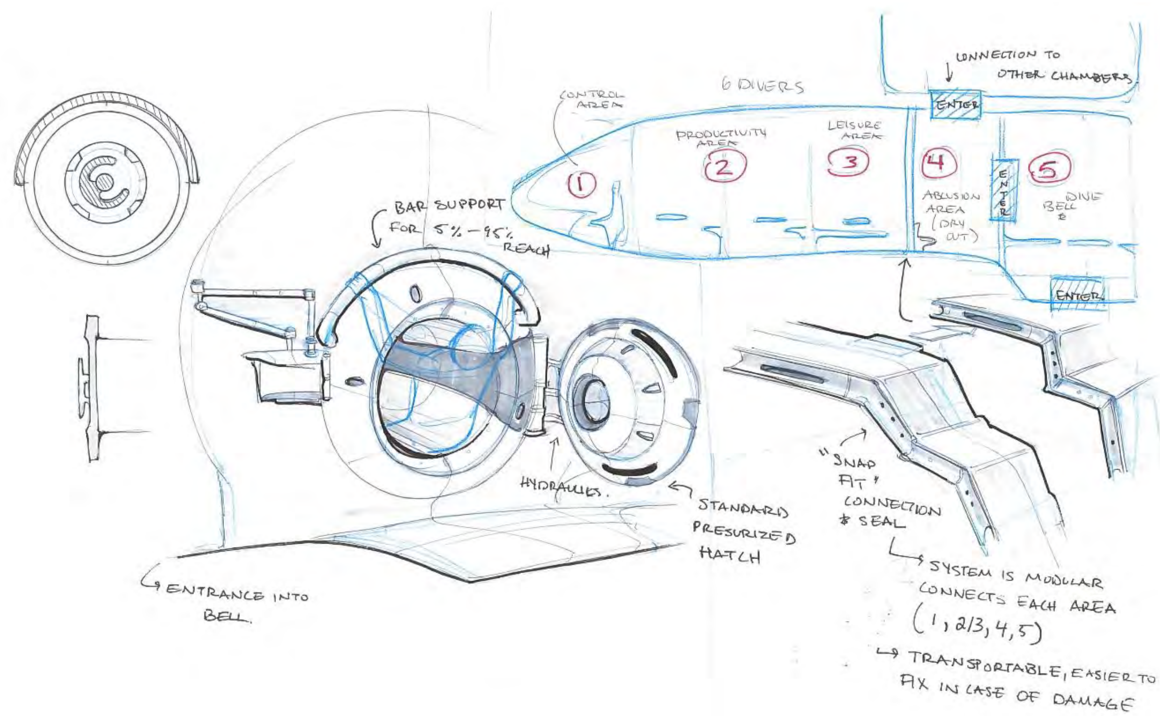


Figure 18 – Modularity and Grab Bar

This illustration shows the improved hatch entrace/exit door with a wide handle, improving grasp for the individual when in use, also explored in the 1:1 sketch model constructed in *section 3.3*.

4.4 Detail Resolution

Detail resolution is centred around the modular and adjustable components throughout the vessel. This includes the adjustable and compact work surface, as well as the privacy feature which will be further implemented into the Final CAD.

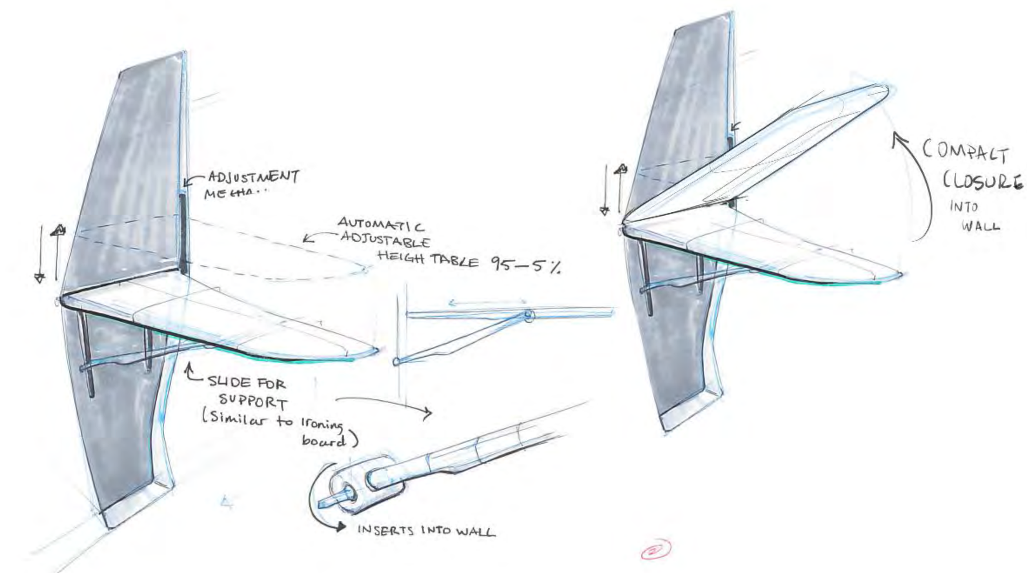


Figure 19 – Modular Work Station in productivity area

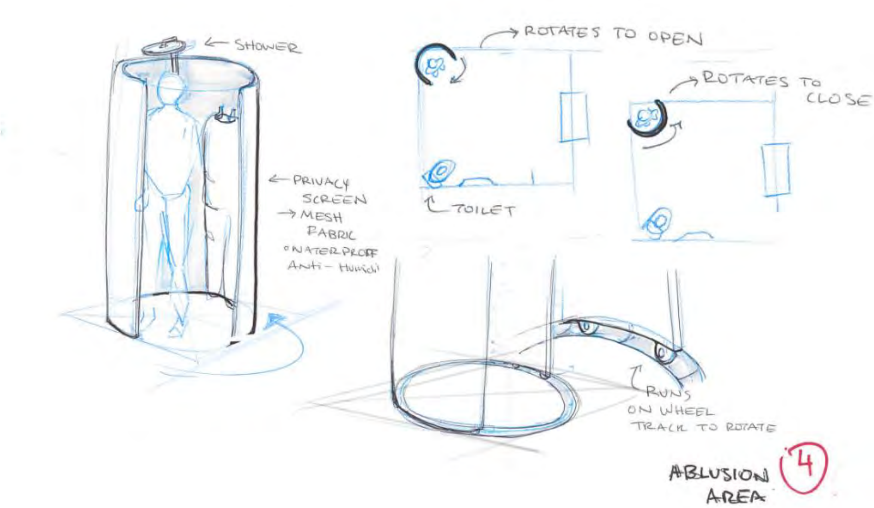


Figure 20 – Privacy Feature in Ablution area

Above Illustrates a retractable privacy feature located in the ablution area for increased privacy when showering.

4.5 Sketch Models

This Section presents sketch model development. A 1:24 scaled model was created out of basic materials such as foam core and illustration board, in order to understand and implement 3D elements to develop the final CAD. Specific portions were taken to be considered for the model, the ablution, productivity and control area.

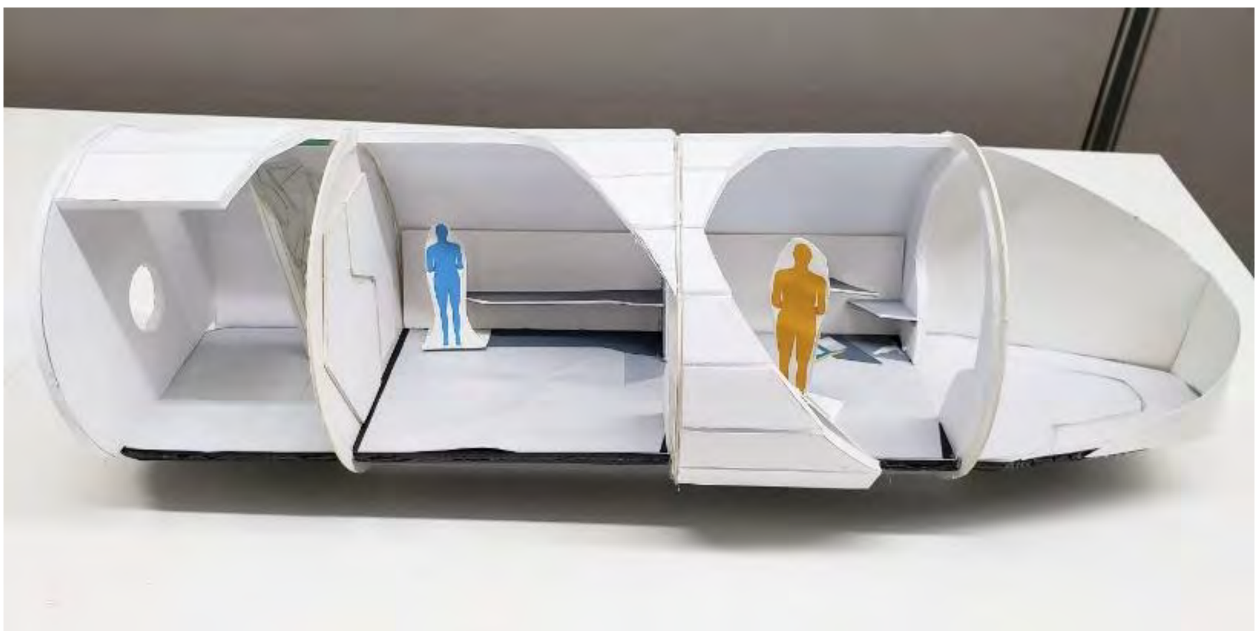
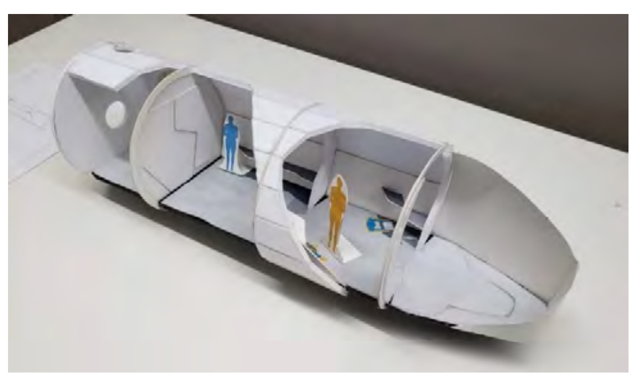


Figure 21 – Sketch Model



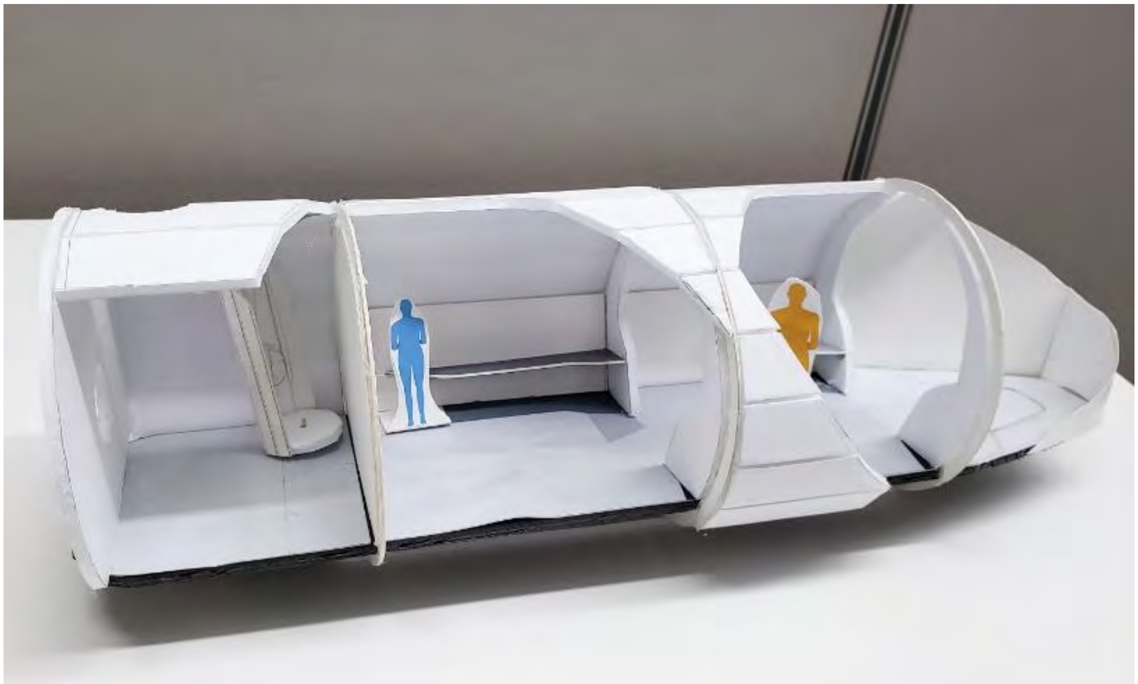


Figure 22 – Complete Sketch Model

Figure 23 – Progress of Model

4.6 Final Design

The final design is comprised of the various areas explored in previous sections. The complete system consists of a futuristic and streamline interior that focuses on the productivity and ablution area. The aim for the design was to portray a spacious area for six divers and modular components to save space.

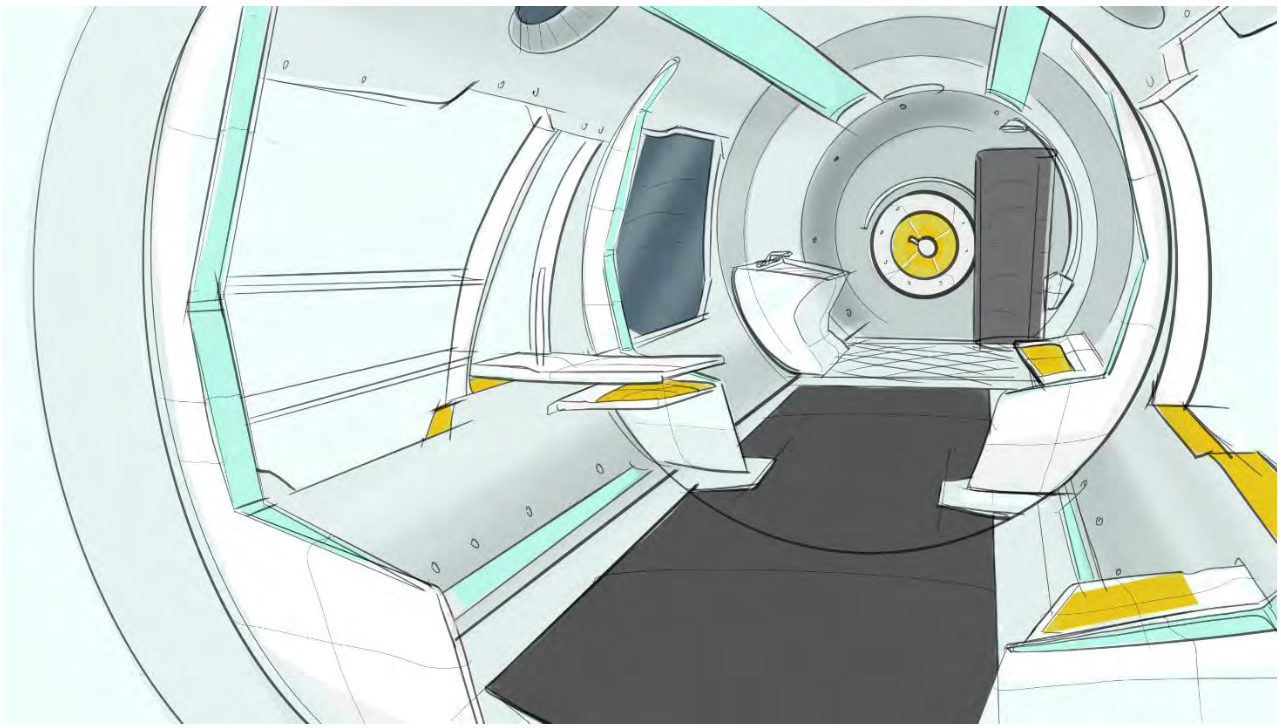


Figure 24 – Final Design Concept

4.7 CAD Models

SolidWorks, a computer aided design program, was used to develop the final model. The system was formed by developing overall shapes and using various features to cut and build onto these bodies. Eventually this produces a detailed product that can then be rendered and prepared for 3D Printing. The focus of the design was an interior solution, the exterior was developed for function after the interior details were finalized. The model is made up of four main areas: Control area, productivity area, ablution area and the dive bell

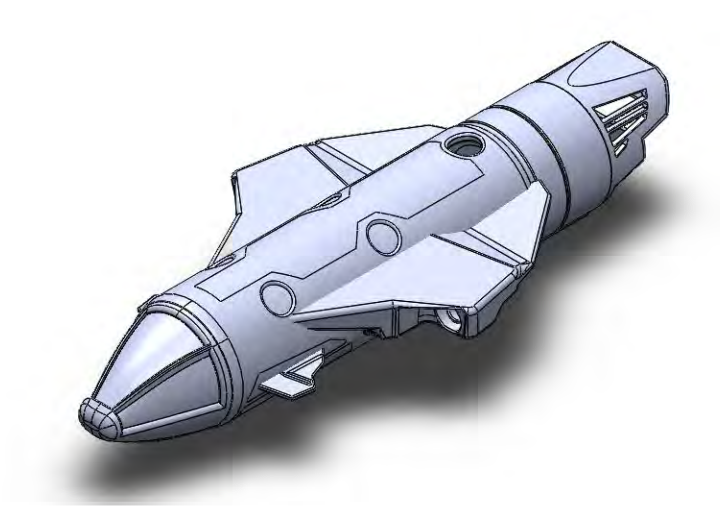


Figure 25 – Solidworks ¾ view of exterior

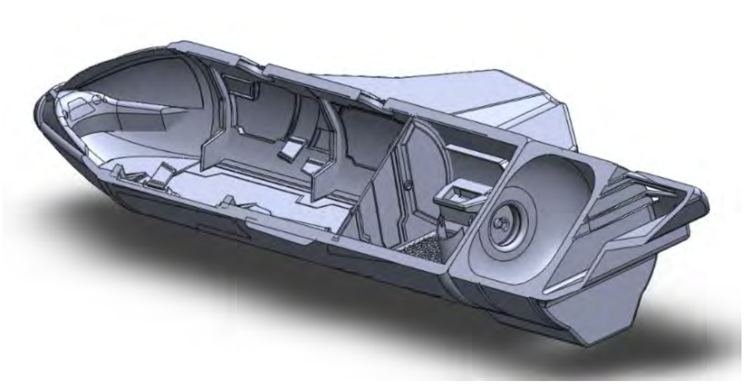


Figure 26 – Section view of interior details

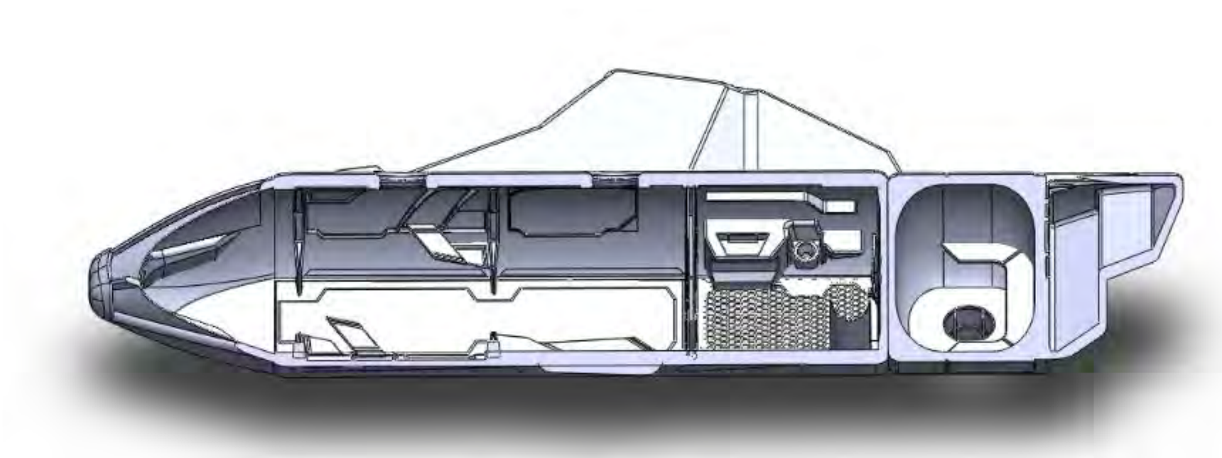


Figure 27 – Section view of interior

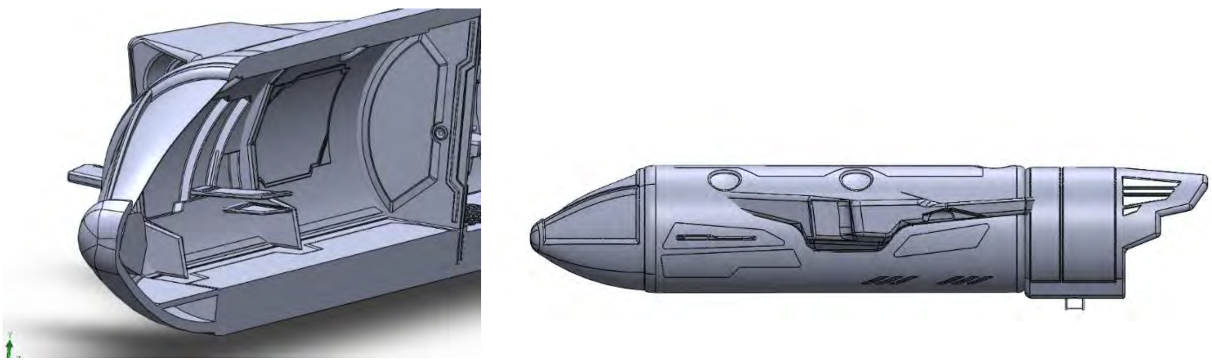


Figure 28 – CAD Development

4.8 Hard Model Fabrication History

After the Completion of CAD, parts were organized and sent for printing. The files were sent to Agile Manufacturing INC and printed in “SLA” as a scaled model, ratio of 1:24. These were then prepared, lightly sanded, set up to be spray-painted and finally assembled. Parts were designed to be dry fitted for easy assembly.

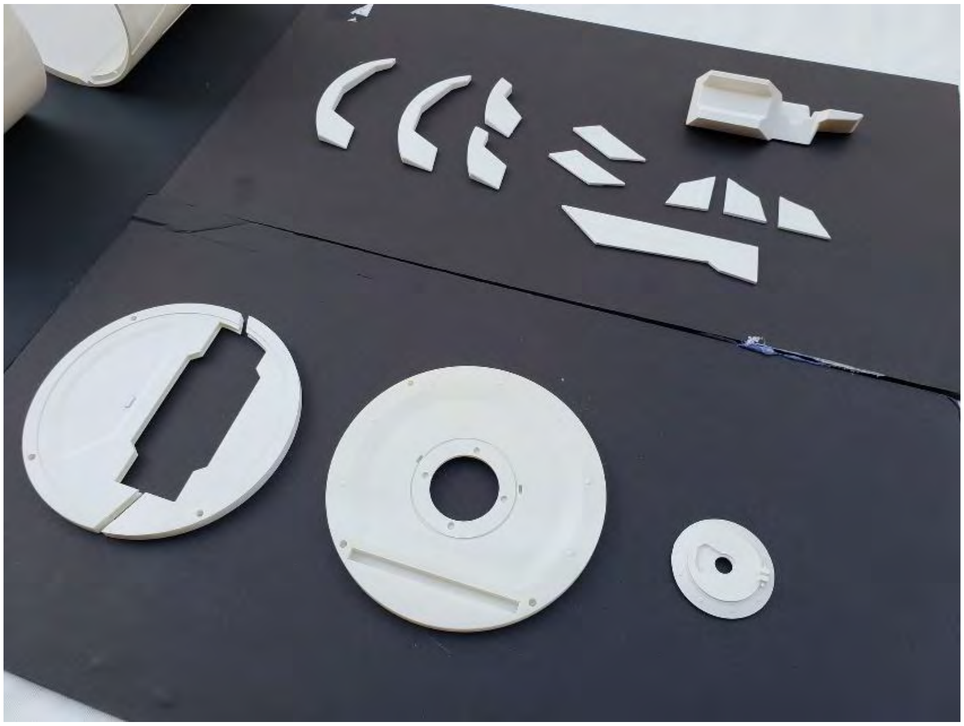


Figure 29 - Hard Model Fabrication, 3D printed parts

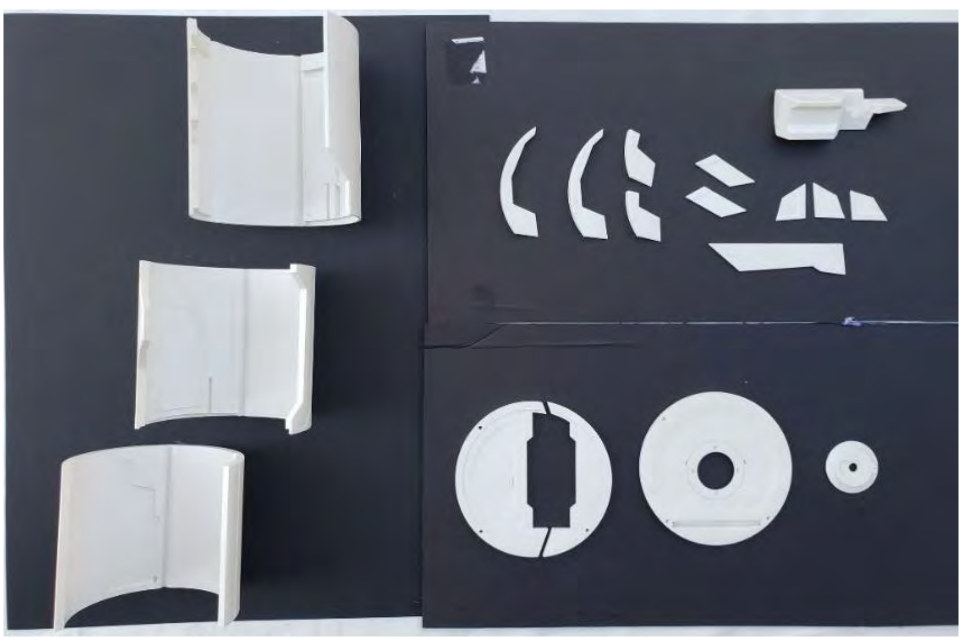


Figure 30 - Hard Model Fabrication, 3D printed parts

Figure 31 - Hard Model Fabrication - Parts were set up to be primed, sanded and painted with a gloss white coat. Masking was done to achieve alternate colours in detailed areas.

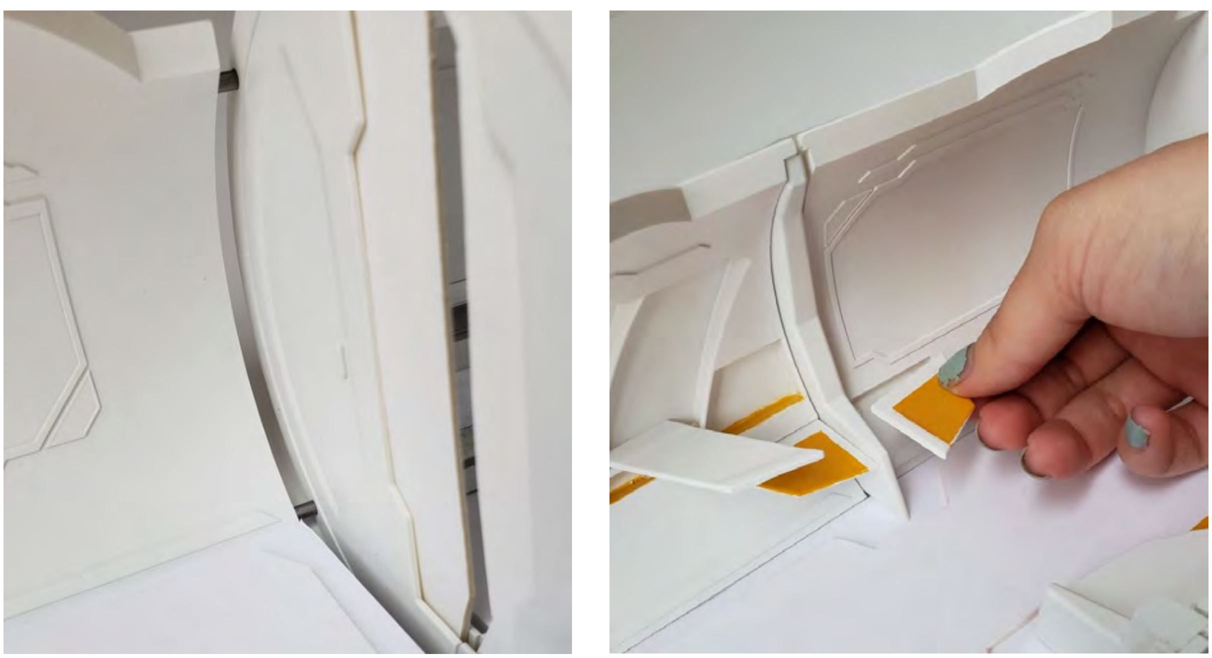


Figure 32 – Assembly of parts

CHAPTER 5 – FINAL DESIGN

This final chapter will summarize the conducted research, observations and design development done throughout the previous chapters, as well as conclude the final design features and technicalities of the proposed concept.

5.1 Summary

Description

ZESU490 is a human-centric environment for saturation divers. The interior space is designed to maximize productivity by providing divers with a comfortable and efficient working environment. This interior solution is meant to improve ergonomics and workflow within the saturation diving industry.

Explanation

ZESU490 is an underwater transportation submersible meant to separate from the main vessel where traditionally, the entire saturation system is stationed. In current systems today, divers are restricted to working in one area of the seabed with a range of only 3 metres. ZESU490 will allow divers to venture further distances while providing the space, comfort and safety one needs to preform their job efficiently. Having a system that is independent from the main vessel allows more opportunities in the saturation diving industry. It gives room for advancements in marine research and in underwater construction. ZESU490 consists of four subsections: The control unit, productivity area, ablution area and diving bell. The entire system provides the necessary equipment and features to function similar to traditional methods. Improvements are made by providing accessibility to emergency kits and passage ways by avoiding cluttered or cramped spaces, implementing privacy in a shared environment between divers which can encourage a more comfortable environment for women who share space with men, improving ergonomic sitting or standing positions and Incorporating sustainable and modular aspects within the system or design to increase sustainability and functionality. Overall, ZESU490 can better the lifestyle and meet the physical and psychological needs of saturation divers who reside in an isolated environment for up to 28 days.

Benefit Statement

ZESU490 is designed to provide a comfortable environment that will reduce psychological stress on divers, allowing them to maintain a focused mindset and thus enable a safer work experience.

5.2 Design Criteria Met

The following section pertains to the overall design concept and its success meeting the design criteria in regards to ergonomics, material, process, technologies and manufacturing.

5.2.1 Ergonomics

Interior Features

ZESU490 allows each diver to adjust their workstation set to their most comfortable height. The individual can choose to sit or stand. The table surface can be folded into the interior walls when not in use to provide more space to move around. The height can be adjusted to sit or stand a 5th percentile female and a 95th percentile man. The adjustability and modularity provide various options for individual comfort where they may choose to eat, read or work on their laptops.

The control area contains any technology that the divers need to keep track of pressure within the system, humidity levels, communication to emergency contacts, heat, water and oxygen controls to each umbilical cord. ZESU490 provides efficient space for the controls to be rearranged compared to a traditional system where most of the controls are located within the dive bell. This enables more room for the divers to sit comfortably within the dive bell before getting ready to enter the water. This also allows more divers to work on the job, creating less stress for each individual, improving workflow and productivity. Traditionally two divers are on the seabed and one remains in the dive bell for safety purposes. ZESU490 can fit up to three extra divers, or a total of six, so divers can have reduced work times for their regimented shifts.

The ablution area or dry room, provides a space where the divers can change, also giving more space within the dive bell where in a current system, two divers put on and take off their equipment. For the productivity area to stay clean and safe, the ablution area's grid floor allows any excess water to be drained from the diver's suits when changing before entering the productivity area. ZESU490 provides a privacy feature in the ablution area where divers can gain more privacy when washing up. This enables a more comfortable environment for female divers.

For proper entrance and exit throughout the system, a simple adjustment was made. The semi-circular grab bar above the hatch door provides a wide area where every diver can comfortably position their hands to support their body weight.

5.2.2 Materials, Processes & Technologies

Processes and Technologies

Manufacturing of ZESU490's submersible hull involves assembly of steel plates. Parts are welded together and are divided between an inner and outer portion along with many other sub compartments to ensure watertight components. Welding seams are grinded by highspeed grinding wheels to smooth out the surface which also allows less friction during travel. A protective “anti corrosion” coating is applied to all surfaces. These processes and technologies were analyzed through existing benchmarked products to be implemented into the proposed thesis design due to similar elements.

The use of composite materials offers the benefit of weight reduction and durability, necessary to withstand harsh underwater environments. Plastics such as acrylic used for clear spherical view ports, fibre reinforced plastics, and metals including aluminum and titanium alloys are used in the production of ZESU490. These components provide resistance to abrasion and tear, energy absorption, low creep and compression set properties, high resistance to seawater, oils, UV and chemical degradation (Delaforce, 2011).

Materials

The exterior support structure of the designed system is made up of recycled aluminum and titanium and the interior structure, that includes storage and seating, is made of fibre reinforced plastics. FRP is used for various advanced engineering structural purposes. Its use is for the ability of forming complex and beautiful shapes/forms. Both materials can provide a lightweight frame and strong support while incorporating long lasting and durable features. These materials are resistant to rust and corrosion allowing the materials to last for decades when exposed to environmental elements. The metals and plastic lightweight features allow easy transportation, without the use of extreme equipment, reducing costs. These materials provide the strength, formability and lifespan needed for an underwater vessel. FRP provides insulation from heat or cold and even sound, reducing echoes from the outer metal structure. Plastic surfaces are easy to clean and maintain. The use of fabrics must consist of materials that provide anti-mildew and fire-resistant qualities. Nylons and polyesters can provide fabrics that are easy to clean and resistant to abrasion and wrinkling. These are suitable for humid environments that the vessel may withhold. These qualities make the fabrics long lasting and durable for extended length of use.

5.2.3 Manufacturing cost report

The following table organizes a breakdown of the estimated cost for ZESU490. It is divided into four sections; concept item represents various products within the entire system. Quantity/Measurement represent the number of products or the measurement in weight or square metres. The cost analysis does not include labour and transportation costs.

Concept Item	Quantity/Measurement	Cost Estimation/Unit	Total
Workstation	2	$150	$300
Seating	3	$30	$90
bench	4	$60	$240
Privacy Mesh	1	$200	$200
Exterior structure	~1000 tons	$1760/metric Ton	$1,760,000
Interior structure	~500 square Metres	$35/metre Square	$17,500
Washing Amenities	1	$200-800	Up to $800
Shower	1	$80	$80
Fabric	10 metres	$3.50/metre	$35
Ladder	2	$35	$70
LED Lighting	10	$40	$400
TOTAL COST			**$1,779,715**

Table 11 – Cost Analysis

5.3 Final CAD Renderings

This section presents the final CAD renderings.

Figure 33 - Exterior view of ZESU490

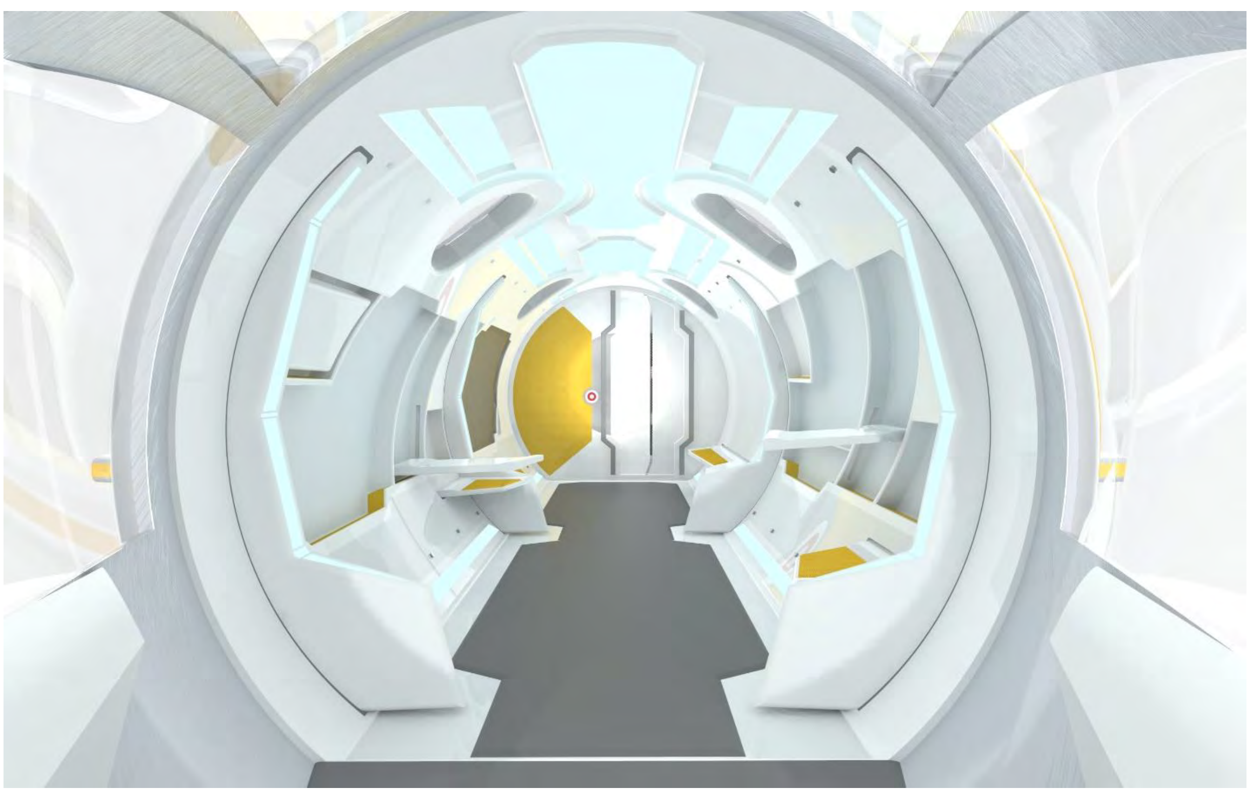


Figure 34 – Interior view of productivity area

Figure 35 – Interior view of ablution area. Contains shower and privacy mesh, sink and toilet.

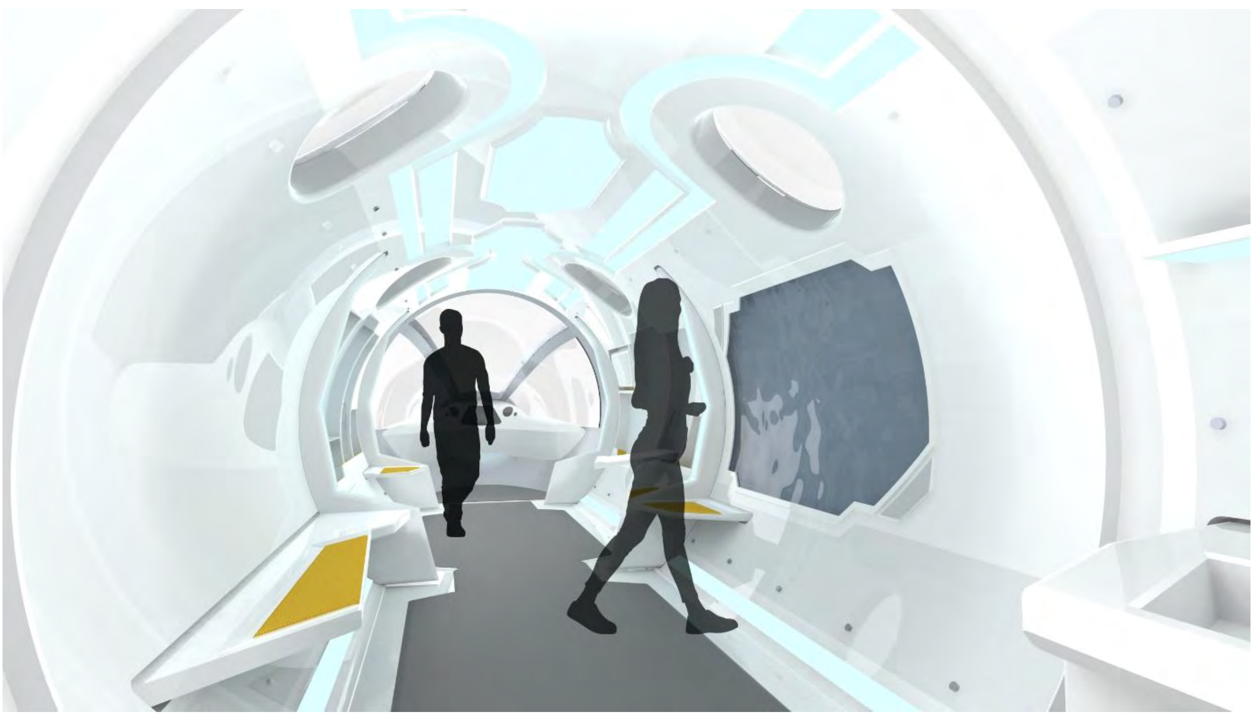


Figure 36 – Interior view of productivity area. Left side shows a screen that can be used to display information and preparation for daily dives.

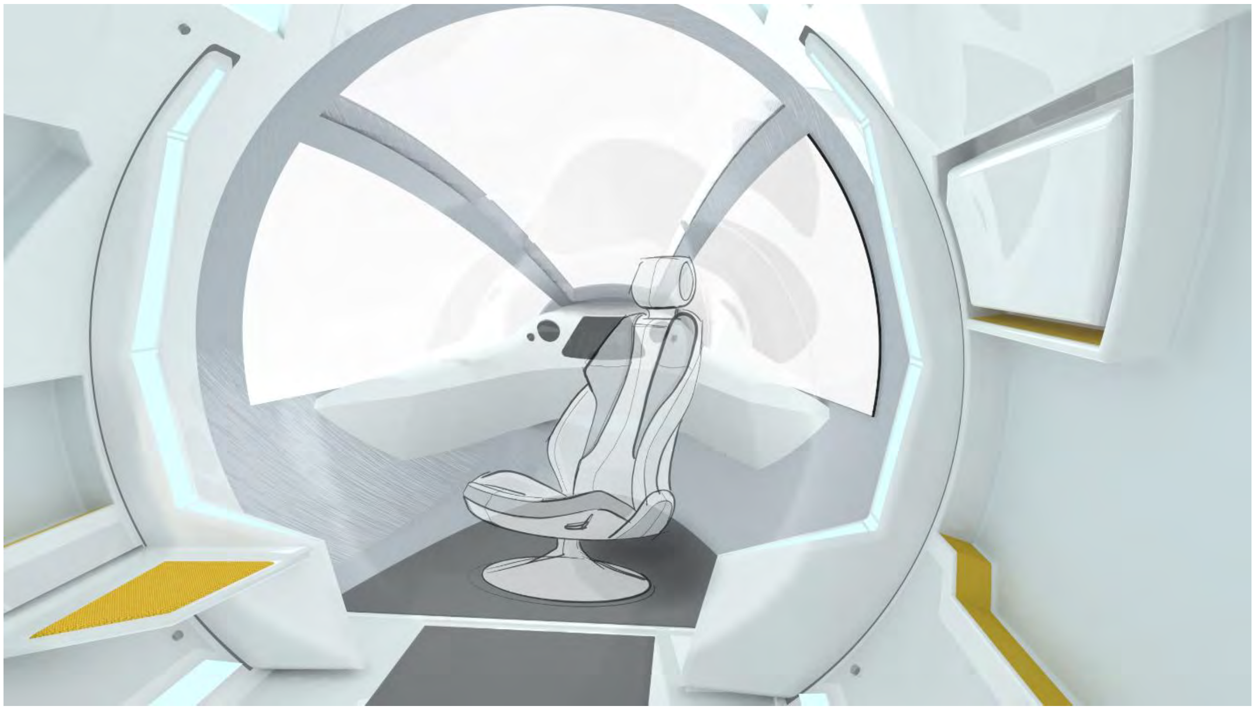


Figure 37 – Interior view of control area. here is where the vessel direction, oxygen and water levels, and other safety procedures would be controlled

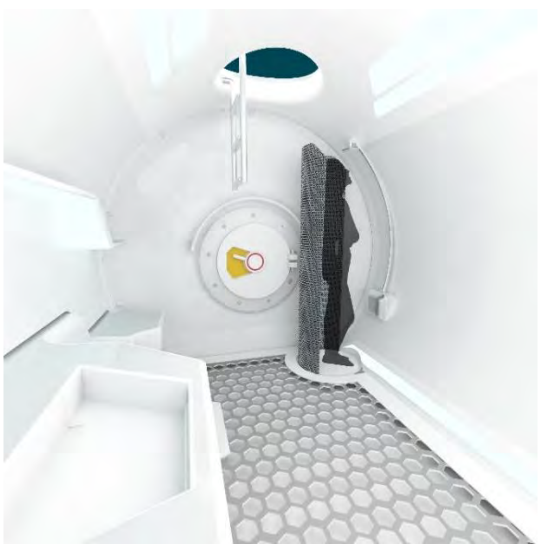


Figure 38- Individual and privacy mesh

Figure 39 – Interior view of dive bell. Shows four divers preparing to submerge underwater. Umbilical chord for oxygen and heat are installed on the left hand side.

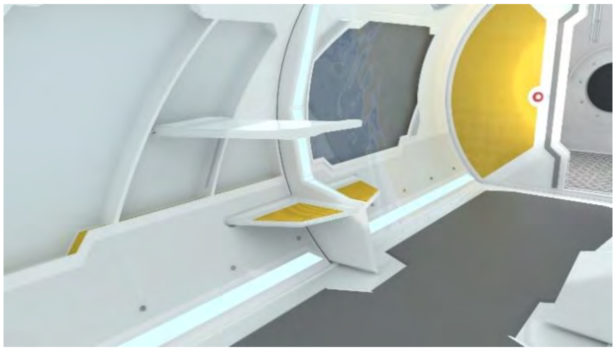


Figure 40 - Table adjusted for seated height

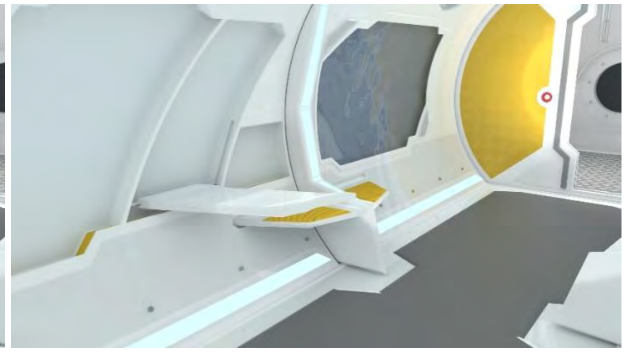


Figure 41- Table height adjusted for 95 percentile man

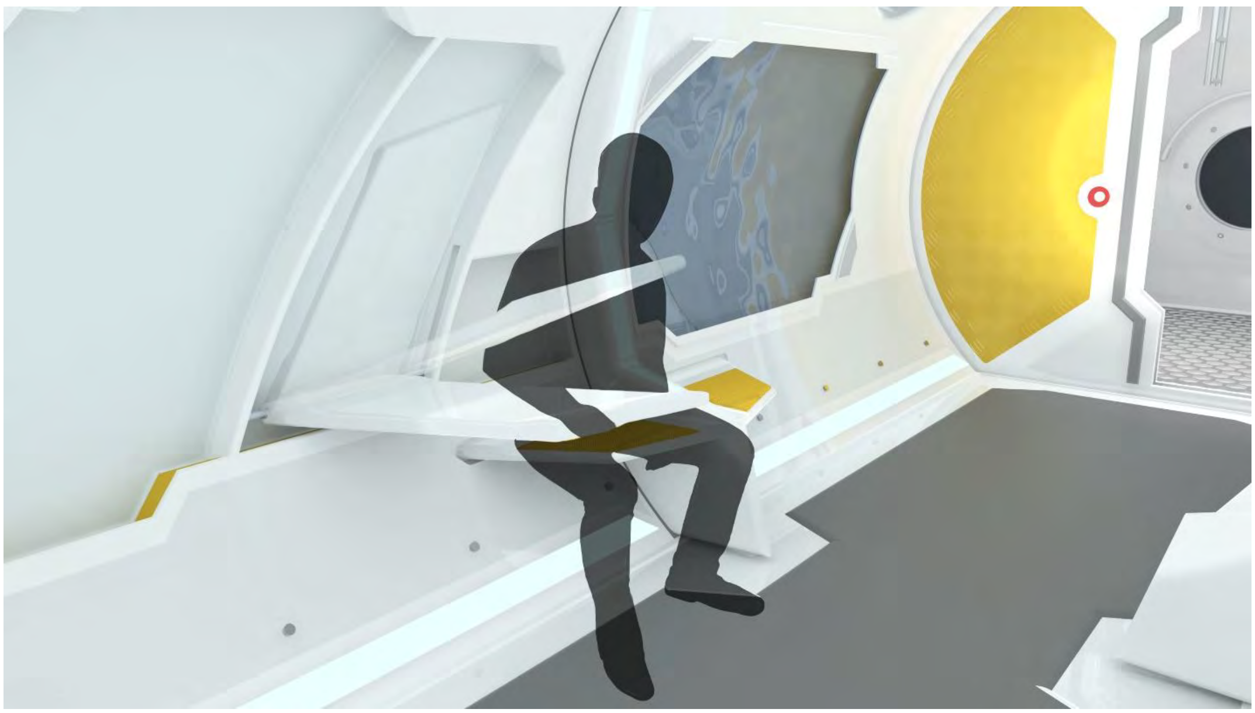


Figure 42 – Modular for compart solution creating more efficient use of space

Figure 43 – Divers Weight is supported to enter or exit the dive bell by semi-circular grab bar.

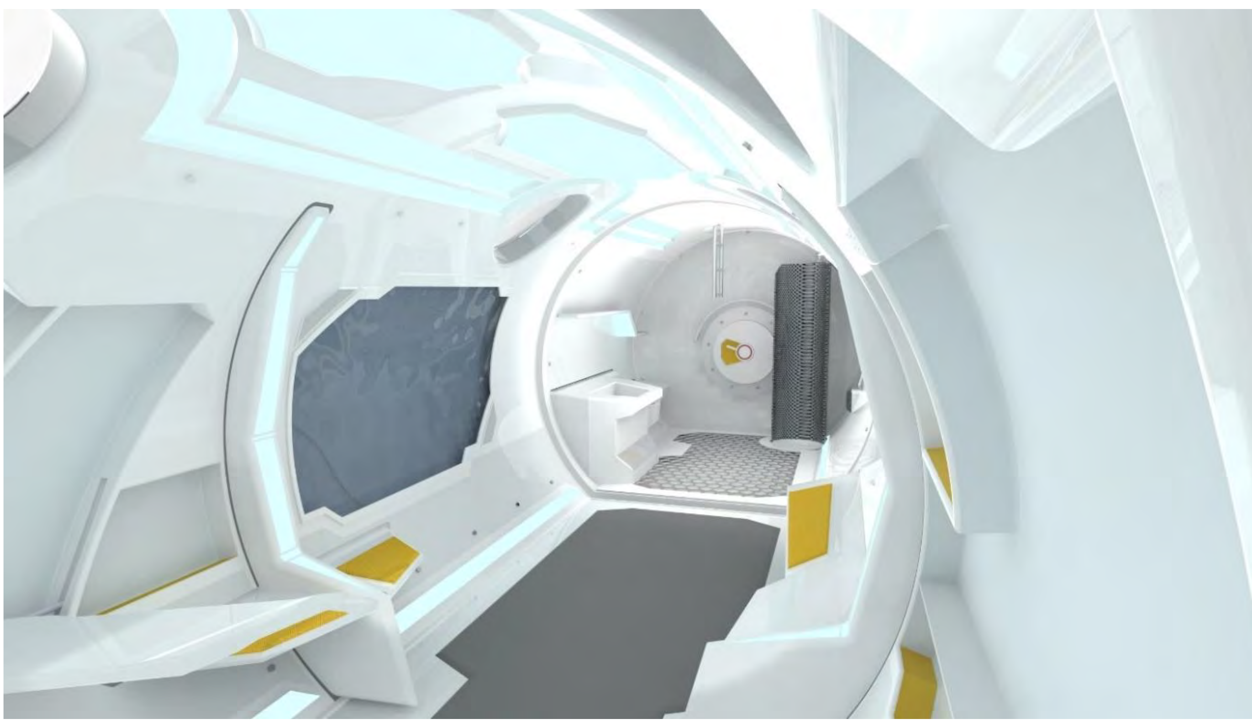


Figure 44 – Interior View to back

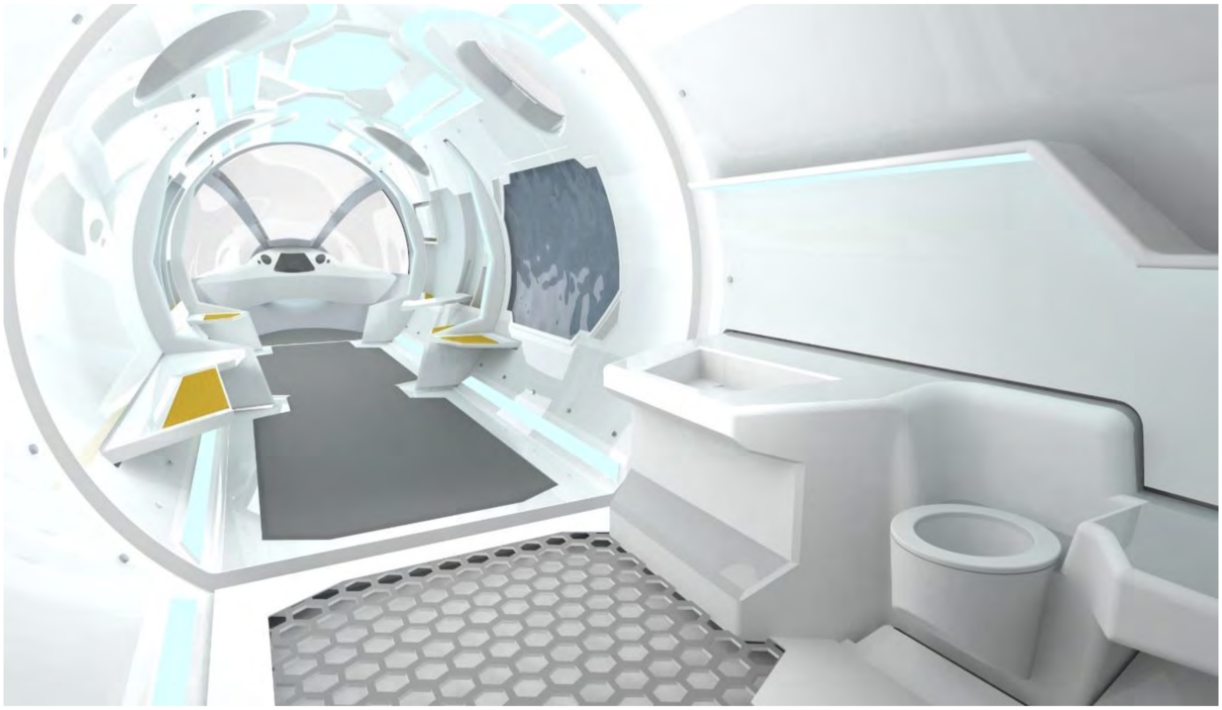


Figure 45 – Interior View to front

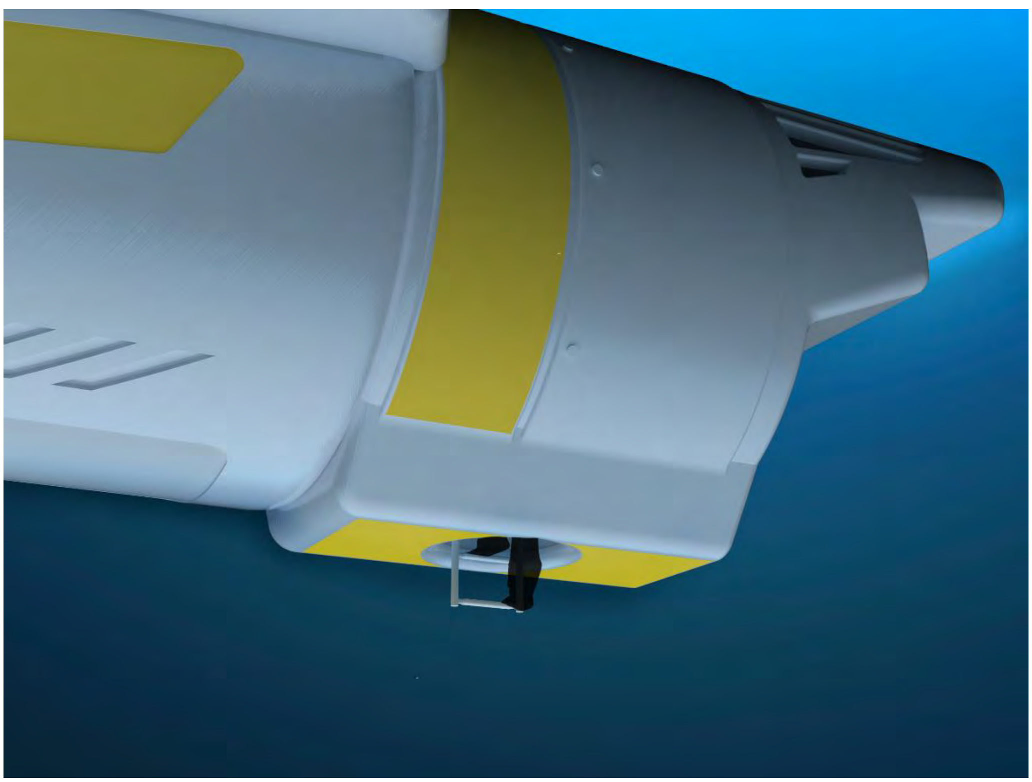


Figure 46 – Man exiting into water from dive bell

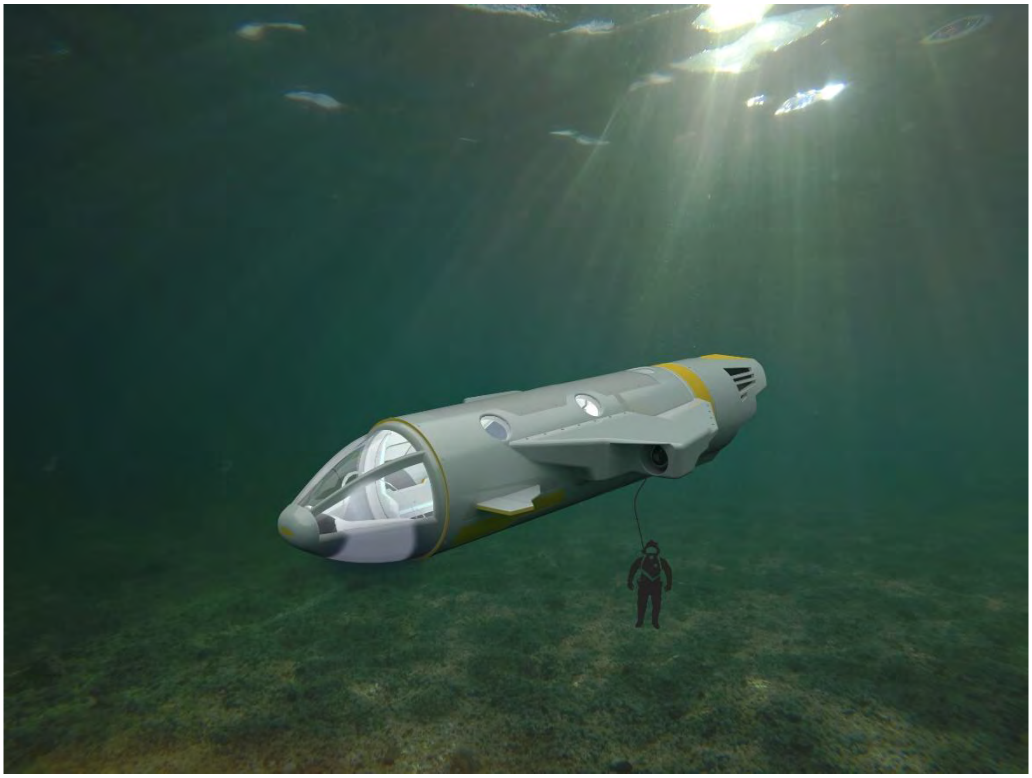


Figure 47 – Underwater view with saturation diver

5.4 Hard Model Photographs

This section presents images of the finished model.

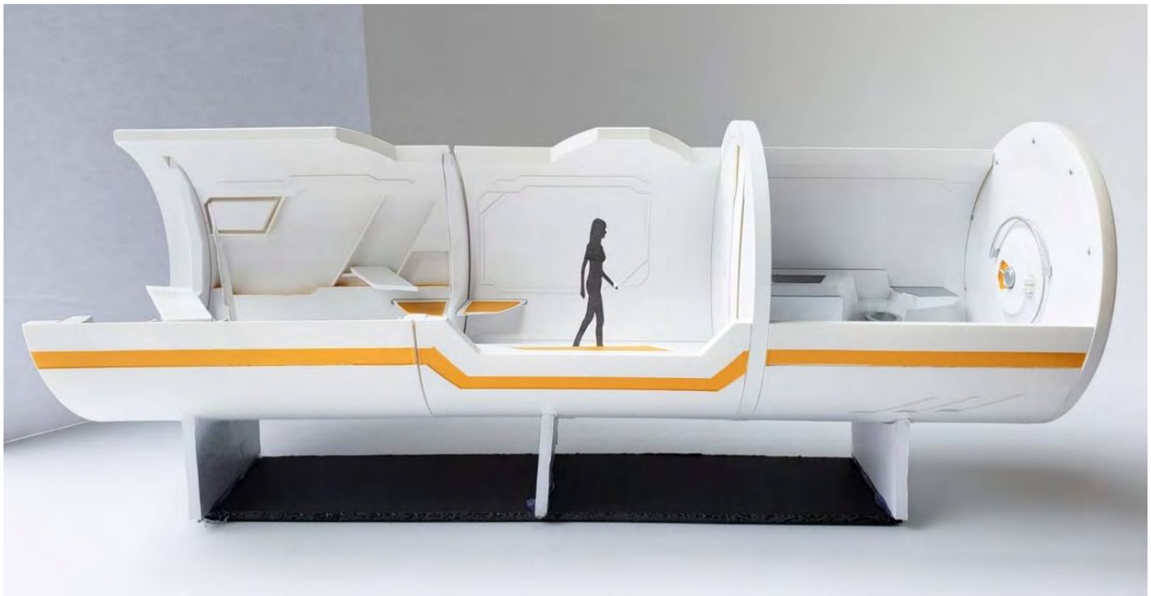


Figure 48 – Front View

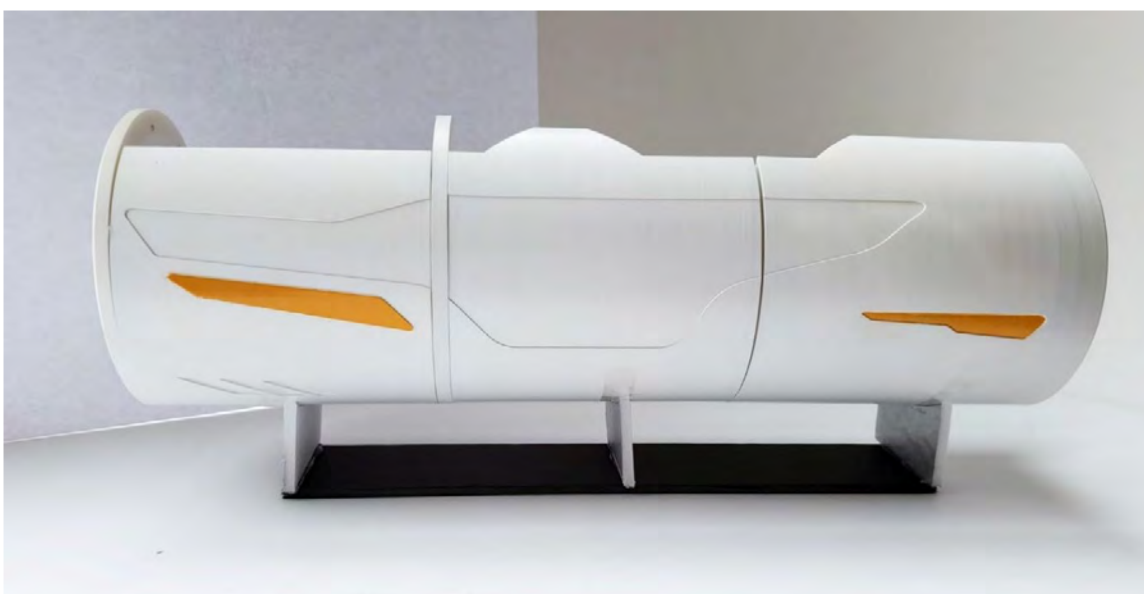


Figure 49 – Back View

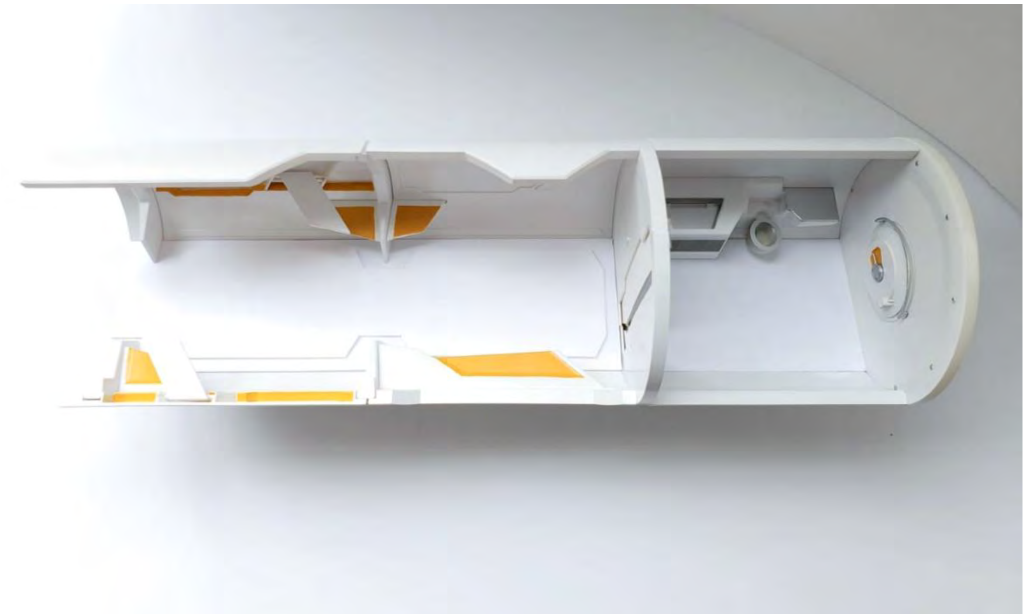


Figure 50 – Top view

Figure 51 – Adjustable work station

Figure 52 – Exterior details

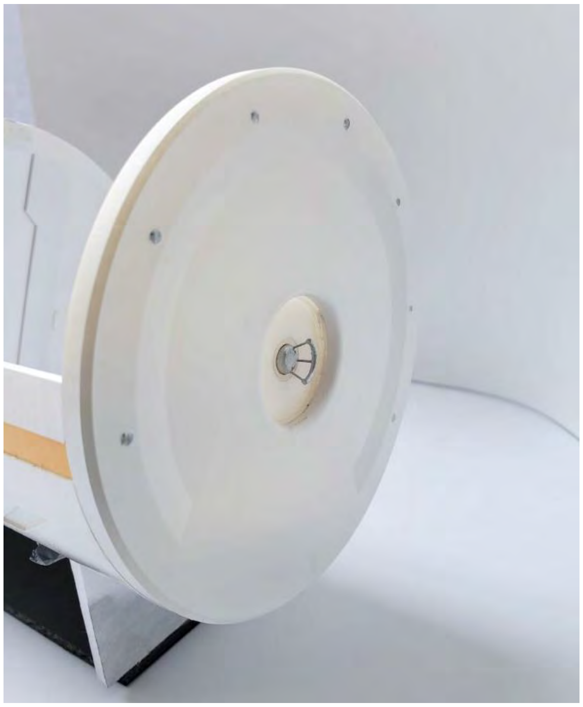


Figure 53 – Handle for hatch door

Figure 54 – Grab bar above hatch door

Figure 55 – Ablution area

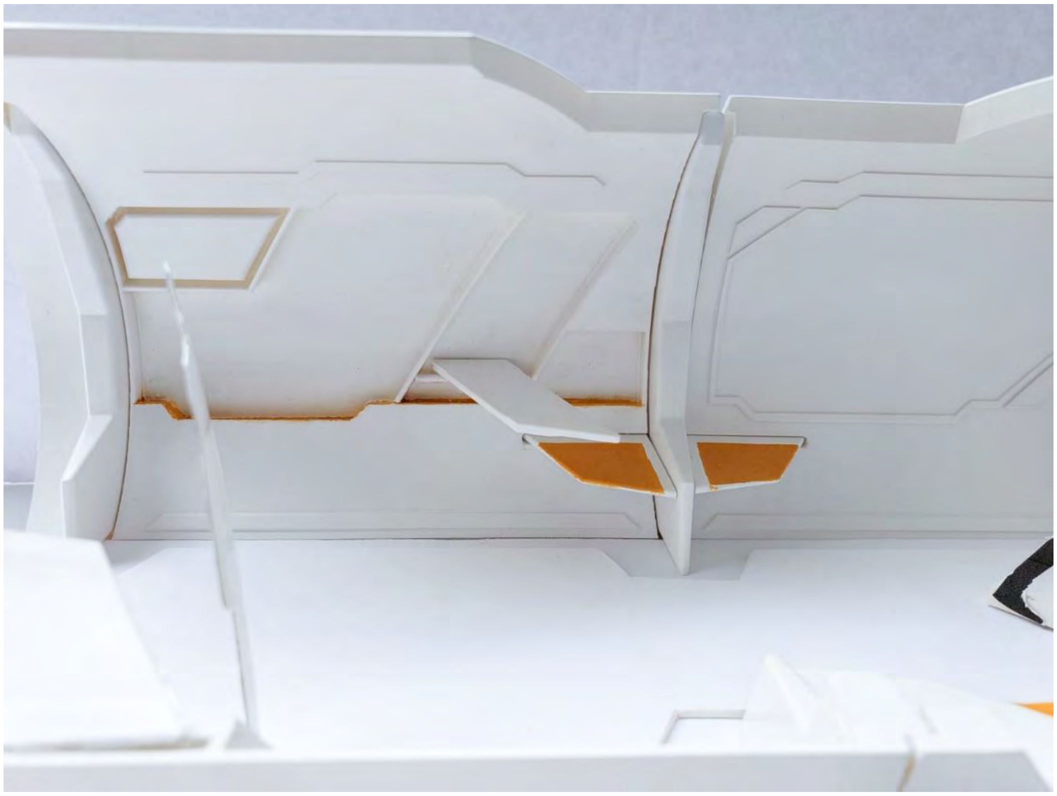


Figure 56 – Productivity area

Figure 57 – 5th percentile female

Figure 58

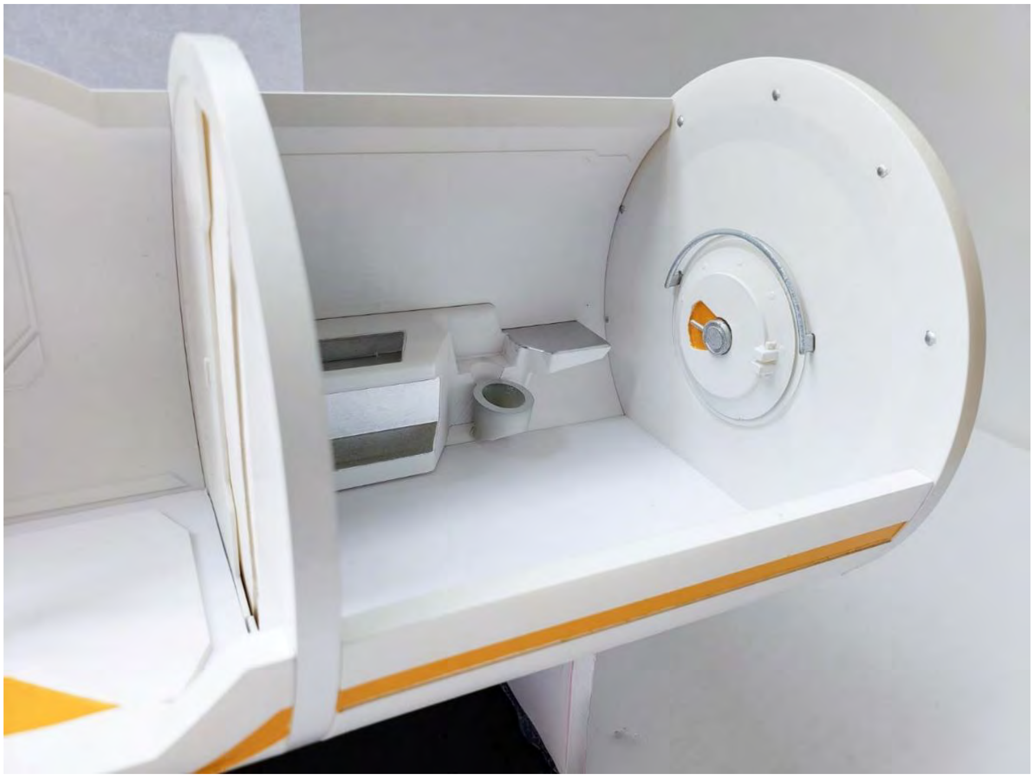


Figure 59 – Ablution area

Figure 60 – 95th percentile man

5.5 Technical Drawings

Dimensions are represented in inches (scale – 1:24)

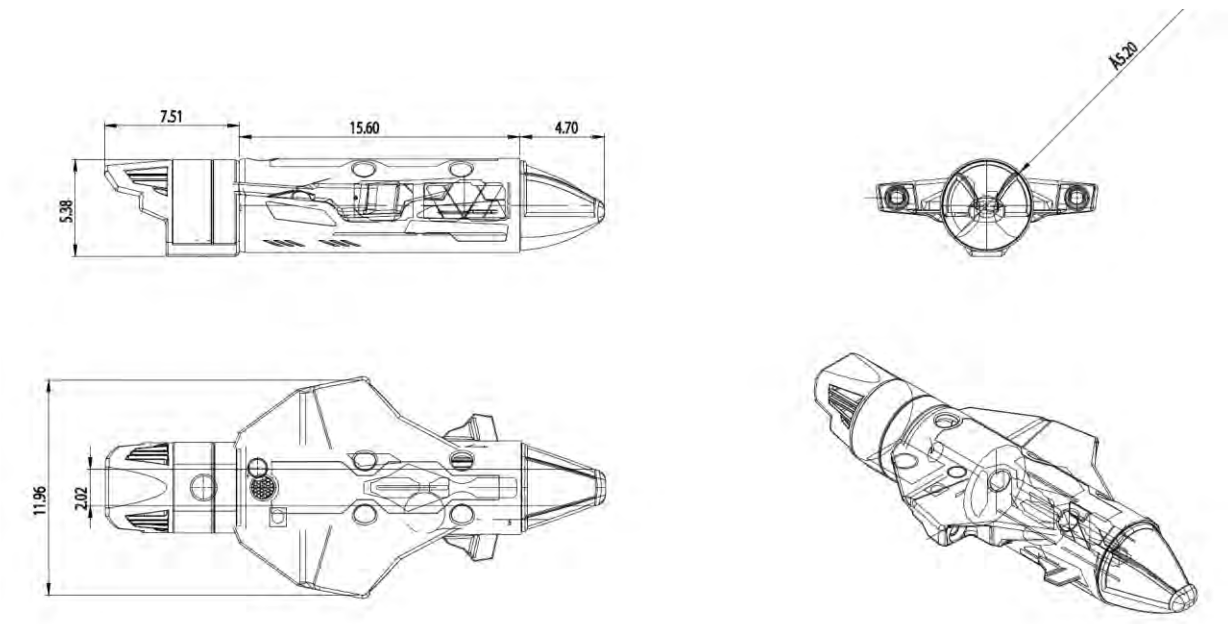


Figure 61 – Technical Drawings

5.6 Sustainability

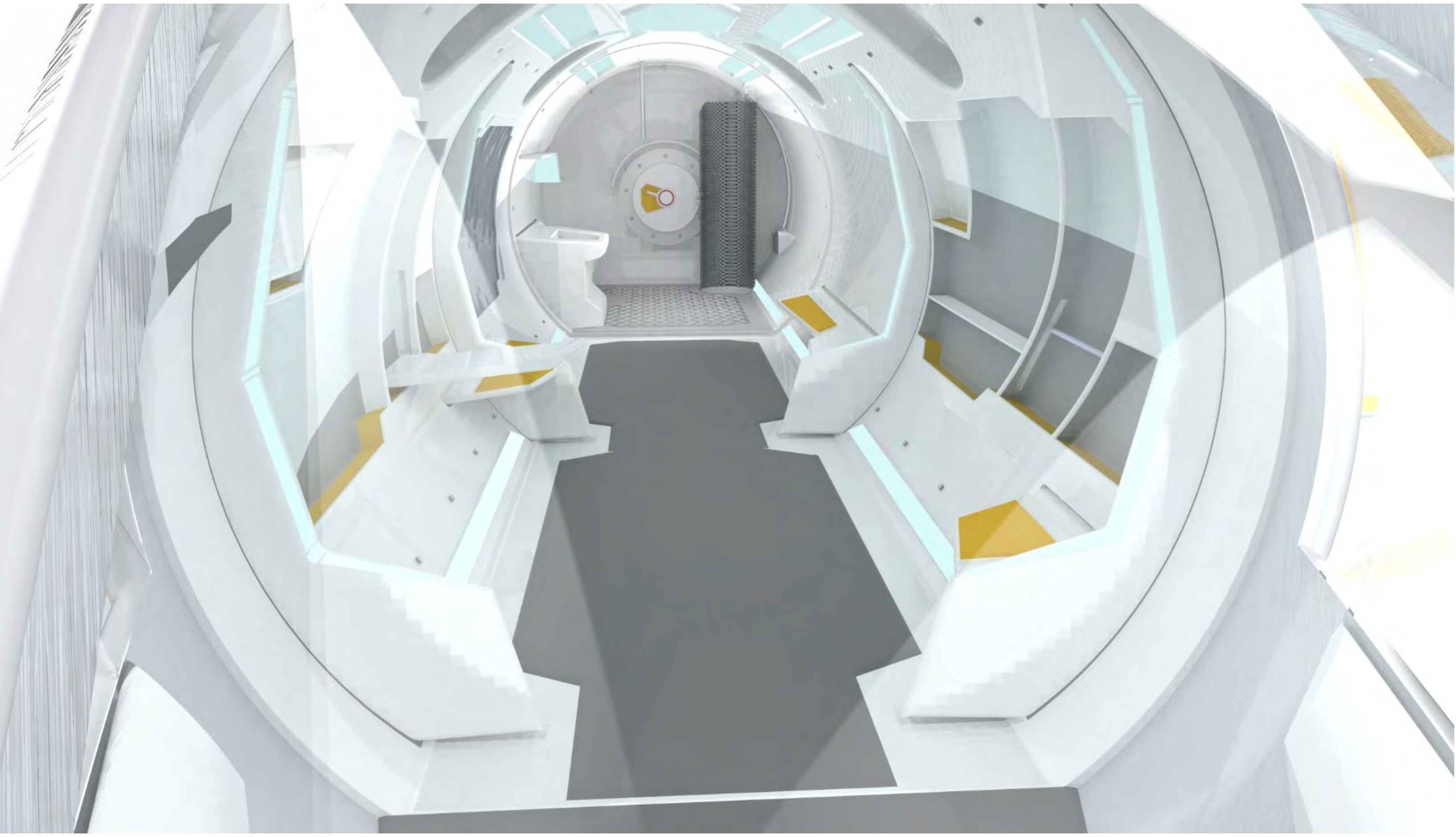
ZESU490 uses anti corrosive metals for its exterior and an easy to maintain fibre reinforced plastic interior. Both materials provide a durable and long-lasting structure for its harsh underwater environment. This prevents the need for continuous production of new parts ensuring a long-term investment.

Politically, safety must be prioritized, which can sometimes be lost in money making industries (such as oil). In order to promote the saturation diving profession, its reputation must uphold the fact that they will be able to provide the safest environment for divers, mitigating their fears that include death, injury, loss of oxygen or being disconnected from main vessel. Ensuring safety will make the industry desirable for those interested in the profession, sustaining employment for the future, and allowing the saturation diving industry to be more invested in.

Exploring materials in relation to the diver's health and long-term survival of the design. Using modular components with durable materials provides an efficient way of use, reducing the number of parts that may be manufactured. Reusability of systems that, instead of being thrown away, are upcycled or reused and can be updated or integrated into something else. They are built to last forever (Since the industry is extremely slow to change, and a lot of money is put into it.) The design incorporates components that will be beneficial to the diver's health as well as cause less harm for the environment regarding the way its produced.

It is difficult to encourage environmental safety within saturation, because a large portion of it is targeted towards the oil industry, something that causes environmental degradation, especially in our oceans. Since this thesis proposal is aimed for the "future", when there will be further technological advancements, the target area could possibly direct and emphasize other industries instead of oil, such as marine research. Using saturation diving as a beneficial addition to the study of our deep-sea environment and unexplored areas can further research development regarding the health of the earth's underwater environment and develop a better understanding of its health and status.

CONCLUSION



ZESU490 provides a comfortable environment to reduce the psychological stress on divers allowing a focused mentality for a safer work experience. It is an interior solution that uses modular components and an innovative layout to maximize space efficiency and includes features that improve productivity, privacy and overall ergonomics. ZESU490 Creates a comfortable work experience in order to ease the mind of the diver in preparation for their dive by improving physical comfort. ZESU490 provides a productive and safer work experience for the saturation diving industry.

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APPENDICES

APPENDIX I - DISCOVERY

Combined Statement of Need for Benefit #1 and #2

Statement of Need *(safety/comfort and exploration)*

A safety / exploration device for a diver that provides a comfortable and adventurous experience

Specific needs include:

- ease of use and control for the diver
- safety and comfort for the diver

Fundamental Human Needs

Linking the product benefits with fundamental human needs will utilize two models: Maslow's 'Hierarchy of Human Needs', and 'Fundamental Human Needs' (according to the school of "Human Scale Development" and Manfred Max-Neef).

The 'Fundamental Human Needs' is similar to Maslow's model, but with some important additional categories.

For example, in the 'leisure' category, one has 'games, parties'. Games are fun and often highly addictive.

Below is a table summarizing these categories.

Need	Being *(qualities)*	Having *(things)*	Doing *(actions)*	Interacting *(settings)*
subsistence	physical and mental health	food, shelter, work	feed, clothe, rest, work	living environment, social setting
protection	care, **adaptability**, **autonomy**	social security, health systems, **work**	co-operate, **plan, take care of,** help	social environment, dwelling
affection	respect, sense of humour, generosity, sensuality	friendships, family, relationships with nature	share, take care of, make love, express emotions	privacy, intimate spaces of togetherness

understanding	critical capacity, **curiosity,** intuition	literature, teachers, policies, educational	analyze, study, meditate, investigate,	schools, families, universities, communities,
participation	receptiveness, dedication, sense of humour	responsibilities, duties, work, rights	cooperate, dissent, express opinions	associations, parties, churches, neighborhoods
leisure	imagination, tranquility, **spontaneity**	**games, parties,** peace of mind	day-dream, remember, relax, have fun	landscapes, intimate spaces, places to be alone
creation	**imagination,** boldness, **inventiveness, curiosity**	abilities, skills, work, techniques	**invent, build, design, work, compose,** interpret	spaces for expression, workshops, audiences
identity	sense of belonging, self-esteem, consistency	language, religions, work, customs, values, norms	get to know oneself, grow, commit oneself	places one belongs to, everyday settings
freedom	autonomy, passion, self-esteem, open-mindedness	equal rights	dissent, choose, **run risks,** develop awareness	anywhere

Table: Benefits and Corresponding Fundamental Human Needs

Safety and Comfort of Saturation Diving

	Benefit	***Possible Corresponding Fundamental Human Needs (FHN)***	***Relationship between Benefits and FHN***
1	Comfort	Control, security, self-esteem (mastery)	strong
2	Style	Esteem, belonging, aesthetically pleasing	moderate
3	Efficiency	Accomplishment, autonomy, self-esteem	strong
4	Ease	Accomplishment, autonomy, protection, security, control, self-esteem (mastery)	strong
5	Fun	Leisure (excitement), Participation, Belonging (shared fun)	moderate

Comfort in this context is increasing the sensory experience for the infant of being protected, connected with the caregiver and the outside environment, with some freedom to move safely)

Comfort also includes the harshness of the ride (ride harshness would contribute to a feeling of a *loss of control*, increasing possibility of injury (risk), both of which decrease one's sense of protection)

Security is the major fundamental human need met.

Style is an important expression of individuality. What is considered by the group as stylish increases **self-esteem**.

Efficiency is defined as the effort required to perform at a particular level. This is related to **control** the user has during the activity (**autonomy**)

Ease is in many ways related to efficiency in terms for fundamental human needs (i.e. **control, autonomy**).

Fun related to **leisure** ('travel' to new interesting environments) and **belonging** (**shared fun, participation** between infant and caregiver).

Statement of Need

Saturation Diving is a purposeful activity based on ease of functioning, comfort and safety of the individual. (**control**), and comfort afforded the diver (**comfort and security**).

Diving must be preformed with **efficiency**. The profession must be performed at a high level of efficiency. This is related to **control** the user has during the activity.

Comfort relates to the performance of the dive, in order to complete their job efficiently they have to feel in control, safe, and at ease. (**Effectiveness, ease and comfort**.)

Report 4: Making Connections

This report analyzes feedback and data collection through various online sources. Through survey platforms and blog communities, a series of 10 open ended questions were provided to be answered by SAT divers from various locations. Some Identities remain anonymous. The data collected from each interviewee will then be analyzed, reflected upon and summarized. 4 individuals responded to the online survey but only 3 out of 4 stated that they were qualified saturation divers. Online discussions were dissected and analyzed gathering the most important information relative to the thesis subject.

Questions

All questions are consistent for each interviewee

Q1. Are you a qualified SAT diver?

Q2. What is your role at (name of diving institute)?

Q3. What motivated/interested you to get into diving (how did you start in this industry)?

Q4. Can you tell me a little bit about yourself (education, age, background)?

Q5. How do you feel about the commercial diving industry? (thoughts, opinions, about team/environment)

Q6. Do you have a goal within this industry? (improve the industry? Inspiration to others?)

Q7. How do you prepare your students/yourself for a dive?

Q8. What are safety precautions you have to consider? (when/where, during submersion/resurfacing, on the job, in habitat, during compression/decompression, physical and mental aspects)

Q9. Can you describe a "regular" day within the saturation habitat? (steps and methods, interaction with team and the environment)

Q10. Regarding your work, can you provide any other feedback or information that may be valuable to know?

Interview 1

Questions were posted on *Reddit.com*, a content rating and discussion website. A profile was made under "Olive5598" and a brief statement explaining an overview of the thesis topic was posted and asked users to fill out an online survey through *surveymonkey.com*, with as much or as little detail as the user may please.

1.1 Background

The first respondent was Matt Aidney (username: moonflowerv), a 32-year-old male. The survey was completed on October 02, 2019 for a duration of 19 minutes 40 seconds. Matt is a qualified saturation diver and works for ADAS (Australian Diver Accreditation Scheme). He has been diving for 14 years.

1.2 Questions

(listed above page 3-4)

1.3 Answers

A1: Yes

A2: ADAS (Australian standards)

A3: Lifestyle - adventure, adrenaline, ability to make decent wages and allow for long periods of time off. Have always loved the ocean and for me it was a toss up between. Career in ROV or Sat diving

A4: 32, have been offshore / diving since 18. I left school at the age of 16 so no formal education, plenty of qualifications related to the industry such as ndt inspection, rigging, medic ect.

A5: Very volatile industry, the highs are great (plenty of work which pressures the companies to provide decent wages and conditions) during the downturns there can be massive periods of unemployment and rates below minimum wages

A6: Most of my career has been through out Asia and the middle East, having recently moved into the Australian market I realise how much the unions do for that sector. Conditions are great, wages are incredible, safety is number 1. I would love to see a world wide adaption of similar standards enforced by IMCA

A7: Read a dive plan if possible, some jobs don't even provide that, it's more cowboy style where you adapt as you work

A8: Working internationally my main concern is the fluidity of dive table. Companies will bend the rules and use tables to suit them instead of using the safest table. I have personally treated dozens of table 6 treatments in my career including a 9-hour cage treatment where the diver was on the brink of death

A9: 1 hour notice is given, we are fed a breakfast and have a little bit of time to use the toilet, drink a coffee and hydrate. Bellman will go to the bell to do bell checks; divers will dress in and transfer to the bell. Bell will lock off and deploy to depth, during this time we are checking or gear and dressing in, when bell is at depth bell man will assist divers to lock out. Under imca our lock out time is 6 hours, that often runs over to 7 hours. When task is complete, we return to bell, bel man will bring us back and assist us disconnecting equipment. We take a seal on the bell and return to system. Back in the sat system we will shower and await meal time to eat. Once we have eaten usually, we all head to bed to watch a movie / read a book and sleep. Typically getting 12-15 hours off before we are required to dive again but this is subject to demand and work scope.

A10: I'm typing this on my phone so my answers are brief but feel free to message me on Reddit (moonflowerv) or email mattaidney@yahoo.com.au and I can offer you detailed answers to any further questions on my laptop

1.4 Reflection

Matt Aidney was contacted through the email he provided (mattaidney@yahoo.com.au) for more in depth information on October 4th but has yet to respond. I recently followed up with the user to verify if he may still be interested in continuing the discussion with more detail.

1.5 Key Points

- Various qualifications are involved in becoming a sat diver such as medical and Nondestructive testing (NDT certification)

- The industry fluctuates; work may be abundant with great working conditions and high wages or there may be phases of downturns, leading to minimum wages and unemployment
- Unionized industries provide much better working conditions, safety regulations, such as Australia. This can be compared to Asia and the Middle East where conditions are poor.
- Inaccuracy of Dive table: “Companies will bend the rules and use tables to suit them instead of using the safest table”

  Dive Table: “A dive table is a chart that is usually printed on cards or come in booklets that will help divers to determine different aspects of particular dives relating to breathing gas and when to take decompression stops during the dive.” (Reading Dive Tables, 2006)
- Divers are at the underwater jobsite for at least 6 hours, there are three men signed to each mission/job.

Interview 2

Questions were posted on *Reddit.com*, a content rating and discussion website. A profile was made under “Olive5598” and a brief statement explaining an overview of the thesis topic was posted and asked users to fill out an online survey through *surveymonkey.com*, with as much or as little detail as the user may please.

2.1 Background

The second respondent is Adam Frampton, a 30-year-old male. The survey was completed on October 3rd, 2019 for a duration of 28 minutes. Adam is a qualified Saturation diver at “Kreuz Subsea” located in Singapore. He has been diving for 12 years.

2.2 Questions

(listed above page 3-4)

2.3 Answers

A1: Yes

A2: Kreuz subsea

A3: My uncle, welding, time spent offshore / versus onshore as I am a professional skydiver and base jumper so home time is important to me.

A4: I'm Adam Frampton, 30 years old, been in the oil and gas / commercial diving industry for coming up 13 years. Started as a welder at age 15 which turned into Rigger / welder on offshore support vessels, and at age 18 started diving.

A5: The industry has its ups and downs, depending on where in the world you primarily world living / vessel conditions play a huge factor. If you are in the North Sea you have brand new vessels with state-of-the-art diving systems and good food. If you are working in Asia / west Africa or India usually it's a [redacted] vessel with a [redacted] diving system and [redacted] food which can be a mental challenge onto of being the most dangerous job in the world but big boys and big money go hand in hand.

A6: Improving the industry would be fantastic but as long as the oil price is lower than what oil companies call profitable then the industry will stay the same. In Norway and the uk the philosophy is you are away from your family so you need to be as comfortable as possible with simple things like decent internet to sent whatsapp messages and do your banking and talk to your family. When you're in other countries companies even the huge ones don't give a [redacted]. Your earning money... be happy that your working... My goal is to be a offshore superintendent with in the next 5- 7 years after diving supervisor.

A7: Very simply put if you wouldn't stick your [redacted] in it dont stick your fingers in it. Before every dive I always say to my 2 other bell partners (3man teams) 10 fingers 10 toes. Listen to good music as long as your bell partners are not [redacted] and everyone gets along generally it's always fun and let's go stretch out legs.

A8: You always need to make sure your team mates are capable. And I dont mean that when it comes to actually doing the job at hand like construction etc. I mean I need to know if I am in the water and myself and my bell partner become incapacitated that my bellman is going to lock out and rescue myself and my diver 2 should [redacted] hit the fan. I have been in SAT with some real [redacted] and untimely it makes an already stressful situation more stressful. Don't be shy to speak out because your life literally depends on it.

A9: We will be sleeping and the life support team (guys that make sure we are breathing the right gas, feeding us, flushing our [redacted] away) will come on the communication system and give us our 1 hours notice to dive. (I prefer 90 minutes personally) A pot of hot and our breakfast will be in the medlock waiting for us. Make coffee and hopefully squeeze in a toilet break) The bellman will go through to the bell and do bell checks to make sure everything in the bell and hats are operating correctly. Once complete the 2 divers will go up to the bell. Close the door and over pressurize the bell by 1 meter and they will take away the trunking that you climbed through into the bell. The bell will then get lowered into the water and once at depth you can release the extra 1m of gas to equalize the bell and can proceed to open the door hydraulically. The lowering to depth usually takes around 15- 20mins. Diver 1 will them get dressed and lock out and grab the diver 3 umbilical from the outside of the bell, he will pass it up into the bell and the bellman will connect it up to a hat and do a comms and gas check and then d1 can leave the bell and drop down to the seabed for his 6 hours in the water. Diver 2 will leave 1 hour after diver 1 and do his 6 hours. After a total of usually 7.5 hours the bell will come back to surface and the next team will do the same routine. Usually 3 teams of 3 cover 3x8hour shift =24 hours. Shower, then eat, watch a movie or depending on how physical your dive was sleep.... And repeat for 18-28 days depending on depth. Decompression take 1m per hour on average

A10: Saturation diving is not to be taken lightly however fun should always be taken. Look after your bell partners and don't be a [redacted]. I hope all this helps you out. If you would like some photos of chambers bell etc please email me. Frampton.adam@gmail.com and I will be happy to help.

2.4 Reflection

The user was contacted the next day through email but has not responded. I have yet to follow up with the user and next time I would follow up with the individual sooner. Reddit has been a platform that initiated strong responses but only on the first day since posted. I have been emailing people from various companies but there have big gaps in replies (3-7 days). I can initiate cold calls to try another method of connecting with people.

2.5 Key Points

- The vessel conditions differ depending on the part of the world you are assigned a job. North Sea has high quality diving systems and good food vs Asia/Africa.

- Working with individuals who one may not get along with can make a stressful situation in an isolated environment.
- Make sure partners are responsible and capable, they are the ones you must rely on in cases of emergencies.
- Lowering to depth from in the diving bell usually takes around 15- 20mins
- Job will last for 7.5 hours and the next team will continue with the same routines, in teams of three. The job can last for 18-28 days.

Interview 3

Questions were posted on *Scubaboard.com*, an online community of divers. A profile was made under "Olivia5598" and a brief statement was posted explaining an overview of the thesis topic and asked users to fill out an online survey through *surveymonkey.com*, with as much or as little detail as they please.

2.1 Background

The third respondent remains anonymous. The survey was completed on October 4th, 2019 for a duration of 15 minutes. Respondent 3 is a qualified saturation diver, 47 years of age and has been a SAT diver for 13 years.

2.2 Questions

(listed above)

2.3 Answers

A1: Yes
A2: Saturation Diver
A3: It was different from anything else I could do
A4: High School education, 47, Commercial Diver since I was 21, Sat Diver since 2006, previous work experience was aquaculture worker, construction labourer, barman
A5: On the face of it, caring, sharing, high ideals. In reality- just like all Offshore industry, profit orientated, twofaced, venal, only safe because it has been legislated to be safe
A6: Survive until I can retire with some cash to enjoy the last few years of life. Maybe consider going into supervising if I can't keep diving long enough
A7: ...I get up, have some coffee, get a dive brief and go diving. That's it.
A8: In Sat, everything is trying to kill you- you have to flush the toilet correctly, or you and others could experience explosive decompression...even making sure doors are closed quickly after using them...you have to be risk aware at all times- honestly, there are way too many precautions to list here
A9: A three-man team gets woken up at the beginning of a 12 hour shift (4 teams in sat, so shifts are 6am-6pm, 12am-12pm and opposite...after breakfast, ablutions etc. a supervisor will brief you on today's task. One of the team will be bellman, and will enter the bell for 'bell checks'. At around 3 hours into the shift, team gets in bell, and is launched to depth, taking over from

the previous team. Divers will lock out for a maximum of 6 hours, before being relieved by the next team. Bell comes back, divers all shower, eat, etc. Maybe watch a movie, read a book, call home then go to sleep. And start again repeating for a maximum of 28 Days

A10: It is not inherently dangerous, it has inherent risk, so to be a good diver, you have to be a good risk manager and be prepared to disagree with doing anything you consider unsafe. If everyone on a DSV does this, everything will be fine.... but it is a commercial concern, with profits central so that is where the bad things happen...

2.4 Reflection

In order to reach more users, I would include questions that are less open ended, or easier to answer such as multiple choice. This may encourage users to continue with the survey instead of possibly being intimidated buy complex or long answered questions,

2.5 Key Points

- Saturation industry is profit oriented, putting safety second
- Be alert at all times. Everything is a risk and safety issue in this environment. This can be from flushing the toilet incorrectly to closing doors in time.
- 12 hours shifts with four-man teams.

APPENDIX II – USER RESEARCH

This report presents qualitative and quantitative research data regarding the profession of saturation diving. This report will review a targeted demographic by collecting information on age, gender, location, education background, family status, occupation, ethnic background etc. as well as analyzing user behaviour by collecting data regarding the motivations, income level, user activity, education and cognitive aspects of divers. This will be based on image and literature searches. The result is a research informed persona that will be used to clarify user profile going forward in the thesis project.
Keywords: Saturation Diving, Saturation Divers, Offshore Divers, Commercial Diving

Demographics

Primary Users
Primary users include the individual divers. Responsible for getting a job done and are involved in underwater construction or marine research. Primary users are grouped and work with secondary users as part of the same team. These individuals remain in the saturation chambers.

Secondary users
Secondary users include supervisors. These individuals stay in chambers are responsible for the safety of those in the dive bell and on job site. They are also responsible for the organization of mission. These individuals are trained in saturation diving as well and participate in the mission.

Tertiary Users

Tertiary users include the instructors responsible for properly training the divers, as well as crew members that are aboard the ship used for the saturation dive.

Image search

Images collected below are based on primary appearances using keywords through google search bar.

Figure 62

Age:40-50
Ethnicity: Caucasian
Two men preparing in the diving bell for Dive

Gopro.com (link broken)

Figure 63

Ross Jackson and bell partner Danny Lowe. Ross, 32, location of travel Nageria, Trinidad and new Zealand
Ethnicity: Caucasian
banks of Loch Linnhe, the Underwater Centre in Fort William
Wages of £1400 a day , 28 days in saturation chamber, work partners
https://www.dailyrecord.co.uk/news/scottish-news/meet-the-saturation-divers-who-spend-1118521

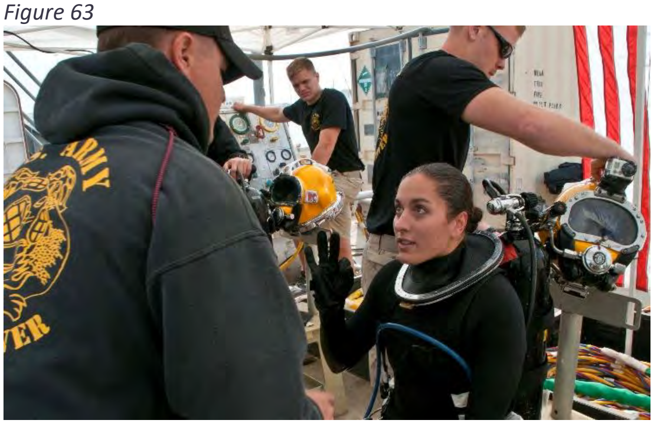


Figure 64

Christie Plackis, the fourth female diver in the history of the Army, who serves as the executive officer for the 74th Engineer Dive Detachment, deployed from Joint Base Langley-Eustis, Va location SHUAIBA PORT, KUWAIT
Age 28-30 American, Caucasian
https://commons.wikimedia.org/wiki/File:Female_diver_leaves_her_mark_in_history_130221-A-KU062-325.jpg

Figure 65

Four male divers
Age: 28-35
Urgent job for Inpex Australia's Ichthys LNG project.
https://www.perthnow.com.au/business/oil-gas/deep-sea-divers-injured-off-wa-coast-in-high-pressure-incident-ng-b88698620z

Figure 66

diving location The Campos Basin, offshore Rio de Janeiro state help maintain pipelines, subsea structures and offshore rigs, divers are required to operate at depths down to 300 metres. Most divers in Brazil are between 30 and 60 years old and have been trained at the navy school in Rio de Janeiro
https://www.fugro.com/media-centre/fugro-world/article/deep-diving-in-brazil-s-campos-basin

Figure 67

Saturation Divers on board INS Nireekshak inside the DCC on completion of their successful dive .. Arabian Sea about 35 nautical miles off Kochi. The Divers from INS Nireekshak – Lieutenant Malkeet Singh, Mukesh Kumar Leading Seaman, BS Bora Leading Seaman, Rithesh Kumar Leading Seaman, M Kumar Leading Seaman and Satender Sharma
Ethnicity east Asian,
https://www.indiannavy.nic.in/content/navy-divers-extend-diving-frontiers

Figure 68

6 divers
Male
Ethnicity: Asian
Group dive, team
https://www.alamy.com/stock-photo/saturation-diving.html

Image data collection can conclude that divers can come from a broad range of backgrounds such as Caucasian, Asian, South American. Majority are Caucasian, male in their 30s-50. Images also conclude that divers almost always are traveling with one or more users, usually other divers.

Literature search

	Age [years]	Total diving [years]	Saturation diving [years]	BMI [kg/m^2]
Mean (range)	46.1 (31 to 61)	21.8 (6 to 42)	15.9 (2 to 39)	26.5 (21.0 to 32.3)

Table 1. The study group consisted of male certified commercial saturation divers (Imbert, 2019)

Region	Country	n
North America		72
	United States	59
	Mexico	8
	Canada	5
Oceania		23
	Australia	14
	New Zealand	6
	Fiji	2
	Micronesia	1
Caribbean		19
	Cayman Islands	4
	Bahamas	4
	Turks and Caicos	4
	Netherland Antilles	3
	Virgin Islands	1
	Antigua and Barbuda	1
	Dominican Republic	1
	Jamaica	1
South America		4
	Colombia	2
	Brazil	1
	Argentina	1
Northern Africa		1
	Egypt	1
Southern Africa		1
	South Africa	1
Middle East		1
	Israel	1

Region	Country	n
Europe		27
	United Kingdom	5
	Italy	3
	France	3
	Malta	3
	Switzerland	3
	Ireland	2
	Scotland	2
	Spain	1
	Bulgaria	1
	Iceland	1
	Norway	1
	Poland	1
	Sweden	1
Asia		18
	Indonesia	5
	Philippines	3
	Thailand	3
	Sri Lanka	2
	China	1
	Singapore	1
	Vietnam	1
	Taiwan	1
	Maldives	1
Central America		1
	Belize	1
Unknown		2
TOTAL		**169**

Table 1.2-1. Distribution by region and country of diving fatalities reported to DAN in 2016 (n=169)

Table 2. Distribution by region of diving fatalities (Buzzacot, 2016)

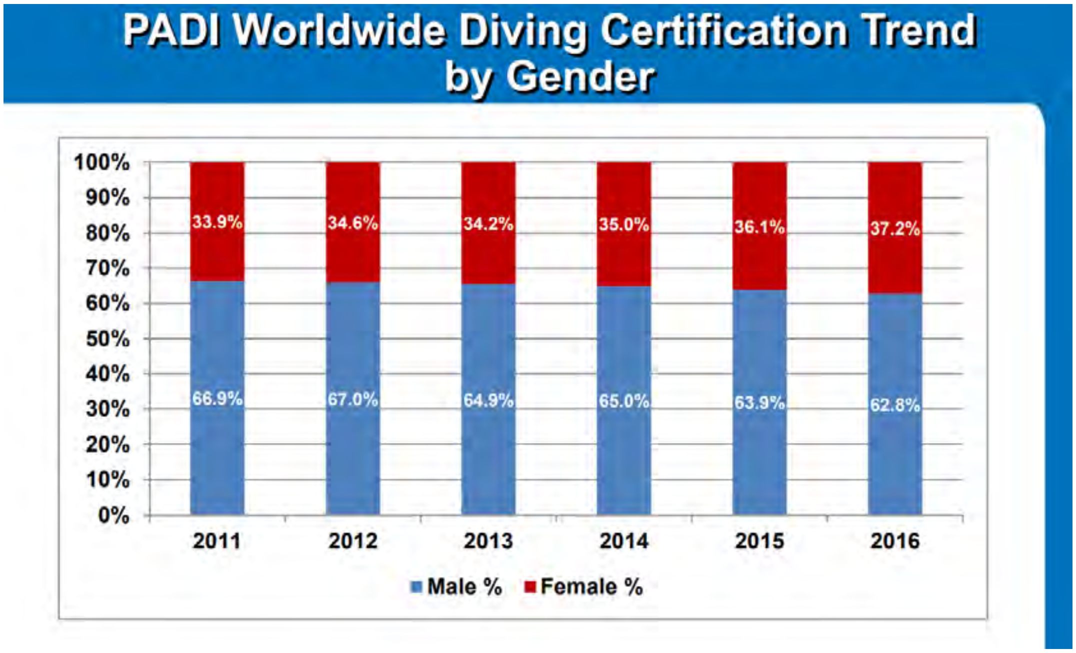


Table 3. shows Worldwide Diving certification trend by gender 2011-2016 (PADI, 2016)

Research collected through images and literature conclude that the age range is 31-61 (Table 1). A Wide range of ethnicities take part in this proffesion but most common are white males. Table 3 indicates that over half of certified divers are male.Table 2 shows that majority of diving fatalities take place in North America, indicating that the North American diving community may be the most populated.

User Behaviour

This section will review and understand the motivations, income level, user activity, education and cognitive aspects of commercial divers.

Employment (1)	Employment RSE (3)	Mean hourly wage	Mean annual wage (2)	Wage RSE (3)
3,380	9.5 %	$28.59	$59,470	3.5 %

Table 4. Shows Total employed divers and their wages. (BLS, 2018)

Saturation diving alters depending on the project operation and location. Typically, divers will remain in the saturation habitat for a week to a months' time commonly each operation will consist of 4-12 SAT divers. For safety purposes there must always be multiple people to supervise and every diver has a partner throughout the duration of their mission(Banbury, 2018). Therefore, it is always a group activity. Once a job is completed divers return to their life on land, and have a month off to recuperate until their next assignment. Divers who make their way up to become a commercial diver can make up to $60,000 US according to table 4. The wage increases with their experience level. Tuition for diving school cost approx. $20,000 a year (cDiver, 2016). The diver is almost always guaranteed a job in the industry after graduation. Saturation diving is profession that requires years of specialized training and takes an individual with endurance, mental strength and passion to be able to withstand the challenges that come along with saturation diving(Campbell, 2019) . Diver prerequisites include “grade 12 or equivalent, SPR and First Aid, Scuba Certification (open Water)” (C.W.D.I, 2005). To get into commercial diving the individual must have completed secondary school or equivalent.

Locus of control & self-efficiency

Since Saturation diving involves many challenges and lots of training involved to be certified, it takes an immense amount of motivation and passion for the industry. If an individual goes into a SAT dive with a negative mindset, it will affect the efficiency and safety of their work due to increased anxieties, risk of panic attack, and loss of focus to complete their task at hand. [REFERENCE]

Blogs

Figure 69

Kelly Korol - DiveSafe International’s founder.

“Kelly began his diving adventures in 1977 in Edmonton, Alberta. From there Kelly moved to Vernon in the beautiful Okanagan Valley where he continued diving and started his commercial diving career. As he started working on larger and larger dive projects in the 1980s, he soon realized he needed more training so in 1984, he went to the College of Oceaneering in Los Angeles CA, where he graduated with his Air/Mixed gas Bell Saturation diploma and an Associate of Applied Science degree.”

https://www.divesafe.com/instructors

Figure 70

Dive Supervisor: Commercial SCUBA Diver & Surface Supply Courses

“Maxwel grew up in Pender Harbour, BC. He became a PADI Open Water Scuba Instructor when he was 18 in Utila, Honduras. For 8 years he travelled abroad working from country to country as a diving instructor at resorts, dive centres and on private yachts. He has experience working as a deckhand on commercial fishing vessels in Alaska and around the coast of BC.”

https://www.divesafe.com/instructors

Note: Real diver background based on instructor description from *divesafe.com.* only two examples shown out of 6 user profiles found on the website.

These individuals have a clear passion for the diving related industry, this ranges from travel/exploration of seas, aquaculture, harvesting, a desire for adventure and challenge. Most of these individuals are in a relationship.

User Profile

Demographics + User Behaviour

Demographics

Overall, commercial divers are predominately male between to ages of 30-60. Divers are only required to have completed secondary education to be qualified to study and practice commercial diving. Due to the fact that divers seem to get into this career at a later age indicates that the individual may have proceeded into post-secondary education, had an alternate occupation or spent time to travel before deciding to get involved with diving.

User Behavior

SAT Divers spend up to 28 days in their saturation chambers and up to 8 hours on the seabed to do their job. Many people are part of the saturation team for safety purposes. Every diver is required to have a partner and supervisors in case of emergencies. This means that saturation diving is a group activity where they live, eat, sleep and carry out other basic activities in the same vicinity. Due to the small living space and limited privacy, the divers are forced to spend time together and is important that they get along for the time they are in the chambers to ensure efficiency in their work. Many divers explain this work to be extremely challenging but are passionate about spending time underwater. Individuals have to motivated, and physically/mentally strong to remain in this industry since spending so much time in isolated environments. Some activates out side of work (according to blogs) seem to involve travelling and spending time with family (DiveSafe, n.a)

Persona

Name: John Grey
Age: 31
Sex: M
Job: Saturation diver 10 years
Education: Commercial Diving Institute of Canada
Family: Recently Engaged
Location: Vancouver, BC
Social: has grown close with saturation team, when not diving likes to spend his spare time with his work crew
Activities: Traveling with friends or fiancee, biking in past time, maintains physical shape and good health
Income: 40k-150k annualy

Image of commercial diver from CDI.

https://www.commercialdivinginstitute.com/careers/industry-sectors/

Profile

John Grey is 31 years of age, Caucasian and grew up in Vancouver British Columbia. He spent a year off after high school backpacking around Europe with his friends. It was during his adventures in Italy where he learned that he had an interest in diving. His interest brought him to start his career path at CDI, the commercial diving institute of Canada. He was able to accomplish his first saturation dive about a year and a half after starting his training. John has been a saturation diver for 10 years. His last dive took place off the coast of New Zealand where he and his dive partner, Alex, had to repair construction of an oil rig that was below the waters surface. He spends his time in a pressurized environment for 14 days with 6 other SAT divers. On his free time, he enjoys spending time with his fiancée and friends. Often, they go biking through forest trails.

NOTE: A large portion of the data collected was only specific to proffesional divers. This includes a very broad range of proffesions that fall under the diving industry. There is a lack of information specifically on saturation

divers.

Discussion 1

The discussions below were formulated on *scubaboard.com*, an online community of divers. A brief overview of the thesis topic was posted referring for the users to fill out the linked survey. Important information was discussed on the posted threads instead. The conversations are documented and analyzed below.

User: Akimbo

- Male, 68-year-old certified SAT diver from Mendocino California USA.
- Principal in Saturation system inc. in the 1970's and systems designer/project in the 80s-90s.
- Trained by US navy.

Important notes taken directly from online discussion:

- The balance between chamber size, weight, cost of very expensive helium to pressurize them, helium reclaim capacity, emergency management due to pressure loss and atmosphere contamination all interact.
- Size of diving bells have a delicate balance because they must be able to float by dropping emergency weights while being able to withstand the internal and external hydrostatic pressures at the design depth and carry mandated emergency gas supplies.
- Handling the bells weight through air/sea interface in heavy seas
- Nuclear submarines are very spacious compared to SAT systems.
- Geometry of the living spaces must be in compliance with pressure vessel design constraints – flat sides are impossible beyond small viewports.
- Material selection must be tested so they don't outgas toxic chemicals in the closed environment at 30-50 atmospheres of pressure.
- Must have low combustibility due to pressurized oxygen concentrations.
- Hyperbaric lifeboats required in most jurisdictions
- Seafoam green was the best colour inside confined spaces for extended periods, white being the most stress inducing (according to NASA)
- Ability to disinfect surfaces in chambers, skin and ear infections are common due to divers spending time in wet suits and heat/humidity
- DVS (diving support vessels) can cost client 250,000 to 500,000 per day.

Discussion 2

User: Heliumthief

- Certified saturation diver from Scotland

Important notes taken directly from online discussion:

- Even if you focus on offshore saturation diving, the experiences, procedures and equipment used varies massively depending on what country or region.
- If you are looking for design factors which might enhance safety or comfort, then you should look into recent systems built by *Divex, Drass Galleazzi, Draeger* and others
- Look into older systems such as *Seaforth* and *Comex*
- Improvements: systems with a chamber per team, no top bunks, phones, wifi and mood lighting.
- Regimented shift system is a major improvement for morale, sleep patterns and efficiency (instead of ratcheting shifts) maximum of 28 days, and ensured breaks.
- Watch episode of “mighty ships” on the Skandi Arctic: a step change for the North Sea industry. The idea of primary gas coming from a rebreather, electrically heated suits means that bulky umbilical cord were cut down, removing need for a reclaim system and hot water hose, bells designed to carry four member teams
- Floor to lower and raise instead of ladder
- Instead of traditional “clump weight, stage and bell” it was a solid column with 3 high speed winches which speeds up recovery and deployment
- Watch tv series “real men under pressure” and “last breath”
- The problem is getting all the companies to spend the money on decent gear.
- Big issues for most SAT divers are enforcing safety management and being treated humanely

APPENDIX III – PRODUCT RESEARCH

Method

A variety of products were gathered through credible sources (the company websites and downloadable specification files). The aim is to understand what is involved within existing diving systems, examining the interior and exterior of each system aesthetically and functionally. Dissecting the research on the background or history of the systems of study will provide an organized platform to determine the benefits and features of each system. The chart below provides a summarized literature analysis based on 8 systems researched. These include rescue systems, chamber portables, diving bells, and submarines for recreational/professional use. *Appendix A* provides a detailed overview of the components and specifications of each system which is organized for manageable reading in *Table 1.* The feature categories for collected data include:

- Capacity: the number of persons that can be held within the system
- Dimensions: The Length and diameter of each system
- Technology: Advanced or innovative technology that is included in each system
- Safety aspects: consideration for health, safety, and emergency situations in each system
- Mission endurance: the power and lifecycle of the system, important for efficiency to consider for a diver on the job
- Depth: the underwater depth or "Metres Sea Water" the system can withstand

Conclusion

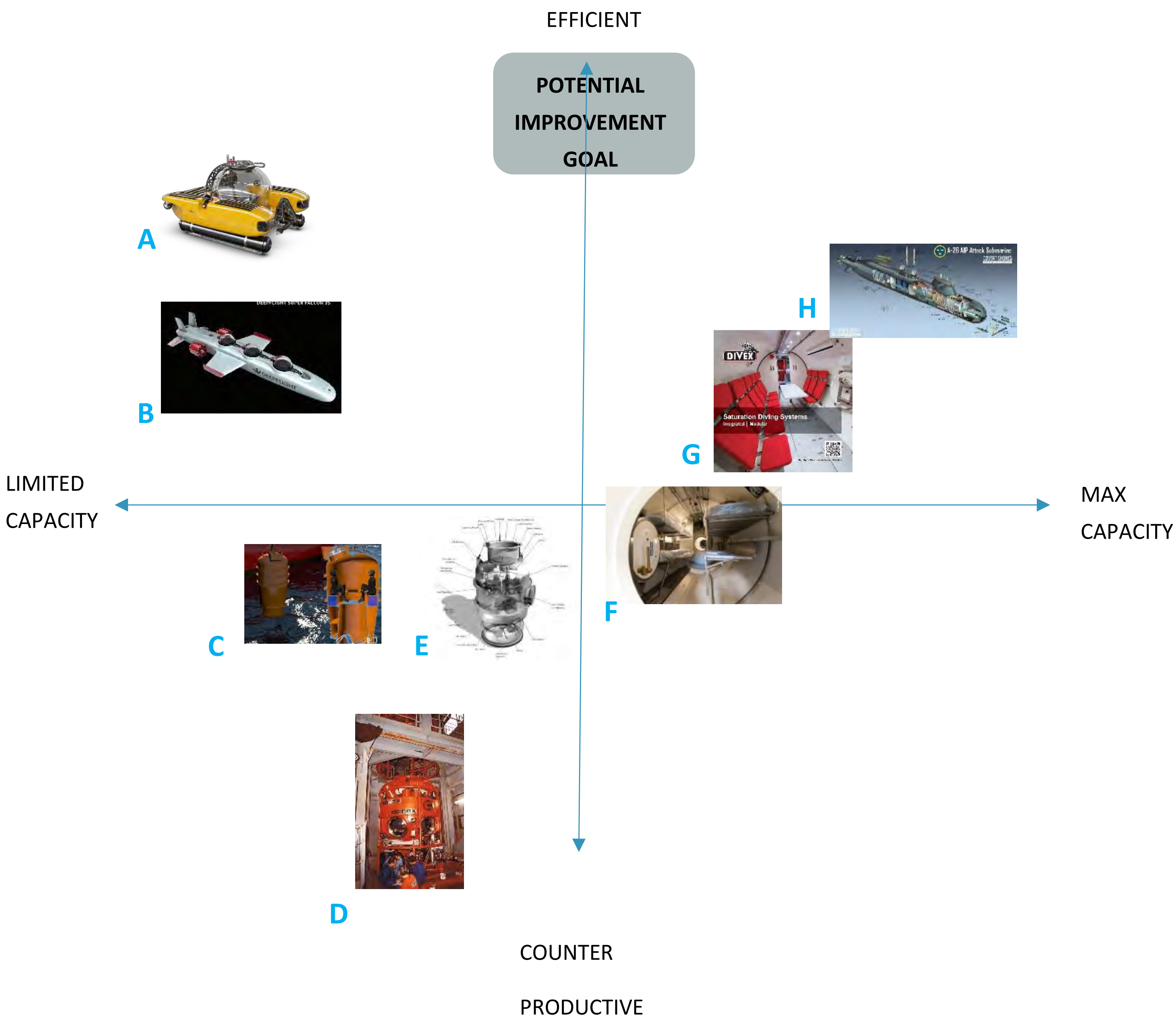
Table 1 can compare the similarities between each system. Certain specifications such as the depth the system is able to withstand will be noted for technical application within the thesis. The dimensions and capacity ratio are useful to understand a realistic proportion as to what a certain space can fit ergonomically. This information will have to be taken as an approximate measurement since some of these systems are currently not "space-efficient", giving divers little space and privacy to be comfortable. The table also provides safety equipment and technologies that are necessary for improved user experience.

Benchmarking 2

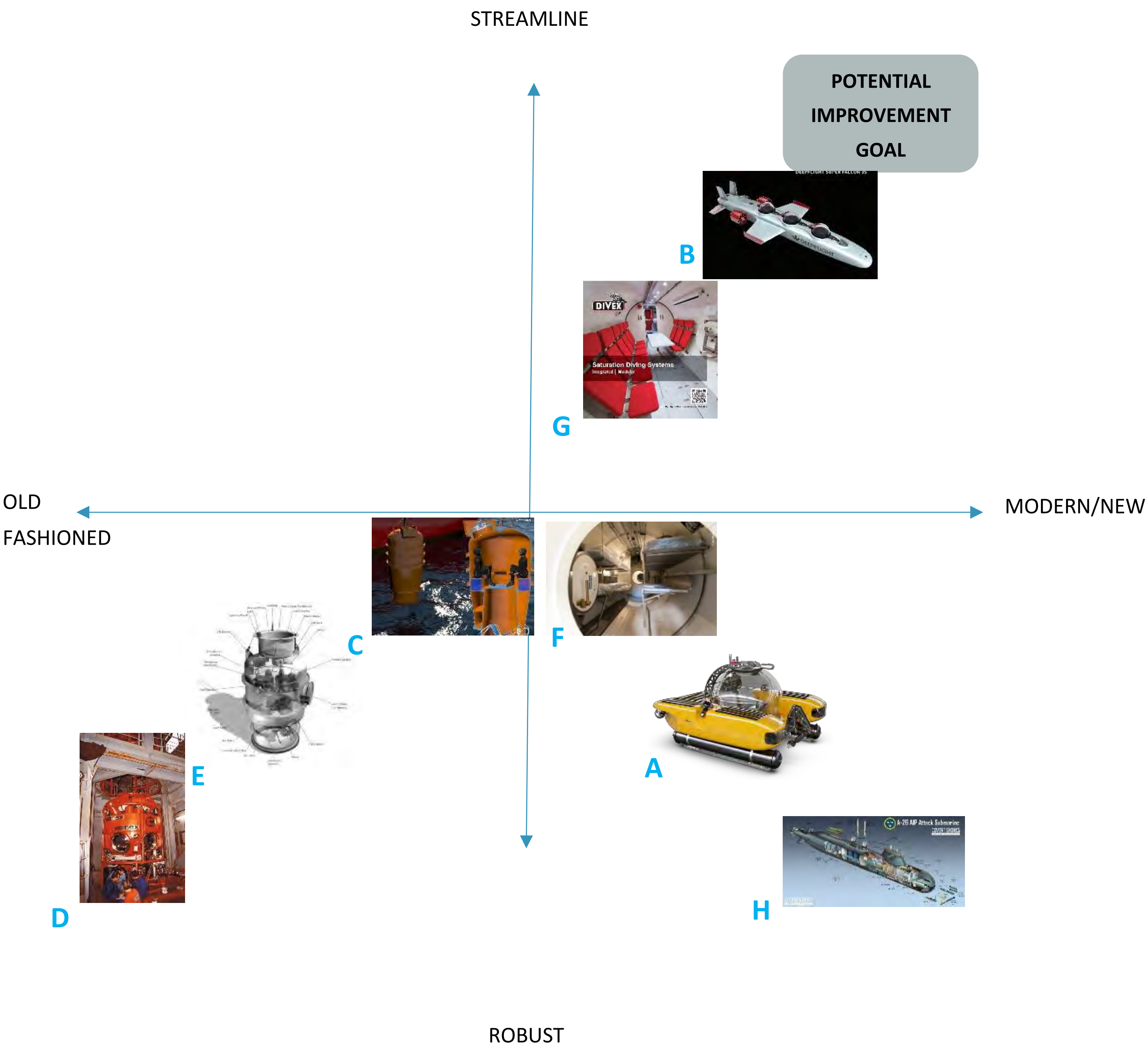
2.0 Method

In order to compare the 8 products listed in reference to "safety and comfort" was to place the data onto an x-y graph, measuring efficiency and capacity. The goal is to develop an "interior to exterior" solution/transportation device that will allow a more comfortable and safe experience. To further develop this thesis, it is important to understand the efficiency of each system. To provide a more productive working space, there will need to be a sufficient number of workers on the job and safety supervisors, all while having space, equipment and other features for a safe and comfortable environment. "Max and limited capacity" will measure the number of persons able to fit in the system from low to high. "Efficient/counterproductive" will measure various capacities for safety, ergonomics, and endurance of the system.

2.1 X-Y graph: Function



2.2 Aesthetic Graph



2.3 conclusion

The aim of the final improved solution to increase safety and comfort in saturation diving is to accomplish the target displayed in the graph above labeled as “Potential Improvement Goal”. This will guide the system design to provide maximum efficiency. This includes safety, space to work/rest/play, ergonomic aspects that will allow to diver to use minimal effort when interacting with the product or system. Having the capacity situated at a neutral position means that there should be only enough people to provide a space comfortable enough to share in comparison to its size. Approximately 6 people are needed in order for the divers to carry out alternating shifts, (three on-site then switch.) too many people for one job can be overwhelming posing potential safety hazards. Overall, the efficiency of the smaller recreational submersibles and their ability to maneuver, travel distance and depth, ease of control/use and aesthetics will be taken into consideration. The capacity of the saturation systems and the dimensions will be replicated for scale, then adjusted in order to comfortably fit the number of persons (to be determined). **Image B** is very close to what the final concept should represent aesthetically. The *Super Falcon Sub* does its job efficiently all while providing the user with an aesthetically pleasing vehicle, enhancing the user experience.\

Benchmarking 3

3.1 Method

Table refers to *Appendix B.* Using the navigation tool on word allows the interface to calculate the frequency of word appearances within the research.

BENEFITS	Frequency Benefits	FEATURES	Frequency Features
comfort	7	Technology	5
Efficiency	5	Modular/Transportable	9
Safety	10	Rescue	11
Spacious	1	Ergonomics	1
Privacy	1	Endurance	6

3.2 List of main benefits and features

Below are the key benefits and features listed in order of the highest frequency appearance.

Key Benefits

1. Safety
2. Comfort
3. Efficiently
4. Privacy
5. Spacious

Key Features

1. Rescue
2. Modular/transportable
3. Endurance
4. Technology
5. Ergonomics

3.3 Conclusion

This frequency table provides a platform to analyze the most basic and necessary needs that are involved throughout the 8 systems, some more significant than others. The number one occurring feature and benefit both relate to the safety of the individual. The least occurring, only listed once within the descriptions include privacy, space and ergonomics. Of course, the safety of the individual is the most essential aspect that should be considered within the development of this thesis. Rules and regulations will be studied in depth in order to fully understand the standard requirements of every diving system and these will be applied to the designs. This will be done while still providing innovative proposals. The word “comfort” is mentioned multiple times throughout the report but is often not backed by any evidence or features that comfort could be connected to. Privacy, space and ergonomics are an essential part of being comfortable but are listed as the lowest frequency. Limiting harsh movements, maximizing space and increasing privacy is essential for an individuals’ mental and physical wellbeing because it all falls back to feeling “safe and comfortable”. The goal of this thesis will also be to increase these benefits and features to achieve the “potential improvement goal”. Lastly, modularity of the system and its ability to be taken apart, transferred and adjusted to different locations is an essential part for manufacturing and client needs, this will be analyzed as well.

Discussion

To conclude, one must consider the function of each system. In this report, efficiency and capacity were analyzed in order to better understand the interior to exterior design and how the user may be situated in those environments. There must be a balance of space to person “ratio” in order to have an efficient system. The individuals must have enough space to be productive while at the same time maximizing the use of the space, not wasting any part of its function. The final thesis development must involve a system that can provide required safety rules and regulations, ergonomic considerations, maximum comfort, modularity and streamlined aesthetics. The goal is to improve an interior solution or transportation vehicle that will allow better productivity and comfort on the job, which will let them perform their job in a safe manner. This will enhance the user experience.

Needs Statement

	Benefit	*Possible Corresponding Fundamental Human Needs (FHN)*	*Relationship between Benefits and FHN*
1	Comfort	Control, security, self-esteem (mastery)	strong
2	Style	aesthetically pleasing, ease of mind, tranquility	moderate
3	Efficiency	Accomplishment, autonomy, self-esteem, productivity	strong
4	Ease	Accomplishment, autonomy, protection, security, control,	strong
5	Fun	Leisure (excitement), Participation, Belonging (shared fun)	moderate

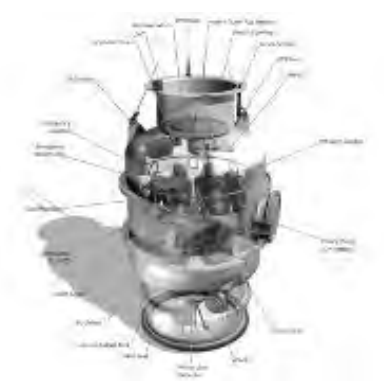
Saturation Diving is a purposeful activity based on the control, comfort and safety of the individual (**comfort and security**). Comfort relates to the performance of the dive, in order to complete their job efficiently they have to feel in control, safe, and at ease. (**Efficiency, ease and comfort**.

BENEFITS A **benefit** is the positive impact something has on the customer.

FEATURES A **feature** is a part of the product or system

APPENDIX A.

Image/name	**description**	**specifications**
DIVEX Integrated/modular saturation system 	-increased system efficiency for the operators and safety and comfort for the divers. -provide more comfortable, quieter and safer environment, this contributes greatly to diver efficiency. -decompression chambers are spacious and comfortable.	-private sleeping berths -day areas with entertainment -ablution facilities. -Enhanced Bell Launch & Recovery Systems employing triple electric winch technology - allowing safe deployment and recovery in heavy seas. -Automated control rooms utilising touch-screen technology. -Divex designs are flexible and can be configured to suit a range of vessel designs and layouts -integrated/modular option - air-conditioned and lined, with marine doors and windows fitted - dimmable led lights

https://unitedsterling.s3-ap-southeast-1.amazonaws.com/Manufacturers/Divex-AU/Divex-Sat-Systems.pdf		- The chambers are of horizontal format of 2.4m diameter to maximise the ergonomic arrangement. - 12, 18 and 24 man chambers - Kinergetics WHE-3 heaters, which provide hot water for the divers operating from the submersible diving chamber (SDC) -designed to deploy 3 divers, with diver one and two's umbilical's housed within the SDC. They are also designed to withstand both internal and external pressure to 300 MSW and has a design temperature of -18 deg to +66 deg. - bottom doors are all Ø800mm -The modules are designed so that they can be quickly assembled and achieve accurate alignment, in order to minimise expensive mobilisation time in port.
JFD's submarine rescue bell  https://www.jfdglobal.com/products/submarine-rescue/submarine-rescue-bell/	the rescue bell is designed to be rapidly deployed in the event of an emergency and is suitable for rescues from depths of 300m and transfer under pressure operations at up to 5 bar gauge.	Length – 2500mm Width- 2500mm height – 3500mm Operating depth – up to 300msw Max capacity -6 rescues, 1 operator Max capacity 450kg The bell and associated equipment (winch and umbilical) can be rapidly mobilised by land and air. Once on deck, the system can be rescue ready in a matter of hours.
DRASS The Submarine Rescue System (SRS)	. The SR11 capsule is composed of three independent sub-systems: the upper lock, the lower trunk and the ballast water tanks. It is fitted with all the necessary equipment for	-Designed for the rescue of up to 9 DISSUB (distressed submarine) personnel and crewed by 2 operators -The Upper Lock is designed to accommodate crew and operators.

 http://www.drass.tech/submarine-rescue-system-srs/	the control of the bell and communications with the support vessel.	-The lower trunk is a cylindrical tunnel representing the transfer lock between the upper lock and the DISSUB. -The hydraulic winch, which pulls the bell to the submarine mating platform, is installed outside the lower trunk -subsystems: the upper lock, the lower trunk and the ballast water tanks. -maximum allowable internal pressure is 5 bar / 6ATA. -maximum depth rating of the SRS is 300msw.
DEEPFLIGHT Super falcon  http://www.deepflight.com/super-falcon/ http://www.deepflight.com/wp-content/uploads/2018/05/df_sf3s_specsheet_feb_2018.pdf	personal submarine technology, allowing you to fly underwater. Cruise alongside dolphins, whales or mantas, bank over a glorious reef, or glide over ancient shipwrecks, all in style, safety, and comfort. Super Falcon is fast, clean and quiet	-streamlined design, 3-axis flight controls, -powerful drivetrain -fixed positive buoyancy – with auto return to the surface. -fly-by-wire technology, At 1800 kg and 5.9 m in length, -high-efficiency brushless DC drivetrain and underwater lithium-iron-phosphate battery pack,. -A 40V system voltage and low electric signature make the Super Falcon safe to operate around swimmers, as well as any large marine animals you might encounter. LENGTH 5.9 m (19.3 ft) WIDTH 2.7 m (8.8 ft) HEIGHT 1.6 m (5.2 ft) WEIGHT 1,800 kg (3,968 lbs) OPERATING DEPTH 100 m (330 ft) PAYLOAD 250 kg (551 lbs)

		Occupants: 1 pilot, 1 passenger Maximum Operating Depth: 100m (330ft) Dimensions LxWxH: 5.9m x 2.7m x 1.6m (19.3ft x 8.8ft x 5.2ft) Weight: 1800 kg (3,968 lbs) Maximum Cruising Speed: 5 knots Endurance / Autonomy: up to 8 hours Payload: 250 kg (551 lbs) Type: Hydrobatic
Triton submersibles Luxury subs  https://tritonsubs.com/wp-content/uploads/2019/10/Triton-Luxury-Submersibles-Iss8-lowrez-WEB-EN.pdf	Dives of 12 hours are easily achievable, affording plenty of time to carry out experiments, witness elusive creatures or to fully enjoy the wonders of a coral reef. Multiple thrusters and dynamic vectoring give the pilot complete control to maneuver the submersible. Piloting a Triton submersible, accurately and safely, for extended periods is simple, intuitive and engaging.	-It can transport two people to depths of 1,000 ft (305 meters), -10.5 ft in length -10 hour endurance Lead acid (lifepo4 battery) Dry weight 6800 lb/3100kg - Manual overrides on all critical systems - Direct air injection to ballast tanks - Jettison able battery pods, drop-weights, manipulators and tooling. -Three-axis joystick for maneuverability
COMEX Diving bell	Comex can design and manufacture complete diving systems from modular and transportable diving spread to build in DSV system	designed for 3 divers, rated 300 msw (internal and external), bottom-mated. all equipment produced by COMANEX: • Gas management panels • Bell heaters • DIV 38 Shuttle valves • Medical locks • O2 add manifolds and interlocks • Releasable sockets • COMEX BIBS • Ballast release systems • Electrical distribution systems • GL bushing release systems

 http://www.comanex.fr/details-diving+bells-37.html		• Emergency battery packs • Umbilical release systems • Flood lights • Emergency respiratory units • CO2 scrubbers • Hyperbaric fire extinguishers\
RANA DIVING Calypso system  https://www.ranadiving.it/assets/diving-system/Calypso-system https://www.ranadiving.it/upload/assets/Calypso.pdf	Calypso consists of three six man chambers and one three man chamber, with associated wet pot/TUP locks. Transportable saturation diving system	CHARACTERISTICS Working depth: 300 msw Class ABS Divers in saturation 15 Divers in bell 3 3 foldable seats Diameter 2156 mm 2400x2400x2900 Weight 10 tons with divers -INNOVATIVE DESIGN FEATURES Containerized modules with isocorner fittings enable to ship the system worldwide by container ship and to transfer it by road within trunk size. -Fast deployment: 3 days to be installed on board of vessels -Entry/Food/Material lock all included within a single manway.

SAAB Modern maritime security Kockums A26  https://saab.com/region/saab-australia/about-saab-australia/latest-news/stories/stories---australia/2015/super-stealthy-saab-submarines/ https://saab.com/globalassets/commercial/naval/submarines-and-warships/submarines/a26/saab_kockums-a26_brochure_a4_final_aw_screen.pdf	MODULARITY Our modular approach comprises flexible payloads for multimission capability, including sending special forces directly into the ocean and retrieving them via Saab's Multimission Portal™. A sectional hull also means the submarine can be modified and future-proofed through rapid updating and reconfiguration. The advanced Stirling AIP system used by the Kockums A26 enables prolonged submerged endurance and its silence is key to maintaining GHOST®. A comfortable environment for the crew increases its staying power and smart procedures are implemented to maximise submarine availability. Saab's commitment to safety, along with extremely effective rescue methods, helps maintain high crew morale and confidence in the submarine. submarine is good for work and leisure time, as well as for physical and mental wellbeing. It is based on Scandinavian design to give	LENGTH ~62 m DRAUGHT SURFACED ~6 m DISPLACEMENT, SURFACED ~1800 tonnes MAXIMUM DIVING DEPTH > 200 m STANDARD COMPLEMENT 26 persons NUMBER OF WEAPON TUBES 4 WEAPONS 53 cm torpedoes, 40 cm torpedoes, mines NUMBER OF HEAVY WEAPONS > 15 MULTIMISSION PORTAL™ Length > 6 m, diameter > 1.5 m UUV CAPACITY Launch and recovery through Multimission Portal™ TOTAL MISSION ENDURANCE > 45 days A key unique feature of the Kockums A26 submarine is the Multimission Portal™ designed to launch and retrieve diverse mission payloads, including those for special operations. The portal is arranged between the 53 cm weapon tubes and has a length of 6 m and diameter of 1.5 m in which up to 8 divers can sit ready for a mission in the sea. propulsion system

	more comfort to crew members	

APPENDIX B.

Collected from Appendix A.

FEATURES	BENEFITS
work	comfort
Rescue methods	Physical wellbeing
silent	Mental wellbeing
Endurance level	leisure
power	morale
reconfiguration	confidence
transportable	morale
modular	safety
Fast	innovative
maneuverability	intuitive
control	engaging
streamline	exploration
technology	style
Sub systems	personal
rescue	time
Auto control	clean
equipment	quiet

automated	efficient
recovery	private
ergonomic	
spacious	

APPENDIX IV – NEEDS ANALYSIS

1.1. NEEDS STATEMENTS

Saturation diving is profession that requires years of specialized training and takes an individual with endurance, mental strength and passion to be able to withstand the challenges that come along with saturation diving. Due to this reason, and the expense of diving programs, there are very few individuals who become offshore/saturation divers. Since the start of commercial diving, there has been technological advancements, but very little research regarding the individual health of the diver or ergonomic improvements within the saturation diving profession. The goal of this thesis is to accumulate through qualitative and quantitative research, existing methods of technology and products that are involved with deep sea diving, and develop revolutionary solutions to improve the comfort and safety of the SAT diver. This topic offers a broad range of study due to its complexity. There are many components and aspects to commercial diving that ranges from the interaction within the habitat between people and product, to the diving bell or the underwater job location. Overall there is the opportunity to enhance the quality of life for the individual diver; ergonomic improvements that can elevate comfort and safety (capable of exploring at least three major body part areas), enhancing the flow of a claustrophobic and isolated work environments, and material adjustments for sustainability considerations.

1.2. DESCRIPTION

User research consists of two important activities; interviews and observation. Interviewing is an important step within the research process but sometimes the information received can be biased or unreliable. In order to understand the user and their interaction with an environment thoroughly and genuinely, the researcher will carry out a user observation. Looking, listening and analyzing the observations will allow a more accurate user-oriented design development.

1.3. RESEARCH OBJECTIVES

The objective of this user observation is to analyze the challenges a saturation diver may face within their industry. In more specific terms, the researcher will observe the primary user(diver) in their situated environment through various videos. Any physical difficulties such as uncomfortable reach or fit. Environment aesthetics and structure such as colour and space, will also be observed and taken note of. In order to better understand the user's psychological challenges, facial expression and body language will be analyzed to rate their comfort levels in reference to the activities they carry out. Reaching these objectives will guide the question as to how we can improve safety and comfort in Saturation diving.

1.4. KEY ACTIVITIES

The key activities to be carried out will be to analyze various videos/documentaries from platforms such as YouTube, and break down sections of the media. Through the dissection of the videos, they will be rated on a scale of "pain to pleasure" on a scale of one to five. This can provide insight of how to improve negative experiences. This data will then be plotted on a user experience map showing the details of a specific moment where a user may have a negative/neutral/positive experience. The second key activity will be analyzing five images that was sent from a qualified saturation diver. Throughout these activities, visual demographics will be noted.

1.5. TARGET USERS

Primary Users:

The divers that are responsible for completing the job or missions. Individuals are most commonly involved in construction, repairs or maintenance, and sometimes marine research. There are three main primary users in SAT diving, the closed bell diver who acts as a stand by and is responsible for the divers on site, the other two are submerged underwater.

Secondary Users:

This includes supervisors that stay in the control room chamber ensuring that everything is stabilized in the pressurized environment. This individual is also a trained diver. They are responsible for the organization of each mission for a duration of 28 days. They keep in contact with the bell diver in case of emergencies. There are Life support technicians on site to provide immediate medical aid.

Tertiary Users:

These individuals can be considered the instructors or teachers who are responsible for properly training the SAT divers.

1.6. USER ENVIRONMENT

The environment in which the users will be observed include the saturation system, the diving bell and the underwater environment.

Preliminary Video Observation

2.1. PRELIMINARY SCOPING

URL: https://www.youtube.com/watch?v=kwjmWQ3xNto

Title: Saturation Diving

URL: https://www.youtube.com/watch?v=7DdJc_P_PPk&list=RDQMCINMAmJ5ASk&index=26

Title: Bell Diving Oslo

URL: https://www.youtube.com/watch?v=slq9lkHWs0I&t=1s

Title: Saturation Diving- You're in a different world

2.2. VIDEO OBSERVATION

Video #1

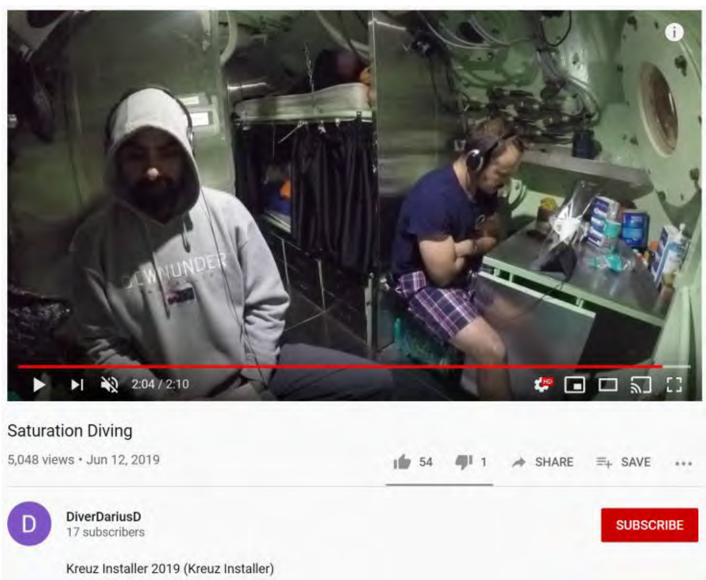


Figure 71

URL: https://www.youtube.com/watch?v=kwjmWQ3xNto

Title: Saturation Diving

Length: 2:10, June 12 2019, Bombay high Kreuz Installer 2019

Brief Description: Shows process of Dive and living within the Saturation System

Relevance to Thesis Topic: Shows real life environment where divers inhabit.

<u>Notes on video:</u>

0:12 crew members on ship deck, possibly setting up dive bell

0:24 chamber 5, pressure monitor, shows interior, seafoam green walls and ports to move through to chamber to chamber. Diver uses handle and goes in feet first through entrance way and reaches back to close door behind him

0:26 control room and small tv playing the Simpsons

0:42 four beds in chamber 2 on each side, bunked. Gear and equipment look like it is hanging to dry[?]. Stuff on bed and floor. Mattresses look about a foot thickness, thin metal path in-between the bunks.

0:43 two individuals, male, sitting in area with cups and bowls on table, small view ports, diver one is drinking from plastic water bottle, hat on and earphones, diver two is on phone

0:44 two divers are eating on metal extendable table, food is in aluminum containers, appears to be eating fruit

0:47 two divers begin to put on their equipment, body suits/tight suits in same vicinity

0:50 diver 1 retrieves package from small portal on wall

0:55 divers in another compartment, have to bend back b/c the cant stand completely straight, roof is not tall enough, smiling conversing

0:59 diving bell rises elsewhere[?]

1:02 diver 1 goes through body size tube to get to another chamber, crouching

1:07 divers are now in the diving bell, surrounded by equipment, chords, tubes, controls, umbilical, tanks and towels

1:15 diver 1 now is alone in bell, eats a sandwich, is waiting, reads book, eats and able, does some chin ups, sits in pool of water, bored

1:30 diver 1 now begins to pull up umbilical from a port on the floor

1:31 diver 2 resurfaces, while the other diver removes his helmet, puts it aside,

1:37 both divers are close proximity to each other, closes port on floor

1:47 diver 1 showers in another area, standing, shows small aluminum sink, and toilet in same area, diver adjust a valve

1:54 diver does push-ups on metal floor in restroom compartment, and chin ups and stretches

2:02 diver 1 on electronic device, sitting on metal at 90 degree, hunched over on small metal table

USER EXPERIENCE CHART

Video source: https://www.youtube.com/watch?v=kwjmWQ3xNto		
Task: Shows environment of a SAT system and preparing to dive.		
Step #	Description	Gradient Scale of Pain – Pleasure Points Negative = 1; Neutral = 3; Positive = 5 1 2 3 4 5

01	Diver maneuvering through chamber to chamber (through doors/ports)	X O O O O
02	Sleeping area (special analysis)	O X O O O
03	Putting on equipment	O O X O O
04	Divers during past time/eating	O O X O O
05	waiting to enter the diving bell	O X O O O
06	Preparing gear for diver 2 to enter water	O X O O O
07	Diver 1 remains in bell (supervising)	X O O O O
08	Diver 2 resurfaces (both divers are in bell removing equipment)	X O O O O
09	Diver 1 washes up	O O X O O
10	Diver 1 exercises (push-ups and sit-ups)	O O O X O
11	Diver 1 has leisure time goes on computer	X O O O O

Table 12

3. Direct User Observation

3.1. Chronology

Below displays' images sent from a qualified SAT diver connected through an online community. Images are slightly biased due to the fact that they were intentionally taken, it is not observing the user in their environment where they behave "naturally". The images give a general idea of the steps taken during the process of diving. The initial plan of observation was to include a video that would have been observed by various qualified divers. With restrictions of time, they were unable to provide feedback in time. In replacement, these following images will be analyzed and connected to the video observation done in part two.

NOTE: all images taken by *Adam Frampton* in SAT system: DSV Kreuz Challenger in Brunei. Sent on 2019-10-17 8:13 AM

STEP 1

Overall demographics: Male, age 30-45, ethnicity, 2 Caucasian and 1 unknown.

Figure 72

Three divers, are shown resting in the living chamber, posing for the picture. The general area looks spacious and organized. The environment contains white/cream walls with tubing running along the walls and two small port windows in cylindrical environment. The seating area is large and looks like it can fit up to 6 people comfortably. Fabric appears to be "leathery" easy for cleaning to wipe. Centre table is made of metal and in the image, it appears to not allow easy passage to walk through the chamber. Door is rectangular, leading to another room and lighting is florescent. This image presents a more organized and spacious interior than in video 1. Expressions on divers are comfortable and happy. Used as a social area.

STEP 2

Figure 73

The three divers are now in the diving bell. This allows a fit of three individuals while video 1, only allowed room for 2 individuals. Both pieces of media present a space that is limited for movement. Divers have most of their gear on, except for their helmet. Expressions on their face present content. The divers standing beside on another are touching shoulder to shoulder which means space is limited for putting on their gear and assisting each other. Their feet are placed on the port door which two divers will eventually need to go through to enter the water also presenting an extreme limitation of space.

STEP 3

Figure 74

Diver one remains inside the bell which means he is in charge of supervising the other divers shift for up to 8 hours. In video 1, the diver waits here, eats, reads and exercises. He will remain in the bell to ensure that the other divers are safe and maintains communication with the crew on the ship in the control room. The environment presents white/cream walls in a spherical environment. Umbilical cords which send heat and oxygen to the divers underwater are displayed on the right-hand side of image. There is an emergency kit above the cords. Various controls, valves and tanks take up space on the left-hand side of the image. There does not appear to be any are in which diver 1 in this image is able to rest or sit comfortably. This also poses the question of what he will do to pass his time in the bell.

STEP 4

Figure 75

Diver 2 and 3 are now out of the bell and submerged in the water. There is a metal ladder and a metal/grid platform to help them get out of the bell. Equipment includes, yellow helmet, yellow gloves, blue suit, umbilical cords, harness, fanny pack, and pressure gauge.

Step 5: This is the environment underwater in which the divers are now ready to begin their work. This may be construction, maintenance or repairs of infrastructure (information was not provided). Visibility is extremely low. The only light they appear to have is coming from the diving bell.

3.2. Organizing the Data

Figure 76

Key activity 1: Residing in Saturation System

- Carrying out basic daily activities such as sleeping, eating, personal hygiene
- Ensure that pressurization is stable
- Bending, reaching and minimal exercise

Key activity 2: Preparing personal equipment for dive in diving bell

- checking and adjusting pressure
- assisting other diver with equipment, helmets, and ensuring umbilical cords and oxygen tanks are working correctly
- connection with members on ship above for emergency situations
- dive supervisor in charge of getting diver 2 and 3 into the water safely

Key activity 3: Underwater Work

- divers are now submerged under water
- here they are responsible for completing their task; repairs and maintenance of underwater infrastructure/systems
- extremely low visibility and cold environment b/c of depth up to 300m
- divers submerge back into bell and begin the assist each other in taking gear off

4. User Experience

4.1. USER EXPERIENCE MAP

The experience map presents pain to pleasure scale, 1 being pain, 5 being pleasure.

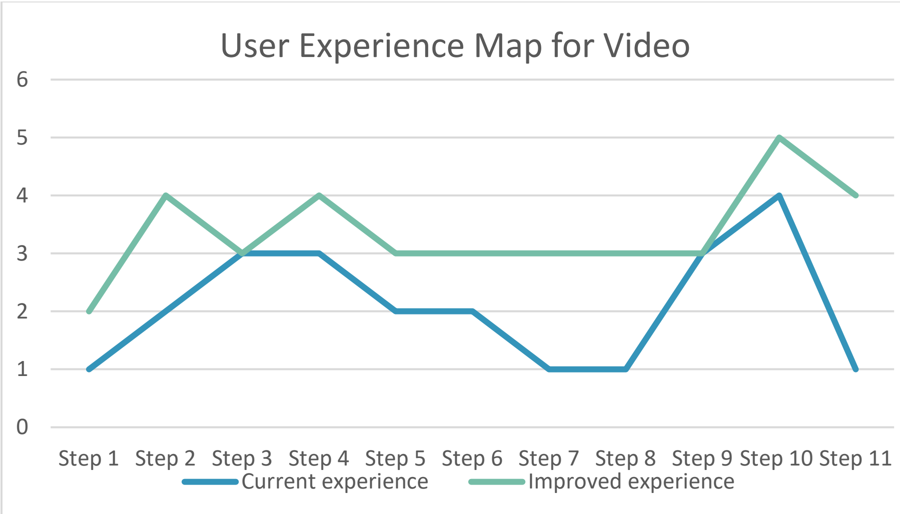


Table 13

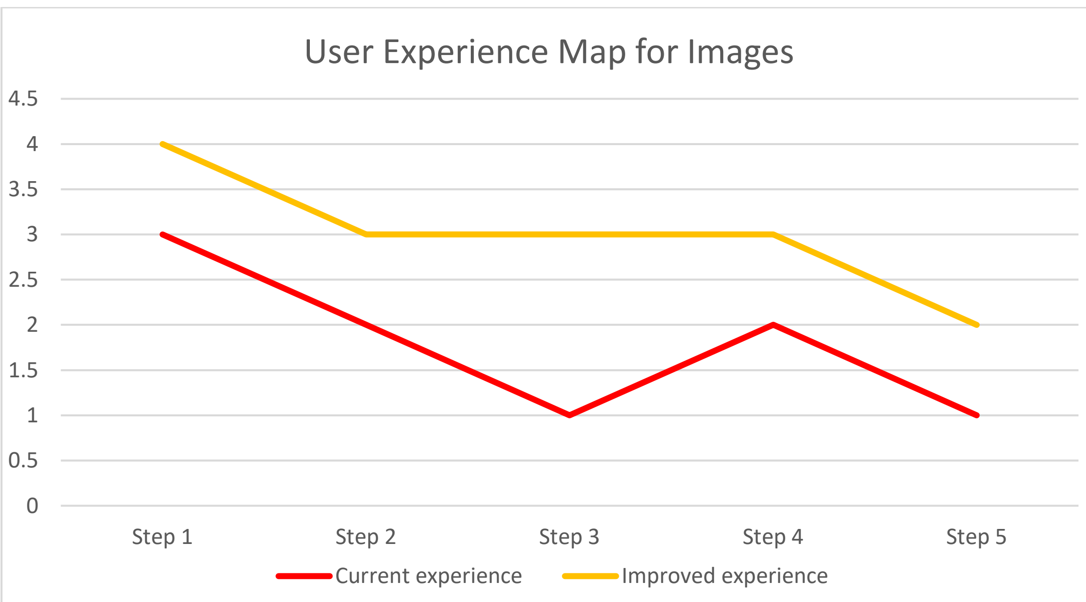


Table 14

4.2. POTENTIAL USER EXPERIENCE IMPROVEMENT CHART

User Experience Map for Video, Table 2.

The user experience for the current experience of divers, shown in blue, is predominately low. Examining the comforts and pleasures of the users starts off low then reaches a somewhat neutral point and ends low once again. Through discussions with divers through online platforms, some have mentioned that divers are somewhat used to the discomforts of the job because they have no other choice. Divers have compared old systems versus new systems that offer better food, more space and a more organized environment but even these new systems are still limited. This is proved in the video that was uploaded in 2019 and images sent in 2019 that takes place in a modern system, the Kreuz Installer/challenger. The improved user experience of the divers and the goal that will be reached is shown in the green. The aim for this thesis is to improve the comfort and safety of saturation diving. This User observation helps guide direction for improvement within the industry. The “end goals” for improvement are listed below.

User Experience Map for Images, table 3

The data shown for the experience of the images only displays the centre portion of the full experience. It does not include the setting/environment involved before a dive or the aftermath of a dive. Steps 1-5 in *Table 3* can be compared to steps 3-8 in *Table 2*. They show a similar pattern of highs and lows. The improved user experience and part of the goal for this thesis is shown is presented in yellow.

Current experience

- *poor ergonomic considerations, poor posture, crouching too low, bending spine too often*
- *extremely limited space, individuals are very close together which allows limited privacy, disorganized and cluttered*
- *system is predominately made of metal which may mean that sound carries easily*
- *users find their own space to exercise wherever they can and if willing*
- *safety features are not clearly identified or accessible*
- *visibility is extremely poor underwater*

Goals for improved experience:

- To improve accessibility to emergency kits and passage ways avoiding cluttered or cramped space
- Limiting extended reach, crouching, bending to avoid injuries and strain to muscles
- Improve spatial area providing more room creating a safer and more comfortable environment
- Implementing privacy in a shared environment between divers, this can encourage a better environment for women who share space with men
- Improving material use for comfort, safety and sustainability; for potentially for cleaner surfaces, cushioned for seating, textiles that provide a sense of warmth and “at home” feeling. Materials that keep the environment dry
- Providing ergonomic angles for sleeping and sitting and carrying out basic activities such as writing, reading or using the computer
- Providing space for exercise which is extremely important for human health and maintains a healthy mindset in isolated environment

5. Overall Analysis

Three observation which inform design include:

1. Analyzing the divers and how they behave in their resting environment. This includes sleep patterns, eating and hygienic habits, social interaction with other divers and their response time to an emergency
2. Examining the divers' mood and body language before (SAT system) during (underwater) and after a dive (SAT system)
3. Observing the diver once the 28 days are over and after decompression; their physical condition and how they feel.

Conversation and discussion with certified divers will be continued as needed through email. In January it is expected that one of the contacts will be able to send Go-Pro footage and more images of the process of their job. Even though our thesis will be further into the development stage, this content will still be examined and analyzed to better understand the challenges in the industry. Details can be analyzed as aesthetics and ergonomics. Next time, the research could have been carried out earlier in order to ensure more time for user response. Overall, if the diver is comfortable, it will allow him to carry out his job properly and more efficiently, which increases the safety of the job. This will meet the goal of *"improving the comfort and safety of saturation diving"*.

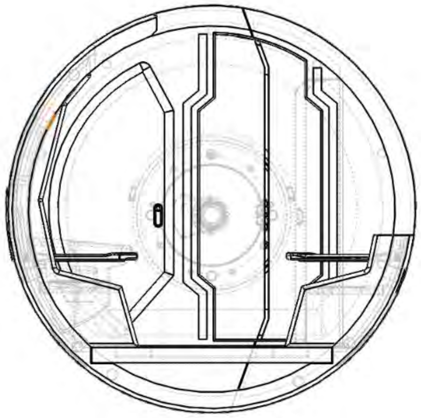
APPENDIX V – CAD MODELS

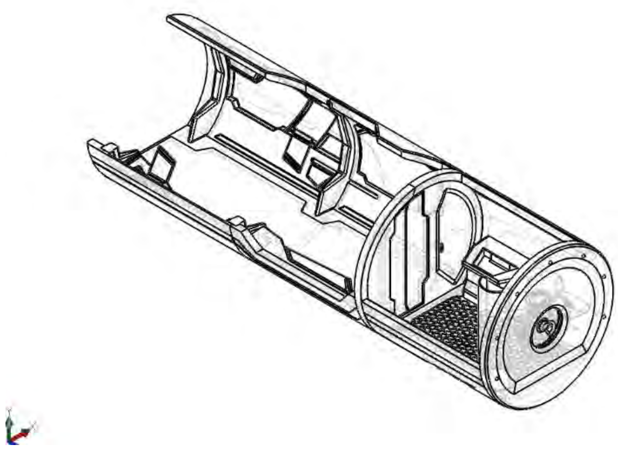
All photos regarding the CAD Solidworks model development and CAD renderings done in KeyShot can be found in section 4.7 and 5.3.

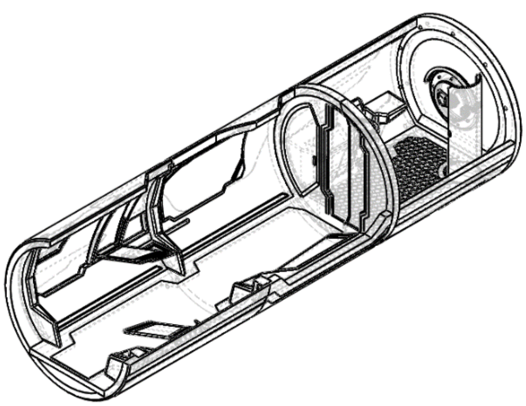
APPENDIX VI – HARD MODEL PHOTOGRAPHS

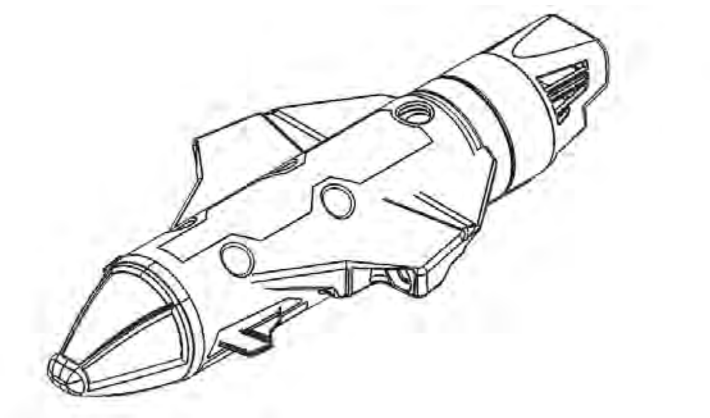
All photos regarding the CAD Solidworks model development and CAD renderings done in KeyShot can be found in section 4.7 and 5.3.

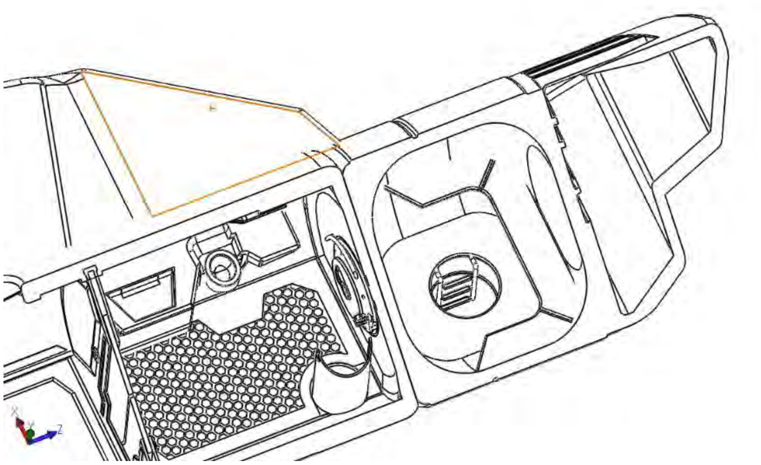
APPENDIX VII – TECHNICAL DRAWINGS

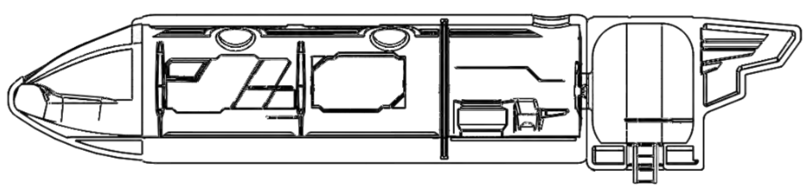












APPENDIX VIII – SUSTAINABILITY REPORT

The following report explores material and manufacturing processes directly related to the saturation diving industry and the technologies used within it. Existing underwater vessels were researched in order to understand the process and details of what a submersible is made up to be. With this, sustainability was explored and summarized.

2.2.4 Benchmarking – Materials and Manufacturing

A collection of materials and manufacturing methods can be gathered through reviewing various benchmarked products. The use of composite materials offers the benefit of weight reduction and durability, necessary to withstand harsh underwater environments and signifies technological advancements. Plastics such as acrylic and metals including aluminum and titanium alloys that are used in the production of submersibles.

Acrylic glass: used for hemispherical viewports. Bag moulded, centrifugal-casted and contact-moulded manufacturing processes. PLEXIGLAS® offers a technology for a larger viewport and can withstand immense tons of water pressure. (Plastics Industry Association, 2020)

Gasket: fills space between mating surfaces to prevent leakage. A Material manufactured by Globe Composite, specifically developed a thermoset elastomer named *"Brandonite".* This is a high strength, flexible and high elasticity material. Provides: resistance to abrasion and tear, energy absorption, low creep and compression set properties, high resistance to seawater, oils, UV and chemical degradation (Plastics Industry Association, 2020)

Metals: Titanium and carbon fibre offers the lightest weight and cost-efficient material for extremely deep ocean depths, simple to replace parts of hull construction (Duration Windows, 2012)

Manufacturing of the submersible hull involves assembly of steel plates. Parts are welded together and are divided between an inner and outer portion along with many other sub compartments to ensure watertight components. Welding seams are grinded by highspeed grinding wheels to smooth out the surface which also allows less friction during travel. A protective "anti corrosion" coating is applied to all surfaces.

2.2.5 Benchmarking – Sustainability

There is limited information on sustainability or environmental concerns regarding the benchmarked systems. The Super Falcon submersible lists one of its features that concerns the environment. The design uses a high efficiency DC drivetrain and an underwater Lithium iron phosphate battery that allows it to run fast, clean and quiet. Its low voltage system allows it to be operated safety around sea life or other divers, reducing environmental disturbance (Plastics Industry Association, 2020). The Swedish manufacturing company, SAAB, mentions sustainability initiations within their annual report of 2016. Their considerations include; to reduce greenhouse gases emissions by 20% by 2020, to phase out the use of hazardous chemicals (replace hexavalent chromium) and have been lead free as of 2007 (Duration Windows, 2012).

3.5 Sustainability – Safety, Health & Environment

Safety:

There are many safety concerns throughout the industry. An important and essential part of ensuring one's safety is communication and efficient access to the those who oversee emergency situations, evacuations and rescue. This communication is key to maintain. The environment should allow emergency exits that allow easy access and smooth flow and quick reach to emergency kits, back up generators and oxygen. Politically, safety must be prioritized, which can sometimes be lost in money making industries (such as oil). In order to promote the saturation diving profession, its reputation must uphold the fact that they will be able to provide the safest environment for divers, mitigating their fears that include death, injury, loss of oxygen or disconnected from main vessel. Ensuring safety will make the industry desirable for those interested in the profession, sustaining employment for the future, and allowing the saturation diving industry to be more invested in.

Health:

Exploring materials in relation to the diver's health and long-term survival of the design. using modular components with durable materials provides an efficient way of use, reducing the number of parts that may be manufactured. Reusability of systems that, instead of being thrown away, can be upcycled or reused and can be updated or integrated into something else. Similar to how some systems are made today, they are meant to last and use recyclable metals such as steel and aluminum, but they are not built to be recycled, they are built to last forever (Since the industry is extremely slow to change, and a lot of money is put into it.) Design can incorporate components that will be beneficial to the diver's health as well as cause less harm for the environment regarding the way its produced, use materials or supporting manufactures that have a small carbon footprint.

Environment

It is difficult to encourage environmental safety within saturation, because a large portion of it is targeted towards the oil industry, something that causes environmental degradation, especially in our oceans. Since this thesis proposal is aimed for the "future", when there will be further technological advancements, the target area could possibly direct and emphasize other industries instead of oil, such as marine research. Using saturation diving as a beneficial addition to the study of our deep-sea environment and unexplored areas can further research development regarding the health of the earth's underwater environment and develop a better understanding of its health and status.

Business

Sustainability in business addresses categories such as equality. Expanding the target market can also improve sustainable aspects of business, for example, promoting woman in the industry just as much as men. This now becomes an industry that can stabilize inequality that is found in saturation diving.

5.6 Sustainability Summary

The following section summarizes the use of sustainable materials and sustainable motives used throughout the design of [name of system TBT].

Metals

The support structure of the designed system will be made up of recycled aluminum and titanium. Both materials can provide a lightweight frame and strong support structure while incorporating long lasting and durable features (Natori Manufacturing Co., 2008). Titanium and aluminum are resistant to rust and corrosion allowing the materials to last for decades when exposed to environmental elements. This is especially important within a slow changing industry. The metals' lightweight features allow easy transportation, without the use of extreme equipment, reducing costs. The recycling process of aluminum does not reduce the quality of its physical properties, also uses only 5% of the energy it takes to make primary aluminum (Plastics Industry Association, 2020). These metals provide the strength, formability and lifespan needed for an underwater vessel.

Plastics

Fibre reinforced plastic is used for the overall interior structure including storage compartments, seating and other surfaces. Plastics provide a sustainable advantage due to its durability and corrosion resistant qualities, allowing for long lasting applications. They provide insulation from heat or cold and even sound, reducing echoes from the outer metal structure. Plastics are lightweight and easily transportable reducing the need for heavy equipment. FRP is recyclable or can be used for "Energy Recovery Technologies", recycling plastic in a way that can be used for fuel or electricity (Plastics Industry Association, 2020) . These plastic surfaces are easy to clean and maintain making them last long in harsh environments. (Englesmann & Spalding, 2010), (Plastics Europe, 2012)

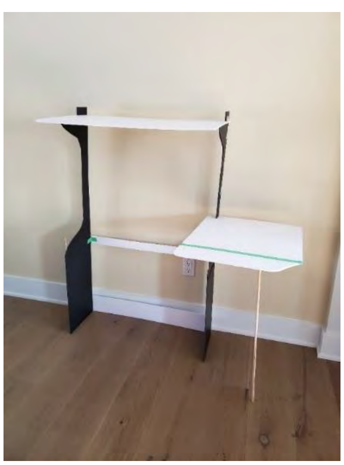
Fabrics

The use of fabrics must consist of materials that provide anti-mildew and fire-resistant qualities. Nylons and polyesters can provide fabrics that are easy to clean and resistant to abrasion and wrinkling. These are suitable for humid environments that the vessel may withhold. These qualities make the fabrics long lasting and durable for extended length of use. Unfortunately, the manufacturing process of these materials release green house gases and harmful chemicals and are not biodegradable for its end of life disposal (Alberto, 2013). The safety of the saturation diving environment must be prioritized in this case.

APPENDIX IX – OTHER – ERGONOMIC STUDY

Primary user interaction

OBSERVATION 1 – Productivity Work station



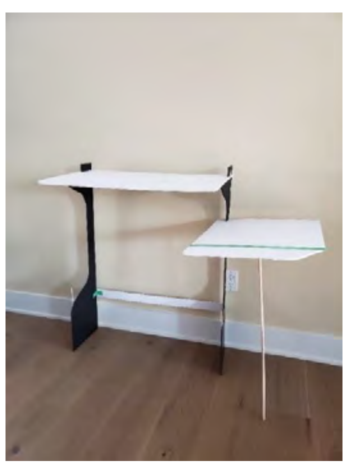


Figure 77 – Workstation at 95% Male *Figure 78 – Workstation at 5% female*

Figure 79 – Workstation at 95% Male standing, 5% female seated

Figure 80 – Workstation at 5% female standing, 95% male seated

Figure 81 - Participants carry out extra curricular tasks, Laptop use and writing

Figure 82 - Participants carry out extra curricular tasks, laptop use and writing

Figure 83 – Participants take time away from individual activity to interact and converse comfortably.

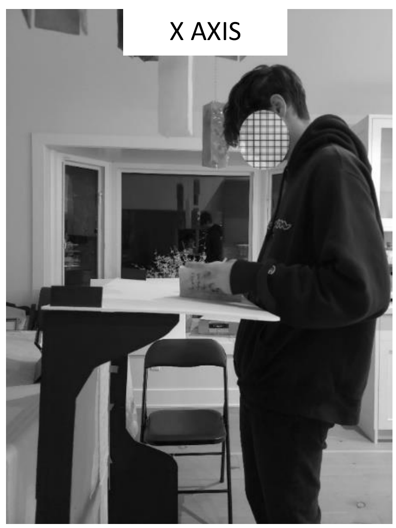


Figure 84 - 5% female positions her forearms at a Comfortable angle to write

Figure 85 – 95% male positions his forearms at a Comfortable angle to write

Image 86 – Tape (green) outlines a 2m width for the vessel interior

OBSERVATION 2 – hatch door exit/entrance

Figure 11 - Hatch door rests 24" off the ground

Figure 12 – 95% male places hands on handle above hatch to assist entrance

Image 13- 5% female places hands on handle above hatch

Image 14 – 95% Male places hands on handle above hatch

Image 15 - 5% female places hands on handle above hatch secondary view

Image 16- 95% Male places hands on handle above hatch, secondary view

Image 87 – Handle above hatch represents current design in SAT systems

APPENDIX X – TOPIC APPROVAL FORM

Humber Institute of Technology & Advanced Learning
School of Applied Technology
Bachelor of Applied Technology – Industrial Design
Winter 2020
iDSN 4502 Senior Level Thesis Project II
Dennis L. Kappen/Catherine Chong/Sandro Zaccolo

THESIS DESIGN APPROVAL FORM

NAME
OLIVIA NACCARATO

TOPIC TITLE (Brand)
HUMAN-CENTRIC ENVIRONMENT FOR SATURATION DIVERS

PS: Ensure that the visualization of the final design, side views and front views in Illustrator or Photoshop are required to be shown to us for securing an approval

Thesis design is approved to proceed for the following:

CAD Design Phase

Rapid Prototyping and model building phase

COMMENTS:

Signed

Catherine Chong / Dennis L. Kappen

APPENDIX XI – ADVISOR MEETING & AGREEMENT FORMS

NOT APPLICABLE. All Interviews and discussions were done anonymously.