UiT The Arctic University of Norway

Faculty of Engineering Science and Technology

Development of concepts for lifeboat evacuation in arctic regions

Dry evacuation from lifeboat to land or sea ice

Bashir Olatunde Olawoyin, Marius Didriksen Hansen

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Abstract

The evacuation of passengers from a ship in distress is an essential measure in marine safety. Safety is only guaranteed when the passengers are evacuated to shore, especially in remote areas like the arctic region.

There has been growing awareness with lack of knowledge, standards, routine, and documentation regarding marine search and rescue in the arctic region in recent years. This has been the reason for subsequent objective exercises like the SARex [4], which simulates real-life evacuation procedure from a ship in distress.

This report is about finding a solution to evacuating passengers from a lifeboat to shore or stable, solid ice in the arctic region. This became apparent after series of events involving passenger cruise ships and shipping vessels running into technical engine-related problems off the Norwegian coast and in the arctic region. The project is developed with the Svalbard area as a case study due to the increase in marine traffic in the area. The region, mainly remote, is a high-risk area for the evacuation of passengers from a lifeboat to shore or stable, solid ice. This project is apparent as there are no current solutions to transfer people from lifeboats to shore or solid ice without getting wet and cold. This master's thesis presents concept solutions for the evacuation of passengers from the lifeboat to shore or stable, solid ice in the arctic region. The concept is detailed with supporting calculations and analyses.

Acknowledgments

As contributing to the development of a safer evacuation system for people in emergency situations when travelling by ship in arctic zones, we would like to dedicate this master thesis to those risking their lives working is such harsh environment.

We would like to state our sincere gratitude and acknowledge the support and guidance provided by our supervisors, Prof. Guy Beeri Mauseth and Prof. Annette Meidell. We are grateful for the opportunity to join the MS Gann exercise which was very helpful in the report.

We appreciate our parents Mr and Mrs Hansen and Mr and Mrs Olawoyin for the constant support and motivation throughout our master's program.

It is under no doubt that the pandemic COVID-19 has set some restrictions to how our work could be performed. This has restricted the work within the team, with mentors and doing more research. However, we appreciate the way everyone involved have adapted to the situation and made it possible to achieve guidance and follow-up of the work.

This report concludes our two-year education with a master's degree in Engineering Design. An education that has been both very challenging but also rewarding.

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1 Introduction

Human existence has been reliant on transportation, migration, and exploration. The zeal for knowledge and technological development has been at the forefront of modern human society. Thus, the need to explore new places and get new resources to aid human life. The earth's surface has 71 percent of it covered by water, with the oceans holding almost 96.5 percent of the water on earth. [1]

This makes water transportation the essential mode of transportation over the years for moving people and goods across the globe. The history of water transport is traced back to the Egyptians, who are regarded as one of the earliest civilizations in the world.

Water transport is the process of moving people, goods, among others, by barge, boat, ship, or sailboat over a sea, ocean, lake, canal, river, and other water bodies. [2]

Apart from the importance of water transport in trade and human civilizations, there has been increased tourism across water bodies as in boat cruises and water sports.

The earth's water bodies are vast and extensive, making water transport highly complicated. Accidents that occur on water have a high tendency of being fatal, and chances of survival and rescue are lower than land transportation.

The vast power of the sea and the unpredictability of the weather out on the sea itself seemed so great that for centuries it was assumed that little could be done to make shipping safer. There have been massive improvements in the water transport system regarding safety, improved comfort, speed, more accurate navigation, and increased capacity.

The increasing number of cruise ships has led to higher safety attention for passengers and crew on board through the entire voyage. This is evident in creating and improving lifeboats and safety equipment. However, one area that has been overlooked is the evacuation of people from the lifeboats to land because safety is not guaranteed till the passengers and crew are dry on shore or solid, stable ice.

There has been an increase in the number of boats and ships visiting the arctic region. The region is becoming a hot spot for fishing, research work, nature lovers, and travel enthusiast. The arctic region's remote location makes it dangerous for ships if they get into problems. It will take time before help can arrive. Thus, the ability for each ship to be self-sufficient in evacuation and dry landing of its passengers and crew is essential. This has brought about the Polar Code [3] for the sustainability of each person to last at least five days in the arctic region before help arrives.

The arctic region is cold, vastly icy, largely untouched, and undeveloped. Thus, a need to have a solution to evacuate people from lifeboats to shore safely with little or no contact with the ocean's cold water is paramount.

1.1 Research problem

There has been growing awareness with lack of knowledge, standards, routine, and documentation regarding search and rescue in the arctic region in recent years. This has been the reason for subsequent objective exercises like the SARex [4], which simulates real-life evacuation procedure and explores the functionality of the present-day approved safety equipment and the Polar Code's practicality.

When evacuation from a vessel happens, the most common focus area is that the passengers are safe when they are transferred to the lifeboat. However, recent studies have shown that safety is not guaranteed until the passengers are transferred from the lifeboat to shore or solid, stable ice. The physical and mental state of the passengers in the lifeboat deteriorates as time goes on.

1.2 Objectives

The master thesis aims to do a thorough research and create a usable concept solution deployable from a lifeboat to land in the arctic region. The problem solution is focused on evacuation to shore and possibly solid ice because it is the safer place to go when trying to get off the lifeboats as observed in the SARex Svalbard, May 2019 exercise [5]. The solution is derived and follows the design-, material selection-, and analysis process.

1.3 Limitations

The following limitations are formulated to evaluate the solution to the research problem.

- Incidents related to evacuation from the lifeboat to land may happen in various sea areas. In this case, the focus will be evacuation in Arctic waters, taking the coastline of Svalbard as a case study.
- The solution is targeted at large vessels and cruise ships.

- The concept solution will be to evacuate passengers to land or solid, stable ice from closed lifeboats, available on most cruise ships and shipping vessels around the arctic waters.
- The evacuation from the lifeboat will be to shore or solid, stable ice. During the evacuation, the passengers should not at any time get wet. This will reduce frostbite or hypothermia due to the extreme cold weather in the arctic regions. Keeping the passengers dry increases the probability of survival. [6]
- Every passenger will have an immersion suit with a personal survival kit (PSK), and the crew will handle the group survival kit (GSK) in accordance with the Polar Code. [7]

1.4 Motivation

The evacuation of passengers from the lifeboat to land or solid, stable ice in extreme weather conditions like in the arctic region has generally not been investigated or widely thought. There is no genuine concept or solution yet to solve the impending problem.

The knowledge and technology in dry evacuation from the lifeboat to land or solid, stable ice is limited or, in some case, non-existent. This makes formulating a usable solution in the evacuation process an essential step for the safety of passengers in arctic waters.

1.5 Similar solutions

There are no known solutions for the evacuation of passengers from lifeboat to shore in the arctic region yet because the knowledge and procedure for the arctic region is still limited.

2 Literature study

2.1 Ships

Ships are large floating watercraft or vessels capable of crossing open waters like seas and oceans, carrying passengers or goods, or other tasks such as fishing, research, tourism, and defence. Ships are generally distinguished from boats based on size, load capacity, tradition, and shape. The term was applied to sailing vessels with three or more masts, but it usually denotes a vessel of displacement of more than 500 tons in modern times. Submersible ships are generally called boats regardless of their size. [8]

Ships have supported exploration of remote areas, development in science and technology, increased trade, instrumental in warfare, used for migration, and a major factor in colonization. Ship transport is responsible for the largest portion of world commerce. [9]

2.1.1 Lifeboats

Lifeboats are either small inflatable or rigid boats carried on vessels for emergency evacuation in mishaps like man overboard, ship accidents, among others, on the vessel. The primary function of lifeboats is the swift and effective evacuation of people in distress from the ship to a safe location.

Lifeboat is an integral part of marine safety, and it is required by the International Maritime Organisation (IMO) for large ships to have them [7, p. 22]. The vessel must have enough lifeboats onboard that can be accessed quickly and available in emergency.

Lifeboats are quickly deployed from ships or an offshore platform, and unlike inflatable rafts and boats, they include a motor. [10]

2.1.1.1 History of lifeboats

A ship ran aground off the coast of Tyne in England in 1789, and even though the crew were in sight of shore, they all died. This inspired the original lifeboat's invention, which was a 30-foot double-ended boat with ten oars, see figure 1. Cork in the hull prevented capsizing, and even when capsized, it right itself and retains its buoyancy when nearly filled with water. Its major drawback was that it was only useful in marine accidents near shore. Regardless of the drawback, countless lives were saved, which inspired the onboard lifeboats used about a century later. [11]

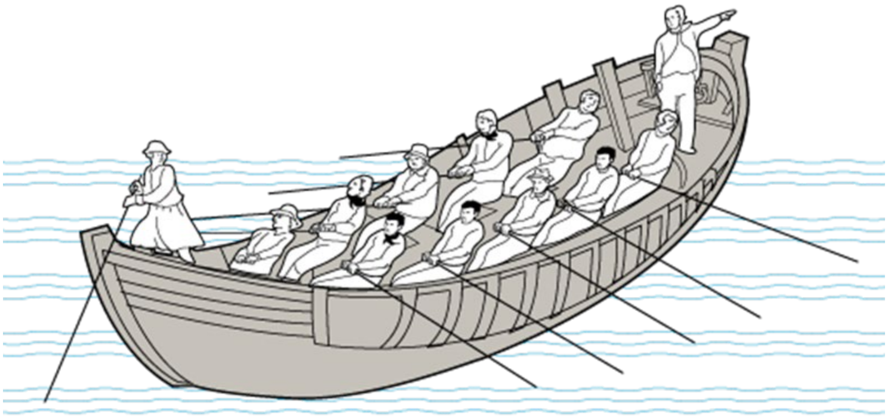


Figure 1: First lifeboat concept [11]

The first lifeboats were simple, small open boats with oars for propulsion by the passengers. In 1890, the first mechanically powered, land-based lifeboat, equipped with a steam engine, was invented. The gasoline engine was introduced in 1904, and a few years later, the diesel-powered lifeboats. [12]

As shown in figure 2 below, modern-day lifeboats have multiple motors, carry survival equipment, and have rigid requirements. Lifeboats on large cruise ships can hold up to 250 passengers inside an enclosed deck, and some even have two levels. The diesel engines follow coordinates set by onboard GPS, sonar, and weather data while delivering coordinates to rescue vessels. The hulls on today's lifeboats, just as on the original, are designed to automatically stabilize the lifeboat in rough seas. [13]

Figure 2: Modern lifeboat [13]

2.1.1.2 Type of lifeboats

Lifeboats are classified under three broad types: open, closed, and free-fall lifeboats.

2.1.1.3 Open Lifeboat

This type of lifeboat, see figure 3, has no roof cover and could be propelled by manual power using hand ores or compression ignition engine for propulsion purpose. Since they do not have a roof, they cannot guarantee maximum safety for their passengers. These lifeboats are becoming obsolete due to their limited safety features and old design. They are the least common lifeboats and are commonly found only on older ships. [14]

Figure 3: Open lifeboat [14]

2.1.1.4 Closed Lifeboat

Enclosed lifeboats are designed to give more protection to their occupants than open lifeboats, see figure 4. They have a rigid, watertight enclosure which makes them much better at keeping occupants safe and dry in adverse conditions. It can also get upright on its own if toppled over by high waves. The enclosed design saves the lifeboat's passengers from seawater, rough weather, or strong winds. [15]

Figure 4: Closed lifeboat [15]

2.1.1.5 Free-fall Lifeboat

Free-fall lifeboats have many of the same features as closed lifeboats, except for their launching style and shape. The launching process of these boats is different from closed lifeboats, see figure 5. These vessels fall off the edge of a ship during evacuation.

They have an aerodynamic structure, making them drop into the water without sustaining damage. They are located at the aft of the ship, which provides them with the maximum clear area to free fall into the water. [14]

Figure 5: Free-fall lifeboat [16]

2.2 Marine Safety

There are over 23 million tons of cargo and 55,000 cruise passengers travelling by ship each day in the present day. This makes the importance of marine safety very high to prevent loss of life and goods. [17]

The maritime industry has been looking for new ways to develop and enhance better safety in the maritime sector. There has been improvement in safety, comfortability, and sustainability over the years to make ships and water transportation, in general, safer, more convenient, and have less impact on the environment. Maritime safety was slow and hampered in the early years because it was reliant on trial and error. However, new technology has been developed with the help of computer modelling and analysis.

There has been the creation of the international maritime organization to standardize maritime safety. Some maritime safety standards include group survival kit (GSK), personal survival kit (PSK), Safety of Life at Sea (SOLAS). Other standards are location-specific, like the Polar Code for ships going to the polar regions. Some countries have local standards to aid the ease of operation in water transportation and improve safety in waterways. [17]

Some of the improvements have been based on design change and optimization, better stability systems and improvements in the ship's engine functionality and capabilities. There has also been the introduction, development, and modification of better onboard lifeboats. [17]

2.2.1 Marine incidences in the arctic region

There has been an increase in the number of boats and ships visiting the arctic region. The region is becoming a hot spot for fishing, research work, nature lovers, and travel enthusiast.

DNV GL's report [18] from 2014 lists up accidents and incidents in Svalbard and Jan Mayen. Between 1998 and 2014, there were 48 ship accidents, including 14 groundings. Passenger ships are at higher risk of running aground, while fishing boats are at greater risk of collisions and fire on board.

Some of the major incidence and accidents in the arctic region are:

- Akademik Ioffe, 2018, 162 people aboard, cruise. The accident happened when the ship ran aground along Canada's Arctic Northwest Passage and damaged the hull. Passengers and crew got rescued by vessels nearby. [19]

- Clipper Adventurer, 2010, 197 people aboard, cruise. The accident occurred when the ship struck a rock shelf three meters below the surface nearby Kugluktuk in Coronation Golf, North in Canada. Everyone got evacuated safely by a Canadian Coast Guard icebreaker. [19]
- Maksim Gorkij, 1989, 954 people, cruise. The ship hit an ice floe on the west coast of Svalbard and began to take in water. All the passengers and parts of the crew evacuated to the Norwegian coast guard vessel "Senja". The rest of the crew tried to save the vessel and stop it from sinking. [20]
- Ortelius, 2016, 146 people, cruise. The tourist's vessel had an engine fault in the Hinlopen Strait, separating Spitsbergen and Nordaustlandet in Svalbard. The Governor's vessel, the Polarsyssel, was sent to the region to tow the Ortelius back to Longyearbyen, Svalbard. Neither the Ortelius nor her passengers were reported to be in any danger during the incident. [21]
- Northguider, 2018, 14 people, trawler. The fishing vessel ran aground on the north part of Svalbard. All crew members were safely evacuated by two helicopters. [22]

2.2.2 Marine safety regulations

2.2.2.1 Polar Code

The international code for ships operating in polar waters (Polar Code) was established by the International Maritime Organization (IMO) and entered into force on 1 January 2017. It applies to all vessels operating in waters around the two poles, the Arctic and the Antarctic. The Polar Code addresses regulations and requirements for ship design, construction and equipment; operational and training concerns; search and rescue; and, equally important, the protection of the unique environment and eco-systems of the polar regions. [23]

Conventions such as the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL) have resulted from large-scale accidents in the polar region. The already existing conventions lacked regulations and requirements that dealt with the severe challenges the vessels could be exposed to in polar areas. Based on this and the increasing shipping in polar waters, the Polar Code was implemented. Unlike before, this regulation will have a preventive effect. [24]

2.2.2.2 SOLAS

SOLAS is an abbreviation for Safety of Life at Sea. It is an international maritime treaty that sets minimum safety standards in ships' construction, equipment, and operation.

The first version of the International Convention for the SOLAS was adopted in 1914. It was a response to the sinking of the "unsinkable" vessel, RMS "Titanic". Since 1914, improvements have been made, and the 5th adopted version is currently in use worldwide since November 1st, 1974. It has since then been updated and amended to meet the safety norms in the shipping industry. [24]

2.2.3 Survival equipment

The Arctic area causes problems for the search and rescue due to a lack of resources, distance, and harsh conditions. When an accident occurs on the sea, the passengers and crew must evacuate the ship. Part of the evacuation plan is to bring survival equipment into the lifeboat or life raft.

From the Polar Code, it is stated from paragraph 1.2.7: "Maximum expected time of rescue means the time adopted for the design of equipment and system that provide survival support. It shall never be less than five days.". This means that the survival equipment should last at least five days. There are two categories: Personal Survival Kit (PSK) and Group Survival Kit (GSK). [7]

The Polar Code has made two equipment lists for the two kits as a template or suggestion. The vessel or ship can decide and make their PSKs and GSKs from these lists. The suggested equipment lists from the Polar Code are highlighted in Appendix A.

2.2.4 Marine safety exercises

2.2.4.1 SARex

SARex is an abbreviation for Search and rescue exercise. It was initiated for understanding and finding the solution to safety of lives and properties in the polar regions because of the increase of marine traffic due to melting icebergs.

The first live arctic search and rescue exercise, SARex-2012, took place in a remote area along Greenland's east coast with varied weather conditions. The exercise involved personnel, authorities, aeroplanes, helicopters and ships operating in the High North from Canada, Denmark, the Faroe Islands, Greenland, Iceland, Norway, Russia and the United States. [25]

More SARex exercises have taken place subsequent years to evaluate procedures, challenges, and equipment needed in evacuation and survival in the polar regions in case there is a marine accident. The exercises were named SARex1, SARex2 and SARex3, and were carried out in April/May 2016, 2017 and 2018.

The aims of the exercises were to:

1. Assess the functionality of standard SOLAS-approved lifesaving appliances regarding providing survival for a minimum of five days according to the IMO 2015 Polar Code requirement.
2. Assess the functionality of high end/ modified SOLAS-approved lifesaving appliances regarding providing survival for a minimum of five days according to the IMO 2015 Polar Code requirement.
3. Assess benefits of evacuation to shore regarding providing survival for a minimum of five days according to the IMO 2015 Polar Code requirement. [26]

2.2.4.2 SARex Svalbard

SARex Svalbard was the most recent project, 2019-2020. The project was established because of discoveries and recommendations from previous projects, SARiNOR (1 and 2) and SARex-projects (2016-2018). SARex Svalbard is based on the prerequisites that occur after an accident.

To identify challenges and issues related to survival, search and rescue, and emergency preparedness for acute pollution, full-scale tests and exercises were planned. The first full-scale exercise took place in Svalbard, May 2019.

The last full-scale exercise performed was February 2020, Mass Rescue Operation Exercise MS GANN in the vicinity of Bodø. The planned cruise with KV Svalbard in March 2020 had to be cancelled because of the pandemic COVID-19. SARex Svalbard project was then settled and finished July 1st, 2020. [27]

2.2.4.3 MS Gann exercise

To understand the search and rescue operation on a ship, we joined the MS Gann exercise in Bodø, Norway, in February 2020. The MS Gann exercise aimed to have a simulation of evacuation procedure from the ship to lifeboat and life raft. We had an assessment of the equipment like the PSK, GSK, immersion suit, lifeboat, life raft capacity, etc., available for each passenger in an emergency on the ship.

Some of the evacuation stages covered by exercise included:

1. Coordination of the passengers to the emergency meeting point.
2. Time to put on the immersion suit and safety.
3. Evaluation of the personal equipment assigned to each passenger and how comfortable it is to bring them on board the lifeboat/life raft.
4. Time to lower and deploy the lifeboat and life raft.
5. The time it takes to embark and disembark from the lifeboat/life raft.
6. Tracking and monitoring the physical and mental conditions of the passengers on board the lifeboat and life raft.

The exercise gave an insight into how the evacuation procedure works and explains the different scenarios and modifications required if the evacuation is to be done in the arctic region.

2.3 Arctic region

The Arctic is the earth's northern polar region. It is a unique area with ice cover, permanently frozen underground ice, and varying snow. The region is cold, vastly icy, largely untouched, and undeveloped. It is characterized by cool summers with an average temperature of 10°C and cold winters with an average temperature of -34°C. [28]

Figure 6: The Arctic region [29]

The Arctic consists of, see figure 6, the Arctic Ocean, adjacent seas, and parts of Alaska (United States), Canada, Finland, Greenland (Denmark), Iceland, Norway, Russia, and Sweden. [28]

2.3.1 Shipping traffic in the arctic region

The traffic of shipping in the Arctic region has increased due to many factors. Some of these are: the melting of the Arctic ice, increase exploration of natural resources, Arctic passages for ships from Asia to Europe and more tourism activities. Shipping has increased from 1298 ships in 2013 to 1628 ships in 2019. [30]

2.3.2 Svalbard

Svalbard is an archipelago in the Arctic Ocean. The archipelago consists of several large and small islands. There are three main islands in the area. This consist of Spitsbergen (the largest island), Nordaustlandet and Edgeøya. Barentsøya, Kvitøya, Prins Karls Forland, are some of the smaller islands. [31]

Figure 7: Svalbard shore [5]

Figure 7 shows one of the shores on Svalbard. Large parts of the islands consist of sharp and steep mountain peaks, up to 1717 meters high. The north and west coast are deeply indented by fjords, some of which are more than 100 km long which makes most of the shoreline shallow. [32]

Glaciers cover nearly 60% of the land with the largest ones in the northeast. Most glaciers reach the sea, where they form ice walls that can reach 50 meters. Svalbard also displays very flat valleys free of ice, covered with lichen, flowers, and strange polygonal stone arrangements created by the frost. [32]

2.3.3 Svalbard weather conditions

Svalbard has a relatively mild climate despite its northern location, thanks to sea currents. On the west coast, temperatures in July are usually inside the range 1-10°C, with an average of 5°C. In February-March, the mean temperature is between -8° C and -16°C. The amount of precipitation is minimal (less than 400 mm a year), and Svalbard is sometimes qualified as an arctic desert. The weather may change a lot between one valley and the next. Strong wind and fog are not unusual, but it is also possible to have very sunny and mild weather. [32]

The average temperature for the Svalbard coast is shown in figure 8 below. The temperature is based on observations from 09/2011 - 03/2021 for Longyearbyen/Spitsbergen, Svalbard.

AVERAGE DAYTIME TEMPERATURES (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAX	6	6	12	19	25	13	21	20	14	10	11	8
AVG	-8	-9	-11	-7	-1	5	8	7	3	-1	-4	-7
MIN	-22	-25	-29	-23	-15	-1	0	0	-8	-17	-20	-23

AVERAGE NIGHTTIME TEMPERATURES (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAX	6	7	5	4	26	16	27	22	13	9	9	8
AVG	-8	-8	-11	-8	-2	4	8	6	3	-1	-4	-7
MIN	-23	-27	-30	-24	-13	-1	3	-1	-8	-18	-20	-21

Figure 8: Average monthly temperature in Svalbard [33]

2.3.4 Wind

When one compares Svalbard to other areas in the Arctic, it has less wind. Wind speed in the Svalbard area differs in any given location, and it is highly dependent on local topography and other factors like the type of shore and length of fjords. The wind can also change a lot in just 30 minutes. There are high wind speeds for six months from October till April and calmer average wind from April till October through the summer months. [34]

The average monthly wind speed in knots on the Svalbard coast is given in figure 9 below. The statistics are based on observations taken from 09/2011 to 03/2021 for Longyearbyen, Spitsbergen, Svalbard.

Figure 9: Average monthly wind speed in Svalbard [33]

2.4 Health risks in the Arctic region

Prolong exposure to cold weather or immersion in cold water causes hypothermia and frostbite.

2.4.1 Hypothermia

Hypothermia happens when the body loses heat faster than it can produce heat. The average normal body temperature is around 37°C, but the body temperature reduces to less than 35°C when hypothermia occurs. The low body temperature reduces the heart rate, slows down the nervous system and makes the body organs malfunction. If left untreated, it can lead to total body organ failure and eventual death. Hypothermia is expected in the winter and cold climates like in the arctic region. [35]

2.4.2 Frostbite

Frostbite is an injury that happens when the skin is frozen. Skin exposure to cold or windy weather conditions is the leading cause, but recent research has shown that covered skin in extreme cold has also been subjected to frostbite. [36]

3 Method – Design methodology

According to the book, Engineering design methods [37, p. 46], design methods are procedures, aids, or tools for designing. They are different activities that a designer might go through or combine to modify an existing product or create a new product.

The design process follows these steps:

a. Identifying opportunities
b. Clarifying objectives
c. Setting requirements
d. Determining characteristics
e. Generating alternatives
f. Evaluating alternatives
g. Improving details

The design process is implemented to design the concept and act as a guideline for creating the product solution for the evacuation of passengers from the lifeboat to land or solid, stable ice.

3.1 Identifying opportunities

The identifying opportunities in creating the system or device for the evacuation from the lifeboat to land or stable, solid ice is quite limited because of lack of customers and because it is an entirely new product. The problem question is assessed, and the identified opportunity is derived. The identified objective is shown below:

Goal: to design a device for evacuees to use in the evacuation process from the lifeboat to shore or solid, stable ice.

Context: an evacuation device that can be used to evacuate passengers from lifeboat to land or stable, solid ice in the arctic region by all age groups without the passengers getting in contact with the ocean water.

Constraints:

The concept solution:

- Fits with the existing lifeboats dimension that can either be permanently attached or added as an external device.

- Safe and water-resistant.
- Simple and robust operating mechanism.
- Useable for all age groups.
- Can support total force (natural forces, weight of the passengers, drag, among others) of 30,000N.

Criteria:

- Easy to operate by two people.
- Can withstand Arctic weather conditions
- Appears robust and safe

3.2 Clarifying objectives

The objectives are listed in sets of hierarchical levels. Higher-level objectives are of higher importance than the others. The objectives are presented in a diagrammatic tree, showing the hierarchical relationships and interconnections. The tree branches represent relationships that suggest means of achieving higher-level objectives. The objective tree is illustrated in figure 10.

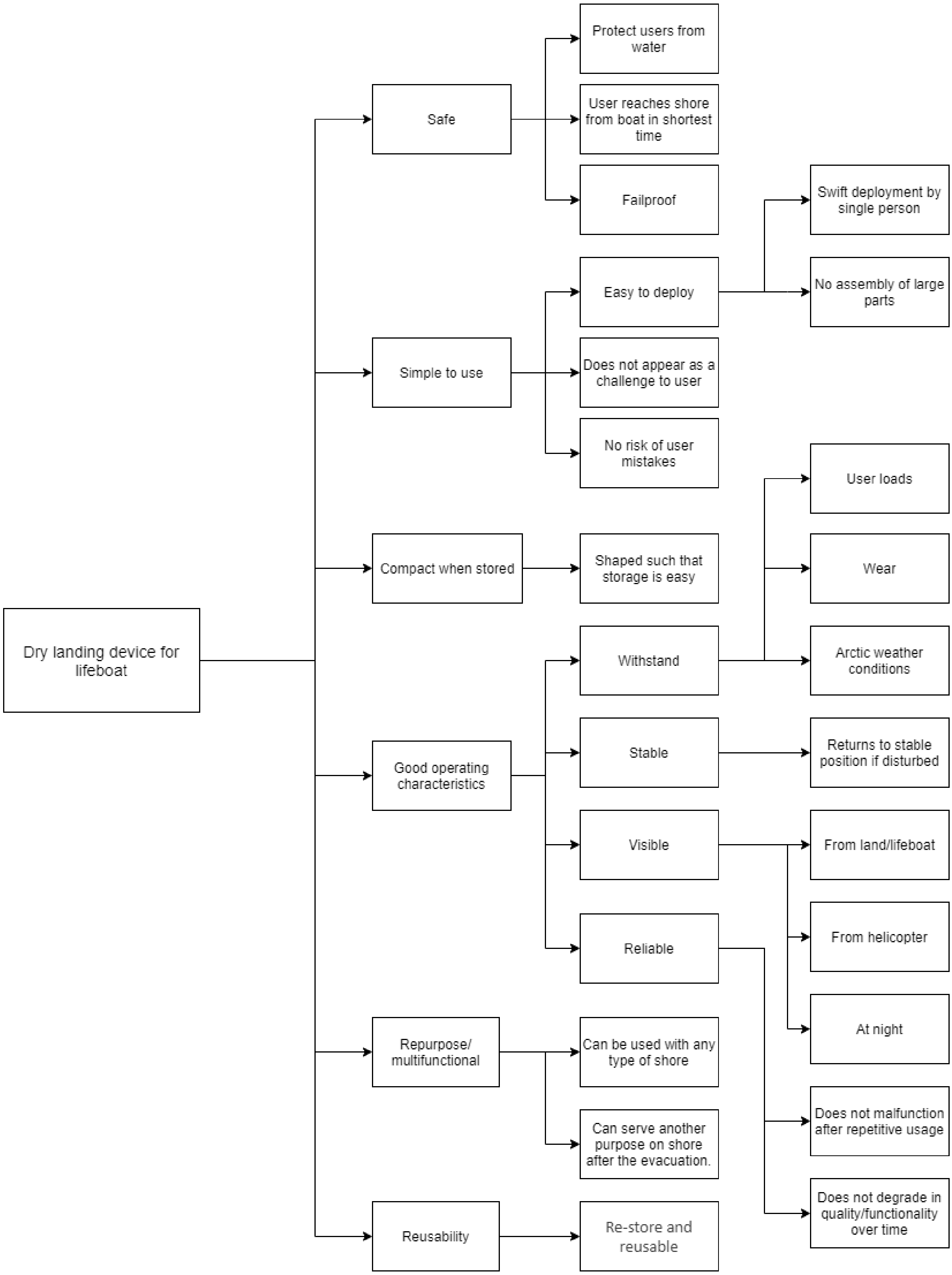


Figure 10: Objectives tree.

3.3 Setting requirements

Requirements are set to include the performance specification of the product. By setting these specifications, the range of acceptable solutions are limited.

By putting early effort into the performance specification, imperfect solutions are prevented. Table 1 shows the specification of the requirements for the product. “D” and “W” in the second left column states “Demands” and “Wishes” in the specification.

Table 1 Specification of the requirements

No.	D W	Requirements	Description
		1. Immersion suit	
1	D	Insulated	
2	D	Water resistant material	
3	D	Usable in temperature down to -30 degrees Celsius	
4	D	Light source on the suit	
5	W	Gloves/mittens to take on and off	
		2. Lifeboat	
6	D	Totally enclosed	
7	D	Scalable capacity of lifeboat, 26-240 passengers	
8	D	Number of crew: 4	
9	D	Lights inside and outside	
10	D	Room for PSK, GSK and water	Polar Code has given guidelines to what should be in the PSK and GSK. The amount of water for one person is 10 litres for 5 days.
11	D	Good ventilation of air	
		3. Lifeboat when evacuating to land	
12	D	Distance from land 30 meters	Because the shores of Svalbard are mostly shallow
13	D	Anchors to stabilize the lifeboat	
14	D	Moored to land	

		4. Weather conditions	
15	**D**	Working temperature of higher or equal to -30 degrees Celsius	
16	**D**	Withstand the Natural forces	Wave-, current-, wind forces
17	**D**	Prevent sea spray and icing	
18	**D**	Wave deflection range of 1,5 meters	The equipment will be able to deflect under the pressure from the wave going up to 1.5m. It floats and buoyant.
19	**D**	Water- and moisture resistant	
		5. Crew and passengers	
20	**D**	Good physical/mental state of crew	
21	**D**	Good physical/mental state of passengers	
22	**D**	Usable for all ages	
		6. Additional requirements	
23	**D**	Deployment time of concept, 5-10 minutes	
24	**D**	Transport time per person, 1 minute	The time it takes for one passenger to get from the lifeboat to dry ground.
25	**D**	Corrosion resistant	
26	**D**	Maximum mass of concept, 100 kg	
27	**D**	Maximum weight the concept can allow, 30 kN	
		7. Other	
28	**W**	MOB boat	Assistance when evacuating to land
29	**W**	Repurpose	Can serve another purpose on land after the evacuation.

3.4 Determining characteristics

Customer requirements are identified as product attributes, and we relate the attributes to engineering characteristics. Numbers indicate the strength of the relationships, and we determined the target numbers for the engineering characteristics. The highest number indicates a more substantial relationship between the attributes and the engineering characteristics. These targets satisfy customer requirements and engineering characteristics. The scheme for the costumer attributes and engineering characteristics is in Appendix B.

3.5 Generating Alternatives

Generating solutions is a central part of designing. The purpose of designing is to make something new or modify an existing product. Using the information gathered on the project, the requirements from the customer and keeping the priority of objectives in mind, we ideate various possible solutions to the problem.

The following concepts were generated:

1. **Rope to shore – zipline**

   Setting up a zipline system, see figure 11, to drag passengers from the lifeboat or straight from the distressed vessel to land.

Figure 11: Zipline system [38]

2. **Sliding gangway**

Figure 12: (a) To the left, sliding gangway. (b) To the right, sliding gangway deployed

   The sliding gangway is a solid structure carried on the top of the boat, as illustrated in figure 12 (a). It is extended onto land and locked into the ground from the front end of the boat, as illustrated in figure 12 (b). The passengers are evacuated by walking on the gangway to shore or solid ice.

3. Fastened floats

Figure 13: (a) To the left, enclosed floats attached to the lifeboat. (b) To the right, deployed fastened floats.

Specialized prefabricated floats are interconnected as a walkway to shore, as illustrated in figure 13 (b). The water buoyancy supports the floats. The combined floats are flexible, reducing the impact of waves on the structure. The system is hauled along with the lifeboat, as illustrated in figure 13 (a). One end is fixed on the boat, and the other end is secured on the shore using cables and hooks. The passengers are evacuated by walking on the floats to shore or solid ice.

4. Inflatable gangway

Figure 14: (a) To the left, attached inflatable gangway. (b) To the right, deployed inflatable gangway.

This solution is like the one found in aeroplanes. The gangway explodes out from the casing, see figure 14 (a), with inert gases, and it stretches out to the shore. The shore end is fixed using a hook or similar tool. The passengers walk or crawl on the inflatable gangway, figure 14 (b), from the lifeboat to shore.

5. **Tube gangway**

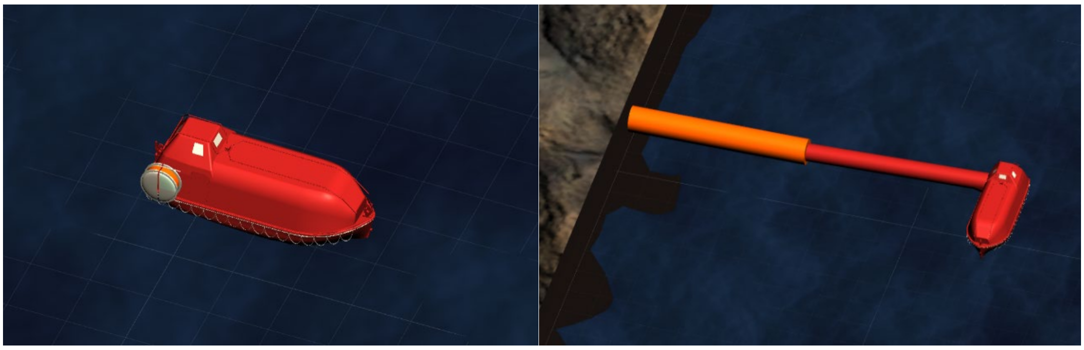


Figure 15: (a) To the left, tube casing attached to the lifeboat. (b) To the right, deployed tube gangway.

Before deploying, it is kept in a casing attached aft on the lifeboat, see figure 15 (a). The device will then be deployed by using an inert gas system to inflate the parts of the structure giving shape to the gangway, see figure 15 (b). The shore end of the tube is secured using hand screws. This solution gives the passengers better protection from rain and water splashes. It provides them with a security feel by not directly exposing them to the ocean or harsh weather. The passengers are evacuated to shore by walking or crawling through the tube. The tube is flexible enough to move with the waves.

6. **Life raft with winch**

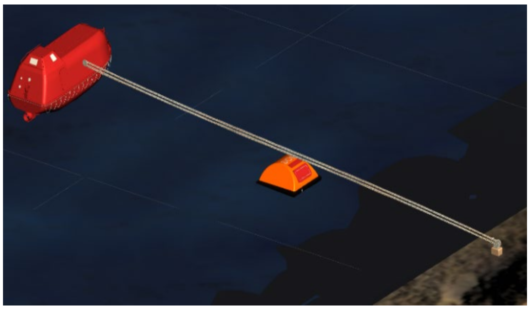


Figure 16: Life raft with winch system

A life raft is attached to a cable system connected to a winch, as shown in figure 16. The passengers are transferred from the lifeboat to the life raft. The winch drags the life raft to shore or stable, solid ice. The life raft can go back and forth till all passengers have been evacuated.

7. **Floating bubble**

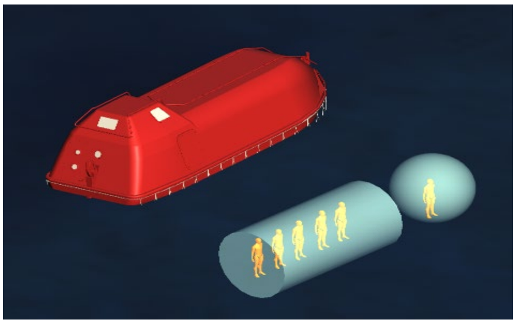


Figure 17: Floating bubbles

A floating bubble is a large buoyant envelope filled with air where a person can safely stand on water. They can be spherical or cylindrical, as illustrated in figure 17. A cable can be used to drag all bubbles to shore. The envelopes are inflated using an electric air pump powered by the lifeboat.

8. **Modifications to the boat**

Figure 18: Modified lifeboat with wheels

The lifeboats could be modified by having wheels to get them ashore, as illustrated in figure 18. Alternatively, hovercrafts could be used instead of lifeboats as they have a seamless transition between different type of terrains.

From the listed alternatives above, we decided to investigate two of them:

5. Tube gangway

6. Life raft with winch

A morphological chart is set up. The main aim for the morphological chart is to widen the search for possible new solutions for the chosen concepts. By doing this, the features/functions and sub-solutions could be more specific or detailed.

3.5.1 Morphological charts

	Functions / features	Sub-solutions 1	2	3	4	5	6
1	Stability / device to increase stability	Support pillar on shore/ice	Additional control cable	Anchor			
2	Power source for the system	Human power	Manual machine	Diesel engine	Petrol engine	Electrical engine	
3	Transmission	Belts	Chains	Ropes	Wire	Oars	
4	Operating location	Lifeboat	Life raft	Land			
5	Propulsion	Wheels	Moving line	Propeller			
6	Fastened to land by	Harpoon to shore/ice	Anchor	Spikes	Human holding	Screw/nails with handdrill	
7	Number of support point on land	1	2	3	4	5	
8	Transmission attachment to lifeboat	Middle	Top, over the escape doors	Rear end	Front end	Top, over the steering house	MOB Boat setup
9	Transmission attachment to liferaft	Inside liferaft	Outside liferaft				
10	Evacuation equipment	Part of lifeboat	Carried on board lifeboat	Carried on board liferaft			

Figure 19: Morphological chart for life raft

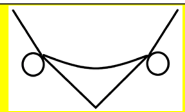
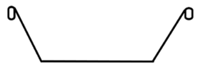
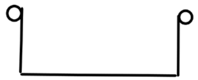
	Functions / features	Sub-solutions 1	2	3	4	5	6	7
1	Floating element	Inflatable	Buoys/ floating balls	Foam	Hybrid of inflatable and fabric	Hybrid of inflatable and Foam	Fabric	Wood
2	Stability / shape to increase stability (Cross-section of the lower part of the gangway)							
3	Device to guide passengers to shore	Rope	Hand rails	Human chain (passengers connected to eachother)	Light	Reflector		
4	Structural support to prevent failure	Rings fixed to the structure	Wire going through the structure	Rings fixed to the structure with a link between them	Support pillars	Solid fences on the side with connecting ropes	Solid base	
5	Mounted / Positioning to lifeboat	Inside on the door	Inside on one of the sides of the door	Outside on the door	Outside on one of the sides of the door	Half inside and half outside	MOB Boat setup	
6	Prevent water	Fully covered (base, sides, top)	Closed on the sides and base	Base only				
7	System of deployment	Pull out	Explodes	Already deployed	Manual pump	Engine pump		
8	Fastening tool to land	Harpoon to land	Hooks	Spikes	Mooring rope	Handdrill (screw/nails)		

Figure 20: Morphological chart for the gangway

The yellow covered cells indicate the possible sub-solutions for the features/functions. The green line in figure 19, is the concept when using a life raft with winch. The red lines in figure 20, shows the concept for the gangway. In Appendix C the two charts are put up without the lines and marked cells.

3.5.2 Description of the concepts

From the morphological charts in figure 19 and 20, functions and features for the two concepts were decided, but the charts do not include how the evacuation process will be performed. The description of the concepts will include both the setup and parts of the concept, and also, the evacuation procedure. Concept A is called "Gangway" and concept B is called "Life raft".

3.5.2.1 Concept A – Gangway

The Gangway concept is shaped like a tube. The stored, undeployed tube is attached to one of the exits of the lifeboat from where it is deployed. It has floating elements on both sides of the device. The lower part of the device has the same shape as the hull of a boat or vessel, a turned triangle. The device is fully closed with a structure/frame that prevents the upper covering from falling. It makes the whole device, with the floatable on the side, steady and robust. The cover prevents the passengers from getting in contact with the water. The device has an anti-slip underlay that allows the passengers to crawl through it. There is a rope/cable for the passengers to hold and pull themselves through the tube if needed. The opposite end of the gangway towards the shore/ice is equipped with mooring hooks. The hooks keep the tube in a fixed position during the evacuation process.

The features of the Gangway are:

- Compressed gas canister for the inflatable tubes
- Casing for the Gangway when stored
- Rope/cable to guide the passengers
- Underlay with anti-slip fabric
- Structure/frame for the upper part
- Inflatable tubes
- Structure frame for the lower part
- Water-resistant fabric to cover the upper and lower frames
- Mooring hooks

The evacuation procedure for the Gangway concept is as following, see figure 21 for illustration:

1. The lifeboat is positioned alongside the shoreline, aligning with the wind and waves.
2. When anchored and positioned, the deployment of the Gangway can begin.
3. The device is deployed, and the compressed gas inflates the tubes.
4. The crew members will secure the framework and the mooring hooks at the shore-end will be fastened.
5. The passengers are evacuated from the lifeboat by crawling to shore.

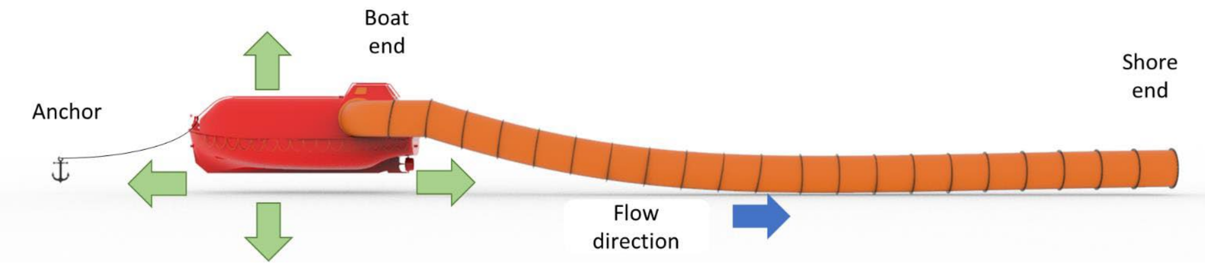


Figure 21: Illustration of the Gangway concept

3.5.2.2 Concept B – Life raft

The concept solution is made up of off-the-shelf equipment put together to become a system for the evacuation of passengers. It is a practical solution that requires less technical input.

The parts that make up the system are listed below:

- Life raft
- Two battery powered winches
- Cables
- Pulley (attached to the lifeboat)
- Two pillar frames
- Guide ropes

Evacuation procedure for the life raft is listed below, see figure 22 for illustration:

1. The lifeboat is maneuvered in position alongside the shore and anchored, and the life raft is deployed by the crew.
2. The lifeboat has a pulley attached to its body frame.

3. The crew transfers the cables and winch to the life raft and use the oars on the life raft to paddle to shore for the setup of the winches and support pillars.
4. Two pillars are set up on shore/ice to hold the winches in position.
5. A cable passes from one winch to the other through the pulley attached to the lifeboat.
6. The cable is fixed to the life raft and thus, pulls it to the lifeboat and back to shore.
7. The winch works in opposite directions in a synchronized way to create a linear motion from the lifeboat to shore/ice.
8. Passengers are moved from the lifeboat to the life raft and the life raft transfers them to shore.
9. There could be a separate guide rope attached to the life raft enable pulling it back if drifting off due to strong winds.
10. When the passengers have been successfully transferred, the system can be used for another lifeboat. It can also be used on shore/ice for other purposes.

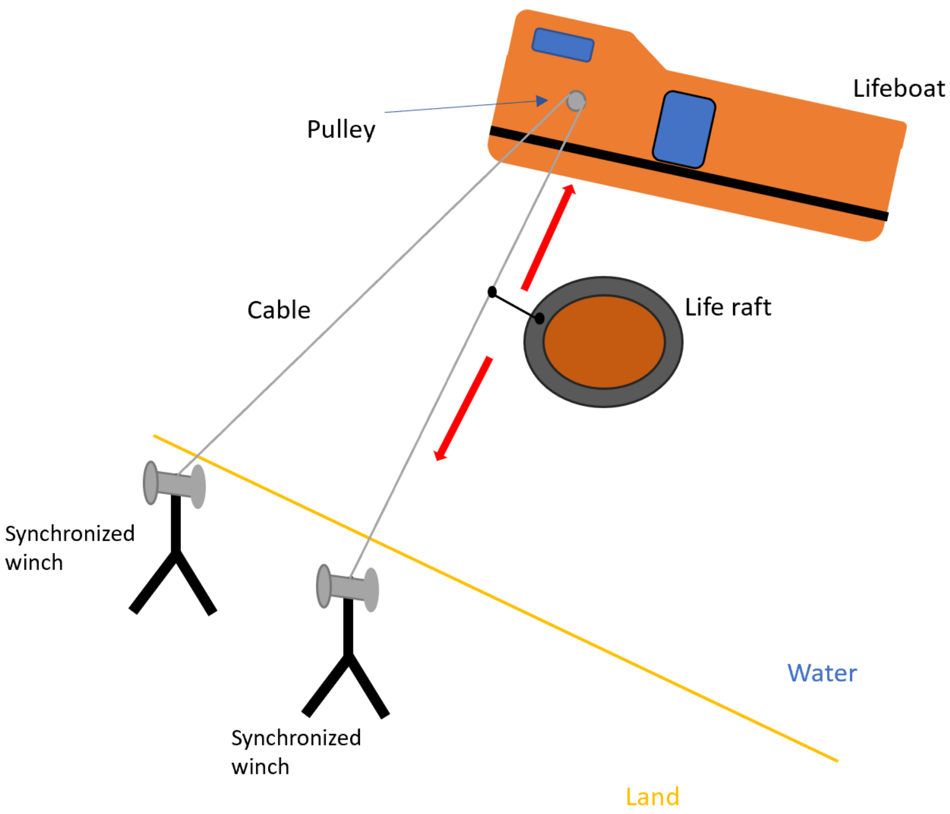


Figure 22: Illustration of the Life raft concept

3.6 Evaluating alternatives

This is the stage of selecting the best solution from the alternative concepts we generated. Selection was done by comparing the compliance with the 11 defined objectives as highlighted in Appendix D, of the concepts and thereby, finding the most suitable.

The 11 objectives were first ranked after importance from 1 to 11, where 1 is the most important and 11 is the least important. The ranking was done by four participants individually giving a wider approach to reflect the participants different priorities. By using the average figure of the individual ranking, the common ranking from 1 to 11 of the objective's importance was set. With this as a basis, a score from 1 to 10 for each objective was given, where higher score represents higher importance.

The weight factor for the objective was then calculated by the score given to it divided by the sum of scores for all objectives. Table 15 in Appendix D shows the ranking and weight factor for the objectives.

Evaluation chart is where the different concepts are evaluated. The two concepts, A and B, were given a score from 1 to 10 for expected compliance with each of the 11 defined objectives; 1-3 acceptable, 4-6 fair, 7-9 good, 10 very good. This multiplied with the earlier derived weight factor representing importance of the individual objective, gives a weighted value. The concept with the highest sum of weighted value would then be the preferred concept. See table 14 in Appendix D.

From the evaluation, concept A, Gangway, achieved a weighted value of 6.61, while concept B, Life raft, got 6.92. Following the procedure, the Life raft was picked as the definite solution. This gives an unbiased ranking of the concepts, where they are evaluated on equal terms.

3.7 Modification and detailing

After performing the stages of the design methodology there was one concept left, concept A "Life raft". The concept consists of both the different parts of the system and the evacuation procedure. Further detailing and modification of the concept was done.

3.7.1 Winch system

From the description of the life raft in chapter 3.5.2.2, the winch system includes two winches with their batteries, pulley, cables, and pillars. After accessing the working simulation of the winch and how it will work in moving the life raft to and from shore, some modifications are implemented to improve the concept.

1. Change of battery powered winch to human powered winch.

This was changed due to the expected lack of steady power source for the winch. The alternative would be addition of more batteries, but this would have increased the weight of the solution, which could hinder carrying to shore.

In addition, the very cold artic weather would rapidly discharge the battery, which makes the use of a battery powered winch limiting and challenging.

2. Replacing sensors with simple radio communication.

Using two battery-powered winches working in opposite/alternating directions means there will be a need to synchronize the motors effectively. The arctic weather conditions could hinder the effectiveness of the sensors, which could reduce the usability of the battery-powered winches.

The change to a human powered winch means that vulnerable sensors can be substituted with simple radio transmitters enabling the crew to communicate during the evacuation exercise.

3. Use of one winch

Since we are changing from the battery-powered winch to the manual winch, we only need one winch compared to having the two battery-powered winches. The pros of using one manual winch are that it weighs less, and there is less risk of failure and power cut is avoided.

4. Removal of the pulley system attached to the lifeboat.

The guideline cable is attached to the lifeboat using a hook. The other cable is attached to the life raft. This eliminates the need for a pulley attached to the lifeboat.

3.7.1.1 Change in the evacuation procedure

Following the modifications in chapter 3.7.1, a new list of equipment parts and working operation is defined. This is a more practical solution that requires less technical input.

The parts that make up the system are listed below:

- Life raft

- Human powered winch
- Cables for
    - Winch
    - Guideline
- Hook attached to lifeboat
- Support pillars
    - For winch
    - For guideline
- Rope
- Connection between life raft and guideline

The steps for the evacuation operation are listed below, see figure 23 for illustration:

1. The lifeboat is positioned, and the life raft is deployed by the crew.
2. The lifeboat has a hook attached to its body frame.
3. The cable that is used for the guideline will be attached to the hook before the crew start paddling.
4. The crew transfers the cables and winch to the life raft and use the oars on the life raft to paddle to shore and assemble the winch and support pillars.
5. Two pillars are set up on shore/ice. One is attached to the guideline and the other to hold the winch in position.
6. The life raft will then be connected to the guideline and winch.
7. The winch is manually turned by the crew which drags the life raft to shore. A rope is used to pull the life raft back to the lifeboat.
8. Passengers are moved from the lifeboat to the life raft and the life raft transfers them to shore.
9. The guideline mentioned in step 3 is attached to the life raft for the purpose of preventing it from drifting off due to strong winds or waves.
10. When the passengers have been successfully transferred, the system can be used for another lifeboat. It can also be used on shore/ice for other purposes.

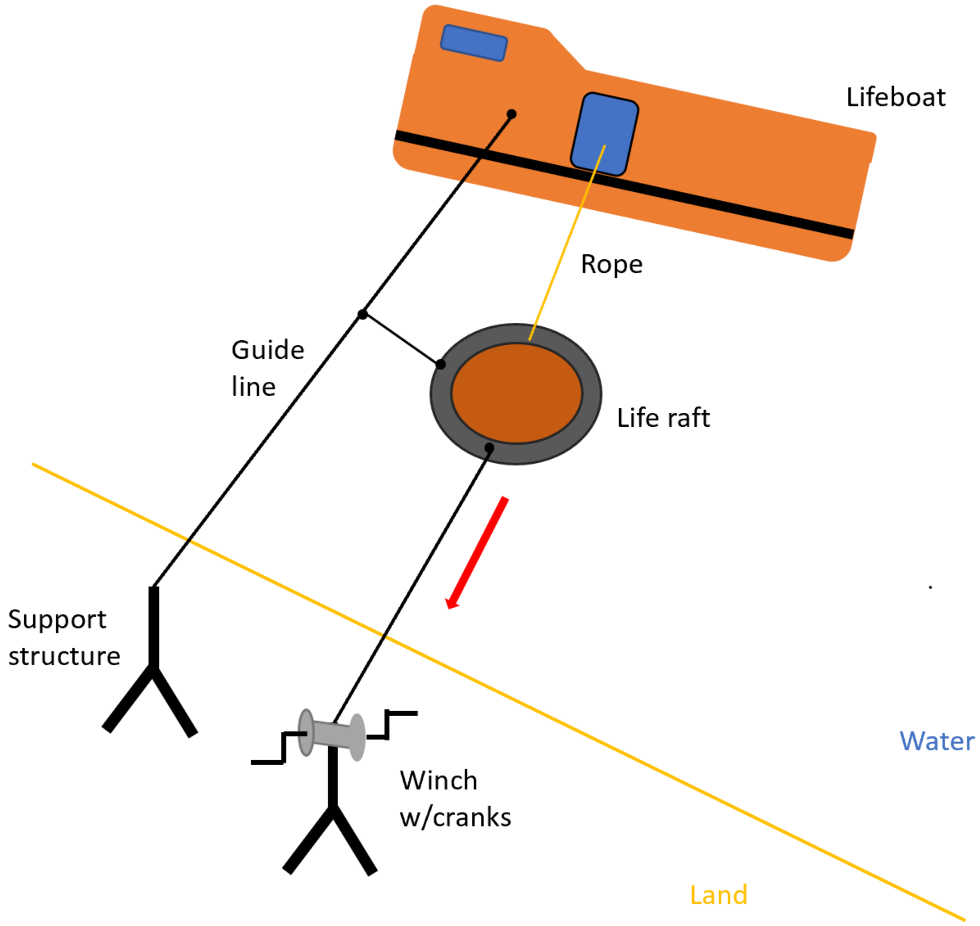


Figure 23: Illustration of the modified life raft solution.

4 Analysis

4.1 Material selection

To find the best materials for setting up the equipment used to evacuate passengers from lifeboat to shore or solid, stable ice, the book, “Material selection in mechanical design” by Michael F. Ashby [40] and material selection software Granta EduPack 2020 were used.

The evacuation concept system has two main parts:

1. Pillar frame.
2. Cable system.

4.1.1 Pillar frame

The pillar is a column that has a winch and guideline attached to it. The column is loaded in bending and should be able to withstand bending moment without breaking. The material should be as light as possible and tough to avoid brittleness. The material must be able to withstand weather conditions of the Arctic region. There are no limits to cost.

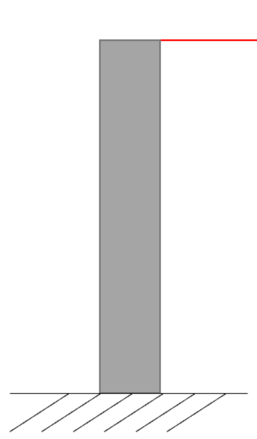


Figure 24: Pillar frame with direction of force and deflection.

Figure 24 shows the pillar frame. Considering the purpose of the pillar frame, we set up a design requirement for it. This covers its functionality, constraints, and objectives. This is shown in table 2 below.

Table 2: Design requirement for the pillar frame

Function	Support structure for the winch and cables
Constraints	Length, L is specific.
	Stiffness – must not deflect too much under design load
	Withstand arctic temperature of -30
	No moisture intake and Water resistant.
	Toughness G_c >1.2KJ/m^2
Objectives	Minimize mass, m
Free variable	Choice of material
	Column radius, r

We obtained the material index, for the design requirement as listed in table 4 above

$$M = \left(\frac{\rho}{E^{\frac{1}{2}}}\right)$$

The material index is maximized. This gives us the maximum value of the stiff column with the lowest mass.

$$M = \left(\frac{E^{\frac{1}{2}}}{\rho}\right)$$

We applied the parameters in the Granta EduPack software and applied limits of toughness, arctic temperature of -30, and water usage capabilities. These are well detailed in the Appendix E.

Table 3: Derived materials for the pillar frame

Material	Material index $(GPa)^{\frac{1}{2}} \Big/ \frac{Mg}{m^3}$	Comment
Titanium alloys	2.3 - 2.4	Light, good mechanical properties.
Commercially pure titanium	2.2 – 2.3	Light, resists corrosion in most chemicals
Cast magnesium alloy	3.7	structural material with high specific strength and low density
CFRP, epoxy matrix	5.5 - 7.7	Offers great stiffness and strength to weight ratio
GFRP, epoxy matrix	2.2 – 2.7	Ductile, tough and can withstand environmental forces.

Following the material selection process, any of the materials in table 3 above could be used for the pillar frame.

4.1.2 Cable system

The cable pulls and guides the life raft from the lifeboat to shore and back to the lifeboat. The cable is under constant tension and must be capable of pulling the design load without breaking, see figure 25. The material of the cable should be as light as possible and must be able to withstand the arctic weather conditions. There are no limits to cost.

Figure 25: A cable with forces acting in both directions.

Considering the purpose of the cable, we set up a design requirement for it. This covers its functionality, constraints, and objectives. This is shown in table 4 below.

Table 4: Design requirement for the cable.

Function	To pull load – Strong and will not break
Constraints	Must have specific stiffness, ${}^{F}/_{\delta}$
	No failure: $\sigma < \sigma_f$ throughout the cable
	Withstand arctic temperature of -30
	No moisture intake and Water resistant.
	Fracture toughness
Objectives	Minimize mass, m
Free variable	Choice of material
	Cross section area, A

We Calculated the material index. In this case, we have two different material indices with respect to the design requirement as listed in table 4 above.

To minimise the mass, we must minimise the material index 1, M

$$M = \left(\frac{\rho}{E}\right)$$

The material index 1, M can be maximised by finding the inverse of the material index 1. This is given as M_1

$$M_1 = \left(\frac{E}{\rho}\right)$$

To obtain the material with minimum mass, we minimise the material index 2,

$$M = \left(\frac{\rho}{\sigma_y}\right)$$

The material index, M can be maximised by finding the inverse of the material index 2. This is given as M_2

$$M_2 = \left(\frac{\sigma_y}{\rho}\right)$$

We applied the parameters in the Granta EduPack software, and applied limits to suit the arctic weather conditions which includes toughness, low temperature of -30°C and water usage capabilities. These are well detailed in Appendix E.

Table 5: Derived materials for the cable

Material	Material index, M_1 $\frac{GPa}{\frac{Mg}{m^3}}$	Material index, M_2 $\frac{MPa}{\frac{Mg}{m^3}}$	Comment
Nickel-chromium alloys	24.1 – 25.9	0.07 – 0.89	Good strength and corrosion resistance
Nickel-based superalloys	25	0.08 – 0.14	High strength with corrosion and oxidation resistance.
Stainless steel	25 – 26.7	0.07 – 0.17	Ductile with good corrosion resistance.
CFRP, epoxy matrix (isotropic)	46 – 93.8	0.37 – 0.66	Offers great stiffness and strength to weight ratio
Cast magnesium alloys	24 - 25	0.07 – 0.15	structural material with high specific strength and low density

Following the material selection process, any of the materials in table 5 above could be used for the cable.

4.2 Cross-section of support structure

We modelled four cross-sections for the support structure in inventor. These are shown in the figures below.

1. Hollow triangle

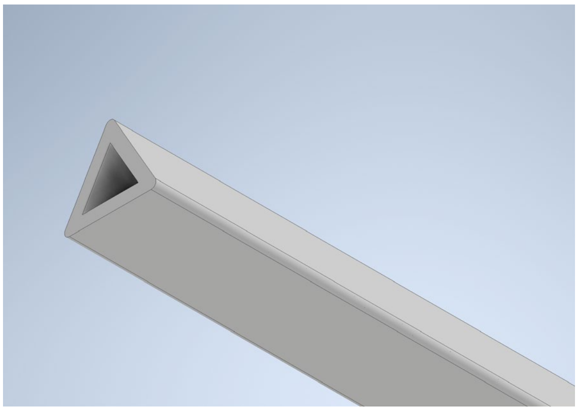


Figure 26: Hollow triangle cross-section.

2. Hollow square

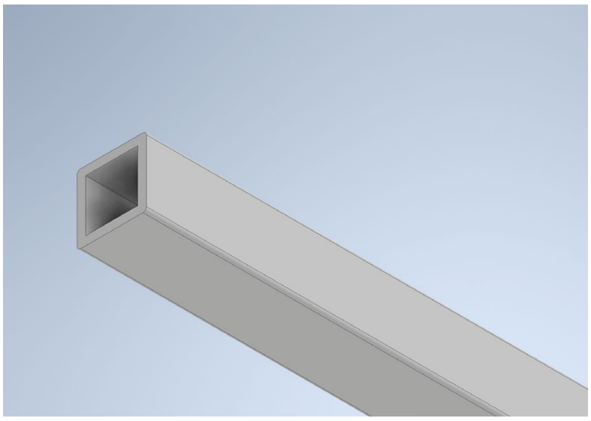


Figure 27: Hollow square cross-section.

3. Elliptical

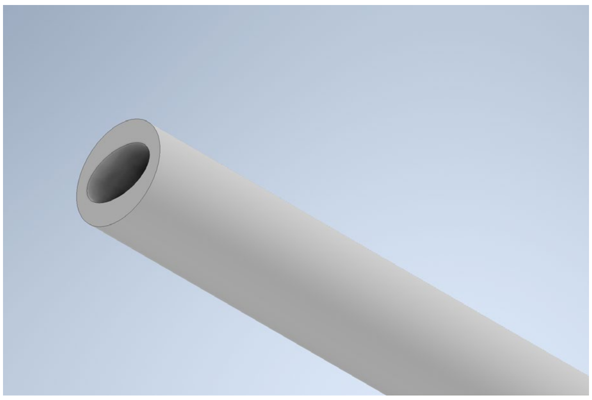


Figure 28: Elliptical cross-section.

4. Cylindrical

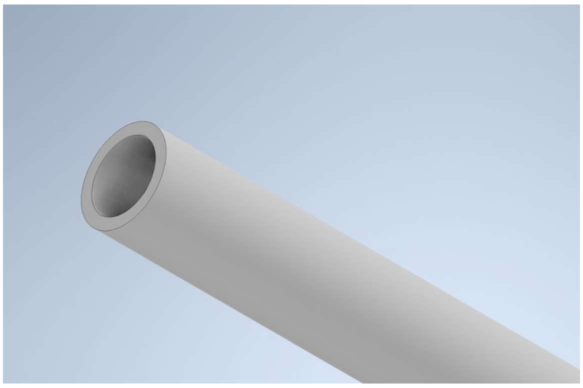


Figure 29: Cylindrical cross-section.

We analysed the cross-sections areas in ANSYS Workbench to derive the best for the support structure. The structure base was fixed, and a force of 30000 N is applied to the other end in the x-direction. The pillar frame is fixed to shore or solid, stable ice, and the guideline and winch attached to the other end, pulling the life raft to shore. This simulates it being used in a real-life situation with the different forces acting on the pillar frame.

We obtained the results for the analysis on ANSYS using two materials, titanium alloys and CFRP, epoxy matrix (isotropic) from the material selection in chapter 4.1.

The ANSYS solution is detailed in Appendix F and the maximum deformation and maximum von Mises stress of the different cross-sections are listed in table 6 below.

Table 6: Analysed result of the cross-sections.

Cross-section	Titanium alloys		CFRP epoxy matrix (isotropic)	
	Maximum Deformation (mm)	Stress (MPa)	Maximum Deformation (mm)	Stress (MPa)
Hollow triangle	2199.8	14796	2311.6	14650
Hollow square	601.97	5438.2	632.63	5343
Elliptical	876.09	5901.3	920.67	5902.6
Cylindrical	1012	6961.9	1063.5	6914.7

From the analysed result derived from ANSYS, we obtain that the hollow square shaped cross-section is best for the pillar frame because it had the lowest maximum deformation.

4.3 Evacuation of passengers

Since the engine which pulls the life raft to shore is human-powered, the winch must require less effort from the operators. In chapter 4.3.1 and 4.3.2 we investigated different set ups for the gear ratio and how the number of passengers in the life raft effects the power needed. In Appendix G there set up more information about the different forces, the winch system, and detailed calculations for the next two sub-chapters.

4.3.1 Gear ratio

The gear system is chosen to be a parallel gear system. The setup is shown in figure 30.

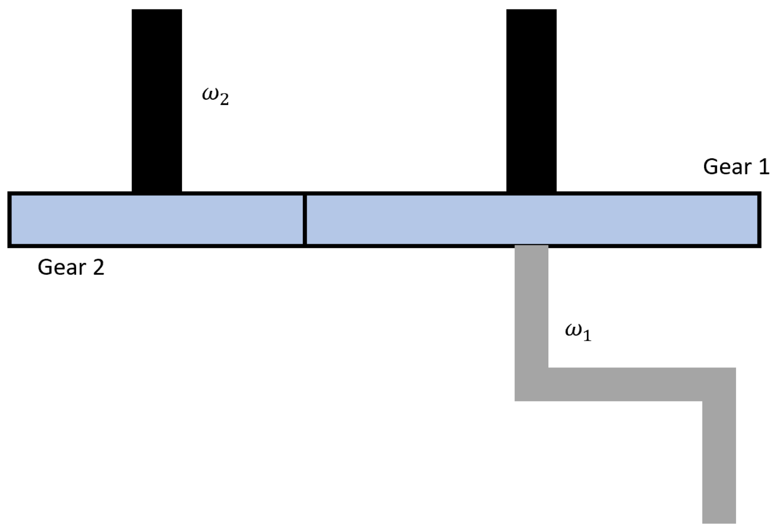


Figure 30 Gear system.

We took a closer look at these cases

- $\omega_1 = 2\omega_2$
- $\omega_1 = \frac{\omega_2}{2}$
- $\omega_1 = \omega_2$

and how the gear ratio affects the winch system.

We started with calculating the velocity of the life raft. From the chapter 3.3, setting requirements, it is stated that the evacuation from lifeboat to land can happen 30 meters from land. It is also stated that the transport time per person is one minute. The velocity, v_{raft}, is found by

$$v_{raft} = \frac{distance}{time}$$

The distance is 30 meters. We decided that maximum capacity of the life raft to be 20 persons. This means that a fully loaded life raft with 20 persons transported from the lifeboat to land must not exceed 20 minutes. This gives

$$v_{raft} = \frac{30\ m}{1200\ s} = 0.025\ {}^{m}/_{s}$$

Under we listed the data needed to find the last numbers to calculate the gear ratio.

- The radius of the spool/shaft was decided to be $r_{Spool} = 0.05\ m$
- The length of the hand crank was decided to be $r_{Crank} = 0.4\ m$
- Sum of forces from life raft, $F_{total\ raft} = 30000\ N$
- Velocity of the raft, $v_{raft} = 0.025\ {}^{m}/_{s}$

The angular velocity, ω_2, was derived by using equation (3) from Appendix G

$$\omega_2 = \frac{v_{raft}}{r_{Spool}} = 0.5\ {}^{rad}/_{s}$$

The torque, τ_{Spool}, needed to pull the life raft was given by equation (1) from Appendix G

$$\tau_{Spool} = F_{total\ raft} \cdot r_{Spool} = 1500\ Nm$$

We have now the needed data to investigate the different scenarios. In table 7 we have all the numbers for the parameters.

Table 7: Data for the gear system.

Radius of the spool/shaft, r_{Spool}	$0.05\ m$
Length of the hand crank r_{Crank}	$0.4\ m$
Sum of forces from life raft, $F_{total\ raft}$	$30000\ N$
Velocity of the raft, v_{raft}	$0.025\ {}^{m}/_{s}$
Angular velocity for Gear 2, ω_2	$0.5\ {}^{rad}/_{s}$
Torque for the spool, τ_{Spool}	$1500\ Nm$

For a closer look at the calculations derived for the gear ratios see Appendix G. The derived results are in table 8.

Table 8: Derived results for the gear ratios.

	Scenario 1, $\boldsymbol{\omega_1 = 2\omega_2}$	**Scenario 2, $\boldsymbol{\omega_1 = \frac{\omega_2}{2}}$**	**Scenario 3, $\boldsymbol{\omega_1 = \omega_2}$**
Gear ratio	2	0.5	1
Force per hand crank	937.5N	3750 N	1875
Power per hand crank	375 W	375 W	375 W

From the derived results the power is equal for all gear ratios, which was as expected. Torque and force varied in relation to gear ratio.

4.3.2 Number of passengers

The number persons in the life raft could have an impact on the power needed to winch it to land. By calculating the power needed for the different cases, we could determine the number of persons in the life raft per transport transition. See detailed calculations in Appendix G.

We put up three cases

- 20 persons
- 15 persons
- 10 persons

Power for 20 persons

In table 9, for 20 persons, the needed data to calculate the power is listed.

Table 9 Data for 20 persons.

Radius of the spool/shaft, r_{Spool}	$0.05\ m$
Sum of forces from life raft, $F_{total\ raft}$, for 20 persons	$16186.5\ N$
Velocity of the raft, $v_{raft,20p}$	$0.025\ {}^{m}/_{s}$
Angular velocity for Gear 2, $\omega_{2,20p}$	$0.5\ {}^{rad}/_{s}$
Torque for the spool, $\tau_{Spool,20p}$	$809.3\ Nm$

It is assumed that all gear meshes transmit power with approximately 100% efficiency because of parallel shaft, the power is given by

$$Power\ in = Power\ out = \tau_{Spool,20p} \cdot \omega_{2,20p} = 404.7\ W$$

This means that for one hand crank the power needed is 202.3 W.

Power for 15 persons

In table 10, for 15 persons, the needed data to calculate the power is listed.

Table 10: Data for 15 persons.

Radius of the spool/shaft, r_{Spool}	$0.05\ m$
Sum of forces from life raft, $F_{total\ raft}$, for 15 persons	$12139.9\ N$
Velocity of the raft, $v_{raft,15p}$	$0.033\ {}^{m}/_{s}$
Angular velocity for Gear 2, $\omega_{2,15p}$	$0.67\ {}^{rad}/_{s}$
Torque for the spool, $\tau_{Spool,15p}$	$607\ Nm$

It is assumed that all gear meshes transmit power with approximately 100% efficiency because of parallel shaft, the power is given by

$$Power\ in = Power\ out = \tau_{Spool,15p} \cdot \omega_{2,15p} = 406.7\ W$$

This means that for one hand crank the power needed is 203.3 W.

Power for 10 persons

In table 11, for 10 persons, the needed data to calculate the power is listed.

Table 11: Data for 10 persons.

Radius of the spool/shaft, r_{Spool}	$0.05\ m$
Sum of forces from life raft, $F_{total\ raft}$, for 10 persons	$8093.3\ N$
Velocity of the raft, $v_{raft,10p}$	$0.05\ {}^{m}/_{s}$
Angular velocity for Gear 2, $\omega_{2,10p}$	$1\ {}^{rad}/_{s}$
Torque for the spool, $\tau_{Spool,10p}$	$404.7\ Nm$

It is assumed that all gear meshes transmit power with approximately 100% efficiency because of parallel shaft, the power is given by

$$Power\ in = Power\ out = \tau_{Spool,10p} \cdot \omega_{2,10p} = 404.7\ W$$

This means that for one hand crank the power needed is 202.3 W.

5 Final product

The life raft concept is suitable for the harsh Arctic environment. No motor driven appliances are then needed, which could easily fail. It is crucial to have non-complicated systems, both because of harsh conditions and the human factor to be able to operate this in stressed situations. In that aspect the proposed procedure is achievable if the ship crew is thoroughly drilled in operating the system. The system is self-evident, which also gives the passengers the possibility to help in the necessary operations. Such work could help them keep warm, and bring their minds away from the scary situation they are in.

As the system is technically quite simple, it should not be very costly to manufacture, and could most likely be used on existing lifeboats with only minor adjustments.

The final product of the evacuation concept system is illustrated using inventor. This is shown in figure 31. The images are rendered, and a 3D prototype is generated. The parts and assembly of the structure can be found in Appendix I.

The support structure and its components are highlighted below.

Main Pillar frame

The mainframe of the support structure holds up most of the load exerted by the concept system. It is secured onshore by hammering it into the shore or solid ice. The guideline and winch is attached to the central pillar frame on top.

The support for the pillar frame

They increase support and stability for the pillar frame. The exerted load is distributed to them to ease the pressure on the mainframe. The length could be adjusted to suit different topography of the shore or solid ice.

Hammer

It is used to hammer the pillar frame into the shore. This is an off-shelf product widely used for securing fences on the floor.

Cable

- It is attached to the lifeboat, life raft and the support pillar frame. It prevents the life raft from drifting away due to weather forces.
- It is attached to the life raft and the winch. The cable is pulled using the winch, pulling the loaded life raft to shore.

Rope

It is attached to the lifeboat and life raft. It is used to pull the life raft back to the lifeboat. It also works as an additional guideline to keep the life raft from drifting.

Winch

The winch is human powered, and it is attached to the main pillar frame of the support structure. It has two handle cranks. The cable from the winch is attached to the life raft and it drags the loaded life raft from the lifeboat to shore.

Support structure

This is how the device will be visualised when manufactured, figure 31,

Figure 31: Final setup of support structure

This is how the system will be visualised in operation. The procedure for evacuation is listed in chapter 3.7.1.1.

6 Conclusion

The development of concepts for the evacuation of passengers from lifeboat to shore or solid, stable ice in the arctic region is an entirely new concept system that has not been done earlier. It is an area that has not been investigated until recently. The lack of knowledge, routines and documentation regarding search and rescue in the arctic region is evident during the search for similar solutions.

The design concept we developed in this project is based on simplicity, practicality, versatility, and protection of passengers. This follows the adaptation of real-life knowledge and experiences to create a usable system for the evacuation of passengers from the lifeboat to shore or solid, stable ice in the arctic region. It follows the design stages [37], modelling using Inventor, structural analysis using ANSYS, and material selection process using the Granta EduPack in creating the concept.

The concept we obtained was chosen after following the design steps as highlighted in chapter 3. The usage of already available, off-shelf products like the life raft and the winch gives the users a sense of safety and confidence in using the concept.

7 Discussion and further work

The basis for our master thesis is to find a solution to evacuating passengers from a lifeboat to shore or stable, solid ice in the arctic region. Up to date no extensive effort has been put into finding solutions to this issue. As the ship traffic in the artic area increases, it is getting more crucial to find solutions to this matter. Through our work we have initiated several potential solutions but concluded the “Life raft” concept to be the most favourable solution.

To define the design criteria, work has been performed to define limitations. Through our research these limitations are set to include typical ships frequenting arctic areas, and the safety and evacuation equipment these ships normally carry. In addition, the solutions are set in context with the marine safety regulations. We have also performed a major research on existing safety evacuation equipment and arctic weather conditions, and we had the possibility to join an on-site rescue operation exercise on the MS Gann in March 2020. This gave us more hands-on experience with current evacuation equipment and the usage of such, and highly important input to our further work.

This work formed the basis for defining what objectives the concept should fulfil, and the requirements defining the performance specification of the product. Several possible concepts were identified but analysing their compliance with the defined objectives and performance specifications reduced the number of alternatives we further investigated to two, whereof the ‘Life raft’ solution was one of these two. These two concepts were further detailed, and a thorough work was performed by an extended team to evaluate how the concepts obtained the defined objectives. Based on this the “Life raft” solution was ranged as the most preferrable solution, mainly by being a more safe and robust solution compared with the “Gangway” solution.

The “Life raft” solution was then further modified to be even more simplified and robust by introducing a less comprehensive winching system. The proposed concept contains a conventional life raft transporting people ashore by using a manual winching system. Calculations have been made of the pillar frame as an onshore basis for fastening the winch and guideline, cable system and support structure, in order to verify the robustness of the proposed concept.

Based on our work, the “Life raft” is evaluated to be the most applicable solution, and the calculations and analyses we have performed substantiates the robustness of this solution. A further development should enable this solution to be a valid evacuation concept.

Further work

Although there is a selection of concept that has been completed in this thesis with supporting calculations and analysis, a further detailed design needs to be worked out to turn the concept into a real product. In the event of further work of this project, some of the future work that could be carried out are highlighted below:

- Make a prototype of the concept solution and carry out a test in real-life environment. Can perform exercises in various areas. Deep seabed, shallow seabed, beach, ice, rocky, could be some of the test scenarios.
- Research of forces acting on the concept solution. Waves, wind, and drag.
- Positioning, anchoring and mooring of the lifeboat.
- Explore the other generated concepts.
- Investigate the cost of production and manufacturing process.
- Material selection – shape factor should be considered for lighter material.
- More analysis could be done on the support structure and winch system.

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Appendix A Suggested equipment lists from the Polar Code for PSK and GSK

The suggested equipment lists from the Polar Code:

Table 12: Personal Survival Kit (PSK) [7, p. 34]

PSK – Suggested equipment
Protective clothing (hat, gloves, socks, face, and neck protection, among others.)
Skin protection cream
Thermal protective aid
Sunglasses
Whistle
Drinking mug
Penknife
Polar survival guidance
Emergency food
Carrying food

Table 13: Group Survival Kit (GSK) [7, p. 34]

GSK – Suggested equipment
Shelter – tents or storm shelters or equivalent – sufficient for the maximum number of persons
Thermal protective aids or similar – sufficient for the maximum number of persons
Sleeping bags – sufficient for at least one between two persons
Foam sleeping mats or similar – sufficient for at least one between two persons
Shovels – at least 2
Sanitation (e.g. toilet paper)

Stove and fuel – sufficient for the maximum number of persons ashore and maximum anticipated time of rescue
Emergency food – sufficient for the maximum number of persons ashore and maximum anticipated time of rescue
Flashlights – one per shelter
Waterproof and windproof matches – two boxes per shelter
Whistle
Signal mirror
Water containers and water purification tablets
Spare set of personal survival equipment
Group survival equipment container (waterproof and floatable)

Appendix B Determining characteristics

Costumer Attributes	CA Importance	Compact when stored	Manually deployment	Inert gas deployment	Buoyancy	Weather resistance	Repurpose	Stability	Mass	Material rigidity	Visibility
Can evacuate passengers safely	9				✓	✓		✓		✓	✓
Easy to install/incorporate the design on the lifeboat	8	✓	✓	✓					✓		
Easy to deploy, including anchoring one end on shore/ice	8			✓					✓		✓
Can be used in waves	8		✓	✓	✓	✓		✓		✓	
Occupy minimal space outside/inside the boat	8	✓		✓			✓		✓		
Can be used with any type of shore(rocks, sand, fast ice, etc)	8		✓	✓	✓	✓	✓	✓		✓	✓
Applicable to all types of lifeboats	8	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quick transfer of passangers from boat to shore	8			✓				✓		✓	✓
Low number of trained personnel needed to execute the solution	7			✓					✓		✓
Low cost	5		✓								
Zero chances of users getting wet	4				✓	✓					
Can use the power available on the lifeboat	3							✓			✓
	EC Importance	3	5	8	5	5	3	6	5	5	7

Figure 32: The determining characteristics matrix

Appendix C Morphological chart

From chapter 3.5 Generating alternatives. Morphological charts for the two concepts without the lines.

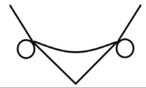
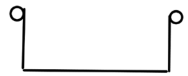
	Functions / features	Sub-solutions 1	2	3	4	5	6	7
1	Floating element	Inflatable	Buoys/ floating balls	Foam	Hybrid of inflatable and fabric	Hybrid of inflatable and Foam	Fabric	Wood
2	Stability / shape to increase stability (Cross-section of the lower part of the gangway)							
3	Device to guide passengers to shore	Rope	Hand rails	Human chain (passengers connected to eachother)	Light	Reflector		
4	Structural support to prevent failure	Rings fixed to the structure	Wire going through the structure	Rings fixed to the structure with a link between them	Support pillars	Solid fences on the side with connecting ropes	Solid base	
5	Mounted / Positioned to lifeboat	Inside on the door	Inside on one of the sides of the door	Outside on the door	Outside on one of the sides of the door	Half inside and half outside	MOB Boat setup	
6	Prevent water	Fully covered (base, sides, top)	Closed on the sides and base	Base only				
7	System of deployment	Pull out	Explodes	Already deployed	Manual pump	Engine pump		
8	Fastening tool to land	Harpoon to land	Hooks	Spikes	Mooring rope	Handdrill (screw/nails)		

Figure 33: Morphological chart for «Tube type gangway»

	Functions / features	Sub-solutions 1	2	3	4	5	6
1	Stability / device to increase stability	Support pillar on shore/ice	Additional control cable	Anchor			
2	Power source for the system	Human power	Manual machine	Diesel engine	Petrol engine	Electrical engine	
3	Transmission	Belts	Chains	Ropes	Wire	Oars	
4	Operating location	Lifeboat	Life raft	Land			
5	Propulsion	Wheels	Moving line	Propeller			
6	Fastened to land by	Harpoon to shore/ice	Anchor	Spikes	Human holding	Screw/nails with handdrill	
7	Number of support point on land	1	2	3	4	5	
8	Transmission attachment to lifeboat	Middle	Top, over the escape doors	Rear end	Front end	Top, over the steering house	MOB Boat setup
9	Transmission attachment to liferaft	Inside liferaft	Outside liferaft				
10	Evacuation equipment	Part of lifeboat	Carried on board lifeboat	Carried on board liferaft			

Figure 34: Morphological chart for «Life raft with winch»

Appendix D Evaluating alternatives chart

Table 14: The evaluation of the concepts

	Objective/Feature/ Function/Requirement	Description	Weight factor	Concepts					
				A Gangway			B Life raft		
				Score	Weighted Value	Explanation	Score	Weighted Value	Explanation
A	**Safe**	The device does not fail when exposed to the different forces like weather and load.	0,14	7	0,98	The shape, fabric, supporting rings, support cables and hooks.	8	1,12	The life raft, cablesystem, support ropes.
B	**Simple to use**	Easy to deploy, operating mechanism and passenger use.	0,11	6	0,66	The device is pulled out and secured to a hook, post or pillar on shore or ice.	5	0,55	Set up the cable system with the pulleys. Life raft guided to shore and back by cable system.
C	**Compact when stored**	Shaped such that storage is easy.	0,09	7	0,63	The system is fixed on to the side of the lifeboat. With half of it inside and the other half outside.	7	0,63	Cable system, two engines and cable, is stored inside of the lifeboat. The pillars are stored on the lifeboat.
D	**Multifunctional**	Can be used with any type of shore and the system can serve another purpose after the evacuation.	0,06	8	0,48	The device can be used on ice or land. The fabric with the device components can be used as sleeping bags, tents and other uses on dry land.	7	0,42	Cable system can be mounted into ice and sand. The cables and the life raft can be used for tent, making a camp.
E	**Reusability**	The device can be repacked and reused several times.	0,01	3	0,03	The device is packed up and returned to its case for it to be used for another evacuation process.	4	0,04	The device is packed up and returned to its case for it to be used for another evacuation process.

The evaluation continues the next page.

	Objective/Feature/ Function/Requirement	Description	Weight factor	Concepts					
				A Gangway			B Life raft		
				Score	Weighted Value	Explanation	Score	Weighted Value	Explanation
F	**Stability**	Returns to stable position if disturbed.	0,12	6	0,72	The shape of the gangway is such that if it tilts to a side, it returns to its stable position. It also has cables that helps in stability.	8	0,96	The life raft itself is stable. Support ropes to keep the life raft in position.
G	**Water resistant**	Protects passengers from water.	0,11	8	0,88	The gangway is fully covered and prevents water from getting to the passengers.	7	0,77	Life raft's material is water resistant. Has two openings in the top of it.
H	**Visibility**	Easy to see the device at night and in bad weather conditions.	0,06	8	0,48	It stretches all the way to shore from the lifeboat. It is visible to see.	6	0,36	Life raft has a distinct colour orange and light on top.
I	**Robust appearance**	How safe the device looks and feels when being used.	0,08	4	0,32	The gangway might not look solid from the outside because of its length.	8	0,64	Life raft should give a robust feeling, made for survival in open sea.
J	**Time frame**	Swift deployment of the device and time for the passengers to get to shore.	0,11	7	0,77	The device only must be assembled once, and it does not need any other input till all passengers are transferred from lifeboat to shore.	7	0,77	The system could spend time on getting to shore and back. Has the possibility to take many passengers at a time.
K	**Weather resistance**	Resistance to the harsh arctic weather.	0,11	6	0,66	The gangway is resistant to harsh weather condition, but the wind is a major concern because of its potential length to shore/ice.	6	0,66	Life raft can carry passengers in any type of condition, supporting ropes will help in harsh areas. Cable system could get icing on the wire/cable, must de-ice.
	Total sum of Weighted value				**6,61**			**6,92**	

Table 15: Importance rank and weight factor for the evaluation.

	Objectives	Importance rank				Total	Ranking	Score	Weight factor [score/sum of score(65)]
		M	**B**	**D**	**A**				
1	Safe	1	1	1	1	4	1	9	0,14
2	Simple to use	6	5	4	5	20	5	7	0,11
3	Compact when stored	8	7	10	9	34	9	6	0,09
4	Multifunctional	10	10	11	11	42	11	4	0,06
5	Reusability	9	11	9	10	39	10	1	0,01
6	Stability	3	4	6	2	15	3	8	0,12
7	Water resistant	2	2	3	3	10	2	7	0,11
8	Visibility	11	8	7	4	30	8	4	0,06
9	Robust appearance	5	9	8	6	28	7	5	0,08
10	Time frame	7	6	2	7	22	6	7	0,11
11	Weather resistance	4	3	5	8	20	4	7	0,11

Appendix E Material selection

To find the best materials for setting up the equipment used to evacuate passengers from lifeboat to shore or solid, stable ice, the book, “Material selection in mechanical design” by Michael F. Ashby [40] and material selection software Granta EduPack 2020 were used.

The evacuation concept system has two main parts:

1. Pillar frame.
2. Cable system.

Pillar frame

The pillar is a column that has a winch and guideline attached to it. The column is loaded in bending and should be able to withstand bending moment without breaking. The material should be as light as possible and tough. The material must be able to withstand weather conditions of the arctic region. There are no limits to cost.

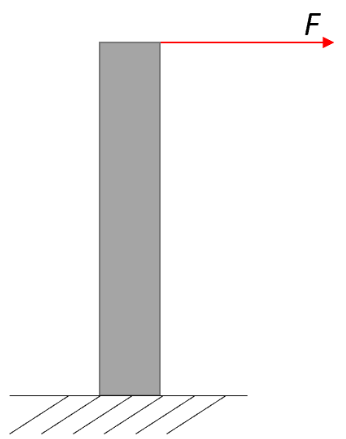


Figure 35: Pillar frame with direction of force and deflection.

Figure 35 shows the pillar frame. Considering the purpose of the pillar frame, we set up a design requirement for it. This covers its functionality, constraints, and objectives. This is shown in table 16 below.

Table 16: Design requirement for the pillar frame

Function	Support structure for the winch and cables
Constraints	Length, L is specific.
	Stiffness – must not deflect too much under design load
	Withstand arctic temperature of -30
	No moisture intake and Water resistant.
	Toughness G_c >1.2KJ/m^2
Objectives	Minimize mass, m
Free variable	Choice of material
	Column radius, r

Stiffness index

Objective function,

$$m = A\rho L$$
$$m = (\pi r^2)\rho L \tag{1}$$

where m is mass, A is the cross-section area, ρ is density, L is length, and r is the radius.

Bending stiffness, S,

$$S = \frac{F}{\delta} \tag{2}$$

where F is the force and δ is deflection.

Deflection of a beam,

$$\delta = \frac{FL^3}{C_1 EI} \tag{3}$$

For a cantilever beam, $C_1 = 3$ from appendix B.3 [40, p. 602], E is Youngs modulus, and I is moment of inertia. Putting equation (3) into (2), we obtain that;

$$S = \frac{C_1 EI}{L^3} \tag{4}$$

Moment of inertia of the circular beam,

$$I = \frac{\pi}{4} r^4 \tag{5}$$

from the appendix, B.2 [40, p. 601]. Inserting equation (5) into (4), we obtain that

$$S = \frac{3\pi r^4 E}{4L^3}$$

Solving with respect to the column radius, r, we obtain that

$$r^4 \le \frac{4\pi S L^3}{3E}$$

$$r \le \left(\frac{4}{3}\pi S \frac{L^3}{E}\right)^{\frac{1}{4}} \tag{6}$$

Inserting equation (6) into (1), we get

$$m \ge \pi \left[\left(\frac{4}{3}\pi S \frac{L^3}{E}\right)^{\frac{1}{4}}\right]^2 \rho L$$

This can be expanded as

$$m \ge \pi^{\frac{3}{2}} \left(\frac{4}{3}\right)^{\frac{1}{2}} S^{\frac{1}{2}} L^{\frac{5}{2}} \left(\frac{\rho}{E^{\frac{1}{2}}}\right)$$

We obtain the material index, M,

$$M = \left(\frac{\rho}{E^{\frac{1}{2}}}\right)$$

The material index is maximized. This gives us the maximum value of the stiff column with the lowest mass.

$M = (E^{\frac{1}{2}}/\rho)$ is maximised and the logarithmic form is

$$\log(\rho) = \frac{1}{2}\log(E) + \log(M)$$

$$\log(E) = 2log\rho + 2logC,$$

which represents the following expression describing the slope of the guideline in figure 37 below

$$y = 2x + Constant.$$

Applying the material index, M, and slope value into the Granta EduPack 2020 material selection software. We set the software in level 2 and applied limits of excellent water usage, both fresh and salt, and the toughness which is derived in the equation below.

$$G_{1c} = \frac{K_{1c}^2}{E(1+v)}$$

where K_{1c}^2 is fracture toughness and v is poison ratio.

The following results were obtained:

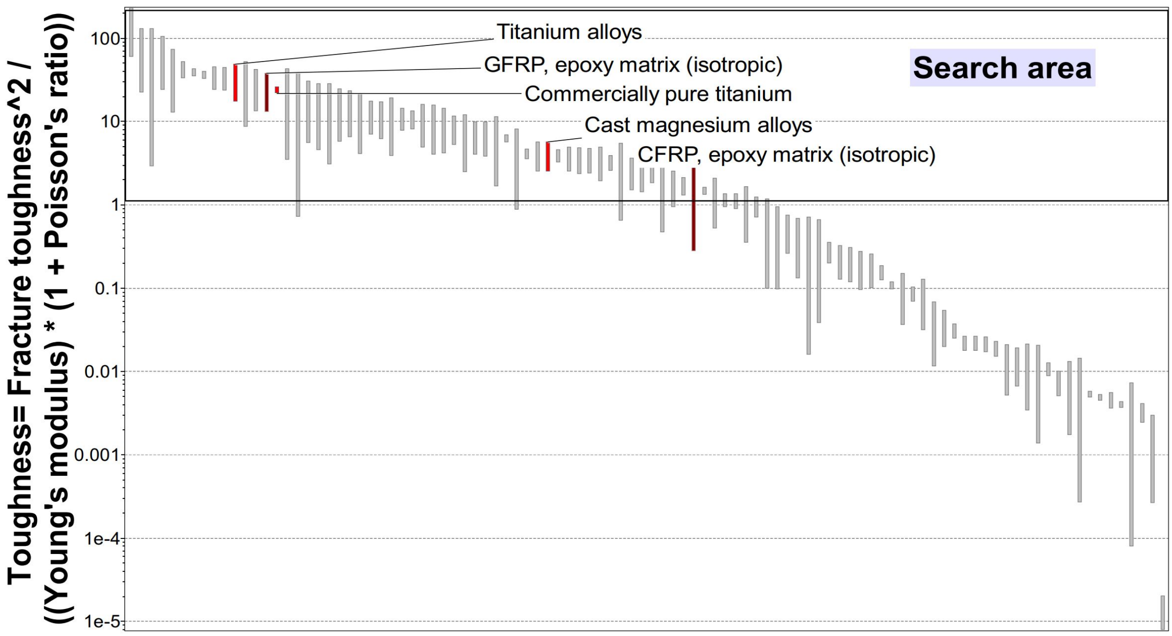


Figure 36: Toughness chart for the pillar frame.

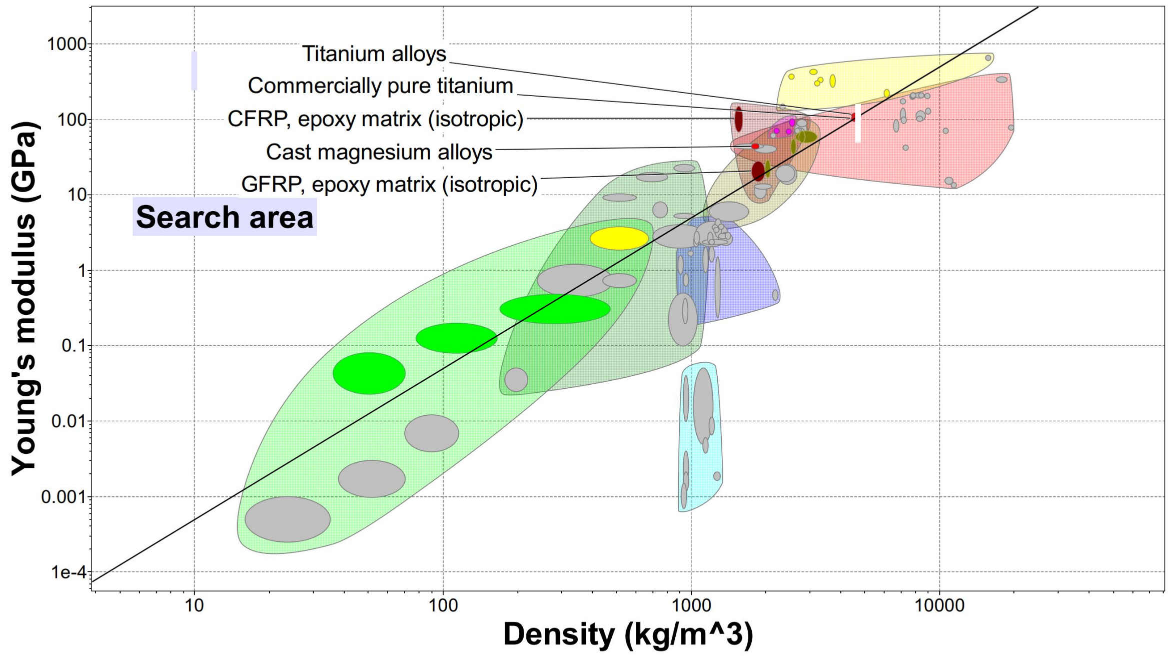


Figure 37: Pillar frame stiffness chart.

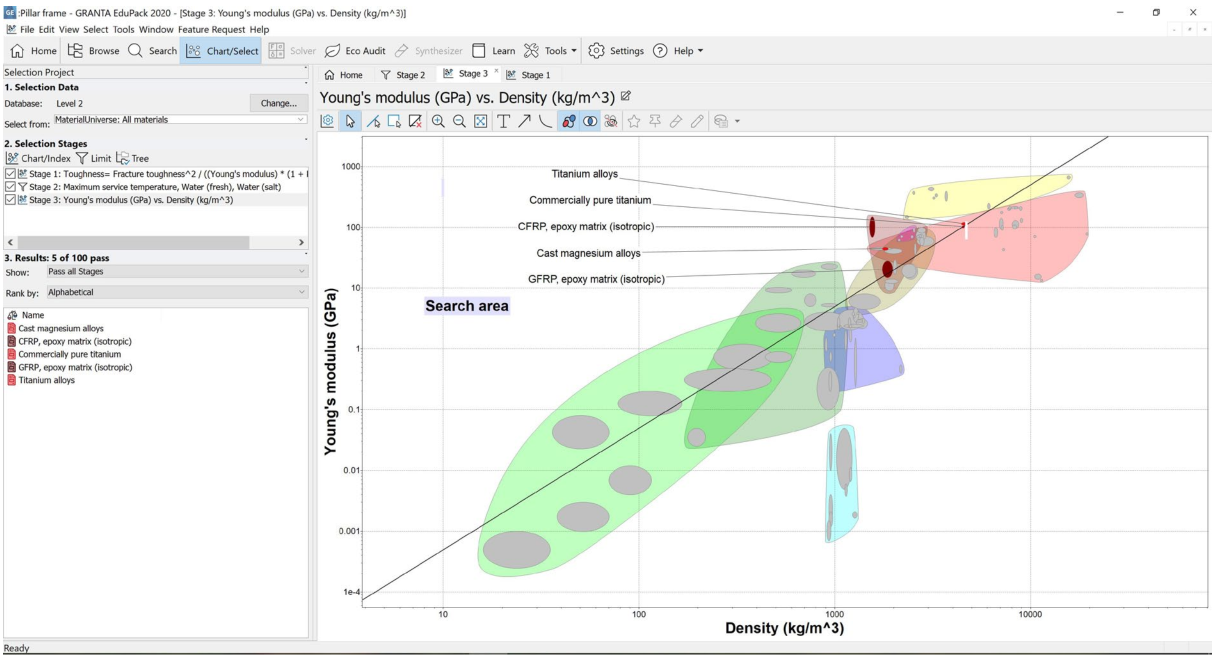


Figure 38: Derived materials for the pillar frame.

The materials derived are listed in table 17 below and the material indices are calculated.

Table 17: Derived material for the pillar frame.

Material	Material index $(GPa)^{\frac{1}{2}} / \frac{Mg}{m^3}$	Comment
Titanium alloys	2.3 - 2.4	Light, good mechanical properties.
Commercially pure titanium	2.2 – 2.3	Light, resists corrosion in most chemicals
Cast magnesium alloy	3.7	structural material with high specific strength and low density
CFRP, epoxy matrix	5.5 - 7.7	Offers great stiffness and strength to weight ratio
GFRP, epoxy matrix	2.2 – 2.7	Ductile, tough and can withstand environmental forces.

Following the material selection process, any of the materials in table 17 above could be used.

Cable system

The cable pulls and guides the life raft from the lifeboat to shore and back to the lifeboat. The cable is under constant tension and must be capable of pulling the design load without breaking, see figure 39. The material of the cable should be as light as possible and must be able to withstand the arctic weather conditions. There are no limits to cost.

Figure 39: A cable with forces acting in both directions.

Considering the purpose of the cable, we set up a design requirement for it. This covers its functionality, constraints, and objectives. This is shown in table 18 below.

Table 18: Design requirement for the cable.

Function	To pull load – Strong and will not break
Constraints	Must have specific stiffness, F/δ
	No failure: $\sigma < \sigma_f$ throughout the cable
	Withstand arctic temperature of -30
	No moisture intake and Water resistant.
	Fracture toughness
Objectives	Minimize mass, m
Free variable	Choice of material
	Cross section area, A

Objective function 1,

$$m = A\rho L$$
$$A = \frac{m}{\rho L} \quad (1)$$

where m is mass, A is cross-section area, ρ is density, and L is length. Stiffness, S,

$$S = \frac{F}{\delta} = EA \quad (2)$$

where F is the force, δ is deflection and E is Youngs modulus. Substituting the value of the area, A, in equation (1) in equation (2)

$$S = EA = E\left(\frac{m}{L\rho}\right) \tag{3}$$

To obtain stiffness in the cable, the critical stiffness, S_{cr}, must be less than the stiffness

$$S_{cr} \leq S = E\left(\frac{m}{L\rho}\right) \tag{4}$$

Solving equation (4) with respect to the free variable, mass, m:

$$m \geq S_{cr}L\left(\frac{\rho}{E}\right) \tag{5}$$

To minimise the mass, we must minimise the material index 1,

$$M = \frac{\rho}{E}$$

The material index 1, M can be maximised by finding the inverse of the material index 1. This is given as M_1

$$M_1 = \frac{E}{\rho}$$

M_1 is maximised and the logarithmic form is

$$\log(\rho) = \log(E) + \log(M)$$

$$\log(E) = \log(\rho) + \log(M).$$

This represents the following expression describing the slope of the guideline in figure 41 below

$$y = x + constant\ C.$$

Objective function 2,

$$m = A\rho l \tag{6}$$

Tensile load, σ,

$$\frac{F}{A} = \sigma \leq \sigma_y \tag{7}$$

where σ_y is yield strength. Making the free variable area, A, the subject of equation (7), we obtain that

$$A \leq \frac{F}{\sigma_y} \tag{8}$$

We insert equation (8) into equation (6) to obtain an equation for the mass, m,

$$m \geq \left(\frac{F}{\sigma_y}\right) L\rho = FL\left(\frac{\rho}{\sigma_y}\right)$$

To obtain the material with minimum mass, we minimise the material index 2,

$$M = \frac{\rho}{\sigma_y}$$

The material index, M can be maximised by finding the inverse of the material index 2. This is given as M_2

$$M_2 = \frac{\sigma_y}{\rho}$$

M_2 is maximised and the logarithmic form is

$$\log(\rho) = \log(\sigma_y) + \log(M_2)$$

$$\log(\sigma_y) = \log(\rho) + \log(M_2)$$

which represents the following expression describing the slope of the guideline in figure 42 below

$$y = x + constant\ C.$$

We set the software in level 2 and applied limits of excellent water usage, both fresh and salt, and the toughness which is derived in the equation below.

$$G_{1c} = \frac{K_{1c}^2}{E(1+v)}$$

Setting the limits for toughness, the following result were obtained for the toughness:

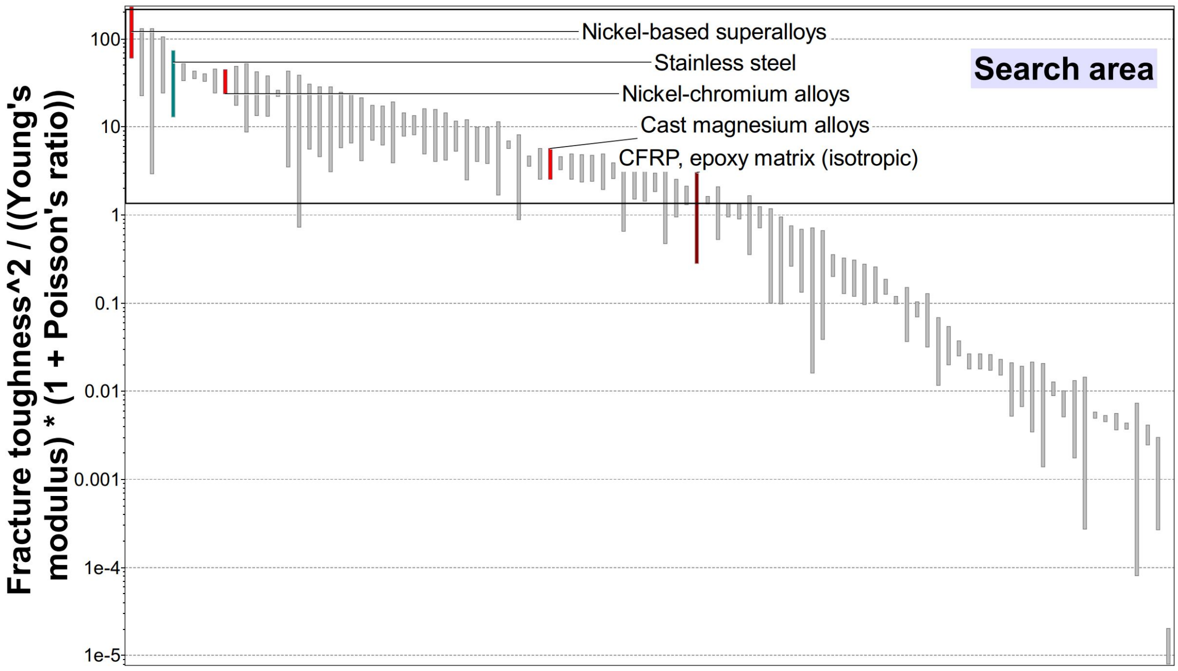


Figure 40: Cable toughness chart.

Applying the material index, M_1 and slope value into the Granta EduPack material selection software, the following results were obtained for the stiffness:

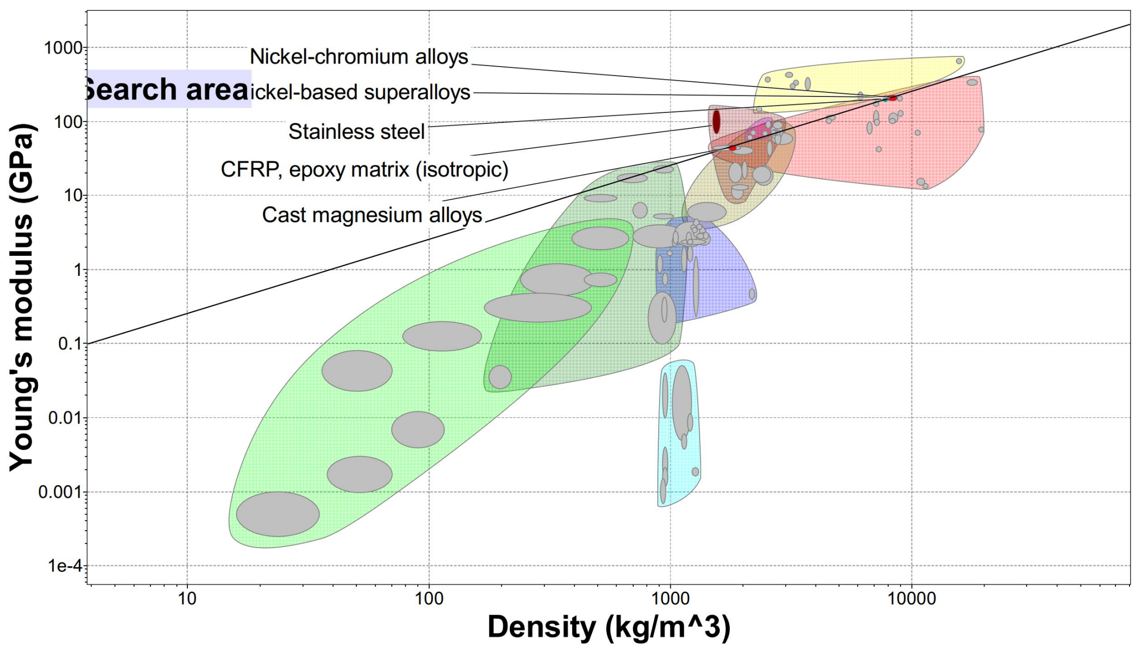


Figure 41: Cable stiffness.

Applying the material index, M_2 and slope value, 1 into the Granta EduPack material selection software, the following results were obtained for the cable strength.

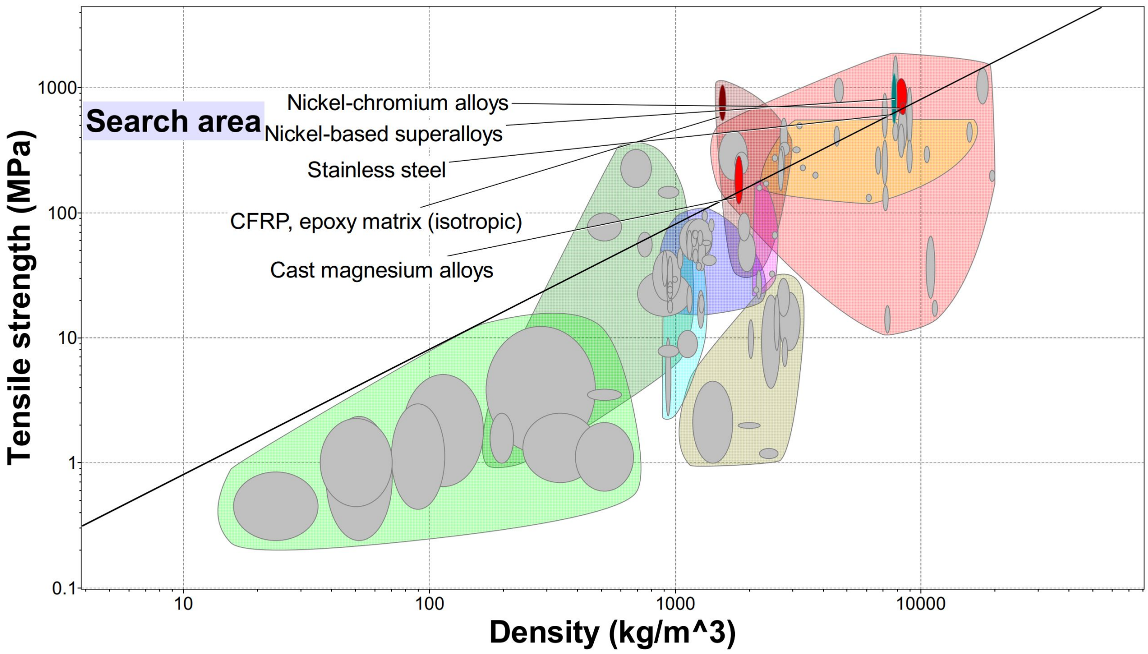


Figure 42: Materials for the cable strength.

The material indices M_1 and M_2 were also applied together on the same chart. This is to confirm the relationship between the stiffness and the strength of the cable. This is shown in figure 43 below:

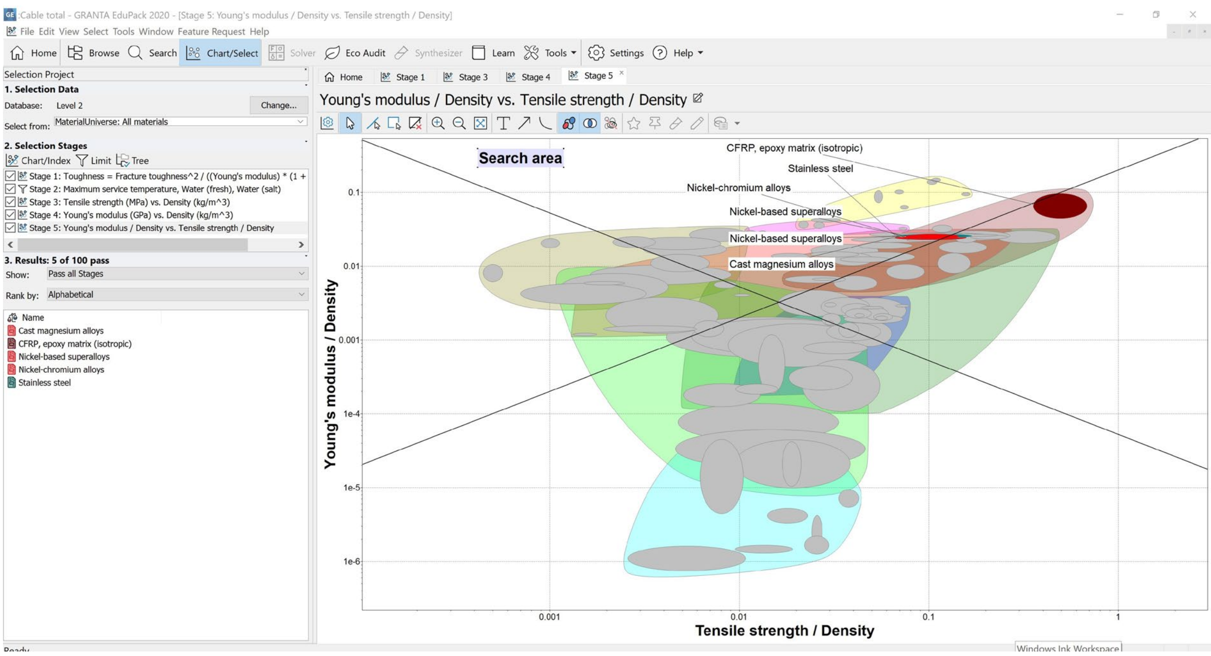


Figure 43: Derived materials for the cable

The materials derived are listed in table 19 below and the material indices are calculated.

Table 19: Derived materials for the cable.

Material	Material index, M_1 $GPa/\frac{Mg}{m^3}$	Material index, M_2 $MPa/\frac{Mg}{m^3}$	Comment
Nickel-chromium alloys	24.1 – 25.9	0.07 – 0.89	Good strength and corrosion resistance
Nickel-based superalloys	25	0.08 – 0.14	High strength with corrosion and oxidation resistance.
Stainless steel	25 – 26.7	0.07 – 0.17	Ductile with good corrosion resistance.
CFRP, epoxy matrix (isotropic)	46 – 93.8	0.37 – 0.66	Offers great stiffness and strength to weight ratio
Cast magnesium alloys	24 - 25	0.07 – 0.15	structural material with high specific strength and low density

Following the material selection process, any of the materials in table 19 above could be used.

Appendix F Cross section of support structure

We modelled six cross-sections for the support structure in inventor. These are shown in the figures below.

1. Hollow triangle

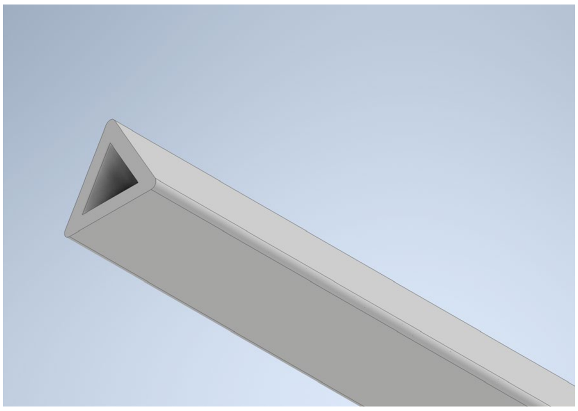


Figure 44: Hollow triangle cross-section.

2. Hollow square

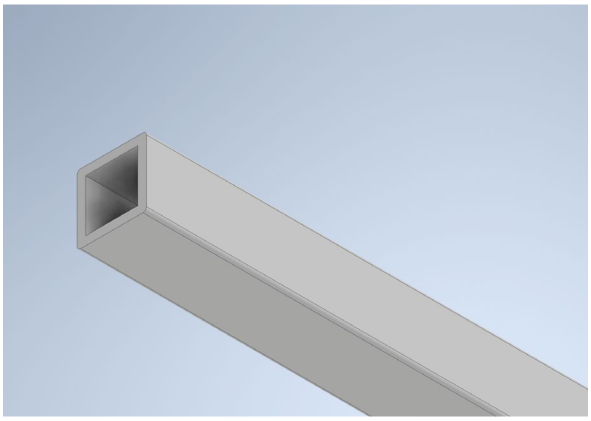


Figure 45: Hollow square cross-section.

3. Elliptical

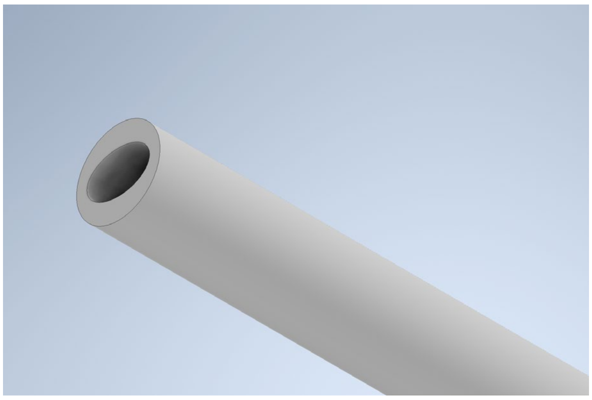


Figure 46: Elliptical cross-section.

4. Cylindrical

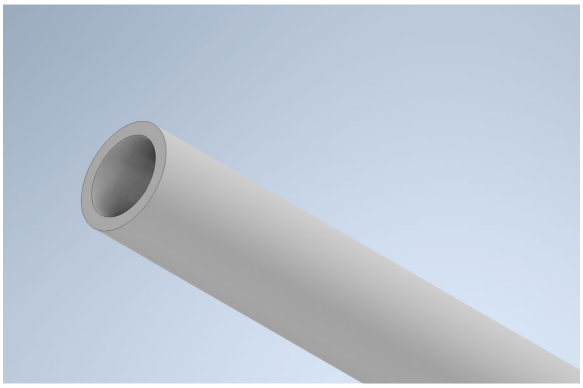


Figure 47: Cylindrical cross-section.

To get the best shape for the pillar frame, we must analyse them. This is done in the ANSYS Workbench to derive the best cross-sectional area for the support structure. The structure base was fixed, and a force of 30000N is applied to the other end in the x-direction. The pillar frame is fixed to shore or solid, stable ice, and the guideline and winch attached to the other end, pulling the life raft to shore. This simulates it being used in a real-life situation with the different forces acting on the pillar frame.

We obtained the results for the analysis on ANSYS using two materials, titanium alloys and CFRP, epoxy matrix (isotropic) from the material selection in chapter 4.1.

Ansys analysis result for Titanium alloys are shown in the figures below.

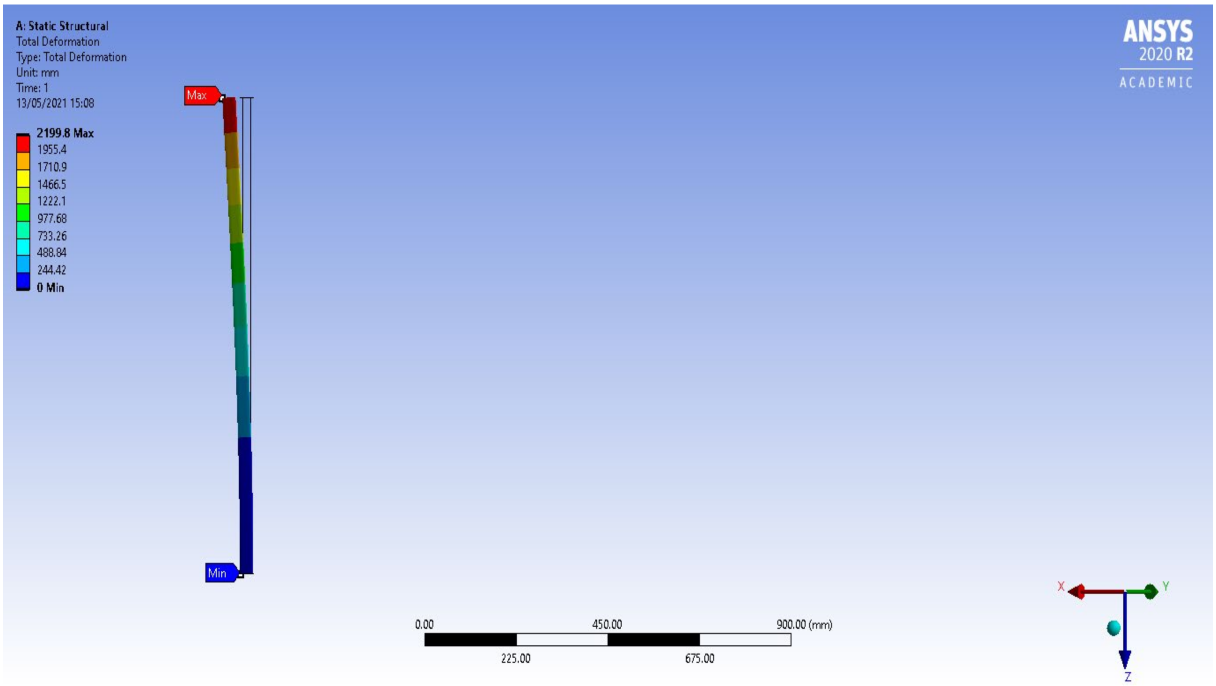


Figure 48: Maximum deformation of Titanium alloys hollow triangular cross-section.

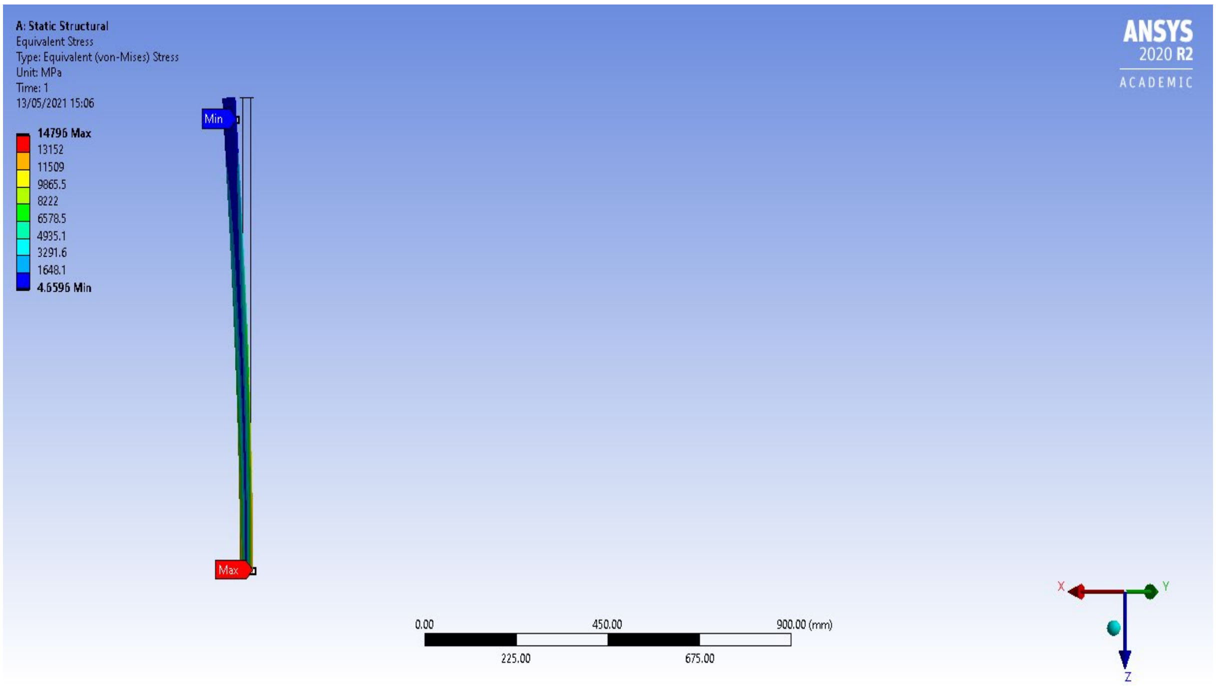


Figure 49: Maximum von-Mises stress of Titanium alloys hollow triangle cross-section.

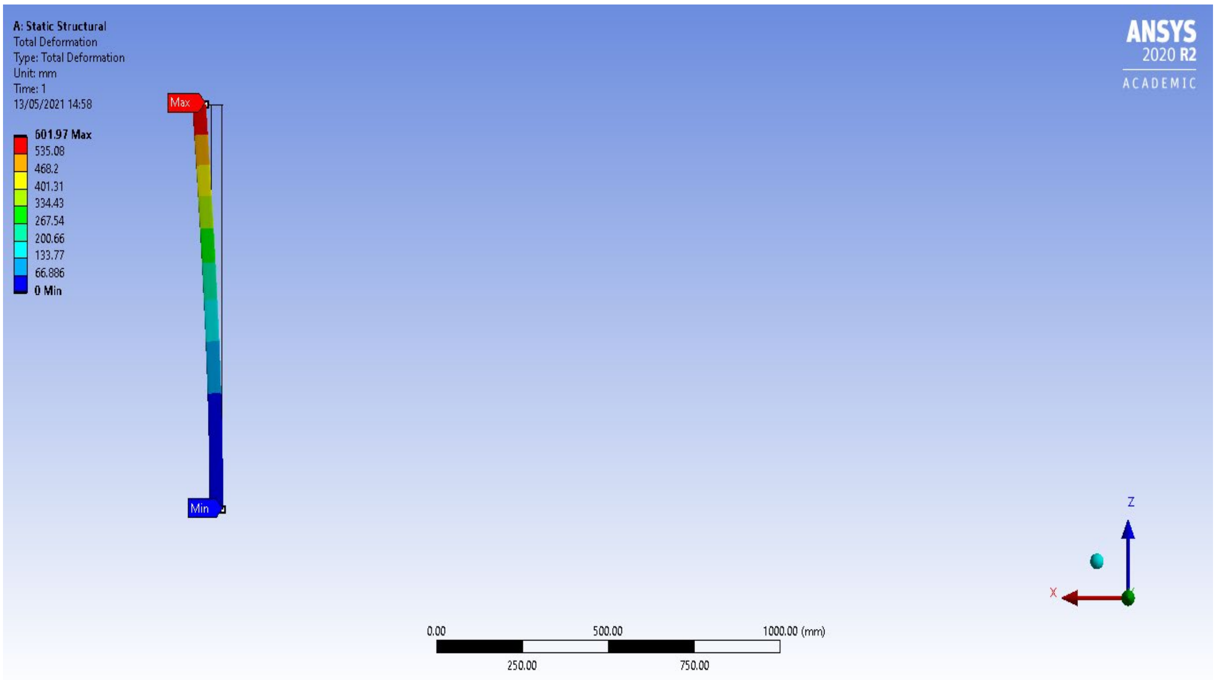


Figure 50: Maximum deformation of Titanium alloys hollow square cross-section.

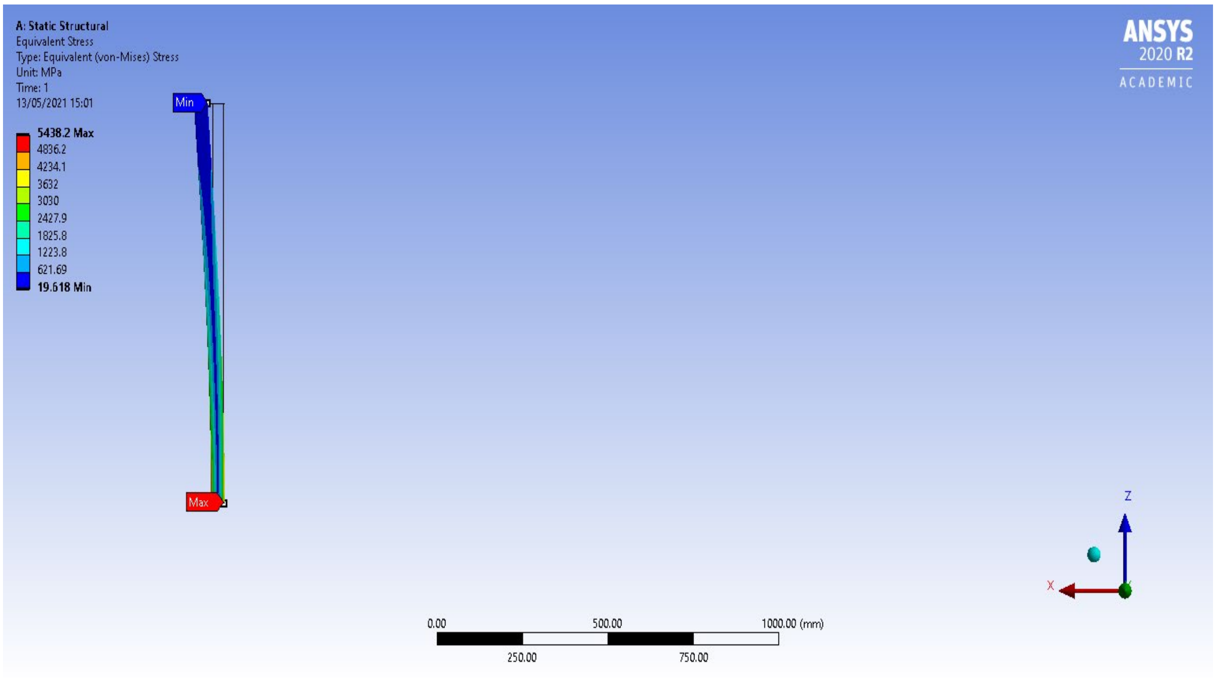


Figure 51: Maximum von-Mises stress of Titanium alloys hollow square cross-section.

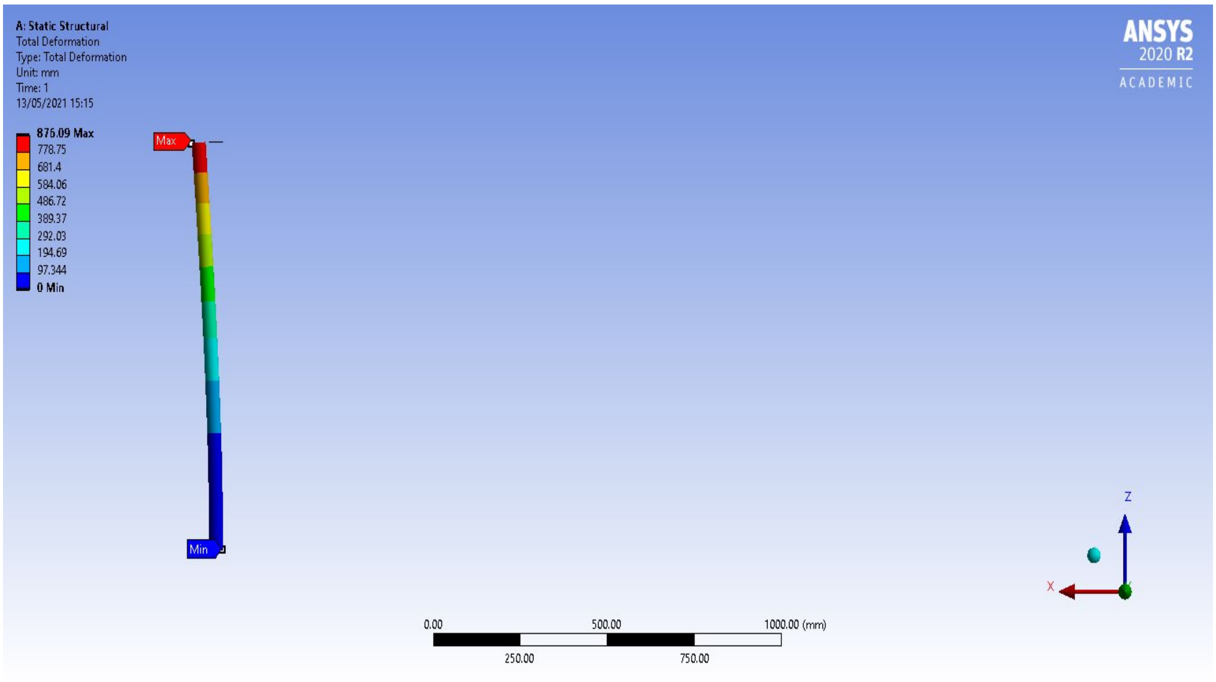


Figure 52: Maximum deformation of Titanium alloys elliptical cross-section.

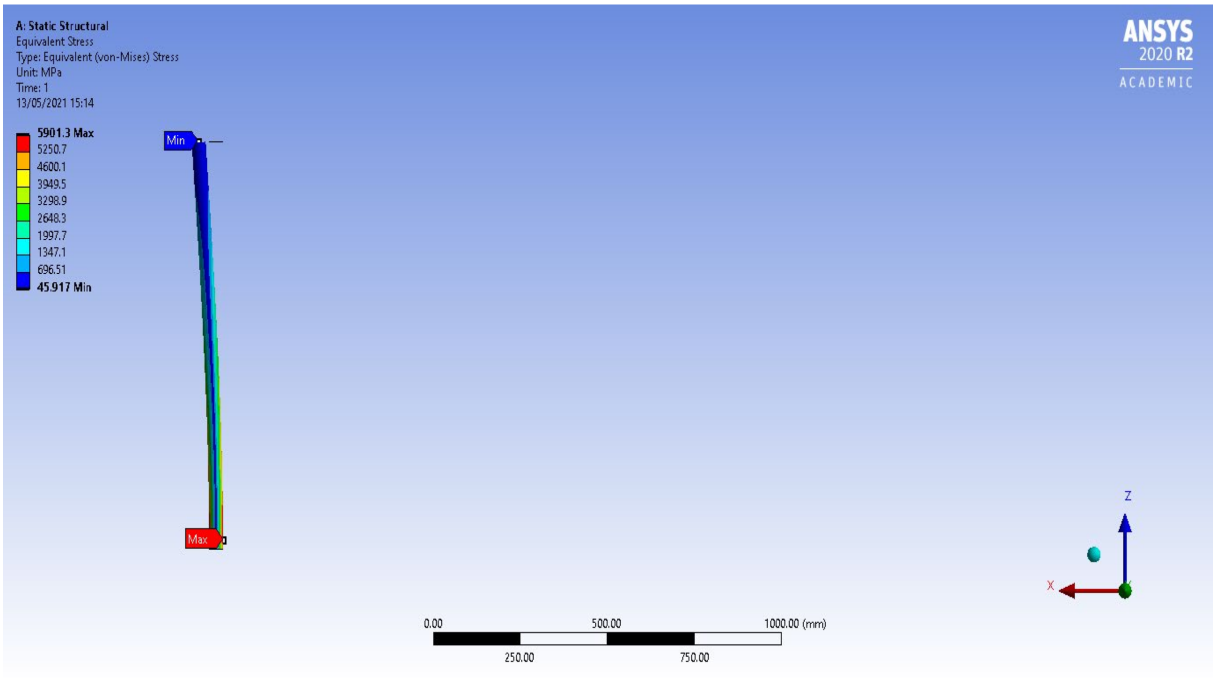


Figure 53: Maximum von-Mises for Titanium alloys elliptical cross-section.

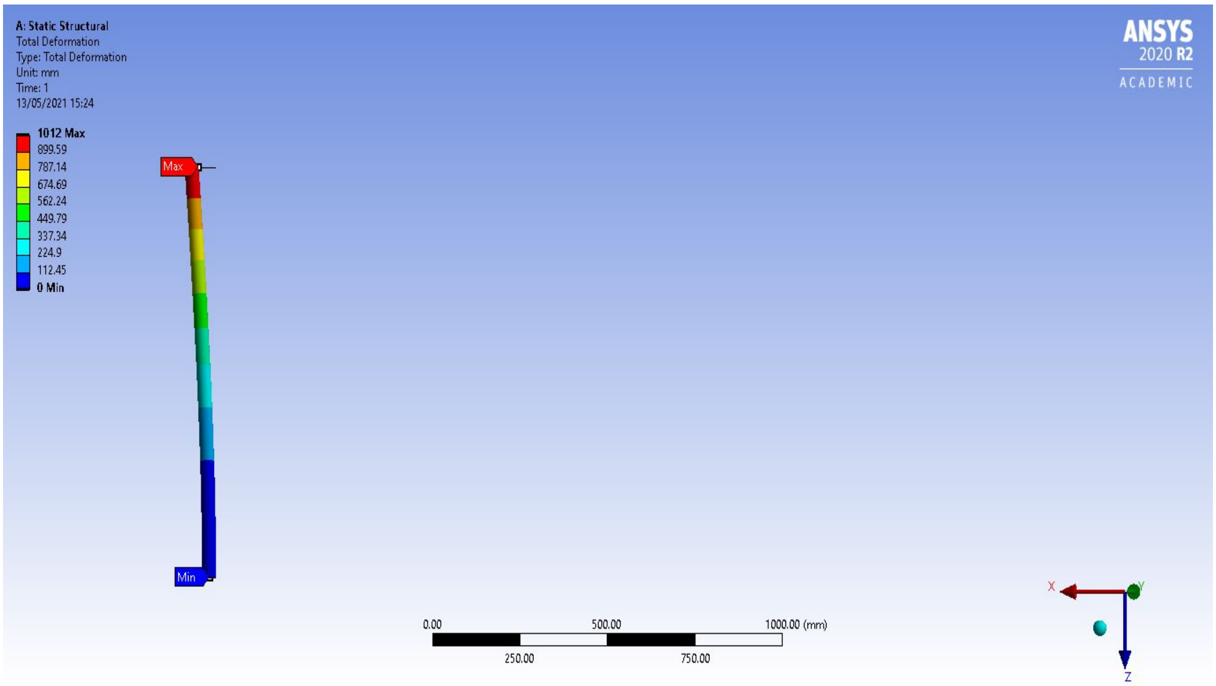


Figure 54: Maximum deformation of Titanium alloys cylindrical cross-section.

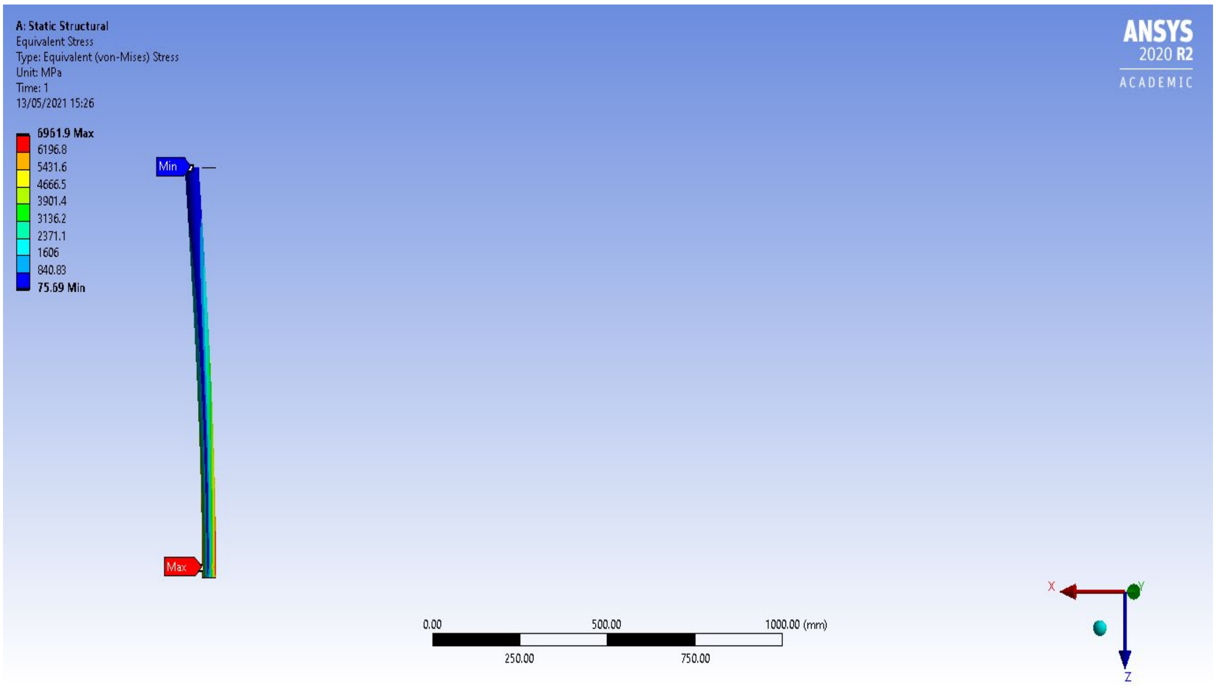


Figure 55: Maximum von-Mises stress of Titanium alloys circular cross-section.

Ansys analysis result for CFRP epoxy matrix (isotropic) are shown in the figures below.

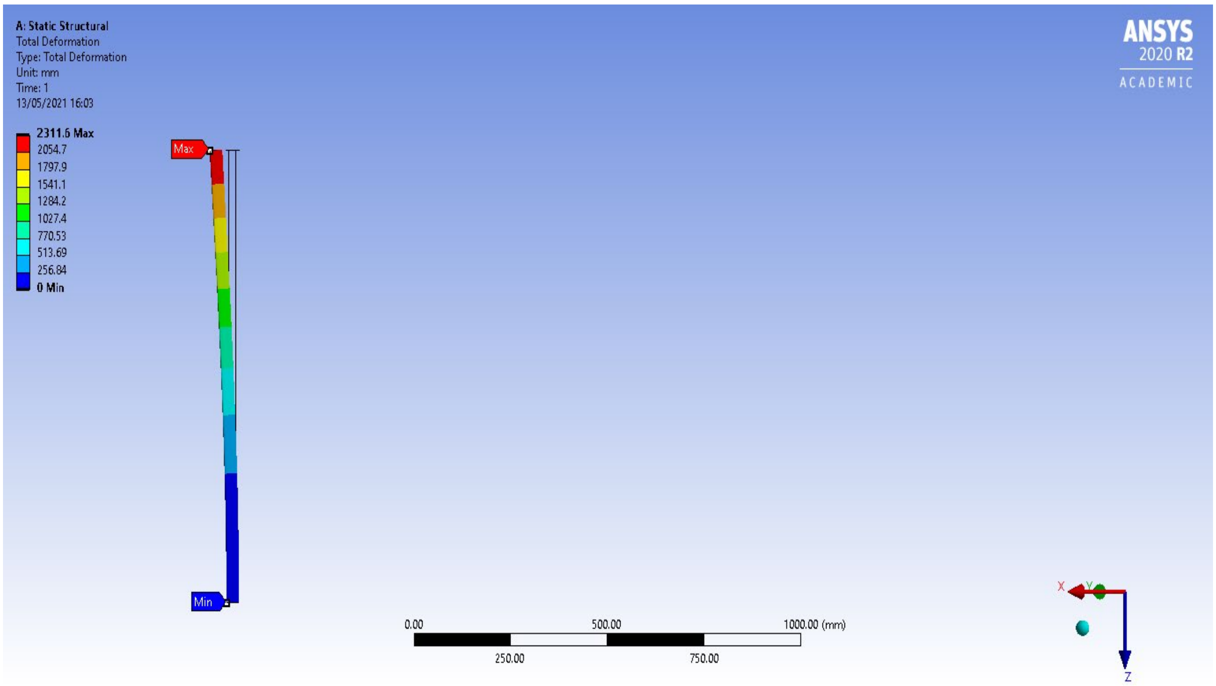


Figure 56: Maximum deformation of CFRP epoxy matrix (isotropic) hollow triangular cross-section.

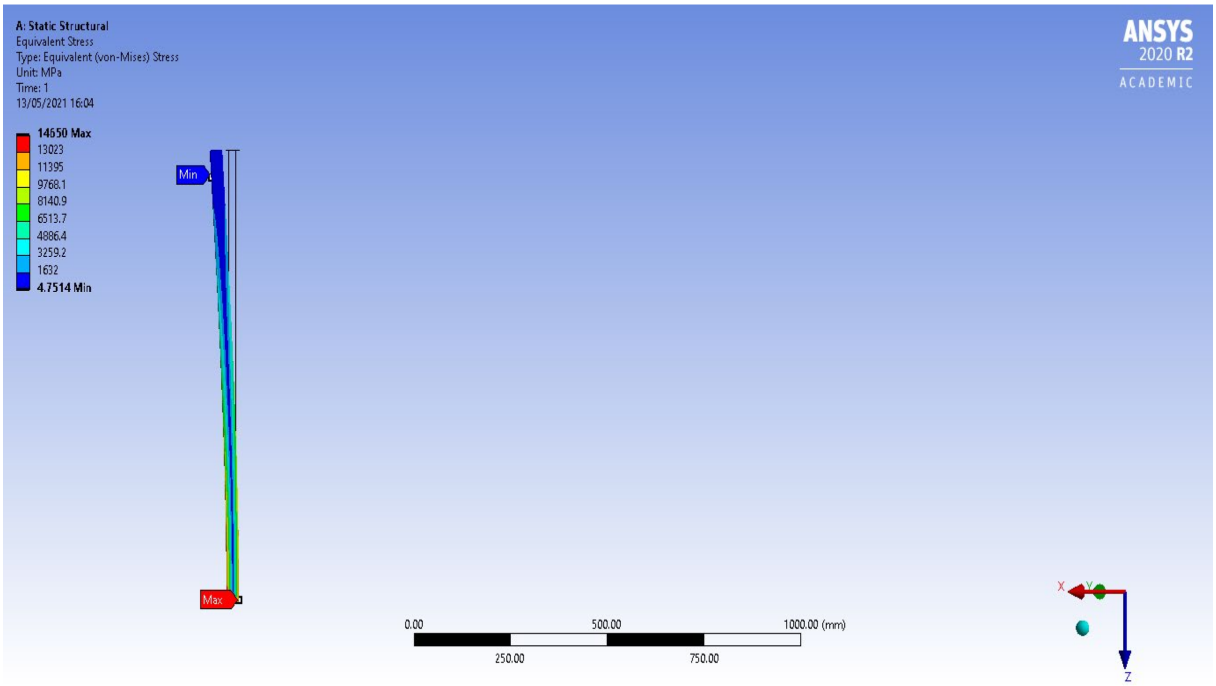


Figure 57: Maximum von-Mises stress of CFRP epoxy matrix (isotropic) hollow triangle cross-section.

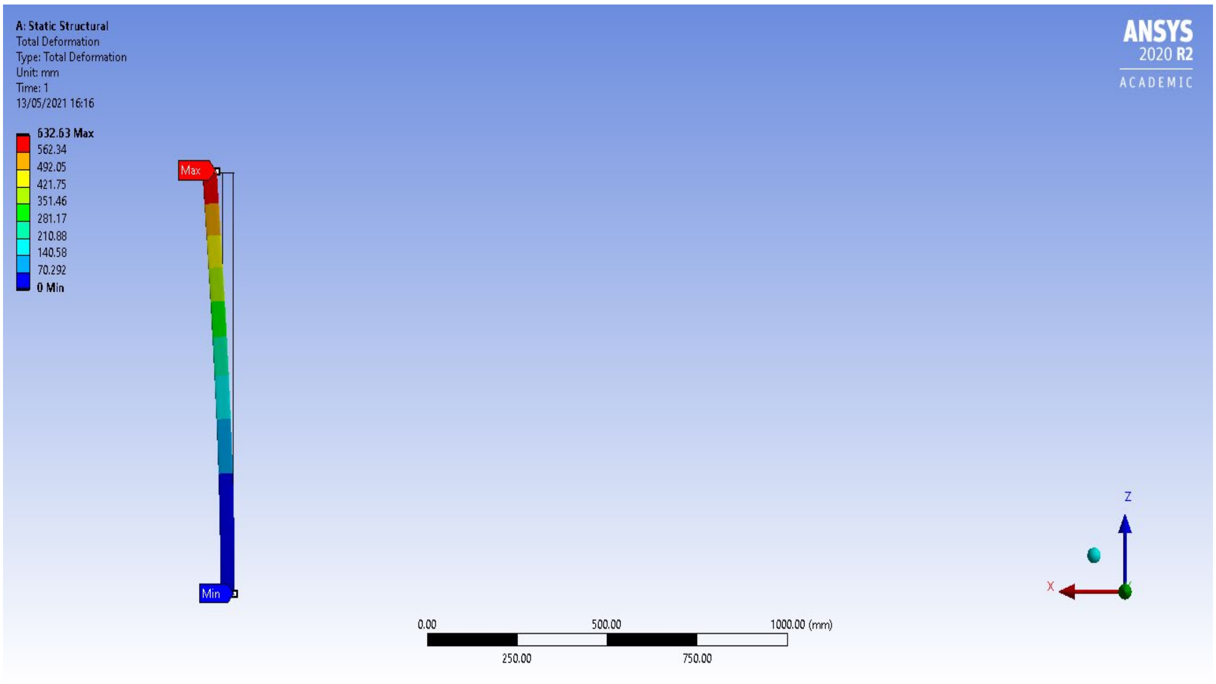


Figure 58: Maximum deformation of CFRP epoxy matrix (isotropic) hollow square cross-section.

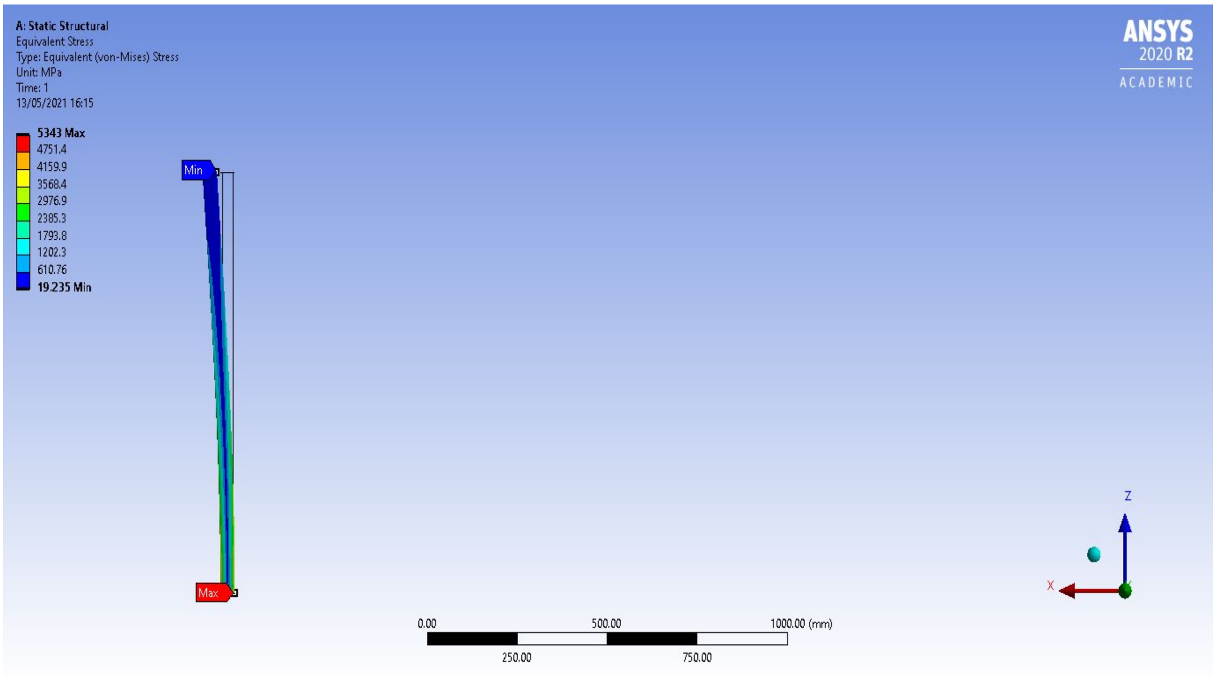


Figure 59: Maximum von-Mises stress of CFRP epoxy matrix (isotropic) hollow square cross-section.

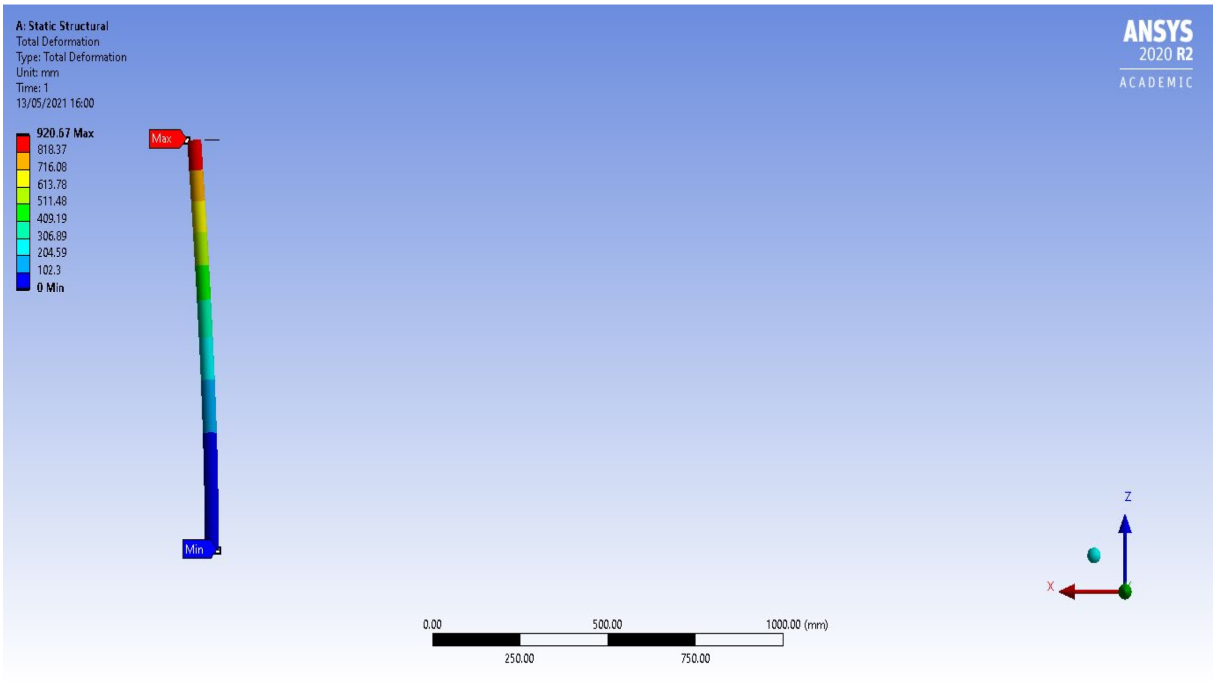


Figure 60: Maximum deformation of CFRP epoxy matrix (isotropic) elliptical cross-section.

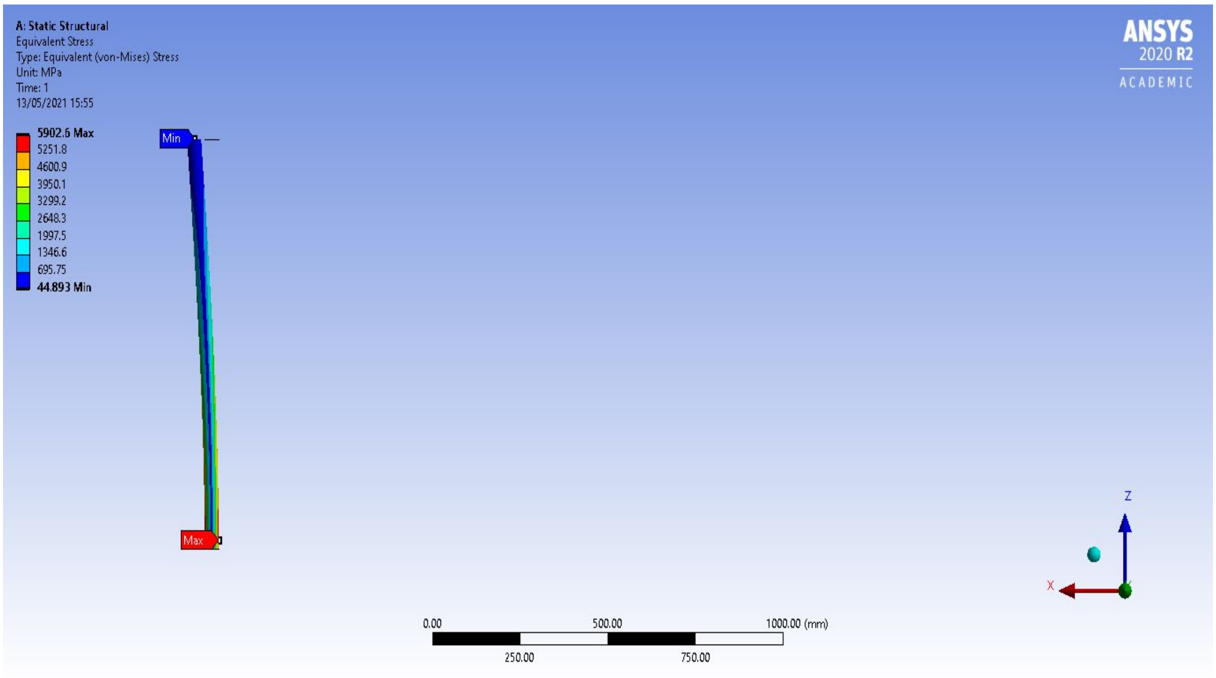


Figure 61: Maximum von-Mises for CFRP epoxy matrix (isotropic) elliptical cross-section.

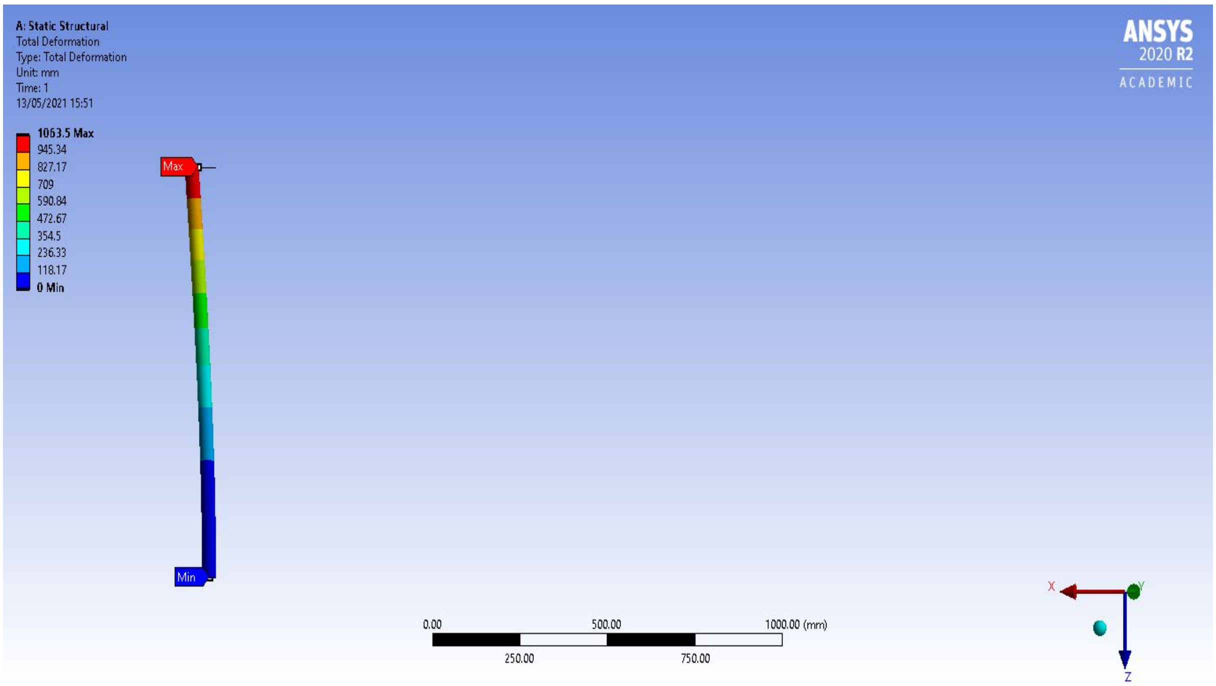


Figure 62: Maximum deformation of CFRP epoxy matrix (isotropic) cylindrical cross-section.

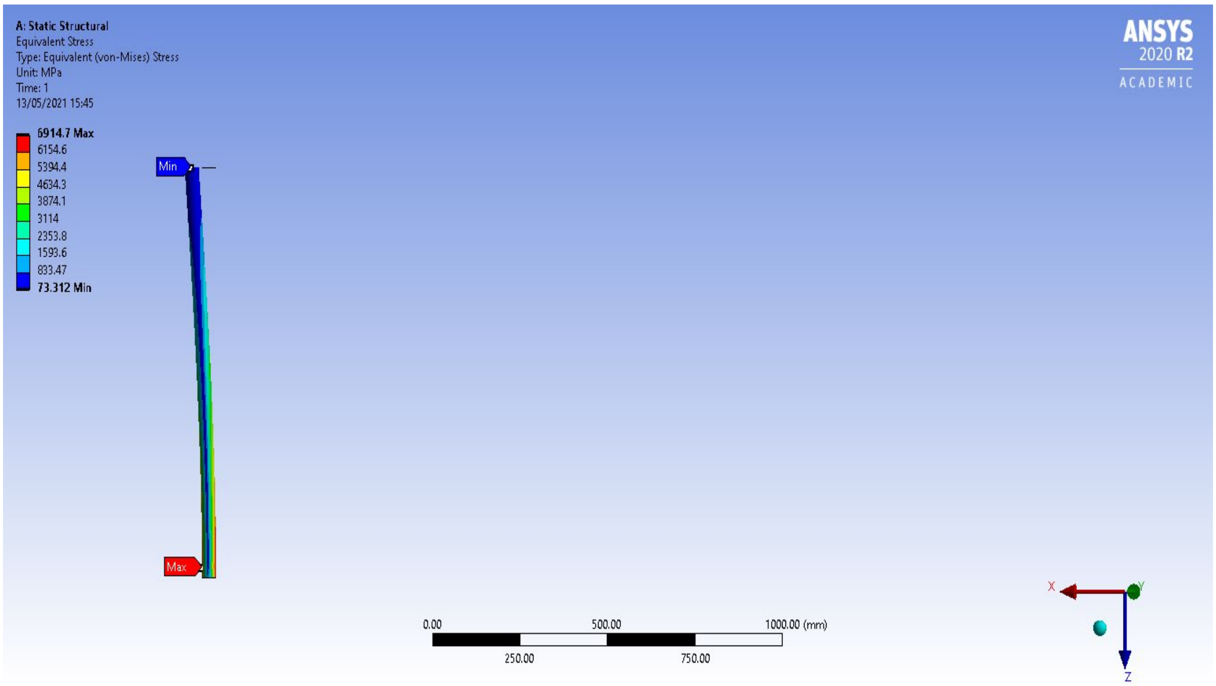


Figure 63: Maximum von-Mises stress of CFRP epoxy matrix (isotropic) cylindrical cross-section.

The maximum deformation and maximum von mises stress of the different cross-sections are listed in table 20 below.

Table 20: Analysed result of the cross-sections.

Cross-section	Titanium alloys		CFRP epoxy matrix (isotropic)	
	Maximum Deformation (mm)	Stress (MPa)	Maximum Deformation (mm)	Stress (MPa)
Hollow triangle	2199.8	14796	2311.6	14650
Hollow square	601.97	5438.2	632.63	5343
Elliptical	876.09	5901.3	920.67	5902.6
Cylindrical	1012	6961.9	1063.5	6914.7

From the analysed result derived from Ansys, we obtain that the hollow square shaped cross-section is best for the pillar frame because it has the lowest maximum deformation.

Appendix G Computations

The life raft concept consists of these parts:

- Life raft
- Human powered winch
- Cables for
    - Winch
    - Guideline
- Hook attached to lifeboat
- Support pillars
    - For winch
    - For guideline
- Rope
- Connection between life raft and guideline

A closed life raft from Viking-Life's for 25 persons is used for the concept. In Appendix H a test sheet and technical drawing of the life raft are attached. Table 21 lists the important dimensions for the life raft:

Table 21 Dimensions from 25 passengers life raft Viking Life

Height of inflatable elements	704.0 mm
Length life raft	4076.0 mm
Height life raft	1785.0 mm
Freeboard loaded	617.5 mm

Freeboard is the length from the waterline to the upper deck level, which in this case is to the top of the inflatable elements. It is illustrated in the figure 64 next page where the freeboard is the length f, and d is the length of the draft.

Figure 64: Illustration of the freeboard

Important forces

When the winch pulls the life raft from the lifeboat to shore there will be resistance forces working against the motion. Figure 65 a) and b) illustrates the forces generated when the life raft is in motion.

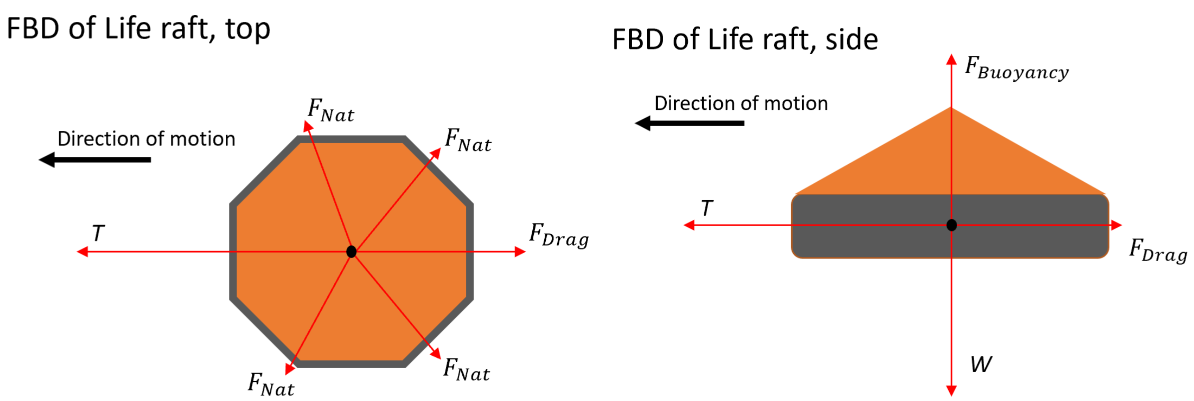


Figure 65: Freebody diagram of life raft. a) To the left, seen from top. b) To the right, seen from the side.

Weight

It was decided transport 20 persons in the life raft. The mass of each person with insulated immersion suit is 82.5 kg, see Appendix H test sheet. The total mass is then 1650 kg, which is a weight of $W = m \cdot g = 16186.5\ N$.

Drag

When an object is in motion through water, a resistive force will act on the object. That resistive force is called drag, F_D. It is given by

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

Where ρ is the density of the fluid, v is the speed of the object relative to the fluid, C_D is the drag coefficient which depends on the shape of the object, and A is the cross-sectional area. The size of the force depends on the shape of the immersed body and the speed. The resistance force, drag, for the immersed part of the raft in water and the upper part in the air can be computed from equation above or from an analysis software.

Natural forces

Natural forces can work with or against the motion of the life raft. The forces are waves, current and wind. How they affect the life raft is, in this case, not calculated or simulated. To compensate for natural forces and drag increased the total force and stated that the total weight needed to be pulled is 30 000 N. figure 65 shows the different directions the natural forces could act on the raft.

The winch system

The winch is chosen to be human-powered. To prevent from it to be too heavy to pull the life raft from the lifeboat to shore, a good gearing system is needed.

The weight that is being pulled is depending on the number of passengers plus crew that are sitting the life raft. We should also think about drag forces and resisting natural forces. Natural forces can be current in the sea, the wind, waves. Since the force or weight is still not known, a formula for solving the gear ratio and the rotational power needed to pull the life raft is formulated. For the calculations performed, we put up some assumptions:

- The bearings are frictionless
- All gear meshes transmit power with approximately 100% efficiency because of the parallel shaft

To calculate the needed information, the system is divided into subsystems to make it easier. The first system goes from the life raft with the cable to a shaft. Figure 66 illustrates the subsystem.

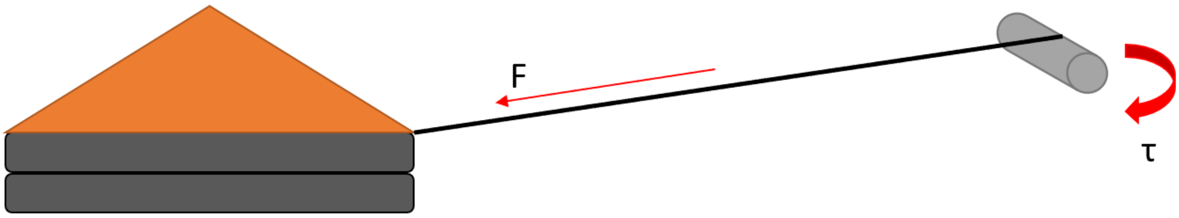


Figure 66: The subsystem from life raft to spool.

The torque needed to pull the life raft is

$$\tau_{Spool} = F_{total\,raft} \cdot r_{Spool} \tag{1}$$

where F is the weight/resistance from the life raft and the natural forces, r is the radius of the spool. The velocity of the life raft is equal to the linear velocity of the spool. The linear velocity is given by

$$v_{raft} = \omega_2 \cdot r_{Spool}$$

By rearranging the formula, the angular velocity will be

$$\omega_2 = \frac{v_{raft}}{r_{Spool}} \tag{2}$$

This will then be the angular velocity of both the shaft and the gear which the shaft is connected to. The power needed to turn the shaft is given by

$$Power = force \cdot velocity$$

$$Power = Torque \cdot angular\ velocity$$

$$\rightarrow P_2 = \tau_{Spool} \cdot \omega_2 = (F_{total\,raft} \cdot r_{Spool}) \cdot \left(\frac{v_{raft}}{r_{Spool}}\right) \tag{3}$$

This subsystem can be associated with the machine of the system. The obtained power, RPM and torque for the subsystem is the specification for the machine to be driven. The motor or engine of the system is the hand crank. To meet the given specification, the velocity, torque and power for the hand crank must be found.

The gear ratio of the system can be found by this formula

$$Gear\ ratio = \frac{input\ rotation}{output\ rotation} = \frac{N_1}{N_2} = \frac{\omega_1}{\omega_2} = \frac{d_2}{d_1} \tag{5}$$

When the input speed or input torque is known, the gear ratio can be calculated. We can assume that no power is lost in the system, ideal gearbox. This will give

$$Power\ in = Power\ out$$

Which leads to,

$$\tau_{Crank} \cdot \omega_1 = \tau_{Spool} \cdot \omega_2$$

Solving for torque input

$$\tau_{Crank} = \frac{\tau_{Spool} \cdot \omega_2}{\omega_1} \tag{6}$$

The force needed by a human to push the crank can be found. This is done by using the input torque and the distance r from the centre of the handle to the axis of rotation of the crank,

$$\tau_{Crank} = F_{Crank} \cdot r_{Crank}$$

$$F_{Crank} = \frac{\tau_{Crank}}{r_{Crank}} \tag{7}$$

The derived equation above shows the force needed to turn the crank for the given torque.

Calculating the gear ratio

The gear system is chosen to be a parallel gear system. The setup is shown in figure 67.

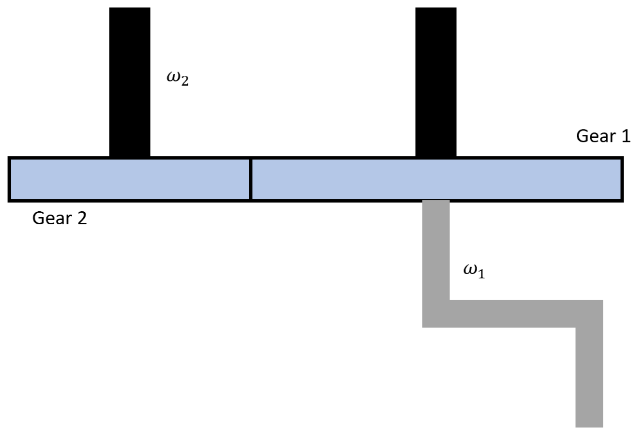


Figure 67: Parallel gear system.

We took a closer look at these cases

- $\omega_1 = 2\omega_2$
- $\omega_1 = \frac{\omega_2}{2}$
- $\omega_1 = \omega_2$

and how the gear ratio affects the winch system.

We started with calculating the velocity of the life raft. From the chapter 3.3 setting requirements, it is stated that the evacuation from lifeboat to land can happen 30 meters from land. It is also stated that the transport time per person is one minute. The velocity, v_{raft}, is found by

$$v_{raft} = \frac{distance}{time}$$

The distance is 30 meters. We have decided that the maximum capacity of the life raft to be 20 persons. This means that a fully loaded life raft with 20 persons transported from the lifeboat to land must not exceed 20 minutes. This gives

$$v_{raft} = \frac{30\ m}{1200\ s} = 0.025\ {}^{m}/_{s}$$

Under we have listed data needed to find the last numbers to calculate the gear ratio.

- The radius of the spool/shaft was decided to be $r_{Spool} = 0.05\ m$
- The length of the hand crank is decided to be $r_{Crank} = 0.4\ m$
- Sum of forces from life raft, $F_{total\ raft} = 30000\ N$
- Velocity of the raft, $v_{raft} = 0.025\ {}^{m}/_{s}$

The angular velocity, ω_2, was derived by using equation (3)

$$\omega_2 = \frac{v_{raft}}{r_{Spool}} = 0.5\ {}^{rad}/_{s}$$

The torque, τ_{Spool}, needed to pull the life raft is given by equation (1)

$$\tau_{Spool} = F_{total\ raft} \cdot r_{Spool} = 1500\ Nm$$

We have now the needed data to investigate the different scenarios. In table 22 we have all the numbers for the parameters.

Table 22: Data for the gear system.

Radius of the spool/shaft, r_{Spool}	$0.05\ m$
Length of the hand crank r_{Crank}	$0.4\ m$
Sum of forces from life raft, $F_{total\ raft}$	$30000\ N$
Velocity of the raft, v_{raft}	$0.025\ {}^{m}/_{s}$
Angular velocity for Gear 2, ω_2	$0.5\ {}^{rad}/_{s}$
Torque for the spool, τ_{Spool}	$1500\ Nm$

Scenario 1, $\omega_1 = 2\omega_2$

When $\omega_1 = 2\omega_2$, the gear ratio will be from equation (5)

$$Gear\ ratio = \frac{\omega_1}{\omega_2} = \frac{2\omega_2}{\omega_2} = 2$$

For a gear ratio equal to 2 we will derive the power, P_{in}, by equation (6) and (7)

$$\tau_{Crank} = \frac{\tau_{Spool} \cdot \omega_2}{\omega_1} = \frac{\tau_{Spool}}{2} = \frac{1500}{2} = 750\ Nm$$

The force needed by a human to push the crank is derived by

$$F_{Crank} = \frac{\tau_{Crank}}{r_{Crank}} = \frac{750}{0.4} = 1875\ N$$

Since we have two hand cranks, the final force needed is

$$\frac{F_{Crank}}{2} = \frac{1875\ N}{2} = 937.5\ N$$

The power need from each hand crank derived by

$$P_{in} = \frac{\tau_{Crank} \cdot 2\omega_2}{2} = 750 \cdot 0.5 = 375\ W$$

Scenario 2, $\boldsymbol{\omega_1 = \frac{\omega_2}{2}}$

When $\omega_1 = \frac{\omega_2}{2}$, the gear ratio will be from equation (5)

$$Gear\ ratio = \frac{\omega_1}{\omega_2} = \frac{\frac{\omega_2}{2}}{\omega_2} = \frac{1}{2}$$

For a gear ratio equal to $\frac{1}{2}$ we will derive the power, P_{in}, by equation (6) and (7)

$$\tau_{Crank} = \frac{\tau_{Spool} \cdot \omega_2}{\omega_1} = \tau_{Spool} \cdot 2 = 3000\ Nm$$

The force needed by a human to push the crank is derived by

$$F_{Crank} = \frac{\tau_{Crank}}{r_{Crank}} = \frac{3000}{0.4} = 7500\ N$$

Since we have two hand cranks, the final force needed is

$$\frac{F_{Crank}}{2} = \frac{7500\ N}{2} = 3750\ N$$

The power need from each hand crank derived by

$$P_{in} = \frac{\tau_{Crank} \cdot \frac{\omega_2}{2}}{2} = 375\ W$$

Scenario 3, $\boldsymbol{\omega_1 = \omega_2}$

When $\omega_1 = \omega_2$, the gear ratio will be from equation (5)

$$Gear\ ratio = \frac{\omega_1}{\omega_2} = \frac{\omega_2}{\omega_2} = 1$$

For a gear ratio equal to 1 we will derive the power, P_{in}, by equation (6) and (7)

$$\tau_{Crank} = \frac{\tau_{Spool} \cdot \omega_2}{\omega_1} = \tau_{Spool} \cdot 1 = 1500\ Nm$$

The force needed by a human to push the crank is derived by

$$F_{Crank} = \frac{\tau_{Crank}}{r_{Crank}} = \frac{1500}{0.4} = 3750\ N$$

Since we have two hand cranks, the final force needed is

$$\frac{F_{Crank}}{2} = \frac{3750\ N}{2} = 1875\ N$$

The power need from each hand crank derived by

$$P_{in} = \frac{\tau_{Crank} \cdot \omega_2}{2} = 375\ W$$

From the derived results the power is equal for all gear ratios, which was as expected. Torque and force varied in relation to gear ratio.

Number of passengers

The number persons in the life raft could have an impact on the power needed to winch it to land. By calculating the power needed for the different cases, we could determine the number of persons in the life raft per transport transition.

We put up three cases

- 20 persons
- 15 persons
- 10 persons

Power for 20 persons

In table 23, for 20 persons, the needed data to calculate the power is listed.

Table 23: Data for 20 persons.

Radius of the spool/shaft, r_{Spool}	$0.05\ m$
Sum of forces from life raft, $F_{total\ raft}$, for 20 persons	$16186.5\ N$
Velocity of the raft, $v_{raft,20p}$	$0.025\ {}^{m}/_{s}$
Angular velocity for Gear 2, $\omega_{2,20p}$	$0.5\ {}^{rad}/_{s}$
Torque for the spool, $\tau_{Spool,20p}$	$809.3\ Nm$

It is assumed that all gear meshes transmit power with approximately 100% efficiency because of parallel shaft, the power is given by

$$Power\ in = Power\ out = \tau_{Spool,20p} \cdot \omega_{2,20p} = 404.7\ W$$

This means that for one hand crank the power needed is 202.3 W.

Power for 15 persons

In table 24, for 15 persons, the needed data to calculate the power is listed.

Table 24: Data for 15 persons.

Radius of the spool/shaft, r_{Spool}	$0.05\ m$
Sum of forces from life raft, $F_{total\ raft}$, for 15 persons	$12139.9\ N$
Velocity of the raft, $v_{raft,15p}$	$0.033\ {}^{m}/_{s}$
Angular velocity for Gear 2, $\omega_{2,15p}$	$0.67\ {}^{rad}/_{s}$
Torque for the spool, $\tau_{Spool,15p}$	$607\ Nm$

It is assumed that all gear meshes transmit power with approximately 100% efficiency because of parallel shaft, the power is given by

$$Power\ in = Power\ out = \tau_{Spool,15p} \cdot \omega_{2,15p} = 406.7\ W$$

This means that for one hand crank the power needed is 203.3 W.

Power for 10 persons

In table 25, for 10 persons, the needed data to calculate the power is listed.

Table 25: Data for 10 persons.

Radius of the spool/shaft, r_{Spool}	$0.05\ m$
Sum of forces from life raft, $F_{total\ raft}$, for 10 persons	$8093.3\ N$
Velocity of the raft, $v_{raft,10p}$	$0.05\ m/s$
Angular velocity for Gear 2, $\omega_{2,10p}$	$1\ rad/s$
Torque for the spool, $\tau_{Spool,10p}$	$404.7\ Nm$

It is assumed that all gear meshes transmit power with approximately 100% efficiency because of parallel shaft, the power is given by

$$Power\ in = Power\ out = \tau_{Spool,10p} \cdot \omega_{2,10p} = 404.7\ W$$

This means that for one hand crank the power needed is 202.3 W.

Appendix H Life raft and test sheet

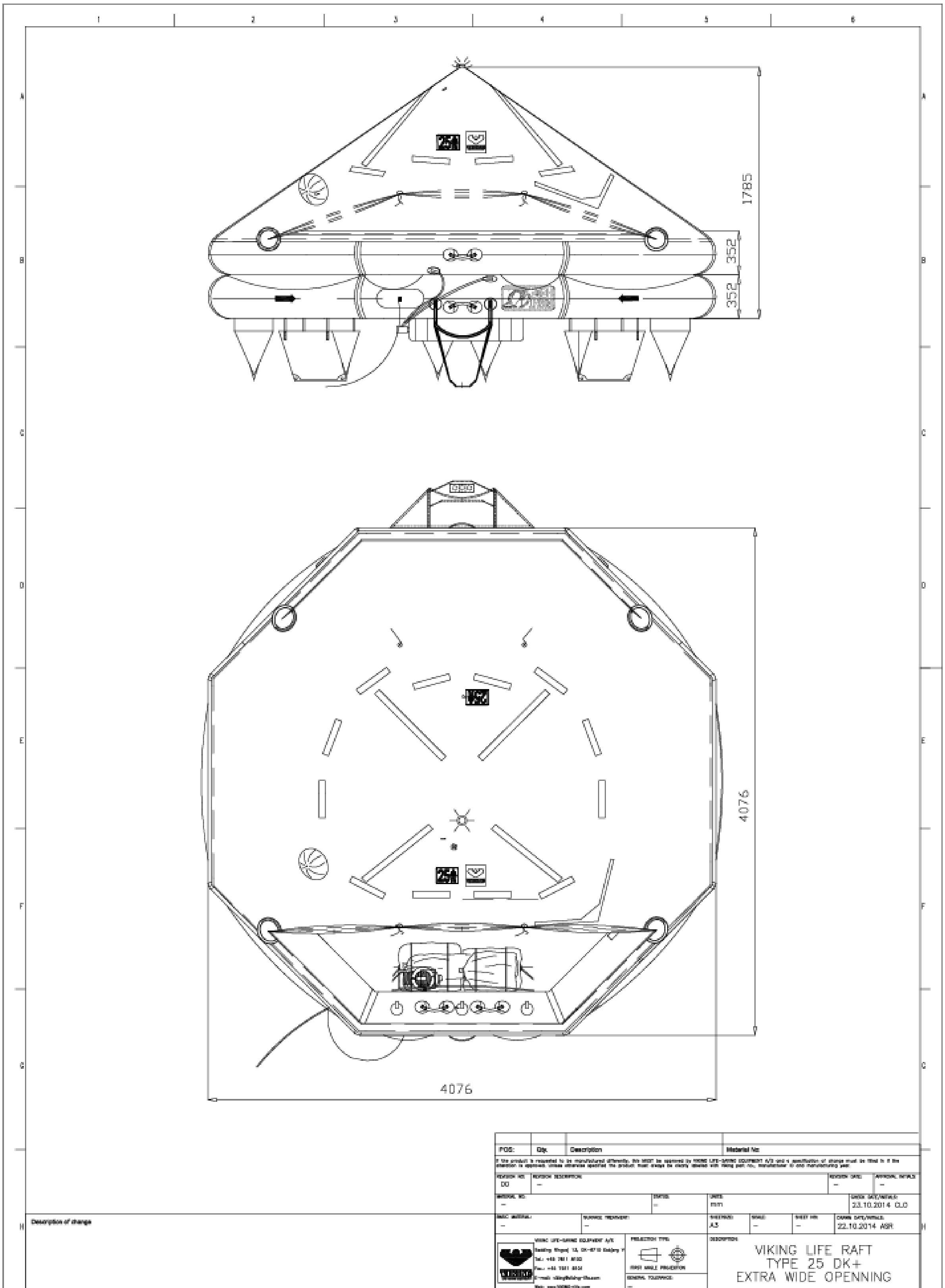


Figure 68: Technical drawing of life raft for 25 persons [39]

Inflatable Liferafts		Surveyor: Kristian Lindelof	
Date: 2011.05.23	Liferaft type: 25 DK+	Organization: Det Norske Veritas	VIKING LIFE-SAVING EQUIPMENT
Time:	Identification: 11430238	Test report no.: 1595	

4.1.11 Loading and seating test (MSC/Circ.980/Add.1)

Regulations: **LSA Code IV/4.1.2.2; MSC.81(70) 1/5.7**
46 CFR 160.151-27(3)

Test Procedure	Acceptance Criteria	Significant Test Data
The freeboard of the liferaft in the light condition, including its full equipment but no personnel, should be recorded. The freeboard of the liferaft should again be recorded when the number of persons for which the liferaft is to be approved, having an average mass of 82.5 kg, and each wearing immersion suit and a lifejacket, have boarded and are seated. It should be established that all the seated persons have sufficient space and headroom and it should be demonstrated that the various items of equipment can be used within the liferaft in this condition and, in the case of an inflated liferaft, with the floor inflated. Unless the configurations of both sides of a canopied reversible liferaft are identical, this test should be repeated for both sides of the liferaft.	All the seated persons should have sufficient space and headroom and the various items of equipment can be used within the liferaft in this condition and, in the case of an inflated liferaft, with the floor inflated. The freeboard, when loaded with the mass of the number of persons for which it is to be approved and its equipment, with the liferaft on an even keel and, in the case of an inflatable liferaft, with the floor not inflated, should not be less than 300 mm. **Acceptance criteria according to** **46 CFR 160.151-27(3):** For a liferaft not intended for use with a launching or embarkation appliance, the persons used to detemine seating capacity shall wear insulated buoyant immersion suits rather than lifejackets.	Type of lifejackets used? Inherent buoyancy ☐ Inflatable ☐ Immersion suits used? Insulated ☒ Uninsulated ☐ Freeboards Light: 12 o'clock **60** cm 3 o'clock **60** cm 6 o'clock **69** cm 9 o'clock **60** cm Freeboard Loaded: 12 o'clock **62** cm 3 o'clock **60** cm 6 o'clock **65** cm 9 o'clock **60** cm Number of persons seated **25** persons Equipment accessible and usable? Yes ☒ No ☐ This test fulfills requirements according to MSC 293(87) and MSC.295(87). Passed ☒ Failed ☐ Tested by: **Christian Jeppesen**

Comments and observations:
Type of emersion suit: VIKING PS 2007 with buoyancy

DET NORSKE VERITAS 1864
Digitally Signed By: Lindelof, Kristian
Location: DNV Fredericia, Denmark
Signing Date: 2011-06-08

Figure 69: Test sheet for the life raft for 25 persons [39]

Appendix I Parts of the support structure assembly

Main pillar frame

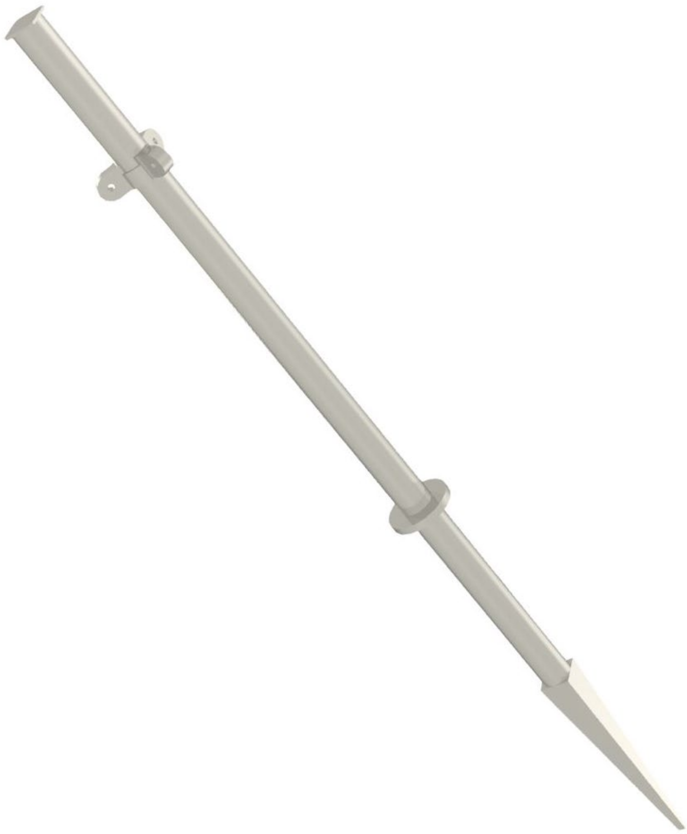


Figure 70: Main pillar frame

Hammer

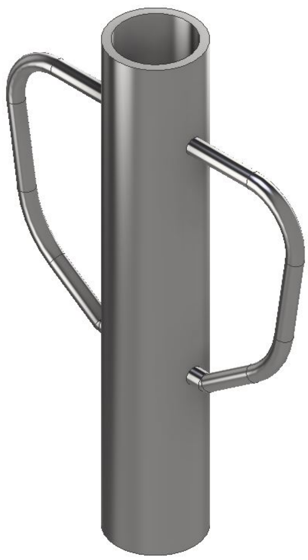


Figure 71: Hollow hammer

The support for the pillar frame

Figure 72: Pillar frame support.

Support structure

Figure 73: The support structure

Winch

Figure 74: Example of a winch with one handle crank [41]

Appendix J Problem Description

University of Tromsø – The Arctic University of Norway
Faculty of Engineering Science and Technology
Department of Computer Science and Computational Engineering

Master of Science

DEVELOPMENT OF CONCEPTS FOR LIFEBOAT EVACUATION IN ARCTIC REGIONS

—

Bashir Olawoyin, Marius Didriksen Hansen
Master thesis in Engineering Design spring 2021

Problem description

One of the common views upon surviving an incident, where one must evacuate a vessel in distress, is that once people embark the lifeboat “they are safe”. However, this is not the case. It is quite common that the condition (both mental and physical state) of the people in the lifeboat is in general deteriorating day by day.

In the recent years, there have been a growing awareness for the lack of knowledge, routines and documentation regarding Search and Rescue in the arctic region.

In 2016 under the umbrella of SARINOR the first full scale exercise SARex Spitzbergen was conducted.

The objective of the SARex exercise was according to the SARex Spitzbergen report “to identify and explore the gaps between the functionality provided by the existing SOLAS (International Convention for Safety of Life at Sea) approved safety equipment and the functionality required by the Polar Code”.

The SARex Spitzbergen exercise was followed by additional 3 projects/ exercises with the latest SARex Svalbard which should have been conducted in Mai 2019 but was canceled due to the worldwide pandemic.

The task of this project is to find a solution where people will be able to conduct dry evacuation from a lifeboat to land, sea ice and if possible to a helicopter.

The solution should take into account the following:

- wind
- waves
- sea spray and possibility for icing
- subzero temperature
- low light conditions/ visibility
- conditions on the lifeboat can effect both mental and physical state
- survivals age, health and general state will vary
- survivals gear, clothing will vary

A fully detailed formulation of the problem should be presented after completing the 4 weeks preliminary study. This formulation after approved will be the base for the evaluation of the solution presented in this master thesis.

The work shall include:

1. **A literature study** both in terms of finding state-of –the art for these types of products and solutions in the market and potential competitors, as well as literature that is necessary in order to solve the problem (regulations, standards for materials, algorithms etc.).
2. **Establishment of some case studies** including specifications (i.e. loading and boundary conditions, physical conditions, requirements for stiffness, strength, weight, materials, temperatures).
3. **Analytical and numerical analysis of the concept.**

4. **Suggestions** for future work and description of remaining work.

The solution of the task should be based on typical engineering design methods and areas of study for the Master Program Engineering Design at UiT – campus Narvik.

General information

This master thesis should include:

❄ Preliminary work/literature study related to actual topic
  - A state-of-the-art investigation
  - An analysis of requirement specifications, definitions, design requirements, given standards or norms, guidelines and practical experience etc.
  - Description concerning limitations and size of the task/project
  - Estimated time schedule for the project/ thesis

❄ Selection & investigation of actual materials

❄ Development (creating a model or model concept)

❄ Experimental work (planned in the preliminary work/literature study part)

❄ Suggestion for future work/development

Limitations of the task/project

There may be information in the report that may not be open, and if so, the report should be restricted. This will be considered before the candidate submits the thesis.

Preliminary work/literature study

After the task description has been distributed to the candidate a preliminary study should be completed within 4 weeks. It should include bullet pints 1 and 2 in "The work shall include", and a plan of the progress. The preliminary study may be submitted as a separate report or "natural" incorporated in the main thesis report. A plan of progress and a deviation report (gap report) can be added as an appendix to the thesis.

In any case the preliminary study report/part must be accepted by the supervisor before the student can continue with the rest of the master thesis. In the evaluation of this thesis emphasis will be placed on the thorough documentation of the work performed.

Reporting requirements

The thesis should be submitted as a research report and must include the following parts; Abstract, Introduction, Material & Methods, Results & Discussion, Conclusions, Acknowledgements, Bibliography, References and Appendices. Choices should be well documented with evidence, references, or logical arguments.

The candidate should in this thesis strive to make the report survey-able, testable, accessible, well written, and documented.

Materials which are developed during the project (thesis) such as software/codes or physical equipment are considered to be a part of this paper (thesis). Documentation for correct use of such information should be added, as far as possible, to this paper (thesis).

The text for this task should be added as an appendix to the report (thesis).

The report (Abstract, Introduction, Material & Methods, Results & Discussion, Conclusions, Acknowledgements, Bibliography, References) should not exceed 50 pages. Any additional material should be included in the appendix.

General project requirements

If the tasks or the problems are performed in close cooperation with an external company, the candidate should following the guidelines or other directives given by the management of the company.

The candidate does not have the authority to enter or access external companies' information system, production equipment or likewise. If such should be necessary for solving the task in a satisfactory way a detailed permission should be given by the management in the company before any action are made.

Any travel cost, printing and phone cost must be covered by the candidate themselves, if and only if, this is not covered by an agreement between the candidate and the management in the enterprises.

If the candidate enters some unexpected problems or challenges during the work with the tasks and these will cause changes to the work plan, it should be addressed to the supervisor at the UiT Campus Narvik or the person which is responsible, without any delay in time.

Submission requirements

This thesis should result in a final report with an electronic copy of the report included appendices and necessary software codes, simulations and calculations. The final report with its appendices will be the basis for the evaluation and grading of the thesis. The report with all materials should be delivered in an electronic format. The report should be in PDF format while the rest of the material should be bundled in ZIP file. A standard front page, which can be found on the UiT Campus Narvik internet site, should be used. Otherwise, refer to the "General guidelines for thesis" and the subject description for master thesis.

The final report with its appendices should be submitted no later than the decided final date. The final report should be delivered/ submitted/ uploaded to WISEflow.

Date of distributing the task: 11.01.2021

Date for submission (deadline): 15.05.2021

Contact information

Supervisors at the UiT Campus Narvik

Guy Beeri Mauseth	Guy.b.mauseth@uit.no
Annette Meidell	Annette.meidell@uit.no

Candidate contact information

Bashir Olawoyin	bol053@post.uit.no
Marius Didriksen Hansen	mha551@post.uit.no