The Autonomous Ship
Research report

Project:
The autonomous ship Calamities

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Place, data: Rotterdam, December 27, 2016

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Management summary

Introduction
The focus of this project is the prevention of, and response to calamities on board (semi-) autonomous vessels. Besides the prevention and response has also the safety, sustainability and efficiency of an autonomous vessel been researched.

Problem description
On board a vessel there are many different calamities that can occur. Because not every calamity is the same, it cannot be all dealt with in the same way. That is why the following calamities and potential calamities have been researched in this report:

- fire on board, calamities involving cargo, piracy, cybercrime, upcoming weather conditions, ship not under command and grounding.

Besides research on (potential) calamities, has also been looked at (potential) solutions for Search and Rescue operations and making the autonomous vessel redundant and fail-safe.

Objective
The aim of this project will be to find a solution to prevent and respond to calamities on board autonomous vessels.

Conclusion
The answer to the question ‘How can calamities on board autonomous vessels be prevented and responded to?’:

Removing the human factor from autonomous vessels does not mean calamities will not occur anymore. However, without crew on board, calamities have to be responded to in a different way. Devices, systems and robots have to be designed, adjusted and/or upgraded so they can replace the human on board. This also includes being resistant against calamities itself. For example: protected against fire, flooding, cyber and/or pirate attacks, etcetera. Furthermore, the systems or devices have to be designed in such a way that they are redundant and fail-safe.

Recommendation
Before the autonomous vessel can be taken into full operation, more research has to be done. This is because it is a new and unique concept, which has never been looked at before.

More research has to be done regarding:

- The effectiveness of software and hardware updates for on board computers;
- The protection against cybercrime on board autonomous vessels;
- The use and costs of robots against fires;
- Cargo calamities involving other cargo than containers, for instance dry bulk;
- The use of drones against piracy with the necessary regulations
- The costs of autonomous weather stations and implementation of maintenance worldwide;
- Further field testing of the ICARIUS project;
- The implementation and costs of the emergency ship towing system;
- The making of a fail-safe and fail-secure autonomous vessel;
- The efficiency of the described innovations for vessels ‘not under command’.
Preface

This project report will describe, prevent and solve the possible calamities that could occur on board (semi-) autonomous vessels. These calamities can be physical, like fire or grounding, but this report also includes “new” calamities like cybercrime and the implementation of fail-safe. This research has been done by Joren van Delft, Coen van Iersel, Arjan de Koning and Bert-Jan van Wilgen. We are all studying for the profession of Maritime Officer at the Rotterdam Mainport University of Applied Sciences. Our supervisor of this project is Mr. van Kluijven, mentor of the first year and English teacher with many years of experience guiding reports.

A number of big companies such as Rolls Royce and DNV GL Group are currently busy with research studies about the autonomous way of shipping. This means that the vessel will be operated from ashore or with only a controlling factor from ashore. For years autonomous sailing was seen as impossible, however concepts like these are becoming more realistic every day.

Our special thanks to:

Mister P.C. van Kluijven for supervising and helping us with our research.

Mister R. Rozeboom from the Koninklijk Nederlands Meteorologisch Instituut for supplying us with information about weather detection, weather bulletins and the automatic weather station.

Kapitein ter Zee N. Woudstra from the Royal Netherlands Navy for supplying us with general information about the anti-piracy mission in Somalia and Operation Ocean Shield, as well as his opinion/vision on the prevention and protection of piracy against autonomous vessels.

December 27, 2016

Joren van Delft, Coen van Iersel, Arjan de Koning, Bert-Jan van Wilgen
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1. Introduction
Centuries ago man started to sail across the seas. Since that time, they have been looking for better and faster ways to cross these seas. During the last century many technological advances have been made in the shipping industry. The standard crew on board a ship went from around 30 seafarers to nowadays not more than 15 seafarers. The next step in this process will be to implement autonomous sailing. These ships are called autonomous vessels. The vessels will be sailed from ashore via satellite or even totally unmanned when the whole process is autonomous.

The focus of this project is the prevention of, and response to calamities on board (semi-) autonomous vessels. Furthermore, will the safety, sustainability and efficiency of an autonomous vessel be researched.

1.1 Problem description:
On board a vessel there are many different calamities that can occur. Because not every calamity is the same, it cannot be all dealt with in the same way. That is why the following calamities and potential calamities will be research in this report:

fire on board, calamities involving cargo, piracy, cybercrime, upcoming weather conditions, ship not under command and grounding.

Besides research on (potential) calamities, has also been looked at (potential) solutions for Search and Rescue operations and making the autonomous vessel redundant and fail-safe.

Since this report is about unmanned shipping, the list of calamities that can occur will grow. Since autonomous vessels will be connected to the maritime cloud, calamities as cybercrime will become a greater problem. The calamities that can occur on manned vessel also pose a problem on board unmanned vessels. The challenge on board unmanned vessels is how to tackle these calamities with no personal on board.

Fire on board autonomous vessels will pose a problem when no seafarers are on board to extinguish the fire, this could lead to catastrophic situations like a vessel ‘not under command’ and maybe even grounding.

Calamities involving cargo on board autonomous vessels can lead to damage of the vessel and/or cargo.

Piracy will be a problem when autonomous vessels sail into pirate infested areas. This can lead to hijacking of the vessel and stealing of cargo. With no crew or security on board, to protect the vessel, pirates can execute well planned and prepared hijackings.

Due to the fact that an autonomous vessel is unmanned, the vessel is less capable to assist during Search and Rescue operations. This could potentially increase the loss of lives at sea.

For years the IMO has made a list with causes for accidents on board seagoing vessels. One of the reasons for loss ship and loss of life is still upcoming adverse weather conditions, (Allianz Global Corporate & Specialty). Because of the fact that there are no seafarers on board autonomous vessel which can respond to upcoming weather conditions, computers have to be installed to fulfil this important task.

A solution to these calamities will be to make all the systems on board the autonomous vessel redundant and apply a fail-safe. This will lead to a safer and more reliable vessel.
1.2 Problem definition:
Autonomous sailing can cause calamities.

1.3 Objective:
The aim of this project will be to find a solution on how calamities on board autonomous vessels can be prevented and responded to.

1.4 Main-question & sub questions:

1.4.1 Main question
How can calamities on board autonomous vessels be prevented and responded to?

1.4.2 Sub-questions:
1. How can cybercrime on board an autonomous vessel be prevented and responded to?
2. How can fire on board an autonomous vessel be prevented and responded to?
3. How can calamities involving cargo on board an autonomous vessel be prevented and responded to?
4. How can piracy on autonomous vessels be prevented and responded to?
5. How can autonomous vessels anticipate or respond to upcoming weather conditions?
6. How can autonomous vessels respond to SAR operations?
7. How can redundancy on board an autonomous vessel prevent calamities?
8. How can grounding be prevented and responded to on board autonomous vessels?
9. How can fail-safe be implemented on board autonomous vessels?
10. How can ship owners and/or authorities prevent and respond to an autonomous vessel ‘not under command’?

1.5 Research methods
This project, Project 2 (module code: MAPJ214), consists of two parts. The first part is desk research:

- Articles on the internet;
- Literature in books;
- Previous studies/research programs;
- Patents.

The second part is field research:

- Interviewing of experts
- Interviewing companies
1.6 Project borders
To meet all the qualities of this research project there will be some project borders defined, these project borders define the amount of research and development. The following items will not be investigated / discussed in this research report:

**Calamities:** Liability after calamities on board autonomous ships.

**Cybercrime:** Situations that can occur after cybercrime and how to respond on these situations.

**Fire:** Environmental effects after fire on board autonomous ships.

**Cargo handling:** Environmental effects after loss of cargo.

**Piracy:** Cybercrime, this will be looked at in a separate research chapter.

Financial costs

The interest of pirates to attack autonomous vessels. For this research project it is assumed that pirates still attack autonomous vessels, the question is how to prevent this.

Will piracy increase or decrease in the future? For this research project it is assumed that piracy activity will remain at the same level. It is impossible to give an accurate prediction of piracy activity the first year these vessels will set sail and after 5 or 10 years.

Autonomous vessels with a speed of 15knts or more and a high freeboard will not be targeted by pirates. Statistics have shown that vessel with such characterize are less likely to be attacked by pirates.

Pirates could blackout an autonomous vessel with an EMP (Electric Magnetic Pulse) theoretically. (Electromagnetic pulse)

Regulations regarding the use of drones against piracy

**Weather conditions:** Financial costs of circumnavigating to prevent damage or dangerous situations.

**SAR operations:** How to prevent a Search and Rescue situation on board other ships from occurring.

**Redundancy** Financial costs

**Grounding:** Environmental effects after grounding.

**Fail-safe:** Financial costs

**‘Ship not under command’**: Possible situations during ‘ship not under command’ and how to respond to such situations.

Financial costs
2. Current situation regarding ocean transport
The current situation is easiest to clarify by the use of an example.

This example involves a company that sells cars in Rotterdam. These cars are made in Korea whereas the iron for these cars comes from Australia. This means the iron first has to be shipped to Korea, where it will then be forced into parts for the cars. After these parts are assembled in Korea, the cars are ready to be shipped to Rotterdam.

Trucks are simply not the best way to transport cars from Korea to Rotterdam because of the great distance and the low capacity of trucks. Transport by plane seems a better option, as it is fast and reliable. However, there are two huge disadvantages of transport by plane: it comes at a very high cost and the quantity that can be transported is relatively small. Of course the best way of transport in this case is by sea. It is relatively cheap, fairly reliable and great distances can easily be crossed.

When looked at from an economic point of view, it is not strange that 90% of all trade worldwide is done by means of shipping (Scheepvaart). The ship that transports the goods from one place to the other needs to be manned by competent and certified sailors. Nevertheless, companies get more and more problems recruiting new sailors. The “new” sailor is not seeking a long career at sea. 80% of the sailors quit sailing before the age of thirty (Klok, 2000). The companies are trying to make the job more appealing by offering a better salary and work schedule.

However, ships do not need to sail in such a conventional way. The number of crew on board has certainly dropped because of automation. Ships could be automated in such a way, that they can sail with no crew on board. For years this idea seemed impossible but nowadays it has become more fact than fiction. Companies like Rolls Royce and DNV GL Group are already busy conducting researches and tests around the idea of autonomous shipping.

Given these points, it does not seem that strange at all. When looked at the APM terminal at the Maasvlakte II – Rotterdam, The Netherlands, which is fully automated, every job is done from an operation tower in the vicinity. So if it is possible to automate a full terminal, likewise, this will also be possible for a ship.
3. Cybercrime

3.1 General
– Sub question
How can cybercrime on board an autonomous vessel be prevented and responded to?

– Methodology
To answer this sub question literature concerning cybercrime and cyber security, as well as the internet has been used.

3.2 The weaknesses of the on board systems
Throughout the twenty-first century manufacturers of GPS, AIS and ECDIS have made their equipment compliant with almost all bridge equipment. This network of bridge equipment has been made part of the network of the vessel itself since a few years. The equipment provided to the vessel will be outdated in roughly 3 to 5 years (Lucy Siegle, The Guardian, 2013), but most vessels keep sailing with this equipment until the vessel or the equipment breaks down. This leads to the on board equipment that is in most cases outdated. This is because of the lack of proper care and understanding of the maintenance they require. Therefore, they are becoming the weakest link in the on board digital computer system, that is in most cases connected each other and to a satellite connection without protecting the network properly against external influences. To add all influencing factors up, the older the system becomes, the greater the chances are a computer will break down due to dust, age, viruses or hackers. So it is vital that on board systems are updated regularly and replaced when manufacturer deem this necessary. (Port-IT, 2016)

3.3 Identifying the cybercrime threat
The risk of losing a vessel caused by a cybercrime is growing by the minute. The reality is that bridge systems and engine room systems rely more and more on the use of on board computers. Most of them outdated but filled with information about the vessel and the equipment on board. Due to the growing digital systems on board that are connected to one another and the great demand of the office to get information from the vessel, most vessels are connected to the internet. This kind of exposure to the outside world can also be used against the vessel by means of cybercrime. There are numerous ways of creating a window for the crime committers to get entry to the network of the vessel. Most personal computers on board are poorly maintained if it comes to anti-virus software or operating systems. From the moment they connect to the shipboard network by means of their own laptop, tablet, Smartphone or USB they can cause open doors for unwanted guests. Due to the lack of proper internet on board most connections are not fast enough to transfer large amounts of data in a short amount of time. But since the start of the 21st century improving the speed of the vessels network has been on the list of many shipping companies. The reason behind this is the improvement of on board equipment and the request of the companies behind the equipment to get feedback. To process this feedback as quickly as possible, most equipment companies have a large staff that process the feedback and innovate the software behind the system, this resulting in an update for the on board equipment available on CD but also as an update downloaded from the internet. The problem is that the internet connection is not sufficient for the update, so the on board internet connection to the satellite will be improved neglecting the security of on board computers.

Most on board computers are built in since the build of the vessel and are only renewed if they break down or become a bottle neck in the on board system due to screen freezing when asking too much of the computer or the hardware becomes outdated and cannot comply with the minimum requirement of the software supplier. By neglecting proper care for the on board computers such as well updated anti-virus software and a good running computer, on board systems become vulnerable to cyber-attacks and intrusions. (Global-Security, 2015)
3.4 Creating the DIGITAL CITADEL

3.4.1 The boundaries of outside signals

In the progress of creating an autonomous vessel, the vessel will need to be configured in such a way the vessel does not require signals from the outside world during the voyage. Because every signal that the autonomous vessel requires from the outside to control the system or its components can be tempered with. This tempering can happen deliberately by means of cybercrime, but occasionally it will happen just by a malfunction from the inside of the system.

To prevent these signals from outside to have devastating effects on the vessel, the vessel will have to be instructed manually before departure. These instructions will have everything to do with the next voyage, alterations to the instruction can only be made within limitations to prevent interference from outside sources. To keep the instructions for the autonomous vessel to a minimum, the only input that can be given is:

- The destination
- Maximum and minimum speed of the vessel (eta)
- Anchor areas
- Safe harbours along the way
- No-go areas

With these boundaries that are given to the system, the autonomous vessel can determine its own course. During the voyage the essential instructions that have been given to the vessel before departure, can only be altered manually to prevent tempering from outside sources.

3.4.2 The on board system

The on board system will be divided in two separate systems. The first computer system will be the system that controls the autonomous vessel by

- Sailing the determined route
- Checking the environs and reacting adequately
- Controlling the power management system and propulsion
- Doing basic maintenance of the vessel
- Reacting on defects on board, or in the system
- Reacting on any calamities that may occur

As described above the first computer system will have the daily control over the vessel itself. This system has a constant connection with a command centre to provide information about the vessel and its components. The command centre uses this information to plan the maintenance for this system since updates and altering the routes can only be done manually to prevent cybercrime.

The second computer system on board is a closed system that is connected with the first system. This separate system has no outside connection and can only be updated manually, just like the first system. The difference is that this system does not control everything on board of the vessel. This separate system checks all the proceedings of the first system. This means that the second system reacts if an error occurs in the first system. This error can occur by a flaw in the system or by cybercrime. What the second system does in case of an error is replace the corrupted data with a backup from its own system. In the case that this does not work the system can take over control from the first system. The first system will mention this to the command centre that can arrange technical support in the next harbour. If in any case the first system has been taken over or is endangering the cargo or the vessel by its decisions, the second system can decide that the vessel is not capable of continuing its voyage and will shut down the first system. In this case the second system can continue the voyage, or it can drop anchor or hold position and wait for technical assistance. (Singtel, 2015)
3.4.3 Delimiting the no go area
As described in previous chapters, instructions have to be given to the vessel prior to the voyage. During the voyage these instructions can only be altered slightly. This means that the new destination cannot be on a different continent. This is to prevent the vessel from getting in the wrong hands. The vessel is limited by the manual input to sail to a destination in one given area. Along the way all the land will be a no go areas except emergency harbours. This is to prevent a vessel from being hijacked or directed wrongly by intruder’s that have entered the system.

This no go area means that the vessel will prevent itself from going within these limits. If the boundaries of the area are exceeded, the vessel will have a limited amount of time to get out of the no go area. If the vessel is does not succeed it will raise alarm and hold position until support arrives. This has to be at least 24 miles outside of the nearest coast to avoid diplomatic issues.

3.5 Conclusion
Before vessels will be able to set sail around the world autonomously, there have to be changes in the on board system and its protection. The changes that have to be made are:

- Keeping all on board systems up to date in software and hardware
- Creating a secure on board system with limited input from outside sources
- Creating boundaries for the on board system, that will trigger the safety switch if exceeded.
- Making a backup system if the first system should fail.
- Delimiting the no-go area to prevent the vessel from being hijacked

This is to create a safe environment against hackers and hijackers, and to ensure that the vessel will arrive safely in the next harbour.
4. Fire on board

4.1 General

– Sub question
How can fire on board an autonomous vessel be prevented and responded to?
– Methodology
To answer this sub question literature concerning the prevention of fires and fire detection systems, as well as the internet has been used.

4.2 Introduction
Fire is one of the most dangerous incidents to happen on board. It is dangerous for crew, vessel and, when not taken action upon, the environment. A fire must be as soon as possible detected and extinguished. However, this is easier said than done because a fire easily “jumps” from one compartment to the next. So when a fire is raging within a compartment the surrounding compartments should be cooled. During these fire fighting operations the safety of the crew should be the highest priority.

When a vessel sails autonomously the human error will be erased from the ship. But with erasing the human error a part of solutions for extinguishing fires will also be removed from the ship. This part of the research lays the focus on the missing part in the human solution for extinguishing of fires.

4.3 Prevention of fires
When it comes to fire it’s better to be safe than sorry. The best way to prevent fire is to build a vessel with a proactive safety model towards fire related deficiencies. To keep records of these deficiencies a databank is needed. This databank should be filled with known incidents/near misses involving fire. Every incident/near miss would need a thorough root cause analysis. When the root cause is known the safety model can be adapted to eliminate this cause.

When the autonomous vessel starts sailing, a good record should be kept. When a newer type of vessel is constructed, the previous causes should be taken into consideration. Also the maritime researchers should be encouraged to do more research about this subject. This way every model is a bit safer with a less chance of fire. (Omer Soner, 2015)

Another idea is to equip the vessel with an inert gas generator, this generator will supply the engine room with inert gas, which replaces the oxygen in the engine room and prevents explosions and fires from occurring.

An inert gas is a gas which does not undergo chemical reactions under a set of given conditions. The inert gas keeps the oxygen content in the atmosphere below 5%, thus making any air/hydrocarbon gas mixture in the too rich (too high a fuel to oxygen ratio) to ignite. (Inert gas, 2016)

Extra design requirements need to be implemented before the inert engine room can become operational. These requirements consist of safety features such as forced ventilation and measuring devices in case the engine room has to be entered by humans, as well as requirements for the engine design, such as the entrance of scavenging air to the engine itself.

For more information about the inert gas engine room, see the research report of Topic 5 – Propulsion and maintenance.
4.4 Fire detection

Early fire detection is the second best thing right after prevention. The fire detection system will detect a fire in an upcoming stage. In this stage it is easier to control and extinguish. Every compartment on board needs to be fitted with a detection system. This will result in a coverage of nearly 100%. Nowadays there are already a lot of different fire detectors on board. However, these detection systems are not automatic yet. Bosch comes up with the following product, the ‘automatic Fire Detector 440 Series’. This product takes over a part of the human element with the ‘Intelligent Signal Processor” (ISP). This processor continuously analyses input data from the sensors. A complex algorithm ensures the sensor pattern matches that of a real fire scenario to provide immunity against possible false alarm rates as can be seen in figure 1. Implementing this on an autonomous vessel it will increase the detection rate of fires on board. (Bosch)

![Figure 1 – (Bosch)](image)

4.4.1 False alarm

To prevent a false alarm from happening arrangements have to be made on board the autonomous vessel that can check if an alarm is false or real. This can be done by the CCTV system, but not everything can be detected by camera. That why the autonomous vessel has to be equipped with an autonomous fire detection robot. This robot is still in development, but results so far are promising. This robot has three kinds sensors available: a light sensor, a Thermal Infrared Sensor (TIS) and a proximity sensor. The robot has only a vision width of 45°, but to give it more coverage ground whilst driving, it drives a sinusoidal path. With the use of the proximity sensor it avoids possible obstacles. The robot also carries a small extinguisher that can be used for small starting fires. (Adeel ur Rehman, 2015)

To demonstrate how this will be implemented a fictional situation will be created.

**Fictional situation**

A sensor receives input of a high temperature. This sensor will send a signal to the ISP. When the ISP checks the signal it gives the alarm of a “real” fire. The ISP will send a signal to the fire detection robot (FDR) with information which compartment to check. When the robot enters this compartment it will drive around to check for fires. When a fire is detected it will drive up to it as close as 30 cm from the flame. With the small extinguisher it will extinguish the fire. When this fire is extinguished the fire detection robot will drive further to check this compartment for other fires.
4.5 Control and extinguish fires
When a fire is detected it has to be extinguished. There are several methods of doing this unmanned, for example with sprinkles or another kind of fixed fire suppressing system. This results in a large area effected by the extinguish medium. Of course the fixed installations are still needed if the fire grows too big or uncontrollable within a compartment. The fire detection robot already has the capacity to extinguish small fires. However, if a fire becomes bigger there will arise a question for more extinguishing capacity. A solution for this problem will be a second robot. This is a so called Fire Fighting Robot (FFR). This Fire Fighting Robot works nearly the same as the Fire Detection Robot but has some important differences such as better thermal insulation, this leads to an operation temperature of 700 degrees Celsius. The FFR has also a greater capacity of extinguishers that can be easily be refilled at a power and refilling station. When necessary a hose can be connected to the rear of the FFR for continuous fire fighting. With a laser pointer it is easy to see where is aimed at. The camera used by the FFR a fire can be located despite smoke in the compartment. This is done by scanning for various wave lengths radiated from the fire. The disadvantage till now is it’s not fully atomised yet and has to be controlled remotely. (AlHaza T, 2015)

4.6 Conclusion
A database has to be made which contains information about calamities involving fire. This database brings designers and shipbuilders the guidance in design and construction of new types of autonomous vessel, which are improved to avoid previous calamities. If despite these preventions a fire breaks out, the sensors on board the vessel will register this and send this to the ISP, which sends in a Fire Detection Robot (FDR). When the fire can’t be extinguished by the FDR, a Fire Fighting Rotor (FFR) will be deployed for a bigger extinguishing capacity. If the fire gets completely out of control, the use of fixed fire suppression systems is needed. The only system which is not yet autonomous in this procedure is the FFR, but for now this is a safer way than fully autonomous fire fighting.
5. Calamities involving cargo on board

5.1 General

— Sub question
How can calamities involving cargo on board an autonomous vessel be prevented and responded to?

— Methodology
To answer this sub question literature concerning the lashing of cargo on board vessels, as well as the internet has been used. Also has there been contact with a specialists of the TU Delft for information about designing a device or robot to check the tension of the lashing bars during the ocean crossing.

5.2 Introduction
There are a lot of different cargoes, for this part of the project the research will focus on containers. This is because MUNIN – Maritime Unmanned Navigation through Intelligence in Networks – says that dry bulk and containers are probably the first type of vessels that will sail autonomously. To prepare the cargo for a voyage everything has to be sea fastened. This means everything needs to be lashed in the right way. If this is not done by procedure, cargo can break loose and slide uncontrollably across the ship. This will result in collateral damage with dangerous situations for ship and environment. Nowadays ships are loaded and lashed by men, during the voyage the crew will check and retention the lashing gear.

5.3 Mechanical stresses in maritime transport
Cargo which is transported overseas will always be subjected to forces. These forces cause mechanical stresses in the vessel itself as well as in lashing gear of the cargo.

Section 1 “General condition” in the IMO/ILO/UNECE Code of Practice for Packing of Cargo Transport Units (CTU Code) clearly states, for example in point 1.1:

“Voyages are made in a variety of weather conditions which are likely to exert a combination of forces upon the ship and its cargo over a prolonged period. Such forces may arise from pitching, rolling, heaving, surging, yawing or swaying or a combination of any two or more.”

Point 1.2 continues:

“Packing and securing of cargo into/onto a CTU should be carried out with this in mind. It should never be assumed that the weather will be calm and the sea smooth or that securing methods used for land transport will always be adequate at sea.”

The acceleration values which have to be anticipated in the maritime transport depend on a few aspect, such as the shape of the surface or sub-surface of the vessel, its beam, the position of the centre of gravity and centre of buoyancy as well as similar parameters which determine the behaviour of the vessel at sea.

The movements of the vessel may be divided into three different types of linear motions and three types of rotational motions, these types of motions are shown in table 1 and visualized in figure 2.

<table>
<thead>
<tr>
<th>Linear motion</th>
<th>Rotational motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surging is motion along the longitudinal axis.</td>
<td>Rolling is motion around the longitudinal axis.</td>
</tr>
<tr>
<td>Swaying is motion along the transverse axis.</td>
<td>Pitching is motion around the transverse axis.</td>
</tr>
<tr>
<td>Heaving is motion along the vertical axis.</td>
<td>Yawing is motion around the vertical axis.</td>
</tr>
</tbody>
</table>

Table 1 – (IMO/ILO/UNECE, 2016)
Vibration from the hull can be transferred to the cargo. The goods will then be exposed to stresses cause by the extremely low frequency oscillations generated by sea conditions and by higher frequency machinery and propeller vibration. By using seaworthy shipping packages, which are fit for purpose, those risks are avoided.

The absolute acceleration values encountered on board a vessel are not excessively high. In favourable stowage spaces, those acceleration values may even be considerably lower than those encountered in land or air transportation. In a great deal of cases will the value stated in table 2 not even occur. However, the frequency with which the motion occurs must be kept in mind. When a vessel encounters a rolling period of 10 seconds, the vessel moves side to side 8640 times a day, this brings metal fatigue in the lashing gear due to the constantly changing forces.

<table>
<thead>
<tr>
<th>Mode of transport: oceangoing vessel</th>
<th>Forward acting forces</th>
<th>Backward acting forces</th>
<th>Sideways acting forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baltic Sea</td>
<td>0.3 g (b)</td>
<td>0.3 g (b)</td>
<td>0.5 g</td>
</tr>
<tr>
<td>North Sea</td>
<td>0.3 g (c)</td>
<td>0.3 g (c)</td>
<td>0.7 g</td>
</tr>
<tr>
<td>Unrestricted</td>
<td>0.4 g (d)</td>
<td>0.4 g (d)</td>
<td>0.8 g</td>
</tr>
</tbody>
</table>

$1 \text{ g} = 9.81 \text{ m/sec}^2$. The values mentioned above should be combined with static gravity force of $1.0 \text{ g}$ acting downwards and a dynamic variation of:

(b) $= \pm 0.5 \text{ g}$  
(c) $= \pm 0.7 \text{ g}$  
(d) $= \pm 0.8 \text{ g}$

Table 2 – (IMO/ILO/UNECE, 2016)

The values stated in the footnotes of the table, (a), (b), (c), describe the accelerations in the vertical direction. Such accelerations are particularly high in pitching and rolling movements and can easily reach $1 \text{ g}$. This is way the CTU packing guidelines state the maximum at $0.8 \text{ g}$. The vertical acceleration reduces friction forces and increases stack pressure. In figure 3 can an overview be seen of the acceleration forces which prevail on board a vessel. (IMO/ILO/UNECE, 2016)
5.3 Prevention
A conventional way of lashing a container stack is with the use of twist locks and lashing bars. The twist locks don’t need any attention of the crew during the voyage, lashing bars on the other hand do need attention. This because of switching forces, it is possible that the lashing bar becomes slack during the voyage. These bars have to be set back on tension again. Normally this is done by the crew, but on an autonomous vessel this should be done in another way.

During the field research contact had been made with a specialist of the TU Delft for information about the forces that can occur on the lashing gear and to design device that is capable to check and adjust the tension of the lashing bars during the ocean crossing.

5.3.1 Calculations
Because the lashing bar is connected between two hinged points, one on the weather deck and one on top of the container itself, will it be exposed to bucking forces.

Because it is not possible to calculate the bucking load on a lashing bar in sea or heavy weather conditions, will be a maxima be taken. In the Rules of Classification and Construction, Ship Technology, Stowage and Lashing of Containers of the Germanischer Lloyd can be found that the lashing rod needs to have an minimal Safe Working Load (SWL) of 23 tonnes and the turning buckle a minimal SWL of 18 tonnes. (Germanischer Lloyd SE, 2013)

Despite that the Safe Working Load indicates the allowable stresses in the rod and buckle, not the Minimum Breaking Load (MBL), and because the turning buckle has the lowest SWL of 18 tonnes will this data be used for the calculations.

Because the lashing bar and turning buckle are connected between two hinged points. The following Euler bucking formula can be used:

\[ F_{cr} = \frac{\pi^2 \cdot E \cdot I}{(K \cdot L)^2} \]

<table>
<thead>
<tr>
<th>( F_{cr} )</th>
<th>Critical load</th>
<th>18 tonnes (180,000 Newton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E )</td>
<td>Young’s modulus or elastic modulus</td>
<td>Steel: 200 GPa (200,000 N/mm(^2))</td>
</tr>
<tr>
<td>( I )</td>
<td>Smallest moment of inertia of the cross-section normal</td>
<td>( 5 \cdot 10^{-6} , \text{m}^4 )</td>
</tr>
<tr>
<td>( K )</td>
<td>Attachment-coefficient</td>
<td>1</td>
</tr>
<tr>
<td>( L )</td>
<td>Length of column</td>
<td>2380 mm</td>
</tr>
<tr>
<td>( D )</td>
<td>Diameter of column</td>
<td>25 mm ( \Rightarrow r = 12.5 , \text{mm} )</td>
</tr>
</tbody>
</table>

But because the critical load is already known, 18 tonnes, this formula becomes unnecessary for the calculations. The next step is to calculate the maximum allowable stresses of the lashing bars, this is done by using the following formula:

\[ \sigma_{cr} = \frac{F}{A} = \frac{180,000 \, \text{N}}{\pi \cdot 12.5^2} = 366.69 \, \text{N/mm}^2 \]
Since $\sigma_{cr}$ is known, the next step is to calculate fractional extension or strain and the change in length. This is done by Hooke’s law which is as follows:

$$\sigma = \varepsilon \cdot E$$

<table>
<thead>
<tr>
<th>$\sigma$</th>
<th>Maximum allowable stress</th>
<th>$366.69 \text{ N/mm}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon$</td>
<td>Fractional extension or strain</td>
<td>Unknown</td>
</tr>
<tr>
<td>$E$</td>
<td>Young’s modules or elastic modulus</td>
<td>Steel: 200 GPa (200,000 N/mm$^2$)</td>
</tr>
<tr>
<td>$l_0$</td>
<td>Original length</td>
<td>2380 mm</td>
</tr>
<tr>
<td>$\Delta l$</td>
<td>Change in length</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

$$\sigma_{cr} = \varepsilon \cdot E \Rightarrow \varepsilon = \frac{\sigma}{E} = \frac{366.69 \text{ N/mm}^2}{200 \cdot 10^3 \text{ N/mm}^2} = 1.83346 \times 10^{-3}$$

By multiplying the fractional extension or strain ($\varepsilon$) with the original length of the lashing bar ($l_0$) the change in length will follow.

$$\Delta l = l_0 \cdot \varepsilon = 2380 \text{ mm} \cdot 1.83346 \times 10^{-3} = 4.36 \text{ mm}$$

As a conclusion can be said that when the turning buckle is subjected to its critical load of 18 tonnes (180,000 Newton) a total change in length of only 4.36 mm will occur, this is well within exactable ranges. In case the forces on the turning buckle excited above the 18 tonnes, it is possible that plastic deformation or fracture occur, these types of deformation are irreversible.
5.3.2 Container lashing securing device

Since the forces on the lashing bars are constantly changing, the lashing bars become slack during the voyage. It is essential that these bars are tensioned again, to the right amount of tension, so the containers stay safely secured on the vessel. On board conventional vessels this is done every day by the crew by hand. But since an autonomous vessel has no crew on board, which can inspected the tension of the bars, it has to be done automatically.

To achieve a good working system a good overview is needed of the tension on all the lashing bars. A possible way to get this working is fitting each lashing bar with a tension meter. This meter will be connected to a central operating panel. The control panel will check the tensions on the bars. If the tension on one of the bars is too low, it needs to be tensioned again.

The idea is to invent an intergraded system of hydraulic cylinders in the weather deck, as shown in figure 4. Each cylinder is connected to the D-ring in which the container lashing bar is secured. In case the tension of the lashing bar is reduced, the operating system will notify the hydraulic power pack to start-up and pressurize the hydraulic cylinder. This will result into downwards motion of the D-ring and re-tensions the lashing bar to the right amount of tension.

For this system to work it is essential that every D-ring, in which a container lashing bar is secured, has its own hydraulic cylinder. This is because not every lashing bar will become as slack as its neighbour, which will eventually result into less hydraulic pressure needed for the re-tension of the lashing bar. The forces acting on the cylinder are mainly pulling forces, but this is not a problem. For example, a hydraulic cylinder with a bore of Ø140 mm, a rod of Ø100 mm and a maximum working load of 300 bar can resist a pulling force of 266 kN (26.6 tonnes), this is more than the SWL of the turning buckle. (MTS Cilinders)

An advances of such an intergraded system is that all arrangements are installed beneath the weather deck of the vessel. This saves space on top of the weather deck and ensures that the equipments is protected against the elements.

A disadvantage of the intergraded system is the cost and maintenance of the hydraulic power pack and hydraulic cylinders. Another issue which has to be solved is the redundancy of the integrated system, e.g. in case of a burst of a high pressure hose.
5.4 Response
If containers are not well stowed the forces on the lashing bars could extend above the SWL. This could result in breaking the bar and let the container stack tumble over. When this problem would occur there will be not much that can be done, not by men or machine. Additional bars can be set on the cargo but most important is to sail as fast and safe as possible to an emergency port to solve the problem.

5.5 Conclusion
Calamities involving cargo on board autonomous vessels could best be prevented. This could be achieved by regular checks of the tension on the lashing bars. If the lashing bar will become less tensioned during a voyage a “tension checking system” will detect that the bar needs to be re-tensioned. This will activate the re-tension system, which consists of a hydraulic cylinder. Because of the downward motion of the cylinder, the lashing bar will be re-tensioned. Because all arrangements are installed beneath the weather deck of the vessel, space is saved on top of the deck and the equipment is protected against the elements. But further research has to be done in order to make the integrated system redundant and capable to be equipped on board autonomous vessels.
6. Piracy

6.1 General

– Sub question
How can piracy on autonomous vessels be prevented and responded to?

– Methodology
To answer this sub question literature concerning the piracy conditions nowadays, prevention and response to piracy attacks on conventional vessels, as well as the internet has been used. Also has there been contact with specialists of the Royal Netherlands Navy about the prevention and response to piracy attacks and their vision on the protection of autonomous vessels.

6.1 Introduction

Head of engineering and technology for the marine division of Rolls-Royce, Oskar Levander: “I believe that in many ways automating a ship should be a lot easier than automating aircraft. For a start, if something did go wrong, instead of falling out of the sky a drone ship could be set by default to cut its engines and drop anchor without harming anyone. As for piracy, with no crew to be taken hostage it would be much easier for the armed forces to intervene. Of course, more modern pirates might try to hack their way into the controls of an autonomous ship to take command.” (The Economist, 2014)

Mr. Levander has a view related to this subject on piracy, many companies and researchers will share with him. This is why it is very important to do research on this subject regarding piracy on autonomous vessels, because piracy might still be a relevant issue for autonomous vessels. But the question is if pirates still have an interest in autonomous vessels. For instance, in 2015 a few (gasoil) tankers near Singapore & the Strait of Malacca have been hijacked to with the intention to steal its cargo/oil. With no crew on board the only matter is to take control of the ship if cargo is the main target. Of course this does not apply to all types of autonomous vessels for instance bulk carriers but still these vessels have fuel on board which can be stolen and transferred to a pirate vessel.

6.2 Piracy nowadays

UNCLOS (United Nations Convention on the Laws of the Sea) are international law regulations at sea. UNCLOS characterizes piracy very specifically. Article 101 of UNCLOS states:

Piracy consists of any of the following acts:

a. Any illegal acts of violence or detention, or any act of depredation, committed for private ends by the crew or the passengers of a private ship or a private aircraft, and directed:
   i. On the high seas, against another ship or aircraft, or against persons or property on board such ship or aircraft;
   ii. Against a ship, aircraft, persons or property in a place outside the jurisdiction of any State;

b. Any act of voluntary participation in the operation of a ship or of an aircraft with knowledge of facts making it a pirate ship or aircraft;

c. Any act of inciting or of intentionally facilitating an act described in subparagraph (a) or (b).

(Fedeli, 2010)

Modern piracy has been a big problem for the maritime transport. In particular major shipping routes like the Gulf of Aden, Singapore Strait and the Strait of Malacca, Gulf of Guinea and around the north coast of South America. The last few years have shown a decrease in piracy activity for the Gulf of Aden and the Indian Ocean because of international navy patrols. Nevertheless, this does not mean that piracy doesn’t occur anymore.
Pirates often favour small boats to attack cargo vessels. These are difficult to spot on radar or to be seen for the lookout. Many times, pirates focus rather than cargo, on taking hostages, the ships safe and/or personal belongings of the crew. But cargo is a big target as well. In the Malacca strait and around Singapore Strait, a number of (small) gasoil tankers were hijacked last year. The crew remains often “unharmed” but one or more pirate tankers come along side and the gas oil is transferred to the pirate vessel(s). In this way it even might look one of the vessels is bunkering fuel. (Crime on the high seas: The world’s most pirated waters, 2014)

6.2.1 The four forms of piracy
There are four forms of piracy, namely:

- Low Level Armed Robbery
- Medium Level Armed Assault and Robbery
- Major Criminal Hijack
- Hijack and Ransom
  (Woudstra, 2009)

**Low Level Armed Robbery**
Low level criminals aiming for a quick loot. They operate in small skiffs and are low level armed as well. (Woudstra, 2009)

**Medium Level Armed Assault and Robbery**
Local criminals with an organization structure and taking everything on board of value. They operate as well in small skiffs but in combination with a mother vessel. (Woudstra, 2009)

**Major Criminal Hijack**
Excellent planning, organization and equipment. Very aggressive and they might even use larger vessels to make them look like authorities. They aim at the bigger profits once they come on board. Mostly they hijack a vessel and sail it to a quiet location. There, the cargo is discharged, the vessel repainted and is given as well another vessels name and registration. (Woudstra, 2009)

**Hijack and ransom (Somalia)**
The crew is taken hostage, the vessel is sailed to an quiet location near the coast and they contact the vessels company to demand a ransom. The crew is mostly unharmed because pirates understand that the crew is their cargo. (Woudstra, 2009)

Once a vessel is under attack, it has to take actions according to the BMP (Best Management Practices, this involves like making maximum speed, manoeuvring and activating the hoses. If these actions don’t succeed against the pirates and manage to get on board, the crew has to go to the vessels citadel. If the crew manage to get into the vessels citadel, a hostage situation is prevented. Marines can go on board of the hijacked vessel and clear it of pirates.

In case crew is not (all) safe in the citadel, the pirates can use them as hostage. From that point there is nothing the Royal Netherlands Navy can do. It is better to pay the ransom, than taking the risk of the crew getting harmed. For most ship-owners is the crew, reputation, the vessel and its cargo more valuable than the ransom which has to be paid.

It is important to mention that the ransom can be marked, numbers of the money can be stored in a database so the money can be traced back. The ransom will come back on the marked by purchases of the pirates, which will show the money flows of the pirates.

All these four forms of piracy can still be applied on autonomous vessel, the only difference is that there is no crew on board which can be robbed or taken hostage for ransom. Nevertheless, the cargo on board of the vessel is still vulnerable.
6.2.2 Prevention and response nowadays

The IMO (International Maritime Organisation) has the vessel’s flag state come up with regulations for arming the vessel with weapons and guards. Vessels take for instance security on board in Egypt after the Suez Channel and drop them off in Sri Lanka. (www.imo.org)

The Maritime Security Centre – Horn of Africa (MSCHOA) has published the BMP4 (Best Management Practices to Deter Piracy off the Coast of Somalia and in the Arabian Sea Area) which contains important information regarding piracy, activities and attacks including preparations to be taken before entering the ‘High Risk Zone’ and information for the crew when the vessel is under attack. The High Risk Zone is illustrated in the BMP4 and shows the zone, piracy activity occurs but this book is usable anywhere in the world against piracy.

It is a fact that vessels with a relatively low freeboard and a cruise speed below 15 knots are a more favourable target for pirates and are easy to attack. This is a reason the BMP4 contains a chapter entitled “Self- Protective Measures” which lays out a list of possible preparations including:

- Watch keeping measures including camera, security and lighting advice
- Bridge protection measures
- Control of accommodation, bridge and machinery space measures
- Psychical, water spray and foam monitor measures
- Information regarding manoeuvring, ship’s tools and alarms including drills and citadels

(BMP4) (Wikipedia piracy)

6.2.3 Difference of piracy for normal and autonomous vessels

The fact that there is no crew on board autonomous vessels that can be taken as hostage, does not change the fact that piracy still occurs and does not guarantee pirates will have no interest in autonomous vessels. If pirates in the future will attack an autonomous vessel, the cargo or vessel will be the target instead of taking hostages. It’s not being used yet as far as is known but in case an autonomous tanker is attacked and it is ‘not under command’ at sea, pirates could take the vessel as “hostage”. Threatening to blow up or sink the tanker to cause a massive environment pollution, they can still claim a lot of money. To prevent this from happening, an innovative solution has to be found.
6.3 Worldwide activity of piracy

6.3.1 Worldwide overview of pirate activity
The website of the IMB (International Maritime Bureau) shows the worldwide activity of piracy. Attached in Appendix 1, the full investigation of piracy activity for the period of 01-01-2016 until 17-05-2016. Appendix two shows another investigation of the IMB regarding piracy activity during the last few years. These two investigations show some very interesting facts, as can be seen in table 3.

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Total incidents</td>
<td>245</td>
<td>246</td>
<td>134</td>
<td>74</td>
</tr>
<tr>
<td>Boarded</td>
<td>183</td>
<td>203</td>
<td>106</td>
<td>50</td>
</tr>
<tr>
<td>Fired upon</td>
<td>Unknown</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hijacked</td>
<td>21</td>
<td>15</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Hostages</td>
<td>442</td>
<td>271</td>
<td>250</td>
<td>At least 44</td>
</tr>
</tbody>
</table>

Table 3

6.3.2 Somali piracy
Somali piracy activity has been a major problem for the maritime world. In 2009 & 2010 the number of incidents peaked around 180 with 51 hijacked vessels in 2010, as can be seen in diagram 1. Different figures appear on the internet, but they are all based on the numbers of the IMB. This difference in figures is probably due to the investigated area of the different investigations. After all, the anti-piracy measures last years have made a huge decrease in these statistics of activity.

Diagram 1
Another investigation based upon IMB figures, shows a decrease in activity as well, only with different numbers, as can be seen in table 4. (Hellenicshippingnews.com)

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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf of Aden</td>
<td>Number of incidents</td>
<td>181</td>
<td>182</td>
<td>237</td>
<td>75</td>
<td>15</td>
<td>11</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 4

But BMP’s Mr Mukundan said: "Somalia remains a fragile state, and the potential for an attack remains high. It will only take one successful hijacking to undo all that has been done, and rekindle this criminal activity"

The conclusion of Mr Mukundan gives reason to investigate piracy related to autonomous vessels because the reaction on autonomous vessels is unclear. (Statista.com) (ICCWBO.org)

6.3.3 Singapore/Malacca Strait

A very interesting article written by Ted Kemp, published on September 2014 says:

Unlike the Somali pirates—who, incidentally, are now almost out of business—the pirates of southern Asia rarely, if ever, seize hostages. They’re in the business of stealing cargoes of liquid fuel. Experts say, they’re highly organized criminal enterprises that gather intelligence, coordinate attacks, work in discrete teams, sometimes have their own tankers and then sell what they steal to big, pre-arranged buyers.

From a business standpoint, the boom in south Asian piracy makes a lot of sense. A third of the world’s shipping moves through the Strait of Malacca and Singapore Strait each year, including most trade between Europe and China, and nearly all the crude oil that moves from the Persian Gulf to the big Asian economies like China, Japan and South Korea. About 130,000 vessels arrive in Singapore each year alone, according to both Singaporean and international estimates.

While the Somalia piracy activity is decreasing after 2011, the South East Asia piracy activity has been rising according to IMB numbers.

The Gulf of Aden numbers compared with the following summarized numbers, see table 5:

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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SE Asia</td>
<td>Number of incidents</td>
<td>42</td>
<td>63</td>
<td>80</td>
<td>104</td>
<td>128</td>
<td>141</td>
<td>147</td>
<td>20</td>
</tr>
<tr>
<td>Gulf of Aden</td>
<td>Number of incidents</td>
<td>181</td>
<td>182</td>
<td>237</td>
<td>75</td>
<td>15</td>
<td>11</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 5

In 2015 actions taken by the Malaysian and Indonesian Authorities against pirate gangs appear to have had the necessary effect. No small tankers have been hijacked in South East Asia in the first quarter of 2016.

Related to autonomous vessels it is unclear to tell how this type of piracy will react to autonomous vessels. Important to mention is that a lot of incidents are low level theft incidents which mean robbery of Crew P.E. (Personal Effects/belongings) and ships store/properties. This does not change the fact small tankers have been hijacked.

(Piracy Singapore) (Hellenicshippingnews.com) (Maritime-executive.com)
6.3.4 Gulf of Guinea (Nigeria)
New figures of the IMB show a major increase of (armed) piracy activity in the Gulf of Guinea and in particular off the coast of Nigeria. Mr Mukundan of the IMB said “Reports in the last quarter indicate unacceptable violence against ships and crews in the Gulf of Guinea, particularly around Nigeria. The current increase in kidnappings is a cause for a great concern”.

Numbers of the IMB shown in Appendix 2 show 29 reported incidents in the first quarter of 2016 (January – 17th May) with 23 reports off the coast of Nigeria. Summarized the following numbers appear: 3 hijacked vessels, 9 fired upon cases, 13 boarded vessels and 5 attempts with most (reported) cases an armed incident involving guns. Furthermore, 26 kidnapped crew members, 2 injured and one stolen (repainted) vessel.

Related to autonomous vessels, the upcoming and latest piracy activity in the Gulf of Guinea is reason to investigate preventions against piracy. However, patrols and actions against piracy show a decrease of activity against Somali pirates and as well for South East Asia. This could be one of the solutions as well for this area. (Maritime-executive.com)

6.4 Possible ways to attack or attempt to enter an autonomous vessel

6.4.1 Sabotage
Without any crew on board autonomous vessels, it could be easy for pirates to, for example blow up the vessel’s propeller, to make the vessel ‘not under command’. Nowadays the crew or security on board could prevent these actions with spraying, (warning) shots etc. But without a crew or security this is a possible option to attack an autonomous vessel. Of course this is just theoretical because it is not known if pirates will attack autonomous vessels by blowing up the propeller because there are more ways to make the vessel ‘not under command’ but still it is a possibility.

Depending on the ships design related to satellite/communication equipment, it could be a possibility to damage communication equipment but actually, this has to be prevented during the vessels design. Still this is a possible way to attack or attempt to enter an autonomous vessel. If the vessel is not under command, pirates can steal its cargo or whatever they are after.

6.4.2 Entering an autonomous vessel
Like Somali pirates for example, coming along side and enter the vessel. Then, depending on the ships design, pirates could ransack the vessel or destroy its equipment to make the vessel not under command. Or pirates could, after entering, threat to sink or burn the vessel and cause a major environmental pollution if they do not get a certain amount of money.

6.4.3 Modern ways of piracy (South East Asia style)
Around the world different types of piracy are happening. For this case, not like Somalia pirates which ordinary attack vessels, but entering a vessel and load its cargo or bunkers into another vessel. This possibility is not focused on the way of entering a vessel but how to prevent piracy like this.

6.4.4 Conclusion
Above a few possibilities to attack or attempt to enter an autonomous vessel had been explained. Mainly these possible ways can be prevented with security, which is currently on board conventional vessels. A possible solution which is investigated in the following chapters is implementing drones on board autonomous vessels.
6.5 Prevention & response to pirate attacks

6.5.1 Already existing prevention & response methods
As explained before, seafarers nowadays use the BMP4 as one of the information sources when entering a piracy area. A lot of preparations are explained to prevent piracy attacks. Patrolling in piracy areas as well as sending mariners after a piracy attack are options against piracy.

Already existing prevention and response which can still be used for autonomous vessels:

- Water spray
- Increasing speed and/or altering course

6.5.2 Sabotage
Imagine an autonomous tanker is being attacked by pirates. The vessel's propeller is damaged by explosives and the vessel in ‘not under command’ in the Gulf of Guinea. Nigerian pirates are threatening to sink the vessel if they do not get a certain amount of money in hours/days. The company refuses to pay the money, the pirates sink the vessel and a massive environmental pollution is happening.

To prevent all of this, pirates may not get a change of attacking the vessel if a solution is implemented on board autonomous vessels. The original prevention methods are an option but it will not stop pirates. The following chapters investigate possibilities.

6.5.3 Implementing drones
For example, the entered vessel had two drones on board. The command centre or a special innovated radar system spotted the pirates. The command centre could have sent the drones and prevented the attack. These drones could be equipped with any kind of gun, Taser or some other device. The concept of drones will be investigated in chapter 6.6.

6.5.4 Prevention and/or response of modern piracy
Again, modern piracy is piracy where cargo and/or bunkers is the main objective for pirates. Cargo/bunkers can be transferred to another vessel. The best known way which already has shown its worth is patrolling like the Malaysian and Indonesian government did in 2015 (chapter 6.3.3). This patrolling could be done as well by drones but this is another type of drone mentioned in chapter 6.5.3 and chapter 6.6. The way of patrolling is up to the authorities and the financial possibilities (chapter 6.7).

6.6 Possibilities of drones on board autonomous vessels

6.6.1 The idea
Implementing a drone on board autonomous vessels to prevent a piracy attack. In case pirates attempt to attack the vessel, the control of the drone is given to an anti-piracy centre or could be done by the normal control centre. But controlling drones requires skill and training, not to mention that the situations at sea are not perfect all the time. For this reason, an anti-piracy centre would give a solution in combination with one or more drones on board autonomous vessels.
6.6.2 Law regulations of ship security

This whole innovation gives a few problems, first of all the legislation for the use of these drones combined with the liability after pirates are injured or killed. Since the navy is using jets to drop bombs in war areas and the military is using drones to bomb in war areas, as well to kill terrorists, the anti-piracy centre could be controlled by a special part of the military. Still international regulations and agreements have to be agreed between countries. The main objective here is to replace drones for the current security measures on board conventional vessels.

Territorial waters

Under UNCLOS, naval vessels are not permitted to pursue pirates within the territorial waters of a state. However, Resolution 1897, which is accepted under UNCLOS, grants permission to all states to enter the territorial waters of Somalia to suppress piracy and unlawful acts. Such regulation is necessary for implementing drones on board autonomous vessels to replace security. When discussing these regulations, in mind should be kept, the requirement that the piratical act occur on the high seas or outside the jurisdiction of any state is particularly important. Pirates know international law as well. Acts of maritime violence within territorial waters are not technically acts of piracy under international law. However, maritime violence within territorial waters may constitute piracy under the state’s domestic law. States have exclusive jurisdiction over their own territorial waters and can punish criminal activity within that zone according to UNCLOS supra note 1, art 2. Therefore, a pirate does not violate international law if the piratical activity occurs within the territorial waters of a state. (Fedeli, 2010)

At sea

Private security guards who kill unarmed civilians at sea are not likely to be held personally accountable for violations of the Laws of War, as set forth by the Geneva Conventions, for two reasons.

First, piracy does not amount to warfare. Generally, war can only be between states, and pirates are private actors.

Second, private actors are generally not accountable under the Laws of War.

In Prosecutor v. Akayesu, the International Criminal Tribunal for Rwanda stated:

The duties and responsibilities of the Geneva Conventions and the Additional Protocols...will normally apply only to individuals of all ranks belonging to the armed forces under the military command of either of the belligerent parties, or to individuals who were legitimately mandated and expected, as public officials or agents or persons otherwise holding public authority or de facto representing the Government, to support or fulfill the war efforts.

Therefore, private security would not be criminally liable for violations of the Laws of War. (Fedeli, 2010)

A disadvantage of the private security sector is that there are not regulations, think of the Wild West. No authorities can question private security contractors for killing pirates at sea. The regulations in territorial waters depend on the law of the county but still, there are possibilities regarding the regulations for private security nowadays, compared to the necessary regulations for drones.
6.6.3 Possibilities of drones to prevent pirates from entering

Using drones instead of guards with the same capabilities for example, with the right to kill or shoot a pirate or any other action to prevent them from entering or damaging the vessel is the idea. But a few problems appear during this investigation.

First of all, the whole drone concept has been already investigated by different countries in the past few years. For example, the United States of America has done a lot of research. This is unfortunately secret information. To investigate if drones could be implemented on board autonomous vessels, these investigations should become public or should be done by an international investigation team.

Second, pirates can possibly shoot the drone out of the sky in a lot of different ways. Anti-measures against this should be investigated as well and the cybercrime dangers since these drones are controlled remotely.

Definitely more research has to be done regarding the implementation of drones on board autonomous vessels against piracy as well as drones preventing pirates from attacking manned vessels but it is obvious that drones could be the solution.

6.6.4 Complicated situation

In paragraph 6.2.1 are the four forms of piracy explained. All these four forms of piracy can still be applied on autonomous vessel, the only difference is that there is no crew on board which can be robbed or taken hostage for ransom. Nevertheless, the cargo on board of the vessel is still vulnerable.

There has been done field research regarding the idea of implementing drones on board autonomous vessels to protect the vessel against piracy, as can be read in Appendix 3. According to Kapitein ter Zee N. Woudstra is this idea in reality very complicated compared to other solutions. A drone has to be maintained, controlled, fuelled and land back on the vessel. In addition do liability and regulation complicate drones to be used.

To protect the cargo on board autonomous vessel other solutions are much more viable that the use of drones. For instance, by applying an incapacitating agent, which incapacitates the pirates, in combination with a squad of marines (8-12 marines).

In addition, the design of the vessel and its accessibility can be made such that it becomes a fortress. This is already done on board of conventional vessel by installing barbwire and fire hoses. In case that the pirates do come on board and into the “vessels accommodation” a incapacitating agent can be released, after which marines can enter and clear the vessel.

Other possibilities can be as well be used instead of an incapacitating agent, for instance non-lethal weapons like lasers, Tazers or a Long Range Acoustic Device (LRAD), which has been used during riots and protests. (Wikipedia)

6.6.5 Incapacitating agent in combination with marines

Depending on the vessel’s design, there will be rooms or some sort of accommodation on board autonomous vessels. In the engine room there has to be done maintenance and repair by technical teams on the systems, this require space and if there is space for technical teams, there is also space for pirates. Assuming pirates find a way to enter the vessel and enter this “accommodation”, releasing incapacitating agent which would stop them from moving further through the vessel. The term incapacitating agent is defined by the U.S. Department of Defense as: "An agent that produces temporary physiological or mental effects, or both, which will render individuals incapable of concerted effort in the performance of their assigned duties". (Wikipedia , 2015)

This will temporarily stop the pirates from their intentions and will create time and an opportunity for marine forces to enter and clear the vessel.
6.7 Actions of owners and authorities

6.7.1 Prevention
Desiderius Erasmus once said: Prevention is better than cure. After an increase of Somali piracy, peaking around 2010, anti-piracy measures have shown a huge decrease of incidents in the Gulf of Aden, Red Sea and off the Somali Coast. After an increase of piracy incidents in South East Asia, anti-piracy measures in 2015 have shown a decrease as well of piracy in that area. Now that the Gulf of Guinea is being terrorized by pirates, anti-piracy measures could have a huge effect as well. Even with the high violence level of pirates in that area. And as Mr. Levander said: As for piracy, with no crew to be taken hostage it would be much easier for the armed forces to intervene (chapter 6.1).

When the time is there and the first autonomous vessels set sail, a solution could be to make convoys of autonomous vessels, which can be escorted by the flag state marine vessels or a NATO collaboration, just like Operation Ocean Shield. The disadvantage of this concept is that it is only possible for a certain amount of time and comes along with high costs. Imagine more autonomous vessels sailing around the globe. Simply not sail through piracy areas sounds as a simple but unrealistic solution. Since a third of the world shipping sails through the Strait of Malacca & Singapore Strait and with 47 vessels passing daily through the Suez Channel, it is almost impossible to sail not through piracy areas in the future.

6.7.2 Navy patrols
Where the navy will patrol the seas depends on where in the world these piracy hotspots are. Statistics show that the piracy activity in Somalia has decreased, see Appendix 2. This is mostly because of patrolling and effective actions of different Navy’s in that area.

In the Somalia area there are a few ongoing international operations against piracy. The Royal Netherlands Navy is taking part in multiple anti-piracy missions like Ocean Shield (NAVO), Atalanta (European Union) and Combined Task Force 150 (one of three task forces operated by the Combined Maritime Forces).

Despite of the fact that there is a decrease of piracy activity, operations in the area will continue to keep the waters safety. This is why there is a good cooperation between different countries and organizations.

Furthermore, hotspots are shifting. For instant has piracy in the Gulf of Guinea – Nigeria increased, see Appendix 1 & 2. At these new hotspot a joint operation between countries has to be setup to combat piracy and protect the interests of the commercial vessels. No matter if these vessels are manned or autonomous.
6.8 Conclusion
The answer to the question ‘How can piracy on autonomous vessels be prevented and responded to?’ is complicated. There are many existing ways as described above to respond to piracy. Drones have been investigated and this solution could be possible if it was not so complicated compared to other solutions. However, if authorities or shipbuilders see a future in implementing drones on board autonomous vessels there has to be done more research by a team which has access to all researches which have been done and all the possible information. Also international regulations are necessary for implementing drones on board autonomous vessels.

The use of an incapacitating agent in combination with a squad of marines is the best solution. Marines are well trained and will be present since Royal Navy’s will be present in the hotspots of piracy. For autonomous vessels but as well manned vessels, implementing the LRAD system is a solution as well which should be a part of the BMP4. To implement this on vessels, more research has to be done regarding the possibility, regulations and the effectiveness of the system against pirates.

For authorities, the statistics show that patrolling is very effective against piracy. However, statistics show as well that piracy will move from one area to the other. It is very important that authorities work together to respond to piracy attacks.
7. Anticipate or respond to upcoming weather conditions

7.1 General
- Sub question
How can autonomous vessels anticipate or respond to upcoming weather conditions?

- Methodology
To answer this sub question literature concerning weather bulletins and the MUNIN research report, as well as the internet for information about weather stations and weather measurements has been used. Furthermore, there has been made use of the program TurboWin and has specialists of the Royal Netherlands Meteorological Institute been contacted for an interview.

7.2 Heavy weather avoidance
Certain complex operations like sailing in very rough weather can be challenging for conventional ships and this goes as well for unmanned ships. However, as sensors and on-board control systems evolve and as high capacity communication systems make remote control easier, it is not unrealistic to foresee that unmanned ships can operate as safely as manned ships in all equivalent conditions. (MUNIN, 2015)

But MUNIN informs that the issue of heavy weather avoidance must be taken into consideration and refers to good weather routing systems that can be used for safe voyage preparation and routines on board the unmanned vessel.

As mentioned above are sensors and on-board control systems evolving, this brings new navigation functions such as:

- Tactical weather routing
- Avoid dangerous sea conditions: surf riding, parametric rolling, broaching etc.

Tactical weather routing can be achieved by creating accurate weather routing system that receives accurate measurements about weather conditions. This can be achieved by placing automatic weather stations on board of autonomous vessels.

Avoiding dangerous sea condition like surf riding, parametric rolling and broaching need to be detected before it becomes a danger for the autonomous vessel. But the detection of these conditions falls outside this topic, for more information about the detection and avoidance of dangerous sea conditions see Topic 1 – Detection.
7.3 Weather bulletins

The oceans are the source of air masses, depressions, hurricanes, rain and wind. That is why meteorological observations at sea are of vital importance for weather and climate research. Satellites, weather buoys and airplanes provide much information on the weather at sea. But the observations on board ships are addition to this information. Satellites are not capable to measure atmospheric pressure. That is why meteorologists keep an accurate record of atmospheric pressures from ships, which are intergraded into mathematical models of the atmosphere on which the forecast and storm warnings are based. This is why meteorological observations by ships are still essential for accurate weather reports and result in more accurate weather routing systems. (KNMI)

During the field research it became clear that it was also necessary to investigated which path the collected data on board a vessel follows; both in the past, present and future. This is because the path has changed considerably over the years. Mr. Rozeboom, Port Meteorological Officer of KNMI, provided the following information.

It all started during the telex era, during this period all weather bulletins were send via the telex. The downside of the telex was the limited range and the cost of the bulletins which were send to the vessels.

In the early nineties, 1992/1993, was decided that the radio officer on board vessels had become obsolete. So the deck officer was responsible for sending weather reports via the Inmarsat-C system. These reports had to be sent to a land earth station (LES), e.g. Burum – Netherlands. KNMI had made agreements will the LES Burum about receiving meteorological data from around the world, this is because the metrological bureau pays all code 41 messages (weather observation messages). These agreements were made so the KNMI does not receives weather data from vessels which are for instance operating in the Indian Ocean, this information will not be used by KNMI. In case a vessel does send this weather data to Burum and KNMI, the data will be put on the Global Telecommunication System (GTS), this is a global network for the transmissions of meteorological data from weather stations, satellites and numerical weather prediction centres, so the information will be used by other countries. Nowadays the deck officer will see in the TurboWin programme which land earth station to select, this ensures that the observations are send to an LES which is as close to the vessels position as possible, where it can be analyzed and used for the weather bulletins. The TurboWin programme is used worldwide as a standard form for weather observations.

The newest system uses buffer messages, the advantages of these buffer messages is that they can hold more informative e.g. measuring heights, height of the deck cargo, this gives a more accurate metadata. This new system is called Format 101, but because of the use of buffer messages is it not possible to send these messages via the code 41. This has led to new international agreements, which states that every country must have its own special access code for the ships under his flag, for ships under the Dutch flag this code is 431. The KNMI made arrangements with the Inmarsat provide for this 431 code and to which address the messages have to be sent, this is in most cases an email address. So the vessels send the 431 messages to a land earth station, which sends it via email to the designated address, here the information will be analyzed and put on the Global Telecommunication System (GTS). This new Format 101 system facilitates the entire distribution of messages, where the messages are mainly sent via email of to a web server. This is essential for the autonomous vessel, which is also connected via the Maritime Cloud or internet.

Because the software that is necessary to process the 431 messages and detect any errors is quite expensive, the KNMI has made agreements with the France meteorologist bureau, Météo-France, to forward all received 431 messages. The France meteorologist bureau will process these messages, the processing of a weather observation message takes only a few minutes after which the information will be put on the GTS. (Rozeboom, 2016)
7.4 Weather stations
The following subchapters are mainly based on information Mr. R. Rozeboom, from the Koninklijk Nederlands Meteorologisch Instituut, supplied via an interview. A transcript of this interview can be found in Appendix 4.

7.4.1 Automatic weather stations on land
Currently there is a difference between the data which is collected on board of ships and which is collected on land and offshore platforms. The stations on land are equipped with sensors which measure the following values: temperature, humidity, wind, precipitation, clouds, solar irradiance, fog and type of precipitation, this is done with the uses of specific sensors.

Visibility & Precipitation
The weather stations on land are equipped with a Present Weather Sensor (PWS). This sensor determines the visibility by measuring airborne dust, fog of precipitation. Another function of the Present Weather Sensor is measuring the precipitation. The intensity of the rain or snow and if the precipitation is continuous or intermittently. The Present Weather Sensor consists of a laser-based sensor that has a sender-receiver sensor. In case that the air is clouded, for instance by rain, fog or dust. The laser beam will scatter, which is pick-up by the receiver sensor. This deviation will be analyzed by algorithms that calculate individual precipitation particle types.

Figure 5 shows a Present Weather Sensor on the testing grounds in the KNMI, the red oval highlights the laser-based sensors with the sender-receiver sensor. It detects the rate of fall, the size of the particles and the number of particles which fall through the laser beam, with this information a precipitation particle type can be calculated. The green circle highlights a back luminous sensor, it measures the background brightness, this is why the sensor is pointing north, away from the sun. The purple circle highlights a rain sensor, this sensor detects whether it rains and uses this as extra information. (Rozeboom, 2016)

Clouds
The automatic weather stations on land are also equipped with a sensor which looks at the clouds. An altitude meter or altimeter determines the height of the cloud base. This information is in particular of great importance for the aviation. For meteorologists is also the change of cloud cover, such as the degree of coverage and the level of the cloud, of importance, this could indicate a change of weather. (Rozeboom, 2016) (KNMI)

Thunderstorm
Another measuring system records thunderstorm. This system is called a SAFIR lightning detection system, which maps lighting discharges and impacts. The SAFIR system consists of an antenna of twenty meter with equipment to record electromagnetic radiation, which is emitted in case of a lighting discharge. (Rozeboom, 2016) (KNMI)
The weather station provides synoptic observations, but the biggest advantage of a fully automatic weather station is the ability to gather frequently data, this results in more accurate information. In fact, data is collected every second. All this data is processed, which is after ten minutes available for use. Every hour a weather report is created which is based on the information gather from these automatic weather stations and information originating from different weather services. (KNMI)

7.4.2 Weather measurements on board ships
The sensors which are mentioned above are not all essential for the measurements on board ships. The values that must be measured on board vessel are international agreed upon. The following values are important for accurate weather reports. The values which are measured are: the air pressure, seawater temperature, air temperature, humidity and wind speed/direction.

Nowadays the deck officer will collect this data and will fill in TurboWin, a programme used worldwide as a standard form for weather observations.

Which information the officer needs to collect and fill in, to make an accurate weather observation, is stated in the following subchapters.

**General information**
First of all the officer has to check if the call sign is correct and needs to enter the UTC date and time. Next the officer has fill in the position of the vessel, this is done by entering the latitude and longitude and the course and speed that the vessel made good for the last 3 hours.

**Wind**
After these first two steps the officer can start with entering the collected weather data. It starts with the wind, this data consists of the wind direction in degrees and wind speed in knots or metres per second, the ship’s heading, ship’s ground course and ground speed.

**Waves**
After the wind data is been filled in, the officer has to fill in the period in seconds and height of the (wind) waves and the presence of a swell with information about the direction in degrees, the period in seconds and height in metres.

**Barometer reading**
The barometer reading is an important measurement of weather observations, the barometer reading is in hPa. It is important to know if the reading indicates the Mean Sea Level pressure. If this is not the case a correction to the barometer reading has to be applied, this is done automatically by TurboWin.

**Barograph reading**
In case the vessel is a selected ship it is equipped with a barograph. This means that the following data has to be enter into TurboWin. The amount of pressure tendency during the last three hours and the characteristic of pressure tendency during the last three hours.

**Temperature**
The temperature is an important measurement of weather observations. The following measurements need to be filled in: the air temperature and method (sling psychrometer or marine screen), wet-bulb temperature and state of the wet-bulb (wet-bulb not frozen or frozen wet-bulb), the relative humidity in per cent but only if the wet-bulb temperature is not available and the seawater temperature and method (intake, bucket, hull contact sensor or other).
**Present weather**
In the observation ‘Present weather’ the officer has to describe the weather at the time of the observation or (where specifically mentioned) during the period of one hour immediately preceding it. For present weather one does not take into account meteorological phenomena which had been experienced more than one hour before the observation.

These general weather conditions can be divided into ‘no precipitation (dry) at station at time of OBS’ and ‘precipitation (wet) at station at time of OBS’.

**Past weather**
The period covered by ‘Past weather’ shall be: six hours for observation at 0000, 0600, 1200 and 1800 UTC; three hours for observation at 0300, 0900, 1500 and 2100 UTC.

‘Past weather’ shall be selected in such way that ‘Past weather’ and ‘Present weather’ together give as complete a description as possible of the weather in the time interval concerned. For example, if the type of weather undergoes a complete change during the time interval concerned, ‘Past weather’ shall describe the weather prevailing before the type of weather indicated by ‘Present weather’ began.

**Visibility**
Meteorological offices also like to know the visibility at sea. The officer has to fill in the visibility via TurboWin, this can range between less than 0.03 nm (less than 50 metres) up to more than 27 nm. In case the visibility is not uniform in all directions it should be estimated or measured in the direction of least visibility.

**Cloud cover**
Another observation that has to be done is a cloud observation. The officer has to fill in if there are any clouds in the sky and the family of the clouds; low (cumulus, stratus, cumulonimbus), middle (altostratus, altocumulus, nimbostratus) or high clouds (cirrus, cirrostratus, cirrocumulus).

Beside the family of the clouds, is it also important to know the total cloud cover and amount of cumulus clouds. The total cloud cover and amount of cumulus clouds is measured in fractions of one eighth. After the total cloud cover has been filled in. The officer has to fill in the height of the base of the lowest cloud in the sky, this could be cloudless or range between 0-50 metres up to more than 2500 metres.

**Ice**
The last observations that need to be made are ice observations, in case the vessel is sailing in icy conditions. First the officer has to fill in the concentration or arrangement of sea ice. Two options are possible: the vessel is in ice or within 0.5 nm of the ice edge or the vessel is not within 0.5 nm of the ice edge. Also the present ice situation and trend of conditions over preceding 3 hours has to be filled in. Here the officer states if the vessel is: sailing in open water with floating ice in sight, sailing through ice easy to penetrate or sailing through ice difficult to penetrate.

Another important observation that needs to be made is ice accretion or icing. Icing on vessels is a serious hazard where cold temperatures (below about -10°C) combined with high wind speeds (typically 8 Beaufort or more) result in spray, which will immediately freeze when it comes into contact with the vessel. The build up of ice has a negative influence on the stability of the vessel and can cause the vessel to capsize (Icing (nautical), 2013).

The officer has to fill in the cause of the ice accretion, this is caused by; ocean spray, fog or rain. Also the thickness of the ice accretion and rate of ice accretion build up are important for the observation. (KNMI)
7.4.3 Automatic weather stations on board autonomous vessels

The deck officer has to collect a lot of data to make an accurate weather observation, as seen in the previous paragraph. Since there is no crew on board autonomous vessels, there is no way to make an accurate weather observation via TurboWin. To solve this problem, it is essential to equip autonomous vessels with automatic weather stations that can send their hourly weather observations automatically to meteorological bureaus.

The following information was provided by Mr. Rozeboom, Port Meteorological Officer of KNMI. The EUMETNET started a pilot project to design an automatic weather station. The EUMETNET is a network of 31 European National Meteorological Services based in Brussels, Belgium. It has been established to make national weather services within Europe so efficient and effective as possible. EUMETNET provides a framework to enable the weather services to work together, share ideas and best practice, and to share the costs of major infrastructure investments. (EUMETNET, 2016) (EIG EUMETNET)

KNMI designed the specifications for such an automatic weather station after which it was contracted out to a French company to build three prototypes. These three prototypes were given to the meteorological bureaus of France, Germany and the Netherlands, where they were tested. This automatic weather station is capable to measure the following values: air pressure, temperature, humidity, wind speed and direction. (Rozeboom, 2016)

The air pressure will be measured by an automatic barometer which is installed inside of the automatic weather station, inside the red circle in figure 6. For an accurate measurement the pressure has to be corrected to the Mean Sea Level pressure, this is automatically done by the software controlling the automatic barometer. (Rozeboom, 2016)

The temperature will be measured by a PT-100 which is installed inside of a static tube, his static tube prevents water from entering and protects the PT-100, the PT-100 is shown in figure 7 with the static tube visible in the background. A PT-100 is a temperature-dependent resistor which measures the change in electrical resistance of the metal or semiconductor by a certain temperature. The abbreviation PT refers to the platinum metal, the material of which the very fine resistance wire is made of. The number 100 refers to the electrical resistance of 100 ohms by a temperature of 0 °C. (PT-100, 2016)
The humidity will be measured by an E+E sensor, see figure 8, this is a capacitive sensor. The amount of moisture in the air will give a certain capacitance value. This value is an indication for the humidity of the air. In addition is the E+E sensor heated, this prevents ice build-up inside the sensor as well as a faster response time for measuring the amount of moisture in the air. The E+E sensor has a deviation of less than 1%. (Rozeboom, 2016)

Figure 8

The wind speed and direction is measured by an ultrasonic anemometer or wind sensor, see figure 9. They use ultrasonic sound waves to measure wind velocity. By measuring the time of flight of sonic pulses between pairs of transducers a wind speed could be calculated. Measurements from pairs of transducers can be combined to obtain the measurement of velocity in 1-, 2-, or 3-dimensional flow. The lack of moving parts makes the ultrasonic anemometer appropriate for long-term use in exposed automated weather stations, where the accuracy and reliability of traditional cup-and-vane anemometers are adversely affected by salty air or dust. (Anemometer, 2016)

Figure 9

All measurements mentioned above and a GPS position, which is also integrated in the system, are stored and will be sent every hour via the Iridium SBD, this is a simple and efficient network for transmitting short data messages between equipment and a centralized host computer. All the received data is collected in an open source library which converts the data into a WMO code to be sent onto the Global Telecommunication System of the WMO. (Sterela) (Iridium)
KNMI is planning to equip fifty vessels with these automatic weather stations, which provide them with hourly weather reports. The only disadvantage of these automatic weather stations is the maintenance, the system and sensors need regular maintenance, e.g. changing sensors. Because most vessels are sailing worldwide, service engineers of KNMI need to fly around the world in order to perform maintenance to the system and sensors.

A solution could be a global cooperation between meteorological bureaus, which maintain the automatic weather stations on a globalized level. Beside the fact that it is a long and time consuming process to globalized agreements on the cost and logistics, it creates another problem.

This problem is caused by the equipment and sensors. Every country uses its own brand of sensors and equipment. There is no standardization and creates a problem when maintenance has to be performed in another country. An example of this is the difference between the Dutch and German E+E sensor, the German E+E sensor has an ASCII output while the Dutch E+E sensor has a hexadecimal output. This means that another setting has to be configured for the same system.

The solution to this problem is to standardize all equipment and sensors which are used by the automatic weather station, this requires international agreements. (Rozeboom, 2016)

7.5 Conclusion

The avoidance of heavy weather conditions is for every vessel an important issue which must be taken into consideration when planning and executing a voyage.

Heavy weather conditions could be avoided by the use of tactical weather routing, but this can only be achieved when accurate weather routing systems, which receive accurate measurements about the weather conditions. The solution to this problem is the equip (autonomous) vessels with an automatic weather stations. These stations are equipped with instruments that are capable to measure the air pressure, temperature, humidity and winds speed and direction.

All the measurements are collected and will be hourly sent via the Iridium SBD to the meteorological bureau who owns the automatic weather station. This will provide the meteorological bureau with accurate measurements about upcoming weather conditions and results in accurate tactical weather routing.

Problems like the use of different equipment and sensors per country, as well as the maintenance of the weather stations, need to be addressed and solved on a globalized level. This could be done by the use of international agreements on standardization.
8. Respond to SAR operations

8.1 General
   – Sub question
   How can autonomous vessels respond to SAR operations?

   – Methodology
   To answer this sub question literature concerning manned search and rescue methods has been used. Furthermore, there has been made use of various internet sites for information about autonomous search and rescue methods.

8.2 Introduction
   Search and Rescue (SAR) is the search for, and provision of aid to people who are in distress or imminent danger. In 1979 the International Convention on Maritime Search and Rescue was adopted to develop an international SAR plan, so that, no matter where an accident occurs, the rescue of persons in distress at sea will be co-ordinated by a SAR organization and, when necessary by co-operation between neighbouring SAR organizations.

   Vessels in distress or vessels passing by, can contact a Rescue Coordination Centre (RCC) or send a regular distress alert with GMDSS equipment (Global Maritime Distress and Safety System). After the received signal, the RCC can undertake action and send for instance the coast guard or SAR helicopters to the position of distress. It has been an old tradition that vessels passing by a vessel in distress, help the vessel in any way possible. The following list situations are situations for vessels to assist a vessel in distress:

   - Man over board
   - Collisions
   - Sinking
   - Capsizing
   - Fire

   In these situations, the vessels passing by can assist in many ways (see 8.4) but an autonomous vessel has no persons on board the vessel. (Wikipedia.org/SAR) (IMO.org/ICMSAR)

8.3 Manned search and rescue
   With manned vessels sailing the oceans, the assistance is possible for the following situations:

8.3.1 Man over board
   The procedures for Man over board are well known for seafarers. Drills are done monthly on most vessels. In case a man is overboard, the vessel should follow the complete procedure but can warn as well vessels passing by. These vessels can start searching for the person overboard as well.

   This is done by the crew on board by looking at the sea very carefully. When a man is overboard, the weather conditions do not have to be rough but unfortunately this is in many time the case which make the search for the person more difficult.

8.3.2 Collision
   A vessel collided with another vessel give in many cases, depending on the damage, a risk of the vessel to sink (8.3.3).
8.3.3 Capsizing and sinking
Regardless of the environment effect a vessel can have after it sinks, the crew of a sinking vessel is in danger as well. Vessels passing by can pick them out of the water to save them out of the water or from the sinking vessel.

8.3.4 Fire
Just like the cases of collision, sinking and capsizing, with fire on board a vessel, the crew has to be brought in safety. But vessels passing by could as well assist the vessel in distress by attempting to extinguish the fire. Some offshore vessels and/or tugs have strong fire pumps on board which are designed extinguish fire on board of a vessel in distress.

8.4 Autonomous Search and Rescue
To prevent Autonomous vessels to be over equipped with Search and Rescue materials to save lives at sea when other vessels are in distress. By taking a good look at the materials that are already on board and some small adjustments the autonomous vessel will be able to take part in SAR operations. To give some examples:

Fire on board another vessel can be fought with some adjustments to the fire fighting system on board. Throughout the vessel are pipes that in case of emergency supply water to the fire hydrant in the vicinity so fires can be put out. To adjust this already existing system so it can take part in the fire fighting of other vessels, a water cannon can be placed. This water cannon will be part of the autonomous vessel, but with the capability that is can be operated both digitally as manually in case of fire.

To be the first in the vicinity means that the crew from the other vessel may need to be saved. This can be done by automating the already on board pilot ladders or fast rescue boats. The ladder or boat on board can be dropped with one push of a button from the command centre. And the crew can climb up or be hauled back in by getting on board the rescue boat. Another adjustment could be the use of nets that drop on each side of the vessel and can be hauled back in with the surviving crew.

When the automated vessel is a fact it will be equipped with cameras and maybe with drones. These pieces of equipment can be used not only for the purpose of safe navigation. But can also be deployed in SAR operations. With a live camera feed, it will give a picture of the ongoing operations and emergencies from various angles. Specialist on the shore can provide information or adjust the emergency plan, to keep damages or casualties to a minimum.
8.5 Research regarding Search and Rescue for autonomous vessels

There is a large variety in technology created in laboratories. However, hardly any of these technologies can be used in the Search and Rescue operations. This was also the conclusion of the European Commission’s Directorate-General for Enterprise and Industry. They decided to fund the ICARUS program. The ICARUS program modifies existing technology so it suitable for Search and Rescue. By doing this it tries to improve the information resolving a better manageable situation. They also try to make the work less dangerous for the personnel working on the “ground”. For this project the maritime research could be easily implemented in the autonomous way of sailing.

There are two possibilities when someone falls overboard. One possibility is that the Man Over Board is quickly noticed by others and results in a known position of the person which fell overboard. This makes the SAR operation considerably easier because action taken is directly targeted at the person in the water. For example, a buoy can be thrown and the ship can make a Williamson turn. The second possibility is that the person falls overboard and is not right away noticed. There is no known position, which will result a great search area. This results in a greater and more time consuming search action.

An autonomous vessel can assist during these SAR operations. It can assist with sweeping of the ocean by sailing in a pattern, the sweeping of the area could be made faster by the use of drones. In the ICARUS project a small solar plane is developed, this plane has a battery span of about a day. This plane can fly up to 300 metres high and is equipped with a small camera. The camera will be connected to the SAR operation centre. When the victim is found by the plane action can be taken. This time the unmanned maritime systems (UMS) take over the dangerous work of getting in the fast rescue boat. A medium sized unmanned surface vessel (USV) will be jettisoned. This USV will be equipped with an unmanned maritime capsule (UMC). The USV will be used for the long distance when close enough to the victim the UMC will be deployed. The UMC will sail almost next to the victim and deploy an inflatable life raft. This life raft will stay connected to the UMC this way it can be moved if needed. This way the victim can climb on board the raft and wait for the (autonomous) ship to get in the vicinity to get him on board. (Cubber, 2013)

8.6 Conclusion

Autonomous vessels can be equipped with several options to improve their part in search and rescue missions. This can be done by simple things as an improvised fire fighting system or by letting down nets or pilot ladders. A more futuristic options could be the use of drones and unmanned surface vessels, these options need to be further tested and developed before putting them into the working field.
9. Redundancy on board

9.1 General
– Sub question
How can redundancy on board an autonomous vessel prevent calamities?

– Methodology
To answer this sub question literature concerning the rules for classification for ships, about Redundant Propulsion by DNV, as well as the internet for information about the general definition of redundancy has been used.

9.2 Defining redundancy
Redundancy is the duplication of components or circuits to provide survival of the total system in case of a failure of single components. (Wiktionary, 2016)

This duplication of critical components or functions of a system is done with the intention of increasing reliability of the system, this is usually done in the form of a backup or fail-safe.

9.2.1 Triple Modular Redundancy
In many safety-critical systems, for example the hydraulic systems in an aircraft, some parts of the control system may be made in threefold. This is called Triple Modular Redundancy (TMR), an example of such a control system is shown in figure 10. This is done to detect an error in one of the components. In case of an error in one of the components, the other two components out-vote the component with the error. In a redundant system with three subcomponents, triply redundant, all three of the components must fail before the entire system fails. Since this rarely happens, and the subcomponents are expected to fail independently from each other, the probability of all three components failing at the same time is calculated to be extraordinarily small; often outweighed by other risk factors, such as the human error. (Wiktionary, 2016)

Figure 10 – (US Department of Defense - Redundant subsystem "B")
9.2.2 Disadvantages of redundancy
Redundancy does sometimes produce less, instead of greater reliability. The author of Normal Accidents, Charles Perrow, said that redundancies sometimes backfire which causes systems to be less, instead of more reliable. This may happen in three ways:

- First, redundant safety devices result in a more complex system, which is prone to more errors and accidents;
- Second, redundancy may lead to shrinking of responsibility among workers.
- Third, redundancy may lead to increased production pressure, which could result in a system that operates at a higher speed, but is less safe.

(Wikipedia, 2016).

9.3 Redundancy on board autonomous vessels
Since there is no crew on board autonomous vessels, the use of redundant safety-critical systems is of great important. This could be done by the duplication of critical components or functions of in safety-critical systems. The redundancy shall ensure the ability of the system to remain in operation.

These safety-critical systems, which have to be made redundant, are both found in the navigational systems of the autonomous vessel as well as in the engine room of the autonomous vessel. A few examples of navigational safety-critical system are the detection systems such as the Advanced Sensor Module, which is responsible for the detection and classification of objects, and the radar systems.

A few examples of engine room safety-critical systems are the propulsion and steering systems, including the monitoring systems. This also includes the auxiliary systems, such as:

- Ventilation systems
- Cooling systems
- Lubrication oil systems
- Fuel oil systems

(Det Norske Veritas, 2012)

Another important safety-critical system which has to be made redundant is the communication system of the autonomous vessel. This is of great importance because all information and collected data about the surroundings and parameters of the vessel will be sent via this system.

9.4 Conclusion
Redundancy on board of autonomous vessels is essential for the safety of the vessel itself, as well as the surrounding vessels and environment. The use of redundant equipment will safeguard instruments and vital system for the navigation and propulsion of the vessel.

For more information about the redundancy of the navigational detection systems, see the research report of topic 1 – Detection. For more information about the redundancy of the engine room systems, see the research report of topic 5 – Propulsion and maintenance.
10. Grounding

10.1 General

– Sub question
How can grounding be prevented and responded to on board autonomous vessels?

– Methodology
To answer this sub question literature concerning a patent about an emergency towing system and the MUNIN research report, as well as the internet has been used.

10.2 Introduction
“The 168 metres long, 20615 dwt container ship TS Taipei broke up just offshore off Taiwan. The TS Taipei had gone ashore on March 10 after suffering engine failure. The vessel remained hard aground while salvage operations attempted to remove fuel off the vessel. However, salvage was suspended due to a severe storm which also caused the vessel finally broke-in-two. The hull cracked amidships and fuel oil was released from ruptured bunker tanks. Authorities dispatched a pollution response team to the scene along with multiple boats. Booms were placed around the pollution to contain any further oil released. Reports also state that several containers have fallen overboard which may contain hazardous chemicals.” (Hancock, 2016)

10.2.1 Deleting the “human factor”
Today’s conventional ship systems are technologically advanced and are highly reliable. But maritime casualty rates are still very high. The current maritime system is a people system, in which about 75-96% of marine casualties are caused, at least in part, by some form of human error. Studies have shown that human error contributes to:

- 84-88% of tanker accidents
- 79% of towing vessel groundings
- 89-96% of collisions
- 75% of allisions\(^1\)
- 75% of fires and explosions

(Rothblum)

\(^1\) The running of one ship upon another ship that is stationary – distinguished from collision (Merriam-Webster)
10.3 Communications
To prevent that an autonomous vessel runs aground the communication, gathering of information and data of the surroundings is an important task which needs to be fulfilled automatically.

This gathered information and data needs to be sent to a computer. Here the data will be processed and sent to a shore station, which keeps track on the vessel. The system which fulfils this task is the Functional Status Indicator, which send each 5 seconds the following information and data as seen in table 6.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Data reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Position, heading, speed, distance from planned position as well as a position quality flag.</td>
</tr>
<tr>
<td>Weather</td>
<td>Wind speed/direction, wave and swell height/length/direction</td>
</tr>
<tr>
<td>Visibility</td>
<td>Visibility IR/Normal, radar range and clutter. COLREG status of ship.</td>
</tr>
<tr>
<td>Collision</td>
<td>Vectors to targets, status/heading/speed of targets. 5 ships/objects in vicinity</td>
</tr>
<tr>
<td>Grounding</td>
<td>Depth, distance to shore, complexity</td>
</tr>
<tr>
<td>Communication</td>
<td>Critical communication directly to ship on VHF, GMDSS, NAVTEX, DSC, AIS</td>
</tr>
<tr>
<td>Stability</td>
<td>Trim, heel, draft, watertight integrity, void space, water ingress.</td>
</tr>
<tr>
<td>Environment</td>
<td>NOx, SOx, PM, Waste, Oil, GHG</td>
</tr>
<tr>
<td>Economy</td>
<td>Fuel use and potential for late arrival, off hire etc.</td>
</tr>
<tr>
<td>Hull equipment</td>
<td>Fuel use and potential for late arrival, off hire etc.</td>
</tr>
<tr>
<td>Propulsion</td>
<td>Direction, speed anomalies</td>
</tr>
<tr>
<td>Machinery</td>
<td>Power, steam, auxiliary, hydraulic etc</td>
</tr>
<tr>
<td>Electric</td>
<td>Generators, switchboard, emergency</td>
</tr>
<tr>
<td>Safety</td>
<td>Main fire zones</td>
</tr>
<tr>
<td>Cargo</td>
<td>Temperature, humidity, levels, 5 holds</td>
</tr>
</tbody>
</table>

Table 6
10.4 Emergency towing equipment

10.4.1 Emergency towing today
The International Maritime Organization (IMO) has made the regulations about mandatory emergency towing systems on board tankers and ships. These regulations are listed in the International Convention for the Safety of Life at Sea (SOLAS), 1974, and can be found in Appendix 5: Emergency towing arrangements and procedures.

There are special arrangements for tanker listed in the regulations, see Appendix 5. One of these regulations states that tankers which are constructed on or after 1 July 2002 have to be equipped with an arrangement which is capable of rapid deployment in the absence of main power on the ship to be towed and easy connection to the towing ship. And has to be pre-rigged ready for rapid deployment.

These typical arrangements for emergency towing systems are seen below, figure 11 and figure 12. As can be seen below, the towing cable is connected to a smaller cable or chain. This cable or chain leads to the pick-up gear box. In this box is a rope situated, mainly made of polypropylene, which is connected to a pick-up buoy. When the vessel is in trouble and a connection between the vessel and a tug has to be made, the crew on board will through this buoy overboard so the tug can pick it up and connect to the vessel in a safe way.

Figure 11 – Emergency towing systems – Aft beneath deck – (Tanktech)

Figure 12 – Emergency towing systems – Typical arrangements forward – (Tanktech)
Currently these special emergency towing arrangements are not equipped on passenger and cargo ships. These vessels have only a ship-specific emergency towing procedure, which shall be carried on board of the vessel for use in emergency situations and is based on existing arrangements and equipment available on board the ship.

10.4.2 Emergency towing on board autonomous vessels
Because autonomous vessels are not capable to respond to engine failure, fire or another calamity, which can cripple the vessel and make it immobile or “not under manned”, it is important that unmanned vessels also are equipped with the required arrangements as stated in the International Convention for the Safety of Life at Sea (SOLAS), 1974.

Because autonomous vessels are unmanned there is no crew on board which can prepare the emergency towing equipment on the arrangements stated in the ship-specific emergency towing procedures and connect the autonomous vessel to a tugboat and bring it to safety and/or port for repair.

To solve this problem it is important that autonomous vessels are already equipped with the necessary emergency towing equipment and a system which can be automatically deploy to ensure the safety of the vessel. One of the ideas is to implement the typical arrangements on board tanker vessel for emergency towing systems. Figure 11 shows an arrangement which is installed beneath the weather deck of the vessel. This saves space on top of the weather deck and ensures that the equipment is protected against the elements.

When such an arrangement is installed on board an autonomous vessel the problem of deployment is still present. To solve this problem a device has to be invented which is remotely operated. This device is capable to shoot out the pick-up buoy from the pick-up gear box. This could be done via a rocket installation such as the already existing line throwing devices. By using a rocket propelled device, a greater distance between the autonomous vessel and a tugboat can be created, this ensures the safety of the crew on board the tug.
10.5 Emergency ship towing system
When an autonomous vessel in distress becomes immobilized at some point during transit it requires an external source of motive power for movement. Nowadays tugboats are used as an external motive power source. However, a tugboat has a substantial transit time when it has to respond on an emergency call from a vessel in distress at some location. This could lead to catastrophic consequences for the environment and the safety of other vessels.

Therefore, it is an important task to make a reliable and quick system which can perform a towing mission for an autonomous vessel in distress. This could be done by involving the use of a motive power source externally of the ship.

The invention which will be taken into consideration for this problem is based on an invention of David B. Coakley assigned by The United States Secretary of the Navy, Washington, DC.

The invention consists of a thruster unit which is connected to the autonomous vessel. The preassembled thruster unit, which provides the external motive power, has a gas turbine type of engine to which a mixture of pressurized air and fuel is supplied via a flexible hose. The thrust unit also includes a rudder and stabilizer assembly through which travel direction and underwater depth control is exercised. All the components of the emergency ship towing unit are selected to perform the towing mission and are of a limited weight. (Coakley, 2001)

All the details of this invention and the equipment it consists of are explained in the patent itself which are included in Appendix 6: United States Patent Emergency Ship Towing System.

In figure 13 is a simplified view of the system shown, hereby the towing system is delivered by a helicopter.

![Figure 13](Coakley, 2001)
The idea is to implement the invention on board autonomous vessels as a back-up system in case of loss of engine power or another form of calamity. This system will ensure the safety of the vessel and prevent the vessel from grounding.

The invented system is currently based on the concept that a helicopter will supply the vessel with the required equipment, which the shipboard personnel has to assemble. Since an autonomous vessel has no shipboard personal there are three types of concepts:

1. All required components and a crew to assemble the system has to be flown to the autonomous vessel.
2. The autonomous vessel is already equipped with the necessary equipment, except the thruster unit itself. The flexible hose, signal wire, pressurized air and fuel for the thruster unit are already on board the vessel and installed.
3. A complete system is already present on board of the autonomous vessel; the system could be activated remotely from personal ashore.

No emergency ship towing system on board:
In case that there is no complete emergency ship towing system on board the autonomous vessel and/or the vessel is not equipped with the necessary equipment, such as the flexible hose, signal wire, pressurized air and fuel for the thruster unit. This makes it necessary that all the required components and equipment of the system are flown to the autonomous vessel. This also applies for a crew, which has to assemble the entire system since there is no standard crew on board an autonomous vessel.

Partially equipped with the emergency ship towing system:
In case that the vessel is already partially equipped with the necessary equipment such as the flexible hose, signal wire, pressurized air and fuel for the thruster unit. The only equipment that has to be flown to the autonomous vessel is the thruster unit itself and a crew to assemble the thruster unit to the rest of the system already present on board the vessel.

Complete emergency ship towing system on board:
In case that the autonomous vessel has been equipped with a complete emergency ship towing system, where the thruster unit is already present on board and connected to the vessel. This thruster unit could be launched via the freefall boat concept or like a torpedo launched out of a torpedo launch tube which is placed on deck of the autonomous vessel. The system could be activated remotely from personal ashore.
10.6 Pre-installed pumps in case of a hull breach

In case that a hull breach arises on board an autonomous vessel, due to a grounding, it has to be equipped with sufficient equipment to stay afloat. This means that the autonomous vessel has to be equipped with a preinstalled pump system, which is capable to start pumping when it detects any water in the hold, engine room or any void space.

On board current vessels this system is already present in the form of a bilge pumping and alarm system. This system detects if any water is present in the bilge well. When water is present it gives an alarm which alerts the engineer on watch to empty out this bilge well. This is done by opening some valves in the system and starting the bilge pump. This pump will transport the water, which could contain some residue or oil, to the oil water separator or store it in the designated stores tank.

In case of a flooding in the hold, engine room or void space the engineer could open the emergency valves, which will bypass the oil water separator and makes it possible to pump the water directly overboard, into the ocean. It is also possible to connect the ballast water pumps, which have a greater capacity, to the bilge system. But in some situations it is necessary to deploy extra submersible pumps, since the capacity of the pumps is not great enough to keep up with the inflow of seawater.

Since there is no crew present on board an autonomous vessel, this bilge system has the be made automatic or be operated remotely by personal on shore. Furthermore, it is necessary to increase the capacity of the pumps on board the vessel. This could be done by installing extra pumps, pre-installed submersible pumps, in the hold and void spaces.

10.7 Conclusion

Studies have shown that the human error is a great contribution to accidents that occur on board of conventional vessels. Since the human factor will be removed on board autonomous vessels, because there will be no crew on board, accidents like grounding, which are caused by human error, will be automatically reduce.

This leaves the mechanical failure of the autonomous vessel. In case the autonomous vessel becomes immobilized due to mechanical failure, e.g. propulsion failure, it is essential that a grounding will be prevented. To solve this problem special emergency towing arrangements must be made, these arrangements consist of an emergency towing cable, which is concealed beneath the weather deck to save deck space and to ensure that the equipment is protected against the elements, and a rocket propelled pick-up buoy, which is connected to the towing cable.

Furthermore, does the use or installation of an emergency ship towing system replace the conventional tugboat. The emergency ship towing system has a faster deployment because of its mobility and versatility compared to a conventional tugboat. The system consists of a thruster unit which is connected to the autonomous vessel and provides the external motive power needed to tow the autonomous vessel out of harm’s way.

In case of a hull breach due to a grounding or collision, the autonomous vessel has to be equipped with sufficient equipment to stay afloat. This means that that the autonomous vessel has to be equipped with a preinstalled pump system, which is capable to start pumping when it detects any water in the hold, engine room or any void space. The system has to be made automatic or could be operated remotely be personal on shore.
11. Implementing Fail-safe

11.1 General

– **Sub question**
How can fail-safe be implemented on board autonomous vessels?

– **Methodology**
To answer this sub question literature concerning fail-safe in general and fail-safe systems, as well as the internet has been used.

11.2 Defining Fail-safe

Before fail-safe can be implemented on board a vessel, it has to be defined. A vessel that is fail-safe, will in the event of any failure cause the least amount of damage to other vessels, the marine environment and people.

Next to fail-safe there is another concept called fail-secure, these two concepts are similar to each other but have a few differences. In the case of an event on board the computers will have a fail-secure measurement that will prevent data from falling into the wrong hands during a break into the system or a system failure, this is described in chapter 3 - Cybercrime.

Fail-secure could also be installed to keep the vessel from harming itself. On board an automated vessel a fail-secure system will in the event of a fire close and lock all doors and shutdown the ventilation to prevent the fire from spreading throughout the vessel. During this event no personnel can enter the area, this is to prevent unauthorized personnel to enter the room without permission. On the other hand, a fail-safe system will only close the doors and stop the ventilation, so fire fighting teams can extinguish the fire.

If a system is called fail-safe, it does not mean that failure will not occur. On the contrary, mechanical failures of electrical failure can still happen but the system is designed in a way that the consequences of the failure will still leave a safe system. Since there are many types of failure possible, it has to be specified on the component to what failures it has been made fail-safe. To give an example a component can shut down in case of fire, this does not mean the component will not go up in flames.
11.3 Fail-safe systems which are already on board vessel

In the engine room alarm circuits are very common, this is to prevent damage to the vessels engines and the parts that make it possible for the engine to run. These alarm circuits ensure that in the event of a wire break or failure the alarm will be triggered. This is called a normally closed alarm circuit. If the circuit was normally open, a wire that is melted or broken would have gone undetected, and would have blocked the actual alarm signals. In this case it means that the alarm circuit is fail-safe.

Another example from already implemented fail-safe components on board the vessel is the live zero used to send a receive data. The component sends a signal between the 4 and 20 milliamp to the receiver that alters the signal into a value. In this case 4 will be the lowest value and 20 will be the highest value, in case of a wire break the value will be 0 milliamp and an alarm will be triggered.

To improve the fail-safe between components two additional wires can be added to carry critically important signals. These two cables are control cables one with signal and one with no signal. Only if the two cables give back two opposite signals will the component react to the input that was provided by the first cable. If the two signals both comeback with only a low or only a high value, there is something wrong. This failure can be back traced to something wrong with the sensor, wires that are connected/unplugged/cut, dead sensors or other failures.

One much older example of a fail-safe system on board is the central Heating Ventilation and Air-Conditioning system also known as HVAC system. Inside the HVAC control system there are actuators, these actuators control the valves and the dampeners so they are fail-safe. For example, if the HVAC is on the verge of overheating rooms or freezing the coils, the older pneumatic actuators would go back to the safe position because the air pressure against the internal diaphragm failed. This was all done by a built in spring that would have enough power to push back the actuators if the air pressures failed. Newer electrical and electronic actuators need additional components such as springs or capacitors to push the actuator back upon loss of electrical power. If done incorrectly the voltage regulator can destroy all the connected equipment. (Mattos, 2013)
11.4 Techniques for Fail-Safe
A few techniques that can be applied, in order to design redundancies and prevent single point failures from happening, are as follows.

**Back-up systems**
To prevent failures from having a critical effect on the main systems, sub systems are often designed with a backup system. For example, most vessel have a backup generator which could prevent the lights and critical on board systems from going dark. It is designed in such a way that the vessel can still manoeuvre on a low velocity.

**Multiple load paths**
To prevent the vessel from breaking under her own weight, trusses are all over the vessel to give extra strength so the load of cargo or the weight of the engine can be carried by a greater part of the vessel. If one truss should fail, the weight will be carried by the neighbouring trusses.

**Intentional “Weak Link”**
To prevent damage to expensive or difficult repairable components, inexpensive or easy replaceable components are used as a weak link. An electrical example of a weakest link is a circuit breaker or a fuse. If there is an over amperage or voltage, the fuse will break and so prevent the component behind the fuse from melting.
Another weakest link can be found in small boats with outboard engines, the propeller of the engine has a mechanical example of a weak link. Inside the propeller is a shear pin, if this pin hits a hard object the pin will break and the propeller will fall off. In this case we are protecting the propeller and the shaft from damaging any further.

**Early Detection**
When a pipe on board a vessel is designed in such a way that cracks in pipes can be detected before they reach a critical point, it may be considered as a fail-safe design. One crucial element of the design has to be the detection of the crack before it reaches the critical point. Therefore, an indication has to be given by the system to prevent the pipe from cracking and creating a leak.
Another important aspect is that the right materials are used, materials that can withstand very high temperature or can withstand very large cracks before fracturing or leaking. The most important aspect of choosing the right materials is knowing how long does it take before cracks appear. And what size are the cracks that are the first to be detected. (Leo Scheltinga, 05-08-2015)
11.5 Fail-Safe means self-preservation
In an event or calamity occurs in which nobody is on board the autonomous vessel, it will need to survive the ongoing calamity, without loss of cargo, fire of hull damage. There are multiple solutions for self-preservation on the vessel.

- If the loss of GPS AIS VSAT or other essential communication devices occurs. Vessel automatically gives full astern, alerts nearby vessels and onshore officer of the watch. If no response or feedback drop anchor at safe position and wait for on scene engineer to resolve the problem. Or if the vessel makes use of dynamic positioning stay on place with dynamic positioning.
- Loss of propelling power, automatically drop anchor like a normally closed valve. If propulsion is gone anchor will be dropped unless commanded otherwise.
- In case of a storm or lightning strike vessel will automatically keep the waves two points of the compass (22,5°) on the aft quarter and will drop anchor when depth is sufficient or will stay in place until waves are limited to a minimum or communication with the operator is re-established
- Components have to be fail-safe and fail-secure, to prevent further damage to the vessel and her surroundings.

11.6 Conclusion
To prevent failures from happening on board an autonomous vessel, means that every component has to be taken care of during maintenance. This means that there needs to be pre-emptive maintenance and early detection to prevent failures from happening on board. Additional to the fail-safe measures that are already on board every system and can create a hazard to be self-preserving to prevent more damage to itself or the vessel. Another aspect of self-preservation lies in making the vessel not only fail-safe but also fail-secure. In the case of an incident on board nothing can leave the vessel, this means that the vessel cannot lose any material or fluid to the marine environment and all the information is protected from outside sources.
12. Prevent & respond to an autonomous vessel ‘not under command’

12.1 General
- Sub question
How can ship owners and/or authorities prevent and respond to an autonomous vessel ‘not under command’?

- Methodology
To answer this sub question literature concerning the International Regulations for Preventing Collisions at Sea, as well as the internet has been used.

12.2 Introduction

COLREG (International Regulations for Preventing Collisions at Sea) are the international IMO (International Maritime Organisation) traffic regulations at sea. According to COLREG rule 3 part (f) of the general definitions, the term “vessel not under command” (NUC) means: a vessel which through some exceptional circumstance is unstable to manoeuvre as required by these Rules and is therefore unable to keep out of the way of another vessel. (IMO)

A vessel NUC can be caused by many reasons. The danger of vessels NUC is, they cannot alter course to keep out of the way of approaching vessels or to avoid a collision. Also, they cannot prevent a collision with quay during entering a port or other objects at sea. Last but not least, they hinder the other traffic which can result in dangerous situations.

COLREG is for normal, manned vessels but there are no regulations yet for autonomous vessels.

12.3 Possible causes of a vessel ‘not under command’
The status ‘not under command’ can be caused by a lot of reasons for instance:

- Blackout. Can have a lot of reasons like generator stops, clogged filter etc.
- Main engine stops. Possible due to fuel stop, overdue maintenance, safety alarms etc.
- Manoeuvring equipment breakdown. For example, the steering gear breaks down, propeller is damaged after touching the ground/rock etc.

Most reports of collisions/groundings due to a vessel NUC is caused by human failures like causing a blackout. Another huge factor is the accumulation of a number of small incidents/mistakes. For example, a small alarm appears in the engine room. An inexperienced engineer is solving it but accidentally closes a fuel valve to the main engine which shuts down. Due to bad communication the master is not informed. When a collision is close to happen, the pilot cannot inform the crew to drop the anchor because the portable VHF battery is empty.

The human factor is a big cause of accidents on board vessels. About 75-96% of marine casualties are caused, at least in part, by some form of human error. (Rothblum)

By removing the human factor on board autonomous vessels, does not mean NUC accidents will not occur anymore.
12.4 Response procedure if a manned vessel is ‘not under command’

12.4.1 Standard procedure
According to COLREG rule 27 part (a), a vessel NUC shall exhibit:

(i) Two all-round red lights in a vertical line where they can best be seen.
(ii) Two balls or similar shapes in a vertical line where they can best be seen.
(iii) When making way through the water, in addition to the lights described in (i) and (ii), sidelights and a stern light.

According to COLREG rule 35 part (c), a vessel NUC sound at intervals of not more than 2 minutes three blasts in succession, namely one prolonged followed by two short blasts in case of restricted visibility. (IMO)

12.4.2 Entering a port (with pilot)
When a vessel is entering a port with a pilot on board, one or two anchors are stand-by to be dropped in case the vessel is NUC. In case such thing happens, the master or the pilot gives the command to the crew at the forecastle to drop the anchor.

12.5 Special regulations or no exemptions for autonomous vessels
Since COLREG has international regulations for preventing collisions at sea with special regulations for manned vessels NUC, a simple solution could be applied to these rules for autonomous vessels as well. With emergency batteries on board autonomous vessels, the navigation lights have the necessary power supply. The two balls or similar shapes can be automatically raised by a simple automated construction like the flags are raised, assumed that the flags will still be raised on board autonomous vessels which has to be automated. While entering port, it depends on the procedure for autonomous vessels for entering a port. But still, the anchor can be automatically dropped.

So at sea, it would be obvious to apply the COLREG rules which are already mandatory for manned vessels. The only problem is the free floating vessel which has to be removed.

While entering port, special regulations could apply for autonomous vessels. These special regulations for port entry depend on the regulations which are made especially for autonomous vessels. Currently is another research project busy with drafting a pilot version of such regulations for autonomous vessels.
12.6 Possible options or innovations to respond to an autonomous vessel 'not under command'

12.6.1 Emergency batteries to comply with COLREG
As mentioned of in the previous chapter, like manned vessels, autonomous vessels should have emergency batteries for navigation lights and two balls or similar shapes so they apply to COLREG regulation 27. In this way, the normal regulations can still apply for autonomous vessels. These emergency batteries should have enough electric power to supply these lights and power the construction to raise the two balls according to COLREG rule 27 part (a). The emergency batteries will start if the vessel is completely blacked out for a short time like one minute. This is all depending on the backup system for autonomous vessels. If the main engine fails, there has to be a redundant system. If this fails as well, the vessel is not under command and these emergency batteries will power the navigation lights as well the system which controls the day shapes in the mast, for a vessel 'not under command' these day shapes are the two balls in a vertical line. The system which controls the day shapes could easily be operate by a simple PLC program the raise the day shapes automatically.

12.6.2 NUCT (Not Under Command Transmitter)
The NUCT is a special innovated device which sends pulses to the X-band radar like a SART (Search and Rescue Transmitter) already does. This sounds as a very simple method to indicate a vessel NUC for all types of vessels, even vessels sailing on charts and vessels having problems with navigation or communication equipment. This system can be automatically started by the emergency batteries as described in chapter 12.6.1.

The pulses have to be special to indicate an autonomous vessel not under command combined with regulations and education so they will be recognised by officers and not confused with the SART pulses.

12.6.3 Navigation lights
The above described innovations (12.6.1 & 12.6.2) could be in combination with special navigation light combined in a special chapter in the COLREG for autonomous vessels. In this way the autonomous vessels will be recognised as well during night. Even without the NUCT (not under command transmitter). Currently another research project is busy with drafting a pilot version of COLREG regulations for autonomous vessels, these regulations include also the navigation lights.

12.6.4 Towing
Towing an autonomous vessel is a possibility to get the NUC vessel out of the TSS (Traffic Separation Scheme) or even to a close port. However, connecting an autonomous vessel to a tug can result in dangerous situations since no crew is on board autonomous vessels to handle ropes. For more information regarding this subject, see chapter 10.4 and 10.5.

12.6.5 Sending a helicopter with (an) engineer(s) for reparation
This is the simplest solution if no dangers occur or will be caused by an NUC vessel. This should be instructed by the vessels owner and depends to the problem which caused the vessel to be NUC.

12.7 Conclusion
Answer to the question 'how can ship owners and/or authorities prevent and respond to an autonomous vessel 'not under command'?' could be simple since the possible options from chapter 12.6 could be very effective. The problem described in 12.2 is already existing for normal vessels, however, on board autonomous vessels there is no crew. After a new COLREG chapter has been made up for autonomous vessels, and the necessary education towards seafarers has been given. His should already reduce the problem. It is for the authorities to decide which rules are necessary and what these rules will be. Ship owners could invest in research for the NUCT for example.
13. Final conclusion

13.1 Sub questions

13.1.1 How can cybercrime on board an autonomous vessel be prevented and responded to?
Before vessels will be able to set sail around the world autonomously, there have to be changes in the on board system and its protection. The changes that have to be made are:

- Keeping all on board systems up to date in software and hardware
- Creating a secure on board system with limited input from outside sources
- Creating boundaries for the on board system, that will trigger the safety switch if exceeded.
- Making a backup system if the first system should fail.
- Delimiting the no-go area to prevent the vessel from being hijacked

This is to create a safe environment against hackers and hijackers, and to ensure that the vessel will arrive safely in the next harbour.

13.1.2 How can fire on board an autonomous vessel be prevented and responded to?
A database has to be made which contains information about calamities involving fire. This database brings designers and shipbuilders the guidance in design and construction of new types of autonomous vessel, which are improved to avoid previous calamities. If despite these preventions a fire breaks out, the sensors on board the vessel will register this and send this to the ISP, which sends in a Fire Detection Robot (FDR). When the fire can’t be extinguished by the FDR, a Fire Fighting Rotor (FFR) will be deployed for a bigger extinguishing capacity. If the fire gets completely out of control, the use of fixed fire suppression systems is needed. The only system which is not yet autonomous in this procedure is the FFR, but for now this is a safer way than fully autonomous fire fighting.

13.1.3 How can calamities involving cargo on board an autonomous vessel be prevented and responded to?
Calamities involving cargo on board autonomous vessels could best be prevented. This could be achieved by regular checks of the tension on the lashing bars. If the lashing bar will become less tensioned during a voyage a “tension checking system” will detect that the bar needs to be re-tensioned. This will activate the re-tension system, which consists of a hydraulic cylinder. Because of the downward motion of the cylinder, the lashing bar will be re-tensioned. Because all arrangements are installed beneath the weather deck of the vessel, space is saved on top of the deck and the equipment is protected against the elements. But further research has to be done in order to make the integrated system redundant and capable to be equipped on board autonomous vessels.
13.1.4 How can piracy on autonomous vessels be prevented and responded to?
The answer to the question ‘How can piracy on autonomous vessels be prevented and responded to?’ is complicated. There are many existing ways as described above to respond to piracy. Drones have been investigated and this solution could be possible if it was not so complicated compared to other solutions. However, if authorities or shipbuilders see a future in implementing drones on board autonomous vessels there has to be done more research by a team which has access to all researches which have been done and all the possible information. Also international regulations are necessary for implementing drones on board autonomous vessels.

The use of an incapacitating agent in combination with a squad of marines is the best solution. Marines are well trained and will be present since Royal Navy’s will be present in the hotspots of piracy. For autonomous vessels but as well manned vessels, implementing the LRAD system is a solution as well which should be a part of the BMP4. To implement this on vessels, more research has to be done regarding the possibility, regulations and the effectiveness of the system against pirates.

For authorities, the statistics show that patrolling is very effective against piracy. However, statistics show as well that piracy will move from one area to the other. It is very important that authorities work together to respond to piracy attacks.

13.1.5 How can autonomous vessels anticipate or respond to upcoming weather conditions?
The avoidance of heavy weather conditions is for every vessel an important issue which must be taken into consideration when planning and executing a voyage.

Heavy weather conditions could be avoided by the use of tactical weather routing, but this can only be achieved when accurate weather routing systems, which receive accurate measurements about the weather conditions. The solution to this problem is the equip (autonomous) vessels with an automatic weather stations. These stations are equipped with instruments that are capable to measure the air pressure, temperature, humidity and winds speed and direction.

All the measurements are collected and will be hourly sent via the Iridium SBD to the meteorological bureau who owns the automatic weather station. This will provide the meteorological bureau with accurate measurements about upcoming weather conditions and results in accurate tactical weather routing. Problems like the use of different equipment and sensors per country, as well as the maintenance of the weather stations, need to be addressed and solved on a globalized level. This could be done by the use of international agreements on standardization.

13.1.6 How can autonomous vessels respond to SAR operations?
Autonomous vessels can be equipped with several options to improve their part in search and rescue missions. This can be done by simple things as an improvised fire fighting system or by letting down nets or pilot ladders. A more futuristic options could be the use of drones and unmanned surface vessels, these options need to be further tested and developed before putting them into the working field.

13.1.7 How can redundancy on board an autonomous vessel prevent calamities?
Redundancy on board of autonomous vessels is essential for the safety of the vessel itself, as well as the surrounding vessels and environment. The use of redundant equipment will safeguard instruments and vital system for the navigation and propulsion of the vessel.
13.1.8 How can grounding be prevented and responded to on board autonomous vessels?
Studies have shown that the human error is a great contribution to accidents that occur on board of conventional vessels. Since the human factor will be removed on board autonomous vessels, because there will be no crew on board, accidents like grounding, which are caused by human error, will be automatically reduce.

This leaves the mechanical failure of the autonomous vessel. In case the autonomous vessel becomes immobilized due to mechanical failure, e.g. propulsion failure, it is essential that a grounding will be prevented. To solve this problem special emergency towing arrangements must be made, these arrangements consist of an emergency towing cable, which is concealed beneath the weather deck to save deck space and to ensure that the equipment is protected against the elements, and a rocket propelled pick-up buoy, which is connected to the towing cable.

Furthermore, does the use or installation of an emergency ship towing system replace the conventional tugboat. The emergency ship towing system has a faster deployment because of its mobility and versatility compared to a conventional tugboat. The system consists of a thruster unit which is connected to the autonomous vessel and provides the external motive power needed to tow the autonomous vessel out of harm’s way.

In case of a hull breach due to a grounding or collision, the autonomous vessel has to be equipped with sufficient equipment to stay afloat. This means that that the autonomous vessel has to be equipped with a preinstalled pump system, which is capable to start pumping when it detects any water in the hold, engine room or any void space. The system has to be made automatic or could be operated remotely be personal on shore.

13.1.9 How can fail-safe be implemented on board autonomous vessels?
To prevent failures from happening on board an autonomous vessel, means that every component has to be taken care of during maintenance. This means that there needs to be pre-emptive maintenance and early detection to prevent failures from happing on board. Additional to the fail-safe measures that are already on board every system and can create a hazard to be self-preserving to prevent more damage to itself or the vessel. Another aspect of self-preservation lies in making the vessel not only fail-safe but also fail-secure. In the case of an incident on board nothing can leave the vessel, this means that the vessel cannot lose any material or fluid to the marine environment and all the information is protected from outside sources.

13.1.10 How can ship owners and/or authorities prevent and respond to an autonomous vessel ‘not under command’?
Answer to the question ‘how can ship owners and/or authorities prevent and respond to an autonomous vessel ‘not under command’?’ could be simple since the possible options from chapter 12.6 could be very effective. The problem described in 12.2 is already existing for normal vessels, however, on board autonomous vessels there is no crew. After a new COLREG chapter has been made up for autonomous vessels, and the necessary education towards seafarers has been given. His should already reduce the problem. It is for the authorities to decide which rules are necessary and what these rules will be. Ship owners could invest in research for the NUCT for example.
13.2 Main question

13.2.1 How can calamities on board autonomous vessels be prevented and responded to?

The answer this question, the main question of this research project, all previous chapters have to be taken into account. By looking back at those previous chapters the following conclusion can be made:

The human factor has always been a major cause for calamities. To exile the human factor from vessels, the humans have to be removed from the vessels. This means the ship has to sail (semi-) autonomous. This does not mean calamities won’t occur anymore. However, without humans on board calamities have to be fought in a different way.

Robots and drones can take over a big part of the work normally done by the crew on board the vessel. This includes work like the detection and extinguishing of fires. But it will only cover a part of the problems which could occur on board of autonomous sailing.

Also authorities and companies play a part in the prevention of calamities on board autonomous vessels. By investing and researching for new inventions, which can be implemented into new concepts of autonomous sailing, a higher level of safety can be achieved. As well as implementing international agreements to keep autonomous vessels uniform. Furthermore, companies should keep investing into software and hardware that provides the autonomous in autonomous sailing to prevent external intruders.

Devices have to be used to tackle other calamities. For instant the use of automatic weather stations for the detection of upcoming weather conditions, the use of the emergency ship towing system which can prevent the vessel from grounding and devices which can check the tension of the lashing bars (and tighten those when necessary).

Furthermore, it is essential to find out the cause and how to prevent calamities and/or incidents in future autonomous vessels, this is why an investigation into former calamities and/or incidents is of great importance. The causes and recommendations on how to prevent such a calamity and/or incident has to be shared at an international level, his is why an international database has to be founded.
14. Recommendations
Before the autonomous vessel can be taken into full operation, more research has to be done. This is because it is a new and unique concept, which has never been looked at before.

More research has to be done regarding:

- The effectiveness of software and hardware updates for on board computers;
- The protection against cybercrime on board autonomous vessels;
- The use and costs of robots against fires;
- Cargo calamities involving other cargo than containers;
- The use of drones against piracy with the necessary regulations;
- The costs on autonomous weather stations and implementation of maintenance worldwide;
- Further field testing of the ICARIUS project;
- The implementation and costs of the emergency ship towing system;
- The making of a fail-safe and fail-secure autonomous vessel;
- The efficiency of the described innovations for vessels ‘not under command’.
Epilogue
During the project we have learned that the future of autonomous sailing is not as far away as we think. Autonomous sailing sounded to us as a delusional idea, but after this project we realized something, there are not much hurdles left before autonomous sailing becomes a reality. Within a foreseeable time, the first autonomous ship will start sailing the oceans. However, we also believe that the sailors are still needed to monitor those ships.
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Appendix

Appendix 1: Worldwide piracy activity 01-01-2016 – 17-05-2016
Piracy active area’s numbered in the chart below and corresponding statistics on the next page.

1. Yellow Sea
2. Peru, Colombia, Guyana & Venezuela
3. Gulf of Guinea
4. Kenai
5. Gulf of Aden / Arabian Sea
6. Bay of Bengal
7. Strait of Malacca
8. Singapore Strait
9. Indonesia

(www.ICC-CCS.org)
<table>
<thead>
<tr>
<th>Area</th>
<th>Date</th>
<th>Action</th>
<th>Type vessel</th>
<th>Primary action</th>
<th>Arming / explosives</th>
<th>Provenance / response</th>
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</tr>
<tr>
<td></td>
<td>67-85</td>
<td>Boarded</td>
<td>67-86</td>
<td>Product tanker</td>
<td>Stone ships store/properties</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>68-87</td>
<td>Boarded</td>
<td>68-88</td>
<td>Chemical tanker</td>
<td>Stone ships store/properties</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>69-89</td>
<td>Boarded</td>
<td>69-90</td>
<td>Container vessel</td>
<td>Stone ships store/properties</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>70-91</td>
<td>Boarded</td>
<td>70-92</td>
<td>Product tanker</td>
<td>Stone ships store/properties</td>
<td>-</td>
</tr>
</tbody>
</table>

The list of ships/locations contains possible variations in spelling and other data points that were extracted from the table above. The list is cumulative and may need to be narrowed down by topic or area. The table above provides a comprehensive list of ships, their actions, and relevant details, including their destinations or origins. The information is useful for understanding the activities of ships in various global regions.
Appendix 2: Investigation regarding piracy activity last years.

Piracy and armed robbery on the world’s seas is persisting at levels close to those in 2014, despite reductions in the number of ships hijacked and crew captured, the International Chamber of Commerce (ICC) International Maritime Bureau’s (IMB) annual piracy report reveals.

IMB’s Piracy Reporting Centre (IMB PRC) recorded 246 incidents in 2015, one more than in 2014. The number of vessels boarded rose 11% to 203, one ship was fired at, and a further 27 attacks were thwarted. Armed with guns or knives, pirates killed one seafarer and injured at least 14. Kidnappings - where crew are taken away and held for ransom - doubled from nine in 2014 to 19 in 2015, all the result of five attacks off Nigeria.

A total of 15 vessels were hijacked in 2015, down from 21 in 2014, while 271 hostages were held on their ships, compared with 442 in 2014. No hijackings were reported in the last quarter of 2015. IMB says one key factor in this recent global reduction was the drop in attacks against small fuel tankers around South East Asia's coasts, the last of which occurred in August 2015.

SE Asian gangs
"IMB particularly commends the robust actions taken by the Indonesian and Malaysian authorities in the arrest and prosecution of two gangs that hijacked tankers. We also applaud the subsequent arrest of some of the alleged masterminds,” said Pottengal Mukundan, Director of IMB, which has monitored world piracy since 1991.

However Mr Mukundan urged shipmasters to maintain strict anti-piracy and robbery watches. South East Asia still accounts for most of the world's incidents. Almost 55% of the region's attacks were against vessels underway compared to 37% in 2014. Most were aimed at low-level theft. IMB cites this rise on moving vessels as a cause for concern as it increases potential risks to the vessels and their crew.

The IMB PRC continues to work closely with the Indonesian Marine Police and other Indonesian authorities to monitor high-risk areas. Reports have reduced in the majority of the 11 designated anchorages with only Belawan and Nipah recording marked increases in attempted thefts, reporting 15 and 26 incidents respectively in 2015.

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Nigeria: oil and kidnappings

Nigeria is a hotspot for violent piracy and armed robbery. Though many attacks are believed to go unrecorded, IMB received reports of 14 incidents, with nine vessels boarded. In the first of these, ten pirates armed with AK47 rifles boarded and hijacked a tanker and took all nine crewmembers hostage. They then transferred the fuel oil cargo into another vessel, which was taken away by two of the attackers. The Ghanaian navy dispatched a naval vessel to investigate as the tanker moved into its waters, then arrested the pirates on board.

Somalia still risky

No Somali-based attacks were reported in 2015. Following a new 55% reduction in the industry-defined High Risk Area, IMB warns vessels transiting the Gulf of Aden and Indian Ocean to stay particularly vigilant.

Mr Mukundan explained: "Somalia remains a fragile state, and the potential for an attack remains high. It will only take one successful hijacking to undo all that has been done, and rekindle this criminal activity."
Elsewhere...

Incidents in Vietnam surged from seven in 2014 to 27 in 2015. The main cause is low-level theft against vessels anchored in Vietnam, with 15 reports from around the port of Vung Tau alone.

In China four incidents were recorded in December 2015, the first in a long time. These include three thefts of bunker diesel oil from large bulk carriers off Tianjin, and one failed attempt to do the same.

Meanwhile, low-level incidents in Bangladesh dropped to 11 in 2015, from 21 in 2014.

(www.ICC-CCS.org)
Appendix 3: Transcript of interview Kapitein ter Zee N. Woudstra – Royal Netherlands Navy

Introduction
Kapitein ter Zee N. Woudstra of the Royal Netherlands Navy answers our questions regarding piracy and his vision regarding autonomous vessels sailing the oceans in the future.

The Royal Netherlands Navy is active in Somalia to patrol and fight against the event of piracy. How is this juridical regulated incase the Royal Netherlands Navy captures pirates?

The action against piracy is an collaboration between the Ministry of Defence and the Ministry of Security and Justice. UNCLOS (United Nations Convention on the Laws of the Sea) states the definition of piracy, which is adopted in the Netherlands law. In the Netherlands is a so-called universal jurisdiction. This means that the Dutch court may take knowledge of any form of piracy. UNCLOS states that any warship may attack any pirate. The Royal Netherlands Navy may only fight piracy in principle on the high seas as the vessel sails under the Dutch flag. The flagging of vessels makes this nowadays very complicated.

But UNCLOS has described some exceptions such as human trafficking, slave trade and piracy. For these cases is the universal jurisdiction adopted into the Netherlands law. This allows the Royal Netherlands Navy to take action in the event of piracy, even if it appears on vessels with another flag state and the Netherlands. The Dutch court may take knowledge of any form of piracy. He may therefore judge a vessel of another flag state, where the Royal Netherlands Navy in action is against Somali pirates. The Ministry of Security and Justice may therefore prosecute in these cases but only if there are Dutch interests. The Royal Netherlands Navy will probably take action at the request of other countries if a vessel, sailing under the flag of that country, needs help.

How does the Royal Netherlands Navy take action against vessels which are under attack of pirates or which have been hijacked?

First of all it is important to understand the four forms of piracy:

- Low Level Armed Robbery
  - Low level criminals aiming for a quick loot. They operate in small skiffs and are low level armed as well.
- Medium Level Armed Assault and Robbery
  - Local criminals with an organization structure and taking everything on board of value. They operate as well in small skiffs but in combination with a mother vessel.
- Major Criminal Hijack
  - Excellent planning, organization and equipment. Very aggressive and they might even use larger vessels to make them look like authorities. They aim at the bigger profits once they come on board. Mostly they hijack a vessel and sail it to a quiet location. There, the cargo is discharged, the vessel repainted and is given as well another vessels name and registration.
- Hijack and ransom (Somalia)
  - The crew is taken hostage, the vessel is sailed to an quiet location near the coast and they contact the vessels company to demand a ransom. The crew is mostly unharmed because pirates understand that the crew is their cargo. (Woudstra, 2009)

Once a vessel is under attack it will take the actions according to the BMP (Best Management Practices) like making maximum speed, manoeuvring and activating the hoses. If these actions don’t succeed against the pirates and they manage to get on board, the crew is moved to the vessels citadel. This is a very important point for the Royal Netherlands Navy.
If the crew manage to get all into the vessels citadel, there is a wall between the crew and the pirates. Now marines can land on board the hijacked vessel and clear the vessel of the pirates since there is no crew to threat with.

If the crew is not (all) safe in the citadel, the pirates can use them to threat, or even worse to hurt or kill them. From that point there is nothing the Royal Netherlands Navy can do. It is better to pay the ransom than taking the risk of the crew getting harmed. For most ship-owners is the crew, reputation, the vessel and its cargo more valuable than the ransom to pay. And after the ransom has been paid, the crew is always released.

Important to mention is that the ransom can be marked, numbers of the money can be stored in a database so the money can be traced back. The ransom will come back on the marked by purchases of the pirates which will show the money flows of the pirates.

**In which way could the Royal Netherlands Navy protect autonomous vessels against piracy and being hijacked?**

Protecting autonomous vessels would be way less complicated and difficult as protecting manned vessels. The ‘hijack and ransom’ does not apply anymore because there is no crew in danger. Marines can get on board and clear the vessel without any risk of harming any crewmembers.

As well there is a possibility of researching methods to use against pirates. For instance releasing an incapacitating agent after an autonomous vessel is hijacked and after a while entering the vessel with marines could make it all even less difficult. Without crewmember on board, the complete focus is at the pirates.

*We have concluded so far during the research that the piracy activity decreases in area’s with Navy patrols. And autonomous vessels should be equipped with 1 or more drones to protect the vessel. Apart from the drones design or weapon capabilities, the drone could prevent the pirates from entering the vessel. What are your thoughts regarding this idea?*

It sounds as a very complicated idea. A drone has to be controlled, fuelled after a while and has to land back on the vessel. Plus this is not an easy thing regarding liability and law regulations.

Sending a squad of marines is less complicated and in combination with an incapacitating agent even more effective. Apart from the vessels design and its accessibility, the pirates get into the “vessels accommodation” where the gas can be released. Once this is done, marines can enter the vessel and clear it. It is unnecessary to take action while there is space for a waiting position since there is no crew to harm. Damaging the communication systems will take knowledge and more important time, time which can be used to incapacitated the pirates. Even if they manage to damage the communication systems there will be a backup system but the system can also be hidden and secured at the vessel.

From sea damaging the vessels communication systems is very difficult because of the small skiffs which are incapable of taking large and heavy weapons. Besides, it is their intention to get the vessel intact and not burn or damage it to heavily.

There are other possibilities as well instead of the incapacitating agent, think of lethal weapons like the Long Range Acoustic Device (LRAD) (Wikipedia) which has been used during protests (Youtube).
What does the future look like regarding the protection of (un)manned vessels by the Royal Netherlands Navy? Will they always be needed at sea?

It depends on the hotspots of piracy worldwide and at these hotspots we will operate together with other countries who have their interests as well. No matter if manned or autonomous vessels are sailing the ocean. Furthermore, once autonomous vessels set sail there will be a long time a mix between manned and autonomous vessels and both vessels need the Navy.

Statistics show that the piracy activity in Somalia has decreased. This is mostly because of patrolling and effective actions of the different Navy’s in that area. There are a few international operations going against piracy near Somalia. The Royal Netherlands Navy is taking part of Ocean Shield (NAVO) and Atalanta of the European Union. Despite the decrease of piracy activity, the operations will continue and the Navy will stay present in the area because the presence of Navy’s is the reason for the decrease of piracy.

Will piracy always exist at the seas?

When I am giving college, I always say that piracy is the second oldest job on earth because everybody knows the oldest job on earth. The last decades is the container industry grown a lot and in the future the trading will only increase. The Netherlands for instance are importing a lot of goods and a developing or third world country will only follow and increase this activity. Besides, it will take at least decades (or longer) to replace the manned vessels for autonomous vessels. Manned vessels will be at the seas for a very long time and manned vessels will always be a target for pirates.

Possibilities to replace the transport by vessel in the future is not relevant as well. Transporting by plane is expensive and way more limited compared to transporting over sea. Besides transporting fruit from farmers in Brazil to the Dutch kitchen takes a few weeks and after that time the fruit is ready to eat. There is no need to replace vessels in the future and as long as vessels are sailing the oceans, piracy will occur.
Appendix 4: Transcript of interview Mr. R. Rozeboom – KNMI

**How is weather information collected in general?**
Weather information is collected via differed systems, e.g.:

- Weather stations on land
- Weather buoys
- Satellites
- Observations on board ships
- Airplanes – AMDAR system takes measures during landing and take-off. This measures the structure of the atmosphere and temperatures. These temperatures are analysed and can predict what these temperatures will do, the predictions are called prognoses temperatures or ‘progtemps’.

**How is weather information collected on board ships?**
The gathering of information on board a vessel is not as easy as on land. This is caused by dynamic motions, e.g. waves and swell. As well as static pressure and air pressures caused by the air-conditioning unit.

**Via what ways is collected data transmitted?**
This all started during the telex era, during this period all weather bulletins were send via the telex. The downside of the telex was the limited range and the cost of the bulletins which were send to the vessels.

In the early nineties, 1992/1993, after it was decided that the radio officer on board vessels had become obsolete, the deck officer was responsible for sending weather reports via the Inmarsat-C system. These reports had to be sent to a land earth station (LES), e.g. Burum – Netherlands.

Nowadays the TurboWin programme is used worldwide as a standard form for weather observations. The deck officer will fill in this form after which it is sent to a land earth station, the deck officer will see in the TurboWin programme which land earth station to select, this ensures that the observations are send to an LES which is as close to the vessels position as possible, where it can be analysed and used for the weather bulletins.

The newest system uses buffer messages, the advantages of these buffer messages is that they can hold more informative e.g. measuring heights, height of the deck cargo, this gives a more accurate metadata. This new system is called Format 101, but because of the use of buffer messages is it not possible to send those messages via the code 41.

**Via what ways is weather information transmitted?**
Weather information is transmitted via weather bulletins. Information which is gathered on board and processed by the meteorological bureaus will be transmitted via a weather message on three different times. These messages are also published on the Global Telecommunication System (GTS).
How quickly will the information be processed?
The process time for every ship weather observation is only minutes of work. Every message is put through few controlling layers after which it is put on the Global Telecommunication System (GTS).

Every ship weather observation which is sent to the KNMI will be forwarded to France metrological bureau, Météo-France, where it is processed and put on the GTS.

Which agencies benefit from the analysed information?
There is a difference between commercial and safety aspect of the weather information. For instant ‘Buienradar’, which earns its money with the information supplied by KNMI.

- Meteorological services provide information used for safety purposes.
- Commercial weather services provide specific forecasts for particular target groups, for example ‘Buienradar’.
- Routing services, for example SPOS.

Which components consists an automatic weather station?
There is a difference between the data which is collected on board of ships and which is collected on land and offshore platforms. The stations on land are equipped with sensors which measure the following values: temperature, humidity, wind, precipitation, clouds, solar irradiance, fog and type of precipitation, this is done with the uses of specific sensors.

The sensors which are mentioned above are not all essential for the measurements on board ships. The values that must be measured on board vessel are international agreed upon, these values are important for accurate weather reports, and are as follows: the air pressure, seawater temperature, air temperature, humidity and wind speed/direction.

Nowadays the deck officer will collect weather data and will fill in the TurboWin form, a programme used worldwide as a standard form for weather observations.

But since there is no crew on board autonomous vessels, there is no way to make an accurate weather observation via TurboWin. To solve this problem, it is essential to equip autonomous vessels with automatic weather stations that can send their hourly weather observations automatically to meteorological bureaus.

The EUMETNET started a pilot project to design an automatic weather station. KNMI designed the specifications for such an automatic weather station after which it was contracted out to a French company to build three prototypes. These three prototypes were given to the meteorological bureaus of France, Germany and the Netherlands, where they were tested. This automatic weather station is capable to measure the following values: air pressure, temperature, humidity, wind speed and direction.
Will it in the future be possible to implement worldwide coverage of maintenance?

KNMI is planning to equip fifty vessels with automatic weather stations, which provide them with hourly weather reports. The only disadvantage of these automatic weather stations is there maintenance, the system and sensors needs regular maintenance, e.g. changing sensors. Because most vessels are sailing worldwide, service engineers of KNMI need to fly around the world in order to perform maintenance to the system and sensors.

A solution could be a global cooperation between meteorological bureaus, which maintain the automatic weather stations on a globalized level. Beside the fact that it is a long and time consuming process to globalized agreements on the cost and logistics, it creates another problem.

This problem is caused by the equipment and sensors. Every country uses its own brand of sensors and equipment. There is no standardization and creates a problem when maintenance has to be performed in another country. An example of this is the difference between the Dutch and German E+E sensor, the German E+E sensor has an ASCII output while the Dutch E+E sensor has a hexadecimal output. This means that another setting has to be configured for the same system.

The solution to this problem is to standardize all equipment and sensors which are used by the automatic weather station, this requires international agreements.
Appendix 5: Emergency towing arrangements and procedures

Chapter II-1, A-1, Regulation 3–4: Emergency towing arrangements and procedures

1. Emergency towing arrangements on tankers
   1.1 Emergency towing arrangements shall be fitted at both ends on board every tanker of not less than 20,000 tonnes deadweight.
   1.2 For tankers constructed on or after 1 July 2002:
      i. The arrangements shall, at all times, be capable of rapid deployment in the absence of main power on the ship to be towed and easy connection to the towing ship. At least one of the emergency towing arrangements shall be pre-rigged ready for rapid deployment; and
      ii. Emergency towing arrangements at both ends shall be of adequate strength taking into account the size and deadweight of the ship, and the expected forces during bad weather conditions. The design and construction and prototype testing of emergency towing arrangements shall be approved by the Administration, based on the Guidelines developed by the Organization.

1.3 For tankers constructed before 1 July 2002, the design and construction of emergency towing arrangements shall be approved by the Administration, based on the Guidelines developed by the Organization.

2. Emergency towing procedures on ships
   2.1 This paragraph applies to:
      i. All passenger ships, not later than 1 January 2010;
      ii. Cargo ships constructed on or after 1 January 2010; and
      iii. Cargo ships constructed before 1 January 2010, not later than 1 January 2012

   2.2 Ships shall be provided with a ship-specific emergency towing procedure. Such a procedure shall be carried aboard the ship for use in emergency situations and shall be based on existing arrangements and equipment available on board the ship.

   2.3 The procedure shall include:
      i. Drawings of fore and aft deck showing possible emergency towing arrangements;
      ii. Inventory of equipment on board that can be used for emergency towing;
      iii. Means and methods of communication; and
      iv. Sample procedures to facilitate the preparation for and conducting of emergency towing operations.

   (IMO SOLAS, 1974)

(12) United States Patent
(10) Patent No.: US 6,260,500 B1
(45) Date of Patent: Jul. 17, 2001

(54) EMERGENCY SHIP TOWING SYSTEM
(75) Inventor: David B. Coakley, Hyattsville, MD (US)
(73) Assignee: The United States of America as represented by the Secretary of the Navy, Washington, DC (US)
(* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.
(21) Appl. No.: 09/599,580
(22) Filed: Jun. 22, 2000
(51) Int. Cl. 7 .......................... B63B 21/56
(52) U.S. Cl. .......................... 114/242, 440/33
(58) Field of Search .......................... 114/242, 253, 114/221 R, 51; 440/33, 34, 40

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5 Claims, 5 Drawing Sheets

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ABSTRACT
A thrust unit having an engine as an external source of motive power for a marine vessel in distress, is delivered by helicopter air drop to a remote seawater location together with other components of the associated towing system, delivered onto the deck of such marine vessel for operational assembly and connection to the thrust unit in order to initiate emergency towing of the marine vessel while immersed in the seawater adjacent thereto under control of personnel on the marine vessel.
AIR DROP OF COMPONENTS AT SHIP DISTRESS LOCATION

DELIVERY OF OTHER COMPONENTS ONTO SHIP DECK FOR OPERATIONAL ASSEMBLY

HELICOPTER TRANSPORT OF TOWING SYSTEM COMPONENTS

THRUST COMPONENT DELIVERY INTO SEAWATER ADJACENT DISTRESSED SHIP

TOWING OF SHIP BY THRUST COMPONENT CONTROLLED BY OTHER COMPONENTS ON SHIP

FIG. 5
EMERGENCY SHIP TOWING SYSTEM

The present invention relates generally to seawater towing of marine surface vessels that are in distress.

BACKGROUND OF THE INVENTION

Marine surface vessels in distress during seawater travel sometimes become immobile at some seawater location so as to require an external source of motive power for movement therefrom. The provision of such external motive power source for ship towing purposes, heretofore involved the use of tugboats through which transport of towing apparatus to some seawater location was performed in order to reliably carry out a towing mission on an emergency basis. However, tugboat transport involved substantial transit time following an emergency call from a marine vessel in distress. Accordingly, it is an important object of the present invention to reliably and more quickly perform a towing mission for a ship in distress, involving use of a motive power source externally of the ship at some remote seawater location in response to a distress call from such remote location.

SUMMARY OF THE INVENTION

In accordance with the present invention, components of an emergency ship towing system are selected to perform the towing mission and of a limited weight so as to accommodate safe and rapid transport by helicopter to a remote seawater location at which the towing system components are delivered and operationally assembled by personnel for reliable performance of the towing mission without delay. One of such towing system components, providing the external motive power source, is in the form of a preassembled thrust unit having a gas turbine type of engine therein, according to one embodiment of the invention, to which a mixture of pressurized air and fuel is supplied through an elongated flexible hose for selective operation of the turbine engine under remote travel speed control. Such thrust unit also includes a rudder and stabilizer assembly through which travel direction and underwater depth control is exercised through elongated signal wiring attached with the flexible hose to an elongated towing cable extending therefrom. The foregoing described type of thrust unit when transported to the required seawater location by the helicopter is dropped through the air for immersion into the seawater adjacent to the ship in distress. The other components of the towing system simultaneously transported by the helicopter to the seawater location, are air dropped onto the deck of the ship in distress for prompt operational assembly thereon by shipboard personnel and attachment to the towing cable, flexible hose and signal wiring extending from the thrust unit immersed in the seawater. On-off control, and selective control over travel speed, direction and underwater depth of the thrust unit during performance of its towing travel operation is thereby effected under control of personnel on the ship through a control box component.

BRIEF DESCRIPTION OF DRAWING

A more complete appreciation of the invention and many of its attendant advantages will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawing herein:

FIG. 1 is a simplified side elevation view of a ship undergoing tow by means of a towing system delivered thereto by a helicopter shown hovering above the ship; FIG. 2 is a partial top plan view of a forward portion of the ship shown in FIG. 1, illustrating an assembled arrangement of operational components associated with the towing system;

FIG. 3 is a side view in partial section illustrating the preassembled thrust unit component of the towing system;

FIG. 4 is a block diagram illustrating selective controls associated with the components of the towing system shown in FIGS. 2 and 3; and

FIG. 5 is a block diagram schematically summarizing the towing system procedure associated with the embodiment of the invention depicted in FIGS. 1-4.

DETAILED DESCRIPTION OF THE EMBODIMENT

Referring now to the drawing in detail, FIG. 1 illustrates a marine vessel or ship 10 in under tow at some location in a body of seawater 12. Hovering above such ship 10 is a helicopter 14 through which components of an emergency towing system are transported upon call to the distressed ship location, and dropped through the air. One of such components, in the form of a towing thrust unit 16, is delivered by such air drop into the seawater 12 in adjacent relation to the forward portion of the ship 10 as illustrated, while the other emergency towing system components are dropped by the helicopter 14 onto the deck 18 of the ship 10 for assembly thereon by personnel into an arrangement such as that shown in FIG. 2. All of the towing system components together weigh approximately 4000 lb so as to be transportable by the helicopter 14.

The emergency towing system components transported by the helicopter 14, in addition to the thrust unit 16, include a flexible towing component 20 connected to and extending from the thrust unit 16 onto the forward end portion of the ship deck 18. As shown in FIG. 2, the towing component 20 has associated therewith a flexible cable 22 hooked at one end by personnel to an anchor windlass 23 for example, and an air hose 24 connected to a compressor and fuel assembly 26. The flexible towing component 20 also includes control signal wiring 28 extending from the seawater immersed thrust unit 16 to a control box 30 on the ship deck 18 connected to the compressor and fuel assembly 26 for selective on-off control of the thrust unit 16 with respect to ship travel direction and underwater depth by shipboard personnel.

As shown in FIG. 3, the thrust unit 16 has an outer hydrodynamically shaped housing 32 enclosing an engine 34 such as a gas turbine connected at its inlet end to the air hose 24 through which air mixed with fuel is fed to the turbine engine 34 for operation thereof under selective control. Water outflow from the turbine engine 34 through the housing 32 is conducted by an exhaust control stop lock 35. A speed reducer gearbox 36 mechanically connected to the outlet end of the turbine engine 34 transfers power of approximately 1000 hp at a high torque and low rotational speed to an output shaft 38 connected to a propulsor generally referred to by reference numeral 40. In the illustrated embodiment, the engine driven propulsor 40 includes propeller blades 42 extending radially and rearwardly from a conical shaped rotational hub 44, surrounded by a stator shroud 46 fixed by struts 48 to the thrust unit housing 32 so as to introduce swirl into the propeller plane. A conventional assembly of rudder 50 and stabilizer 52 are mounted by the shroud 46 in rearward relation to the propulsor 40, for setting depth and travel direction through servomotors 54 and 56.

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As diagrammed in FIG. 4, the servomotors 54 and 56 are respectively under pneumatic control of direction and depth signals supplied thereto by the wiring 28 from the control box 30. Such depth signals are derived from readings of a depth gage combined with depth command from the control box 30 pursuant to a control scheme such as proportional, proportion a 124 derivative or proportional-derivative-integral to maintain depth by control of stabilizers 52. The gas turbine 34, on the other hand, is controlled by the control box 30 through a valve 58 supplying fuel from a fuel source 62 in the assembly 26 to the hose 24 for mixing with pressurized air therein supplied thereto through a valve 60 from an air compressor 64.

FIG. 5 diagrammatically summarizes the operational procedure associated with the present invention as hereinbefore described. The towing system components are transported for helicopter air drop, as denoted by reference numeral 66, to the ship distress location 68. Delivery 70 of one of the towing system components, in the form of the thrust unit 16, is thereby effected into the seawater 12 adjacent to the distressed ship 10 while the other towing system components connected to the thrust unit 16 by the flexible towing assembly 20, undergo delivery and operational assembly 72 on the ship deck 18. Towing 74 of the distressed ship 10 is thereby effected under selective operator control with respect to travel speed, direction and underwater depth through the control box 30 as hereinbefore described.

Obviously, other modifications and variations of the present invention may be possible in light of the foregoing teachings. For example, the gas turbine engine 34 could be replaced by a Diesel engine while the propulsor 40 may be replaced by one employing contra-rotating blades. The elongated cable 20 may be replaced by one without the air hose 24, connected to a thrust unit in the form of a shackle. The thrust unit 16 may accordingly be replaced by one having an electric motor with an electromagnetic cable connected to a portable generator on the ship, or by one having limited fuel and air supplies therein. As yet another alternative, the thrust unit which crawls down the side of the ship may be utilized, involving use of electromagnetic tracks and stops on the bottom of the ship hull and magnets to maintain the thrust unit in place while approximately 1000 hp is delivered as motive power for the ship. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. In combination with a system for towing a marine vessel in distress from a seawater location under selected travel speed, direction and underwater depth by means of a thrust unit in the seawater connected by flexible means to the marine vessel and a plurality of other components of the towing system through which control of said selected travel speed and underwater depth are effected from the marine vessel, a method including the steps of: transporting said thrust unit and the other components by helicopter to the seawater location; respectively delivering the thrust unit by helicopter air drop at said location into the seawater and the other components onto the marine vessel; and operationally assembling said other components on the marine vessel for connection by the flexible means to the delivered thrust unit to initiate towing.

2. The combination as defined in claim 1, wherein said thrust unit includes an engine through which said control over the selective travel speed is effected, and a rudder/stabilizer assembly through which said selective control over the travel direction and underwater depth is effected.

3. The combination as defined in claim 2, wherein said other components delivered by said air drop onto the marine vessel include: a fuel source; an air compressor; valve means respectively supplying fuel from the source and air from the compressor for intermixing and feeding by the flexible means to the engine; and control box means connected to the valve means and the rudder/stabilizer assembly for effecting said selective control over the travel speed, direction and underwater depth.

4. The combination as defined in claim 1, wherein said other components delivered by said air drop onto the marine vessel include: a fuel source; an air compressor; valve means respectively supplying fuel from the source and air from the compressor for intermixing and feeding by the flexible means to the thrust unit; and control box means connected to the valve means and the thrust unit for effecting said selective control over the travel speed, direction and underwater depth.

5. In combination with a system for towing a marine vessel in distress from a seawater location by means of a thrust unit in the seawater connected to the marine vessel and a plurality of other components of the system through which travel imparted to the marine vessel by the thrust unit is selectively controlled from the marine vessel, a method including the steps of: transporting said thrust unit and the other components by helicopter to said seawater location; delivering the thrust unit and the other components to said seawater location by helicopter air drop; and operationally assembling said other components on the marine vessel after said delivery thereof to initiate towing.