Launch and Recovery of Unmanned Surface Vessels from a Mothership

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Abstract

Currently, there is no established Launch and Recovery System (LAR) for Unmanned Surface Vessels (USVs) as it is a new field of research. This project discusses a LAR system for USVs from a Mothership through a modified stern ramp system. The modified stern ramp system features a scaled model of the stern ramp, movable ramp extensions and supporting structures. The movable extensions allow for a better hydrodynamical nature of the Mothership in the retracted position while allowing the USV to enter the Mothership with greater ease. The project evaluates the effectiveness of the proposed system through the use of Finite Element Analysis (FEA) by accounting for possible load cases and the LAR system's maximum operational capacity. The LAR system was evaluated to sustain up to 250,000N of force. Taking into account the fact that the stern ramp is an inclined plane and the presence of buoyancy force, the proposed LAR system has proven to be effective. This project also creates an algorithm for the recognition of the Mothership for the recovery of the USV. However, due to data protection policies, the project was unable to access video footage of the Mothership as training data for the algorithm. The model was modelled and analysed using Solidworks Computer Aided Design (CAD) Software.

Words: 211

1.0 Introduction and lit review

1.1General problems faced

Currently, there is no established Launch and Recovery System (LAR) for Unmanned Surface Vessels (USVs) as it is a new field of research. The LAR of USVs face the following general problems.

1.11 Ocean currents

Ocean currents are underwater currents that are caused by the earth's gravitational pull and the relative densities of water. These currents are predictable by nature, and cause a large flow of water from one place to another. As Singapore's waters do not extend to the open ocean, the ocean currents experienced are inherently weaker than normal. However, reaching speeds of up to 2 m/s (Chen et al, 2005), they can affect the velocities and trajectories of ships and cause them to stray off their path, meaning it can impede the launch and recovery of surface vessels at sea, considering that both objects will be affected by these ocean currents.

1.12 Relative velocity

Whilst traversing at sea, the launch and recovery of the surface vessels will be impeded by the fact that the Relative velocities between the mothership and the surface vessel. Hence the pilot of the surface vessel that is being launched or recovered must be experienced enough to ensure that the difference in relative velocities of the two ships is very little, to ensure that the smaller vessel can safely be recovered.

1.13 Waves

Waves on the surface of the ocean are transverse waves of water. They are the medium in which kinetic energy on the surface of the ocean travels. They are caused by the effect of wind when it blows across the surface of the ocean, transferring kinetic energy onto the water's surface. As the sovereign waters of Singapore are largely close to land, the waves are much smaller than in the open sea, allowing small surface vessels to stay afloat. Having said that, in sub-optimal surface conditions, waves can still reach heights of 3m high when affected by monsoon winds (Cannaby et al, 2016) causing significant changes in the velocity, trajectory and roll of a surface vessel, impeding the launch and recovery of a surface vessel.

1.14 Wakes

The movement of a boat in water will displace water, known as the wake. This wake forms a pattern consisting of two wake lines that form the arms of a chevron, V, with the source of the wake at the vertex of the V. For sufficiently slow motion, each wake line is offset from the path of the wake source by around $\arcsin(1/3) = 19.47°$ and is made up of feathery wavelets angled at roughly 53° to the path. (Thomson, 1887). The wake of a boat can cause large waves behind the boat, and the size of these waves will vary depending on the size of the boat. When two boats move in the water, either boat can be affected by the other's wake, causing the affected vessel to experience a change in velocity, direction and roll. Considering that the launch and recovery of the surface vessel may be from a non-stationary mothership, and that the mothership is a large vessel upwards of 30m in length, the wake of the mothership can significantly affect the smaller boat, impeding the efforts to launch or recover it.

1.2 Possible mechanisms for the recovery or launching

Having found out the general challenges posed to the launch and recovery of unmanned surface vehicles from motherships, more research was conducted regarding the different mechanisms for the launch and recovery of unmanned surface vessels from a mothership

1.21Crane like Systems

This category of mechanisms for recovering and launching surface vessels involves any form of crane or crane-like structure or davit structure, which can be used to launch and recover vehicles from the water surface. Crane-like structures are commonly used on the sides of the ship, allowing the launched vehicle to be parallel to the mother ship and parallel to the direction of travel, if any. Such structures can be used by attaching the crae to the ship and lowering or raising the boat from the water surface. The system can potentially be remote controlled. This method has the main advantage of not using up any lower deck space, hence allowing it to be very space efficient (Gelling, 2008).

1.22Ramp like systems

This category of mechanisms involve stern ramps or slipways that can allow for the surface vehicle to slide into or slide out of the water (Sheinberg et al., 2003). These structures are normally placed at the stern of the ship, so as to allow for a boat to be launched or recovered while parallel to the boat. Such structures can be used to launch the surface vessel by sliding it down the ramp and into the water, and be used for vessel recovery by either driving it up the ramp quickly and securing it before it slides back down, or alternatively, using an intermediate capture device. Such a method can only be used when a ramp or a slipway is built into the design of the vessel, meaning that it cannot be added on once the vessel is built.

1.23 Intermediate capture devices

An intermediate capture device is not a mechanism to launch or recover surface vessels per say, but instead a device that can significantly aid the mechanism. It refers to any form of net or cage-like structure that can be used to capture the surface vessel, allowing the surface vessel to be launched or recovered more easily or with much less damage to the structure of the smaller vessel. Such a device usually captures vehicles by ensnaring it using some form of rope or wires. Such a device is commonly used in conjunction with the other mechanisms mentioned above, and is considered to be multi purpose. The different types of such devices will be detailed below

1.231 Cage like intermediate capture devices

The cage-like intermediate capture devices involve a form of cage-like structure that is big enough for the unmanned surface vessel to fit into (Artzner 2008). This cage-like structure is deployed around the ship, such that when the unmanned surface vessel needs to be recovered, it simply travels into the encapsulating cage-like structure. From there, the vessel is then locked into the cage-like system, and then the entire cage itself can be recovered directly into the boat via a crane-like structure. Such an intermediate capture device has the advantage that it is very sturdy by nature, and will help protect the vessel as it enters the other vessel.

1.232 Towed underwater bodies

The towed underwater bodies function similarly to the aforementioned cage-like structures (Mulhern 2005). They both involve a device that can encapsulate the surface vessel, allowing the vessel to be recovered or launched safely without the risk of damaging the vessel. This system differs from the cage like system in the sense that it is designed for the underwater body to be driven to the vessel, not the vessel driving into the device. Overall, it has similar advantages as the cage-like system.

1.233 Sled like systems

The sled like system of intermediate capture devices can only apply to the sled like system of recovery, unlike the above systems which only apply to the davit like system. The sled like system involves a movable carriage or sled which can be controlled to move up and down the ramp like system in the ship, so as to launch and recover the ship (Seiple 2008). This system has the main advantage of allowing vessels to move up and down the ramps without the risk of any damage to the vessel once it is inside the cage, and as such can help protect the ships.

1.3 The mothership

The mothership that is used to conduct the launch and recovery of unmanned surface vessels in Singapore is the Independence class littoral mission vessels. These vessels are newly commissioned ships, by the Republic of Singapore navy, to replace the Fearless-class patrol vessels in Singapore. These vessels are designed with the intention to reduce the manpower requirements of such maritime vessels throughout Singapore, considering the declining birth rates through Singapore which could cause a manpower shortage. It contains increased amounts of monitoring and automation systems and is designed to handle a wide variety of roles. The vessel has a length of 80m, a width of 12m, a draught of 3m, and a displacement of 1200 tonnes

1.4 The unmanned surface vessel

According to the current data, the Unmanned surface vessel that is currently in trials for this operation in the Singapore navy is approximately 17 metres in length, and has a width of around 5.2 meters. According to estimates, the bow of this unmanned surface vessel lies approximately 2 metres below the water surface, and it has a mass of at most 30 tons.

1.5 Launch and recovery of the current vessel from a mothership

Having conducted a large amount of research in this field to gain a better understanding of the maritime environment where the vessels will be operating, research was conducted on how the Republic of Singapore Navy conducts its launch and recovery operations

1.51Current system

The current system that the mothership employs to launch and recover all surface vessels is a stern ramp. This stern ramp is of a “v” shape so as to better conform to the shape of the smaller surface vessel, allowing the smaller surface vessel to smoothly rise up the ramp. It has a length of about 17 metres, a width of 5.2 metres, a depth of about 2 metres. It is made from carbon fibre reinforced composites, and is angled at roughly 15 degrees away from the water surface. It is located at the stern of the mothership, and the end of the ramp extends into the water surface.

1.52 Operating procedure

1.521 Launch

During the launching of the surface vessel from the mothership, the mothership itself often remains stationary in the water so as to not generate too much wake for the surface vessel to be launched into. During the creation and testing of the current stern ramp system on the mothership, it was discovered that for a boat to be launched solely using gravity, the ramp itself must be angled at a minimum of 12 degrees away from the water surface. Considering that the ramp in question used by the navy is angled at 15 degrees from the water surface, Once the mechanism securing the surface vessel in place inside of the mothership is released, the surface vessel will naturally slide down the ramp and into the sea.

1.522 Recovery

When compared to the launching of surface vessels from the mothership, the recovery of vessels to the mothership is far more complex.

1.5221 Overcoming gravity

Since the stern ramp is angled at approximately 15 degrees, the surface vessel needs to overcome gravity to rise up the stern ramp to be secured on the mothership. However, as the surface vessel rises up the stern ramp, it is no longer in contact with the water. This means that it cannot rely on its own propulsion system to get it up the stern ramp. Meaning that it has to rely on its initial velocity relative to the mothership to get it up the ramp. This however, encounters another problem. Too fast an initial velocity, and the surface vessel will slam into the stern ramp at a high enough velocity to cause damage to the surface vessel or the stern ramp. Too slow a velocity and the surface vessel will be unable to rise up the stern ramp. Through experimentation, the team which is in charge of the launch recovery of surface vessels, the appropriate relative velocity between the surface vessel and the mothership is 1.5 to 2 knots.

1.5222 Getting the bow of the boat angled upwards.

The stern ramp is angled. However, when the surface vessel, when traveling at slow speeds, has its bow angled at a low angle on the surface of the water. This low bow angle is an issue for the recovery of the surface vessel, as if the difference in angle between the bow of the boat and the stern ramp is too large, the area of contact between the surface vessel and the stern ramp when the surface vessel first makes contact with the stern ramp will be extremely small, which can lead to damage to the hull of the surface vessel. To remedy this, the angle of the surface vessel relative to the water must increase. To do so, the surface vessel itself will have to travel at a speed of approximately 7 knots to tilt the front of the boat out of the water and angling it upwards, so it makes contact with the stern ramp with a larger surface area, and the impact force will not damage the hull of the ship as much.

1.53 Problems encountered

The problem with moving the surface vessel at a higher speed, is that the mothership must also travel at speed to maintain the appropriate relative velocity. This can cause issues as the ,othership needs to travel at approximately 5 knots to maintain the relative velocity, and at such a speed, the wake generated by the mothership is increased, and can throw the surface vessel off the desired path significantly. This is the main reason why the launch and recovery of an unmanned surface vessel has not been attempted yet, as an experienced captain is required to navigate the surface vessel through the wake of the mothership and up the stern ramp.

2.0 Proposed solution

From the research conducted, the main reason why the launch and recovery of surface vessels from a mothership is so difficult, is because of the wake caused by the mothership during the recovery phase. Without this, the mothership would have a much easier time aligning with the stern ramp to rise up the ship. Having realised that the main reason why the wake from the mothership was so large, is because the stern ramp angle is relatively steep, so the surface vessel must travel at a high speed to tip its bow out of the water enough to spread out the initial impact between the boat and the ramp so as not to break either of them. Hence, if a way to reduce the angle of the main ramp, then the surface vessel need not travel at such a high speed to allow the bow of the boat to tip out of the water as much, in turn reducing the speed that the mothership has to travel at, which reduces the wake caused by the mothership, which makes it easier for the surface vessel to align itself with the ramp. There are several issues with doing this.

Firstly, decreasing the angle of the ramp would cause the gravitational force acting on the boat parallel to the ramp to be less and unable to overcome the static friction to launch the boat. To overcome this, the overall shape of the ramp was made to be curved, such that the ramp angle at the top of the ramp is 15 degrees, while the ramp angle at the entry of the ramp is closer to 5 degrees. This ensures that when the boat is at rest at the top of the ramp, the gravitational force that acts on the boat would be able to overcome the static friction between the surface vessel and the ramp. Considering that the kinetic friction between the surface vessel and the ramp would be less than its static friction, the momentum that has been gained initially when the boat is sliding down from the top of the ramp should allow it to slide past the less inclined sections near the bottom of the ramp.

However, merely making the stern ramp curved would cause another problem. The ramp would overall need to be longer, as it still must rise out of the water to the same height as before, and must also extend to the same depth below the water surface, but the average angle of the ramp would be less. Considering that the mothership itself does not have an infinite amount of space, it was decided to make the end of the ramp extendable. This ensured that the end of the ramp which was curved would be able to be extended into and out of the water when needed for launch and recovery.

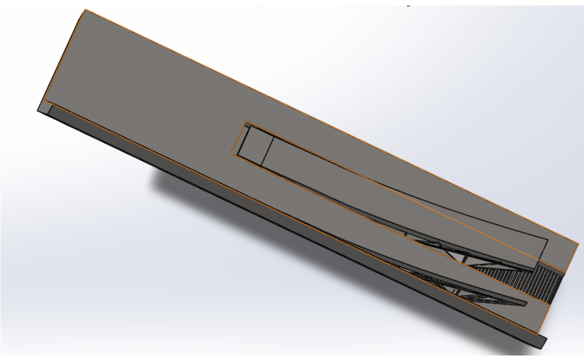
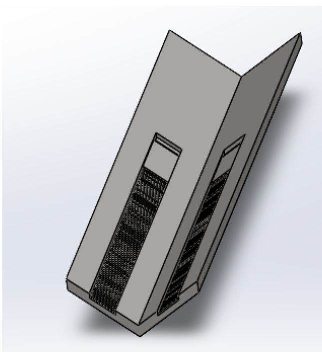
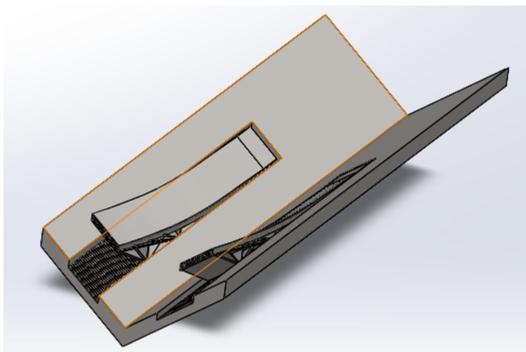
This would help reduce the overall space that the ramp takes up even when not in use. Also, it is important to consider the area of the ramp which is exposed to the largest amount of force is the area where the surface vessel first makes contact with the stern ramp. Also, since the ramp itself is made of carbon fibre, if it breaks at one location, it most likely has to be replaced. Hence by adding these extensions, in the case where these extensions break due to a failed attempt at surface vessel recovery, only the extensions have to be replaced, not the whole ramp, which can potentially save some money.

2.1 The model

The model was constructed using Solidworks computer aided design software. It was chosen as it would allow for better meshing of the 3d model, allowing for the finite element analysis to be conducted more efficiently.

2.11 Main ramp

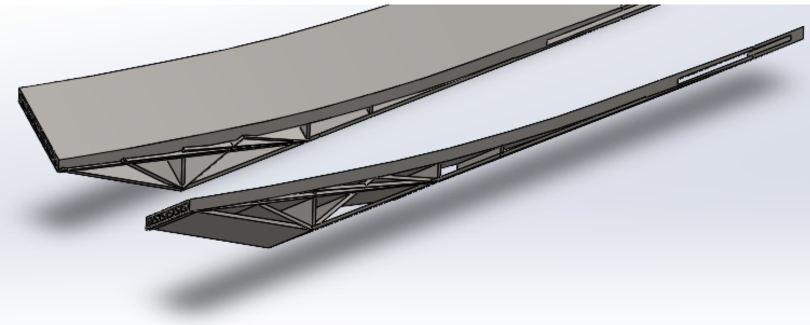
The model consisted of the main stern ramp, which is 17 metres long, had a width of 5 metres, and had a depth of 2 metres. 11 metres from the bottom of the ramp, there were 2 indentations for the curved extensions for the ramp to lie in. These indentations were 11 metres long, 1.15 metres wide and 20 cm deep. To allow the ramp extensions to slide up and down the stern ramp into the extended or retracted position, cylindrical rollers were inserted between the extensions and the indentations in the main ramp. These rollers were15 cm in diameter each, and cover the length of the indentations.

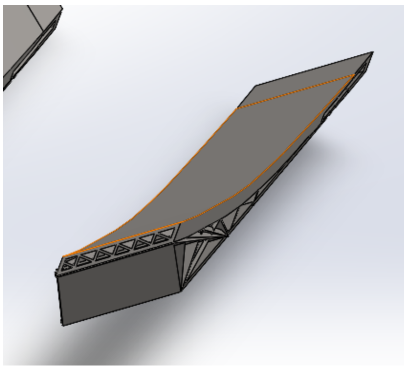
2.12 Extensions

In these indentations lie the ramp extensions, which were roughly 0.18 metres thick, 1.13

metres wide and had an overall length of about 9 metres. As the ramp extensions themselves could not feasibly be made from a solid piece of material, and as such we decided to make the ramp extensions a shell with a thickness of 4 cm, with internal trusses with width 3 cm for extra strengthening. External supports were implemented to strengthen the extensions further. These external supports first consist of a lower beam connected to the ramp extensions. These lower beams were parallel to the ramp, and would lie flat on the rollers. They were of width 1.03m, and had a thickness of 4cm, and extended 7 metres from the end of the extensions which lie on the stern ramp. From this lower beam, trusses of a thickness of 3cm extend from the end of the lower beam which was not connected to the extension, which supported the extension at various points. This ensured that force which was exerted on the end of the extensions, was directed into the trusses which supported the extension, which directed it on

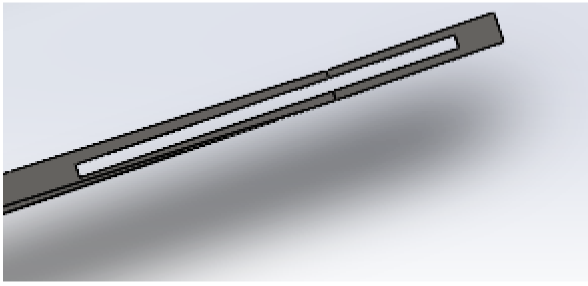


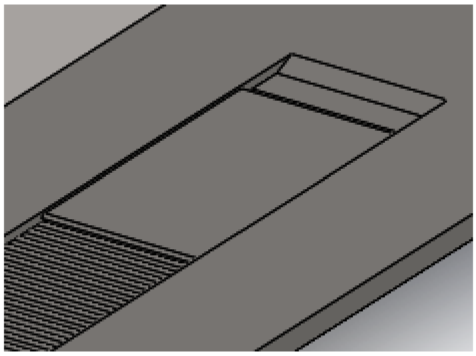
the bottom beam and hence into the rollers on the main stern ramp, overall strengthening the extension. To slide the extensions up and down the stern ramp, a winch should be connected to the end of the stern ramp, allowing it to winch the extensions up and down the stern ramp.



2.13 Locking mechanism

To lock the extensions in place in the retracted and extended position, locking mechanism to lock the extensions oto the main stern ramp was inserted. It consisted of a rectangular hole in the rear of the stern ramp, which is of a length of 1.8 metres long and a width of 8 cm, into which a rectangular bolt connected to the stern ramp, of length 1.78m and width 4 cm, fitted through, locking the extension in place. These bolts would be operated via a hydraulic piston. There were 4 of them on the stern ramp, one for each extension in the retracted and extended stern ramp position





2.14 Operation

When the stern ramp was not being used during launch and recovery, the extensions should be in the retracted position, allowing the extensions to be flush with the back of the main vessel, allowing the doors to the stern ramp to be shut. During vessel launch and recovery however, the extensions needed to be lowered down the stern ramp and into the water. This was done by firstly retracting the bolt which currently held the extension in the retracted position. Before lowering the extensions 3 metres towards the water surface via the winch, and finally securing it in place by extending the bolt at the bottom of the stern ramp. This process should be done in reverse to retract the extensions back into the mothership after launch or recovery of the surface vessel.

2.2 The code

2.21 Introduction

The code was written in python 3.7.6 programming language, using pip to install libraries: "ImageAI, Tensorflow (2.4.0), Keras (2.4.3), numpy (1.19.3), pillow (7.0.0), scipy (1.4.1), h5py (2.10.0), matplotlib (3.3.2), opencv as well as keras-resnet (0.2.0). Images used during the project were in (JPG) format.

The algorithm was intended to be used during recovery and when the USV is close enough such that the Mothership was recognisable within the frame of the camera. Due to COVID restrictions, images and data of the mothership and the stern ramp fed into the algorithm were insufficient, hence only data found on the internet which were not high definition and had irrelevant objects in frames were fed into the training algorithm. Thus, a model which could identify the stern ramp of the mothership with only around 30% accuracy was created.

2.22 The Code

The code can be broken down into 3 important parts. First, the annotation phase, next the training and evaluation phase, and finally the manual testing of the program.

For the annotation phase, online videos of vessels recovering were found and broken up into frames, taking care to include as little impurities as possible such as water droplets on the lens or subtitles. After selecting around 180 of the cleanest images from the pile, a program known as LabelImg was used to manually create bounding boxes around the stern ramps in the images and label them. These annotated images were stored in Pascal VOC annotation format in two different files, one containing 70% for training and the other one containing the remaining 30% for evaluation.

Next, the original images together with their annotated counterparts were fed into a piece of code which creates multiple models which have the ability to recognise the stern ramp of the mothership. Due to hardware and time constraints, only 6 different models were created rather than the optimal 200 models. After this, the models are then fed into another piece of code which evaluates the accuracy and ability of each model.

Below is the code used

Training

```
from imageai.Detection.Custom import DetectionModelTrainer

trainer = DetectionModelTrainer() trainer.setModelTypeAsYOLOv3()
trainer.setDataDirectory(data_directory="stern ramp") trainer.setTrainConfig(object_names_array=["stern
ramp"], batch_size=4, num_experiments=6, train_from_pretrained_model="pretrained-yolov3.h5")
trainer.trainModel()
```

Evaluation

```
from imageai.Detection.Custom import DetectionModelTrainer

trainer = DetectionModelTrainer() trainer.setModelTypeAsYOLOv3()
trainer.setDataDirectory(data_directory="stern ramp") trainer.evaluateModel(model_path="stern ramp/models",
json_path="hololens/json/detection_config.json", iou_threshold=0.5, object_threshold=0.3, nms_threshold=0.5)
```

Manual Testing

```
from imageai.Detection import ObjectDetection
import os

execution_path = os.getcwd()

detector = ObjectDetection()
detector.setModelTypeAsRetinaNet()
detector.setModelPath( os.path.join(execution_path , "detection_model-ex-05--loss-4.42.h5"))
detector.loadModel()

detections = detector.detectObjectsFromImage(input_image=os.path.join(execution_path , "image.jpg"),
output_image_path=os.path.join(execution_path , "imagenew.jpg")) for eachObject in detections:
print(eachObject["name"] , " : " , eachObject["percentage_probability"] )
```

2.23 The results of the Algorithm

The best model was fed into the algorithm, which was unfortunately of only 33% accuracy, into another piece of code which uses the model generated to recognise the stern ramp from photos inputted into the program.

In an ideal scenario, the algorithm would be able to identify the stern ramp of the mothership with over 90% accuracy as well as recognise if the unmanned surface vessel was aligned with the stern ramp so the vessel can advance. Other than that, it would function real time, feeding intel to the programme to allow the vessel to recover safely and efficiently.

3.0 Result and discussion

3.11 The Finite Element Analysis

A series of Finite Element Analysis (FEA) studies was conducted on the proposed LAR system against the forces anticipated on the stern ramp and extension during LAR operations of the fast craft. Structures were modified for strengthening, and re-analysed to satisfaction.

The FEA aims to identify areas for modification and strengthening in earlier LAR system prototypes. After all modifications and further strengthening, the FEA aims to analyse the maximum operational capacity of the final LAR system design and draw a conclusion to whether the proposed design is a viable LAR system.

For the purpose of the Finite Element Analysis, several assumptions are made. Carbon fibre is assumed to be a homogenous material. The main failure mechanic of carbon fibre is fibre fracture and fibre fracture is assumed to occur under displacements greater than 2mm. The USV is assumed to be a uniformly distributed load. For the purpose of structural analysis, the stern ramp, extensions and bolts are structurally connected into a singular piece.

The main failure mechanics identified for this model was the possible excessive tensile stress experienced by the model, resulting in fibre fracture and high displacement resulting in material failure or misalignment of the extension from the stern ramp. Correspondingly, the main boundary conditions for this analysis are the tensile stress experienced by the LAR system and the displacement of the extension.

The USV has a mass of 30 tonnes (30 000 kg). Under regular loading circumstances, the USV exerts a force of 300 000 N downwards. However, as the stern ramp is an inclined plane, the force that it will be exerting perpendicularly downwards on the stern ramp would be resolved into its x- and y- components, which yields a force lesser than 300,000N. Furthermore, there will be a presence of buoyancy force acting on the USV by the water, further reducing the load on the stern ramp.

The force the USV will exert perpendicularly downwards on the ramp is given by:

$$perpendicular\ component\ =\ mg \times\ cos\theta$$

$$\therefore perpendicular\ component\ =\ 30\ 000kg \times 9.81 \times\ cos(15°)\ =\ 2.84 \times 10^{5}\ N\ (3\ s.f.)$$

Therefore, it is anticipated that the maximum possible load of the stern ramp is 2.84×10^5 N.

With the USV assumed to be a uniformly distributed load, static finite element analysis could be conducted for the model. Without excessive displacement, a fundamental assumption is that the stiffness of the structure remains constant independent of the load being applied. Therefore, small displacement analysis could be conducted.

The maximum operational capacity will first be determined, based on a series of indicators: von Mises Stress, Resulting Displacement and Factor of Safety.

The maximum operational capacity determined from the Finite Element Analysis tests will then be cross-referenced against the loading conditions of the LAR system.

Should the maximum operational capacity exceed that of the loading conditions, the LAR system will prove structurally sound.

Below are the volumetric and material properties of the model.

Volumetric Properties of Stern Ramp

Mass: 1.85583e+06 kg

Volume:1,042.6 m^3

Density:1,780.01 kgm^{-3}

Weight:1.81872e+07 N

Volumetric Properties of Extension

Mass: 75,124.1 kg

Volume: 42.2047 m^3

Density:1,779.99 kgm^{-3}

Weight: 736,216 N

The Finite Element Analysis was conducted on carbon fibre which was custom made with the following material properties:

Model type: Linear Elastic Isotropic

Yield strength: 3.5e+09 Nm^{-2}

Elastic modulus: 7e+08 Nm^{-2}

Poisson's ratio: 0.28

Mass density: 1,780 kgm^{-3}

With the USV assumed to be a uniformly distributed load, static finite element analysis could be conducted for the model instead of dynamic analysis.

Without excessive displacement, a fundamental assumption is that the stiffness of the structure remains constant independent of the load being applied. Therefore, small displacement analysis could be conducted.

3.12 Analysis of Results

The model was first tested with a load of 1N to analyse its structural integrity. The model responded favourably, with the highest stress experienced at a point in the model being a level below carbon fibre’s yielding strength, a high factor of safety and no excessive displacement.

The model was concluded to be structurally sound, with all parts physically connected.

The model was then tested with its maximum loading condition of 300,000N.

The model responded with the highest stress experienced at a point in the model being a level below carbon fibre’s yielding strength and a high factor of safety. However, there was moderate displacement of 2.2mm. Having evaluated 2mm as a failure criterion for the material failure of carbon fibre, the LAR system was assessed to fail under loads of 300,000N.

The model was then tested at 200,000N and 250,000N. The model responded favourably, with the highest stress experienced at a point in the model being a level below carbon fibre’s yielding strength, a displacement level below 2 mm and a high factor of safety. Therefore, 250,000N was assessed to be the maximum operational limit of the LAR system.

Table 1: Summarised Table of Results

Load / N	Highest stress / Nm-2	Highest displacement / mm	Lowest Factor of Safety
1.00000	9.208e+00	7.304e-06	1.000e+16
200,000	1.841e+06	1.461e+00	1.901e+03
250,000	2.302e+06	1.826e+00	1.521e+03
300,000	2.762e+06	2.191e+00	1.267e+03

Table 2: Results of 250,000N test case - Stress

Name	**Type**	**Min**	**Max**
Stress1	VON: von Mises Stress	0.000e+00N/m^2 Node: 1	2.302e+06N/m^2 Node: 10186

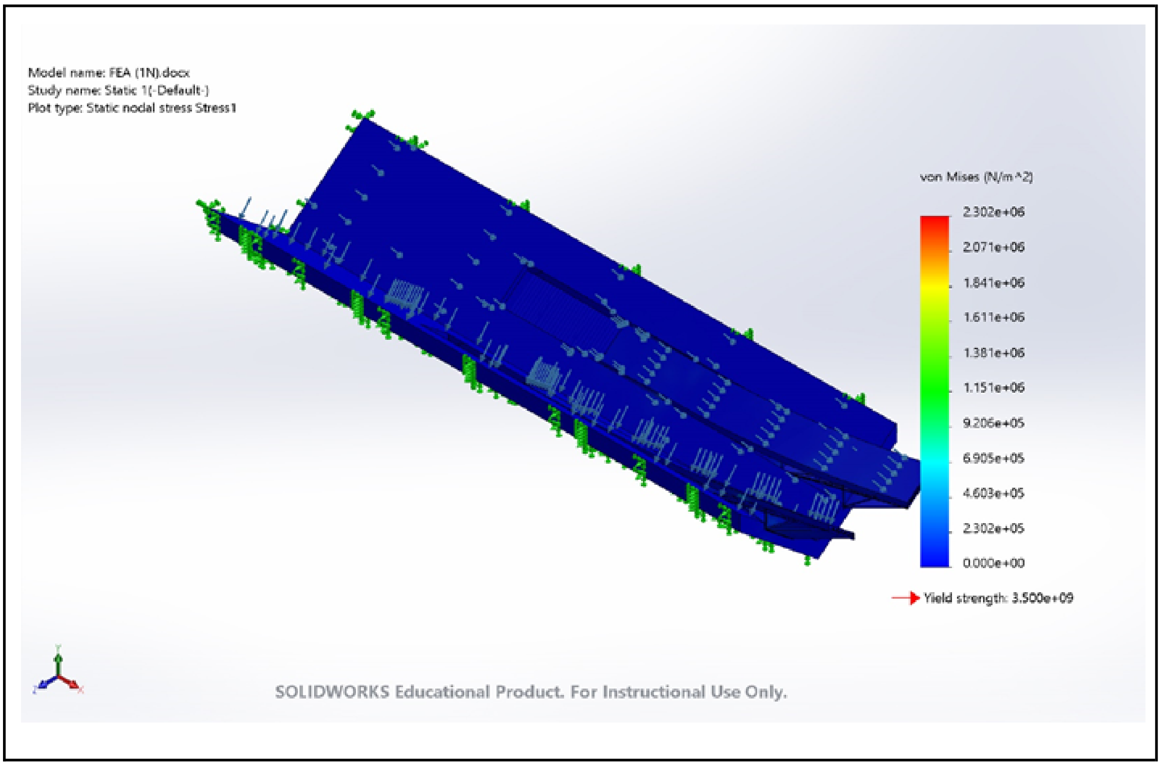


Table 3: Results of 250,000N test case - Displacement

Name	**Type**	**Min**	**Max**
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 1	1.826e+00mm Node: 3232

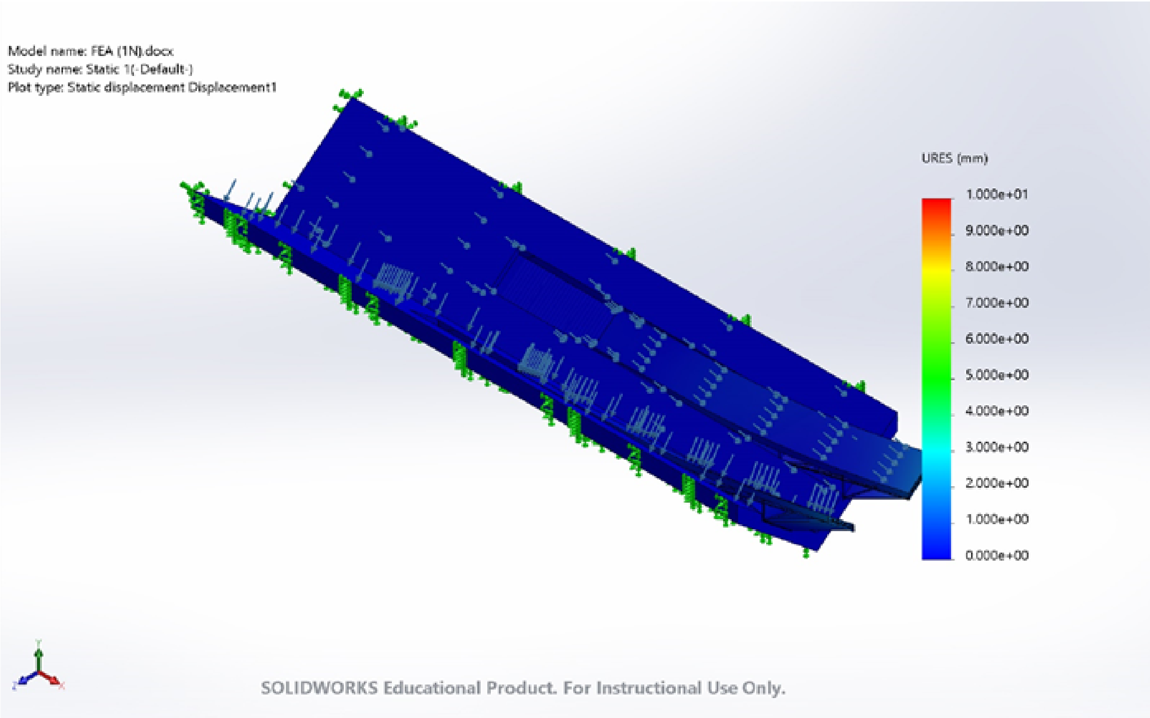
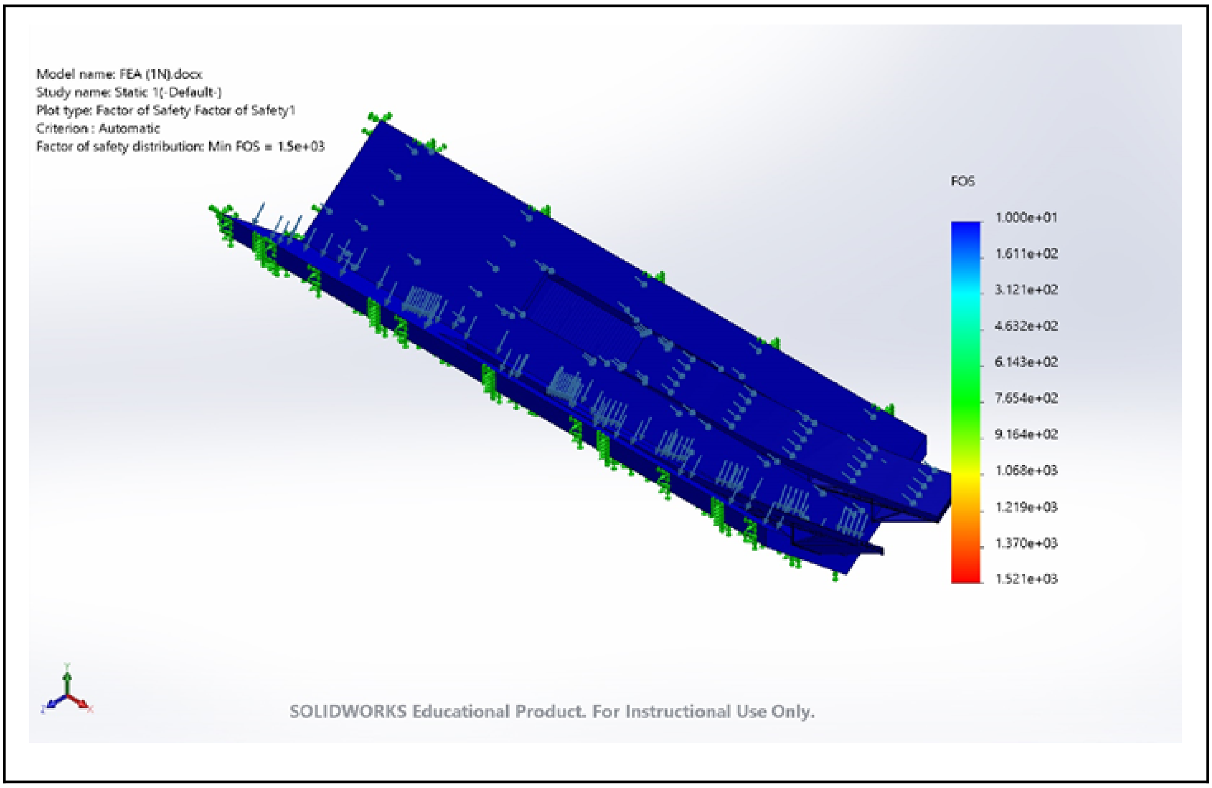


Table 4: Results of 250,000N test case - Factor of Safety

Name	Type	Min	Max
Factor of Safety	Automatic	1.521e+03 Node: 10186	8.707e+14 Node: 2248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Study name: Static 1(-Default-)
Plot type: Factor of Safety Factor of Safety1
Criterion : Automatic
Factor of safety distribution: Min FOS = 1.5e+03
FOS
1.000e+01
1.611e+02
3.121e+02
4.632e+02
6.143e+02
7.654e+02
9.164e+02
1.068e+03
1.219e+03
1.370e+03
1.521e+03
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4.0 Conclusion and Future Work

From the results of the FEA, it was concluded that the maximum operational limit of the proposed LAR system was 250,000N.

Taking into consideration the fact that the USV was entering the stern ramp from the water surface, there was also the presence of buoyancy force acting on the USV, resulting in the USV exerting less force on the stern ramp itself, with the buoyancy force exerted given by the equation:

$$buoyancy\ force = pvg = mg$$

$$284000 - 250000 = 1024 \times v \times 9.81$$

$$v = 3$$

Therefore, should the USV displace about 3m^3 of water upon entry into the LAR system, the LAR system would prove structurally sound.

This project made several material assumptions and structural assumptions, such as material properties, default failure criterion, etc. For future works, these assumptions can be revisited. Furthermore, other major failure criterions of carbon fibre such as shearing and buckling can be further evaluated. In the future, scaled model tests such as open harbour tests can be carried out. Also, the model can be further strengthened, such that the condition that the USV must displace at least 3m^3 of water while entering the stern ramp can be removed.

As for the algorithm, it can be improved to a greater accuracy with the right dataset. The algorithm can also be connected to the unmanned surface vessel's motor so as to directly control the movements of the vessel during recovery. The algorithm can also be improved to function real time.

5.0 Referencing and citation

Chen M. , Murali K. , Khoo B. , Lou J. , Kumar K. (2005). “Circulation Modelling in the Strait of Singapore” *Journal of Coastal Research* 21. 960-972.
DOI:10.2112/04-0412.1

Cannab H., Palmer M., Howard T., Bricheno L., Calvert D., Krijnen J., Wood R., Tinker J., Bunney C., Harle J., Saulter A., O’Neill C., Bellingham C., and Lowe J. (2016). “Projected sea level rise and changes in extreme storm surge and wave events during the 21st century in the region of Singapore” *Ocean Sci.*, 12, 613–632, 2016
DOI:10.5194/os-12-613-2016

Thomson W.(1887) "On ship waves," *Institution of Mechanical Engineers, Proceedings*, 38 : 409–34; illustrations, pp. 641–49.

Gelling, J. (2008) “Launch and Recovery Systems: Our Customer’s Experiences,” *ASNE Launch and Recovery of Manned and Unmanned Vehicles from Surface Platforms Proceedings* (presentation)

Sheinberg R., Minnick P.V., Beukema T.G., Kauczynski W., Silver A.L., Cleary, C., (2003) “Stern Boat Deployment Systems and Operability,” *2003 World Maritime Technology Conference, SNAME, San Francisco* (presentation).

Artzner, L., (2008) “CALISTE concept: Cage Line Semi-immergee Teleoperee A compliant Launch management and recovery System,” *ASNE Launch and Recovery of Manned and Unmanned Vehicles from Surface Platforms Proceedings* (presentation)

Mulhern, F., (2005) “Surface Combatant Optimized for Unmanned Vehicle Operations - A Selection of Launch/Recovery Concepts,” *ASNE Launch & Recovery of Manned and Unmanned Vehicles from Surface Platforms Proceedings* (presentation).

Seiple, R., (2008) “Soft Rail Launch and Recovery System,” ASNE Launch and Recovery of Manned and Unmanned Vehicles from Surface Platforms Proceedings (presentation).