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AZIMUTH THRUSTER MANEUVERING

-TRAINING VESSEL

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Abstract

Azimuth thrusters are increasing in use as the primary propulsion systems aboard ships. In order to more adequately prepare students in the operation of azimuth thrusters, smaller scale working models are proposed in this thesis; smaller boats that afford students the opportunity to train with azimuth thrusters, to feel the g-forces affected upon them, as well as how maneuvering is different not only from traditional propeller-rudder systems but also between different configurations of azimuth thrusters.

Keywords

Maneuvering, azimuth thruster

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Abstract
Roderpropellern ökar i användning som det främsta framdrivningssystemet ombord på fartyg. För att på ett mer adekvat sätt förbereda studerande för användning av roderpropellrar föreslås mindre övningsbåtar i detta examensarbete. Detta ger studerande möjlighet att träna med roderpropellrar och att känna av g-krafterna som det gör upphov till. Studerande ska då också lära sig skillnad i manövrering mellan traditionella propeller-rodersystem och olika konfigurationer av roderpropellrar.

Keywords
Manövrering, roderpropeller

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FIGURES & TABLES

1 INTRODUCTION

The prevalence of azimuth thruster style propulsion systems increases with each passing year, thus increasing the need for cadets in training to become proficient with this type of system.

The intention of this project is to examine the types of azimuth thruster systems applied in commercial shipping and to develop methods for aspiring cadets to gain experience in the use of said systems. The results of this project will provide a practical method to augment the existing maneuvering courses at the Åland University of Applied Sciences as well as describe the tools by which such augmentation is possible.

Many aspects will factor into the design and component choices, with the prevailing one being simplicity. The aim is not to overcomplicate, but to provide a training aid that is relatively straightforward and easy to implement. Through research I will select hulls, engines, and components that best coincide with the intention of this thesis.

In the pages that follow, I will describe what azimuth thrusters are, and highlight their position in history, as well as describing how theoretical maneuvering principles can be utilized on a scale more appropriate to class-sized practical application.

2 BACKGROUND

The concept of the azimuth thruster, though more popular in modern times, is not a new one. English inventor Sir Francis Ronalds first proposed the idea of a ‘propelling rudder’ as he called it, in March of 1859, which combined the steering and propulsion systems of a vessel into one component. His idea lay dormant, however, until 1862, at which time several articles were published concerning the poor steering capabilities of the HMS Defense, a British armored frigate that performed especially poorly at slow speeds, to the extent that she was grounded while conducting sea trials. Sir Francis replied to the newspaper articles describing in detail how his designs function and how they could be applied, however, due to illness he was unable to produce working models and his letters were never published. (Ronalds, 2016)

In 1950 the concept was reformed into an early design of the z-drive transmission method (a straight propeller shaft connected to the propeller via two right angle drives) by Schottel founder Josef Becker. In Becker’s design, the engine powering the propeller is located inside the vessel, and transferred to the propeller by way of shafts and angle drives, a design feature prevalent in many more modern designs as well (American Society of Mechanical Engineers et al., 2005). The basic premise of all azimuth thrusters, regardless of design, is that they are capable of providing 360^0 angles of thrust resulting in unrivalled maneuvering ability and do not need tugboats to dock (Desai-Patil et al., 2015).

The modern azimuth thruster has two main design types, dependent upon where the motor is located, mechanical transmission, powered by either a diesel or diesel electric motor, and electrical transmission, predominantly diesel generator driven. In a mechanical transmission type, the driving motor is located within the ship’s hull, connected to the thruster by a system of gears. Sir Francis Ronalds’ and Josef Becker’s designs are examples of this type. However, in an electrically driven thruster, the motor itself is contained within the pod itself, hence why most electrically driven azimuth thrusters are instead called azipods. The term azipod may be colloquially used to describe this type of thruster, but in fact, is the trademarked name of ASEA Brown Boveri’s (ABB) thruster. In 1990 ABB introduced the first electrically driven azimuth thruster; since then several other companies have recreated and improved upon the design. There are several advantages and disadvantages in the argument of electrical vs mechanical transmission, however the primary tradeoffs are that mechanical transmission requires more space inside the ship, specifically near the thrusters, whereas electrical transmission pods run on generators, which can be placed anywhere throughout the ship. (Kulas, 2016)

2.1 Advantages

Compared to traditional propulsion and maneuvering methods, azimuth thrusters offer significantly improved maneuverability. They are able to act as primary propulsion, bow/stern thrusters, all contained in a single, though usually paired, unit. This is accomplished while performing at a lower cost, due to the more effective nature of their operation. (Kulas, 2016)

2.2 Configurations

There are two primary types of azimuth thruster, electrically or mechanically driven pods, which are affixed with either a fixed or controllable pitch propeller. The vast majority of azimuth thrusters are designed for use in larger ships; in order to create a means to train in the use of this type of propulsion system, a smaller scale mechanism will have to be devised. Affixing two smaller motors, low effect outboard engines for example, to a jon boat, connected via servos to echo controller input, would in effect mimic maneuverability comparable to what can be expected with large azimuth thrusters on full-scale ships.

2.3 Delimitations

Rather than designing every component used in this vessel, it has been decided to use parts already available commercially. By using equipment already on the market, tried and tested, it will reduce the overall complexity of the proposed vessel design. A notable exception to this is the modified motor mount in figure 7, to facilitate the azimuthing capabilities of the outboards.

2.4 Geographical advantages

Though there are several maritime academies throughout the world, few have access to the calm, sheltered waters such as those provided by the harbor in Mariehamn. One other such academy that has access to such waters is the Warsash Maritime Academy, a part of Solent University located in Southampton, UK. Like the Åland University of Applied Sciences, Warsash also has access to sheltered waters, however, this was procured at great expense, in their acquisition of the manmade lake, Timsbury Lake, near Romsey. That Mariehamn has access to this natural resource absent expense is a boon; one that we would be unwise not to take advantage of. *Figure 1* shows a brief overview of the Warsash Academy, the manmade lake, as well as an example of their ship models (*Ship handling centre*, 2020). While the vessels used by the Warsash Academy are aesthetically pleasing, they are limited by the number of cadets able to partake in training per vessel at once. This has been mitigated by them by fabricating more vessels, of which they have a total of eleven. With the vessel proposed in this thesis, this workaround is unnecessary. Additionally, many of the vessels at Warsash are configured with traditional propulsion and maneuvering methods; another unnecessary feature for the Åland University of Applied Sciences as we are able to train in these methods aboard the school ship, Michael Sars.

Figure 1. Warsash Maritime Academy (Ship handling centre, 2020)

3 PURPOSE

The intention of this project is to develop a real-world working course of study, focusing on the principles of navigation as it pertains to the operation of azimuth thrusters, as well as to provide a mechanism for students to implement their classroom learned techniques through practical application. Theoretical models which could reasonably be implemented would provide the tools necessary to familiarize students with how a vessel reacts under azimuth thruster operation. At the Åland University of Applied Sciences the maximum class size is 16 students; should two or three of these theoretical boats be built it would allow a full-sized class to alternate time studying theory in the classroom and applying said theory in practice. As azimuth thrusters come in various configurations, it is ideal to use outboard motors on a rowboat that are movable. Most vessels fitted with azimuth thrusters have two thrusters in the aft of the ship, as it is more efficient for longer routes, however some smaller vessels, especially short distance ferries, are configured such that there is a thruster forward and aft. One such example is the Ro-Pax ferry M/S Skarven as shown in *figure 2*.

Figure 2. M/S Skarven (Pettersson, n.d.)

Additionally some vessels, predominantly tugs, have two thrusters aft and one forward, or vice-versa depending on their intended function. For the sake of learning how to maneuver, focus will be on the two thruster configurations. As stated above, to accomplish this, the mounted outboards will by necessity need to be able to be moved to demonstrate the different effects of various configurations.

An argument can be made for conducting this type of training in a simulator, however that does not properly equip the students. Maneuvering with azimuth thrusters can be counter-intuitive when compared with traditional propeller and rudder vessels, as you ‘turn’ in the opposite direction of where you wish the vessel to travel. Training in a smaller boat affords the students to feel the forces as they act on the vessel when maneuvering, which in turn helps make the process more innate, as opposed to having to mentally calculate each and every movement. This same principle is seen in training courses for fast rescue boats (FRBs), where ‘getting the feeling’ for how to maneuver is far more useful than discussing theory in a classroom setting.

The end goal is to give students an understanding of how to maneuver a vessel equipped with azimuth thrusters, with adequate proficiency to navigate to and from quay, as well as maneuvering in restricted waterways.

4 MODEL

In order to provide the tools necessary for azimuth thruster operation it was imperative to determine first what size and type of vessel ought to be used. While a larger pontoon boat able to fit upwards of twenty people would certainly afford the ability to involve an entire maximum capacity class of sixteen students and one professor, such a boat would be quite expensive, require powerful motors, and would result in the vast majority of the class spending the day uninvolved in maneuvering practice. The goal is of course to devise a vessel that is both cost and time effective; to that end it is better to focus on smaller vessels that fit up to six people at a time, can be effectively operated by lower-power, and thus lower-cost, motors, and allow for the entirety of the embarked 'crew' to take part in the exercises.

4.1 Vessel type

After thorough and deliberative research the most cost-effective boat model is the L1852MT AURA flat-bottomed aluminium fishing boat, shown in *figure 3*, at a base cost of €3,575. Because the vessel is flat-bottomed it is more efficiently affected by the two motors in any of the directions implemented (Gasmire, 2019a). The low base price also provides a cost-efficient addition to the university's current training program. The hull weighs approximately 188 kg, which also reduces the engine requirements for maneuvering exercises(Steve, 2016).

Figure 3. AURA flat bottom Jon boat (Lowe Boats 2020, n.d.)

Table 1 displays the vessel's specifications, whereas *figure 4* below demonstrates the typical configuration of a single engine mounted on the selected boat.

Table 1. AURA specifications (Lowe Boats 2020, n.d.)

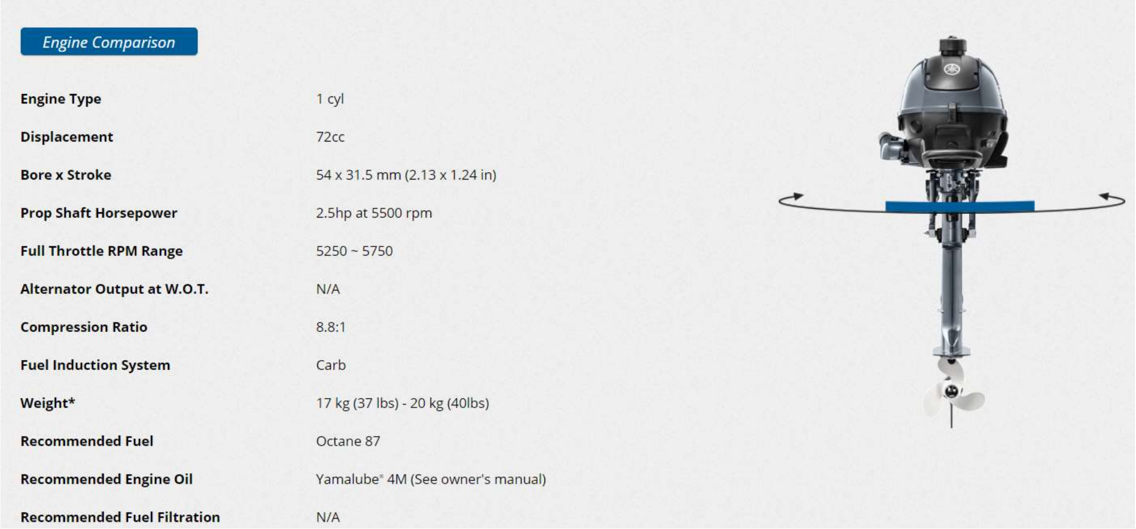
Overall Length	17'9"	5.41 m	Max Person Weight	815 lb	369.68 kg
Beam	75"	190.50 cm	Max Weight Capacity	1375 lb	623.69 kg
Approx. Basic Hull Weight	416 lb	188.69 kg	Ribs	10	10
Bottom Width	52"	132.08 cm	Seats	1	1
Fuel Capacity	Portable	Portable	Side Depth	21"	53.34 cm
Hull Gauge	.072"	1.83 mm	Transom Height	20"	50.80 cm
Max Person Capacity	6	6			

Figure 4. AURA with standard engine configuration (Lowe Boats 2020, n.d.)

4.2 Motor selection

When choosing the motors needed for the vessel, it is important to remember that the focus is not speed, but maneuverability. This is why in the previous step a flat bottomed vessel was chosen so that the boat more easily moves in all directions. To this end, no more than 2.5 hp is needed per motor, as that will be more than sufficient to practice maneuvers. (Gasmire, 2019b)

The next question became whether to use electric outboard motors, or gas driven motors to simulate azimuth thrusters. Ultimately, gas motors were chosen to minimize the complexity required for installation and operation. Since our motors are designed for multiple configuration placements, that is to say, that one can mount both in the aft part of the vessel, midships, or one forward and one aft; for simplicity's sake the gas-driven motors fit best. Gas-driven outboards are a closed-loop system that do not require a large battery mounted in the boat which would consume a significant amount of both space and weight, not to mention the cables and slip-rings that would be required to transfer power to the motors while ensuring 360 degrees of freedom. The model chosen for this design is the Yamaha F2.5LMHB, Long Shaft 2.5 horsepower outboard motor, shown in *figure 5*.



Engine Comparison

Engine Type	1 cyl
Displacement	72cc
Bore x Stroke	54 x 31.5 mm (2.13 x 1.24 in)
Prop Shaft Horsepower	2.5hp at 5500 rpm
Full Throttle RPM Range	5250 ~ 5750
Alternator Output at W.O.T.	N/A
Compression Ratio	8.8:1
Fuel Induction System	Carb
Weight*	17 kg (37 lbs) - 20 kg (40lbs)
Recommended Fuel	Octane 87
Recommended Engine Oil	Yamalube® 4M (See owner's manual)
Recommended Fuel Filtration	N/A

Figure 5. Yamaha 2.5 hp outboard specifications (Yamaha Outboards, 2020)

In addition, each motor will be mounted with a servo motor, remotely controlled to adjust motor throttle as input by the control system. This will be accomplished by affixing a radio receiver which picks up the command transmitted by the control system. Ready-made kits are already commercially available for this purpose, of which the Trollmaster TM216 has been selected for these purposes. *Figure 6* shows the TM216 Pro 3+ installed.

Figure 6. Wireless throttle control (TROLLMaster 2020, n.d.)

4.3 Motor mounts

In order to facilitate several different motor configurations, two aft, two amidships, as well as one forward one aft, a modified outboard mount will be constructed. Each of these mounts will be wired, providing power to the azimuthing motor from an onboard battery. Each mount will effectively be a geared collar which the motors will then be affixed to the azimuthing motor via a chain ensuring stable, full rotation of the motors. The geared collars will be protected from corrosion by environmentally friendly grease, sufficiently viscous and adhesive as to ensure proper lubrication and rust protection but also to ensure it is not simply swept away by water. Figure 7 below illustrates the modified motor mount connected to the servo motor.

Figure 7. Outboard as affixed on the modified motor mounts

4.4 Azimuthing motors

Mounted next to and connected to each outboard, based on the desired configuration, will be a servo motor connected wirelessly to the control system. The servo motors will receive power from an onboard battery, with permanent wiring connecting them to said battery. A 24 volt car battery will suffice for directional control, though it will require recharging post maneuvering exercises. These servo motors will mimic the input from the control system, applying the appropriate rotation angle as commanded by the user by the use of affixed radio receivers. *Figure* 8 below shows the expanded view of the mount and azimuthing system.

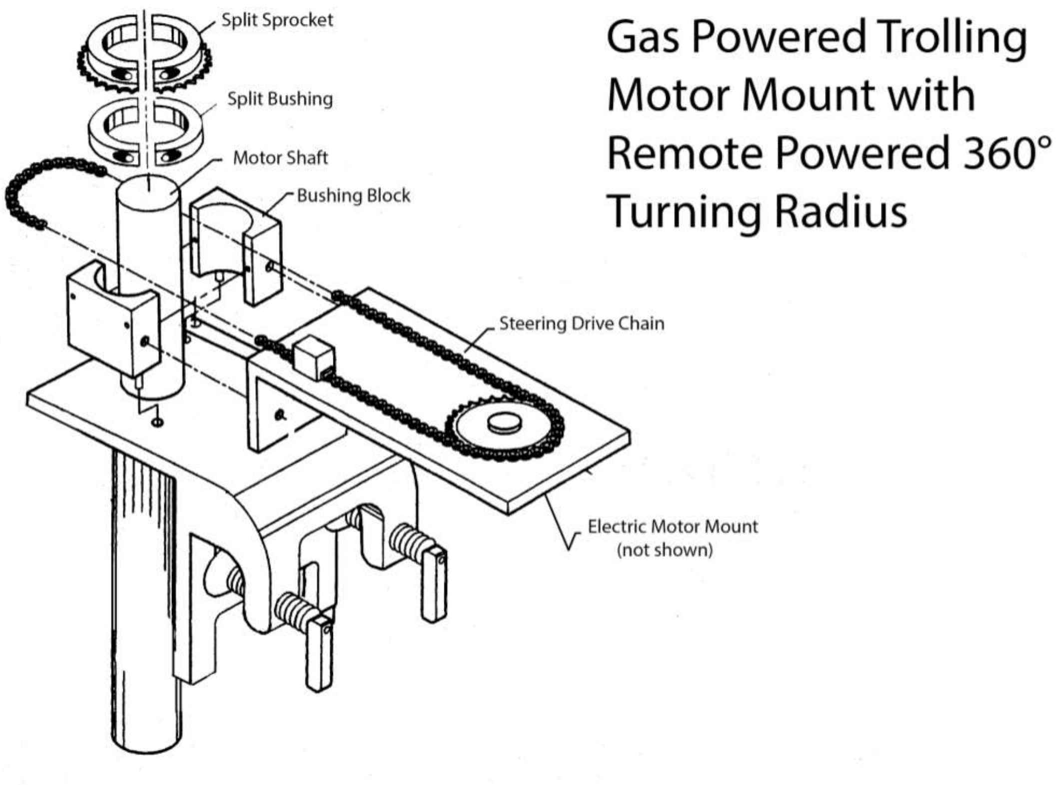


Figure 8. Outboard motor mount and rotational transfer from azimuthing motor

The outboard motors will attach in a similar manner to industry standard, however the mounts will be altered to allow the mounting of the rotation apparatus. An additional bracket, which mounts the servo motor to the underside, transfers the rotational force to the shaft of the outboard motor via a chain.

4.5 Control system

The two outboards will be controlled in a combination of wired and wireless. That is to say, the rotation inputs to the controls will be relayed by wire to the servo motor responsible for altering the direction of each motor. The thrust inputs will however be transmitted wirelessly to the Trollmaster modification installed on the outboard. Power will be provided by an onboard battery box, and cabled to the servo motor. Shown in *figure 9* is the azimuth lever chosen, a Kwant RCU MK3 (*Kwant 2020*, n.d.), which will be mounted on the control panel in *figure 10*. It is worthy of noting that in the event of a failure of some kind, the outboard motors can be operated manually as a form of emergency steering to navigate the vessel back to the pier.

Figure 9. Kwant RCU MK3 azimuth lever (Kwant 2020, n.d.)

The panel in figure 10 below indicated the configurations of the controls to be monitored and operated by the pilot. While the motors are interchangeable in their positions, it will be up to the individual operator to keep track of and configure which control mechanism operates each motor.

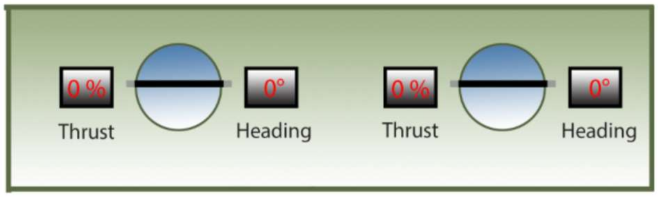


Figure 10. Control Panel

Figure 11 illustrates in a block diagram how the steering and maneuvering systems are correlated to each other. The azimuthing levers will control all aspects of the motor operation, with throttle controls being transmitted wirelessly as opposed to position commands, which will be transmitted by wire directly to the servo motors. Position sensors are mounted to the servo motors in order to provide live feedback and adjustments as required.

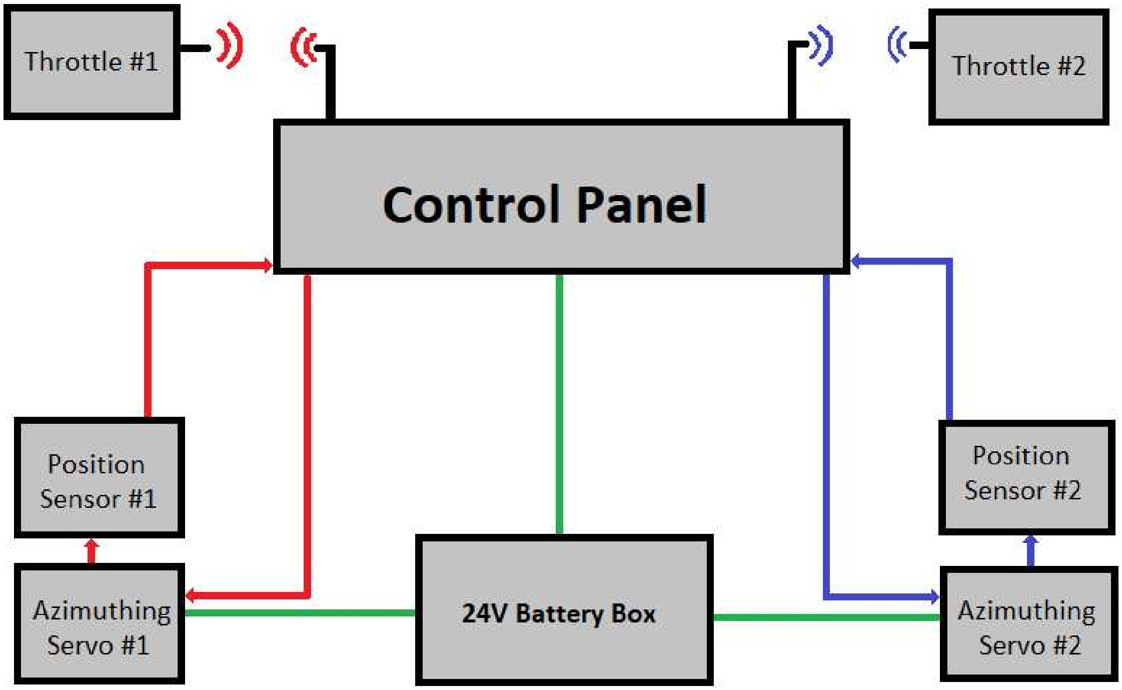


Figure 11. Control system

5 METHOD

Two areas of operation close to university grounds present themselves for use to students in practicing azimuth thruster maneuvers. West of the Mariehamn peninsula is the ÅSS marina, east of which is the MSF marina. Both marinas comprise a multitude of boat slips and bouys. For the sake of convenience, maneuvers will be presumed to take place in the nearer of the two, the ÅSS marina. Usually full of sail and motorboats during the summer months, exercises will by necessity be limited to fall and early-/mid-spring, after the ice has melted.

5.1 Training schedule

The exercise is envisioned as a two-day event, with the first day focused primarily on configuration 1, with a half day each planned for configurations 2 and 3. After a brief familiarization of the controls and a demonstration by the attending professor, students will try their own hand at maneuvering in each of the three configurations that follow. As the ultimate aim is to give students a 'feel' for azimuth thruster operation, other than a basic understanding of how the thrusters operate, how one can combine the different thrust vectors into a resulting vessel movement or rotation, the exercise will begin with the students testing their way forward for a few minutes, under guided supervision of the attending professor. After a basic introduction the students will be instructed to maneuver in a zig-zag pattern through a series of buoys, followed immediately by the same maneuver, albeit in reverse. Each student will have one attempt forward, backwards, and then will be instructed to maneuver alongside to the nearest pier. At that point the student will switch out for the next student. The process will repeat until each student has had one iteration of the exercise. At this point the entire exercise will repeat, with each student completing another attempt, having had time to observe their fellow students and consider how they might improve upon their previous effort.

Day two of the maneuvering exercises will be nearly identical, with configuration 2 taking place in the morning, and configuration 3 in the afternoon, or vice versa depending upon the supervising professor's preference. The only difference will be that each student will only conduct one exercise with each configuration, as opposed to two with configuration 1. This is due to the first configuration being the most likely arrangement students can expect to encounter in the workplace. *Figure 12* below shows the area and proposed training evolution.

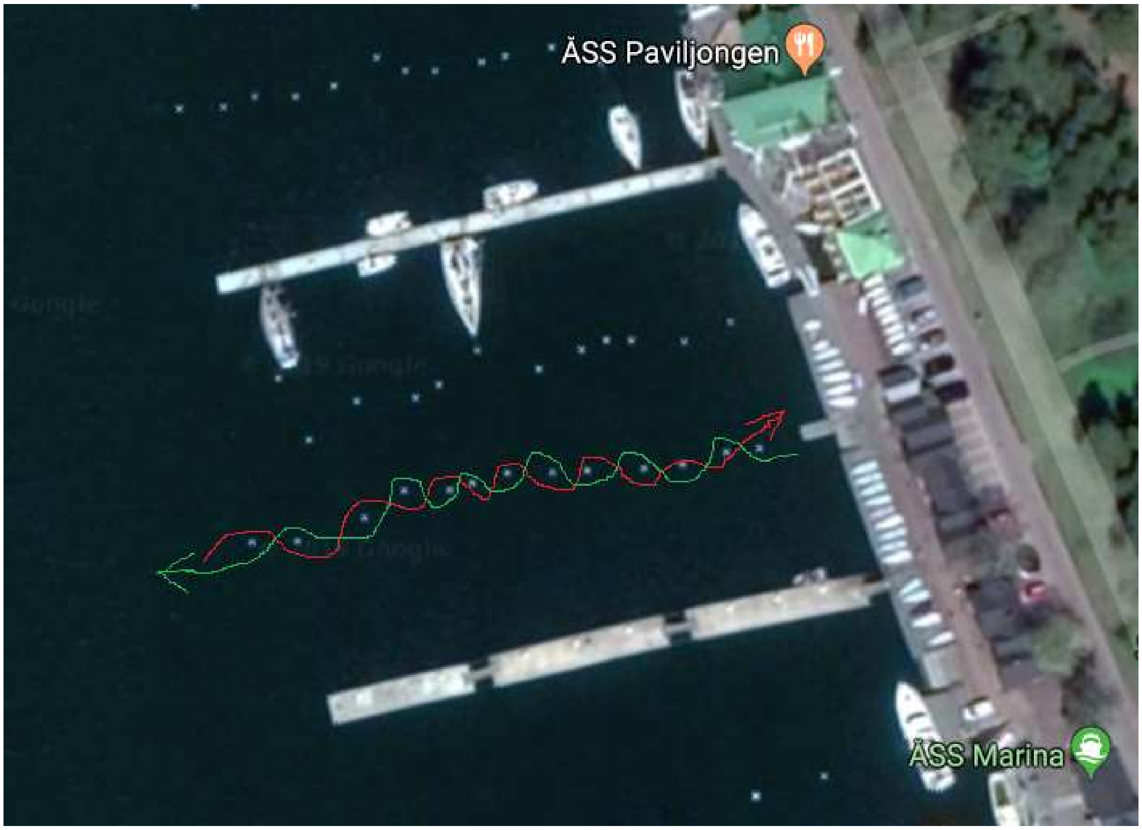


Figure 12. Proposed maneuvering route, Mariehamn west harbor

5.2 Configuration 1: Two motors aft

The first configuration will be the primary focus of the maneuvering exercises, as two motors aft is the predominant arrangement on commercial vessels. As with all configurations of azimuth thrusters, this configuration, shown in *figure 13*, offers substantial maneuvering characteristics, but is also optimal for forward propulsion.

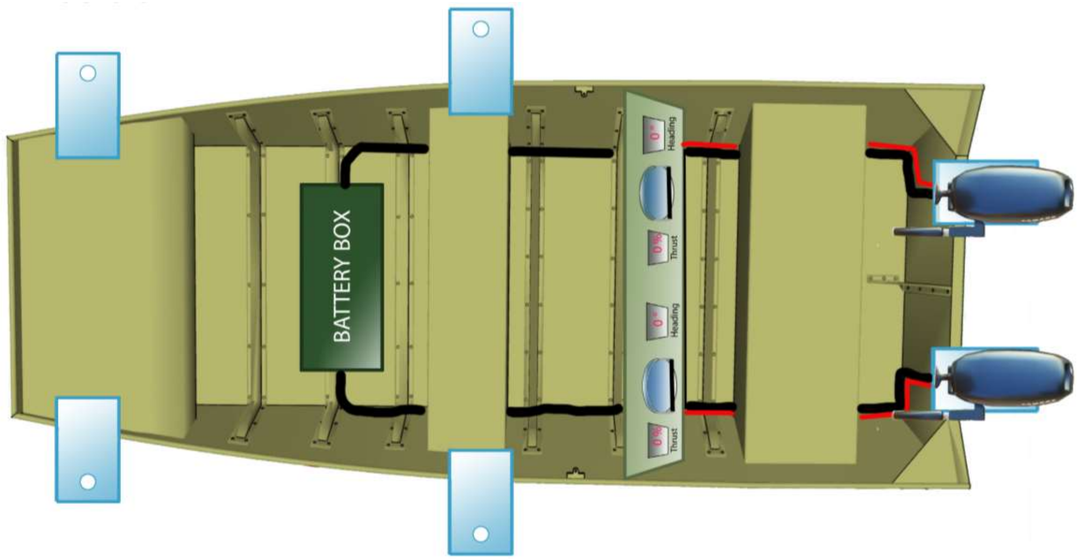


Figure 13. Configuration 1, two motors aft

5.3 Configuration 2: Two motors amidships

While less common than configuration 1, two azimuth thrusters amidships, as seen below in *figure 14*, nearer the vessel's center of gravity offers more efficient movement in any direction, which is particularly useful in tugboat operations.

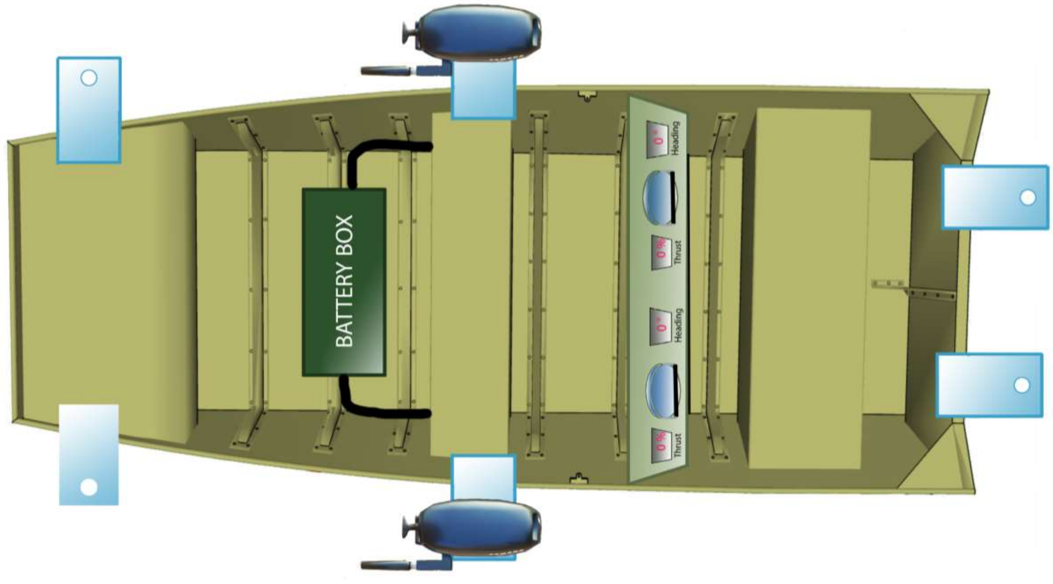


Figure 14. Configuration 2, Two motors amidship

5.4 Configuration 3: One motor forward, one aft

As with configuration 2, configuration 3 is also less common on most commercial vessels. This does not hold true to short-route ferries however, where turning the vessel 180º after each berthing is impractical. Ships such as M/S Skarven, as previously discussed, are fitted with this configuration of azimuth thrusters. This vessel travels equally as well whether it is transiting forward or aft. An additional advantage to this configuration is the effectiveness of sharper, more rapid turns, should the need arise. This is because the thrusters are located further from the center of gravity, thus increasing the turning moment for each thruster as it pertains to the vessel's orientation. *Figure 15* illustrates configuration 3 below.

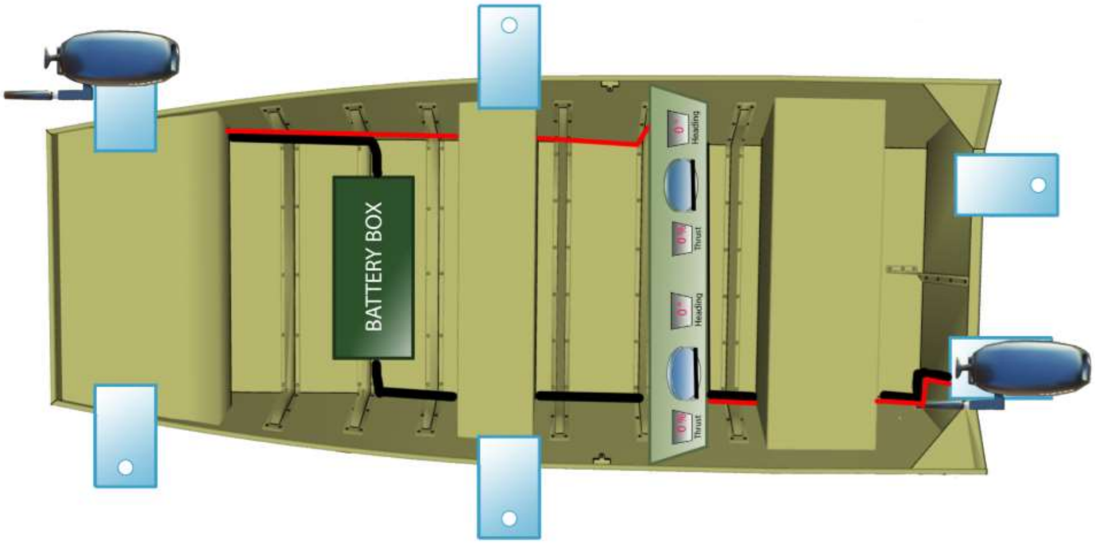


Figure 15. Configuration 3, One motor forward, one motor aft

6 CONCLUSIONS

During the course of this project, I researched the prevailing uses and configurations of azimuth thrusters, regardless of vessel type or size, which I then used to design this training vessel. The use of gas-powered outboard motors was chosen for simplicity's sake, however an interesting variant would be to exclusively use electrical equipment. There are a variety of electric motors that could be modified to serve the same purpose, albeit it would require some additional components to accomodate for the alternative power source, namely a waterproofed slip ring for power transfer to the motors, as well as a more substantial battery bank. This would result in a more environmentally friendly vessel and one that operates more quietly.

There are several other areas which I would have preferred to expand upon, namely the construction of at least one of the proposed training vessels, as well as attending courses at other maritime academies already equipped to train cadets in the use of azimuth thrusters. By researching how other academies train their cadets, I would have been able to integrate the most effective methods into this thesis as well. Unfortunately, due to financial and time constraints I was not able to realize these enhancements to the thesis. Given time and funding, I could have combined outside techniques with those developed in the testing of a working model of the training vessel.

Ultimately, I am very pleased with the result of this thesis, as I feel it gives a model for an efficient vessel in accordance with the intention of this thesis. I assert that not only is this a design that will effectively assist in training students in the operation of azimuth thrusters, but that it does so without excess complexity or cost.

The aim of this thesis has been to provide the tools and methods by which naval captain students can acquaint themselves in the operation of azimuth thrusters. By using the aforementioned model and training regimen, students will have the tools to practice maneuvering with various thruster configurations, learning how the vessel reacts to various inputs and thruster vectors. By conducting these operations on a smaller scale vessel, the students will feel the forces acting upon the vessel, which will aid them in maneuvering full-scale ships where the resulting g-forces may not be as apparent.

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