Joachim G. Colbensen

Trawl-Kite

Marine Technology for Environmental Sustainability

Bachelor's thesis in Electrical Engineering
Supervisor: Lars Ivar Hatledal
Co-supervisor: Paul Steffen Kleppe
May 2023

Bachelor's thesis

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Preface

This bachelor thesis is written by a single student from Electrical Engineering - Automation and Robotics at NTNU Ålesund. The project and thesis were carried out in the spring of 2023 and were done for Pål Arne Roaldsnes, a shipowner in the fishing industry. My motivation to choose this task stems from a lifelong interest in sealife, the maritime industry, and the fascination of automated solutions within it. This project provided an opportunity to delve into advanced control systems and devise solutions for real-life situations. The purpose of the project was to conceptualize and develop a novel solution that did not previously exist, involving tasks such as component selection, conceptualization, and CAD modeling. The aim was to create an innovative design that would push the boundaries of what is currently possible in the field, offering new insights and opportunities for advancement in the industry.

I would like to express my sincere gratitude to Pål Arne Roaldsnes for providing the opportunity to work on such an exciting task for my bachelor's project, and for all the knowledge and guidance he has provided along the way. I would also like to extend my appreciation to my advisors Lars Ivar Hatledal and Paul Steffen Kleppe at NTNU, for their invaluable guidance and support throughout this project.

I am equally thankful to my family and friends who have been a constant source of encouragement and provided insights and support throughout this project period. Lastly, my gratitude goes to all those who, directly or indirectly, contributed to this project and helped in shaping this endeavor.

Summary

This bachelor's thesis explores the design process of a trawl-kite system, an exciting advancement within marine technology. The trawl-kite is conceptualized as an autonomous system with the aim to make demersal trawling, a significant part of global fisheries, more sustainable. This innovative system is designed like a kite, equipped with hydrofoils for lift generation, and is intended to be attached from the boat to the trawl. Its goal is to reduce or even eliminate bottom contact during demersal trawling. With current fishing tools, this remains a challenge. By addressing this issue, the trawl-kite contributes to more environmentally friendly trawling practices.

The primary focus of the thesis is the iterative design process of the trawl-kite, from its initial concept to the current version. This process involves the careful selection and evaluation of components, and the creation of comprehensive 3D models to ensure that the kite is light to tow and can be controlled by automatic or semi-automatic solutions.

The design detailed herein is a preliminary version, and it is open to further refinements based on future testing and adjustments. Despite the ongoing development of steerable trawl doors by various manufacturers, the need for an automatic device that controls the height of the trawl and reduces its 'ground pressure' on the seabed persists.

This thesis presents an understanding of the decisions made during the design process and their implications on the system's functionality. The narrative provides an insightful perspective on the engineering design process in a specific, practical application within the realm of ocean technology. It underlines the need for innovative solutions in the face of environmental challenges in marine operations.

Sammendrag

Denne bacheloroppgaven utforsker designprosessen for et trål-kitesystem, en spennende fremgang innen marinteknologi. Trål-kite er konseptualisert som et autonomt system med mål om å gjøre bunntråling, en betydelig del av de globale fiskeriene, mer bærekraftig. Dette innovative systemet er utformet som en kite, utstyrt med hydrofoiler for løftgenerering, og er ment å være festet fra båten til trålen. Målet er å redusere, eller til og med eliminere, bunnkontakt under bunntråling. Med dagens fiskeverktøy, forblir dette en utfordring. Ved å ta for seg denne problemstillingen bidrar trål-kite til mer miljøvennlige trålingsmetoder.

Kjernen i denne oppgaven er den iterative designprosessen for trål-kiten, fra det innledende konseptet til den nåværende utformingen. Denne prosessen omfatter en grundig utvelgelse og vurdering av komponenter, og opprettelsen av omfattende 3D-modeller, alt for å sikre at dette systemet er lett å slepe og kan kontrolleres av automatiske eller delvis automatiske løsninger.

Designet som er presentert her, er en innledende versjon, åpen for videre forbedringer basert på fremtidige tester og justeringer. Selv med pågående utvikling av styrbare tråldører fra flere produsenter, oppstår behovet for en automatisk enhet som kontrollerer høyden på trålsekken og reduserer dens 'bunntrykk'.

Denne oppgaven skal gi innsikt i beslutninger som er tatt gjennom designprosessen, og hvordan disse påvirker systemets funksjonalitet. Gjennom oppgaven får leseren et inngående perspektiv på ingeniørdesignprosessen i en spesifikk, praktisk anvendelse innen marinteknologi. Samtidig understreker den behovet for innovative løsninger for å møte miljøutfordringene i maritime operasjoner.

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Terminology

Acronyms:

CAD Computer-Aided Design

CAM Computer-Aided Manufacturing

CAE Computer-Aided Engineering

CAN Controller Area Network

CFD Computational Fluid Dynamics

I2C Inter-Integrated Circuit

NACA National Advisory Committee for Aeronautics

NASA National Aeronautics and Space Administration

ROV Remotely Operated Vehicle

RS Recommended Standard

SPI Serial Peripheral Interface

SRAM Static Random-Access Memory

UART Universal Asynchronous Receiver/Transmitter

Terms:

Benthic - of, relating to, or occurring at the bottom of a body of water

Crowfoot - an arrangement of ropes in which one main rope exerts pull at several points simultaneously through a group of smaller ropes

1 Introduction

This chapter offers a detailed glimpse into the problem of marine habitat destruction caused by traditional trawling methods and proposes a novel solution: the trawl-kite. We start with the background, discussing the environmental issues associated with trawling and the industry's need for innovative, sustainable solutions.

The problem statement lays out the technical and practical challenges involved in designing a functional trawl-kite device that can reduce ground contact and increase trawling efficiency.

In the motivation section, I share personal experiences and academic pursuits that have led me to undertake this project.

The scope explains the focus of this thesis, which involves the theoretical design of an autonomous trawl-kite system and the selection of key components.

The chapter concludes with the thesis outline, offering a walkthrough of the report's structure and what the reader can expect from each section. Through a step-by-step analysis of the design process, this chapter sets the stage for a comprehensive exploration of a sustainable solution for trawling.

1.1 Background

In the ever-growing global demand for seafood, trawling has established itself as a widely used fishing technique due to its ability to capture large quantities of fish in a single operation. However, the environmental implications of trawling are becoming increasingly apparent. The disturbance caused by trawling has led to substantial changes in benthic communities, with repercussions for biodiversity and ecosystem function.

This environmental concern has spurred interest in technologies and strategies aimed at reducing the ground contact of trawling gear. A promising avenue for this lies in the development of autonomous or semi-autonomous devices that can effectively control the trawl's height above the seafloor, thereby minimizing its impact on the benthic environment. The concept of such devices is not new, with multiple manufacturers developing steerable trawl doors that regulate the height of the gear, one of them being Polar Trawl Doors ([1]). However, these solutions focus primarily on the trawl doors used in pelagic trawling rather than bottom trawl, which makes considerable ground contact.

In this context, Pål Roaldsnes has expressed interest in exploring solutions that address the environmental concerns related to trawling. The idea is to develop a device that can regulate the height of the trawl, thus reducing ground contact and minimizing the negative effects on the seafloor. While doing this, it should also eliminate the need of trawl floats. This reduces the use of somewhere around 400kg of plastic.

In the fishing industry, there's a growing demand for improved efficiency and sustainability, particularly in trawling methods. Efficiency of trawling is usually measured by how much catch a vessel can acquire per unit of time or fuel consumption. Essentially, it's the ratio of catch volume to diesel fuel used. ([5]). Furthermore, the cost per kilogram of fish is another key efficiency indicator. With these measurements in mind, an autonomous or semi-autonomous trawling system has been proposed with the potential to improve trawling efficiency. It's anticipated that such a system could guide a greater volume of fish into the trawl, thereby increasing the yield while minimizing the operational costs and environmental impact.

From this hypothesis emerges the idea of a 'trawl-kite.' This autonomous or semi-autonomous device, when attached to a trawl, has been designed with a dual purpose: to mitigate the environmental impact of bottom trawling by minimizing seafloor disruption, and to increase the capture efficiency. This novel approach presents a substantial step towards the future of sustainable and efficient bottom trawling.

1.2 Problem Statement

The main challenge lies in the development of a functional trawl-kite device that can efficiently reduce ground contact while enhancing the effectiveness of the trawling operation. The device must be robust enough to withstand mechanical stress such as impacts with the ship's deck and railings, and resistant to high pressures up to depths of 700 meters. Furthermore, it must operate effectively in strong ocean currents and be able to compensate for drift, allowing it to trawl along steep underwater edges and irregular seafloor terrain.

The development of this innovative solution involves several complex problems that need to be addressed. First, designing a device that can dynamically adjust the height of the trawl while minimizing ground contact is a significant engineering challenge. The device must be able to respond to varying ocean currents and seafloor topographies, requiring sophisticated control systems and potentially advanced sensor technologies.

Secondly, energy consumption and power supply are crucial considerations. The trawl-kite must have enough battery capacity to sustain the duration of trawling operations and include a system for easy battery replacement on deck, considering user-friendliness. The trawl-kite's energy efficiency will significantly affect its practicality and long-term feasibility as a solution.

Another important aspect of the problem is the necessity of maintaining a trawl-kite design that does not compromise the trawl's effectiveness in catching fish. The device should ideally enhance the trawl's efficiency by directing more fish downwards and into the net.

Additionally, the trawl-kite must be designed with user-friendly attributes, considering the harsh conditions and time constraints often encountered in fishing operations. This includes easy installation and detachment procedures, simple battery replacement systems, and minimal maintenance requirements.

The multifaceted nature of this problem makes it a complex engineering challenge that requires an interdisciplinary approach, integrating aspects of mechanical design, control systems, energy management, and an understanding of marine environments. This project aims to investigate possible solutions to these challenges and develop a preliminary design for a trawl-kite device.

1.3 Motivation

The motivation behind selecting this bachelor thesis originated from a blend of personal interest, prior work experience, and educational pursuits. As the sole contributor to this work, my unique background has significantly influenced the project's direction.

With four years spent as a fisherman, albeit in line- and net-fishing, I've gained a comprehensive understanding of the fishing industry's trials and tribulations. These firsthand experiences have provided a valuable context for this project, granting an appreciation for the real-world challenges the industry faces.

Additionally, a lifelong passion for fishing has always been a part of me. This enthusiasm has continually fueled a personal commitment to improving fishing practices, lending a sense of purpose to the project. I firmly believe in the transformative potential of technology and innovative approaches like the trawl-kite system developed in this thesis.

Lastly, my academic trajectory has played a crucial role. My background as a ship electrician, along with my current studies in electrical engineering with an emphasis on automation and robotics, has prepared me with a solid technical foundation necessary for this project. This thesis offers a tangible opportunity to apply my academic learning to a practical problem, underscoring the real-world impact of my studies.

In essence, this project combines my passion for fishing, firsthand industry experience, and technical education, all directed towards an initiative I care for - advancing the industry's sustainability and efficiency through innovative technological solutions.

1.4 Scope

The central focus of this bachelor's thesis is the research-based conceptualization and design of an autonomous trawl-kite system, a novel proposition envisioned to bring about sustainable practices in trawl-fishing.

The scope of the project revolves around two principal aspects: the design of the trawl-kite structure and the identification of potential components suitable for the system. The trawl-kite design is primarily based on a rigorous analysis of the system's theoretical requirements, existing research, and industry trends. The identification of suitable components is driven by their compatibility with the envisioned system, their performance potential, and their aptitude for use in marine environments.

However, there are certain explicit limitations to the scope of the thesis. Firstly, while the project identifies potential components for the trawl-kite system, the actual assembly or integration of these components into a physical prototype is beyond the project's purview. The emphasis is on the theoretical compatibility of the components rather than on their practical implementation.

Secondly, the construction, physical testing, and validation of a working prototype based on the design developed in the thesis do not form part of the project scope. Although the design work conducted in the thesis could lay the foundation for future prototyping, the creation of an operational model is considered beyond the current scope.

Finally, despite the importance of flow dynamics and computational fluid dynamics (CFD) simulations in the overall design and optimization process, they are not included in this thesis. Given the constraints of resources and time, detailed CFD simulations and flow dynamics analyses are considered future work.

In essence, the thesis endeavors to pave the way for future development of a fully operational autonomous trawl-kite system by providing a detailed theoretical design and a list of potential components. The ultimate aim is to stimulate further research and development towards sustainable and efficient trawl-fishing practices.

1.5 Thesis outline

This thesis begins with a theoretical foundation, starting with the basics of hydrodynamics including fluid dynamics, Navier-Stokes Equations, drag and lift forces, and pressure distribution. The chapter then pivots to the principles and techniques of trawl fishing, focusing on trawl design, various trawling methods, and the environmental impact of trawling. The chapter concludes by exploring the functioning of electric rotary actuators and the software tools AGX Dynamics and Siemens NX utilized in the study.

The Materials and Method chapter presents an in-depth discussion of the components of the trawl-kite system: the electric rotary actuator, echolocation technology, microcontroller, control system, communication system, and the battery pack. Furthermore, the software and the design process, encompassing NACA profiles, initial design considerations, and design evolution and optimization, are detailed.

In the Results chapter, the outcomes of the study are presented, categorizing findings based on components and design process. The findings related to components looks into the actuator, echolocation transducers, microcontroller, and battery pack. The results on the design process shed light on the various iterations and improvements in the trawl-kite system.

Following the results, the thesis includes a discussion chapter that reviews and analyzes the key findings. Here, the choices and performance of the actuator, echolocation technology, microcontroller, control system, communication system, and battery pack are scrutinized. The chapter also reflects on the design process, illuminating the merits and potential shortcomings of each stage.

Finally, the thesis closes with the Conclusion and Future Work chapter, which sums up the significant findings and their implications. This chapter also identifies potential future directions for improving and enhancing the trawl-kite system.

2 Theoretical Foundation

In this section of the report that provides the necessary theoretical background and principles that underlie the design and operation of the trawl-kite system. This part will introduce and explain the fundamental concepts and theories that are needed to understanding the system's functioning and the rationale behind the design choices.

2.1 Hydrodynamics

Hydrodynamics is the study of the behavior and movement of fluids in response to various forces, including fluid dynamics, pressure, and buoyancy. In the context of underwater applications, such as the design and operation of a trawl kite, understanding hydrodynamics is essential. This chapter will provide an overview of key hydrodynamics principles and their relevance to underwater devices.

2.1.1 Fluid Dynamics and the Navier-Stokes Equations

Fluid dynamics is the study of the motion of fluids, both liquids and gases. The behavior of fluid flow is governed by a set of partial differential equations known as the Navier-Stokes equations. These equations describe the conservation of mass, momentum, and energy in a fluid flow.

Solving the Navier-Stokes equations for a specific problem can be challenging, especially for complex geometries and turbulent flows. Computational Fluid Dynamics (CFD) is a common approach used to solve these equations numerically and predict fluid flow behavior around objects.

2.1.2 Drag and Lift Forces

When an object moves through a fluid or a fluid flows around an object, two primary forces act on the object: drag and lift. Drag is the force that opposes the motion of an object through a fluid, and lift is the force that acts perpendicular to the direction of motion.

Drag can be divided into two components: skin friction drag and pressure drag. Skin friction drag is caused by the friction between the fluid and the object's surface, while pressure drag is due to the pressure difference between the upstream and downstream sides of the object.

The drag coefficient (Cd) is a dimensionless quantity that characterizes an object's resistance to motion in a fluid. Similarly, the lift coefficient (Cl) quantifies the lift generated by an object. The calculation of these coefficients depends on the object's shape, size, and orientation, as well as the fluid's properties.

2.1.3 Pressure Distribution and Hydrostatic Pressure

The pressure distribution around an object in a fluid is an important factor influencing the forces acting on the object. For submerged objects, hydrostatic pressure plays a significant role. Hydrostatic pressure is the pressure exerted by a fluid at rest due to its weight.

Understanding hydrostatic pressure is essential for the design and operation of underwater devices, as it affects the structural integrity and buoyancy of the object. As depth increases, hydrostatic pressure increases, posing challenges for devices operating at great depths.

2.2 Trawl Fishing: Principles and Techniques

Trawl fishing is a widely used commercial fishing method that involves dragging a large, cone-shaped net through the water to catch fish. Understanding the principles and techniques of trawl fishing is essential for effective and sustainable fishing practices. This chapter will provide an overview of key concepts related to trawl fishing, including trawl net design, trawling methods, and the environmental impact of trawling.

2.2.1 Trawl Design

The design of a trawl net is crucial for its effectiveness and selectivity. Trawl nets consist of several components shown in Table 1.

Table 1: Description of Net Parts

Net Part	Description
Mouth	The front opening of the net, where the fish enter. The mouth is held open by a combination of horizontal spread (created by trawl doors or otter boards) and vertical lift (created by buoyancy or hydrodynamic forces).
Wings	The sections of netting that extend from the mouth, leading fish into the net.
Body	The main, cone-shaped section of the net, where the fish are guided towards the codend.
Codend	The closed end of the net, where the catch is collected.

Figure 1 shows a more detailed illustration of a trawl.

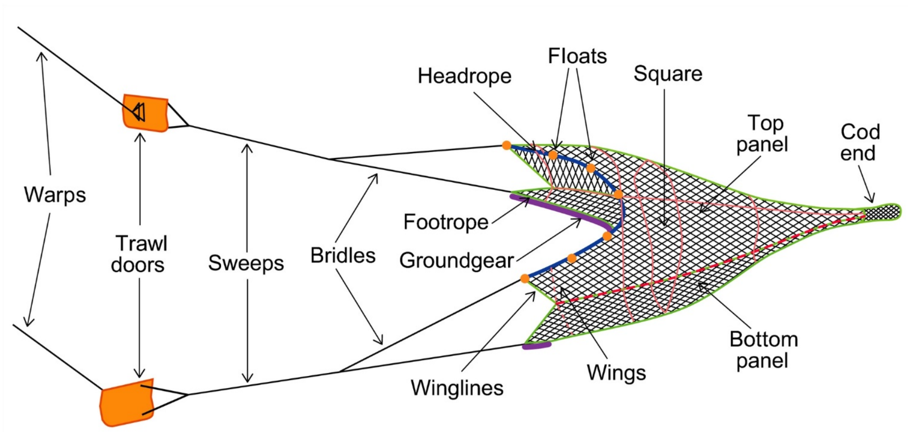
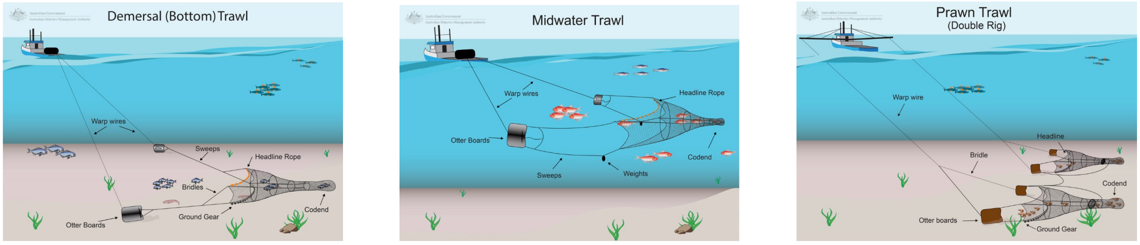


Figure 1: Detailed illustration of a trawl.

Trawl nets can be designed with different mesh sizes, shapes, and materials to target specific species or sizes of fish. Various devices, such as grids or escape windows, can be incorporated into the net to improve selectivity and reduce bycatch.

2.2.2 Trawling Methods

Various trawling methods are used depending on the target species, fishing depth, and environmental conditions. Some common trawling methods are shown in Figure 2.



(a) Illustration of Demersal Trawling

(b) Illustration of Midwater Trawling

(c) Illustration of Double Trawling

Figure 2: Various illustrations of trawling methods.

Table 2 describes the different trawling types shown in Figure 2.

Table 2: Description of Trawling Types

Trawling Type	Description
Demersal Trawling	A single trawl net is dragged along the seabed to catch demersal (bottom-dwelling) species. This method can be further classified into beam trawling (using a rigid beam to hold the net open) and otter trawling (using trawl doors to spread the net).
Midwater Trawling (or Pelagic Trawling)	The trawl net is towed in the water column to catch pelagic (open-water) species. This method typically uses larger, lighter nets than bottom trawling and may include devices like kites or floats to maintain the desired depth.
Double Trawling	In this method, a single boat tows two trawl nets simultaneously. The nets are kept apart and open using trawl doors and additional lateral spread from otter boards. This technique increases the catch area without requiring the resources of operating an additional boat

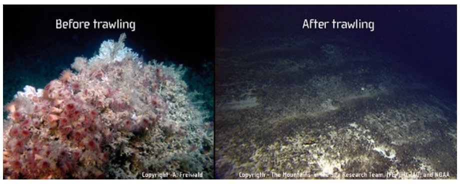
Each trawling method has its advantages and challenges, and the choice of method depends on factors such as target species, fishing depth, and environmental considerations.

2.2.3 Environmental Impact of Trawling

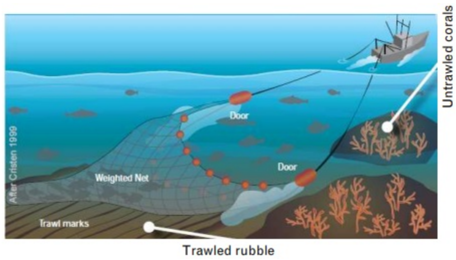
Trawl fishing can have significant environmental impacts, including:

- Bycatch: The unintentional capture of non-target species, including juvenile fish, endangered species, and other marine organisms. Bycatch can be reduced through modifications to the trawl net design, such as using selective devices like grids or escape windows, and adjusting the mesh size to allow smaller or non-target species to escape. [2].

- Habitat damage: Bottom trawling can cause physical damage to seabed habitats, such as coral reefs, seagrass beds, and other sensitive ecosystems. This can result in the loss of habitat for various marine species, potentially affecting the structure and function of marine communities. To mitigate habitat damage, it is essential to implement spatial and temporal restrictions on trawling activities, avoid sensitive areas, and develop devices which can lead to less impact on the seabed. Figure 3 shows a before and after picture of the seabed with an illustration of how the trawl drags over the bottom. [9].



(a) Before and after trawling



(b) Illustration of trawl imapct

Figure 3: Habitat damage by bottom trawling

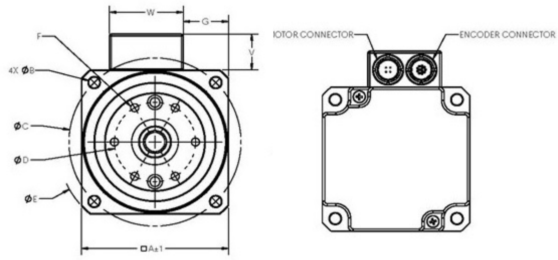
- Overfishing: Trawl fishing can contribute to overfishing, especially when regulations and quotas are not adequately enforced. Overfishing can lead to the decline of fish populations, reducing the productivity and sustainability of fisheries. Implementing effective fishery management strategies, such as catch limits, size limits, and closed seasons, is crucial for ensuring the long-term sustainability of trawl fisheries. [2].

- Carbon footprint: Trawling, particularly bottom trawling, is energy-intensive due to the drag created by the net and associated gear. This results in a higher carbon footprint compared to other fishing methods. Reducing fuel consumption through improved gear design, energy-efficient fishing practices, and the use of alternative energy sources can help mitigate the carbon footprint of trawl fishing. [10].

2.3 Electric Rotary Actuators

Electric rotary actuators are electromechanical devices that convert electrical energy into rotational motion, providing a precise and controlled output for various applications. At the core of these actuators is an electric motor, typically either a stepper motor or a servo motor, which generates the required torque through the conversion of electrical input into mechanical output [3]. The choice between stepper and servo motors depends on the desired performance characteristics, such as torque, speed, and positional accuracy.

(a) Rotary actuator from Harmonic Drive



(b) Illustration of outline dimensions

Figure 4: Example of an electric rotary actuator.

The electric motor is often coupled with a gear train, which amplifies the torque and provides a desired gear ratio. This gear train ensures that the output rotational motion meets the specific force and speed requirements of the application, such as the trawl-kite system. The combination of the electric motor and gear train allows for precise control of the actuator's output, enabling accurate positioning and motion control.

Electric rotary actuators offer several advantages over other actuator types, including high efficiency, scalability, and simplified control. These characteristics make them suitable for a wide range of applications, including marine systems where precision, reliability, and energy efficiency are essential.

2.4 Software

In the realm of engineering and design, software plays a crucial role. They serve as indispensable tools for precise modeling, simulation, and analysis, aiding in the verification of design decisions and in the prediction of a system's behavior under varied conditions. This section provides an introduction to two such software platforms, Siemens NX and AGX Dynamics, highlighting their essential features and capabilities.

2.4.1 AGX Dynamics

AGX Dynamics by Algoryx is a powerful and versatile physics engine designed for advanced multibody simulations. It provides accurate, realistic, and real-time simulations of complex mechanical systems, including rigid and flexible bodies, granular materials, and fluids. AGX Dynamics is particularly suited for applications in the fields of robotics, material handling, mining, and virtual reality training environments, where it allows users to create, test, and validate design prototypes in a controlled and repeatable environment. The platform enables users to simulate physical behaviors, including collisions, friction, and joint constraints, which are essential when evaluating the performance of mechanical systems. This high-fidelity physics simulation software aids in reducing the need for physical prototypes and facilitates the design process by offering rapid testing and validation capabilities.

2.4.2 Siemens NX

Siemens NX is a highly integrated computer-aided design, manufacturing, and engineering (CAD/CAM/CAE) software suite that enables the seamless fusion of design and simulation processes. Used globally by numerous industries, including automotive, aerospace, medical, and consumer products, NX offers a wide range of functionalities from sketching initial design concepts to simulating product performance under various operating conditions. This platform is lauded for its robustness and versatility, allowing engineers to create intricate 3D models, perform finite element analysis, examine thermodynamics, fluid dynamics, vibration analysis, and even facilitate the production process through its CAM capabilities. Siemens NX is an effective tool in the product development cycle, providing a comprehensive solution that accelerates innovation and reduces time to market.

3 Method

This chapter offers a comprehensive breakdown of the practical considerations that guided the selection of materials and formulation of methodologies for the design of the trawl-kite system. It delves into the criteria and processes utilized in choosing suitable components, alongside an explanation of the methods and techniques that underpin the design.

3.1 Components

This section delves into the key elements that make up the proposed trawl-kite system. Each part is discussed in detail, explaining its role, the selection rationale, and how it contributes to the overall functionality and efficiency of the system.

3.1.1 Electric Rotary Actuator

The selection process for an electric rotary actuator suitable for the trawl-kite system involved the evaluation of several options. Criteria such as torque capacity, precision, compact design, and suitability for the marine environment were all key considerations. A list of the considered actuators is provided in Table 3, highlighting their main characteristics.

Table 3: Evaluated electric rotary actuators for the trawl-kite system

Electric Rotary Actuator	**Characteristics**
Moog Rotary Actuators	High-performance electric rotary actuators designed for various applications.
Exlar Tritex II Series	Known for performance and durability, however, lacking better customization options for marine environments.
Tolomatic RSA-ST Series	Provide high torque and accurate positioning but lacks compactness.
Parker Helac L20 Series	Designed for heavy-duty applications, but lacks the high precision.

Upon evaluating these options and considering their specifications, performance, and compatibility with the trawl-kite system requirements, the Harmonic Drive FHA-32C was the final choice. It has a high torque capacity, precision, compact design, and can be customized for the marine environment, making it an ideal choice for ensuring efficient and reliable pitch control in the challenging underwater environment of the trawl-kite system.

3.1.2 Echolocation Technology

The selection process for the echolocation technology to be incorporated into the trawl-kite system considered several factors. These included the accuracy, range, power consumption, and the potential for seamless integration with the existing system. A range of echolocation transducers were deliberated during this evaluation process, and these are summarized in Table 4.

Table 4: Evaluated echolocation technologies for the trawl-kite system

Echolocation Transducer	**Characteristics**
Lowrance StructureScan 3D Transducer	Offers high-resolution imaging, but its compatibility is limited to non-Lowrance devices, and it has a higher power consumption.
Humminbird MEGA Imaging Transducer	Provides high-resolution imaging and a good depth range, but integration is limited to Humminbird devices.
Raymarine RealVision 3D Transducer	Features high-resolution imaging and accurate depth measurements but has limited compatibility with non-Raymarine devices.

Upon a comprehensive assessment of the available options and the specific needs and conditions of the trawl-kite system, the Garmin Panoptix PS51-TH LiveVü Forward Transducer and the Garmin GT23M-TH DownVü Transducer were selected. Their compatibility with the system and aptness for underwater applications stood out, making them the best choices for the task at hand.

3.1.3 Microcontroller

An optimal microcontroller to regulate and coordinate the components of the trawl-kite system was sought, taking into account crucial factors such as processing capabilities, memory capacity, communication interfaces, compatibility with other system elements, and power efficiency. The evaluation process included the consideration of several microcontrollers, among them shown in Table 5.

Table 5: Assessed microcontrollers for the trawl-kite system

Microcontroller	Characteristics
Texas Instruments Tiva C Series	Offers solid processing power and multiple communication interfaces, but is limited in terms of memory capacity.
Microchip PIC32MZ Series	Provides high processing power and ample memory capacity, but has higher power consumption.
NXP LPC54000 Series	Has good processing capabilities and power-saving modes, but offers limited communication interfaces.

Upon scrutinizing these alternatives and reflecting on the specific requirements and constraints of the trawl-kite system, the STM32F767ZI microcontroller, manufactured by STMicroelectronics, was selected. This decision was motivated by the microcontroller's robust processing capabilities, compatibility with the system, and effective power management.

3.1.4 Control System Selection

The coordination and harmony of the multiple elements that make up the trawl-kite system – such as echolocation technology, electric rotary actuators, and the communication system interfacing with the fishing vessel – require the development of a sophisticated control system. The design of such a system necessitates the examination of different control system architectures. This process takes into consideration factors such as reliable performance, adaptability, and the simplicity of implementation. Control system architectures such as model predictive control, adaptive control, and fuzzy logic control were among those evaluated.

In this preliminary design stage, a model-based control approach is being considered for its potential balance between performance and complexity.

3.1.5 Communication System Selection

The trawl-kite system requires a robust communication link between the underwater unit and the fishing vessel for real-time control and monitoring. Key aspects considered for the communication protocol selection included noise resistance, capability for long-distance communication, support for a multi-drop configuration, and compatibility with the system's components. After evaluating protocols such as RS-232, Ethernet, and Controller Area Network (CAN), the Recommended Standard 485 (RS-485) was identified as the most suitable choice, as presented in Table 6.

Table 6: Comparison of RS-232, Ethernet, RS-485, and CAN for the trawl-kite system

Protocol	**RS-232**	**Ethernet**	**RS-485**	**CAN**
Noise Resilience	Moderate, susceptible to noise over long distances	High, differential signaling provides good immunity	High, differential signaling provides excellent immunity	High, excellent error detection and recovery, but more effective over short distances
Long-distance	Moderate, effective up to 15m without additional hardware	High, up to 100m with appropriate hardware and setup	High, effective up to 1200m	Moderate, technically up to 1km but typically used for shorter distances due to speed constraints
Multi-drop	No, supports point-to-point	Yes, supports multiple devices	Yes, supports multiple devices	Yes, supports multiple devices
Data Rate	Moderate, up to 20kbps	High, up to 1Gbps with appropriate hardware	Moderate, up to 35Mbps at shorter distances	Moderate, up to 1Mbps, but data rate decreases with increased distance

RS-485's suitability is due to its noise immunity, extended transmission distance of up to 1,200 meters, and support for multi-drop configuration. Additionally, RS-485 is recommended by the NORSOK U-102 standard for communication in underwater operations, further solidifying its choice for the trawl-kite system [4].

3.1.6 Battery Pack

The battery pack for the trawl-kite system is responsible for powering a variety of components. These include the actuator, echolocation devices, and the communication system. To establish the necessary battery capacity and specifications, it is crucial to conduct a thorough examination of the system's power consumption, desired operational time, and voltage requirements.

Refer to table 7 for a breakdown of the power consumption for each component in the trawl-kite system:

Table 7: Power Consumption of Trawl-kite System Components

Component	**Power Consumption (W)**
Electric Rotary Actuator	1700
Garmin Forward Transducer	15
Garmin Downfacing Transducer	15
Communication System	40
Control System	25

To compute the total power consumption, we sum up the individual component power consumptions as described in table 7, resulting in a total power consumption of 1795W.

Given this total power and the desired operational time, the energy requirement can be calculated as shown in Equation 1:

$$\text{Required Energy (Wh)} = \text{Total Power (W)} \times \text{Operational Time (h)} \tag{1}$$

Substituting the known values into Equation 1, as shown in Equation 2, yields:

$$1795W \times 5h = 8975Wh \tag{2}$$

An inverter is required to provide VAC by converting the DC voltage from the battery. With an inverter efficiency assumed to be 90%, we can calculate the adjusted energy requirement using Equation 3:

$$\text{Adjusted Required Energy (Wh)} = \frac{\text{Required Energy (Wh)}}{\text{Inverter Efficiency}} \tag{3}$$

Substituting the given values into Equation 3 (refer Equation 4) gives:

$$\frac{8975Wh}{0.9} = 9972Wh \tag{4}$$

Assuming the battery pack voltage is 100VDC, the battery capacity can be calculated using Equation 5:

$$\text{Battery Capacity (Ah)} = \frac{\text{Adjusted Required Energy (Wh)}}{\text{Battery Voltage (V)}} \tag{5}$$

Applying the values into Equation 5 results in Equation 6:

$$\frac{9972Wh}{100V} = 99.72Ah \tag{6}$$

For a 5-hour operation of the trawl-kite system, a battery pack with a minimum capacity of 99.72Ah at 100VDC is necessary. An inverter with at least a 1795W power rating is required to convert the DC output of the battery to the needed 100VAC.

Alongside the numerical assessments, other critical parameters were taken into consideration. These included the physical dimensions, weight, and compatibility of the battery pack with the operational and environmental requirements of the trawl-kite system.

An inverter is integrated to supply power to the AC components in the trawl-kite system. Its power rating must be at least equivalent to the total power consumption of the AC components (1795W), as derived from table 7. The chosen inverter is designed to be compatible with the battery's voltage and the system's power requirements.

3.2 Software

The primary software used for the design process was Siemens NX (2.4.2), a leading product design, engineering, and production solution. Siemens NX provides an integrated toolset that allows for the creation and manipulation of 3D models. It supports a wide range of functionality, from simple 2D sketching to advanced surface modeling, which was crucial in forming the complex geometrical configurations in the trawl-kite designs. Moreover, Siemens NX has a powerful suite for conducting analysis and simulations, although these capabilities were not used in this project due to time constraints and the scope of work.

3.3 Design Process

The design process employed was iterative, evolving with each version to enhance the trawl-kite's features and performance. Each version focused on refining certain aspects based on feedback and limitations identified in the previous version.

3.3.1 NACA profiles

NACA airfoils, or NACA profiles, are a series of shapes for airplane wings developed by the National Advisory Committee for Aeronautics (NACA) [11], the precursor to National Aeronautics and Space Administration (NASA), in the United States. NACA airfoils are described by a series of digits that denote specific geometric properties of the airfoil section.

While originally developed for use in aeronautics, NACA profiles have also found widespread application in hydrodynamics due to their efficient and streamlined shapes. Their use spans a broad range of marine vessels and technologies, from boats and submarines to tidal turbines and, in our case, the trawl-kite system.

There are several reasons why NACA profiles [8] are suitable for use in hydrodynamics, these are shown in Table 8.

Table 8: Advantages of NACA Profiles in Hydrodynamics

Advantage	**Description**
Efficiency	NACA profiles are known for their high lift-to-drag ratio, meaning they can generate a significant amount of lift (upward force) while minimizing drag (resistive force), making them exceptionally efficient.
Versatility	NACA profiles come in a broad range of shapes, each suited for a specific set of conditions. This makes them adaptable to various design requirements and performance needs.
Predictability	Since NACA profiles have been extensively studied, their performance characteristics are well-known and predictable. Designers can use established data and equations to predict how a particular profile will perform under certain conditions, which is crucial in design optimization.
Ease of Manufacture and Design	NACA profiles are mathematically derived and described, making them easy to replicate accurately in design and manufacturing processes.

In the context of our trawl-kite system, the use of a NACA 6-series hydrofoil is intended to maximize lift and operational efficiency while minimizing drag. This hydrofoil's performance attributes align with the system's need to maintain stability and effective trawling operation in various sea conditions.

3.3.2 Initial Design Considerations

Creating the trawl-kite system started with generating the initial concept, drawing inspiration from naturally efficient hydrodynamic life forms. An article discussing performance comparison of various aerodynamic shapes for autonomous underwater vehicles also inspired the initial design [6]. The goal was to simplify these shapes, creating a device that could move fluidly underwater while minimizing drag.

From the shapes analyzed in the mentioned article, a suitable form was selected that would inform the trawl-kite's core structure. The design incorporated a central, streamlined structure reminiscent of a fish body, believed to offer excellent flow characteristics, reduce drag, and promote efficient forward motion.

In the early stages of the design process, the trawl-kite's hydrofoils were the primary focus. The hydrofoils were based on aerodynamic and hydrodynamic shapes, designed to generate lift and maintain the trawl-kite's stability underwater. The first version was conceived to be 2 meters long and included two 50cm hydrofoils positioned on either side of the central structure, similar to fish's pectoral fins. This choice was a compromise between generating sufficient lift and ensuring maneuverability, a key factor for this preliminary version.

Taking into account the challenging conditions under water and the forces that the trawl-kite would face, it was important to focus on the system's structural strength. This led to the choice to use a rectangular frame that would cover the entire structure. This frame should provide physical protection for the hydrofoils and also acts as a secure point of attachment for them.

3.3.3 Design Evolution and Optimization

The design of the trawl-kite system went through various iterative changes, each one building upon the learnings of the previous version to better balance performance, efficiency, and durability.

For Version 2, a specific focus was placed on refining the hydrofoil design and the protective frame. A single NACA 63-412 foil was chosen based on research suggesting this profile yielded better lift-to-drag ratios. Concurrently, modifications to the protective frame aimed to further streamline the trawl-kite, intending to reduce drag and offer enhanced protection for the hydrofoils.

Version 3's design adjustments centered on the optimization of the side profile. The objective was to lower drag while retaining sufficient lift and structural integrity. By studying hydrodynamic profiles, a blend of the NACA0016 and NACA0022 profiles was selected. These profiles were chosen as they resemble the shape of manta rays, and appeared to be an effective solution to meet the desired goals.

For the fourth version, the design was improved to address structural rigidity and safeguarding the trawl-kite. Streamlined struts were incorporated to form a protective cage around the device, bolstering the trawl-kite against potential damage while providing additional structural support. This version also included a single connection point at the front of the protective cage, designed to enhance stability during maneuvers.

The last iteration of the design, labeled as Version 5, marked the implementation of a symmetrical mid-unit concept. In this version, a dual hydrofoil setup was reintroduced, taking into account stability factors and the operational demands of the system. Sidewalls were also added on either side of the mid-unit. The flat ends of these sidewalls were designed keeping in mind the optimal use of the trawl path's width, and they were intended to provide additional space for the system's integral components. The total length of the trawl-kite system in this version was extended to 3 meters.

The process of design evolution and optimization was an iterative journey, guided by a constant quest for performance improvement, efficiency, and reliability. Each step in the design process incorporated lessons learned from previous iterations, and enhancements were made in response to specific challenges and objectives.

4 Results

The forthcoming chapter unveils the outcomes derived from the development process of the underwater trawl-kite system. It encapsulates the decisions made throughout the design process and how those decisions have shaped the final form of the design. Through the assessment of different component options, considerations around the system's operational needs and constraints, and the iterative improvements made in each design version, the results presented here depict the culmination of a comprehensive design journey. This section offers an opportunity to reflect on the process, evaluate the outcomes, and understand the implications of the decisions made. It sets the stage for discussions and considerations about potential improvements and future work. It is an integral part of the narrative, providing a window into the progress made thus far.

4.1 Components

This section provides a general overview of the main elements that constitute the trawl-kite system, highlighting their fundamental roles and the reasoning behind their selection.

4.1.1 Actuator and Monitoring

The Harmonic Drive FHA-32C electric rotary actuator, as discussed in section 3.1.1, was selected for its superior performance and compatibility with the trawl-kite system. This actuator's key features such as high torque capacity, precision, compact design, and adaptability to marine environments, make it well-suited for the system.

This actuator's high torque capacity is crucial for controlling the hydrofoil's pitch and maintaining the trawl's optimal depth during operations. Its precision ensures accurate and reliable pitch control, while the compact design facilitates integration within the system. Its customization for marine environments enhances durability and reliability in challenging underwater conditions.

For effective performance and status monitoring of the actuator, two types of sensors were selected. The characteristics of these sensors are summarized in Table 9.

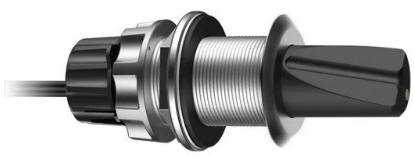
Table 9: Selected Sensors for Monitoring the Actuator Performance

Sensor Type	**Functionality**
Position Sensors (e.g., rotary encoders, potentiometers)	Provide real-time feedback on the angular position, enabling necessary adjustments to maintain the desired depth and lift.
Torque Sensors (e.g., strain gauge-based, magnetic sensors)	Measure actual torque output, providing insights into the system's mechanical load. This data can help detect potential issues or overloading, enabling proactive maintenance or adjustments.

The integration of these sensors into the trawl-kite system should enable real-time monitoring and control, contributing to reliable operation..

4.1.2 Echolocation Transducers

The Garmin Forward- (Figure 5a) and Downward-facing (Figure 5b) transducers were identified in the section 3.1.2 as the most suitable choices for the trawl-kite system. They provide comprehensive underwater imaging, both in front of and beneath the unit. The key features of these transducers are summarized in Table 10.



(a) Garmin Panoptix PS51-TH LiveVü Forward Transducer

(b) Garmin GT23M-TH DownVü Transducer

Figure 5: The two transducers selected for echolocation

Table 10: Characteristics of the Selected Echolocation Transducers

Characteristic	**Description**
Accuracy	Both transducers offer high-resolution imaging and provide accurate depth measurements with a resolution of 0.1 meters or better, essential for the precise control of the trawl-kite system.
Range	The transducers have a depth range of up to 100 meters, suitable for various fishing depths and conditions.
Power Consumption	Both the Garmin Panoptix PS51-TH and GT23M-TM have low power consumption, which is compatible with the battery-powered trawl-kite system, thereby maximizing operational life and reducing battery drainage.
Integration	The transducers are designed for easy integration with other marine electronics, including control systems and GPS devices, enabling seamless communication and control between the echolocation technology and the electric rotary actuators.
Waterproofing	As underwater transducers, the Garmin Panoptix PS51-TH and GT23M-TM are built to withstand marine environments. They feature waterproof designs and robust construction that ensures reliable performance in varying water conditions.

The combination of these characteristics ensures that the Garmin Panoptix PS51-TH and GT23M-TH transducers provide accurate and reliable underwater imaging for the trawl-kite system.

4.1.3 Microcontroller

The STM32F767ZI microcontroller (Figure 6), as identified in section 3.1.3, operates on an ARM Cortex-M7 processor with a frequency of up to 216 MHz. Its substantial processing power enables the efficient coordination of the trawl-kite system's components and tasks. The microcontroller's storage capacity includes 2 MB of Flash memory and 512 KB of SRAM, sufficient for system operation, data management, and data logging.

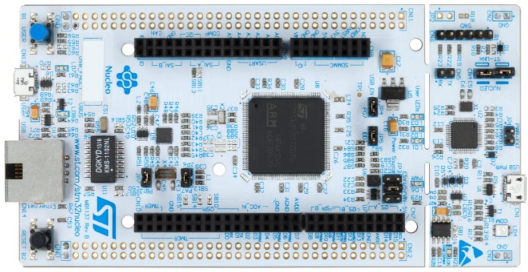


Figure 6: STM32F767ZI microcontroller

The microcontroller supports a wide range of communication interfaces, including Universal asynchronous receiver-transmitter (UART), Serial Peripheral Interface (SPI), Inter-Integrated Circuit (I2C), and CAN. This breadth of support facilitates the integration of the echolocation device, electric rotary actuators, and the battery management system. Its flexibility in terms of communication interfaces and powerful processing capabilities ensure compatibility with a wide array of equipment and sensors. It also emphasizes power efficiency, featuring multiple low-power modes and energy-saving functions. These features aid in managing power consumption effectively, contributing to the overall system's longevity.

4.1.4 Battery Pack and Inverter

Following the methodical calculations and evaluations provided in section 3.1.6, the results for the battery pack and inverter specification determination were conclusive. The power demand of the trawl-kite system necessitates a battery pack with a capacity of 99.72Ah at a voltage of 100VDC. This capacity is pivotal in ensuring the smooth operation of all components, including the actuator, echolocation devices, and the communication system, for the full operational period of 5 hours.

In tandem with the battery pack, an inverter with a minimum power rating of 1795W is required to convert the DC output of the battery to the necessary 100VAC, as per the demands of the system's components. This selection was made based on the total power consumption and an inverter efficiency of 90%, ensuring that the system's power demand is met consistently during operation.

Given that the total length of the trawl-kite is 3 meters, with the hydrofoils taking up about 50 cm each, it leaves 2 meters for the mid-unit and sidewalls. This space must accommodate not only the battery pack but also the other components such as the actuator, transducers, communication and control systems.

After evaluating these spatial constraints, it was found that the battery pack's dimensions must not exceed a specific size to be appropriately housed within the mid-unit while allowing space for other essential components. The weight should also be kept within certain limits, say W kg (to be specified based on balancing and load-bearing requirements), to ensure that the system's maneuverability and operational efficiency are not compromised.

4.2 Design Process

The design process of the trawl-kite system represents an iterative and progressive evolution, leveraging lessons learned from each version to refine and improve subsequent iterations. This approach aimed to address challenges identified in the previous designs and ensure the trawl-kite meets the operational requirements effectively. The process involved evaluating diverse elements, including hydrodynamic efficiency, structural integrity, protective measures, and the incorporation of various NACA hydrofoil profiles. Each iteration presents a unique set of features, pros, and cons, providing valuable insights into the design evolution and informing future improvements. This section presents a detailed examination of the various trawl-kite system versions, illustrating the development process from the initial concept to the current design.

4.2.1 Version 1: Initial Concept

The first design iteration, as detailed in section 3.3.2, sought inspiration from the natural, hydrodynamic shape of fish. The system's design incorporated a fish-like structure at its core, with two hydrofoils affixed on either side. This layout was enveloped by a simplistic rectangular frame, intended to provide requisite stability and rigidity to the construct.

The primary advantage of the fish-like structure was its inherent hydrodynamic profile, which was hypothesized to minimize drag and optimize the system's performance. This layout, combined with the twin hydrofoils, was designed to enable both lift generation and stability. Another positive aspect of this configuration was that the rectangular frame offered much-needed structural support, acting as an anchor point for the hydrofoils, preventing any loose oscillations.

Furthermore, this design incorporated ample internal space to accommodate the essential components of the system, such as the actuator, echolocation devices, and control system. The generous allowance for component housing meant that, at this stage, the placement and integration of key elements could be accomplished with relative ease.

However, several challenges were also evident at this preliminary stage. The most notable issue was the vulnerability of the hydrofoils due to the lack of protective features in the frame's design, exposing them to potential damage. Additionally, the hydrofoil design was rather rudimentary, not fully optimized for maximum lift generation or operational efficiency. These issues, coupled with the understanding that the fish-like structure, although hydrodynamic, may not represent the most efficient configuration for this specific application, signaled the need for further design optimization.

The key considerations of the initial design, along with the identified advantages and potential challenges, are summarized in Table 11. These insights laid the foundation for future iterations and enhancements.

Table 11: Pros and Cons of the Initial Concept

Pros	**Cons**
Natural hydrodynamic shape from fish-like structure potentially reduces drag, improving efficiency.	Lack of hydrofoil protection within rectangular frame design exposes them to potential damage.
Twin hydrofoil design offers lift generation and stability.	Hydrofoil design is rudimentary and not optimized for efficiency or lift.
Rectangular frame provides needed structural support, acting as an anchoring point for hydrofoils.	Fish-like structure, although hydrodynamic, might not be the most efficient shape for this specific application.
Ample space available for housing required components like the actuator, echolocation devices, and control system.	

Figure 7 provides a graphical representation of this initial trawl-kite design.

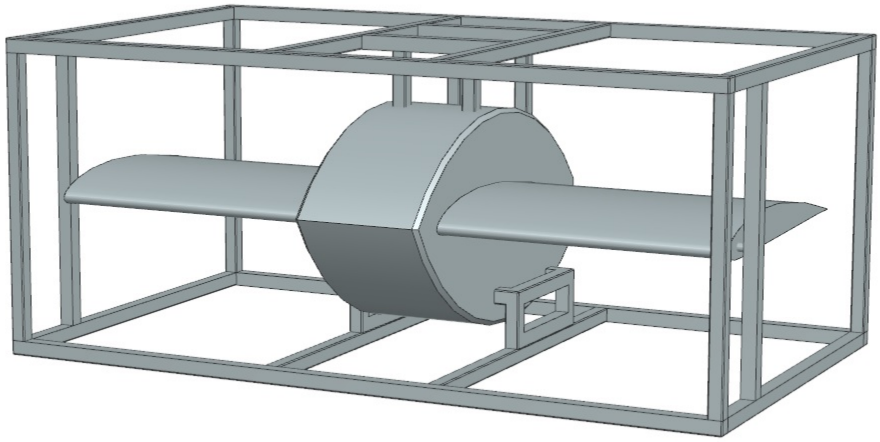


Figure 7: Version 1 of the trawl kite

4.2.2 Version 2: Hydrofoil Optimization and Frame Redesign

The second iteration of the trawl-kite system, as discussed in section 3.3.3, represented a significant evolution from the initial concept. Building on the foundation established in the first design, this version introduced several modifications and enhancements aimed at overcoming identified shortcomings and bolstering system performance.

The most notable change in Version 2 was the incorporation of a NACA 6-series hydrofoil. This hydrofoil was expected to boost lift generation and overall operational efficiency. The hydrofoil's streamlined profile and precise design attributes were optimized to reduce water resistance and improve glide performance.

However, a significant design shift from two hydrofoils to a single one was made. This change was primarily driven by the aspiration to streamline the design and focus on optimizing a single lift-producing element and more space for components on both sides. While this configuration had the potential to enhance hydrodynamic efficiency, it also introduced a potential trade-off in the form of reduced lateral stability, a property inherently provided by the previous dual-hydrofoil design.

A departure from the first version was also evident in the redesigned frame. Intended to provide a more hydrodynamic profile, the new frame was expected to reduce drag and further improve system efficiency. Importantly, this design also offered better protection for the hydrofoil, mitigating the vulnerability issues faced in the initial design.

Despite these enhancements, the Version 2 design also presented a few potential drawbacks. The redesigned frame, while more hydrodynamic, might not provide sufficient stiffness and robustness, essential attributes for enduring the rigors of marine operations. Furthermore, achieving the ideal balance between the hydrofoil's protection, hydrodynamics, and the frame's structural integrity required further optimization.

The key enhancements and potential challenges of the Version 2 design are summarized in Table 12. These observations formed the basis for subsequent design improvements and optimizations.

Table 12: Assumed Pros and Cons of Trawl-Kite Version 2

Pros	**Cons**
Inclusion of NACA 6-series hydrofoil to enhance lift generation and overall system efficiency	Shift to single hydrofoil design may compromise lateral stability
Redesigned frame presents a more hydrodynamic profile, reducing drag and improving efficiency	New frame, despite its hydrodynamic shape, might lack the required stiffness and robustness
Improved hydrofoil protection due to frame redesign, reducing risk of damage	Further optimization required to strike an ideal balance between hydrofoil protection, system hydrodynamics, and frame structural integrity

Figure 8 showcases an overview of the Version 2 design, providing both front and back views of the unit. These views highlight the integrated NACA 6-series hydrofoil and the newly designed protective frame.

(a) Front view

(b) Back view

Figure 8: Version 2 of the trawl kite

4.2.3 Version 3: Side Profile Optimization

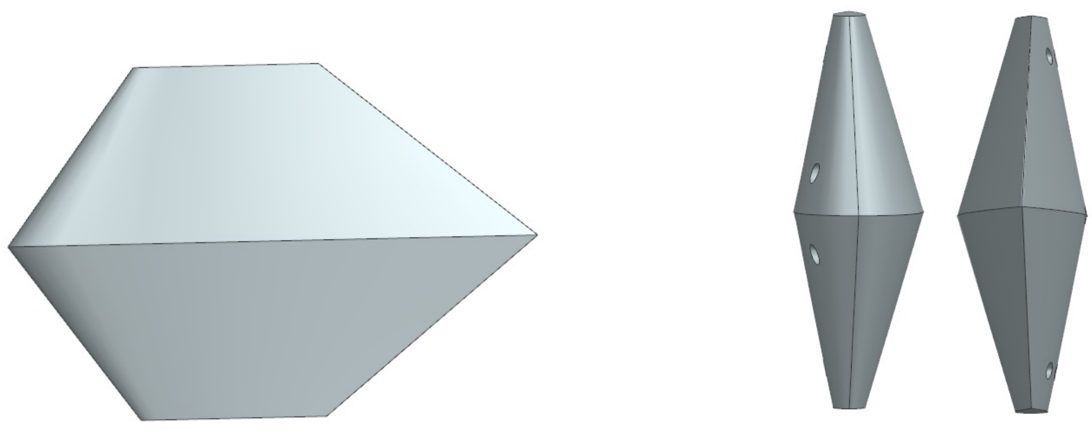
Following the iterations and changes to the initial trawl-kite concepts, Version 3 was developed, as mentioned in section 3.3.3, with a substantial focus on optimizing the side profile of the design. This process was led by the need to further enhance the hydrodynamic efficiency and operational performance of the trawl-kite system in its operational environment. The design inspiration for this version came from the natural world, more specifically the mantaray, an aquatic creature well-known for its efficient movement in water.

A significant feature in this version was the use of a combination of two NACA profiles, the NACA0016 and NACA0022. NACA profiles have long been acknowledged for their high efficiency and adaptability, particularly in hydrodynamic applications. By combining the low-drag characteristics of the NACA0016 and the structural robustness of the thicker NACA0022, the design managed to achieve a balance of efficiency and durability.

The new side profile design resulted in a more streamlined shape which should reduce water resistance. The NACA0016 profile, known for its low-drag characteristics, improved the system's hydrodynamic efficiency, while the NACA0022 profile, with its thicker structure, enhanced the system's structural robustness.

Along with the NACA profiles, the mantaray-inspired design facilitated smoother transitions between the profiles. This feature should reduce the chances of flow separation and turbulence, which often contribute to drag.

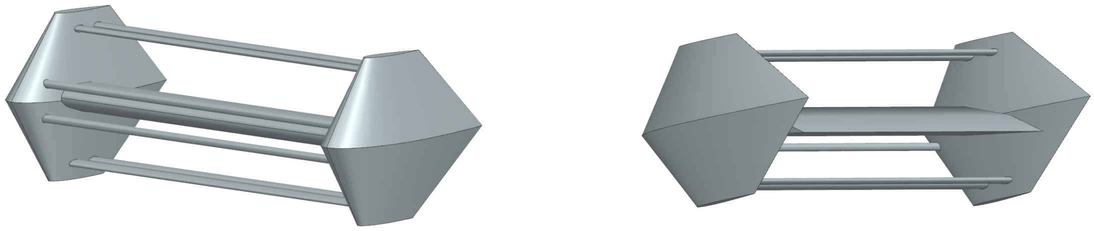
Figure 9 presents an overview of the optimized side profile design, capturing views from the side as well as the front and back.



(a) Side view **(b)** Front- and back view

Figure 9: Mantaray inspired sideprofile viewed from side, front and back

The further implementation of the optimized side profile can be seen in the complete assembly of Version 3, as shown in Figure 10.



(a) Front view **(b)** Back view

Figure 10: Version 3 of the trawl kite

The enhancements made to the Version 3 design were validated by analyzing the drag coefficient, which confirmed a more favourable balance between hydrodynamic efficiency and structural strength. The study was performed by The Society of Naval Architects of Korea, providing an independent and expert evaluation of the design's hydrodynamic performance [7].

This balance is a vital aspect in the design of the trawl-kite system, as it directly influences the system's ability to operate effectively in a range of underwater conditions without compromising structural integrity. As such, this version marked a step forward in the evolution of the trawl-kite system, creating a solid foundation for subsequent improvements and optimizations.

4.2.4 Version 4: Protective Caging and Stiffness Enhancement

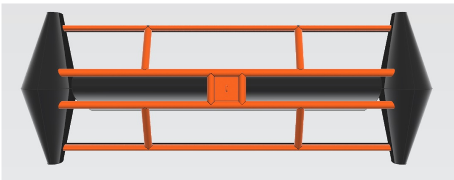
Building upon the learnings from previous iterations, Version 4 of the trawl-kite system incorporated significant improvements to address the identified challenges related to protection and stiffness. The main focus of this version was on developing a protective caging system and enhancing the overall structural stiffness of the trawl-kite, as detailed in section 3.3.3.

A notable feature of Version 4 was the introduction of a comprehensive protective cage, specifically designed to provide protection for the hydrofoil and other critical components of the trawl-kite system. This protective cage was designed with a hydrodynamic shape to reduce water resistance and drag, thus ensuring the overall hydrodynamic efficiency of the system wasn't compromised.

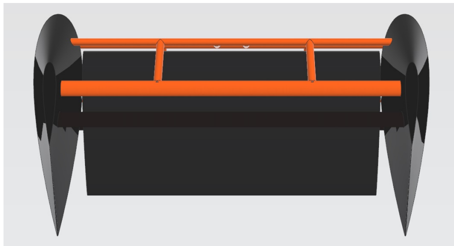
In addition to the protective cage, the structural stiffness of the trawl-kite was enhanced by incorporating streamlined struts into the design. These struts should provide the necessary rigidity to withstand various operating conditions, thereby ensuring reliable performance.

One of the novel features in this version was the singular connection point located at the front of the protective cage. This feature is supposed to effectively maintain stability during maneuvers and prevent the trawl-kite from being dragged off course during operation.

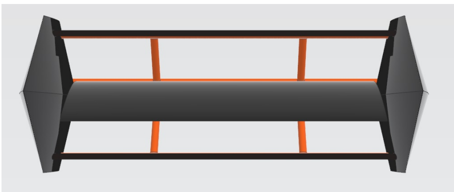
Figure 11 illustrates Version 4 of the trawl-kite system, providing multiple views of the design, including its protective cage, enhanced stiffness, and central connection point.



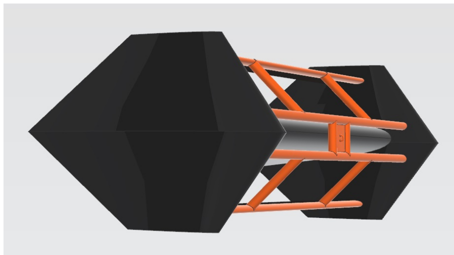
(a) Front view



(b) Top view



(c) Back view



(d) Side/front view

Figure 11: Different views of Version 4 of the trawl kite

This fourth iteration marked an important step in the evolution of the trawl-kite system, effectively addressing the design challenges posed by protection and structural stiffness. With its enhancements, Version 4 demonstrated a promising foundation for subsequent versions, highlighting the continued progress towards a trawl-kite system.

4.2.5 Version 5: Mid-unit Design and Enhanced Protection

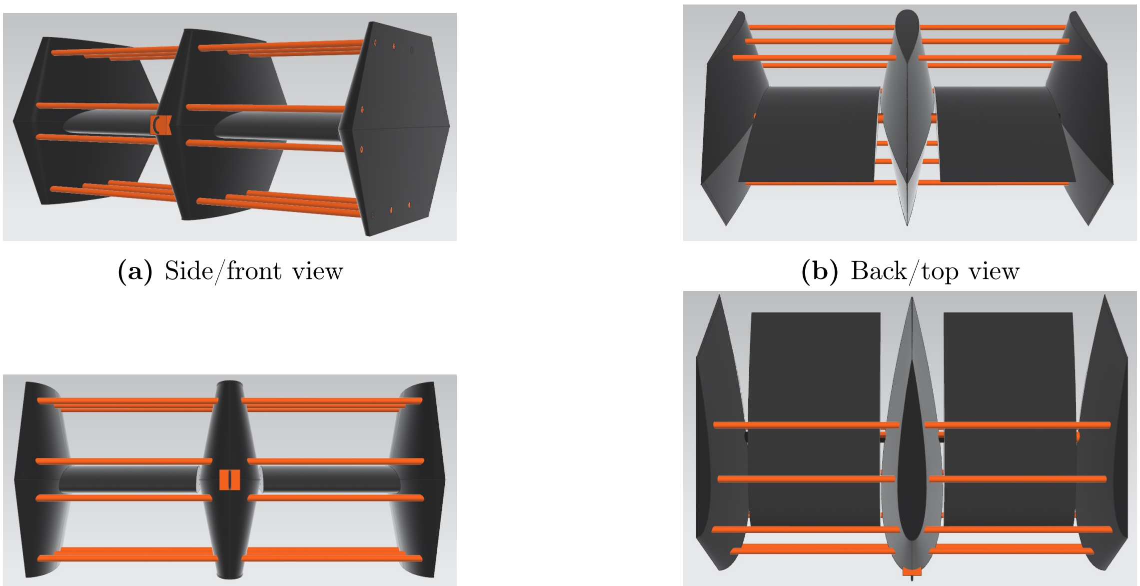
The fifth iteration of the trawl-kite system brought some significant improvements over the previous designs, and it marked the transition to a symmetrical mid-unit design. As discussed in section 3.3.3, this design was inspired by the natural model of a manta ray but refined to better suit the operational requirements of the trawl-kite system. The final design landed on a total length of 3 meters.

A notable feature of Version 5 was the return to dual hydrofoils. The decision to use two hydrofoils was driven by the hypothesis that a single hydrofoil might not provide enough stability, especially during turning maneuvers. As a result, the use of two hydrofoils aimed to increase the system's lateral stability and overall performance.

To further enhance the system's adaptability and versatility, Version 5 added flat sidewalls to both sides of the mid-unit. These sidewalls were included not only to add structural strength but also to provide extra space that could potentially house essential components such as batteries and bearings for the actuator.

Responding to client feedback, the sidewalls were designed with flat ends. This design choice was aimed at optimizing the use of the width of the trawl path and providing end support to the structure, thereby maximizing operational efficiency while maintaining structural integrity.

Figure 12 displays Version 5 of the trawl-kite system, highlighting the symmetrical mid-unit design and the additional space provided by the sidewalls.



(a) Side/front view

(b) Back/top view

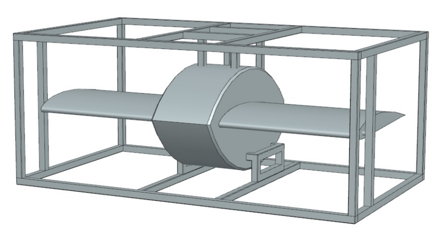
(c) Front view

(d) Top view

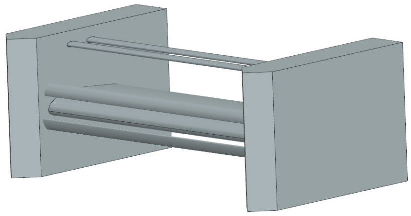
Figure 12: Different views of Version 5 of the trawl kite

4.2.6 Version comparison

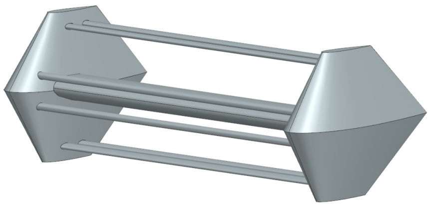
Figure 13 is a comparative illustration that provides a visual progression of the trawl-kite design through its various iterations.



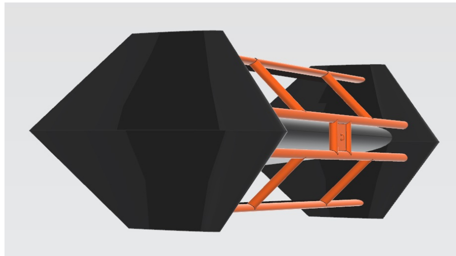
(a) Version 1 from section 4.2.1



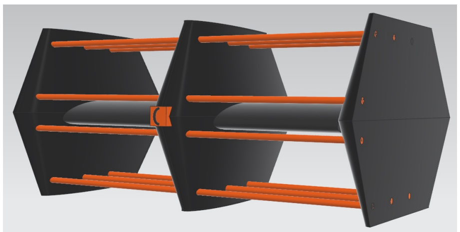
(b) Version 2 from section 4.2.2



(c) Version 3 from section 4.2.3



(d) Version 4 from section 4.2.4



(e) Version 5 from section 4.2.5

Figure 13: Comparison of trawl kite versions

5 Discussion

This chapter presents an in-depth analysis and discussion of the results gathered from the iterative design process of the trawl-kite system. Each design iteration introduces unique attributes and challenges that are explored to augment the understanding of the system's overall functionality and potential. Further, the importance and effectiveness of the chosen components within the framework of the trawl-kite system are discussed.

5.1 Actuator Selection

The choice of the Harmonic Drive FHA-32C from section 4.1.1 as the electric rotary actuator for the trawl-kite system has significant implications for the overall performance and effectiveness of the system. Its high torque capacity ensures that the hydrofoil can be controlled effectively even in the presence of strong currents and varying water conditions. This capability is crucial for maintaining the trawl's desired depth and maximizing the efficiency of the fishing operation.

The precision of the FHA-32C allows for accurate control of the hydrofoil's pitch, which in turn results in a more stable and controlled motion of the trawl-kite system. This stability is essential for ensuring that the system operates as intended and maintains the desired depth while minimizing the risk of entanglement or damage to the trawl.

The compact design and customization options offered by the FHA-32C make it an ideal fit for the trawl-kite system. Its small footprint allows for easy integration within the system, while its ability to be customized for the marine environment ensures that it can withstand the challenges of underwater operation, including corrosion and high pressures. These factors contribute to the overall durability and reliability of the trawl-kite system, making it a more sustainable and effective solution for modern fishing operations.

5.2 Echolocation Technology Choice

The Garmin Panoptix PS51-TH LiveVü Forward Transducer and the Garmin GT23M-TH DownVü Transducer analyzed in section 4.1.2 were chosen for the trawl-kite system due to their superior performance and compatibility with the system's requirements. They provide the necessary accuracy, range, low power consumption, and integration capabilities, making them well-suited echolocation devices for the trawl-kite system.

Other options, such as the Lowrance StructureScan 3D Transducer, Humminbird MEGA Imaging Transducer, and Raymarine RealVision 3D Transducer, were not selected because they either had limited compatibility with nonproprietary devices or higher power consumption. The Garmin transducers offer a more versatile and efficient solution for the trawl-kite system, ensuring reliable performance and seamless integration with other marine electronics.

5.3 Microcontroller

The STM32F767ZI microcontroller in section 3.1.3 was chosen for the trawl-kite system due to its powerful processing capabilities, compatibility with other system components, and efficient power management. It provides the necessary processing power, memory capacity, and communication interfaces to ensure reliable performance and seamless integration with other marine electronics.

Other options, such as the Texas Instruments Tiva C Series, Microchip PIC32MZ Series, and NXP LPC54000 Series, were not selected because they either had limited memory capacity, required higher power consumption, or had limited communication interfaces. The STM32F767ZI offers a more versatile and efficient solution for the trawl-kite system, ensuring reliable performance and seamless integration with other marine electronics.

5.4 Control System

The design and implementation of an efficient control system are paramount to the overall success and functionality of the trawl-kite system. The integration of several components, including echolocation technology, electric rotary actuators, and a communication interface with the fishing vessel, hinges on a system capable of harmonizing these elements, adapting to changes in the environment, and ensuring reliable performance.

The consideration of different control system architectures introduced in section 3.1.4 serves as a key aspect of this design process. These architectures included model predictive control, adaptive control, and fuzzy logic control, each offering distinct benefits and limitations. The choice of architecture will impact the system's responsiveness, adaptability, and the ease of implementation.

In the preliminary design phase, a model-based control approach seems a fitting choice, due to its balance of performance and complexity. It could offer a framework to predict the system's behavior, allowing the controller to adjust its actions based on these predictions. However, the final selection of the control system architecture requires careful consideration and must be substantiated by further studies and detailed simulations.

These simulations would allow the validation of the chosen control architecture's efficiency and reliability under varying conditions, thus ensuring the overall system's performance in real-world trawling operations. Hence, the design of the control system remains an open and evolving component of the trawl-kite system's development.

5.5 Communication System

After an in-depth analysis of the different protocols introduced in section 3.1.5, RS-485 appears to be the most suitable communication protocol for the trawl-kite system. One reason is its known robustness and resilience to noise, making it particularly suitable for underwater environments where communication can be affected by various interferences. Moreover, it is capable of long-distance communication, a crucial requirement for the trawl-kite system.

RS-485 also supports multi-drop configuration, allowing multiple devices to communicate over the same data line, potentially simplifying the communication network within the trawl-kite system. Finally, it's compatible with a wide range of devices, easing integration with other components of the system.

Additionally, it's worth noting that according to the NORSOK U-102 standard for ROVs, RS-232 and RS-485 are typically utilized for underwater communication, which further strengthens the case for RS-485 in the trawl-kite system.

However, while RS-485 appears suitable for the trawl-kite system, its actual performance in this specific application will need to be validated through further testing and simulations. The final choice of the communication protocol should ensure reliable and efficient communication between the trawl-kite underwater unit and the fishing vessel for optimal system operation.

5.5.1 Battery Pack

Selecting the appropriate battery pack and inverter for the trawl-kite system was a process that needed a careful balance between power capacity, size, weight, and the ability to withstand the harsh marine environment. The specifications of the system necessitated a battery pack with a capacity of 99.72Ah at 100VDC and an inverter rated for 1795W power. However, these necessities had to be fulfilled without negatively affecting the system's maneuverability, operational efficiency, or the integrity of its structure.

Taking into account the spatial constraints of the system, it was determined that the dimensions of the battery pack had to be within a specific size to be correctly housed within the mid-unit, leaving room for other vital components. Furthermore, the weight had to be kept within specified limits to maintain the balance of the trawl-kite system and to ensure its operational efficiency wasn't hindered.

The size and weight of the battery pack significantly influence the system's performance. A larger, heavier battery could offer longer operational times, but may also pose challenges in maneuverability and structural integrity. Conversely, a smaller, lighter battery could improve maneuverability, but might not provide sufficient power to meet the system's needs.

The system's power supply needed to be reliable and durable, considering it will be operating in demanding marine conditions. Therefore, the choice of battery pack and inverter was driven not only by their power specifications but also their resilience in challenging environments.

One potential solution to consider could be a self-generating energy source to power and recharge the system's battery. Using a turbine or similar mechanism to convert the water resistance encountered during movement into electrical energy could potentially create a self-sustaining power supply. This would reduce the need for frequent battery replacements and could improve operational efficiency. However, implementing this would require in-depth research into the feasibility of such energy conversion, and potential design modifications would be necessary to accommodate the additional components. Despite the challenges, this approach could enhance the system's self-sustainability, improving its efficiency and reliability further.

5.6 Design Process

The trawl-kite system's design process bears testament to the dynamic and iterative nature of engineering design, with each version building on the previous iteration's strengths and addressing its weaknesses. This progression was driven by the quest for enhanced hydrodynamic efficiency, improved protective measures, and robust operational performance.

At the onset of this project, a comprehensive exploration into existing Towed ROVs was undertaken, revealing a concept developed by NTNU Ålesund. Although this Towed ROV informed the early stages of the project, the focus later shifted towards the unique trawl-kite system. Hence, the preliminary research, while valuable, did not substantially influence the final report.

In the journey from Version 1 to Version 5, the design evolved dramatically. Starting with an innovative concept inspired by the hydrodynamic capabilities of marine creatures, the design confronted several challenges. The initial version, though inventive, fell short in providing adequate protection for the hydrofoils and optimizing the design for hydrodynamic performance. These lessons learned in the first iteration greatly informed the design approach for the subsequent versions.

Version 2 signified the first major evolution, with the adoption of a NACA 6-series hydrofoil and a redesigned frame. These changes were aimed at boosting the lift generation and enhancing overall efficiency. Yet, with these advancements came new challenges. There were uncertainties about the system's lateral stability and structural integrity, calling for further optimizations.

With Version 3, the design incorporated an optimized side profile, demonstrating the flexibility of the design approach. This change contributed to the improvement of hydrodynamic efficiency. Despite these advancements, the design needed additional protection and enhanced stiffness to be practically viable.

In the fourth iteration, the design process introduced a protective caging system and increased structural stiffness. These changes aimed to bolster the design's robustness and adaptability, making it suitable for a variety of operating conditions. A distinctive feature of Version 4 was the implementation of a singular central connection point for trawling operations. This design choice was driven by the understanding that a central connection point would ensure more balanced dragging and stability, as compared to potential misalignment issues that could arise from side connection points as a crowfoot or two separate chords.

In the final iteration, Version 5, the design integrated a symmetrical mid-unit model, housing two hydrofoils and sidewalls on both sides of the unit. This offered better stability and space to house essential components. However, the need for further simulations and refinements was still significant to validate the design's performance and structural integrity.

It's important to note that the design and testing process was hindered by the introduction of new software, AGX Dynamics from Algoryx (2.4.1), which caused a steep learning curve and required additional time for proficiency. The simulations that were meant to be performed with AGX Dynamics could not be completed due to the short timespan for learning and mastering the new software by a single person. This not only affected the number of design iterations that could be completed but also impacted the depth of testing and validation for each design. However, this experience serves as a valuable learning point for future projects, emphasizing the need for adequate time allocation for learning and becoming proficient in new software tools.

Overall, the design process showcased the iterative and dynamic nature of engineering design. Each design iteration presented its unique set of strengths and challenges, demonstrating the importance of adaptability and continual improvement in the design process. While the design has evolved significantly from its initial concept to its current state, each step in the process has contributed valuable insights that have collectively shaped the evolution of the trawl-kite system.

6 Conclusion and Future Work

This thesis chronicles the design evolution of an underwater trawl-kite system, from its conception through five iterative stages. The process demonstrates the necessity of continuous refinement and adaptation, responding to emerging challenges and providing valuable insights.

The trawl-kite system is an integration of meticulously selected components, including a high-torque electric rotary actuator, innovative echolocation transducers, an efficient microcontroller, a model-based control system, a robust communication protocol, and a compact yet powerful battery pack. Together, these components construct a promising solution intended to enhance the efficacy of trawl fishing operations.

The progress from the initial design to the fifth iteration embodies an iterative cycle of innovation and problem-solving. Each version has served to address specific challenges, refine the overall design, and enhance the system's resilience and performance. This progression underscores the importance of ongoing testing and validation, pointing towards the necessity of future efforts to verify the system's operational viability.

The design process encountered a significant challenge when a new software tool, AGX Dynamics, was introduced. The learning curve associated with this tool impacted the pace of design iterations and the depth of testing for each design. This emphasizes the importance of allocating sufficient time for learning new tools in future projects.

As the development of the trawl-kite system continues, the focus for future work should be post-implementation investigation of each selected component and extensive system simulations. Potential areas of exploration include the pursuit of a self-sustaining power supply, further optimization of hydrodynamic efficiency and structural integrity, and the potential introduction of design modularity.

The trawl-kite system represents significant potential for enhancing the efficiency and sustainability of trawl fishing operations. However, the need for continued research and development is evident. The design process has demonstrated substantial advancements, yet it also underlines the importance of ongoing efforts for further improvement and innovation.

One notable area for future exploration is the implementation of more detailed Computational Fluid Dynamics (CFD) simulations. These simulations could provide insights into the system's hydrodynamic performance and uncover potential areas for further optimization and structural enhancements. Such an approach would enable the trawl-kite system to evolve in accordance with new learnings and technological advancements, exemplifying the dynamic nature of engineering design.

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Appendices

Appendix A: Preliminary Report

PRELIMINARY PROJECT - REPORT

FOR BACHELOR THESIS

NTNU
Norwegian University of Science and Technology

TITLE:
Trawl-kite

CANDIDATES(NAMES):
Joachim G. Colbensen

DATE:	SUBJECT CODE:	SUBJECT:	DOCUMENT ACCESS:
18.01.23	**IELEA2920**	**Bachelor Thesis Automation**	- Open

STUDY:	NO.PAGES/APPENDIX:	BIBL. NR:
AUTOMATION	10/0	

PRINCIPALS/SUPERVISORS
Lars Ivar Hatledal and Paul Steffen Kleppe

TASK SUMMARY:

This preliminary report encapsulates the early stages of a project aimed at innovating in the realm of trawling through the development of a trawl-kite system. This system, conceived in partnership with Pål Roaldsnes and Scantrol/Deep Vision, is designed to reduce the environmental impact of demersal trawling by minimizing trawl contact with the seafloor.

The trawl-kite is a response to the limitations of existing fishing tools, which currently struggle to reduce seabed contact. Even with the advent of steerable trawl doors capable of regulating trawl height, the need for a solution that further lessens the trawl's seabed impact is evident. This project hence centers on the development of an autonomous unit that not only regulates the height of the trawl but also mitigates its seafloor impact, contributing to a more sustainable future for marine operations.

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Contents

List of Figures

1 Introduction

Trawl fishing is a method that utilizes a trawl as a tool, and represents a significant aspect of the fishing industry due to the large volume of catch that can be obtained. There are various forms of trawl fishing, which are adapted to different target species, boat sizes, and local conditions. Due to increased focus from society on sustainable fishing, trawl fishing has come under increased criticism, particularly bottom trawling has faced opposition due to negative effects on the benthic fauna.

This bachelor's thesis aims to make trawl fishing more sustainable by developing an automatic or semi-automatic device for the trawl, in the form of a "kite." This is to minimize the impact that current trawl fishing leaves on the seabed while simultaneously optimizing the amount of fish caught in the trawl. This device can then contribute to more fish typically swimming away, to swim down and into the trawl. The client for this thesis is Pål Arne Roaldsnes, a shipowner within the fishing industry, who wishes to explore opportunities to reduce negative effects of trawl fishing on the environment. The fundamental question of the thesis is to investigate what can be done to develop such a device.

2 Project organization

2.1 Project group

Studentnumber:
536137

The entire bachelor thesis is undertaken by a single individual.

2.2 Control Group (supervisor and client contact)

Supervisors:

- Paul Steffen Kleppe
- Lars Ivar Hatledal

Client Contact:

- Pål Arne Roaldsnes

3 Agreements

3.1 Agreement with the Client

The agreement entered into between the employer and the project team focuses primarily on the physical aspect of the product. One of the main challenges in the project is to develop a physical design of the product that is functional and practical. This entails investigating and evaluating different design options, as well as conducting tests and evaluations to ensure that these alternative designs meet the requirements set for the product. If time permits, it is also desirable to model a 3D design of the product at a "proof of concept" level, in order to enable the client to envision the product as a realistic possibility for increasing sustainability and catch rate in the fishing industry.

3.2 Workspace and Resources

Access to a workspace is an important factor for being able to perform work effectively and productively. In this case, the workspace is a home office and school area, and there is good access to these locations to perform the work. This is important to be able to work flexibly and to have the ability to focus on the work without interruptions.

Access to resources is also important for being able to perform the work in a good manner. In this case, there is good access to the resources that are needed, and this makes it possible to perform the work efficiently. This can range from having access to relevant literature, to technology and tools that are necessary for the work.

Access to people from different fields is important for getting feedback and advice during the course of the work. In this case, there is good access to people from different fields, and this provides the opportunity to get input and help in solving any challenges that may arise.

Data security and information protected from the public is an important topic in many fields. In this case, this topic has been handled, but no agreement has been necessary to write, just individual discretion.

Agreed reporting can be an important part of the work, and it may be wise to have a fixed schedule for this. In this case, there is no agreed reporting, but it may be wise to have meetings once a week and regular conversations to stay updated on the work and any challenges that may arise. This provides the opportunity to get feedback and adjust the work as necessary to achieve the best possible result

3.3 Attitude

As a practitioner of the profession of automation engineering, I aim to uphold an attitude that combines technological expertise with ethical awareness and responsibility. This entails staying updated on the latest technological developments and using my knowledge to solve problems in a sustainable manner, while also taking into consideration the social and environmental consequences of the technology I develop and use. I strive to be a responsible practitioner of the profession, considering how technology can contribute to improving society and the world we live in.

4 Project description

4.1 Problem Statement - Objective - Purpose

The main objective of this project is to develop a unit for trawl fishing that contributes to making trawling more environmentally friendly through the use of a smart autonomous solution. The unit should help the trawl and weights to have very little or no contact with the sea floor, which reduces the damage to the bottom while also making much less noise. This solution could also contribute to more efficient fishing, as the fish can be forced to swim down and thereby into the trawl.

4.2 Requirements for solution or project result - specification

The specifications outlined in this project are intended for the final solution, and it should be noted that achieving all of them within the given time-frame may not be feasible. The focus of this thesis will therefore be on the development of a "proof-of-concept" design, to demonstrate the feasibility and practicality of the proposed solution for commercial use.

Functional requirements:

- Can operate in strong sea currents and compensate for drift
- Can trawl along edges with large depth differences and rough sea floor
- Can withstand mechanical stresses such as impact and shocks against the deck and racks
- Can withstand high pressure, down to 700m depth
- Has sufficient battery capacity and a system for battery replacement on deck

Quality requirements:

- The unit should be of high quality and built to withstand harsh marine environments and mechanical stress

- The unit should have good usability and be easy to operate and maintain.

Standard and regulation requirements:

- The unit should comply with all relevant safety standards and regulations
- The unit should comply with all relevant environmental standards

With regards to the documentation and design development of the unit, the client has not specified any specific requirements. However, it is understood that the scope of this project is extensive with a small time-frame and as such, the client expects a degree of a conceptualized design to be achieved. Additionally, it is expected that the research conducted in this project will provide sufficient evidence to support the feasibility of the proposed solution and its potential for further commercial development.

4.3 Planned procedure for the development work – method

The proposed methodology for this project is to utilize a combination of Scrum as the project management method and V-model as the development method.

Scrum is a method for project management that is particularly suitable for projects that require managing uncertainty and changes. This method is known for its flexibility and adaptability, allowing for continuous adjustments of plans based on insights and learning throughout the project. Scrum is characterized by dividing the project into short iterations with a clear defined goal and regular meetings to evaluate progress and plan the next sprint.

The V-model is a system development method that is known for being a structured approach to developing complex systems. It is characterized by a clear distinction between the planning phase and the implementation phase, and a clear dependency relationship between the requirements specification and testing. The V-model's strength is that it ensures all requirements are covered and that there is a systematic and controlled process for developing the system. A weakness could be that it can be time-consuming and that it may be difficult to adapt to changes during the project. By combining Scrum and V-model, this project will have a strong focus on handling uncertainty and changes, while ensuring that all requirements are covered and that there is a systematic and controlled process for developing the trawl.

4.4 Information collection – carried out and planned

In the initial stages of this project, research was conducted on existing applications, system solutions, and knowledge within the area of Towed ROVs. This research was conducted as part of the preliminary project, and revealed the existence of a Towed ROV concept developed by NTNU Ålesund, which will serve as the basis for the current project. The Towed ROV is designed as a multipurpose platform to be towed behind a surface vessel, and can be used for explorations and surveys, taking pictures of the seabed, and providing a live camera feed of its surroundings. The main objective of the ROV project was to develop a fully functional unit that can regulate its depth relative to the seabed and the water surface, and is controlled through a graphical user interface.

The collection of information was also facilitated through a meeting with the client, during which valuable insights were gained regarding the desired functionality of the unit under development. The client, possessing a wealth of knowledge and experience with trawl equipment, provided valuable input on the feasibility and realism of various proposed developments.

As the project progresses, additional research will be conducted to ensure that sufficient information is obtained on existing applications, system solutions, and knowledge within the area of Towed ROVs. This will involve conducting literature reviews, consulting with peers in the field, and conducting theoretical analysis on the different iterations. It will also be appropriate to meet with the client and control group multiple times to gather more information and inputs as the projects continues.

4.5 Assessment – analysis of risk

In executing this project, various potential risks have been identified and considered to ensure its successful and timely completion.

Firstly, time management is paramount. With a commitment to the task at hand, effective prioritization is critical for maintaining efficiency. It is important to have a clear sense of what tasks are crucial and need to be attended to promptly to avoid any wastage of time.

Next, procurement of necessary components presents another potential risk. Any delay in the arrival of these parts could significantly hinder the project's progress. As such, it's imperative to order these components as early as possible.

Furthermore, unforeseen circumstances such as personal illness or unexpected work commitments can impact productivity. In such situations, the ability to adapt and find ways to continue contributing to the project, even in a reduced capacity, will be essential.

Lastly, the risk associated with technical feasibility cannot be overlooked. Before commencing any significant work, a thorough preliminary investigation is required to ensure that the planned hardware and software components are compatible. This precautionary step will help avoid wasting valuable time and resources on unworkable solutions.

By identifying and understanding these potential risks, I believe that I am well-prepared to navigate any challenges that might arise, ensuring the project's progress stays on track.

4.6 Main activities in further work

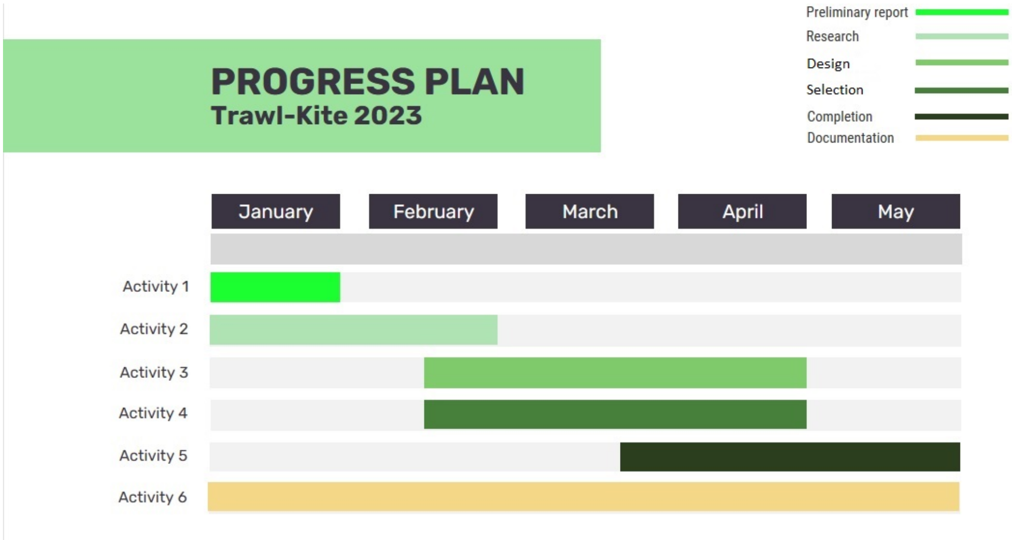


Figure 1: Progress plan

Research:

- Conducting literature review
- Identifying existing equipment and technologies
- Meeting with the client to gather information

Design and selection:

- Choosing suitable components
- Designing the unit

Completion:

- Finalizing any remaining tasks
- Conducting a final review of the unit

4.7 Fremdriftsplan

4.7.1 Master Plan

- Research and Component Selection
  Start date: 11.01.2023
  Estimated date of completion: 01.02.2023

- Initial 3D Modelling
  Start date: 02.02.2023
  Estimated date of completion: 28.02.2023
- Initial Design Review
  Start date: 01.03.2023
  Estimated date of completion: 07.03.2023
- Design Refinement and Detailed 3D Modelling
  Start date: 08.03.2023
  Estimated date of completion: 08.04.2023
- Final Design Review
  Start date: 09.04.2023
  Estimated date of completion: 15.04.2023
- Report Writing and Presentation Preparation
  Start date: 16.04.2023
  Estimated date of completion: 15.05.2023
- Review and Revision of Report and Presentation
  Start date: 16.05.2023
  Estimated date of completion: 22.05.2023

4.7.2 Development tool

- Siemens NX

4.7.3 Internal Control - Evaluation

Project control will involve routine self-assessment and proactive planning. A detailed project plan with tasks, milestones, and deadlines will be utilized to track progress. A project management tool will help manage tasks and provide a visual representation of progress. Regular status updates will be communicated to advisors. To manage risks, a risk management strategy has been outlined, which includes identifying potential risks, estimating their impact, and developing mitigation strategies.

Evaluation of the project will ensure that objectives are met. A set of criteria will be established to gauge whether goals and sub-goals have been achieved.

- **Goals:** The main goal is the development of a comprehensive design for a trawl-kite system, measured by the completion of a detailed 3D CAD model and corresponding documentation.
- **Sub-goals:** These include completion of component selection, initial 3D modeling, design reviews, design refinement, and report writing. Each task's completion according to the timeline will serve as an indicator of success.

Success will also be judged by the quality of the final design and its potential for further development and use. The ultimate criterion of success will be the submission of a well-written thesis that communicates the design and thought process behind the trawl-kite system effectively.

4.7.4 Decisions and Decision-Making Process

The process of making critical decisions during the preliminary phase of the project was marked by careful consideration and thorough research. Decisions about the project's scope and precise tasking were made based on a combination of personal interest in marine technology, the client's requirements, and the potential for innovation within the field. The process was iterative, involving consultations with advisors, and revisions based on feedback received.

For the main project, decisions will be made strategically and with a view to the bigger picture. Key areas of decision-making will relate to design choices, component selection, testing, and revisions. Decisions will be informed by a combination of research, consultation with advisors and the client, and learning from earlier stages of the project. A critical component of the decision-making process will be the continual assessment of the project plan's feasibility (4.7.1), with adjustments made as necessary.

5 Documentation

5.1 Reports and Technical Documents

The documentation for this project will include a project report detailing the research, design process, and results. The report will adhere to the university's guidelines for bachelor theses in terms of format and content.

- **Routine:** Regular updates will be made to the report throughout the project's lifespan.
- **Approval:** The report will be reviewed and approved by the project advisors before final submission.
- **Distribution/Copying:** The finalized report will be submitted digitally to NTNU, with copies distributed to the advisors and the client. Any copying or further distribution must respect copyright laws.
- **Storage:** The digital version of the report will be stored safely with backups.
- **Maintenance:** Any necessary corrections or revisions will be carried out before the final submission deadline.

6 Planned Meetings and Reports

6.1 Meetings

6.1.1 Steering Group Meetings

While exact dates for meetings with the steering group are not predetermined, the goal is to conduct these meetings approximately once a week. The general purpose of these meetings is to discuss the progress of the project and receive valuable feedback on the research and development undertaken.

6.1.2 Project Meetings

Project meetings are also aimed to take place roughly once a week, with the main purpose of discussing the overall progress and any necessary adaptations or adjustments to the project timeline and tasks.

6.2 Periodic Reports

6.2.1 Progress Reports

Progress reports will be produced as needed to communicate the state of the project. These reports will be a tool for ensuring that the project is on track and for identifying any potential issues or challenges early.

7 Planned Deviation Management

If the project's progress or content does not proceed as planned, the following steps will be implemented:

1. **Identify the Deviation:** The first step is to identify the deviation and assess its impact on the project.
2. **Evaluate the Situation:** The severity and potential implications of the deviation will be evaluated. This involves understanding how the deviation affects the project timeline, objectives, and resources.
3. **Develop a Plan:** Once the deviation has been evaluated, a plan to address the deviation will be formulated. This could involve adjusting timelines, reallocating resources, or modifying project objectives.
4. **Implement Changes:** The devised plan will then be implemented to bring the project back on track.

5. **Monitor:** The situation will be closely monitored to ensure that the changes have the desired effect and the project is progressing as intended.

Responsibility for handling deviations lies solely with me. However, significant changes or deviations that affect the scope or timeline of the project will be discussed with the advisors before any decisions are made.

8 Equipment Requirements/Conditions for Implementation

The primary software necessary for the implementation of this project is Siemens NX. This software, a leading integrated solution for computer-aided design, manufacturing, and engineering (CAD/CAM/CAE), is essential for developing 3D models and simulations for the trawl-kite system.

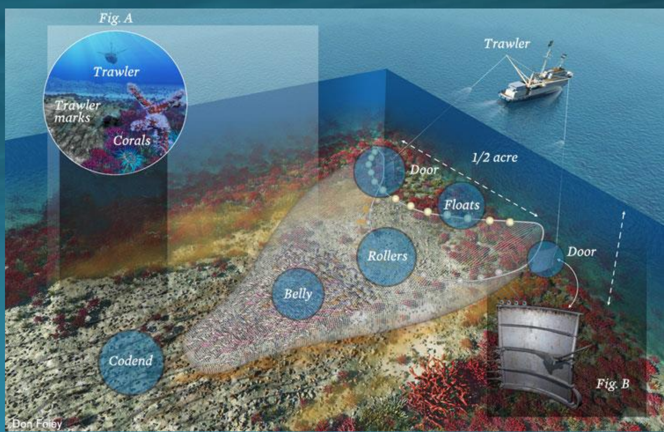
While Siemens NX is the main tool required, any additional equipment or software needs will be evaluated and sourced as the project progresses. The responsibility for the provision of such additional tools will be decided based on the project's progress and requirements.

Appendix B: Project Pitch


Underwater Kite
System for Trawl fishing
Joachim G. Colbensen

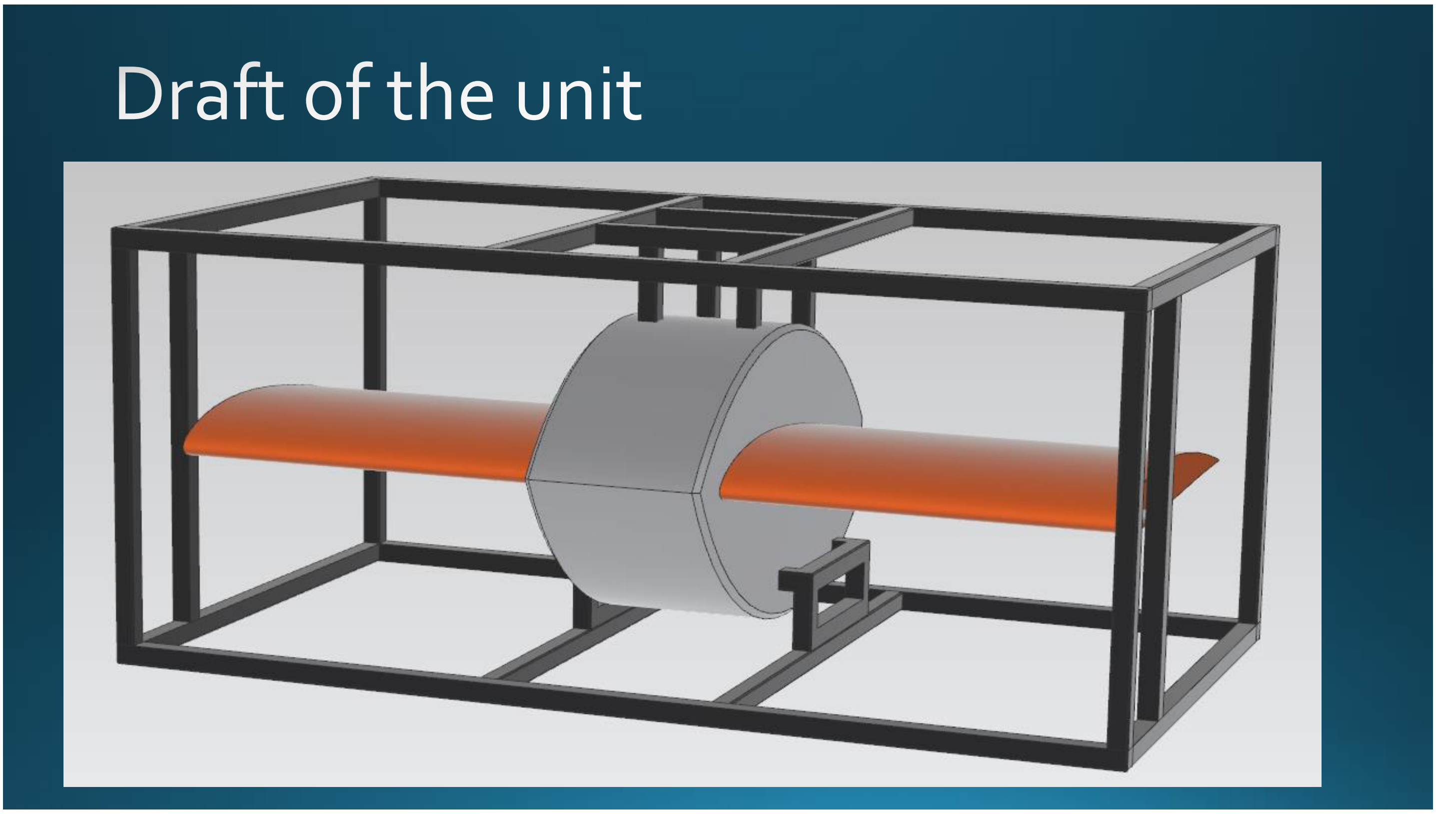
Overview

- Objective: Develop an underwater kite system for trawling to enhance efficiency and reduce environmental impact
- The unit is meant to elevate the trawl bag, and reduce the need of buoyancy balls.
- Key features:
  - Hydrodynamic design
  - Echo-location technology
  - Powerful actuators for optimal wing control
  - Stable underwater performance



Environmental impact on sea bed by bottom trawl.
(https://www.synchronicityearth.org/a-landmark-victory-for-the-deep-seas/)


Design and specifications
• Mainbody: Streamlined, hydronamic shape
• Wings: NACA 6-series
• Protective cage: Lightweight, strong, corrosion-resistant material with a streamlined design
• Sonar system: Small dome or transducer for depth control
• Actuators and control systems: Powerful actuators to control wings pitch; batterypack and control system housed within the main body


Draft of the unit

Appendix C: Project Poster

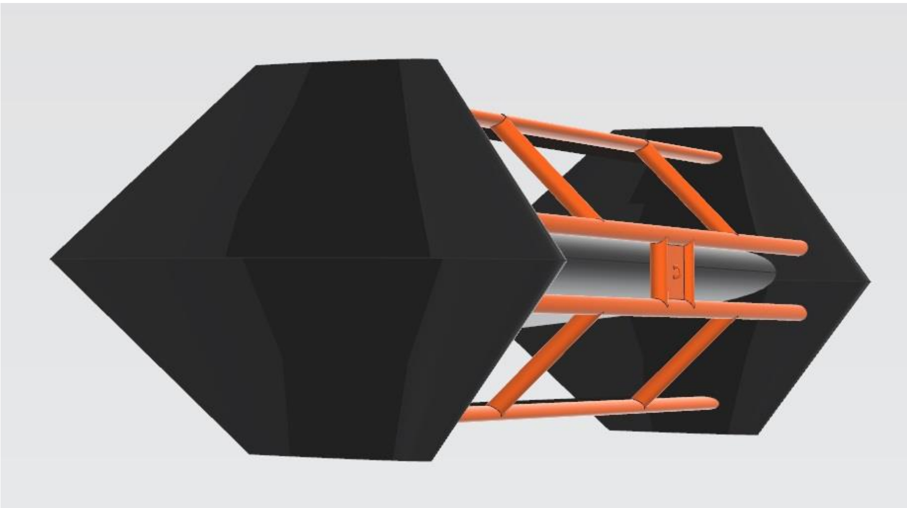
NTNU
Institutt for IKT og realfag

By: Joachim G. Colbensen

Trawl-kite

Autonomous device for use in bottom trawling

Introduction:
This thesis explores the design and implementation of a 'trawl-kite,' an autonomous device aimed at improving the sustainability and efficiency of bottom trawling. It addresses the pressing need for reducing the environmental impact of bottom trawling. The trawl-kite presents a novel approach to fishing that reduces contact between the trawl and the seafloor using a hydrofoil, marking a stride towards sustainable bottom trawling.



Method:
A methodical design process for a trawl-kite system, focusing on both the system's hydrodynamics and the selection of optimal components for efficiency and sustainability.

Results:
The outcome of this thesis includes several trawl-kite design iterations for future simulation, along with a detailed selection of potentially suitable components for the device.

Appendix D: Progress Reports

IELEA2920 Bachelor thesis	Project Trawl-kite	Number of meeting this period. 1	Company - Client Pål Arne Roaldsnes	page 1 av 1
Progress report	Period/week(s) 2	Number of hours this period. Approx. 15	Projectgroup (navn) Joachim G. Colbensen	Date 18.01.23

Main goal/purpose for this periods work - Kick-off the project and set clear objectives. - Balance focus between this project and the parallel subject. - Start looking at the preliminary report.	
Planned activities this period - Initiate the project and establish main objectives and timelines. - Distribute time effectively between this project and the parallel subject.	
Actually conducted activites this period - Successfully initiated the project with clearly set objectives. - Looked at the preliminary report.	
Description of/ justification for potential deviation between planned and real activities - Distributing the time effectively between the projects proved difficult, as the other subject needed a substantial amount of attention.	
Description of/ justification for changes that is desired in the projects content or in the further plan of action – or progress report -	
Main experience from this period - The importance of effectively distributing time and focus between parallel tasks was understood.	
Other	
Wish/need for counceling - None	
Approval/signature group leader Joachim G. Colbensen	Signature other group participants

IELEA2920 Bachelor thesis	Project Trawl-kite	Number of meeting this period 1). 1	Firma - Oppdragsgiver Pål Arne Roaldsnes	Side 1 av 1
Progress report	Period/week(s) 4	Number of hours this period. Approx. 20	Prosjektgruppe (navn) Joachim G. Colbensen	Dato 01.02.23

Main goal/purpose for this periods work

- Continue balancing the project with the ongoing parallel subject.
- Make progress on project objectives as per initial plan.
- Write the preliminary report.

Planned activities this period

- Dedicate appropriate time to both the project and the parallel subject.
- Initiate steps towards achieving project objectives.

Actually conducted activites this period

- Spent a majority of time on the parallel subject, underestimating its demands.
- Limited progress was made on project objectives due to time constraints.
- Wrote the preliminary report.

Description of/ justification for potential deviation between planned and real activities

- The time required to complete the parallel subject was significantly underestimated, resulting in less time being available for this project than planned. As a result, the progress on the project was not as expected.

Description of/ justification for changes that is desired in the projects content or in the further plan of action – or progress report

- It is recognized that a better balance between the two parallel tasks is needed, with a more accurate estimation of the time requirements for each.

Main experience from this period

- Understood the challenge of managing two parallel tasks and the importance of accurate time estimation for each task. The need for improved project planning and time management was recognized.

Main purpose/focus next period

- Continue balancing the project with the ongoing parallel subject.
- Make progress on project objectives as per initial plan.
- Write the preliminary report.

Planned activities next period

- Dedicate appropriate time to both the project and the parallel subject.
- Initiate steps towards achieving project objectives.

Other

Wish/need for counceling

- None

Approval/signature group leader	Signature other group participants
Joachim G. Colbensen	

IELEA2920 Bachelor thesis Progress report	Project Trawl-kite	Number of meeting this period 1). 4	Firma - Oppdragsgiver Pål Arne Roaldsnes	Side 1 av 1
	Period/week(s) 4	Number of hours this period. Approx. 130	Prosjektgruppe (navn) Joachim G. Colbensen	Dato 01.03.23

Main goal/purpose for this periods work

- Start trawl-kite design iterations.
- Continue necessary research.
- Start research on suitable components for the system.

Planned activities this period

- Dedicate appropriate time to both the project and the parallel subject.
- Initiate steps towards achieving project objectives.

Actually conducted activites this period

- Design iterations of the trawl-kite system were developed.
- Much research was conducted.
- Suitable components were researched.

Description of/ justification for potential deviation between planned and real activities

- Activities aligned well with the initial plan. The design iterations of the trawl-kite system were developed as planned, and significant research was conducted, both in terms of system-specific research and component-specific research.

Description of/ justification for changes that is desired in the projects content or in the further plan of action – or progress report

- The current plan of action has been effective, but continuous adjustments may be needed based on further research findings and design iteration outcomes.

Main experience from this period

- The design iteration process and research activities were insightful and provided valuable direction for project development. Additionally, research into suitable components has helped refine the technical requirements of the system.

Main purpose/focus next period

- Mastery of AGX Dynamics software.
- Further refinement of the trawl-kite system design.
- Begin researching self-sustaining power supply solutions.
- Start drafting the project report.

Planned activities next period

- Continue to become proficient with AGX Dynamics.
- Refine the system's design based on insights from research and simulations.
- Initiate research into potential self-sustaining power supply solutions.
- Further explore the components.
- Progress with the project report writing.

Other

Wish/need for counceling

- None

Approval/signature group leader	Signature other group participants
Joachim G. Colbensen	

IELEA2920 Bachelor thesis	Project Trawl-kite	Number of meeting this period. 2	Company - Client Pål Arne Roaldsnes	page 1 av 1
Progress report	Period/week(s) 4	Number of hours this period. Approx. 45	Projectgroup (navn) Joachim G. Colbensen	Date 01.04.23

Main goal/purpose for this periods work

- Complete mastery of AGX Dynamics software.
- Advance trawl-kite design iterations.
- Commence research on self-sustaining power supply.
- Start drafting the project report.

Planned activities this period

- Master AGX Dynamics software.
- Further refine the trawl-kite design.
- Begin research into self-generating power supply options.

Actually conducted activites this period

- Continued progress in mastering AGX Dynamics software.
- Made significant strides in trawl-kite design iterations.
- Did not start research into self-sustaining power supply due to a work-related trip.
- Began the report writing process.

Description of/ justification for potential deviation between planned and real activities

- A work-related sea trip for 20 days hindered the start of research into self-sustaining power supply options and the mastery of AGX. This was unavoidable due to personal obligations.

Description of/ justification for changes that is desired in the projects content or in the further plan of action – or progress report

- In future plans, contingencies need to be made for potential personal obligations that may arise unexpectedly, affecting the project timeline.

Main experience from this period

- It was recognized that unexpected professional obligations can greatly impact the progress of a project. The work-related sea trip set back the initiation of research into self-sustaining power supply and the mastery of AGX.

Main purpose/focus next period

- Finalize proficiency with AGX Dynamics software.
- Continue refining trawl-kite design.
- Begin researching self-sustaining power supply solutions.
- Continue with report writing.

Planned activities next period

- Fully master AGX Dynamics.
- Further develop trawl-kite design based on iterations.
- Initiate research into potential self-sustaining power supply solutions.
- Progress with the project report writing.

Other

Wish/need for counceling

- Continued guidance on AGX Dynamics and starting research on self-sustaining power supplies would be beneficial

Approval/signature group leader	Signature other group participants
Joachim G. Colbensen	

IELEA2920 Bachelor thesis	Project Trawl-kite	Number of meeting this period. 4	Company - Client Pål Arne Roaldsnes	page 1 av 1
Progress report	Period/week(s) 3	Number of hours this period. Approx. 100	Projectgroup (navn) Joachim G. Colbensen	Date 01.05.23

Main goal/purpose for this periods work

- Finalize proficiency with AGX Dynamics software.
- Continue refining the trawl-kite design.
- Initiate research into self-sustaining power supply solutions.
- Continue with report writing,

Planned activities this period

- Achieve full mastery of AGX Dynamics.
- Further develop trawl-kite design based on iterations.
- Begin research into potential self-sustaining power supply solutions.
- Make progress with the project report writing.

Actually conducted activites this period

- Continued learning AGX Dynamics software, but mastery not yet achieved.
- Continued refinement of the trawl-kite design.
- Research into self-sustaining power supply solutions was not initiated.
- Continued with report writing.

Description of/ justification for potential deviation between planned and real activities

- Mastery of AGX Dynamics software continues to be more challenging and time-consuming than initially anticipated, hindering its completion within the set timeframe.
- The research on self-sustaining power supply solutions was not initiated due to time constraints and focus on AGX Dynamics and trawl-kite design.

Description of/ justification for changes that is desired in the projects content or in the further plan of action – or progress report

- The plan to master AGX Dynamics software was overly ambitious given its complexity and the time required to become proficient.
- Research into self-sustaining power supply solutions was postponed due to competing priorities and time constraints.

Main experience from this period

- The complexity of AGX Dynamics was further reinforced, highlighting the need for sufficient time to fully grasp it.
- The importance of balancing project tasks and effectively managing time was understood, as the initiation of research into self-sustaining power supply was delayed.

Other

Wish/need for counceling

- None

Approval/signature group leader	Signature other group participants
Joachim G. Colbensen	

NTNU

Norwegian University of
Science and Technology