BRP 1003
PART 1 OF 4

# Final report Evolo






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| | |
|---|---|
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**Summary**
Evolo is a new type of watercraft that travels on a hydrofoil and is intended for one person. It is powered by an electric motor and is controlled only by means of center of gravity movement. This report presents a brief summary of the results from the project with detailed analysis in appendices. As Evolo's weight was slightly higher than the requirement set out in the project's introduction, there is a risk that requirement 3.2; that the vessel must be able to transport a person weighing 100 kg will not be fulfilled. For an overall picture of how the design work proceeded, see Appendices 76-78. Evolo's design is presented in Figure 1.

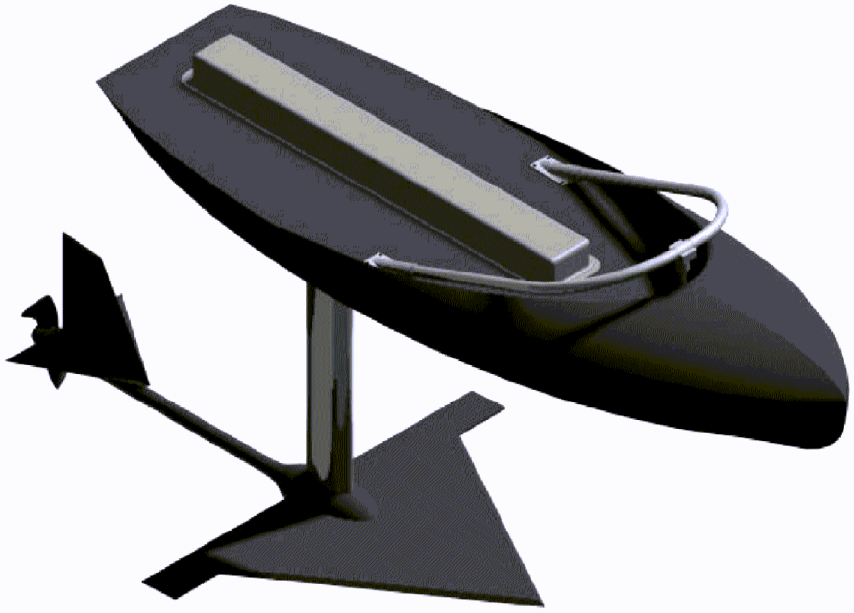


**Figure 1 Evolo's final design**

A general arrangement for Evolo is shown in Figure 2. The quantities defined in the figure are reported in Table 1.

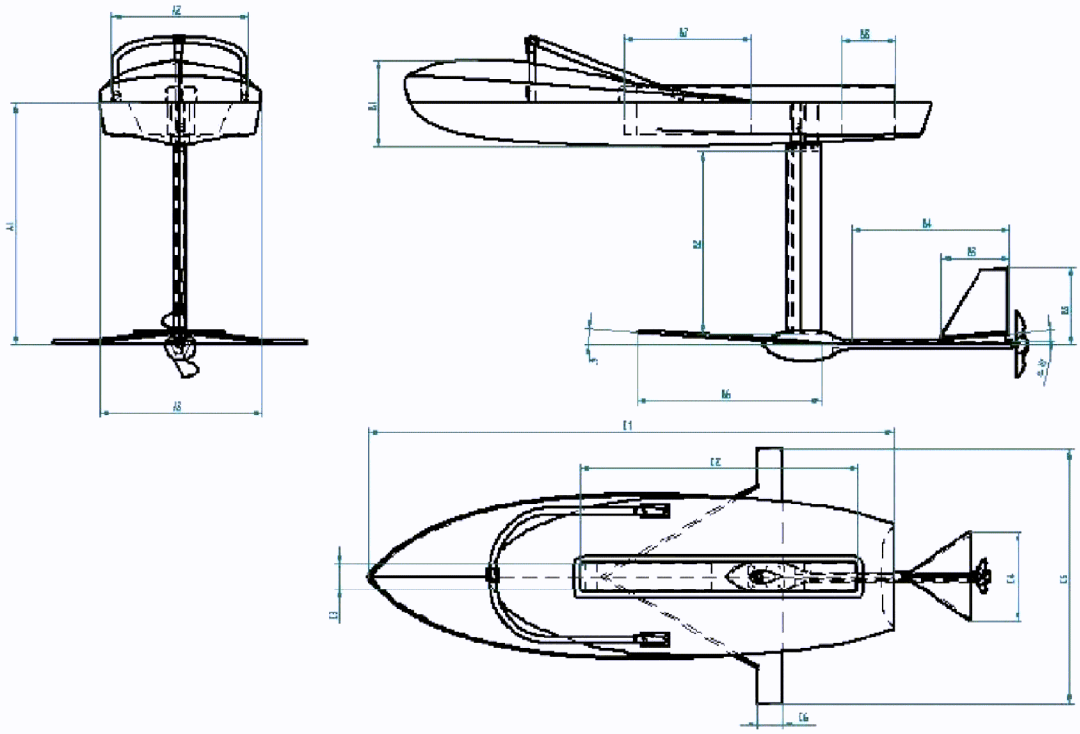


**Figure 2 General arrangement of Evolo**

Table 1 Measures of quantities from general arrangements

| Parameter | Size [mm] |
|---|---|
| A1 | 1065 |
| A2 | 600 |
| A3 | 700 |
| B1 | 380 |
| B2 | 790 |
| B3 | 299 |
| B4 | 695 |
| B5 | 341 |
| B6 | 808 |
| B7 | 550 |
| B8 | 240 |
| C1 | 2313 |
| C2 | 1226 |
| C3 | 115 |
| C4 | 400 |
| C5 | 1120 |
| C6 | 115 |

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## Introduction

Evolo is a modern water toy with innovative design which is aimed at active people. Target group survey is shown in Appendix 1. The goal of the project is to create a new way of playing on water without disturbing the surroundings with e.g. sound and surge, but still have fun. To minimize energy consumption and meet an environmentally thinking profile, Evolo is based on hydrofoil technology, which lifts the floating body out of the water and thereby reduces Evolo's resistance and power requirements. With regard to Evolo's environmental profile, an electric motor was chosen for propulsion. Its location below the water surface also reduces the motor's already low noise profile. The requirements that drove the development of Evolo are shown in Appendix 4.

## Floating body

The design of the floating body is inspired by a Riva boat, see Figure 3



**Figure 3 The source of inspiration for Evolo's floating body**

The floating body has sufficient volume to be able to stay afloat with the driver. It also has room for batteries. The floating body is made of carbon fiber according to the sandwich principle, the superstructure is also made of carbon fiber. An image of the floating body is shown in Figure 4.

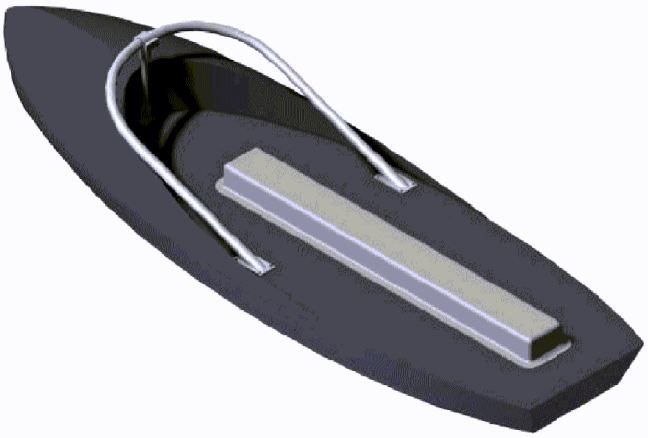


**Figure 4 Illustration of Evolo's floating body**

Detailed investigations involving the floating body are reported in Appendices 6, 8, 14, 19, 27, 28, 36, 43,57-64.

## Strut

The strut is the part that connects the floating body and the hydrofoil. It has the shape of a wing to reduce the resistance but also to increase the course stability. When the strut is considered, only the carbon fiber cover layer is seen as supporting, despite the fact that it has a certain core and a metal rod runs inside it. This is because the metal bar cannot absorb all the forces and moments as it does not run through the entire strut. The metal rod is part of the original motor structure and is retained as it has a guaranteed waterproof link down to the motor bulb. A figure of the strut is shown in Figure 5.

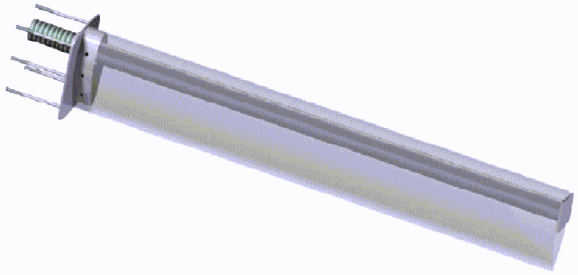


Figure 5 Illustration of Evolo's strut

Detailed investigations that include the strut and its mountings are reported in Appendices 7, 11, 15, 18, 21, 39, 57-59.

## Hydrofoil/underwater body

Evolo's underwater body and hydrofoil placement are made to work with Torqeedo cruise 4.0 *R. As can be seen in Figure 6 below, it was chosen to integrate the motor in the front hydrofoil and that the propeller is placed behind the aft hydrofoil.* The propeller shaft runs from the motor to the propeller inside a carbon fiber stay.

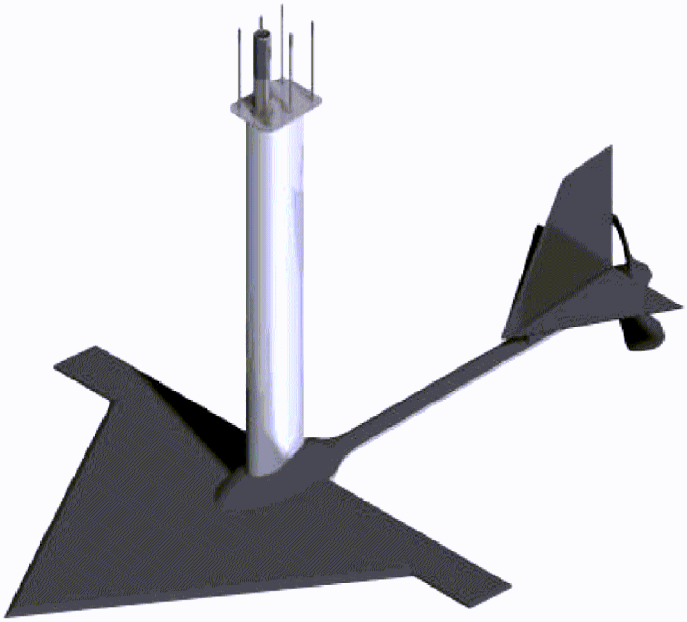


**Figure 6 Illustration of Evolo's underwater body**

For a clearer account of the underwater body and hydrofoil, see Appendices 5, 7-10, 14, 15, 17, 24, 38, 42, 45, 46, 50, 57-64, 70.

## Handle/steering handle

The handles on the Evolo are designed for a kneeling driver's position. Its appearance is shown in Figure 7. The handles are made of aluminum that is curved to the correct shape and its mountings to the floating body are made of stainless steel, see Appendix 40. Documentation for the construction is presented in Appendices 12, 25, 28, 47.



**Figure 7 Illustration of Evolo's handle**

The throttle handle is located on the handle rail. An illustration of how the throttle works is shown in Figure 8 below. This is designed like a bicycle brake, see Appendices 20 and 44, and its wiring is passed through the strut down to the motor and its control unit. Documentation for the construction is shown in appendices 20, 21, 28, 72.

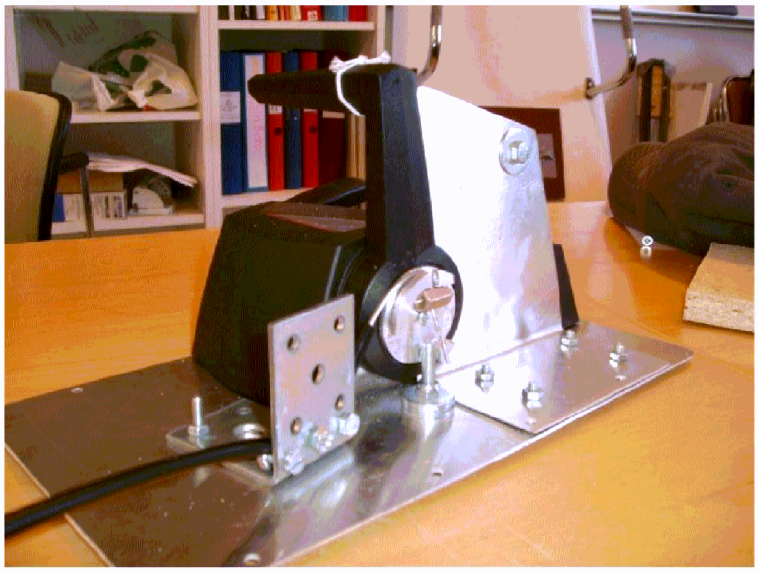


**Figure 8 Picture of Evolo's control system**

## Propulsion

### *Motor*

The motor for Evolo was chosen after extensive investigation, see appendices 19, 22, 64, 71, 72, to *Torqeedo cruise* *4.0 R*. This is because this motor delivers the power required to drive the Evolo to the flying position, without weighing too much. Another, probably driving, reason for a Torqeedo cruise 4.0

*R* chosen for Evolo is that an motor from the same manufacturer was already available. The motor was placed after investigation, see appendix 17, integrated in the front hydrofoil, with a shaft to the propeller in the aft hydrofoil.

***Batteries***

In order to be able to use the selected electric motor, new batteries were purchased for the project. The batteries are manufactured by Thunder Sky, Appendix 39, however, the decision to purchase the company's LCP batteries in favor of LFP batteries was changed. This is to minimize the risk of explosion. The batteries were then purchased from the company *Elite Power Solutions*, ,http://elitepowersolutions.com under the name EB 40 16. To get a fast and smooth delivery. A battery charger from the supplier was also included. There are 16 batteries. Lithium Iron Polymer cells at 40Ah. These were chosen as they have superior power in relation to their weight, and that they are still affordable in price.

***Propeller***

In order to have an advantageous propulsion system for Evolo, there were originally two alternatives: Either the motor can be switched and a standard propeller used or a propeller dimensioned for Evolo is manufactured. The latter alternative was chosen as this is considered more instructive and it is not considered more cumbersome than the work of a switch. The finished propeller is shown in Figure 9.



**Figure 9 Propeller manufactured for Evolo**

To determine how the propeller for Evolo would be designed, blade element theory is applied, according to Appendix 16. The estimation of the resistance of the vessel has been based on a combination of the experimentally measured and the analytically calculated resistance, Appendices 8, 16, 33 62.

The theory behind the propeller is described with its assumptions and limitations in the report 16. The propeller's dimensions optimized for *Torqeedo cruise 4.0 R* and for a design speed of 12 knots. The reason for the lower speed than 15 knots was that Evolo's weight became higher than intended.

## Materials/Manufacturing

Sandwich construction has been used as much as possible to minimize the weight of the vessel. The surface layer consists of carbon fiber, see Figure 10, vinyl ester and the core material is Divinycell H45. The decision to use carbon fiber is based, among other things, on its good mechanical properties and that it has a higher specific E-modulus than fiberglass. The material weight of the vessel is thereby halved compared to fiberglass, see Appendix 30. Vinyl ester is a thermosetting plastic and is used because it has good resistance and that it can withstand moisture. Epoxy would have been preferable but could not be used due to health risks.



**Figure 10 Carbon fiber, which is the type of fiber used in the manufacture of Evolo**

The manufacturing method has mainly consisted of vacuum injection.An example of vacuum injection is shown in Figure 11.



**Figure 11 Vacuum injection of stern hydrofoil with stabilization wing**

In necessary cases, hand placement has been used due to the fact that certain components have advanced structures or shapes. To ensure the mechanical properties of the materials, tensile tests are

performed. All manufacturing and testing has been performed in Lightweight Structures laboratory permises at KTH. An overview of the mountings between the various components on the Evolo is shown in Appendix 26.

Detailed investigations of Manufacturing/Materials are reported in Appendices 13, 30-32.

# Economy

## *PR/Sponors*

The work of finding sponsors for the project went very slowly at the beginning of the project until the end of the autumn term. A major reason for this was the prevailing recession, which meant that most companies became very hesitant to sponsor various projects. Another contributing reason was that most companies did not want to provide sponsorship as the project was still just work in theory and no product had yet started to be built. An overview of the sponsorship work is initially shown in Appendix 65. However, this turned around at the beginning of the spring semester. This can be explained, among other things, by our success in KTH's advertising campaign KTH på insidan, where the project went on from a competition to represent KTH for advertising purposes.. The increased exposure given to the project and the fact that the construction of Evolo had then begun, which gave a physical product to show off, meant that the project received a number of sponsors. A summary of Evolo's finances, PR and sponsorship is presented in Appendices 2, 56, 65-69.

As part of the information flow to the outside world, a separate website has been set up, ,www.evolo.se there, pictures, films, sponsor links and a continuously updated blog have been posted. As part of the assignment for KTH på insidan, the group has also blogged on KTH's website at regular intervals.. The project has also been mentioned on several marine forums on the internet.

# Discussion

In this part of the report, a discussion will be held and conclusions will be drawn from the project in general, it will also be reported what experiences have been drawn and proposals for improvement are proposed.

## *Summary*

The whole project has in many ways gone well during the academic year. There has been good support for meetings and other project-related commitments. The whole group has worked well and a lot of time has been spent on the project. At the time of submission of this report, the group has spent a total of 5066 hours. To show how much time was spent each week and in total during the project, Figure 12 and Figure 13 are shown below.

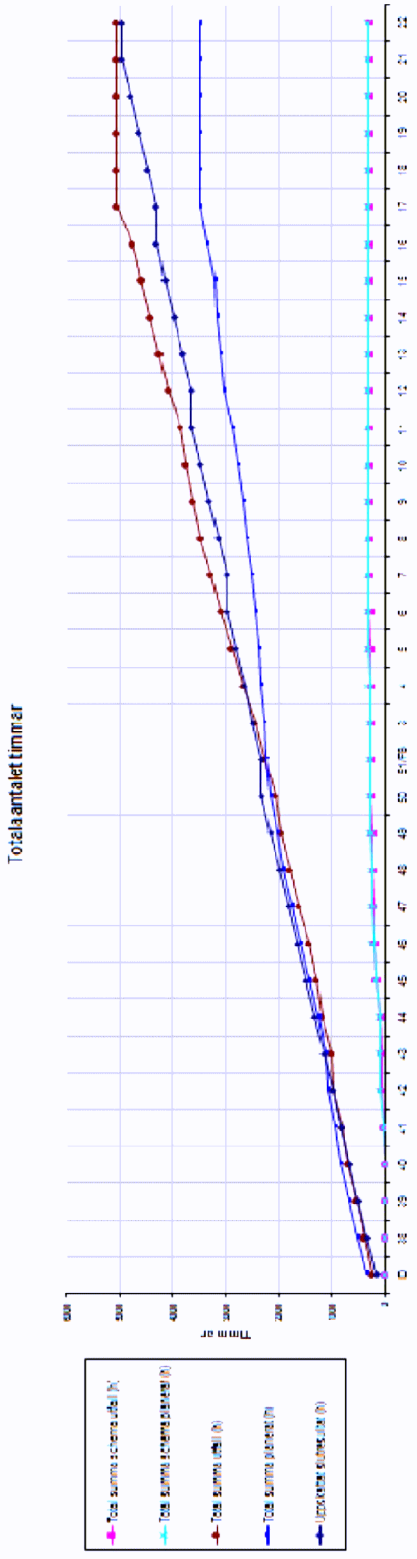



Figure 12 Time spent, in total

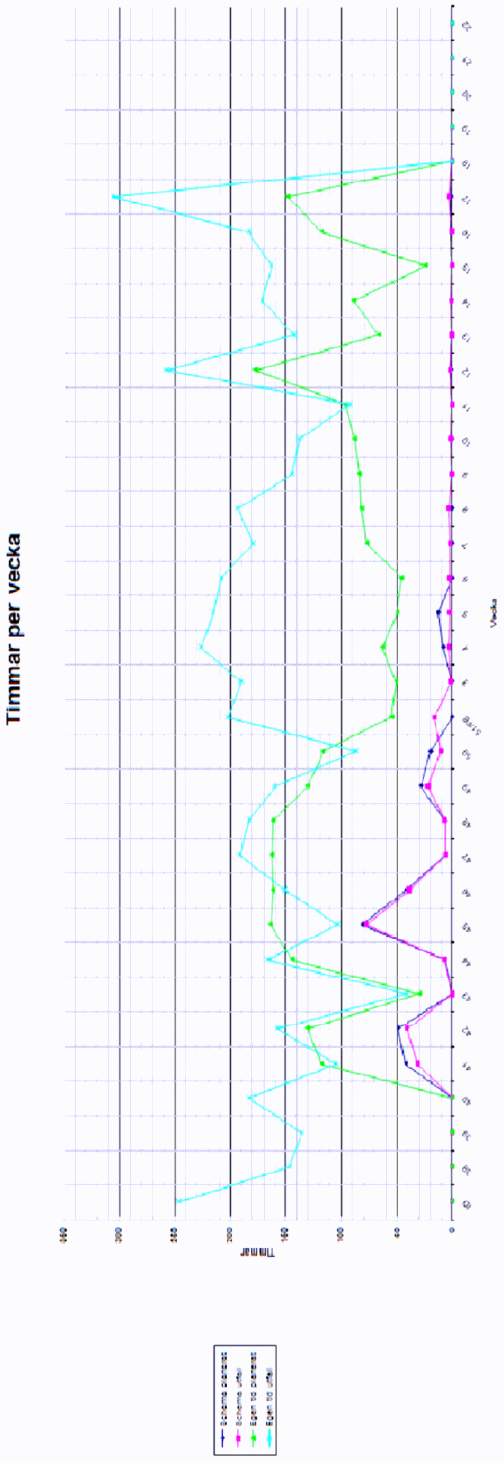



Figure 13 Time spent, per week

In the figures on the previous page, it is clear when it is exam week, for example week eleven, and less time is spent on the project. It can also be seen that the group worked the most now in the end. The majority of the project group is shown in Figure 14.



**Figure 14 The project group, with supervisors**

The two biggest bottlenecks when it comes to time consumption were waiting for materials or components as well as mistakes in the manufacture of components. The mistake that was made was often because the communication was not always the best but also because the experience of the creation was not so extensive in the group, then excluded the group members from Light Constructions.

Another time-consuming factor was also misunderstanding when it came to which questions to answer and which answer was expected. This was mainly a problem in the initial stage of the project when the group members were unfamiliar with the form of the work and that it was then not entirely clear which task would actually be solved. But the project has also had its ups and downs with reduced commitment and motivation. A typical example of this is when we did not know what the economy would look like and if we could construct an Evolo at all. Poor response from sponsors, due to the prevailing recession, and uncertainty as to whether we would move forward in KTH på insidan were probably the biggest reasons for this decrease in commitment and motivation.

As this is a project with the aim of developing the participants' ability to work in groups as engineers, it is important that the project group's roles are rotated. However, it is inevitable to lose momentum in a project change of leadership. In order for the work speed not to decrease and for the group to have clear management, it is an advantage if an incoming project manager gets to know it before the change of leader.. If the incoming project manager, for example, has the Christmas holiday to prepare the work, not as much time is lost.

In summary, the work efforts in the project have maintained a high standard. The morale of the project members has been high as this course encourages commitment more than other courses. The members place dignity in completing the assumed task and with as high a quality as ever possible.

### *Experiences and suggestions for improvement in the coming years*

The project has progressed very well. The setbacks encountered were resolved relatively quickly and this is largely due to the fighting spirit shown by the project members. To maintain good productivity, good morale is required in the group. As an example, cake and rum were served for the whole group on certain occasions. The group also had a very successful event, as the preliminary report was presented in a relaxed manner at the Aviation Section's section room and pub. Previous years' students and representatives from the industry in question were invited to this. This was very well received and should be repeated in future courses as it really built on our relationship with each other and gave a good end to the autumn semester.

## Experiences

- Good morale on the project members gave good results
- Short deadlines were a good method for delivering results
- Good to work in groups of a maximum of two people or individually
- It is important to have clear recommendations after solving the task
- It is important that the project members can stand up for their solutions
- Clear information means that the project gets answers to the right questions
- It was very difficult to plan a project of this size without a fixed budget
- The time reporting did not work quite well, due to carelessness by project members
- A weak financial situation gives great difficulties with sponsors
- Getting goods delivered takes a lot of time and work

In summary, it is important to be careful about setting up tasks that are given to small groups with short deadlines. Everyone in the project must work to get the tasks done on time so that the project does not suffer. The same applies to, for example, time reporting. This must be done seriously as otherwise it will be impossible to plan the project. Having good foresight with ordering and building as early as possible in the project means that a very stressful ending can be mitigated. As it is easy to make mistakes either depending on developed technologists or faulty equipment, it is also necessary to order more when ordering consumables.

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## Appendix 1 F1.Target group and market

Written by Erik Jerilgård and Torvald Manners

### *Basis*

We have conducted an interview with a company that sells Air chairs to order. This is attached as an appendix to this document. We are working to get a little more information from, above all, Air chair users or sellers in Sweden. In other respects, we have used the web to try to form an idea of which attributes above all seem to attract practitioners of water sports with a bearing on our product.

### *Results*

General features that seem to be important for successful products:

- Speed
- Close contact with the water
- Differentiated difficulty scale, i.e. relatively easy to use but at the same time endless possibilities for those who want to become professionals and that the development steps between different levels are not too great
- Physically strenuous
- Design that stands out
- Differentiated price

Examples of these products:
Wakeboard, jet ski, waterskii, RIB boats, kayaks
General features (in addition to the opposites above) on products that have not been so successful:

- Difficult for ordinary people to understand how they work
- Geeky
- Too hard to use
- Too expensive
- Few uses, i.e. you get tired of it
- Dangerous

Examples of products that have not been so successful:
Air chair and hydrofoils solutions in general, monoski,

### *Trends*

The vehicles and toys used on or in water have, paradoxically enough, despite their proximity to an extremely sensitive environment, historically not been characterized by particularly widespread environmental thinking. However, there is a clear trend that this is turning around and what we are now seeing of environmentally friendly solutions is probably only the beginning of a changed attitude, but also probably something that will be followed by much stricter legislation.

### *Recommendation / Conclusion*

We do not believe that the success of our product lies in reaching a small narrow target group, but rather trying to attract a wider range of people. At the same time, it is unrealistic to believe that this is a product that will revolutionize the world and become everyone's property. However, we do not want to point to a target group but rather to the characteristics of this potential target group. The most important characteristics of this are:

- Environmentally conscious
- Youthful
- Normal to high income
- Previous experience in water sports
- Proximity to a suitable area of practice

## *Appendix 1.1*

Interview with anonymous shop assistant at Skimarine in Stockholm
Skimarine is one of the major retailers of Wakeboards and other water toys. However, they only sell Air chairs to order due to very little demand. According to her, they had not sold anyone in 10 years. She herself had used it a lot many years ago when they came on the market. It was a bit tricky in the beginning before you learned to start, but it should not be overly difficult and once you have made a successful start, you can do it again. Much like cycling was her description of the difficulty of being able to start. An important detail was how high you held your hands and that your upper body ended up in right position. To initiate jumping, you changed the height of your hands and to steer, you leaned in one direction. Her theory as to why it did not hit more was above all that the price is too high and that you get tired of it quickly.




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| Date: | *2/12-2008* |
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| Reviewed by: | *Mattis Kennestad* |

## Budget

The purpose of setting the budget for the project is to illustrate possible costs, their scope and when they may arise. Due to the nature of the project and the difficulty of determining a specific cost size at an early stage, the budget is largely based on estimates and the information search carried out on certain components. Examples include the cost of an motor or batteries that are not yet ready. We can only start from those we know of motors that could be suitable before we know which one will actually be used.

### *Costs*

Table 1 below shows the costs that have so far been identified and valued. Most of these are estimated values based on estimates based on what we know today about our end product. The costs that will be prioritized are of course those that are directly linked to enabling Evolo to fly in May.

| ***Costs*** | |
|---|---|
| Motor | 25 000 SEK |
| Batteries | 20 000 SEK |
| Controls/electrical components | 2 000 SEK |
| | |
| Core | 3 000 SEK |
| Fiber | 5 000 SEK |
| Matrix | 2 000 SEK |
| Metal | 1 000 SEK |
| Experiment | 5 000 SEK |
| Varnishing - painting | - |
| | |
| Allt för sjön* | 25 000 SEK |
| Panels/Print | 1-2 000 SEK |
| Website | 450 SEK |
| Profile clothes | 3,500 SEK |
| | |
| ***Subtotal*** | ***About 94 000 SEK*** |
| | |
| *Assets* | |
| Fund money | About 20 000 SEK |
| (any material from the previous year) | |
| | |
| ***Total*** | ***About 74 000 SEK*** |

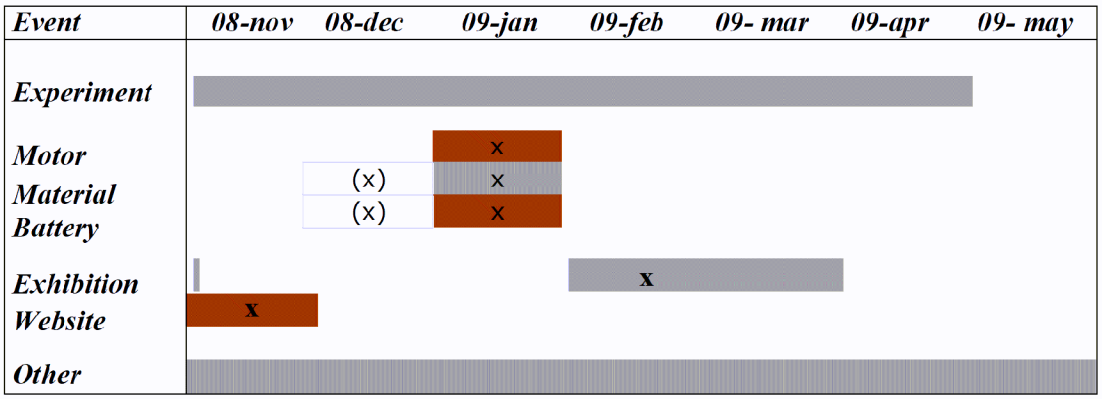
*Table 1. Costs for the project.*

* *Participation in the exhibition Allt för Sjön is still unclear due to schematic difficulties.* In the event that they could not be solved, the costs of the project are of course reduced, but

at the cost that we lose a great opportunity to show ourselves to the public and create interest in our project.

### When do the costs occur?

Many of the costs are related to specific dates or periods. For example, costs for materials fall at the end of January, while other costs such as the website and experiments arise already in the autumn and to some extent continuously. The diagram below illustrates this distribution. Events in parentheses then mean that it would be desirable for the current cost to arise and the material to be within our reach. By other is meant less unforeseen expenses that may arise.




### *What do we have today?*

The project has about SEK 20,000 from KTH at its disposal. As can be seen above, these will not be enough to finish the project. The goal is for our excess costs to be covered with the help of sponsors. More about this will follow in future headings.

A very interesting alternative that has been presented to the group is *KTH på insidan*. An initiative from KTH's management to highlight student projects conducted at the school for the public. The group agrees that we should apply to participate in the competition. The three winning entries will be financially supported with SEK 75,000, which for us would ease the financial situation and reduce the work of hunting for sponsors. In addition to the financial support, an advertising agency will also follow and help the group to document the work, as well as reach out to the outside world. More information about this can be found on KTH's website and

From last year's project, some components are available. At the time of writing, it is unclear whether these will suit our design. The components that may be of interest today are motors, materials and batteries. The uncertainty today lies partly in the uncertainty surrounding the need for power.

### *Handling*

Most of the purchases that must be made in connection with construction and experiments will be made individually by the people involved. In order to supervise the project's expenses, any purchases must always be checked by the person in charge with the finance manager. Receipts of purchases must be

collected in the project folder that is in the pool under the tab economy. Based on these receipts, money will then be paid back to the person or persons who paid for the purchase. In the event of major costs, purchases will of course be handled in direct connection with the sponsor / supervisor concerned and the finance manager.




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| | |
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| Course: | Marine design/Lightweight design |
| Project: | *Evolo* |
| Date: | *07/10 2008* |
| Version number: | *1.1* |
| Supervised by: | |
| Hours worked: | *70* |
| Reviewed by: | Mattias Schönning |

## *Background*

This project is a part of the courses Lightweight Design (course code SD2432) and Marine Design (course code SD2702) which is given at KTH during the academic year 2008-2009. The project aims to give all participants an opportunity to use the knowledge acquired during the education and to apply the knowledge both practically and analytically to the development and production of a watercraft. The project also aims to give participants an opportunity to make contacts in working life and to get a feel for what it is like to work in a project group.

Previous versions of this course have been shown to be much appreciated by both students and working life as it contributes with useful experiences that everyone can take with them further into working life. The course structure is based on the participants themselves being able to organize themselves and assign different positions within the group in order to have a functioning organization.

Before the project phase began, a concept study took place for two weeks together with students at Industridesign at Konstfack. The concept generation led to the course management selecting two concepts that would form the basis for this project's requirements specification.

The reference documents that have formed the basis of this project plan are:

- lecture on project planning by Joakim Lilliesköld on 30/9 and lecture notes from this
- a group contract signed by all participants in the project
- a course pm that indicates the course and thus the project's time frames
- the requirements specification which states what requirements are placed on the final vehicle and what rules and values we worked on the basis of

## *Goal*

This project will in many ways be a final part of the education at KTH. The participants thereby agree that the goal is high in terms of achieving what is stated in this project plan. The goal is to stay within the time frame and to deliver interim reports, presentations, etc. no later than the set date until the project ends on April 25, 2009.

## *Organisation*

The organization of the project is divided into management and working group. The management consists of a project manager, two technical managers and a manager for finance and PR. The technical managers are divided into experiments and analysis. The working group is fluid and is distributed during the project to the tasks that need resources, with the project participants' interest in focus.
Organization and roles are described in Figure 15 below.

1. See requirements spec.

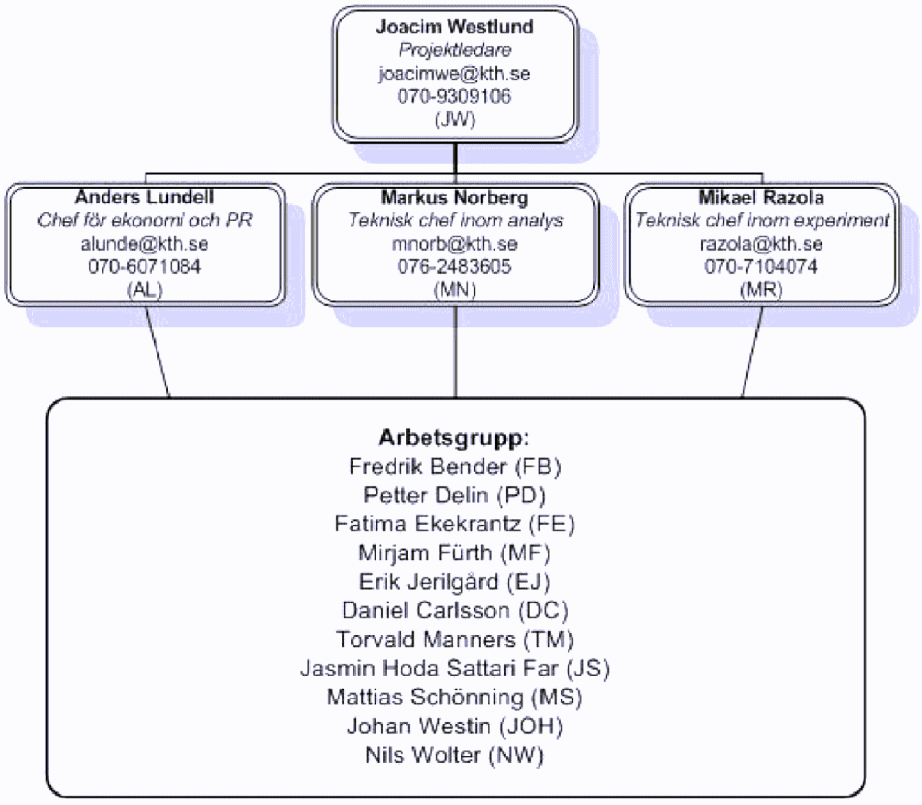



**Figure 15 - Organization and roles**

## *Responsibility*

The ultimate responsibility for the project lies with the project manager. Thus, the project manager is responsible for, among other things, submissions on time and that the project works. The activities that are referred to as design activities are also the responsibility of the project manager. In the same way, the ultimate responsibility for analysis activities lies with the technical manager within analysis, experimental activities with the technical manager within experiments and financial activities with the head of finance and PR. However, the responsibility for individual activities is free for management to delegate.

## *Decision making*

The person from the management who delegates an activity is responsible for decisions regarding this activity. However, decisions are also free to delegate in advance, either to the activity performer or upwards in the organization, where the highest instance is the entire group in consensus.

1. See requirements spec.

## *Project model*

The project is divided into six phases, see Figure 16 below. In the figure, the milestones are placed on a time scale and the phases of the project are described below this.

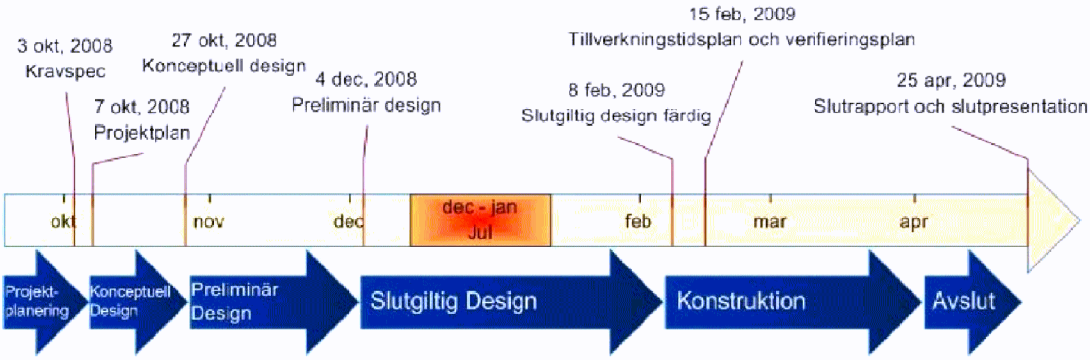



**Figure 16 - Project model**

## *Time and Resource Planning*

The project has been planned with reverse planning and activity breakdown. Based on this, activities have been located in a WBS (Work Breakdown Structure) and set up in an Activity List (Sheet 1 in the Excel file Appendices to the Project Plan). Based on this, the management has in turn estimated the time required for all activities and set up a schedule, after which the start date and deadline for the activities in the near future have been specified and entered in the activity list. The schedule is set up in the form of a Gantt schedule and is Sheet 2 in the Excel file Appendices to the Project Plan. The schedule also includes an estimate of how many people (resources) are needed for each activity.

The project operates in a dynamic environment where there is a great risk that unpredictable circumstances will affect the project. At the same time, it is a project that aims to develop a new product with relatively loose requirements and specifications that makes it impossible to predict what will need to be done in the future. For these reasons, the project is scheduled only until the presentation of the preliminary design on December 11, further planning would be unnecessary work.

The project is divided into a number of activities that the management has identified and appreciated with regard to time and resources. The activities have been titled with an identification number (ID) and name, and they fall into four main categories; Analysis (ID A #), Experiment (ID X #), Economy (ID E #) and Design (ID D #). The project group has half Tuesdays and Thursdays to work on the project, which is why the weeks in the schedule are divided into two. With short deadlines and personal responsibility, the work with the project becomes easier to follow up and more efficient, which is why the planning is done so that the activities are as small as possible and include as few people as possible. The first time is planned in detail while the future is planned in a little less detail and with great opportunities for change and resource redistribution. The planning is also done so that there is a buffer in the form of both time and resources before the submissions.

1. See requirements spec.

In general, the project is planned keeping in mind that the development of a watercraft is an iteration process where few things can be decided purely analytically and where it will take time to come up with a satisfactory solution, and even longer to come up with a really good solution. Many planned activities aim to develop a model that you can easily change input data to.
At the same time, two experiments are given the opportunity to compare with, and assess the reasonableness of, mathematically produced data.

### *Risk assessment*

In addition to the deadlines for external deliveries set by our client, there are other loopholes and risks within the project. We have chosen to divide the project into parallel stages at an early stage, where different parts are developed simultaneously. The advantage we see in this is to minimize the risk of the whole project getting stuck due to a smaller subproject getting stuck. These two stages will eventually be brought together before the critical dates for the determination of preliminary and final design, which will be very critical points in the planning. If one of the two lines ends up too far behind, the whole project will suffer.

To counteract this happening, the project has been divided into several different smaller sub-projects and activities to more easily follow the development. At the same time, the organization between the ranks is kept afloat to enable resources to be shared or moved between different activities.

Another critical aspect that can delay and affect the development of the project is the financial side. In order to prevent the economy from becoming a problem, emphasis is placed on this early and continuously. We have already learned from the members of the previous project who pointed out that this point should not be expected.

In addition to these risks, there is also the fact that all project members in addition to this project have several different courses and interests that affect us. Even if most of the project time is scheduled, there will be phases when the workload becomes high and the project may clash with other things. Or vice versa when the external workload affects the time it is possible to spend within the project. In general, we can find these situations around exam weeks and will therefore try to plan along these so as not to negatively affect other courses. The fact that everyone feels that the project does not go beyond other studies also strengthens the spirit of the group.

### *Document management*

All activities should result in a report of varying scope, which will often serve as a basis for the next activity. The documents must always be saved in two places, with the author and on the internet (Bilda), and the file name must contain name and version number. On Bilda, the documents belonging to an activity are saved in a folder titled with the activity's ID number and name. These activity folders are placed in one of the four main folders Analysis, Experiment, Economy and Design. In addition to the main folders, there is the folder General documents, which includes requirements specification and project planning. The project manager is responsible for backing up all files on Bilda.

1. See requirements spec.

All points in the requirements specific apply regardless of time. Ie. in order for a point to be fulfilled, all other points must also apply.

*The vehicle shall:*

1. Design:

    1.1. Be a playful means of transport.
    1.2. Use a hydrofoil solution at cruising speed.
    1.3. Have a device that prevents the driver from being injured by the propeller.
    1.4. Have dead man's grip.

2. Stability:

    2.1. Be able to float and balance in a stationary position with the driver.
    2.2. Performed in a controlled manner.
    2.3. Controlled by means of center of gravity shift.

3. Performance:

    3.1. Be electrically powered.
    3.2. Be able to transport an adult of 100 kg.
    3.3. Have a cruising speed of 15 knots.
    3.4. Can be performed at cruising speed for a minimum of 40 minutes.
    3.5. Do not weigh more than 70 kg.

4. Environment:

    4.1. Resist wet and Swedish spring and summer climate.
    4.2. Clear stresses from the motor, ie. heat and vibrations.
    4.3. Follow current requirements for noise and environmental impact according to SJÖFS 2005:4.
    4.4. Be able to be transported with a B driving license on land.

5. Framework:

    5.1. Be ready to drive within the schedule, ie. on 25/3 -09.
    5.2. Produced within financial and time budget, ie. SEK 20,000 plus possible sponsorship money and 8,000 hours.

1. See requirements spec.

# Appendix 5 A1. Hydrofoil calculation

## Hydrofoil calculation

MARKUS NORBERG

**IN COOPERATION WITH:**

MATTIAS KENNESTAD

TORVALD MANNERS

MIRJAM FÜRTH

| | |
|---|---|
| Course: | Marine design |
| Project: | Hydrofoil |
| Date: | *30/10-2008* |
| Version number: | |
| Supervised by: | |
| Hours worked: | *20* |
| Reviewed by: | |

1. See requirements spec.

3098022.v1



CONFIDENTIAL

1. See requirements spec.

3098022.v1



CONFIDENTIAL

## Introduction

The purpose of this report is to give the reader an idea of the dimensions of the hydrofoil that will be required to meet the set requirements.[1] The technical study carried out in this report and the results that follow from it are not definitive.
The design process of the hydrofoil is progressing, but the results from the technical investigation described here form the basis for the continued work. The study in this report includes calculations on straight hydrofoil wings and delta wings.

[1] See requirements spec. (See Appendix 1)

## Problem formulation

The purpose of the study is to analytically determine what dimensions will be required on a hydrofoil. The requirement placed on the hydrofoil is that a lifting force of 1700 N must be able to be generated in the speed range that is interesting. In this case, the speed range is from 0 knots up to 20 knots. To tackle the problem, a lifting speed must be adopted. Lifting speed means the speed at which the vehicle lifts up on the hydrofoil. After this speed has been assumed, the wing area required to achieve the given lifting force at the lifting speed can be calculated. To perform the calculation, assumptions are made regarding the lift coefficient, these assumptions are further described in the analysis. When the wing area is determined, a certain perception is created of what the hydrofoil should look like. However, a hydrofoil with a certain area can have many appearances, therefore a variable called aspect ratio is introduced for the straight wing. Aspect ratio is a relationship between the hydrofoil area and the wingspan. Since the area is determined, the wing span can now be varied to find the most suitable hydrofoil. For the delta wing, the appearance is given by the opening angle. By opening angle is meant the top angle of the delta wing.

## Analysis

The starting point for the problem is to employ a lifting speed for the craft. This speed is set to 6 knots. This assumption was made on the basis that the lifting speed wants to be kept as low as possible, because the faster the craft lifts up on the hydrofoil, the less power is required. Then the wing area is calculated using an equation to calculate the lifting force.[2] This equation is rewritten so that the wing area is calculated instead according to:

$$A = \frac{L}{0.5 \cdot \rho \cdot v^2 \cdot CL} \qquad (1).$$

Where $L$ is the lift force of Newton, is the density of water in kg/m$^3$, v is the speed of the vessel in m/s and $CL$ is the three-dimensional coefficient of lift. The value of the lift force is obtained from the requirements spec (See Appendix 1). According to the requirements, the vessel must weigh a maximum of 70 kg and be able to carry a person weighing 100 kg, which leads to a total weight of 170 kg. This means that the hydrofoil must generate a lift force of approximately 1700 N. The density of water is approximately 1000 kg/m$^3$.
The speed had been assumed to be 6 knots, which corresponds to about 3 m/s. To determine the value of the lift coefficient, certain assumptions must be made. One of the assumptions made is that when lift speed, the maximum lift coefficient can be taken out, ie. the angle of attack is equal to the stable angle. Here, the calculations for straight wing and delta wing differ. The same approach is used but the calculations are done in different ways.

### *Straight wing*

The maximum lift coefficient of the wing is set to 1.5.[3] It is important to keep in mind that this coefficient is for the two-dimensional case. To convert the two-dimensional coefficient to a three-dimensional, it is used that the 3-D coefficient is about 90% of the 2-D coefficient.[4] This conversion can be done when the hydrofoil wing has an aspect ratio greater than 5. This gives a $CL$ of 1.35. With all these values inserted in (1), the following is obtained:

$$A = \frac{1700}{0.5 \cdot 1000 \cdot 3^2 \cdot 1.35} = 0.24\text{m}^2 \qquad (2).$$

Now that the area required to meet the lift requirement at 6 knots has been determined, use (1) again. This time to determine the $CL$ required at each speed. As even a lift force as possible in the entire speed range is desirable, so the lift force is set constant. The speed varies between 6 and 30 knots, $CL$ is calculated according to:

$$CL = \frac{L}{0.5 \cdot \rho \cdot v^2 \cdot A} \qquad (3).$$

[2] J.Kuttenkeuler. Segling så funkar det. s.44.
[3] J.Kuttenkeuler, Segling så funkar det, s.56-64.
[4] John D.Andersson. Aircraft performance.

A good way to compare different hydrofoils is to calculate the resistance that the hydrofoil generates.[5] This resistance is calculated according to:

$$D = 0.5 \cdot \rho \cdot v^2 \cdot A \cdot CD \qquad (4).$$

In this equation, everything is known except *CD*, which is the three-dimensional coefficient of resistance. This coefficient consists of two parts according to:

$$CD = CD_0 + CD_i \qquad (5).$$

$CD_0$ is a coefficient of resistance that refers to the lift area to the wet area, the wet area is estimated to be about 4 times as large as the lift area. If the wet area is estimated, the resistance of the entire underwater body is covered. $CD_0$ is calculated according to equ (6) where $CD_f$ is the coefficient of friction which is estimated to be between 0.0034 and 0.0055[6] and S is the lifting area and $S_{wet}$ is the wet area.

$$CD_0 = \frac{S_{wet}}{S} \cdot CD_f \qquad (6)$$

$CD_i$ is called the lift-generated resistance coefficient. This occurs due to the overcurrent that occurs at the wingtips. The overflow contributes to the total resistance and is directly linked to the generation of lift force, hence the name. By calculating the coefficient of lift, the $CD_i$ can then be calculated.[7] This is done according to:

$$CD_i = \frac{CL^2}{\pi \cdot e \cdot AR} \qquad (7).$$

Where *e* is the "span efficiency factor" that can be assumed to be 0.85.[8] AR, the wing aspect ratio is calculated according to:

$$AR = \frac{b^2}{A} \qquad (8).$$

Where *b* is the wing span of the hydrofoil and A is the wing area of the hydrofoil. Now *b* is varied to calculate the resistance for different *AR*s but for the same *A*, the *A* determined earlier. The wingspan varies between 0.4 m and 2 m. The resistance was calculated for the different wingspan.
The air resistance is now calculated using (4) there $\rho$ now the density of air is 1.22 kg/m$^3$,
*CD* is an estimated coefficient of resistance[9] 1.18 and *A* is an estimated front area of man plus vessel 0.6 m$^2$. the air resistance was added to the rest of the resistance and plotted against the speed, the result is shown in figure 1.

[5] J.Kuttenkeuler, Segling så funkar det, s.43
[6] John D.Andersson. Aircraft performance.
[7] J.Kuttenkeuler, Segling så funkar det.46
[8] John D.Andersson. Aircraft performance.
[9] John D.Andersson. Aircraft performance.

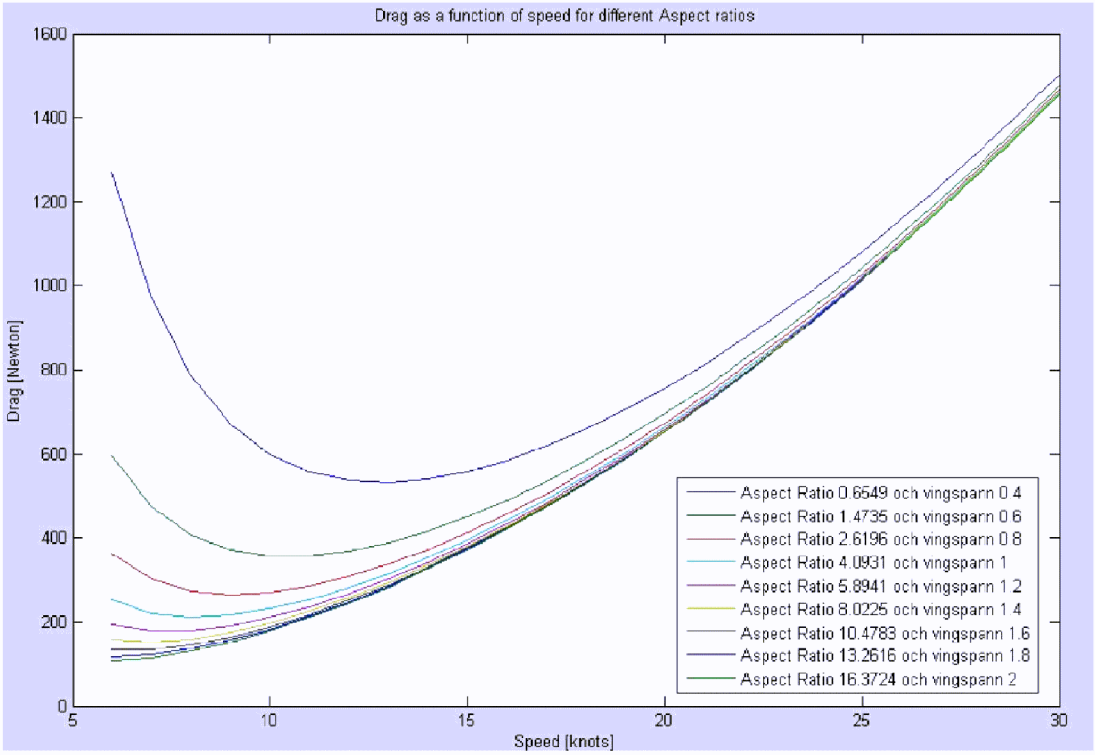



**Figure 1. The resistance of the different hydrofoil plotted against the speed.**

If the plot is considered, it is noted that a high aspect ratio gives less resistance. But the 5 wings with the highest aspect ratio do not differ much at all. This means that virtually any of these could be chosen as a hydrofoil from a resistance point of view. However, since the hydrofoil is to be applied to a water toy, demands are made on both strength but also on the product being easy to move, if this is considered, the hydrofoil with the lowest aspect ratio of the 5 would be most suitable.

### *Delta wing*

The same approach is applied to calculate the delta wing. The lift speed is also set here to 6 knots, however, the maximum lift coefficient is set to 1.2.[10] This is because the *CL* curve looks different for delta wings compared to straight wings. The delta wing's *CL* curve runs over larger angles of attack but does not reach the same high value of *CL* (See CL curves in Appendix 2). When these assumptions have been made, the wing area is calculated according to:

$$A = \frac{L}{0.5 \cdot \rho \cdot v^2 \cdot CL} \tag{9}$$

When the area of the delta wing is determined, the lift coefficient required to generate the given lift force 170 N is calculated according to:

$$CL = \frac{L}{0.5 \cdot \rho \cdot v^2 \cdot A} \tag{10}$$

This is done throughout the speed range. When this is done, the next step would be to compare the resistance between the different delta wings, but the expression for calculating the *CD* for delta wings is complicated[11] and requires that the angle of attack is known. CD is calculated according to:

$$CD = \left(\frac{s}{l}\right)^2 \cdot \cos(\alpha) \cdot \left( 2\pi \frac{\alpha}{\left(\frac{s}{l}\right)} + 4.9 \frac{\alpha}{\left(\frac{s}{l}\right)^{1.7}} \right) \tag{11}$$

There is the angle of attack *s* is half the width of the wing, *l* is the "height" of the wing. The angle of attack must therefore be determined. This is done by calculating *CL* according to:

$$CL = \left(\frac{s}{l}\right)^2 \cdot \sin(\alpha) \cdot \left( 2\pi \frac{\alpha}{\left(\frac{s}{l}\right)} + 4.9 \frac{\alpha}{\left(\frac{s}{l}\right)^{1.7}} \right) \tag{12}$$

This is done for all angles of attack, when this is done these are matched with the *CL* from (10). When this is done, the angle of attack can be determined by seeing which in (12) generates the same *CL* as in (10). When the angle of attack is determined, the coefficient of resistance is then calculated according to (11). This coefficient of resistance does not take into account the frictional resistance and this must therefore be determined.[12] The coefficient of friction coefficient is determined according to:

[10] John D.Andersson. Aircraft performance.
[11] John D.Andersson. Aircraft performance.
[12] J. Aircraft. Vol 6. No 3

$$C_f = \frac{0.472}{(\log^{10}(\mathrm{Re}))^{2.68}} \quad (13)$$

Where *Re* is Reynolds' number. *Re* is calculated according to:[13]

$$\mathrm{Re} = \frac{v \cdot L}{\nu} \quad (14)$$

There, the viscosity of the water is $1 \cdot 10^{-6}$ and *L* is a characteristic length in this case half the length of the delta wing and *v* is the speed. The coefficient of friction can now be determined. After this, just as for the straight wing, the total coefficient of resistance should be determined according to:

$$CD - CD_0 + CD_i \quad (15)$$

$CD_0$ is a coefficient of resistance that refers to the lift area to the wet area, the wet area is estimated to be about 4 times as large as the lift area. $CD_0$ is calculated according to equ (6) where $CD_f$ is the coefficient of friction calculated according to (13) and *S* is the lifting area and $S_{wet}$ is the wet area.

$$CD_0 = \frac{S_{wet}}{S} \cdot CD_f \quad (16)$$

*Re* is calculated according to:[11] When all coefficients are calculated, the total coefficient can be determined according to (15). When the total coefficient of resistance is determined, the resistance is calculated according to (4). Here, too, the air resistance is calculated in the same way as for the straight wing and added to the total resistance. The result is shown in Figure 2.

[13] J. Kuttenkueler. S.

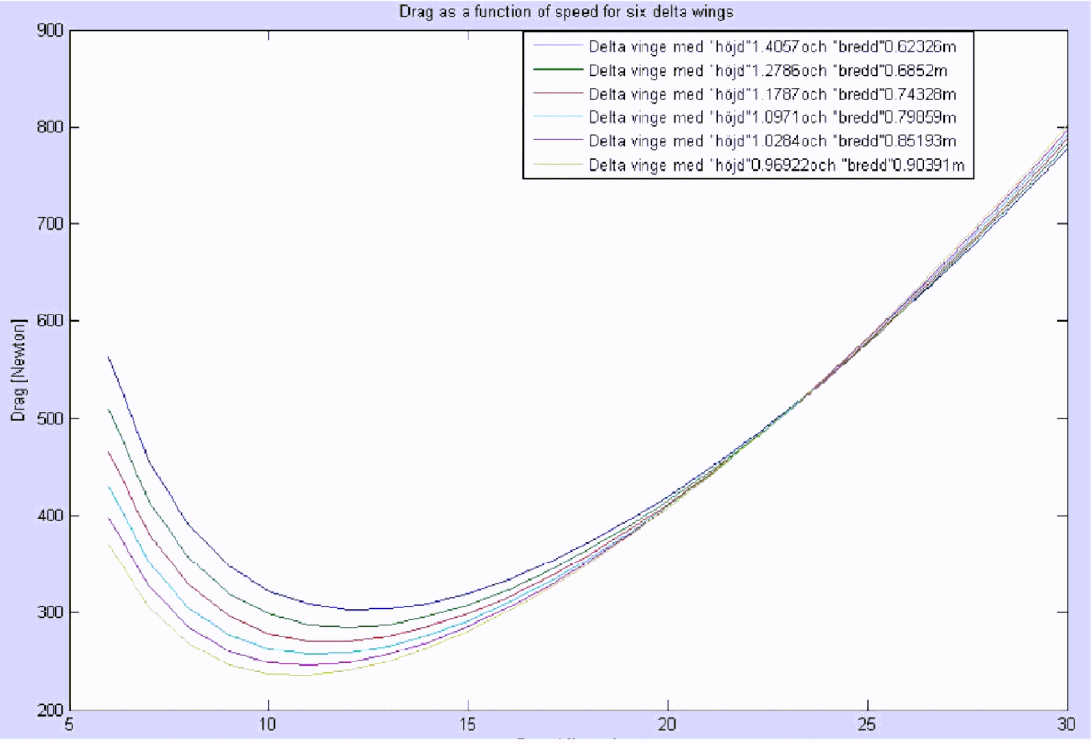



**Figure 2. The resistance of the different hydrofoil plotted against the speed.**

If the plot is considered, it is noted that the wider the delta wing, the less resistance, ie. larger opening angle gives less resistance. To obtain a safety margin, the maximum lift coefficient was varied. This will be reflected on the area of the wing but also on the resistance. In Figure 3, the maximum coefficient of lift has been varied and the best wing has been selected from a resistance point of view.

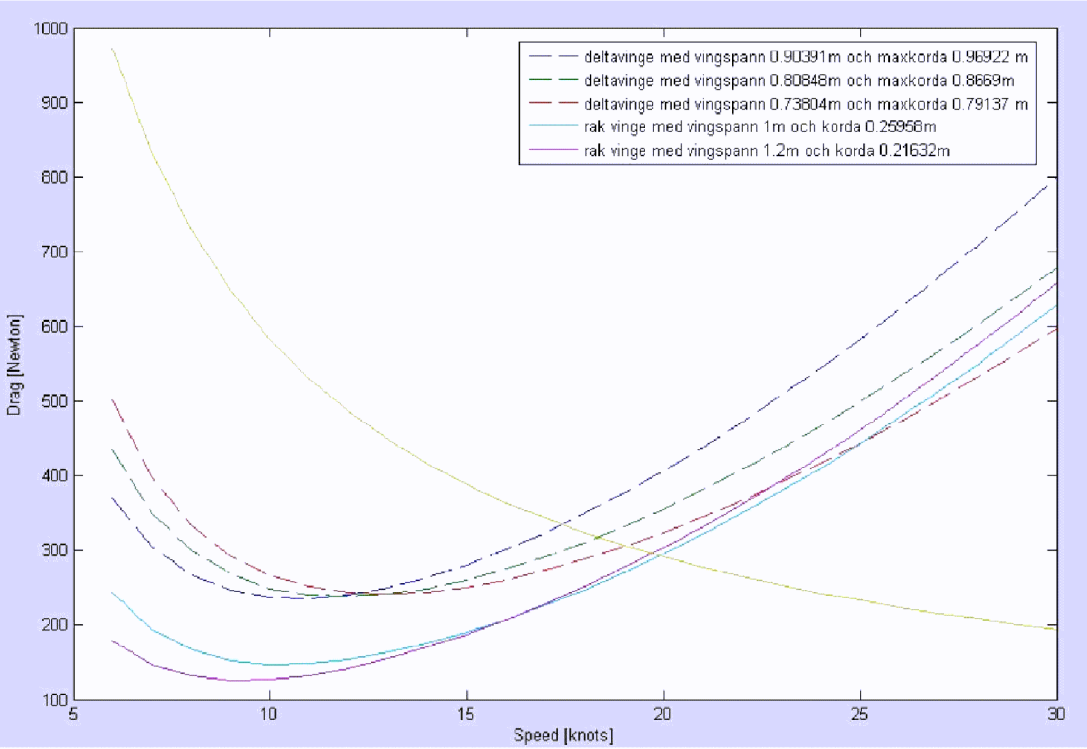



**Figure 3. Plot of the three best delta wings and the two best straight wings.**

## Conclusion

Based on the calculations and assumptions made, the author has come to the conclusion that a hydrofoil with dimensions according to Table 1 would be most suitable.

| | | |
|---|---|---|
| Wingspan | [m] | 0.8 |
| max chord | [m] | 0.2 |
| Open angle [degrees] | | 25 |

**Table 1. Results from the technical investigation**

This is because the delta wing's *CL* curve has a much lower derivative than the straight wing. This means that a small change in angle of attack gives a smaller change in lift force in the delta wing than in the straight wing, this results in a smoother "flight" with the delta wing. Another advantage is that the delta wing can withstand higher angles of attack before it stalls. This is desirable as Evolo should be a toy according to the requirements.

## References


1. Kuttenkeuler, J: *Segling så funkar det.* Department of Marine Systems, KTH, Stockholm, 2008.
2. Flygsnubbe: *Flyga* Department of Marine Systems, KTH, Stockholm, 2008.
3. www.bilda.kth.se
4. J. Aircraft. Vol 6. No 3

# A12 - Floating Body Analysis Evolo




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| Project: | Evolo |
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| Hours worked: | 20 hours |
| Reviewed by: | - |

## Summary

In this report, the floating body of Evolo is investigated primarily with regard to resistance. The report is largely reasoned in terms of influencing factors linked to extremes. A simpler model for resistance calculation is described, however, and in addition there is a fully developed matlab code that can estimate the resistance within certain limits.

Based on the investigation, it can be stated that it is difficult in theory to arrive at an optimal hull shape and an exact hull resistance. Before a final decision on form is made, model testing should therefore be carried out. So far, the conclusion is that the surfboard shape pointed out in the report conceptual design can be used. However, the forebody should be taken into account with regard to increased buoyancy and improved cutting ability in the water.

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General impression ..... Bookmark not defined.
Technical content ..... Bookmark not defined.
Presentation ..... Bookmark not defined.
Other ..... Bookmark not defined.

## Background

A floating body for Evolo will be constructed. In this report, influencing factors are investigated and a simpler model for resistance is developed in Matlab.

According to the requirements specification, Evolo must be able to float and balance in a stationary position with the driver and he must be able to weigh up to 100 kg. An experiment has been carried out with an experimental vessel towed after a boat and analyzes of the size and resistance of the hydrofoil have been made.

## Problem formulation

In order to design the floating body in the best way, the following parameters should be considered:

- The resistance of the vessel in the water
- Necessary volume and volume distribution
- Need for planning properties
- Ability to "dip" from flying position (described in more detail below)
- Product expression and aesthetics

The analysis shall, among other things, provide a minimum guideline value for the minimum motor power required to make the vehicle reach a flying position on the hydrofoil.

## Analysis

VEHICLE RESISTANCE IN WATER

The resistance of a body in the water is generally given off

$$= \quad - \qquad (1)$$

where ρ is the density of the water, V is the speed of the body and S is the wet surface. $C_T$ is given by

$$= (1 + \ ) \quad + \quad + \Delta \quad + \qquad (2)$$

where k is a form factor, $C_F$ is a coefficient of frictional resistance, $C_R$ of waveform resistance, $C_F$ for surface roughness supplement and $C_{AA}$ for air resistance (Garme 2007).

Evolo's length is about 2.3 m and its speed range is 0 - 6 kn before the floating body is lifted out of the water. The air resistance on the vehicle is judged to be low at speeds of 0 - 6 knots, but is treated together with the resistance on the hydrofoil structure in a special report on the dimensioning of the hydrofoil.

The coefficient of friction is calculated by the formula

$$= \frac{\cdot}{(\qquad)} \qquad (3)$$

which is recommended by ITTC-57, where Re is Reynolds number based on ship length. The form factor k in equation 2 can be estimated for displacing hulls with

$$= -0.095 + 25.6 \frac{}{- \ -} \qquad (4)$$

where $C_B$ is the block coefficient for the floating body and L, B and T are length, width and draft respectively. The surface roughness supplement is calculated with the formula

$$\Delta = (105 - \bar{} - 0.64) \quad 10 \qquad (5)$$

Here is the k surface roughness in meters which is set to 50µm which corresponds to smooth plastic. The validity of formulas 4 and 5 should be taken into account as it applies to large vessels, but it gives a rough estimate here. The form factor makes a relatively small contribution, but it should be mentioned that it also contains a contribution to viscous resistance other than friction and that it can be set to 0 for planning vessels.
To estimate the other parts of the $C_T$ coefficient of resistance, a semi-empirical method is used based on compiled statistics of hull resistance in Delft in the Netherlands (Larsson/Eliasson 2000). The method is developed for sailboat hulls and has a limited area of validity. This is reported in Table 1.

Table 1. Scope of resistance calculation with Delft series

| | |
|---|---|
| Length in waterline / Width in waterline | 2.76 – 5.00 |
| Width in the waterline / Depth | 2.46 – 19.32 |
| Length in the waterline / volume displacement^1/3 | 4.34 – 8.50 |
| LCB | 0.0 – 6.0 |
| $C_p$ | 0.52 – 0.60 |

Of the parameters in Table 1, most are probably self-explanatory except for LCB as the location of the center of gravity of the displaced water and $C_p$ as the prismatic coefficient. The latter indicates how full the stern and foreship are. The valid area presupposes relatively slender hulls without, for example, a sharp stern. The model is thus not directly applicable to, for example, planing hulls. The method consists of two different models, one for low-speed range Froude's number <0.4 and one for semi-planing speed range Froude's number> 0.4 but <1.0. The model then returns the resistance based on input data corresponding to the variables in Table 1 for different speed ranges (Froude's numbers). This is implemented in Matlab by Jakob Kuttenkeuler as a script (residuary.m). Together with a self-developed script for the frictional resistance (friction.m), a main program has been constructed (hull resistance.m) which with these two scripts returns the total resistance as a function of speed as a plot. An example of this plot is presented for a hull in the chapter conclusions. The Matlab files are available as appendices 1 - 3 in this report and also on Bilda. For the production of input data and modeling of the hull, it has off
A. Rosén developed the matlabscript Quicklines has been used.

## VOLUME AND VOLUME DISTRIBUTION

Evolo's mass displacement consists largely of the vehicle's weight, driver's weight, batteries and motor. If the driver is to be able to sit on the craft without it sinking, the floating body must have a volume of 0.17 $m^3$ according to the requirements specification. In order for it not to tip over in a stationary position with the driver, a sufficient transverse stability is required, which is largely determined by the width of the floating body. The various parameters in the problem formulation affect how the volume is to be distributed optimally in the ship longitudinal. Above all, the bow should not dive at start or "dipping" probably requires a certain volume in the bow.

When the driver position and weight distribution are not completely clear in this situation, transverse stability and volume distribution in the ship longitudinal are calculated in more detail at a later time.

NEED FOR PLANNING PROPERTIES

Froude's number = f~~or E~~volo in the lifting speed 6 knots is 0.65. The transition to planning permission for boats takes place at Froude's number 1.0 - 1.2 (Faltinsen 2005) and due to the formed bow wave, Froude's number for fully displacing boats is defined as 0 - 0.4 (Garme). Evolo thus moves in the area known as "semi-planing" before it lift.

Planing hull normally has an angle to the water surface τ according to Figure 1 which means that the boat is lifted up in planing dynamically when Fn> approx. 1.0. At lower speeds, the typical shape of a planing hull is poorly designed for low flow resistance, especially at possible blows or angles and at the stern if it is flat.

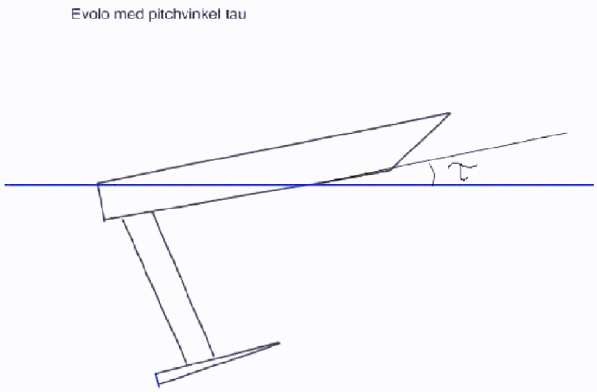



*Figure 1. Picture of Evolo with the floating body in the water with a pitch angle to the water surface.*

Typically displacing (cutting) hulls are optimized for minimized resistance in a lower speed range and have a greater increase in resistance compared to planar hulls at Fn = 0.4 and that the design of the stern, which is usually rounded in some way, means that the stern is sucked down at increased speed .

What planing hulls typically look like is shown in Figure 2. They are optimized for high speeds and produce lift force that is sufficient to get over their own bow wave (with sufficient traction). This critical position occurs just at Fn ≈ 0.4 due to the wavelength being approximately the same size as the boat length.





*Figure 2. a, A typical planing hull of a RIB boat. b, Hull image from the front of planing rubber dinghy.*

A craft with a hydrofoil that lifts the hull out of the water does not have the same need for lifting force from the hull to lift because the hydrofoil creates the lifting force in its own medium (the water) already at low speed. Other hydrofoil carried vessels, such as those in Figure 3, generally prioritize that the hull is slim and has low resistance to water and air than that the hull shape has good planing properties. Many also have a vertical cut for which means that you have no contribution to the lifting force from the bow other than the volume.



*Figure 3. Hull shapes on other watercraft with hydrofoil solution.*

"DIP ABILITY"
In the experiment carried out, it was discovered that the floating body is greatly slowed down when the craft is in flight position and the floating body dives down to the surface or meets a sufficiently high wave in the bow. This phenomenon probably had a greater impact on the test vessel than it will have on the finished vessel because the test vessel was towed after a boat and had almost constant draft from the boat. The traction of the finished vessel will be able to be regulated in another way, but it is still considered important to minimize the effect of the phenomenon.

EXPRESSION AND AESTHETICS
An important part of the final hull construction is the appearance. At this stage, enough function may be considered to precede form. There is an investigation done on governing parameters for this which is presented in more detail in the report user identity.

## Conclusion

In terms of hull design, two extremes regarding selection can be distinguished. One is a short relatively wide planing hull and the other is a long slender displacing hull. It is difficult

to say for sure that one is better than the other. At the present stage, the shape of the hull model is probably of less importance. More important is, for example, sufficient displacement and increasing the buoyancy and decreasing the braking effect in the bow as dips often led to crashes on the first try (see X3 report). Our recommendation is to continue for the time being with the surfboard-like hull that is illustrated in the report conceptual design. For the final design of the hull model, model testing should be sought for at least two variants of hull.

An alternative somewhat innovative form has also been developed. This is illustrated in Figure 4.

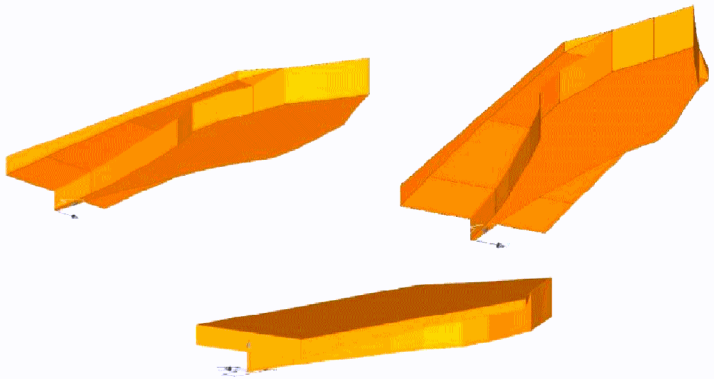


Figure 4. An alternative design proposal

The shape illustrated in Figure 4 should be considered as a principle and in reality the surfaces should be softer. The proposal can be seen as a combination of surfboard and canoe, considering that a full foreship but still slim hull should provide low resistance and clear dips while the board on top should provide stability in the water and the opportunity to move during movement. Figure 5 shows the total resistance of the hull in Figure 4 calculated with the model developed.

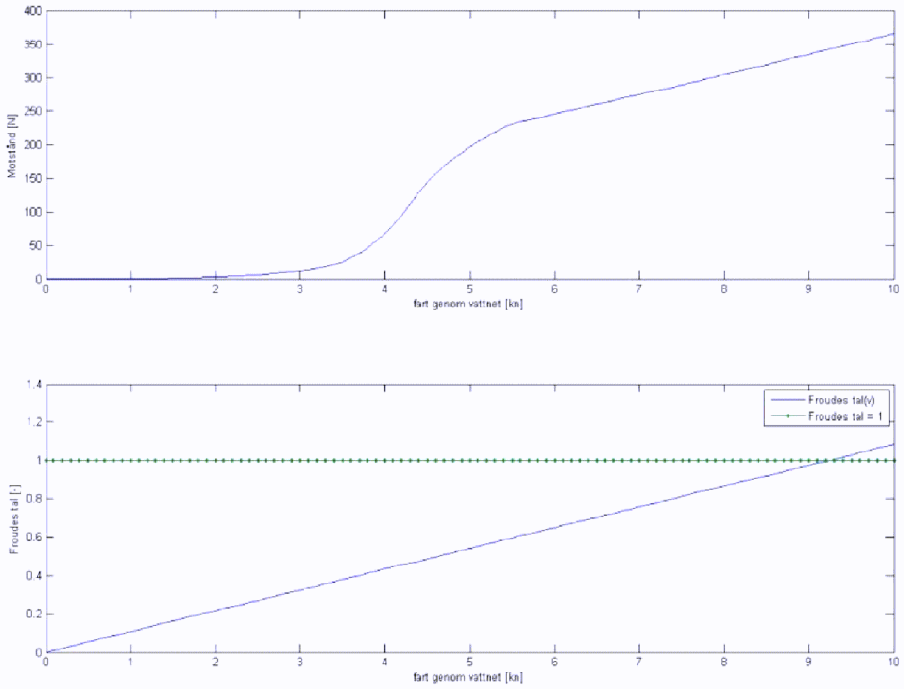



Figure 5. Resistance and Froude's number as a function of the speed of the hull in Figure 4

Figure 5 clearly shows the resistance hump around Frode's number 0.4-0.5.This is mainly a function of the ship's length. Reduced length will move the hump to the left.

## References


5. Garme, K: *Fartygs motstånd och effektbehov.* Marine Systems, KTH, Stockholm, 2007.
6. Faltinsen, O M: *Hydrodynamics of High-speed Marine Vehicles.* Cambridge 2005
7. Larsson, L/Eliasson, R E: *Principles of Yacht Design, 2nd Edition.* Adlard Coles Nautical, 2000.
8. Requirements specification, Marine design project Evolo, Marine system, KTH, 2008.
9. Unpublished reports in the course Marine Design are available

Appendix 1 - Matlab code for resistance calculation

*Hullresist.m, main program*

```
clc, clear all

%-------------------------------------------------------------------------
% This program evaluates the resistance functions for the Hull of Evolo:
%
% Rr                = residuary(vs,depl,Cp,Lwl,LCB,Bwl,Tc,Awl) Residuary resistance
%                     inputdata need some limits, thoose are defined in the function file
%
% Rf                = friction(vs,Sw,Lwl,Tc, Bwl, cb)         Friction resistance ofcanoe body
%-------------------------------------------------------------------------
% Rr                : [N]       Residuary resistance
% vs                : [m/s]     Boat speed
% depl              : [m3]      Volume displacement
% Cp                : [-]       Prismatic coefficient
% Lwl               : [m]       Length of water line
% LCB               : [-]       In percent of Lwl from mid ship, positive forward
% Bwl               : [m]       Beam of waterline amidship
% Tc                : [m]       Draft of canoe body
% Awl               : [m2]      Waterline area
% T                 : [m]       Total draft of yacht
% heel : [rad] Heel

% by Torvald Manners & Mattias Kennestad
%-------------------------------------------------------------------------


kn      = 0:.1:10;          %  [knots]
vs      = kn*1852/3600;     %  [m/s]
depl    = 0.15;             %  [m^3]
Cp      = 0.58;             %  [-]
Cb      = 0.46;             %  [-]
Lwl     = 2.3;              %  [m]
LCB     = -1.2/Lwl;         %  [-]
Bwl     = 0.7;              %  [m]
Tc      = 0.2;              %  [m]
Awl     = 1.13;             %  [m^2]
Sw      = 1.09;             %  [m^2]

g = 9.81;
Fn = vs/sqrt(g*Lwl);

Rr = residuary(vs,depl,Cp,Lwl,LCB,Bwl,Tc,Awl); Rf = friction(vs,Sw,Lwl,Tc, Bwl, Cb);

Rtot = Rr + Rf;

subplot(2,1,1) plot(kn, Rtot)
xlabel('speed through the water [kn]'), ylabel('Resistance [N]'); subplot(2,1,2)
plot(kn, Fn, kn, ones(1,length(kn)), '.-')
xlabel('fspeed through the water [kn]'), ylabel('Froudes number [-]'); legend('Froudes number(v)',
'Froudes number = 1')
```

## *friction.m, function file for calculating frictional resistance*

```
function Rf = friction(vs,Swl,Lwl,Tc, Bwl, cb)


%Denna funktionsfil räknar ut friktionsmotståndet
%--------------------------------------------------------------------------
%vs                 : [m/s] fart genom vattnet
%Lwl                : [m] Längd genom vatten linjen
%Swl                : [m^2] Våt yta
%ny                 : [m^2/s] dynamisk viskositet
%g                  : [m/s^2] tyngdacceleration
%rho                : [kg/m^3]densitet
%k                  : [m] ytråhet
%Tc                 : [m] djup vid midskeppssektionen
%Bwl                : [m] Bredd vid midskeppssektionen
%cb                 : [-] Blockkoefficient

% by Torvald Manners & Mattias Kennestad
%--------------------------------------------------------------------------

ny = 1.35*10^-6; g = 9.82;
rho =  1000; k = 50*10^-6;
k2 = -0.095 + 25.6 *(cb/((Lwl/Bwl)^2 *sqrt(Bwl/Tc)))

Re = vs*Lwl/ny;                                          %Reynolds tal

CF = (1+k)*0.075./((log(Re)-2).^2);                      %Friktionskoefficient [-]
dcf = (105*(k/Lwl)^(1/3) - 0.64)*10^-3;                  %Ytråhetstillägg [-]

CT = CF + dcf;                                           %total motståndskoefficient
    Rf = 0.5*rho*vs.^2*Swl.*CT;                          %motstånd

    end
```

## Residuary.m, Function file for calculating other resistance

```
function Rr= residuary(vs,depl,Cp,Lwl,LCB,Bwl,Tc,Awl)
%
% Rr : [Newton] Residuary UPRIGHT resistance of the canoe body (i.e. wave
% generation and viscous pressure resistance) by interpolation using the Gerritsma
% University of Delft systematic experimental series data for displacement
% hulls. Note that the friction resistance in NOT included. The input parameters
% are checked to ensure that the interpolation is done within the experimental
% data. Fn (and consequently Rr) can be either scalar or a vector.
%
% Parameters:
% u                 : [m/s] Boat speed
% depl              : [m3]      Volume displacement
% Cp                : [-]       Prismatic coefficient
% Lwl               : [m]       Length of water line
% LCB               : [-]       In percent of Lwl from mid ship, positive forward
% Bwl               : [m]       Beam of waterline amidship
% Tc                : [m]       Draft of canoe body
% Awl               : [m2]      Waterline area
%
% by Jakob Kuttenkeuler 2005
%-------------------------------------------------------------------------
g   = 9.81;                 % [m/s2] Gravitational acceleration
Fn = vs/sqrt(g*Lwl); % [-]      Froude number
% Check input against Delft experimental data limits err=0;
if min(Lwl/Bwl)<2.76;           disp('Lwl/Bwl too small');          err=1;end;
if max(Lwl/Bwl)>19.32;          disp('Lwl/Bwl too large');          err=1;end;
if min(Bwl/Tc)<2.46             disp('Bwl/Tc too small');           err=1;end;
if max(Bwl/Tc)>19.32;           disp('Bwl/Tc too big');             err=1;end;
if min(Lwl/depl^(1/3))<2.46     disp('Lwl/depl^(1/3) to  small');   err=1;end;
if max(Lwl/depl^(1/3))>19.32;   disp('Lwl/depl^(1/3) too big');     err=1;end;
if min(LCB)<-6.0                disp('LCB too small');              err=1;end;
if max(LCB)>0.00;               disp('LCB too big');                err=1;end;
if min(Cp)<0.52                 disp('Cp too small');               err=1;end;
if max(Cp)>0.600;               disp('Cp too big');                 err=1;end;
if err==1;                      disp('Calculation terminated...');  disp('************************');
    SSTTOOPP;
end
%---------
for ii=1:length(Fn) F=Fn(ii);
      if  F<0.125 % Extreme low speed
            Rr_2     = delft_lowspeed(0.125,Lwl,Bwl,depl,LCB,Tc,Cp);
            Rr(ii)   = interp1([0 0.125],[0 Rr_2],F);
      elseif F>=0.125&F<=0.450 % Low speed
            Rr(ii) = delft_lowspeed(F,Lwl,Bwl,depl,LCB,Tc,Cp);
      elseif F>0.450&F<0.475      % Intermediate speed..
            Rr_1     = delft_lowspeed(0.450,Lwl,Bwl,depl,LCB,Tc,Cp);
            Rr_2     = delft_highspeed(0.475,Lwl,Bwl,depl,LCB,Tc,Cp,Awl); Rr(ii) = interp1([0.450 0.475],[Rr_1
            Rr_2],F);
      elseif F>=0.475&F<=0.6 % High speed
            Rr(ii) = delft_highspeed(F,Lwl,Bwl,depl,LCB,Tc,Cp,Awl);
      else                                                  % Too high speed
          Rr(ii) = delft_highspeed(0.6,Lwl,Bwl,depl,LCB,Tc,Cp,Awl)*(F+0.4); %
This is assumed
```

```
            %disp('Froude number too large...');
        end
end
%--------------------------------------------------------------------------
function Rr = delft_lowspeed(Fn,Lwl,Bwl,depl,LCB,Tc,Cp);
% Applicable for 0.125<Fn<0.450
%--------------------------------------------------------------------------
% Calculate the residuary resistance (upright wave generation and viscous
% pressure resistance) by interpolation using the University of Delft systematic
% experimental series data for displacement hulls.
%--------------------------------------------------------------------------
  g = 9.81;                    % [m/s2] Gravitational acceleration constant
  rho = 1025;                  % [kg/m3] Density of water
  wdepl = depl*rho;            % [ton] Weight displacement

A=[0.125 -6.7356 38.3683 -0.008193 0.055234 -1.9972 -38.86081
     0.9566 -0.002171 0.2728 -0.01752
0.150 -0.3829 38.1729 0.007243 0.026644 -5.2953 -39.55032
     1.2195 0.000052 0.8246 -0.04784
0.175 -1.5035 24.4080 0.012200 0.067221 -2.4485 -31.91370
     2.21609 0.000074 0.244345 -0.015887
0.200 11.29218 -14.51947 0.047182 0.085176 -2.673016 -11.41819
     5.654065 0.007021 -0.094934 0.006325
0.225 22.17867 -49.16784 0.085998 0.150725 -2.878684 7.167049
     8.600272 0.012981 -0.327085 0.018271
0.250 25.90867 -74.75668 0.153521 0.188568 -0.889467 24.121
     10.4852 0.025348 -0.854940 0.048449
0.275 40.9755 -114.2855 0.207226 0.250827 -3.072662 53.01570
     13.02177 0.035934 -0.715457 0.039874
0.300 45.8375 -184.7646 0.357031 0.338343 3.871658 132.25
     10.86054 0.066809 -1.719215 0.095977
0.325 89.20382 -393.0127 0.617466 0.460472 11.54327 331.1197
     8.598136 0.104073 -2.815203 0.155960
0.350 212.6788 -801.7908 1.087307 0.538938 10.80273 667.6445
     12.39815 0.166473 -3.026131 0.165055
0.375 336.2354 -1085.134 1.644191 0.532702 -1.224173 831.1445
     26.18321 0.238795 -2.450470 0.139154
0.400 566.5476 -1609.632 2.016090 0.265722 -29.24412 1154.091
     51.46175 0.288046 -0.178354 0.018446
0.425 743.4107 -1708.263 2.435809 0.013553 -81.16189 937.4014
     115.6006 0.365071 1.838967 -0.062023
     0.450 1200.620 -2751.715 3.208577 0.254920 -132.0424 1489.269
     196.3406 0.528225 1.379102 0.013577];

for ii=1:10
   a(:,ii) = interp1(A(:,1),A(:,ii+1),Fn,'spline');
end
Rr=g*wdepl/1000*a*[ 1 Cp LCB Bwl/Tc Lwl/depl^(1/3) Cp^2 Cp*Lwl/depl^(1/3)
LCB^2 (Lwl/depl^(1/3))^2 (Lwl/depl^(1/3))^3]';
%--------------------------------------------------------------------------
function Rr = delft_highspeed(Fn,Lwl,Bwl,depl,LCB,Tc,Cp,Awl);
% Applicable for 0.475<Fn<0.750
%--------------------------------------------------------------------------
% Calculate the residuary resistance (upright wave generation and viscous
% pressure resistance) by interpolation using the University of Delft systematic
% experimental series data for displacement hulls.
%--------------------------------------------------------------------------
g          = 9.81;           % [m/s2]    Gravitational acceleration constant
rho        = 1025;           % [kg/m3]   Density of water
wdepl      = depl*rho;       % [kg]      Weight displacement
```

```
   A=[0.475   180.1004    -31.50257    -7.451141    2.195042    2.689623    0.006480
      0.500   243.9994    -44.52551    -11.15456    2.179046    3.857403    0.009676
      0.525   282.9873    -51.51953    -12.97310    2.274505    4.343662    0.011066
      0.550   313.4109    -56.58257    -14.41978    2.326117    4.690432    0.012147
      0.575   337.0038    -59.19029    -16.06975    2.419156    4.766793    0.014147
      0.600   356.4572    -62.85395    -16.85112    2.437056    5.078768    0.014980
      0.625   324.7357    -51.31252    -15.34595    2.334146    3.855368    0.013695
      0.650   301.1268    -39.79631    -15.02299    2.059657    2.545676    0.013588
      0.675   292.0571    -31.85303    -15.58548    1.847926    1.569917    0.014014
      0.700   284.4641    -25.14558    -16.15423    1.703981    0.817912    0.014575
      0.725   256.6367    -19.31922    -13.08450    2.152824    0.348305    0.011343
      0.750   304.1803    -30.11512    -15.85429    2.863173    1.524379    0.014031];
for ii=1:6
   a(:,ii) = interp1(A(:,1),A(:,ii+1),Fn,'spline');
end
Rr=g*wdepl/1000* a*[ 1 Lwl/Bwl Awl/depl^(2/3) LCB (Lwl/Bwl)^2
(Lwl/Bwl)^2*(Awl/depl^(2/3))^3]';

% end of file
```

# A13 Pitch stability




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| | |
|---|---|
| Course: | Marine design |
| Project: | Pitch stability |
| Date: | *20/11-2008* |
| Version number: | *1.1* |
| Supervised by: | Jakob Kuttenkeuler |
| Hours worked: | *5* h |
| Reviewed by: | |

## Introduction

The conclusion of test one is that Evolo is unstable in pitchled. [14] Therefore, an analysis should be performed to investigate how Evolo should be configured prior to test two.

[14] Xf2-protocol, ref. [2]

## Problem formulation

The purpose of this analysis is to establish a configuration of the hydrofoil so that it is stable in pitch. By stable is meant that if Evolo is exposed to a disturbance, it will return to its initial position. The actual dimensions to be determined are the distance between the wings ($a_1 + a_2$) and the location of the center of gravity ($x_{tp}$).

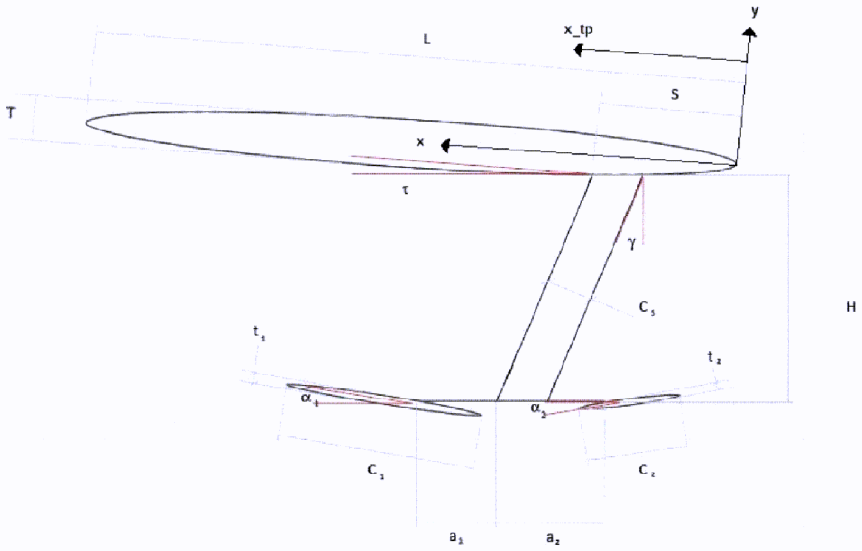



**Figure 17. Evolo**

These distances are determined by simple torque calculations on Evolo, when the floating body is above the water surface.

Analysis

Figure 2 shows the forces to which Evolo is exposed at the hydrofoil.

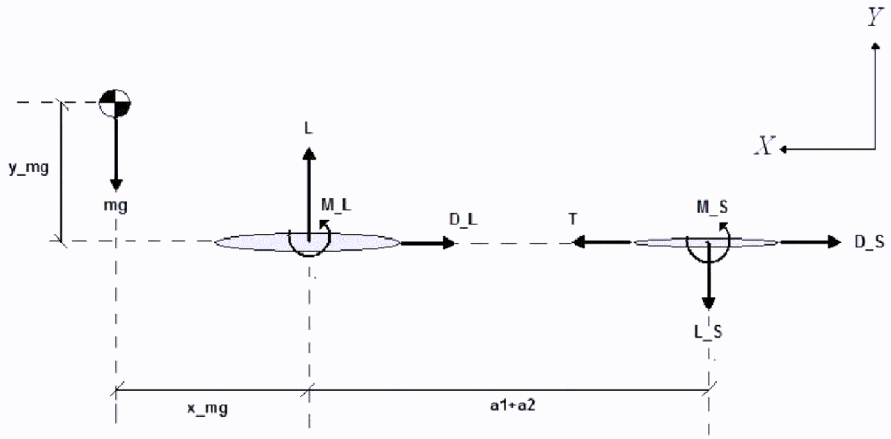



**Figure 18. Sketch of torque and forces.**

The torque equation around the center of gravity is set up for evolo in the "flying" state.

$$+ \quad - \quad + \quad + \quad + \quad -( \quad + \quad ) \quad + \qquad (1)$$

Torques ( , ) that occur due to the wings generating lift are so small that they can be neglected. Constant speed is assumed so that drag resistance ( , )is taken out by the propulsive
force ( ). What remains of the torque equation is

$$+ \quad + \quad - \qquad (2)$$

, where is the distance between the lifting force and the center of gravity and + is the distance between the lifting force ( ) and the force ( ) generated by the stabilizer wing.
The lifting force depends on the dynamic pressure ( ), the effective area ( ) and
the coefficient of lift ( ) which can be said to be linearly dependent on the angle of attack
( + ). Note that the angle of attack ( ) for each wing includes a disturbance ( ). This is entered into Equation 2 and leads to

$$\frac{( \quad )}{} ( \quad + \quad ) \qquad + \quad + \quad - \frac{( \quad )}{} ( \quad + \quad ) \qquad (3)$$

Hereinafter, the derivative is denoted by the lift coefficient ( ) with respect to the disturbance of the front lift wing which

$$= \frac{( \quad )}{}$$

and the derivatives of the coefficient of lift ( ) with respect to the disturbance of the aft stabilizer wing which



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WD086303

$$= \frac{(\quad)}{\quad}$$

For Evolo to be stable, it is required that the derivative of the torques with respect to the disturbance is less than zero.

$$\frac{}{} < 0$$

$$+ \quad + \quad - \qquad\qquad < 0 \quad (4)$$

$$> \frac{(\quad)}{} \qquad\qquad (5)$$

The aft stabilizer wing is assumed to be identical to the front lift generating wing but with a ratio of the effective area of 1: 5. The result is reported by plotting the distance between the points of attack of the lifting and stabilizing forces against the limit value for the location of the center of gravity.

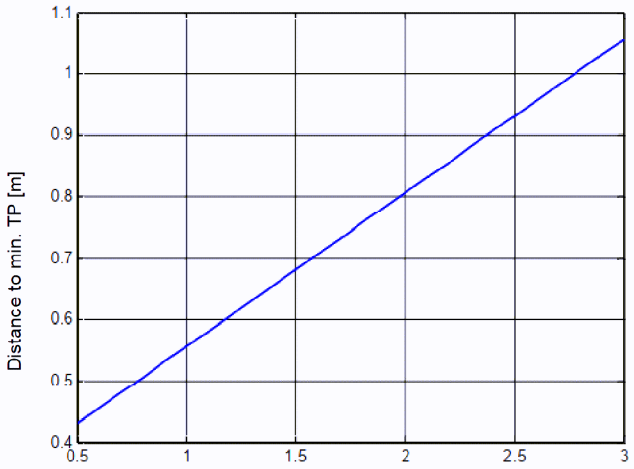



**Diagram 1. The limit value for placement of the center of gravity depends on the distance between the wings.**

In diagram 1 it can be read that if e.g. the distance between the lifting and stabilizing wing is 1 m, the center of gravity shall be placed at a distance in the x-direction that is greater than 0.55 m.

## Conclusion

This analysis has not straightened out whether this is an optimal configuration of the hydrofoil. This result should be weighed against the corrective action when exposed to a particular disturbance. The fact that a disturbance will lead to a vertical acceleration should also be taken into account. Further analysis should thus be performed in order to be able to determine how a disturbance affects the system. Even if the righting torque exists, it is not certain that it will have time to straighten the Evolo before the floating body hits the water.

## Verification plan

When experiment two is performed, the results of this report will be verified. At this time, the date for experiment two is 11/18/08.

## References


1. Norberg, M, A1 – Bärplan, Stockholm, 2008
2. Razola, M, Xf2 – Protokoll, Stockholm, 2008

# Appendix 8 A14 Power requirements

**Power requirements**




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| | |
|---|---|
| Course: | Marine design / Lightweight design |
| Project: | Evolo |
| Date: | *05/11-2008* |
| Version number: | *1.0* |
| Supervised by: | |
| Hours worked: | *2* |
| Reviewed by: | Fredrik Bender |

## Introduction

The purpose of this document is to give the reader an idea of what power needs are needed to generate such a large force (Thrust) that overcomes the resistance. This document does not take into account speeds below 6 knots as the resistance in this speed range is not fully calculated.

## Problem formulation

Evolo's power requirements must be calculated and this is done by using resistance calculations.[15]

[15] M.Norberg. A1-Bärplan 2008-10-25.

## Analysis

When the resistance is now calculated, the power requirement required to generate a propulsive force (Thrust) that is as large as the resistance can be calculated. This is done by taking the calculated resistance for the different speeds and multiplying by the speed according to:

$$E = F \cdot v \qquad (1)$$

Where ***E*** stands for power, ***F*** stands for resistance and *v* stands for velocity related to that resistance. The resistance calculations for the craft are taken from earlier, see Figure 1.

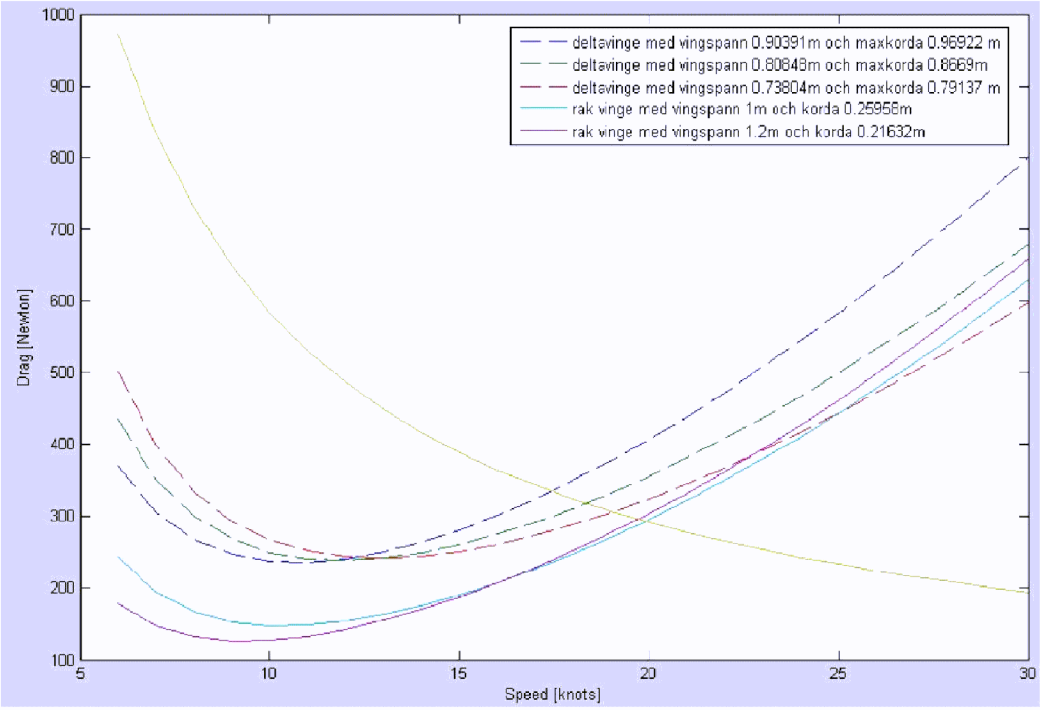



**Figure 4. Shows the resistance as a function of the speed of the 3 best delta wings and the two best straight wings.**

With these resistors as input data, the power is now calculated according to (1), the result is reported in figure 2.

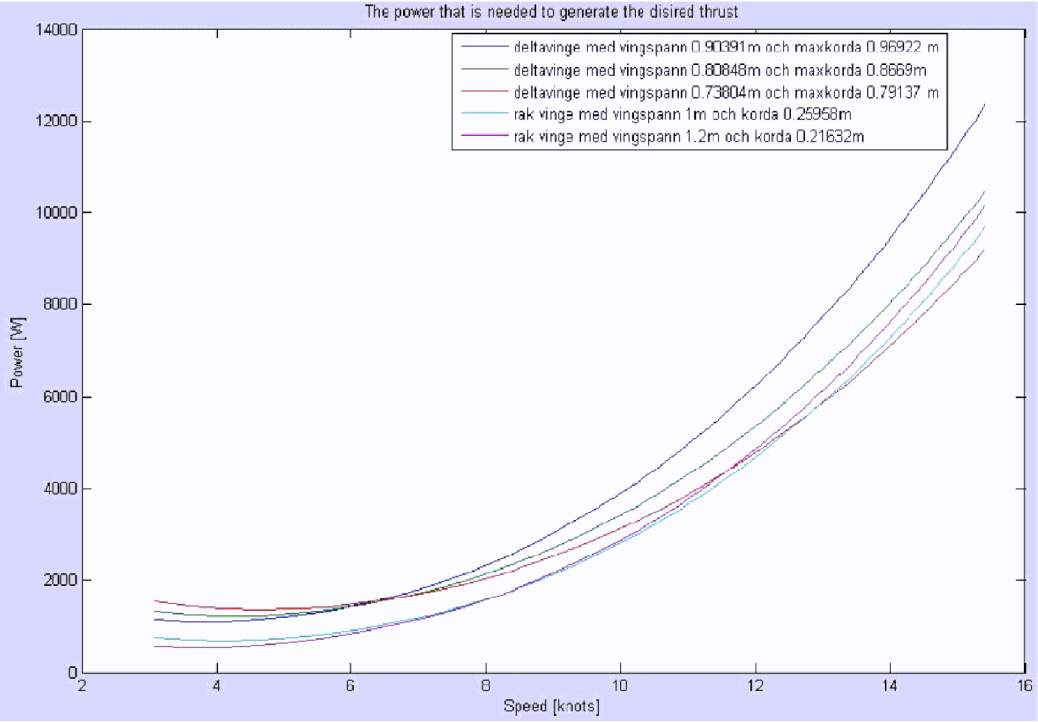



**Figure 5. The power required to propel the craft forward.**

Now the effect is calculated for a speed range that is a bit too large actually as the goal is for the craft to be able to reach 15 knots. If the focus is on the speed range up to 15 knots, figure 3 is obtained.

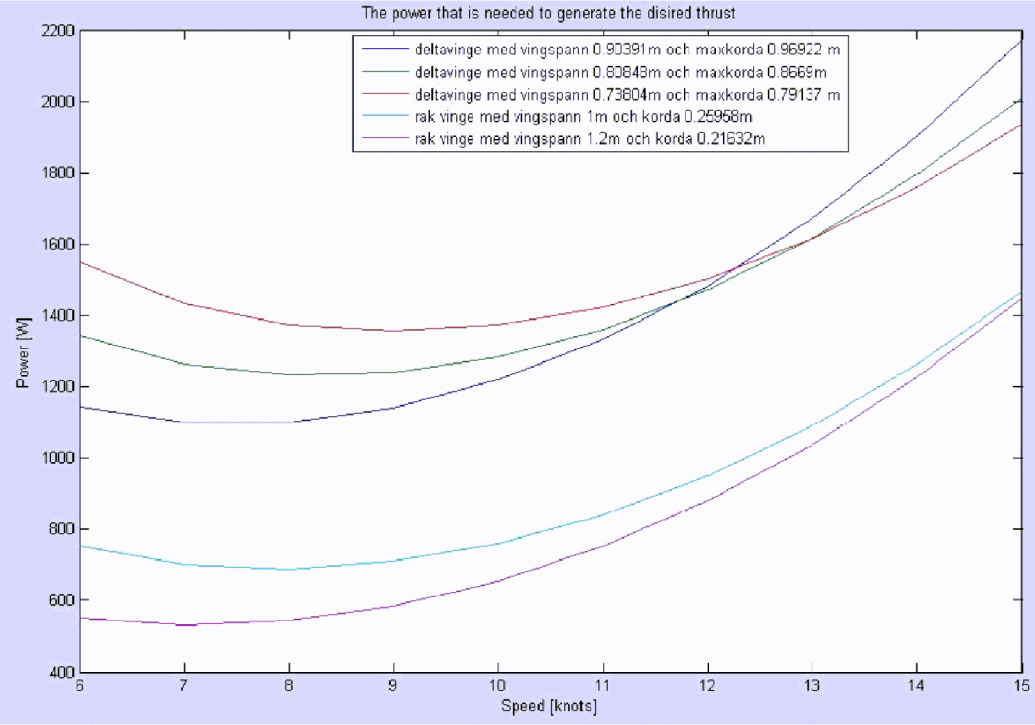



**Figure 6. The power required to propel the craft forward in the current speed range.**

In Figure 3, the efficiencies from the propeller and the motor are not included. If the efficiency of the propeller is estimated at 0.6 and the efficiency of the electric motor is estimated at 0.85, Figure 4 is obtained which shows the rated power required on the motor.

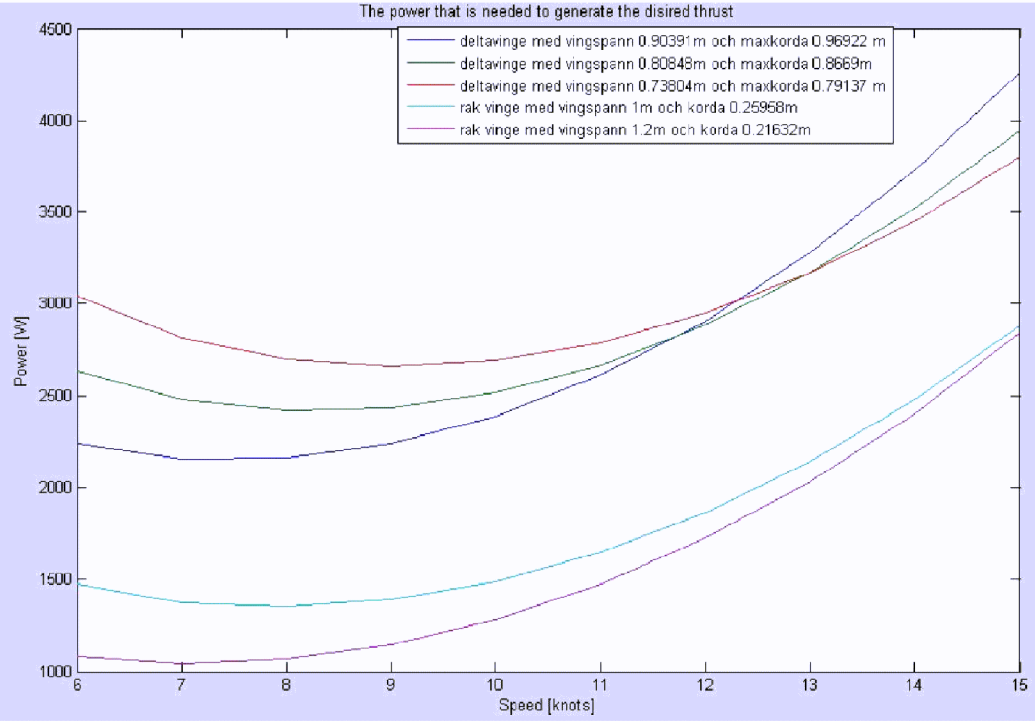



**Figure 7. The power required to propel the craft forward in the current speed range with the motor and propeller efficiency included.**

## Conclusion

If Figure 4 is considered, it is noted that the straight wings are effective from an effect point of view. The straight wing with a wingspan of 1.2 m requires a maximum power of 2.8 kW, but the delta wing with a wingspan of 0.74 m requires a maximum power of 3.7 kW. Should only the power requirement control, a straight wing would be by far the best, but if all factors are weighed in such as maneuverability size, the author believes that a delta wing would be most suitable. Perhaps a configuration with a delta wing as the primary and a straight wing as the secondary would be appropriate. This is because the secondary wing would then respond more quickly to a change in the angle of attack than a delta wing. Since the secondary wing gives a correcting torque, it is desirable that it responds quickly, if it also responds faster than the primary wing, it is also good.

## References

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# Appendix 9 A15 Final hydrofoil solution

## Wing and propeller configuration




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## Summary

Since all underwater components depend on - or affect - the flow, their relative location is important for optimizing the vessel's performance. The hydrofoil requires undisturbed flow, after which the propeller should be placed after them. This means that the aft hydrofoil should be placed under the flow around the front hydrofoil. Finally, the motor should be placed close to the propeller, after which it must be attached below or above the aft hydrofoil.

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## Problem formulation

How should wings and propellers be placed in relation to each other to optimize their performance?
The problem is divided into the following sub-problems:

- What happens if you place the propeller in the middle between of the hydrofoils?
- What happens if you place the propeller at the rear?
- How is the performance of the propeller affected by a protective cover?

## Analysis 1 - Placement of hydrofoil and propeller

The flow behind the propeller is extremely complicated. What we know about propellers is that they accelerate water in a negative direction relative to the direction of travel.
In addition, the water is accelerated to a rotary motion with the same direction of rotation as the propeller itself. In the initial state, the accelerated water has the same radius as the propeller, but the acceleration means that the flow tube decreases (due to ”conservation of mass”), see figure 1 ref [1].

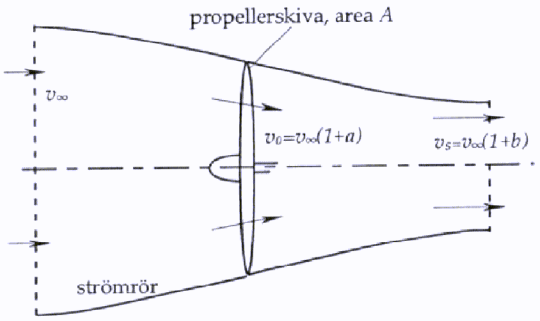



***Figure 1.*** Relative velocities along the considered flow tube which are limited by the propeller diameter.

In figure 1 we see how the speed behind the propeller increases (the flow tube decreases). The relationship between the constants $a$ and $b$ is $a = 2b$, ref [1].

The radius of the flow tube then increases with time until the motion is attenuated for the same reason as above. The flow is turbulent and will affect a wing placed in the current direction negatively. By "negative" is meant that its lifting force is reduced because the wing requires laminar flow to generate lifting force. In addition, the flow over the smaller hydrofoil will have a smaller relative angle when tilting the primary hydrofoil. This means that the flow over the wing will no longer be completely horizontal as the water accelerated by the propeller when tilting outside the design position will have a velocity component in the relative angle of the aft hydrofoil. The result is that the aft hydrofoil will not experience the same angle of attack as it actually has.

This means that if the propeller is to be placed between the two hydrofoils, the aft carrier plane, see figure 1, will lose part of its ability to generate lifting force and be more or less ineffective. To avoid the problem, the propeller must be placed above or below the hydrofoil so that the flow around the aft hydrofoil remains laminar. The disadvantages of placing the propeller above the hydrofoil are that it can drive air down to the hydrofoil when walking close to the surface, which will affect the hydrofoil's lifting capacity. The disadvantage of

placing the propeller below the hydrofoil is that the draft increases and there is a risk that the propeller will be damaged during a grounding

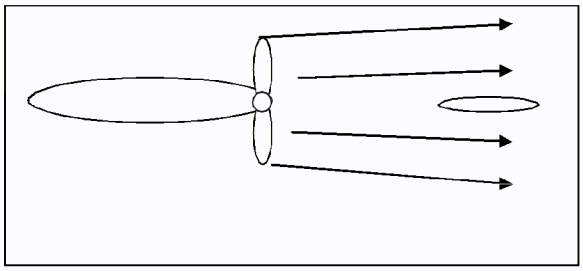


***Figure** 2.* Aft hydrofoil placed above the propeller.

An alternative is to place the aft hydrofoil above or below a configuration with propeller and front hydrofoil in the same plane because it is assumed that the flow around the wing profiles has approximately the same cross section relative to the direction of travel as the profiles themselves. If the aft hydrofoil is placed above the propeller, see figure 3, this will lose lifting force before the front hydrofoil when going in the direction of the surface and the straightening torque, which the aft hydrofoil is designed to meet, will be completely absent. If the aft hydrofoil is instead placed under the same configuration of the front hydrofoil and propeller (ie that these are in the same plane), the above problem is avoided, see figure 4. The disadvantage is an increased depth and aesthetically unattractive design.

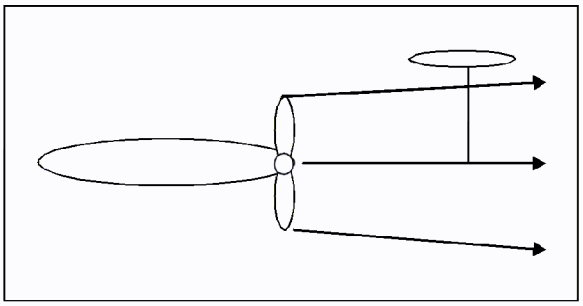


***Figure 3.*** Aft hydrofoil placed above the propeller.

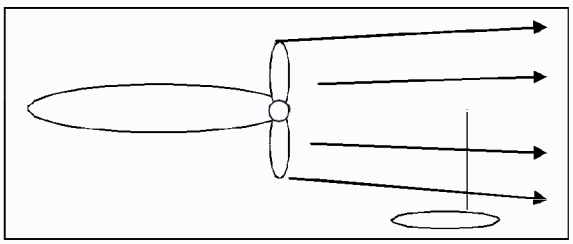


***Figure 4***. Aft hydrofoil placed below the propeller.

If the smaller hydrofoil is instead placed in front of the primary hydrofoil at the same time as the propeller is placed behind this, the flow around the primary hydrofoil will instead be affected. However, the impact of turbulence from the smaller hydrofoil (formerly referred to as the "aft hydrofoil") is assumed to be small as the flow around it is assumed to be laminar at small angles of attack. At larger angles of attack, the turbulence will increase, but this is considered favorable as the aft hydrofoil loses lift and the righting moment from the smaller hydrofoil increases in relation to the torque generated by the primary hydrofoil. However, the configuration assumes that the primary hydrofoil is placed behind the center of gravity so that this generates a moment, as the front hydrofoil will otherwise generate a torque with the same direction of action as the primary hydrofoil (ie no straightening torque will be generated during heeling). This torque must be counteracted by the front hydrofoil so that torque equilibrium is obtained when operating horizontally. This means that the front hydrofoil will always generate resistance, which is negative.

To avoid impact from the propeller, it can be integrated in the aft hydrofoil at the same time as the motor is integrated in the primary, front hydrofoil. This means that the propeller's flow will not affect any of the hydrofoils. The disadvantage is that the motor must be integrated in the front hydrofoil so that its angle relative to it is equal to the relative angle of the aft hydrofoil, see figure 5. This is to avoid a hinged shaft between the motor and the propeller. However, the solution is probably outside the project's time frame due to the complicated structure this solution entails.

Since the propeller accelerates the waters in a negative direction relative to the travel course, this can instead be used with a rudder. The rudder efficiency will be increased if it is placed close to the propeller as it benefits from a high flow rate. The disadvantage of a rudder is that its effect depends on the speed of the craft and requires continuous adjustment of the driver.

## Analysis 2 - The propeller's impact from the cover

With an encapsulated propeller, the induced resistance will be reduced because the path of the water over the propeller tip will be prevented by the cover. The induced resistance is usually introduced (for propellers without a cover or similar device) as compensation for the blades of the propeller not being infinitely long. With the introduction of a cover, the water is prevented from overflowing from the overpressure side to the low pressure side, which means that we can neglect this compensation. However, the cover will increase the frictional resistance as the water will flow along the cover. The flow around the cover is assumed to be able to be divided into two parts. Partly the flow that affects the outside of the cover and partly the flow that affects the inside of the cover. For the flow on the inside of the cover, the flow can be assumed to be (1 + a) times the free-flow velocity.

Where $a$ for known efficiency can be expressed as

$$= \frac{\quad}{\quad} \qquad []$$

The speed on the outside is assumed to be the same as the free flow speed, ie. the speed of the craft. The friction from the cover can be assumed to be as great as an infinitely long naca2412 profile because it is closed. The friction can then be calculated with data from a semi-empirical model according to ref [2]. The two-dimensional coefficient of friction, , is read from Figure 5.

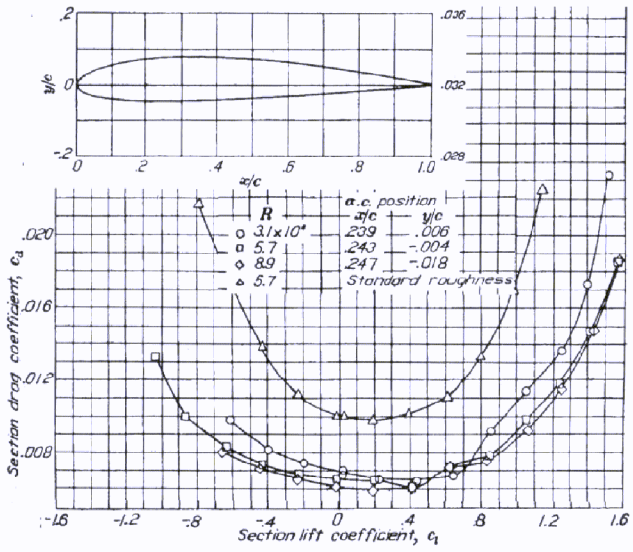



***Figure 5.*** Two-dimensional coefficient of resistance for naca2417 profiles.

Where $R$ is Reynolds' number, $C_l$ is the lift coefficient (in our case zero).

Reynolds' number is further calculated as

$$= \frac{}{} \qquad []$$

There is the length of the cover (chord), *v* is the speed and is the viscosity. The total resistance can now be calculated as

= – – + []

There is the density of the water, is the free-flow velocity, is the velocity of the water inside the cover (ie (1 + a) ) and is the area of the cover.

For reasonableness assessment, the coefficient of friction can be calculated without the addition of the profile thickness according to

$$= \frac{\cdot}{( \ ( ) \ )}$$

To test the theory, the following values have been assumed:

L = 0.1 m
D = 0.16 m
A =
= 15
= 60%

The two-dimensional resistance then becomes 34 N.
Only the frictional resistance then becomes 28 N.

Here, the lowest value for has been assumed as Reynolds' number is lower than what the scale contains values for in Figure 5.

Note that this model only applies when the craft is traveling in a straight direction. When the craft turns, additional resistance will arise because the cross-sectional thickness of the cover relative to the flow can no longer be neglected.

## Conclusion

The motor should be placed in a streamlined cover below the aft hydrofoil. This is because it is primarily the top of the aft hydrofoil that will generate a straightening torque.
The propeller should then be placed in a protective cover behind the aft hydrofoil. This means that none of the hydrofoil will be affected by turbulent flow from the propeller. The fact that the propeller is encapsulated in a cover reduces the risk of injury to the user. That the link arm between the hydrofoil has an angle is due to the fact that it is desirable that the aft hydrofoil should, as often as possible, lie outside the guard of the front hydrofoil. Since the size of the deflection is unknown, an angle of five degrees is assumed to be sufficient. The set angle means that the aft hydrofoil The fact that this angle is not set larger is because the depth wants to be minimized and because the insights about how much a larger angle affects performance are limited. The solution is illustrated in Figure 6 below.

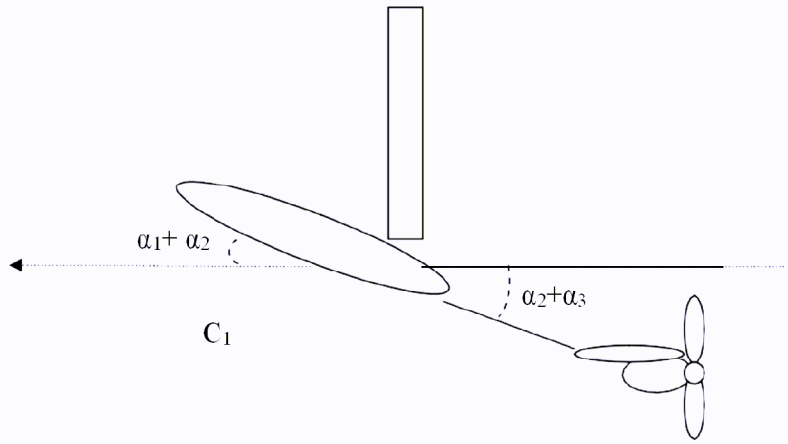
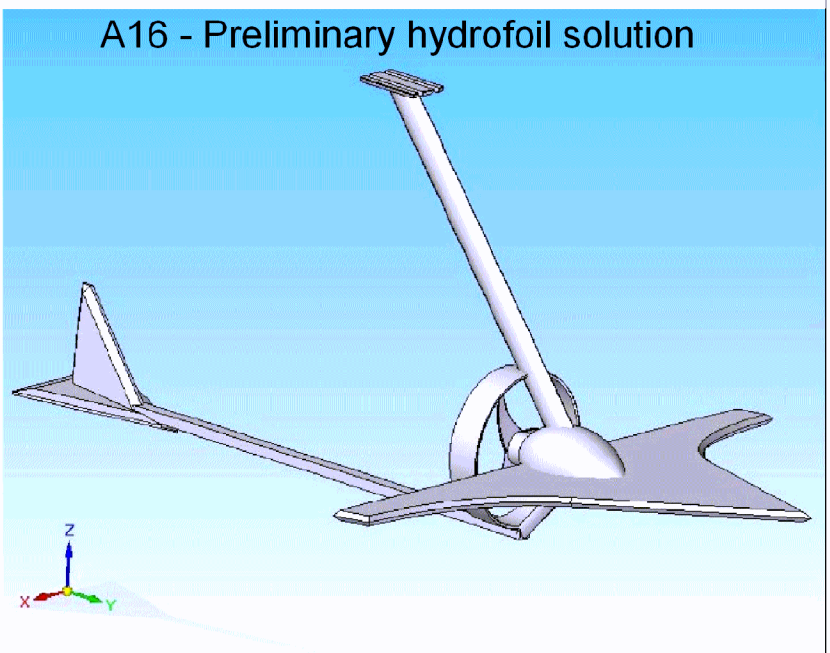



***Figure 6***. Aft hydrofoil placed below the propeller at lifting position $\alpha_1$ plus $\alpha_2$ about 15 degrees.

The solution recommended above provides the following dimensions for the hydrofoil configuration.

$\alpha_3 = 5^o$




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Summary

Evaluation of analyzes and experiments has resulted in the following hydrofoil design.

Table 2. Dimensions for the hydrofoil configuration

| | | unit | |
|---|---|---|---|
| H | height of strut | [m] | 0.83 |
| | angle of strut | degrees | 0 |
| a1+a2 | Distance between points of attack for the lifting and stab. force. | [m] | 1.1 |

Dimensions for the front hydrofoil

| | | | |
|---|---|---|---|
| C1 | chord | [m] | 0.87 |
| $C_{1A}$ | chorda | [m] | 0.11 |
| b1 | wing span | [m] | 0.8 |
| $b_{1A}$ | wing span | [m] | 1.1 |
| 1 | open angle | degrees | 57 |

Dimensions for the aft hydrofoil

| | | | |
|---|---|---|---|
| $C_2$ | chorda | [m] | 0.39 |
| b2 | wing span | [m] | 0.36 |
| 2 | open angle | degrees | 57 |

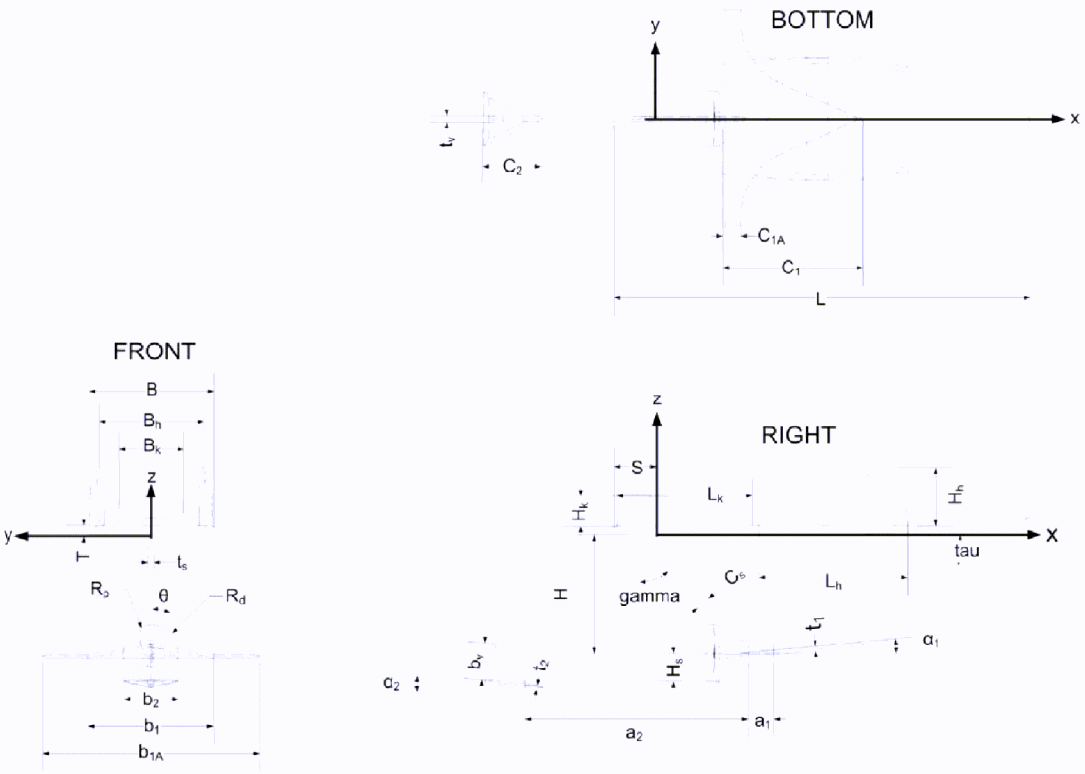



**Figure 19. Drawing of Evolo's hydrofoil configuration**

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Appendix 1 - Checklist for Quality Assurance

## 1.0 Problem formulation

A final hydrofoil design shall be determined. What is to be determined is what the configuration should look like under the the floating body. Where should the hydrofoil be placed. How to integrate motor and propeller in this design. All information need to be considered and weighing the pros and cons of different suggestions of placement of the hydrofoil and the motor with propellers.

## 2.0 Evaluation

The results from analyzes and experiments are evaluated. Conclusions are presented briefly from each report.

### *2.1 A1 – Hydrofoil*

A delta wing is preferable because the derivatives of the $C_L$ curve are much lower. This means that a change in the angle of attack leads to a smaller change in the lifting force in comparison with the straight wing. Another advantage is that the delta wing has a higher maximum angle of attack, when stalls occur. In order for the delta wing to generate 170 kg in lifting force at 6 knots, its dimension is according to Table 2 (for the definition of the opening angle, see Figure 1).

Table 3. Hydrofoils dimensions

| | | |
|---|---|---|
| Wingspan | [m] | 0.8 |
| max chord | [m] | 0.87 |
| Open angle [degrees] | | 57 |

### *2.2 A5 – Resistance*

The selected hydrofoil configuration according to Table 2 gives rise to a drag resistance of a maximum of 525 N, at a speed of 6 knots. The aft hydrofoil is assumed to be the same as the front hydrofoil but in a scale of 1: 5. Diagram 1 shows the drag resistance for the speed range 6-15 knots. 6 knots is the speed when Evolo lifts and this results in only the hydrofoil, mountings and the strut giving cause to a drag resistance.

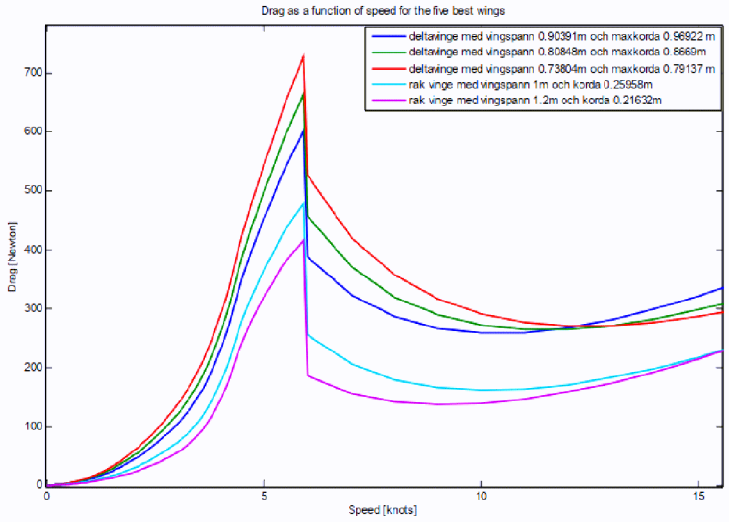



**Diagram 2. Drag resistance with respect to speed**

### 2.3 *A13 – Pitch stability*

For the previously selected dimensions on the aft and front hydrofoil, the pitch stability is analyzed. The question is where the center of gravity should be placed ($x_{TP}$) for a given distance between the lifting and stability wing ($a_1 + a_2$) for a correcting torque to exist when Evolo is exposed to a disturbance.

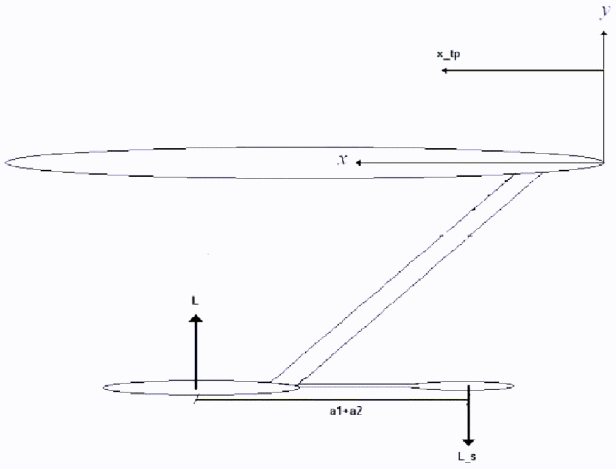



**Figure 20. Side view of Evolo**

The result of A13 is shown in diagram 2.

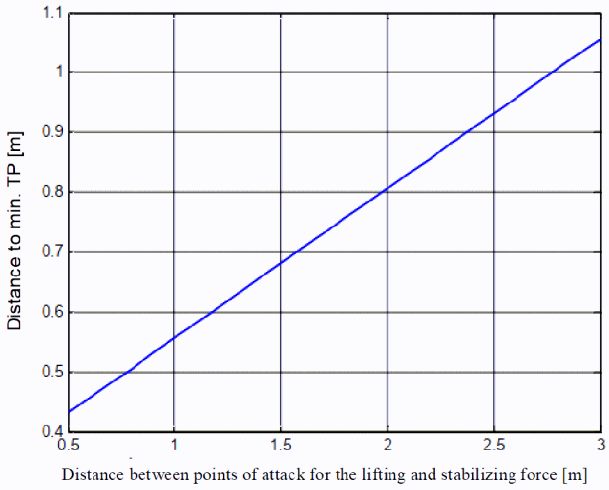



**Diagram 3. The limit value for placement of the center of gravity depends on the distance between the wings.**

The results from A13 are verified by experiment X7.

### 2.4 *A15 – Location and flow around the motor and hydrofoil*

The conclusion from A15 is that the aft hydrofoil should be placed below the lifting wing. The motor is integrated in the aft hydrofoil (figure 3).

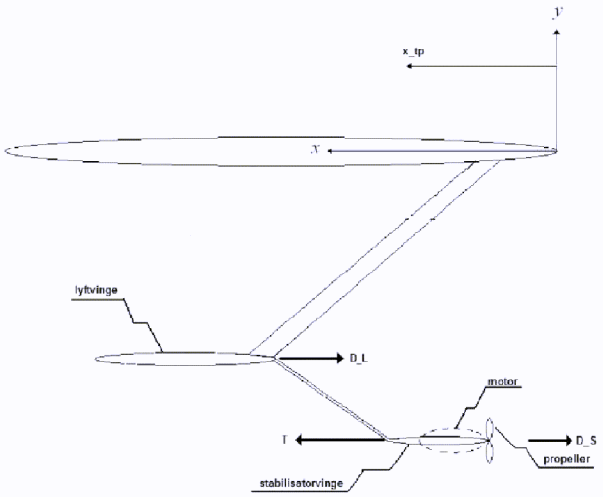



Figure 21. side view of Evolo

The advantage of this design is that the propeller will never break the water surface. In addition, the aft hydrofoil is avoided by the turbulent flow generated by the front hydrofoil. A further conclusion is that the propeller is placed behind the aft hydrofoil so as not to disturb the flow around the hydrofoil.

### 2.5 *X7 – Experiment*

The conclusion from experiment X7 is that a distance ( + ) of 1.1 m between the point of attack of the lift and the stabilizer force gave the best results. This distance has been found to provide satisfactory stomping stability. The center of gravity must therefore be placed over a distance ($x_{TP}$) of 0.6 m according to A13. The results are obtained with a hydrofoil design according to Figure 4. Since the dimensions of the lifting wing are according to Table 2 and the stabilizer wing is in scale 1: 5 compared to the lifting wing.

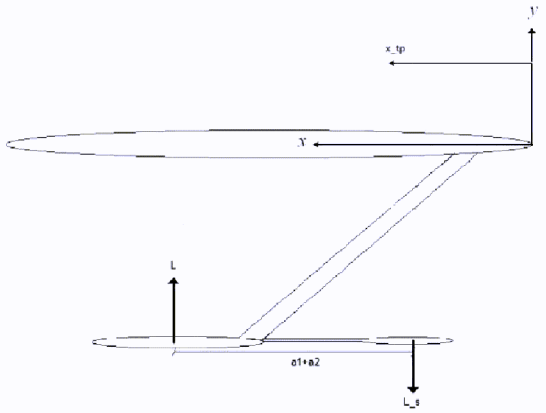



**Figure 22. Side view of Evolo**

### *2.6 X8 – Experiment*

For experiment X8, the same configuration as X7 was used, but with a different design on the front hydrofoil in order for Evolo to have better rolling stability. To increase the inertia in the rolling directiont, the wing span is increased. This reasoning leads to additional surface being added to the delta wing in the base to widen the wing span (see Figure 5).

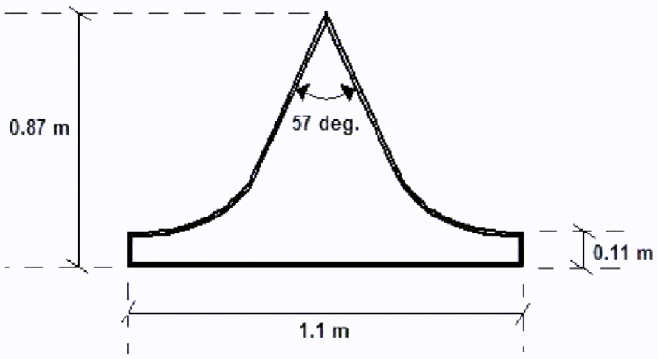



**Figure 23. Delta wing with widened wing span.**

The result from X8 is that with dimensions on the front hydrofoil according to figure 5, Evolo is more stable in the rolling direction. By stable is meant that the system is slower so that the driver has an opportunity to compensate for a disturbance in the rolling direction.

## 3.0 Final hydrofoil design

The dimensions of the front hydrofoil are set based on the conclusion in A1. It is verified by X7 that this dimension provides a satisfactory lifting force. Furthermore, the X7 verifies that the aft hydrofoil must be in a scale of 1: 5 compared to the front hydrofoil and that it must be placed at a distance of 1.1 m. This provides a satisfactory rolling stability.

Experiment X8 results in the wing span being widened on the front hydrofoil to improve rolling stability.

The mounting for the strut is placed at the front lifting wing and the angle ( ) is zero.

This gives the driver a large area to move within considering that the center of gravity should be placed at a minimum from the origin defined by GA [ref. 4].

The propeller is placed just after the lifting wing and the motor is integrated into it. The advantage of this is that the propulsive force, which is significant, is as close to the strut as possible. The link between the front and aft hydrofoil does not need to be dimensioned according to the propulsive force.

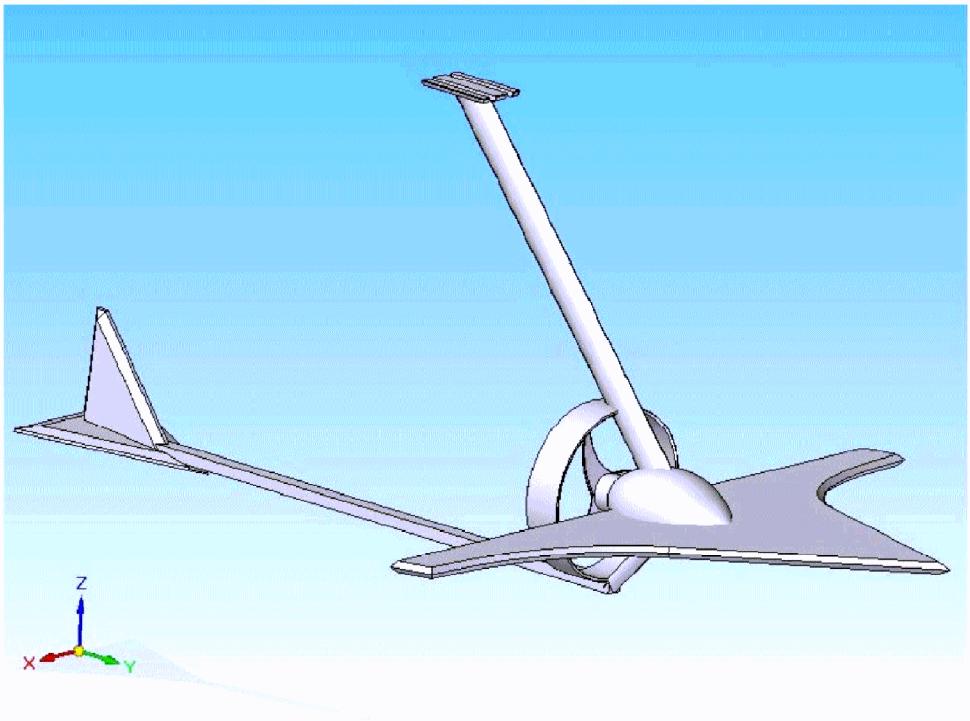



**Figure 24. Sketch of Evolo's hydrofoil configuration**

## 4.0 Discussion

Discussion has led to the propeller being placed in the calm water from the lifting wing. In the calm water, it is the lower flow rate which in turn increases the efficiency of the propeller.

It is unclear exactly how the calm water from the front hydrofoil affects the aft hydrofoil. It is thus useful for the project to investigate whether the aft hydrofoil can be placed in the calm water without its properties being affected. If it is adversely affected, a distance in the vertical direction should be determined so that the aft hydrofoil is placed outside the calm water.

Stability in the rolling direction is considered to be of high priority to analyze. This has been established in X7.

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# A 17-Maximum load cases for the structure




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## Summary

The report shall identify and determine the critical load cases to which the large stay between the board/hydrofoil and the small strut between the front wing/aft wing may be exposed. The model analyzed consists of Evolo with battery and motor, as well as a driver. With a plausibility assessment based on information on how many G-forces are exposed in different situations, it is concluded that Evolo is able to absorb 3G in the structure in the event of a difficult maneuver or crash. Also a case where Evolo drives at a cruising speed of 15 knots when the wing is turned up towards the water in pitch direction. This is to investigate how large the forces become in such a maneuver, if they are smaller than the corresponding inertial forces at 3G, they are instead the dimensioned case. The stays have been exposed and are considered permanently clamped in the calculations.
Based on this simplification, it is obtained that the stay will be exposed to the forces according to Figures A and B.

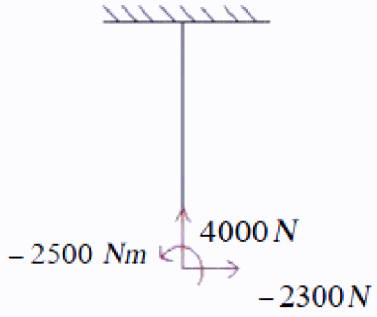



Figure A.The developed load case for the large stay.

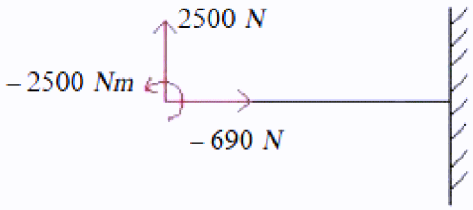



Figure B. The developed load case for the small stay.

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## 1.0 Problem formulation

The purpose of the study is to analytically determine which forces will affect the stay between the board and the hydrofoil and the link between the wings, see figure 1. A plausibility assessment regarding how many G-forces Evolo can respond to is needed to set a maximum load case. To even see if these forces are reasonable, a theoretical load case is analyzed where Evolo's hydrofoil is quickly turned up against the waters in a pitch direction at a cruising speed of 15 knots. To find the largest reasonable load case this angle is varied in pitch direction, $\tau = [0 - 30°]$. A schematic picture of what the load case for the large stay looks like is seen below in figure 1. To get load case for the small stay, basically the same case is used, but then only the aft wing is in the water with the angle $\tau$ .
To make the calculations possible and not so time-consuming, some assumptions have been made, which are explained in the analysis.

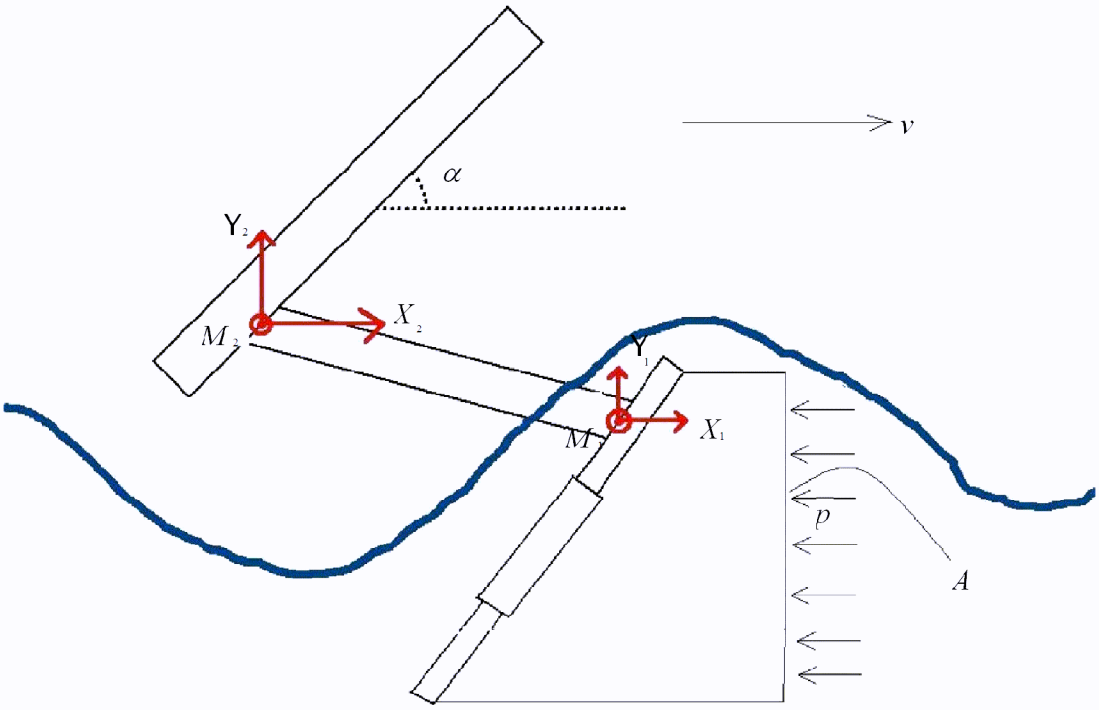



*Figure 1. The hydrofoil has been quickly angled up towards the water at an angle$\tau$ . In order to find out which reasonable load case is largest, the analysis is performed over a degree interval $\tau = [0 - 30°]$ A is the projected area from the hydrofoil in the direction of velocity, v the velocity and p the pressure acting on A.*

## 2.0 Analysis

The first part, part 2.1, calculates how much load the mentioned stayss on Evolo could theoretically be exposed to. during analysis deals with the estimate of the maximum load case that can affect Evolo. Part 2.2 investigates how many G-forces Evolo is structurally capable of absorbing. If the theoretical load case in 2.1 is less than the estimated load case in 2.2, it is the maximum load case, if it is higher, the estimated load case is set to the maximum.

### *2.1 Theoretical calculated load case*

The lower part will be subjected to a dynamic pressure on the two wings and the small stay. The stay is chosen to be neglected as it can be built to only make a small contribution. To investigate the largest load case, the angle of the pitch direction needs to be varied. The angle $\tau = [0 - 30°]$ does not vary to higher angles as future calculations do not apply to larger angles. To make the calculations simpler, it is assumed that there is no angle on the delta wings, they are parallel to the board.

The delta wing will be subjected to the forces traction, $F_D$, and lift, $F_L$, see equations *1* and *2* [1].

$$F_D = \frac{1}{2} \cdot \rho \cdot v^2 \cdot A \cdot CD, \qquad (1)$$

$$F_L = \frac{1}{2} \cdot \rho \cdot v^2 \cdot A \cdot CL, \qquad (2)$$

there $\rho$ = 1000 is the density of water, $A$ is the projecting area of the hydrofoil in the direction of flow, $v$ velocity, CD and CL are coefficients of resistance, see *figure 2* for the model setup. The maximum $CD$ and $CL$ are set to 1.2 [1]. These coefficients of resistance are the normal coefficient of force of the delta wing divided into components, see *equations 3* and *4* [2]

$$CD_p = \left(\frac{s}{l}\right)^2 \cdot \sin(\alpha) \cdot \left( 2\pi \frac{\alpha}{\left(\frac{s}{l}\right)} + 4.9 \frac{\alpha}{\left(\frac{s}{l}\right)^{1.7}} \right), \qquad (3)$$

$$CL = \left(\frac{s}{l}\right)^2 \cdot \cos(\alpha) \cdot \left( 2\pi \frac{\alpha}{\left(\frac{s}{l}\right)} + 4.9 \frac{\alpha}{\left(\frac{s}{l}\right)^{1.7}} \right), \qquad (4)$$

There $\tau$ is the angle of attack $s$ is half the width of the wing, $l$ is the "height" of the wing, see *Table 1* for these values of the current wings.

| | $s$ [m] | $l$ [m] |
|---|---|---|
| Front wing | 0.305 | 0.71 |
| Aft wing | 0.185 | 0.39 |

Table 1. The dimensions of the front and aft wing

I $CD_p$ does not include the coefficient of friction which we must add to get the total CD according to *equation 5*

$$CD=CD_0+CD_p. \quad (5)$$

$CD_0$ is a coefficient of resistance that refers to the lifting area to the wet area according to *equation 6*

$$CD_0 = C_F \cdot \frac{S_{wet}}{S}, \quad (6)$$

where the wet area, $S_{wet}$ , is estimated here to be 4 times as large as the lift area according to [1], $S$ ,and $C_F$ described by *equation (7)*

$$C_F = \frac{0.075}{(\log_{10}(R_e)-2)^2}, \quad (7)$$

Where Reynolds' number $Re$ , given according to *equation 8* is

$$R_e = \frac{v \cdot L}{\nu}, \quad (8)$$

where $v$ is the speed which is 15 knots, $\nu$ is the kinematic viscosity that is $1 \cdot 10^{-6} \frac{m^2}{s}$ and $L$ is the characteristic length which in this case is half the height of the delta wing $l$.
*Equations 1* and *2* can now be calculated and the forces and torque that the delta wings generate on the stay can be produced.
The stay is fixed at the point on the wing where its force attacks, after which only torque from the aft wing affect the strut. To see which forces attack the stay at the mounting, the forces from the two hydrofoils are added together to the force components F*px* ,F*py* and a torque *Mpz* from the aft wing is added, see *figure 2*.

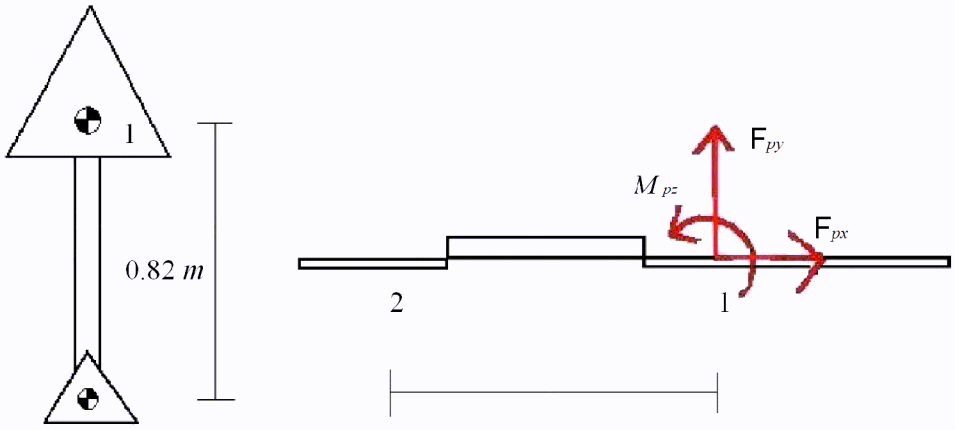



*Figure 2. The traction and lift forces affect the delta wings in their midpoints 1 and 2 which are seen in the left part of the figure.*

*To transfer these forces to the mounting for the stay, those force components $F_{px}$ and $F_{py}$ are replaced by a moment $M_{pz}$.*

In response to this deceleration in the water, an acceleration a is obtained, which together with the mass of Evolo,$m_{tot}$ = 170 *kg* [3], form the corresponding inertial forces to $F_{px}$ and $F_{py}$ .
The acceleration is obtained from the force equation, see *equation 9*

$$a = \frac{F}{m}. \qquad (9)$$

When acceleration is known, *Equation 9* can be applied to the upper and lower part of the Evolo, this to calculate the inertial forces forces that these parts have on the stray.
The upper part of the Evolo in this model consists of the board, battery and driver. The weight of the battery is assumed to be 20 kg, the board is assumed to weigh 15 kg and the driver 100 kg, which is the latter according to the requirements specification [3]. The lever to the center of gravity of the upper part is seen in *figure 3* and is assumed so as to get a large load on the mounting to the strut.

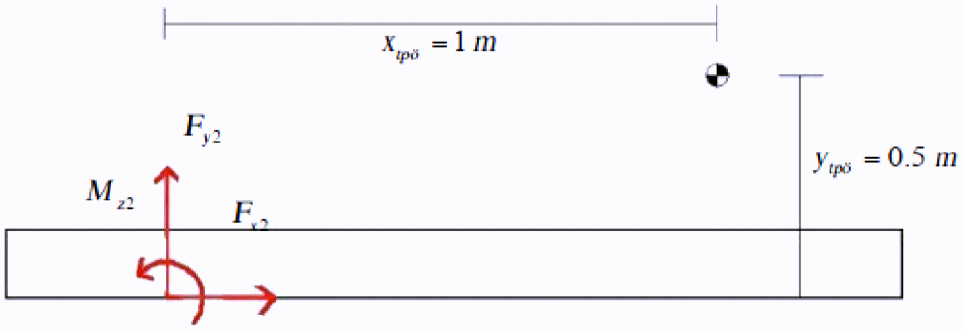



*Figure 3. The upper part of the Evolo consisting of board, battery and driver has its center of gravity placed 1 m and 0.5 m respectively*
*from the mounting in the x and y directions. The force attacking in this point is replaced by the forces $F_{x2}$, $F_{y2}$ the mounting.$M_{Z2}{}^{i}$ And torque in*

*Equation 9* gives the force with which the upper part affects the strut and it can be replaced by the forces $F_{x2}$ , $F_{y2}$ and torque $M_{z2}$ in the mounting shown in *Figure 3*. The component $F_{y2}$

also contains the contribution of gravity from the upper part.

The lower part consists of the hydrofoil, the beam between them and the motor. The small stay is assumed to weigh 1 kg, the front and aft wings together weigh 9 kg and the motor is assumed to weigh 20 kg. The center of gravity of the motor is set close to the aft wing to increase the forces that affect the stay. Their common center of gravity will then be according to *Equation 10*

$$X_{tpu} = \frac{\sum_i x_{tpi} m_i}{\sum_i m_i}, \qquad (10)$$

there $x_{tpi}$ the different parts are distance from their center of gravity to the lower mounting in the large

stay in the x-direction and $m_i$ their mass. This is also done in y-direction to get $y_{tpu}$ , see figure 4 for a picture of the lower plane.

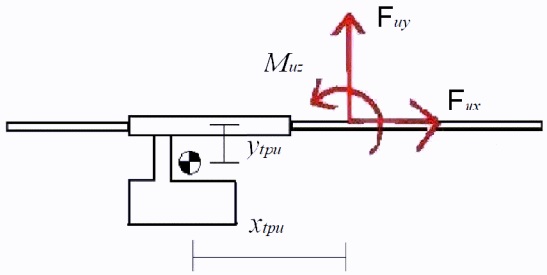



*Figure 4. The inertia forces that are formed in the lower part of the center of gravity and have here been replaced with the force components $F_{ux}$, $F_{uy}$ torque $M_{uz}$ in the mounting to the strut.*

Here, too, *Equation 9* gives the inertia force that arises due to the acceleration and in order to obtain the forces that arise on the stay, it is replaced by the F*ux* ,F*uy* and force components.

the torque *Muz* in the mounting to the stay. In addition to the forces already mentioned,

the gravitational force and the motor power for the propulsion, which is assumed to be 500 N [1], will also be included in these components.

Now the stay and the forces that affect it can be added together and exposed, as seen in *figure 6*, and it can now be examined at what angle these forces make the greatest total contribution.

The forces $F_{px}$ , $F_{py}$ And torque $M_{pz}$ added with $F_{ux}$ ,$F_{uy}$ and the torque $M_{uz}$ to get the total loads $F_{x1}$ ,$F_{y1}$ and $M_{z1}$ which acts on the lower mounting to the stay. The inertia forces and gravity of the stay are also included in the calculations, as can be seen in *Figure 5*.

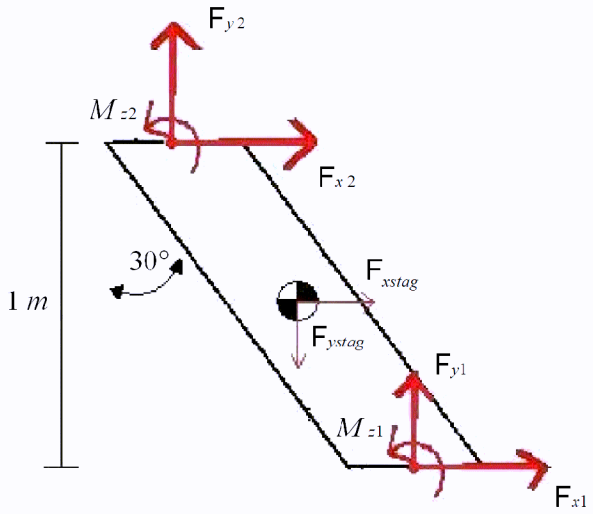



*Figure 5.* The stay is exposed with the combined forces, torques and its own inertia force. It is these forces that will dimension the stay.

### *2.2 Estimated maximum load case*

When Evolo crashes or similar, it is reasonable to assume that this happens over a period of time and does not happen infinitely quickly. During that time period, an acceleration is obtained which Evolo responds with inertial forces. To prevent these inertial forces from becoming too great, acceleration must not be too fast. Acceleration is chosen to be compared as G-forces in order to easily assess from other situations how many G-forces can be exposed to.
Roller coasters are equated with G-forces and the extremes reach just over 4 G, e.g. the Oblivion attraction, see *Figure 6*, which in a vertical fall reaches 4.5 G [4].



*Figure 6.* Vertical fall in the ride Oblivion where the rider is exposed up to 4.5 G.

A fighter pilot is trained to handle 9 G while a cough produces a 3.5 G effect on the body [5]. Why

a cough has such a high G compared to the other examples is because a cough lasts for a much shorter time. A hosting is about a tenthof a second, while a turn in a fighter aircraft lasts for a number of seconds.
As there is a certain inertia in the material and no part is completely firm, a high acceleration in a very short time should not have time to affect Evolo. To give an example, Formula 1 driver Robert Kubica collided with a wall at 230 km/h, then an acceleration of 75 G was recorded in one millisecond [6]. Therefore, a relatively slow acceleration should be treated.

When acceleration is set, a simplified model is made according to *Figure 7*.

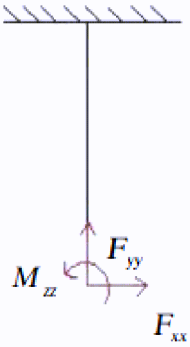



*Figure 7. The strut is exposed according to this simplified model.*

In the model, the strut and its forces are exposed. The forces of inertia of the upper part then become the forces with which the lower part must respond. The lower part of the Evolo is then replaced with that force and the torque becomes the torque that the aft wing has on the lower mounting. This is to get such large loads when dimensioning.
In the model, the forces act in a rod that is firmly clamped up on the board. The rod is here the stay which for the sake of simplicity is drawn without any angle. The boundary condition is not true, but since it makes it possible to calculate the case and it gives an oversizing, it is a good assumption.
The force of inertia is obtained by the force equation, see *equation 9*.

## 3.0 Results

What is analyzed are 2 different struts, the large strut between the board/hydrofoil and the small strut between the wing/aft wing, the prefix l is used when forces on the small strut are examined.

### *3.1 Large stay*

#### 3.1.1 Theoretical load case

The first thing to do is to determine at what angle $\tau$ the stay is exposed to the most load. An interval of $\tau = [0 - 30°]$can be seen in Figure 8 where the force and torques are shown as a function of $\tau$ .

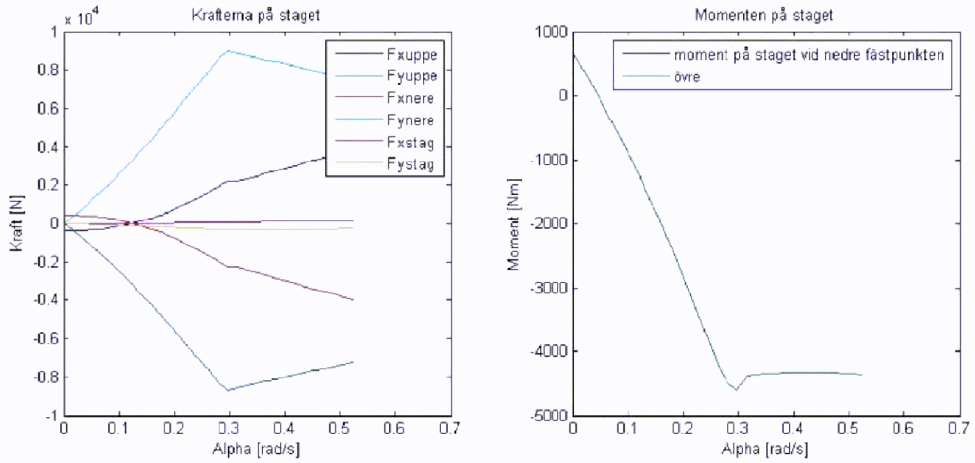



*Figure 8.* Shows the theoretical forces and torques that can occur on the large stay.

As can be seen, there is a point that looks critical, which turns out to be 18°. This will be the case on which the ongoing calculations will be based.

The tensile and lift forces described by equations 1 and 2 provide for that front wing

$F_{Ds} = -2400\ N$

$F_{Ls} = 7900\ N$

and for the aft wing is obtained

$F_{D} = -800\ N$

$F_{Ll} = 2900\ N$ .

If the forces are moved to the lower mounting on the stay, the forces are obtained as in figure 2 above,

$F_{px} = -3200\ N$

$F_{py} = 10800\ N$

Inertial forces are obtained by using equation 9 where the acceleration in the x and y directions is calculated to

$$a_x = -16 \frac{m}{s^2}$$

$$a_y = 54 \frac{m}{s^2}$$

Using $F_{px}$ ,$F_{py}$ and$M_{tot}$ to then be used again in the same equation but with then only the lower part, the lower part is in this case the delta wings, the beam between them and the motor. This gives forces in the lower mounting of the stay which is

$F_{ux} = 1000N$

$F_{uy} = -1800\ N$

The inertia forces for the upper part are made in the same way as for the lower part, use the mass of the upper part which consists of board, human and battery which gives

$F_{x2} = -2200\ N$
$F_{y2} = 8700\ N.$

In order to get the total loads on the lower mounting to the stay, the loads from the resistance on the lower hydrofoil are added with the inertial forces from the lower part, which gives

$F_{x1} = -2300N$
$F_{y1} = 9000\ N\ .$

These loads also include gravity from the various parts and the motor's propulsion. The gravitational force of the stay will be

$F_{xstag} = 80\ N$
$F_{ystag} = -320\ N\ .$

When these forces are exposed to the mountings in the stay, the contributing elements must be calculated. Its levers from mountings to centers of gravity can be calculated using the dimensions given in *Figures 4,5* and *6*.
The elements from the various load contributions are added and become

$M_{z1} = -4600\ Nm.$
$M_{z2} = -4600\ Nm\ .$

### 3.1.2 Estimated maximum load case

Based on the information available, it seems reasonable that Evolo can be exposed to accelerations of max 3 G in both the x and y directions, where it is used as in our maximum load case. *Equation 9* gives us with the mass of the upper part and an acceleration 3G, a force

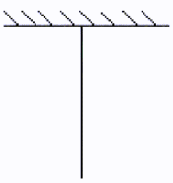
$$|F_{max}| = 4000\ N\ .$$

To estimate the maximum torque, the torque that the aft wing affects the mounting to the stay is taken. The forces that affect the stern wing can be produced with *equations 1* and *2* and the lever is known, see *figure 2*.

The torque that is then obtained is

$$M_z = -2500\ Nm$$

It is now being investigated whether any of the theoretical load cases are smaller than the estimated load case. If this is the case, they are replaced by the theoretical load case, see *Table 2* and *Figure 9* for the final dimensioned loads for the large stay.



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| | |
|---|---|
| $F_{xx}$ | -2300 N |
| $F_{yy}$ | 4000 N |
| $M_{zz}$ | -2500 Nm |

Table 2 .The determined maximum load case on the large stay.

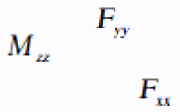



*Figure 9.* Shows the directions of the loads.

## *3.2 Small stay*

### 3.2.1 Theoretical load case

The first thing to do is to determine at what angle $\tau$ the stay is exposed to the most load. An interval of $\tau = [0 - 30°]$ can be seen in Figure 7 where the force and torques are shown as a function of $\tau$ .

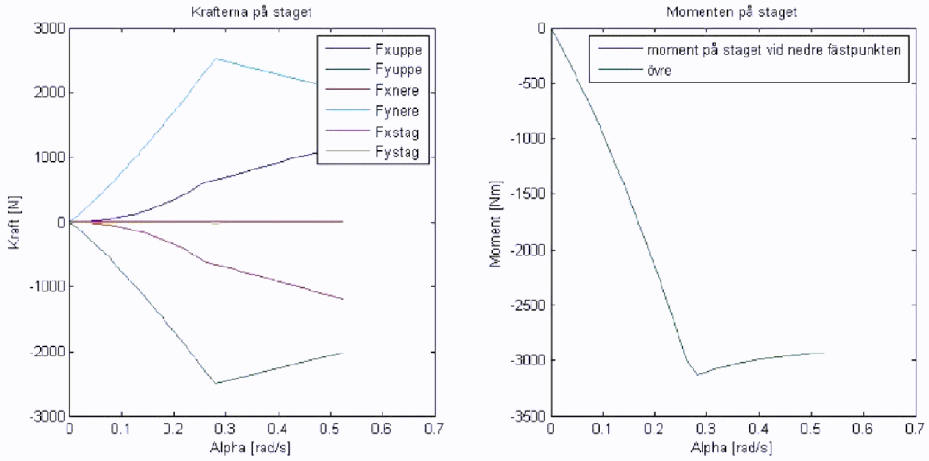



*Figure 10.* Shows the theoretical forces and torques that can occur on the small stay.

At 17° the maximum load case is obtained and progressive calculations will count on this case.
As these calculations and processes follow the same path as for the large stay, the results are written down in tabular form, see *Table 1*.

| | |
|---|---|
| $F_{pxl}$ | -800 N |
| $F_{pyl}$ | 2900 N |
| $a_{xl}$ | -4,7 $\frac{m}{s^2}$ |
| $a_{yl}$ | 7 $\frac{m}{s^2}$ |
| $F_{uxl}$ | 100 N |
| $F_{uyl}$ | -380 N |
| $F_{x2l}$ | 650 N |
| $F_{y2l}$ | -2500 N |
| $F_{x1l}$ | -650 N |
| $F_{y1l}$ | 2500 N |
| $F_{xstagl}$ | 5 N |
| $F_{ystagl}$ | -17 N |
| $M_{z1l}$ | -3000 Nm |

| | |
|---|---|
| $M_{z21}$ | -3000 Nm |

*Table 3*. The results for the theoretical calculated forces that load the small stay.

### 3.2.2 Estimated maximum load case

Here, too, the maximum acceleration is set to 3G, which gives the same maximum load as on the large stray

$$|F_{l\,max}| = 4000\ N\ .$$

The torque is calculated in the same way as for the large stay, with the lift of the aft wing. However, there is another lever in this case. The lever is the distance from the center of gravity of the aft wing to the top of the wing, ie where the small stay begins, see *figure 2*. The torque is thus

$$M_{zl} = -2500\ Nm\ .$$

It is now being investigated whether any of the theoretical load cases are smaller than the estimated load case. If this is the case, they are replaced by the theoretical load case, see *Table 4* and *Figure 11* for the final dimensioned loads for the small stay.

| | |
|---|---|
| $F_{xx}$ | -690 N |
| $F_{yy}$ | 2500 N |
| $M_{zz}$ | -2500 Nm |

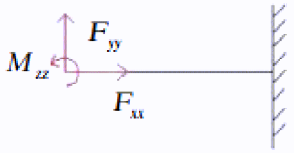



Table 4. The specific maximum load case that affects the small stay. *Figure 11.* Shows the directions of the loads.

## 4.0 Discussion and Conclusion

Our first attempt to only calculate the theoretical load case turned out not to be true because Evolo will then not be in torque equilibrium and therefore it is not possible to perform any strength of materials calculations. Therefore, these maximum load cases were assumed based on how many G-forces are likely to occur and how much of it the craft will respond to depending on the inertia of the system. This is the largest and most crucial estimate made in the report. Measures to obtain a safety margin have been taken as most assumptions, such as the boundary condition firmly clamped and the location of the motor. 3G sounds reasonable but it is a rough estimate that is not based on any reliable sources or tests. In the end, therefore, the strength of materials calculations must determine how reasonable these results are.
The report does not examine which load cases arise if it is exposed to the force to the side, but if the stays are dimensioned so that they are symmetrical, they should also be able to handle these load cases as they are reasonably smaller than those examined here.
Unfortunately, when this report began to be worked on before the current construction, not all dimensions and hydrofoil solutions agree, however, this should give a good indication of the load case.

## 5.0 References

[1] M.Norberg. A1-Bärplan 2008-11-17.
[2] John D. Andersson, Jr. Aircraft performance.
[3] Kravspev_version_1, Bilda
[4] [4] http://www.rcdb.com/id777.htm, 2008-12-01
[5] ,http://www.popularmechanics.com/science/medicine/1281111.html?page=2 2008-12-01
[6] ,http://www.autosport.com/news/report.php/id/59988 2008-12-01

## Appendix 1 - Checklist for Quality Assurance

The purpose of the list is to function as a structuring support for planning, writing and proofreading reports and as support for self-reflection. The list should be used for feedback from proofreaders. Evaluate each point with yes / no and sometimes with a grade of u, 3,4,5. Note that the completed checklist must be attached to each report!

| ***General impression*** | **Author Yes/No** | **Reviewer Yes/No** |
|---|---|---|
| 1. Are all elements of the problem addressed? | yes | Yes |
| 2. Have the purpose and conditions been reported? | yes | Yes |
| 3. Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective? | yes | Yes |
| 4. Is the purpose achieved? | yes | Maybe |
| 5. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors? | ? | No |
| *Technical content* | | |
| 6. Have simplifications and assumptions been clearly stated and justified? | ? | Maybe... |
| 7. Has the choice of solution methods been clearly reported and justified? | yes | Yes |
| 8. Are calculations controlled and reasonably assessed? | yes | Yes |
| 9. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text? | yes | Yes |
| 10. Are equations written as part of the running text, presented in separate lines and numbered? | yes | Yes |
| 11. Can the technical reasoning be followed? | ? | yes |
| 12. Is there a difference between facts, statements and the author's opinion? | yes | Yes |
| 13. Is there a realistic verification plan for the work in the report? | no | No |
| 14. Is there an acceptable follow-up of the verification plan? | no | no |
| *Presentation* | | |
| 15. Is the report well structured with regard to section and chapter division, common thread and logical sequence as well as balance between different sections? | yes | It's ok |
| Is the report provided with: appropriate title, date, author name, e-mail, possible supervisor, summary/abstract, table of contents, reference list and page numbering | yes | Yes |
| Is the report written in third person passive form? Are experiments described in imperfect, e.g. "Trailing tests were performed to verify…" while descriptions of analysis methodology and calculations are rewritten in the present tense, e.g. "Calculations show that the natural frequency…"? | I do not think so | No |
| Are figures and tables clear and informative, provided with figure / table text and clear numbering? Do all figures have units inscribed on all axes? Can figures be interpreted even after printing in black and white, and preferably after black and white copying? | no | No |
| 19. Are appropriate references made to figure, table and equation numbers in the text? | yes | Yes |
| 20. Are appropriate references made to references in the reference list? | yes | Yes |
| 21. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.? | ? | No |

| | | |
|---|---|---|
| ***Other*** | | |
| 22. Has the report been written by you individually? | no | |
| 23. The work has been carried out in collaboration with: Nils Wolter | | |
| 24. The report has been proofread by: Erik Jerilgård | | |
| 25. I believe that this report as a whole is worth rating (u, 3-5) | 4 | 3-ish |
| The following is a reflection on how I believe that the work with this report and related projects relates to set learning goals (relevance of the work, which goals have been met, etc.):<br>A report that has been remade about 3 times when we found out that our calculations have been wrong. Apart from that, it has been an instructive task | | - |

# Security assessment




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| | |
|---|---|
| Course: | Marine design |
| Project: | Evolo |
| Date: | *20/11-2008* |
| Version number: | A risk assessment is never completed |
| Supervised by: | Jakob Kuttenkeuler |
| Hours worked: | *8* |
| Reviewed by: | Mattias Kennestad (Schönning Emeritus) |

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## Introduction

In most contexts during the development of Evolo, safety has been the subject of discussion, partly in connection with the experiments, but also for the final product. The purpose of this report is to identify risks to the driver of Evolo and trial participants and to suggest solutions to minimize these and in some cases point out factors that need to be further developed with regard to technical solutions.

## Problem formulation

A risk assessment must be carried out. In this analysis there are two parts, one includes the experiments that have already been conducted twice up to date, 2008-11-20 and the other part includes the finished product.

## Analysis

Risks are identified in this part. These are described in terms of what can happen, how likely it is, what consequences it will have and what measures should possibly be taken. The basis for the risks assessment is shown in Figure 1.

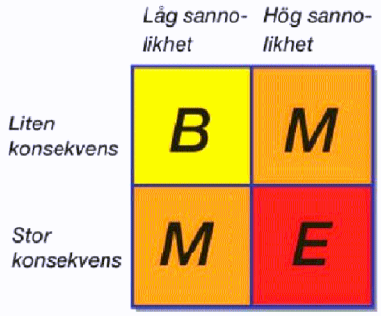



Figure 1. Risk assessment matrix [1]

The image in Figure 1 is taken from the Swedish Armed Forces' security series SÄKI [1]. The principle is that a risk is assessed on the basis of probability and consequence. Risks that can occur with a high probability and have a large consequence must be eliminated (E), risks with a high probability and a small consequence and a large consequence and a low probability, respectively, must be minimized (M) and those with a low probability and a small consequence must be monitored (B).

### *Experiment*

| | | |
|---|---|---|
| Risk: | Minor Fall Injuries<br>Evolo is still very unstable and each time has ended with the vehicle overturning and or the driver falling off. The fall itself has so far not involved more serious injuries than minor bruises. | |
| Probability: | High | → Risk assessment: M |
| Consequence: | Low | |
| Measure: | In the two completed experiments, a total of three people acted as | |

| | |
|---|---|
| | test drivers, two of whom drove in both experiments. Since these people have already gained experience and have a feeling of how Evolo works, one way to minimize the risk of continuing with the same test driver for the time being. |

| | | | |
|---|---|---|---|
| Risk: | More severe fall injuries<br>In the tests, the Evolo is towed by a motorboat and in the event of a fall, the hand-held tow line is detached, which in principle means that the pull ceases immediately. In the event of a fall backwards or to the side, the driver also falls away from the vehicle. One risk is that the towline gets stuck and that the driver simultaneously falls in front of the craft. Such a fall entails a great risk of injury for the driver as Evolo in its design has many parts that can cause not insignificant damage. | | |
| Probability: | Low | → | Risk assessment: M |
| Consequence: | High | | |
| Measure: | As before, the use of a limited group of drivers is preferred. Likewise, the tow line should be carefully configured so that it can always run freely. It is also important that someone is constantly designated to communicate with the driver of the boat, as this primarily has forward-looking supervision and must be notified immediately in the event of an immediate speed deduction. The Evolo driver must also strive to fall backwards at all costs.<br>The test vessel is also bulky manufactured. Unnecessarily sharp edges and extremities must therefore be removed or rounded off. | | |

| | | | |
|---|---|---|---|
| Risk: | Drowning<br>In connection with a more severe fall, the risk of drowning is not negligible as it e.g. could mean that the driver became unconscious. | | |
| Probability: | Low | → | Risk assessment: M |
| Consequence: | High | | |
| Measure: | The driver must always wear a life jacket and should wear a helmet. | | |

| | | | |
|---|---|---|---|
| Risk: | Boat risks<br>In the last attempt, Marina systems G-boat was used. This is water jet driven and the motor continuously drives the unit. Two risks are considered to be dominant:<br>• Navigational, grounding, collision etc.<br>• Maneuvering, collision with Evolo driver, crushing injuries during mooring etc. | | |
| Probability: | Low | → | Risk assessment: M |
| Consequence: | Low - high | | |
| Measure: | As the boat is special, it should only be driven by a limited group, especially when maneuvering around the quay and person in the water. When approaching a person in the water, this must always be done with the bow first at the lowest speed. The driver must be prepared to switch off the motor immediately in case the person comes closer to the stern than the center of the boat. To minimize navigational risks, the experiments must be carried out in low-traffic areas with a lot of open water. | | |

| | | | |
|---|---|---|---|
| Risk: | Hand injuries<br>In the experiments, the tow line is held by one person. When the Evolo driver falls, the line has to run out until the tugboat's speed is stopped, which can sometimes take a few seconds. When the line runs out, it must be allowed to run completely free. There are two risks; on the one hand, burns can occur due to the friction against the hand or other body part that gets in the way, and on the other hand, a bend in the rope can easily cut off, for example, a finger. | | |
| Probability:<br>Consequence: | Low<br>High | → | Risk assessment: M |
| Measure: | The person who handles the line must always wear gloves. The free part of the line<br>that is in the boat should always be put in a roll and preferably in a container such as a bucket so that no one can stand on it. | | |

| | | | |
|---|---|---|---|
| Risk: | Cold injuries<br>The experiments are conducted in relatively extreme weather with water temperatures of only a few plus degrees and air temperatures and winds that give significant cooling effects. The risk of cold injuries and hypothermia can not be neglected. | | |
| Probability:<br>Consequence: | Low<br>Low | → | Risk assessment: B |
| Measure: | In previous attempts, there has not been a problem with the cold as there has been a relatively good supply of equipment in the form of dry suits for the Evolo driver and the fact that Marina System has lent floating overalls. The biggest risk is probably exposed areas such as the face and hands. In extreme weather, everyone should be observant of signs of cooling such as bruising, numbness, loss of sensation, etc. As the experiments are conducted close to the city with the possibility of using the marine educational institution's<br>premises, early identification of injuries should be easily eliminated. In the worst case, there is also medical care close by. | | |

*Final product*

| | | | |
|---|---|---|---|
| Risk: | Propeller injuries<br>The propeller on the Evolo will probably risks of be one of the biggest injury. | | |
| Probability:<br>Consequence: | High<br>High | → | Risk assessment: E |
| Measure: | In order for the propeller to stop immediately in the event of a fall, some form of deadman switch is required. This can either be solved by a classic dead man's switch in the form of a line which, if it is pulled, turns off the power. Since Evolo will require movement of the body while driving, this may<br>be perceived as limiting. An alternative is therefore a throttle control that requires constant pressure to provide propulsion and springs back as soon as it is released | | |

| | |
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| | and thus turns off the power<br><br>In addition to this, the area around the propeller should also have some form of protective device so that it is impossible to get caught in it. |

| | | | |
|---|---|---|---|
| Risk: | Fall injuries<br>In the same way as in the experiments, there is a great risk of fall injuries. Admittedly, the degree of control on the craft will be higher than in the experiments as the driver himself can react directly with the throttle. | | |
| Probability: | High | → | Risk assessment: E |
| Consequence: | Low - high | | |
| Measure: | An important measure is, as for the risk of propeller damage, dead man's switch and or resilient throttle control. Likewise, many risks can be eliminated by avoiding<br>sharp edges and protruding details as far as possible. | | |

| | | | |
|---|---|---|---|
| Risk: | Drowning<br>The risk of drowning is probably considered low, but still fully possible. An unfavorable fall with a blow to the head could lead to unconsciousness and in an unfavorable situation involve a risk of drowning | | |
| Probability: | Low | → | Risk assessment: M |
| Consequence: | High | | |
| Measure: | The craft should under no circumstances be driven without a life jacket. The recommendation should also be to wear a helmet. | | |

| | | | |
|---|---|---|---|
| Risk: | Grounding / collision<br>The title speaks for itself, but is strongly linked to judgment and person. | | |
| Probability: | High | → | Risk assessment: E |
| Consequence: | High | | |
| Measure: | Clear instructions. Choose the area of operation smartly | | |

| | | | |
|---|---|---|---|
| Risk: | Abrasions / pressure injuries<br>Are primarily comfort-related for longer-term use | | |
| Probability: | High | → | Risk assessment: M |
| Consequence: | Low | | |
| Measure: | The floating body must be designed with ergonomic aspects in mind. See other report | | |

| | |
|---|---|
| Risk: | Electric risks<br>This risk is highly dependent on the electrical power at which the system will operate. If it is a 12 V system, which is common for marine applications, there is no risk of electric shock. However, there is a high risk of burns in the event of a short circuit in the system. |

| | | | |
|---|---|---|---|
| Probability: | Low | → | Risk assessment: M |
| Consequence: | High | | |
| Measure: | The system should be designed with proper fuses and enclosed pools. This is a factor that should be further analyzed at a later stage. | | |

## Conclusion / recommendation

A number of risks have been identified and a template has been developed to evaluate these risks. This document should be seen as living and it is up to each project participant to have risk awareness in mind during design and experimental activities. The most important thing about risk analysis is that it is carried out regardless of whether it is carried out in the head before or written down on paper. For the sake of documentation, however, write-downs are preferable.

Based on the analysis, a couple of risks that require technical solutions and thus further investigation can be identified:

- Dead man's switch
- The electrical system
- Propeller protection
- Ergonomics for the driver while driving
- Minimization of hard sharp surfaces

Other points are not summarized as these are written in short form and already of a summary nature. Above all, those involved in the experimental activities should read this part and reflect on the content.

## References

18. CD SÄKI på EMIL 2008, Säki G, Bilaga 8, http://217.10.106.34/saki/Sak_I_2008_v1a/SakI_bokpaket_2008_v1a//verksamhetsakerhet/saki/saki/saki_g/G_Bil_08/G_Bil_08.htm#BABHBDJA available 2008-11-20

## Appendix 1 - Checklist for Quality Assurance

The purpose of the list is to function as a structuring support for planning, writing and proofreading reports and as support for self-reflection. The list should be used for feedback from proofreaders. Evaluate each point with yes / no and sometimes with a grade of u, 3,4,5. Note that the completed checklist must be attached to each report!

| ***General impression*** | Author Yes/No | Reviewer Yes/No |
|---|---|---|
| 27. Are all elements of the problem addressed? | Y | |
| 28. Have the purpose and conditions been reported? | Y | |
| 29. Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective? | Y | |
| 30. Is the purpose achieved? | Y | |
| 31. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors? | - | |
| ***Technical content*** | | |
| 32. Have simplifications and assumptions been clearly stated and justified? | - | |
| 33. Has the choice of solution methods been clearly reported and justified? | - | |
| 34. Are calculations controlled and reasonably assessed? | - | |
| 35. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text? | Y | |
| 36. Are equations written as part of the running text, presented in separate lines and numbered? | - | |
| 37. Can the technical reasoning be followed? | - | |
| 38. Is there a difference between facts, statements and the author's opinion? | Y | |
| ***Presentation*** | | |
| 39. Is the report well structured with regard to section and chapter division, common thread and logical sequence as well as balance between different sections? | Y | |
| 40. Is the report provided with: appropriate title, date, author name, e-mail, eventual supervisor, summary/abstract, table of contents, reference list and page numbering | Y | |
| 41. Is the report written in third person passive form? Are experiments described in imperfect, e.g. "Drag tests were performed to verify…" while descriptions of analysis methodology and calculations are rewritten in the present, e.g. "Calculations show that the natural frequency…"? | Y | |
| Are figures and tables clear and informative, provided with figure / table text and clear numbering? Do all figures have units inscribed on all axes? Can figures be interpreted even after printing in black and white, and preferably after black and white copying? | Y | |
| 43. Are appropriate references made to figure, table and equation numbers in the text? | Y | |
| 44. Are appropriate references made to references in the reference list? | Y | |
| 45. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.? | Y | |
| ***Other*** | | |
| 46. Has the report been written by you individually? | Y | |
| 47. The work has been carried out in collaboration with: _____ | | - |
| 48. The report has been proofread by: Mattias Kennestad | | - |

| | | |
|---|---|---|
| 49. I believe that this report as a whole is worth rating (u, 3-5) | | |
| The following is a reflection on how I believe that the work with this report and related projects relates to set learning goals (relevance of the work, which goals have been met, etc.): | | - |

# Weight analysis




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| | |
|---|---|
| Course: | Marine design / Lightweight design |
| Project: | Evolo |
| Date: | *05/11-2008* |
| Version number: | *1.0* |
| Supervised by: | |
| Hours worked: | *13* |
| Reviewed by: | |

## Introduction

The purpose of this report is to provide the reader with a thorough understanding of the weight analysis of the Evolo craft. All input data on the measurements have been taken from the experiment and description of the general arrangement of the document. The document does not take into account stiffness calculations in different parts and the mass center on Evolo.

## Analysis

It is already known that stiffer carbon fiber materials give rise to fewer layers of laminate and thus a reduced weight in the construction. A sandwich material becomes stiffer by using a thicker core. Thicker core gives rise to a reduced number of laminate tiles which are relatively much heavier in a sandwich material compared to the core.
The weight of the vessel's structure has been approximately calculated using the sandwich concept. It has been assumed that the floating body is built of two layers of carbon fiber laminate of type DBT 700-C05-A with the directions [+ 45.90, -45] where the total thickness of the laminate plates is 2 0.72 mm.
The table below shows the volume of different parts of the craft:

| Component | Inner volume (foam) [$m^3$] | External volume (carbon fiber) [$m^3$] |
|---|---|---|
| Hydrofoil | 0.0715 | $3.2798\ 10^{-3}$ |
| Link between hydrofoil and board | $6.107\ 10^{-4}$ | $1.759\ 10^{-5}$ |

| | | |
|---|---|---|
| Large hydrofoil | $8.402\ 10^{-3}$ | $1.631\ 10^{-3}$ |
| Small hydrofoil | $1.3421\ 10^{-3}$ | $2.7784\ 10^{-4}$ |
| Link between the hydrofoils | - | - |

Table 1. Volume distribution in different components.

In this case, the following materials have been selected (see Table 2) as the constructing material in the sandwich concept. These have been considered as sufficiently strong materials for the components.

| Material | Density[kg/m$^3$] |
|---|---|
| Carbon fiber - vinyl ester | 1600 |
| Foam (H60) | 100 |

Table 2. Density of selected materials.

The weight of each proportion of the materials in the sandwich concept has been calculated using the density and volume of the constituent materials. In Table 3, these weights can be considered.

| Component | Weight of foam [kg] | Weight of carbon fiber [kg] |
|---|---|---|
| Hydrofoil | 7.15 | 5.24 |
| Link between hydrofoil and board | 0.061 | 0.028 |
| Large hydrofoil | 0.84 | 2.609 |
| Small hydrofoil | 0.13 | 0.445 |
| Link between the hydrofoils | - | - |
| Total weight | 8.181 | 8.322 |

Table 3. Weight on each piece of sandwich material.

The total weight of the main components of the craft has been calculated to:

| **Part** | **Weight[Kg]** |
|---|---|
| Board | 12.39 |
| Links | 0.1 |
| Hydrofoils | 4.02 |
| Motor | 19 |
| Batteries | 30 |
| **Total** | **65.5** |

## Conclusion

The total weight has been calculated at 65.5 kg, which is 4.5 kg less than the set requirement. The weight has been calculated for the heaviest and foremost parts of the craft and other weight-important loose parts have been neglected in the calculation.

# Compilation resistance




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| | |
|---|---|
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| Project: | Evolo |
| Date: | *16/11-2008* |
| Version number: | *1.0* |
| Supervised by: | |
| Hours worked: | *5* |
| Reviewed by: | |

## Introduction

The purpose of this report is to compile the results from resistance calculations on the hydrofoil/underwater body [16] and the floating body. [17] Based on these results, Evolo's power requirements can then be determined.

[16] M.Norberg,T.Manners,M.Kennestad,M,Fürth. Bärplan 2008-10-25. Marina System KTH.
[17] T.Manners,M.Kennestad. Motstånd flytkropp. *2008-11-10.* Marina System KTH

## Problem formulation

The resistance calculations for the underwater body in the speed range 6-15 knots are generally considered to be complete. The only thing missing in these calculations is the lift-induced resistance from the stabilizer wing. This resistance is further discussed in the Analysis section.
The resistance from the floating body is calculated for the speed range 0-6 knots as the craft is calculated to lift at 6 knots and thus does not receive any contribution in resistance from the floating body after 6 knots. The resistance of the underwater body from 0-6 knots is calculated in the same way as for 6-15 knots with the difference that a constant angle of attack is assumed. This angle of attack is assumed to be the same as the angle of attack that the wing has when the craft takes off. In addition to this, the resistance of a straight wing that is placed at the rear edge of the delta wing (see figure 1) is calculated in order to generate a little extra added water mass. This is to make Evolo a little "slower" in the roll direction.

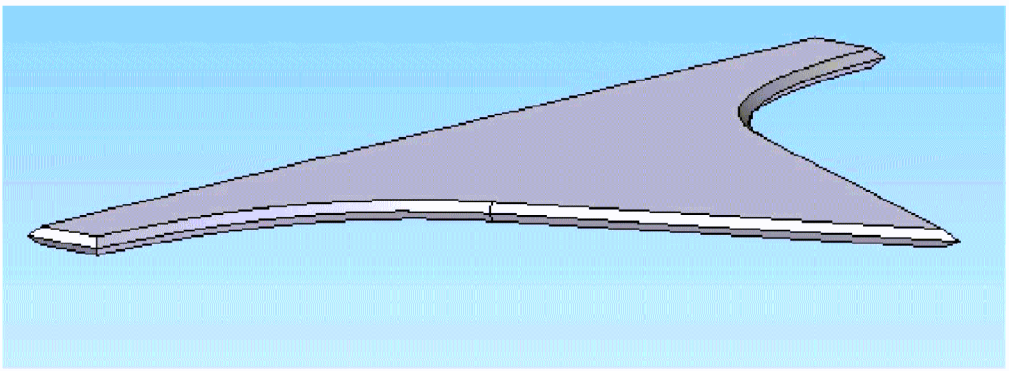


**Figure 8. Front hydrofoil wing.**

## Analysis

The resistance calculations for the underwater body in the speed range 6-15 knots lack the lift-induced resistance from the rear wing. Since the angle of this wing is not yet determined, the contribution in resistance from the rear wing is assumed to be small at 6 knots (5%) and increase linearly to 15 knots (30%). The contribution from the extra wings, which has the purpose of providing a slower craft in the roll direction rather than generating lifting force, is calculated in the same way as for straight wings. The resistance from the floating body is calculated in the speed range 0-6 knots and is added to the resistance of the underwater body in the same speed range which is calculated in the same way as for 6-15 knots. When this has been done, the resistance in the entire speed range 0-15 knots is determined and is shown in figure 2.

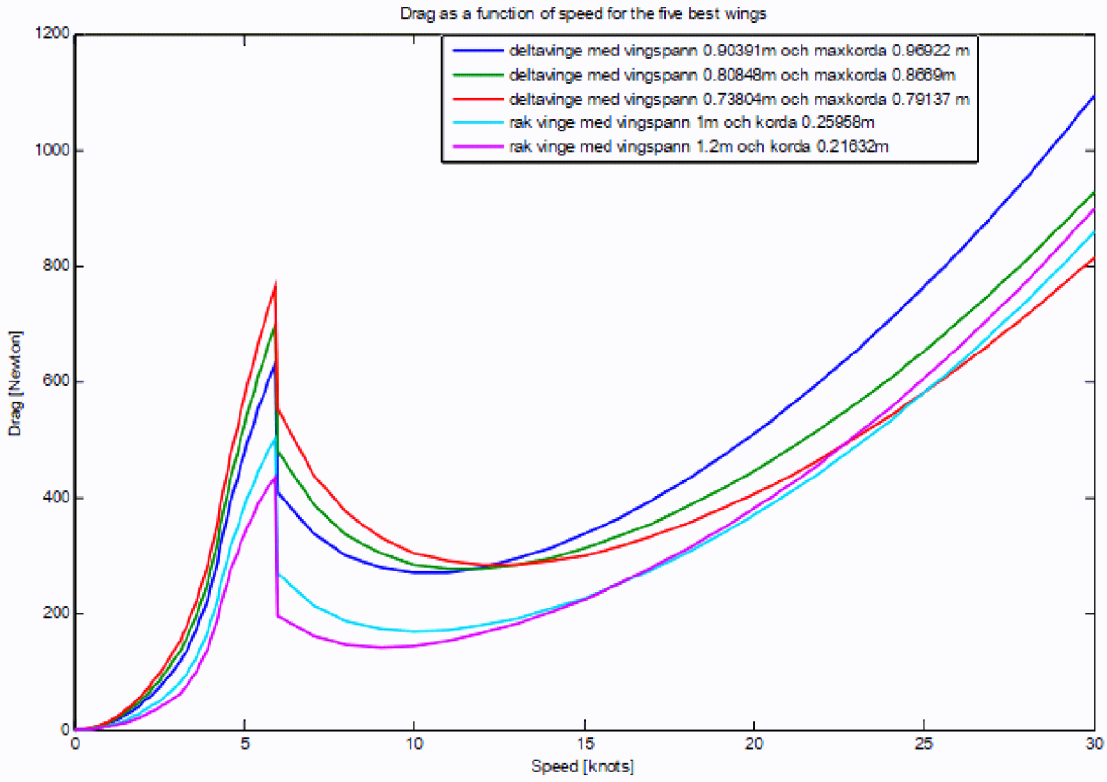



**Figure 9. Displays the resistance of the Evolo for different speeds.**

## Conclusion / Discussion

The result shows what the resistance looks like in the entire speed range. But the resistance up to 6 knots is probably quite overestimated as firstly the model for the floating body is not exact, secondly the effect of the support plane is not included in the resistance calculations for the floating body. This means that the hull lifts up gradually as the speed increases. This means that less surface of the hull is in the water hence less resistance. As the model looks today, the hull is completely in the water up to 6 knots. The reason why the force-induced resistance is considered to be small at low speeds is that the primary wing is assumed to have a fairly high angle of attack at these speeds and this means that the angle of attack of the aft wing is smaller. But as the speed increases and the angle of attack on the large wing decreases, the angle of attack on the aft wing increases. The author assumes that the contribution in resistance from the aft wing is 5% at 6 knots and that the contribution increases linearly to 30% at 15 knots. The results from this report form the basis for the power requirement calculations that are to be made.

# A9 Rolling stability




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| | |
|---|---|
| Course: | Marine design |
| Project: | Rolling stability |
| Date: | *02/12-2008* |
| Version number: | *1.0* |
| Hours worked: | *5* h |
| Reviewed by: | Mattias Kennestad |

## Introduction

Already early in the project, insufficient rolking stability was suspected to be a problem at Evolo. This then proved, through experiments, to be true. That rolling stability needed to be investigated was clear in experiment no. When the stability in the stomping direction was remedied and the craft lifted as planned, rolling stability was a clear problem.

## Procedure

In order to obtain a configuration that could be tested quickly, a simpler investigation was chosen of which factors can affect the rolling stability. This is to be able to investigate this in more detail at a later stage. In this way, the experiments can continue without interruption.

### *Wider wing*

A very simple way to create stability in the roll joint is to increase the inertia of the wings in the roll joint, ie. make it take more force to move them in rolling direction Moments of inertia using Steiner's theorem are seen in Equation 1.

$$I = I_G + md^2 \tag{1}$$

Equation 1 says that the moment of inertia is equal to the known moment of inertia plus the added mass multiplied by the distance squared to the center of mass. This means that in order to increase the moment of inertia of a wing, the wing should be made wider, since the distance to the inertia increases squarely with the distance to the center of mass. It is not only the moment of inertia of the wing that increases as the wing is made wider. As the wing moves in water, the increased added water masses will also contribute to the increased moment of inertia. The added water masses are the water closest to the wing that is also moved as the wing moves.
Exactly how this works for a wing in free flow is currently unclear. However, the phenomenon of the added water masses is well documented through experiments.

When a delta wing has been shown to fit Evolo according to [1], the delta wing is chosen to be extended in width so much that the wing becomes wider but without the extra part of the wing giving too much lifting force. The wing is shown in Figure 1 [2].

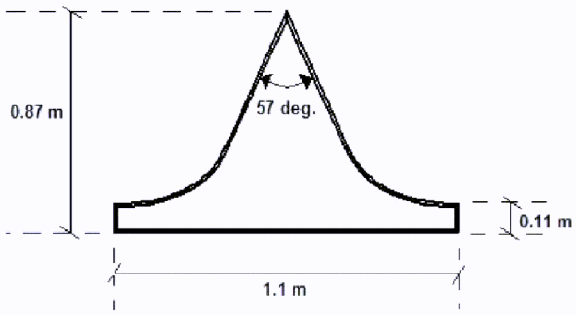



**Figure 10 Delta wing with increased width**

Experiments show that this gives an Evolo more rolling stability, however, so does the resistance [1].

Another alternative is a completely straight wing, however, it is more difficult to maneuver than the delta wing according to [3] but provides less resistance according to [3]. The straight wing can also be easily extended and thereby increase the moment of inertia, at the same time as the entire wing generates lifting force.

***Dihedral wing***

Other ways to increase rolling stability are to choose a dihedral wing [4], ie the wings point obliquely upwards. A dihedral wing is often used on aircraft and provides greater rolling stability. By, when the aircraft tilts in roll, forming a force that gives rise to a lateral glide. This means that the lower wing has a larger angle of attack in the aircraft's reference system than the higher one, thereby increasing the lifting force of the lower wing. This causes a straightening moment to form, which causes the aircraft to return to the unobstructed position. The principle is illustrated in Figure 2 [4].

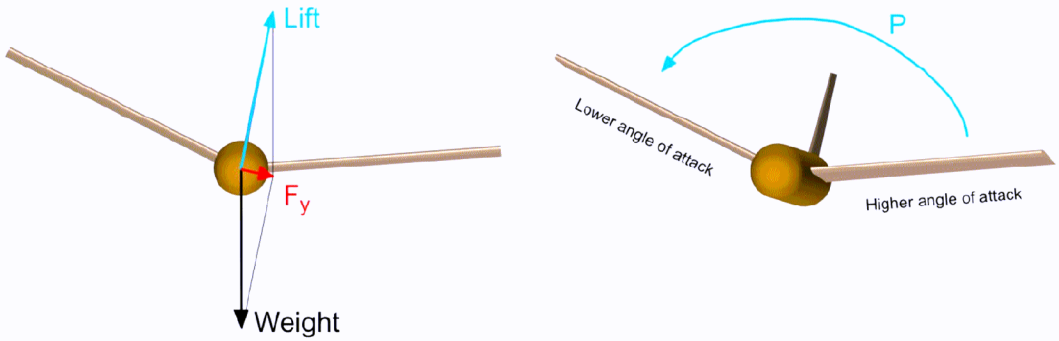



**Figure 11 The principle of a dihedral wing**

It turns out, however, that when the aircraft turns and rolls at the same time, a force is formed from the higher wing obliquely backwards. Experiments [5] show that this force is so great that it causes the craft to overturn. This excludes the dihedral wing.

***Anhedral wing***

Also an anhedral wing [4], the wings point downwards ie. as opposed to a dihedral wing, can increase rolling stability. In an initial assessment is made where it is considered that even here the angle of attack of the longer wing increases, which means that a correcting moment would be created, but not as large as for the dihedral wing. To investigate this in more detail, a transformation system is picked up to describe the lifting force of a rotating hydrofoil. This will be described in more detail in the next version of this report.

**The author's recommendations**

The recommendation is that the investigation of the anterior wing continues, this gives if nothing else an opportunity to describe the lifting force of the wing in all movements. And can thus be useful for the project to configure the most suitable wing.

In addition, a straight wing with a larger wingspan than before should be tested via experiments.

The extra-wide delta wing at present should be considered the best configuration for general performance.

## References


19. Razola, M: *Experiment X7.* Marina system, KTH, Stockholm, 2008, unpublished.
20. Bener, F: Preliminär Bärplanslösning A16. Marina system, KTH, Stockholm, 2008, unpublished.
21. Norberg, M: Bärplan A1. Marina system, KTH, Stockholm, 2008, unpublished.
22. http://en.wikipedia.org/wiki/Dihedral 2008-12-02
23. Manners, T: *Experiment X8.* Marina system, KTH, Stockholm, 2008, unpublished.

## Appendix 1 - Checklist for Quality Assurance

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| *General impression* | Author Yes/No | Reviewer Yes/No |
|---|---|---|
| 51. Are all elements of the problem addressed? | Y | Y |
| 52. Have the purpose and conditions been reported? | Y | Y |
| 53. Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective? | Y | Y |
| 54. Is the purpose achieved? | Y | Y |
| 55. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors? | Y | Y |
| *Technical content* | | |
| 56. Have simplifications and assumptions been clearly stated and justified? | Y | Y |
| 57. Has the choice of solution methods been clearly reported and justified? | - | - |
| 58. Are calculations controlled and reasonably assessed? | - | - |
| 59. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text? | - | - |
| 60. Are equations written as part of the running text, presented in separate lines and numbered? | Y | - |
| 61. Can the technical reasoning be followed? | Y | Y |
| 62. Is there a difference between facts, statements and the author's opinion? | Y | Y |
| *Presentation* | | |
| 63. Is the report well structured with regard to section and chapter division, common thread and logical sequence as well as balance between different sections? | Y | Y |
| 64. Is the report provided with: appropriate title, date, author name, e-mail, eventual supervisor, summary/abstract, table of contents, reference list and page numbering | Y | Y |
| 65. Is the report written in third person passive form? Are experiments described in imperfect, e.g. "Drag tests were performed to verify…" while descriptions of analysis methodology and calculations are rewritten in the present, e.g. "Calculations show that the natural frequency…"? | Y | Y |
| Are figures and tables clear and informative, provided with figure / table text and clear numbering? Do all figures have units inscribed on all axes? Can figures be interpreted even after printing in black and white, and preferably after black and white copying? | Y | Y |
| 67. Are appropriate references made to figure, table and equation numbers in the text? | Y | Y |
| 68. Are appropriate references made to references in the reference list? | Y | Y |
| 69. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.? | Y | Y |
| *Other* | | |
| 70. Has the report been written by you individually? | Y | |
| 71. The work has been carried out in collaboration with: _____ | | - |
| 72. The report has been proofread by: Mattias Kennestad | | - |

| | | |
|---|---|---|
| 73. I believe that this report as a whole is worth rating (u, 3-5) | | |
| The following is a reflection on how I believe that the work with this report and related projects relates to set learning goals (relevance of the work, which goals have been met, etc.): | | - |

# A101-Propeller selection

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| | |
|---|---|
| Course: | Marine design / Lightweight design |
| Project: | Evolo |
| Date: | *29/01-2009* |
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## Summary

This report deals with a wing configuration for fifteen knots and a wing configuration that allows Torqeedo Cruise 2.0 to be used. What is done is to see if the power requirement for the wing configuration can be overcome with the existing Torqeedo motor, or if a new motor is needed.
This report also shows the results of a propeller dimensioned for Evolo with modified wing configuration, see ref [1]. The propeller is optimized for a speed of eight knots, which means that Evolo must be towed up to the mentioned speed and then fly for its own machine. The propeller developed is shown below in table (1) and with an illustration, figure (1), of how a half propeller blade is modeled.

**Table 4 Dimensions and technical data for developed propellers**

| Evolo Propeller | | |
|---|---|---|
| Diameter | 0.35 | [m] |
| Geometric pitch | 0.34 | [m] |
| Shaft effect | 2000 | [W] |
| Drag resistance | 219 | [N] |
| Blade area ratio | 2.2 | [-] |
| Number of blades | 4 | [-] |
| RPM | 920 | [rpm] |
| Dimensioned speed | 8 | [kn] |

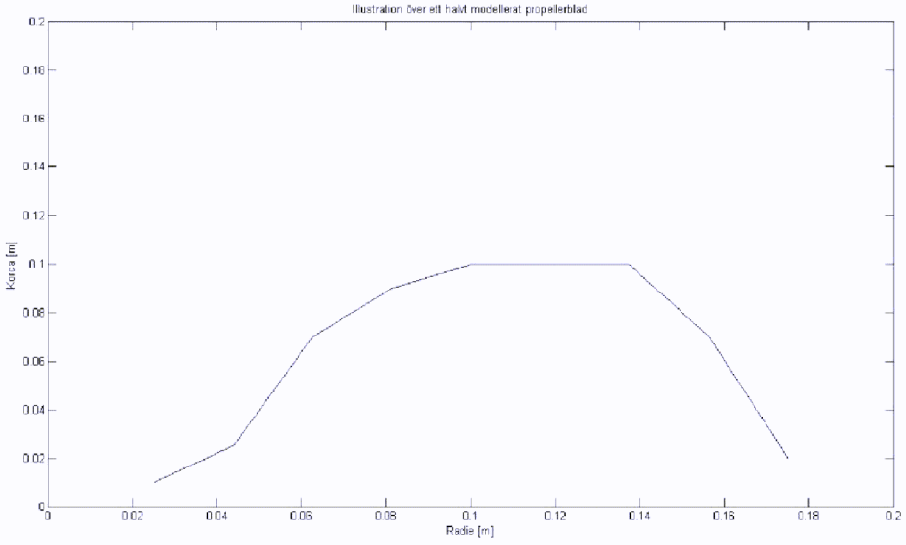



**Figure 25 Illustration of a semi-modeled propeller blade**

## Introduction

The original purpose of this work was to develop an optimal propeller. This meant that all propeller parameters would be varied to find this optimal propeller. Based on this, an motor would then be selected that delivered sufficient power at a given rpm. As this task was too extensive, and assumed that an motor that met the requirements set by the optimal propeller could be obtained, it was therefore abandoned. What was now being tried was to investigate whether there is a propeller that can make the Torqeedo Cruise 2.0, which may be available, deliver enough power at Evolo's lift speed. When this was done, it was mistakenly assumed that the given motor could deliver the required power.

The propeller dimensioned in this report is dimensioned on the basis of a newly developed wing configuration, see ref [1], and that Evolo is towed up to eight knots and then runs for its own motor.

## Problem formulation

Evolo's trailing power is between 1800-2100W. This means that it is this effect, which the motor via the propeller and with other losses taken into account, that must be transferred into the water. It places demands on the efficiency of both the motor and the propeller.

To obtain a high efficiency, a large propeller is better than a small one. However, a large propeller entails a greater risk that the blades will reach the water surface and the propeller blades will then be forced to work in another medium, air will also be drawn down to the propeller, which means reduced efficiency.

The alternative available to Torqeedo Cruise 2.0 is the larger Torqeedo Cruise 4.0. This larger motor has a power output of 4000W. It has the same overall efficiency as 2.0, which means that it delivers double the output power compared to 2.0. Furthermore, the motor operates at a fixed speed of 920 rpm. It also affects the size of the propeller because a low speed means large dimensions on the propeller for the craft to travel at the desired speed.

## Analysis study 1

There are thus two ways to go with the motor. The first alternative is to manufacture a sufficiently large propeller to use the motor at 920 rpm and the second option is to change the motor with e.g. a planetary gear. The advantage of changing the motor is that it would possibly be possible to use an existing propeller, ie. the problem of building propellers is avoided. The downside is that it can be difficult to find planetary gears that are suitable for the purpose. The gear must be both small and have the desired gear ratio. From experience, the small planetary gears are mainly made of plastic, which means that such a gear is excluded. Below in figure (1), Evolo's trailing effect is shown as a function of the speed analytically calculated in ref [2].