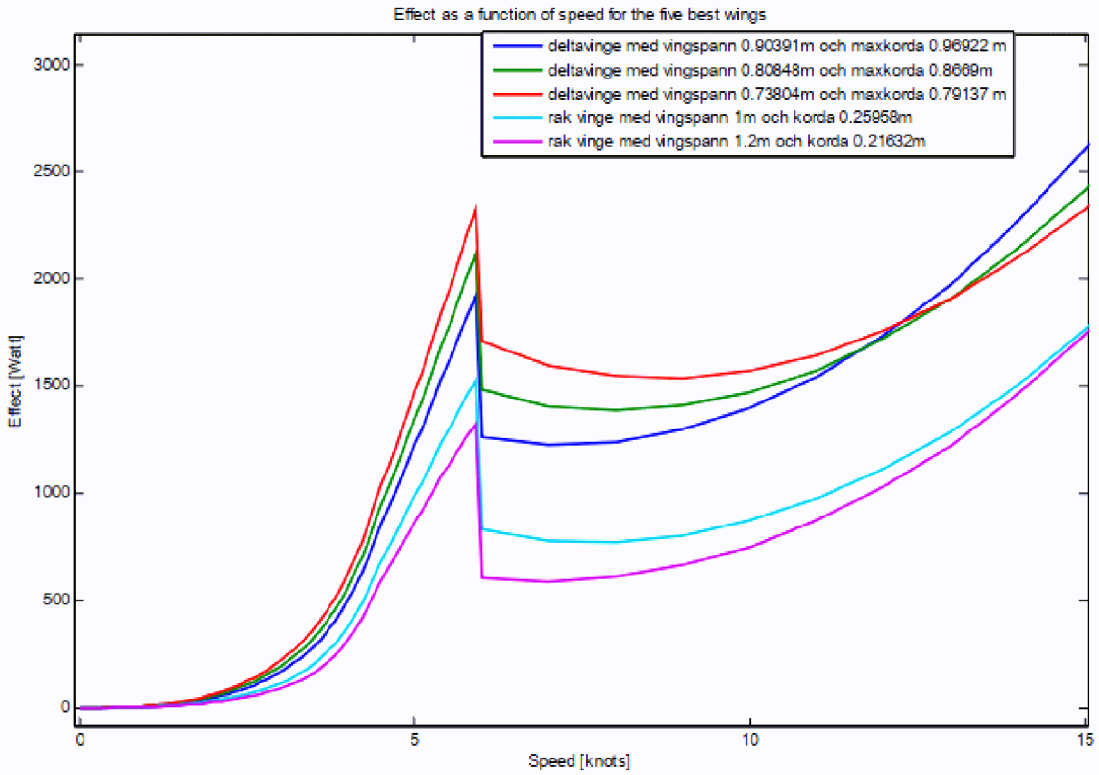


Figure 26 The power required to propel the craft forward in the current speed range, [1].

To validate the calculated power, it is compared with the measured trailing power from trailing tests, ref [3]. The input power of the available Torqeedo Cruise 2.0 is 2000W and with the current propeller configuration, the output power is about 900W. As can be seen from the figure above, this motor has far too little power to be able to drive the Evolo so that it lifts with the selected wing configuration.

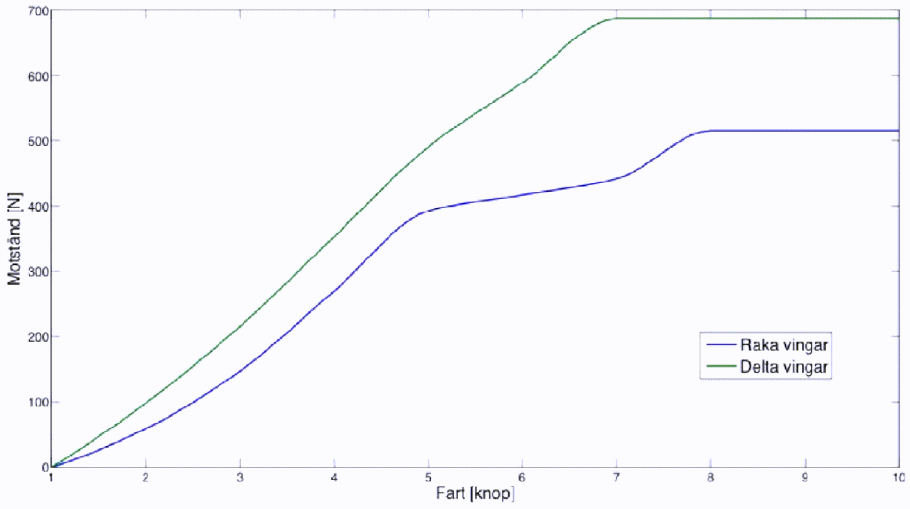


Figure 27 Experimentally measured drag resistance for Evolo as a function of speed

Since the power is defined as the power multiplied by the speed, it can be seen from the figure above that the towing power at six knots is about 1800W. This means that the analysis and the experiments agree fairly well, which means that the results are considered reliable with a certain margin of error.

Propeller for Evolo with Torqeedo Cruise 2.0

When the propeller is dimensioned, this is done with the resistance taken from ref [2] where a new wing configuration has been determined. This new configuration allows the existing motor to drive the Evolo at eight knots provided that the Evolo is towed for lifting. The fact that a speed that is above the lifting speed has been dimensioned is because a dimensioned speed is needed and it is considered more reasonable to be able to fly with Evolo in eight than in five. In order to optimize a propeller that can handle the given task, theory from ref [4] was used. Then iteration was used to achieve power balance. The propeller must also deliver a power out into the water that is equal to Evolo's towing power at the design speed for an motor speed of 920 rpm. To make a conservative dimensioning, the underwater body is assumed to have a co-current factor of zero. This means that the suction factor is zero, which means that the required propeller force is equal to the drag resistance force. The fact that the co-current factor is zero also means that the flow velocity at the propeller is equal to the free-flow velocity. As the propeller is more efficient at low speeds, this assumption about the co-current factor gives a conservative dimensioning.

In order to obtain a propeller that meets the set requirements, an iterative process was used where it was assumed that the geometric pitch is approximately with the propeller diameter and that the blade area ratio should be large to keep the diameter down. Furthermore, it is assumed that it is easier to build a propeller with four blades than one with three. This is because it is assumed to be easier to get a four-bladed propeller symmetrical.

Dimensioning input data and calculated dimensions are reported in table (2).

Table 5 Dimensions and technical data for developed propeller

Evolo Propeller		
Diameter	0.35	[m]
Geometric pitch	0.34	[m]
Shaft effect	2000	[W]
Drag resistance	219	[N]
Blade area ratio	0.46	[-]
Number of blades	4	[-]
RPM	920	[rpm]
Dimensioned speed	8	[kn]

When the propeller is calculated, this is done for a dimensionless speed J which is defined according to equation (1) below

$$= \frac{\quad}{\quad}$$

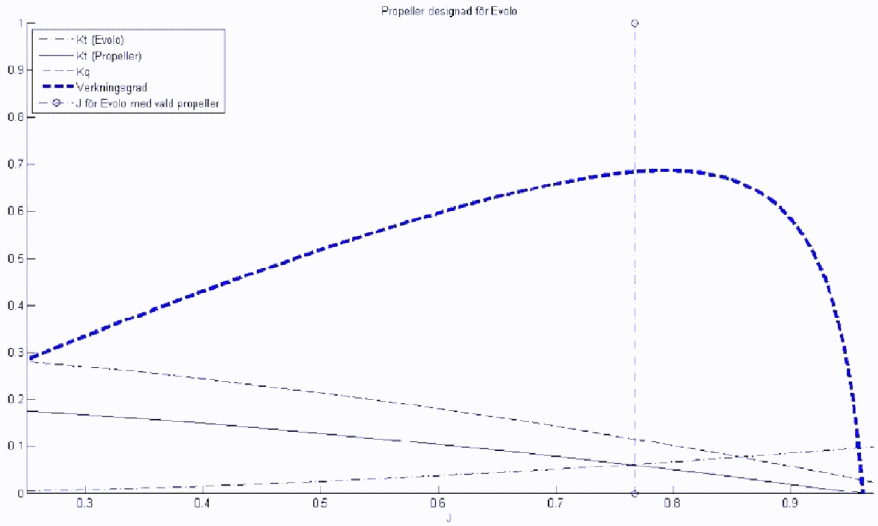
Where V_{inf} is the free-flow velocity, n is the speed and D is the diameter of the propeller. Since the propeller is dimensioned for the design speed, the change of J only means a change of the propeller speed. What is then plotted are dimensionless forces and torques as well as efficiency. The required dimensionless force is defined according to equation (2)

$$K_T^{erforderlig} = \frac{T}{\rho D^2 V_A^2} J^2$$

Where T is the Evolo's drag resistance, V_A is the propeller's flow rate, and is the density. Other variables have been defined previously. The delivered dimensionless propeller force is calculated as the required but with the difference that the delivered force is used, which varies. The dimensionless resistance is defined according to equation (3) below

= ———

Where M is the required shaft moment and the other parameters are defined earlier. A propeller characteristic of the selected propeller is shown below in Figure (5).



In the figure above some different dimensionless forces and moments and at which J, dimensionless speed, Evolo has and what efficiency the propeller has at different J.

Conclusion

The conclusion is that the Torquee motor available will not be able to drive the Evolo at the desired speed. As this is the case, either an motor with greater power must be used or the wing configuration on the Evolo must be changed so that it lifts at lower speed. In both cases, the recommendation is not to change the motor but to build your own propeller to achieve the desired efficiency.

References

1. Carlsson D, Delin P, Westin J, TB-105 Bärplan och Stag, KTH, Stockholm 29/1-2009
2. Norberg M, A-14 Effektbehov, KTH, Stockholm 5/11-2008
3. Kennestad M, X-9 Motorexperiment, KTH, Stockholm 2/12-2008
4. Kuttenkeuler, J., Propellrar - så funkar de, Marina system, KTH, Stockholm 3/4-2008

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
75. Are all elements of the problem addressed?	Yes	Yes
76. Have the purpose and conditions been reported?	Yes	Yes
77. Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective?	Yes	Yes
78. Is the purpose achieved?	Yes	Yes
79. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors?	Yes	Yes
Technical content		
80. Have simplifications and assumptions been clearly stated and justified?	Yes	Yes
81. Has the choice of solution methods been clearly reported and justified?	Yes	Yes
82. Are calculations controlled and reasonably assessed?	Yes	Yes
83. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text?	Yes	Yes
84. Are equations written as part of the running text, presented in separate lines and numbered?	Yes	Yes
85. Can the technical reasoning be followed?	Yes	Yes
86. Is there a difference between facts, statements and the author's opinion?	Yes	Yes
87. Is there a realistic verification plan for the work in the report?		
88. Is there an acceptable follow-up of the verification plan?		
Presentation		
89. 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	Yes
90. Is the report provided with: appropriate title, date, author name, e-mail, eventual supervisor, summary/abstract, table of contents, reference list and page numbering	Yes	Yes
91. 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…"?	Yes	Yes
92. Are figures and tables clear and informative, provided with figure / table text and clear numbering? numbered? 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?	Yes	Yes
93. Are appropriate references made to figure, table and equation numbers in the text?	Yes	Yes
94. Are appropriate references made to references in the reference list?	Yes	Yes
95. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.?	Yes	Yes
Other		
96. Has the report been written by you individually?		

97. The work has been carried out in collaboration with: _____		-
98. The report has been proofread by: Markus Norberg		-
99. I believe that this report as a whole is worth rating (u, 3-5)		
100. 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.):		-

Appendix 2 Propeller Code

```
%%

clc, clf, clear all, close all

D = 0.35;                                   % Propellerdiameter
vinf = 8*1852/3600;                         % Friströmsfart
Mplot = [];
Tplot= [];
ETAplot = [];
Ktplotprot = [];
Ktplotprop = [];
Kqplot = [];
J = [0.01:0.001:3];
PTplot=[];
PDplot=[];
Tplot=[];
for ll = 1:length(J)

rpm = vinf/(J(ll)*D)*60;                    % Varvtal
omega = rpm*2*pi/60;                        % Vinkel frekvens

ry = D/2; ri =0.025;
dr = (ry-ri)/8;                             % Radiellt inkrement
r = ri:dr:ry;                               % Radie till element
cc = 0.1;                                   % Lokal korda
Tc = [0.1 0.25 0.7 0.9 1 1 1 0.7 0.2];
gp = 0.34;                                  % Geometrisk pitch
N = 4;                                      % Antal propellerblad

e = 0.9;                                    % ... effektivitets faktor
rho = 1000;                                 % Densitet
Cb = 0;
w = 0;                                  % Medströmsfaktor
t = 0;                                  % Sugfaktor
Pe = 900;
R = Pe/vinf ;
Treal=R/(1-t);                              % Erfoderlig propellerdragkraft

a = 0.1;
a_ = 0.01;

M=[];
T=[];
A1=[];
A2_=[];
ETA=[];
PT=[];
PD=[];

for i=1:length(r) c = cc*Tc(i) ;
        AR =ry^2/(N*c*(ry-ri));                                         % Geometriskt sidoförhållande
[dT,dM,eta,a,a_,alfa,Pt,Pd]=bladelem(omega,vinf,gp,N,c,r(i),dr,rho,a,a_,AR, e);
M=[M dM];
T=[T dT];
```

```
A1=[A1 a];
A2_=[A2_ a_];
ETA=[ETA eta];
PT=[PT Pt];
PD=[PD Pd];
end
T = sum(T);
Mplot = [Mplot sum(M)];
ETAplot = [ETAplot sum(ETA)/9];
Ktplotprop = [Ktplotprop T/(rho*(rpm/60)^2*D^4)];
Ktplotprot = [Ktplotprot Treal/(rho*(rpm/60)^2*D^4)];
Kqplot = [Kqplot sum(M)/(rho*(rpm/60)^2*D^5)];
PTplot=[PTplot sum(PT)];
PDplot=[PDplot sum(PD)];
Tplot=[Tplot T];

end

bar = (ry^2*pi)/(sum(cc*Tc*dr)*N)
title('Propeller designad för Evolo')

xlabel('J')
Kqplot = Kqplot*10;
figure(1)
axis([0.25 0.97 0 1])
hold on
plot(J,Ktplotprot,'-.')
plot(J,Ktplotprop,'-')
plot(J,Kqplot,'--')
plot(J,ETAplot,'--.')
plot([vinf*60/(920*D) vinf*60/(920*D)],0:1:1,'--')
legend('Kt (Evolo)','Kt (Propeller)','Kq','Verkningsgrad','J för Evolo med
vald propeller',2)
hold off
figure(2)

hold on
plot(J,PTplot,J,PDplot)
plot([vinf*60/(920*D) vinf*60/(920*D)],0:max(Tplot):max(Tplot),'--')
axis([0 3 0 2000])

legend('Nyttig','tillförd')
hold off
figure(3)

subplot(2,1,1)
hold on
plot(J,Mplot)
plot([vinf*60/(920*D) vinf*60/(920*D)],0:max(Mplot):max(Mplot),'--')
hold off
axis([0 3 0 500])
subplot(2,1,2)
hold on
plot(J,Tplot)
plot([vinf*60/(920*D) vinf*60/(920*D)],0:max(Mplot):max(Mplot),'--')
hold off
axis([0 3 0 1000])
```

```
figure(4)

plot(r,Tc*0.1)
axis([0 0.2 0 0.2])
xlabel('Radie [m]');ylabel('Korda [m]')
title('Illustration över ett halvt modellerat propellerblad')
```

Appendix 3 Blade element function file

```
function [dT,dM,eta,a,a_,alfa,Pt,Pd] =
bladelem(omega,vinf,gp,N,c,r,dr,rho,a,a_,AR,e);

any=a;
a_ny=a_;
clalfa = 2*pi;
teta = atan(gp/(2*pi*r));
diff1=1;
diff2=1;
while diff1 && diff2 > 10^-9
a = 0.9*a+0.1*any;
a_ = 0.9*a_+0.1*a_ny;
v0 = vinf*(1+a);
v2 = omega*r*(1-a_);
v = sqrt(v0^2+v2^2);
alfa = teta-atan(v0/v2);
cl = clalfa*alfa;
cd = 0.008-0.003*cl+0.01*cl^2;
CL = cl/(1+2/(AR*e));
CDi = (CL^2)/(pi*e*AR);
CD = CDi+cd;
q = 0.5*rho*v^2;
dT = q*c*N*(CL*cos(teta-alfa)-CD*sin(teta-alfa))*dr;
dM = q*c*N*(CL*sin(teta-alfa)+CD*cos(teta-alfa))*r*dr;
any = -0.5+sqrt((dT/(4*pi*r*rho*dr*vinf^2))+1/4);
a_ny = dM/(4*pi*rho*r^3*vinf*(1+any)*omega*dr);
diff1=abs(a-any);
diff2=abs(a_-a_ny);
end

Pt = dT*vinf;
Pd =omega*dM;
eta = Pt/Pd;
```

A102 - Suggestions for the design of underwater body

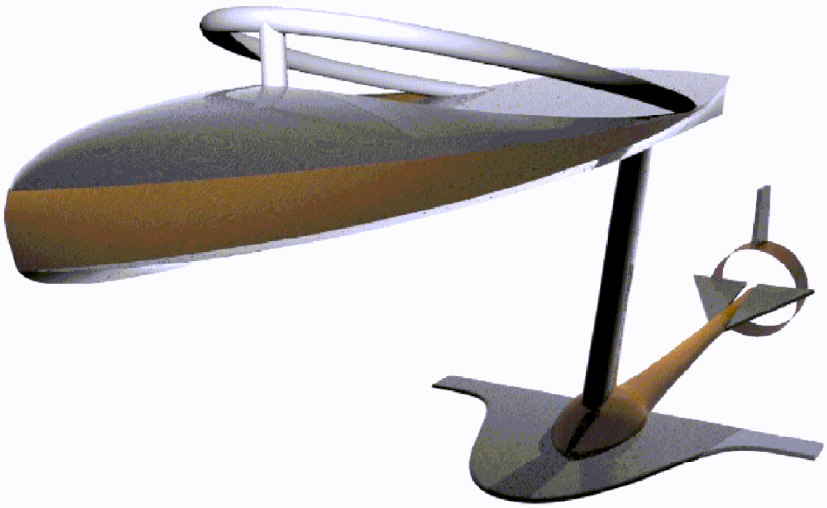
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Course: Marine design / Lightweight design
Project: Evolo
Date: *20/01-2009*
Version number: *1*

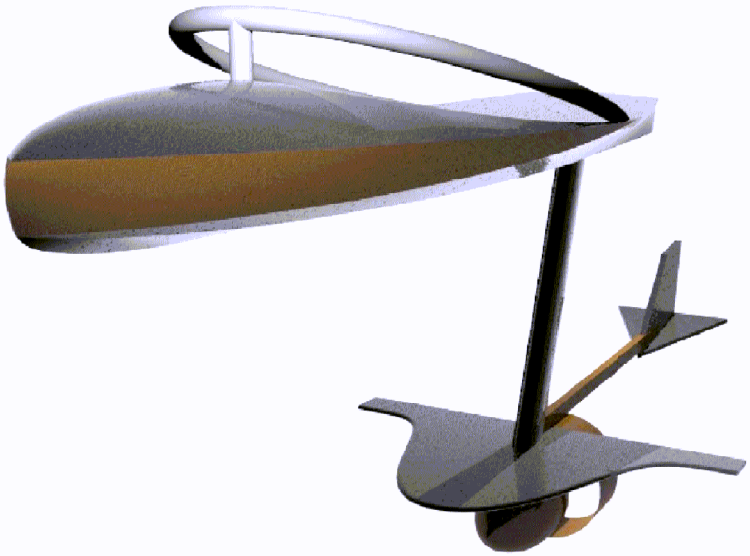
Hours worked: *15*h
Reviewed by: Mirjam Fürth

Summary

Several proposals for the underwater body's arrangement have been proposed and the best ones have been screened out. The result of this is two proposals, each of which has two variants. One is more difficult to build but will have less resistance and less deep. The proposal is called Jesus and is presented in the picture below.



The alternative to this proposal is to push behind the motor and support to the middle to, among other things, avoid building the support plane and the motor together. The second option, which is easier to build, is called Zeppelinare and looks like this:



Here, too, there is the option of having an motor and support in the middle to reduce the risk of the motor deteriorating the properties of the hydrofoil.

Other recommendations to the project management:
Before we can draw drawings on underwater bodies, we should determine a cruising speed that is less than 15 knots and adjust the angles of attack of the wings to this speed.

Introduction and problem formulation

Prior to the final design of the Evolo, a decision must be made on the design of the underwater body. The purpose of this report is to provide the project group with proposals for solutions based on a number of identified relationships established by the project group with the help of the hydrofoil expert Alexander Sahlin. At the moment, the priority is on a solution that is as simple to build as possible, while at the same time the studied conditions and properties of the hydrofoil must be maintained. The analysis assumes that a torqeedo cruise 2.0 can be used, but can hopefully be adapted to other motors. The analysis is only based on assumptions.

Analysis

The following relationships are identified:

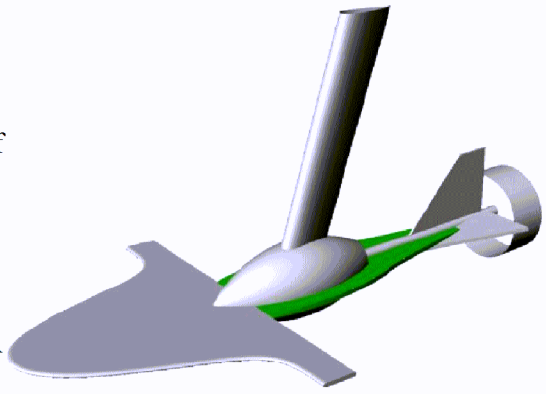
1. Evolo must be built for a fixed cruising speed. This speed affects the angle of attack of the main wing and thus the lifting force.
2. The thrust of the propeller, and thus the motor shaft, must be completely horizontal at cruising speed.
3. The main wing must have an angle relative to the motor shaft. This angle is the same as the angle of attack of the main wing at cruising speed.
4. The angle of attack of the main wing should be a maximum of 5 degrees.
5. At take-off, the angle of attack of the main wing must be greater than at cruising speed, which means that the motor shaft has an angle relative to the horizontal plane. The thrust of the propeller will therefore have an upward component, which should facilitate starting.
6. The floating position of the floating body should allow the angle of attack of the main wing relative to the horizontal plane to be 10 degrees at take-off.
7. Vertical surfaces should be as far back as possible and should not be so spread out, to facilitate turning.

A number of possible proposals that, as far as possible, meet the above have been developed and presented below. In the analysis, it is assumed that the motor has a strong mounting point on the top, which is the case for the Torqeedo motor. Whether the strut is straight or oblique does not really matter as long as the upper mounting point of the strut does not fall too far back so that the floating body must be extended. The analysis is divided into two parts, the first of which is a proposal with an integrated motor and the latter is a proposal where the motor is placed under the hydrofoil. The proposals are followed by a sorting out of reasoning.

Part 1 - Integrated motor

By an integrated motor is meant here that the motor is level with the hydrofoil. An integrated motor can be more difficult to build and is highly dependent on which motor is used. However, the benefits are many. An integrated motor gives the craft a less deep and makes the torque arm that the motor's compressive force has less. At the same time, there will be less resistance to having a well-built module underwater instead of two.

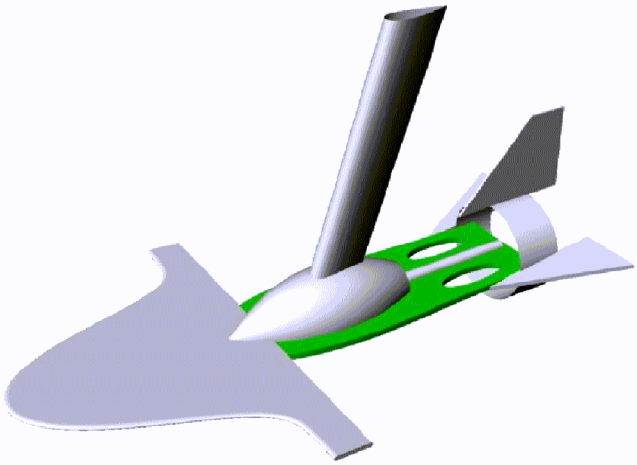
Ray:



The motor is mounted directly in the strut and the hydrofoil is level with the motor and motor shaft. A load-bearing frame (green) is constructed lying around the motor and attaching to the front hydrofoil, the motor, the motor shaft and to the aft hydrofoil, but not to the strut.

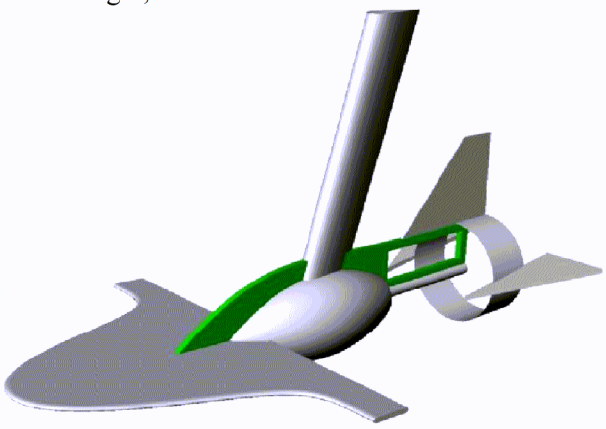
- Probably requires a rebuild of the front of the motor cover, which can be difficult due to the risk of leakage.
- The solution will strain the motor mounts with, among other things, the lift from the hydrofoil and the torque this creates.

- The aft hydrofoil can interfere with the propeller's efficiency, and the increased speed around the propeller can affect the effect of the aft hydrofoil. A rolling torque may occur when the aft hydrofoil are in a rotating flow.
- As the front hydrofoil has a positive angle in relation to the frame, the mounting between these can be difficult to build and sensitive. For the same reason, the mounting between the frame and the aft hydrofoil can be sensitive.
- The frame becomes a wing in itself and can affect pitch characteristics.



Ghost:

An alternative way is to make the load-bearing frame larger, move the nozzle forward and attach the aft support plane and the stabilizing fin to the nozzle. The frame must be as wide as the nozzle for the nozzle to attach to it, which can make the area of the frame unnecessarily large. A solution to this could be to either build the frame of beams or to make holes in the frame.



- The nozzle, and the mounting points to the aft wings, will be difficult to build.
- Delta wing The effect on the three hydrofoils will be reduced because they do not sit together. Possibly easier (but not necessarily better) to use straight wings at the back.
- Shorter solution, which is good especially for the motor shaft.
- Moving the aft hydrofoils apart could have a positive effect on rolling stability.

Airplane:

Instead of having a horizontal frame that will have difficulty absorbing the bending torques from the hydrofoil, you could set up the frame and use the strength of the bracket between the strut and the motor.

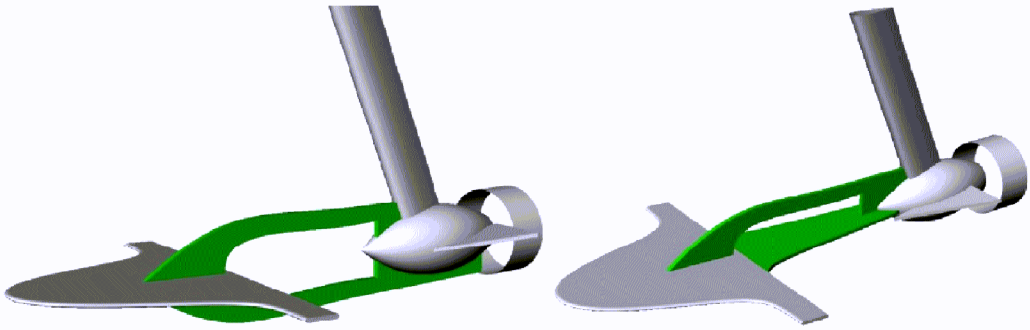
- The frame has a vertical projection which makes turning slower.
- The solution may become weak in the torsional direction during rolling movements.
- Same problem with aft hydrofoil and nozzle as before.

Vacuum cleaner:

Since the aircraft solution can absorb the torques better, you can imagine that you move behind the motor and completely avoid extending the motor shaft and building it in. However, this means that the entire underwater body is moved forward, so in such cases you need either a longer floating body (approx. 1 m) or that you angle the support in the other direction. Then you could also solve the mounting of the aft hydrofoil relatively easily, by attaching them to the motor, and that you can possibly avoid the rear stabilizing fin because the strut acts as a fin.

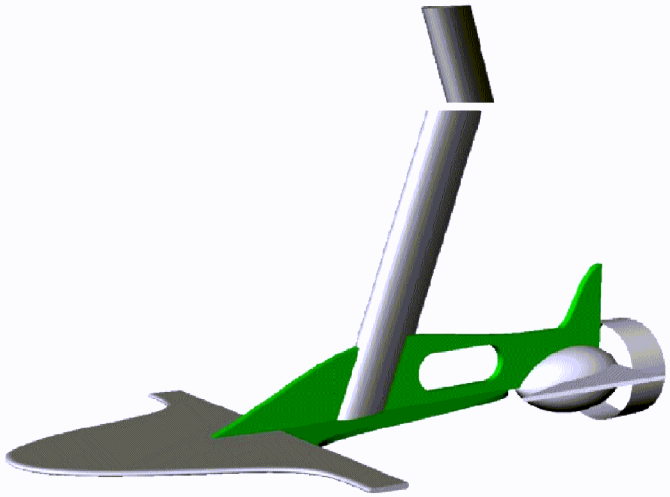
- The solution may be easier to build and have fewer parts, but probably requires more of the strength of the strut, as it is directed backwards.
- The risk of the main hydrofoil and frame wobbling is big. The frame must be very torsionally rigid.
- Again problems with the aft hydrofoil which will partly have other properties and partly can disrupt the flow to the propeller and vice versa.

Of course, you can also build a vertical frame also from the underside of the supporting plane or a combination of standing and horizontal frames:



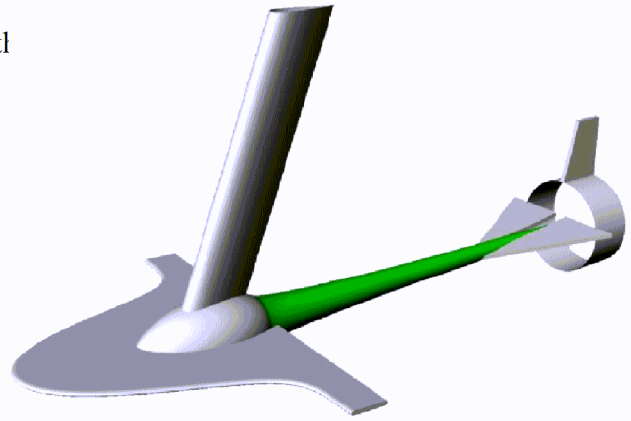
JAS

It is also conceivable to separate the strut and the motor and have both a horizontal frame on which the strut stands and a vertical frame that carries the torques, or alternatively that you combine these frames into something more cylindrical.



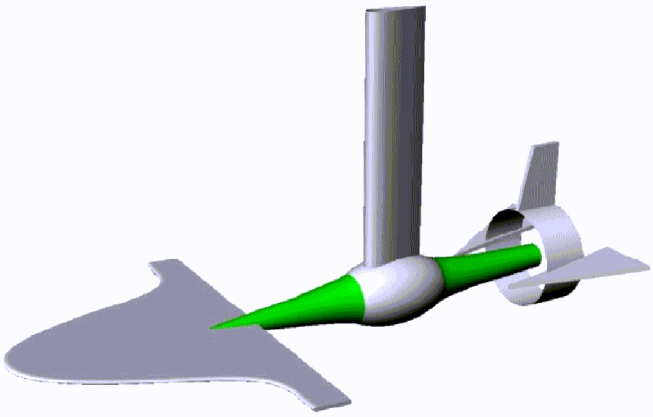
- The strong link between the motor and the strut cannot

be used to carry torque.
- Feed-throughs in the frame witl



Jesus

Actually the same as the Ray, but with the motor further forward in the hydrofoil and with a sleeve, or a tube, around the propeller shaft that carries the load from the aft hydrofoil and the pressure from the propeller.



- The pipe must be strong and must contain ball bearings for the shaft.
- The integration of the motor in the hydrofoil can interfere with the lifting force
- The motor and the hydrofoil must be built at an angle relative to each other, which can cause difficulties.
- Probably the nicest option and the one with the least resistance in the water.
- Very spread out vertical surfaces

T-Profile

To reduce the impact on the hydrofoil and to reduce the distance between the vertical surfaces, you can move the rear of the motor to the center. It also shortens the possibly difficult motor shaft extension. The round frame in the picture between the front hydrofoil and the motor can of course be constructed in a simpler way, for example with a vertical frame.

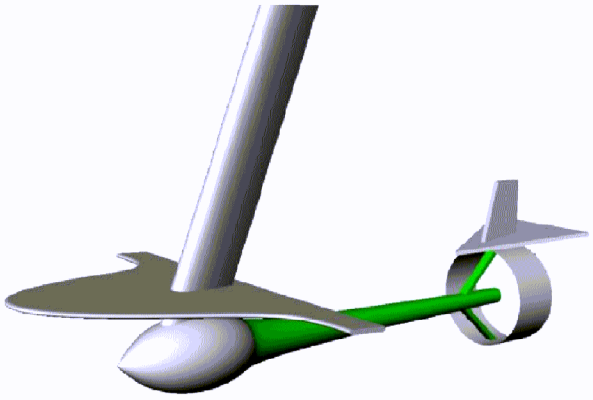
- Requires rebuilding of the motor front cover.
- Low resistance

Part 2 - The motor under the hydrofoil

Placing the motor further down creates more front area and greater resistance but can prove easier to build.

Jesus Under

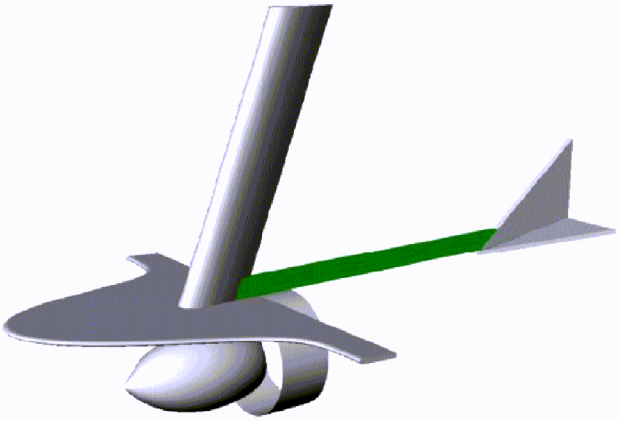
The aft hydrofoil is placed on top of the nozzle and the support is extended so much that the hydrofoil is level.



- Easy installation of the front hydrofoil and unaffected flow around it.
- Unclear flow around the aft hydrofoil
- Same problem with the extended enigne shaft as before.
- Large distance between the vertical surfaces.

Zeppelin

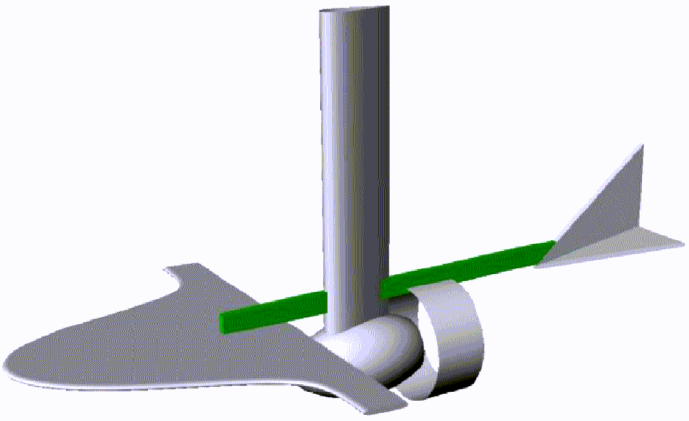
The extension of the motor shaft is removed and instead a beam extends from the strut to the aft hydrofoil.



- Probably the alternative that is easiest to build.
- Probably impairs the lifting force of the hydrofoil as the overpressure on the underside is eliminated by the motor.
- Large distance between the vertical surfaces.

Paper airplane

To prevent the motor from destroying the lift of the hydrofoil, move the motor to the rear to the center.



- Easy to build
- Perhaps the ugliest option

Sorting out

Which configuration is chosen naturally depends on many factors and is largely a matter of priority. All configurations are possible to build and few are obviously bad.

A first finding is that it is good to be able to take advantage of the strong mounting point between the motor and the strut that is on the torqeedon and which is obviously dimensioned to push significantly heavier vessels than the Evolo. Therefore, it is foolish to invest in JAS, because the motor there is separated from the strut.

The obviously weak links in Ray and Ghost, where a horizontal frame is to be attached to an angled (also horizontal) hydrofoil, could certainly be built strong enough but entails a great deal of risk and is therefore prioritized away.

Airplane is a viable alternative, but the extended motor shaft should still be built in because a rotating shaft has great resistance, and then it is basically the same as Jesus or T-Profile, except that the latter have less resistance.

In the proposal Vacuum cleaner, the frame must take up a large torque from the hydrofoil because the strut is so far back. The frame must be made very strong and will therefore be large, which means a lot of resistance, which is why these are also given lower priority.

Jesus Under is more difficult to build than the other proposals that have the motor further down and also has a higher water resistance than the others, so this is given lower priority.

Conclusion

There are four suggestions left; Jesus, T-Profile, Zeppelin and Paper Aircraft. Which of these to choose is a question that the project group should consider. If the project wants to invest in the most easily built alternative, you have to pay with more resistance and greater depth. The lightest is Zeppelin, but an investigation into how the motor's suction impairs the hydrofoils lifting capacity should then be done, and if it turns out that this becomes a problem, Paper airplane should be chosen. If the project instead wants to build a nicer and more streamlined underwater body, Jesus should be given priority, but it may prove too difficult to build, and then T-Profile may be the best alternative.

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
101. Are all elements of the problem addressed?	Yes	Yes
102. Have the purpose and conditions been reported?	Yes	Yes
103. Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective?	Yes	Yes
104. Is the purpose achieved?	Yes	Yes
105. Is the report readable without access to task formulation, project instructions, etc. that you have received	No	No
Technical content		
106. Have simplifications and assumptions been clearly stated and justified?	No	No
107. Has the choice of solution methods been clearly reported and justified?	No	No
108. Are calculations controlled and reasonably assessed?	No	No
109. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text?	No	No
110. Are equations written as part of the running text, presented in separate lines and numbered?	No	No
111. Can the technical reasoning be followed?	No	No
112. Is there a difference between facts, statements and the author's opinion?	Yes	Yes
113. Is there a realistic verification plan for the work in the report?	No	No
114 Is there an acceptable follow-up of the verification plan?	No	No
Presentation		
115. 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	Yes
116. Is the report provided with: appropriate title, date, author name, e-mail, eventual supervisor,summary/abstract, table of contents, reference list and page numbering	No	No
117. 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…"?	No	No
118. Are figures and tables clear and informative, provided with figure / table text and clear numbering? numbered? 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
119. Are appropriate references made to figure, table and equation numbers in the text?	No	No
120. Are appropriate references made to references in the reference list?	No	No
121. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.?	Certainly not	No
Other		
122. Has the report been written by you individually?	Yes	

123. The work has been carried out in collaboration with: _____		
124. The report has been proofread by: _____		
125. I believe that this report as a whole is worth rating (u, 3-5)	4	4
126. 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.):		-

A103-Plan Abaqus



JOHAN WESTIN
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Course:	Marine design / Lightweight design
Project:	Evolo
Date:	*08/02-2009*
Version number:	*1*
Supervised by:	-
Hours worked:	*6*
Reviewed by:	Markus Norberg

Introduction

Since the process of designing critical parts in a structure like Evolo, some optimization may be required so as not to incur unnecessary losses in the event of an oversizing of the problem. Therefore, it can be good to use an optimization algorithm and a FEM program such as Abaqus to get a favorable design. This report examines what is needed for such an analysis and the time required for that work is estimated to see if it is worth doing.

Problem formulation

To account for what is needed and the time required for a possible modulation and optimization of struts and stays for Evolo in Abaqus.

Analysis

In the GA, see figure 1, the strut is seen, no. 1 with blue color, and the stay, no.2 with red color. These two are relevant for modeling and optimization in Abaqus [1].

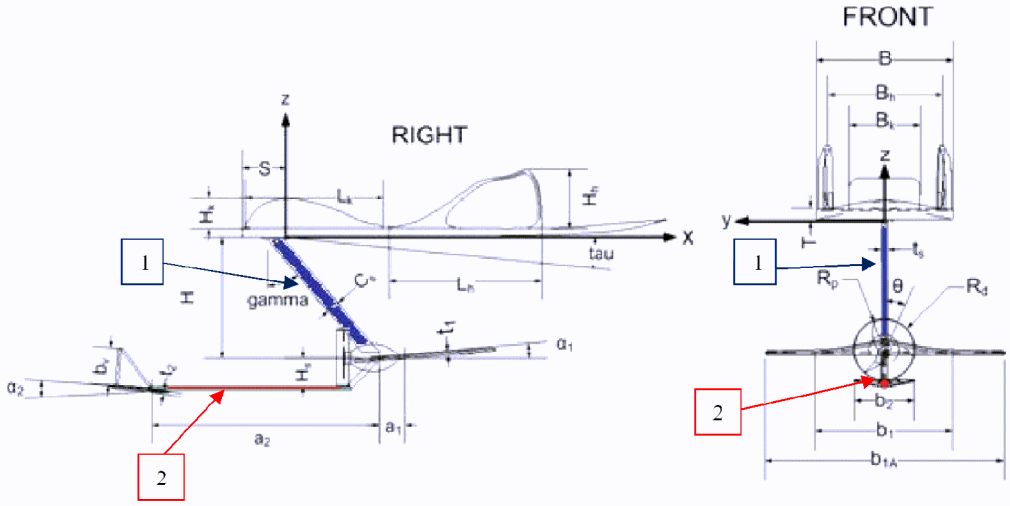


Figure 1. The two marked stays in the GA, blue is stay 1 and red stay 2, are exposed to the largest loads and should therefore be carefully dimensioned.

The struts and struts are critical from a strength point of view and should therefore be dimensioned carefully so that they can withstand the loads but do not become too heavy. The forces assumed to load the parts and the boundary conditions are already determined and can be seen in *Figure 2* [2].

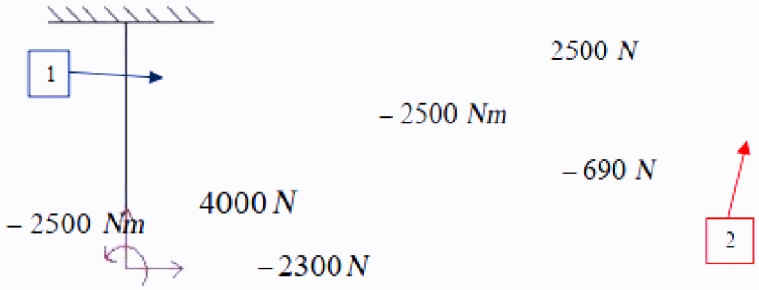
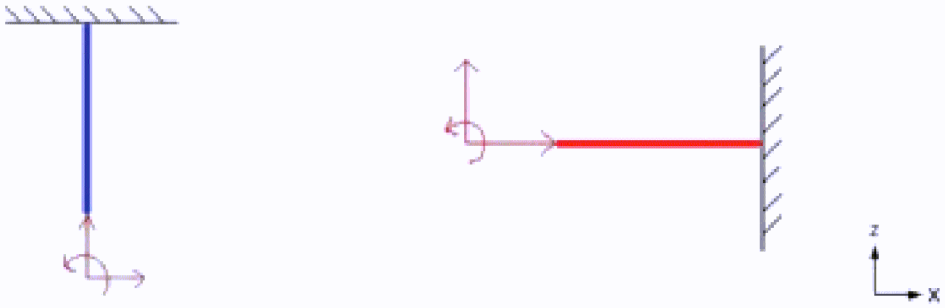


Figure 2. Here are strut, no. 1, and struts, no. 2, with simplified and fixed load cases.



In order to be able to make an analysis in Abaqus and get some of it, input data is needed. In addition to the forces and boundary conditions that have already been specified, additional data is needed to reduce the quantities that can be varied and thereby reduce the time it takes to optimize.
The material should be determined, then many of the parameters are clarified. Select e.g. carbon fiber that is relevant in the project, it has eight material parameters and fiber directions to take into account. What remains is the length and dimensions of the cross section of the stay/strut, which then gives two to three parameters to optimize according to. What is further needed is a goal function, i.e. something to strive for which should be to minimize the weight of the structure. To limit the optimization, coercion is needed, which can be bending, twisting, buckling and the like.

Conclusion

The difficulty in making this work lies in whether there is knowledge about Abaqus and its compatibility with optimization codes. Knowledge of modulating a problem in Abaqus and writing an optimization algorithm is in the project group, which should mean that doing this would be possible. Since the material and lengths will be determined will certainly be determined until this is the case, only the cross section will be varied which makes it a one or two dimensional problem if it is a simple cross section. Such an analysis should be done now when the power requirement needs to be reduced and it should take an estimated 25 hours. In addition, it is a good opportunity for someone or some in the project to learn more about Abaqus, get practice in how an optimization process that works with Abaqus is written.

References

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25. www.bilda.kth.se, A_17_Maximala_lastfall_för_strukturen_V1.0.docx.

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
127. Are all elements of the problem addressed?	Y	Y
128. Have the purpose and conditions been reported?	Y	Y
129. Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective?	Y	Y
130. Is the purpose achieved?	Y	Y
131. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors?	Y	Y
Technical content		
132. Have simplifications and assumptions been clearly stated and justified?	Y	Y
133. Has the choice of solution methods been clearly reported and justified?	Y	Y
134. Are calculations controlled and reasonably assessed?	Y	Y
135. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text?	Y	Y
136. Are equations written as part of the running text, presented in separate lines and numbered?	Y	Y
137. Can the technical reasoning be followed?	Y	Y
138. Is there a difference between facts, statements and the author's opinion?	Y	Y
139. Is there a realistic verification plan for the work in the report?	-	?
140 Is there an acceptable follow-up of the verification plan?	-	?
Presentation		
141. 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	Maybe
2. Is the report provided with: appropriate title, date, author name, e-mail, possible supervisor, summary/abstract, table of contents, reference list and page numbering	Maybe	Maybe
143. 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	No
144. 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

145. Are appropriate references made to figure, table and equation numbers in the text?	Y	Y
146. Are appropriate references made to references in the reference list?	Y	Y
147. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.?	Y	Y
Other		
148. Has the report been written by you individually?	Y	Maybe
149. The work has been carried out in collaboration with: _____		-
150. The report has been proofread by: Markus Norberg		-
151. I believe that this report as a whole is worth rating (u, 3-5)	3-4	
153. 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.):		-

Appendix 19
A104 Motor selection



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Course:	Marine design / Lightweight design
Project:	Evolo
Date:	*5/2-2009*
Version number:	*1.0*
Hours worked:	*5*h
Reviewed by:	Mirjam Fürth

Summary

With the support of previous investigations and many discussions at meetings and around the table, three different options for the motor have been developed. All have their pros and cons, problems and difficulties. Two of the options are based on ready-made concepts that are to some extent available on the market and are marketed by Torqeedo, the third is to manufacture the system ourselves. After

careful consideration, it has been decided to build on the motor we have available today, Torqeedo Cruise 2.0R, but continue the work of trying to find one of the two more powerful options.

Introduction

Previous investigations have focused on clarifying the options for the motor. In addition to this, investigations have been conducted to map the possibilities with the motor that the project today, more or less has available. This report aims to clarify recent discussions and describe the decisions made.

Options and discussions

Torqeedo Cruise 2.0

The motor available today is a Torqeedo Cruise 2.0R. So far, it is unclear exactly what is allowed to do with this. The propulsion power amounts to 900 watts, which is below the level required today for Evolo to be able to lift [1]. The advantages of this system are that it is a complete driveline. Control systems are available and can be modified to work on Evolo. The batteries available today work very well with this motor. The disadvantages, on the other hand, are that the speed is low, which has different consequences for propulsion. To reach a speed higher than about 5 knots, it is necessary to change the speed or that a new propeller is produced [2].

Torqeedo Cruise 4.0 R

This motor is the latest release from Torqeedo, which is based on the same principle as 2.0. Both are optimized to act as support motors up to 5 knots. The essential difference between the two is the effect. Cruise 4.0 R produces 1800 Watts in propulsion power but requires twice the voltage from the batteries, which means that new batteries are needed. From conversations with Watski who market Torqeedo in Sweden, this motor is not yet really on the market. The first appeared in Sweden in connection with the boat show in Gothenburg week 5. That is why the information about this is relatively sparse. According to Torqeedo, the speed is 1250 rpm, which is slightly higher than for 2.0. Despite this, the speed probably has to be shifted up on the propeller.

Own motor system

Several motors that can suit our needs are constantly being sought. Some options have been found from different types of retailers. A discussion is currently underway with VIAB, which brings home smaller and more powerful motors from China. The power of the proposed model amounts to 3.5 kW, the speed to about 2300 rpm and the weight to about 16 kilos. The voltage is 24 Volts, which is in line with the batteries available. The big challenge in building your own motor system lies not only in getting the components to fit together but also in constructing a tight installation for the motor to be placed in. Something that can still be seen as a very interesting and educational challenge.

Summary

There are different options that lead to different changes in development. Either we find an motor that fits what we have today, or we adapt Evolo to the motor and the batteries we have. Table 1 below presents the different options in relation to the project.

Table 1. Motor options

Motor	*Cruise 2.0*	*Cruise 4.0 R*	*VIAB 5.0*
Effekt [W]	900	1800	3500
Voltage [V]	24	48	24
Speed max [rpm]	1020	1250	2300
Torque [Nm]			9
Weight [kg]	18.5 (incl. Rig)	18 (incl. Rig)	15.8
Are new batteries needed?	No	Yes	No
New propeller?	Yes	Yes	Yes
New gear?	Yes, or above	Yes, or above	No
New Control System?	No	No	Yes
Price	0 SEK	28000 SEK	3000 SEK

Conclusion

As can be seen in Table 1 and mentioned above, there are pros and cons to all options. In whatever option we choose, there are various elements that we must develop further in order to have a working system. In the Torqeedo case, it is propellers that must be manufactured or ordered so that we reach sufficient speeds to fly. Alternatively, the speed must be changed in order for this to be realistic and the propeller not to become too large. A propeller that matches the calculations that have been made is available on the market according to our request. No investigation has yet been made for the speed that applies to 4.0 R with regard to the type of propeller that would match this. VIAB 5.0 has a speed that is in good agreement with that of ordinary petrol-powered boat motors. This potentially makes it easier to find a propeller that matches our purposes.
When it comes to controlling the motors, there is no major difference as Torqeedo's options include complete systems and VIAB's only need some form of potentiometer to regulate the current.

Results

The choice based on the facts presented here and in the reports referred to, is that we primarily try to optimize Evolo to reduce the power requirement [3]. The lower we manage to get, the closer we get to the motor we have available today. In parallel with this, we are pushing for a focus on gaining access to a more powerful motor package. Whether it will be a more powerful torqeedo or its own arrangement depends partly on economy, access to batteries, possibility of delivery, etc.

References

1. A14 - Effektbehov, Markus Norberg, 2008
2. A101 - Propellerval, Daniel Carlsson, Petter Delin, 2008
3. TB105 – Bärplan och Stag, Daniel Carlsson, Petter Delin, Johan Westin 2008

A105 Control system



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Course:	Marine design
Project:	Evolo
Date:	*29/01-2009*
Version number:	*1.0*
Reviewed by:	Mirjam Fürth

Summary

To be able to control the throttle to Evolo, a throttle control solution is required that can be controlled with your hands while holding the handles firmly. The throttle must also be able to automatically decrease when the grip on the throttle is eased and completely decrease if you fall off the craft. This is solved by building a handle that is both resilient and equipped with a dead man's switch. The throttle should be able to be controlled with just a few fingers to ensure the grip around the handle.

Introduction

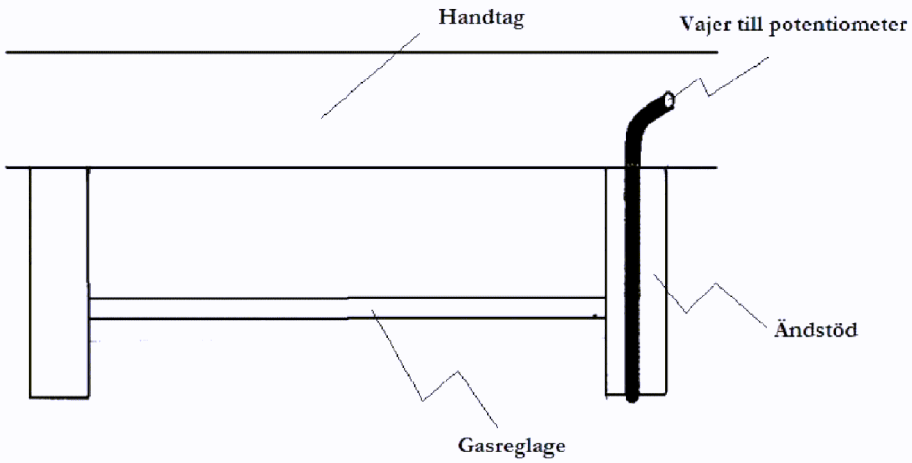
This work provides a recommendation for the design and construction of a throttle control for Evolo. The throttle is designed to control a potentiometer, which is the most common control for electric motors [1]. It is also designed to make minimal impact on the Evlolo during assembly, which also makes it easy to move.

Problem formulation

Controlled gas regulation of the motor for Evolo places great demands on the design. This is because the throttle must be applied with the hands as the body must be able to be moved around the floating body. At the same time, it is also the hands that the driver will use to stay on the floating body and to tilt it to maneuver. This only leaves a solution that requires the driver to be able to hold a firm grip around the handle while the throttle can be varied without obstacles. At the same time it must be possible to move the hands.

Analysis

Since it must be possible to move the throttle control without moving the hands on the handle, the proposal is made to do so in the form of a spring-loaded rod between two end supports, as in figure 1. This has a great advantage in view of the fact that the potentiometer, or control unit for the motor, can be placed separately from the handle and that the handle can then be moved more easily. The end supports can be designed as hose clamps in the mounting to the handle and in this way easily moved to fit the driver. The cable to the potentiometer can be selected as a regular bicycle brake cable. If the motor is a torqeedo, the wiring to the motor bulb, which is an ordinary telephone cable with connectors at the ends, can be easily spliced and extended, which provides easy movement and separation of handles, control unit and motor.



In the end piece of the end piece for the throttle control, see figure 2, a return spring is inserted which will cause the handle to return to its original position when it is released.
An additional safety feature that is highly recommended is a dead man's switch, or so-called kill switch. This can be obtained from marine or motorcycle shops [2] and is relatively easy to mount on a cable from control unit to motor.

Figure 1. Handle and throttle control.

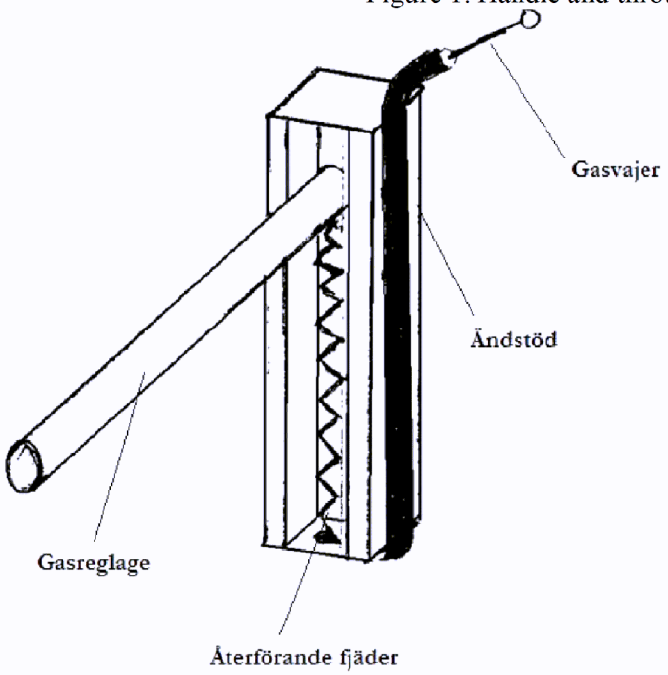


Figure 2. End piece with return spring.

Conclusion

By designing the throttle control and its details as described above would provide a throttle control that can be maneuvered with just one finger, which provides an opportunity to still hold the handle of the craft and maneuver it. The components are easy to procure or manufacture

and allow a wide variety of final placement. However, the control itself should not be made too far as it will then be pulled obliquely if you do not apply the throttle in the middle of the control.

References

26. Erik Jerilgård *Motorstyrning_1.0* KTH 2008
27. ATV-huset Feb 2009. http://www.atvhuset.se/Shop/Index.php?sArtId=U-502

Appendix 21 A106 Batteries

A107 – Own motor manufacturing



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Course:	Marine design
Project:	Evolo
Date:	*2009-02-05.*
Version number:	*1.0*
Supervised by:	
Hours worked:	*20*
Reviewed by:	Mirjam Fürth

Introduction

The purpose of this study is to make a benchmarking of what opportunities there are to develop your own motor solution instead of modifying an existing one and what consequences and opportunities it gives the project.

Motor options

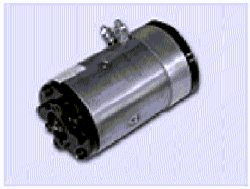
Above all, the internet has been used as a source of information. The starting point was to try to find solutions that could work for the project based on a rough specification.

About the motor

Since the project already has batteries of 24 Volts and the easiest would be to use existing outboard propellers that operate around 2300 rpm, these have been natural input parameters. Since it is still unclear how much power is needed to drive the Evolo, the starting point has been that the motor should be able to provide at least 2 kW of shaft power at 2300 rpm, which is on a par with or just below what the mythical Torquedoo motor cruise
4.0 gives. Below is a presentation of the options I have found so far.

Option Stegia

Stegia is one of Sweden's leading importers of electric motors. On a request for quotation, I immediately got in touch with Per Lindström who is a sales engineer. He has been very helpful and put in more work than you can probably expect to try to find something for us. According to him, the motor type is very unusual, but after a bit of searching, he found an option that could work. Figure 1 shows an image and specification of the motor [1]



■ Φ5.0″ (Φ127)D.C.Motor

item	order code	rated voltage	nominal power	rotation speed	torque	rotation direction	operation mode	surface color	weight	note
D1	MD12260	12V	2.6KW	2300rpm	9N.M	(CW)	S2=2.0MIN	(GOLD)	15.8KGS	Matched Center Manifold type CMB. CMC. CMD
D2	MD24350	24V	3.5KW	2300rpm	9N.M	(CW)	S2=1.2MIN	(GOLD)	15.8KGS	

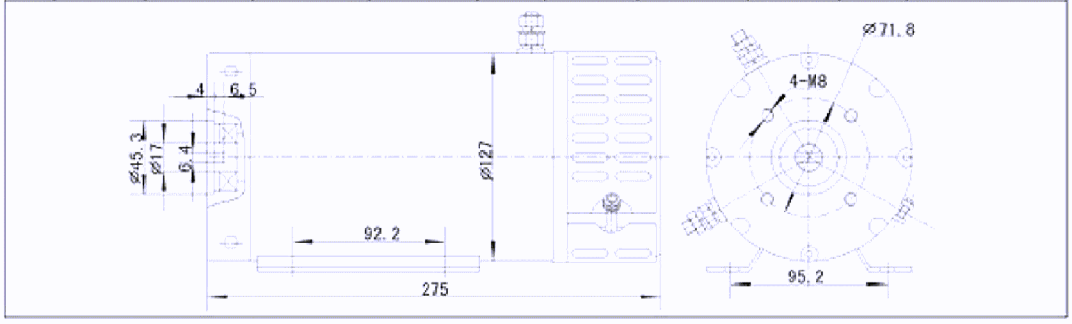


Figure 1. Specification and picture of the motor from Vibo-hydraulics

The most interesting of these for us is the 24 Volt version. Stegia has never taken this motor home before and at the time of writing it is still unclear whether the manufacturer can even think of selling just one motor. Likewise, the exact price is not known, but according to Per Lindström, it should be in the range of SEK 2000-3000 with shipping. Delivery time is also difficult to say before contacting the manufacturer VIBO-Hydraulics which is located in China, but a couple of weeks is probably most likely. The ball is currently with Stegia who will contact VIBO about price, more detailed specification and hopefully a CAD picture and a somewhat clearer message about possible delivery. In all probability, it should be possible to give notice of this solution in week 907.

Based on the available data, this motor provides a torque of 9 Nm, which with 2300 rpm gives a shaft power of just over 2.15 kW. The input power is 3.5 kW, which with 24 volts means that the current with which the motor is fed will be 145 A. If the batteries we have are about 50 Ah, it gives a theoretical operating time of about 20 minutes. More realistic, however, is 10 min.
The solution with this motor presents a lot of new challenges. First, we need to build a watertight housing that preferably has direct contact with the housing to cool the motor efficiently. An option to this is flanges between the motor and the housing, but then you instead have problems with suspensions etc. A solution on the cover would be a pipe where you cut out grooves for the terminals and then made a cone to attach to the front edge. Another problem is the power transmission as the motor must be exactly level with the shaft. One solution is that between the motor and the propeller shaft you have a plastic disc, a so-called flex coupling that forgives angular errors between the motor and the shaft. These are on the market but it is doubtful if they would fit here. So probably it will be to make one ourself. So probably it will be to make one yourself.

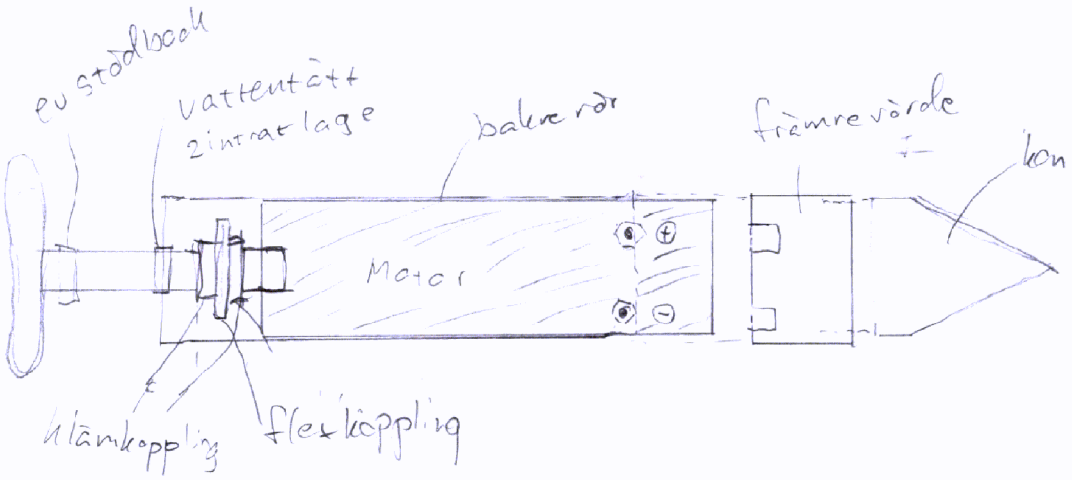


Figure 2, Idea of installation seen from above

Another challenge is that such an motor requires control. This is not built yourself. There are high currents so there are great risks associated with hauling 145 A, (especially fire and explosion). Per Lindström will also check which control systems are available, but it should definitely be solvable. Another thing to keep in mind is that real cables are required for these currents, we probably have to go up to the dimension of 70 mm2, which is expensive, but at the same time probably relatively easy to get sponsorship for.

Option Östergren's electric motors

Östergren is Stegia's biggest competitor and has delivered motors for KTH projects in previous years, but above all for land applications, including eco-cars. I have been in contact with them but have not come further than the switchboard. A look at their website means that they do not seem to have anything that would suit us in the regular range in any case. Since there is already a good contact with such a company, it does not feel worthwhile to put more energy into this option.

Option OZ- Marin / Perm-Motors

OZ-marin is a relatively young company that sells innovative solutions, especially for sailboats. Their biggest product is that they convert sailboats to electric propulsion. Their motor is an electric permanent magnet motor that can run at 24-72 volts. Their motor can be bought for around SEK 11,000 plus VAT, but it did not sound completely impossible to discuss the price according to Oscar Theen who is a salesman at OZ-Marin. This motor comes from a German company and there is a lot of data on it. With 24 volt operation, the speed becomes too low, around 1000 rpm so then it needs to be geared. According to Oscar Theen, this could be solved with the help of a belt exchange, but I am skeptical about how it will fit. If 48 volts is used, it looks much better. Figure 3 shows the power curve for 48 volt operation [2].

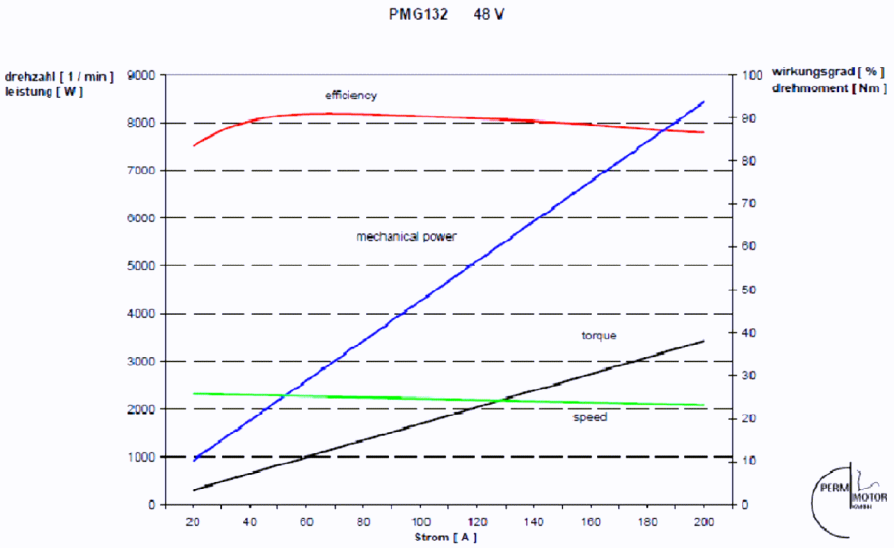


Figure 3, Power curves for the PMG132 electric motor at 48 volt operation [2]

As can be seen, this motor gives exactly the speed we want for 48 volt operation, in the same way it can be seen that the efficiency is high. With this system we would have significantly more power than 2 kW could get. Depending on the capacity we can get on our power source, we should be able to at least cream out 4 kW and shorter periods even more. The disadvantage is then that we can not use the batteries we have or must have a similar package and connect these in series. Another disadvantage of this motor is its dimensions. Figure 4 shows a picture of the motor.



Figure 4, Perm PMG132

It measures at most 22.5 cm in diameter 17.3 cm from the shoulder tip to the other end. The weight is 13 kg. It is a bit unclear how it would feel to be encapsulated because it is completely built on having circulation according to Oscar Theen at OZ-marin. Building it in the same way as the Stegia option is certainly possible but much more difficult. An idea on how to do this is to disassemble the gear for an outboard motor (lower part) and simply assemble the shafts. This way you do not have to build your own system with shafts and bushings for the propeller. However, this must be investigated further as the author does not really know what it looks like inside the gear for one. Figure 5 shows an idea sketch of what this could look like.

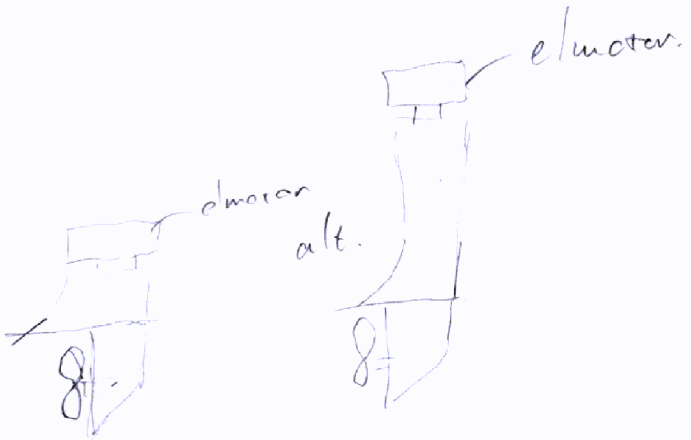


Figure 5, Idea sketch of motor mounting

As for steering, they have a fairly advanced truck controller from Semcon which I want to remember cost around SEK 10,000, but it is not impossible that you can get one from Semcon.

Option Hub motor

The tip about Hub motor came after I joined a forum for people interested in electric power on boats on yahoo. They sell an motor not entirely different from the one that Perm has. The manufacturer is located in China and they have an motor called the HPM-5000B. This motor is very similar in appearance to the one from Perm, although slightly smaller dimensions. Figure 6 shows a

picture of this motor with dimensions.

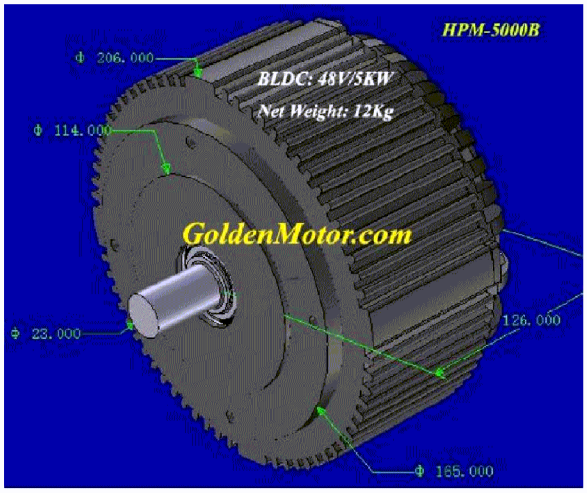


Figure 6, The motor from HUB

This motor should also be "waterproof" what it means and some other technical questions including price and delivery times I have emailed and asked about, but have not yet received an answer on February 6, 2009. According to the tipper on the forum, he had received the price of 290 dollars plus shipping. The company could also sell a control unit for about 350 dollars plus shipping. If we get the same price, then it's probably 700 dollars with shipping. With a dollar exchange rate of SEK 8, this gives a cost of just under SEK 6,000. Then there may be Swedish VAT and import tax if we are unlucky.
Figure 7 shows a power curve from their website [3]. It is unfortunately specified for 48 volt operation and then the speed is too high as seen, provided that my interpretation of the horizontal axis as current in the Ampere unit is correct.

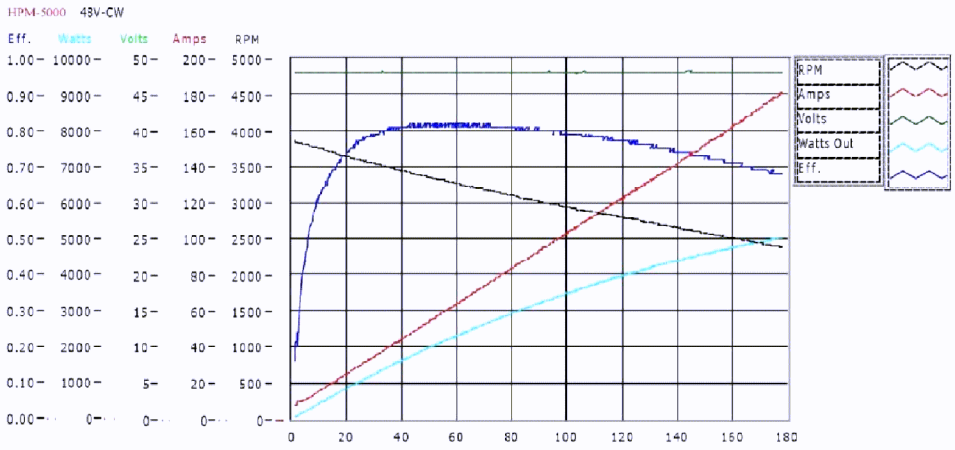


Figure 7, Power curves for the HUB motor HPM-5000 at 48 volt operation

The weight of the motor is also attractive 11 kg, which is the lightest of all options. This motor is slightly smaller than the one from Perm and it has a better exterior for installation.
In addition, if it is already waterproof, it is definitely a good option. For this option, we need to get hold of the power curves for 24 and 36 volt operation before it is possible to say anything more

about usability.

Option Bellman

This is no joke, there is a Dutch manufacturer that makes a lot of electrical solutions for different types of boats. They have a variant that could work for us. It's basically a pod much like the bottom of the Torqeedo motor. Among other things, they have a version with a built-in synchronous motor of 48 volts that provides enough power, 4.2 kW a little unclear whether it is in or out. The advantage of these motors is that they are completely ready and "only" to integrate and connect with a control unit. I have emailed about more information such as weight and power curves. The disadvantage is the price, which for an all-inclusive unit is between 4000 and 5000 euros plus tax. Figure 8 shows two images of this solution [4].

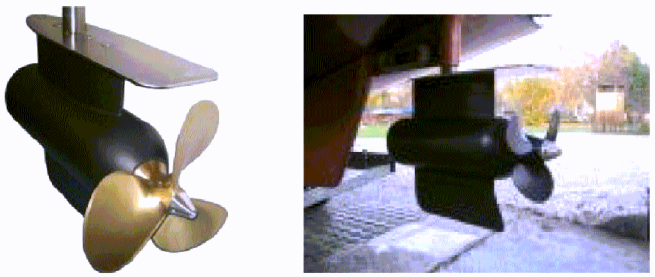


Figure 8, Pod motors from Bellman in Holland

Conclusion / recommendation

There are still several pieces of the puzzle missing to be able to make a good final decision. If we do not get the input data that I pointed out in the report, the most attractive option motor is probably the one from PERM for its own solution. It is guaranteed to be available. It is an expensive solution which in turn requires a new battery solution with 48 volts, but it is guaranteed to provide sufficient power. However, more work needs to be done on integration. Considering 48 volt operation is probably not so bad idea anyway, as it halves the currents and increases efficiency (less heat). My recommendation for the project is to go all in to get hold of Torqedoo cruise 4.0. This is because it is the absolute simplest solution to build on and we have already done so many investigations around this motor and that the final design is very adapted to it. I continue to monitor this question as there are many threads out there that can provide new answers.

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29. Internet, http://www.perm-motor.de/site/pdf/Gleichstrommotoren_PMG/Massbaetter_PMG_080_132/PMG132_Massblatt_Deutsch_mit_Diagrammen.pdf tillgänglig 2009-02-05

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A108 - Planetary gear

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Course:	Marine design
Project:	Evolo
Date:	*3/2-2009*
Version number:	*1.0*
Supervised by:	-
Hours worked:	2 hours
Reviewed by:	Mirjam Fürth

Summary

The following planetary gear, NT17-003 (figure 1), meets the set requirements for torque and gear set earlier. The total length without any adapters to the shafts is 58 mm and the largest diameter is 42 mm, well within the size requirements. These planetary gears are supplied by Servotronic AB [2], which has a large range of this type of gear. The cost is between 5000 - 10000 SEK.

A potential problem with the use of a planetary gear is the shaft dimensions, as these are not currently determined, no evaluation of this can be carried out. However, there are options to use an adapter to correct this.

The gear option is thus possible, but should be used as a last resort, as it only involves another possible complication in joining the motor.

Introduction

The purpose of this report is to recommend a planetary gearbox for use with existing Torqueedo motor and existing propellers for the purpose of modifying the motor and propeller configuration to allow Evolo to reach a higher speed, greater than 8 knots.

Problem formulation

The existing Torqueedo 4.0 motor has a speed of 920 rpm and an output of 1800 W [1]. With a required output power of 1800 W and a required speed of 2300 rpm, a gear ratio of at least

$$n = \frac{2300}{920} = 2.5:1 \quad (1),$$

and a minimum torque of

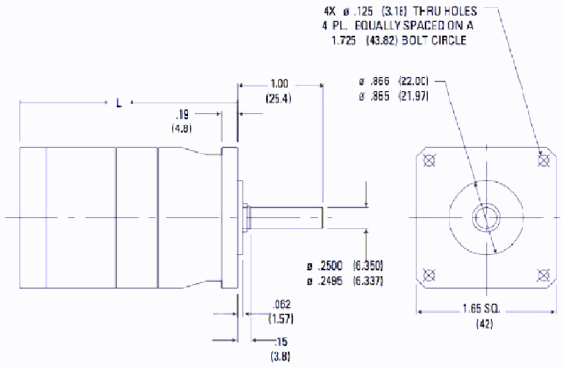
$$T = \frac{1800}{\frac{920}{60} \cdot 2\pi} = 19 \text{ Nm} \quad (2).$$

This places the following demands on the planetary gear

- Gear ratio 3: 1
- Low weight
- Small, should not be larger in diameter than the motor
- Handle a torque of 20 Nm
- Shaft dimensions should be compatible with existing propellers and motor shafts

Results

The following planetary gear, NT17-003 (figure 1), meets the set requirements for torque and gear set earlier. The total length without any adapters to the shafts is 58 mm and the largest diameter is 42 mm, well within the size requirements. These planetary gears are supplied by Servotronic AB [2], which has a large range of this type of gear.



Performance Specifications

Part Number	Ratio[1]	20000 Hour Life T_r (1000 rpm) in-lb [Nm]	T_r (2000 rpm) in-lb [Nm]	T_r (3000 rpm) in-lb [Nm]	T_r (4000 rpm) in-lb [Nm]	Tpeak in-lb [Nm]	J in-lb-sec²x10⁻⁴ [kg-cm²]	Torsional Stiffness in-lb/arc-min [Nm/arc-min]
NT17-003	3:1	41 [4,7]	34 [3,8]	29 [3,3]	27 [3,1]	170 [19,2]	0.115 [0,013]	2.36 [0,268]

Figure 28. Performance data for NT17-003.

A potential problem with the use of a planetary gear is the shaft dimensions, as these are not currently determined, no evaluation of this can be carried out. However, there are options to use an adapter to correct this.

References

32. Carlsson, D: *A101 - Propellerval*. Bilda.kth.se, KTH, Stockholm, 1998.
33. Servotronic AB, www.servotronic.se 2009-02-02.

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
153. Are all elements of the problem addressed?	Yes	Yes
154. Have the purpose and conditions been reported?	yes	Yes
Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective?	yes	Yes
156. Is the purpose achieved?	Yes	Maybe
157. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors?	yes	Yes
Technical content		
158. Have simplifications and assumptions been clearly stated and justified?	Yes	yes
159. Has the choice of solution methods been clearly reported and justified?	Yes	Yes
160. Are calculations controlled and reasonably assessed?	-	-
161. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text?	Yes	Yes
162. Are equations written as part of the running text, presented in separate lines and numbered?	Yes	Yes
163. Can the technical reasoning be followed?	Yes	Yes
164. Is there a difference between facts, statements and the author's opinion?	yes	Yes
Presentation		
165. 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	yes
166. Is the report provided with: appropriate title, date, author name, e-mail, eventual supervisor,summary/abstract, table of contents, reference list and page numbering	Yes	Yes
167. 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…"?	Yes	Yes
168. 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?	Yes	Yes
169. Are appropriate references made to figure, table and equation numbers in the text?	Yes	Yes

170. Are appropriate references made to references in the reference list?	Yes	Yes
171. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.?	yes	Yes
Other		
172. Has the report been written by you individually?	Yes	
173. The work has been carried out in collaboration with: _____	-	-
174. The report has been proofread by: _____	-	-
175. I believe that this report as a whole is worth rating (u, 3-5)	-	
176. 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.):	-	-

Feedback from Alexander Sahlin



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Course:	Marine design
Project:	Evolo
Date:	*3/2-2009*
Version number:	*1.0*
Supervised by:	-
Hours worked:	*0.1*
Reviewed by:	-

Summary

This is a summary of the feedback we received from Alexander Sahlin.

- Steering in turning direction would work better if the load-bearing strut from the floating body down to the wing were moved behind the main wing, see Airchair
- For our steering to work, the hydrodynamic center of gravity of the vertical surfaces must be some distance behind the center of mass. It is also good if they are not too scattered in length direction as the moment of inertia in the turning direction becomes large.
- It is important to place the propeller shaft in the direction of flow at cruising speed
- Integrate the motor in the front wing and place the propeller shaft in a tube to the aft wing
- Smaller angle of attack, but larger wing on the stabilizer fin

Appendix 1 - Checklist for Quality Assurance

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General impression	Author Yes/No	Reviewer Yes/No
177. Are all elements of the problem addressed?	Yes	Yes
178. Have the purpose and conditions been reported?	-	-
179. Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective?	-	-
180. Is the purpose achieved?	Yes	Yes
181. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors?	Yes	Yes
Technical content		
182. Have simplifications and assumptions been clearly stated and justified?	-	-
183. Has the choice of solution methods been clearly reported and justified?	-	-
184. Are calculations controlled and reasonably assessed?	-	-
185. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text?	-	-
186. Are equations written as part of the running text, presented in separate lines and numbered?	-	-
187. Can the technical reasoning be followed?	-	-
188. Is there a difference between facts, statements and the author's opinion?	Yes	Yes
Presentation		
189. 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	Yes
190. Is the report provided with: appropriate title, date, author name, e-mail, eventual supervisor,summary/abstract, table of contents, reference list and page numbering	Yes	Yes
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192. Are figures and tables clear and informative, provided with figure / table text and clear numbering? numbered? 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?	-	Yes

193. Are appropriate references made to figure, table and equation numbers in the text?	-	Yes
194. Are appropriate references made to references in the reference list?	Yes	Yes
195. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.?	Yes	yes
Other		
196. Has the report been written by you individually?	Yes	
197. The work has been carried out in collaboration with: _____	-	-
198. The report has been proofread by: _____	-	-
199. I believe that this report as a whole is worth rating (u, 3-5)	-	
200. 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.):	-	-

A109 - Handle

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Project:	Evolo
Date:	*7/2-2009*
Version number:	*1*
Supervised by:	Stefan Hallström
Hours worked:	*15*
Reviewed by:	Anders Lundell

Introduction

When the drawing for the handles was produced, the dimensions developed in TB107-Floating body, Construction plan, ref [1] were followed. Incidentally, the thickness of the handles was set to 30 mm because this corresponds to a bicycle handlebar and these are easy to grip. The problem with the handles is the manufacture of the frame that is the part that the driver of Evolo must hold. If this frame is to be made of composite material, the process will be tricky and the chosen manufacturing method must be tested before construction to validate the chosen method. The problem is that the handle is not easy to manufacture in any material. If it is made of metal, the metal must be heated in order to be able to shape it. There is a possibility, however, that the pipe could be made of aluminum and bent to the right shape.

Problem formulation

The purpose of the work is to investigate what the handles should look like and how they can be manufactured. The proposals that have been thought through during this work are two variants for making the arc in composite and a variant where the frame is made of aluminum and bent to the correct shape.

The first proposal is that a tube of foam rubber is slit, to facilitate shaping, and then clad in selected fiber. When the tube is clad in fiber, it is formed to then vacuum inject the matrix. Here, the foam tube will remain in the composite material. Here it must also be investigated which matrix can be used if a foam tube is to be the shape.

The second proposal is the opposite of the first. And basically means that a tube that is shaped to the right shape is clad on the inside with fibers and then the matrix is injected. This means that afterwards the outer tube must be "sacrificed" to get the handle out.

If the arc were to be made of aluminum and bent to the correct shape, the problem is to bend the pipe without plasticizing. This manufacturing method would also mean that it will be difficult to bend the pipe so that it gets the right shape. As this is an aesthetic detail, this can be overlooked if the other proposals are considered too difficult to carry out. It would be advantageous if the aluminum was heated before forming as the arc would then be easier to form. As at the time of writing there is no knowledge of whether the necessary equipment is available, it is considered that it is desirable but not necessary.

An overview of what the handle might look like is shown below in figure (1).



Figure 29 Overview of the handles

Conclusion

The manufacture of the handles is considered a rather difficult problem to solve. Of the composite options reported above, what means that a foam rubber tube is clad in fibers is considered to be the one that will have the greatest chances of success. However, with regard to both manufacturing methods, further investigation is needed as to whether they are feasible and what the result will be for the two methods. The assessment is made that the arc would be easiest to manufacture in aluminum. This is because material tests do not need to be performed and it is relatively certain that this method is feasible. The recommendation for the project is therefore that the arc should be made of aluminum. Here it is considered that it is worth overlook the aesthetics to get a good result.

Verification plan

To determine if any of the proposed composite manufacturing methods are feasible and deliver handles with desired mechanical properties, the methods should be tested.

References

34. *TB107-Flytkropp, Konstruktionsplan*, Joacim Westlund, Stockholm, KTH, våren 2009

Appendix 1 - Checklist for Quality Assurance

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204. Is the purpose achieved?	Yes	Yes
205. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors?	Yes	Yes
Technical content		
206. Have simplifications and assumptions been clearly stated and justified?	Yes	Yes
207. Has the choice of solution methods been clearly reported and justified?	Yes	Yes
208. Are calculations controlled and reasonably assessed?	Yes	Yes
209. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text?	-	-
210. Are equations written as part of the running text, presented in separate lines and numbered?	-	-
211. Can the technical reasoning be followed?	Yes	Yes
212. Is there a difference between facts, statements and the author's opinion?	Yes	Yes
213. Is there a realistic verification plan for the work in the report?	Yes	Yes
214. Is there an acceptable follow-up of the verification plan?	No	No
Presentation		
215. 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	Yes
216. Is the report provided with: appropriate title, date, author name, e-mail, eventual supervisor,summary/abstract, table of contents, reference list and page numbering	Yes	Yes
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219. Are appropriate references made to figure, table and equation numbers	Yes	-

in the text?		
220. Are appropriate references made to references in the reference list?	Yes	Yes
221. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.?	Yes	Yes
Other		
222. Has the report been written by you individually?		
223. The work has been carried out in collaboration with: _____		-
224. The report has been proofread by: _____		-
225. I believe that this report as a whole is worth rating (u, 3-5)		
226. 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.):		-

M110 – Mounting strut / hydrofoil

NILS WOLTER

JASMINE SATTARI FAR

Course: Lightweight design
Project: Evolo
Date: *3/3-2009*
Version number:
Supervised by:
Reviewed by:

The purpose of this report is to determine what the mounting between the strut and the hydrofoil should look like. F*ig.* 1 shows what the mounting should look like. F*ig.* 2,3,4,5 shows step by step how the production should go.

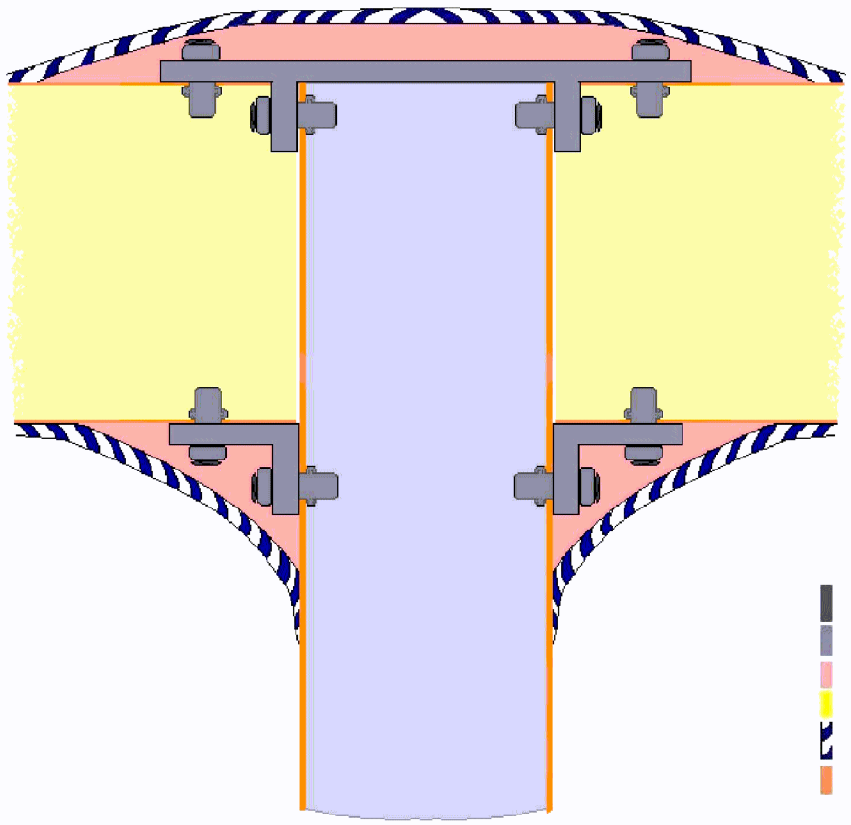


Figure 1. Final mounting

Critical parts of manufacturing are the metal flanges that are to be shaped to fit the elliptical shape of the strut. Between the composite cover layer and the metal flanges, a filler should be used so that the fibers will lie better against the metal flanges. This filler must be sufficiently rigid to carry the resulting loads. Depending on the core material to be used, wood or Divinycell with a high shear modulus, different types of screws should be used. If wood is used, wood screws can be used. If Divinycell is used, a tensile test must be performed to see if wood screws are to be used, which is advantageous. If Divinycell does not fit together with wood screws, a type of rivet must be used that attaches to the cover layer. These can be ordered from www.colly.se. However, both solutions are feasible. The recommendation is to use Divinycell H200 and rivets to save time and not have to perform tensile tests.

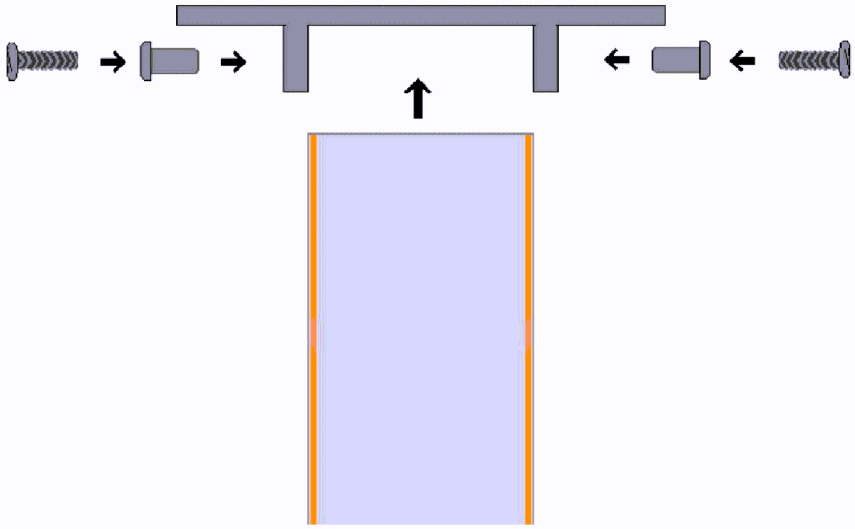


Figure 2. mounting step 1

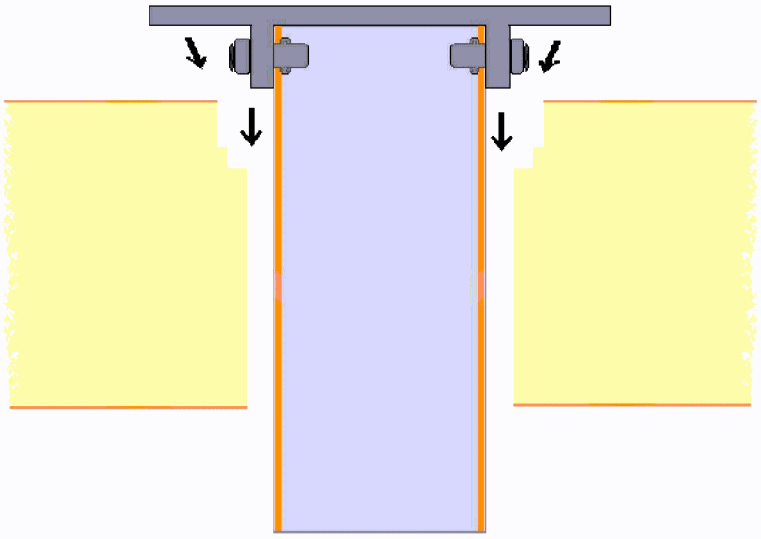


Figure 3. Mounting step 2

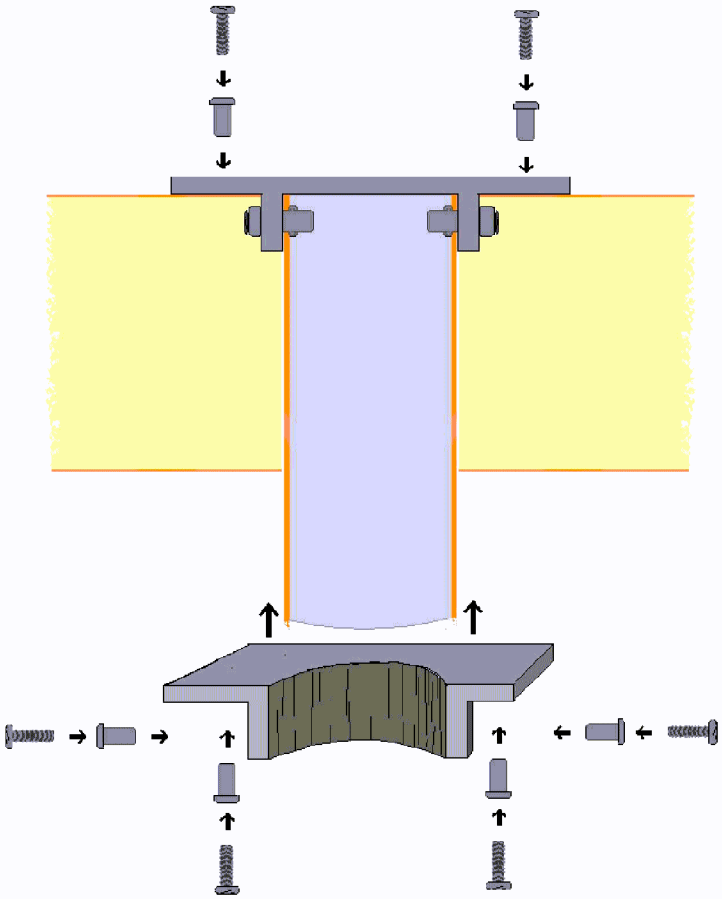


Figure 4. Mounting step 3

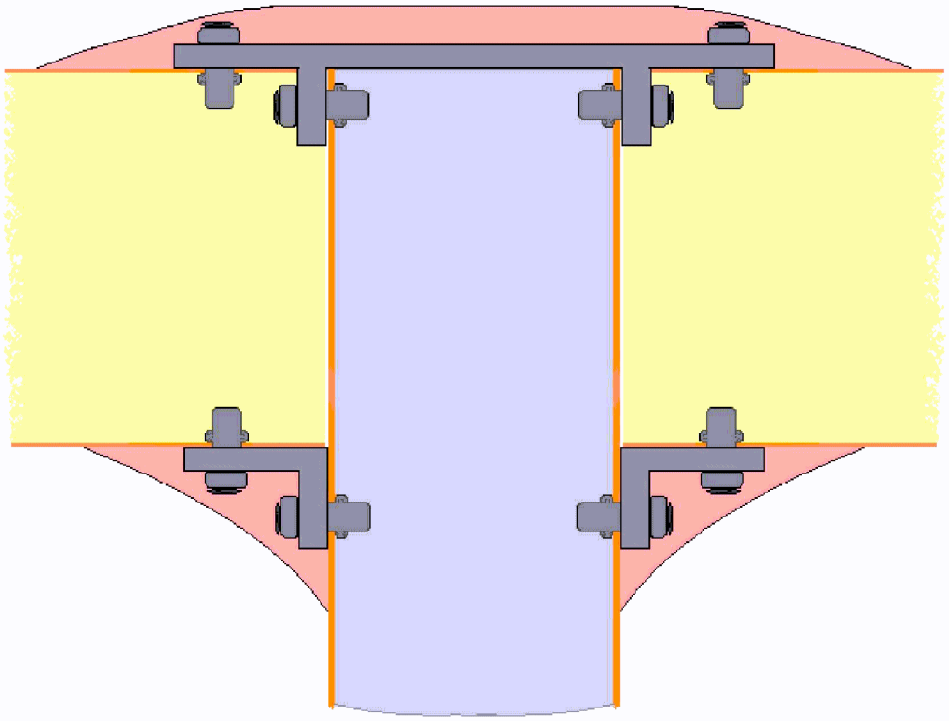


Figure 5. Attachment step 4

TB101 – Floating body Base



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Course:	Marine design
Project:	Evolo
Date:	*20/1-2009*
Version number:	*1.0*
Supervised by:	Jakob Kuttenkeuler
Hours worked:	*12*
Reviewed by:	Markus Norberg

Summary

In order to proceed with the design of Evolo's floating body and decide in general how it will be built, this investigation is made. The inquiry deals with some design proposals that can be chosen and various details that must be sorted out before the final design, which must be ready in early February.

From a total of 4 types of proposal, the proposal called "Riva" is selected. Furthermore, the factors that need to be taken into account when drawings for the floating body are described. They are summarized under the heading *conclusions*.

Summary 217
Problem formulation 219
Design 219
Manufacturing method and construction loads 220
Batteries 220
Bracket for strut 221
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Floating ability and floating position 221
Resistance and need for towing attempts 221
Conclusion 221
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Problem formulation

The purpose of determining this floating body data is to have tried to identify all difficulties in the manufacturing phase of the floating body and to be able to proceed in the dimensioning of the floating body. Based on the dimensions, it can also be verified that the construction can withstand the loads to which it is subjected and dimensions can be used to start production.
The previous report A2 - Floating body Analysis states that the resistance will not be affected to any great extent depending on whether you choose a planing or a displacing hull shape. At present, however, it is unclear whether the end product will meet the requirement of 15 knots speed and to lift at a given speed. In other words, it may be that Evolo's compliance with the requirements depends on the small difference in resistance. Therefore, an assessment is also made as to whether towing tests of models on different hull shapes or not.

Design

The four different proposals for Evolo's design are presented in Figure 1-4 and are briefly described in the captions. The proposal "Anders" is designed by Anders Lundell and the others are designed by Joacim Westlund.

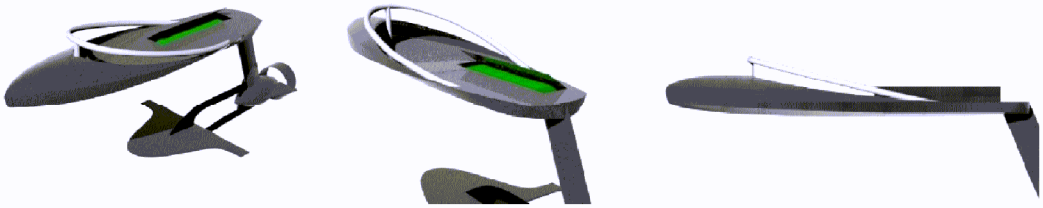


Figure 1. "Riva" inspired by the classic Italian boat brand of the same name.

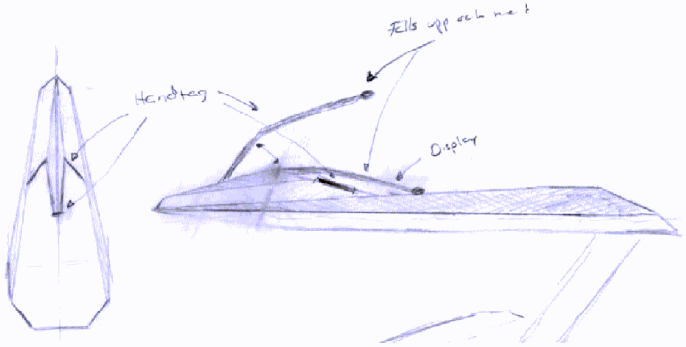


Figure 2. Anders Lundell's proposal, it is called "Anders" here.

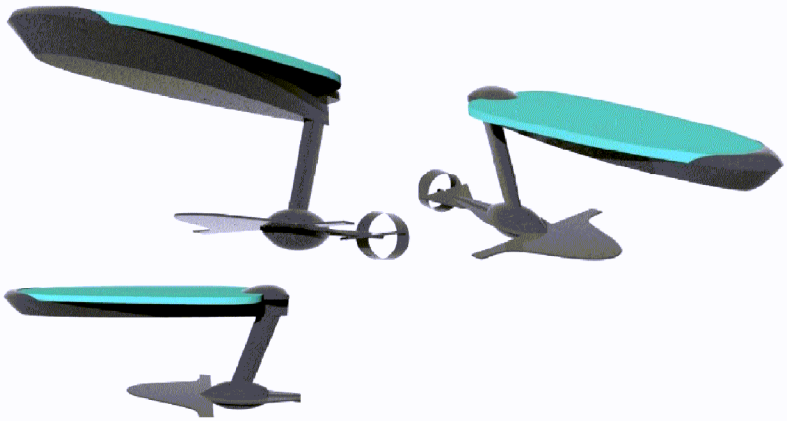


Figure 3. "Block" which is intended to be built up of a smaller hull with a part of the floating body as a light and simple block to facilitate production above all.

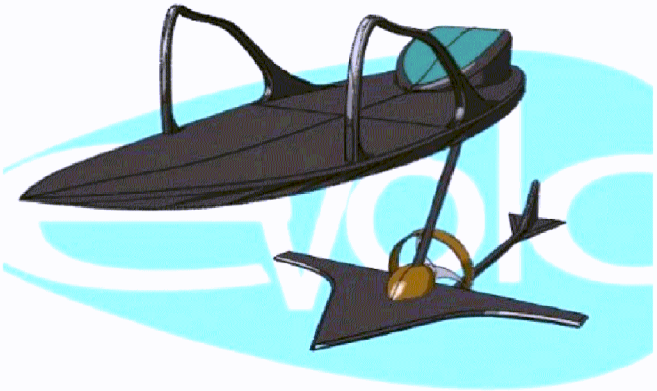


Figure 4. "Board" that represents what Evolo looked like in the preliminary design.

In a vote during a project meeting on January 22, the proposal "Riva" was adopted, which thus becomes the form to be built.

Manufacturing method and construction loads

In the preliminary design of Evolo, it was decided that it would be built from a sandwich construction with carbon fiber as a cover layer. For details of how the floating body and other parts of Evolo are to be manufactured, material tests must be performed.
After discussion with Jasmin and with Per Wennhage, it is nevertheless established that the dimensions that Evolo has according to the preliminary design are sufficient for it to withstand the stresses to which it is exposed. This can be done because the number of carbon fiber layers at the critical points can be made more for increased stiffness and strength. For example, placement of batteries is a parameter for how strong the structure becomes and is treated below together with other identified parameters.

Batteries

Figure 1 shows a cover on the top of the floating body that represents one of two battery covers. The battery cells that can be used for the project today are 8 3.2-volt cells that measure 6.5 x 16

x 21 cm each. The idea is to build them as much as possible into the float for aesthetic and ergonomic reasons and they are included when the float in the Riva version is drawn.
In another project activity that is taking place in parallel with this, it is being investigated whether a new motor from Torqeedo will be used. The intended motor is powered by 48 volts voltage instead of 24 volts which is the voltage on the batteries available today. In the event that twice as many cells would be needed connected in series to be able to drive Evolo, there will also be room in the floating body, but this may mean that the thickness must be slightly greater in the bow and that the center of gravity is shifted. This could adversely affect Evolo's floating position in the worst case. With two rows of batteries next to each other along the floating body, there is still at least 25 cm of the floating body width that can form one (or divided into several) longitudinal sandwich beam (s) to meet the strength requirement of the Evolo.

Bracket for strut

For the mounting between the strut and the floating body and other parts of the Evolo, an activity takes place in parallel. In the worst case, given the weight above all, an aluminum plate can be built into the lower part of the floating body with a pin to attach the strut to. Regardless of what the mounting looks like, cables between batteries and motor must be considered. Feedthroughs must be provided so that cables of sufficient dimension can fit and can be led down through the strut.

Handle and throttle control.

Mounting of handles should be done with the dimensions specified in the ergonomics report (Appendix 20 in the preliminary design) and with the methods recommended by the investigation of mountings mentioned above. After discussions with the investigator concerned, there should be great opportunities to adapt how handles should be mounted.
The throttle control can in its simplest, and perhaps most likely, design be a standard control that is attached to the handle at a suitable position for the driver. When manufacturing the floating body, however, it should be taken into account that lines for controls may need to be planned how they are to be pulled in to get them in smoothly from the beginning. This is to avoid cables getting in the way of the driver or being subjected to unnecessary violence, which can be the risk of a poorly laid cable.

Floating ability and floating position

According to the requirements specification, it must be possible to carry a certain weight of driver, plus Evolo's unladen weight with batteries and motor. When the final drawing is produced, it must be examined that the buoyancy force becomes sufficient and also how the buoyancy position in the water will be.

Resistance and need for towing attempts

After an assessment of the usefulness of making model tests to investigate the difference in resistance for different designs of the floating body, the decision is made that towing tests should not be carried out. It is anchored with those in the project group who have had to do with the design of the floating body and is mainly due to the lack of time before the final design.

Conclusion

At a meeting, the project decided to use the *Riva* design according to Figure 1 for the final design of Evolo.

More details should be observed during the preparation of drawings for the floating body. They can be summarized as:

- Batteries and their location
- The mounting between the floating body and the strut
- Handles and controls
- Wires and bushings for cables for motor and controls
- Floating ability and floating position.

Furthermore, decisions are made mainly due to lack of time not to carry out towing tests on different floating body designs.

References

35. Rapport, P*reliminär design* a*v Evolo*, med bilagor, Joacim Westlund m fl, 2008. Unpubl.

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
227. Are all elements of the problem addressed?	Yes	Yes
228. Have the purpose and conditions been reported?	Yes	Yes
229. Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective?	Yes	Yes
230. Is the purpose achieved?	Yes	Yes
231. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors?	Yes	Yes
Technical content		
232. Have simplifications and assumptions been clearly stated and justified?	Yes	Yes
233. Has the choice of solution methods been clearly reported and justified?	Yes	Yes
234. Are calculations controlled and reasonably assessed?	-	Yes
235. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text?	Yes	Yes
236. Are equations written as part of the running text, presented in separate lines and numbered?	-	Yes
237. Can the technical reasoning be followed?	Yes	Yes
238. Is there a difference between facts, statements and the author's opinion?	Yes	Yes
Presentation		
239. 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	Yes
240. Is the report provided with: appropriate title, date, author name, e-mail, eventual supervisor,summary/abstract, table of contents, reference list and page numbering	Yes	Yes
241. 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…"?	Yes	Yes
242. 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?	Yes	Yes
243. Are appropriate references made to figure, table and equation numbers in the text?	Yes	Yes

244. Are appropriate references made to references in the reference list?	Yes	Yes
245. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.?	Yes	Yes
Other		
246. Has the report been written by you individually?	Yes	Yes
247. The work has been carried out in collaboration with: _____		-
248. The report has been proofread by: Markus Norberg		-
249. I believe that this report as a whole is worth rating (u, 3-5)		
250. 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.):		-

Mountings



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Version number:	*1.0*
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Summary

To be able to design Evlolo, different techniques are needed to attach the different details of the construction to each other. These are briefly described with the pros and cons in this overview report. The results show that the construction will be sensitive to torque load and will need to be constructed especially with this in mind, and that attempts must be made to determine which dimensions and which materials the different joints need to be constructed with.

Introduction

This work aims to provide a summary of the possible fastening techniques that are possible in the points between e.g. hydofoil and floating body, and to give suggestions on which techniques should be used for each area.

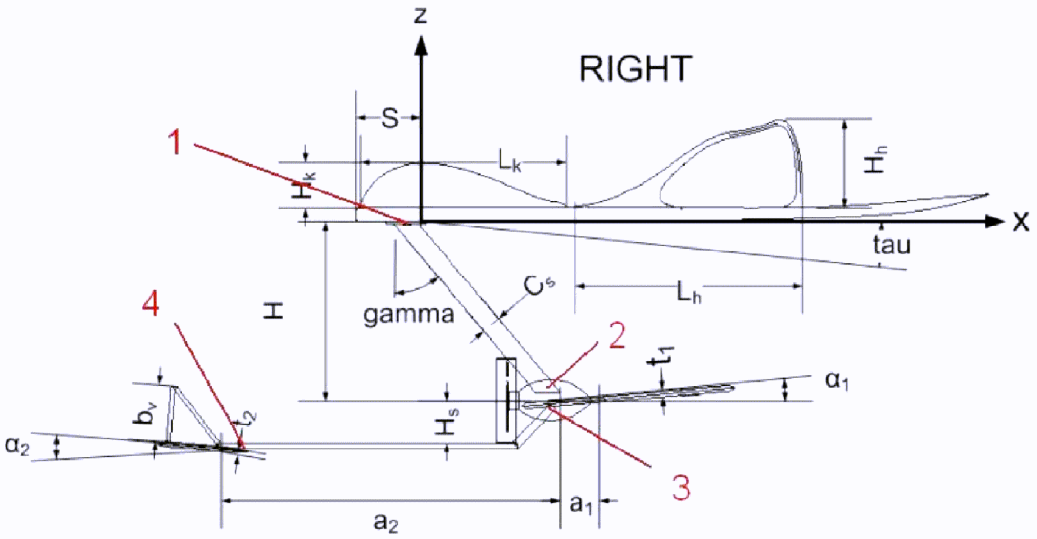
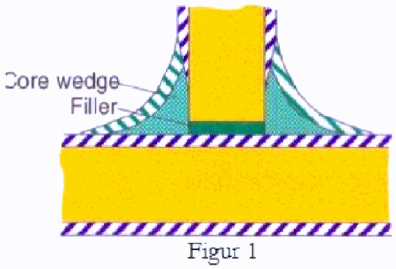


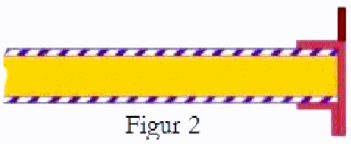
Figure 1. GA

Problem formulation

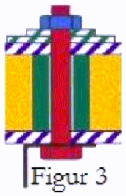
As the different mountings in the construction require different solutions, the different points below refer to the respective figure.



Figur 1



Figur 2



Figur 3

Methods

Figure 1 shows a T-joint between two sandwich elements with an angle of 90º between the panels. This is a common construction solution in ship construction of e.g. mounting of bulkheads and hull. In this it can be seen that between the two plates there is an intermediate layer of a softer material than the cover layers, this can e.g. be vinyl putty and gives a spread of load so that it is not only carried by the cover layer which then easily delaminates. However, this solution gives a weakness during torque loading as this gives rise to creep stress in the contact between the oblique cover layer and the connecting plate, which can be very difficult to handle for the construction which easily delaminates in the joints.

Figure 2 shows an insert on a sandwich panel which allows an opportunity to bolt this panel to another. This is suggested to be a continuous bolt, which is illustrated in figure 3 where one also sees an insert in the panel consisting of either a sleeve in a stiffer material than the core or a stiffer core material. The stiffer material has the function of stiffening the core which otherwise cannot withstand a high load and of providing a spread of the load to spare the cover layers. The through bolt means that the load will be carried by both cover layers, unlike a bolt which attaches only to the insert, to some extent the core, and a cover layer. But even this solution gives great strain on the cover layers as it is only these that take the load and not the core.

Analysis

point 1

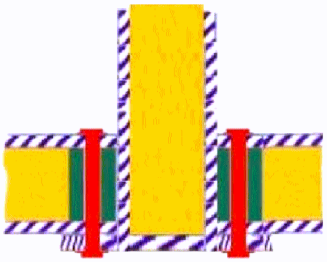
Option 1.

As point 1 marks the transition from the strut into the floating body, this is the point in the structure that will probably be exposed first to the largest torque [1]. However, a combination of several techniques can be used to increase safety. An option to the method shown in Figure 1 is that shown in Figure 4 where the cover layers of the constituent panel have been extended and drawn into the other panel, where also a stiffer core material is present in the joint to spread the load further. As the extended cover layers go all the way to the outer cover layer in the second panel, the load will also be taken by this cover layer at a bending moment and the lifting force transmitted from the support can be taken up by this cover layer.



Figur 4

Option 2.
A further option is that, like the fin solution on the majority of suction boards, to mill a through hole in the floating body and that an insert, see figure 2, is attached to the strut. This strut is then lowered from above into the floating body and bolted in place, as illustrated in Figure 5. Even in this solution, a stiffer core material must be used at the joint to contribute to the load absorption. The construction in this case means that the torque is partly absorbed by the bolts and the insert which abut against the surface layer and by the two cover layers in the sawn-out panel. However, this places a very high demand on fit.

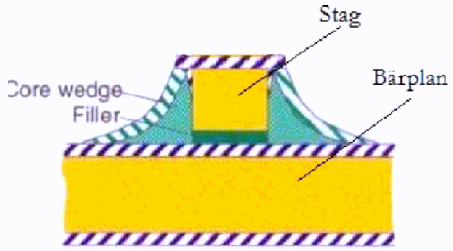

Figur 5

Point 2 and 3

As it is not currently clear which motor will be used or how it will be attached to the structure, the solution shown in GA2 is used. This is based on the motor being attached to the front hydrofoil. This means that a fastening with bolts becomes very difficult to handle as it is not desirable to have boreholes in the motor cover. The solution should then be a construction similar to that shown in Figure 1, with an oversizing of the cover layers to withstand the stress that arises at this point.

Point 4

The mounting of the aft hydrofoil in the strut between the hydrofoils will need to connect from a panel (wing) to a strut lying in the same plane, see figure 1. This means that a fixed mounting similar to that of Figure 1 with some changes is preferred. This is illustrated in Figure 6, where a cover layer is laid over the entire mounting to the strut. This will also need to be oversized to withstand torque loads.



Figur 6

Conclusion

Depending on the geometry and the material properties of the components to be fastened together as well as load cases, different types of fasteners must be chosen. With regard to the mounting points analyzed in this case, there are essentially three basic principles that can be used and these can then be combined to achieve the requirements that are set. The mountings on the Evolo will be exposed to relatively large load cases, especially the mountings on the large stay, and numerical calculations are complicated. Therefore, it is recommended that models of the mountings be built and then tested practically to see their limitations.

References

36. Sundström, B: Handbok och formelsamling i Hållfasthetslära. Institutionen för hållfasthetslära, KTH, Stockholm, 1998.
B.T. Åström: Manufacturing of Polymer Composites. Department of Aeronautics, KTH, Stockholm

Appendix 29 TB103 Exploded view of the surface

Empty

Available materials and comparison between carbon and fiberglass composites



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Summary

With the same strength requirements, fiberglass composite weighs about 2 times as much as carbon fiber composite and costs half as much. All components in the two material systems are available or can be ordered.

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Problem formulation……
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Introduction

The purpose of this report is to provide a brief summary of the materials available and to briefly compare carbon and glass fibers.

Problem formulation

In the construction of Evolo, a number of material choices must be made. These materials must fit the needs that exist, i.e. withstand the environment Evolo is exposed to, have the right mechanical properties and not cost more than the budget allows. Table 1 shows the cost of commonly occurring materials in the lab that may be relevant in the construction of Evolo. Table 2 shows the mechanical properties of carbon and fiberglass composites. Table 3 shows the density of carbon and glass fibers as well as vinyl ester.

Table 1, cost of commonly used materials in the lab.

Material	Cost
Aluminium	100 sek/kg
Steel, nut, bolt	20 sek/kg
Fiberglass	40 sek/kg

Carbon fiber	300s ek/kg
Polyester	50 sek/kg
Vinyl ester	100 sek/kg
Divinycell	50 sek/kg
Consumables for lamination	100 sek/ m^2

Table 2, mechanical properties of carbon and fiberglass composites. 1 stands for along the fiber direction, 2 for the transverse fiber direction, t for tensile and c for compression.

	E_1 [GPa]	E_2 [GPa]	υ_{12}	σ_{1t}[MPa]	σ_{1c}[MPa]	σ_{2t}[MPa]	σ_{2c}[MPa]
Carbon fiber composite	150	10	0.3	1800	1200	40	200
Fiberglass composites	40	10	0.3	1100	600	20	140

Table 3, the density of carbon and glass fibers and vinyl ester.

	ρ [kg / m3]
Vinylester	1000
Carbon fiber	1700
Fiberglass	2600

Analysis

The density and cost of carbon and glass fiber composites with vinyl ester as matrix are reported in Table 4 and are based on the assumption that the volume fraction fiber / matrix is 50/50%.

Table 4, density and cost of carbon and fiberglass composite.

	ρ [kg / m3]	Cost [sek/kg]
Carbon fiber/vinyl ester	1350	226
Fiberglass/vinyl ester	1800	57

To get an estimate of how the mechanical properties of carbon and fiberglass composite affect factors such as deflection and maximum stress, calculations are made below for the two material cases with beam theory. The calculations are made for a bracket beam which is fixedly clamped at one end and free at the other where it is subjected to a vertical load P. The deflection at the free end is then obtained by equation 1, where L is the length of the beam, and I is the moment of inertia of the beam.

$$\delta = \frac{PL^3}{3EI} \qquad (1)$$

With data from Table 2 and all dimensions equally, the deflection for carbon and glass fiber composites is compared and the result is that the deflection for glass fiber is 3.75 times larger than for carbon fiber.

Using equation 2, the maximum allowable axial stress is compared and the result shows that carbon fiber composite can handle a load 2 times as large P as fiberglass does, both in tensile and compression.

$$\sigma_{max} = \frac{M}{I} z_{max} \qquad (2)$$

For Evolo, the external dimensions will be broadly set and what can be varied is the composite thickness, i.e. number of layers of fiber to achieve the desired strength. For the floating body, the composite thickness then corresponds to the height of the cross section, h, in equation 3 where the surface inertia is calculated. If the requirement that the deflection and the maximum axial stress should be equal for carbon and glass fiber composites, equations 1, 2 and 3 can be combined to calculate the mass ratio between the two composites.

$$I = \frac{bh^3}{12} \qquad (3)$$

You then get that a construction in fiberglass will weigh about twice as much as a construction in carbon fiber, but the cost will be about half as much.

Conclusion

The materials reported in this report are materials that are usually used by KTH and are well proven. They are either already available or can be ordered relatively easily.
Constructions in fiberglass composite weigh about twice as much as constructions in carbon fiber composite but cost only half as much. For components with a large volume and high requirements for strength, the use of carbon fiber composite is recommended to save weight and meet the strength requirements. The mechanical values used in the calculations in this

report vary depending on the manufacturing method and therefore test production of composite materials is also recommended to see what values can be achieved in the manufacture of Evolo.

References

37. D Zenkert and M Battley: *Foundations of Fibre Composites.*
38. B.T. Åström: Manufacturing of Polymer Composites.
Lecture notes from the course SD2414 by M Å

Vacuum injection and tensile test



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Introduction

The purpose of this report is to serve as a guide and to provide an overview of how vacuum injection and tensile tests are performed. No results are presented. All manufacturing and testing described has been performed in Lightweight Structures laboratory premises at KTH.

Vacuum injection

Vacuum injection is a process for manufacturing a composite laminate. The process means that the matrix wets the fibers through a negative pressure. To enable this, the fibers are placed on a vacuum board and then covered by a release fabric followed by a varied number of layers of distribution fabric. With the help of tacky tape, everything is covered with plastic film and then pipes are placed at the inlet for the matrix and outlet to be able to switch on the vacuum pump, see figure 1.



Figure 1. On the vacuum table, the fibers are placed and then a layer of release fabric is placed (not visible in the picture) which is covered by a couple of layers of distribution fabric (the green one in the picture). On top of this, a layer of plastic is laid which is attached with tacky tape. The inlet is visible in the picture and is also attached with tacky tape to close tightly.

There are a variety of matrices whose properties can be adapted for different purposes. The styrene may be more or less added with respect to lowering the viscosity. The matrix is mixed with accelerator and hardener to start the reaction, see figure 2. An inhibitor may also be added if a delay is desired.

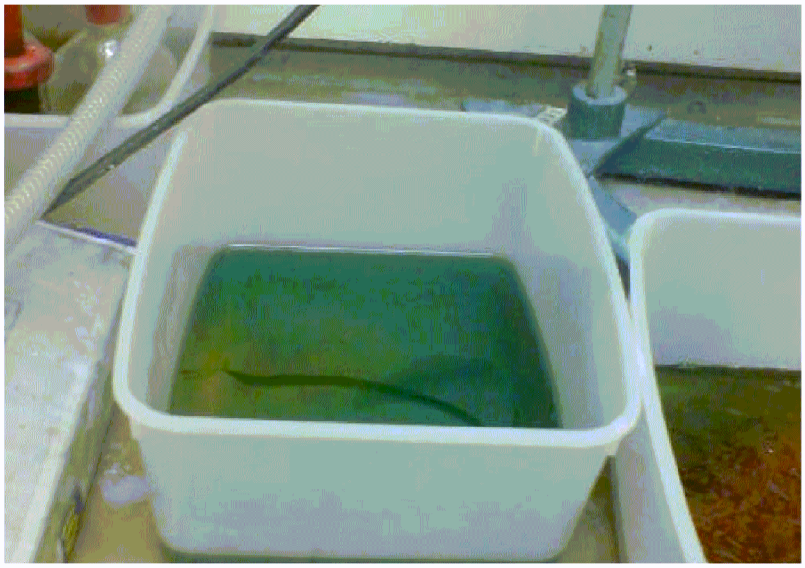


Figure 2. Two different matrices, the right one has started to harden.

In the Lightweight Construction Lab at KTH, there is a table for mixing if there is uncertainty about the number of weight percentages that must be added to get the desired properties, see Table 1.

Table 1. Table for mixing vinyl ester.

Component	Weight percentage	Function
Vinyl ester + styrene	95.50%	Matrix
Cobolt	2.00%	Accelerator
DMA	0.50%	Accelerator
Peroxide 24	2.00%	Hardener

When the plastic film is tight and the inlet/outlet is connected, the vacuum pressure is tested by starting the pump, any leaks are detected and can be remedied before the injection is started. During the injection, it is important that the inlet does not absorb air but only the matrix. The fibers are wetted from the inlet to the outlet and the time it takes varies depending on, among other things, the number of layers of fiber, viscosity and temperature. Depending on how the matrix has been mixed, it takes different lengths of time before it hardens. The pressure is kept constant during curing and for a time thereafter to prevent air from slipping into the laminate, see figure 3. When the matrix has hardened, the laminate is ready to be dismantled.

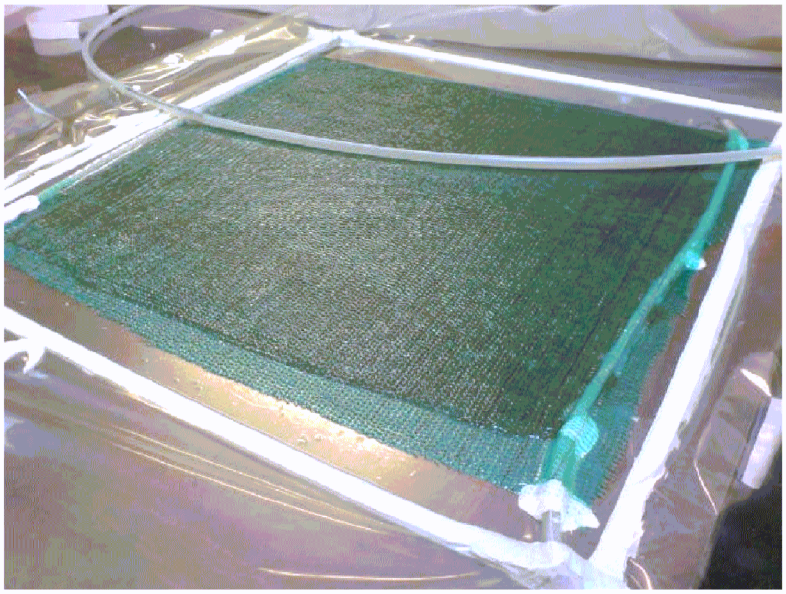
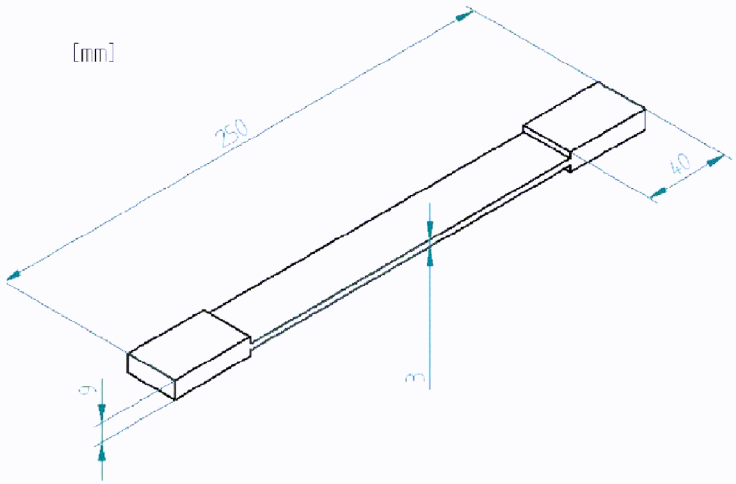


Figure 3. The laminate must harden under pressure to prevent air from seeping in and deteriorating the properties of the laminate.

Tensile test

Performance

The tensile test is performed in an Instron tensile testing machine. A 250 x 25 x 3 mm test rod is sawn out of the laminate and four tabs are attached to the ends of the test rod, *see picture 1*. The function of the tabs is to strengthen the test rod at the mountings where stress concentrations occur.
The test rod is then clamped in Instron, *see figure 2*, with tensioners dimensioned for a load of a maximum of 100 kN. Instron is connected to a computer with the program Cyclic installed where a drag speed of 4 mm / min is set. During the tensile test, Instron measures applied force and deformation and sends these values to Cyclic, which plots the result in the form of a graph. When the breaking stress is reached, the test ends.

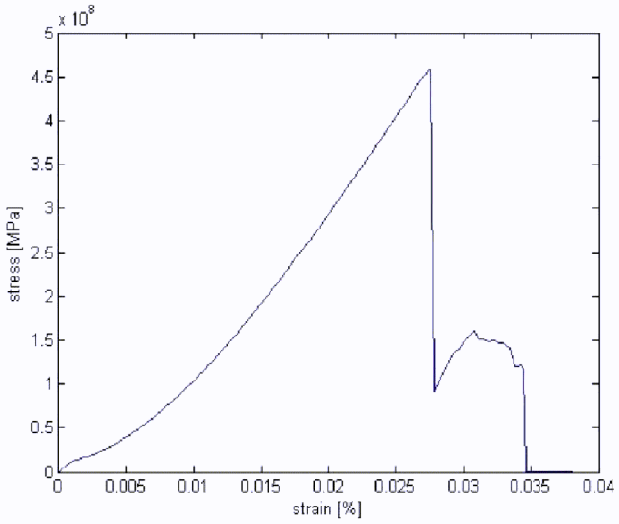


Picture 1. Dimensions of the test rod.

Results

The applied force and deformation are converted by means of the test rod dimensions into tension and elongation. These values are then plotted in a new graph, *see Figure 3*. From this graph, the breaking stress of the test rod can be read out and its modulus of elasticity is calculated using *equation 1* There $\varepsilon_{0,2}$ is the stretch limit and $\sigma_{0,2}$ is the strain at this.

$$E = \frac{\sigma_{0,2}}{\varepsilon_{0,2}} \qquad (1)$$



Picture 2. Tensile test curve where stress is plotted against elongation. The non-linear part of the curve at small deformation is due to slippage that occurs before the test rod is completely fixed by the applied force In this case, the test rod has broken in two different steps, which can be seen when the curve has two peaks.

Conclusion and discussion

The processes described in this report apply to a simple laminate with an uncomplicated structure. In the construction of Evolo, more advanced shapes and sandwich construction will also be used. It is therefore recommended that more experiments be performed where the manufacture of a more complicated structure and sandwich construction are tested. Tests on hardening time and surface treatment are also recommended.

Vacuum injection and tensile test Results experiment 1



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Project: Evolo
Date: *14/2-2009*
Version number:
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Reviewed by:

Introduction

The purpose of this report is to investigate the mechanical properties that carbon fiber and vinyl ester have in a manufactured composite laminate. The results of this report form the basis for further decisions as to whether the materials produced meet the requirements imposed on the constituent parts of the craft. The report forms the basis for the material choices and manufacturing methods that will later be used in the Evolo project.

Vacuum injection

Working with the manufacture of composite materials is associated with certain risks. The chemicals themselves are hazardous to health and often reactive. Inhalation as well as skin contact should be avoided as this may lead to eczema, allergic reactions or other inconveniences. To stay in Light Construction premises at KTH, protective equipment such as a labcoat, gloves and in some cases respiratory protection and goggles are required.

Method

There are several methods for making composite laminates. One of these is vacuum injection which is a popular method as it eliminates some damaging factors for the people staying in the manufacturing environment. From a health perspective, the method contributes to improving the working environment as no direct contact with the matrix is required. As the injection takes place in a closed system, it also helps to keep the inhaled air relatively free of chemicals. Another aspect is that vacuum injection results in a higher volume fraction of fiber than hand-laying, which leads to a stiffer laminate.

Two vacuum injections were performed where the number of layers and matrix mixture were varied. Before laying, the fibers are weighed in order to subsequently be able to determine the volume fraction in the manufactured laminate. The amount of matrix that is weighed is usually in the order of 2-3 times the weight of the fibers.

The lay-up sequence of the first experiment consisted of six layers with fiber directions [0/90] where each layer has a thickness of 0.45 mm. The fiber mat was laid out in a symmetrical pattern with the following fiber directions: [0/90/0/90/0/90/90/0/90/0/90/0]. The symmetry aims to ensure that the finished laminate behaves equally on both the underside and the top. When the matrix was to be weighed up, it turned out that it was lumpy and therefore unusable. Delays occurred when efforts were made to find an option vinyl ester source. When the new matrix was mixed in, this was done according to a recipe from the manufacturer which was obtained from Lightweight constructions laboratory manager. When the laminate had not hardened after 48 hours, an attempt was made to add heat in order to allow the matrix to harden. The parts of the laminate which were exposed to the highest heat proved to be suitable for use as test rods.

Since much rests on the matrix hardening as planned, an attempt was made to get a working matrix based on vinyl ester. This time the additives were mixed according to Table 1. After 7 minutes, the matrix was homogeneously mixed and then timekeeping for solidification and hardening began. After about 40 minutes, the matrix was rubbery but not yet completely rigid. After

another 15 minutes, the matrix had solidified further but was not yet hard. The timing ended after 1 hour and 20 minutes when the matrix had solidified and was hard.

Table 1. Table for mixing vinyl ester.

Component	Weight percentage	Function
Vinyl ester + styrene	95.50%	Matrix
Cobolt	2.00%	Accelerator
DMA	0.50%	Accelerator
Peroxide 24	2.00%	Hardener

The lay-up sequence of the second experiment consisted of four layers of carbon fiber with fiber directions [0/90] in a symmetrical pattern. This time, too, the mixing method described in Table 1 was used. When the matrix was homogeneously mixed, the one described in report *TB104-Vacuum injection and tensile test* was injected. After a while, air bubbles were discovered along one short side, which was an indication that a leak had occurred. An injection started should not be interrupted when the materials are destroyed and therefore an attempt was made to minimize the damage by clogging the areas where it sounded as if it was leaking. However, a large part of the laminate did well to avoid any visible damage.

When the laminates have hardened, they are dismantled and weighed before further treatment. The total weight is needed to determine the volume fraction of fiber and matrix. It is desirable to have a high proportion of fiber in the laminate as it has a higher specific E-modulus than the matrix. Vacuum injection usually results in a relatively high fiber fraction as the method efficiently distributes the matrix over the fibers. The fiber fraction is usually between 50-70%. Based on Table 2, the volume fraction of the laminates produced was calculated.

Results / Discussion

The fiber fraction in the two manufactured laminates was 60%, which is to be considered good. However, it is uncertain whether all fiber layers have become sufficiently wet.

The fibers used in vacuum injection were of low quality. Carbon fiber is delivered on rolls and these come in a number of different configurations. The roll that has provided the tests included in this report consists of fiber directions [45 / -45]. These pieces have then been cut to be rotated and counted as [0/90]. It was found during the layouts that some fibers were missing in certain directions.

The first vacuum injection was somewhat misleading in terms of results as the vinyl ester did not react as expected. A recipe from the manufacturer did not work, which led to the matrix not hardening. Experiments with heat were also performed, which resulted in some test rods being sawn out where the heat was at its highest.

Vacuum injection is a continued good method to use for the parts that are to consist of composite material when a high fiber fraction is obtained.

Analysis

Using the volume fraction above and mechanical properties of the individual components (carbon fiber and vinyl ester), *see Table 2*, the mechanical properties of the finished carbon fiber composite can be calculated. This is done using the method R.O.M. (rule of mixture), *see equations 1,2,3 and 4*. The results are summarized in *Table 3*. *Table 4* shows the mechanical properties of carbon fiber composite (IM, intermediate modulus) taken from Foundations of Fiber Composites (D. Zenkert). Note that the volume fraction in this case is unknown and that it is therefore considered necessary to supplement these data with those from *Table 3*.

Table 2. Mechanical properties of vinyl ester and carbon fiber. Data are taken from Foundations of Fiber Composites (D. Zenkert). Index 1 stands for the fiber direction for carbon fiber, mechanical data for vinyl ester are isotropic.

	ρ [kg / m3]	$E1$ [GPa]	$\sigma 1$ [MPa]	ε_1 [%]
Vinylester	1120 – 1130	3.1 – 3.3	70 - 81	3 - 8
Carbon fiber (IM)	1700 – 1830	276 – 317	2340 – 7070	0.8 – 2.2

Table 3. Calculated mechanical properties of carbon fiber composite with a volume fraction of fiber of 58.9% and a volume fraction of vinyl ester of 41.1%. Index 1 stands for the fiber direction of carbon fiber.

E_1 [GPa]	$E2$ [GPa]	$\sigma 1$ [MPa]	$\sigma 2$ [MPa]
166.8	7,62	1432	167.5

Table 4. Mechanical properties of carbon fiber composite (IM), volume fraction unknown.

	E_1 [Gpa]	E_2 [Gpa]	υ_{12}	σ_{1t} [MPa]	σ_{1c} [MPa]	σ_{2t} [MPa]	σ_{2c} [MPa]
Carbon fiber composite	151	9,4	0.31	2260	1200	50	190

Results from tensile tests

The tensile test is performed according to the instructions in report TB104-Tensile test and vacuum injection. The results are presented in *Table 2*. Note that these data apply to a laminate with fiber directions in both 0° and 90°. *Figure 2* shows a typical fracture from the tensile test, it can be seen that it is not a fine fracture surface that is usually the case with carbon fiber composite. Using lamination theory, see Appendix 1, the mechanical properties of the laminate are predicted using input data from *Table 3*. Since the fiber layout is 0/90, the value $E1$ and $E2$ equal in size and get one will be 88.5 GPa. The maximum stress will be 754 MPa.
The result of the tensile test is that the modulus of elasticity is 23.8 GPa and the breaking stress 793 MPa (average value calculated on seven tensile tests). *See Figure 1* for examples of tensile test curves.

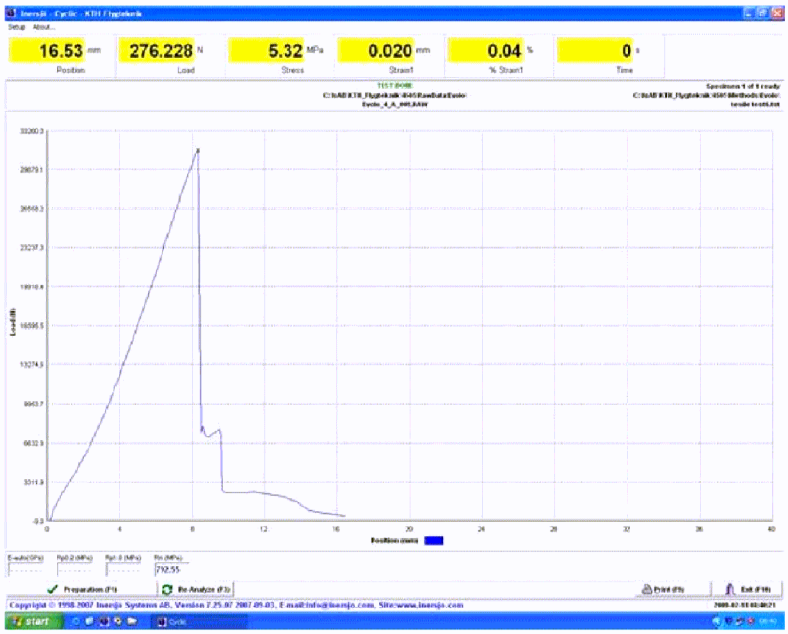


Figure 1. Typical tensile test curve from the tensile test. At low loads, you can see that slippage occurs because the slope is not linear.

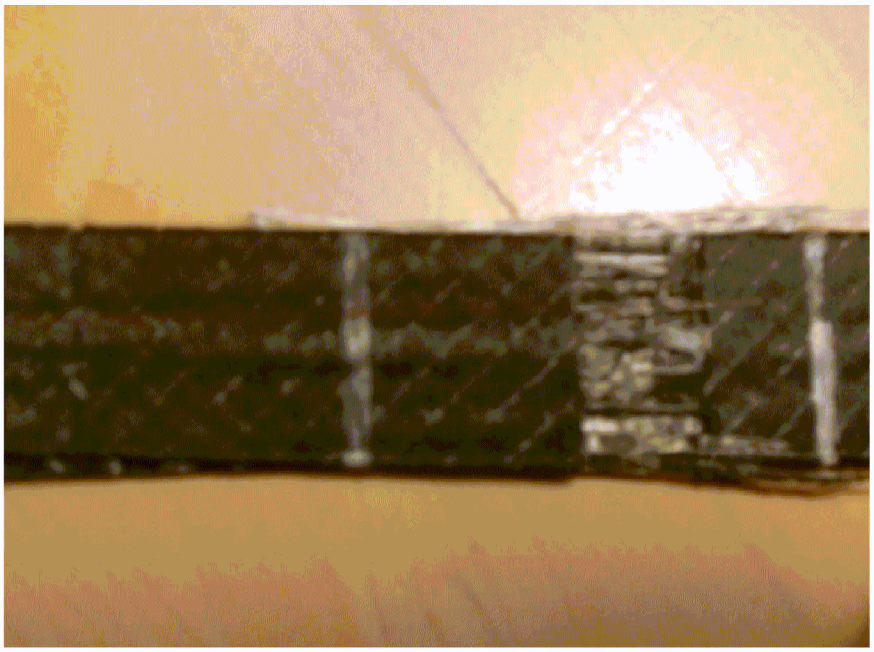


Figure 2. Typical break in the tensile test.

Discussion tensile test

The breaking stress from the tensile test is in good agreement with the calculated one. The measured modulus of elasticity from the tensile test is much lower than the calculated one. This may be due to slippage in the glued link between the test rod and the tab. But probably the biggest reason for the low E-modulus is that the fibers have not been sufficiently wet throughout the laminate and / or that the matrix does not maintain the required quality. The fibers were also of poor quality.

Recommendations for continued work

Measured values for the E-module do not correspond to the calculated or existing table values. The recommendation for further work is that because there is a lack of test material to calculate the calculated values and table values that are available. Based on these calculations, materials can be ordered and when these are available, any further tests can be performed. Results from these tests can be analyzed according to this report.

Appendix 1, Metlab code

```
clear all
close all

[data,layup,loads]=indataEvolo(); nn=size(layup);
n=nn(1); lagertyp=layup(:,1); vinkeltyp=layup(:,2)*pi/180;

for ii=1:n
    thicknessvector(ii)=data(1,layup(ii));
end

thickness=sum(thicknessvector);

for ii=1:n+1
    if ii==1
            z(ii)=-thickness/2;
             else
    z(ii)=z(ii-1)+thicknessvector(ii-1);
    end
end

A=zeros(3,3);B=A;D=A;

for ii=1:n
    k=lagertyp(ii);
    vinkel=vinkeltyp(ii);
```

```
   E1=data(2,k);
   E2=data(3,k);
   G12=data(4,k);
   v12=data(5,k);
   v21=E2/E1*v12;
   Ql((ii*3-2):ii*3,1:3)=1/(1-v12*v21)*[E1          v21*E1      0
                                        v12*E2      E2          0
                                        0           0           G12*(1-v12*v21)];

   c=cos(vinkel);
   s=sin(vinkel);
   T=[c^2 s^2 -2*s*c
      s^2 c^2 2*s*c
      s*c -s*c c^2-s^2];
   Q((ii*3-2):ii*3,1:3)=T*Ql((ii*3-2):ii*3,1:3)*T';
   A=A+Q((ii*3-2):ii*3,1:3)*(z(ii+1)-z(ii));
   B=B+Q((ii*3-2):ii*3,1:3)/2*(z(ii+1)^2-z(ii)^2);
   D=D+Q((ii*3-2):ii*3,1:3)/3*(z(ii+1)^3-z(ii)^3);

End
ABD=[A B;B D];
S=inv(A/thickness);
E1=1/S(1);
E2=1/S(5);
G12=1/S(9);
e0K=ABD\loads;
u=1;
el=zeros(3*n,1);e=el;sigmal=el;sigma=el;

for ii=1:n
    if z(ii)>=0
       e(u:(u+2))=e0K(1:3)+z(ii+1)*e0K(4:6);
    else
       e(u:(u+2))=e0K(1:3)+z(ii)*e0K(4:6);
    end
    c=cos(vinkeltyp(ii));
    s=sin(vinkeltyp(ii));
    T=[c^2     s^2     -2*s*c
       s^2     c^2     2*s*c
       s*c     -s*c    c^2-s^2];
    el(u:(u+2))=T'*e(u:(u+2));
    sigmal(u:(u+2))=Ql(u:(u+2),1:3)*el(u:(u+2));
    sigma(u:(u+2))=T*sigmal(u:(u+2));
    u=u+3;
end
```

TB105 Hydrofoil and stays

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Course:	Marine design / Lightweight design
Project:	Evolo
Date:	*5/2-2009*
Version number:	*1.5*
Hours worked:	*50*
Reviewed by:	Mirjam Fürth

Summary

In this work, the assumption is made that the motor that will be available is the Torqeedo Cruise 2.0. The following plan is thus based on the assumption that we will not get a new motor. This means that the power requirement must be significantly reduced. This can be done with the following actions presented below. In short, these are:

1. Reduce cruising speed (now set to 8 knots)
2. Reduce weight significantly (eg let Fatima drive, optimize weight, etc.)
3. Tow the craft for lifting
4. Move the hydrofoil in relation to the center of gravity so that the stabilizing fin does not have to pull up resistance in the unobstructed position.
5. Let the primary hydrofoil have a smaller angle of attack during use

Introduction

This report describes how the underwater body can be modified to make it possible to use the existing Torqeedo Crusie 2.0 motor and how this underwater body can be manufactured. The following plan is based on us using the existing Torqeedo 2.0R motor and towing the Evolo to flying mode. Plan B is to try to get hold of the new Torqeedo 4.0R motor. This is considered unreasonable, but if this were to happen, the propeller would have to be redesigned and new 6V batteries procured.

Conclusion

Hydrofoil

The size of the front hydrofoil has been increased to make Evolo deliver enough lifting power at lower speeds and with a smaller angle of attack than before. To be able to travel at about 8 knots, however, the Evolo must be towed up to a flying position before the motor can deliver enough power to drive the Evolo [1]. The angle of attack of the calculated wing has been lowered from ten to five degrees to reduce the resistance. The choice has been made to tow the Evolo to eight knots is due to the fact that at higher speeds it is assumed that it is easier to control the craft and that a dimensioned speed is needed to be able to optimize a propeller. Based on the power demand calculations made in ref [1], eight knots is assumed to be a good choice of cruising speed as the power demand curve around this speed has a local minimum.
The front hydrofoil will have the dimensions:

Wing span 1.25 m
Max chord 1.35 m

Which will mean a power requirement that is exactly on the limit of what we can get out of the motor provided that the vehicle does not weigh more than 140 kg (incl. Driver).
The aft hydrofoil that exists to stabilize the vehicle has previously been designed to constantly counteract the moment that arises when the driver is in front of the lifting center for the hydrofoil. This has meant that the aft hydrofoil has constantly contributed resistance (increased power requirement). This is considered unnecessary and the center of gravity of the craft has therefore been moved to the lifting center of the front, carrying hydrofoil. If the center of gravity is shifted and torque should arise, the stabilizing aft wing will have an angle of attack because the craft wants to rotate in the direction of the torque. The resulting angle of attack will then generate a lifting force. The direction of the lifting force will thus always be the opposite

tilting moment direction which means that the craft will always want to straighten up and an equilibrium position will be found by the craft itself.

+ Less resistance increases our chances of getting on the hydrofoil with an electric motor.
- The center of gravity of the craft must be vertically above the center of the front hydrofoil (roughly counted), which means that if the support between the floating body and the hydrofoil is not angled, the Evolo will have a less aggressive look as the strut will have to be placed in the middle of the floating body.

The aft hydrofoil

Wing span 0.4 m
Max chord 0.45 m

The length of the stay is "picked out of the air" and the wing area is based on the assumption that the stabilizing wing should generate as much straightening moment as is achieved when moving the center of gravity 0.1 m. This means that the straightening force must be 1/7 of the front hydrofoil lift. In order to have a margin, the lifting force has therefore been assumed to need to be 1/4 part, whereupon the area on the aft hydrofoil has been assumed to need to be approximately 1/4 of the front one.

Propeller

Since it is judged to be difficult to change the motor, 920 revolutions per minute will be controlling at the propeller selection. The reason why the motor will not be geared is that it would increase the losses and means that we have to find a gear that can withstand the stresses to which we expose it while it must be small, which means that such a gear probably does not even exist.

The propeller will further be manufactured by ourselves in e.g. carbon fiber. This means that we can either cast a propeller blade shape and mold 4 identical blades which are then screwed into the hub like the propeller for the previous student project "Phyxius". Another option is to "Sand" out the blades from a block in a slightly softer material. However, it should be commented that this is not a recommendation but rather two options!

Stay

The length of the stay has been set to 0.75 m

As stated, the measurement is in principle "taken out of the air" but is considered reasonable based on estimates of the torque in the shaft that will go through the stay between motor and propeller. It is also in the same order of magnitude as the stay used in the experiments, which makes this length feel like a reasonable assumption.
These calculations are based on the maximum torque that the motor can deliver (180 Nm) [2] and set restrictions on the shaft deflection in torsional direction (1 degree has been considered ok). This means that the shaft must be 2 cm thick, which has been considered to be lower than what will actually be used.

Mounting

The following plan is based on the assumption that we may disassemble the motor provided that we can screw it back to its original condition without permanent damage.
This means that the hydrofoil must be fixed to the motor without the use of glue or screws. To solve this the easiest way, we recommend molding the entire underwater body into two

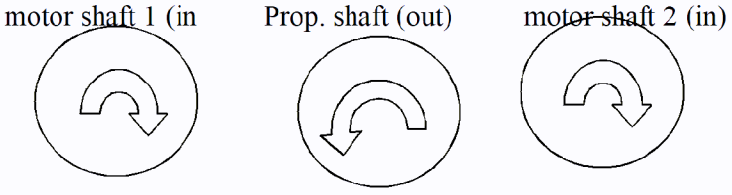
parts. These parts are then enclosed around the motor so that the hydrofoil is prevented from shifting in all degrees of freedom. In addition, the mold must contain a hole for the strut that will prevent the mold from rotating around the motor bulb. In addition, the shape should be fixed by screws to the fin that usually sits under the bulb. This means that metal rings (washers) must be cast into the mold so that cracking is avoided. In addition, holes in the mold must be left around the center of the motor because the cooling to the motor is there.
To prevent excessive forces from arising and the fibers to be broken, aluminum plates must be cast into the mold around the motor's cooling part.

Verification plan

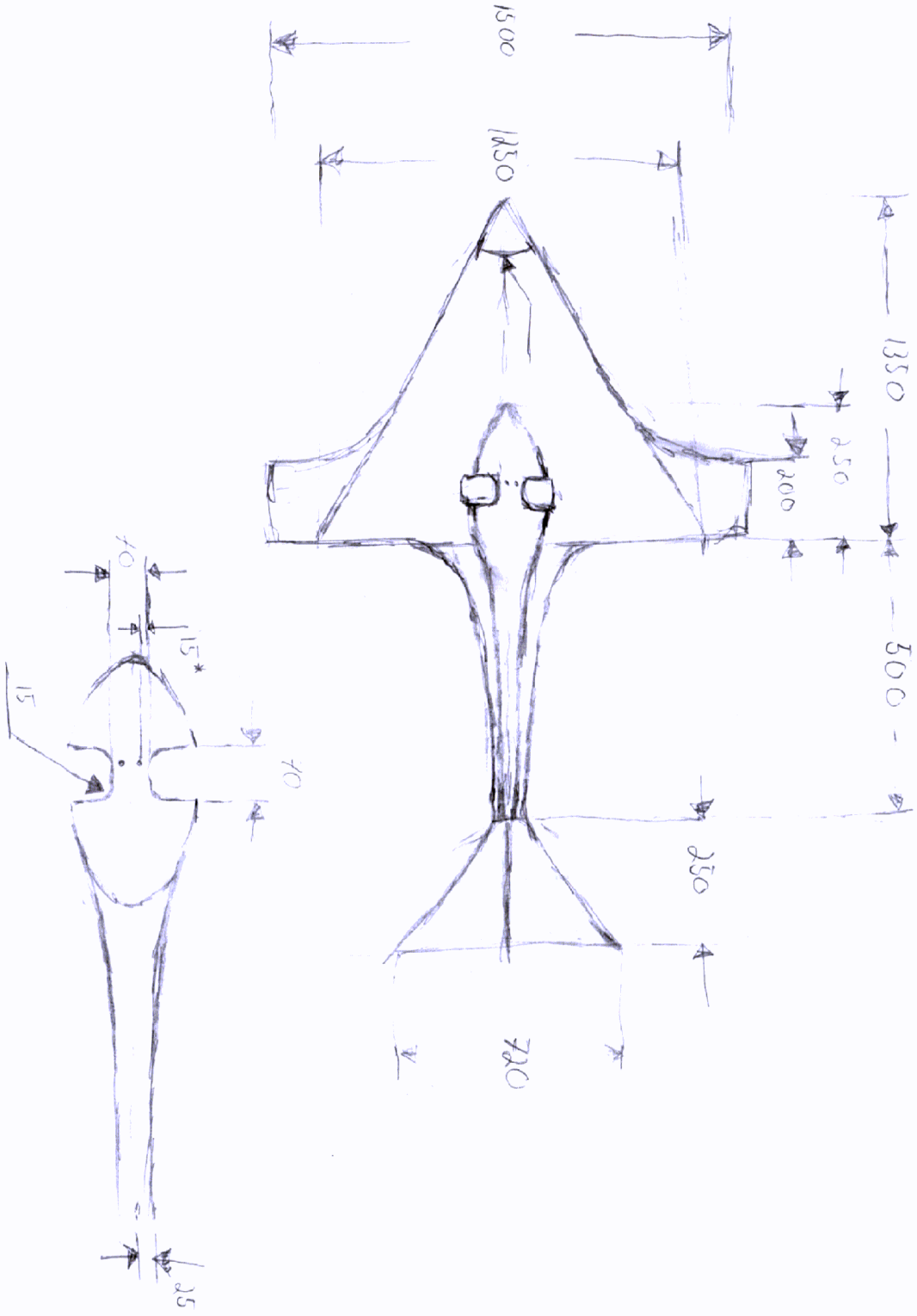
As the proposed underwater body differs in many respects from the previous version of the Evolo, a new experiment is proposed. The focus of the experiment should be to try to properly measure the resistance as this is extremely critical. This means that a new dynamometer must be procured and evaluated before the test. Furthermore, the motor bulb and stay should try to be modeled for more accurate resistance calculations. Note that these have not been included in the resistance calculations. The strut should also be able to be moved so that the lifting center and the center of gravity do not coincide (with the experimental board, the driver is in principle prevented from moving his own center of gravity). In addition, the position of the strut on the current experimental vehicle is based on previous assumptions about stability.

Other options

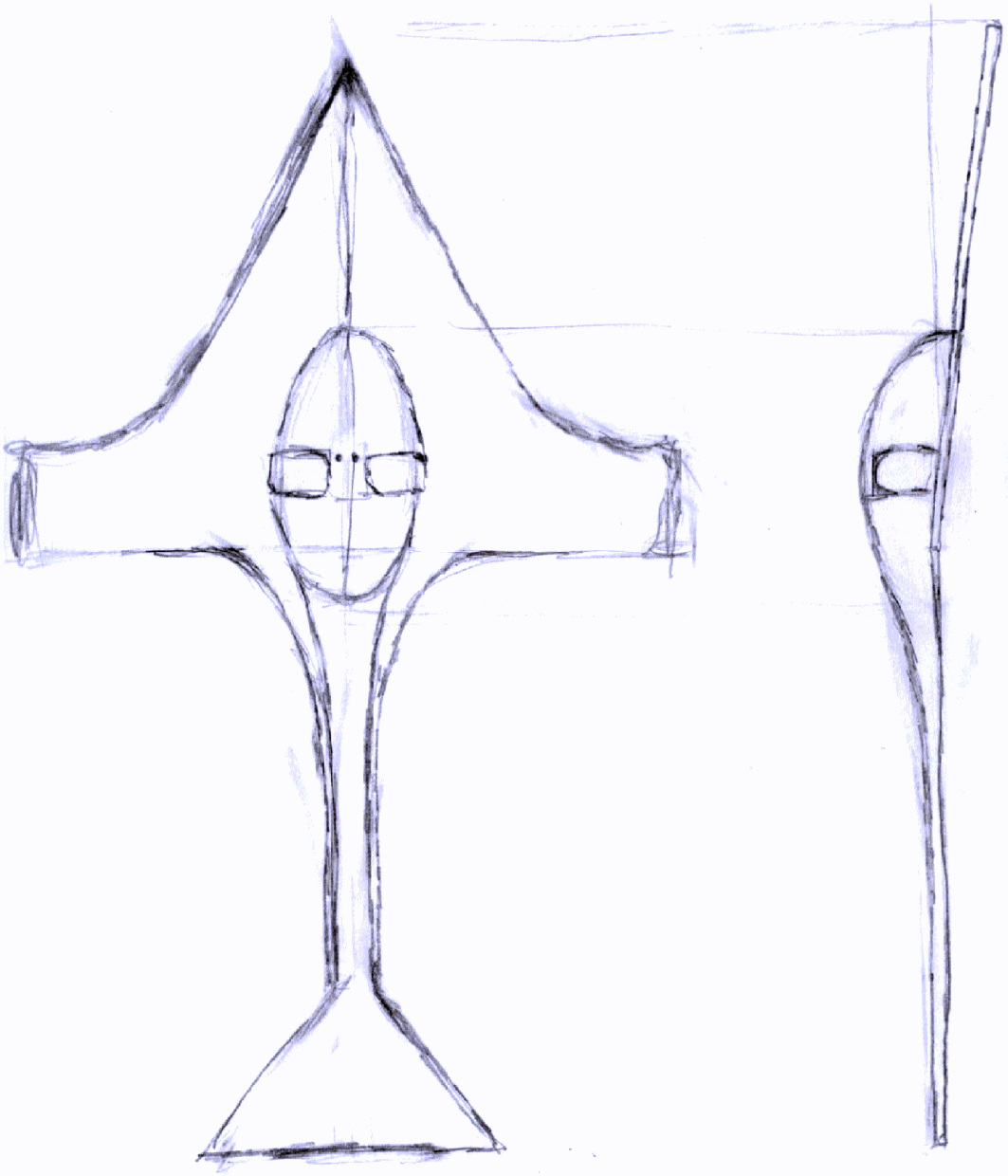
Other options could be to use a petrol motor, but the project's environmental profile is then considered damaged and is not seen as an option worth investing in. Consequently, an extra electric motor can also be considered for use. Either by using two identical propellers or syncing the motors with a gear similar to the one below. However, this would mean a little increased resistance because we then have to have two motors that are in the water.



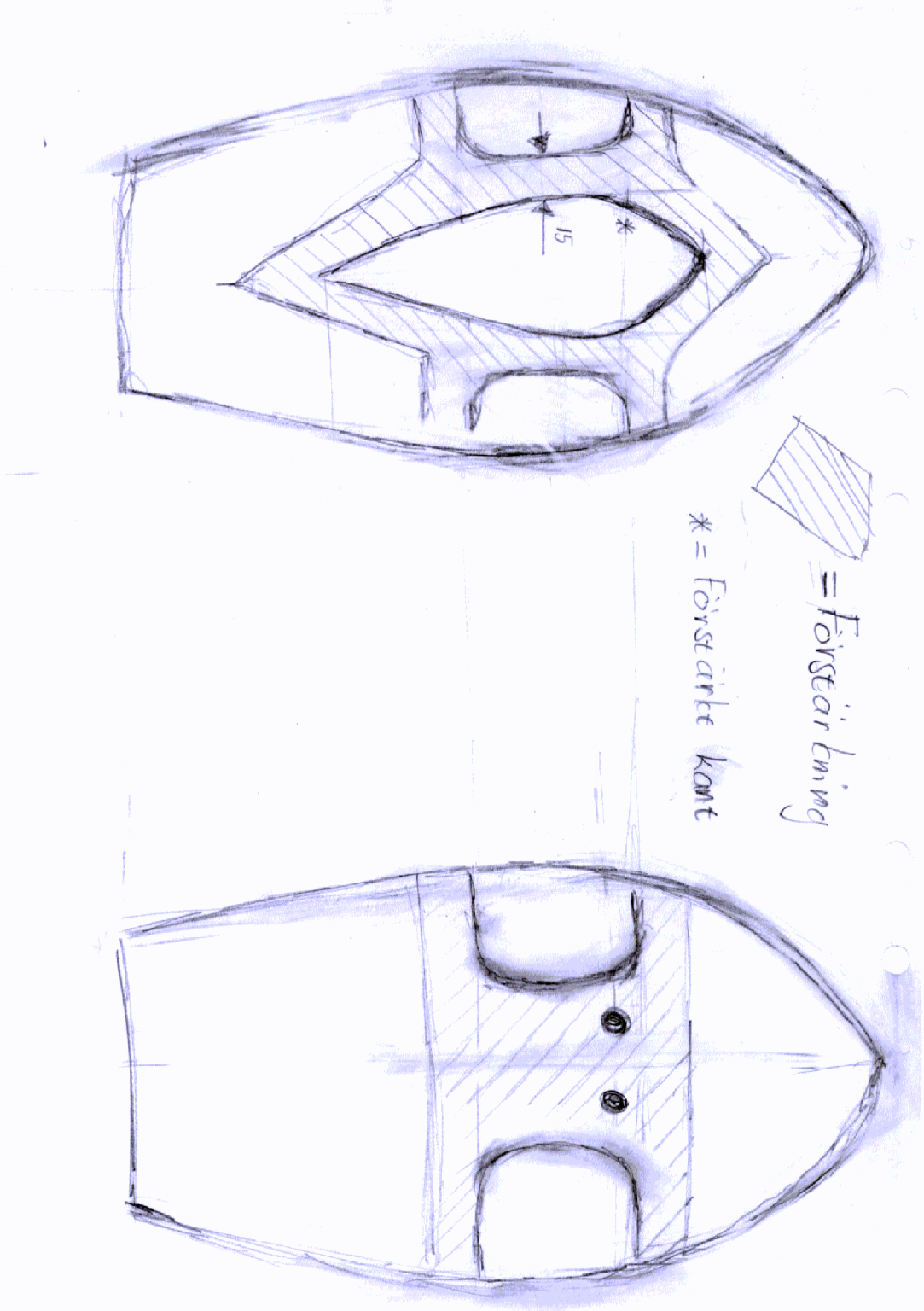
Appendix 1 - The lower part of the underwater body and enlargement around the motor bulb



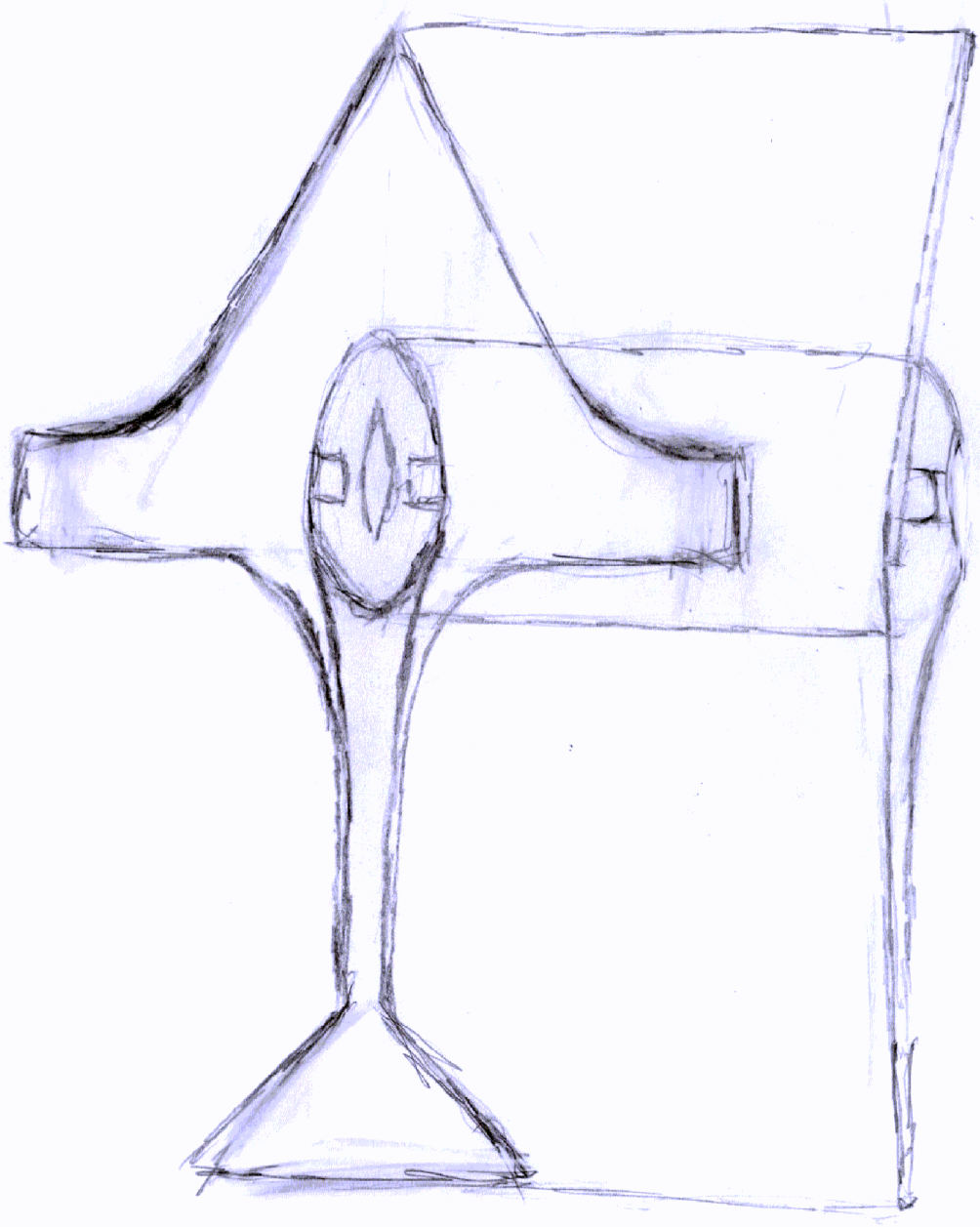
Appendix 2 - The lower part of the underwater body



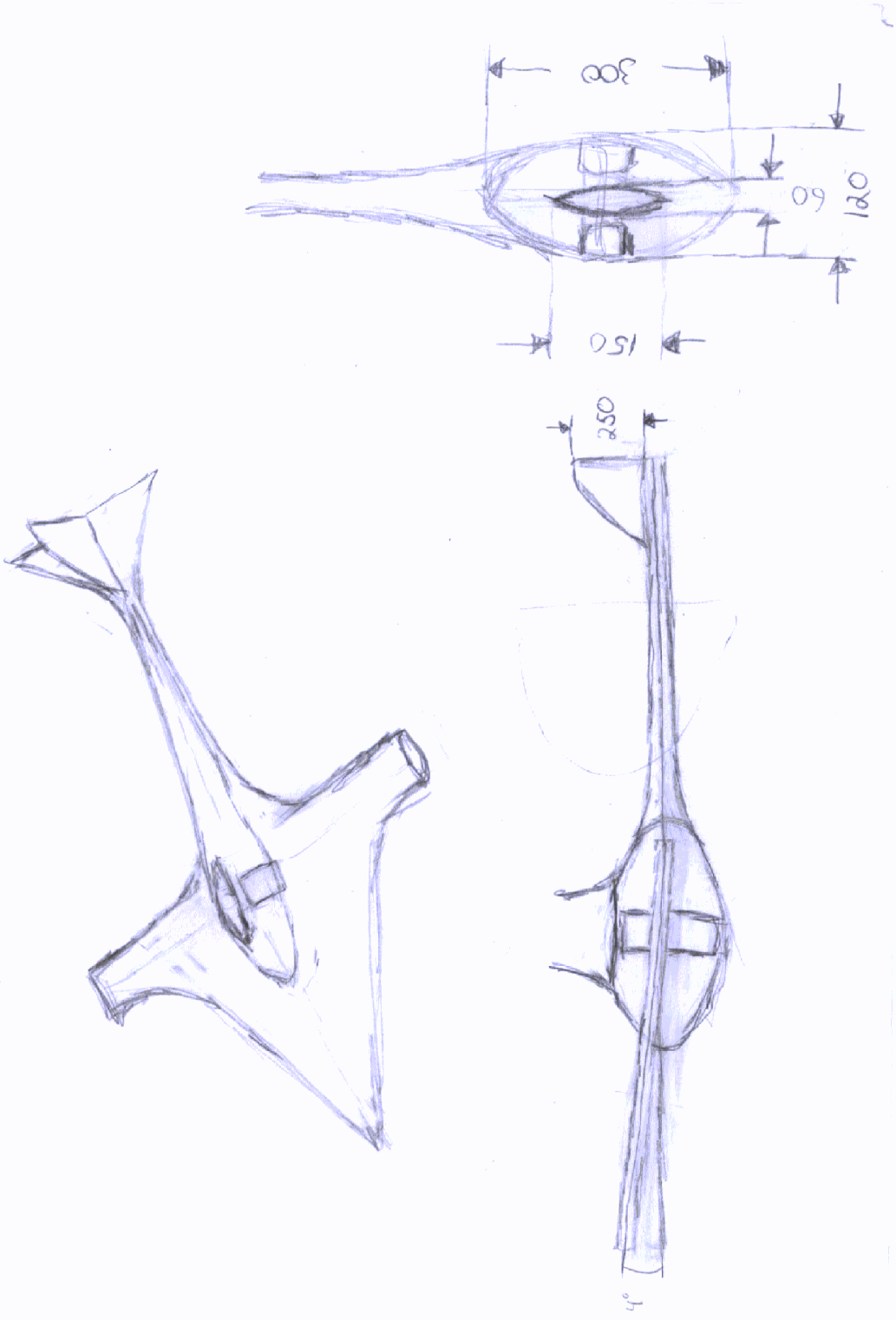
Appendix 3 - Reinforcement around the mounting around the strut



Appendix 4 - The upper part of the underwater body



Appendix 5 - Side view and 3D view



1

References

39. A14 - Effektbehov.doc www.bilda.kth.se / Analys
40. A101 - Propellerval.doc www.bilda.kth.se / Analys /

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
251. Are all elements of the problem addressed?	Yes	Yes
252. Have the purpose and conditions been reported?	Yes	Yes
253. Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective?	Yes	Yes
254. Is the purpose achieved?	Yes	Yes
255. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors?	Yes	Yes
Technical content		
256. Have simplifications and assumptions been clearly stated and justified?	Yes	Yes
257. Has the choice of solution methods been clearly reported and justified?	Yes	Yes
258. Are calculations controlled and reasonably assessed?	-	-
259. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text?	Yes	Yes
260. Are equations written as part of the running text, presented in separate lines and numbered?	-	-
261. Can the technical reasoning be followed?	Yes	Yes
262. Is there a difference between facts, statements and the author's opinion?	Yes	Yes
263. Is there a realistic verification plan for the work in the report?		
264. Is there an acceptable follow-up of the verification plan?		
Presentation		
265. 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	Yes
266. Is the report provided with: appropriate title, date, author name, e-mail, eventual supervisor,summary/abstract, table of contents, reference list and page numbering 267. 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…"?	Yes Yes	Yes Yes
268. Are figures and tables clear and informative, provided with figure / table text and clear numbering? numbered? 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?	Yes	Yes

269. Are appropriate references made to figure, table and equation numbers in the text?	Yes	Yes
270. Are appropriate references made to references in the reference list?	Yes	Yes
271. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.?	Yes	Yes
Other		
272. Has the report been written by you individually?		
273. The work has been carried out in collaboration with: _____		-
274. The report has been proofread by: _____		-
275. I believe that this report as a whole is worth rating (u, 3-5)		
276. 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.):		-

TB105 – Hydrofoil, stay and shaft



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Course:	Marine design
Project:	Evolo
Date:	*2009-04-13.*
Version number:	*1.0*
Supervised by:	
Hours worked:	6 h
Reviewed by:	

Manufacturing plan front hydrofoil

The front hydrofoil is manufactured according to the drawing (forward_foil.dft) shown in the picture. Dimensions of hydrofoil from TB105 - Hydrofoil and stays by D. Carlsson, P. Delin and J. Westin [1].

1. Saw out the planar mold from a 10 mm divinycell board of H180. Wait to saw out the horseshoe shape for the motor until we have confirmation of exact dimensions of this
2. Sand edges according to drawing
3. Lay up carbon fiber [0 90 -45 45] S, so there will be four layers of fiber on each side of the divynicell
4. The fibers should protrude on all edges according to figure 1 and the same layout is used on both sides of the core

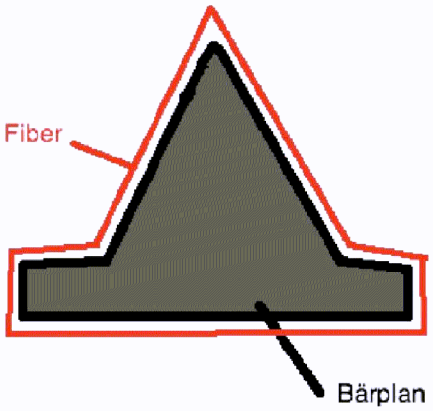


Figure 30. Illustration of fiber and hydrofoil.

5. Above the fibers, peel-ply, bleeder and then a breather are added to distribute the matrix.
6. Check with Nisse to find the most suitable way to place inlets and outlets
7. Then saw the edges, almost to the core
8. Sand edges and irregularities on the surface
9. Apply a layer of matrix
10. Sand
11. Repeat until the desired finish is reached

Aft hydrofoil

Manufactured according to drawing (aft_foil.dft) which is in the picture here too, measurements come from TB105 - Hydrofoil and stay. The aft hydrofoil and the vertical steering wing are made of solid laminate, not core material. The fiber layout is the same as for the front hydrofoil, ie [0 90 -45 45] S.

Shaft dimensioning

The shaft between motor and propeller has a length L = 0.75 m, this shaft must be dimensioned strength and stiffness for Torqueedo 4.0 R [2]. According to the manufacturer, the motor provides a torque of 15 Nm. This is calculated from the shaft power which is 2200 W and the speed which is 1500 rpm. The shaft is made of stainless steel with approximate mechanical properties according to Table 1.

Table 6. Material data.

E-module	208 GPa
G-module	80 GPa

τ MAX	180 MPa
σMAX	280 MPa

The shaft is dimensioned against rotation and shear, ie stiffness and strength. The maximum permissible rotation is set to 2° and the maximum shear stress according to Table 1. Rotation and shear stress can, for a homogeneous circular cross-section, be calculated according to

$$\theta = \frac{M_v L}{GK}, \quad \tau_{max} = \frac{M_v}{W} \qquad (1),$$

where W and K are

$$W = \frac{\pi \cdot r^3}{2}, \quad K = \frac{\pi \cdot r^4}{2} \qquad (2).$$

This gives the following minimum diameters on the propeller shaft, for stiffness is 12 mm dimensioning and for strength 7.5 mm. Thus, a stainless steel shaft of 12 mm is recommended. This gives a total weight for the shaft of 0.66 kg.

Bearing choice for propeller shaft

A suitable bearing for the propeller shaft may be a stainless steel roller bearing from SKF W61801 for shaft dimension 12 mm (Figure 2). This bearing has a total weight of 6.3 grams. This bearing allows up to 3 degree angular deviation of the shaft for optimal working condition [3].

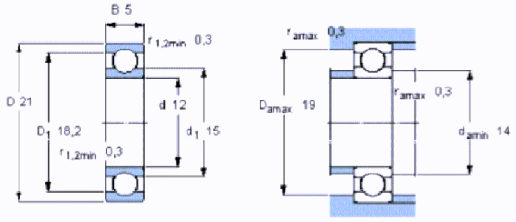


Figure 31. Bearing for propeller shaft.

Mounting of front hydrofoil

Two variants of mounting between the front hydrofoil and strut are presented, as it is uncertain whether the Evolo will be built with or without an motor.

Without motor

If no motor is delivered to Evolo, it is recommended to laminate the strut to the front hydrofoil using a so-called hollow joint (figure 3), for further information on this type of mounting, see [4].

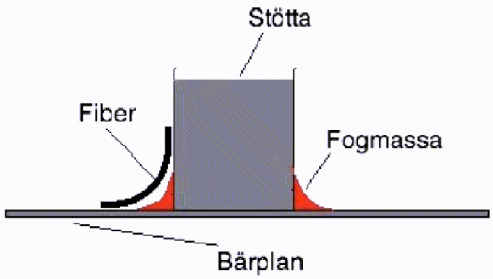


Figure 32. Mounting hydrofoil and strut without motor.

Use the following procedure.

1. This can be done by sawing to a straight surface on one side of the strut and then rigging the strut against the hydrofoil. The sawn surface must have an angle of 4 degrees to the horizontal plane so that the front hydrofoil has the correct angle of attack.
2. Glue the strut to the hydrofoil using a suitable glue, such as Araldit.
3. Then fill a joint with vinyl ester and filler around the entire contact surface.
4. Laminate [0 + 45 -45] S fiber from the support over the joint, ie six layers, and down on the hydrofoils by hand

With motor

The mounting of the front hydrofoil and the strut with motor is done by bolting the hydrofoil against the flange located on the motor pod. The angle between the horizontal plane and the front hydrofoil must be 4 degrees and a wedge must be manufactured to achieve this.

Stay between hydrofoils

The stay between the front hydrofoil and the aft hydrofoil can be manufactured as a circular pipe in carbon fiber. It is critical for propeller shaft and bearings that this pipe does not bend more than the allowable limit. The length of the pipe is 750 mm and it is assumed that the maximum allowable deflection is 2% of the length. This gives a deflection of 15 mm. This results in a maximum angle between the stay and the horizontal plane of 1.15 degrees, which is within the limits that the bearing can handle.

The maximum deflection, δ, for a circular cross section is calculated as

$$\delta = \frac{PL^3}{3EI}, \text{ där } I = \pi r^3 t \qquad (3),$$

where **P** is the externally applied load, *r*, the average radius of the cross-section and *t* the wall thickness of the cross-section. The assumed load case on the aft wing is 400 N. Since the area of the stabilizer wing is one fifth of the front hydrofoil wing which delivers 1700 N lifting force during flight, the lifting force from the smaller wing is assumed to be one fifth of this, ie 340 N. safety margin, the force is set at 400 N. A carbon fiber laminate with directional fibers and an E-module of 70 GPa with a thickness of 3 mm gives a minimum radius of 16.2 mm. It is recommended to manufacture the pipe with a diameter of 40 mm to build in a safety factor.

A check of the strength of the pipe can be made by calculating the maximum stress according to

$$\sigma_{MAX} = \frac{PL}{I} r \qquad (4).$$

With the assumed load case, the greatest stress in the pipe will be 80 MPa, which is below the breaking limit of the laminate of approximately 900 MPa.

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TB106 – Structural design of strut



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Course:	Marine design
Project:	Evolo
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Version number:	*1.0*
Supervised by:	
Hours worked:	*20*
Reviewed by:	Mirjam Fürth

Summary

Structure The arrangement with a load-bearing steel shaft and composite profile meets the requirements set out in the introduction to this report, including demountability, cabling space and module construction. It is of the utmost importance that the fit on these parts is good, to minimize backlash in the system, which will make Evolo difficult to control. The total weight of 2.95 kg is estimated to be within a reasonable interval. A potential problem could be the extension of the existing steel shaft, an examination of whether this is possible with either welding or a pipe sleeve arrangement should be carried out. The exact dimensions and laminate layout for the profile have not yet been determined, the recommendation is to use a [+45-45] laminate in a suitable thickness to handle both bending and torque. For complete construction drawings, please refer to the Evolo final draft stötta.dft, which can be found under TB106 at bilda.

1. Problem formulation

The purpose of this report is to describe the design of Evolo's strut. The report intends to justify the appearance of this construction and describe its function. This work also includes complete construction drawings that can be found at www.bilda.kth.se.

The purpose of the strut that links the hydrofoil with the floating body is to transfer the elements and loads produced by the driver and hydrofoil, respectively, and to provide Evolo with course stability.

2. Method

2.1 *Structural requirements*

The structural design of the strut is dictated partly by the strength and stiffness requirements according to [1] and partly by the practical requirements for the strut such that the strut must

- protect the motor from water penetration.
- be detachable from the floating body to facilitate transport
- built in modules for a shorter production time
- have low weight
- Can fit control and power cables
- be compatible with the current Torqeedo motor.

It is of great importance that the design of the strut does not affect the motor more than necessary, ie that the least possible modification of the motor structure is made.

2.2 *Design*

The existing motor construction consists of the motor unit which is linked to the steering by means of a 750 mm long steel shaft with an outer diameter of 35 mm, through which shaft control cables and power cables run. By using this shaft, the design is modified to suit Evolo's purpose, in which case the shaft must be extended to give Evolo the desired deep of 830 mm [2].

2.3 *Wing profile*

A wing profile with the same dimensions as on the Torqeedo motor is used to provide Evolo course stability in surge direction (figure 1). This profile can advantageously be made of carbon fiber and epoxy or vinyl ester with a light foam core. Note the three holes for rivets, which allow the profile to be fixed to the floating body.

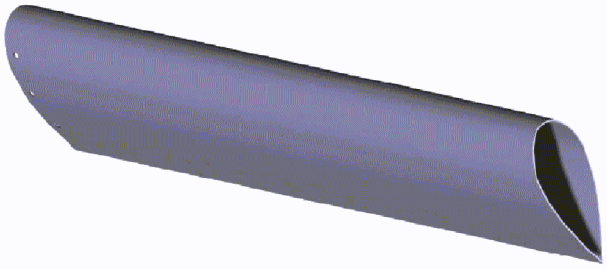


Figure 12. Wing profile for the strut.

2.2.1 Steel shaft

According to the calculations made in [1], the existing shaft is not enough to give the desired strength and rigidity. To solve this problem, the profile is used as a load-bearing structure together with the steel shaft. As the motor cannot be detached from the shaft, the profile and any other parts must be put on the shaft from above. This means that the diameter of the shaft is maintained at 35 mm and other parts are constructed around it (figure 2).



Figure 2. Steel shaft from motor.

In this figure, the motor represents the square plate. Note the hole for the cabels at the aft towards the battery boxes [3], as well as the threaded upper part of the shaft.

2.2.2 Base plate

The function of the base plate is to transmit the forces and torques absorbed by both the shaft and the profile to the floating body. This design allows the profile, strut and base plate to be produced in parallel and the profile to be mounted on the shaft before the base plate is mounted. Note the corresponding rivet holes observed on the profile (Figure 3).

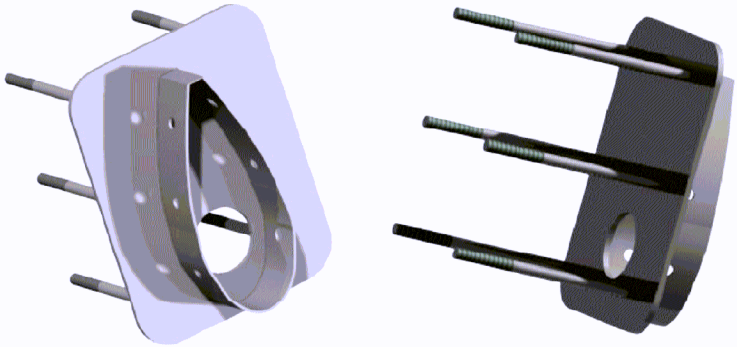


Figure 3. Base plate for joining the strut and floating body.

The longer bolts join the base plate with the floating body and are slightly shorter than the thickness of the floating body, which allows nuts to be set into the floating body.

2.2.3 Joining

The joining of the base plate and the steel shaft is done by means of a stop washer which is fixed by a bolt. The profile is then joined to the base plate using 7
6.5 mm rivets (figure 4).

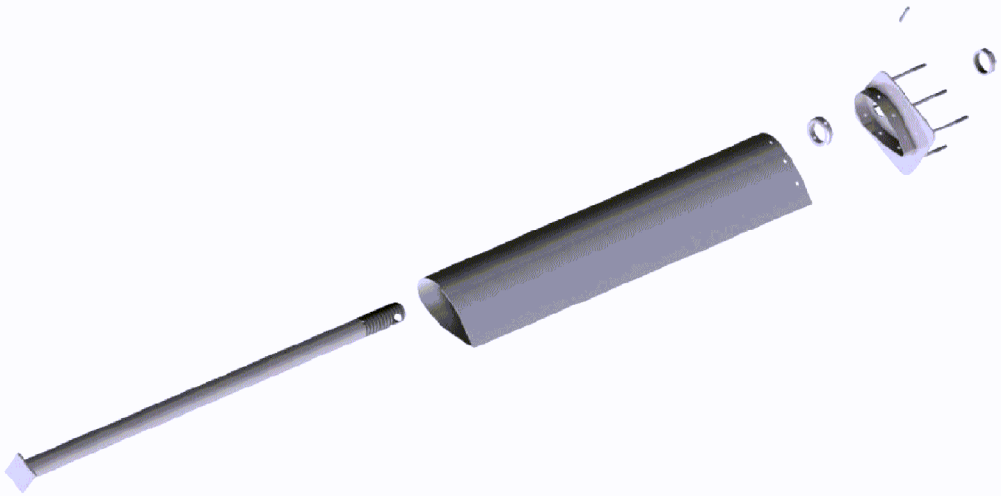


Figure 4. Joining the parts of the strut.

The total weight of this structural arrangement is 2.95 kg (Figure 5).

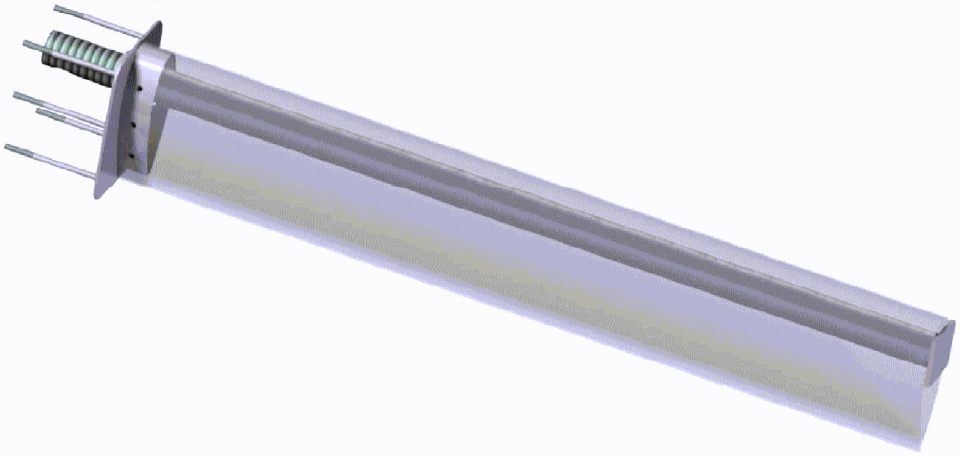


Figure 5. Structural arrangement for the strut.

Summary

Structure The arrangement with a load-bearing steel shaft and composite profile meets the requirements set out in the introduction to this report, including demountability, cabling space and module construction. It is of the utmost importance that the fit on these parts is good, to minimize backlash in the system, which will make Evolo difficult to control. The total weight of 2.95 kg is estimated to be within a reasonable interval. A potential problem could be the extension of the existing steel shaft, an examination of whether this is possible with either welding or a pipe sleeve arrangement should be carried out. The exact dimensions and laminate layout for the profile have not yet been determined, the recommendation is to use a [+45-45] laminate in a suitable thickness to handle both bending and torque. For complete construction drawings, please refer to the Evolo final draft stötta.dft, which can be found under TB106 at bilda.

References

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42. M, Fürth, *D4 Beskrivning av generalarrangemang Evolo.* KTH 2008

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
277. Are all elements of the problem addressed?	Yes	Yes
278. Have the purpose and conditions been reported?	Yes	Yes
279. Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective?	Yes	Yes
280. Is the purpose achieved?	Yes	Yes
281. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors?	Yes	Yes
Technical content		
282. Have simplifications and assumptions been clearly stated and justified?	Yes	Yes
283. Has the choice of solution methods been clearly reported and justified?	Yes	Yes
284. Are calculations controlled and reasonably assessed?	-	-
285. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text?	Yes	Yes
286. Are equations written as part of the running text, presented in separate lines and numbered?	-	-
287. Can the technical reasoning be followed?	Yes	Yes
288. Is there a difference between facts, statements and the author's opinion?	Yes	Yes
Presentation		
289. 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	Yes
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292. 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?	Yes	Yes
293. Are appropriate references made to figure, table and equation numbers in the text?	Yes	Yes

294. Are appropriate references made to references in the reference list?	Yes	Yes
295. Is the language cared for, free from spelling errors, sentence construction errors, special spellings, etc.?	Yes	Yes
Other		
296. Has the report been written by you individually?	Yes	
297. The work has been carried out in collaboration with: _____	-	-
298. The report has been proofread by: _____	-	-
299. I believe that this report as a whole is worth rating (u, 3-5)	-	
300. 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.):		-

TB107 – Construction plan floating body



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Version number:	*2*
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Introduction

A drawing of Evolo's floating body has been modeled in three dimensions and has subsequently been analyzed with regard to weight, center of gravity and construction methods. A justified weight and center of gravity estimate and a construction plan describing how the floating body is to be built are presented.

The requirements imposed on the floating body are that it must have dimensions according to the general arrangement, which means a total length L = 2.3 m and a width of max B = 0.7 m. According to the requirements specification, the entire craft must not weigh more than 70 kg and the floating body should therefore have a lifting capacity of about 170 liters.

Weight estimate

In the estimate of weight and center of gravity in Table 7, surfaces and volumes from the CAD model are measured as densities are estimated and introduced into the model. From the model, the center of gravity of the different parts is then measured in relation to the anterior perpendicular.

Table 7: Weight and center of gravity calculations

Part	Material	Density [kg/m^3]	Volume [m^3]	Weight [kg]	Center of gravity [m]
Floating body - *carbon fiber laminate*	4 layers carbon fiber each 0,25 mm	1350	3,16 m^2 * 1 mm = 0.00316	4.26	1.25
- core material	Divinycell	50	0.1572	7.86	1.25
Floating body upper part	4 layers carbon fiber each 0,25 mm	1350	0,60 m^2 * 1 mm = 602*10^{-6}	0.81	0.44
Handle	Aluminium	2700	-	1.51	0.6
Batteries	-	-	-	27.0	1.54
Strut - *pipe*	Stainless steel	7750	0.00027	2.7	1.7
- *profile*	6 layers carbon fiber each 0,25 mm	1350	0,28 m^2 * 1.5 mm = 0.00042	0.57	1.7
Motor	-	-	-	10	1.7
Shaft	Stainless steel	7750	0.00024	1.8	2.1
Hydrofoil & motor housing	Carbon fiber & divinycell	500	0.005	2.5	1.8
Propeller	Carbon fiber, Aluminium	-	-	1.3	2.5
				60.3	1.53

At the time of writing, the greatest uncertainty lies in the weight of the hydrofoil and the motor. The craft's center of gravity is estimated to be 1.53 m behind the front perpendicular. To this calculation, however, is added the driver's weight, which is of great importance for the total center of gravity. According to the ergonomics study, the driver's center of gravity should be 45 cm behind the handles, and if the person weighs 70 kg, the total center of gravity will be moved to 1.25 m behind the front perpendicular. The total center of gravity should be a distance (approx. 2 dm based on

experiment 4) in front of the lifting center of the hydrofoil. Exactly where the hydrofoil's lifting center is located is difficult to say, but can be approximated to a third of the hydrofoil's max chord in front of the hydrofoil's aft end. The dimensions that define the drawing are based on the (hole for) the strut being 1.7 m in behind. This means (and is based on) that the batteries are divided into two boxes, a stern box that contains six cells and a front one that contains eleven. The total center of gravity then ends up 0.22 m in front of the lifting center of the hydrofoil.

Construction plan

Construct battery boxes

The boxes for the batteries should be designed first to ensure that the aft of the floating body is large enough to accommodate the boxes. The boxes are two and should be kept as small as possible. Smaller outer dimensions of the boxes mean slimmer stern and less resistance. However, the internal measurements are very important not to fall short.

According to previously, two boxes will be built, a stern containing six cells and the one in the front with eleven. The size of a battery cell is HxWxD = 193*115*46 mm. The proposal for the inner dimensions of the boxes is presented in Figure 33. It should be checked that the margins are sufficient; 8 mm in width, 5 mm in height and 15 and 10 mm in length respectively. Most critical is the width, because the cables must fit.

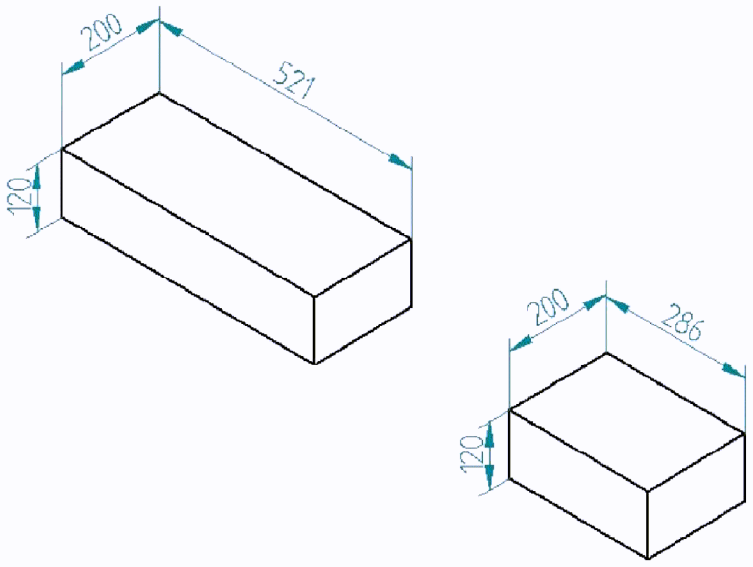


Figure 33: Internal dimensions of battery boxes.

The drawers must be built of a very light divini cell that is covered with carbon fiber on all sides except the top. The reason why there should be light core material in the boxes is that it should be easy to dig out this material. You could build the core in styrofoam as well, but then you can not use vinyl ester as plastic when laminating the floating body itself, because the styrofoam then melts.

Test of vacuum injection on lower body

A test must be performed to see if it is possible to inject plastic along the entire width of the floating body. This should be done by building a middle section of the floating body where it is widest. This section should in principle be square seen from above and have a cross section similar to that of the floating body. The section should be covered with carbon fiber and vacuum injection (from one side to the other) of vinyl ester should be done to see if the plastic can reach the full width. However,

it is a decision of the material manager and finance manager whether this test can be done with fiberglass for financial reasons.

Construction of lower body

Drawer constructions are laid upside down and on top of this the lower body is built up of core material. It will be difficult to follow the drawings exactly, so when designing you have to go by feeling, but monitor the size so that the volume does not become too small! It is suggested that most of the craft should be built of a light divini cell that is glued together and grounded down.
The distance between the boxes should be 400 mm. The hole for the strut should sit in the middle between the boxes; with center 186 mm behind the aft edge of the front battery box. The area around the strut must be of a harder core material, for example hard plastic. Therefore, it may be appropriate to glue a 400 mm long piece of plastic between the boxes at the beginning. This should be at least as deep (= high) as the boxes and can possibly reach all the way down to the bottom of the hull to attach to the carbon fiber of the hull. The brackets for the handles should also be glued together with the mold, these should preferably be metal plates that can be threaded afterwards.

When the lower body is shaped, the volume is controlled and all parts are in the right position, the shape must be covered with carbon fiber on both the bottom and top. Less carbon fiber, or no carbon fiber if possible, needs to cover the battery covers. It is estimated that just over 5 m^2 of carbon fiber will be required per layer.

The structure is then plasticized with, preferably, vinyl ester and vacuum injection. The injection should take place from one side to the other, instead of from front to stern.

Upper body construction

A plug in any material (not styrofoam if vinyl ester is to be used) is formed based on the shape of the lower body and based on the drawings. Carbon fiber is laid over the plug according to the drawing, but a piece of carbon fiber in the order of 2 cm must protrude "under" the plug along the entire bottom of the plug. This flange should then be glued to the lower body. Optionally, a layer of carbon fiber can be laid over the joint if it should be needed; for example, if the joint becomes bad or if it turns out that parts of the joint will be under water.

Installation

Cut out covers for the batteries. Cut exactly inside the edges of the boxes. Remove all the light core material from the boxes.

Locate where the strut is to be mounted and drill holes for this. Then drill passages from the battery box to the hole for the strut for the power cables.

Manufacture carbon fiber plates for battery covers. These should be slightly larger than the boxes. Drill holes for screws on the edges of the doors and rivet threads in the hull, where the holes for the covers will end up. Seal with rubber strip and screw tight.

Drill and thread the metal plates to which the handles are to be attached. Assemble the handles, connect the cables and fly away! Do not forget the motor control cord, which in this case may most easily protrude from the strut mounting.

Propeller manufacturing

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Hours worked:	3 h
Reviewed by:	

Summary

An option to designing your own propeller would be to have a similar propeller manufactured. This can be done through, for example, Capella Marin [2]. The recommendation, however, is to try to make our own propeller, this should be an educational task for a person with an interest in composite construction in the spring.

Introduction

This report aims to describe a proposal for a manufacturing process for a composite propeller suitable for Evolo. Drawings as well as construction method shall be investigated on the basis of A101 - Propeller selection [1]. Advantages and disadvantages versus other propeller options are investigated and a recommendation for the project must be given.

Problem formulation

On the recommendation of [1], a separate propeller will be built to achieve the desired speed for Evolo. This means creating, based on the data given on the propeller, suitable construction drawings and describing a suitable construction method for this propeller. The following dimensions describe the design of the propeller, the unknown factor is the shaft dimension, this should be considered in the choice of construction method (Table 1).

Table 8. Propeller data.

Diameter	0.35	[m]
Geometric pitch	0.34	[m]
Shaft effect	2000	[W]
Drag resistance	219	[N]
Blade area ratio	0.46	[-]
Number of blades	4	[-]
RPM	920	[rpm]
Dimensioned speed	8	[kn]
Hub diameter	0.06	[m]

A suitable material system for the propeller must also be presented.

Drawings

The four blades have a geometric pitch of 0.34 m, this means that the propeller theoretically moves this distance during one revolution of rotation. This means that the pitch must be varied locally, α , as the distance that a small part of the blade moves during a turn is different depending on where on the blade the part is located. It may be appropriate to start from the vertical plane when defining the different angles of the propeller blade (Figure 1).

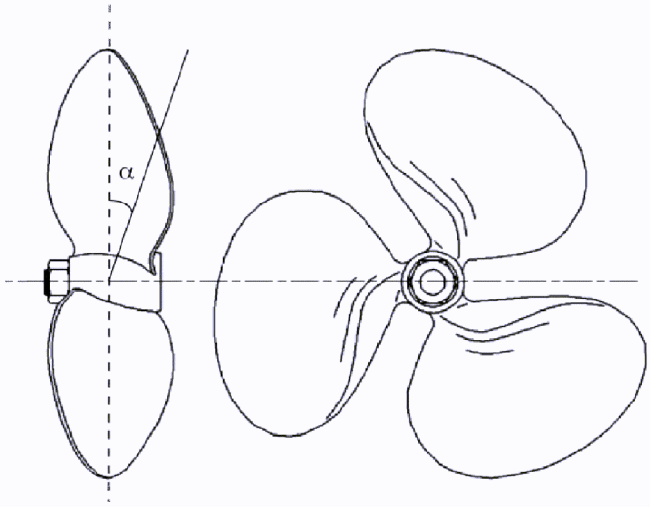


Figure 34. Propeller geometry.

Furthermore, each blade can be divided into 6 parts or blade elements. The choice to divide it into 6 parts is based on the assumption that this division provides sufficient accuracy to describe the geometry of the blade. The blade shape of the blade is also evaluated for each such element.

The following classification of the blade is assumed where the radius of the hub, 60 mm, has been subtracted from the total radius of the propeller (Table 2).

Table 9. Angles of attack for each blade element.

Radius [mm]	30	59	88	117	146	175
Angle, α[°]	70	67	38	28	22	18

This generates a curvature for the entire blade, which must be manufactured as close to these calculated values as possible. The following floor plan drawing can be used for the manufacture of the blade. This plane shape must therefore be rotated from the vertical axis according to the angles given in the table.

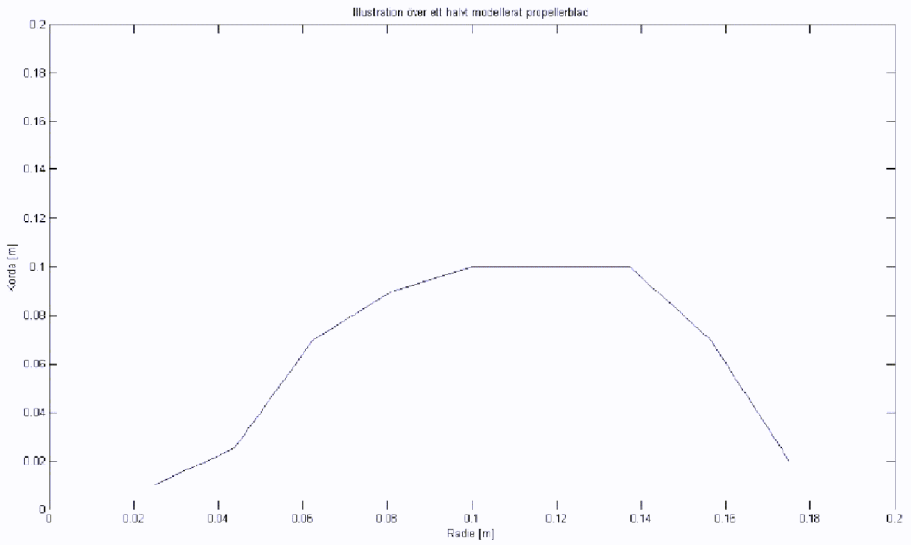


Figure 2. The plan shape of the propeller.

Construction method

One approach to constructing this propeller may be as follows:

1. Four rectangular aluminum plates are cut out. These must be large enough to accommodate the plane shape of the propeller.
2. On all aluminum plates, the pattern of the plan form is punched out by hand.
3. These aluminum plates are rotated according to previously presented angles, or as close to them as possible.
4. A hub with the correct shaft dimension and type, with a diameter of 60 mm is suitably made of aluminum. At the time of writing, the shaft dimension is not determined.
5. The hub should be sanded with coarse sandpaper to provide a good attachment surface.
6. The hub is fixed on a sturdy thick plywood board.
7. Aluminum plates are milled out to fit the hub on the short side.
8. A jig in e.g. wood is designed to place the blades in the correct position around the hub at right angles to what has now become the horizontal plane. It is important that the punched surfaces on the aluminum plates are visible from above (figure 3).

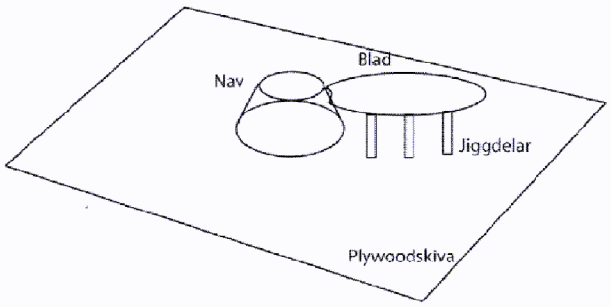


Figure 3. Sketch of construction jig.

9. Apply wax or release agent to the aluminum sheets.
10. Now laminate the desired thickness with carbon fiber and matrix on aluminum sheets and hubs so that these parts are joined together.
11. When the laminate is hardened, carbon fiber hubs and blades can now be detached from the construction jig. The plane shape of the blades can now be sawn out based on the markings transferred from the aluminum plates to the blades.
12. Sand, sand and sand

This is broadly a work schedule for the construction of Evolo's own propellers. For more information about construction technology, contact Stefan Hallström.

Summary

An alternative to designing your own propeller would be to have a similar propeller manufactured. This can be done through, for example, Capella Marin [2]. The recommendation, however, is to try to make our own propeller, this should be an educational task for a person with an interest in composite construction in the spring.

References

1. A101 – Propellerval, Petter Delin & Daniel Carlsson, KTH 2009
2. Memmo angående egen propellertillverkning, Torvald Manners, KTH 2009

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!

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324. 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.):		-

TB114 – Testplan mountings



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Version number:	*0.1*
Supervised by:	
Hours worked:	20 hours
Reviewed by:	

Introduction

In Evolo's design, there are areas that will be critical from a load case point of view. These areas are usually the mountings between two parts in an already exposed area. This report will identify the vulnerable areas and draw up a plan on how the proposed solutions will be tested.

Problem formulation

To find out which mounting points are on Evolo and then make a test plan for these.

Analysis

To be able to identify the critical mounting areas, Evolo's construction is studied, *see figure 1*.
The areas that need to be tested are the mounting points for the handle, the mountingt of the strut to the floating body, the mounting of the strut to the engine bulb and the mounting of the stay between the engine bulb and the aft wing, these are numbered in the respective order 1,2,3,4 in *figure 1*.

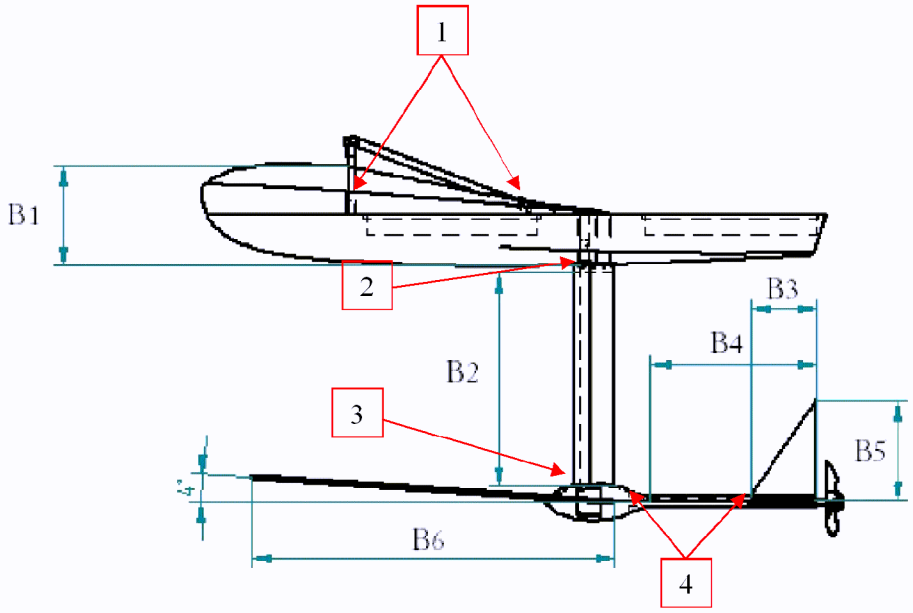


Figure 1. The mountings that must be examined are numbered 1, 2, 3 and 4

The handle has three metal plates as mountings in the floating body [1], the metal plates can either be screwed on, laminated into the floating body or a combination of the two. In order for the screws to have a better mounting and not damage the core material, it is replaced with a harder core material and a metal plate at the mounting area, see figure 2.

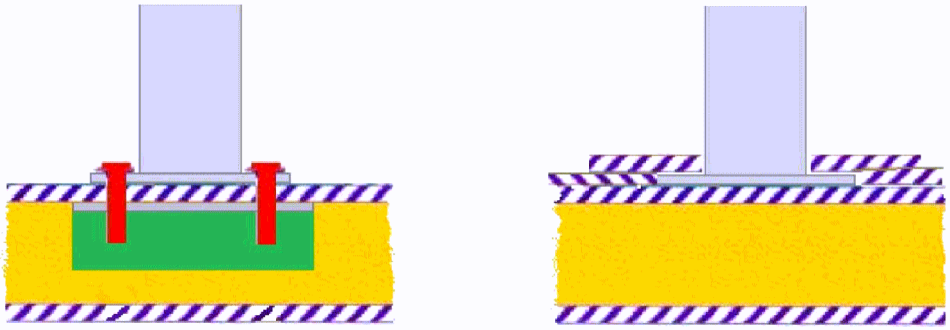


Figure 2. Two different suggestions on what the mounting from the handles to the floating body can look like. In the left figure, the core material at the screws is replaced with balsa wood, seen in the figure as

The mounting number 2, which is between the strut and the floating body, must be mounted in accordance with [2]. The important areas to study in this mounting are where the base plate is screwed into the floating body and where the wing profile is to be riveted and / or glued to the base plate, *see figure 3*.

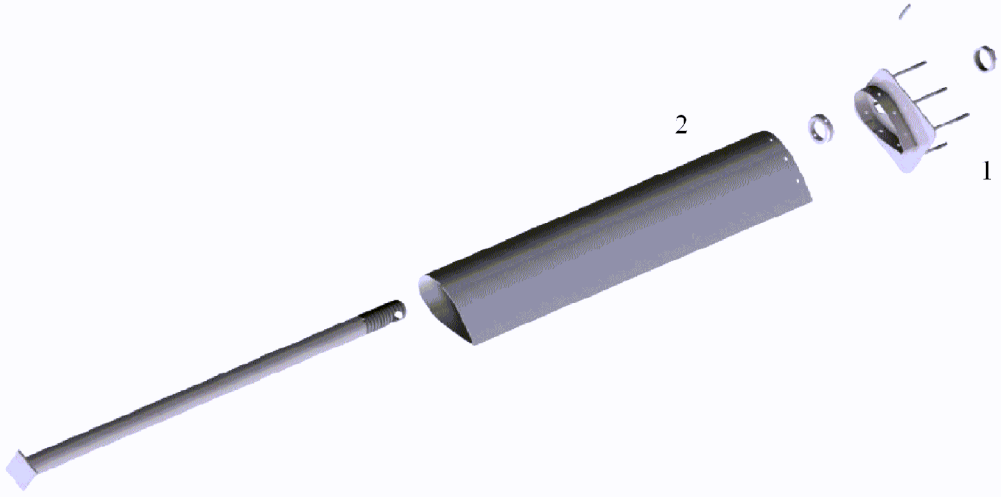


Figure 3. Here you can see the assembly of the strut, where the base plate is number 1 and the wing profile number 2

Mounting number 3, between the strut and the motor bulb, is the most complicated of the 4. It involves attaching the strut to an egg-like engine compartment shell which in turn is assembled with the front delta wing, *see Figure 4*. There is currently no written complete solution for how this mounting should look like.

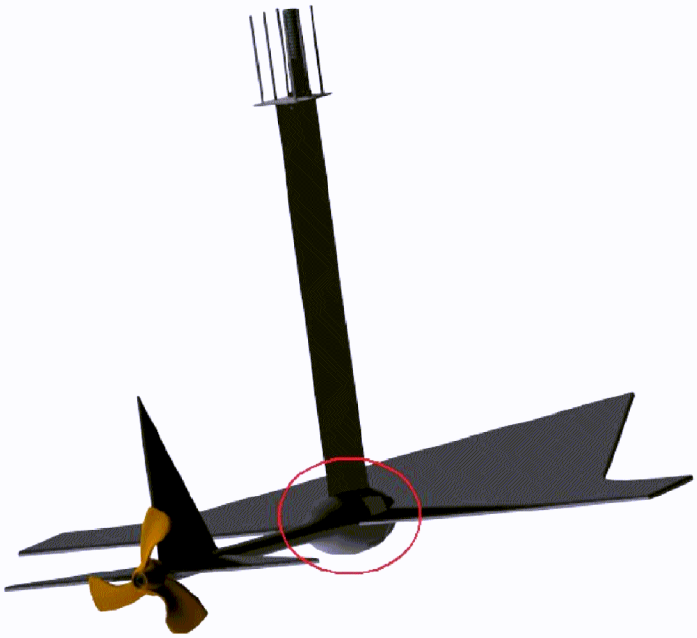


Figure 4. The critical mounting between the strut and the motor bulb is circled.

The stay from the motor bulb to the aft hydrofoil must be constructed by making the entire lower body in two parts and gluing it together [4]. In this way, mounting problems with screws and the like at number 4 in *figure 1* are avoided.

Test plan

Mounting no.1

The mounting to be used and tested is the first illustration, at the top right of *Figure 2*. A metal plate is attached with four screws to the sandwich and the metal plate should also have a lever to apply the force on. To perform the test, the panel is forced onto a beam and the lever is loaded with an increasing load P_1 until the mounting breaks. Since the largest forces that will occur on the handles are along the floating body, the test according to *figure 5* is performed on a lever for the mounting.

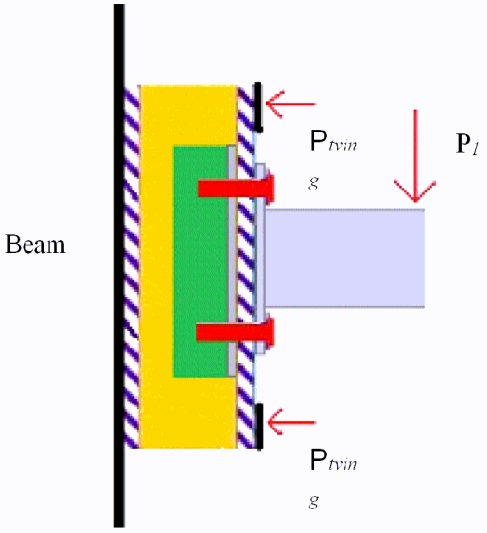
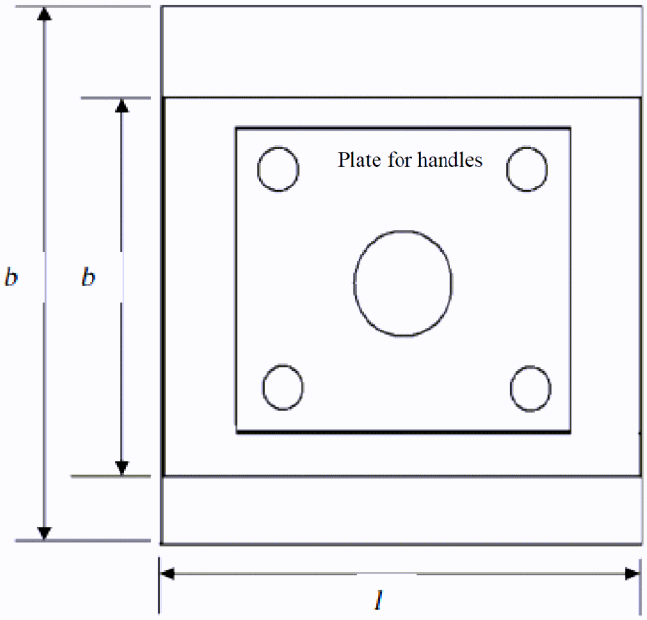


Figure 5. Test part to investigate the impact of the screws on sandwich constructions at

The metal plate made for the front handle bracket can with good advantage be used in this test as it is finished and a lever is already welded there.

The sandwich is made for the sake of simplicity as a panel to facilitate production and results should not be significantly affected as the distance between the cover layers is actually greater than what this panel will have. The fiber layout of the composite is *[45, -45.0]*, which gives a total thickness of *1.2 mm*. The core material is Divinycell H50 and is made *100 mm* thick.
The composite should be placed with the *+45* direction on both sides against the core material to get symmetry in the fiber directions. The panel has a width *b = 200 mm*, a length of *l = 140 mm*.
The reinforcement seen in *figure 5* consists of a stiffer core which is topped with a metal plate, its width is *bb = 120 mm* and its thickness is *60 mm*.



Mounting no. 2
Because this test piece is so large and the mounting is complicated, a full-scale test is performed only once.
A metal plate with similar surface dimensions as the base plate in *figure 3* is fastened with 6 screws through the entire sandwich structure into a metal plate on the opposite side, the panel is then forced up onto a beam, *see figure 6*. A distance should be inserted between the panel and the beam so that the screw and bolts do not touch the beam. The lever is then loaded with an increasing force P_2 until it breaks.

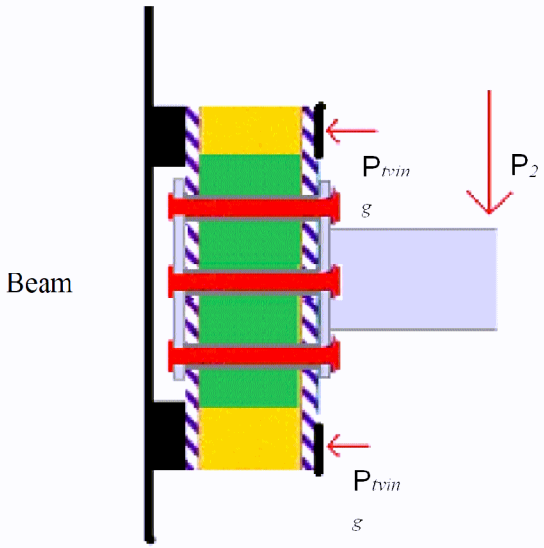


Figure 5. Test part to investigate the effect of the screws on sandwich constructions during torque loading

The section that is made to test the vacuum injection possibilities for the floating body can be used to advantage in this test as it has the right dimensions. Two metal plates with sides *200 mm* and *150 mm* are to be manufactured. The lever will be made similar to *figure 3* with a flange which is fixed in one of the metal plates and on which the lever is glued. The flange is proposed to be rectangular and with the sides to fit a hollow beam with the sides *150 mm* and *50 mm* and the height of the flange to be *40 mm*. If there is no metal beam with these dimensions, the dimensions can be changed as long as the area of the flange is reasonably correct.

Discussion

As the critical parts of the Evolo will be at the mounting, it is important that these tests are performed to verify that they last. These tests are somewhat simplified compared to the real case, but the advantage is that they are conservative. Such a simplification is where the test piece is forced into the beam and it resembles a fixed clamped condition, the parts on the Evolo are never clamped. The production of these test pieces will be time consuming and it is then important that they are done correctly. The purpose of using already made parts is to reduce the production time, the problem is that those parts are made right now. Therefore, those who make the parts should be informed immediately what they need to do so that duplication of work is avoided. In case of

mounting no. 2 two things are tested at the same time, that the screw connections hold and that the gluing between flange and strut lasts

References

43. P. Dahlin, *A109 – Handtag*. KTH 2009
44. M. Razola, *TB106 – Strukturell design av stötta.* KTH 2009

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
325. Are all elements of the problem addressed?	Yes	
326. Have the purpose and conditions been reported?	Yes	
327. Have relevant conclusions for the benefit of the project been drawn, reported and related to the objective?	Yes	
328. Is the purpose achieved?	Yes	
329. Is the report readable without access to task formulation, project instructions, etc. that you have received from teachers and supervisors?	Yes	
Technical content		
330. Have simplifications and assumptions been clearly stated and justified?	Yes	
331. Has the choice of solution methods been clearly reported and justified?	Yes	
332. Are calculations controlled and reasonably assessed?	-	
333. Are all used terms, variables, designations, abbreviations, etc., clearly defined and explained the first time they are used in the text?	Yes	
334. Are equations written as part of the running text, presented in separate lines and numbered?	-	
335. Can the technical reasoning be followed?	Yes	
336. Is there a difference between facts, statements and the author's opinion?	Maybe	
337. Is there a realistic verification plan for the work in the report?	-	
338. Is there an acceptable follow-up of the verification plan?	-	
Presentation		
339. 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	
340. Is the report provided with: appropriate title, date, author name, e-mail, eventual supervisor,summary/abstract, table of contents, reference list and page numbering	What is needed	
341. 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…"?	Hope so.	
342. Are figures and tables clear and informative, provided with figure / table text and clear numbering?numbered? Do all figures have units inscribed on all axes? Can figures be interpreted even after printing in black	Maybe	