Conceptual design of a blue water cruiser based on the Storm Bird

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ABSTRACT
This report describes the process of developing a conceptual design of the Storm Bird, a long distance sailing cruiser. The starting point was a boat designed in the mid nineties by the famous Swedish naval architect Håkan Södergren and the aim with the project is to present an idea as to the renewal of the design in a more modern boat. The new Storm bird was supposed to be a full on blue water cruiser concept, a boat that the presumed owner would not have to change in order to set off on his trip.

To get insight in the minds and the needs of long distance sailors an extensive market and customer analysis has been undergone. This together with experience in the design team is a base to the thoughts and the ideas incorporated in this design.

The hull design was limited to the existing hull moulds meaning that no changes in the hull shape could be made. An alternative however was the transformation from negative to positive transom which proved a very effective way of making the boat feel bigger.

The design and layout have been focused on making an effective, well planned but most of all social yacht. The clear boundary between the inside and outside has been removed thanks to a large opening to the cockpit with big windows and good connection. The cockpit and interior areas have been focused towards each other so as to create one big social area, boundary free.

Further on the living quarters, as the rest of the boat, are focused on the main idea of the customer being mainly a cruising couple. Therefore an optimal interior layout with focus on the one master cabin has been developed.

In the cockpit, seats are comfortable as well as facing forwards and everyone onboard can follow what is going on through the forward placed navigation central. The wide opening between cockpit and interior makes traditional rope handling impossible. All controls are led aft through a clever arrangement to clutches and winches placed on either side of the cockpit instead of on the deck house. This way all functions are in the right position, close to the helmsman. The ropes are later hidden in boxes to ensure a tangle free cockpit.

An intelligent overall solution when it comes to onboard systems has been developed as well. Key words have been weight distribution, serviceability and ease of installation. Stowage space and tank volumes correspond to the yacht’s intended use.

The structural design has been carried out focusing on arriving at a realistic weight calculation in order to be able to determine centers of gravity and place equipment and ballast to achieve a working concept. Material and manufacturing techniques have been chosen so as to fit the expertise available at the company.

Appendage design has focused on modernizing the underwater body by incorporating a new keel and rudder. The performance of the boat has been increased significantly whilst not making it too extreme for its intended purpose.

The finished design concept is believed to be a really attractive choice for a blue water sailor.
ACKNOWLEDGEMENTS

First of all we would like to point out what a great experience this has been. In no course or project previously have we ever learnt as much about boat design as we have in doing this work. A lot of people deserve a thank you for their contribution to our project.

We would like to thank:

Håkan Södergren for taking us on and believing in our ideas. Håkan’s incredible experience has been invaluable to us throughout this project.

Kenth Lindqvist for always challenging our ideas and for pointing out what works and what does not. Kenth’s experience comes from many years of building boats and that has been extremely helpful for us.

Niklas Lundh for his ever presence and positive remarks during many long evenings at the office. An economic director with a lot of insight in the design work, Niclas has helped in many ways.

Mattias for helping us with remarks on the interior and what building techniques are possible to apply.

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All the sailors who answered our survey. Their comments and remarks have been a base to the design presented here.

Thomas.
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ABBREVIATIONS & DEFINITIONS

ABS – American bureau of Shipping
AC – Accumulating Current
AIS – Automatic Identification System
AR – Aspect ratio
AR_e – Effective aspect ratio
b – Breadth of panel or stiffener
B_{MAX} – Maximum beam
BWL – Waterline beam
c – Curvature of curved panel or stiffener
CAD – Computational Aided Design
CE – Centre of Effort
C_D – Drag coefficient
C_L – Lift coefficient
C_{L_{max}} – Maximum lift coefficient
CLR – Centre of Lateral Resistance
CoG – Centre of Gravity
DC – Direct Current
DNV – Det Norske Veritas
FLC – Fully Loaded Condition
F_n – Froude Number
GRP – Glass fiber Reinforced Plastics
I – Moment of inertia, cm^4
ISO – International Standard Organisation
Hp – Horse Power
Kn – Knots
l – length of panel or stiffener
LCB – Longitudinal centre of buoyancy
LCG – Longitudinal Centre of Gravity
LCR – Centre of Later Resistance
L_d – Distance deck edge to hull side with inward flange
L_o – Distance deck edge to hull side with outward flange
L_{OA} – Length overall
LWL – Waterline Length
m_c – canoe body displacement
MSC – Minimum Sailing Condition
NACA – National Advisory Committee for Aeronautics
PVC – Polyvinyl Chloride
PYD – Principles of Yacht Design [1]
GZ – Righting arm
S_{A/D_{2/3}} – Sail Area to Displacement ratio
S_{A/SW} – Sail Area to Wetted Surface ratio
S_{MI} – Section Modulus of inner skin, cm^3
S_{MO} – Section Modulus of outer skin, cm^3
STIX – The Stability Index
t_c – Core thickness, mm
t_i – Inner skin thickness, mm
T_k – Keel draft
t_o – Outer skin thickness, mm
T_r – Rudder draft
t_{shear} – Required thickness due to shear
t_{single} – Thickness of single laminate
TWA – True Wind Angle
TWS – True Wind Speed
VCG – Vertical Centre of Gravity
VPP – Velocity Prediction Program  
SW – Wetted Surface  
σ_y – Yield strength, N/mm²  
σ_u – Ultimate strength, N/mm²  
τ_u – Ultimate shear strength, N/mm²  
QFD – Quality Function Deployment

COORDINATE SYSTEM
Longitudinal distances – x  
Vertical distances – y  
Transversal distances – z
Preface

The company

History
CMI Composites was founded in 2008 by Swedish boat designer Håkan Södergren in an attempt to oversee the production of the new J-Craft 40 he recently designed. In the production facility Nimbus motorboats had been produced since 1985 and until the decision was made to move production to Mariestad the yard was Scandinavia's biggest and most modern boat industry.

Current
CMI Composites incorporated the core producer Airex and started producing boats. Now production includes the luxurious J-Craft boats as well as a small portion of Nimbus's. The Tarac as well as hulls for SwedeStar yachts are also produced here.

Future
The future looks bright with enhancements of the work force in sight as well as new models and interesting new areas of expertise.

The team
Håkan Södergren
Håkan Södergren, a well known designer of high performance cruisers as well as a row of family powerboats. His designs can be found in Scandinavia, Europe as well as the rest of the world. Currently CEO and major share holder of CMI Composites.

Kenth Lindqvist
Kenth has worked his way up from boat builder to head of production in the factory under employment from Nimbus AB. In the new organization at CMI he takes the role as head of development.

The students
Jens Blomquist
Jens studies Naval Architecture at Marina System at the Royal Institute of Technology. A keen long distance sailor Jens handles the technical design work.

Patrik Ekman
Patrik studies Integrated Product Development at the Royal Institute of Technology. Patriks area of expertise is product development linked to production.

The design task

Aim
As a master thesis project [9] CMI Composites has asked the students to make a conceptual design of a blue water cruiser based on the Storm Bird. Previously conceived during an article series in the sailing magazine Segling, the Storm Bird was supposed to be an ideal blue water cruiser. The aim of the project is to develop a modern cruiser with the same object as the initial design but more suited for the modern yachting market.

Limitations
Since a small number of Storm Birds have been produced, the existing mould for the hull is supposed to be used for the presumed production of the new version. The hull therefore has to be the same as the
previous model. All other aspects of the yacht could be changed. To keep complexity down in the design, a clause was added that the boat should be possible to produce in-house, i.e. solutions in production should fit the expertise available at CMI.

**SPECIFICATIONS**
Before the start of the design work some preliminary specifications were set up together with Håkan and Kenth. As stated above the design should be a blue water cruiser but the team wanted to see beyond normal yachts in the same genre. The goal with this design would be to develop a more complete concept for a long distance sailor, not a yacht which the owner would have to convert or complete himself in order to be ready for the seas.

A clear downside with the previous design was the lack of standing headroom in the interior, a feature needing improvement in the new design. A concept to cope with the issue of sunroof, cockpit tent and spray hood was also sought. Also the dinghy, an obvious detail on a long distance cruiser needed a specific concept for handling and storage on the boat.

The new Storm Bird should be optimized for a cruising couple with occasional guests or kids sailing with them. The concept therefore needs to represent this in terms of handling, living quarters and storage space. To this comes the inevitable safety issue stating that safety equipment should be intelligently integrated in the boat and that the boat should meet with Communauté Européenne (CE) standard Category A and all the structural calculations should comply with ISO 12215 [1].

The goal with the design is to create a feasible and attractive blue water cruiser but still use two young minds’ innovative approach so as not to create “another white boat”.

**DELIVERABLES**
The conceptual design will be presented with material such as drawings, renderings, 3D-models and calculations. Making construction drawings could be seen as a continuation of the study should the concept be fit for production. This report is the documentation of the work done and is presented along with the material stated above.

**THE STORM BIRD TODAY**

**BACKGROUND**
The Storm Bird was conceived during an article series in the sailing magazine Segling 1994 where Håkan Södergren and Bengt Jörnstedt were working towards designing the perfect long distance cruiser. The idea was to appeal to long distance sailors who wanted something different than ordinary blue water cruising boats. The characteristics were good looks, functionality and speed. A small number of boats were later built in Finland.

**EXISTING MATERIAL**
The existing material included a number of 2D-AutoCAD drawings, a few photographs along with original weight and stability calculations.
FACTS
Some basic facts follow in Table 1. Drawings of the deck and profile can be seen in Figure 1.

Table 1. Basic data on the original boat

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<tr>
<td>$L_{oa}$</td>
<td>11.05 m</td>
</tr>
<tr>
<td>$L_{wl}$</td>
<td>10.08 m</td>
</tr>
<tr>
<td>Beam</td>
<td>3.46 m</td>
</tr>
<tr>
<td>Draft</td>
<td>1.71 m</td>
</tr>
<tr>
<td>Displacement</td>
<td>5161 kg</td>
</tr>
<tr>
<td>Sail area</td>
<td>69.80 kvm</td>
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<tr>
<td>Water/Diesel</td>
<td>100/100 l</td>
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Figure 1. The profile and deck drawings of the original Storm Bird

COCKPIT AND DECK
The deck and cockpit are fairly traditional with a normal deck house, bulwarks and a rigid bowsprit. In the cockpit the benches are straight. There is a tiller steering and the mainsheet track is all the way aft. The bathing platform is integrated in the negative transom.

RIG
The mast is placed relatively far aft and with a massive boom the mainsail is big. There is also a cutter staysail along with a big masthead genoa. This is certainly a powerful as well as flexible sail plan.

INTERIOR LAYOUT
The interior layout can be seen in Figure 2. The thought behind the interior arrangement was to appeal to a cruising couple. The only cabin forward, large kitchen and navigation area and ample stowage are key words. An important feature is the sea berths in the saloon.
CONSTRUCTION

Hull and deck was built with GRP, Glass-fiber Reinforced Plastic, sandwich where applicable. The hull featured quite a large bilge or keel sole so as to collect water and supply storage space in the bottom of the boat.

![The original interior layout](image)

Figure 2. The original interior layout

NEW TECHNOLOGY OF INTEREST

In any product development new technology and keeping track of trends is very important. Here follows a brief summary of what the authors regard important for the future and worth trying to integrate in the new version of the Storm Bird.

HYBRID DRIVES

With a number of electric propulsion systems appearing on the yachting market the future might just see totally energy independent yachts. Large solar panels power the battery bank from which consumers like refrigerators and computers and navigational equipment but also the electric propulsion are driven. The technology is available but batteries and charging techniques are not jet effective enough for this to really work. On a blue water cruiser, the need for sufficient power is probably still governing so the idea is to combine a dedicated power plant in the shape of a diesel generator with an electrically driven propulsion system in order to fulfill all needs. This would allow for a more effective power generation thanks to a more optimal charging process than that on a conventional diesel propulsion engine. When charging or energy storing improves, the gen set could easily be switched for more batteries.

NO PETROL ON BOARD

The dinghy is as mentioned above really important on a blue water cruiser. Outboard motors however are noisy, pullutive and heavy to handle. Added to this you have the need to stock up on petrol and oil in order to keep them working. A solution for the future, especially combined with a proper diesel generator, is an electrically driven outboard engine that you simply plug in and charge from the mother ship when not in use. Where you would otherwise store petrol and oil or the complete engine you can instead store more diesel.

Ideal would be not to have any gas onboard either. Kitchen stoves however are so much more effective on gas than electrically driven ones. There are diesel driven alternatives but they are often smelly and heavy and rather complicated.

NEW DECKING MATERIALS

Teak deck has always been the choice to get that luxury feeling on a yacht. It also gives good grip, looks good and gives the boat a cool feel in the tropics when soaked with water. Teak is however a natural material which is expensive, does not last forever and has a negative impact on the environment.

Alternatives to teak include a number of natural rubber, cork and composite decking materials. Especially the composite decking materials are interesting because they are composed to enhance the qualities of the natural teak but with less impact on the environment. They are often nearly indestructible and do not get
bleached by the sun. Composite decking gives freedom in the design when it comes to color and pattern and thus gives the opportunity to personify the boat. Incorporating composite decking in a new design at least as a choice for the customer is probably important in the future.

Clever Sunroof/Cockpit Tent Solutions
With influence from the super yacht market more and more smaller yachts are beginning to address the need for a clever cockpit protection system. It is not uncommon that a boat has a spray hood, a bimini and a cockpit tent, all as different units. A combined solution that works well with the esthetics of the boat would probably be very attractive on the market.

Dinghy Handling
To a long distance sailor the need for a dinghy is evident. A big comfortable dinghy is on most sailors’ wish list but stowing it whilst sailing is not. This is usually a big problem, especially on a small yacht since towing it, even small distances, is not an option. The company therefore wishes that a clever solution for the handling of the dinghy that is fast, safe and not devastating for the looks of the boat is incorporated.

Product Design Specification
A product design specification was set up in close collaboration between the students and the company. Stating all goals with the design it is a useful and important tool in the product development. Appendix 1.

Market Overview and Research
Market overview is essential for the evolving project, learning about competition and the use of blue water cruisers. The aim with this part is to learn more about the presumed customer in order to better address the needs and wants in the coming design.

User Profiles
To enhance the developed product’s value, it is essential to understand every aspect of it. Critical questions like *Who is it for?*, *Vital equipment needed?* and *Priorities?* are relevant. The following list is a description of a characteristic long distance sailor.

- The user lives on board a great deal, either on long vacations or during long journeys.
- The user value sailing characteristics. Balance, rigidity, security and simplicity are important factors.
- The user spends most of the time in port; therefore the living comfort is as important as the sailing characteristics.
- The user needs to be self sufficient for long periods.
- Long distance sailors value high quality due to the dependence in systems reliability. Service ability is important.
- Long distance sailors are couples and like to be able to take on guests for a longer period of time.

Summary, long distance sailors value comfort, space and sailing characteristics for long periods of time.

Characteristics of a Blue Water Cruiser
With the user profile established parallels can be drawn to the yacht.

- Spacious and efficient interior layout where it is easy to move around.
- The hull should be easily driven and well balanced and should feel safe during crossings.
- Large holding tanks, energy self sufficient as well as a lot of stowage space.
- High quality installations and components are essential.
- One spacious master cabin, preferably one guest cabin.
SURVEY
A survey, Appendix 2, was sent to Swedish long distance sailors with boats ranging from 32 to 40 feet. In this survey they were asked questions about their boat and improvements/changes they had done or have in mind doing. They also got to specify where onboard the time is spent, in port and during crossings.

Result
60 surveys were sent out of which 20 answers could be collected. These represent the views of 35 people with their own hands on experience of long distance sailing and living onboard yachts. The analysis shows that for most long distance sailors most of the time in harbor is spent above deck, in the cockpit. The time spent down below is mainly for resting. Other than that, the time is mainly spent ashore. The result is shown in Figure 3.

At sea it looks a bit different but the time disposal still follows the same pattern. The time spent down below is mainly for resting although vital tasks such as cooking and navigating also occur. Results in Figure 4.
Another relevant question regarded the number of people normally residing on the yacht. Results can be seen in Figure 5.

[Figure 5: Survey result of number of persons onboard over time]

In most cases, nearly 75%, long distance sailors are only two persons onboard. Occasionally, 25%, there are guests or kids along for the trip. This is a mean value of the survey however it does not take into account the actual number of persons on each boat. This is shown in Figure 6.

[Figure 6: Actual number of people per boat]

Comment
The results from the time disposal along with comments in the survey underline the known fact that sailors spend most of their time above deck. Some participators wrote “if we didn’t teach our children during our trip, we wouldn’t spend any time at all in the saloon” or “We can’t see out from the saloon, that is a bad thing”. This research shows that in a traditional monohull, sailors prefer not to spend their time in the saloon and appreciate a well functioning cockpit. This is fundamental in the development of the new Storm Bird.

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1 An ordinary sailing boat, i.e. not a multihull or a deck saloon yacht
Another important fact is that the actual time a long distance sailor spend sailing is exceedingly small. This means that the layout, in the interior as well as in the cockpit/on deck, should be comfortable in port, but not jeopardize the sailing experience.

Also to make the boat as appealing to a long distance sailor as possible there should be one really good cabin. However important that a guest cabin exists it does not need to be as good as the main owner’s cabin seeing as it will only be used 25% of the time. Further it can be seen in Figure 6 that about 65 % are never more than two persons on board. The interior layout should reflect on this.

**COMPETITION**

Because of the narrow market there are not many boats that are fully developed blue water cruisers, although there are boats more or less suited for the task. The range of interest among competitors is stretching from 34-40 feet. In this fleet one boat is particularly interesting, the Ovni 365. This boat is a fully equipped blue water cruiser made of aluminum. It is a bit larger than the Storm Bird, but definitely a competitor. Fact sheet in Appendix 3.

Because of the fact that the blue water cruiser market is narrow, an idea would bet to design the yacht to be adaptable. This means that the yacht should work in both the blue water cruiser market as well as on the broad commercial cruiser market.

**METHODS**

In this study many different methods have been utilized. The starting material was mainly 2D drawings in AutoCAD. These where used to develop a 3D hull surface in Rhino which was later imported to Maxsurf where all hydrostatic and performance calculations where undergone. In Rhino the yacht was modeled along with all its different parts. Renderings where made using V-Ray for Rhino. Excel work-sheets where used for some calculations where others applied a Matlab script.
Design phase

IDEA GENERATION
Here follows a description of how ideas were generated and evaluated for the new Storm bird.

SUB AREAS
First the concept as a whole had to be divided into smaller sub areas to organize the idea generation in an easy way. Interior layout, cockpit, deck, wind and sun cover, energy, navigation and so forth are all sub areas that needed evaluation. The sub areas where decided after the market research and the characteristics of a blue water cruiser was determined, a way to focus on important aspects.

By making small sub areas, solutions could be mixed together to get a well functioning yacht with as few compromises as possible.

METHODS
Even though much of the development phase was informal communication here is the presentation of three different idea generation methods.

Design paper
The design paper is an A4 paper with one figure of the hull in side view and two figures of the hull in top view. This way one boat could easily be designed and brainstormed around the appearance, deck, cockpit and interior. Main thoughts about the design where written down. Mostly it was just a way to draw ideas, but it could also be restricted to one sub area or the market overview. This means that a boat for example could be designed just to fit one sub area or to be designed from the time disposition from the market research. This way of overdesigning can contribute with solutions that would not normally be thought of.

This was a way to get ideas on paper in a fast and understandable way that later could evolve to greater solutions.

Brainstorming
All sub areas were brainstormed around. The difference between the brainstorming and the design paper is that the brainstorming is focused on one specific sub area. This way you could get more into ideas and develop them further, but also think of new ideas/solutions in this area.

Concept combination table
This is a more strict way to think of solutions to ideas. It is a way to get around the obvious solution, and attack it from a different angle. It parts the different subareas to actual physical motions or usages so you end up with different techniques and ways to execute the wanted idea.

EVALUATION METHODS
When enough ideas were generated they needed evaluation. Of course some solutions were more or less favorites, but it is essential to break them down and evaluate which solution that actually is the best.

QFD
Quality function deployment is a great way to evaluate the actual benefits of the different solutions and in an easy way compare them with each other. Every aspect of the solution is considered and then given a score, in this case on a scale from one to five. The solution with the highest score fulfills the criteria best. Solutions could also be mixed together to get one even better solution, if possible. Example, one solution that overall have high scores, but lack in one area could be combined with another solution that fulfills that criteria better.
Evaluation paper
The evaluation paper is a way to select ideas or solutions in the beginning of the evaluation process. Even though QFD is a great way of evaluating different solutions it is time consuming, and it ignores one important thing, your gut feeling.

This paper is as follows; one box with a picture of the idea, sub area and a quick description. One scale stretching from one to five where gut feeling and realizability is determined. Lastly three good and three bad qualities are written down. This way you get a good overview of all solutions and ideas and an efficient way to select the best ones.

Main sub areas
Here follows a compilation of the main sub areas concerning the finishing product. These were decided on early in the project and together they represent a fair over all concept. Other sub areas where kept in mind or integrated in the main ones but are not presented explicitly.

Interior
The main idea is to create an interior that connects the inside with the outside. No cabin is located in the rear part of the yacht in order to separate living quarters from social areas. This will also contribute to a large stowing space in the aft as well as enabling a lower more protected cockpit with more contact with the interior. According to the survey, 73% of the time long distance sailors are only two persons, therefore the second accommodation is less important, but still necessary. This means that one can afford to concentrate on one good cabin and scrap the common alternative with a cabin under the cockpit.

These different layouts are quite the same, navigation table by the sofa, linear kitchen and similar cabins. This is what the idea generation stagnated towards.

Bathroom front
In this layout the bathroom is located in the front part of the yacht. This way there is nothing in the transition between the interior and the cockpit to interfere with the connection. However the bathroom needs to be in the front of the yacht and will affect the size of the saloon.

Raised saloon
This layout does not differ much from the previous one. The only difference is that the sofa is in the same level as the cockpit i.e. raised. This way the lounge will be even more connected with the cockpit and the outside. A larger berth in the lounge is gained but the interior height and roominess is affected negatively.
Bathroom aft
In this layout the bathroom is located in the aft part of the yacht. The lounge and second accommodation will gain size but the connection interior/exterior will be affected negatively due to the bathroom blocking the view.

Cockpit cover
An important aspect to take under consideration is all the different pieces of equipment often found on a blue water cruiser. Spray hood, sun cover, targa bow for navigation systems, rain protection and main sail sheeting position are a few. All these systems together will take up a lot of space in the cockpit and will not be esthetically appealing. Therefore one universal solution that suites the yacht is definitely of interest. This is what the idea generation stagnated towards.

The arcs
This solution is a combined sun cover, sprayhood, wind protection, instrument position and sheeting point for the main. It will also be equipped with solar panels on the extractible sun cover. It could also be equipped with a system to collect rainwater.
Targa

This solution is a combined sun cover, instrument position and sheeting point. It could also be equipped with solar panels on the extractible sun cover located on a roll. This solution needs to be supplemented by a spray hood.

Cockpit

The cockpit layout is essential for a yacht and needs to be suitable and functional both during sailing and in harbor. As mentioned earlier the lounge and the cockpit are the social areas on the yacht and should be well integrated. There are a lot of different features to consider in the development of a cockpit, but the main feature on this kind of yacht is that it must be comfortable and safe. Navigation systems must be placed near the helmsman’s seat. It needs to work well for shorthanded sailing but at the same time be roomy and easy to move around in. All cockpits presented are equipped with a swing pedestal because it gives a big reachable radius without being too much in the way when not needed.

Steering forward

This layout has the steering wheel in the front of the cockpit and a large u-shaped sofa in the aft. This layout would not be possible if there was an aft cabin. Large stowing space beneath the sofa area and sail controls located near the steering pedestal for shorthanded sailing. A feel of safety because of the closed aft.

Traditional

A traditional cockpit layout with an open transom for easy access to the sea. Sail controls are located near the steering pedestal for shorthanded sailing. There is stowage space underneath the benches.
Asymmetric
This layout is a combination of the two above, u-shaped sofa with the steering wheel aft.

Dinghy
The dinghy solution for a blue water cruiser is a fundamental feature. Due to the size of this yacht, a dinghy garage is not possible. Though hanging in the aft from a davit is the most common solution, this is not often an esthetical choice and the davit takes a lot of space, especially relatively when not in use. Despite the problems with davits, keeping the dinghy in the aft is a practical solution.

Beams
This solution is two ejectable beams on which the dinghy is supported. When not in use they can slide inside the stowage area beneath the sofas in the cockpit. They could also be used as a gangway when in port, or an external sundeck or hammock support.

Triangle
The triangle concept is two removable triangular consoles hanging over the aft, supported by the transom. When not in use it can be removed and stowed away, or it could function as a gangway or external sundeck.
APPEARANCE

A sail yacht is like a moveable summer cottage. No one would buy a summer cottage where the kitchen and the living room were located in the cellar and connected with the terrace through a tiny little door. None the less this is what a common sailboat looks like and even the survey results validate that common sailboats give a confined feeling. The main idea during this project has been to create a social yacht with that dream summer cottage as role model. Spacious, social and esthetically good looking but still apprehending the performance and handling needed.

A bright interior and a spacious feeling are achieved by designing the whole deckhouse in glass. A social yacht is achieved by connecting the exterior with the interior, not separating them. This was the first step towards the appearance of the Storm Bird, see Figure 7.

![Figure 7. First appearance of the Storm bird from the design paper](image)

As everything started to come together the Storm Bird started to take shape. With large windows the Storm Bird will feel spacious and connect in- and outside.

![Figure 8. Design sketch of the developing Storm Bird](image)

With this combination it is a blend between a motor yachts social layout and a sailing yachts neat lines and traditional beauty, with a modern touch.
Concept development

The design work has been carried out using the spiral approach described in [2]. This way the design concept could develop over time from different ideas of solutions in the first spiral to proper working functions in the end.

CONCEPT CHOICE

Together with Håkan and with basis in the evaluation methods described above, one total concept was chosen from the main sub areas. This was the choice deemed most interesting and with the biggest amount of innovation.

The chosen concept has the steering forward cockpit with the bathroom forward interior and combines the arched cockpit cover and the triangle dinghy handling system. With a decision regarding the product to be, concept development could begin.

DESIGN

Here follows a presentation of all design features and solutions with motivations.

EXTERIOR

The result of the exterior design is shown in Figure 9.

![Figure 9. Exterior design of the new Storm bird](image)

Anchor box

The anchor box is part of the deck mould and has three main tasks. It supports the cutter stay attachment, stores the anchor gear and acts as a bulkhead. Being part of the deck mould it will keep the mould count down and also be more production effective. On the hull mould there is an outgoing flange. On an ordinary sailboat the flanges are normally inwards and this means that if integrated in the deck the anchor box cannot be wider than the inner measurement of the hull, see Figure 10. This means that the anchor box would not get any support from the hull sides but only from the bottom part of it. In this case the bulkhead created by the anchor box has to support the cutter stay and thus needs to be structurally capable. On the Storm bird the flange is outwards and connects to the hull far up which provides enough glue surface and makes this solution possible.
The anchor fitting is integrated in the bowsprit. The chain is led into the anchor locker under the deck for a clutter free foredeck, Figure 11.

Cover board
To achieve the special look the window is covered with a board. This way the window can be fitted on the outer side of the deckhouse without any recess and it will cover up the joint, see Figure 12. The cover board also covers the ropes stretching from the mast to the cockpit, see Figure 13.
Deck hardware

As shown in Figure 13, there are no winches on top of the deckhouse. As a result of the cockpit layout a special rope handling system has been incorporated. On a blue water cruiser you spend several days sailing in a row and it is of great importance to get the ropes organized. With winches on the deck house they tend to end up on the cockpit floor.

![Figure 13. Deck hardware layout](image)

To get the ropes from the mast to the rear part of the cockpit with as few nicks as possible the ropes are diverted higher up on the mast than usual. This way the ropes can be led underneath the board covering the windows and down to a rope organizer taking them straight back to the clutches. This also proved to be gentler to the fixings than an ordinary solution due to less angle change.

The standard sailing equipment is designed with four winches; the two in front are for the mainsheet and all controls coming from the mast and the two in the rear are for the jib and genoa sheets, see Figure 14. The winches are reversible winches from Sélden, [8]. Between the clutches and the front winch on both sides there is an integrated box for rope handling. This way of organizing the winches everything is reachable from the helmsman’s seat or from the cockpit sofa. The winches and clutches are flushed to be out of the way and also not to interfere with the lines of the yacht. If necessary there is space for a third pair of winches at the rear of the other two.

The steering is a Jefa design swing pedestal, [7]. The yacht is also compatible with two small pedestals near the helmsman’s seat, with removable steering wheels, if that is preferred. The steering arrangement is designed to be adaptable to the desired steering position regardless of it being on the coaming to windward or on the seat to leeward. It is also designed for a comfortable standing steering position. The swing pedestal is an attractive solution due to the fact that it gives the possibilities of a twin wheel arrangement without having two wheels.

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2 mast base to deck organizer to clutches
Cockpit design
The layout of the cockpit can seem to be rather controversial. Here is a list of comments for the final design, see Figure 14.

- The sofa is facing forwards for better control during sail and to connect the outside with the inside.
- The navigation area is located in the front, partly for control but also for easier wiring.
- The layout of the cockpit is as semi open cockpit. This means it is a blend of a traditional closed aft cockpit and a modern open aft, but with the positive sides from both. It provides space for a life raft and the gasoil tube under the hatchet.
- The main sheet position is on the roof to keep the cockpit floor clean.
- A movable backrest can be placed near the bathing platform or as in the picture to divide the large sun bathing area for greater comfort in the sofa.
- The aft deck is shaped for sitting
- A folding table in the middle for support during sailing for the feeling of safety.
- Helmsman’s seat in the center with every control within reach
- Large stowage under the sofa on both sides
- Four small spaces for daily items
- Storage such as drink rest incorporated in cockpit table
- Emergency steering easily accessed

Door
The large glass doors are an important detail differentiating this yacht from other sailboats. It gives an open feeling and is essential for the concept of a social yacht. It is made of four glass hatches where the middle two open. To get a clean look and keep the complexity down, the hatches do not slide open, they have a sort of canting lift that is opening in a half circle. Due to the long but narrow glass hatches a sliding
A solution would be hard to get working properly without it becoming very solid and expensive structurally. A hatch that is lifted in place do not require the same precision, it just has to fit in the extremes. It will also be flushed in the extremes because of the different movement that comes with the lifting, compared to a sliding door where there would have to be an overlap.

For the version without the arcs there is a spray hood. When this is not in use it will fit in the framework around the doors, with a flap of glass to hide and secure it. This way the spray hood will be out of the way during sailing and also kept from tampering with the design too much. Explaining pictures on both doors and spray hood cover pieces in Figure 15 and Figure 16.

![Figure 15. Glass doors closed and spray hood up](image)

![Figure 16. Glass doors open and spray hood down](image)

Locking is taken care of with special glass door locks from Dorma SG, [10]. There will be a flap in the opening as well to give sufficient height of walls in the cockpit according to ISO\(^3\).

**Helmsman’s position**

The helmsman’s position is designed for both left and right handed steering. The seat and controls are user friendly designed so that vital controls are easily reached without moving around. The seat supports an ergonomic position and can be supplemented by a pillow on the lifelines, see Figure 17. There is also a

\(^3\) Reference to cockpit height stated by Kenth.
convenient foot rest for a safe and comfortable position. The clutch for the main sail is a special jammer which makes the trimming as easy as possible whilst not being in the way.

Figure 17. The helmsman’s position

**DINGHY HANDLING**

A dinghy handling solution has been discussed above. The result is a simplified dinghy davit system with a low level of complexity. Since the boom is quite long and stretches far aft, a lifting system can be fitted to the aft end of it. This is then used to lift the dinghy up on the transom where supports are put to hold the dinghy in position. Figure 18. With the bathing platform in the down position the dinghy bottom is easily accessed and secured to the supports. If no dinghy is used on board this system need not even be supplied or if seldom used it can be stowed in the boat and mounted when needed. It can also work as a gangway or an extra sun bed in port.

Figure 18. Dinghy handling system and gangway/sun deck

**COCKPIT PROTECTION**

The chosen cockpit protection system is a bent arch starting where a spray hood would be attached but extending further aft to incorporate a bimini top if needed. Figure 19. When a complete cockpit cover is needed, sides are attached to the arches to complete the cockpit tent. The arches also provide a good place
to mount radar and additional antennas. This way, four different needs are addressed in one product. A system that collects rain water from this big surface is also integrated. Since all water collected on the top of the canvas runs forward a massive amount of water can be fed to the tanks in a rain storm. To the buyers’ wishes, a normal configuration with a spray hood can be fitted as well.

![Figure 19. The arches for cockpit protection](image)

**LAYOUT**

The layout is based on experience from the market research and the idea of good contact between different areas on the yacht. Results from the market research as to where time onboard is spent has been used as a base to the shape and function of the different areas in the layout. This together with the social aspect of having good contact between social areas in the interior and the cockpit has resulted in the layout of the yacht. Figure 20. Ergonomic norms have been applied in the design to ensure functionality of all areas both during sailing and in harbor, [2].

The interior is designed to separate the living quarters with the social areas and to connect the interior with the exterior. Because of this the extra cabin and bathroom ends up in the front and the bulkhead for the bathroom is quite near the entrance. This may result in a bit of a cramped feeling for a 37-footer. To achieve a more spacious feeling there is a mirror placed on this bulkhead and the striping makes the interior more elongated. There is good standing headroom of 195 cm which was a design goal.

![Figure 20. The interior layout](image)
Cockpit
The cockpit is facing forward. The best seats are purposely designed to face forward as that is where the action onboard is. In the aft part a longer bench/sun lounge is created when the bathing platform is in its up position. The wheel can be tilted to both sides. All the instruments are mounted in front of the wheels to be visible to everyone on board. All sail controls are led to the side winches and ropes are then hidden in deep containers. There is stowage space under the cockpit benches and under the aft lounge place where the life raft and gas bottles have their appointed places.

Wet locker
With access from the cockpit a wet hanging locker can be found. This way wet foul weather gear never has to go in the boat. The locker is properly drained through a skin fitting that also takes care of the water drain from the Swing steering pedestal.

Kitchen
The kitchen is large and straight with lots of counter top space as well as stowage. The fridge is hidden under the middle part and access is through a big opening door from the side, a better solution than a counter top filled fridge which forces the cook to move everything from the counter in order to open it. To make the kitchen safe in a swell there is something to lean or brace against at all positions. Good contact with the lounge area as well as with the cockpit. The kitchen's three main parts; stove, counter top and sink area are placed so as to get a user friendly environment. Above the stove there is an openable hatch in the window to ensure good ventilation.

Table module
In the middle of the kitchen and lounge area there is a small table module. This is designed to use to brace against in the kitchen and to mount a table on when needed. Inside the module the batteries can be found.

Lounge area
The sofa has been designed facing aft to ensure good contact with the cockpit and also good views through the big aft facing windows. To make it extra comfortable the seating depth has been exaggerated.

Navigational area
Directly under the cockpit mounted instruments the navigational area is placed. Here all electric devices are controlled and the table holds charts and other equipment. A big 24 inch flat screen can be placed here to act as a screen to a computer but also as a TV visible from the lounge and the kitchen.

Bathroom
The bathroom is placed in the middle of the yacht. It features a separate shower compartment and a central sink. The mast, which is keel stepped, comes down in this compartment making sure the boat stays dry.

Cupboards
To port on the way forward there is a large area with cupboards and hanging lockers. Here a dedicated book stowage is incorporated.

Extra cabin
The extra cabin features bunk beds. The entrance is through a sliding door and ample ventilation is ensured through a hatch in the roof. Stowage is ample through the use of the cupboards opposite the entrance and hanging space inside the cabin as well as some storage space under the lower bunk.

Master cabin
The master cabin is forward with a large V-bed and dressing space behind the bed on the port side. A hatch in the roof gives ventilation and light. Storage space is in the cupboard on the port side, in the lockers along the sides and in front of the berth as well as under it.
ERGONOMICS

Much effort has been put into making the cockpit as comfortable as possible, during sailing as well as in port. The sofa is designed for five dining guests. The sofa can also be used for sunbathing. As can the sun berth which is equipped with a comfortable pillow. Inside all functions and spaces are sufficiently proportioned. All beds are at least 200 cm long with the forward bed stretching 235 cm. The lounge is comfortable for four and the kitchen has a lot of space whilst still giving bracing positions against the table module and interior structure. The toilet is designed to give enough space and not to give a cramped feeling whilst still providing a safe position at sea. The same goes for the shower. See Figure 21.

![Figure 21. Plan and profile views of ergonomics](image)

There is full standing head room in the lounge, kitchen and bathroom and a bit lower in the front cabins.

ALTERNATIVE LAYOUT

An alternative to the standard interior layout has been developed as well. To address the needs of the cruising couple even more, a version without the extra cabin is presented. In this case the master cabin is huge, with a sofa where the extra cabin otherwise would be situated. The sofa could then be used as a sea berth or just as a place to relax and spend some alone time when needed.

![Figure 22. The alternative front cabin (left) and the standard one (right)](image)
To ensure flexibility the sofa could be turned into a bunk bed by lifting the back rest if the need for an extra cabin arises. In this case the boat could be supplied with a foldable drag-out wall for privacy.

**SEA BERTHS**

An important feature on a blue water cruiser is the ability to berth people comfortably in a seaway. The sea berths should ideally be placed near the motion centre of the boat, give good support on both tacks without allowing the person to slide around and be placed so that one travels feet first. A plus is a sea berth where basic information about the state of the boat can be seen. On the Storm bird the sofa area converts into a longitudinal sea berth and a lee cloth can be added. The thought is to be close to the instruments and that sails should be visible through the large window in the opening. The extra cabin also provides sea berths located in a favorable position on the boat. These are more out of the way and give more privacy. A minus is the fact that all sea berths are located on the same side of the boat. For a cruiser however this should not be an issue.

**STORAGE SPACE**

There is vast stowage under the cockpit. Accessed through hatches on both sides the space is supposed to hold everything from sails and ropes to fenders and tools. There is also space for piping and installation of autopilot and heater. On the starboard side big things such as sails go. Also access for service of the equipment installed under the cockpit is through there. On the port side a more shallow storage space is found.

**SYSTEMS & FUNCTIONS**

A schematic figure of the systems described under this heading is supplied in Appendix 3.

**STEERING SYSTEM**

The wheel is unconventionally placed forward in the cockpit. To allow for a proper sailing position to windward in all conditions the tilting wheel solution from Danish manufacturer Jefa [6] was chosen. This has a module that is mounted in the cockpit floor where the wire is led aft to the quadrant. This needs drainage from water, a problem addressed by connecting the drain to the wet weather gear locker placed nearby that is drained through a skin fitting. The tilting pedestal makes the cockpit more flexible with a small wheel which is out of the way when not in use and at the right place when in use. Figure 14.

**NAVIGATION AND INSTRUMENTATION**

Since the wheel is forward in the cockpit the instruments can be placed flush on the deck sides facing into the cockpit. This allows for easy connection and service because of the proximity to the navigation central just underneath. At the same time the esthetics of the boat improve when no instrument pod is needed. Added to this the instruments are visible from all positions in the cockpit which makes it possible for all crew members to take part in the navigation work. Figure 14.

**PROPULSION AND ENERGY**

As mentioned earlier an electrical propulsion system is an interesting alternative to a conventional propulsion diesel engine. The chosen system comes from Fisher Panda and features a 10 kW propulsion electric sail drive. It comes with a diesel generator from the same manufacturer that can power the propulsion continuously. The charge control uses an inverter to the onboard 230 V AC consumers and as soon as power in the battery is low, the generator starts automatically. With a powerful battery bank, solar panels and the ability to charge with the propeller while sailing this will probably prove to be a very versatile system. Other pros include very quiet and vibration free propulsion and power generation.

The propulsion unit is 48 V DC and the generator delivers 48 V DC. Because of the fact that boat equipment only exists in 12 and 24 V DC versions, the onboard power system is chosen as a 24 V DC system. Everything except the VHF can be powered that way. This means that the generator directly supports the propulsion system with 48 V and charges the battery bank converted into 24 V DC. The opposite happens when the propulsion system is driven by the battery bank in which case the battery...
power needs to be converted to 48 V. Explaining electric scheme in Figure 23. This is a proposition of a system that realizes the idea above.

**Figure 23. Schematic electrical system**

**TANKS**
The boat has one big fresh water tank placed neatly in the middle of the boat under the sofa, very close to the motion centre. Figure 24. This way the boats motion and static heel angle is nearly independent of how much water is being carried. 370 liters was deemed necessary for a long range cruiser of this size to ensure long self-sufficiency.

**Figure 24. Water, holding and diesel tanks**
The fresh water pump is situated next to the tank under the longitudinal part of the sofa where there is also space for a water maker, both with easy access for service. The piping is uncomplicated since the heads are very close to the tank and the kitchen is right next to the bathroom. A clever detail is the placement of the water heater under the sink in the bathroom. This way eventual leakage from this area is contained in the water tight heads module. Piping is also led aft to the bathing platform where there is a fresh water shower.

Black water is contained in a holding tank by the toilet. The size is 70 liters and it can be emptied through a deck fitting as well as through a skin fitting. A double emptying system is advised since this makes toilet use possible even if the tank is full or not functioning.

A 250 liter diesel tank is placed under the aft port stow locker.

Sufficient tank space is one of the things regarded important in the design of the new Storm bird. A massive increase in tank volume compared to the original version has been made. On a long distance cruising boat, capable of crossing oceans big tanks will always be an asset. This way carrying diesel or water in external jerry cans on deck or in the aft stowage space and thereby changing the centre of gravity can be avoided.

**Electronic Installations**

All electric appliances have their dedicated space on board. There is a space under the cockpit floor next to the navigational table, with access from the interior of the boat where installation of AIS, navigational computer, the onboard power system and the likes is intended. All systems are close together which makes wiring easy and of course proper ventilation and water tightness is ensured. Figure 25.

![Figure 25. Electric appliances and their appropriate position](image)

**The Deck Joint**

As mentioned earlier the flange of the hull mould on the original Storm Bird is outwards. With this type of hull to deck joint the boat gets built in bulwarks but the interior height is affected negatively. Figure 26. Due to the problem with the lack of standing headroom in the interior, the deck joint is a relevant feature to change. Done properly the interior height could be increased without making the deck house look bulky. This is a crucial part in the development of the Storm bird project. Even though the bulwark solution is scrapped, a foot rest still needs to be incorporated in the design of the hull deck joint as prescribed in [5].
Problems
The main issue is to get a neat and strong merge but there are many problems in changing the joint. 
- The hull and deck can differ up to 0.05% depending on different discrepancies in the production.
- There must be enough glue surfaces between the hull and deck to ensure water tightness and strength.
- No visible hard edges or poor surfaces.
- During decking the edges must be fixable so as to hold the deck in place.
- The complexity needs to be kept down for production efficiency.
- The new joint has to work with the physical geometry of both the deck and hull mould.

Change the hull mould
One way to attack this problem is to change the hull mould to an inwards flange. This would be the easiest solution to get a strong and neat joint. On modern yachts an inward joint is the most common way to design the joint. In this case however, the merge in the hull mould would leave a poor surface on the hull, stretching from stern to bow, see Figure 27. This could be coped with afterwards, by grinding or covering it with a board.
Adapt deck mould

Instead of changing the hull mould the deck could be adapted to fit the hull covering the joint. Many solutions would be possible but incorporating a core piece the length of the deck protruding upwards to create a foot rest and downwards to supply glue surface in the joint could prove an interesting alternative. Figure 28

Figure 28. The alternative deck joint and the gain in interior height (mm)

Evaluation

Changing the flange inwards would be the best way to get a neat and strong joint, but not the most efficient way due to the poor surface. An inlay would be improper and grinding it afterwards would be time consuming and intervention with the hull mould would be necessary. Therefore adapting the deck to the hull is the most efficient solution. The gain in interior height is 55 mm.

Solution

This solution is a development of the joint used today and is described in Figure 29. The hull and deck merge flange will be cut in the same way as today, (1). To get enough glue surface and to ensure the deck will end up in its right position, a piece of core, (2), is placed along the deck edge creating both foot rest and glue surface. The poor surface by the cut off is covered with a board, (3). This board would be easy to fix due to the continuity and straightness of the hull to deck joint.

Figure 29. The new deck joint with its different parts
STRUCTURAL DESIGN

The aim with the structural design is a light, strong and easy to build yacht, well fitted for its intended use. An important factor is the interior height which is somewhat governed by the size of the floors. Emphasis is put on strength, not low weight as a long distance sailor rather sees a strong build than a light one, according to survey results. Building techniques and thoughts on rationalizing the building process is also discussed. The structural members do not only stiffen the boat but also support the interior and make for clever ideas to be incorporated in the design. The main goal with the analysis is to arrive at a realistic weight and centre of gravity calculation to evaluate the boat in that respect.

MATERIALS

The decision to build the boat in glass fiber sandwich was made based on experience together with the company. This is also a material with which the company has a lot of experience. The sandwich core material used is the in house brand called Airex with a density of 80 kg/m³. Material properties have been approximated according to [1]. The fiber content of mass has been conservatively taken as 0.45. This corresponds to at the least a woven roving fabric in an open mould with a simple surface, hand laminated. Ideally hull and deck should be vacuum infused in which case the fiber content could be taken as 0.60.

STRUCTURAL LAYOUT

The layout of the stiffening members can be seen in Figure 30. In the bow a system of stringers and bulkheads will account for strength when it comes to slamming loads. By the horizontal orange lines the anchor box which is integrated in the deck will sit. This as well acts as a bulkhead which is important in the bow area where slamming loads are big and panels have little curvature. In the middle of the boat, exactly aligned with the loads from the rig there is a space frame/bulkhead. Further aft there is a structural bulkhead supporting the boat in the forward part of the cockpit and also giving rotational strength where the big opening is. The green parts are the floors taking the loads from the keel and also giving longitudinal strength. The keel is mounted on a sole in order to have a bilge onboard to collect water in. It also lowers the centre of gravity of the keel. The longitudinal standing plate in the aft supports the cockpit floor and is also the boundary for the aft fuel tank.

Floors

Marked with green in Figure 30 are the floors. This is a net of structural stiffening members that support the loads in the bottom area and especially around the keel. The dimensioning of these has been undergone using the method described in [2] with stiffening member data from [1]. This approach heels the boat to a 90° angle and uses the moment from the keel to calculate the required sectional modulus for the keel bearing floors. The longitudinal parts as well as the floors not in direct contact with the keel have all been dimensioned to at least the same sectional modulus as the above. Having similarly sized floors makes production easier because stacks of fiber mats can be cut to the same sizes.
Bulkheads

The bulkheads are marked in blue in Figure 30. The forward watertight bulkhead is included in the deck. They were all dimensioned using expertise at the company together with methods from [2]. The central bulkhead could rather be seen as a space frame. This frame of structural support works together with a built in beam structure in the deck to absorb the loads from the rig. Adequately placed right where most effective, i.e. directly under the shrouds, the space frame gives a dedicated and structurally superior attachment point for the chain plates. Figure 31.

Stringers

The stringers were dimensioned using the approach in [2] using formula specified for stiffening members such as stringers and with an over exaggerated length input to make them independent of other members as well as a bit over dimensioned to cope with really rough conditions.

A different idea as to the slamming strength would be to use the interior already supposed to be installed as a stiffening member. The required sectional modulus of the stringer above is

\[
SM_{\text{stringer}} = \frac{83.3 \cdot P \cdot s \cdot l^2}{\sigma_n} = 86.6cm^3 \tag{1}
\]

A requirement easily met with a wood set up likely to be put in place in the above area anyway. The design stress can be considered the same in both cases. With a wooden frame at least 15 mm thick and with 200 mm depth would provide a sectional modulus of 100 cm³. This would cover the same area as the stringers above and run through the forward berth and aft in the guest cabin and the wardrobes on the port side. Figure 32.
The concern however is for a wood stringer to be too pointy and thereby give a stress concentration right where it is supposed to give support. Experience says that such a set up could be risky.

**KEEL BOLTS**

The keel sits on a keel sole which is like a hollow space lowered under the hull so as to have a low point inside the boat to collect bilge water. The strength in the keel area comes from the floors. The keel sole is single laminate, 20 mm. A schematic image of how the actual reinforcement is aligned with the keel can be seen in Figure 33. The floor taking the loads from the rig need to have a hollow space for tightening of the forward most keel bolt which sits right under the mast.

The actual keel bolts have been calculated according to the method described in [2]. This method simply uses the weight and the lever of the keel ballast and distributes this moment on the keel bolts using their offset distance. The yield strength of the keel bolt material was taken as 440 MPa, stainless steel with high corrosion resistance. The keel bolts minimum diameter, with three rows of bolts came to 20.6 mm which correspond to M24.
SCANTLINGS

The hull and deck are designed to be built with a combination of sandwich and single lamina. The hull will be mainly sandwich. Parts with single laminate include the entire keel area, i.e. under the floors, in strips stretching all the way forward and aft in the middle of the boat and around areas for skin fittings. The scantlings have been calculated using [1] for both sandwich and single laminate plating. The scantlings have been dimensioned to apply with CE category A-Ocean. The calculations are based on design pressures and simple plate theory. Panels are ranked differently based on their position, meaning that the area around the bow is considered most exposed. The hull and deck was divided into panels according to Figure 34. Results are written as minimum sectional modulus for the inner and outer sandwich laminate and also a minimum total thickness based on shear strength and a minimum moment of inertia. For the single laminate parts simplified calculations are made and a result of only minimum thicknesses is displayed. The deck is only presented as three different panels although many more could be distinguished. Figure 35. The mentioned ones are the largest and therefore dimensioning. Results are shown in Table 2 and Table 3.

Table 2. Scantling requirements for hull panels

<table>
<thead>
<tr>
<th>Panel nr</th>
<th>l length (mm)</th>
<th>b breadth (mm)</th>
<th>c curvature (mm)</th>
<th>min SMi (cm^3)</th>
<th>min SMo (cm^3)</th>
<th>min I (cm^4/cm)</th>
<th>min t shear (mm)</th>
<th>min t single (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1007</td>
<td>1006</td>
<td>0</td>
<td>0.1613</td>
<td>0.1248</td>
<td>0.12</td>
<td>16.1864</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1336</td>
<td>437</td>
<td>109</td>
<td>0.0769</td>
<td>0.0658</td>
<td>0.034</td>
<td>13.1456</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2220</td>
<td>904</td>
<td>52</td>
<td>0.2477</td>
<td>0.212</td>
<td>0.2192</td>
<td>23.051</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1106</td>
<td>786</td>
<td>133</td>
<td>0.2223</td>
<td>0.1902</td>
<td>0.1558</td>
<td>24.4071</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2034</td>
<td>857</td>
<td>42</td>
<td>0.2209</td>
<td>0.1891</td>
<td>0.1845</td>
<td>21.8184</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2034</td>
<td>706</td>
<td>42</td>
<td>0.1842</td>
<td>0.1576</td>
<td>0.1304</td>
<td>20.5158</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>3369</td>
<td>858</td>
<td>42</td>
<td>0.0975</td>
<td>0.0835</td>
<td>0.089</td>
<td>4.3767</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3429</td>
<td>737</td>
<td>77</td>
<td>0.0929</td>
<td>0.0795</td>
<td>0.0756</td>
<td>3.5011</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2450</td>
<td>904</td>
<td>38</td>
<td>0.0818</td>
<td>0.07</td>
<td>0.0735</td>
<td>7.3741</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2374</td>
<td>923</td>
<td>87</td>
<td>0.1264</td>
<td>0.1082</td>
<td>0.1149</td>
<td>10.5133</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>764</td>
<td>400</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>3.06</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>787</td>
<td>593</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>4.19</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>578</td>
<td>583</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>3.51</td>
<td></td>
</tr>
</tbody>
</table>
To meet with these requirements the hull and deck will be dimensioned according to Table 4. The minimum single laminate thickness in the deck panels has not been evaluated. However it is written as the thickness that would occur if the core was removed. In the deck in places where e.g. cleats and winches are mounted the laminate will be single but with reinforcements to cope with the extra loads in those areas. This is however not taken into account in this study.

The outer laminate is thicker in both cases although the inner laminate is dimensioning. This comes from advice from the company and has to do with normal use, i.e. the outer laminate has to withstand more direct hits and difficult environments. The single laminate thickness will vary from 20 mm in the keel area, to the prescribed minimum thickness. A proper fiber layup is a matter for a different study or could be seen as a continuation of this study should the company decide to manufacture the boat.

**MANUFACTURING**

A proposition regarding the building technique is presented here. Considerations regarding this include cost, complexity, in house expertise, finish and effectiveness in production.

**Hull**

The hull is built in a female form by hand lamination or vacuum infusion. In either case it is a sandwich construction with precut mats of fiber and chunks of core material placed in the right position before lamination.
Because of the length difference that may occur between the hull and the deck the anchor box needs a heel in the hull for fastening. This has to be parallel with the glue surface on the box and along with the yacht. This is to ensure that the joint between hull and anchor box provide enough glue surface. The heels are built with small strips of core laminated in place when the hull is ready.

**Hull lengthening**

The existing hull mould has a negative stern angle and an outwards flange as mentioned before. To make the transom positive the hull mould must be lengthened by an external part. The existing mould has an outgoing flange throughout the whole aft part where to fit the transom from the deck mould. By changing to a positive angle the transom must end up in the hull mould instead of the deck, see Figure 36. The outgoing flange in the existing mould is glued with the flange on the external part and will create a strong joint. After this there will be a visible joint inside the mould that has to be treated afterwards.

![Figure 36. Hull mould with flanges](image)

By extending the mould the deck hull joint is transferred from the transom outer edges to the inward edges following the bathing platform cut out. It would be necessary to treat this joint in the cut out.

This external part could be in one piece and not be fastened on the hull mould. This way the transom could be more adapted to the bathing platform and the deck hull joint could be transferred to where it is not visible. There will however be a visible joint on the hull that has to be treated afterwards.

The keel sole was much bigger and deeper on the previous boat so the moulds have to be completed with a plunger so as to create the new smaller keel sole.

**Deck**

The deck is built in the same way as the hull. Stiffening members included in the deck are the space frame beam and the arched beams bearing the deck structure. These are built into the deck during manufacture. The space frame beam is an integrated structure that doubles as channels for the ropes coming from the mast. This integrates with the bulkhead part of the space frame through a glue surface. There is room for a bit of play in the hull size. The arched beams that make the deck line structure are bits of foam core integrated during the lamination process. The same goes for the foot list.

The deck must have a rind in the mould to highlight where to cut the hole for the window. The aft hatch could be manufactured in the space where the glass door will later be fitted, to keep down the mould count and reduce spill.

The hatches on the foredeck are flushed and will need a frame in the deck. That goes for the cockpit hatches and rope handling too, see Figure 37
Stringers
There are two different alternatives to the integration of the stringers in the bow section, as mentioned earlier. The base interior made of plywood could be used and laminated into place. If the core stringers are used they are applied as strips of core material, glued to their appropriate place and then laminated. Later they can be used as support for the interior in the same way as the plywood.

Inner liner
The inner liner or the floors are built in one piece in a male mould. This is then glued into place inside the hull. Pipes for tubing and electric wiring can be hidden in the hollows. The inner liner could be used to cover the rugged parts of the inside of the hull where the interior or the floorboards do not provide any cover, see Figure 38. This uses the nice surface of the inner liner for good looks at the same time as the extension bits provide glue surface.
**Bulkheads**
The bulkhead cores are made of wood with a surface of laminate where needed. The actual bulkheads are sawed out and fitted to their appropriate place with glue. After hardening they are laminated into place on both sides. Later screws are fitted as well to ensure a rigid construction.

**Space frame**
The bulkhead part of the space frame is made of a 24 mm wooden core fitted the same way as the other bulkheads. This integrates with the structure in the deck to act as a space frame. To make up for its weakened structure close to the deck there is an integrated beam in the deck that connects with the wooden bit through a glue surface. See Figure 31.

**Stiffening interior parts**
Parts of the interior working as stiffening members include the base for the kitchen and the sofa foundation. These are wooden parts laminated into place much like the bulkheads. Also the diesel tank acts as a stiffening member. It is made of stainless steel and glued into place under the cockpit. Glued to this is the longitudinal wall that the cockpit sits on. This also acts as attachment point for the steering system as well as the autopilot.

**Interior**
The interior uses the floors and bulkheads as attachment points. The idea is to save on interior structure. The bathroom is a module made of GRP and the outer side will be covered with laminate. This way the weight and the production cost are kept down. Figure 39.

![Figure 39. Non structural interior parts](image)

**Doors and windows**
The doors and windows are made of acrylic. To deal with the heating inside caused by large glass sections the acrylic could be treated with a reflective film.

The window can be cut into smaller pieces to simplify the handling and will be glued in place, the cover board hiding the joint. The door parts are also glued together. The two rigid door panels have one flange each towards the centerline that will give the opening parts a watertight seal. One of the opening swing doors will also be suited with a flange and a seal to prevent leaking. The deck is adapted for the swing opening with required angle. The swing arms are fitted with a plain bearing in bakelite, to give support for the construction. Figure 15

44
Deck surface
As an alternative to teak deck a composite decking material from Esthec [7] is used. This allows for freedom in the design of both deck pattern and color. The weight is reduced and the deck surface is virtually indestructible.

Bathing platform
This will be a rather complex mould and the result must be light and have a nice surface all around. The most common way of manufacturing a bathing platform is in a dual or closed mould. The dual mould will leave a rind which has to be grinded. If one presumes that the bathing platform is covered by a decking material this means that the upper surface is unimportant and it could be manufactured in one mould and cast with Esthec [7] on the ruff surface and edges. The composite decking material would act as anti slip pattern in white (to go with a white hull) or go with the rest of the yacht’s color scheme.

Moulds
To manufacture all the different parts of the boat made of GRP there need to be moulds. Every item needing a mould is listed in this part. It is relevant to keep the mould count down in an effective production since moulds are rather expensive to produce. With clever use of and adaptive moulds the complexity in the product is kept down.

Mould count
Here follows a list of all the moulds required in the manufacturing process of the Storm Bird. Figure 40 and Table 5.

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hull</td>
<td>Two halves</td>
</tr>
<tr>
<td>2</td>
<td>Deck</td>
<td>Aft hatch made from deck mould</td>
</tr>
<tr>
<td>3</td>
<td>Cover board starboard</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Cover board port</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Anchor box hatch</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Rudder</td>
<td>Complex double mould</td>
</tr>
<tr>
<td>7</td>
<td>Inner liner</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Hatch cockpit</td>
<td>Symmetrical so fits on both sides</td>
</tr>
<tr>
<td>9</td>
<td>Bathing platform</td>
<td>Complex technique</td>
</tr>
<tr>
<td>10</td>
<td>Breaker hatch</td>
<td>Symmetrical so fits on both sides</td>
</tr>
<tr>
<td>11</td>
<td>Rope hatch deck</td>
<td>Symmetrical so fits on both sides</td>
</tr>
<tr>
<td>12</td>
<td>Rope box</td>
<td>Symmetrical so fits on both sides</td>
</tr>
<tr>
<td>13</td>
<td>Bathroom</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Cover sheet instruments</td>
<td>Covers installations above chart table</td>
</tr>
<tr>
<td>15</td>
<td>Drain wet locker</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Cover sheet kitchen</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Glove box</td>
<td>4 pieces to fit in cockpit</td>
</tr>
<tr>
<td></td>
<td><strong>Optional</strong></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Arc starboard</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Arc port</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Bowsprit</td>
<td></td>
</tr>
</tbody>
</table>
PERFORMANCE
The performance of the Storm Bird has been assessed using Maxsurf’s Span and Hullspeed modules. The aim was to determine but also to provide data regarding the sailing capabilities of the yacht. Also the resistance and the propulsive power needed have been determined.

RESISTANCE ANALYSIS
In Hullspeed the geometry of the hull and its appendices are the input data. These are then analyzed using Delft series I, II and III basically using different hull and appendix parameters to determine the resistance of the boat. To compare and confirm the results two other methods were used as well, Fung’s and van Oortmerseen’s, showing very similar results. The resistance is shown in terms of propulsion power of only the hull, without any appendices in Figure 41.
The propulsion power is further estimated including the appendices in Figure 42. The keel is then modeled with its appropriate fin area and the hull and rig with their respective projected surfaces. A headwind of 20 knots was added as well.

To choose the appropriate machinery for propulsion the efficiency of the propeller must be considered. Assuming an efficiency of 60% renders the following power need for the propulsion. Figure 43.
Propulsion choice
To give the boat a cruising speed of 7 knots in the conditions stated above, the machinery needs to give about 10 kW on the axis. Lowering the speed to 5.8 and the power need is halved. It must be pointed out that no additional resistance due to waves is included in these calculations. All above is in calm water.

Normal diesel propulsion
To choose the appropriate diesel propulsion the efficiency of the gearbox and the saildrive need to be known. The choice depends on the wanted cruising speed under engine and the fact that the engine wants to run on lower revs than on which it gives the most power. Assuming again that a loss of 25 percent would account for the above the preferred diesel engine power would be at least 18 hp.

Electric propulsion
Continuing the discussion on electric propulsion the thoughts on efficiency are a bit different in that area. Safe would be to assume no loss in the electric propulsion unit. A 10 kW motor would give 10 kW on the axis.

Scanning the market the largest electric sail boat propulsion unit is actually 10 kW. This would according to the above work but without any extra resources to account for added resistance in waves. This analysis is based on a preferred cruising speed of 7 knots. If the customer can stand going slower the electric propulsion unit is certainly a good choice. Seeing it from an energy/economic point of view the velocity increase in the upper speed range is not worth the effort when compared with the corresponding power increase.

SAILING
Performance under sail has been evaluated using Maxsurf's Span module which is a basic VPP, Velocity Prediction Program. The VPP computes boat speed in different angles from the wind by an algorithm based on forces on the sails, forces on the underwater body and equilibrium between the two depending on heel angle. Still this is ideal conditions in calm water.

Hull modeling
Span analyzes the hull in terms of parameters such as width, righting moment and waterline lengths even under heel. The user specifies crew weight and additional appendages such as a saildrive or propeller. The resistance curve looks like Figure 44.
Sail plan
The sail plan is modeled using parameters from [3] and can be seen in Figure 45.
This is input in Span. Output comes in the form of a polar diagram Figure 46.

To determine the validity of the VPP the heel angles for different wind speeds and angles are studied in search of inconsistencies or extreme values. Examples show normal values, see Table 6.

<table>
<thead>
<tr>
<th>TWS, kn</th>
<th>TWA, deg</th>
<th>Hull speed, kn</th>
<th>Heel angle, deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>45</td>
<td>6.65</td>
<td>10.62</td>
</tr>
<tr>
<td>12</td>
<td>90</td>
<td>8.26</td>
<td>8.3</td>
</tr>
<tr>
<td>12</td>
<td>120</td>
<td>7.29</td>
<td>2.72</td>
</tr>
<tr>
<td>16</td>
<td>45</td>
<td>6.95</td>
<td>12.8</td>
</tr>
<tr>
<td>16</td>
<td>90</td>
<td>8.84</td>
<td>9.7</td>
</tr>
<tr>
<td>16</td>
<td>120</td>
<td>8.49</td>
<td>3.85</td>
</tr>
<tr>
<td>20</td>
<td>45</td>
<td>7.15</td>
<td>14.67</td>
</tr>
<tr>
<td>20</td>
<td>90</td>
<td>9.35</td>
<td>14.46</td>
</tr>
<tr>
<td>20</td>
<td>120</td>
<td>9.69</td>
<td>4.98</td>
</tr>
</tbody>
</table>
Balance

The balance of the yacht is governed by the location of the centre of effort of the underwater body, LCR, and the centre of effort of the sails, CE. Although hard to predict the balance of the yacht largely determines the feeling of the boat but is also a measure of safety.

When designing the Storm bird the aim has been to design a boat built to cross oceans and sail long distances under autopilot. This calls for a well balanced yacht in terms of good course keeping through gusts and wind shifts. Even though this has been the aim it is important not to design the boat to be dead and boring to steer manually.

The approach as to finding LCR and CE respectively has its base in methods described in [2] but with input from experience gathered by Håkan’s many years as a naval architect. In any method CE is placed in front of LCR and the horizontal distance between the two is called Lead. There are recommendations as to the amount of lead applicable to different types of yachts. For masthead sloops (like the Storm Bird) the recommended lead is 5 to 9% of Lwl. The diversion from the method in PYD [2] is that the rudder is considered in the calculation of LCR. This because the rudder is relatively big compared to the average yacht.

For all yachts the tendency to luff up in a gust is sought. This is for safety reasons because luffing up spills wind from the sails and reduces power which in turn makes for a self controlled, stable system. The opposite situation would be close to dangerous.

CE was found using the geometric centers of effort of the sails calculating the distance forward of CE on the line between the latter and CE Fore a. For definitions see Figure 47.

\[
a = \frac{1}{\frac{A_{\text{Main}}}{A_{\text{Fore}}} + 1} \quad (2)
\]

LCR was found using the same method using the centers of effort of the rudder and the keel respectively. The rudder area was weighted to 25%. This approach gave a lead of 500 mm or about 5%. On the low side but considering sailing balance with a big cruising chute on the bowsprit which increases the lead a lot this should be a good compromise. Also to be considered are factors that increase the lead

- Large beam which makes the hull more asymmetric under heel
- Low stability since heel increases lead

But considering the good stability and the hull shape of the Storm bird there should be little increases to the lead. The hull shape makes for maintained sections during heel which is positive when it comes to predicting lead.
STABILITY

The purpose of this analysis is to determine the stability of the yacht and also to evaluate the stability in the context of a long distance cruiser. Also it describes the manner in which items were placed in order to achieve the right floating attitude.

The stability analysis of the Storm Bird was done using Maxsurf and Maxsurf’s Hydromax and Span modules. Maxsurf analyzes the hull and calculates stability factors using the modeled hull and weight distribution parameters. To comply with CE-Category A Ocean the yacht must reach a specific Stability Index value called STIX hence this was also calculated.

The stability of the current Storm Bird is good enough. The STIX-value indicate Category A, Ocean capabilities and experience tells of the yacht being stiff to sail but also with pleasant dynamic qualities. The
aim is therefore not to make the boat more stable than its predecessor and risk making it unpleasant in a swell. A fair starting point is to make the new version as stable as the former one.

LOADING CONDITIONS
To evaluate the boats behavior thoroughly, two different loading conditions have been studied. This is to assess how loading affect the boats stability and static heel angles.

Minimum sailing condition - MSC
- No payload
- No crew
- No tank contents
- 155 kg miscellaneous weight

Fully loaded condition - FLC
- 2 crew and gear
- All tanks full

WEIGHT DISTRIBUTION
Evaluation of the centre of gravity is a delicate task on a small yacht. Placement of equipment and gear as well as the filling grade of the tanks could affect the position in the water a great deal. Ideally on a sailing yacht the mass distribution should be kept close to the motion centre to give good motion characteristics on board. This, along with other factors have been kept in mind when designing the yacht in order to get a good mass distribution with most of the weight kept close to the motion centre. To get a fair estimate of the weight distribution, all parts of the yacht have been taken into account in a list of items used for calculation of the centre of gravity. All items were taken into account. In Table 7 a simplified and shortened list of items is shown. A complete list in Appendix 5.

<table>
<thead>
<tr>
<th>Part</th>
<th>Mass</th>
<th>LCG</th>
<th>VCG</th>
<th>TCG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull &amp; Deck</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hull GRP and Core</td>
<td>650</td>
<td>5.9</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Keel reinforcement</td>
<td>50</td>
<td>5.66</td>
<td>-0.4</td>
<td>0</td>
</tr>
<tr>
<td>Mast step</td>
<td>10</td>
<td>4.6</td>
<td>-0.3</td>
<td>0</td>
</tr>
<tr>
<td>Engine bed</td>
<td>5</td>
<td>8.3</td>
<td>-0.3</td>
<td>0</td>
</tr>
<tr>
<td>Rudder reinforcement</td>
<td>5</td>
<td>10.3</td>
<td>-0.05</td>
<td>0</td>
</tr>
<tr>
<td>Deck GRP and Core</td>
<td>140</td>
<td>6.5</td>
<td>1.15</td>
<td>0</td>
</tr>
<tr>
<td>Deck house of GRP</td>
<td>99</td>
<td>6</td>
<td>1.3</td>
<td>0</td>
</tr>
<tr>
<td>Cockpit of GRP</td>
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<td>0</td>
</tr>
<tr>
<td>Bathing platform</td>
<td>30</td>
<td>11.1</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>Bowsprit</td>
<td>7</td>
<td>-1</td>
<td>1.2</td>
<td>0</td>
</tr>
<tr>
<td>Engine &amp; installation</td>
<td>385</td>
<td>7</td>
<td>-0.01</td>
<td>0.35</td>
</tr>
<tr>
<td>Rudder &amp; steering</td>
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<td>9.825</td>
<td>-0.025</td>
<td>0</td>
</tr>
<tr>
<td>Mast &amp; rigging</td>
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<td>5.18</td>
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</tr>
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<td>Keel</td>
<td>2000</td>
<td>5.1</td>
<td>-1.327</td>
<td>0</td>
</tr>
<tr>
<td>Deck equipment</td>
<td>168.1</td>
<td>6.75</td>
<td>1.375</td>
<td>0</td>
</tr>
<tr>
<td>Construction fittings</td>
<td>114</td>
<td>4.409</td>
<td>0.465</td>
<td>0</td>
</tr>
<tr>
<td>Fore cabin</td>
<td>100</td>
<td>3</td>
<td>0.25</td>
<td>0</td>
</tr>
<tr>
<td>Tanks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>370</td>
<td>6.3</td>
<td>-0.15</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Items could then be placed with care so as to get the desired position of CoG. A design goal was the position of the centre of gravity on the previous Storm bird which of course also corresponds with the longitudinal and the transversal centers of buoyancy. The desired and actual centre of gravity can be seen in Table 8. The displacement and different ballast ratios are shown in Table 9.

Table 8. The centre of gravity

<table>
<thead>
<tr>
<th>Centre of gravity</th>
<th>Desired value, m from 0</th>
<th>MSC, m from 0</th>
<th>FLC, m from 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
<td>5.925</td>
<td>5.8724</td>
<td>6.025</td>
</tr>
<tr>
<td>Vertical</td>
<td>-0.1</td>
<td>0.04665</td>
<td>0.0427</td>
</tr>
<tr>
<td>Transversal</td>
<td>0</td>
<td>0.01105</td>
<td>0.021</td>
</tr>
</tbody>
</table>

Table 9. Displacement and ballast ratios

<table>
<thead>
<tr>
<th>Displacement, MSC/FLC</th>
<th>Ballast ratio</th>
<th>MSC</th>
<th>FLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>5311/6221</td>
<td>Depl/keel ballast</td>
<td>0.376</td>
<td>0.334</td>
</tr>
</tbody>
</table>

PLACEMENT OF EQUIPMENT

The purpose of this study is to design a boat made for long distance sailing. As stated earlier the concept should be well planned to start with and needing little or no altering from the owner before setting off. With this in mind all imaginable equipment onboard has its own dedicated space. This way everything from mass distribution through serviceability to electric wiring and connecting can be planned on beforehand. In Figure 48 the different tanks can be seen in blue. Electric equipment can be seen in orange and the power and propulsion unit in red.
STIX
Stability Index or STIX analyses the boat's stability using the following parameters
- Righting energy
- Inversion recovery
- Knockdown recovery
- Displacement to length
- Beam to displacement
- Wind moment
- Downflooding angle
- The vessel's base size

The resulting factors are accumulated into a "score" which rates a vessel for Ocean, Offshore, Inshore or sheltered waters. Most of the factors are taken directly from Maxsurf. A calculation sheet for the Storm Bird STIX rating can be found in Appendix 6. The score is 33.14 which is just over the ocean rating limit of 32. As stated earlier the factor is dependent on vessel size and with this being a relatively small yacht with a large sail area that would explain the lack of margin.

GZ-CURVE
Some of the parameters in the STIX calculation are taken from the GZ-curve, the curve of the righting arm versus heel angle, Figure 49. This was obtained in Maxsurf where the area under the graph, the righting moment could be obtained. Values from Span were also used. Refer to the performance heading.

CONCLUSIONS
The Storm Bird rates as an ocean sailing boat which gives confidence that the behavior will be safe enough. The static heel angles in MSC and FLC are very small. The boat sits comfortably in the right position almost unaffected by the loading condition. This is a result of the positioning of all the different parts of the boat. The desired value of the vertical centre of gravity was not reached. This did however not affect the rating of the boat and was therefore regarded of less importance.
APPENDAGE DESIGN

KEEL
One of the aims with the project and also a wish from the company was a new keel design. The former keel was made with a combined bulb/wing on a fin with a very deep bilge. The aspect ratio on the old keel was low. Average values on boats in the same range are close to three. Also according to fig 6.8 in [2] the sweep angle is not optimal given the taper ratio of the keel. This increases the induced resistance. The tip of the keel is also not optimal. According to lifting line theory, this should be as deep as possible so that the tip vortices trailing behind the keel are as deep as possible, thereby increasing aspect ratio. The effect of the big wing on the bulb could perhaps increase AR when heeled but the windward wing could as well give interfering vortices which reduce AR and increase resistance. Regarding the bottom of the hull as a big flat surface, the effective aspect ratio is double the geometric AR.

Possible improvements
The draft of less than 1.5 m is fairly modest so a first improvement would be to make the cord shorter and the keel blade deeper to enhance aspect ratio. The bulb is probably not optimal. With more draft the bulb size can be reduced which will affect the wetted surface positively and in turn reduce resistance. Another aspect regarding the keel is that a wing configuration is sensitive to impacts. The new keel should be sturdier than the old one since long distance sailors tend to go aground or at least touch the bottom at some point.

Since the keel is relatively very heavy it has a lot of impact on the centre of gravity calculations. A good aim with the new keel is to keep the old righting moment but enhance effectivity and reduce resistance.

The new keel
The new keel was designed with Håkan’s keels on models like Tarac and SwedeStar in mind. These keels are designed using the same NACA profile throughout the entire keel. The bulb is incorporated by smoothly sizing up the profiles to create a full but still effective profile all the way down and including the bulb.

The keel on the new Storm bird was modeled in the same way but with a more slender, deeper blade and smaller bulb. Main parameters according to Table 10, Figure 50 and Figure 51. The joint between keel sole and keel must be as fine as possible. In the transition between keel and bottom, the round radius should correspond to the thickness of the boundary layer.

Figure 50. The keel with keel sole and lead part marked
Figure 51. Perspective view of keel

Table 10. Keel parameters

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Old design</th>
<th>New design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft</td>
<td>m</td>
<td>1.718</td>
<td>1.944</td>
</tr>
<tr>
<td>Sweep angle</td>
<td>degree</td>
<td>22.4</td>
<td>8</td>
</tr>
<tr>
<td>Taper ratio</td>
<td>-</td>
<td>0.73</td>
<td>0.8</td>
</tr>
<tr>
<td>Geometric aspect ratio</td>
<td>-</td>
<td>0.72</td>
<td>1.37</td>
</tr>
<tr>
<td>Effective aspect ratio</td>
<td>-</td>
<td>1.43</td>
<td>2.75</td>
</tr>
<tr>
<td>Centre of gravity</td>
<td>m below 0</td>
<td>1.303</td>
<td>1.327</td>
</tr>
<tr>
<td>Blade surface</td>
<td>m²</td>
<td>2.05</td>
<td>1.85</td>
</tr>
<tr>
<td>Mean chord</td>
<td>m</td>
<td>1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Keel area to sail area</td>
<td>%</td>
<td>2.9</td>
<td>2.65</td>
</tr>
</tbody>
</table>

Comments

The keel is about 20 cm deeper than the previous one. The plan form is also much more effective since the bulb is integrated in the keel blade. This will greatly affect aspect ratio and make the new keel much more effective. The keel ends as deep as possible to get as high aspect ratio as possible. It is a relatively sturdy design and it is not sensitive to impacts to the front. Neither will it tend to get stuck in nets or lines or the likes.

Improvements can also be seen in the relation between taper ratio and sweep angle according to [2]. The taper ratio is however not optimal because this keel design would not allow for that. This probably comes with a small increase in induced drag but not much compared to the old design.

The keel blade area is 2.65% of the sail area which is below the recommended area in [2] however reasonable for a modern and well performing cruiser. It is lower than on the previous design but then the keel will be much more effective.

In total the resistance will be massively reduced thanks to the reduction in surface area on the new keel. The bulb on the old keel has not been modeled but is deemed to have a surface of at least 1.5 m². This is a reduction of friction related resistance of almost 35%.
RUDDER
Since the keel draft was increased the rudder could be made deeper as well, hence a change of the old design was made. The idea was to make a more effective rudder without increasing resistance.

New rudder
The design of the new rudder had the basis in the thought of making it deeper. With extended draft the cord length could be decreased with maintained surface area. The surface of the old rudder was 0.635 m² so the new area was set to 0.65 which is 0.93% of the sail area, an increase from the former rudder but still below the recommendation in [2] of 1-1.8%. The four digit foil section creates most lift and is recommended for rudders in [2]. This also fits well with incorporating a round rudder axis at the desired position. A NACA 0015 that gradually decreases in thickness ratio to 13 is chosen. Figure 52 and Table 11.

Rudder stock
The rudder stock was dimensioned according to the ABS (American Bureau of Shipping), Appendix 5. This approach utilizes the maximum lifting coefficient and the maximum applicable boat speed to calculate the dimensioning side force and bending moment on the shaft. The rudder stock diameter has to be at least 55 mm which works with the desired rudder profile and chord lengths.

The rudder stock is taken through the hull and is also supported by the cockpit floor. This is important both when it comes to structural considerations but also seeing as the emergency steering needs to be applied somewhere if needed. This is taken care of without compromise, Figure 14.

The rudder stock is a lot of weight to carry so far aft in the boat. A carbon rudder stock would reduce weight considerably and is therefore recommended.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Old</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rudder draft</td>
<td>mm</td>
<td>1410</td>
<td>1647</td>
</tr>
<tr>
<td>Root chord</td>
<td>mm</td>
<td>540</td>
<td>390</td>
</tr>
<tr>
<td>Tip chord</td>
<td>mm</td>
<td>292</td>
<td>229</td>
</tr>
<tr>
<td>Taper ratio</td>
<td>-</td>
<td>0.54</td>
<td>0.58</td>
</tr>
<tr>
<td>Mean chord</td>
<td>mm</td>
<td>453.5</td>
<td>365</td>
</tr>
<tr>
<td>Aspect ratio</td>
<td>-</td>
<td>3.11</td>
<td>4.51</td>
</tr>
<tr>
<td>Rudder area</td>
<td>m²</td>
<td>0.635</td>
<td>0.65</td>
</tr>
<tr>
<td>Foil section</td>
<td>-</td>
<td>0014/0012</td>
<td>0015/0013</td>
</tr>
</tbody>
</table>
FURTHER WORK

The conceptual design presented here is a proposition of a yacht believed to be a real contender on the blue water cruiser market. Should a production of the Storm Bird be realized, there are a number of parameters that need refining or developing in order for the yacht to be ready for production.

To start with the hull moulds would need inspection regarding shape and measurements so as to verify that the model worked on in this project match the actual hull shape.

Then the interior needs a proper plan regarding material choice and building technique before the finishing touch with proper construction drawings can be made.

The planned deck to hull joint would need to be evaluated and maybe tested before the deck mould and the lengthened parts for the hull could be manufactured. The deck needs synchronizing with the interior parts as well.

A proper fiber layup plan for hull and deck as well as smaller details is then needed. To match everything with construction fittings especially for the rig this needs to be verified and chain plates along with their appropriate attachment points need designing.

The electric and propulsion system would need further specification. This lack thereof in the report is due to insufficient information on this rather newly developed system from the supplier.

All components also need to be specified in a complete list after which a total cost analysis could be made.

DIVISION OF WORK BETWEEN AUTHORS

Although a group effort in a whole this project consists of work done by two individuals. This section’s aim is to specify what has been done by whom, for future reference but also for grading purposes.

Jens has been responsible for the analysis parts, i.e. the structural design, stability and performance analysis, keel and rudder design. He has also done most of the hull and interior modeling in CAD.

Patrik has been responsible for product development, i.e. the project planning, the market analysis and the methods used to chose and evaluate designs. He has also done the modeling of the deck in CAD and most of the rendering work.

The concept has been developed regarding layout, functionality and systems integration strictly as a team effort with no one in particular in charge.
DESIGNERS’ COMMENTS

Designing a new yacht based on an old one is no easy task. Particularly if it comes to making a modern yacht with all of the expectations thereof, especially regarding internal volume, with the starting point in a 15 year old hull. However challenging the task the result mixes traditional lines with modern ideas in an appealing way. Living space has been optimized with respect to how different areas are actually used.

In an extensive idea generation process inspired both by own experience and the survey results the base to the design was founded. Arriving at this concept required deep analysis and evaluation of different factors and models but seeing as major yacht companies have reached similar thoughts regarding the development of long distance cruisers, the process might just have been successful.

The unconventional rope handling system was developed as the need for a new solution arose. This was due to decisions taken regarding the interface between cockpit and interior. In the process however, a system with many pros regarding for example angle change took shape and that made the attractive cockpit design possible. Getting rid of unattractive and unpractical roof top winches can also be seen as a progress in this yacht design especially since it clears the roof top to enhance solar panel space.

The interior arrangement is based on the realization of how the conventional saloon area on yachts is actually used. Reducing this seldom used area to the gain in size and effort when it comes to more important areas on board has resulted in a very attractive layout. One area so often mentioned among long distance sailors as down prioritized is stowage space. However on the Storm bird storage is more than plentiful.

With this design one aim has been to incorporate new ideas when it comes to power generation and propulsion to fit this segment of yachts. Effective charging is an issue on a blue water cruiser and in many situations charging and propulsion is carried out ineffectively by the same engine. As the need to power on board appliances rise, why not concentrate on charging whilst at the same time being able to reduce noise and vibrations. The Storm Bird’s energy solution is a dedicated diesel generator and electric propulsion together with solar panels and propeller charging.

With the Storm Bird a step is taken towards a new kind of social, smart, elegant, environment friendly and well performing blue water cruiser.
REFERENCES


9. Course PM. 4E1020 Master’s Thesis in Naval Architecture, 30 hp. KTH Stockholm 2010

Appendix I. Product design specification

1. PROJEKTET
1.1. Projektet ska gå mellan 100410-110325
1.2. Projektet ska resultera i minst ett fungerande koncept som ska levereras till CMI Composites 110311.
1.3. Arbetet skall dokumenteras i en teknisk rapport som ska levereras 110325
1.4. Arbetet ska presenteras på KTH 110318
1.5. Projektet ska motsvara 40 timmars arbetsveckor för två studenter i 20 veckor
1.6. Arbetet ska inkludera och summera studierna på KTH

2. PRODUKTKRAV
2.1. Konceptet ska utgå från befintligt skrovform men med utrymme för modifikationer
   - Höjning av fribord
   - Ändring av akterskepp
2.2. Konceptet ska utformas med möjligheter för segling längre sträckor och för längre perioder
   - Genomtänkt energihushållning och generering
   - Tillräckliga ytor och utrymmen för förvaring av proviant
   - Fungerande och lättillgänglig navigationsutrustning
2.3. Konceptet ska ha logi för två personer
2.4. Konceptet bör ha logi för ytterligare två personer
2.5. Konceptet bör utformas från ergonomiska normer
2.6. Konceptet ska utformas med en säkerhetsnivå speglad av användningsområdet
   - Livflotte ska ha därför avsedd plats utomhus
   - Plats för grab bag, epirb och övrig nödutrustning skall vara genomtänkt
   - Plats för utrustning för sjukvård, läcktätning, brandbekämpning skall vara genomtänkt
   - Innerutrymmen ska utformas så att all utrustning ligger säkert i sjögång
2.7. Konceptet bör kunna seglas/hanteras ensam
   - Vitala segelfunktioner neddragna till sittbrunnen
2.8. Det ska vara säkert att röra sig runt och i båten
   - Däck; grabbräcken, mantåg, däckutformning, livlinefäste samt halkskydd
   - Sittbrunn; grabbräcken, fotstöd, livlinefäste
   - Inredning; grabbräcken, inga stora fallytor i tex kök och toalett
2.9. Konceptet bör utformas på ett sätt att minska farligt arbete
2.10. Konceptet ska visa förbättringar, övergripande, jämfört med befintlig produkt
     - Fastsätta förbättringar/försämringa objektivt

3. EKONOMI
3.1. Produktionskostnaderna bör inte överstiga …
   - Vad är de i dagsläget
   - Vad kostar en motsvarande båt
3.2. Ex, produktionskostnaderna ska inte överstiga …
4. PRODUKTION

4.1. Produktionen bör hållas inom företagets resurser
   - Så stor del som möjligt ska göras internt

4.2. Konstruktionen bör utformas för en enkel produktion

4.3. Produktionsplan för konstruktionen
   - Däckskarv, överbyggnad

5. PRESTANDA

5.1. Båtens fartprestanda ska inte försämras jämfört med den befintliga produkten
   - Långfärdssnabb

5.2. Båtens ska ha erforderlig stabilitet för avsett användningsområde

5.3. Köl och roder ska designas för avsett användningsområdet
   - Grundstötning
   - Dynamik

5.4. Båtens prestanda på samtliga punkter bör förbättras jämfört med den befintliga produkten

6. KONSTRUKTION

6.1. Konceptet bör designas så lätt som möjligt för bibehålla klassning och egenskaper

6.2. Konceptet ska uppnå CE kategori A

7. UTRUSTNING/UTFORMNING

7.1. Lösning för jollehantering bör utformas
   - Ska kunna skötas av en person och bör vara enkel och snabb
   - Bör vara estetisk tilltalande
   - Ska vara sjö och vindsäker

7.2. Lösning för radar bör utformas
   - Avsedd plats för antenn och instrument

7.3. Lösning för plotter bör utformas för ett bra användargränssnitt

7.4. Plats för en autopilot ska finnas

7.5. Avsedd plats för segelförvaring bör finnas
   - Bör inte vara placerad i boytan

7.6. Lösning för ankare i stäven bör finnas

7.7. Förenklad access till vattnet ska finnas

7.8. Livflotte ska ha en avsedd plats utvändig

7.9. Instrumentgivarredundans bör finnas
Appendix II. Survey

Ålder; Kvinna/man; 
Vad har ni för båt? Årsmodell;

1. **Om ni hade möjligheten att ändra vad som helst på båten, vad skulle det vara?**

2. **Om ni fick möjlighet till att konstruera om båten, dispositionsmässigt, vad skulle det första ingreppet vara?**

3. **Närminn en detalj som förbättrar båten.**

4. **Vad är bra respektive dåligt med båten vid segling?**
   - **Positivt**
     - •
     - •
   - **Negativt;**
     - •
     - •

5. **Vad är bra respektive dåligt med båten vid hamn eller för ankar?**
   - **Positivt**
     - •
     - •
   - **Negativt**
     - •
     - •
6. Viktig utrustning vid längssegling enligt er.
1. 
2. 
3. 
4. 
5. 
6. 
7. 
8. 
9. 
10. 

7. Vad använd flitigt respektive vad använd knappt alls?

Kommentar

8. Uppskattingsvis, var tillbringas tiden vid atlantenöverfart resp i hamn/ankring på ett ”normalt” dygn.

Svara i antal timmar

<table>
<thead>
<tr>
<th></th>
<th>Hamn; Segling;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sittbrunn------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Däck-----------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Salong---------------</td>
<td></td>
</tr>
<tr>
<td>Pentry---------------</td>
<td></td>
</tr>
<tr>
<td>Koj/lytt-------------</td>
<td></td>
</tr>
<tr>
<td>Sjökoj (om det finns)</td>
<td>Hamn; Segling;</td>
</tr>
<tr>
<td>Navigationsbord-----</td>
<td>Hamn; Segling;</td>
</tr>
</tbody>
</table>

Kommentar

9. Uppskatta hur många personer som brukar vara med ombord på en längre tids segling

<table>
<thead>
<tr>
<th></th>
<th>% av tiden</th>
</tr>
</thead>
<tbody>
<tr>
<td>En person</td>
<td></td>
</tr>
<tr>
<td>Två personer</td>
<td></td>
</tr>
<tr>
<td>Tre personer</td>
<td></td>
</tr>
<tr>
<td>Fyra personer</td>
<td></td>
</tr>
<tr>
<td>Fem eller fler</td>
<td></td>
</tr>
</tbody>
</table>

10. Övrigt (ex. egna fungerande lösningar ni gärna framhäver)

Om ni har bilder på båten och då främst på detaljer nämnda i enkäten får ni gärna skicka med dem.

*Tack för att ni tog er tid!*
Appendix III. Facts Ovni 365

Teknisk data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Värde</th>
</tr>
</thead>
<tbody>
<tr>
<td>Längd över allt</td>
<td>11.94</td>
</tr>
<tr>
<td>Skrovslängd</td>
<td>11.44</td>
</tr>
<tr>
<td>Längd i vattenlinjen</td>
<td>10.67</td>
</tr>
<tr>
<td>Bredd</td>
<td>3.92</td>
</tr>
<tr>
<td>Djupgående</td>
<td>2.35/0.77</td>
</tr>
<tr>
<td>Segelyta</td>
<td>71</td>
</tr>
<tr>
<td>Vatten, diesel</td>
<td>320, 180</td>
</tr>
<tr>
<td>Deplacement</td>
<td>8800</td>
</tr>
</tbody>
</table>

Marknad

Aluminiumbyggda Ovni 365 vänder sig till långseglare med seriösa avsikter och är en båt med samma målgrupp som Stormfågeln. Ovnin tilltalar med sin stora bredd, rymliga interiör, byggnadsmaterial samt varierbart djupgående i form av fällköl. Tillverkaren, Alubat, jobbar med avsikten att köparen ska kunna personalisera sin båt utan att för den skull betala priset av en one-off-båt.


Ett annat viktigt försäljningsargument är fällköl då de påstår sig vara ensamma om att erbjuda fällköl till oceanglare.

Däck och sittbrunn

Ovni 365 har traditionell, stängd sittbrunn med rattsstyrning, negativ akter med integrerad badbrygga, storskotet på rufftaket och rorsmansplats bakom ratten. Det finns en fast targabåge långt bak för montering av radar, antenner och dylik. Denna kan också användas som jolledävert.
Inredning

Inredningen är traditionell med dubbelhytter i förpiken och i aktern. Toalett akteröver och bra navigationsbord. Köket är litet i L-form men det finns en avställningsyta i mitten av salongen som kan kopplas samman med pentryt. Detta för att fällkölenätens trumma behöver plats och detta ger även en naturlig bas för salongsbordet.

Rigg

Mastheadrigg med inre förstag. Gennaker halsas från ett kombinerat peke/ankarbeslag.
Appendix IV. Systems

- Electrical wiring
- Diesel piping
- Black water piping
- Fresh water piping
# Appendix V. Centre of gravity

<table>
<thead>
<tr>
<th>Part</th>
<th>Mass</th>
<th>LCG</th>
<th>Sum</th>
<th>VCG</th>
<th>Sum</th>
<th>TCG</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hull &amp; Deck</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hull GRP and Core</td>
<td>650</td>
<td>5.9</td>
<td>3835</td>
<td>0.1</td>
<td>65</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Keel reinforcement</td>
<td>50</td>
<td>5.66</td>
<td>283</td>
<td>-0.4</td>
<td>-20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mast step</td>
<td>10</td>
<td>4.6</td>
<td>46</td>
<td>-0.3</td>
<td>-3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Engine bed</td>
<td>5</td>
<td>8.3</td>
<td>41.5</td>
<td>-0.3</td>
<td>-1.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
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69
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### KEEL BOLT CALCULATIONS

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<td>Number of bolts / side (except bolts in CL)</td>
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<td>Diam. keel bolt acc. to ABS</td>
<td>in mm</td>
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<tr>
<td>Min. thickness</td>
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<td>Min. thickness</td>
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**Håkan Södergren Yacht Design**

Övre Tegnersvägen 4, 130 54 Dalarö
Phone. +46 8 501 503 09 Fax +46 8 501 510 06
Appendix VIII. Brochure

Storm Bird

Södergren Group
Håkan Södergren Yacht Design

Master Thesis
Centre for Naval Architecture
Royal Institute of Technology

Patrick Edman
+46 733 33 99 05
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Jon Bohnquist
+46 739 09 25 89
jonboh@itb.se
A perfect blend of traditional, sleek, seaworthy lines and a brand new concept regarding blue water cruisers; here is the new Storm Bird.

The cockpit features large and comfortable areas deliberately facing forward, where the action is. Sailing the boat is a dream, singlehanded or with a crew. All controls are led aft and stowed in dedicated boxes to ensure a clutter free, functional sailing area.

Safety and functionality are key words, everything from the easy accessed life raft, through the large bathing platform to the always optimized steering position will grant you a pleasant journey wherever you’re going.

**Exterior**

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<th>LOA</th>
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<td>Draught</td>
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<td>Beam</td>
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<table>
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<td>Diesel</td>
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<td>Designer/Naval</td>
<td>Patrik Ekman &amp;</td>
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<tr>
<td>Architect</td>
<td>Jens Blomquist</td>
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Inside, the social areas extend almost boundary-free between the lounge and kitchen areas to the cockpit. Visibility both aft and to the sides are granted through large windows giving an airy and light interior.

Moving forward you find the accommodation and the bathroom with dedicated shower space. A large owner’s cabin complemented by a guest cabin makes the boat ideal for the cruising couple with occasional guests. Stowage space is plentiful.
The arches combine the ever present sprayhood, bimini, cockpit tent and instrumentation position in one aesthetically appealing product. Functionality and adaptability, you can even collect rain water in it.

To maintain the appealing looks of the Storm bird, a new dinghy handling system has been incorporated. Replacing davits this system is effective, invisible whilst not in use and can be used as a gangway in port.