You want it by when? - A Structural Design Study of an Americas Cup Catamaran in 30 days

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Version 23

Well, time is running out to design your new AC72 for the 2012 race. With a build time of around 100,000 hours we need to get drawings to boat builders for quotes ASAP! The new Wing and huge jibs require a substantial platform and being a Yacht Structures Engineer I’m really keen to find out what is required to hold these things together. So let this journey begin!

What I’m working towards, a centre beamed boat with no under platform rigging. I imagine it will have a centre cockpit like the WSL70 Class catamaran. A centre cockpit puts the controls only 7m away from the crew at any time versus 14m away from the crew if they are in the hulls. Cockpit mock ups will need to be built and trialled to determine the best layout.

Introduction
I’ve had a huge interest in the Americas Cup ever since Alan Bond won the “Auld Mug” for Australia in 1983. Since then I’ve been “mucking about with boats”, become a Yacht Structures Engineer and kept up to date with the Cup Rules and the ever changing Cup Boats. Being a catamaran sailor I was chuffed when the America’s Cup changed over to Multihulls. Recently I’ve been designing a small trimaran for myself and realised that the amount of basic work involved in the design is the same whether it be a small or large boat, so why not design an AC72? This also sounded like a good idea for a magazine article so I contacted XXXXXXXXXXXXX to see when the next issue was out and the Editor replied “by the end of the month”, so 30 days to design an AC72! That’s a challenge!

I have enough professional background to do the basic Aero & Hydro work, but due to the 30 day timeline, shortcuts will have to be taken. For example, usually to determine accurate sail edge loads I would contract this to specialist sail
design companies, but there’s no time for that, so the sail edge loads will have to be estimated, similarly with the detailed hydrodynamics. A quick look at the schedule and trying to plough through the work, including my commercial obligations, it becomes apparent that this won’t happen in 30 days, so it’s decided to limit this article to the hull and its appendages and do the rest in a following instalment.

Readers please keep in mind that this is a first-cut study & will have gaps and perhaps faults! How many, we shall soon see.

**The Modified Objective**
- To design a suitable AC72 hull form & appendages
- Carry out suitable structural analysis and identify target weights
- Identify design or technical opportunities and issues
- Assemble enough information to move to the next design cycle

**The Complete Project Workflow**
Digest the Rules, pay very close attention to the rules
Design the hull, daggerboards and rudders
Review the rig, establish aero loads and translate these to platform loads
Design the Cross Structure or “Platform”
Integrate the hulls, wing and platform
Review the results…
Take a deep breath and find out where we are!
Go around the next Design Spiral, again…

This article will cover the first two items and the rest will be revealed in Part 2.

**The AC72 Rules**— The “AC72 Class Rules” have 36 pages to define the design space. They are available for download from the site www.americascup.com

**The Rule Intent**
In terms of the AC72 structures, the “AC72 Class Rule” (the Rule) has several geometric and material constraints to consider.

The Rule is a “box rule” type. Its hull maximum length is 22m and maximum beam is 14m. Two rigs were allowed, a tall one and a short one but during this work the small one was dropped so we only need to consider the Tall Rig. The target design sailing displacement is 7500kg.

Design Considerations:
- Overall length – this is good as it removes the problem of dealing with load waterline lengths
- Overall width & Inboard Beam Waterline minimum width
- All of the minimum or maximum weights
- Containerisation. The boat must be able to be broken down and packaged into specified containers for shipping. This aspect will not be considered in this design cycle but I need to keep this in mind
- Replaceable stem and stern sections in case of accidents
- Only one rudder and one daggerboard per hull and it must be a catamaran
- All “normal” boat building materials and processes are OK
- We require hulls with maximum prismatic coefficient and its maximum cross sectional area optimised for the hulls design speed
- Where is the wiggle room in the rules? Where is the scope to jump ahead? Are there technical opportunities? Keep thinking!

There are various tolerances on components allowing scope for some design variation. All of these factors need to be digested and sketched out to establish what is possible. This is the traditional coffee shop; napkin and blunt 3B pencil stage with a suitable mental digestion time.

Materials Allowed- Rule 13: General Limits on Materials and Construction
Materials are restricted by their modulus. By specifying the maximum material modulii for different boat components this eliminates exotic materials and potentially high costs. Exotic materials are attractive as they are very stiff and light but some of them like boron are very dangerous to our health. The maximum allowable fibre modulus is 395GPa so the low end, high modulus carbon fibres are allowed. The maximum metal modulus is 220GPa so steel, titanium and aluminium are allowed, I love titanium but it’s still too heavy compared to good carbon laminates.

A panel loading of 30KPa (a submerged depth of 3m) over the external hull surfaces. This is a 0deg fibre direction stress plot of one of the carbon fibre plies in the outer skin. It is low stressed as it is not yet optimised. The higher the ply stress the more optimised the ply is, but this also means it is closer to failure. I have not yet turned the bulkheads into ringframes. This plot allows me to estimate how deep the ringframes need to be.

To short circuit a long materials development programme I make the following decisions, Hull - use standard modulus carbon (230GPa) such as Toray T700. Wings and appendages can use HM carbon such as Toray M40J (380GPa) or for high strength applications use T800 (294GPa). Foam is chosen as the sandwich core as there is a minimum 50kg/m³ specification on these, so
lightweight Nomex is out, although 60kg/m$^3$ Nomex could be used. Plus using foam we can then use infusion to produce the structures. Infusion will produce mechanical properties as good as autoclaved laminates. Standard autoclave, infusion and wet vacuum bagged parts are all allowed. The maximum processing temp of 135degC at 7bar pressure does not technically limit any of our materials performance.

The V-11 Hull Form Story
There is very little published data on high performance slender hulls for sailing, so I shall use some guidelines proposed by Joseph Norwood Jr and others. Looking at the current A-Class, AC45 and 2010 AC Multihulls also gives clues to good potential form. The general design requirements are as follows: A high prismatic co-efficient, hulls are to be like canoes, a balanced longitudinal section of areas for sailing steadiness, optimal heel angle 10-15degs, reversed or vertical clear bows so the water goes under the boat rather than around it, near semicircular cross sections to minimise wetted area and minimise heeling effects, stern overhang for a smooth water exit and clean rudder flow, possible stern flattening for pitch damping and reserve stern buoyancy. Plus the usual request for it to be as light as possible.

Key ratios are also decided as follows; a Prismatic Co-efficient of Cp=0.70 plus, Area Max, Centre of Floatation and Centre of Buoyancy all at 53-55% of static waterline length. Beam to length ratios are 17:1 and all the above ratios can be optimised against form drag and surface resistance by the Hydro Team later. One area to investigate is a parallel midsection. Discussions I’ve had with hydrodynamicists are encouraging. This will provide a large Cp and even cross sectional area distribution.

Designing hulls using general purpose NURBS software is analogous to manually lofting. 3D boundary lines are drawn such as the gunnel and keel lines then hull Stations and Waterlines are created that need to be fair and true to the designers intent. Then a surface is lofted over that network. This is often called “skinning”. The surface is analysed for fairness and its hydrostatic statistics... then its back to adjusting the curve network and reskinning the surface until the desired hull shape is produced. Specialised marine software automates these processes to a degree.

With parametric modelling it’s always a deep question on which geometric basis is it best to build the model? 3, 4 or more stations? Blocked and filleted or network lofted? Each approach has pros and cons. I choose to use 4 stations and network loft. Four stations gives me control over where the underwater Area maximum section is placed and network lofting gives a very fair surface. After several trials the result is version 11 so it will be called the V-11 Hull.

I have mental images of the 2010 Alingi 5 hull, a svelte long slender hull. But a recent visit to Auckland and seeing the AC45’s up close tells me that to get the Prismatic coefficient up I’ll have to have a much flatter bottom. I move from Alibre to Rhino and back as Alibre does not have surface analysis tools. Another personal aim of the project is to completely model the AC72 in the parametric environment. Rhino has a selection of surface tools that allows me to check how fair the hull is. My other aim is to not have any hollow in the bow.
To keep the Cf,Cb & Area max in place I have to move the ¾ station back a bit… then forward slightly. Ah that’s it!

Hull Version No3 is a squarish block form with variable radius fillets. The intent with the squareness is to maximise Cp. The filleting and station placement however makes it difficult to control the Maximum Area position. So this approach is not pursued.
A parametric curve network. This is V10 which is very close to the intent. The four stations can be moved and the section shapes can be changed. The lofting lines remain connected when any of the station curves are moved. The lofting lines are quadratic Bezer Splines which can then produce very fair surfaces.

The Lines of V-11, LOA=22m, DWL=20.2m. The green station is the Maximum Area Section. Magenta is the design waterline and blue are the other waterlines.
Hull Detailing - Rule 6.7 to 6.11: Hulls
There are a few dimensions and profiles to be observed in the Rules. The lead design is imported into Orca3d to observe its hydrostatics and then we go back to the parametric model, change the dimensions “very thoughtfully” until a good looking hull that fulfils the target ratios and form is created. The main hurdle here is keeping the Cp up, keeping a well faired shape and keeping Amax where I want it.

As we get close to the right ratios small changes are made, if the wrong dimension is changed the ratios change dramatically and the hull distorts terribly. Spline control can be a tricky thing!

An example of a poorly selected loft spline parameter
A screen shot of the hull midsection in one of the hull models. Change one dimension and the section changes shape, consequently the whole hull changes shape.

It is difficult to judge large surfaces on a computer monitor, partly because a monitor is such a small image. It is also partly because we are not looking at the analytical surface directly but at a rendering mesh which is purposely tweaked by the render software to be smoother than perhaps the real surface is. Although CAD software has surface curvature analysis tools it’s very worthwhile having scale models cut to confirm its surface quality. It’s very costly, disappointing and embarrassing to have to manually re-fair CNC machined surfaces.

My two main issues at this point are time and accuracy. It’s very easy to spend a couple of weeks or more developing a hull shape. But in this project I don’t have much time. How accurate does the form have to be? Well this depends on how the geometry will be used. If the hull will be built by a builder using jig saws and chipboard stations then high accuracy is not required. If however the geometry is going to a five axis CNC mill and we want to minimise manual work on the plug then its imperative that quality time is spent on the geometry.

Another factor is what other software and machinery will use the hull geometry? A NURBS package like Rhino can be very accurate or very wrong depending upon how you set up its tolerances. This is because NURBS are not definite analytical objects. They are actually fuzzy stretchy sheets that live between limits. Also Finite Element Analysis (FEA or FE) requires high quality geometry as when the software meshes the geometry the original surface disappears and the resulting “surface mesh” changes slightly in this process. As this hull won’t be made I decide to set the tolerance at +/-1.0mm for the project. If we were going to CNC machine the hull I’d work at +/-0.001mm for
the entire CAD work. This is mainly because the CNC machines I use work at +/-0.01mm. It’s always wise to work at a 10x factor better than the manufacturing precision needed.

A parametric 22m (72ft) hull model is built enabling design cycling to progress quickly. Once the underwater body has achieved the target ratios and the surfaces are fair we move to the structural model.

**Design Loadcases**

It’s been decided to remove the rig loads from the hull in this study, therefore its Design Loadcases can be simplified for now. It is intended that the rigging loads will be borne by the platform not the hulls. The hulls simply hold up the crew & platform and resist the appendage loads. The hull can be considered as a beam with all the crew and platform weight placed in the middle (Hogging and Sagging case). This load shall also be placed on the hull transversely to simulate the boat turning turtle. The hull could submarine to 3m plus in depth giving a starting design panel pressure of 30kPa. A load factor of 1.5x will be used on all estimated service loads.

I’m tempted to use one of the Classification Societies Design Rules but I don’t think they ever anticipated such boats. The structural design philosophy is for the boat to be reliable, not to be on the nervous edge of failing somehow so experience and sound engineering will be the guiding principle.

**Finite Element Pre-Processing**

The V-11 hull model is then imported into Rhino3D and sliced up into its structural groups. Occasionally the surfaces are imported into the FE package and test meshing is done. This identifies areas that don’t mesh well or we find mesh cracks allowing these problems to be fixed early. NURBS modellers can create shapes that parametric modellers and FE systems need to simplify to mesh. In this simplification process the surface changes shape and this is not the intent. So care needs to be taken in creating certain shapes for downstream use.
Structural groups are defined such as bulkheads, decks, reinforced areas around holes and various panels of interest. Once a good mesh is created, all the material properties are assigned and the loads and restraints are defined, the analysis can begin.

A hull model divided into structural groups, each CAD layer is a different group ready to be identified and imported by the FE program. With NURBS surfaces every time the surface is split it gets less accurate, so we need to model at a high tolerance so the surfaces remain precise for downstream work.

Typical Test Mesh - The first model will break the boat into about 11,000 “finite” elements of around 100x100mm size. This will solve fast so design cycling can occur quickly. The yellow lines indicate free edges, which show that there are no cracks in this model.

Composites and Analysis
Composites require a slightly different approach to simulation than do metals. Metals have well developed failure theories and their elastic-plastic behaviour is well defined. Metal stress theory can reduce the failure criterion to one number such as Von Mises Stress and we can look at a couple of plots to determine if the metal object has failed. Composites consist of many parts and the failure
theories for these are not yet easily implemented. If a ply by ply model is built each ply has to be looked at and understood. This takes considerable time. For instance V-11 has 12 skin plies and one core ply in each element, meaning that we have 13 structures to look at, all hidden within the one model.

The V-11 hull model uses plate elements but there are some elastic behaviours of sandwiches that engineering plate theory misses. So once the design is very close to “final”, a “solid or brick” model shall be produced to check that “through thickness” effects have not been missed in the plate model. A typical sandwich problem missed by plate elements is “rolling shear” due to asymmetric skin loading. This is a potentially bad core failure. On a boat this effect occurs every time a sandwich panel goes over a bulkhead so it’s not an insignificant issue in minimum weight sandwich designs.

V-11 Hull Laminates- Rule 14
The Rule minimum allows an external skin weight of 900gsm including the fibre and resin. This equates to three plies of 200gsm carbon unidirectional with a 32% by weight resin ratio. It would be 0.6mm thick. Three or four suitable laminates are created in the FE software and set up as modules. The FE mesh is “draped” so the software knows which direction the plies are laid and on which side the mould was for each element. Hull panels will generally be sandwich construction as these offer improved flexural stiffness at less weight then solid laminates. The FE analysis will provide information about local shear stresses in the core and this will determine which core density to use.

When developing new structures I often model them as aluminium and take them as far as it can go. In this way a weight target is set based on aluminium and I get a feel for how the structure will behave without the extra complexity of the composite set up and interrogation. Once comfortable with the aluminium simulation I can convert the model to composites and then try to make it half the weight of the aluminium version. The aluminium V-11 model weighed 1300kg and was very prone to local buckling as the hull was only 3mm thick, the Carbon V-11 however weighs 588kg and is very stable. Its increased stability is mainly a function of using sandwich construction. Although our carbon sandwich structure has an in-plane thickness of 1.6mm of carbon fibre (2x0.8mm skins & a 20mm core, see later) its flexural stiffness is equivalent to 12.7mm thick of carbon fibre. This increased flexural stiffness is what stops it buckling. This is the beauty of sandwich panel construction.

Analysis Types and Reasoning
“Finite Element Analysis” is a mathematical approach that breaks a structure into small elements. Each element is of known elastic properties and geometry. Square and triangular elements are most commonly used as they are very simple shapes to mathematically formulate. By organising an assemblage of these finite elements into the same global shape as the structure we are interested in; similar to using a lego set or floor tiles, we can then analyse it using a suitable computer programme. V11 has 11,032 elements and has 197,132 equations to solve. It takes 45secs for my computer to solve these and microseconds to render the result on my screen. The final model will be more detailed and will likely contain around 100,000 elements and would be run overnight.
“Linear Static Solutions” are equivalent to manual calculations and are the workhorse problem solver in most structural projects. In linear modelling the mathematics assume that the deflections are relatively small and the structure remains the same general shape as when it was unloaded. This is what we expect rigid structures to look and feel like in the real world. I use this solver to calculate the general stress, ply by ply stresses and deflections in the hull, daggerboard and rudder. For example the image below shows the shear stresses in the central area of the hull. The stresses in this case are acceptable.

Maximum Shear Stress Plot in each element – typical CF ply ultimate shear stress is 80MPa so this area of the boat is lightly stressed in shear as the max SS=8.7MPa
“Linear Buckling” solvers are used to check if the structure is elastically stable. Possible global buckling modes and local instabilities are identified in this process. Buckling is particularly important with high performance structures; in fact with optimal designs buckling should be the first failure mode, not stress related failures.

Buckling plot of spine beam due to the Wing compression on the deck. In this case the buckling load is greater than the applied load so the buckle can be ignored.

“Inertia Relief” solvers are used as boats are not tied down like buildings or machinery, so there are no definite reaction points in the structure. With an Inertia Relief model the loads push against the models mass inertia just like it does in the real world, so no reaction points or “constraints” as they are called are needed. Inertia relief solutions are good to use for the daggerboard, rudder and rig work.

“Non-Linear (NL) Static” solutions are used to validate the linear models and confirm that the early major structural buckles described in the linear buckling solver are correct or different. The NL solver places a small load on the structure and lets it deform, then the load is increased slightly and the model is recalculated. In this way the geometry changes shape as the load history changes. This cycle is repeated until the solution reaches its full load or maybe not. In this way any “deflection determinate” problems with the structure are identified. Some structures are “strain stiffening” which means when they deflect they get stiffer. Some are “strain softening” and when they are loaded up they buckle and fail. The AC72 structures should behave in a linear manner or be strain stiffening in their intended operating load range. Obviously if a structure is overloaded then something has to give! With composites this is usually accompanied with a BIG BANG!

Non linear geometric solutions are much closer to how real structures behave but take considerably more time to set up and solve than a linear model. If the
NL and linear solutions give the same result then I’m confident to do more
detailed analysis with the linear solver. The V-11 linear solution takes seconds,
its NL counterpart takes 2.6hrs and this limits my ability to cycle the non-linear
design rapidly.

After 3 or 4 hull design cycles and when most of the details have settled down
the non linear transient dynamic solver is used to actually float the boat on the
water and check its trim. Transient Solvers take time into account and by using
a combination of hydrostatics and time the boat model can be “floated on” or
“pushed” into the water to establish its various equilibrium conditions.

We can also check some basic floating stability issues such as the crew moving
around and pitch-poling. The trim analysis may indicate that the hull shape has
to change to account for the actual mass distribution vs the assumed mass
distribution in the first design cycle. I won’t get that far for this article but the real
Americas Cup Designers will be going through this about now. We are less than
one year away from having boats in the water, so actual drawing sigh offs will
be occurring right now.

**Daggerboards & Rudder Sizing- Rule 9 & 8**
To design the foil casings and rudder stock foundations we need to know their
size and their service loads.

Saving the reader some maths, the transverse sail force is pushing the boat
sideways and the foils have to resist this action. Mainly because water is 850x
denser than air we only need a foil of about 0.8% the area of the sails if the boat
is travelling at twice the wind speed and at 30kn across the water. These boats
will be very fast! So let’s start there.

The Rules also state that the maximum board dimension can be 7m. There is a
2.0m bury in the boat at the point of lateral resistance in V-11, so there is a
potential foil span left of 5.0m. But the maximum water draft by the Rules is
4.4m, therefore this limits the actual foil span. V-11 has 500m² of upwind sail
area so we need 4.0m² of foil. V-11 has a 0.4m “canoe body” draft leaving a
max span of 4m. (ie 4.0x1.0m=4m²). 4:1 is a small aspect ratio board & 6:1 or
more would be better hydrodynamically, so curved boards or end plates may be
investigated. Or, this just may be about race venues and sailing close to shore.
The Manual Method – Daggerboard loads at 30kn and 5deg angle of attack. Perhaps a NACA 63-009 would be a good starting point for the rudder and the board.

Another consideration is that the daggerboards of the AC72 can be gybed i.e. they can be rotated like a rudder. This means it may be in a barrel arrangement so we need to put a 1.0m hole through our hull model near or at the point of lateral resistance.
Daggerboard models showing deflection at 30 knots and 10 degrees angle of attack

First buckle of Daggerboard at a BLF=2.78 which is acceptable

Similarly with our rudder the rules allow a 5m maximum dimension and we have 1m bury in V-11 at the stern. Transom hang rudders are not allowed. The result is a 2m long rudder with its area estimated as a 5% ratio of the underwater lateral area. The rudder area is quite a complex consideration. Do we have a big rudder so pre-race slow manoeuvres are easy? Remember BOR90 stalling at the line last race? Or do we minimise its area so we have minimum drag at
high speed? Can we have both? Perhaps a skeg type is useful here, rather than a spade rudder? As the rudder is easy to change we just start with our best guess and see how it goes on the water.

Rudder Modelling

Also the rudder loads are potentially so high that we need to set its lead at neutral or very small. The potential 18+ tonnes of rudder load will need to be controlled by a tiller or a wheel and be ratioed back to a manageable hand load. My first rudder model was set up with a typical small boat lead but the torque was enough to twist the blade 220degs and wring it right off the stock!

The design & analysis process for the foils is the same as for the hulls. Linear Static work is done to get a general picture of the stress & deflection state, linear buckling is done to check general stability, followed up by non linear when the design is matured to qualify the linear work. The current rudder model is 100kg so we shall budget on 150kg per rudder. This will allow for bearings and other associated bits.

I drag out years of test data and manufacturers specifications to set up suitable elastic and failure properties of the plies. Since the rudder and foils are very highly stressed we will use High Strength fibres such as T800 or T1000 to enable high design stress to service stress ratios to be achieved. These fibres fail at a strain of 2.0%+ (around 6000MPa or 870ksi) whereas high modulus fibres fail at only 0.8% strain.

The structural “team” want fat foils as they are stiffer and lighter but the Hydro “team” want thin foils as they have less drag, probably an 8%-10% thickness foil will do the job. Considering the rudder and board need to develop steerable lift and fatter shorter foils stall later than a thin long foil, the Structural Team may get their head this time. The foil specialists will be concentrating on drag minimisation or drag bucket widening as we can’t increase the lift co-efficient much with this type of foil section.
V-11 Hull Results – First Engineering Review

It's 15 days into the work with every spare bit of time put into the task. After building and interrogating several models, the hull model weight settles at 588kg. The core weight is 150kg (25%) of the hull weight. Early project computer models are usually light as they do not have lots of the smaller bits included so let's add ~15% to this figure, giving 700kg each.

Different core thicknesses were trialled to determine the sensitivity to this variable. Only marginal improvement in buckling performance with 25mm core vs 20mm core was achieved even though the 25mm is 50% stiffer than the 20mm laminate in bending. The main troubles are around the central barrel hole on the hull sides. Extra ring frames or much thicker cores in this area will need to be evaluated to raise the linear buckling load factor (BLF) from 1.7 to the target of BLF=2.0. We need a high design buckling load factor to make allowance for the real world variables. Will the hull be exactly the shape of the model? Will the compressive properties always exceed the design compressive properties? Will the real boat behave “exactly” like the model? Unlikely… should be close, so when buckling is involved it pays to be as conservative as possible.

Local buckle at a load factor of BLF=1.7, an extra ring frame or thicker core is needed to get this to the BLF= 2.0 target. Linear Buckling does not consider the load/deflection history of the structure. It calculates the onset of buckling. A nonlinear analysis will confirm if this prediction is correct or not.

To produce a suitable hull laminate at the minimum Rule weight requires custom cloth to be run. If a standard 200gsm unidirectional cloth is used the skin laminate would be 1200gsm not 900gsm to produce what I think is a suitable general laminate. V-11 uses the 1200gsm (0.8mm thick) skin laminate at present but this could be modified in future depending on fabric availability or a suitable budget.

At this point the first major error was found. The original sailing displacement was based on the sailing weight “including” the wing weight, you’d think that the
“sailing weight” would include the wing weight wouldn’t you? Unfortunately the “sailing weight or measurement condition” does not include the wing so we have an extra 1325kg to add to the displacement. V-11 sinks 100mm with this load and the bow and stern just go under by 13mm. Its ratios are good but having sunken bows and stern is not the design intent. So it’s onto V-12 to correct this error... the tyranny of Design! But being a parametric model means it should only take a few “guesses” to adjust. Which it did, 5 changes and the new specs are DWL=21.23m, Fb=Ax=Fl=52%, and the bow and stern are 40mm above DWL or the MWP in Cup speak.

Rule 5.7 states that the inboard beam waterline (IBW) shall not be less than 11.500m. Unfortunately when we cant hull V-12 10deg s and set it out to the maximum beam width of 14m the IBW is 11.400m so V-12 is no good. This means we need to make hull V-11 narrower and deeper rather than a bit fatter as I’ve done in V-12. This hull becomes V-11a and fits into the required IBW. It’s a bit deeper then I want but that’s it for now.

The V1.1 Rule weights are: boat measurement section 5.10 “sailing weight” 5700-5900kg with rig, the rig shall not weigh less than 1325kg and the 11 crew can’t weigh more than 1012kg. There is also a maximum sail weight of 250kg. This means we have 2700kg left for the platform. A figure of 7500kg has been decided on for the racing displacement. This figure has been derived through analysis of the rules.

<table>
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<th>Component</th>
<th>Weight</th>
<th>Reference</th>
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<tr>
<td>Crew</td>
<td>1012kg</td>
<td>section 18.1 also see 25.1(d)</td>
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<tr>
<td>Platform</td>
<td>2700kg</td>
<td>what’s left</td>
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<tr>
<td>Sails max</td>
<td>250kg</td>
<td>section 26(c)</td>
</tr>
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<td>Wing min</td>
<td>1325kg</td>
<td>section 10.12</td>
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<td>Hulls</td>
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<td>Daggerboards</td>
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These may be good or bad figures but it’s a starting point. I suspect that as the study progresses we will be stealing weight from the platform budget, but this is what a study is all about. The next step is to itemise all the hardware required on the boat and extract this weight from the platform weight. Then we go around the cycle again to further refine the schedule.

Typical vertical beam sagging of the hull in millimeters

Local buckling of the hull at a load factor of LF=2.1. This is the linear prediction. The NL solution shows that the curved plates strain stiffened and were stable at a satisfactory load factor of LF=2.5
Conclusion
The preliminary hull weight budget is 700kg. The design review identifies that V-11’s sheer could be lowered to reduce weight and windage and that an error in the displacement specification needs to be addressed. The Senior Engineer was fired for his error as it came to light that a Junior had memo’ed this issue to him some time ago.

Cockpit arrangements have to be added and hardware placement clarified & included in the weight schedule.

Issues may arise with a short daggerboard but gybing the board may overcome the low aspect ratio. Perhaps the draft specified has something to do with the proposed venues and sailing close to shore.

The AC72 Rules have been developed in collaboration with the Defender and the Challengers. The AC72’s DNA is now being blueprinted by many teams. This Study has started to unravel its secrets and now survival of the fittest will soon come into play. Please note it pays to read the rules on a daily basis.

Onward - Part 2
Part 2 will cover the basics of wing design particularly for the AC72. It will also discuss how we control wings in general. The platform and its possible structural configurations will be dealt with. Standing Rigging will be discussed and their possible materials covered including the sail load derivations. Finally a general arrangement comes together arriving at the end of the first design cycle. Comments are made on what could be done in the next Design Cycle in the Second Engineering Review.

Post Script
Since writing this article and attending a design forum in Auckland “Oracle Racing” have released a “Shared Design Program”. For $1.2M USD the Challengers can purchase a generic AC72 design package. An International Design Team has been working on the design since October 2010. Over 60 people and lots of computer time have been working very hard to realise this design. Oracle has commissioned this work to allow the late comer teams to have a catch up opportunity. I’ve seen pieces of the drawings but not a whole design. Below is an image that has been used by Oracle for promoting the AC72 and I imagine it will be close to what is offered.
Resources
High Speed Sailing – Joseph Norwood Jr, thank you Joseph great work
Principles of Yacht Design – Lars Larsson & Rolf Eliasson
High Performance Sailing – Frank Bethwaite
Sail Performance – C.A Marchaj
Thesis: Stochastic Optimisation of America’s Cup Class Yachts by Andrew Mason
Aero-Hydrodynamics & the performance of sailing yachts – Fabio Fossati
Alibre.com
Rhino3D.com
Orcha3d.com
Strand7.com
The World Wide Web - Sailing and Boat Design Forums – Thank you all

About the Author
Peter Schwarzel is a Registered Engineer in Queensland, Australia. His company CarbonWorks designs and analyses yacht structures for Naval Architects and Boat builders. He sails as much as possible and looks forward to seeing Australia back in the Americas Cup competition.