AC72 Hydro-flyers - "Why is it so?" MYCQ 20-07-2013

Author: Peter Schwarzel

Figure 1 - Team USA Boat No2 in training with the L shaped port daggerboard clearly seen. Plus the machined aluminium prototypes rudder elevators are bolted on so modifications can be made easily. Once the design is settled carbon fibre versions are made to reduce weight.

I'm one of the generation that grew up watching Dr Julius Sumner Millers TV show, once described as "cool experiments, interesting science and fantastic hair!" I can see him in his lab using spoons and running tap water to explain how hydrofoils work. My main aim today is not to explain how they work but why they are needed on an AC72. For those interested there are huge amounts of information on why and how aerofoil's and hydrofoils work so I'll leave this part of the puzzle up to you to discover.

The AC72's rudders and daggerboards fulfill the same basic functions as any other set of foils on a sailing boat. The rudder steers or trims the boat & the daggerboard stops the boat from being blown sideways by the transverse sail loads. The extra function of the AC72 foils is to provide lift. By lifting the boat out of the water the hulls wetted surface area and its associated wave drag is removed. Both these drag sources form a relatively large drag component of the entire drag equation. Removing drag always allows boats to go faster. Speed is the game here and anything that improves speed is pursued relentlessly. Hence we now have flying AC72's.

When the draft AC72 design rule was released the teams where intending to design "skimmers" not "flyers". An AC72 in racing condition weighs 7500kgs, this is quite a big hole in the water and if the boat can lift 3 tonnes out of the water this hole is much smaller hence the drag is much less. At some time during the AC72 design development some of the Designers realised that they could lift the entire boat out of the water and remove wave drag and skin friction entirely! A Eureka moment that would have Julius shrieking with excitement! But this moment did not occur in the Artemis camp and they had to radically rethink their big blue No2 boat.

Team New Zealand also found a loophole in the measurement condition that allowed them to use bigger daggerboards. Bigger boards lift-off earlier and they can fly in lighter winds so can be a big advantage in short races with lots of tacks and gybes as we shall see in San Francisco. This was such an advantage that Artemis and Oracle went to an International Jury claiming that they were illegal. Team New Zealand however won that sitting and their foils where deemed fit to race.

One of Alinghi 5 S foil that was not used for racing in the 33rd America's Cup - Jean Philippe Jobé Click Here to view large photo

Figure 2- A huge S type daggerboard from Alingi 5 built for the 33rd Americas Cup

Daggerboards

There are many daggerboard foil shapes: C, J, S, L, Banana & their many combinations. Originally developed by the Orma trimaran class to lift the boat, the curved board is an attempt to get some of the board to be near horizontal yet allow the top of the board to remain inside the maximum beam rule that exists in most classes. For instance the AC72 has a maximum allowable beam of 14.000m. If you built a long straight board it would extend past the maximum allowed beam in its up or down position depending on what direction you canted it. The AC72 board can be up to 7m long creating a maximum water draft of 4.400m.

The aim with the more complex shaped boards is that the angle of the foil (angle of attack or area submerged) can be controlled depending on how much board is projecting out the bottom. But over the years the design has been simplified to the L shape with the least radiused vertical part possible. The near horizontal part of the daggerboard provides lift and the vertical part provides resistance to leeway. The simpler the design the better. If the boat is not flying, the horizontal part generates more drag then its worth so it is imperative to fly most of the time, or have a selection of boards to suit the conditions. Just like a skiff class will select a rig size, the AC72 teams have different size boards for the expected wind ranges.

AC72 daggerboards are also active components. ie they can be controlled by the sailors. The main control on the AC72 is that the boards can be raked. ie the angle of attack can be changed to vary the lift generated. Although the mechanical and hydraulic details are not known I'd expect one sailor to be trimming the daggerboard while another grinds to provide the required power.

The trick has been to design a board that provides the required lift to take-off, but by adjusting the angle of attack it does not lift the foil entirely out of the water resulting in a stall and a big splash as the boat falls back into the water!

You may also notice that when flying, the vertical part of the boards leading edge is angled rearward which encourages water and air to flow up the front of the board. This discourages ventilation of the board which again would stall it.

Figure 3 - Reversed leading edge discouraging ventilation

An interesting possibility is windward heel. Ultimate sailing boat power is proportional to the Righting Moment of the boat. The heeling moment is generated by the sails and this drives the boat. By leaning the boat to windward like Moths do, the weight of the wingsail increases the righting moment hence we can get more power from the sails. Will they do this? Only time will tell. Another possibility that is eliminated in the rules is using the windward daggerboard to hold the boat down, therefore increasing the righting moment to our hearts content! But this has been deemed dangerous therefore the windward foil must be clear of the water while under sail.

Why is it so? - Is it Ventilation or Cavitation?

Outboard powerboat owners may have noticed small wings on their motor leg. The propeller creates a large suction force just like the AC72 foils do. This suction can draw air down into the prop stalling it. This effect is called ventilation. The wings are called "fences" and these are used to stop ventilation in the outboard leg case. Fences can't be used on an AC72 daggerboard as it has to slide up through its casing.

The suction side of the propeller and the AC72 foils reduces the local pressure in the water to such a level that the water can boil. If this occurs the resulting steam stalls the foil. This effect is called cavitation and it is a problem experienced by Moth sailors as well. To prevent cavitation we use the biggest foil possible to produce the lowest suction pressure. But big foils produce more drag so the foil area to lift ratio has to be compromised to a "best fit" solution.

Figure 4 - Artemis' asymmetric foils that comply with the safety rules but not the AC72 rules putting the team in a jeopardy position.

Rudders
AC72 rudders are "static" devices in terms that they are not allowed to be trimmed or controlled to change their lift characteristics by the sailors. They can only be used to steer the boat. This creates a dilemma for the designer. We need the rudder to lift the boat out of the water initially but once up we actually need it to pull down to stop the boat from pitch-poling. Downwind the sail drive force is trying to push the boat over while going forward; usually this is resisted by the forward buoyancy of the hulls but when flying, the hulls are 2m in the air!

Firstly some new words. An Elevator is the horizontal part of the rudder. Elevators are popular in classes that allow them even if the boat is a monohull or does not fly. Elevators keep the boat sailing flatter and produce a damping force that keeps the hulls from hobby horsing. New regulations proposed by Iain Murray required the elevator to be longer and bigger therefore extending past the maximum beam width. This created problems for Artemis, Luna Rossa & Team New Zealand.

Mitigation of the matter failed leading to the so called "Rudder Gate" situation. Luna Rossa refused to sail until the matter was cleared up by an International Jury. The Americas Cup is always fraught with interesting incidents, usually off the water!

The AC72 takes advantage of Elevators as follows: if the bow of the boat dives the elevator pulls the stern down recovering the dive. If the bow goes up, the elevator "lifts" pulling the bow down. The designer has to size the elevator to provide just the right amount of lift and suck at about 40 knots yet minimise its drag. Oracles elevators are adjustable by divers, so up to the five minute preparation time they can be set for the expected conditions of the race. This is further complicated as they could have one or two rudders in the water sometimes so the required forces halve or double as the rudders enter and exit.

So the sequence to get the boat flying is as follows: 1) trim the daggerboards to produce maximum lift to get the entire boat moving upward 2) allow the bow to ride slightly high so the elevator also pushes upwards 3) once flying, trim the daggerboard so it flies flat or the bow is slightly down so the elevator sucks down to stabilise the boat pitching. Otherwise if the elevator continues to lift the boat will pitchpole... oops operator error! Orchestrating all of this takes time and anyone viewing early videos of the AC72's in training would have seen lots of kangarooing going on until they sorted their systems & timing out.

Why is it so? - Perturbations and Dampers
In some respects boats are like cars when they hit wave peaks and troughs. Peaks are like speed bumps and troughs are like pot holes. In a seaway or on road corrugations the vehicle or vessel can become "excited" and become unsteady. In our boats case the mast sways about and chops up the air reducing our drive. Cars use motion dampers called shock absorbers to mitigate this effect. A bump "perturbs" the cars steady condition and as the wheel moves up the shock absorber produces a damping force in the opposite direction that the wheel moves. This eventually stops the wheel from vibrating. Traditionally in multihulls we make the sterns bottom flat to act as a damper but as boats get faster this does not produce enough force to stop hobby horsing. A rudder elevator however produces a force that is strictly proportional to the perturbation therefore acts as a very effective damper. If we can tune the angle of attack like on a Moth dinghy we can optimise the damping to the wave conditions.

Figure 5 - Luna Rossa bow high and about to "kangaroo" during early sailing trials in Auckland

Now Team NZ is as smooth as silk in all of their maneuvers. They call this "sailing mechanics" or the ability for sailors to carry out tasks smoothly and efficiently. As the rudder does not need to slide through a case you may also see small fences on them to prevent ventilation. It is also an advantage to have the leading edge raked forward to help prevent ventilation.

Now we have boats that have sailing modes that do not have wetted area drag and wave making drag we need to start thinking about "spray drag". In racing the search for reducing drag is never ending!

To put the AC72 catamaran into perspective the new Volvo 65 class is 65ft long and weighs 11600kg, 4920kg is in the keel! Its upwind sail area is 468m2. So its power to weight ratio is 40m2 per tonne. The AC72 weighs 6000kg and has a SA=340m2. ie its power to weight ratio is 57m2 per tonne. Also consider that the rigid wing produces twice as much drive per square metre of sail then a soft sail and we are really looking at a boat with over 100m2 per tonne of power. This ratio is even bigger downwind. This is quite a powerful beast! They are sailing at twice the wind speed and recently ETNZ was clocked at 44knots. The racing maximum wind speed is 28 knots so well over 50knots of boat speed is possible! If they are game?

Figure 6 - Artemis daggerboard up close and personal

The Big Picture

When Melvin and Morrelli were tasked with drafting an Americas Cup rule no one at the time thought the boats would fly. Some of the rules were constructed to prevent flying but no express prohibition was placed upon it. Plus the sailing community has a general inertia against multihulls, so the selection of the multihull option was a great surprise to many!

Figure 7 - Team NZ with two slightly different foils installed. What better way to sort out differences just by sailing port and starboard courses!

The Americas Cup has always been a design and technology challenge as well as a sailing challenge. The Americas Cup has introduced aluminum spars, better sail materials, better hull materials, better sailors and a host of other innovations to our sailing world. The 33rd and 34th Americas Cup have improved the profile of Multihulls and now has boosted interest in foiling. Although wing sails and foiling have been around for at least 40 years they have never been main stream sailing solutions until now.

Very clever designers have overcome the technical challenges to make flying one of the sailing modes of the AC72. Its really a must have weapon in the AC72 tool box. Artemis missed the opportunity early and have been forced to play catch up. To an extent Oracle have had to do the same. Some sources say Boat USA17.1 was not intended to fly. These issues where addressed in USA17.2 after its dramatic pitchpole, breakup and recovery. Artemis' red boat failed dramatically and ended in tragic circumstances. This lead to new safety measures being proposed with some being rescinded. Team New Zealand and the Italians however have been steadily improving all round and working towards the real Challenge in September 2013.

The wing has taken a back seat to the AC foil development and look out if the AC45 series comes back, as my guess is that these will become foilers as well. Looks like Circa 2013 is a breakthrough time for sailing!

Peter Schwarzel specialises in the manufacture, design and supply of lightweight structures. Past projects include: Carbon Yacht Masts & Yacht Structures. See carbon-works.com.au & aacc1.com.au