Technical Meeting — 3 March 2021

Eric Desjardins, General Manager Australia, McConaghy Boats, gave a presentation on *Construction of Advanced Composite Racing Yachts* as a webinar hosted by Engineers Australia using the WebEx software platform with the Deputy Chair of the NSW Section of RINA, Phil Helmore, as MC on 3 March. This presentation attracted 156 participating on the evening.

Introduction

Eric began his presentation with an overview of the initial stage of the construction of a high-performance racing yacht—the feasibility study, which aims to find out whether the yard can do what the customer wants in the required time. Items to be considered include the type of racing envisaged, the design considerations for that type of racing, and the timing and budget for the construction.

Types of yacht racing include:

- Twilight racing: Social evening (or afternoon) racing held throughout the summer months; the criterion often being "Ïs the Esky big enough to hold all the beers?"
- Club racing: Weekend racing hosted by a local yacht club, generally more competitive than twilight racing.
- Windward–leeward: Windward–leeward courses consist of an upwind and a downwind leg, each sailed between on and four times; these are short, fast races where precision is key.
- Passage: A race of varying distance which passes around multiple marks (buoys or landmarks) usually encompassing multiple points of sail.
- One design: Competitive, fast and generally close racing using a single type of yacht; class rules determine allowable crew numbers, sail and vessel requirements; this includes match racing.
- Regatta: Multiple races held over several days with an overall winner determined for the event.
- Offshore: A long-distance race held over many days or even weeks; held in open waters, where navigation, endurance and experience are critical — e.g. the Sydney–Hobart Yacht Race.
- Special Races: Such as the America's Cup, the Volvo race, the Vendee Globe, and the TP52 Circuit.

The designs of yachts to suit these different types of racing are very different.

Design considerations include:

- Lightness: Lightness and strength are prime considerations. Success for race yachts largely boils down to how light a structure can be achieved. The materials of choice are predominantly cored carbon fibre and epoxy solutions.
- Naval Architecture and Preliminary Design Considerations: Is this for offshore or inshore racing? What are the dominant conditions? Will the yacht be fully crewed or single handed? Are there class rules and/or regatta rules? Are there other regulations? Other things to consider include hydrostatics, hydrodynamics and aerodynamics.
- Engineering: Dynamic loads, slamming, wave load, safety margins, class rules, regulations and certification bodies.
- Design development: Appendages, sails, mast, equipment (electronics, systems, etc.)

For example, a customer may advise that he/she wants to win the Sydney–Hobart Yacht Race or, in rare cases, wants a yacht like *Name*. This tells the designer basically what they need to know about the type of racing and they can get to work on the shape of the yacht. The outcomes of the preliminary study generally results in a new custom design comprising a deck and profile drawing, an interior general arrangement drawing, a sail plan, an appendages drawing, a mass estimate, a preliminary bill of materials and, ideally, some detailed specifications.

Timing and budget considerations include:

- How long does it take to build a racing yacht?: A 45 ft (13.7 m) racer with 10 people working on it can be completed in 9 months; a 60 ft (18.3 m) racer with 20 people working 12 months; a 100 ft (30.5 m) maxi racer with 30 people working 16 months. There have been notable exceptions to these rules-of-thumb: *Wild Oats XI*, 100 ft (30.5 m) was completed in 9 months, and a Trans-Pacific 52 ft (15.8 m), commonly referred to as a TP52, was completed in 3 months—but they would not do that again! Race yachts typically have minimal interiors ("spartan" is not inapt), whereas cruising vessels demand a much higher standard of comfort and take much longer to fit out.
- How much does it cost to build a racing yacht? For a 45 ft (13.7 m) racer, the labour involved is of the order of 15 000 hours; 60 ft (18.3 m) racer, 40 000 hours; and 100 ft (30.5 m) maxi racer, 70 000 hours.
- The cost of the composite materials varies from around $230 000 for a 45 ft (13.7 m racer) to $1 million for a 100 ft maxi racer.

- However, this is only the tip of the iceberg; there are other elements, including the design fee, rigging, sails, safety gear, shipping, and on-going costs (maintenance, slipping, crew, etc.), none of which are included.

Project Kick-off

Who are they building for? Fairly obviously, the owner. However, the owner selects the naval architect to do the design, and the naval architect may recommend the yard (if the owner has not already chosen). Additionally the owner usually selects all the specialists (such as the hydrodynamicists, the mast maker, the sailmaker, etc.)

When the owner selects the yard, this may be for a "turn-key"" solution, where the owner talks only to the yard, or a "bare-boat" solution, in which the owner has a team of professional sailors who can assemble and fit out the yacht. In this latter case, the yard would complete the structure and install the owner-supplied items.

Ideally, there would be a contract for the construction. However, quite a few builds have gone ahead with a simple agreement and do not always have a contract!

Here Eric showed a slide of a 42 ft (12.8 m) Reichel Pugh design which had an extreme canting keel, able to cant to 90º either side of the centreline. This sounds simple, but was extremely difficult to achieve on a short vessel. Anything difficult like this becomes a cost-plus item.

Reichel Pugh 42 with extreme canting keel
(Photo courtesy McConaghy Boats)

Following the meeting with the owner to kick the project off, one of the principal tasks is ordering the materials, as composite materials are not on the shelf at the yard, and often require two months for delivery. During this time, the yard is busy tooling up the mould, while the naval architect is hard at work preparing the hull construction drawings so that they are ready to go. The materials are required on site the day they complete tooling, and about one week after the drawings are received.

Once the deck is on, they can move to painting and fit-out. The main driver of success throughout the project is whether the design work can stay ahead of the build.

Tooling

Any shape is achievable in composite materials, but each part needs adequate tooling.

Tooling considerations include:

- Materials to be used for the structure, and their stability at temperature if heating is required.
- The number of uses of the mould: Racing yachts are usually one-off, so the mould is only used once and tooling must be started from scratch each time.
- Accuracy required: They work to a general accuracy of 1 mm; however, for canting keels they have to work more closely than that.
- Will the mould be male or female?: this determines which side the laminate will be on.
- The level of surface finish.
- Air-tightness of the tooling surface: It must be airtight for vacuum bagging.

A traditional female mould starts with a base jig which is set up on a plane horizontal surface, and a centreline string is set up. Everything is measured from the horizontal reference plane and the centreline string.

Base jig, centreline string and frames stacked at side
(Photo courtesy McConaghy Boats)

The frames are set up, the stringers are installed, and then 3 mm plywood is laid inside to make the mould. The mould is usually used only once; twice if they are lucky!

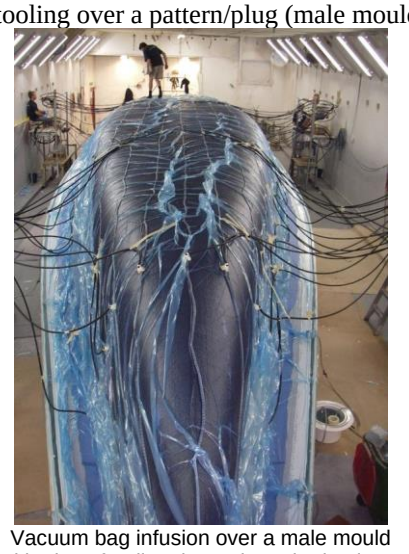
Frames up and stringers going in
(Photo courtesy McConaghy Boats)

Plywood being installed
(Photo courtesy McConaghy Boats)

Female mould for 44 ft (13.7 m) hull with Teflon release film, keel plant and red centreline, midships and waterline marks, ready for laminating
(Photo courtesy McConaghy Boats)

There are tooling solutions other than the standard female mould; these include:

- CNC aluminium tooling: this is not really possible for racing yachts, as it is much too expensive.
- CNC epoxy tooling boards.
- CNC foam tooling.
- 3Dd printed moulds and fixtures; these have started being used for small parts in the last 5–10 years.
- Infused carbon (vacuum bag) tooling over a pattern/plug (male mould).



Vacuum bag infusion over a male mould
with pipes feeding the resin to the laminate
(Photo courtesy McConaghy Boats)

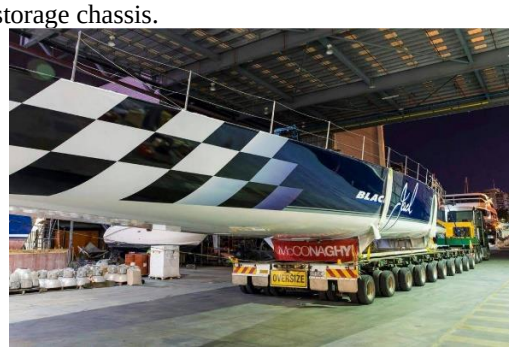
Staff and Factory

McConaghy Australia currently employs over 45 skilled composite specialists, craftsmen, engineers and designers, forming a team of unmatched passion and commitment. These include shipwrights, pattern makers, spray painters, CNC machinists, labourers and apprentices, project managers, engineers and naval architects.

The factory in Gosford is a dedicated manufacturing facility for large carbon-fibre prepreg structures, featuring a 30×8×4.5 m computer-controlled oven capable of reaching 120°C.

McConaghy factory at Gosford
(Photo courtesy McConaghy Boats)

In addition to the facilities and staff, a yard needs logistics and other manufacturing capacities. It must have experience in manufacturing or contracting all required activities supporting the manufacturing and finishing of the composite parts, from concept to their safe delivery. These include tool design, licenced CAD and CAM software, scaffolding, heating and environment-control facilities, coordinating lifts up to 20 t on the premises, and purpose-built and certified storage chassis.



Black Jack ex-*Alfa Romeo*, completed in 2005
(Photo courtesy McConaghy Boats)

Racing Yacht Construction

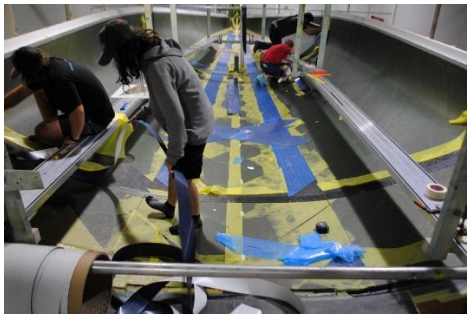
Composite construction comprises a fibre and a matrix. There are different types, brands, weights and fire-retardancy of fibres. The usual fibres are carbon, glass and Kevlar, but also Dyneema, quartz and "bio" fibres. The usual resins are mostly epoxies, vinylesters, polyesters and phenolics. A variety of cores can be used (for panels and cored structures). To add to the possible combinations, fibres come with different types of stitching, and weights per unit area. On occasion, fillers can be used for the resin, such as flame-retardant products. Then there are different manufacturing processes, including hand laminating, infusion, and prepreg under vacuum bagging and/or autoclave.

Carbon fibre and epoxy resin are the materials of choice for their mechanical properties, mostly in a "prepreg" form. Pre-impregnated materials (prepregs) are reinforcement fibres or fabrics into which a pre-catalysed resin system has been impregnated by a machine, giving the perfect fibre-to-resin ratio. The resin systems in these materials react very slowly at room temperature, so there is plenty of time for set up. The parts are usually made of thin carbon skins, laminated on each side of a core made of honeycomb or structural foam. The parts are then cured at 100ºC for 10–15 hours, under vacuum bag consolidation.

McConaghy builds all tools and composite structures from raw elements, and offers a full spectrum of services: prototyping, manufacturing, final assembly, launching and testing.

Here Eric showed a slide of laminating the hull outside skin. The carbon prepregs come with backings of different colours, depending on whether they are unidirectional or off-axis.

The fibres have to be orientated as per the drawings of the structural engineers. Each layer is 0.2–0.5 mm thick, and layup is very labour intensive. The black colour is the outside laminate.



Laminating the hull outside skin
(Photo courtesy McConaghy Boats)

The next step is fitting the honeycomb core. It can be done in strip plank fashion, or thermoformed to the hull shape.

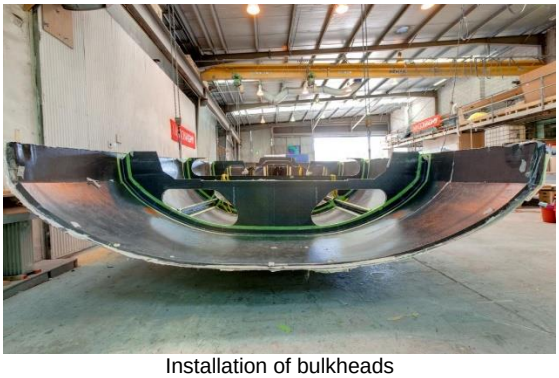
Fitting the honeycomb core
(Photo courtesy McConaghy Boats)

Then, with the hull shell completed, it is time to fit the bulkheads.

Hull shell completed
(Photo courtesy McConaghy Boats)

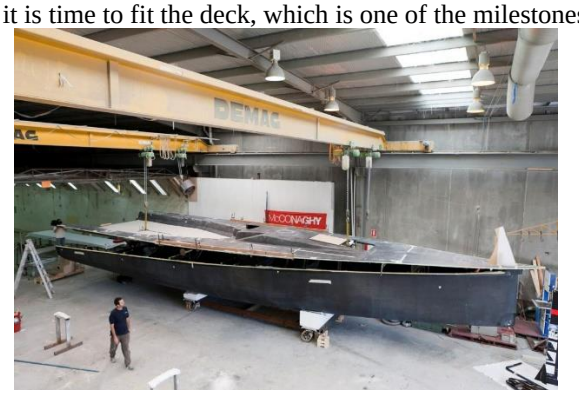
Flat structural elements (beams, bulkheads, etc.) are laid up on a table, then installed in the boat.

Flat structural elements being laid up
(Photo courtesy McConaghy Boats)



Installation of bulkheads
(Photo courtesy McConaghy Boats)

With the bulkheads installed, it is time to fit the deck, which is one of the milestones of the project.



Fitting the deck
(Photo courtesy McConaghy Boats)

Rig attachments to the hull are of vital importance, as these points are heavily loaded—especially on the maxis! A substantial amount of unidirectional strands is used to distribute the loads.

Rig attachment
(Photo courtesy McConaghy Boats)

The painting process is important, as the yacht has to look good for the sponsors. McConaghy Boats pays attention to the detail, and respects the designer's wishes. Then comes the hardware installation, systems integration, painting and transport.
The construction of the TP52 *All4One* was completed in three months. All the design work had been done, as she was a sister to a yacht previously built in Europe. She was trucked to a ship in Sydney for transport to Europe, together with the mast, keel, etc., all built separately. McConaghy Boats sent a team to Europe for the assembly, launching, trials and, finally, race day!

Transport
(Photo courtesy McConaghy Boats)

Race day
(Photo courtesy McConaghy Boats)

Quality Control
It is important to have a culture of quality excellence and weight optimisation, because lighter and stronger means faster—which is the name of the game.
A constant focus on weight saving is required to optimise the weight of every component going into a race yacht at each step of their manufacturing process. The weight of each component (big and small) is checked against its theoretical value, and tracked and recorded individually in a weight register before the final assembly to the main structure. The yard needs to remain in constant contact with the designer throughout the build process. The measured weights are regularly communicated back to ensure that the weight study will remain as current and accurate as possible throughout construction.
The international moth class has been using hydrofoils for years, and is exciting to race. These boats are all carbon everywhere and have a complete mass, ready to race, of 30 kg. They are foiling above 8 kn and can reach speeds of 40 kn!

International moth class
(Photo courtesy McConaghy Boats)

McConaghy's quality-control systems have been developed over decades of practical application and in conjunction with external certifying bodies, composite engineers and materials suppliers.
These quality-control processes include:

- test panel construction and analysis;
- weighing parts;
- recording and batch selecting core materials and prepregs;
- 3D scanning and template checking moulds for dimensional accuracy;
- laminate schedules and key processes recorded with sign-off by independent supervisors;
- curing cycles and vacuum pressure data logged and recorded; and
- where appropriate, some components are bend tested or samples tested to destruction.

Optimisation and Refit

McConaghy Boats also undertakes optimisation and refit work.
Wild Oats XI, a Reichel Pugh design, was launched in 2005 and was immediately successful—in her first Sydney–Hobart Yacht Race she became the first yacht to win the "treble", i.e. both line and handicap honours and in a race-record time, since *Rani* in the inaugural event in 1945.
However, in 2015 she was facing stiff competition from the much beamier *Comanche*, and needed some modifications to remain competitive. The proposal was to move the mast and keel aft by about 2 m. The easiest way to achieve this was to move the boat around the keel and mast, rather than the other way around. In a highly-publicised event at Woolwich Dock, the bow was cut off nearly back at the mast, and the boat then transported to the factory at Gosford.

Bow removal on *Wild Oats XI* at Woolwich Dock
(Photo courtesy McConaghy Boats)

McConaghy Boats made up a new bow, 2 m longer than the previous one, fitted it to the forward end, and then cut 2m off the stern. The new bow shape made a significant difference to the yacht's speed both upwind and down and, when racing downwind offshore, she could be sailed at more than 30 kn without any fear of nose-diving.
In a tribute to the expertise at McConaghy Boats, you cannot now tell where the cut in the hull was made!


New ow being fitted to *Wild Oats XI*
(Photo courtesy McConaghy Boats)


Wild Oats XI racing again
(Photo courtesy McConaghy Boats)

Future Trends in Yacht Construction
Some future trends in yacht construction—this is not an exhaustive list!—include:

Additive Technology
In 2019 the first 3D printed 25 ft (7,62 m) motor boat was produced and launched. For sailing race yachts operating under specific loads and being extremely weight sensitive, this may be a long-term evolution. In the short term, however, there is high potential for 3D-printed tooling, rather than for the boat itself.

Automatised Fibre Placement
This technology has existed for a long time in aviation. A multi-axis robotic arm lays strips of pre-impregnated fibre with high precision and reliability. Example of lamination of an hydrofoil at Avel Robotics

Electrical Stored Power and Propulsion
Currently yachts requiring stored power are running on diesel engines which power hydraulic motors. Going forward, more and more racers will use electrical winch motors, taking advantage of the recent improvements in batteries.

Embedded Sensors
Embedded sensors are already at play in America's Cup yachts, with over 1000 sensors collecting 100 measurement per second each, enabling dynamic load recording and fine tuning of the yacht when racing. These record such things as loads on winch handles, heart rates of crew, fibre optics on the mast and in hydrofoils, etc. These are becoming more important, not only for fine tuning, but also for passing knowledge of working loads back to the naval architects and engineers.

New Materials
Who knows? Carbon nano-tubes show promise.

Conclusion
Construction of racing yachts using advanced composite materials is a complex business. It requires good communication between the owner, the designer and the yard, detailed knowledge of the materials and their properties, significant trade skills in the yard, project management, and a command of the logistics required. McConaghy Boats has developed a well-deserved reputation for the quality of their product.

Questions
Question time was, unfortunately, limited and we fielded less than half the queued questions, but some more interesting points were elicited.
Impact loads on the hull and keel are not always known with absolute data, and they have to rely on safety margins. For items like frictional resistance, one option is to use towing tank modelling.
One attendee reported that a TP52 experienced delamination after falling off a 3–4 m wave. This could have been a manufacturing fault, but not necessarily. There is a racing circuit for TP52s in the Mediterranean which is a less harsh environment, and these boats are often second-hand by the time they are converted to race offshore! However, if the hull has received a significant impact load (as in falling off a wave), this could have started a delamination. If no-one noticed, then the delamination will expand over time.
Sourcing the materials at the beginning of a project is always a challenge. On one project, the specific fibres they wanted were all being used in the aircraft industry, and so there were none available! Honeycomb core is manufactured in Europe, and so the order needs to be placed before the design is completed.
What are the drivers for using a male or female mould? A rudder, for example, would use a female mould. A male mould is easier to machine or fabricate than a female one, and so usually quicker and cheaper, but it depends a lot on the shape.
The fibre:resin ratio remains pretty standard for each project when using prepregs, usually within ±3%, although this can vary from one supplier to another. It is usually engineered to give the optimum ratio.
McConaghy Boats undertakes work other than marine. For example, the have done work for SUNSWift, UNSW Sydney's solar car, components for the square-kilometre array for CSIRO Astronomy, the Sydney Opera House, and on the submarine for James Cameron to dive the Marianas Trench.
The certificate was subsequently posted to Eric, and the "thank you" bottle of wine delivered via an eGift card.
Eric's presentation was recorded, and is now available on the RINA YouTube channel.