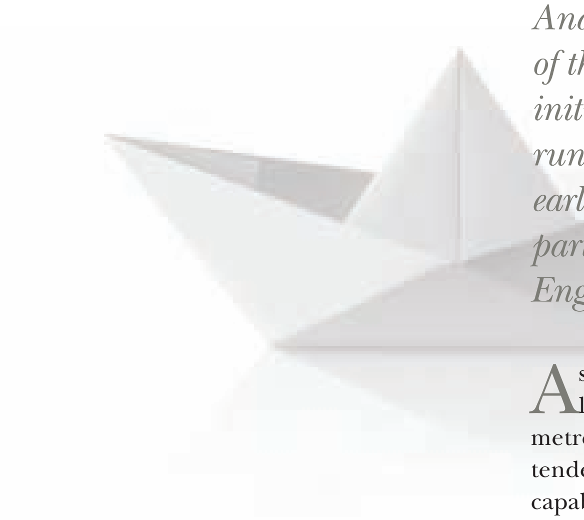
Models Avoid Rocking the Boat

Despite number crunching in three letter acronyms like CFD (Computational Fluid Dynamics), FEA (Finite Element Analysis) et al*, the free running model is still an essential part of that Naval Architect and Designer's tool box. Even where initial studies may be done solely "in soft" radio control, free running models often show up fundamental flaws or validates earlier work – both rapidly and relatively cheaply. This applies particularly to high-speed hulls as Dickon Buckland, Senior Engineer at Wolfson Unit MTIA, explains here.*



A significant proportion of large luxury motoryachts (30–60 metres length overall) and the tenders that service them are now capable of high speeds in the region of 40–60 knots. As Froude number (ratio between speed and waterline length) rises, control problems associated with directional stability become more and more prevalent and most people in the industry will have a horror story to tell of a yacht with an undesirable, or even dangerous, handling characteristic.

For example, a yacht operating in calm water, which is not directionally stable may have a tendency to turn with no input from the helm and without warning. This can be alarming, and in severe cases, hazardous to the crew and guests on board.

This article discusses manoeuvring characteristics that are desirable and features of the hull design that influence directional stability. It also describes model testing techniques and technology that can be employed to assess and highlight any problems in the handling characteristics prior to build.

So what are the desirable manoeuvring characteristics for most craft?

1. Good directional stability.
This quality will ensure that the yacht will hold a steady course in the absence of external forces, and will respond positively to helm angle changes. A yacht with negative directional stability will continue to turn after the rudders have been put amidships or even to the opposite side. This is tiring for the helmsman and the constant rudder adjustments add to the resistance.

2. Good manoeuvrability at speed.
The yacht should be able to manoeuvre within a reasonable turning circle. Unfortunately manoeuvrability and directional stability are opposing characteristics, and an improvement in one is usually to the detriment of the other.

Image: istock.com

3. Good response to the helm.
The yacht should respond with a significant heading change following the application of helm. This should not be confused with positive directional stability, for example a yacht with high directional stability and small rudders will be difficult to turn.

4. Moderate heel in a turn.
Excessive heel in a turn, particularly if it is outward, gives the crew a feeling of insecurity, and frequently leads to other control problems. Outward heel of only a few degrees will be significant in the crews' perception of the yacht's safety.

5. Good control in following seas, with little tendency to broach.
Vulnerability to broaching usually results from a combination of influences due to the hull form, stability and appendage arrangement.

6. Moderate influence of heel on control.
Excessive changes to the manoeuvring characteristics may occur when the yacht is heeled, so that operation in waves or under the influence of other heeling forces becomes degraded.

So what elements of hull design affect the above characteristics? The following are considered to be the most important parameters for planing craft:

1. Hull deadrise aft.
In general, lower deadrise hulls (around 8 degrees or less), or those with excessive warp (longtitudinal change of deadrise), are more prone to control problems.

2. Hull deadrise forward.
High deadrise forward, resulting in deep forward sections, tends to reduce directional stability.

3. Distribution of lateral area.
The longitudinal distribution, or location of the centre of lateral resistance (CLR), affects the directional stability, with increased area aft being beneficial.

4. Skegs and bilge keels influence the heel angle in a turn.
They generate a side force directed into the turn and, being centred low down, this produces an outward heeling moment.

5. Vertical centre of gravity (VCG).
A high centre of gravity will increase the outward heel in a turn, and this may have a strong influence on the directional stability.

Reliability is key and engineering a long-lived propulsion system is problematical

6. Trim control devices.
By controlling trim with transom wedges, trim tabs, interceptors or variable drive angles, the directional stability will also be adjusted. Running with a low trim generally reduces directional stability.

7. Secondary chines and styling lines.
Secondary topside chines, the afterbody, that are close to the water surface can create areas of low pressure on the hull topsides which can induce a dynamic heel angle, which then causes the yacht to turn even when the helm is amidships.

Most aspects of the hull design will be driven by cost, the owner's specification or practical constraints. Many designers will start with a hull form that has a proven track record and by doing so they minimise the risk in encountering a badly behaved design. However, it is likely that at some point in the designer's life he/she will be asked to produce a design that requires a hull form which is unfamiliar. The designer will call upon a host of analytical tools typically consisting of computer programmes (FEA [Finite Element Analysis], CFD [Computational Fluid Dynamics], stability and powering software for example) that go a long way to proving the design before construction begins.

Unfortunately, due to the dynamic nature of the problem, the manoeuvring characteristics of planing hull forms and more importantly their directional stability cannot be predicted by computation or published data alone. Scale model testing, however, offers a cost effective and accurate means of assessing a proposed design prior to production.

The Wolfson Unit specialises in testing fast craft and has many years of experience in the investigation of their manoeuvring characteristics through free running model tests.

The award-winning **Ermis II**, *tested extensively for Rob Humphreys Yacht Design*

Top: Model of a 26-metre luxury motor yacht executing a turn at 30 knots – Rob Humphreys Yacht Design
Above: 25-metre patrol craft operating at 55 knots

The objective of most manoeuvring test programmes will be to ensure that the design has no adverse handling characteristics and, if any are encountered, that changes can be made relatively quickly and cheaply to the hull or appendages with the aim of improving or eliminating the bad behaviour. It is relatively simple and quick to change certain characteristics, the VCG (vertical centre of gravity) height for example, to identify the envelope of acceptable behaviour within a range of values. This will give the designer confidence if the VCG turns out to have moved from the original design location, once the final hull lines and hydrostatics are produced.

Additionally, we have often found that rudder areas are too small to arrest the onset of broaching in following seas. Fitting a larger rudder is normally a trivial task at model scale and its effect can be assessed during a re-test with all other variables kept constant. This would be difficult and costly to achieve at the full scale.

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A model must be representative of the full scale in terms of its speed, weight, centre of gravity and inertia. Scaling laws dictate that the model weight is the full scale weight divided by the scale cubed, and small models need to be very light indeed. If most of the weight is in the propulsion system, there is little ballast available to obtain the correct centre of gravity and inertia and hence the power to weight ratio of the propulsion system must be maximised. The inefficiency of model propellers and jets, and the fact that skin friction is higher at model scale, combine with the result that the power installed in the model must be greater than might be expected if one factors the power of the full size yacht down to the model's scale.

Reliability is key and engineering a long-lived propulsion system is problematical. Sending 5–6kW down a 6–8mm-diameter shaft rotating at 15,000RPM into a propeller, which fits in the palm of your hand is fraught with difficulty. A typical 6kW (8 horse power) outboard weighs around 40kg. The challenge of fast free running models is installing the same power level within a weight limit of 6–8kg.

Recent advances in motor and battery technology, the availability of high quality model water jet drives and small data logging and GPS systems have enabled accurate cost-effective modelling of very fast craft requiring high power to weight ratios.

Up until now, model tests at speeds of 50–60 knots full scale have required two-stroke internal combustion propulsion, which is noisy, difficult to regulate in terms of power output and induce high-frequency (250Hz) structural vibrations which invariably leads to fatigue problems with fragile components.

Electric flight air-cooled brushless motors are now capable of producing the equivalent power of an Internal Combustion engine for the same or less weight and have the advantage of high efficiency (95%), they are quiet, easily controlled and induce a minimal amount of vibration. High-frequency digital radio control has eliminated the problems with Radio Frequency interference emanating from electric propulsion systems.

Owing to the decline in battery voltage with use, it is necessary to regulate the on-board power in order to maintain a constant trial speed. This has been made possible by recent advances in light, high-efficiency DC - DC converters.

In summary, it is now possible to conduct manoeuvring trials accurately and at high speeds using models typically 2–4m in length where scaling effects are small. The mass production of a wide range of the components required to outfit the

Above: Twin water-cooled 2-stroke engines with direct drive to water jets in a 22-metre, 50-knot patrol boat. Right: Model installation of electric air-cooled brushless motors with voltage regulation.

model has enabled the tests to be conducted in a cost-effective way. The tests provide the designer with the manoeuvring characteristics of the hull and highlight problems with the handling should they exist. It is then relatively quick and straightforward to make changes to the model and conduct further tests in order to assess their effect. It is not uncommon to find that the basic hull form is the cause of poor handling, and identification of this before the design has progressed too far is perhaps the largest benefit that these tests can offer.

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Synfo Extra: for video footage of high-speed manoeuvring go to www.synfo.com/extras