Power Catamarans and the LCG

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An overweight multihull with trim problems is not easy to fix.

Some keelboat designers and builders take a rather cavalier approach toward mass and longitudinal center of gravity (LCG) calculations. In many ways this is quite understandable. By adding and subtracting ballast, the displacement of most monohulls can be adjusted relatively easily after the vessel is built. (This excludes high-tech boats, such as America's Cup competitors, which have ballast ratios of around 80% and ballast concentrated in the keel bulb.) The LCG position can be changed by moving the ballast fore-and-aft to affect trim; the keel can be repositioned; and the mast can often be moved-admittedly all a bit drastic and undesirable. But post-hoc solutions to a trim, or an overweight, problem are possible. In fact, these things may often be done so the vessel will achieve a more favorable rating for racing.

Multihull-sailboat designers, on the other hand, don't have any of these luxuries. They may be able to move some fluid tanks around a bit, but this is only a partial solution, since the tanks change weight as they consume the fluid and they constantly need to be topped off to maintain trim. There is no ballast; there is no keel; and the mast stays right where it is, unless you're willing to tear out the structure the mast rests and rebuild a major part of the internal framework. To compound this problem, the difference between the light-ship condition and the full load displacement can be as high as 30% or more; so mass calculations that are not precise can result in a major trim problem.

An overweight vessel also affects the safety factors calculated into the rig and structure. Loads on rig and structure are calculated for the full-load situation, and with a particular safety factor appropriate to the vessel's intended use. if the vessel is heavier than the designed full-load displacement, then such things as the righting moment and transverse bending moments are higher, which erodes the safety factors in the structural calculations. Unless the overload situation is extreme, it's unlikely it will lead to immediate rig or structural failure. But it will almost certainly mean that the rig will need replacing earlier than would otherwise have been the case, and some structural problems, such as cracking, may occur with age.

Power-monohull designers are in a similar saturation. They don't really want to add ballast to correct a trim problem if they can help it; this could exacerbate an existing weight problem.

Power-multihull designers, however, must treat the mass estimates and the calculation of the LCG position as the proverbial Holy Grail. If the vessel is a planing power cat, then the mass estimate and the LCG position are critical, The planing catamaran tends to have a smaller planing surface and higher bottom-loading than the equivalent monohull. Because it almost certainly has more skin area, it also tends to weigh more than the monohull, unless it's built out of advanced composites. If it's overweight and the LCG is in the wrong position, affecting the trim, then there's going to be a major problem getting it to plane. It may, in fact, end up as a rather inefficient displacement boat. [There are also critical factors in dynamic instability. For more on this, see PBB No.31, page 20-Ed.]

You may think that because weight, per se, is not the same problem from a performance point of view for a displacement catamaran, the mass and LCG calculations would not seem so critical. Wrong! The displacement cat usually has finer hulls than a planing cat (and much finer than a monohull), which gives it a higher hull speed. This makes it more susceptible to changes in longitudinal trim because of the narrower waterplane. It's basically the difference between a plank floating on its edge or on its flat. If weight is added to the end of the plank floating edgewise, then it will "dip" a lot more than the plank floating on its flat with the same added weight. So the position of the LCG relative to the longitudinal center of buoyancy (LCB) and the longitudinal center of flotation (LCF) is crucial, since relatively small shifts in the position of the LCG can cause serious trim problems. What this means in practice is that it's very difficult to keep a power cat in level trim in all conditions from light-ship, through half-load, to full-load displacement; this is especially true of the displacement cat. On vessels with a substantial difference between the light-ship and full-load conditions (such as those craft with transoceanic or long-range capabilities), it's common to arrange a fuel-transfer system to keep the craft in trim as the fuel and water loads change. More seriously, it also means that any increase in weight or shift in the designed LCG position during construction can be disastrous.

An increase in weight may have very little influence on the performance of a displacement power cat (one of our ferry designs, for example, performs with 150 people much the same as when it's empty). This is because the major determiners of hull speed, such as the prismatic coefficient and the ratio between the waterline-length and waterline-beam, are little affected by any immersion.

If the extra weight affect the trim, however, then it adversely affects the performance. Stern-down trim can often reduce speed by a knot or two but more important, the weight increase may also compromise the performance of the vessel by lowering the height of the wingdeck off the water, causing the waves to hit the wing in milder conditions than might have been the case if the vessel were at its correct displacement. And, in similar fashion to the sailing catamaran, the structural integrity is compromised because the loadings on the structure are higher than those in the original structural calculations. This lower wingdeck height severely disturbs passenger comfort -their peace of mind notwithstanding- since waves thump more frequently on the wingdeck.

Weight also increases the longitudinal rotational moments of inertia of the craft, particularly if the added weight has been distributed toward the ends of the vessel. The bows are slower to rise to wave action, which further increases the likelihood of wave impact on the wing, particularly at the leading edge. When the bows come back down again, the wingdeck will hit the water harder, Even in normal conditions, weight should be concentrated toward the center of the vessel as much as possible to minimize the pitching effects that are more evident on the slim-waterplane catamaran.

To counter wingdeck impact, some designers place a vestigial third hull in the center of the wing, up forward - similar to the center "hull" on a wavepiercing catamaran, though somewhat smaller. This obviously costs more to construct than the flat wing, but may be a way of minimizing the impact of the additional weight that always seems to sneak in. It doesn't do any harm to have extra length of empty boat at the ends and to keep the wingdeck as short as possible, and as far back from the bow as practicable, If I can, I prefer to bring the wingdeck up to gunwale level some distance back from the bow; the area forward of this is then left open. A "pickle-fork" bow, with perhaps a trampoline or a forward deck from gunwale at sheer height, is fitted. This forward deck is well off the water (right up at gunwale height) and the central anti-slamming nacelle is brought forward under this area. I carry the nacelle right aft thought the underside of the wingdeck where it becomes a very convenient duct for pipes, holding tanks, etc. On my more recent rough-water performance designs, I have used a "double arch", which has a cross section similar to (but smaller than) those employed on some early wave-piercing catamarans. All these approaches minimize slamming should it occur. Keeping level trim with the wing at the designed height, however, is the real name of the game.

It has also been suggested that the "unknown-items factor" should be increased to compensate for any possible added weight. This "fudge" factor allows for the weight of those small things that are difficult to estimate, such as bolts, screws, clips, hinges, and the like. If this factor is assessed with any precision it will increase the design cost considerable because of the amount of time involved. The unknown-items factor is usually expressed as a percentage of the structural weight, or light-ship displacement.

To some extent, an increase in the unknown-items factor can be justified as compensation, but there are a few problems associated with this approach. First, it degrades the accuracy of the whole weight-estimating process and makes it more and more of a guess. If the factor is too big, then there isn't much of a reason to even estimate the weight; you may as well just stay with the original "best guess" established at the beginning of the design process, which is based on previous experience. If you don't have a lot of experience, then you would just have to accept all the uncertainty that goes with it, particularly if you haven't designed a similar vessel before. The basic assumption about all the small items that make up the factor is that they're evenly distributed around the structure of the vessel and, therefore, do not affect the LCG position, only the weight . But. if major items are added to or moved around the vessel after the weight estimates are completed, then they can have a marked effect on the LCG position.

Power-multihull designers must make sure that the mass and LCG calculations are as precise and comprehensive as possible, Impress upon clients, in the strongest possible terms, that they must tell you everything they're going to have on the boat, even if they're not going to fit it at the moment. (I have a checklist these days to help with this.) A client can't keep adding equipment to the boat after the design stage is finished. This is a major problem with catamarans of all types because of the amount of interior volume that's generally available, Unfortunately, the large load-carrying capability, and owners must be restrained from filling up every available space, particularly with heavy items.

Assuming that the owner can be kept under control, then there's the question of possible differences between the builder and the designer. How do you ensure that the builder is working to the same weights as the designer? This isn't too much of a problem with alloy [aluminum] construction. Because the plating is produced under tightly controlled conditions, you can rely on its being a particular weight per square meter within very close tolerances, and this makes the mass estimates relatively easy, aside from the question of filler. But, in the case of a composite craft, whether it's wood, foam, fiberglass, balsa, or various combinations of these, the construction material isn't manufactured in a factory - it's made on site. Designers use particular fiber-to-resin ratios, thicknesses of plywood, weights of fiberglass, etc., for their mass estimates. These should be based on actual achievable, as-built-in-a-yard weights, not laboratory perfection. But if the builder is not achieving the same weights per square meter as the designer intends - or the builder changes the material - then things can get seriously out of whack very quickly. The solutions to this problem are twofold. One, the designer can get actual, as-built weights from the builder. Unfortunately, this only works with the second boat from a particular builder, and doesn't necessarily work for all of them since laminate-weight variations can be as high as 25% from builder to builder; even with individual laminators at a given shop applying open-mold, hand-layup techniques. Second, some builders institute careful quality-control procedures covering the laminating techniques and the fiber-to-resin ratios to ensure that they're getting the correct weight estimates. SCRIMP (Seemann Composites Resin Infusion Molding Process), pre-preg fabrics, and wet-out machines may offer better control over fiber-to-resin ratios, at least for a primary structure.

Communication between the designer and builder concerning the actual weights is crucial, And this is no less true for a wood/epoxy composite boat. [See the sidebar on page 49.] To this end, it's advantageous for the designer to supervise construction and be aware of any problems as soon as they become evident. In fact, designers who supervise construction should be constantly on the lookout for any deviation from the plan that's going to have a deleterious effect on the mass of the vessel. The builder can also construct the boat on load cells, or at least weight the vessel at particular intervals, allowing the builder and designer to monitor the vessel weight and the LCG position as construction progresses, At a particular stage of assembly, if weight is high and the LCG is not where it should be, then it may be possible to take corrective measures. If all weighing happens at the end of construction, then it may be far too late and the unhappy owner is left with a boat that doesn't perform as expected, and with a set of problems that will be expensive to remedy.

A Cautionary Tale

My assistant and I performed nearly three weeks of calculations on a comprehensive spreadsheet to get the mass and LCG estimates as precise as possible on a 19.6m (64.3') power catamaran designed for strip-plank/ply/foam/fiberglass composite construction. In fact, it was probably the most careful mass estimate we had ever done.

When the vessel was launched, it appeared to be floating over its lines. We took measurements from the waterline, and the computer confirmed that in light-ship condition the boat was 27% heavier than the weight estimates. So what had gone wrong?

I had only visited the vessel once in the early stages of its construction because it was being built at a considerable distance from my home base. Somebody told the owners that extra weight did not have an adverse effect on displacement power catamarans. That was correct with regard to speed, but they seemed to be totally unaware of the negative effects on vessel trim-despite my earlier emphasis on weight when discussing the design with them.

So where had all this extra weight come from? Unbeknownst to us, the builder had substituted 150kg/m3 (9.37 lb/ft3) end-grain balsa for the specified 60kg/m3 (3.75lb/ft3) PVC foam in the core of the ply/foam/ply structures of the wingdeck, bulkheads, and cabintop. The area involved was several hundred square meters. The exterior sheathing glass was 750g/m2 (22 oz/yd2) instead of the specified 300g/m2 (8 oz/yd2). Factoring in the resin, this is a significant increase in weight. The plywood specified for the interior cabinetry was 4mm to 5mm (.16" to .2"); actual ply in a lot of places was 12mm (.5"). Was the builder the source of the problem? He certainly contributed, and commented that none of the increases in weight was very much. But if you say that 200 times, the result represents a significant increase.

The owners also had the builder move the rather large galley some 2m (6,6') forward and they installed commercial/hotel appliances rather than the domestic units we had allowed for. To compensate for the resulting bow-down trim, the builder put 500kgs (1,100 lbs) of batteries aft. This may have corrected the bow-down trim, but it magnified the longitudinal moment of inertia already initiated by the forward galley.

What could we have done? The owners weren't willing to pay for supervision, but we should have insisted on being informed -in writing- of any design changes. We should also have insisted that the vessel be built on load cells, or at least weighed several times. If these things had taken place we might have been able to notice the problem earlier. Isn't hindsight wonderful?

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