Roll Motion of Boats at Anchor

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What is the problem?

You invest considerable resource in acquiring a boat which is comfortable and safe. Part of the dream is to be able to anchor in a secluded bay surrounded by nature with a modicum of luxury on board. The reality can turn into a stomach churning nightmare if the vessel starts to roll.

Roll motion is a nuisance on both motor boats and sailing yachts for the following reasons:

- it causes sea sickness;
- crew and passengers may fall and hurt themselves;
- embarking and disembarking become difficult and possibly dangerous;
- noise is generated through water slap on the hull and motion of inadequately secured objects;
- some on board equipment will not perform adequately.

All boats, sail or power, roll to a greater or lesser extent when subject to waves. When a boat is on passage and travelling at reasonable speed the roll motion can be controlled adequately by the use of fin stabilisers if it has plenty of power available on board (which implies a large motor yacht). However, when a yacht is moving slowly or is at anchor, fin stabilisers do not work because they require water to flow over the foil at high speed in order to generate the roll-reducing forces. A different solution is required when the vessel is not moving through the water.

What influences rolling?

Whilst the most obvious way of reducing roll motion is to avoid anchoring in waves, most of the more attractive bays are, by nature of their geography, places where waves can work their way in. The headland that shelters us from the wind will often cause the associated waves to curve into the bay, striking the boat beam-on.

Many possible solutions are available, but first we need to identify the two possible targets that such solutions must aim at:

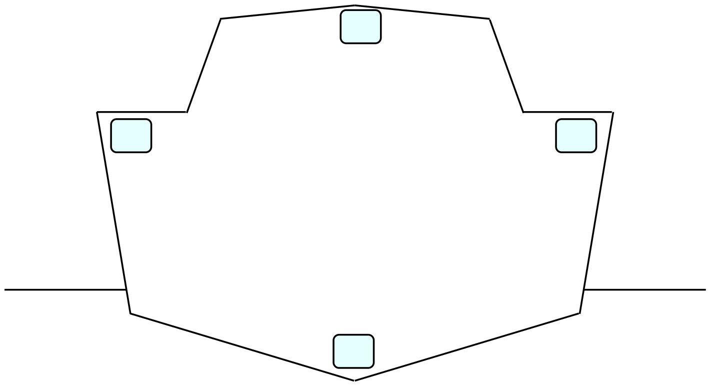
- avoiding resonance and
- increasing damping.

Resonance

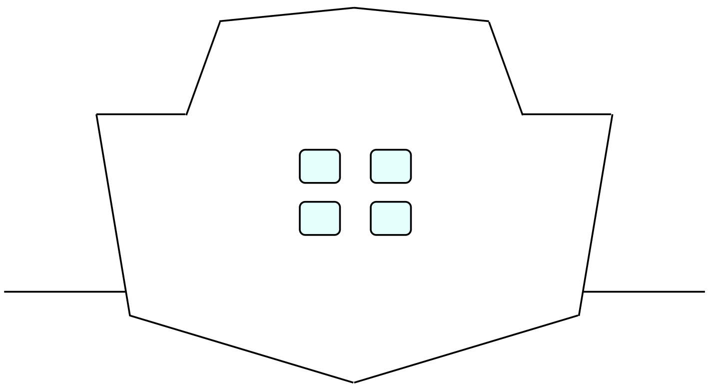
A rolling yacht has a natural period, just like a pendulum. If you heel it over in calm water then let it go, it will oscillate at a set period (the time taken for the boat to swing from port to starboard ,and back again). This is called the natural period. If instead of just letting the boat oscillate, you expose it to waves of various periods, the motion will be greatest in waves which have a period the same as the natural period of the boat. i.e. when resonance is occurring between the boat and the wave. Avoiding resonance is achieved by making the natural roll period of the boat as different as possible from the range of wave periods likely to be experienced. The natural roll period for a typical monohull cruising yacht is about 4 seconds; unfortunately this is also typical of the wave periods encountered in semi-sheltered bays. The natural period of the boat depends on the following:

- Stability (resistance to heeling). A more stable vessel will have a shorter natural period than an equivalent vessel with less stability. This is why most catamarans have a more rapid motion than monohulls.
- Distribution of weight in the boat – the "inertia". A boat with a large inertia will have a slower natural period than a boat with a small inertia. So if there are large weights on board which are placed either at the maximum beam, or very high up or very low down, the inertia will be large and the period slow (figure 1).

Figure 1: effect of inertia



a) heavy items spread out – long (slow) roll period



b) heavy items close to centre – short (fast) roll period

Note that the weight of the boat does not enter directly into the equation; a heavier boat will have the same roll period as a lighter boat of equivalent shape and weight distribution. However, heavier boats often do not require such a high stability, and the extra weight tends to be in the extremes of the boat (top, bottom and well outboard) leading to a higher inertia. So a heavy boat tends to have a longer roll period than a light one because of the inertia and stability change, not simply because of the weight difference.

Damping

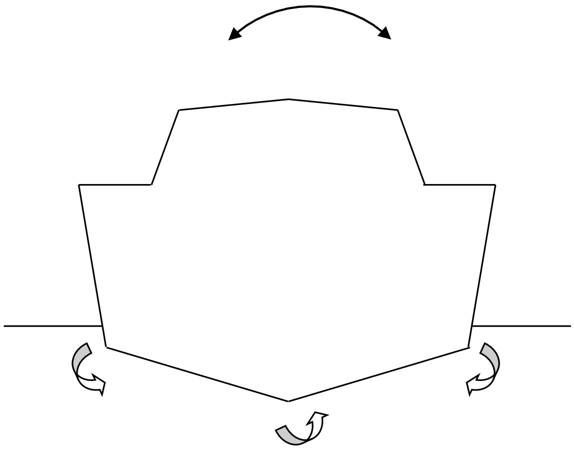
Damping is the opposition to roll motion. It does not affect the natural period, rather it determines the amount you roll at that period. Damping is generated by a number of mechanisms (figure 2):

- The biggest contribution comes from generating vortices (large eddies or swirls) as the boat rolls. Vortices are most easily generated at sharp edges e.g. chines, keels and rudders.
- The next most significant contribution comes from generating waves as the boat rolls. A square or triangular section hull will generate waves as it rolls; those waves require

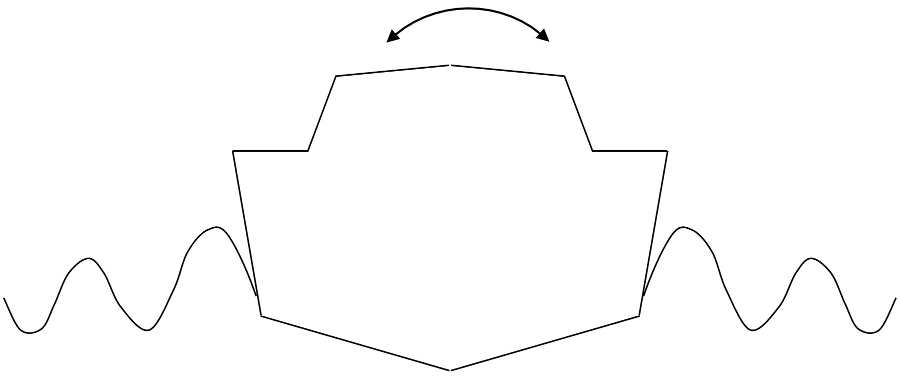
energy to exist, and the energy comes from the roll motion. So the bigger the generated waves, the more energy is being taken from the boat, so the less energy is available to generate the roll motion. Circular section hulls do not generate waves as they roll so do not have any wave damping.

- There is also a damping contribution from the friction between the water and the rolling boat, but this is usually so small it can be neglected.

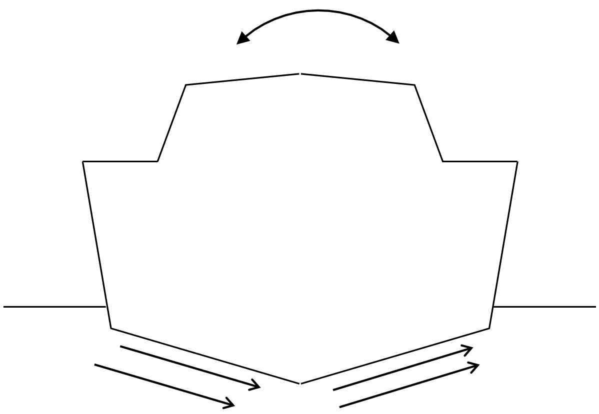
Figure 2: Sources of damping



a) eddies



b) wavemaking



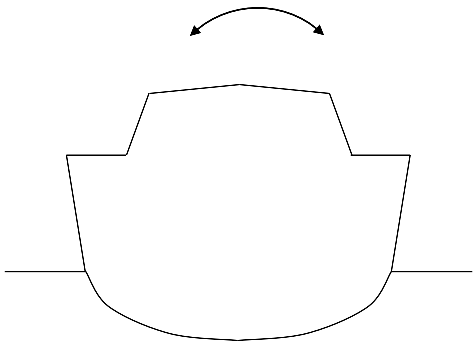
c) friction (negligible)

How can roll be reduced?

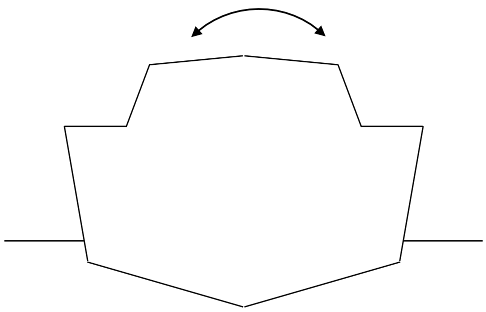
Changes to hull underwater sections

The section shape affects the damping. A rounded hull shape usually has less damping than a rectangular or chined hull (figure 3a, 3b). Computer modelling I carried out on a typical modern cruiser-racer yacht demonstrated that the hull sections make only a very small contribution to damping, compared with the keel and rudder, so there is little scope for improvement through this variable. However, if radical hull forms are permitted in the vessel specifications, there is scope for some innovative thinking here. For example, the use of chines, steps, winglets etc. could yield worthwhile improvements.
On motor boats, the hull shape contributes a higher proportion to the total damping, because the appendages are relatively small in area. However, the corollary of this is that motor boats often roll more because they don't have as much keel to generate damping, so motor boats need a "bigger fix".

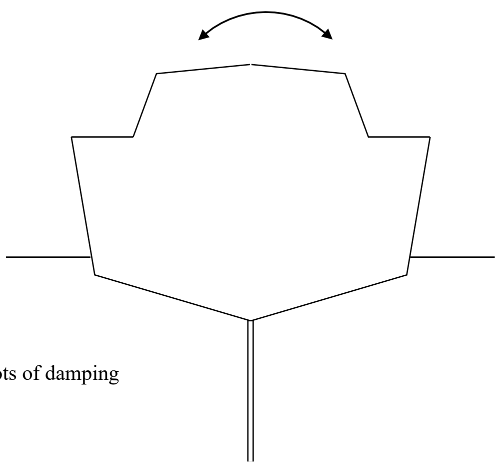
Figure 3: Damping changes



a) round sections – little damping



b) chined sections – moderate damping



c) keel – lots of damping

Additions or changes to keel or rudder

Computer modelling and model tests in a wave basin I conducted have shown that the keel and rudder on a yacht can have a very large effect on roll motion, by increasing both the inertia and the damping (figure 3c).

- For a given profile area of keel, a deep draft keel will have more damping (hence less roll) than a shallow draft keel, other things being equal. A similar effect is found with the rudder.
- The inertia of the boat is affected by the keel for two reasons. Firstly, the keel is a large mass situated a long way down, so any changes in shape or size will have a large effect on the total inertia. Secondly, as the keel moves through the water when rolling, it must accelerate water around it. This accelerated water has its own inertia, called the "added inertia" (naval architects can be very unimaginative at times). A large keel has more added inertia than a small keel.

Flopper-stopper

A flopper stopper is similar in configuration to the paravanes used by fishing boats. It usually consists of a hinged flat plate positioned horizontally below the surface well outboard of the boat. The plate is held by, for example, a rope attached to a spinnaker pole braced athwartships. As the boat rolls the flat plate absorbs energy by being pulled through the water. This creates a roll-opposing moment which dampens the motion. As the boat rolls back, the hinge allows the flat plate to fold and offer minimal resistance. This latter characteristic is employed to eliminate the complication of compressive loads in the bracing structure. It is common to rig a flopper stopper on each side of the boat.
Anecdotal evidence is that these devices work to some extent, but roll reduction is rarely more than 30% . One difficulty with flopper stoppers is the logistics of deploying them in the presence of a current; as they tend to become unstable.

Steadying sails

These have similar potential to underwater appendages in terms of roll motion reduction. The challenge lies in maintaining effectiveness for all wind strengths without creating operational difficulties. That's techno-speak for saying you have to stop the boat sailing off its anchor.

Anti-roll tank

This is a tank filled with water, with the shape tuned to yield a natural sloshing period close to the natural period of the boat. The tank is configured so that the sloshing water is out of phase with the roll motion, thus generating an opposing roll effect. This can be very effective at wave periods matching the natural period of the tank. However the tank is heavy, voluminous and can lead to stability problems. It can also be noisy.

Gyroscopes.

Roll-stabilising gyroscopes have been used on ships for about 100 years and have been developed for recreational boats over the last 10 years. Like all motion reduction options they have their merits and drawbacks, but they can reduce roll motion by up to 80%.

Fin stabilisers at anchor

Research has shown that if you rotate a fin stabiliser back and forth at a fast rate, it will generate some roll damping even if the boat is anchored. Clearly this requires a lot of power, but if you have a large motor boat this is a possible solution. You wouldn't catch me swimming round the boat whilst they were operating though!

What to make of all this?

- If you are trying to reduce roll at anchor with an existing boat, your options are limited. The best bet is to add a roll reduction device.
- If you are looking to buy an existing boat, you can use the explanations in this article to make a better judgement about the likely roll characteristics of the boat. At the very least, you should be better able to compare the roll characteristics of one boat with another.
- If you are lucky enough to be in the position of having a boat custom-designed, you can now talk with the designer on a more knowledgable basis about how any proposed design changes will affect roll at anchor, and whether you need to fit an anti-roll device.

Further reading:

The following papers are downloadable from http://cmst.curtin.edu.au/publications/

Klaka K., Penrose J.D., Horsley R.R. & Renilson M.R. (2004) "Roll Motion of Yachts at Zero Froude Number" *International Journal of Small Craft Technology* v146 part B2 pp2-15.

Klaka K. & Renilson M.R. (2004) "Experimental Study on the Influence of Appendages on a Yacht Rolling at Zero Froude Number" *Marine Technology* v41 no.5 pp200-206.

Klaka K., Penrose J.D., Horsley R.R. & Renilson M.R. (2003) "Roll Motion of Yachts at Anchor" *RINA Modern Yacht Conference,* Southampton.

Klaka K., Krokstad J. & Renilson M.R. (2001) "Prediction of Yacht Motion at Zero Forward Speed" *14th Australasian Fluid Mechanics Conference,* Adelaide.