Storm tactics: some forgotten science

The attrition rate in the recent Golden Globe Race around the world has led to some lively debate about the safety of these old designs compared with modern ocean racers. Those decrying the use of traditional long keel yachts point out two differences compared with modern high performance yachts. Firstly they are much slower, so they have very limited opportunity to get out of the way of approaching storms. This seems irrefutable to me. The second point they make is not nearly so clear cut – they claim that the greater directional stability of a long keel means that if the yacht is surfing on the back of a wave, it will go out of control once it stops surfing. This comment made me recall a piece of work I did many years ago, attempting to explain why ocean sailors adopt different tactics when running with a storm.

As shown by Robin Knox-Johnston's report in the July 2019 edition of Sailing Today, debate still rages over whether you should deploy drag devices such as drogues and warps to slow a boat down when running before a gale, or whether you should run as fast as you can in order to maintain steerage. Applying a bit of science reveals that this might be a false dilemma, because each technique may be effective at different stages of the storm.

Assumptions and simplifications

The ocean is a mish-mash of waves coming in all shapes and sizes from many directions. That is much too complicated to investigate mathematically, so I follow standard engineering practice and strip it down to something simple enough to understand, but not so simple that it is meaningless. I shall assume we are dealing with a yacht sailing in a regular pattern of waves all from the same direction, none of them breaking over the boat. I also assume we are in deep ocean, not coastal waters (the physics of coastal waves is similar, but the final numbers come out different). We will also only consider the situation where the yacht is travelling in exactly the same direction as the waves – broad reaching brings in extra complications.

Clearly these simplifications lead the reader to think" Yes, but what about all those important other factors that are not being considered?". My response to that is "Yes, they are important but we have to start somewhere".

I am not going to examine other storm tactics such as heaving to, lying a-hull, or active steering; they are topics for another article.

Some oceanography

Waves can be described by their height, steepness, length, speed and period. We first need to clarify these terms – see figure 1.

- Period is the time between successive crests passing.
- Height is the vertical distance from peak to trough.
- Length is the distance between successive crests.
- Steepness can be many things, but an easy definition is height divided by length.
- Speed is the speed at which a wave crest moves across the surface. It is important to note that the particles of water in a wave do not move at this speed, it is the speed of the *shape* of the wave we are talking about here; more on that in a moment.

Fortunately we can reduce this list to just height and speed because length, period and speed are directly linked e.g. if the wave period is known, then speed and length can be calculated. A typical deep ocean wave might have a period of 10 seconds. The oceanographic equations show that such a wave would have a length of 150 metres and travel at 30 knots. Height is not directly linked to length, though there are limits to the height of a wave of given length. A 150 metre long wave would typically have a height of up to around 7 metres, though it could be as high as 14m. If its

height is more than about 20m it will break due to its own weight of water. (Of course it will break at a much lesser height if there is a cross-sea).
Let us return to the issue of the speed of the water particles making up the wave. The particles of water do not travel with the wave, they go round in a circle – see figure 2. They travel with the wave at the crest, in the opposite direction at the trough, and vertically at the mid-slope in between. This can be proven mathematically and verified by putting a cork in the ocean and tracking its movement. This circular movement of the water particles is given the term orbital velocity. Our example wave of period 10 seconds and height 7m will have a wave particle (orbital) velocity of about 4kn.

And now the naval architecture

Consider the effect of those orbital velocities on the effectiveness of the rudder. The greater the speed of the water flowing over the rudder, the more steering force it can generate. If a boat is sitting with its stern on the crest of a long wave doing, say, 7 knots, then the flow speed over the rudder will not be 7 kn, it will be 7 kn minus the orbital velocity of the water particles at the wave crest. A 10 second wave of 7 m height, has an orbital velocity of about 4 kn, so when the yacht rudder is on the wave crest, the flow over the rudder is just 3 kn (7 kn minus 4 kn). This is what gives the helm that soggy helpless feel just before the wave gets a hold of the boat. Conversely, the orbital velocities in the trough are 4 kn in the opposite direction, giving you a healthy 11kn flow speed over the rudder if you can maintain boat speed. Let's park this bit of knowledge about rudder effectiveness for the moment and move onto surging and surfing…..
There is a very old and oft forgotten piece of research (du Cane and Goodrich, 1962), where they measured what happens to boats travelling down waves at model scale in a test basin. They happened to be interested in high speed power boats, but subsequent tests (Kan, 1987) on a range of hull shapes led to similar generalised conclusions. The tests revealed two important findings. Firstly, if a yacht is moving at say, 8 kn in calm water then you put the boat in waves with the same propulsive force from the wind, you can pick up and surf-ride a wave that is about 50% faster than your calm water boat speed. So if you have enough wind force to travel at 8 kn in calm water, that will enable you to surf steadily on a wave travelling at up to 12 kn. (This would be a 4 second, 25 m long wave). The second important finding from the model tests is that the more the boat surges (increases and decreases its speed as the wave passes), the more likely it is to go out of control (usually a broach). So less surge means lower likelihood of broaching.
These two observations are linked, as shown in figure 3. It shows that as the speed of the boat increases it surges more, and when the surge speed momentarily reaches the wave speed, the boat will surf-ride on the wave.

Putting it all together

If you bundle all the above observations together you discover that there are two conflicting requirements – the need for good rudder control means you want boat speed to be high, but the need to reduce surge means you want to slow the boat down. Let us set the two criteria for safe travel as:

- you need at least 2 kn of water flow over the rudder to have control, and
- you must travel at less than 60% of the wave speed to avoid surf-riding.

Taking a 50 kn storm as representative of when things start to get hairy, when you do the sums you get the answers shown in the table below.

Storm duration (hrs)	6	24
Modal wave period (s)	5.6	10.3
Significant wave height (m)	3.3	8.9
Wave speed (kn)	17	31
Orbital velocity (kn)	3.5	5.3
Min. safe boat speed (kn)[1]	5.5	7.3
Max. safe boat speed (kn)[2]	10.2	18.6

The results show that at the beginning of the storm the boat speed must be kept below 10.2 kn, which suggests towing warps or a drogue, but not generating so much drag that speed falls below 5.5 kn. Then as the storm develops, the warps should be recovered in order to maintain speed above 7.3 kn if possible; there is little chance of surf-riding in this later part of the storm because it requires a boat speed of more than 18.6 kn to do so. Hence the raging debate about different downwind storm tactics over the years misses the point somewhat; a cruising yacht needs to adopt different tactics for different wave conditions. Specifically, you deploy drag devices at the beginning of a storm when the waves are slow and short, then run at speed later in the storm when the waves have developed into long, fast ones - other things being equal, which they rarely are!

The proof of the pudding

So is this all just theoretical nonsense or is there some real-world evidence to support it? We can test the theory by going through first-hand accounts of successful ocean sailors in conventional cruising yachts. Bearing in mind all the assumptions made in this analysis – non-breaking waves from dead astern etc. - it is difficult to find a first hand account where the two tactics were used at different points in a storm. Nevertheless, there are many reports which do support the general thrust of the theoretical conclusions reached.
Firstly, examine three compilations of first-hand accounts.

Shane

Shane (1990), summarises 71 accounts of yachts using drogues, nine of which are for monohulls deploying drogues off the stern. Two of the most famous (Moitessier, 1969 and Smeeton, 1959) are discussed separately later. Four of the remaining seven accounts support the theory, two disagree with it and one does not have enough detail to inform.

Bruce

Bruce (1999) describes more than 14 storms, some involving several yachts. The majority of reports involve lying a-hull or heaving to, but there are 6 reports of direct relevance to this article. Two of them support the theory, one disagrees, and three are indeterminate.

Knox-Johnston

This recent compilation in Sailing Today summarises 10 incidents in the recent Golden Globe and a further 3 separate incidents. There is limited information about whether each incident occurred early or late in the storm so the results are indeterminate. The experience summarised by Knox-Johnston in the original Golden Globe race on *Suhaili* was that towing warps at all stages of a storm was effective. However, the winner of the recent Golden Globe, Jean Luc van Heede, did not tow anything during storms in his Rustler 36 *Matmut*.

1 Must be 2 kn more than the orbital velocity for rudder to work effectively
2 Must be less than 60% wave speed to avoid surf-riding

Now let us examine two detailed famous accounts:

Moitessier

Probably the strongest supporting evidence is that of Moitessier (1969) sailing his yacht *Joshua* in the Southern Ocean in December 1965. He deployed warps during the first part of the storm, hand steering easily at first but with increasing difficulty as the storm developed. 20 hours into the storm he realised he should not be towing the warps so he cut them loose. The yacht became much easier to steer and survived the storm relatively unscathed. This account is the only one I can find where both techniques are used at the appropriate point in a storm. Whilst Moitessier's experience might be seen as full vindication of the theory, it should be tempered by the observation that Moitessier was actively steering and also keeping the waves slightly off dead astern.

Smeeton

The pitch-poling of *Tzu Hang* in the Southern Ocean in February 1957 is one of the most famous storm descriptions in sailing history. They dropped all sail and streamed warps about 8 hours into the storm, hand steering fairly easily. They even managed to film the seas. They continued under trailed warps until about 15 hours into the storm, when they were pitchpoled. We can never know if they would have avoided the pitch pole if they had cut the warps free, but it shows that warps worked to start with but they did not prevent catastrophe later in the storm.

Conclusions

There is almost certainly an element of sub-conscious cherry-picking in the above examples, but they do provide some support for the theory. What does stand out are the additional influences of active steering, hull shape, wave breaking (steepness) and sailing at an angle to the waves. It also becomes evident that a drag device capable of adjusting the drag according to boat speed could provide a single solution to both sets of storm conditions. All these factors need to be added to this preliminary analysis, but at least we now have a sound scientific basis to work from.

References

Bruce P. (1999). *Heavy Weather Sailing*, 5th ed. Adlard Coles.

du Cane P. & Goodrich G.J. (1962). *The following sea, broaching and surging*. Transactions Royal Institution of Naval Architects vol 104 no 2.

Kan M. (1987). *Surf-riding of a ship in following waves*. Session on Manoeuvrability, 18th International Towing Tank Conference, Kobe, Japan.

Knox-Johnston R. (2019). *Rough stuff.* Sailing Today, July 2019.

Moitessier B. (1969). *Cape Horn: the logical route*. Adlard Coles Ltd.

Shane V. (1990) *Drag device data base*. Para-Anchors International Ltd.

Smeeton M. (1959) *Once is enough*. Rupert Hart Davis.

Tucker M.J. (1991) *Waves in Ocean Engineering*, Ellis Horwood. (Section 10.6 in particular)

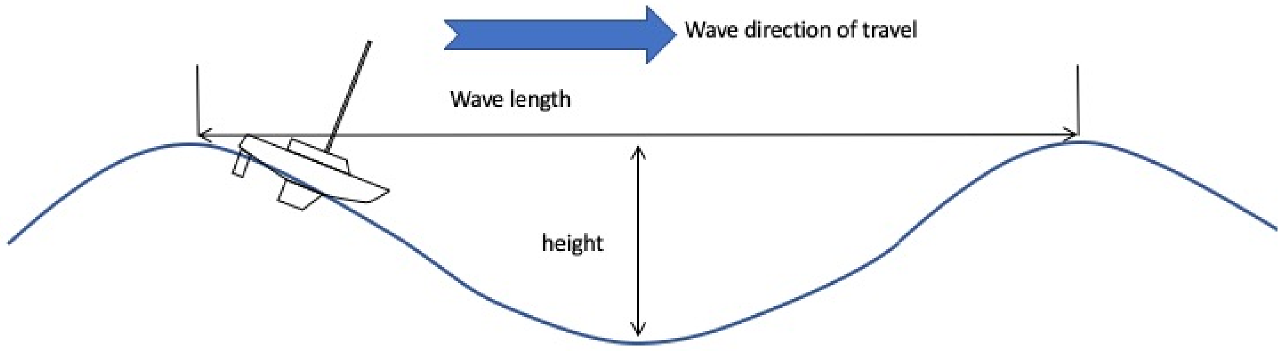

Figure 1: Definition of height and length

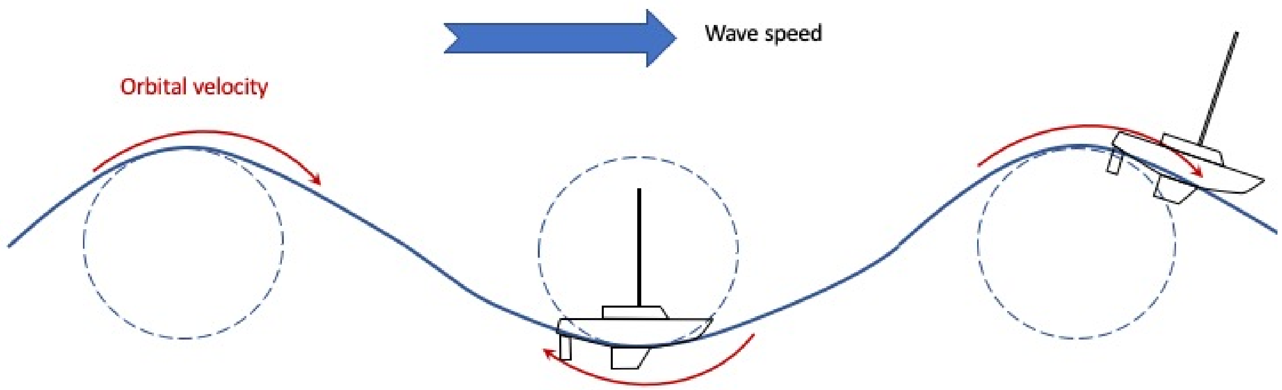

Figure 2: Orbital velocity of wave particles

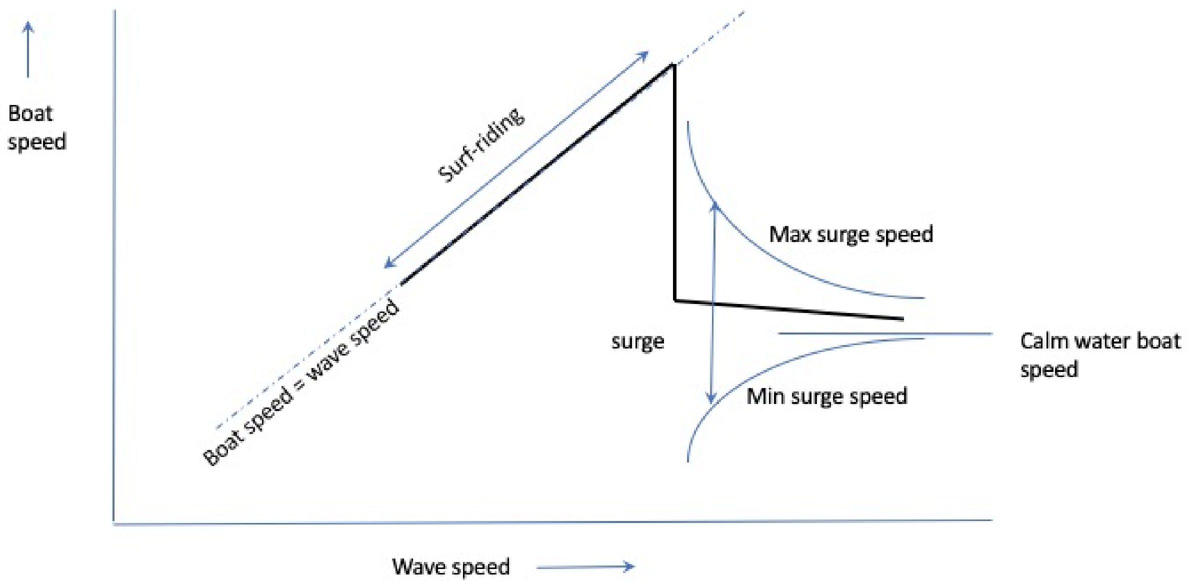

Figure 3: Boat speed in waves (from du Cane and Goodrich)