Why the Safe Leeward Works

"Arvel Gentry analyzes the principles behind this tactic"

By Arvel Gentry

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Interaction between sails on a boat has been confusing to many sailors. Not surprisingly, this confusion continues when one discusses what happens between sails located on two separate boats: one boat in the safe-leeward position. The old explanation of the slot effect between two sails on the same boat, and what we experience when the sails are on two different boats, seemed to create a paradox.

When the sails are on the same boat, the old theory had the jib forming a venturi of high speed air that helped the mainsail. But when the sails are on different boats in a close safe leeward situation, somehow the boat behind and to windward (like the mainsail) is ***hurt*** by the boat to leeward. How can such sail interaction help in one case, and be a hindrance in the other?

Previous articles in this series have totally disproved the old venturi slot-effect explanation, and we have seen how the jib influences the main, and how the main, in turn, actually helps the jib. Exactly the same type of thing happens between the sails on two different boats, and this article will explore this situation.

Obviously, there is no paradox between the safe-leeward position and the slot-effect of two sails on the same boat. Everything is in fact consistent if proper streamlines and flow solutions are used.

Let's look at the complete flow field around a single boat (Figure 1). The dotted lines show the streamlines about the boat, and spaced along these lines are pairs of numbers. The top number is the local wind velocity at that point in the flow. All these numbers are what I call relative values for they include both the true wind velocity, and the velocity created by the actual movement of the boat through the water.

The bottom number is the local flow angle. The plus angle number represents an upwash flow direction from the freestream direction, and a negative number is the local downwash. In this example, the freestream conditions out in front of the boat were taken at 10 knots and zero flow angle (apparent wind speed and angle). We would have to go several boat lengths upstream before these conditions are reached.

The air is significantly influenced for a considerable distance all around the boat; to windward, to leeward, and

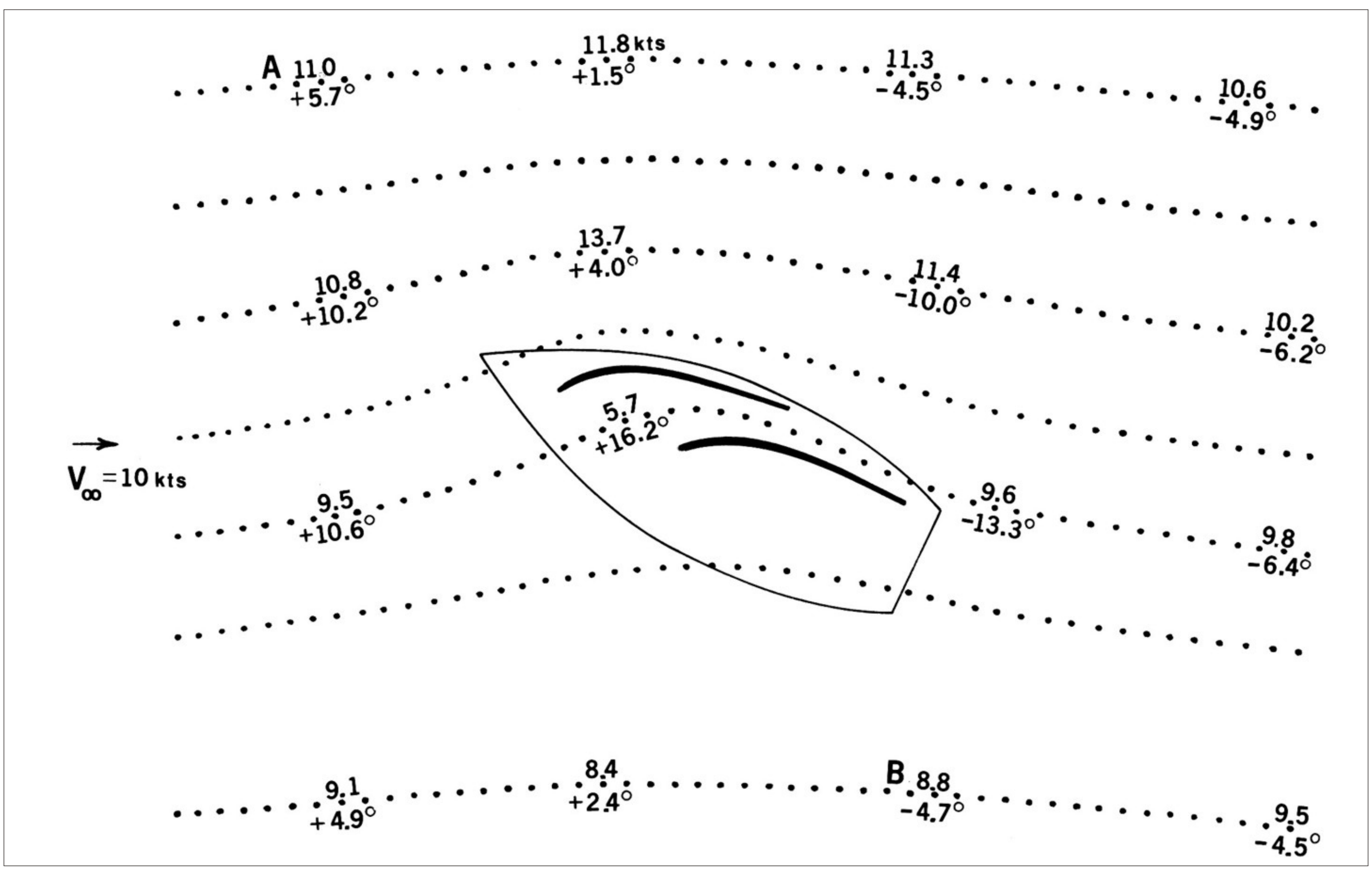

Figure 1

downstream. The effects are strongest near the boat and decrease as you move away. Because small differences in local wind speed or flow angle can make a considerable difference in the performance of a boat, it comes as no surprise that the safe-lee situation is in fact a dynamic example of sail interaction.

In Figure 1, the favored safe-lee position is the flow field area marked by the letter A. The flow conditions at this point are a wind speed of 11.0 knots and a flow angle of +5.7°. This means a boat in the safe-lee position has a wind speed higher than freestream, and it sails in a wind-shift corresponding to a lift (increased upwash), all created by the boat to windward.

The safe-lee boat creates a downwash flow field that produces both a heading wind-shift and a reduction in wind speed on the aft boat, the flow field area marked B. Here the wind speed is down to only 8.8 knots and the flow angle is a header of 4.7°. Obviously, this is not a good place to be!

A complete flow field about the two boats is shown in Figure 2. Both boats have been placed at the same angle to the freestream wind so we can judge the relative interactions between the two sets of sails. Comparing the single-boat flow field in Figure 1 with the flow field about the two boats, we see that the windward boat W has much less upwash than it does in Figure 1. The reason is that it is suffering from the downwash created by boat L.

The shape of the streamlines downstream of boat W have not changed very much, but boat L has a far greater upwash in front of it than was the case in Figure 1. It is experiencing a lifting wind shift that is created by boat W.

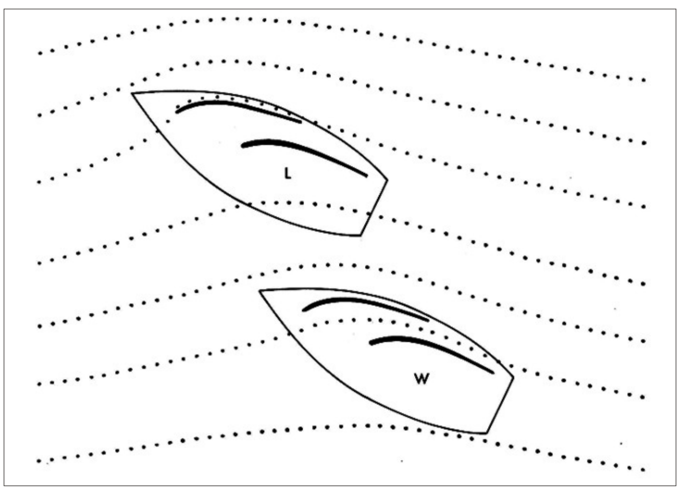

Figure 2

How do these changes in the flow fields affect the pressures on boat W's sails? The answer to this lies in the pressure distribution plots shown in Figure 3. The dashes represent the pressures on the sails when the aft-windward boat is sailing alone, and the solid lines show the pressures when the safe-lee boat is present.

The negative pressure coefficients represent pressures less than the free-stream value (suction pressures) and the larger the number, the higher the suction pressure on the lee side of the sail, and the higher the lift. Note, however,

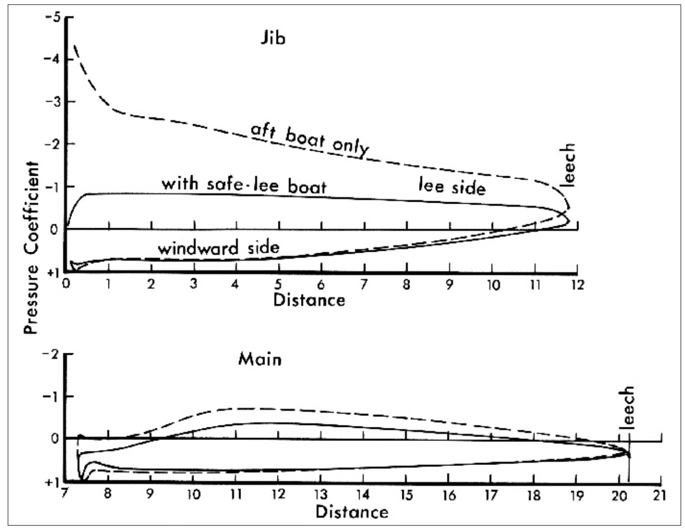

Figure 3. Aft windward boat.

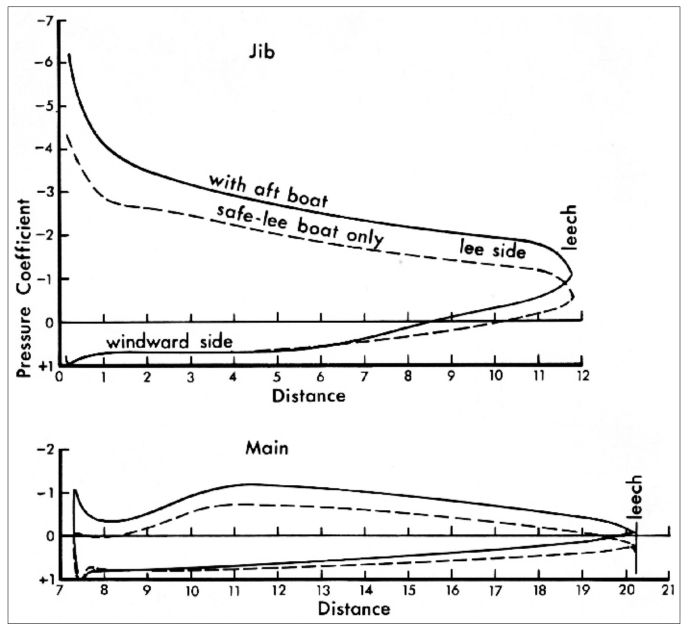

Figure 4. Safe-lee boat.

that with the safe-lee boat present, the aft windward boat has much lower lee-side suction pressures and therefore much less lift. We see that both the jib and mainsail of the aft windward boat are seriously hurt by the safe-lee boat.

Equally important, however, are the effects the aft-windward boat has on the safe-lee boat. The first effect we have already seen; the aft boat creates increased wind speed and a favorable wind shift that benefits the safe-lee boat. You might ask whether the aft-windward boat creates a higher speed wind flow region on the ***windward*** side of the safe-lee boat, and if it does, shouldn't this actually hurt the safe-lee boat?

It is true that the effect does tend slightly to increase flow speeds on the windward side of the safe-lee boat over what they would be if it were sailing all by itself. The windward side of the safe-lee boat does, therefore, suffer a slight reduction in contributing to the drive of the sails on the safe-lee boat. Why, then, does the safe-lee boat still leave the aft-windward boat behind?

The explanation lies in what happens to velocities on the lee side of the sails of the safe-lee boat. First, let's assume the safe-lee boat has only one sail, and its leech is in the high-speed flow region created by the aft-windward boat. Because of this, the leech speeds on the safe lee boat do not have to return to freestream conditions, as they would have to with the mainsail of the aft windward boat. This is the same situation that was discussed last month when a jib came under the influence of the mainsail.

The airflow on the lee side of the sail of the safe-lee boat does not return to freestream speed at the leech. Instead, it is at a much higher velocity. This higher velocity on the lee side occurs because the Kutta condition on the safe-lee boat must be satisfied in a high-speed region created by the aft-windward boat. This means the entire velocity distribution on the lee-side of the sail of the safe-lee boat is higher than it would be without the aft-windward boat.

These increased velocities and, therefore, reduced pressures on the lee side of the sail of the safe-lee boat will more than offset the loss in drive on the windward side of the sail. This is the "dumping-velocity" or "bootstrap" effect described last month.

Only this time the sails are on different boats, and the aft-windward boat actually helps the safe lee boat by increasing its air velocity and angle, and by maintaining increased velocities all along the lee surface of the safe-lee boat's sails.

If the safe-lee boat has a mainsail and jib, there is a "double bootstrap" effect. The aft-windward boat helps the mainsail of the safe-lee boat. This in turn, helps the jib of the safe-lee boat even more. The proof of all this is shown in the pressure distribution plot in Figure 4.

These plots show that the pressures at the leech of both the main and the jib are more negative (higher airspeeds) when the aft boat is present, and the lee sides of both sails have higher negative pressures (higher velocities) all along their surfaces. There also is a slight reduction in windward side positive pressures. However, this loss in lift is more than compensated for by significant increases in the lee suction pressures.

How does this situation actually affect the two boats? First, a boat to windward and aft of the safe-lee boat has a lower windspeed than the safe-lee boat; and it also sails in a header. Because he will have to bear off from his original course to keep his sails at the same angle to the local wind, his speed-made-good to windward goes down.

The safe-lee boat, however, can point higher because of the increased upwash caused by the aft windward boat, and a higher local wind speed. Although he does suffer a slight loss in lift contributed by the windward side of his sails, this is more than compensated for by increased velocities and suction forces on the lee-side of his sails. The result is that he can point higher and go faster than the aft-windward boat and, in fact, ***points higher and goes faster*** than he would if he were merely sailing alone!

All my analysis assumes the sails on both boats are trimmed to perfection and have no flow separation. The analysis uses two-dimensional airfoils; that is, a cut is made through the sails of both boats at the same height. On a real boat, there are different airfoil shapes and sizes that run from the deck to the highest point on the sails. This means the relative influence of the effects just discussed will vary at different heights above the deck. The effect is still there at every level; it's just the relative magnitude that changes.

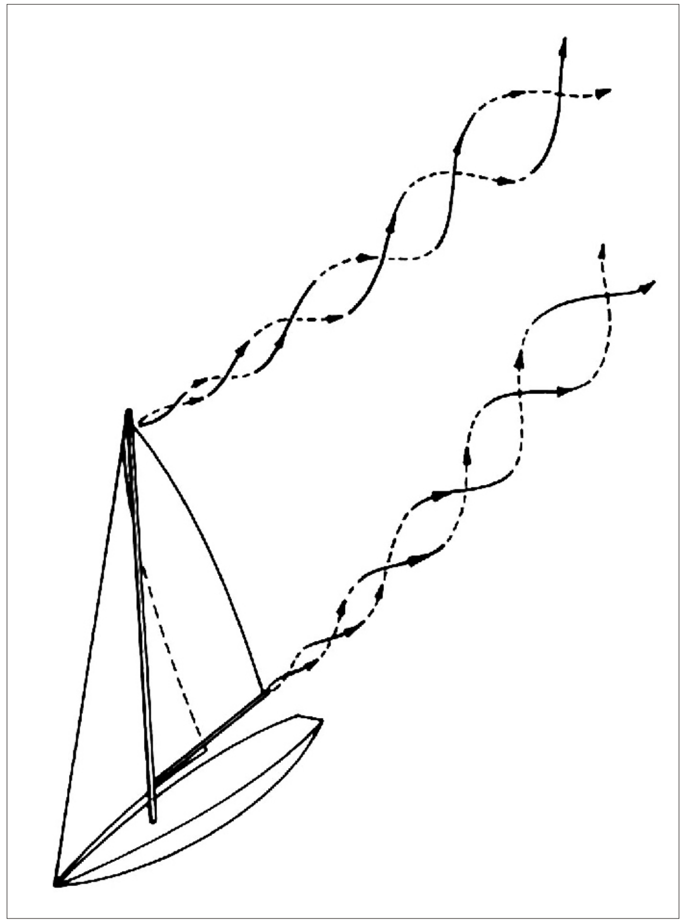

Figure 5

Look back at Figure 1. You will see that, although there are large differences in speed and flow angle in the flow field about the boat, there are no sudden changes in short distances. If this is so, why do we sometimes experience a sudden change in our own boat when we cross behind another? One explanation may be that the sails on the other boat have large regions of separated flow, which cause a wide unstable wake behind the boat. This is particularly noticeable when you pass a boat on a reach.

Another reason lies in the fact that a sail is three-dimensional. It has a foot and a head that create a trailing tip-vortex system just as airplanes do. The tip-vortex system is illustrated in Figure 5, though I want to emphasize that this figure is just a sketch of what is really a very complex phenomenon. The sketch shows a swirling vortex of air that is shed off the top and bottom of the sail. Each sail has its own tip vortex system, and those flowing from the jib will interact and possibly merge with those from the main.

Each vortex is caused by high pressure air on the windward side of the sail, either at the top or bottom, trying to flow around and on to the lower pressure lee-side. Although this twisting is present to a certain extent all along the leech, its major influence is felt at the ends of the sail. If a boat passes nearby, it will experience a sudden flow change as its sails pass through these trailing vortex wakes. Interestingly, in the center part of the sail flow speeds and angles are not affected too much by these vortex systems and remain about as shown in Figures 1 and 2.