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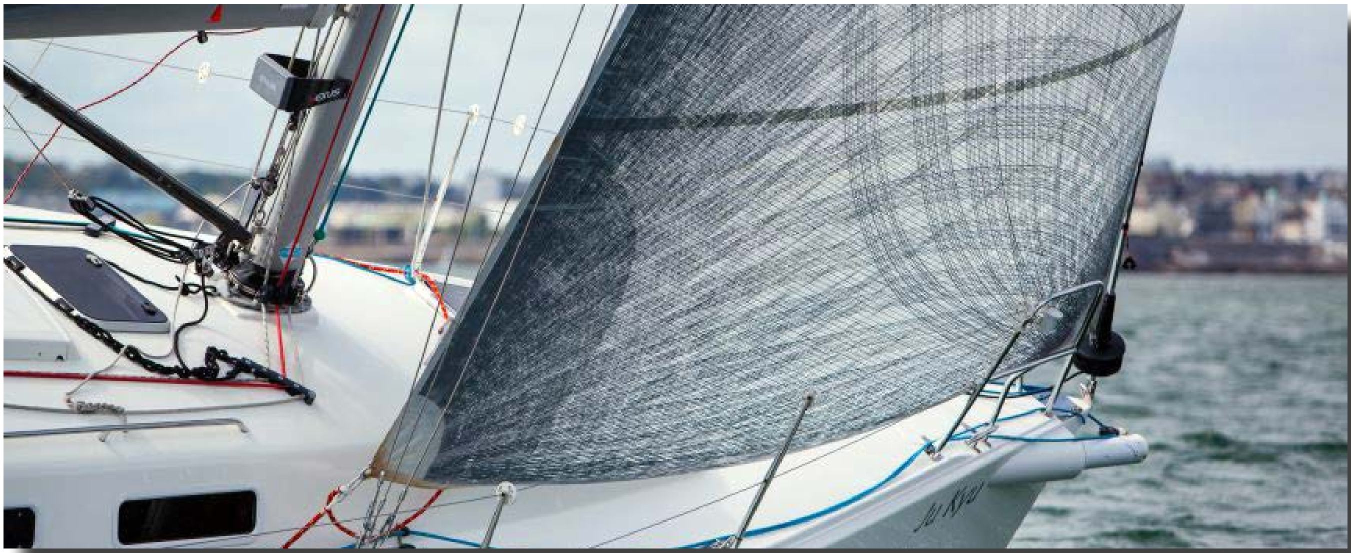
MAXIMUM SAIL POWER

CHAPTER 6

WHERE ART AND SCIENCE MEET - Part 2



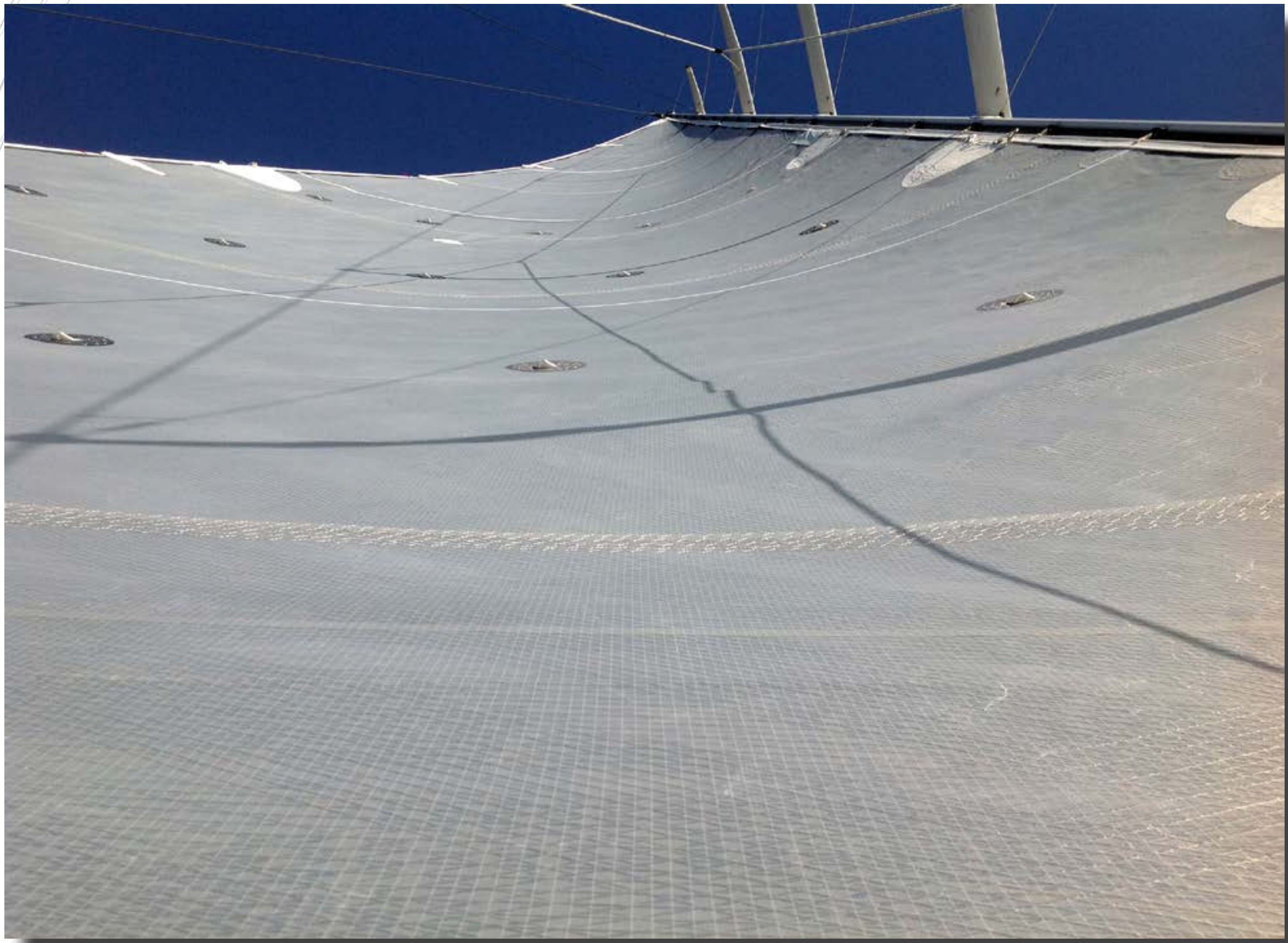
Chapter 6 is an in-depth look at the sailmaking process from how we used to make to how they are made these days in a modern sail loft. There is a lot to cover from basic design elements like sail geometry and engineering to a look at the manufacturing process. There will be four parts to Chapter 6. This is part 2 that continues to look at some of the elements of sail design that were started in Part 1. I urge you to download Part 1 and 2 as well as Part 3 and 4 when they are published so that you will have a comprehensive knowledge of sail design as well as the manufacturing process which will also be covered.

Induced Drag

In terms of the physics of how a boat sails, there are a number of different types of lift and drag that are fundamental to performance. Two obvious types of drag are form drag, which occurs when any object presents a surface to the movement of air, and frictional drag, which is a function of the amount of friction between any surface and the surrounding air. Race cars and airplanes, for example, are streamlined in an effort to minimize the former, and their surfaces are kept smooth in order to minimize latter. But while both of these forms of drag inhibit the free flow of air, neither comes close to slowing a boat down like induced drag. So what is induced drag and how does it relate to the vertical distribution of camber in a sail?

When a boat is sailing to windward there are two areas of differing pressure: a high-pressure area on the windward side and a low-pressure area on the lee- ward side. In an attempt to reduce these pressure differentials, air from the windward side pushes over the top of the sail and under the bottom of the sail to get to the area of low pressure on the leeward side. This air flowing up and over and down and under combines with the natural flow around a foil to create spinning pockets of air called vortices, which detract from the amount of energy available to move the boat forward since the vortices them- selves require energy for their formation. For a more striking example, think about the induced-drag vortices that flow off the end of an airplane wing. They are so powerful that smaller planes are not allowed to take off directly behind larger aircraft for fear of the smaller plane encountering these violent vortices and crashing. That's a lot of energy, and it's the reason you will see small winglets on the end of the plane's wings. It's also the reason why, since the 1982 America's Cup when Australia II won with a winged keel, winglets have become critical to keel design. Swirling vortices of water require even more energy for their formation. In an ideal situation you want the wind, and in the case of the keel, the water, to flow onto and off the foils with as little disturbance as possible.

So bearing in mind induced drag let's look at the geometry of a sail. It's obvious that the bottom of a sail has the potential to provide the most lift because it has the longest chord and is the largest part of the sail. But it is also closest to the foot of the sail, i.e., the area of the most induced drag. Fortunately, sail designers have figured out that by keeping the lower third of a sail flatter they may sacrifice some lift, but they will also be able to reduce induced drag, which actually improves the lift-to-drag ratio. This is because flat lower sections serve to keep the wind flowing across the sail rather than allowing it to dip under the foot. The result is that the overall driving force of the sail is improved.



Flatter lower sections in this membrane mainsail

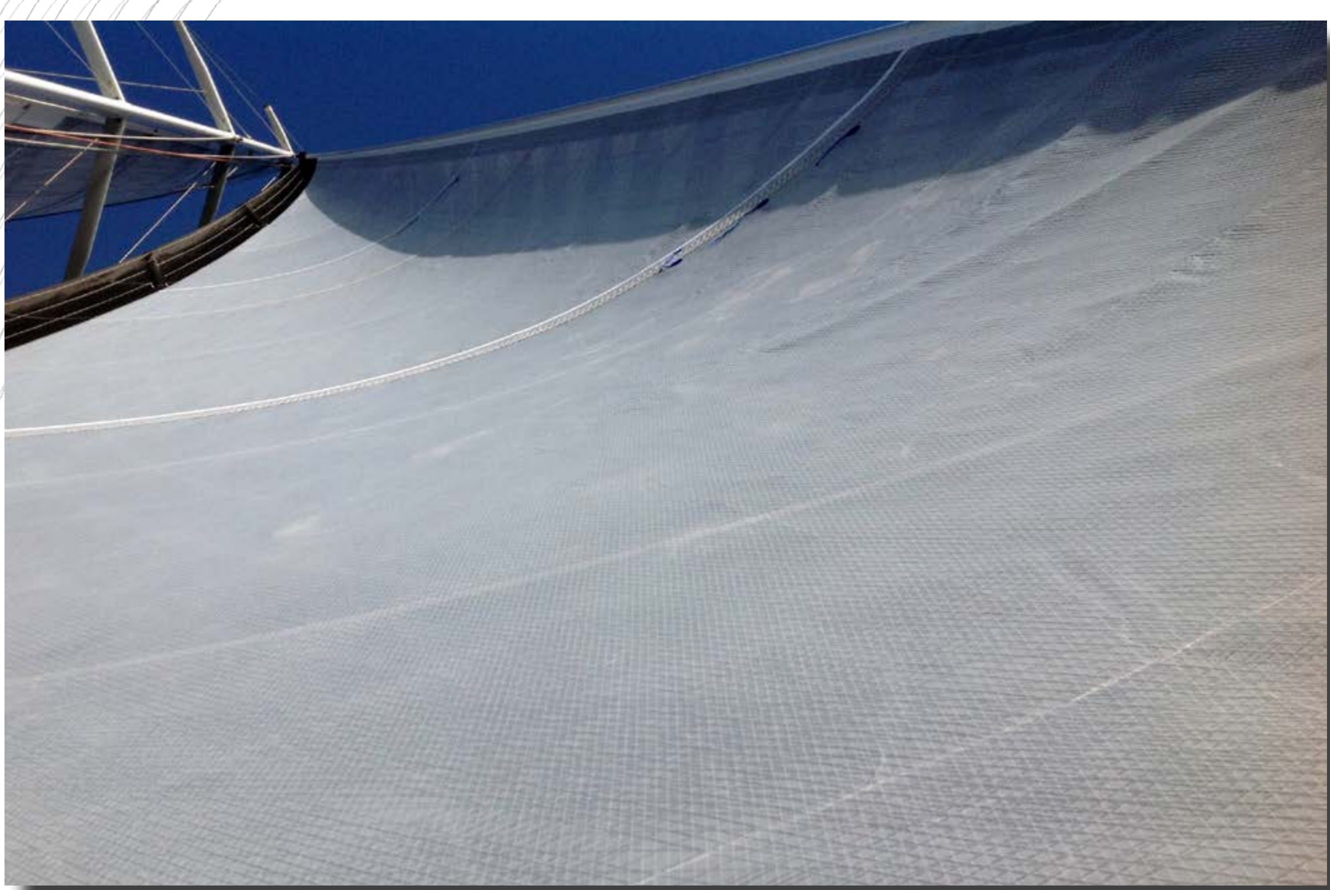
So if the lower third is flatter, how does the rest of the sail shape up? Ultimately it is the middle of the sail that generates the most force and gets the most attention from designers trying to create the perfect shape, since it is away from the areas of induced drag and still has a reasonable chord length. The top third of the sail, on the other hand, carries a deeper draft to compensate for the natural twist in the apparent wind and the fact that the top of the sail is actually sailing along in a big lift, in other words it can afford to be a bit fuller than the rest of the sail. Furthermore, because the chord length is so short as the sail tapers to a point at the head, sail designers simply add depth to give the sail more power, a design feature that plays into the apparent wind situation perfectly. The problem with induced drag is also less significant because the sail is comparatively narrow at the top, so designers can design in the extra drag without the price that would have to be paid along the lower third of the sail.

To recap, sails are generally flat down low, the right shape through the middle sections, and full toward the top. It's the sail designer's job to make this transition smooth and at the right place to create a perfect sail.

Leading Edge Angle

The very front of a sail, called the leading edge, is the part of the sail that first comes into contact with the wind and therefore is vital to overall aerodynamic shape. It is here, especially with headsails, that the sail generates its power since it is the first place that the wind comes into contact with the sailplan. The obvious goal of the sail designer is to create a sail with an angle of entry that facilitates a smooth introduction of the flow of air over the sails, i.e., the front of the sail should be directly in line with the wind. But as is so often the case with sails, this is not quite as easy as it sounds and involves a number of trade-offs.

For example, if a sail has a fine entry then the boat should be able to sail closer to the wind, so why would anyone choose anything else when the basic goal of sailing to windward is to steer a course as close to the wind as possible? Actually there are a number of reasons, including the fact that the angle at which the sail starts out will have an effect on the rest of the camber of the sail, which can result in a number of unintended consequences. Take, for example, two sails with an identical chord length. If the designer wants to keep the area of maximum draft in the same place in both sails, then a sail with a fine entry will end up being flatter (higher



Smooth leading edge on this membrane headsail

chord-depth ratio) than one with a rounder entry . Along these same lines, if he wants to keep the chord-depth ratios the same, the sail with the fine entry will end up having the area of maximum draft further aft while the draft will be forward with a rounder entry. It is at this point that sail design becomes a delicate balance of competing interests since pointing ability is a good thing, but the draft-aft sail increases drag and runs the risk of having the flow stall over the leeward side of the sail, especially toward the leech. This means it will be more difficult for the helmsman to steer the boat to the sails, since even the smallest mistakes will result in a loss of aerodynamic efficiency. A round entry, on the other hand, might not allow the boat to point as close to the wind as a fine entry, but the maximum camber will be forward, increasing lift and reducing drag with a flatter leech section. Because this sail is less likely to stall, steering does not need to be so precise, which will make life much easier for helmsman. Unfortunately, there is a bit of a dichotomy here since flat sails are generally desirable when the wind is fresh and the waves are kicking up — precisely the time when helming is the most difficult. In fact, what you really would like for these conditions is a sail with a rounded entry, but unfortunately those sails end up being full and inappropriate for strong winds. There will be more on this dilemma and trimming your sails accordingly in the chapter on sail trim. For now understand that the sail designer has to think about these differences and design the sail with them in mind.

Luff Curve

Because the mainsail is attached to the mast, it follows that the way in which it is attached will have an influence on the shape of the sail. For example, the sail designer designs a luff curve on a mainsail that he assumes will match the curve of the mast. In some cases he might add more luff curve than there is mast bend so that some of that excess curve can be fed into the body of the sail in the form of sail shape. Imagine, however, what would happen if the sail is set on the mast and the owner of the boat has the mast bent twice as much as the sail designer allowed. The curve of the mast would distort the shape of the sail, and all the thought and creative energy that went into the sail design will be lost. The same thing happens when the sail designer calculates the amount of headstay sag when designing a jib or genoa. In every boat there will be at least some sag in the headstay, so it's the designer's job to estimate just how much sag there will be and then design the front of the headsail to accommodate it. Imagine, however, what would happen if the sail designer was told, or assumed, that there was a hydraulic ram on the backstay to tighten and thereby straighten the headstay. If, after the sail is built, the designer finds out that there is no hydraulic ram his sail will not fly as designed, since the excess headstay sag will affect the location of the draft in the sail as well as the leading-edge angle. In fact, this very thing happened a few years back when I was involved with an IMOCA 60 project that called for the boat to have a 100-foot mast, and the designer decided to leave the hydraulic ram off the backstay in an effort to simplify the overall sailplan. As soon as we went out sailing, it was immediately obvious that we were going to have a problem, since without the ability to tension the backstay, and in doing so tighten the headstay, the carefully designed shape of the sail was largely ruined by the huge amount of sag in the headstay. Once again, the more accurate information the designer has the better job he can do for you.

Part 3 of Where Art and Science Meet will cover sail design 101. A look at how the designer has to take into account all these various aspects of an ideal sail shape and incorporate them into the actual design.

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