Practical Explanation of the Theory used in Sailmaking

The author, Steve B. is a retired sail maker and avid yachtsman. Born and raised on Long Island, New York he began sailing at 12 years of age. Following a 2-year enlistment in the Navy, which included an uneventful tour in Vietnam, he returned to his native Long Island. In 1967 he joined the Seafarer Yacht Co. as an apprentice sail maker. In 1972 he was promoted to Master Sail maker and continued to work along side veteran masters. The recession in the late 1970's hit the pleasure yacht business hard. In 1982 he and a co-worker left the company and started their own sail making business. The closing of Seafarer Yachts in 1985 led to a boom in business, with owners looking for new sails for their Seafarer yachts. Through numerous marinas, yacht clubs, and word of mouth, the business continued to grow and in 1990 a third master sail maker joined the company. During the mid 90's the shop was turning out 12 to 15 full sets of new sails per year, for a variety of yacht owners. Following the retirement of 2 partners 2000, the business began to scale down, and in 2005 officially stopped production. Steve and his wife of 35 years continue to sail year round, whenever possible, all along the east coast, from New York to Florida.

Overview

The dynamics of airflow around a three dimensional object are extremely complex. This document is a basic explanation of only a fraction of the unlimited number of force vectors and their effects. A more precise and technical explanation can be found in books on physics, and aerodynamics. This is only a general explanation and most of the graphics will be exaggerated to help with the visualization. For simplification, all objects in this document will be shown in cross-section, at a 90º angle to the wind direction.

Introduction

In order to shape the optimum sail for a given application we first must visualize, in our mind's eye, the invisible forces that are present around the sail as it 'catches' the wind. The most important of these forces is lift. It is important to understand that the lift on a sail **pulls** the boat foward just as lift on an airplane's wing pulls the plane upwards.

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Resistance and Drag

Air flowing over an object has resistance and drag. For this example, we'll use red to show positive pressure or resistance, and black to show negative pressure or drag. In figure 1 we have a sphere, fixed in space, with wind passing around it. The concentration of color shows the approximate intensity and location of each force upon the sphere.

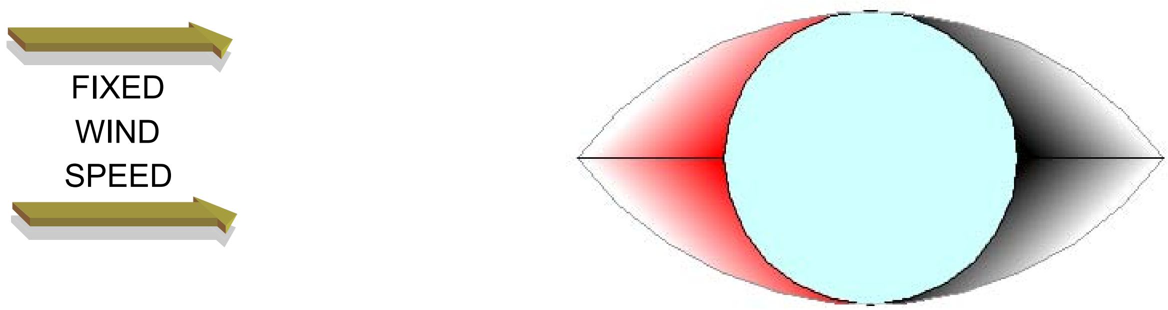


Figure 1

Now let's changed the sphere into a shape that minimizes the resistance and drag for that given wind speed.

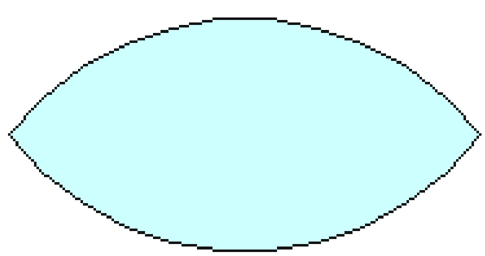
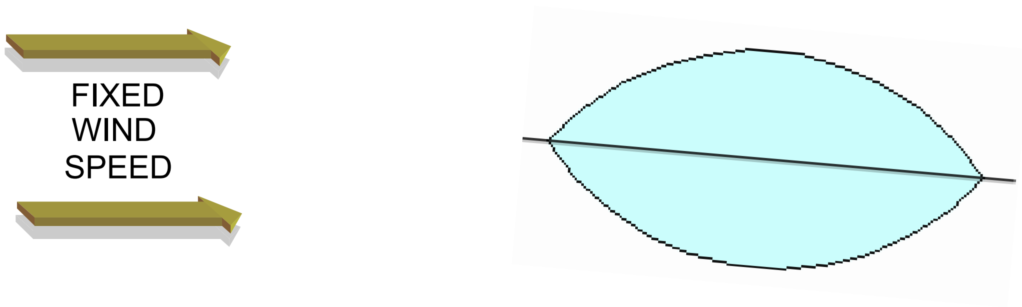


Figure 2

The sharp point on the end towards the wind (Leading edge) causes the object to make abrupt movements if there is even the smallest change in the angle of attack. (hunting)



A slight rounding of the nose will stabilize the object and make it less susceptible to this behavior at the expence of some increase in resistance.

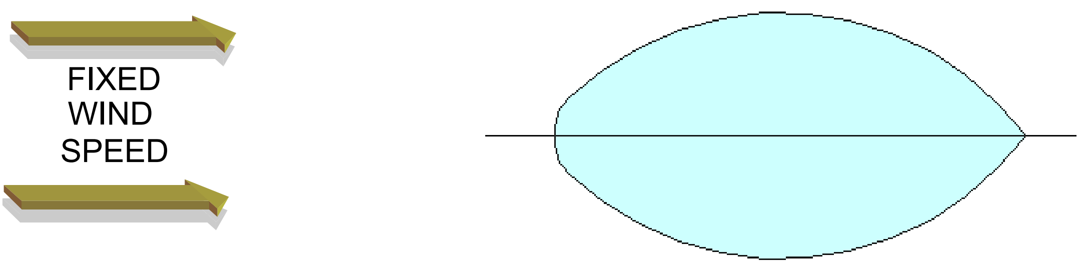


Figure 3

As the wind speed increases the resistance and drag increase. At some arbitrary wind speed we reach the condition shown in figure 3a. The resistance is not shown. We know it's there, but our shape has minimized it as best we can.

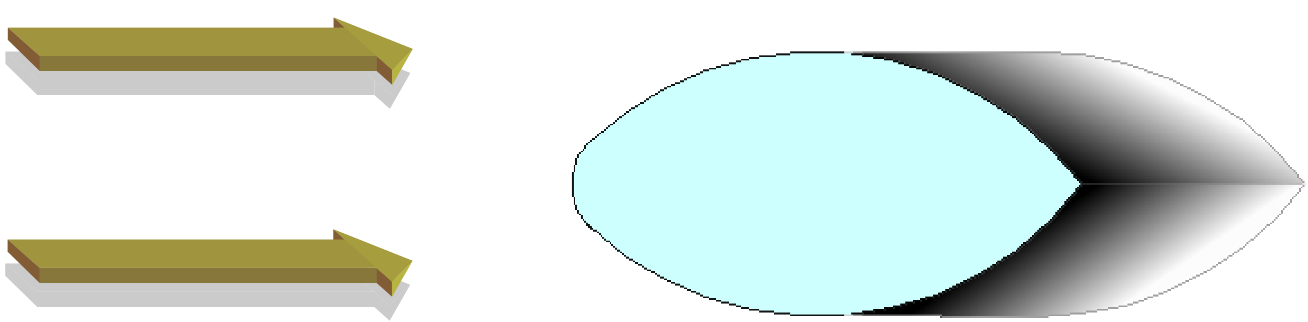


Figure 3a

The Airfoil

Taking figure 3a and stretching the back half equally along the centerline to a point where the resistance in front and the drag in the rear are balanced, for a given wind speed, we recognize a common shape in figure 4, the teardrop. Recent studies using high speed film have shown this to be the approximate shape used by the Peregrine Falcon to achieve dive speeds in excess of 200 mph.

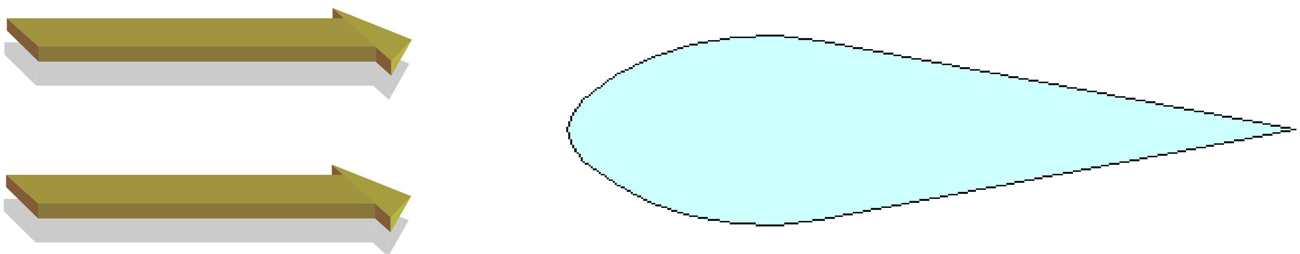
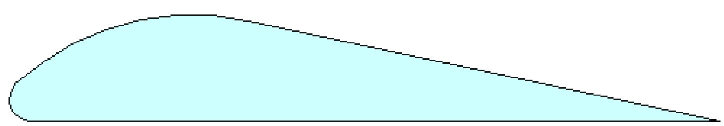


Figure 4

Removing the bottom half from figure 4 along the centerline and rounding the nose(LE), we have the basic airfoil.



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Since this section is about the airfoil, we need to talk about air, just for a moment.

Air molecules are free moving, they can easily be moved around whenever a force is applied. They have molecular adhesion, meaning, they tend to stick to each other and to the surface of solid objects, similar to the way water clings to the inside of a drinking glass, forming a meniscus. Finally, air doesn't like to be compressed, it can't change it's volume, and it resists being pulled apart creating voids. These 3 properties, under the right conditions, can be brought together to create the invisible force known as lift.

NOTE: For the following images, the **airfoil** is now moving through air from right to left.

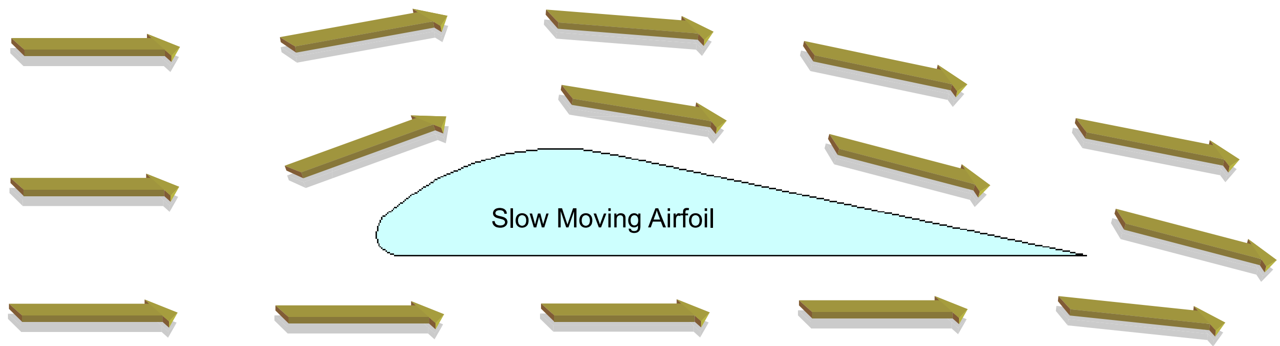

Figure 5

As can be seen in figure 5, air hitting the front of the airfoil is directed up and over, following the contour of the upper surface, arriving at the trailing edge **before** the air from below, and at a **downward** angle. The air below the airfoil passes essentially unobstructed, until reaching the trailing edge where it is turned downward by the air coming off the top. According to Newton's first and third laws of physics, there must be a force on the air to bend it down (action) , and an equal and opposite force (up) on the airfoil (reaction).

Lift

To generate lift sufficient to overcome the force of gravity, an airfoil must bend a lot of air downwards. There are 2 ways to do this. Newton's second law says, force equals mass times acceleration. We can bend more air (mass) downward, or increase the speed of the downward air. The airfoil does both. Increasing the downward air speed is the easy part. The speed of the air over the **top** surface is proportional to the forward speed of the airfoil. Since the air is coming off the trailing edge at a **downward** angle, if the airfoil goes faster, the lift is greater. As the air speed over the airfoil increases the air pressure above the airfoil **decreases**. Since air does not like to be compressed or pulled apart, the surrounding air is drawn in to compensate for the drop in pressure. In other words, **additional air is pulled down from above**.

For a more detailed explanation you can research what is known as the "Coanda Effect" as it applies to aerodynamics.

Consider the airfoil below which is moving at the same speed as the airfoil in figure 5.

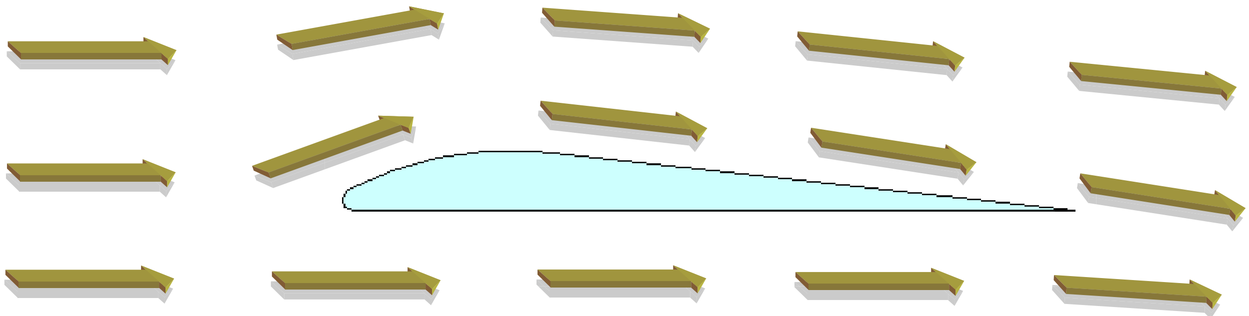

Figure 6

This airfoil is directing less air over the top. This air has less acceleration, less negative pressure pulling down less air from above, leaves the trailing edge at a lower angle, and has less influence on the air passing below. This airfoil obviously generates less lift for the same forward speed. Whether or not the lift created by either airfoil is sufficient to overcome the force of gravity will depend on the weight of the airfoil, and the amount of surface area. The important concept to understand about the airfoil at this point in the discussion, is that it lifts because of what is happening on the **TOP** surface, not the bottom. Comparing figures 5 and 6 the next logical step would be to create and airfoil with a much bigger curve, which in turn, would generate ever increasing lift proportionate to it's forward speed. This reasoning is true, to a certain extent. The bigger the curve the more resistance, requiring more force to move it forward. Additionally the air will start to separate from the top surface if we try to bend it more than about 15 degrees. The solution is to increase the contribution from the bottom of the airfoil by increasing the angle of attack. This also increases the speed of the air flowing over the top which increases the negative pressure and draws in even more air from above.

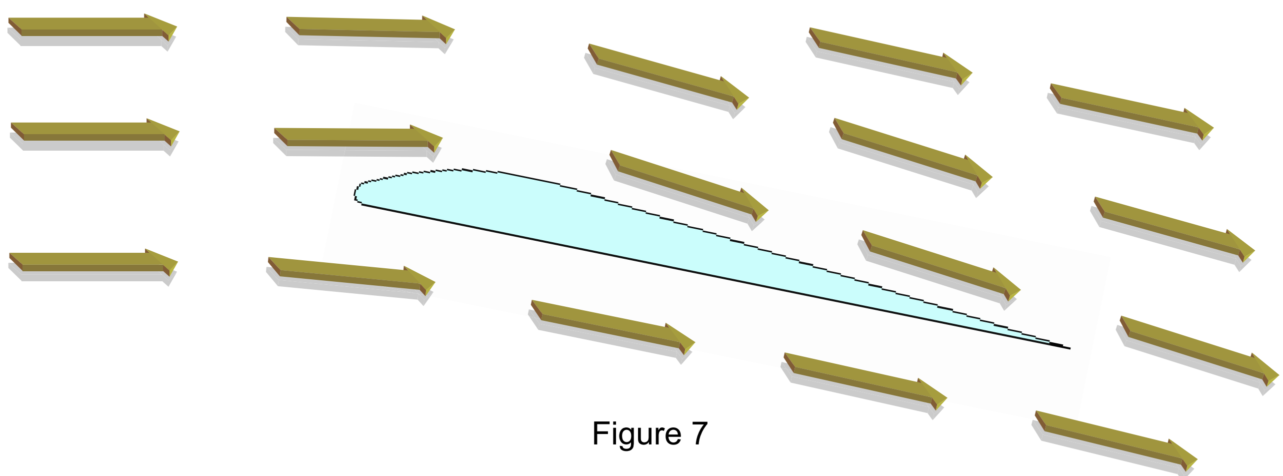

Figure 7

The airfoil in figure 7 has increased the lift, and **moved** the resistance on the top front, which wasn't contributing to lift, to the bottom.

The above photograph published by the Cessna Aircraft Co. shows the huge downward thrust of air as a plane flies just above a fog bank.

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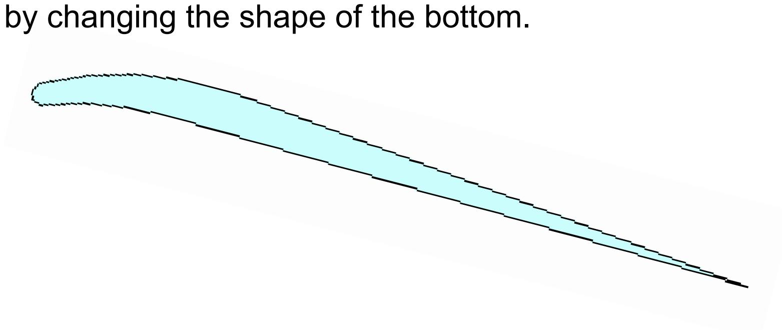
Referring back to figure 2 we can reduce the resistance on the bottom, while preserving the contribution to lift, by changing the shape of the bottom.



Better . . . . . but we can do more . . . . . .

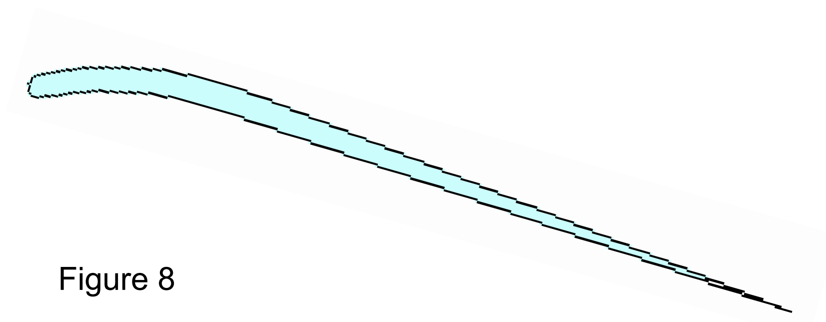


Figure 8

The airfoil in figure 8 is turning as much air downwards with the smoothest airflow, with virtually all the resistance contributing to the production of lift.

Not only do we have a great low speed airfoil, we have also created a *SAIL.*