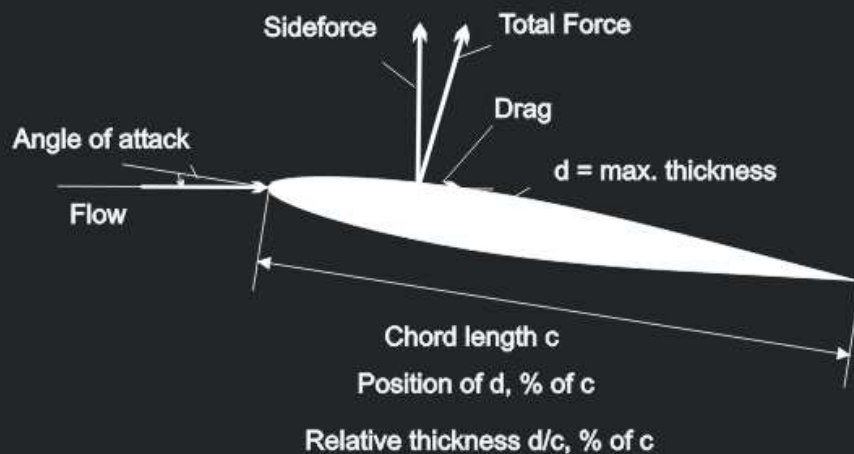


Fin secrets





Fin Secrets

Rick Hanke, Maui Ultra Fins, 2010

Introduction

With the myriad of discussions on fin characteristics and performance at present and the associated postulations on how fin forces are created, what spin out actually is and what is the real purpose of the fin in windsurfing, this article will attempt to clear up the main issues, i.e. the physical principles of windsurfing, the role of the fin, how it works and which parameters are important.

In order to understand the impact of a fin, which is only a small – though fairly important – part of the whole system, we first have to describe the whole system in order to understand the interaction of all elements.

Principle of equilibrium

In order to describe the motion of a sailboard we can take a simple approach by using the equilibrium principle where the resultant vectors of all acting forces applied to a body must be balanced or – talking maths - the sum of all forces and moments must be zero. The underlying principle was developed by Isaac Newton in 1687 and it is still valid today.

According to the equilibrium principle, the motion of a body is defined by all forces and moments acting on it. For all bodies in steady conditions or in steady motion the sum of all acting forces and moments must be zero. That means that all forces must be balanced as in the forward movement generated by the sailboard which is resisted by friction of an equal force, otherwise the body would accelerate or decelerate.

Forces and Moments when Sailing

All forces can be determined from the body weight, because the force that the weight creates must be in balance with the aero- and hydro dynamical forces of the sail and the fin. There is no need to meticulously calculate the aero dynamical sail or hydro dynamical fin forces here but we have to understand the general concept.

The board lift

When planing, the lift of the board is dynamically created by the water streaming against the incised board. The water flow is deflected downwards and an upward force is induced (action = reaction). That's the lift which carries the whole weight of board, sail and sailor.

From the equilibrium condition it follows:

Lift (board) = Total weight, **Figure 1**

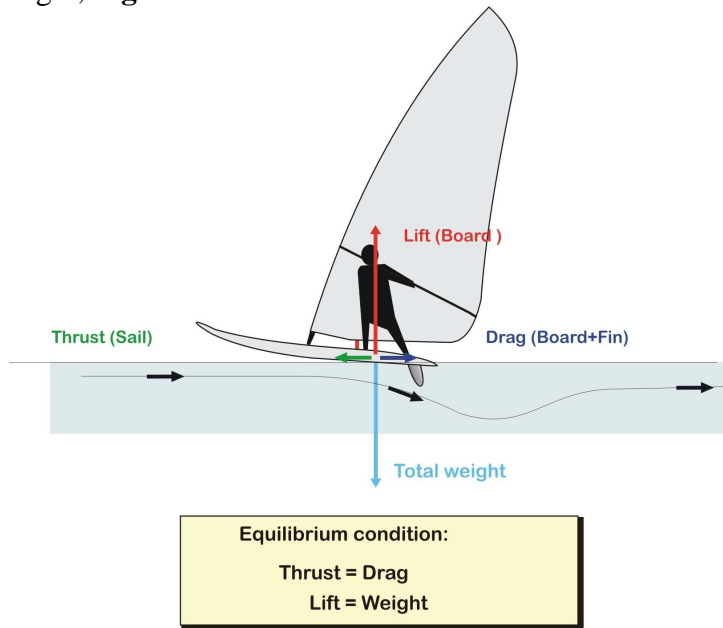


Figure 1: Vertical forces acting on the windsurf board



Sail, board and fin forces

The airflow (apparent wind) induces in the sail a force perpendicular to the airflow direction, and slightly forward of perpendicular to the longitudinal axis of the board depending on angle of attack into the wind and water currents etc. The total sail force can be divided into two components, the forward thrust along the axis of the board and side thrust that is perpendicular to the board axis.

In order to sail in the same direction at a constant speed, all acting forces and moments must be balanced. That means:

Thrust (sail) = Drag (board) and
 Side force (sail) = Side force (fin and board)

In addition all moments must be zero (**Figure 2**).

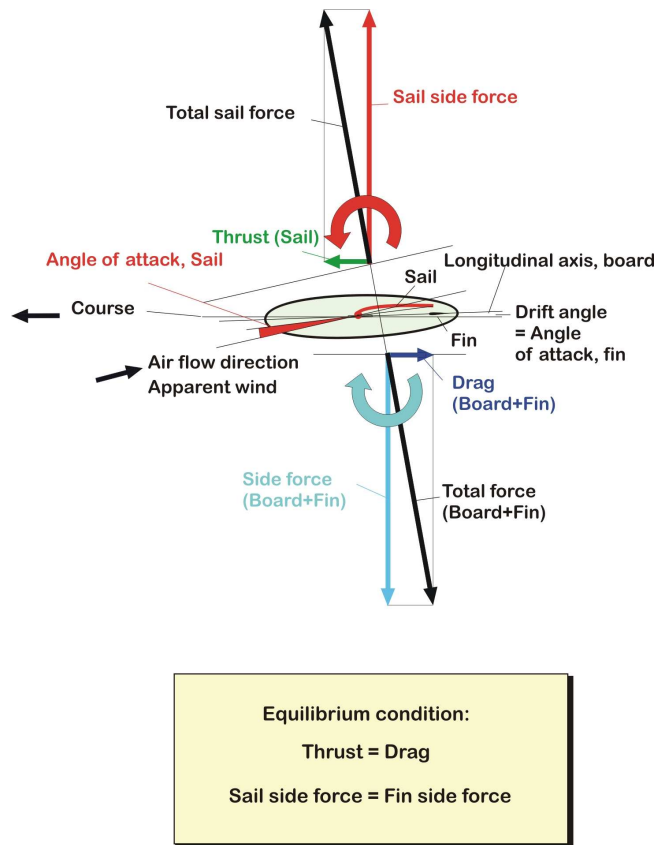


Figure 2: The horizontal forces on the windsurf board

The side force of the fin is created in the same way as the sail force by inclining the fin against the water flow (angle of attack). In the case of the fin, the drift angle of the board is the angle of attack which is needed to produce a side force.

All physical phenomena to create a force on an airplane wing are also valid for the fin. The only differences are, the density of the medium water, which is 850 times denser and the viscosity which is 14 times lower than air. That's why the fin can be so much smaller than the sail to produce the same amount of force. The flow speed for the fin is the sailing speed and for the sail it is the apparent wind which can be higher than the real wind speed.

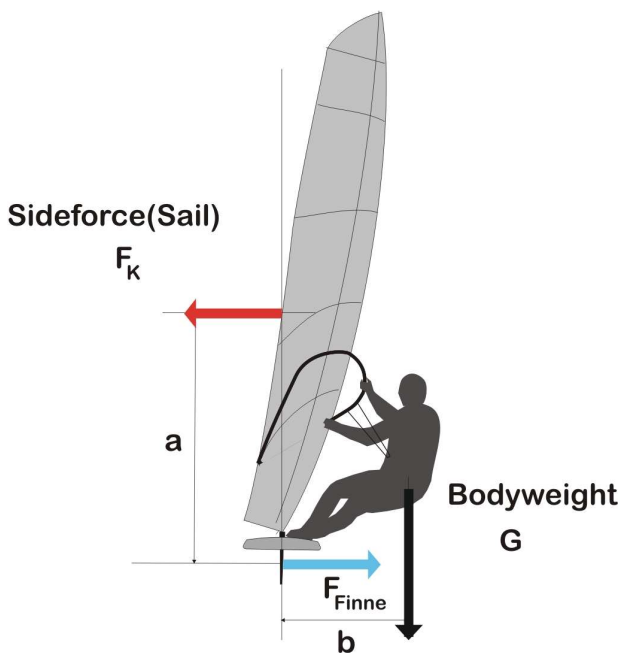
Sail- and Fin Force

How big then is the sail force which must eventually be balanced by the fin?

If we look at all the forces and moments acting on the board from the front of the board it follows from the equilibrium conditions that the maximum sail force is limited by a specific amount of body weight.

Otherwise the sailor would be pulled across the board (**Figure 3**).

What does that mean? Under all conditions regarding wind forces, sailing speeds / directions, sail sizes etc., the effective sail side force on the fin is **limited**.



Considering typical dimensions of the body and the sail, it follows that the maximum side force which can be balanced by the body is about 37.5 percent of the body weight of the sailor (figure 3).

Assuming a body weight of 176 lbs, the maximum side force is 66 lbs and for 220 lbs body weight it is 82.5 lbs side force.

The unit should correctly be labelled Newton ($37.5 \text{ kg} = 367.8 \text{ Newton}$).

The result is that the maximum force which must be balanced by the fin solely depends on the body weight of the sailor.

Still, a small amount of the force can be balanced by the board but in principle the fin must carry the load. More fin force is required in the case of a wider board tail because of the additional moment, which is produced by the sailor, that must be compensated for by the fin.

Equilibrium of moments and forces:

$$F_k a = G b$$

$$F_{Finne} = F_k$$

$$F_{Finne} = G \frac{b}{a}$$

$$F_{Finne} = G \frac{0,9}{2,4}$$

$$F_{Finne} = 0,375 G$$

Figure 3: Sail and fin forces

The Fin

Definitions

The fin and foil geometries are described as shown in **figure 4 and 5**.

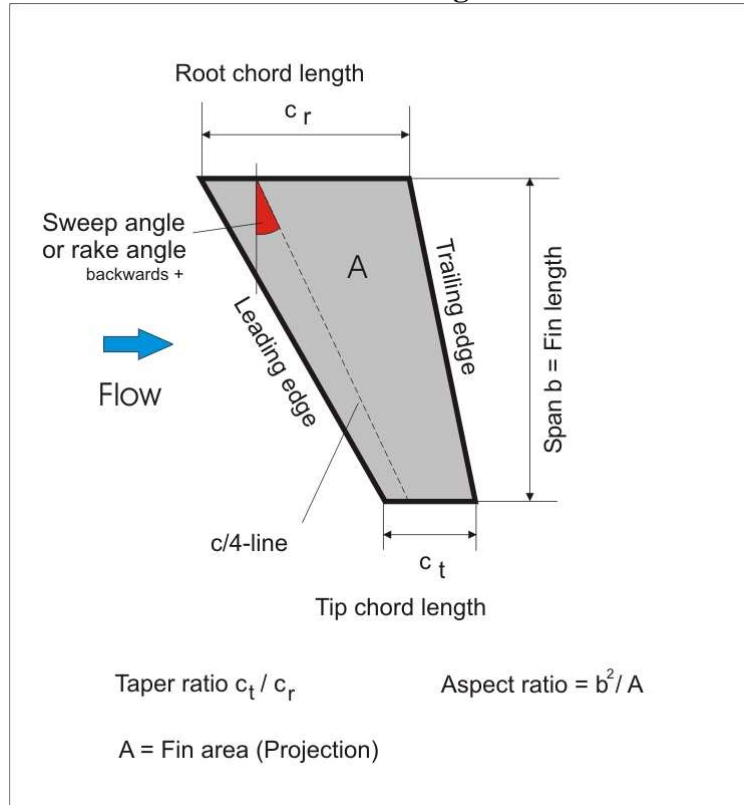


Figure 4: Fin parameters

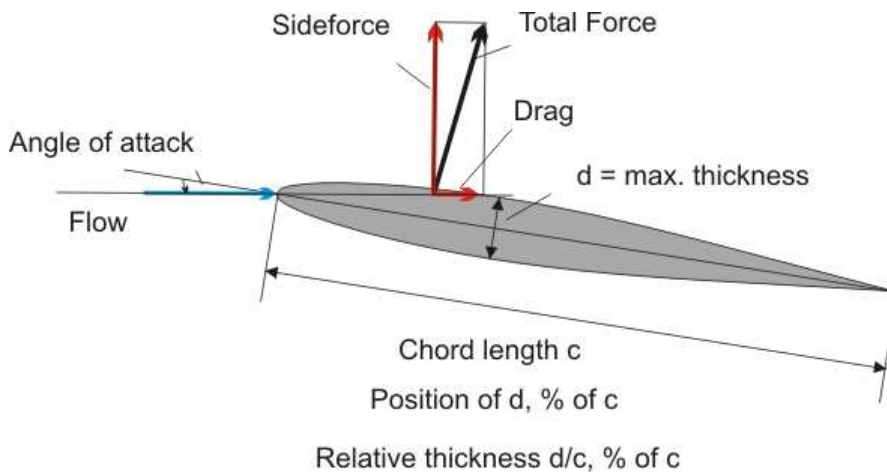


Figure 5: Foil parameters

Factor affecting fin efficiency:

- fin length
- taper ratio
- aspect ratio
- fin area
- relative foil thickness
- position of maximum thickness
- foil nose radius
- foil trailing edge angle

Lift and Drag

How is the fin side force created?

As the fin is nothing but a small wing, we can use the same definitions as in aerodynamics. The forces created are lift and drag which also define the efficiency of the fin. Since the fin is placed vertically and not horizontally like a wing, the lift becomes a side force. Still, the general physics of produced forces is identical to the lift production of a wing.

The lift of a wing is created by inclining the wing foil against the airflow in a specific angle of attack (**Figure 6**). The flow around the fin is not symmetric. On the upper part of the foil, the flow must pass a longer way than on the lower part. As a result, the flow has to be quicker on the upper part providing a lower pressure compared to the lower part of the wing. The pressure difference produces the lift force. Lift is always combined with drag which depends on the foil geometry and friction of the water molecules on the surface of the fin.

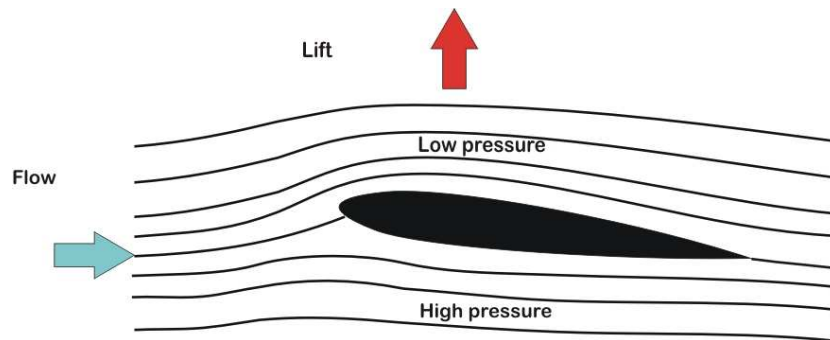


Figure 6: Streamlines and lift on a foil

The lift increases in a nearly linear fashion with the angle of attack until the angle becomes so great that the flow can't follow the low pressure side of the fin and stalls (**Figure 7**). The lift ceases rendering the fin ineffective, that's the so called spin-out.



Figure 7: Stalling

It depends on the foil geometry up to which angle of attack the flow can follow the foil without stalling. Sharp nosed foils (= sharp leading edge) show an early flow separation, thick foils with more rounded noses have a greater angle of attack range.



Besides the lift, the foil geometry also defines the drag characteristics. Laminar foils, for example, produce very low drag for a narrow angle of attack region because the water flows without turbulences near the fin's surface. This however requires a smooth foil surface with an intact leading edge.

The fin's performance depends strongly on the Reynolds number (Re). Re gives a measure of the ratio of inertia forces to viscosity forces in a flow. The Reynolds number very much depends on the speed of flow which in turn is down to the surrounding medium. Meanwhile foils are available which produce good results also at fairly low Reynolds numbers (low speeds).

Foil Polars

Foil characteristics are represented in a lift vs. angle of attack graph. A comparison between different foils immediately reveals the different efficiencies. Figure 8 shows two different polars (A and B).

Both foils have the same linear lift curve slope when increasing the angle of attack. But with foil B, the flow separates at just 9 degrees of angle of attack (spin-out) while with foil A the flow separates much later at 13 degrees. Foil A therefore provides much more lift in general and also sufficient lift at low speeds. On top of this, it has a much better upwind performance.

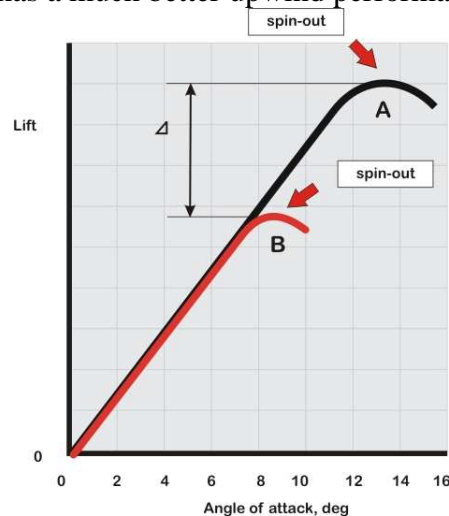


Figure 8: Foil polars

For the whole fin as a three dimensional wing, lift, drag and moments are proportional to:

- water density
- square of speed
- fin area
- angle of attack
- foil geometry
- fin geometry (outline).

Just like for a sail, the most important parameter is the fin area. A large area produces more lift but also more drag. Furthermore, the fin performance can be optimized by the fin geometry (outline). Long, slender fins like slalom fins provide a good ratio of lift to drag, they are hydro dynamically very efficient (just like sailplanes with extremely large spans and slender wings). In order to avoid a spin-out, the fin area must be chosen in such a way that the required lift can be produced under all conditions without the danger of flow separation.

But there are also conditions where the fin is not completely in the water. The low pressure on the surface can suck air and a flow separation will follow (ventilation). Further, dynamical motions like radical manoeuvres with a lot of pressure to the board / fin can lead to a spin-out.

Apart from the general performance, we have to look at the sailing characteristics which are not only determined by the fin area but also the outline, the rake (sweep) and the stiffness of the fin.



Spin-out

A flow separation (= stall) is called a spin-out in the windsurfing community. A stall on an airplane is usually terminal as once you stall you lose lift. To regain lift you must reduce the angle of attack plus have sufficient velocity to produce lift again. Very difficult when you're falling out of the sky pointing upwards! The same is true for the windsurfer except it is much easier to reduce the angle of attack whilst maintaining speed thus regaining lift and sailing away happily. Airplanes use electronic flight control systems to control lift, velocity, angle of attack etc, the windsurfer makes dynamic alterations by intuition, feel and experience, much the same way as a bird limits stalling by natural talent.

Cavitation

Often the spin-out is incorrectly linked to cavitation. Yet, cavitation is a completely different physical phenomenon than flow separation. Cavitation can occur when the pressure on the foil falls below the vapour pressure of water. That means that the water becomes vaporized and small vapour bubbles (bubble cavitation) are created on the fin surface. The vapour bubbles lead to a loss in lift and drag increase. Cavitation can also occur at low angles of attack but very high speeds.

Stiffness, Flexibility and Torsion (Twist) (Figure 9)

Stiffness is determined by the elastic behaviour of the material. A fin load leads to a bending (flex) of the fin which influences the flow on the foil: The larger the bending, the bigger the difference to the ideal lift contribution. Bending results in a loss of lift (side force) and so performance is reduced. Bending or flex cannot be avoided with very long fins because there is no material with infinite stiffness. Still, there could be reasons to have some flex, to provide a smoother less harsh feeling of control, for example!

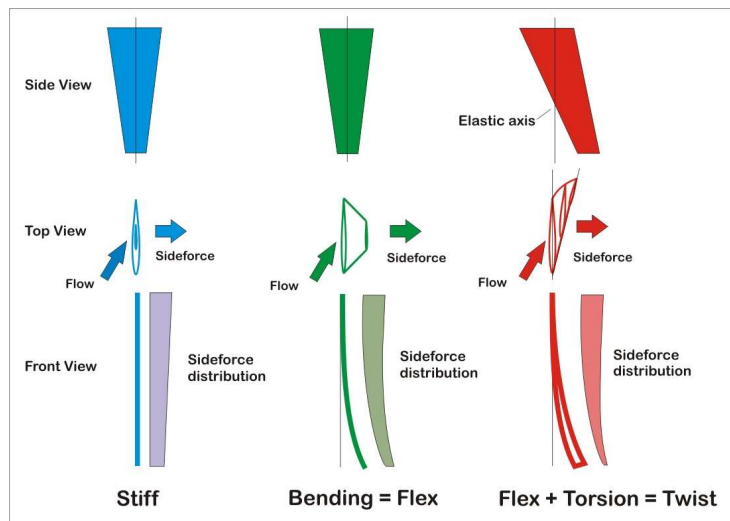


Figure 9: Stiffness, Bending (Flex) and Torsion (Twist)

Twist

Twist is torsion along the longitudinal axis of the fin. Twist is only possible when the fin is raked and the lift force acts off the elastic axis. Then a momentum is created.

In case of a positively raked fin, the foil at the tip of the fin is twisted into the flow so that the angle of attack is reduced. This can momentarily avoid a spin-out. In general though, twist reduces the performance of a fin.

Twist of a fin is identical to twist in a sail where a gust provides a twist just like more foot pressure causes a twist on a fin.



Fin and sailing characteristics

The previous principle considerations were relatively simple.

Nowadays, by using a GPS device you can comfortably measure how fast a board goes in any given direction and how good the upwind performance is. It is also fairly easy to identify the spin-out behaviour of a fin.

But it is much more difficult to come to an objective judgement on the sailing characteristics like controllability, agility in the waves or in moves. Those characteristics are influenced by the sail, the board, the fin, and depend a lot on the skills and personal preferences of the individual windsurfer. What one sailor experiences as agile, might be seen completely different by somebody else with a higher or lower skill level.

Fins can be tested in the same way as boards are tested by using adequate rating scales. Doing that, it is important to have the same board, the same sail, the same sailor, the same conditions and the same fin area.



Summary

The fin is the sail in the water, without a fin there is no real directional control.

Heavy sailors need a bigger fin area just as boards with a wider tail do.

Fins are unfortunately not defined by area like sails are but length. When we compare different fin makes, we can see that there are huge differences in fin area at the same length (Figure 10). The length on the other hand influences the agility of the board.

Therefore, each board and condition requires an individual fin solution.

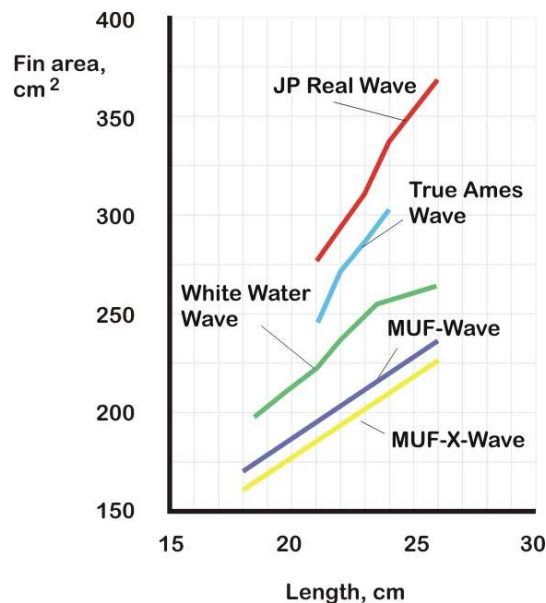


Figure 10: Fin area and length for different fin products.

As with every technical development, a scientific approach is required for fin development in order to develop a great product that takes into account the latest physics, R&D and testing procedures. Fortunately there are computational procedures available which allow us to calculate the foil characteristics with sufficient precision alleviating the need for expensive water tunnel tests.

But also fins designed and optimized with computational flow dynamics have to be tested under real conditions. Maui Ultra Fins are therefore constantly tested using GPS data and questionnaires which are completed by professionals and amateurs alike.

Only a high performance fin improves your board and your fun.

More speed, more grip, more fun.

I would like to say MAHALO to Michael Benkert, Gereon Westphal, Timm Köpke, Charlie Gilman and Bob Waterman for their valuable contributions and critical minds concerning this article.