Fin hydrodynamics of a windsurfer

L. Sutherland & P.A. Wilson
Department of Ship Science, University of Southampton, Highfield, Southampton, SO17 1BJ, Hampshire, UK

1 Introduction

Windsurfing is a relatively new technical sport and has advanced rapidly in the quality of equipment, with the consequent increase in speed and technique that only time can allow. The initial developments were aimed at the obvious components such as the sail rig and the shape of the board itself. The remaining item of the windsurfer, the fin, was initially thought of as providing a control surface for directional stability, similar to the effects of a tail fin of an aeroplane. Of course this is far from the truth, since the driving force derived from the sail rig, has to be resisted by the fin. Thus the windsurfer must be thought of as a combined system of a board, rig and the fin. This paper will concentrate on the fin geometry and our ability to derive design force estimates, so that suitable matching of board to fin and rig can be achieved for the combination that is desired.

The actual shape of the fin has developed initially by trial and error, with some equally improbable names, such as football, fencer or winged. Nowadays the fin is made from high quality advanced materials such as composites or polymers. Typically windsurfers have three main type of competitions, known in common parlance as wave, slalom and course racing. Each has different characteristics for the fin to withstand, as well as providing surface lift for the fin to be able to make headway, back after riding the waves.

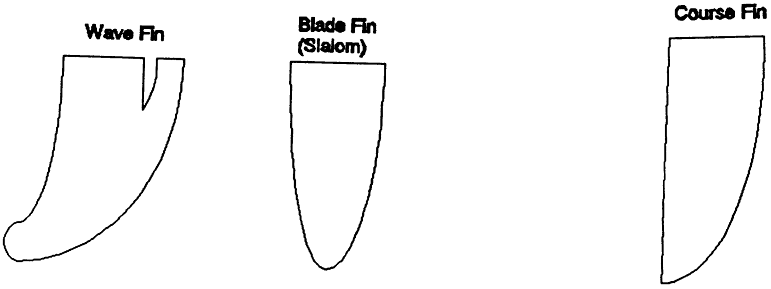

Figure 1 Types of Fin

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It is therefore important to be able to simulate the flow conditions that are near to the fin, when in the race conditions it was designed for. Thus the fin design techniques must be able to simulate the effects that the sailor feels when on the board. There appear to be very few technical papers or articles written that deal with this subject. References [1], [2], [3] deal with the flexible fin and the surface finish and the effects on the board performance. Another source of *technical* information can be found in windsurfing magazines (ref.[4]), but these tend to be very shallow in there theoretical arguments.

2 Theoretical Estimation of Forces

Using standard techniques for estimating the forces on the rig, the overall force balance can be achieved, Figure 2, gives the basis of these forces.

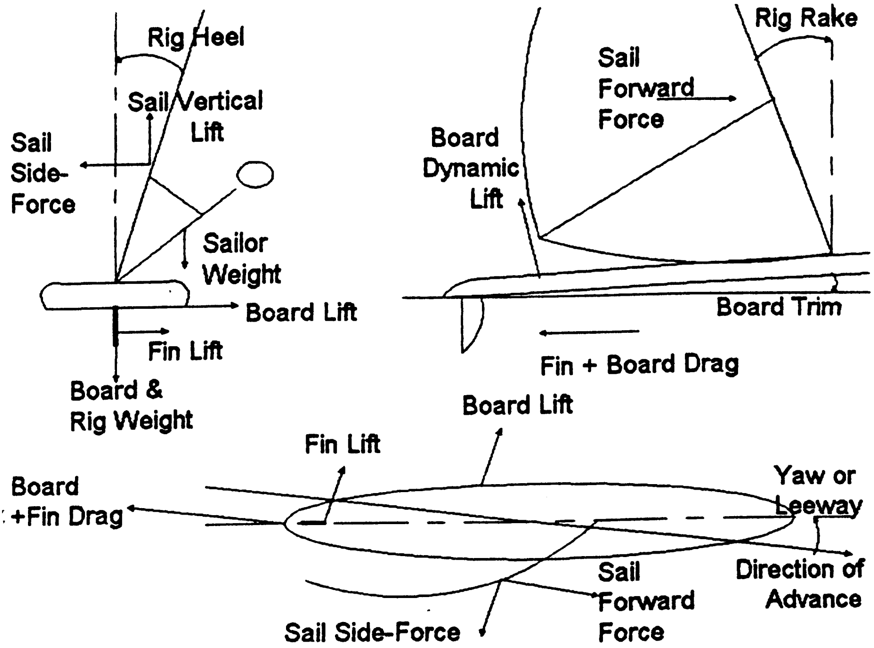

Figure 2 Global Force balance

Given the data available in ref.[6], and ref.[1], then the lift force from the fin is approximately 500N, with an estimated drag force of approximately 30N. This gives an idea of the size of the forces that are generated in normal sailing conditions. This allows a yard-stick to be used to compare with theoretical and experimental data.

Classical aerofoil theory was used to help to predict the type and size of forces on these fins, but was soon found for various reasons, to be substantially lacking. This led to the use of an already developed computer program within the Department of Ship Science that solved the flow around aerofoils by the use

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of discrete panels where the boundary conditions are satisfied. The technique involves the use of an approximate Navier Stokes solver, assuming that Laplaces Equation holds true

$$\nabla^2\phi = 0 \tag{1}$$

The velocity potential ϕ can be written as

$$\phi = \int_{S_B}\int(\frac{\sigma}{r} + \mu\frac{\partial}{\partial n}(\frac{1}{r}))dS + \int_{S_W}\int \mu\frac{\partial}{\partial n}(\frac{1}{r})dS \tag{2}$$

where μ is the dipole strength and σ is the source strength. S_B is the surface of the body, S_W is the trailing wake sheet.

The boundary conditions that have to be satisfied are:

1. The leading edge is in region outside the wake and body.
2. $\phi = 0$ at ∞
3. $\frac{\partial\phi}{\partial n} = 0$ on the whole body
4. The Kutta-Joukowsky condition is satisfied at the trailing edge.
5. The trailing wake sheet has no pressure differential across it.

With these conditions the velocity potential is discretized as:

$$\phi_i = \frac{1}{2\pi}\sum_{j=1}^{N}(V_\infty n_j S_{ij} - \phi_j D_{ij}) + \sum_{k=1}^{N}\Delta\phi_k w_{ik} \tag{3}$$

where V_∞ is the input flow speed, n_j is the panel normal, S_{ij} is the source influence coefficient, D_{ij} is the dipole influence coefficient, w_{ik} is the influence in the wake.

The local pressure coefficient C_p is found from conventional theory to be:-

$$C_p = 1 - (\frac{V_t}{V_\infty})^2 \tag{4}$$

This then allows the force to be calculated from:

$$F = \frac{1}{2}\rho V_\infty^2 \sum_{i=1}^{N} C_{Pi} A_i n_i \tag{5}$$

$$C_l = \frac{F \cdot j}{\frac{1}{2}\rho V_\infty^2 A_T} \tag{6}$$

$$C_d = \frac{F \cdot i}{\frac{1}{2}\rho V_\infty^2 A_t} \tag{7}$$

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3 Tank Testing

There were two experimental facilities available for tank testing. These were the Austin-Lamont tank in the Department of Ship Science at the University and the tank at S.I.H.E. There were limitations in both these facilities in that the top speed at the University tank is $2ms^{-1}$ whilst at SIHE it is $6ms^{-1}$. These are well below the normal operating speeds of windsurfer boards, which are typically in excess of 20 knots, with speeds of more than 40 knots being achieved in exceptional conditions.

A commercial company F-HOT fins provided a pair of fins that are in current use, and also manufactured three newly designed fins, all of which are detailed later in the paper. To aid the tank testing the same company provided a board, of which only the last 100cm were used. This provided the fin retaining block, enabling an easy method of changing the fin, since all are manufactured to fit the retaining block.

Figure 3 shows the 'board' on the dynamometer balance. It will be noticed that a scale was drawn on the board so that the running water line length could be easily estimated. This was compared, by one of the authors to the real situation. The following set of experiments were conducted,

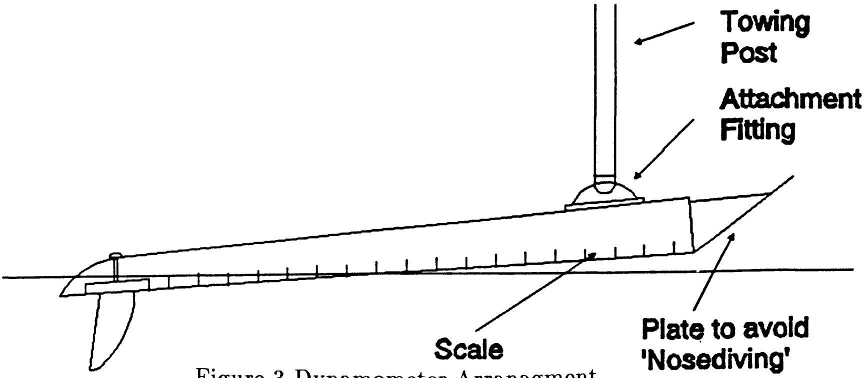


Figure 3 Dynamometer Arranagment

1. Austin-Lamont Test Tank. Seven different speeds from $0.5ms^{-1}$ to $2.0ms^{-1}$ in increments of $0.25ms^{-1}$ all at yaw angles of 0 deg, 5 deg, 10 deg, 12.5 deg, 15 deg for the *Speed* and *Blade1* fin blades.

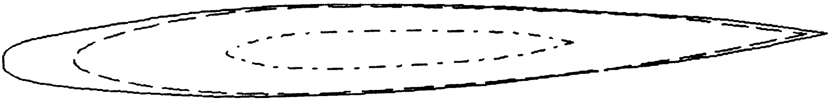
2. SIHE. Two speeds were used $2.2ms^{-1}$ and $4.1ms^{-1}$ with the yaw angles were 0 deg, 5 deg, 10 deg, 12.5 deg, 15 deg for all five fin blades.

This meant more than two hundred test runs were performed.

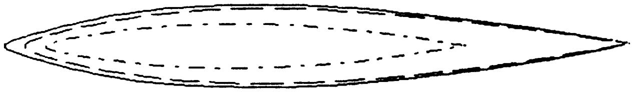
4 Fin Description

1. *Blade 1* A high aspect ratio slalom blade fin with a standard foil shape, length 262mm, root chord length 81mm.

2. *Blade 2* A very high aspect ratio blade fin with a sharp leading edge and maximum thickness at about 40% of the chord from the leading edge. The length is 295mm and a root chord of 61mm.
3. *Blade 3* This fin is similar to *Blade 1* with a length of 280mm and a root chord length of 89mm. However the foil section has roughly parallel sides between 30% and 80% of the chord length form leading edge.
4. *Speed* A *Dolphin* planform fin of lower aspect ratio and a straight trailing edge. The overall length is 228mm and a root chord of 113mm.
5. *Course* This is designed to operate with the *course* board Its length is 405mm, and has a root chord of 108mm.

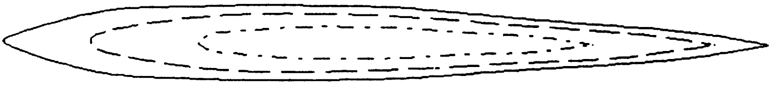


Blade 1

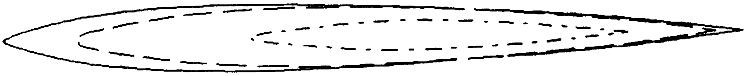


Blade 2

Blade 3



Course



Speed

Figure 4 Fin Profiles

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5 Discussion of Theory and Experiment

Some results based upon the calculations using the panel method computer programme, have been plotted for *blade 1*, in figure 5. As can be seen there is not an appreciable difference in the lift force coefficient, between each of the fins. The results for the drag on the fins do not appear to be accurate enough to help distinguish the different fin types. This is probably due to the method that was used in determining the panels used in the programme. In the results from the trials at SIHE the *speed* fin although providing less lift, stalls at a higher angle of attack, equating to a higher degree of control, with a consequent larger C_L. The *course* fin could not be tested to its full because of it's large surface area, however those tests that were able to be performed did show acceptable results.

The experimental drag results were much as one would expect, with *blades 1,2* and *3* producing less drag than the *speed.* The theoretical results have mirrored the experimental results, showing that *blade 2*, gives a higher drag coefficient at smaller angles of attack, than lower aspect ratio foils. The *course* fin produced the least drag at low angles of attack, probably because its maximum foil thickness is smaller than those of the smaller fins when compared to the chord length and span.

6 Conclusions

It is believed that, given the limitation of range of speed and run length in the test facilities available to the authors, it is possible to achieve a particular design force and hence moment for the fin under consideration from the use of existing theoretical methods that have now been computerised. The actual limitations of the panel method have not been explored but are known to be under discussion and development.

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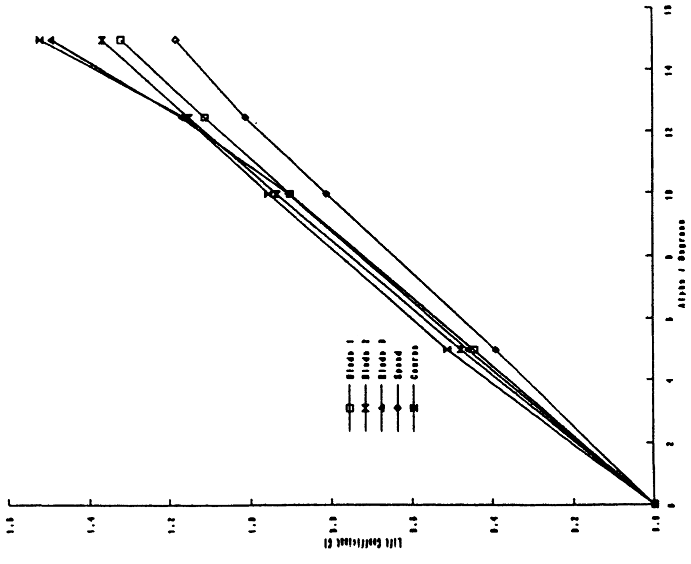

Figure 5 Theoretical Lift Coefficient of Fins using Panel Program

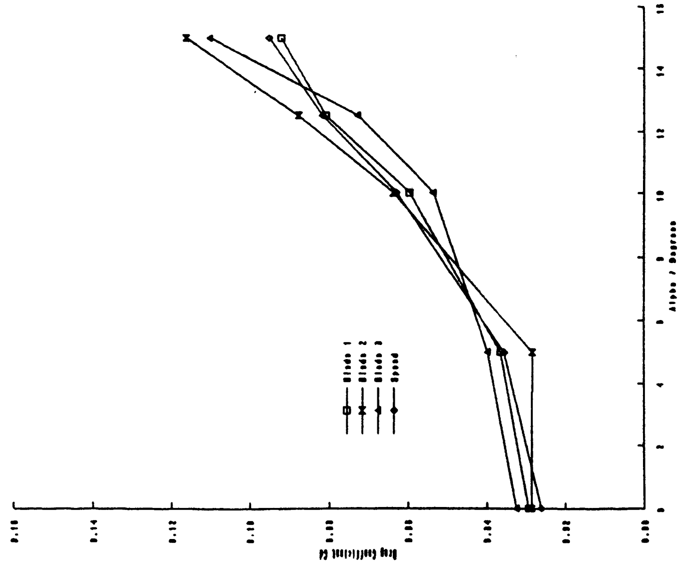

Figure 6 Theoretical Drag Coefficient of Fins using Panel Program

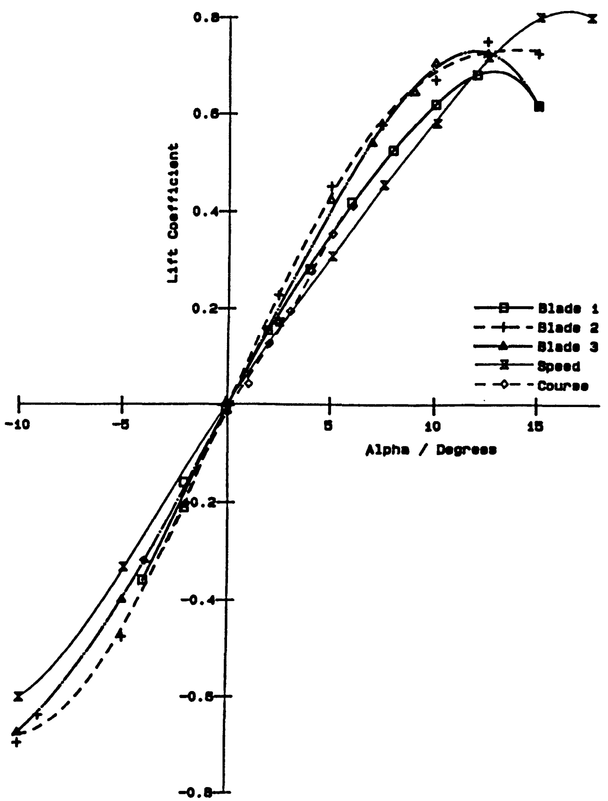

Figure 7 Variation of Lift with Fin type

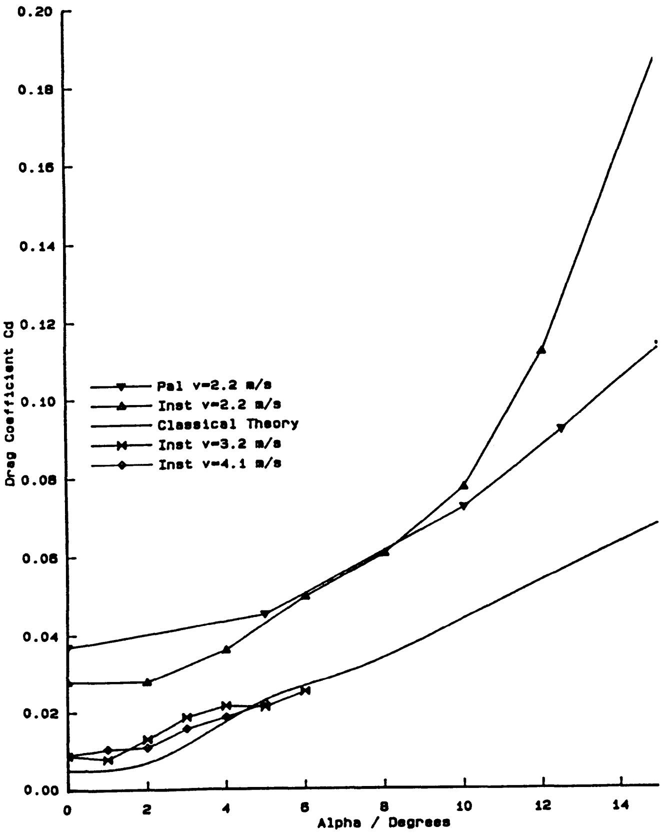

Figure 8 Drag Coefficient vs Yaw Angle