

CONTROL OF HYDROFOILS USING DYNAMIC WATER PRESSURE

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Front View...Fixed foils



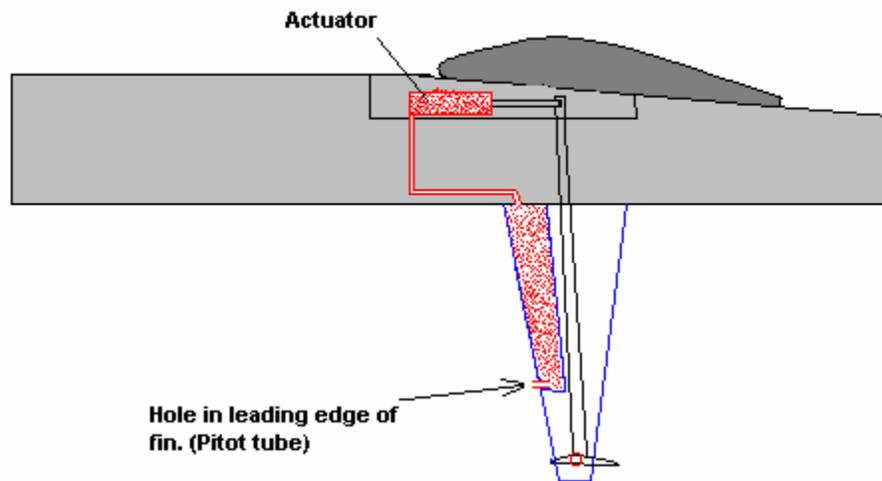
Submerged, variable angle foils

Hydrofoils are used on watercraft to provide lift, and/or stability. Generally, foils may be fixed or capable of varying their angle of incidence. Fixed foils may be angled to be part submerged, and part above the water surface, so that as they rise, the submerged area of foil decreases, and an equilibrium will be achieved. But foils which break the surface cause wave drag and suffer from ‘ventilation’ (pulling air down to the upper surface of the foil due to decreased pressure). Thus, fully submerged foils, with some means to prevent them reaching the surface, are potentially more efficient.

FOIL ACTUATION

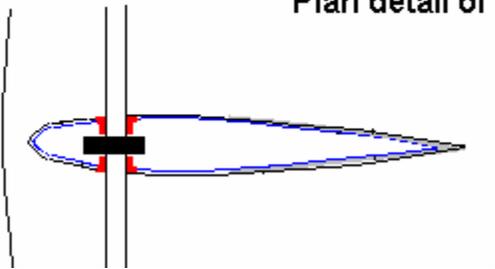
A foil boat generally requires some means to keep the boat from pitching and heeling excessively when lifting. If the foils, mounted on the tip floats, have a variable angle of incidence, they may be adjusted to provide variable lift, independently. This could be by manual control, requiring a skilled ‘pilot’, or by an automatic system which maintains each foil at a constant depth below the water surface. Existing, state-of-the-art foil boats (such as the sailboats, Rave and Hobie Trifoiler) use devices which follow the surface (a kind of water ski on the Trifoiler), connected by a mechanical linkage to the adjacent foil. These provide increased water drag, and are vulnerable to damage.

The following diagram illustrates the proposed pressure-controlled system, in which dynamic water pressure is utilized to adjust the angles of the lifting foils.



Hole in leading edge of fin. (Pitot tube)

Plan detail of pivot

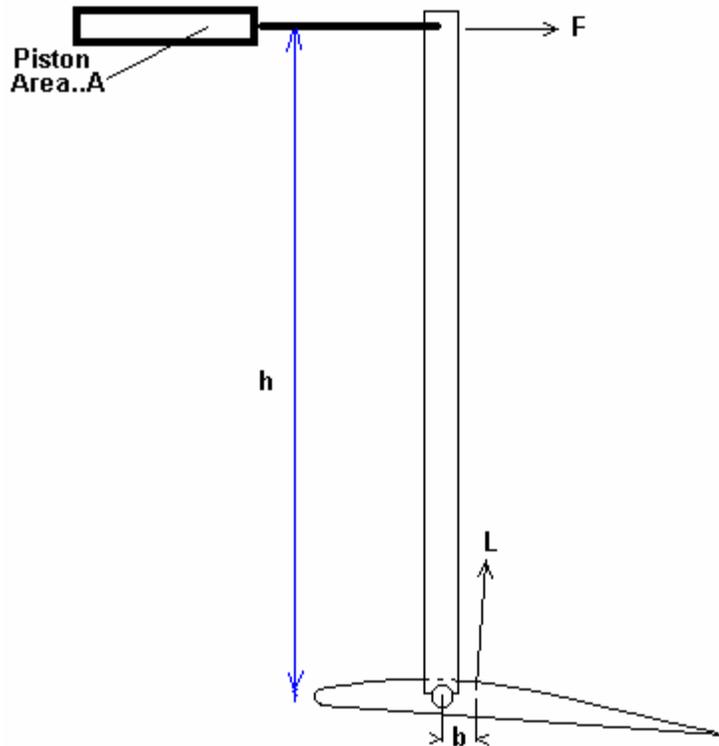


In this design, a short tube, called a 'pitot tube', in the leading edge of the 'fin', about 8 in. above the foil, is pressurized by a combination of depth below the surface, and the dynamic pressure due to speed through the water. This pressure compresses the air trapped inside the fin, and is picked up by a bellows (or other sealed type) actuator. This has a piston which pushes on a lever fixed to the hinged foil, as shown. Positive pressure produces a positive angle on the foil, increasing its' lift. When the hole reaches the surface of the water, pressure will be lost and the foil angle will decrease. As there will be a time delay as some water enters or leaves the tube, the pressure in the fin and actuator will tend to settle to just maintain the pitot at a 'mean' water level. The diameter of the hole in the pitot tube controls the rate of change of the foil angle, hence the sensitivity to waves. Static water pressure, at the pitot, also acts on the actuator, but the effect is relatively small as the craft rises on the foils.

The position of the foil pivot in relation to the center of lift of the foil determines the force required on the control lever, to increase the foil angle. It is advantageous to pivot the foil a small distance ahead of the lift center, so that the lift will act to reduce the foil angle. This is a stable condition and avoids any tendency for the angle (and hence lift) to increase uncontrollably. If the pivot is close to the lift center, the force required at the actuator will be relatively low and the size of the actuator can be minimized. This is important in order to reduce the volume of the air-space in the fin (as shown in the diagram of the system).

The reason a space is sealed in the fin (rather than connecting the pitot tube to the actuator with tubing), is to provide a reservoir of trapped air in the fin to prevent water from entering the actuator. If the system filled with water, the reaction rate of the mechanism would be slow, and the static water pressure at the pitot tube would not assist in pressurizing the actuator.

BALANCE OF FOIL FORCES



Foil Lift (L) acts at a distance ' b ' behind the pivot center
 Actuator Force (F) acts on a lever of length ' h '.
 The moments of these forces must balance for equilibrium.

$$L \cdot b = F \cdot h$$

But, $L = 0.97 S V^2 C_l \dots (1)$

where 0.97 is a constant (density/2)

S is area of foil (sq. ft.)

V is speed (ft./sec.)

C_l is lift coefficient of the foil

And $p = 0.97 V^2 \dots (2)$

p is dynamic pressure on the pitot tube

Also $F = pA \dots (3)$

A in sq. ft.; p in lbs./sq. ft.

Hence $SC_l b = Ah$ (p cancels on both sides of the equation)

Or $C_l = Ah/Sb = \text{constant depending on the dimensions.}$

This implies that the foil lift coefficient will remain constant until the pitot tube reaches the surface (when p decreases).

The system performance can be modified by a return spring, which holds the foil at its' minimum angle until the speed is sufficient to pressurize the actuator to overcome

the spring. This arrangement is preferred, as the craft has less drag with the foils at minimum angle, and will reach “foil speed” more easily.

In this case:-

$L.b = (F-P).h$ (4) where P is the spring force acting at the actuator
The factor, $0.97V^2$ does not cancel in this case

$$P.h = F.h - L.b$$

$$P.h = pA.h - pSCl.b \quad \dots(5)$$

And $p = 0.97V^2 \quad \dots(2)$

Equations (1) (2) (3) and (5) can be used to find the proportions of the specific foilcraft.

Step 1. Knowing the design weight (W) of the craft, assume that L is 0.5W

A practical maximum value for Cl is assumed as 0.8

The design lift-off speed can be used to determine the foil area, S, from equ. (1)

Pressure, p, for this speed is found from equ. (2)

Step 2. Assume a speed at which the foils should begin to provide lift. This must be within the fully immersed speed capability of the craft. At this speed, $F = P$, and $Cl = 0$. Calculate the pressure, p_0 , at this speed, from equ. (2).

Then $P = p_0 A$. (The piston area, A, is not known at this stage)

Step 3. Using equ. (5) at lift-off speed, the area A can be found by substituting p_0A for P.

SAMPLE CALCULATION

Step 1. Craft weight, W = 260 lbs.

Foil lift, L = 130 lbs.

Lift-off speed, $V_l = 16$ ft./sec.

$L = 0.97V^2SCl$ equ. (1)

$S = 0.654$ sq. ft. at $Cl = 0.8$

$p = 248$ lbs./sq. ft.

Step 2. Assume speed when foils start lifting, $V_0 = 10$ ft./sec.

$p_0 = 97$ lbs./sq. ft.

$P = 97A$

Step 3. Using dimensions; $h = 24$ ins.; $b = 0.5$ ins.

$P.h = pA.h - pSCl.b$

$97A.24 = 248A.24 - 248 \times 0.654 \times 0.8 \times 0.5$

Giving, $A = 0.0179$ sq. ft. (= 2.58 sq. ins.)

(Actuator piston diameter = 1.82ins.)

Return spring preload, $P = 97 \times 0.0179 = 1.74$ lbs.

(The above numbers apply to a sailboat being developed by the author.)