THE DEVELOPMENT OF THE FOIL-ASSISTED 26 FT. PLEASURE CATAMARAN[1]

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RESUMEN

La adaptacion de un sistema sencillo de hidroaletas (hydrofoils) en catamaranes (transportables en trailers) mejora las caracteristicas de performance y los costos. Los catamaranes pequenos pueden ser mas rapidos, usar menos combustible, y requerir maquinas de menos potencia debido al levante creado por los hidrofoils incorporados a los cascos. El proposito de este estudio es el de desarollar un procedimiento de ingenieria que determine el tamano del sistema del hidroaleta que produzca el levante necesario para mejorar las caracteristicas de performance del catamaran. Se presentan dos casos: 1. El primer caso consiste solamente de la adicion del sistema de hidrofoil al catamaran. 2. El segundo caso consiste en la combinacion del sistema de hidroaleta y la reduccion de potencia que va a mantener por lo menos el criterio del catamaran original.

1. INTRODUCTION

One of the most fascinating vessels built is the catamaran. Her large deck area and multiple hulls make her definitely unique. These qualities are favorable for both recreational and commercial use. In particular, the vessel we are going to consider is the 26-ft. trailer-able recreational pleasure catamaran.

Since catamarans perform well at small drafts, it is beneficial to fit them with a simple hydrofoil system. This results in improved performance characteristics and cost benefits. Fitting hydrofoils to trailer-able catamarans would enable them to go faster, use less fuel, and possibly require smaller engines as a result of the additional-lift created by hydrofoils.

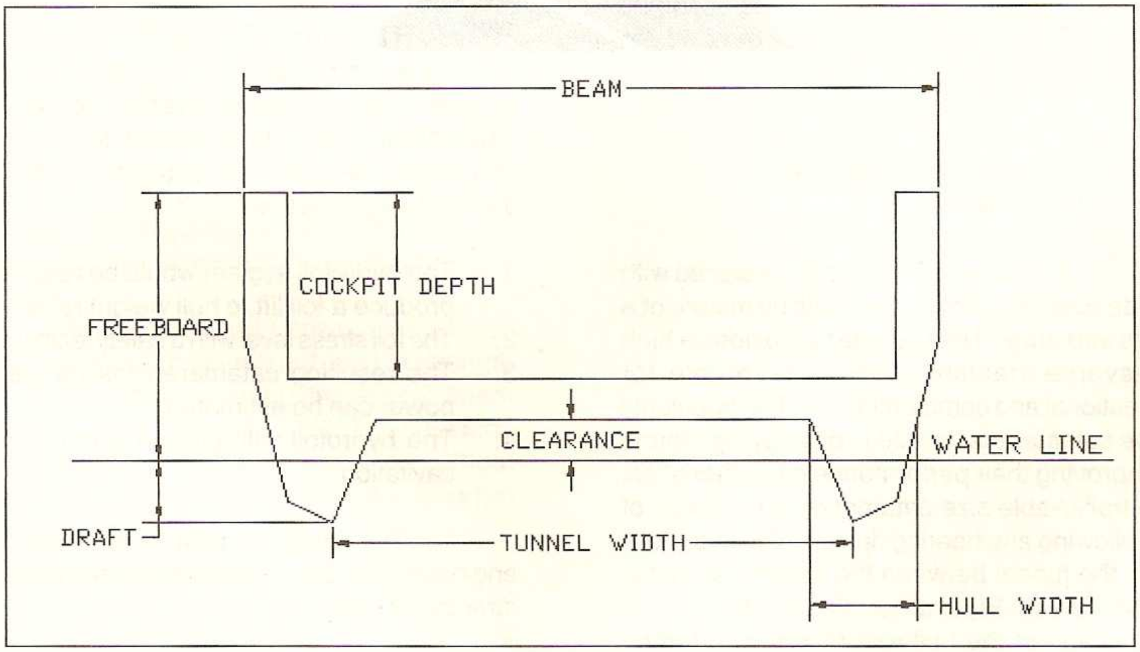

Figure 1. Catamaran Cross-section Dimensions

The purpose of this paper is to develop an engineering procedure for sizing the hydrofoil system to produce the necessary lift for improving the catamaran performance. The procedure considers both foil-lift and foil-strength. Two cases can result from the retrofitting of the system. The first case is that the only alteration to the vessel is the addition of the foil system. This case results in less power to achieve design speed so the catamaran is able to reach higher maximum speeds. The second is to use the foil system to reduce outboard power and achieve 30-knot speeds. This second case results in a more economical catamaran. Both cases will be discussed along with their respective benefits.

2. NOMENCLATURE

B = overall beam
c = chord length of foil
C_L = lift coefficient
g = gravitational acceleration
HP = engine horsepower
L = length of the catamaran
L_f = foil lift
QPC = propulsive coefficient
R_T = total resistance
s = foil span
t = maximum hydrofoil thickness
T = draft
V = speed in [ft/s]
V_k = speed in knots
α = angle of hydrofoil incidence
ρ = density of water
∇ = displacement volume
Δ = displacement

3. REVIEW OF THE FOIL-CAT DEVELOPMENT

A catamaran is a vessel designed with a wide deck connecting two hulls by means of a cross structure. The wide deck provides a high transverse stability. This is favorable for recreational and commercial use. The popularity of the catamarans has led to developing means to improving their performance characteristics. The trailer-able size catamaran is the focus of the following engineering design. The hydrofoils span the tunnel between the catamaran hulls, as shown in Figure 1. When running, a percentage of the hull weight is supported by the foils' lift. This reduces the catamaran draft resulting in improved performance.

The trailer-able catamaran for this engineering analysis has a length of 26 feet and a beam of 8 feet to comply with U.S. highway transportation laws. Figure 1 shows that the maximum tunnel width is near the bottom of the catamaran. This is the location where the hydrofoils will be retrofitted.

The hydrofoil is a wing-like cross piece that will be attached to the hulls of the catamaran. The foil geometry is shown in figure 2. The foil is a lift-producing surface when moving in water. A combination of foils will support a percentage of the vessel's weight. The plan, bow and isometric views of the catamaran hydrofoil arrangements are shown in Figures 3-5. The foils actually lift the catamaran, reducing the wetted surface resistance (less hull surface is in contact with the water). The reduction of surface drag results in a combination of increased speed and decreased powering requirements.

The idea of retrofitting catamarans is not a new one. There has been extensive work done in the area hydrofoil assisted catamarans. The availability of the foil-cat tank test data for design is limited because of the large financial investments made by different companies. The details of these hydrofoil designs remain more or less unavailable to the general public. Nevertheless it is possible to analyze the hydrofoil system from "First Principles".

The goal here is to develop an engineering procedure using "First Principles" to size the hydrofoils system for a 26-ft catamaran. This requires that the foils be made of a simple material. This design approach has the following objectives:

1. The hydrofoil system would be required to produce a foil lift to hull weight ratio.
2. The foil stress level with a safety factor of 1.5.
3. The resulting catamaran resistance and power can be estimated.
4. The hydrofoil will operate with minimum cavitation.

The design procedure will follow basic engineering fundamentals in hydrodynamics and strength of materials.

There are several problems encountered in the foil design. The first is that the foil lift decreases as it approaches the surface. The second is in the geometry of the foil that results in a very thin and narrow beam. In order to install the foil to the necessary span you would need to support it properly. This requires solving strength of materials problem using beam theory. The catamaran has two hulls that have a lot of wetted surface. The foils would have to reduce the wetted surface by decreasing the draft of the vessel. This is also related to whether the catamaran uses planing or displacement hulls and the reduction in wave making resistance. The addition of foils makes it possible to develop low resistance hulls, which can be discussed in terms of the foil-lift:

1. Hydrofoil catamaran where at design speed the Cat hull is fully supported (bracketed support between 90%-100% by the hydrofoils). [Caulkins & Miyata]
2. The partially supported foil-cat (40%-90%) [Zhao,90 , Amfilev,70, HysuCat, SA]
3. Fully supported catamaran, where a hydrofoil blade section is used. For partially supported a simpler blade section is utilized.
4. Location of foil for maximum wave cancellation.

4.0 DEVELOPMENT OF THE FOIL-CAT DESIGN SCHEME

A design guideline to size foils to meet foil hydrodynamics and foil strength has been developed. The procedure is shown in the flow chart in figure 6. It begins with an assumed percentage of catamaran displacement to be supported by the foils. This leads to determining the shape and size of the foil to create the lift force equivalent to the percentage of displacement. A hydrodynamic analysis covers the calculations necessary to size the foil.

As the flowchart shows, after the foil geometry has been developed, the foil strength is analyzed. This is done using simple beam theory with a safety factor of 1.5. The structural analysis leads to having the foils span without midspan support, or the addition of support(s) along the span of the foil.

The next step is to examine the catamaran's new resistance and powering characteristics. The resistance curves of the catamaran are modified to reflect the results of lower draft (less displacement). This analysis estimates the attainable speeds or the savings in power.

4.1 Foil Lift/Drag

The hydrofoil design uses an asymmetrical foil section. There are two types of foil systems that exist. The first is a surface piercing foil and the other is the fully submerged foil. The foil-cat design considers only the fully submerged foil. The foil chosen was a plane-convex foil section with a camber distribution shown in Figure 4 and Table 3. The foil lift and drag has been extensively tested in Russia. The lift force is normal to the free stream and the drag force is parallel to the free stream flow. The foil-lift force is calculated to improve the performance characteristics of the catamaran.

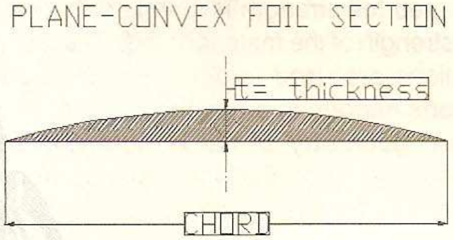

Figure 2. Foil cross-section

The foil-lift coefficient is dependent on two parameters: the submergence to chord ratio h/c and the angle of incidence a. The thickness to chord ratio is a constant t/c=0.06. For the purposes of this design the angle of incidence will be zero and the submergence set at the catamaran draft T=h=1 ft. The lift equation is as given below.

Lift = 0.5*r*CL*s*c*V2 (3)

For this foil the lift coefficient has been experimentally determined from data [ref}. The equation is

$$C_L = C_{L\infty}(1-0.5e^{-2.5\frac{h}{c}}) \tag{4}$$

If equation (3) is solved for the chord c

$$C = \frac{L}{0.5V^2 C_L S_{span} \rho} \tag{5}$$

and equation (4) is substituted into equation (5), resulting in the following.

$$C = \frac{L}{0.5V^2(C_{L\infty}(1-e^{-2.5\frac{h}{c}}))S_{span}\rho} \qquad (6)$$

Equation (6) is solved for the chord by the Newton-Raphson method. This gives the necessary chord size to finally determine the foil dimensions.

4.2 Foil Strength

After sizing the foil, the next step in the flowchart in figure 6 (foil-lift), is determining the foil's ability to support the load. The load is calculated by assuming a percentage of hull displacement that will be supported by the foils. The foils are modeled as a beam with both ends clamped. Using simple beam theory, the estimated foil strength is checked against the yield strength of the material used. The following equations are used to determine the number supports needed to brace the foil. For this foil section geometry of flat bottom and semi-elliptical top, such that the distance from the neutral axis for this foil section is:

$$z_{NA} = \frac{4 \bullet t}{3\pi} \cong 0.42 \bullet t \qquad (7)$$

The maximum bending moment according to beam theory occurs at the fixed ends: where,

$$M_{max} = \frac{W\ s^2}{12}, \qquad (8)$$

$W' = \frac{W}{s}$, W = total load acting on the foil

s = foil span. The area moment of inertia of the foil cross-section is given by:

$$I = \frac{c \cdot t^3 \cdot \pi}{16} \qquad (9)$$

The bending stress will be:

$$\sigma = \frac{M_{max} \cdot z_{NA}}{I} \qquad (10)$$

A satisfactory design regime foil can be supported at mid-span to reduce the stress in the foil. The support at the mid-span is modeled as an additional clamped end. The two segments of the foil between fixed ends at the hull and the mid-span support are now idealized as two separate clamped beams. Another way to reduce the stress in the foils is to use higher strength material.

5. EXAMPLE OF A HYDROFOIL CATAMARAN

The benefits of a foil cat can be realized in a larger scale vessel. Miyata has reported the performance of a 12 m-25 knot hydrofoil catamaran. This hull is supported by 2X300mm with 70 mm trailing flaps. The catamaran is powered by twin 200 HP waterjets, operating at 23-25 knots.

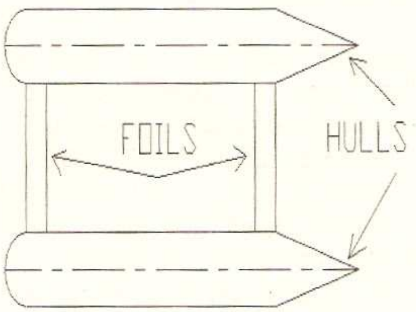

Figure 3. Plan view of foil-cat

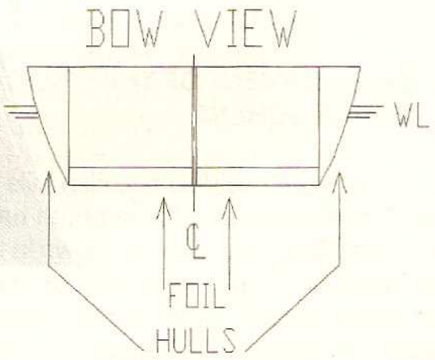

Figure 4. Bow view of foil-cat

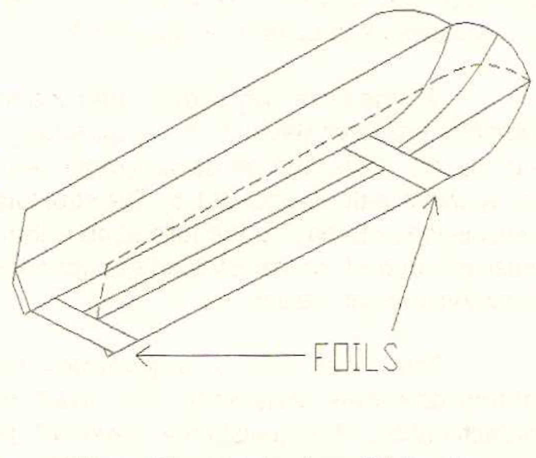

Figure 5 Isometric-view of foil-cat

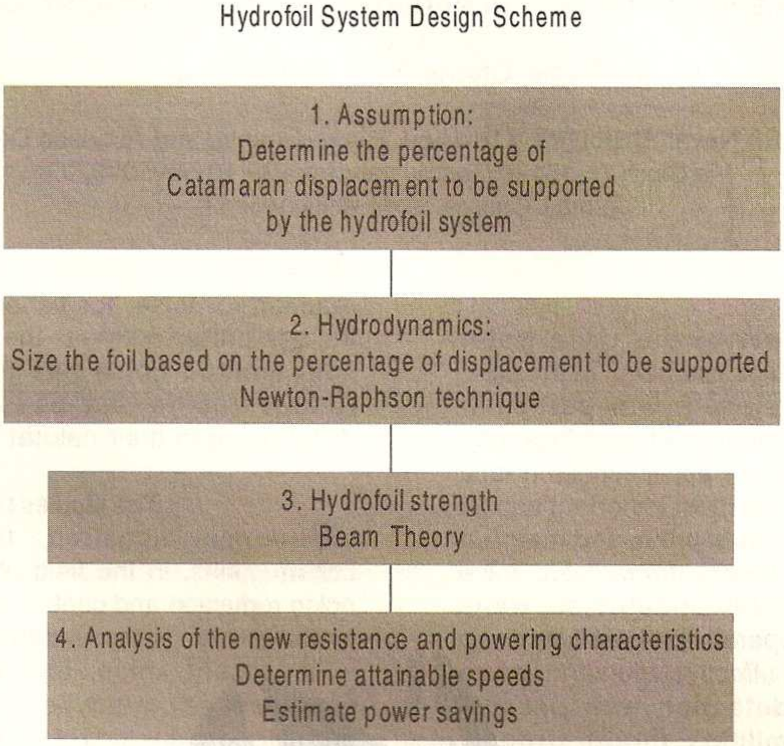

Figure 6. Design Flowchart

6. CONCLUSIONS

The design process for a foil-assisted catamaran has been developed. The results show that the foil-assisted catamaran can maintain speed with smaller outboard motors. This makes the foil-assisted catamaran extremely attractive for recreational boats. They can have high-speed catamaran performance at less cost, in engine and fuel.

The results of the design procedure are quite useful in designing the foil-assisted 26-foot trailerable catamaran.

1. The calculations show a ratio of foil lift to vessel weight of 0.2 is best.
2. For this design a steel foil can be manufactured.
3. The optimum foil system is a three-point support with the foil mounted in the catamaran side hulls and supported at midspan.
4. The design speed can be maintained using half the outboard power (ei. 2X150 hp engines at 30 knots without the foils and 2X75 hp engines at 30 knots with the foils).

7. REFERENCES

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