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FLUID FOIL

Filed May 9, 1938

2 Sheets-Sheet 1

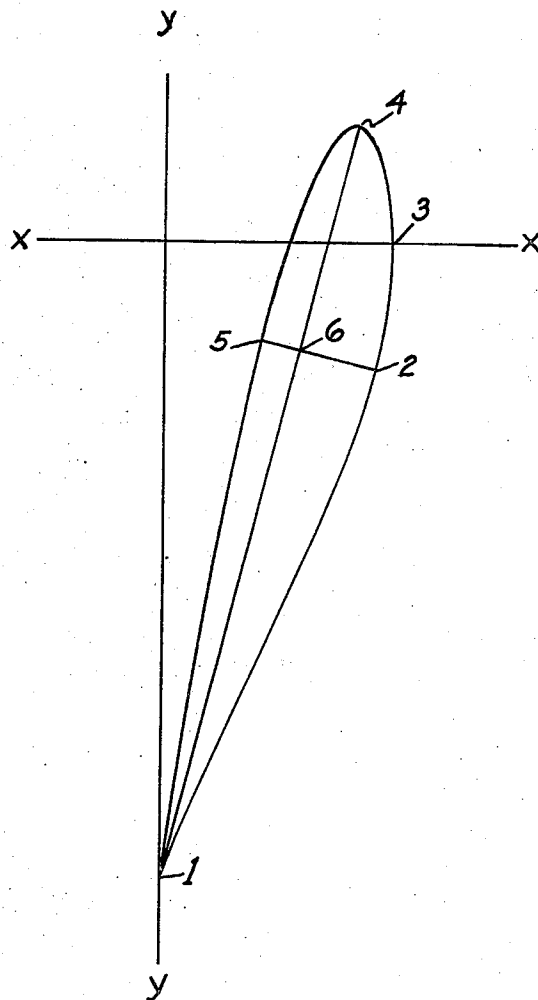


Fig. 1

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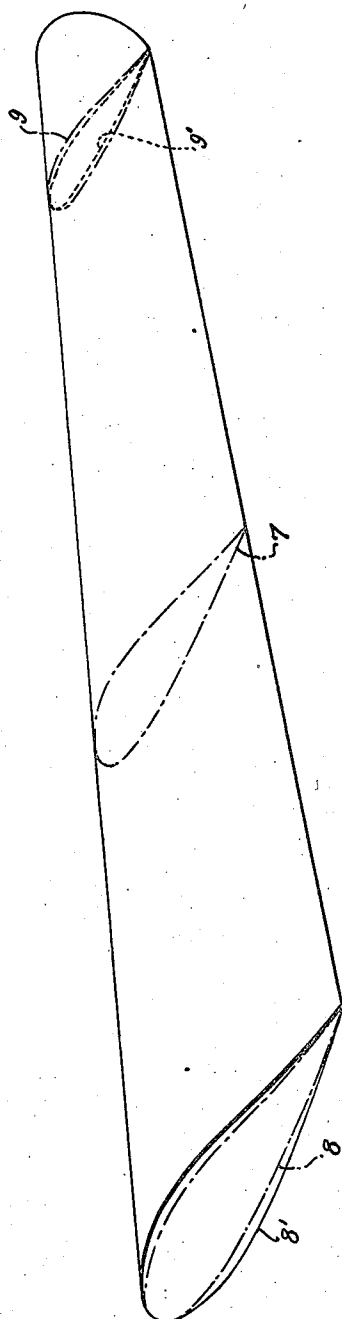
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Fig. 2.



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FLUID FOIL

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4 Claims. (Cl. 244-35)

This invention relates to the construction of foils to be driven through a fluid, and particularly concerns the profiles of the foils. While the invention may be applied to a foil used in any fluid medium, it has its greater usefulness when applied in the construction of wings for air vehicles.

The upper and lower surfaces of an airfoil should be curved to function in an air stream to produce lift, without producing excessive drag. The upper and lower curves of the sectional profile of a fluid foil each affects the fluid flow around the other and they are, therefore, interdependent.

The general object of this invention is to provide foils having profiles in their fore-to-aft sections whose upper and lower curves are mutually dependent and have a particular relationship, and to provide a formula having but one variable co-efficient which if employed in laying out the profile lines for the upper and lower surfaces of the coils will determine a definite relationship for each given type of foil profile.

A further object of this invention is to provide a formula, such as referred to above, and having one variable co-efficient, this variable co-efficient being constant for the development of the curve of any given foil section, the value of this co-efficient determining the shape of the profile.

A further object of this invention is to provide a family of master foil section shapes, determined by the formula referred to above, which deviate regularly from each other in profile, and in the character of their profile curvature, and which can be readily tested to determine the most advantageous form of foil section for certain purposes.

A further object of this invention is to provide a family of master foil sections, determined by the formula referred to above, and to provide a method to vary the thickness of these master sections, without destroying the character of the curves of the upper and lower cambers of said master sections.

A further object of this invention is to provide foil sections and a method for determining certain profiles for same, which may be used on a fluid foil to function in a fluid to produce a lift curve slope which is one hundred per cent efficient, according to the accepted theory.

Further objects of this invention will appear hereinafter.

The invention consists of novel parts and com-

binations of parts to be described hereinafter, all of which contribute to produce an efficient fluid foil.

A preferred embodiment of the invention is described in the following specification, while the broad scope of the invention is pointed out in the appended claims.

Figure 1 illustrates by rectangular coordinates a basic foil section profile according to my invention.

Figure 2 is a perspective view of a half span of an airplane wing constructed in accordance with my invention and tapering both in plan and in thickness ratio. In this view the increase in thickness ratio at the root and the decrease in thickness ratio at the tip are illustrated.

Figure 1 illustrates a foil section profile embodying my invention, and in which the points of the upper and lower profile lines are determined in accordance with my formula and with reference to a horizontal (X axis) and a vertical (Y axis). To develop the particular profile illustrated, co-efficient "A" in my formula was given the constant value 1.00. The points for determining the profile line 1, 2, 3 of the foil section are determined for both coordinates in accordance with the following formula, which is expressed in parametric form:

$$X_u = \sin.\theta(4/\pi - 1)A + \tan.\theta(1 - 2\theta/\pi)(1 - A)$$

$$Y_u = \cos.\theta(4/\pi - 1)A - A(1 - 2\theta/\pi)$$

In order to determine the profile line 1, 5, 4, 3, I employ the following formula, which is expressed in parametric form.

$$X_b = \sin.\theta(4/\pi - 1)A + \tan.\theta(1 - 2\theta/\pi)(1 - A)$$

$$Y_b = \cos.\theta(4/\pi + 1)A - 3A(1 - 2\theta/\pi)$$

In all four of my equations constituting my formula, values of theta are assumed varying from zero, to

$$\frac{\pi}{2} \text{ radians}$$

The value of A is constant for any one foil profile. A sufficient number of values of theta should be used in order that the points found will be numerous enough to determine fair curves. By developing a series of master foil sections in which constant A is given regular increments and decrements in value, a series of master foil section shapes can be constructed which vary gradually in their performance on account of the fact that they vary very slightly from each other,

and the most desirable form may be selected for a given purpose.

In the drawings, chord line 1, 6, 4 has been drawn between the foil sections trailing edge 1, and leading edge 4, and connecting those two points on the profile which are most widely separate. Line 5, 6, 2 is normal to chord line 1, 6, 4 and intersects it at 6, a point 30% of the chord measured rearward from the leading edge 4, or at the 30% station. Hereinafter when the term "chord line" is used it shall be defined as a straight line extending throughout the longest distance across a foil section profile and connecting the leading and trailing edge thereof.

In the example illustrated in the drawings, and heretofore described, A being given the value of 1.00, values of theta (θ) shown in the following table, when substituted in the formula, result in the values of the rectangular coordinates X and Y, shown in the table, which in turn determine the position of the corresponding points on the profile line of the foil section.

θ radians	X_u	Y_u	Pt.	θ radians	X_b	Y_b	Pt.
0	0	-0.726760	1	0	0	-0.726760	1
1.169370	0.251518	-0.148795	2	0.430049	0.113961	-0.112583	5
1.570796	0.273240	0	3	1.028653	0.234058	0.137507	4
				1.570796	0.273240	0	3

For example, substitution of the value 0 for θ in the formulas for X_u and Y_u results in a value of $X_u=0$ and a value of $Y_u=-0.726760$. The point 1 may then be plotted on the XY graph in accordance with these values. Substitution of the value of 1.169370 radians for θ in the formulas for X_u and Y_u results in a value of $X_u=0.251518$ and a value of $Y_u=-0.148795$. The point satisfying these conditions is the point 2. When a value of $\pi/2$, or 1.570796 is substituted for θ in the formulas for X_u and Y_u , a value of $Y_u=0$ and a value of $X_u=0.273240$ result. This point, when plotted, is the point 3. Ordinarily a large number of values of θ , from 0 to $\pi/2$, are substituted in the formulas for X_u and Y_u to determine points between point 1 and point 3 sufficient to determine accurately the line 1, 2, 3. In the same manner, the value 0 may be substituted for θ in the formulas for X_b and Y_b , resulting again in the values $X_b=0$ and $Y_b=-0.726760$, again determining the point 1. Values of $\theta=0.430049$ and $\theta=1.028653$ may be substituted in the formulas for X_b and Y_b , resulting, respectively, in values of $X_b=-0.112583$, determining the point 5; and $X_b=0.234058$ $Y_b=0.137507$, determining the point 4. When the value $\theta=\pi/2$ is substituted in the formulas for X_b and Y_b , the values $X_b=0.273240$, $Y_b=0$ result, again determining the point 3. Numerous values of θ may be substituted in the formulas for X_b and Y_b to accurately determine the entire profile line from point 1 around to point 3.

Upon substituting a value $\theta=\pi/2$ in the formulae for X_u and X_b , it will be found that the last term of the formula includes a quantity, $(1-2\theta/\pi)$, which equals zero and another quantity, $\tan \theta$, which equals infinity. The product of these two quantities is indeterminate. It is, therefore, preferable to evaluate the product $(\tan \theta) (1-2\theta/\pi)$ as a whole for the value of $\theta=\pi/2$. The value of this product is determinate and is $2/\pi$, so that for $\theta=\pi/2$ the last term in the formulae for X_u and X_b is $2/\pi (1-A)$.

It is customary in the art to describe a foil section profile by measuring the distances be-

tween the upper and lower camber lines and the chord line of the section, at numerous points along the chord, and to express all such distances in percentage of chord length. These percentages are referred to as the foil section ordinates.

For example, the foil section ordinate of the camber line 1, 2, 3, 4 at the 30% station along the chord line is equal to 100 times the distance 6, 2 divided by the distance 1, 4. And the foil section ordinate of the camber line 1, 5, 4 at the 30% station along the chord line is equal to 100 times the distance 6, 5 divided by the distance 1, 4.

The foil section ordinates for the upper and/or lower cambers of any master section expressed by my formula may be multiplied or divided by a constant value to produce new ordinates for foil sections having profiles which are proportionally thicker or thinner than the master section from which they were derived, while they retain the characteristics of the master section's profile

curvatures in an exaggerated or diminished degree.

This is known in the art as increasing or decreasing the thickness ratio of the foil section. This is shown in Figure 2 wherein the dot and dash line designated by the reference numeral 7 illustrates a basic foil section in accordance with the formulae. The thickness ratio is increased near the root as illustrated by the line designated by the reference numeral 8', the basic foil section according to the formulae being shown by the dot and dash line designated by the reference numeral 8. The thickness ratio is decreased near the tip as illustrated by the dotted line designated by the reference numeral 9', the basic foil section according to the formulae being shown by the dot and dash line designated by the reference numeral 9.

By practicing my invention a series of master foil profiles which deviate gradually from each other in their curvature characteristics, can be produced with mathematical accuracy, and each master profile can be increased or decreased in thickness ratio to produce a series of foil profiles which retain similar contour characteristics, and this possibility is particularly valuable because when such a series is tested, the performance of any intermediate foil profile can be calculated without test.

In the art, an airfoil's efficiency is measured by the value of the airfoil's efficiency factor " η ," which is expressed as follows:

$$\eta = \frac{dC_L/d\alpha_0 \text{ (radians)}}{2\pi}$$

in which C_L is the coefficient of lift and α_0 is the angle of attack corrected for infinite aspect ratio, expressed in radians.

The better foil profiles now known to the art will function on a foil to produce an airfoil efficiency " η " equal to about 9.

Numerous competitive tests in the California Institute of Technology Wind Tunnel on various types of wing models employing the finest profiles now known to the art, on the one hand, and the

sectional profiles described herein, on the other, indicate that the foil profiles described in this invention function to produce an eight per cent to twelve per cent increase in airfoil efficiency. One wing model employing sectional profiles derived from the master section produced by giving constant A in my formula the value 1.00, the ordinates of said master profile being increased to give a thickness ratio of 18% at the wings' root section and being decreased to a thickness ratio of 12% at the tip section, functioned to produce an efficiency factor "η" which was greater than 1.00. According to accepted theory, this wing functioned with an efficiency of more than 100%. Careful check tests were repeated on this airfoil on at least two later occasions, without change in results.

When functioning at high speed, or a large Reynold's number, the most efficient master foil section profiles are expressed by my formula when constant A is given a value which is not less than .93, or greater than 1.05, and the ordinates for these master profiles may be increased or decreased by a constant per cent to produce allied profile shapes which are particularly efficient. It is to be understood, however, that master profiles derived by using other values of A, and their allied profiles, are useful for particular purposes. Decreasing the value of A results in foils which are thicker relative to the length of the chord line, while increasing the value of A results in foils which are relatively thinner.

The most important portion of a fluid foil sectional profile is the forward 50% thereof. Layout tolerances over the leading half of the foil profiles are comparatively small, while larger tolerances are allowable over the remainder of the foil profile.

It is evident that a fluid foil may utilize one sectional profile at one point in its span, and other section profiles at other points in its span.

The inventor wishes it to be clearly understood that the increased performance enjoyed by fluid foils using his sectional profiles can be directly attributed to the character of the curvature of the upper and lower camber lines, as described by his formula, and that the character of these curves is not changed when the ordinates for a given camber are multiplied or divided by a constant.

This invention accomplishes an important improvement in the art and the discoveries disclosed herein are of great value to all types of aircraft, throughout their entire flying range.

I claim:

1. A fluid foil having a sectional profile producible by modification of a sectional profile conforming substantially to the following formula, in which theta varies from zero to

$$\frac{\pi}{2} \text{ radians}$$

and the value of A is constant and equal to approximately one:

$$\begin{aligned} X_u &= \sin \theta (4/\pi - 1) A + \tan \theta (1 - 2\theta/\pi) (1 - A) \\ Y_u &= \cos \theta (4/\pi - 1) A - A (1 - 2\theta/\pi) \\ X_b &= \sin \theta (4/\pi - 1) A + \tan \theta (1 - 2\theta/\pi) (1 - A) \\ Y_b &= \cos \theta (4/\pi + 1) A - 3A (1 - 2\theta/\pi) \end{aligned}$$

said modification consisting in multiplying all foil section ordinates of any camber line by a constant value whereby the foil thickness is increased or decreased depending on the value of the constant.

2. A fluid foil having a sectional profile producible by modification of a sectional profile conforming substantially to the following formula, in which theta varies from zero to

$$\frac{\pi}{2} \text{ radians}$$

and the quantity A has a value not less than .93 or more than 1.05:

$$\begin{aligned} X_u &= \sin \theta (4/\pi - 1) A + \tan \theta (1 - 2\theta/\pi) (1 - A) \\ Y_u &= \cos \theta (4/\pi - 1) A - A (1 - 2\theta/\pi) \\ X_b &= \sin \theta (4/\pi - 1) A + \tan \theta (1 - 2\theta/\pi) (1 - A) \\ Y_b &= \cos \theta (4/\pi + 1) A - 3A (1 - 2\theta/\pi) \end{aligned}$$

said modification consisting in multiplying all foil section ordinates of any camber line by a constant value whereby the foil thickness is increased or decreased depending on the value of the constant.

3. A fluid foil having a sectional profile defined by a first profile line and a second profile line, said first profile line conforming substantially to the following formula:

$$\begin{aligned} X_u &= \sin \theta (4/\pi - 1) A + \tan \theta (1 - 2\theta/\pi) (1 - A) \\ Y_u &= \cos \theta (4/\pi - 1) A - A (1 - 2\theta/\pi) \end{aligned}$$

in which X_u and Y_u are the rectangular coordinates of points on said first profile line determined by holding the value of A constant and equal to approximately one and giving theta various values from zero to

$$\frac{\pi}{2} \text{ radians}$$

and said second profile line conforming substantially to the following formula:

$$\begin{aligned} X_b &= \sin \theta (4/\pi - 1) A + \tan \theta (1 - 2\theta/\pi) (1 - A) \\ Y_b &= \cos \theta (4/\pi + 1) A - 3A (1 - 2\theta/\pi) \end{aligned}$$

in which X_b and Y_b are the rectangular coordinates of points on said second profile line determined by holding the value of A constant and equal to approximately one and giving theta various values from zero to

$$\frac{\pi}{2} \text{ radians}$$

4. A fluid foil having a sectional profile defined by a first profile line and a second profile line, said first profile line conforming substantially to the following formula:

$$\begin{aligned} X_u &= \sin \theta (4/\pi - 1) A + \tan \theta (1 - 2\theta/\pi) (1 - A) \\ Y_u &= \cos \theta (4/\pi - 1) A - A (1 - 2\theta/\pi) \end{aligned}$$

in which X_u and Y_u are the rectangular coordinates of points on said first profile line determined by holding A constant at a value not less than .93 and not greater than 1.05 and giving theta various values from zero to

$$\frac{\pi}{2} \text{ radians}$$

and said second profile line conforming substantially to the following formula:

$$\begin{aligned} X_b &= \sin \theta (4/\pi - 1) A + \tan \theta (1 - 2\theta/\pi) (1 - A) \\ Y_b &= \cos \theta (4/\pi + 1) A - 3A (1 - 2\theta/\pi) \end{aligned}$$

in which X_b and Y_b are the rectangular coordinates of points on said second profile line determined by holding A constant at a value not less than .93 and not greater than 1.05 and giving theta various values from zero to

$$\frac{\pi}{2} \text{ radians}$$

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