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FLUID FOIL

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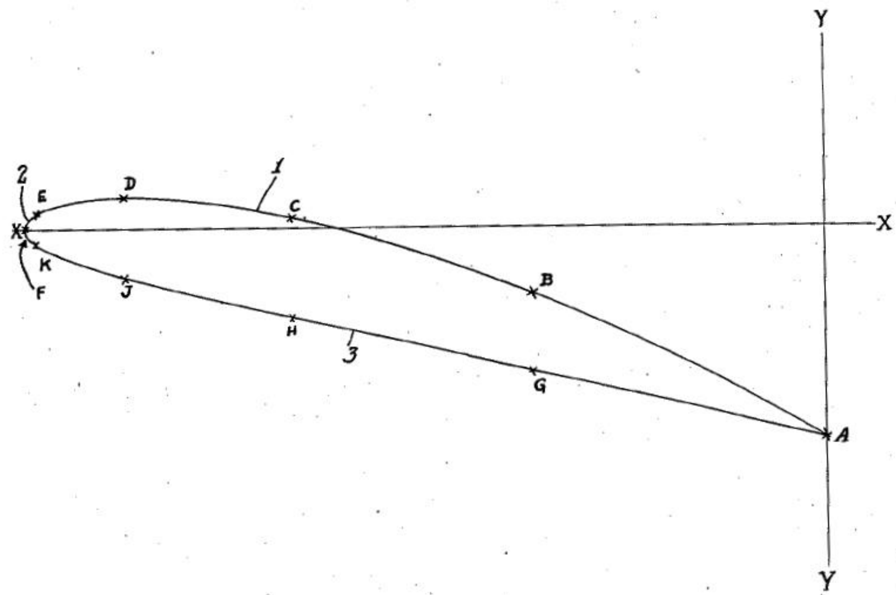

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FLUID FOIL

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This invention relates to a construction of foils to be driven through a fluid, and particularly concerns the profile of the foil in its front to rear section. While the invention may be applied to a foil used in any medium, it has its greatest usefulness when applied in the construction of airfoils for air vehicles.

The upper surface of a fluid foil should have a profile, which, when the foil is driven through the fluid, will develop a region of reduced pressure on the upper side of the foil, and the under side of a foil should have a profile which will develop a region of increased pressure on the under side of the foil. These differential pressures result in a force which may be resolved into a lift component perpendicular to the direction of movement and a drag component parallel to the direction of movement.

For any given upper curve of a foil profile there is but one best complementary lower curve, that is to say, one most efficient complementary lower curve. The upper and lower curves of the 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-and-aft sections whose upper and lower curves are mutually dependent and have a particular relationship, and to provide a formula which if employed in laying out the profile lines for the upper and lower surfaces of the foils will determine a definite relationship for each given type of foil.

A further object of the invention is to provide a foil, the profile of which is determined by a formula, such as referred to above, and having two variable coefficients, these variable coefficients being constant for the development of the top and bottom curves of any given foil section, the value of these coefficients determining the shape of the profile; also to provide a foil in which, when the upper profile has a definite form, a lower profile line can be determined to correspond with the determined upper profile line and all in accordance with the same formula.

A further object of the invention is to provide a formula, such as referred to above, and having two variable coefficients to determine a series of related foils obtained by the variation of one or two coefficients in the formula.

In the design of air foils, two factors are of paramount importance, namely, drag and lift, and one of the objects of the invention is to provide a foil constructed in accordance with a certain formula having two variable coefficients, changes in which will alter the drag and lift of the foil, one of my purposes being to enable slight variations in coefficients of the formula to produce slight variations in the drag and lift to the end that a series of foils having a profile deviating regularly from each other can be readily tested to determine the most advantageous form of foil for certain purposes.

Further objects of the invention will appear hereinafter.

The invention consists of novel parts and combinations 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.

The drawing illustrates a foil 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). The points for determining the upper profile line 1, that is to say, for the upper camber and suction face of the foil are determined for both coordinates in accordance with the following formula, which is expressed in parametric form:

$$Xs = \sin\theta[0.6366198(A-B)+B] + \tan\theta[[1-(0.6366198)(\theta)](1-A)]$$

$$Ys = \cos\theta[0.6366198(A-B)+B] - A[1-(0.6366198)(\theta)]$$

In order to determine the profile of the pressure face, or lower camber, I employ the following formula; which is expressed in parametric form:

$$Xp = \sin\theta[0.6366198(A-B)+B] + \tan\theta[[1-(0.6366198)(\theta)](1-A)]$$

$$Yp = \cos\theta[0.6366198(A-B)-B] - (A-2B)[1-(0.6366198)(\theta)]$$

In all four of my equations constituting my formula, values for theta are assumed varying from zero to pi divided by two radians. The values of A and B are constant for any one foil. 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 constructing a series of foils in which the constants A and B are given regular increments and decrements in value, a series of foils can be constructed which will vary gradually in their performance on account of the fact that they vary very slightly from each other. Hence, by employing this formula in the construction of foils, it will be evident that a series of foils can be constructed, which, when tested, will enable the most desirable form to be selected for a given purpose. The equation was developed from formulas based on the mechanical action of a rotor having rotation and translation through a fluid and giving the Magnus effect. For any given top profile developed by this equation, there will be a single corresponding bottom profile, and any change in the top profile will develop a different bottom profile corresponding to that profile.

As an example in laying out a profile for a foil, let us assume that A=0.717257 and B=0.208228. With the above assumptions, when theta has the values given in the first column in the table below, corresponding values for X_s, Y_s, X_p, and Y_p determined from the equations will be as shown in the corresponding columns:

θ (radians)	X_s	Y_s	Point	X_p	Y_p	Point
0	0	−.18497	A	0	−.18497	A
.3491	.26210	−.05769	B	.26210	−.12512	G
.6981	.47395	+.00928	C	.47395	−.07838	H
1.0472	.62421	+.02706	D	.62421	−.04235	J
1.3963	.70236	+.01274	E	.70236	−.01331	K
1.5708	.71229	+0	F	.71229	0	F

In the drawing, the letters A, B, C, D, E, etc., indicate the points having the coordinants indicated in the table with reference to the X and Y axes. In laying out the profile lines, the values for the angle theta may be given very slight successive increments where the points lie near the leading edge 2 of the foil. For the remainder of the upper profile line 1 and the lower profile line 3, these points can be further apart because the variation in direction of each curve in the after part of the foil is relatively slight, and the profile lines at this part of the foil may be determined with reasonable accuracy by using a relatively small number of points and passing a fair line through them.

It will be evident that in practicing my invention it is possible to develop a series of very closely related foils. This is possible because in my formula the values of A can be gradually increased, or decreased, to develop a slightly modified foil and in the same way the values of B can be varied to produce another series of modified foils. For any given value of B in the formula, the drag of the resulting foil will become less as the value of A is diminished. For any given value of A, the lift of the foil will increase as the value of B is diminished.

When B is given the same value as A, a streamline will be formed. If this value is changed, but maintaining A and B equal, other streamlines will be formed. If a complete streamline foil is developed in this way, and as the value of A becomes less, the maximum vertical ordinate of the streamline expressed in percentage of the chord will become smaller and the maximum ordinate will occur near the nose of the foil. If the value of A becomes greater, the reverse is true. Therefore, in the equation, a value given to A denotes the streamline from which this foil illustrated has been derived.

The value of B determines the angle of attack of the foil, in other words, the orientation of the foil in a vertical plane with respect to the horizontal axis X, X.

By varying these constants A and B one at a time, foils having special characteristics desirable for special service can be readily determined. I am using the term "varying" in its mathematical sense, and hence either of these terms of my equation may be negative while the other is positive.

By using the formula an upper profile curve and, or, a lower profile curve will be determined, which, I believe, has a character never before employed for determining the suction or pressure curve of a foil.

It will be evident that in employing my formula when the upper, or suction, profile line has been determined, then for the same values of A and B, a certain single definite lower camber outline will be determined that corresponds to the upper curve.

By practicing my invention, fluid profiles suitable for particular purposes may be determined with mathematical accuracy, and it is possible to develop a number of series of profiles deviating from each other gradually, and this possibility is particularly valuable because when such a series is tested, the foil having the characteristics best suited to particular service can be determined.

The upper and lower camber outlines have mutual action one upon the other, so that only a particular combination of outlines will give the most effective fluid foil. This system gives such a combination, and is at the same time adaptable to producing foils for a certain definite purpose, in other words, fluid foil profiles may be determined by this system to give high lift or low drag, or a high ratio of lift to drag; also to determine effective foil outlines to meet any given structural requirement.

I believe that foils constructed in accordance with my formula will give the most satisfactory results when the value B is from 18% to 33% of the value of A.

The most important portion of the upper profile line of a foil is the part forward of 50% of the chord of the upper camber and the most important portion of the lower profile line or suction line is the part extending from the forward edge of the foil to a point about 25% of the chord of the lower camber.

I claim:

1. A foil having an upper and lower profile, said profiles being correlated and conforming to the following formula, substantially as described: suction face or upper camber

$$Xs=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Ys=\cos\theta[0.6366198(A-B)+B]-A[1-(0.6366198)(\theta)]$$

pressure face or lower camber

$$Xp=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Yp=\cos\theta[0.6366198(A-B)-B]-(A-2B)[1-(0.6366198)(\theta)].$$

2. A foil having a profile in its fore-and-aft section, including an upper profile line for the upper side of the foil, and a lower profile line for the under side of the foil, said lower profile line having a definite form determined by the upper profile, according to the following formula, substantially as described:

suction face or upper camber

$$Xs=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Ys=\cos\theta[0.6366198(A-B)+B]-A[1-(0.6366198)(\theta)]$$

pressure face or lower camber

$$Xp=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Yp=\cos\theta[0.6366198(A-B)-B]-(A-2B)[1-(0.6366198)(\theta)].$$

3. A foil having a profile in its fore-and-aft section, including an upper profile line for the upper side of the foil and a lower profile line for the under side of the foil, said profile lines

being capable of being plotted so as to conform to the following formula, substantially as described:

suction face or upper camber

$$X_s=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_s=\cos\theta[0.6366198(A-B)+B]-A[1-(0.6366198)(\theta)]$$

pressure face or lower camber

$$X_p=\sin\theta[0.6366198\ (A-B)+B]+\tan\theta\ [\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_p=\cos\theta[0.6366198(A-B)-B]-(A-2B)[1-(0.6366198)(\theta)].$$

4. A foil having a profile in its fore-and-aft section, said profile being defined by a continuous line the points on which are determinable by reference to the following formula, substantially as described:

suction face or upper camber

$$X_s=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_s=\cos\theta[0.6366198(A-B)+B]-A[1-(0.6366198)(\theta)]$$

pressure face or lower camber

$$X_p=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_p=\cos\theta[0.6366198(A-B)-B]-(A-2B)[1-(0.6366198)(\theta)].$$

5. A foil having a profile in its fore-and-aft section, including an upper profile line, and a lower profile line determinable from, and corresponding to, the upper profile line in accordance with the following formula, substantially as described:

suction face or upper camber

$$X_s=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1--A)]$$

$$Y_s=\cos\theta[0.6366198(A-B)+B]-A[1-(0.6366198)(\theta)]$$

pressure face or lower camber

$$X_p=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}1-)A]$$

$$Y_p=\cos\theta[0.6366198(A-B)-B]-(A-2B)[1-(0.6366198)(\theta)].$$

6. A foil having a profile in its fore-and-aft section in which the profile at the leading edge conforms to the following formula substantially as described:

suction face or upper camber

$$X_s=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_s=\cos\theta[0.6366198(A-B)+B]-A[1-(0.6366198)(\theta)]$$

pressure face or lower camber

$$X_p=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_p=\cos\theta[0.6366198(A-B)-B]-(A-2B)[1-(0.6366198)(\theta)].$$

7. A foil having a profile determined by a formula to determine the profile of its fore-and-aft cross section having but two variable coefficients, the lift and drag of the resultant foils being dependent upon the values of these coefficients.

8. A foil having a profile in its fore-and-aft section, in which, beginning at the entering edge and extending along the upper line of the profile to a point 50% of the chord of the suction or upper camber and that part beginning at the entering edge and extending to 25% of the chord on the pressure or lower camber and lying on points determined by the formula as described:

suction face or upper camber

$$X_s=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_s=\cos\theta[0.6366198(A-B)+B]-A[1-(0.6366198)(\theta)]$$

pressure face or lower camber

$$X_p=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_p=\cos\theta[0.6366198(A-B)-B]-(A-2B)[1-(0.6366198)(\theta)].$$

9. A foil having a profile in its fore-and-aft section, with a profile line, the points on which are determined with reference to a vertical and a horizontal axis according to the following formula substantially as described:

suction face or upper camber

$$X_s=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_s=\cos\theta[0.6366198(A-B)+B]-A[1-(0.6366198)(\theta)]$$

pressure face or lower camber

$$X_p=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_p=\cos\theta[0.6366198(A-B)-B]-(A-2B)[1-(0.6366198)(\theta)].$$

10. A foil having an upper profile line in its fore-and-aft section, the points whereof are determined by the following formula with reference to a vertical axis and a horizontal axis and in which the value of A of the formula is less or greater than 1, substantially as, and for the purpose, described:

$$X_s=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_s=\cos\theta[0.6366198(A-B)+B]-A[1-(0.6366198)(\theta)].$$

11. A foil having its upper profile in its fore-and-aft section conforming to the following formula substantially as described:

suction face or upper camber

$$X_s=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_s=\cos\theta[0.6366198(A-B)+B]-A[1-(0.6366198)(\theta)]$$

pressure face or lower camber

$$X_p=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_p=\cos\theta[0.6366198(A-B)-B]-(A-2B)[1-(0.6366198)(\theta)].$$

12. A foil having its lower profile in its fore-and-aft section conforming to the following formula:

suction face or upper camber

$$X_s=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_s=\cos\theta[0.6366198(A-B)+B]-A[1-(0.6366198)(\theta)]$$

pressure face or lower camber

$$X_p=\sin\theta[0.6366198(A-B)+B]+\tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Y_p=\cos\theta[0.6366198(A-B)-B]-(A-2B)[1-(0.6366198)(\theta)].$$

13. A foil having its profile line in its fore-and-aft section determined by the following formula in which the value B is 18% to 33% of the value of A in said formula substantially as described: suction face or upper camber

$$Xs = \sin\theta[0.6366198(A-B)+B] + \tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Ys = \cos\theta[0.6366198(A-B)+B] - A[1-(0.6366198)(\theta)]$$

pressure face or lower camber

$$Xp = \sin\theta[0.6366198(A-B)+B] + \tan\theta[\{1-(0.6366198)(\theta)\}(1-A)]$$

$$Yp = \cos\theta[0.6366198(A-B)-B] - (A-2B)[1-(0.6366198)(\theta)].$$

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