October 1975

B75-10256

NASA TECH BRIEF

Langley Research Center

Design Procedure for Low-Drag Subsonic Airfoils

A procedure has been developed for designing an airfoil for use at subsonic speeds. The airfoil has the least amount of drag under the given restrictions of:

Boundary-layer transition position

Lift coefficient

Thickness ratio

Reynolds number based on the airfoil chord.

Low-drag subsonic airfoils are not only suitable for use as wing and propeller aircraft sections operating at subsonic speeds but also for hydrofoil sections for boats and blades for fans, compressors, turbines, and windmills.

The low-drag subsonic airfoil design procedure consists of four steps:

1. Development of a Formula To Calculate Airfoil Drag — The formula to determine this is derived from Betz' formula for the calculation of airfoil drag from surveys of the wake behind the wing. By suitable assumptions, such as static pressure being constant through the boundary layer and velocity in inviscid flow being constant across the boundary layer, Betz' formula can be expressed in terms of the boundary-layer momentum thickness Θ and shape factor H so that:

$$C_d = \frac{2\Theta}{c}\left\{\left(\frac{u_d}{u_\infty}\right)^2 + H\left[\left(\frac{u_d}{u_\infty}\right)^2 - \left(\frac{u_d}{u_\infty}\right)\right]\right\}$$

where C_d = drag coefficient of the airfoil,

Θ = momentum thickness of the boundary layer at the trailing edge,

c = chord of the airfoil,

u_d = velocity at the edge of the boundary layer at the trailing edge of the airfoil,

u_∞ = velocity in the free stream,

H = δ^*/Θ = shape factor of the boundary layer at the trailing edge, and

δ^* = displacement thickness of the boundary layer at the trailing edge.

2. Calculation of Optimum Pressure Distribution — Using the formula for drag coefficient and a suitable boundary-layer computation method, the drag of the airfoil can be calculated if the Reynolds number is known. Also, the lift coefficient on one side of the airfoil can be closely estimated if the pressure distribution on that side is known. Not every pressure distribution can be calculated, but a computer program has been developed which explores a great many in a small amount of time. The printout permits quick determination of the range of the constants which lead to lower drags and exploration of these areas in greater detail.

3. Calculation of Airfoil Shape To Conform to Optimum Pressure Distribution — After the optimum pressure distribution is obtained for a given lift coefficient, this pressure distribution is used in another computer program which develops the geometry of the airfoil. This program calculates the pressure distribution on the surface of a certain airfoil at a given angle of attack and systematically modifies the airfoil geometry until the desired pressure distribution is obtained. The input to the program is an initial geometry, the direction of the free stream, and the specified pressure distribution.

4. Calculation of Airfoil Performance in Viscous Flow — When the airfoil configuration is obtained from the design program, use is made of a two-dimensional viscous-flow computer program to examine the performance of the airfoil in different modes of operation. Computed results for an airfoil optimized for minimum drag at a lift coefficient of 0.9 reveal that, at the climb lift coefficient, the drag is less than for conventional airfoils currently in use on many popular general-aviation aircraft.

This design procedure will provide different airfoil configurations which generate the same optimum pressure distribution, because the optimum pressure

(continued overleaf)

distribution exists only on the upper surface of the airfoil and no pressure distribution is specified on the lower surface during the iterative procedure. Different thickness distributions and/or maximum thickness/chord ratio may be incorporated in the initial geometry. Based on this nonuniqueness, a series of airfoils may be developed which will have a wide range of applications. To broaden the spectra even further, the optimization program may be applied to pressure distributions which result in different lift coefficients. This will lead to families of airfoils which have the minimum amount of drag for various lift coefficients.

Note:

Requests for further information may be directed to:

Technology Utilization Officer
Langley Research Center
Mail Stop 139-A
Hampton, Virginia 23665
Reference: B75-10256

Patent status:

NASA has decided not to apply for a patent.

Source: John B. Peterson, Jr.
Langley Research Center and
Allen W. Chen of
National Research Council
(LAR-11351)

Categories: 03 (Physical Sciences)
06 (Mechanics)
09 (Mathematics and Information Sciences)