Airfoil Optimization

Per Krantz* and Sven G. Hedman†
The Aeronautical Research Institute of Sweden (FFA), Bromma, Sweden

Abstract

TWO new features have been added to a computer program system used for the optimization of airfoils. The system includes an approximate method for optimization, an aerodynamic code for subsonic and transonic viscous flow, and a geometry package for description of the airfoil. The additions have been made to increase the practical use for airfoil optimization. To avoid oscillations in the interpolation of the geometry, the ordinary cubic spline functions have been replaced by taut cubic splines, and because airfoil design requires the consideration of characteristics under nondesign conditions, the possibility of implying constraints at off-design has been included.

Contents

Because there now exist efficient methods for accurate analysis of high-speed flows, even those containing shock waves, and because the design of airfoils requires the consideration of the effects of a large number of geometric variables, it becomes natural to automate the process of generating airfoils with improved characteristics.

The program system contains

1) COPES, an approximate optimization program with a fast convergence characteristic (Ref. 1).

2) DOFOIL, an aerodynamics module for calculation of exterior potential flow and boundary-layer characteristics (Ref. 2).

3) GEOM4, a geometry package that interpolates and defines the airfoil contour, now by means of taut cubic splines (original system described in Ref. 3).

The optimization process is performed in a design space of n variables ($x1 \dots xn$), defining the vertical coordinates in a specified modification region, for example, the leading-edge region of the airfoil. For each optimization cycle a new airfoil geometry is defined in two steps:

1) A cubic spline fit is generated through all the airfoil points, both fixed and changeable points.

2) From the spline functions, ordinates for the aerodynamic calculations are evaluated at the nodal stations of the region to be modified.

As cubic splines often tend to model extraneous inflection points in regions of modifications, especially if the curvature is large, the alternative of using taut cubic splines has been added to the program. The cubic spline has additional knots placed so that the interpolant can make sharp bends, where required, without breaking out into oscillations as a consequence. The taut cubic spline is a good alternative to the less practical, from the computational point of view, exponential spline functions.

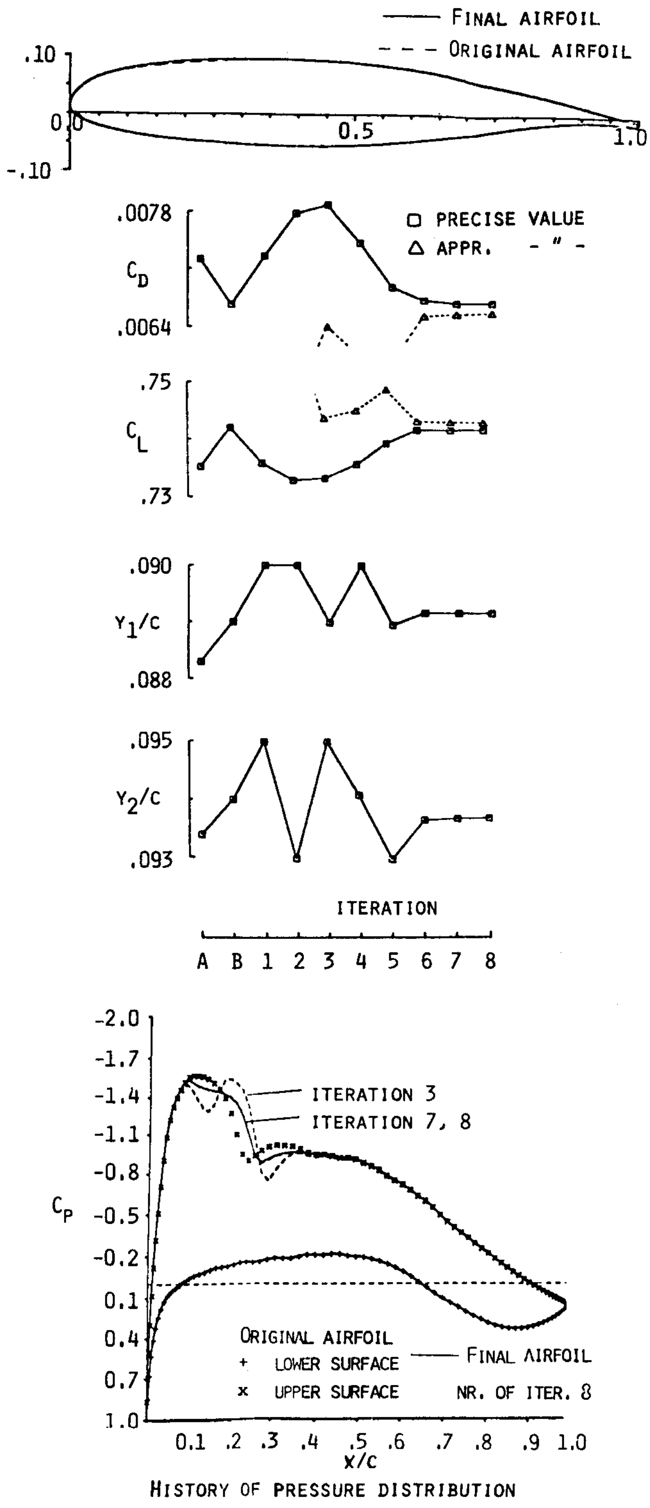

Fig. 1 Example 1—total drag minimization, $M = 0.65$, $Re = 13.0 \times 10^6$, $\alpha = 0$ deg (A and B are starting designs).

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*Aerodynamisist; currently at Ericsson Radio Systems.
†Head, Theoretical Aerodynamics Section.

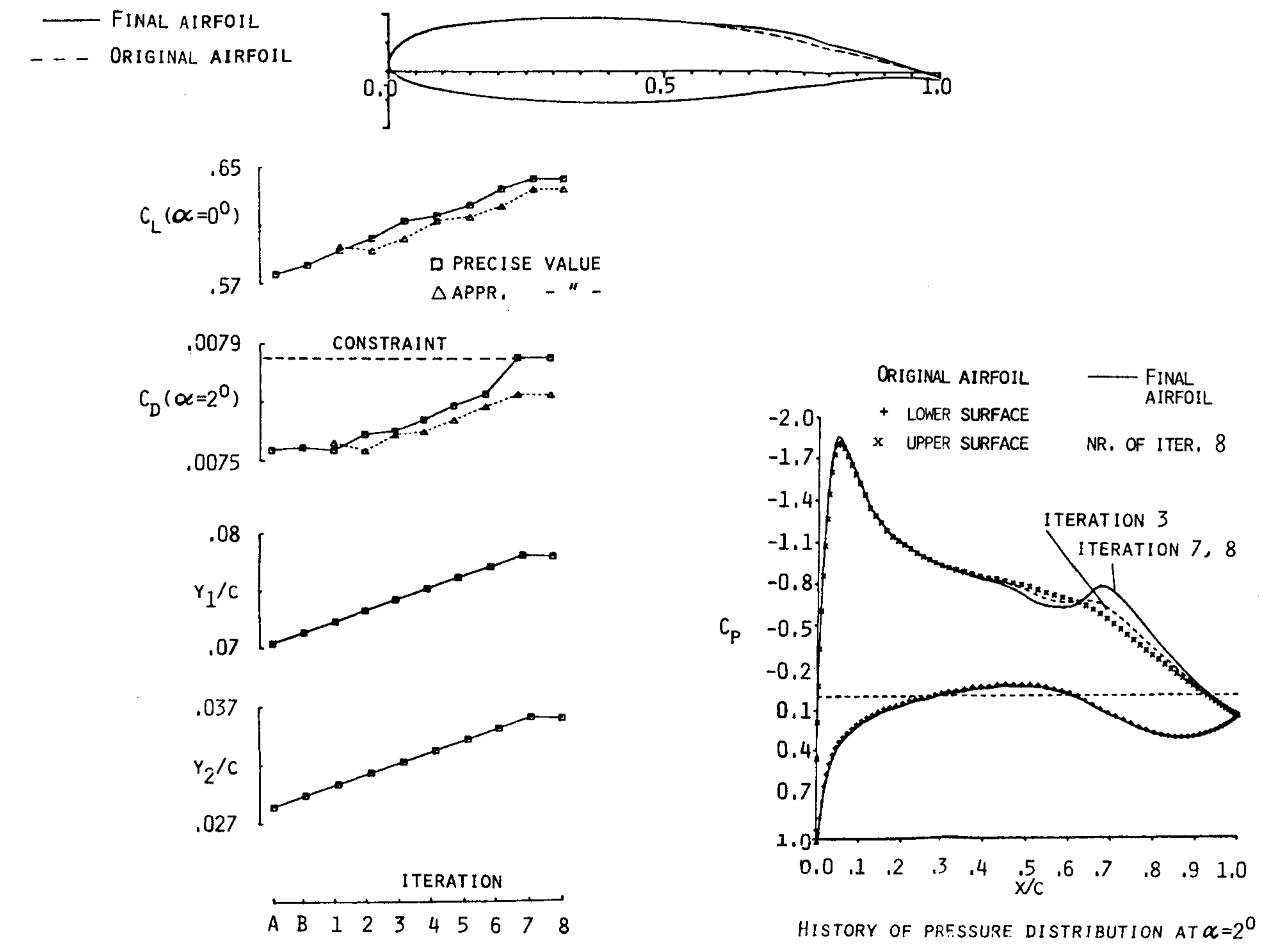

Fig. 2 Example 2—lift maximization, $M = 0.41$, $Re = 13.0 \times 10^6$, $\alpha = 0$ deg (A and B are starting designs).

For illustration purposes, two optimizations performed on a rear-loaded MS profile will be shown.

Example 1—Total drag minimization:

$$(C_\ell \geq 0.72)\, M = 0.65,\ \alpha = 0\ \text{deg},\ Re = 13 \times 10^6$$

Only two design variables, the ordinates at 17.5 and 25% of the chord, were used. Because of the rather high curvature, the degree of tension of the taut spline fit is quite high.

Figure 1 shows the optimization history and the outcome of optimizing the transonic region of the profile. The results were satisfactory. In this case the constraint on the lift coefficient was unnecessary. The relatively small changes in the design variables increase the lift and decrease the total drag.

Example 2—Lift maximization:

$$M = 0.41,\ \alpha = 0\ \text{deg},\ Re = 13 \times 10^6$$

This example shows the possibilities of optimization with constraints at off-design, e.g., another flight condition, such as a new Mach number or angle of attack. Here the lift coefficient is maximized at $\alpha = 0$ deg, while the drag, evaluated according to Squire and Young, is limited to .0078 at 2 deg angle of attack. The lift is increasing (~12%) with increasing drag (~6%) until the limit of drag is reached at 7 iterations (Fig. 2). The bump in the pressure distribution indicates that the design may not be satisfactory at higher angles of attack (early separation).

An optimization, like these examples, requires a computer time of approximately 30 CPU min on a VAX 11/780 computer. The examples indicate that the program system works. However, under certain circumstances the optimized design may show undesirable characteristics. The user needs considerable experience in order to pose the constraints so that the obtained results are of practical value. There are also the risks that the solution may reach a local minimum and that the procedure may be unable to find the global minimum. The accuracy requirements of the aerodynamic code are very high.

References

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