Navier- Stokes Optimization Using Genetic Algorithm and a Flexible Parametric Airfoil Method

Ava Shahrokhi*, Alireza Jahangirian, Nematolah Fouladi
Aerospace Engineering Department, Amirkabir University of Technology
PO. Box 15875-4413, Tehran, IRAN
Email: ajahan@cic.aut.ac.ir

Key Words: Aerodynamic Shape optimization, Genetic Algorithm

ABSTRACT

Aerodynamic shape optimization problem is typically a difficult problem to solve. Aerodynamic objective functions are often multimodal and rough. In traditional deterministic gradient-based methods, the design is updated iteratively in the direction of the steepest descent from the initial design guess. However these methods only search one part of the design space which is suspected to converge to local optimum. On the other hand, because of non-linear behavior of the flow equations especially in the presence of viscous effects, CFD methods for solving these equations are very time consuming. These all confirm the necessity of using a robust tool in aerodynamic optimization field. Among different methods for optimization, genetic algorithms (GA) are known to be the best way for such problems. One of the key features of GAs is that they search from a population of points and not from one special point resulting in a global optimized point. Another advantage of using GA is that it only uses the objective function not its derivatives. Such features cause GA to be a robust and attractive method for aerodynamic shape optimization.

Aircraft wings are the main subject for optimization efforts in aerodynamic design field. Airfoils are the basic element of the wing geometry. They determine a large share of wing flow phenomena although they are two dimensional section of the wing.

In the present study, genetic algorithm is coupled with a Navier-Stokes flow solver to optimize an airfoil in transonic speed. To obtain a good transonic airfoil shape such as supercritical airfoils, airfoil definition with a large degree of freedom is necessary [1]. One of the most usual methods for airfoil representation is PARSEC method, which has been used widely in airfoil design optimization [2]. A remarkable point of this technique is that it has been developed aiming to control important aerodynamic features effectively by selecting the finite number of design parameters. However, this method lacks of the geometry flexibility especially does to the trailing edge where important viscous effects come from.

PRESENT APPROACH

In the present investigation, airfoil shapes are represented by a flexible method which is a combination of PARSEC and a method for trailing edge modeling. The method for trailing edge modeling was proposed by Sobieczky [2] which is mainly based on viscous flow control near the trailing edge that may extremely influence aerodynamic efficiency. The practical consequence of using this method for optimizing usual airfoils is a convex upper surface contour shaping with curvature increasing toward the TE and a more smoothly curvature distribution on the concave lower surface of the airfoil. This results in having more freedom to decrease the thickness a few percent upstream of the TE. Increasing curvature quite close to the trailing edge can create a favorable pressure gradient in this area that compensates the probable decrease in lift mainly due to decreased camber on the upper surface. Therefore, as will be shown an optimum shape can be obtained by the present method for viscous flow application with the PARSEC method.
To decrease the huge computational time required for viscous flow solver, a new implicit method is used to solve the flow field over the unstructured grid [3]. One of the most important advantages of using this method is reducing the computational time due to simultaneous use of convergence acceleration tools of explicit methods, in addition the primary mesh generated around initial airfoil are moved to be fitted to the new generated airfoils using spring analogy and then flow properties of the primary airfoil are considered as initial guess for new computation. These techniques, also, help decreasing the computational time to a reasonable amount.

RESULTS

Using the combined method which was mentioned above, 12 airfoil shape parameters for each member are introduced to Genetic Algorithm and changed until the optimum parameters are obtained. Each generation has 20 members and the best member of each generation is directly copied to the next generation as one of its members. Objective function is considered as $C_l/C_d$ which is computed using Navier-Stokes equations at transonic Mach number of 0.73 and fully turbulent flow of Re=6.5 million. The incidence angle is considered as 2.0 degrees. The thickness of the airfoil is limited between 0.122 and 0.100 to avoid impractical results.

Considering RAE-2822 airfoil as initial airfoil, optimum airfoil obtained by new combined method is compared with PARSEC method. Initial RAE-2822, and both designed airfoils are shown in figure (1). This figure proves the above idea about the flexibility of airfoils obtained from Sobieczky method in changing the curvature of the ending part of airfoil. Pressure coefficient distributions for designed and initial airfoils are plotted in figure (2). According to the figure, there is a considerable strong shock wave on the upper surface of the initial airfoil. However, this shock is nearly damped after optimization with both methods. As expected, moving toward the ending part of airfoil, the curvature is increased in both upper and lower surfaces by the new method in comparison with the PARSEC. Figure (2) proves this idea by showing that how $C_p$ from Sobieczky method distributes better than PARSEC method at the ending part of airfoil. On the other hand, when using PARSEC method, the optimization process tends mainly to increase $C_l$ rather than change both $C_l$ and $C_d$, so we had to apply additional constrain to limit increasing $C_l$ to force the optimization process to eliminate the shock by decreasing $C_d$. Otherwise we had to change the objective function [4]. The additional constrain also causes extra computations of objective function that increases the total time of optimization but using the combined method, we can eliminate such difficulties.
Mach contours for initial and two optimum airfoils are shown in figures (3) to (5). These figures show the occurrence and weakening of the shock on the initial and design airfoils respectively. Convergence rate of the maximum objective function is shown in figure (6). According to this figure the new method can obtain highest objective function compared with PARSEC method.

Initial value of the objective function and its final values from two methods are illustrated in table (1).

<table>
<thead>
<tr>
<th>Airfoil</th>
<th>$C_l$</th>
<th>$C_d$</th>
<th>$C_l/C_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAE-2822</td>
<td>0.642</td>
<td>0.01340</td>
<td>47.90</td>
</tr>
<tr>
<td>Design (PARSEC)</td>
<td>0.663</td>
<td>0.01121</td>
<td>59.09</td>
</tr>
<tr>
<td>Design (Combined)</td>
<td>0.694</td>
<td>0.01093</td>
<td>61.13</td>
</tr>
</tbody>
</table>

According to the obtained results, objective function using the PARSEC method is increased about 23.36 percent; however the increase in objective function from combined method is about 27.62 percent.
REFERENCES


