Workflow- Based Shape Optimization of Airfoils and Blades using Chained Bezier Curves

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Summary

This paper gives a new method for 2D and 3D shape optimization as a function of prescribed criteria with reference to cost function. Such optimization techniques can be used for generating new and optimization of existent shapes and geometries. The introduced optimization tool is developed in general terms and can with slight modifications be used for shape recognition and damage identification. The procedure allows significant design freedom in creating shapes at the cost of numerical intensity.

Keywords

Shape optimization, Workflow, Bezier curve, Airfoils

Introduction, Shape optimization in modeFRONTIER tools

The correct definition of shape variables is of utmost importance in the layout of an optimization problem. As the variables are in charge of changing geometry, it is necessary to filter out all the satisfactory geometric shapes and to find the best solution amongst those. The trend nowadays is towards reverse engineering, where the technical design of a product is a consequence of required functions and constraints.

So, we are trying to determine the shape variables which give the most acceptable solution, depending on the requested accuracy. In evolutionary optimization, the initial shape in optimization is absolutely random, and the subsequent change is partially random. Therefore the shape to be subjected to analysis is not known in advance, since it is generated based on required functionality, verified and optimized using technical criteria. The number of optimization variables for shape definition must be small due to limited computer resources and CPU time. Using adequate parameterizations, we describe the geometry with a reduced number of variables. This paper develops a 2D parameterization using chained piecewise Bezier curves. Chained Bezier curves with low numbers of control points are capable of describing complicates geometric shapes, but we have to ensure continuity at joints.

The Bezier curve in polynomial form is given as:

$$P(u) = \sum_{j=0}^{n} B_{i,n}(u) \cdot P_i = \sum_{j=0}^{n} \binom{n}{i} \cdot u^i \cdot (1-n)^{n-1} \cdot P_i = \sum_{j=0}^{n} \frac{n!}{i! \cdot (n-i)!} \cdot u^i \cdot (1-n)^{n-1} \cdot P_i ,$$

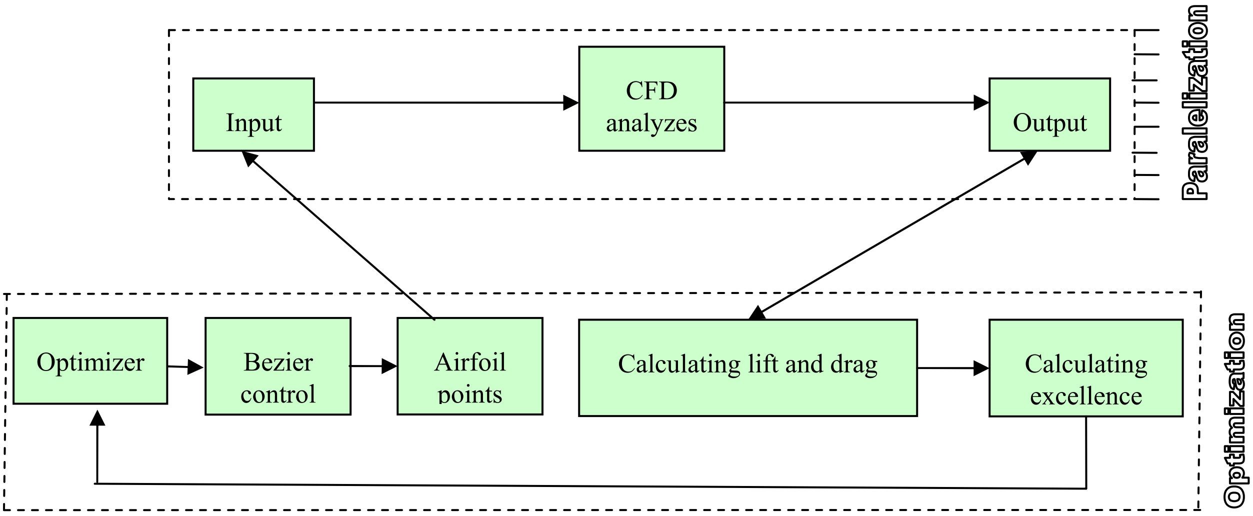
where:

n – degree of Bezier curves,

i – takes values 0 to n

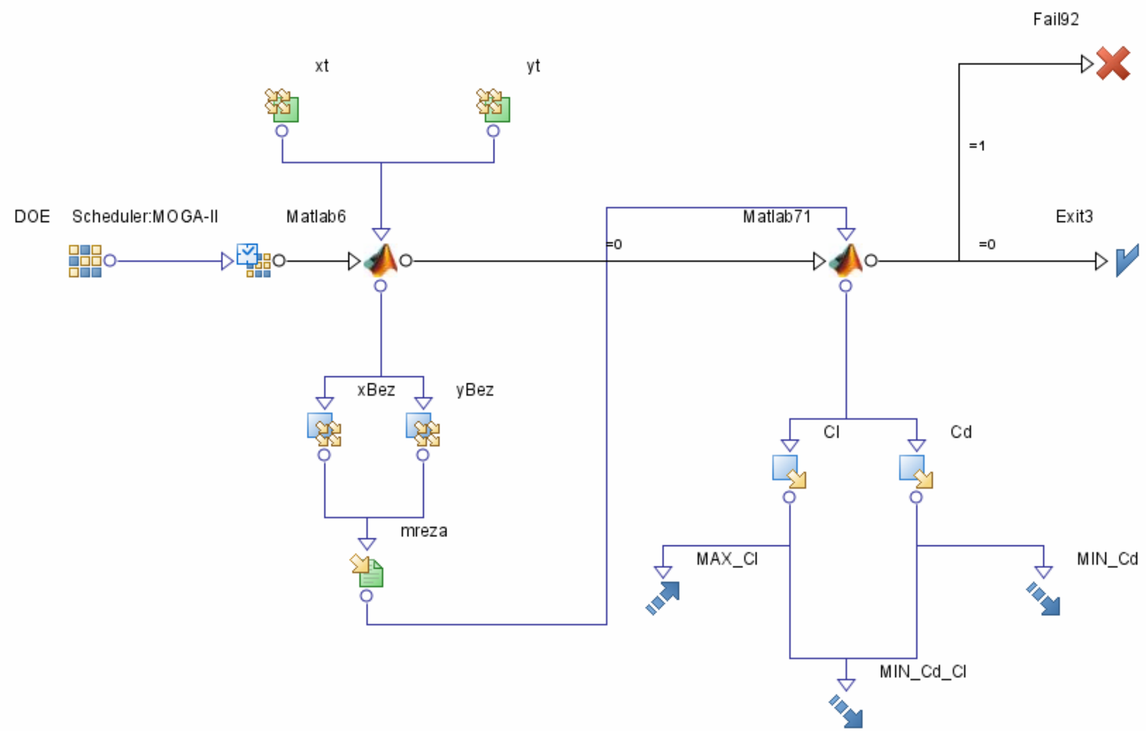
u –parameter for approximation points from P_1 to P_4 with random division.

In this paper the airfoil for wind turbine blades is studied as a test case. The aim is finding the respective optimal shape. Picture 1.1 shows a process diagram for the corresponding shape optimization.



Picture 1.1. *Block diagram of geometry optimization plan using chained piecewise Bezier curves with ADINA tool.*

To perform such an optimization process, several applications are required. The optimizer, modeFRONTIER, varies the shape variables and send the current shape to ADINA (CFD) that calculates load on 2D airfoil. Then the results from ADINA are read by another in-house developed program from the respective output file, which then calculates drag and lift coefficients. These drag and lift coefficients represent elements for the criterion of the airfoil's excellence. As ADINA is a non-standard application for modeFRONTIER, it was needed to develop an own application to execute and control ADINA. The applications used in this optimization workflow process are: modeFRONTIER, MATLAB, Visual Basic, Visual C and ADINA-F. Picture 1.2. presents a block diagram of the airfoil shape optimization workflow for wind turbine airfoil shape optimum design within the modeFRONTIER environment.



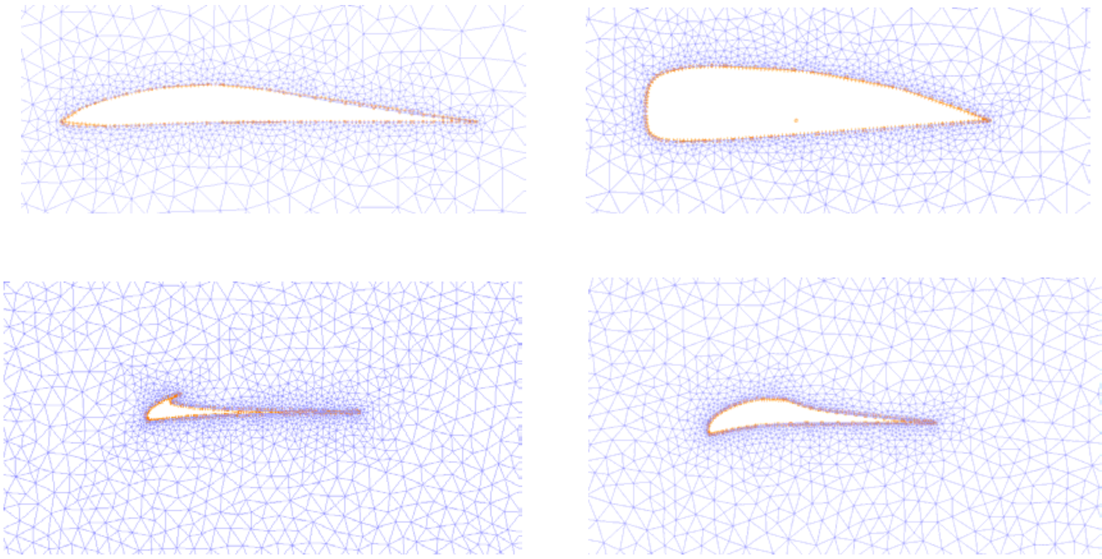
Picture 1.2. *Diagram of airfoil shape optimization process in modeFRONTIER.*

The process starts from a randomly generated population of 2D airfoils. The shape variables are data arrays that define airfoil geometries. The array size depends on the required precision of geometry representation and complexity of shape. Six points are typically sufficient to define a 2D geometry, but in order to allow for more freedom in shaping the geometry it is defined with 10 Bezier control points. Constraints are imposed to limit the scope of the shape variables. A small script is written in MATLAB that generates the contour points along the airfoil which is given by the respective shape variables (control points) data array. The required continuity between chained piecewise Bezier curves is imposed numerically. The aerofoil shape points are essential for aerodynamic analysis and resulting force calculations on the aerofoil. The flow simulation and optimization are linked with data mining in modeFRONTIER. The data mining provides for the exchange of data during the process of changing the geometry in shape optimization. The flow simulation (finite elements) provides the elementary forces acting on the aerofoil. These forces are the basis for the calculation of lift and drag coefficients using MATLAB scripts.

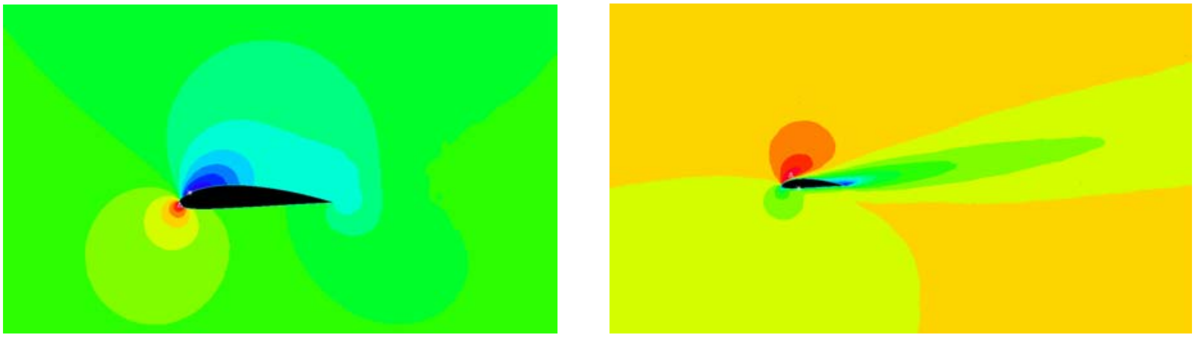
The flow is simulated using ADINA. The data mining process is used to transfer the geometric data between the optimizer and ADINA. ADINA is started from MATLAB using an in-house script written in Visual Basic. The script includes system commands such as “shell”, “sendkey”, etc, that allow it to communicate with other applications within Windows. Also, it was necessary to set delays (waiting times) between such system operations, allowing them to be completed before subsequent system calls are launched. This is necessary because of problems that otherwise appear using ADINA in batch mode. Two typical cases appear during the course of the process: ADINA provides a good solution, and ADINA does not provide a proper solution or breaks. The second case is caused by improper (invalid) geometry generated by the optimizer. Which of the cases has occurred is detected by verifying the ADINA output file existence and completeness. In the second case, the corresponding candidate shape is dismissed since ADINA could not produce a complete analysis output file. The existence and completeness of the output file is checked by a separate routine.

The optimization method used in this paper is the genetic algorithm, convenient for this multi-objective design problem. The optimization method is set within the modeFRONTIER tool including all the parameters such as the number of generations, parameters of cross-over, selection (the best units for clone), mutation, etc.

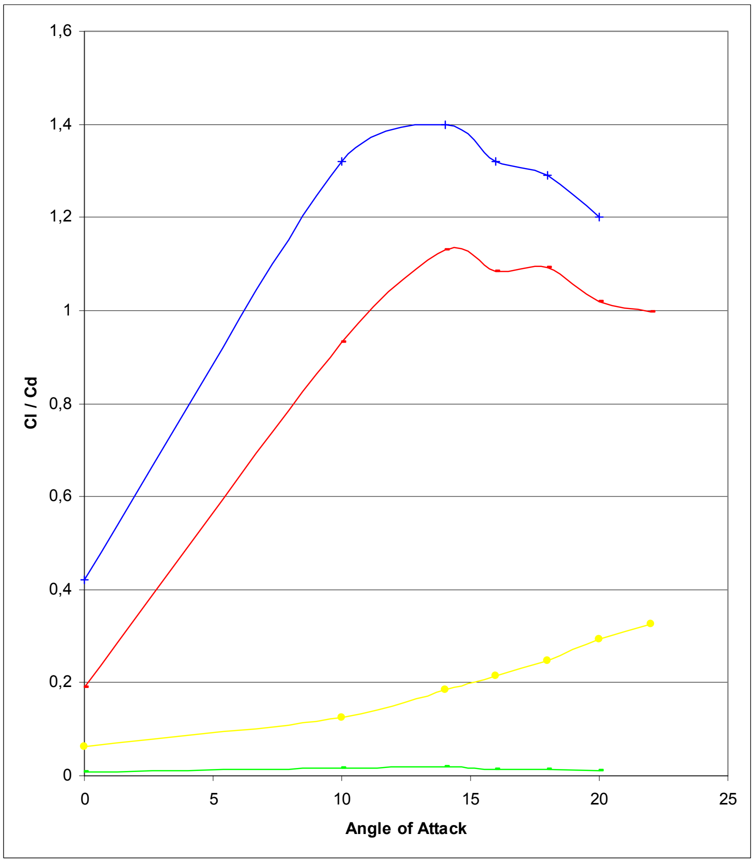
The following pictures illustrate the optimization progress:



Picture 1.3. *Airfoils in optimization progress.*



Picture 1.4. *Pressure and velocity distributions around airfoils.*



Picture 1.4 *Lift and drag coefficient for NACA 4415 airfoil in wind tunnel (Abbo – blue Cl and green Cd curve) and ADINA simulation (red Cl and yellow Cd curve)*

Conclusions

This paper presents an approach of generating object geometries by optimization of shape variables, applicable to 2D and 3D cases. Piecewise curves are employed and continuity at joints is ensured by adding extra points. This approach is applied to airfoils for wind turbine blades. Corresponding CFD simulation results and experimental wind tunnel values generally agree in shape, but the respective lift and drag coefficients differ somewhat. The difference in values can be attributed to the complexity of numerical flow simulations and corresponding assumptions as well as the fact that limited computer resources and CPU time are available for the finite element model. On the other hand, experimental graphs are also obtained by experiments where the conditions can not be controlled fully. Anyway, the degree of agreement and the evolution of shape from the random initial to the NACA- similar final shapes make the shape optimization process as proposed here successful.

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