Aerospace Science and Technology 55 (2016) 449–457

Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Automatic modelling of airfoil data points

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ARTICLE INFO

Article history:
Received 23 February 2016
Received in revised form 14 June 2016
Accepted 21 June 2016
Available online 27 June 2016

Keywords:
Airfoils
B-splines
Parametric design
Least squared fitting

ABSTRACT

This paper presents a computer-based technique to construct B-spline parametric models from a large set of airfoil data points, with a reduced number of parameters involved in the geometric representation of the airfoil profile. The proposed method uses different techniques related with the B-spline properties adapted to the geometry of an airfoil (a thin section with great changes of curvature) and produces a B-spline curve that is close to the data points maintaining a maximum tolerance distance. This curve can be used for calculations and is expected to provide a good framework for aerodynamic or hydrodynamic optimization, based on its reduced number of geometric parameters and on its calculation time, when compared with other methodologies. The method stresses the fitting of the airfoil's leading edge, which has a significant impact on the properties of the airfoil. B-spline curves and surfaces are used in this method because they are widely used in CAD-CAM software products and can be easily exported to other programs.

1. Introduction

Geometric representation and parameterization are crucial when dealing with optimization methods. A wrong parameterization, with a large number of parameters, will produce unpractical solutions due to the computational time dedicated in optimization methodologies. As a result, robust and efficient parameterizations are required. In this paper, B-spline curves are used for the geometrical representation of airfoil shapes, because they are widely used in CAD-CAM software products and can be easily exported to other programs.

But the main reason to work with a B-spline curves definition is that they can be used to reduce the number of design parameters as much as possible, while maintaining enough freedom and flexibility to represent a large number of airfoil data points due to their mathematical properties: considering how these curves are defined (see the Appendix for more details), notice that all the equation systems that are used in this paper are linear ones, Eqs. (2), (8), (9), (10), and this has the advantage that they no dot need an initial guess for the control points position. Rational curves such as NURBS need the use of numerical weights that multiply the control points. If these kind of curves are used, non-linear sets of equations have to be solved because the position of the control points is not known at the beginning.

Non-linear techniques would need initial guess and will require more computational time than linear ones. B-spline curves are also used by all CAD software products. These are the main reasons why B-spline curves are used.

The objective of this paper is to produce a B-spline approximating curve, which fits a large number of airfoil data points, see Fig. 1(a), under a given tolerance with a reduced number of control points. As seen on this figure, the B-spline does not contain the data points, but is close enough below the tolerance crossing all the circles. In the case of Fig. 1, the radius of the circles or tolerance is 0.001 m for an MH43 airfoil of chord one.

This curve will reproduce well the curvature field of the airfoil, when compared with interpolating methods, see Fig. 2, while maintaining the geometric characteristics of the original data points. Several authors demonstrated that curvature is a principal factor in determining the quality of a geometrical representation, [1,2] and this indicator has been used traditionally in CAD methodologies.

As mentioned, this is a method that reduces the design parameters involved in the geometric representation of a 2D airfoil and simplify further optimization procedures, or even 3D surfaces constructed using the 2D curves to create wings, keels or foils. The final B-spline curve can be used as an initial guest for an aerodynamic or hydrodynamic optimization procedure, since it will adequately reproduce the original data points (hundreds) with about 7 to 12 control points as in Fig. 1(b). These control points can be used as design variables of the optimization process where the objective function could be the minimization of the difference be-

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http://dx.doi.org/10.1016/j.ast.2016.06.016

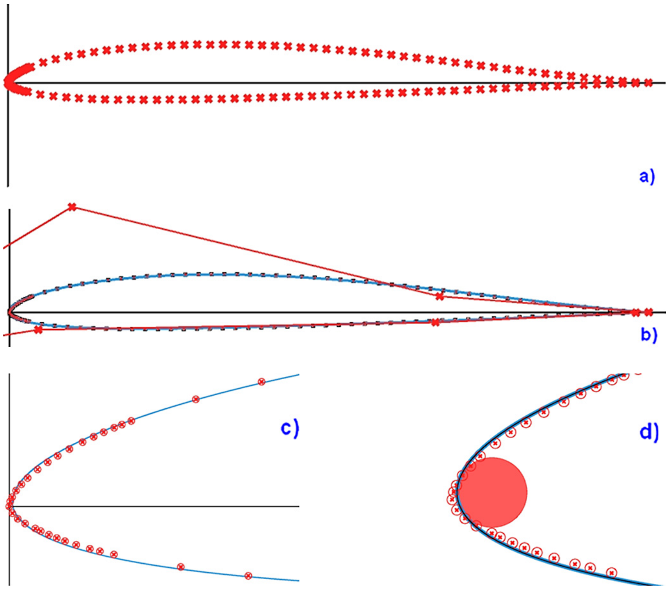

Fig. 1. Example of the method: airfoil data points, B-spline fitting and leading edge details.

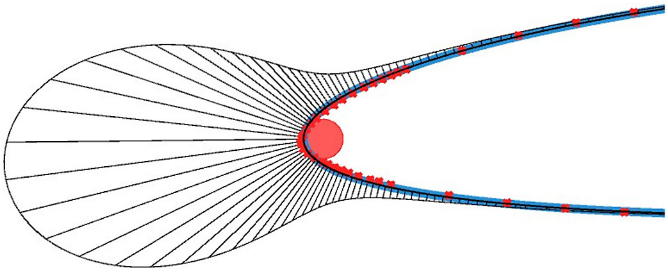

Fig. 2. Curvature field of the example at the leading edge, 5th degree.

tween the airfoil pressure distribution and a prescribed pressure distribution, or a different target, [3,4]. It is not the goal of this paper to create an optimised design from a performance point of view, but to enable the parametric definition of an airfoil with the use of a B-spline curve.

Modelling the geometry of an airfoil is different from modelling other industrial objects; for example, an accurate representation of the shape of the airfoils is required, and this needs working with a large amount of information. A discrete set of data points, usually more than 100 points per airfoil is employed. If standard techniques are used, e.g. interpolation of the data points, very complex surfaces with a large number of control points are obtained and will likely present poor smoothness in the resulting surface computed from an interpolation of the data sets. In the case of an interpolating B-spline, the number of control points would be equal to the number of data points (see Eq. (2), considering $N = np$), so the same number of variables as the number of data points are needed to obtain the airfoil representation, and this means usually more than 100 variables. Another disadvantage is the aspect of the curvature graph that interpolating curves of large number of data points present: the curvature graph will oscillate, specially near the leading edge.

As an example, Fig. 3 shows the curvature field of the same MH43 profile of Fig. 2, using interpolating B-spline curves of different degree. The curvature field of the proposed method is more uniform and faired.

A constraint of the present problem is that the leading edge of the airfoil must be accurately reproduced by the curve because most of the aerodynamic characteristics are induced by this region.

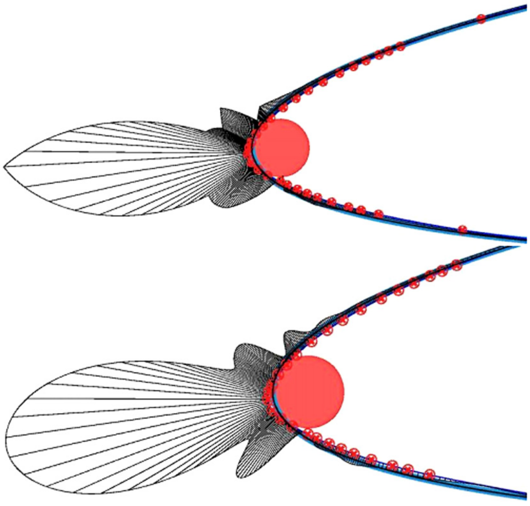

Fig. 3. Curvature field of the example, interpolating curves of the 3rd and 5th degrees.

According [17], pressures in the subsonic flow around an airfoil are governed by surface curvature, so in this case it will be important to reproduce well the curvature especially at the leading edge.

This part of the surface presents high curvature values when compared with the rest of the shape of the blades. If for example a rudder is modelled with an inadequate definition of the leading edge of the sections that make up its body, additional drag to the one that has been predicted will be present in the final design.

An iterative least squares (ILS) fitting process [5] with an original selection of the parameterisation based on the Haussdorf metric (the minimum of the maximum Euclidean distances) is described in Section 3 and also considers accurate modelling of the leading edge, see Fig. 1(c) and (d).

The proposed method allows a reduction in the number of control points of the curve without reducing accuracy. The main reason for this reduction is the use of a non-uniform knot vector, as will be explained in Section 4 of the paper, with the knots located near the leading edge. This way, the control points are automatically located near this high curvature area, so this part of the airfoil will be well reproduced under a tolerance. Another key factor is the iterative parameterization as will be described in Section 3. Validation is produced in Section 7, where the presented method is compared with different ones available at the literature, showing a reduction in the number of control points for airfoils with equivalent tolerance.

Data reduction in an object representation speeds up most of the downstream processes, improves the fairing of the resulting surface and decreases storage requirements in following design stages.

Regarding related work about the modelling of airfoils, most of the references are based on interpolation of certain points amongst the large set of data points, trying to reduce the number of parameters. Reference [6] proposed a NURBS method that interpolates the data points instead of approximating them. They modified the data points to produce more points in the leading edge, whereas the presented method does not alter the data points. The same authors in [7] produced a new NURBS method based on interpolation resulting in 26 control points. Both references are related with aerodynamic optimization of wings.

An interesting reference is [8], which focused on aerodynamic airfoil optimisation and used B-spline curves for its definition, obtaining curves for different cases with an error of about 0.002 and 14 control points, when applied to airfoils of chord one. The examples in that paper are compared with real airfoil shapes in