Parameterization Formulations for Aerofoil Shape Optimization

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ABSTRACT: The wing aerofoil of a medium/high aspect ratio wing (>6) is the major single contributor to the overall aerodynamic performance of a winged aircraft and therefore its careful design is paramount. The mathematical formulation used to define the aerofoil's shape must be sufficiently flexible to represent the maximum shapes possible within the design space and to allow the best performance to be captured during the design process. For design optimization purposes, the efficiency of a parameterization approach is essential. As such, a geometry model with few parameters and a good ability to represent a wide variety of airfoils is desired. In this paper, a comparison between several parameterization techniques currently in use is presented. The parameterization approaches discussed include: the B-Spline, a fifth order polynomial, the Kulfan-Bussoletti and the Bezier-PARSEC. The comparison is based on the number of parameters used in each formulation and its accuracy in representing a few known low Reynolds number airfoils of several classes, both cambered and uncambered.

1 INTRODUCTION

The process of optimization of aerofoils is of the utmost importance in wing design. Sustained by the exponential increase in computational power of the last decades, more and more complex optimization algorithms have been developed based on increasingly accurate aerodynamic simulation tools. This increase in complexity translates into very high computation effort and, conversely, very high computation time, despite the advances mentioned earlier. To mitigate this issue, several strategies are used, the most obvious being the use of an aerodynamic simulator of lower accuracy, as the flow solver is responsible for most of the computational effort. The problem here is, depending on the applications, a loss in fidelity. Another strategy is to modify the optimization algorithm to minimize the number of aerodynamic simulations needed. A great example is provided by Rogalsky (2004) where an acceleration factor of three was achieved with an algorithm enhancement, by hybridizing a differential evolution algorithm with the downhill simplex method. In the same work, Rogalsky also accelerated the convergence by changing the parameterization of the aerofoil. This was achieved by representing an aerofoil by twelve PARSEC parameters that in turn form four Bezier curves (Derksen & Rogalsky 2010). The good results of this parameterization are related with the aerodynamic significance of the PARSEC parameters, which permit a better control of the aerodynamic characteristics of the aerofoil. Another way of improving the aerofoil parameterization is to minimize the number of design variables, while maintaining a wide design space. The Daniel Nelson polynomial (Nelson 2009) achieves a very low parameter number, with only 6 parameters in total. The Kulfan-Bussoletti Parameterization (KBP) uses a modified form of the Bernstein polynomial to parameterize the aerofoil (Kulfan & Bussoletti 2006). The greatest advantage of the KBP is scalability. While there is a class of aerofoils that need only three or five parameters for an accurate representation, the number of parameters can be increased as needed to account for a wide variety of aerofoils, resulting in a wider design space.

In this paper, a comparison of representation efficiency, measured by the normalized square difference between a given aerofoil and its parametric representation and accounting for the number of parameters, is made between the traditional B-Spline representation, the Daniel Nelson Polynomial (DNP), the KBP and the Bezier-PARSEC Parameterization (BPP). The goal is to achieve an acceptable representation of a given aerofoil with the least parameters possible. The method that can represent the most aerofoils accurately with the least parame-