Airfoil Topology Optimization using Teaching-Learning based Optimization

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ABSTRACT

This paper primarily deals with the optimization of airfoil topology using teaching-learning based optimization, a recently proposed heuristic technique, investigating performance in comparison to Genetic Algorithm and Particle Swarm Optimization. Airfoil parametrization and co-ordinate manipulations are accomplished using piecewise b-spline curves using thickness and camber for constraining the design space. The aimed objective of the exercise was easy computation, and incorporation of the scheme into the conceptual design phase of a low-reynolds number UAV for the SAE Aerodesign Competition. The 2D aerodynamic analyses and optimization routine are accomplished using the Xfoil code and MATLAB respectively. The effects of changing the number of design variables is presented. Also, the investigation shows better performance in the case of Teaching-Learning based optimization and Particle swarm optimization in comparison to Genetic Algorithm.

Keywords: *Genetic Algorithm, MATLAB, Non-Uniform Rational B-Splines, Particle Swarm Optimization, Teaching-Learning Based Optimization, XFOIL*

1. INTRODUCTION

Airfoil characteristics are of paramount importance in aircraft design as they directly influence the primary function of an aircraft. Airfoil design essentially consists of two methods namely the direct and the inverse method[1]. In the direct method, a baseline airfoil is used to obtain the pressure distribution and the geometry is manipulated to achieve desired results, whereas in inverse design the surface flow is prescribed for specific operational conditions and the shape imposing the target pressure distribution is solved for.

The primary motivation of this study was to achieve a higher edge in characteristics of a low Reynolds number airfoil for the SAE Aerodesign Competition. The competition involves

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fabrication of a UAV and achieving an efficient flight given a fixed engine power, and maximum weight constraints. A list of numerous high lift low Reynolds number airfoils are available for direct use. In order to improve performance, an existing airfoil needs to be tailored to suit the desired application. Optimization of airfoils is therefore required in conceptual design. With regard to airfoils, optimization in essentially achieved by manipulating the flow over it. The flow directly depends on the topology of the airfoil, which is required to be optimized for achieving desired performance. Since this study is aimed at optimizing an existing airfoil, the direct design method is employed to generate shapes and optimize desired parameters about the existing characteristics of the base airfoil in question.

Due to the highly non-intuitive nature of the discipline, it is rather important to parameterize the airfoil for studying the effects of changing the topology. Literature study (Song & Keane, 2004) reveals an exhaustive usage of point co-ordinates to fit airfoil shapes using B-splines (Song & Keane, 2004) and rather recently, NURBS (L'epine, Trépanier & Pépin, 2000). Intuitive parameterization was proposed by Sobieczky (1998), using 11 parameters e.g. leading edge radius etc. A recent work (Giammichele, Tr´epanier & Tribes, 2007) introduces the concept of multiresolution decomposition using b-spline interpolation to study the effects of number of constraints, increased global control at various decomposition levels, and associated advantages. It is clear that the process of parameterizing the airfoil has hitherto been essentially done using methods of interpolation. Since, there are no specific metrics specifying the best method, the effects of choosing any method are to be studied for choosing a suitable one. An inherent difficulty with free-form parameterization is the lack of intuitive control which affects generation of airfoil like shapes which leads to difficulty in aerodynamic analyses and optimization. Another disadvantage is the trade-off between number of points used for curve fitting, for accuracy, and the computational time. As a solution to the former, design space restrictions have been addressed using thickness and camber constraints at various locations as dictated by the user. As shown by Song & Keane (2004), the direct b-spline interpolation method is more accurate and simple but comes with a higher computational cost. Since, the time required to fit co-ordinates is incurred only to fit the base airfoil and not in the optimization routine, we chose the direct b-spline interpolation method.

Evolutionary processes have shown immense potential over recent decades for problems pertaining to aircraft design (Raymer, 2002).Specifically for airfoil design, Genetic algorithms and Particle Swarm Optimization have successfully yielded results (Wickramasinghe, Carrese & Li, 2010; Liu, Li & Zhou, 2006). Wickramasinghe, Carrese & Li, (2010) successfully optimized airfoils using a modified multi-objective Particle Swarm Optimization. Genetic Algorithms have been implemented by Liu, Li & Zhou (2006). However, these algorithms require tuning of either the algorithm or the problem itself for efficient computation. This led us to investigate for alternatives where such issues could be addressed. A rather recently proposed namely Teaching-Learning based optimization has proven to be efficient in terms of computational time and number of function evaluations required for convergence on application to mechanical design problems and benchmark test functions algorithm (Rao, Savsani & Vakharia, 2011). This promising potential instigated the application of this algorithm to the non-intuitive problem of airfoil optimization.

Though widely used GA and PSO have been used separately for airfoil topology optimization, there is no data on their comparative performance. It is thus useful to study their relative performance on the same problem, enabling scope for reduction in time cost or a better solution. The implementation of Teaching-Learning based optimization for a single objective airfoil design problem and a comparative study of its performance with implementations using GA and PSO techniques is novel to this paper.