Multi-objective Optimisation of Turbomachinery Blades Using Tabu Search

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Abstract. This paper describes the application of a new multi-objective integrated turbomachinery blade design optimisation system. The system combines an existing geometry parameterisation scheme, a well-established CFD package and a novel multi-objective variant of the Tabu Search optimisation algorithm. Two case studies, in which the flow characteristics most important to the overall performance of turbomachinery blades are optimised, are investigated. Results are presented and compared with a previous (single-objective) investigation of the problem.

1 Introduction

The optimisation of airfoil designs is a challenging, computationally expensive, highly constrained, non-linear problem. As with most real-world problems, there are multiple (usually conflicting) performance metrics that an engineer might seek to improve in optimising, for example, the design of turbomachinery blades, wings or other aerodynamic surfaces. This suggests a multi-objective approach, a notion that is reinforced by the recognition that any consideration of robustness – the retention of performance over a range of operating conditions, in the face of geometry changes (e.g. through creep) etc. – must also inevitably entail multiple objectives.

Despite this obvious motivation, multi-objective aerodynamic optimisation seems to have been somewhat overlooked. However, two recent studies in particular have embraced multi-objective optimisation and show the possible benefits compared to single-objective optimisation with a composite objective function.

Gaiddon *et al.* [9] perform multi-objective optimisation on a supersonic missile inlet. They compare a number of optimisation algorithms using both composite and multiple objective functions, and conclude that "performing real multi-objective optimization and finding a Pareto front is the only effective way to find a set of designs satisfying several performance criteria in an industrial context".

Nemec *et al.* [17] perform multi-objective optimisation on both a single and a multi-element 2-D aerofoil. Their integrated approach combines a Newton-

C. A. Coello Coello et al. (Eds.): EMO 2005, LNCS 3410, pp. 897–910, 2005.

Krylov adjoint CFD code, a b-splines-based parameterisation scheme and both a gradient-based optimiser and a Genetic Algorithm (GA). They obtain good results on some simple test problems.

The multi-objective integrated design system used in the present work has been developed and described by Kipouros *et al.* [16] building on the single-objective integrated design optimisation system (BOS3D) developed by Harvey [11] and described by Dawes *et al.* [6]. The system combines an existing, efficient and flexible geometry parameterisation scheme, a well-established CFD package and a novel multi-objective variant of the Tabu Search (TS) optimisation algorithm for continuous problems [13]. The system can readily be run on parallel computers, which can substantially reduce wall-clock run times – a significant benefit when tackling computationally demanding design problems.

In previous work [16] the performance of this system has been investigated considering a compressor blade design test case. The effectiveness of the multi-objective optimisation procedure was verified and the expected trade-offs between the chosen objectives confirmed. In the work presented in this paper we use our system to tackle more realistic turbomachinery design test cases, taking advantage of the greater computational power offered by exploiting its parallel processing capabilities.

2 Description of the Integrated System

Fig. 1 presents a flow diagram showing the stages of the process executed by our integrated multi-objective turbomachinery blade design optimisation system. The first stage is the parameterisation of the initial blade design, input through an initial CAD geometry together with boundary conditions for the flow solution. The geometry is parameterised using a Partial Differential Equation approach [3], giving a compact but flexible representation of the design, in a design vector comprising 26 variables. This design vector is the input to the main loop of the design system, which consists of the flow simulation and optimisation processes. On receipt of a new design vector, a computational mesh is automatically generated from the geometry specification, and then a detailed CFD analysis (blade to blade) is performed. The mesh is a 3D structured grid consisting of $21 \times 87 \times 23$ nodes in each direction. The flow simulation is performed by a CFD code solving the 3D Navier-Stokes equations, and this routine returns all the necessary metrics that describe the flow around the blade [5]. Based on this evaluation, the optimisation routine generates a new design vector that is meshed and evaluated, and this process continues until a stopping criterion is met.

At the end of the optimisation process, the best design vectors identified and their associated flow solutions are converted into a single file, in the final stage of representation. This stage is accomplished by using Non-Uniform Rational B-Splines (NURBS) [18]. The optimal geometries can then be examined in detail through, for instance, contour plots.