An Introduction to a Coupled Structural and Aerodynamic Design Method for Shape-Adaptive Compressor Blades

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Abstract:

A sustainable and eco-friendly aviation is necessary for reducing global emissions and achieving currently set worldwide environmental goals. In order to satisfy these ambitious demands highly efficient and adaptable aircraft capable of offering an optimal performance at all flight stages need to be developed. Additionally, alternative propulsion concepts, such as fuel cells and synthetic fuels need to be considered in this process. Developing such innovative designs presents however new challenges, not only in aircraft design, but also and especially in engine design, since this system's performance is essential for the overall system's efficiency. A central component for defining an engine's efficiency is the compressor. This component increases the pressure of the airstream furnished by the intake and delivers highly pressurized air to the combustion chamber. By implementing form-variable blades to compressor front stage rotors, it is possible to modify the shape of the blades according to the aerodynamic requirements at the current operating state of the engine. Therefore the compressor can be adapted to different incoming airstreams and compression ratios, increasing operation flexibility and overall system efficiency. To achieve this goal, the use of structurally integrated piezoceramic-based macro fibre composite actuators on the blades' suction and pressure sides is investigated. By expanding or contracting, the integrated actuators are capable of modifying the shape of the blade aiming to reach the desired aerodynamic shape. To consider the multidisciplinary character of the proposed technology, a design methodology enabling a strong and robust coupling between the structural and aerodynamic design aspects is developed.

To evaluate the proposed approach and therefore the potential of shape adaption for future engine concepts, the introduced method is applied to the blades of the NASA67 first stage rotor. The starting point of the coupled design process is the design-point geometry of the rotor and its aerodynamic behavior at maximum efficiency. An aerodynamic re-design of the rotor for extreme operating conditions provides the target geometries for the shape morphing blade on the structural side of the methodology. The basis for the structural analysis is a detailed parametric study where the influence of geometric variables, loading conditions and possible material properties are considered. The goal of this preliminary study is to design an actuation system capable of structurally morphing the blade as close as possible to the aerodynamic peak performance shapes. Within the development of the shape morphing concept, blade deformations covering changes in twist, camber, trailing edge deflection and staggering are considered. To minimize the deviation between aerodynamic target blade geometries and structurally actuated deformed blade, a close coupling between the design variables of both disciplines is necessary. For every iteration step in the design process, the deviation between both shapes is monitored. This allows an evaluation of the potential of the different types of blade deformation to influence the aerodynamic performance. The selection of actuation concepts offering more flexibility and high overall engine efficiency will lead the way towards the application of this technology in future aircraft engine design.