Influence of transonic inducer design on the performance of high pressure ratio centrifugal compressors

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Long Abstract

Introduction

High pressure ratio centrifugal compressors (PR>5) as those used for aviation and turbocharger applications normally require a broad operating range, high flow coefficients and low sensitivity to tip clearance. Typically an increase in the compressor pressure ratio leads to an increase in shock losses and a reduction of operating range, making it desirable to look into aspects of the design that will reduce the losses and improve the operating range of the impeller.

High flow coefficients on the compressor design will lead to high relative Mach numbers on the inducer (Mrel > 1.3), to high shock losses and reduced operating range. An important aspect to minimize the efficiency penalties expected is to leverage the learnings from axial compressor design on transonic compressor blade design. Cumpsty [1] provides a general overview of transonic compressor design for axial compressors and indicates that a key aspect to reduce the shock losses consists in maintaining a flat suction surface in an attempt to decelerate the supersonic flow into subsonic flow early on. He also points out that in some cases applying a negative camber could be used to compensate for the curvature created due to boundary layer growth.
Ginder and Calvert [2] also summarize the critical aspects of the aerodynamic design of transonic blades indicating that the following aspects need to be considered:

1. Precompression
2. Incidence in supersonic inlet flow
3. Distribution of camber

The studies from Ginder and Calvert [2] show that the usage of negative camber leads to reduced shock losses and to reduced Mach numbers in front of the shock.
Wadia and Law [3] discuss the impact of the position of the maximum thickness on a transonic compressor design, and point out that having little turning on the supersonic part of the blade and even negative turning (S shaped blades) is beneficial for the performance of the compressor. Their studies indicate that displacing the maximum thickness of the blade aft improves the performance of the stage.

In the area of centrifugal compressor design several examples indicate the usage of transonic impeller design but the examples discussed are not compared to a conventional blade design in order to quantify or understand the potential benefits expected. Some of the cases reported in the literature are the ones from Rodgers [4], Arnone, Baldassarre et al [5], Senoo et al [6] Hayami et al [7], Mc Anally [8], Higashimori et al [9], Ibaraki et al [10], and Hah and Krain [11]. The proposed paper discusses the impact of transonic inducer design on high pressure ratio centrifugal compressors in comparisson with conventional designs, and discusses some of the aspects that need to be considered on the design of a compressor with a transonic inducer.

1.Methods

The numerical studies conducted were analyzed using an internal 3D steady state viscous code. The k-omega (Wilcox) turbulence model was used for the calculations. Air was used as the working fluid for all the calculations presented. The meshes were generated using a commercial mesh generation tool from NUMECA (Autogrid 8.9). The domain included a single passage with a structured mesh with 2.17 million elements, and 17 spanwise elements on the tip clearance. The mesh resolution used was selected based on a previously conducted grid independence study on the baseline impeller. The variations on pressure ratio between the fine and the medium mesh were found to be below 0.05%, the variations on efficiency between the fine and medium mesh were below 0.003%. The results indicate that the usage of negative camber on a portion of the inducer to decelerate the relative Mach number towards the tip of the impeller as proposed by axial compressor literature could provide up to 0.7 points of efficiency, and may provide slight benefits in terms of operating range of the compressor. A careful selection of the passage area distribution towards the tip of the compressor is key to avoid the acceleration of the flow and to minimize the losses caused by the shock.

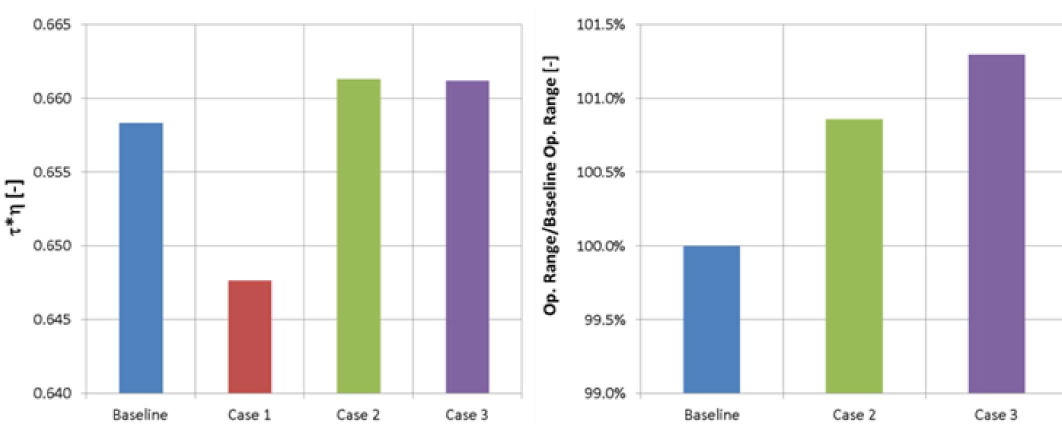

Figure 1. Effect of transonic inducer design on the compressor performance

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