Effect of Tip Injection on an Axial Compressor Using Recirculation Ducts - Part II: Numerical Investigations

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Long Abstract

Introduction

The proposed paper is the second part of a two-part publication. It covers the results of a numerical analysis concerning the impact of a passive flow control technique on a 1.5-stage axial compressor are presented. In order to examine the effects occurring due to the application of discrete tip blowing in the rotor domain, transient flow simulations are conducted. In low speed axial compressors the rotor blade tip area is critical concerning the effect of flow separation because of low momentum fluid in the endwall boundary layer and the rotor tip gap vortex. These flow effects cause a loss in efficiency and are furthermore responsible for a cutback in the compressor working range. As a potential method to increase the working range the impact of recirculation ducts in the rotor casing is investigated in this study. Due to the static pressure gradient over the rotor passage fluid flows through the recirculation ducts, reenergizing the boundary layer at the leading edge of the rotor tip. Their design and positioning take the limited available space in aeroengines into account. This survey focuses on the impact of the tip blowing jet on the rotor performance, in particular the interaction of the recirculated mass flow and the tip gap vortex will be discussed. It will be shown that for the considered configuration the recirculation duct has a positive effect on the compressor performance at near stall operating conditions but a negative effect at operating conditions with higher mass flow rates. In the proposed paper the mechanisms which cause the beneficial and accordingly the detrimental impacts will be examined. An additional focus will be on the characteristics of the time-dependent mass flow in the recirculation ducts.

1. Numerical Setup

The numerical study compares the aerodynamic characteristics of the smooth casing configuration and the ducted configuration at design speed. The numerical model includes the whole 1.5-stage setup consisting of IGV, rotor and shrouded stator, which was also examined in experimental studies (Part I). The simulation of a rotor blade passage with discrete flow injection necessitates transient flow simulations, due to the fact that the rotor passes the duct inlet and outlet. To ensure comparability of the numerical studies the smooth casing configuration is likewise treated as unsteady flow problem. For the numerical study Ansys CFX is applied. The meshing is implemented using Numeca Autogrid. The recirculation ducts are partly meshed unstructured by means of ICEM CFX. A mesh study is executed for every domain, resulting in a mesh with a size of 12 million knots for the complete model. To ensure

good solutions for the tip blowing and flow extraction area, special attention is turned to the meshing of the shroud sector of the rotor domain.
The numerical analysis of the two examined configurations is done on the basis of four operating points respectively: two points at the stall arm of the characteristic, one point at the choke arm of the characteristic and the design point.

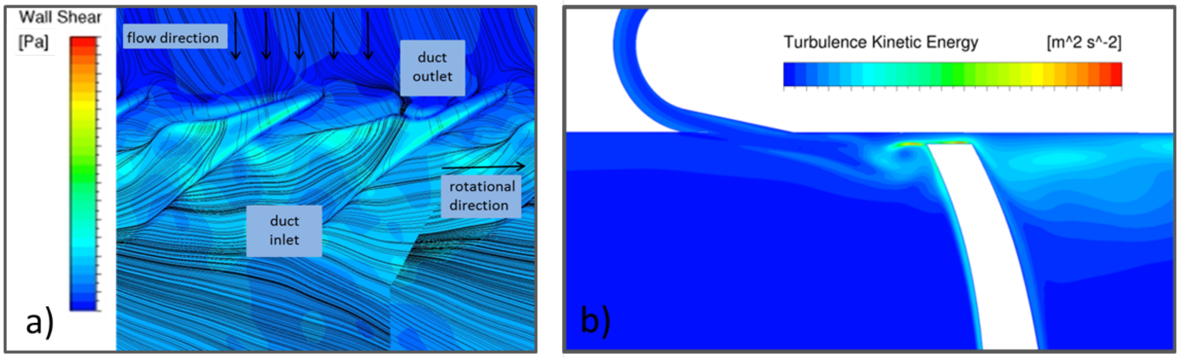

Figure 1. a) Path of Rotor Tip Gap Vortex at Shroud, b) Impact of Tip Blowing Jet on the Formation of the Tip Gap Vortex

2. Results

The stage performance will be discussed using efficiency and pressure ratio plots as well as radial profiles of flow parameters. The changes in the radial pressure distributions resulting from the application of the recirculation ducts will be explained. Furthermore the pressure loss coefficient and efficiency profiles will be discussed. It will be shown that the integrated recirculation ducts cause a shift of rotor loading from tip to hub.
The results of the transient numerical simulations provide the opportunity to examine and comprehend certain flow phenomena, which can not be recorded in static simulations or even in the experimental investigations. Using the transient results, the impact of the tip blowing jet on the tip gap vortex will be visualized using contours of different flow parameters. The path of the tip gap vortex at the rotor shroud is shown in figure 1a. The contour of the nondimensional turbulence kinetic energy in an axial plane in the rotor domain is shown in figure 1b. The different characteristics of the tip gap vortices will be presented using traced streamlines. It will be shown that the recirculated mass flow successfully prevents the tip gap vortex from propagating into the rotor blade passage.
The time dependence of the recirculated mass flow at the duct inlet and outlet will be discussed. The recirculated massflow varies depending on the relative position of the rotor blade and the duct inlet and outlet. It will be shown that the position of the peak value concerning inlet and outlet mass flow shifts with changing operating conditions.