Numerical simulation of rotating instabilities in an annular compressor cascade by Delayed-Detached Eddy Simulation

Ruben van Rennings, Department of Numerical Fluid Dynamics and Engineering Acoustics, Technische Universität Berlin, Berlin, Germany

Frank Thiele, CFD Software Entwicklungs- und Forschungsgesellschaft mbH, Berlin, Germany

Klaus Ehrenfried, Institute of Aerodynamics and Flow Technology Fluid Systems, German Aerospace Center, Göttingen, Germany

Long Abstract

Introduction

The development of modern axial compressors strives for systems which are smaller, lighter, more efficient, and feature less emissions. To fulfill these requirements, stage pressure ratios increase, whilst blade structures are reduced in robustness. Following from that, detailed knowledge of instability phenomena occurring in the vicinity of the stability line of the compressor system is crucial in terms of performance and potential vibration loading of the structure.

The rotating instability (RI) [1] is a flow instability occurring under conditions of high blade loadings and is provoked by large radial clearances [2]. RI is a phenomenon known to excite non-synchronous blade vibrations, cause increased acoustic emissions, and affect the performance for worse [3]. The occurrence of RI is accompanied by wall-pressure fluctuations in the endwall vicinity featuring characteristic spectral and azimuthal mode patterns [4].

1. Methodology

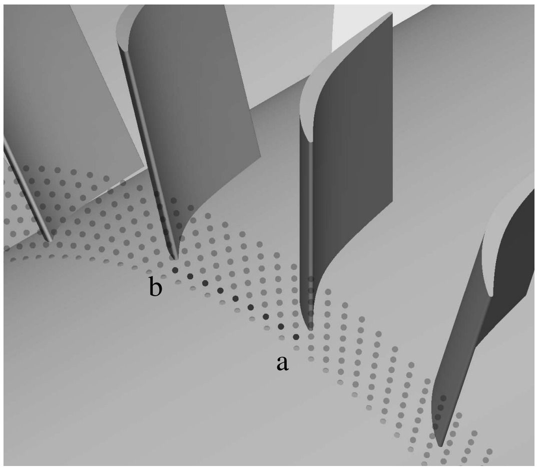
The occurrence of RI, its characteristics, and analysis of the associated mechanism is investigated in an annular compressor cascade. A test-rig of the configuration is operated at the Chair for Aeroengines of the Institute of Aeronautics and Astronautics of the Technische Universität Berlin. The blade row is designed to meet the geometric and fluid-dynamic figures of a typical cantilevered stator blade row in a high pressure compressor [5].

The flow at highly loaded operating conditions within the annular cascade is simulated by means of a transient, compressible, finite-volume-based flow solver. The turbulent content of the flow is treated by the delayed-detached eddy simulation methodology [6]. A numerical interpolation methodology has been employed, which features a low numerical dissipation. Thereby, even the propagation of acoustic pressure fluctuations is incorporated within the flow simulation. In oder to capture all relevant azimuthal modes associated to the RI mechanism, the full circumference has been modelled, consisting of 20 blades. The set-up of boundary conditions has been chosen to reduce reflection at the in- and outflow-boundaries of acoustic pressure waves originated within the flow field.

A large number of time-steps has been taken into account for the statistical evaluation of the flow configuration. Firstly, the occurrence of RI within the flow simulation has been validated by comparison against measured data from the test-rig. Subsequently, detailed analyses have been performed in order to identify the source region and mechanism of the characteristic wall-pressure fluctuations.

2. Results

Briefly, results validating the occurrence of RI within the flow simulation will be presented. Subsequently, more detailed analyses will be presented, which provide further insight into the mechanism of RI. E.g., the turbulent state in the vicinity of the blades leading edges close to the hub are characterized by analyzing the invariants of the Reynolds-stresses anisotropy tensor.



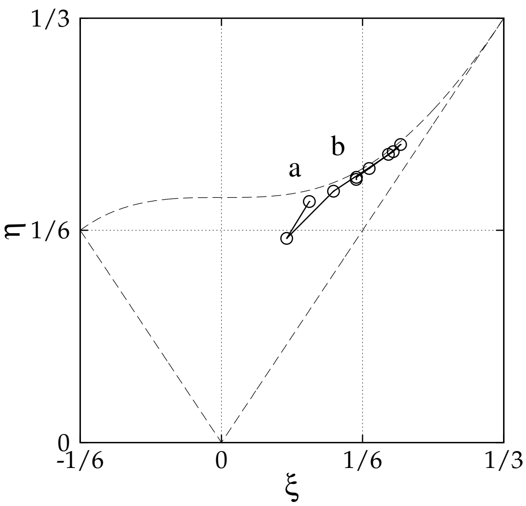


Figure 1. Characterization of turbulence anisotropy according to the invariant theory by *Lumley* [7] at $h/H = 5.9\,\%$ upstream of the blades leading edges.

References

[1] F. Kameier and W. Neise. Rotating blade flow instability as a source of noise in axial turbomachines. *Journal of Sound and Vibration*, 203(5):833 – 853, 1997.

[2] Christian Beselt, Benjamin Pardowitz, Ruben van Rennings, Robert Sorge, Dieter Peitsch, Lars Enghardt, Frank Thiele, Klaus Ehrenfried, and Paul Uwe Thamsen. Influence of clearance size on rotating instability in an axial compressor stator. In J. Backman, G. Bois, and O. Léonard, editors, *Tenth European Conference on Turbomachinery Fluid Dynamics and Thermodynamics*, pages 459 – 470, 2013.

[3] Christian Beselt, Dieter Peitsch, Ruben van Rennings, and Frank Thiele. Impact of hub clearance on endwall flow in a highly loaded axial compressor stator. In *Proceedings of ASME Turbo Expo 2013, June 3.–7., 2013, San Antonio, Texas, USA*, number GT2013-95463 in ASME Turbo Expo, 2013.

[4] Benjamin Pardowitz, Ulf Tapken, Lars Neuhaus, and Lars Enghardt. Experiments on an axial fan stage: Time resolved analysis of rotating instability modes. In *ASME Turbo Expo*, 2014.

[5] I. Ulbricht. *Stabilität des stehenden Ringgitters*. PhD thesis, Technische Universität Berlin, 2002.

[6] P.R. Spalart, S. Deck, M.L. Shur, K. Squires, M.K. Strelets, and A.K. Travin. A new version of detached-eddy simulation, resistant to ambiguous grid densities. *Theoretical and Computational Fluid Dynamics*, 20:181 – 195, 2006.

[7] John L. Lumley. Computational modelling of turbulent flows. *Advances in Applied Mechanics*, 18:123 – 176, 1978.