Robust aero-thermal design of high pressure turbines at uncertain exit conditions of low-emission combustion systems

Marius Schneider

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Herausgegeben von Prof. Dr.-Ing. H.-P. Schiffer

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Editor’s Preface

The series Research Reports from the Institute of Gas Turbines and Aerospace Propulsion accounts for the advances made in turbomachinery research and development at Technische Universität Darmstadt. Because of the strong application oriented focus of the research in this area, the academic problems reflect actual industrial development trends.
The current development foci adapt to the changing political, economic and ecological framework which keeps carrying the turbomachine towards the border of technological feasibility. In consequence, it is not unusual for findings to be transferred to the industrial application directly.
It is within this environment, that the industry and application oriented research works of this series originate. The reports describe current findings of experimental investigations and numerical simulations which were obtained at the Institute of Gas Turbines and Aerospace Propulsion at Technische Universität Darmstadt.

Heinz-Peter Schiffer
Darmstadt, 2019

Author's Preface

Acknowledgements

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Marius Schneider
Frankfurt am Main, 2019

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The dissertation results to a large part from work that was funded by a scholarship of the Graduate School GRK 1344 "*Instationäre Systemmodellierung von Flugtriebwerken*" of *Deutsche Forschungsgemeinschaft* and the *Luftfahrtforschungsprogramm* LuFo V-2 "Advanced Components for Turbines" (AdCoTurb) of the *Bundesministerium für Wirtschaft und Energie* under grant FKZ 20T1312A. Calculations on the *Lichtenberg* high-performance computer of TU Darmstadt were conducted for this research.

Abstract

A key challenge in the development of novel, low-emission combustion systems in jet engines is the analysis of combustor turbine interaction. The exit conditions of the combustor are accounted for in the design of the first high pressure turbine stage in order to increase the efficiency of the system. Due to the extreme temperatures in jet engine combustors the knowledge of these conditions is subject to large uncertainties. The goal of this work is the development of a method to account for these uncertainties in design. This shall enable the development of robust components that do not fail if conditions deviate from the design point.

A major component of the method is a model that generates two-dimensional flow profiles of modern lean burn combustors based on a parameter set. These are used as boundary condition of a three dimensional flow simulation of the turbine. Stochastic deviations of the input parameters within the uncertainties can thus be accounted for. The developed process chain which couples parameters of turbine inlet conditions with performance parameters of the engine is analysed by means of statistical methods for uncertainty quantification. The model is able to reproduce both, conditions of a test rig as well as those in real engines, with sufficient accuracy. Strong swirl at the combustor exit, which is characteristic for modern combustors, interacts with the first row of stator vanes of the turbine. Secondary flows in the vane passage, known from the literature, are influenced and additional structures are induced by the inlet swirl. By means of the developed process, a significant correlation between the circumferential position of the inlet swirl core and the radial position of the induced structures is identified. The relation transforms variations in the circumferential position of inlet swirl to variations in the local thermal load of the vanes and hub end wall and thus of the turbine's life time. Uncertainties in thermal efficiency result mainly from uncertainties in the position of hot streaks at turbine inlet.

Contents