Optimization of Transonic Axial Compressor Blades

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Outline

- The Axial Compressor
- Project Overview
- The Optimization Process
- The Tip Clearance
- Summary
- Work in-progress
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The Axial Compressor

• Consist of rotating and stationary blade rows
• Does work to the flow, increase density and pressure
The Axial Compressor
The Axial Compressor

• Distance between the rotor and the casing to avoid contact during engine operation

• Called **tip clearance** or **tip gap**
The Axial Compressor

- Factors that influence the tip clearance size
  - Blade shape change due to rotational speed
  - Temperature variation
  - G-forces, e.g. at landing
  - Manufacturing tolerances
  -...

Simplified view
The Axial Compressor

Total pressure ratio vs. Mass flow

- Design point
- Surge limit
- Operating line
- Choke
- Surge margin

RPMs:
- 10 000 rpm
- 13 000 rpm
- 16 000 rpm

Design point
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Project Overview

• Improve robustness of compressor blades

• Optimization has been used as a tool to evaluate how surface degradation and the tip clearance can be considered in the design phase

• Industry partner: GKN Aerospace
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The Optimization Process

• Genetic algorithm, mimics evolution in nature

• Design variables are represented by a number of ones and zeros (genes)
  • decoded to return the variable value

• Improving designs generation by generation
  • Tournament selection
    • individuals compete to pass along their genes to the next generation
  • Mutation, $1 \rightarrow 0$ or $0 \rightarrow 1$
The Optimization Process

- **Initial design set**
- **Geometry generation**
- **Grid generation**
- **Optimization**
  - Genetic algorithm
  - Radial basis function
- **CFD calculations and evaluation**
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The Tip Clearance

- Can be the source of a large part of the total losses
  - Blade height decrease further back in the compressor
  - Tip clearance size relative to the blade height increase

- Limit the stable operating range of a compressor rotor
The Tip Clearance

- Two studies have been made so far within this project related to tip clearance

1. **Comparing computational models.** Predicting performance of an axial compressor with tip clearance. Geometry and test data provided by GKN Aerospace

2. **Optimization of a compressor stage with and without considering a tip clearance**
The Tip Clearance

First study: **Compare three computational models**

- **Simplified model**
  - High degree of modeling
  - Steady state k-ε turbulence model
  - Wall functions

- **Intermediate model**
  - Steady state k-ε turbulence model
  - low-Reynolds model

- **Advanced model**
  - Low degree of modeling
  - SAS-SST
The Tip Clearance

First study: **Compare three computational models**

- **Simplified model**
  - High degree of modeling
  - Steady state
  - k-ε turbulence model
  - Wall functions
  - Appears to predict performance trend well
  - Closer to the experimental results in terms of surge margin compared to the second approach
  - Computational time: 2 h to evaluate one operating point
The Tip Clearance

First study: **Compare three computational models**

- Intermediate model
  - Steady state k-ε turbulence model
  - low-Reynolds model

- Close to the experimental values in terms of efficiency and total pressure ratio
- Underestimate surge margin
- Good for validation studies for operating points away from surge
- Computational time: 10 h to evaluate one operating point
The Tip Clearance

First study: Compare three computational models

- Closest to the experimental data in terms of surge margin
- Good in predicting both efficiency and total pressure ratio
- Computational time: 1 – 2 weeks to evaluate one operating point

Advanced model
Low degree of modeling
SAS-SST
The Tip Clearance

Second study: Optimize stage with and without tip clearance

Optimization objectives

- High efficiency and high stability

Two Optimizations

1. Optimize without any tip clearance
   - Evaluate best designs including tip clearance
2. Optimize taking the tip clearance into account
The Tip Clearance

Second study: **Optimize stage with and without tip clearance**

**Lessons learned**

- Optimize without any tip clearance.
  - New design will not reach design point when evaluated with a tip clearance
  - Sub-optimal designs both in terms of efficiency and stability

- Optimize with a tip clearance
  - Blade geometry was modified to allow for a higher mass flow away from the tip region. Compensate for a lower flow rate at the tip.
  - Efficiency gain of 1.6% for the design with highest efficiency

- Computational time for an optimization increased from 2 days to 7 days
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Summary

• Work in my project has been done on the influence of tip clearance and surface degradation on performance

• Optimization is used as a tool in the project

• Optimize including the tip clearance
  • If the increase in computational time can be allowed for: A high gain in efficiency (1.6% in the presented study) could be possible
  • Stage geometry re-designed to reach the design point

• Collaboration with GKN Aerospace
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Work in-progress

- Working with a conference article in the VINK project (Virtual Integrated Compressor Demonstrator) together with Lund University and KTH.

- Working on a publication on how to re-design an axial compressor rotor to improve the surge margin when the tip clearance flow is the cause for surge.
Acknowledgements
Thank you for your attention!

Further reading:

Additional slides
Surface Degradation

• Caused by ingestion of dust, sand, dirt, foreign objects, …

• Several percent lower efficiency has been reported for fan blades with a level of surface roughness representative of a long time of in-service use