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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

Figure from rolls-royce.com

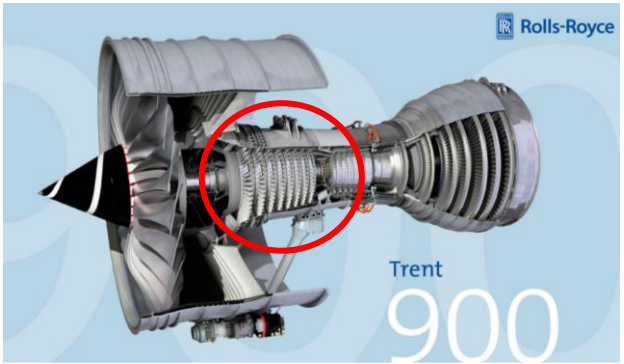
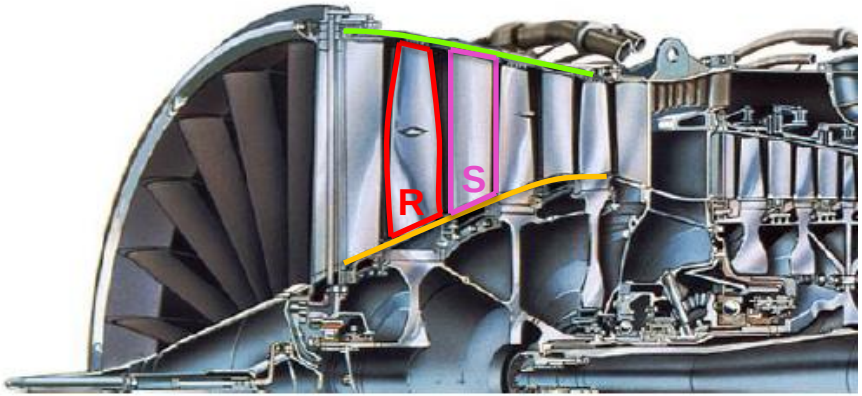
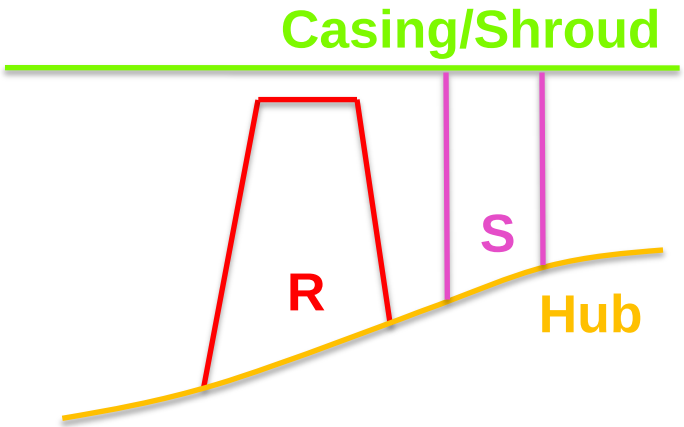


Figure from rolls-royce.com

The Axial Compressor



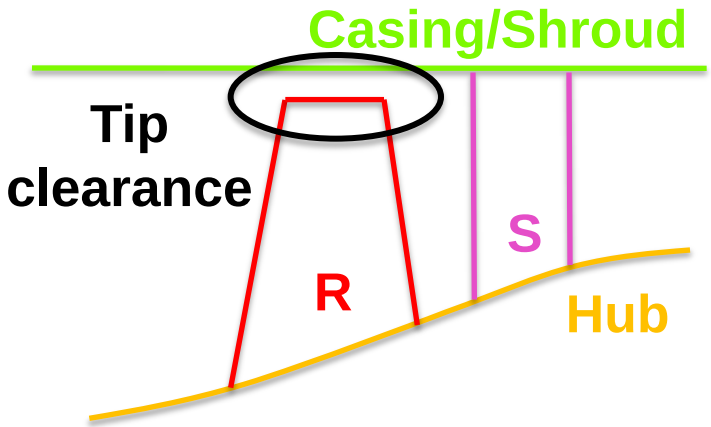


Simplified view

The Axial Compressor

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

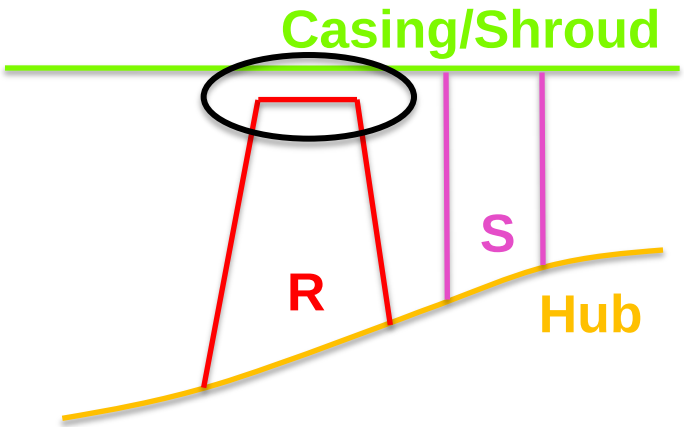
- Called tip clearance or tip gap



Simplified view

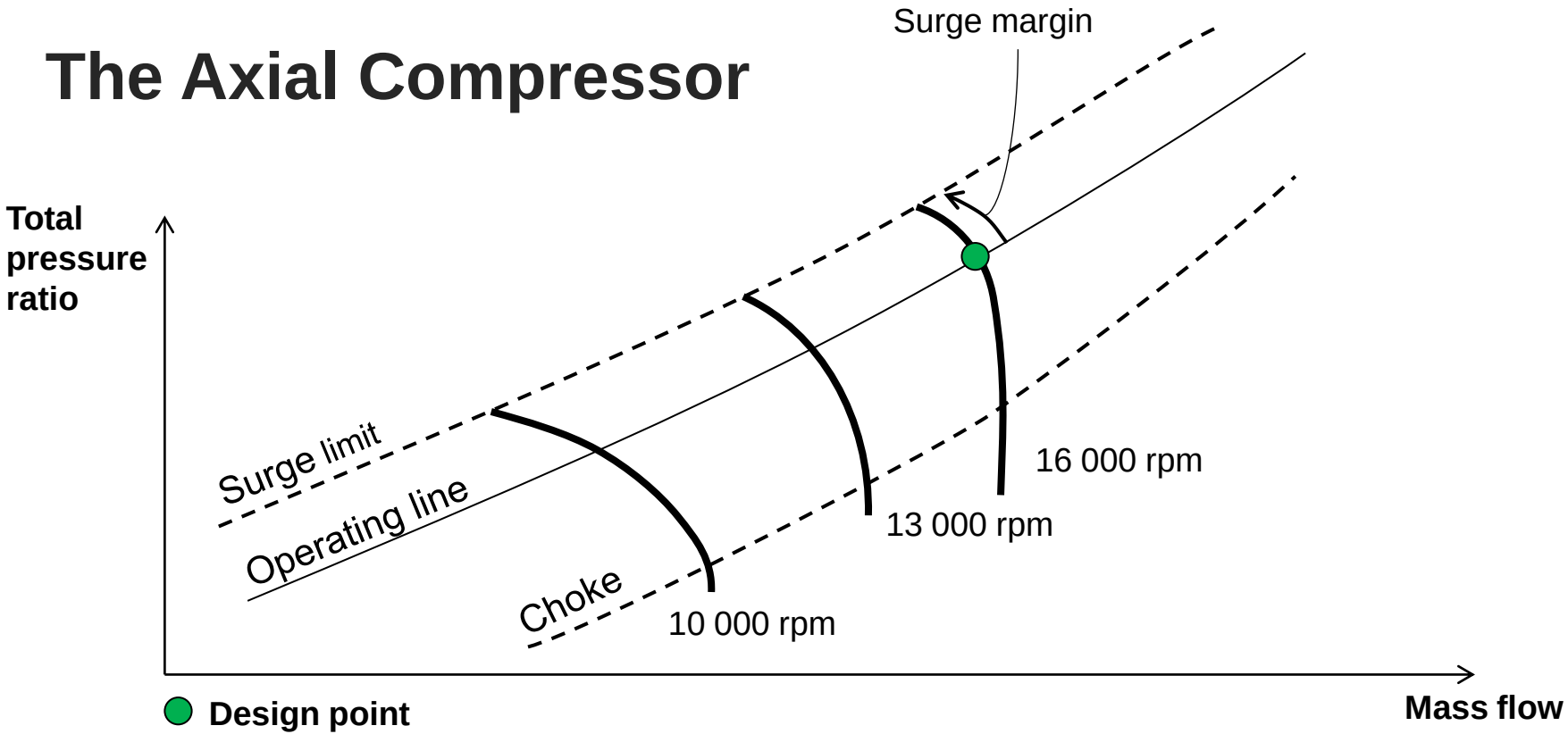
The Axial Compressor

- **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



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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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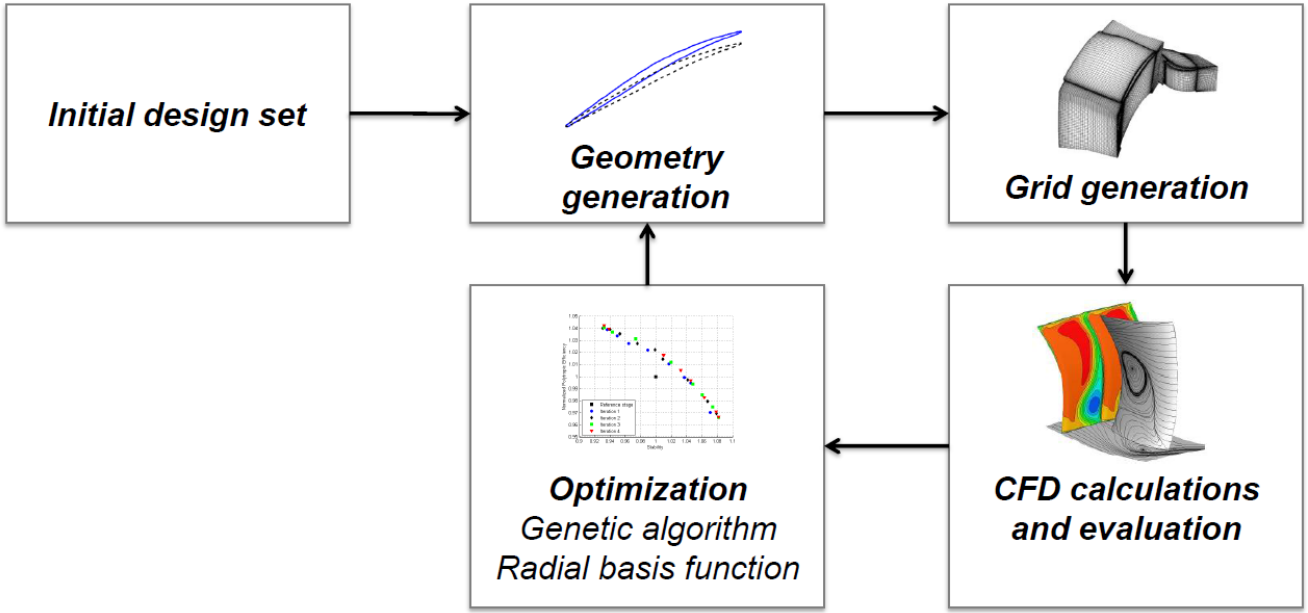
The Optimization Process

- 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 → 0 or 0 → 1

The Optimization Process



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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

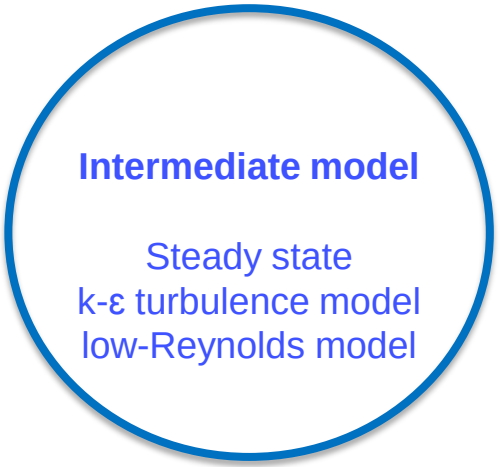
High degree of modeling

Steady state
k-ε turbulence model
Wall functions

- **Appears to to predict performance trend well**
- **Closer to the experimental results in terms of surge margin compared the second approach**
- **Computational time: 2 h to evaluate one operating point**

The Tip Clearance

First study: Compare three computational models



- **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

Simplified model

High degree of modeling

Steady state
k-ε turbulence model
Wall functions

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

Simplified model

High degree of modeling

Steady state
k-ε turbulence model
Wall functions

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**
- **Computional 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

GKN AEROSPACE

VINNOVA

FMV

SWEDISH ARMED FORCES

C³SE
Chalmers Centre for Computational Science and Engineering
Chalmers University of Technology
Göteborg University

NSC

Thank you for your attention!

Further reading:

- M. Lejon, L-E. Eriksson, N. Andersson and L. Ellbrant, 2015, **Simulation of Tip-Clearance Effects in a Transonic Compressor**, Proceedings of ASME Turbo Expo 2015, June 15-19, Montreal, Canada
- M. Lejon, N. Andersson, L. Ellbrant and H. Mårtensson, 2015**, CFD Optimization of a Transonic Compressor Stage with a Large Tip Gap**, 22nd ISABE Conference, October 25-30, Phoenix, USA
- M. Lejon, N. Andersson, T. Grönstedt, L. Ellbrant and H. Mårtensson, 2016, **Optimization of Robust Transonic Compressor Blades**, Proceedings of ASME Turbo Expo 2016, June 13-17, Seoul, South Korea

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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**