Alternative Approach for Solving a Multi-Objective Optimization Problem in Aerodynamic Compressor Blade Design

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2D Blade Design Problem

\( \omega \) [%]

inlet flow angle \( \alpha \) [°]

Loss Curve

\( \omega^0 \)

\( \omega^0 \)

\( \omega^0 \)

\( \omega^0 \)

\( \alpha^L \)

\( \alpha^R \)

\( \alpha^0 \)

objectives:

1. loss reduction at design conditions
   \( \min_p \omega^0 \)

2. increase of working range
   \( \max_p \ WR \)
Alternative 2D Blade Design Problem Definition 1

**Objectives**

\[
\begin{align*}
\min_{p, \Delta \alpha^L, \Delta \alpha^R} & \quad \omega^0 \\
\max_{p, \Delta \alpha^L, \Delta \alpha^R} & \quad \widehat{WR} = \Delta \alpha^L + \Delta \alpha^R
\end{align*}
\]

**Constraints**

\[
\begin{align*}
\alpha^L I & \leq \alpha^0 I \leq \alpha^R I \\
\omega(\alpha^L I) & \leq \omega^{WR} \\
\omega(\alpha^R I) & \leq \omega^{WR}
\end{align*}
\]

\[
\begin{align*}
P_{LB} & \leq P \leq P_{UB} & \text{pos. max. thickness} \\
TC & \geq \widehat{TC} & \text{thickness / chord} \\
A & \geq \widehat{A} & \text{area} \\
\overline{H}_{TE} & \leq \widehat{H}_{TE} & \text{boundary layer} \\
CM & \geq \widehat{CM} & \text{choke margin} \\
\delta & \leq \widehat{\delta} & \text{deviation}
\end{align*}
\]
Alternative 2D Blade Design Problem Definition 2

objectives

\[
\begin{align*}
\min_{p, \tilde{\omega}} & \quad \omega^0 \\
\min_{p, \tilde{\omega}} & \quad \tilde{\omega} \\
\end{align*}
\]

constraints

\[
\begin{align*}
\omega(\alpha^L_I) & \leq \tilde{\omega} \\
\omega(\alpha^R_I) & \leq \tilde{\omega} \\

P_{LB} & \leq P \leq P_{UB} \quad \text{pos. max. thickness} \\
TC & \geq \hat{TC} \quad \text{thickness / chord} \\
A & \geq \hat{A} \quad \text{area} \\
\hat{H}_{TE} & \leq \hat{H}_{TE} \quad \text{boundary layer} \\
CM & \geq \hat{CM} \quad \text{choke margin} \\
\delta & \leq \hat{\delta} \quad \text{deviation}
\end{align*}
\]
Process Integration and Optimization Loop

- Input
- Blade Geometry Creator
- Output
- Geometry Checker
- Optimizer (NSGA-II)
- Flow Solver (Mises)

Design vector (leading edge/suction side)

Objectives
Constraints

Infeasible
Feasible
Boundary Conditions and Optimization Settings

Rolls-Royce high pressure compressor stator blade mid-section

inlet flow conditions
Ma = 0.776
\( \alpha_i = 46.8^\circ \)
\( T_0 = 447 \text{K} \)
\( P_0 = 439 \text{kPa} \)
\( Re = 1.09 \times 10^6 \)
\( Tu = 4\% \)

optimization strategy
algorithm: NSGA-II
number of individuals: 50
number of generations: 200

computational environment
CPU: 1x Pentium IV
Speed: 3.6 GHz
RAM: 3 GB
Multi-Objective Optimization Results

Alternative Approach 1

\[
\begin{align*}
\min_{\mathbf{p}, \Delta \alpha^L, \Delta \alpha^R} & \quad \omega^0 \\
\max_{\mathbf{p}, \Delta \alpha^L, \Delta \alpha^R} & \quad \hat{WR} = \Delta \alpha^L_I + \Delta \alpha^R_I
\end{align*}
\]

Criterion Space

5188 feasible solutions

datum design
Multi-Objective Optimization Results

Alternative Approach 2

\[
\begin{align*}
\min_{p, \tilde{\omega}} \quad & \omega^0 \\
\min_{p, \tilde{\omega}} \quad & \tilde{\omega}
\end{align*}
\]

Criterion Space

7477 feasible solutions
Multi-Objective Optimization Results

Loss Curve

\[ \text{loss } \omega \% \]

2D Blade Geometry

\[ \text{inlet flow angle } \alpha_1 [^\circ] \]

Datum design

Alternative definition 1

Alternative definition 2

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Summary

• two alternative formulations of 2D blade design problem have been investigated

• both definitions have been applied on a given initial Rolls-Royce high pressure compressor blade design

Conclusions

• multi-objective optimization approach has found improved designs w.r.t. both objectives
  → working range improvement more than 20%
  → loss reduction at design point more than 4%

• 2D blade design problem has been accelerated due to new problem definition (3 point calculation instead of 30)
  → process acceleration factor 10