41st European Rotorcraft Forum
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Applying Multi-Objective Variable-Fidelity Optimization Techniques to Industrial Scale Rotors: Blade Designs for CleanSky

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• Innovation Takes Off

www.cleansky.eu
Motivation

• The goal of GRC is the effective reduction of required fuel and noise emission in contrast to state-of-the-art helicopters

• DLR has been working on two topics:
  – active blade twist blades
  – Improve “passive” blade design – geometric enhancements

→ This presentation focuses on the “passive” approach
Tools for Numerical Optimization
Aerodynamic Models for Optimization

Hover

Forward Flight

Low-Fidelity

Inviscid CFD

BET+Prescribed Wake

High-Fidelity

Viscous CFD

Viscous CFD
Simulation Toolchain

- Preprocessing
  - HOST-Discretization
  - FLOWer-Mesh

- Comprehensive Code
  - HOST
  - Elastics
  - Trim procedure

- CFD Flow Solver
  - FLOWer
  - Porous surface
  - Rotor blades
  - Sound pressure
  - Deformations
  - Loads

- Aero-Acoustic Code
  - APSIM
  - Microphones/sound carpet

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Numerical Optimization Approach
Universal Kriging for single and low fidelity

\[ \hat{y}_{LFM}(\bar{x}) = f(\bar{x})_{poly} + \epsilon_{LF}(\bar{x}) \]

Variable Fidelity for cheap high fidelity

\[ \hat{y}_{VFM}(\bar{x}) = \rho \hat{y}_{LFM}(\bar{x}) + \epsilon_{HF}(\bar{x}) \]

More details in the ERF 2012/13 papers
Parameterization

- 10 design variables
- Focus laid on robustness
- Limited pitch link loads in hover and forward flight
- Acoustic post-processing
**Best FF**

- Forward power: -5.9%
- Hover power: +30.7%
- Overflight noise: -3.3 dB

**Trade-Off**

- Forward power: -2.4%
- Hover power: -2.0%
- Overflight noise: -1.1 dB

**Best HV**

- Forward power: +8.0%
- Hover power: -6.5%
- Overflight noise: +9.5 dB

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Off Design Analysis
Thrust-FM Polar Hover

![Graph showing Thrust-FM Polar Hover performance](image)

- **Baseline**
- **Best FF**
- **Best HV**
- **Trade-off**

**Y-axis**: $F_M / F_{M, ref} \cdot 100\%$

**X-axis**: $c_t / \sigma$

**Design Point**

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Advance Ratio-Power Polar Forward Flight

Absolute

Relative

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Acoustics of Reference Blade

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Acoustics of Selected Blades

Delta SPL

Overflight EPNL

-3.3 dB

-1.1 dB

9.5 dB

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Conclusions
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• The speed of the numerical optimization process was significantly improved by using the variable-fidelity approach.

• Additionally going for a multi-point optimization methodology granted insight into many potential designs.

• Nevertheless, there is no free lunch:
  - Forward flight blades perform bad in hover and vice versa.
  - Hover blades are often louder in forward flight.

→ We revealed the cost-effectiveness of each design!