41st European Rotorcraft Forum Munich

Applying Multi-Objective Variable-Fidelity Optimization Techniques to Industrial Scale Rotors: Blade Designs for CleanSky

1st – 4th Sept 2015

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Institute of Aerodynamics and Flow Technology

- **Innovation Takes Off**

www.cleansky.eu

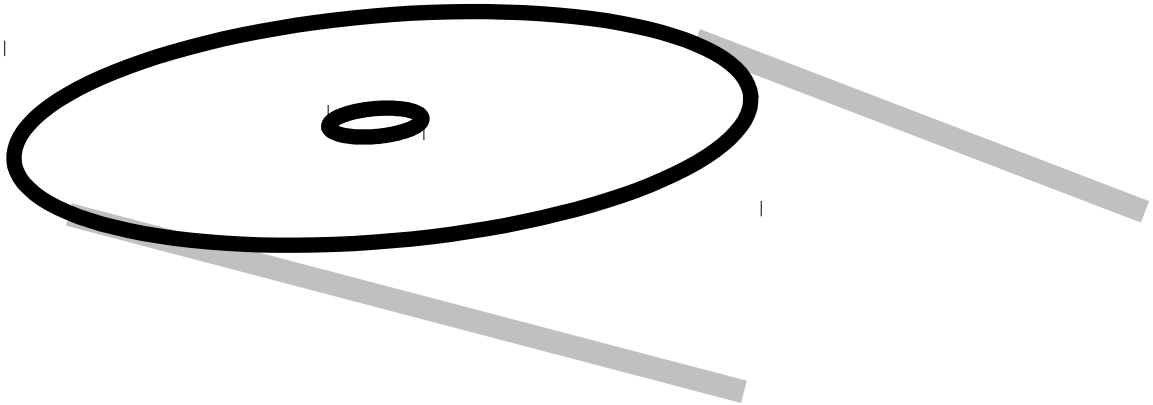
Motivation

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

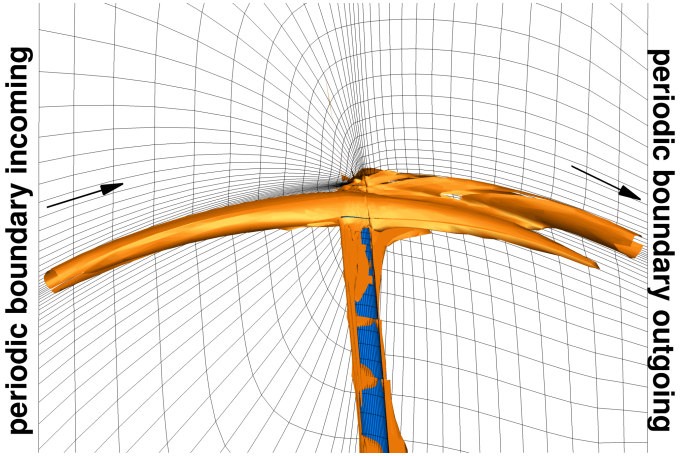
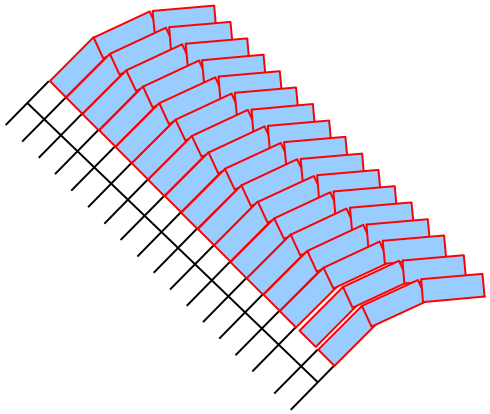
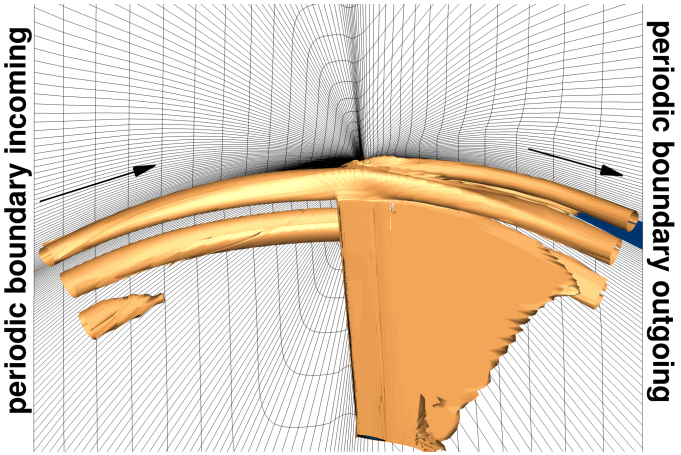
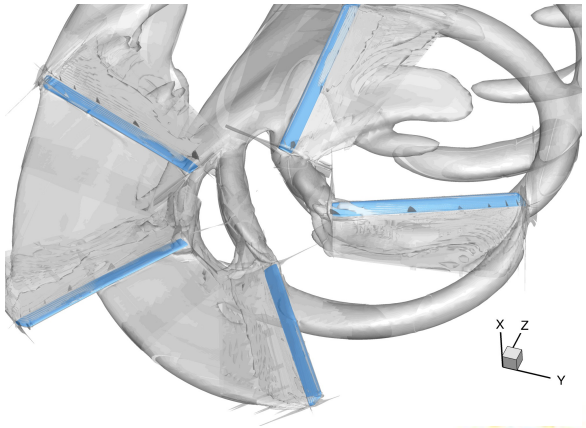
- DLR has been working on two topics:
  - active blade twist blades
  - Improve “passive” blade design – geometric enhancements

→ This presentation focuses on the “passive” approach

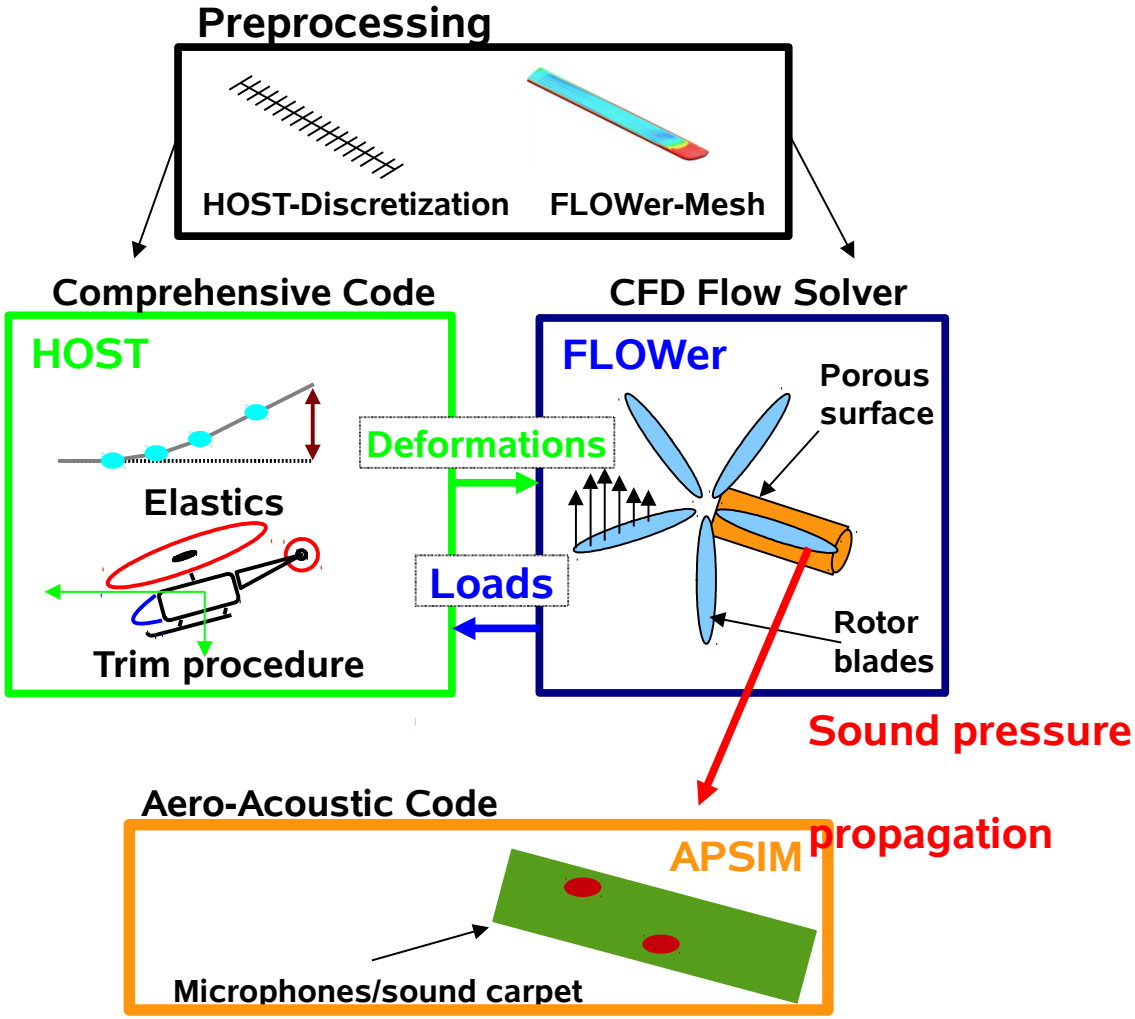
Tools for Numerical Optimization



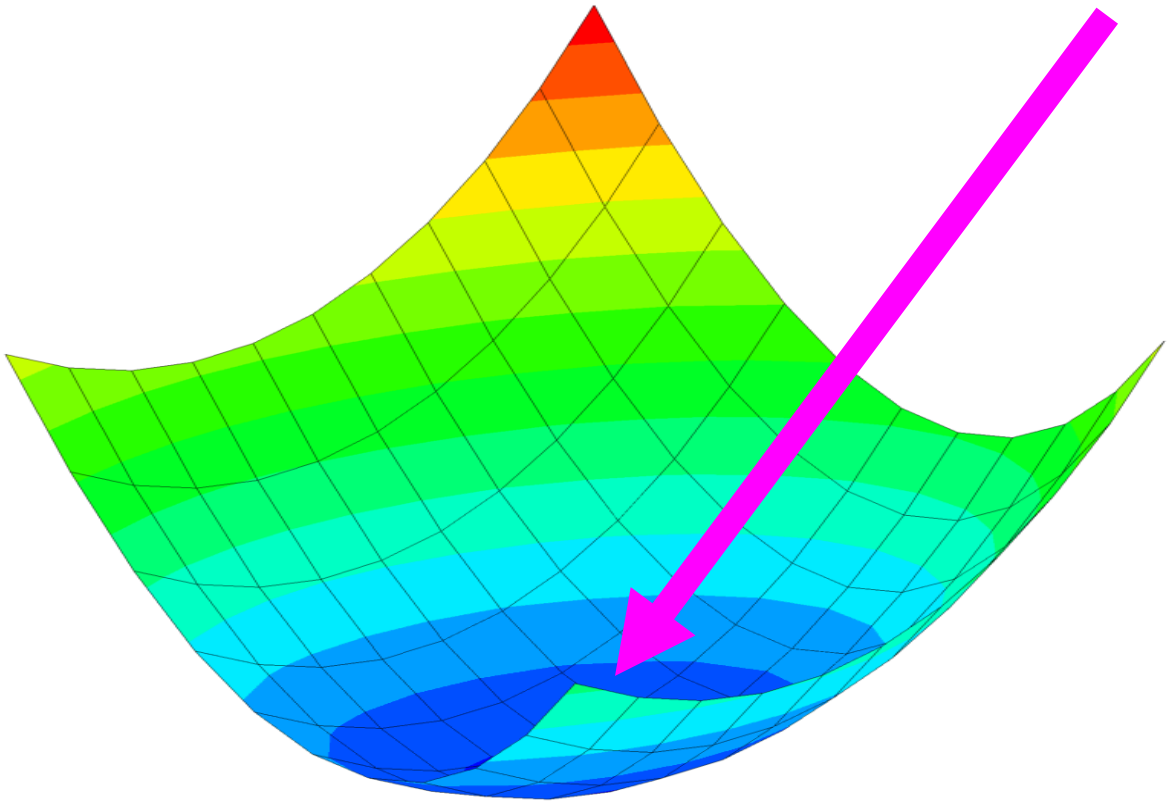
Aerodynamic Models for Optimization

	Hover	Forward Flight
Low-Fidelity	 Inviscid CFD	 BET+Prescribed Wake
High-Fidelity	 Viscous CFD	 Viscous CFD

Simulation Toolchain



Numerical Optimization Approach



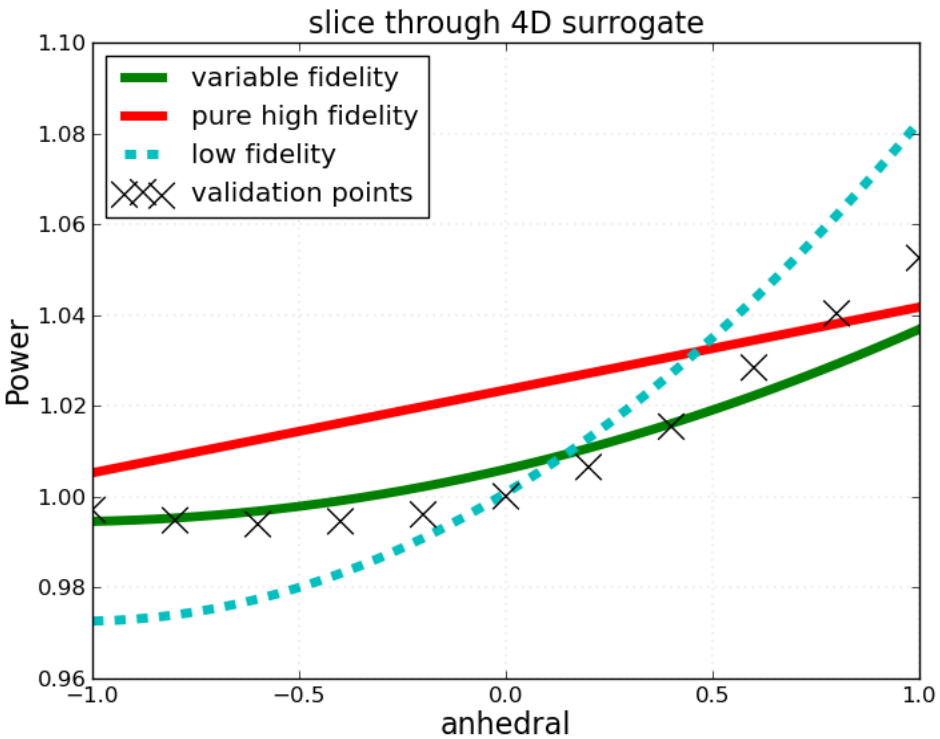
Single/Variable Fidelity Surrogate Model

Universal Kriging for single and low fidelity

$$\hat{y}_{LFM}(\vec{x}) = f(\vec{x})_{poly} + \epsilon_{LF}(\vec{x})$$

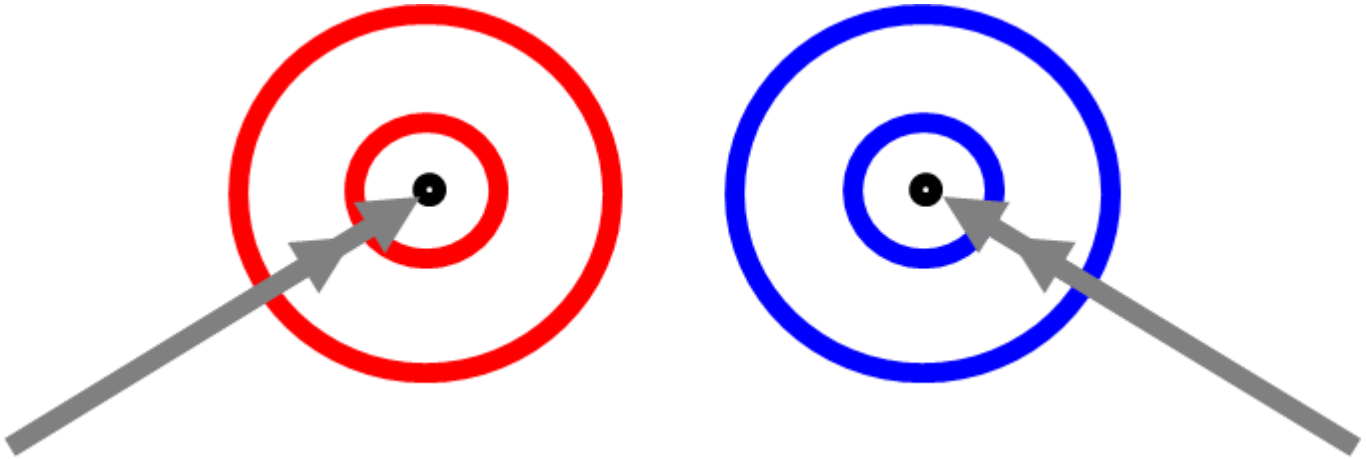
Variable Fidelity for cheap high fidelity

$$\hat{y}_{VFM}(\vec{x}) = \rho\, \hat{y}_{LFM}(\vec{x}) + \epsilon_{HF}(\vec{x})$$



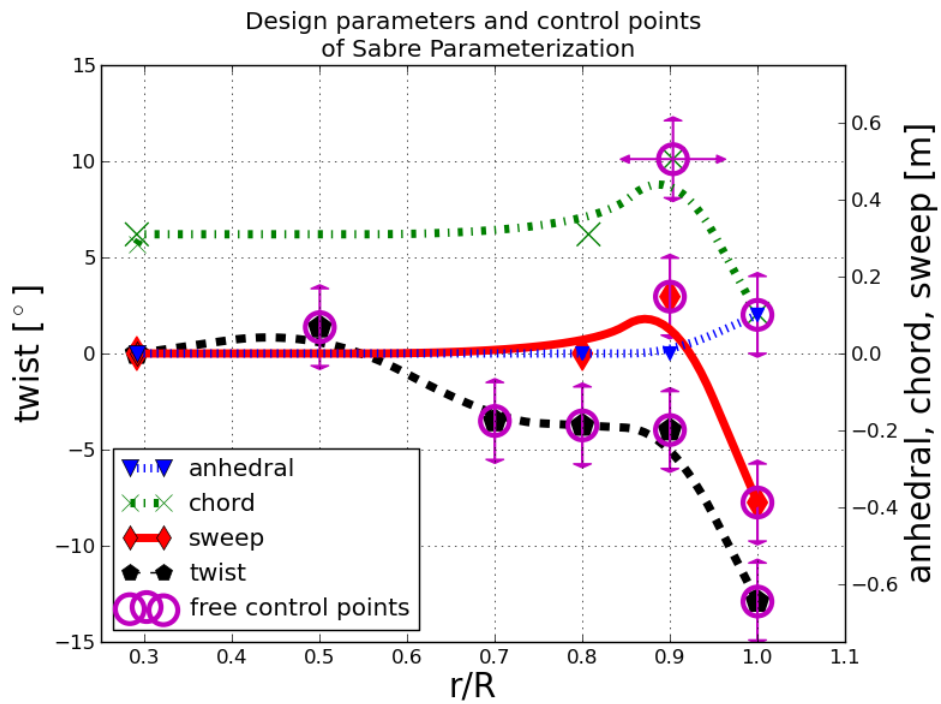
More details in the ERF 2012/13 papers

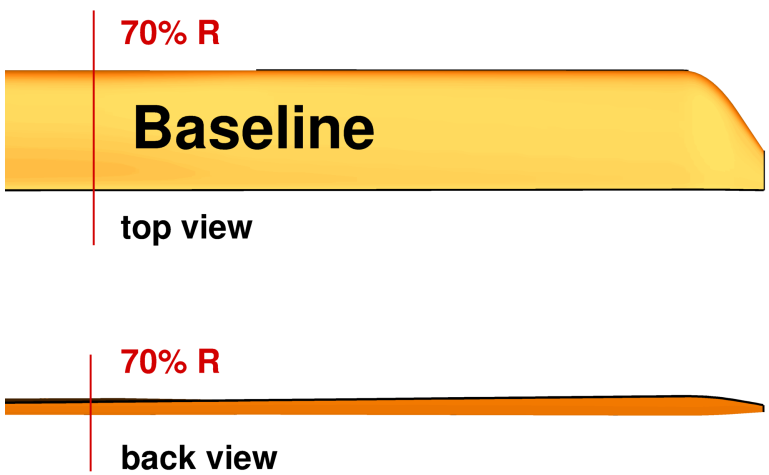
Multi-Objective Optimization

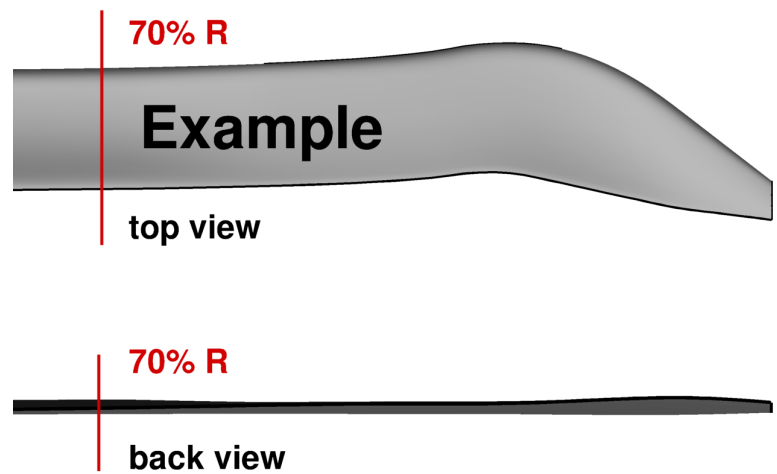


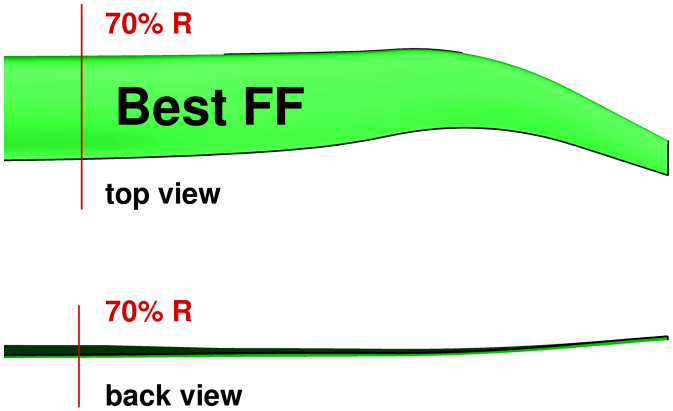
Parameterization

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

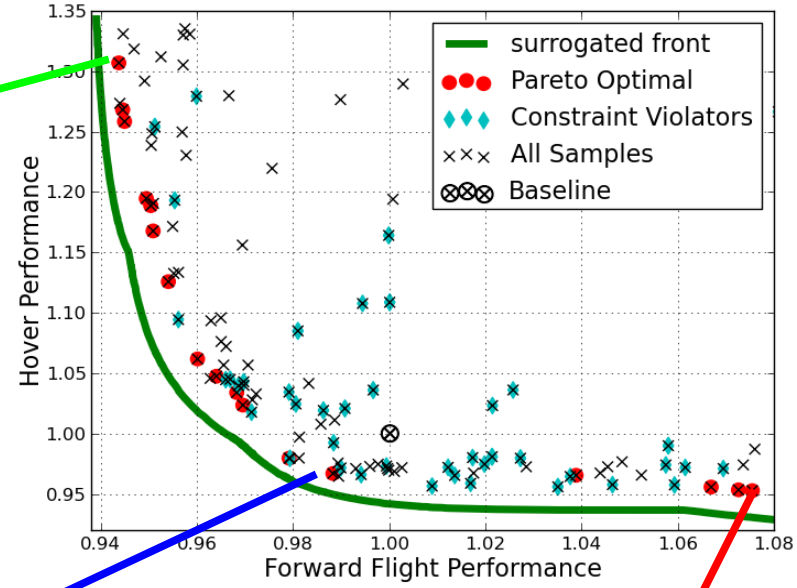


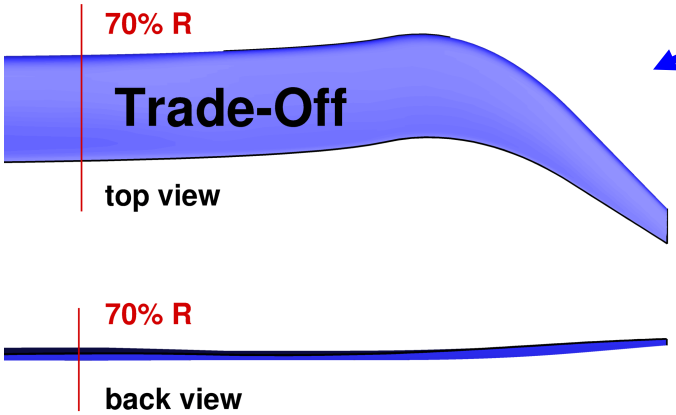




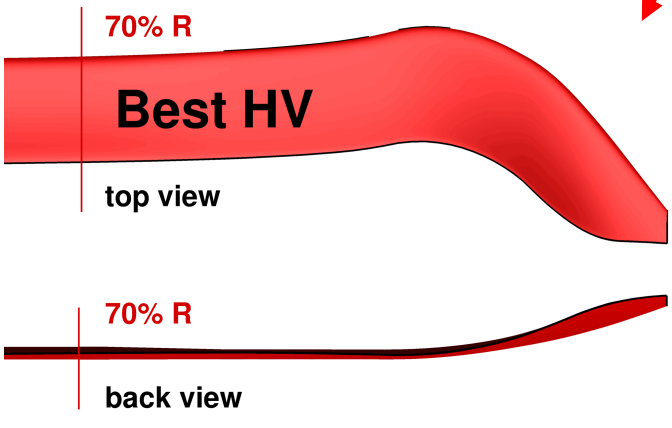


Required power	Forward	Hover
	-5.9 %	+30.7%
Overflight noise: -3.3 dB		

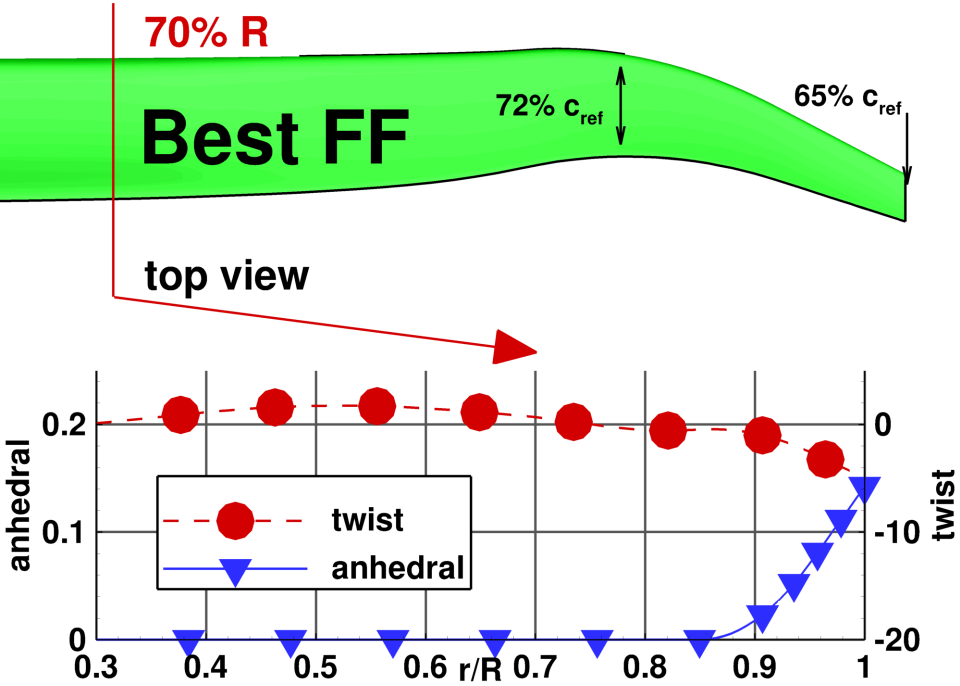


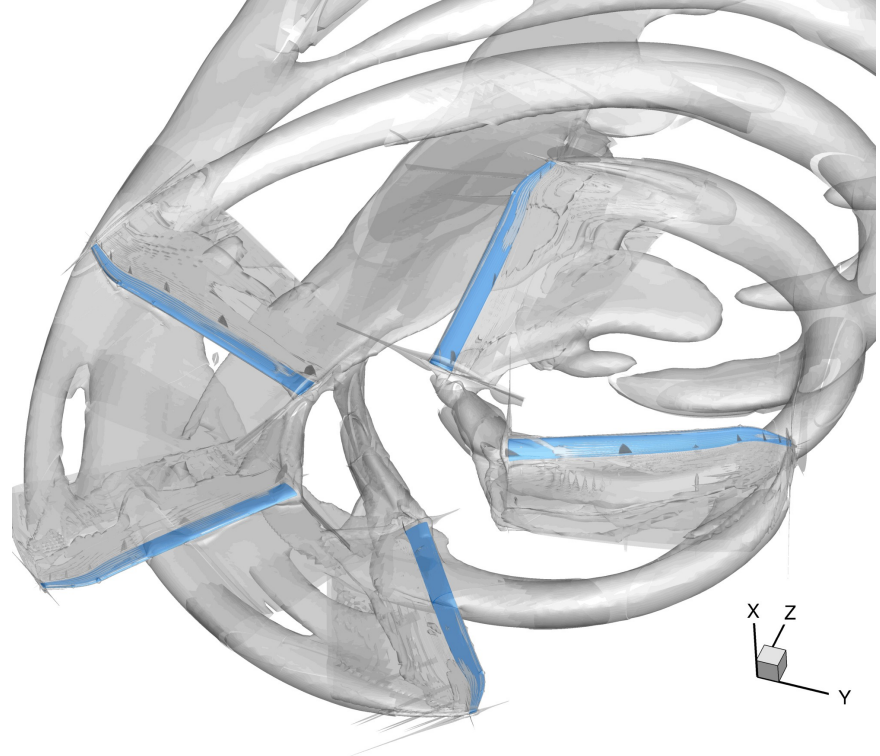


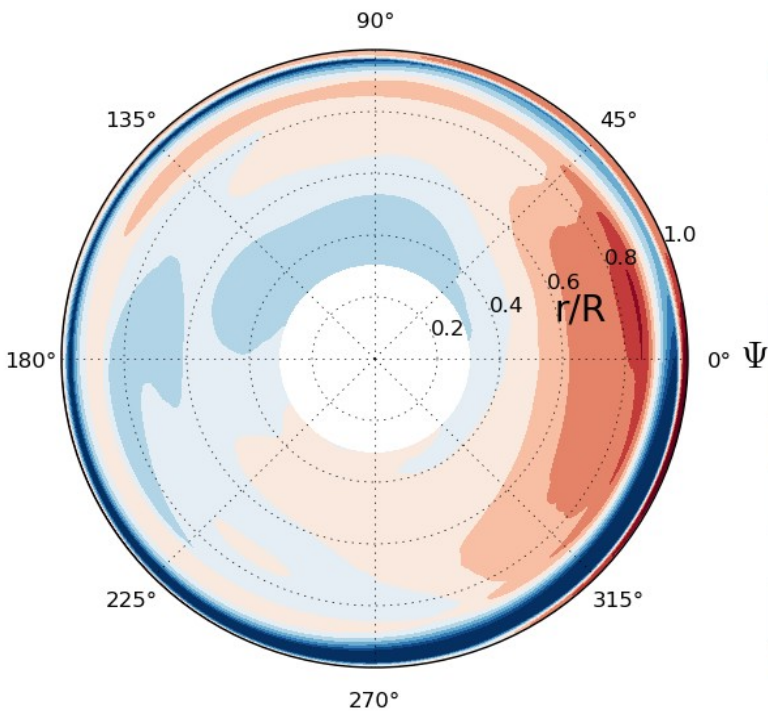
Required power	Forward	Hover
	-2.4 %	-2.0%
Overflight noise: -1.1 dB		

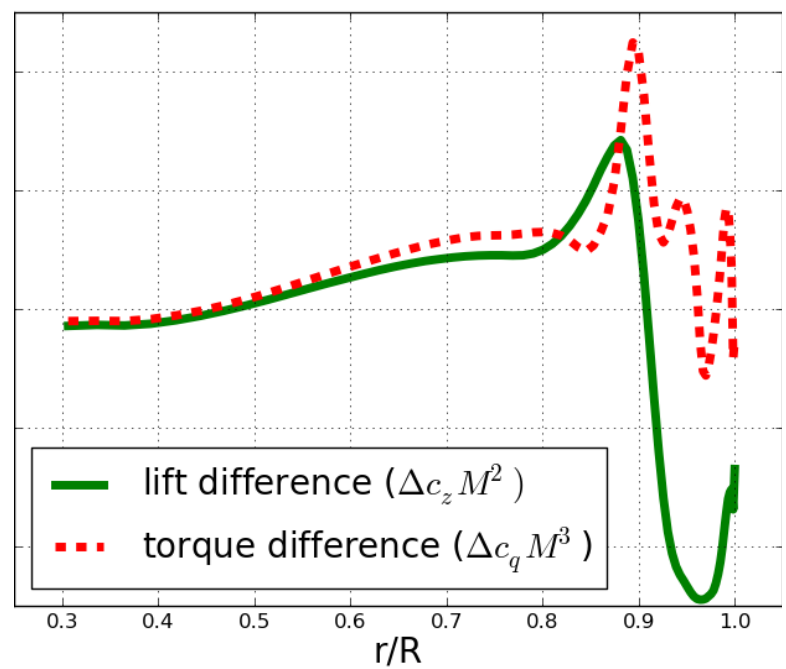


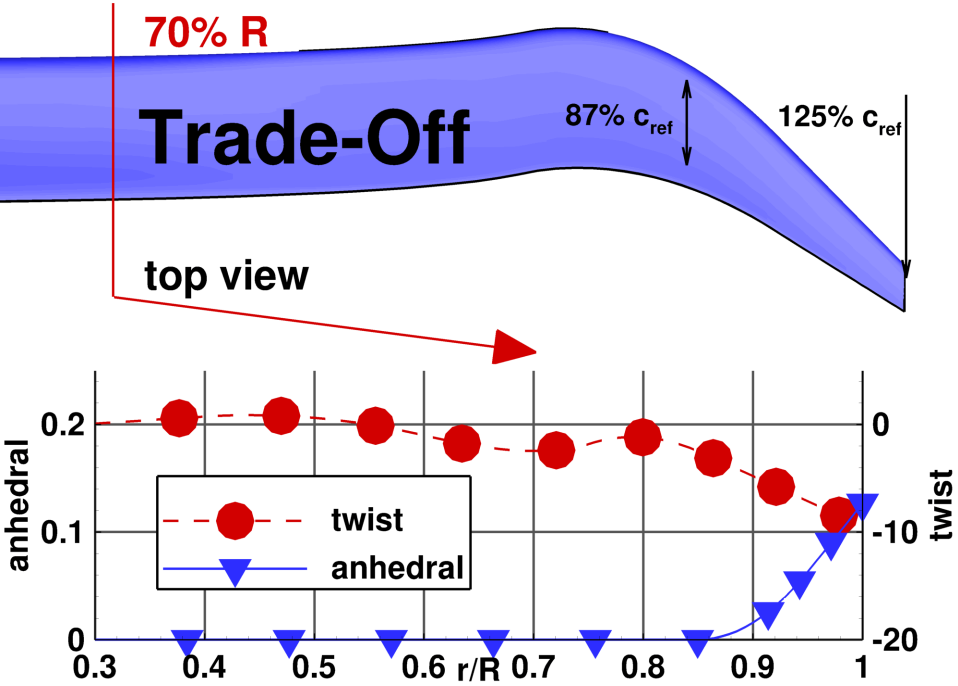
Required power	Forward	Hover
	+8.0 %	-6.5%
Overflight noise: +9.5 dB		

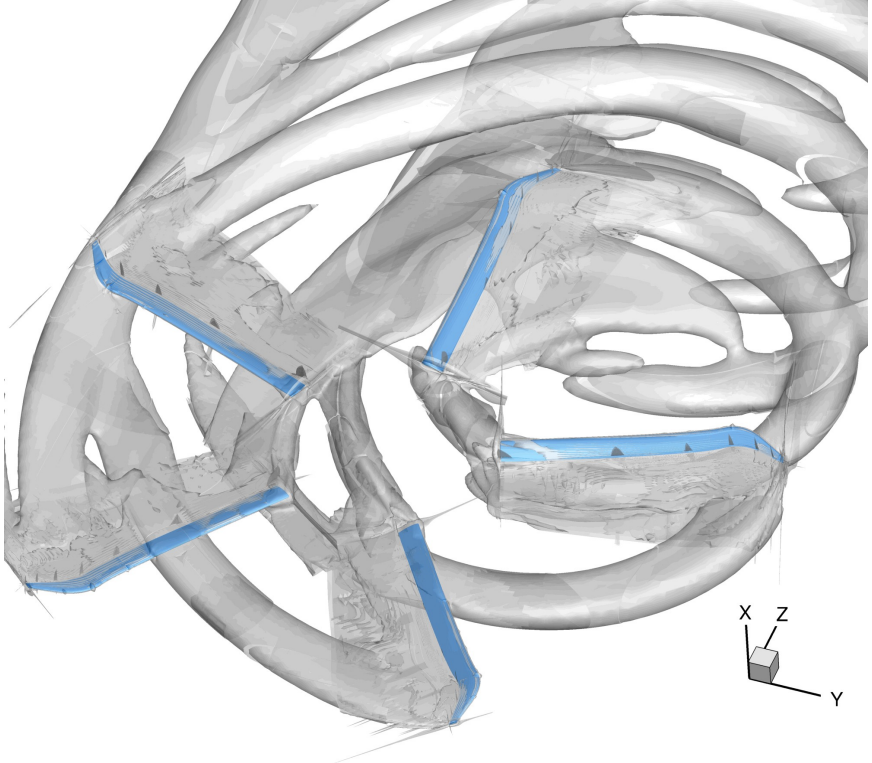

70% R
Best FF
72% c_ref
65% c_ref
top view
anhedral
twist
r/R
0.2
0.1
0
0
-10
-20
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

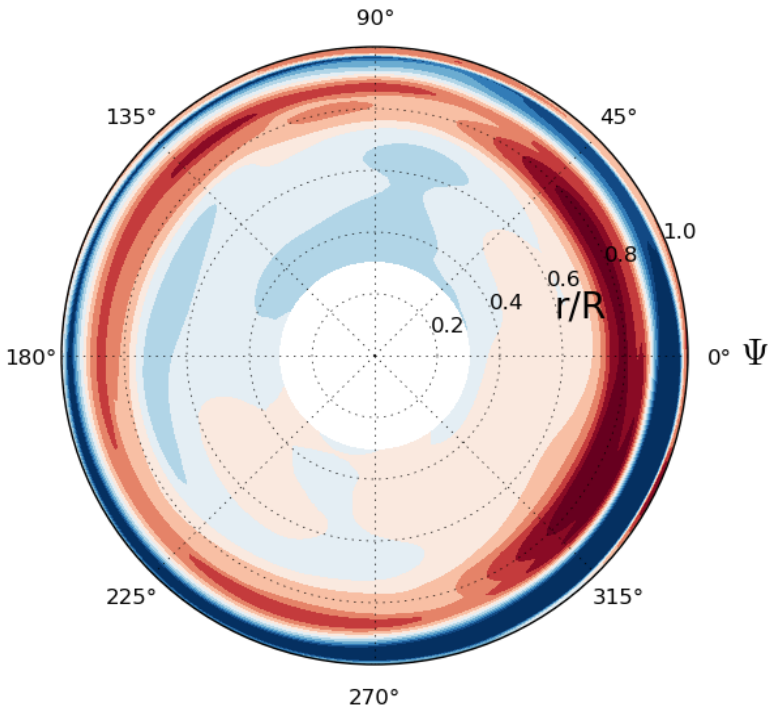

X
Z
Y

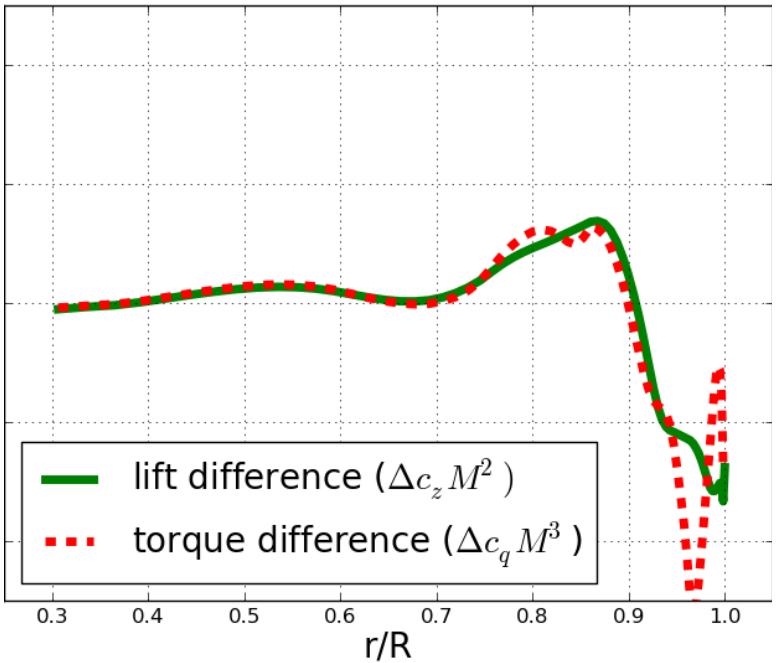

90°
135°
45°
180°
0°
Ψ
225°
315°
270°
0.2
0.4
0.6
0.8
1.0
r/R

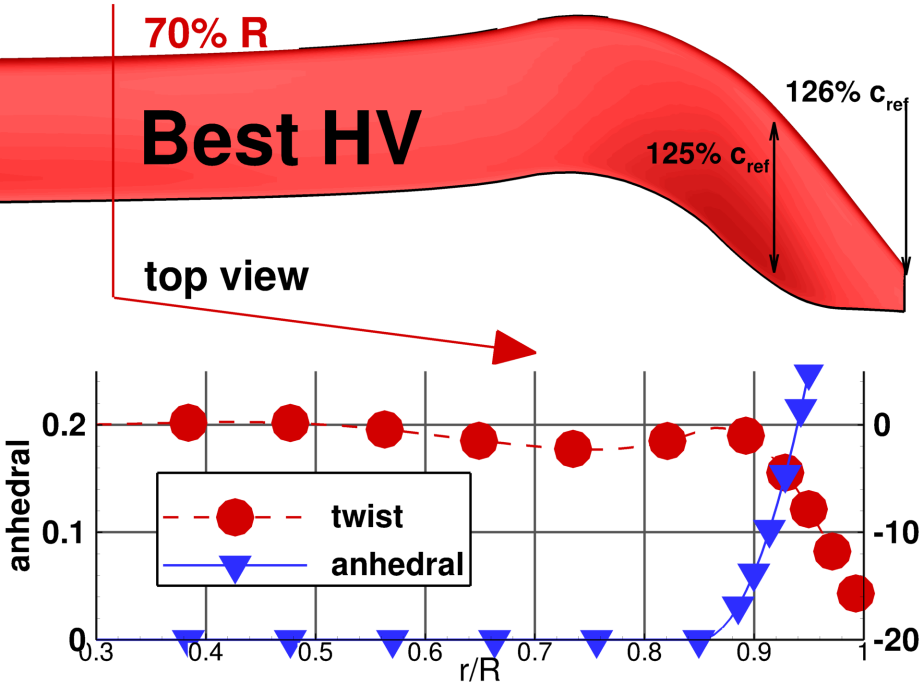

lift difference ($\Delta c_z M^2$)
torque difference ($\Delta c_q M^3$)
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
r/R

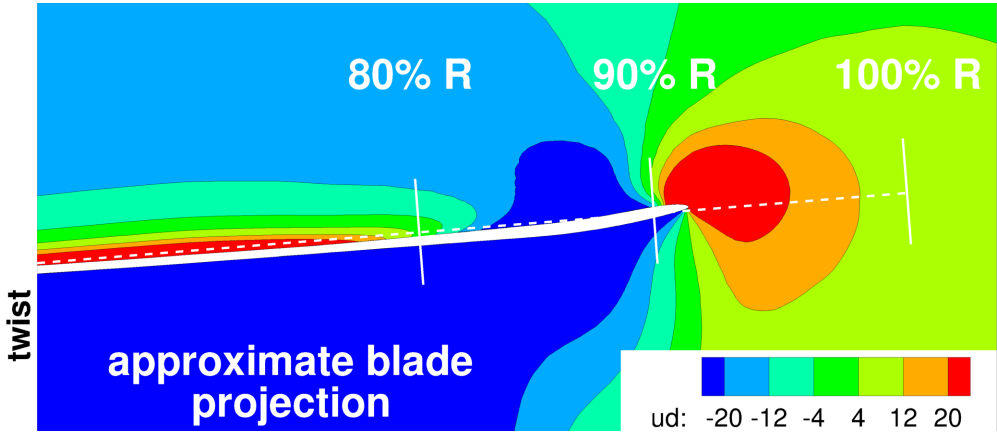

70% R
Trade-Off
87% c_ref
125% c_ref
top view
anhedral
twist
r/R
0.2
0.1
0
0
-10
-20
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

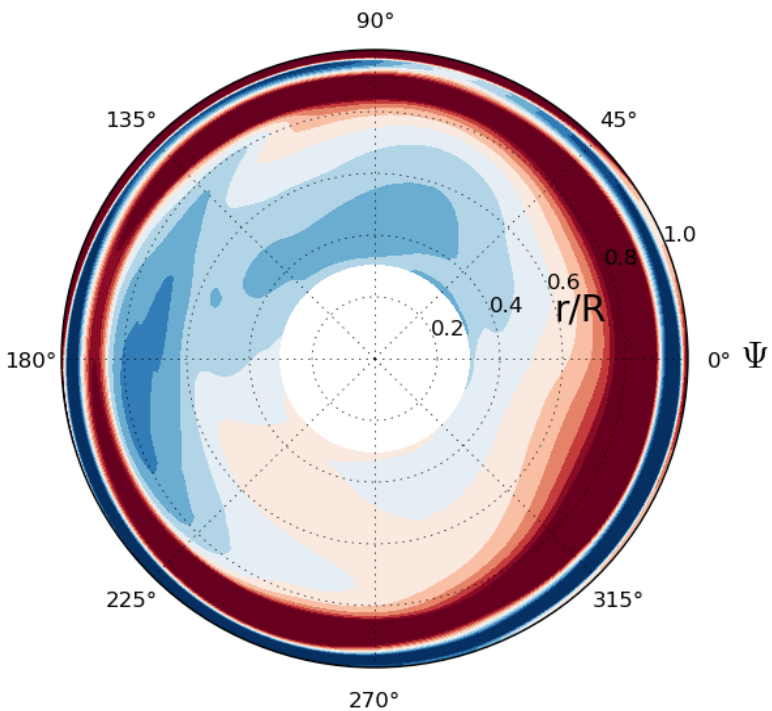

X
Z
Y

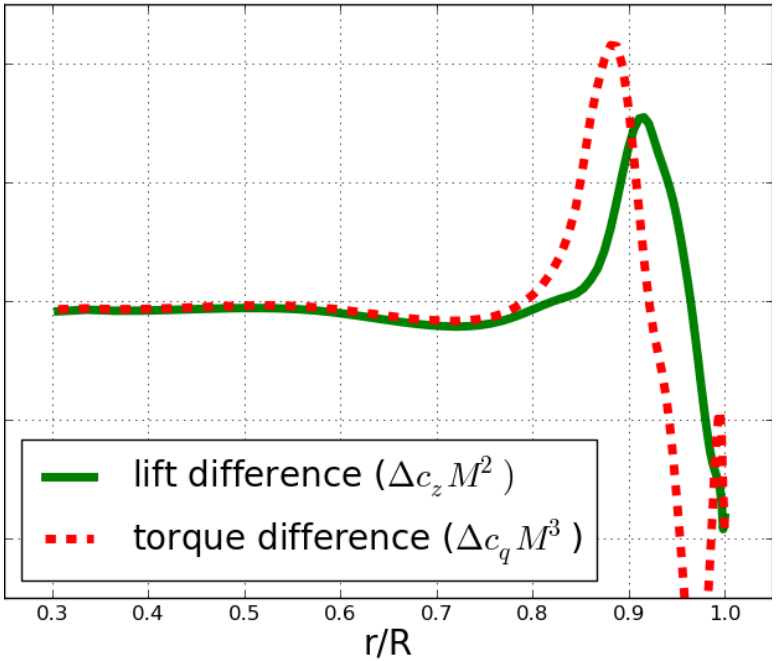

90°
135°
45°
180°
0°
Ψ
225°
315°
270°
r/R
0.2
0.4
0.6
0.8
1.0


lift difference ($\Delta c_z M^2$)
torque difference ($\Delta c_q M^3$)
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
r/R

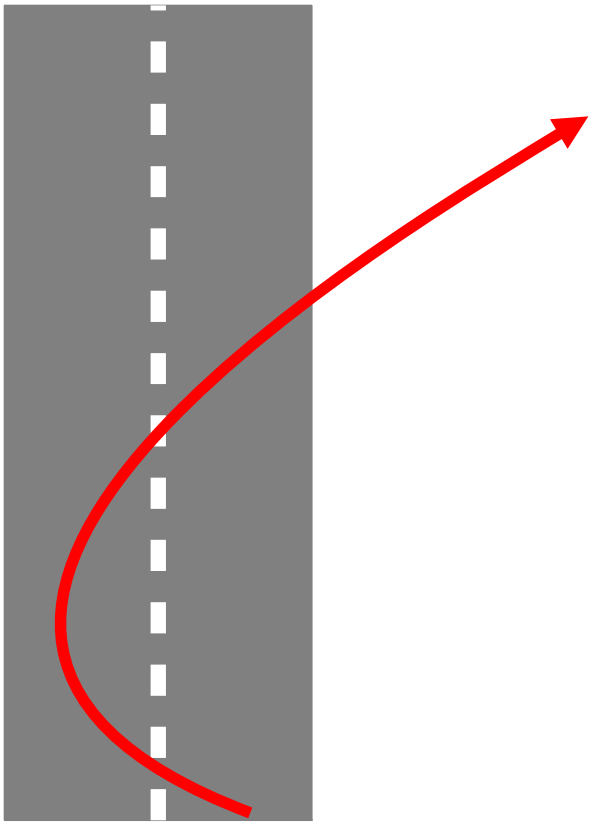

70% R
Best HV
126% c_ref
125% c_ref
top view
anhedral
twist
anhedral
r/R
0.2
0.1
0
0
-10
-20
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


80% R
90% R
100% R
twist
approximate blade projection
ud: -20 -12 -4 4 12 20

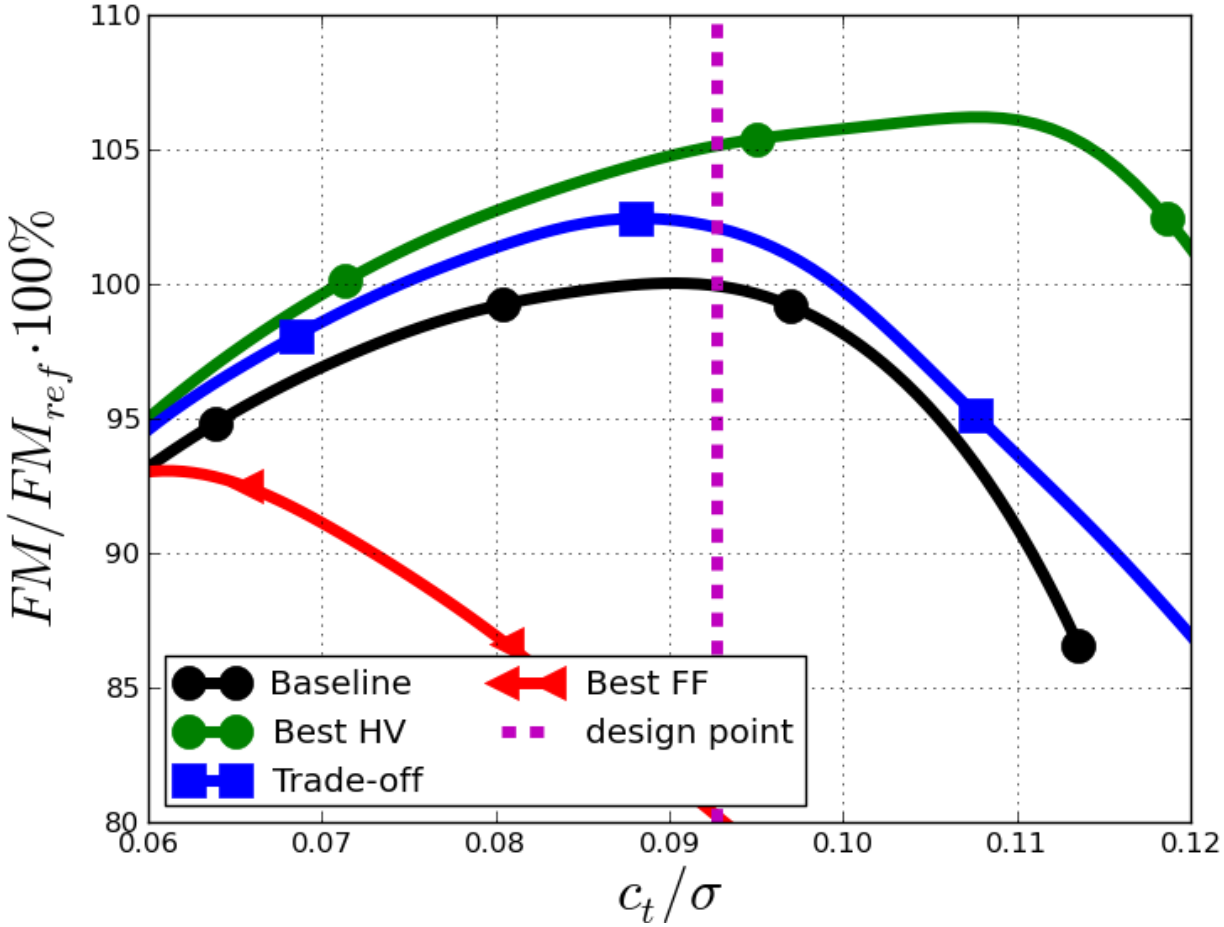

90°
135°
45°
180°
0°
Ψ
225°
315°
270°
r/R
0.2
0.4
0.6
0.8
1.0


lift difference ($\Delta c_z M^2$)
torque difference ($\Delta c_q M^3$)
r/R
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

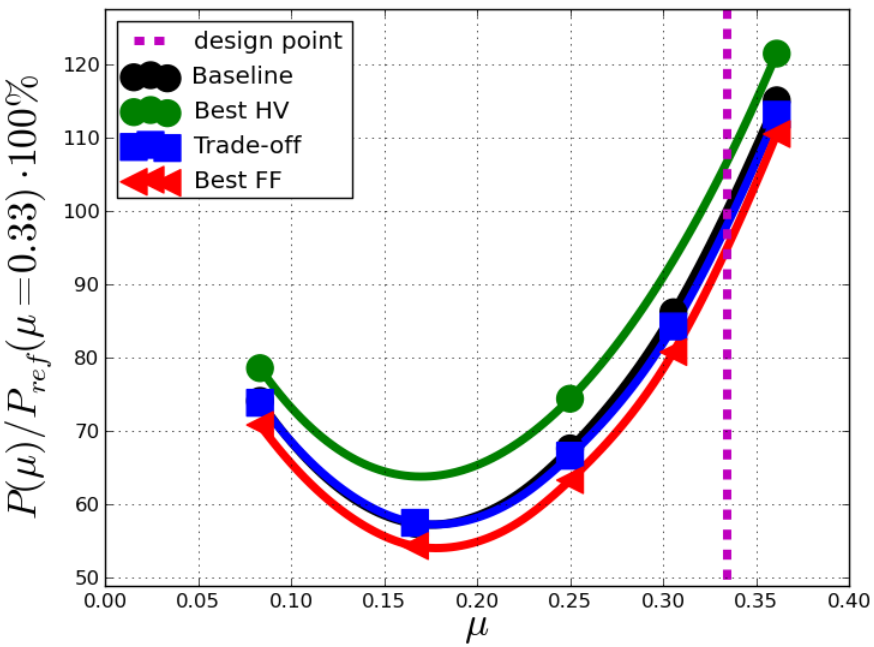
Off Design Analysis



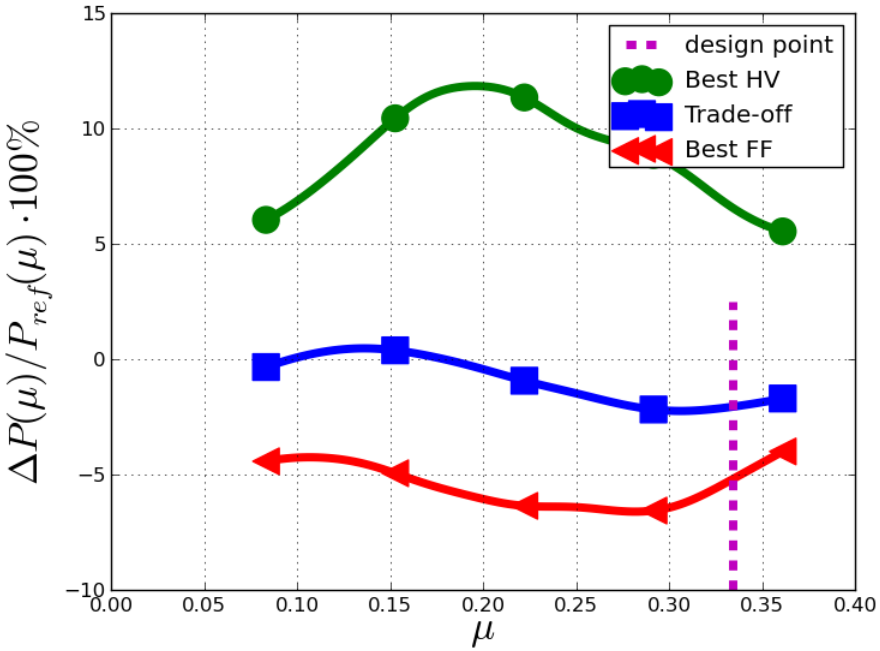
Thrust-FM Polar Hover



Advance Ratio-Power Polar Forward Flight



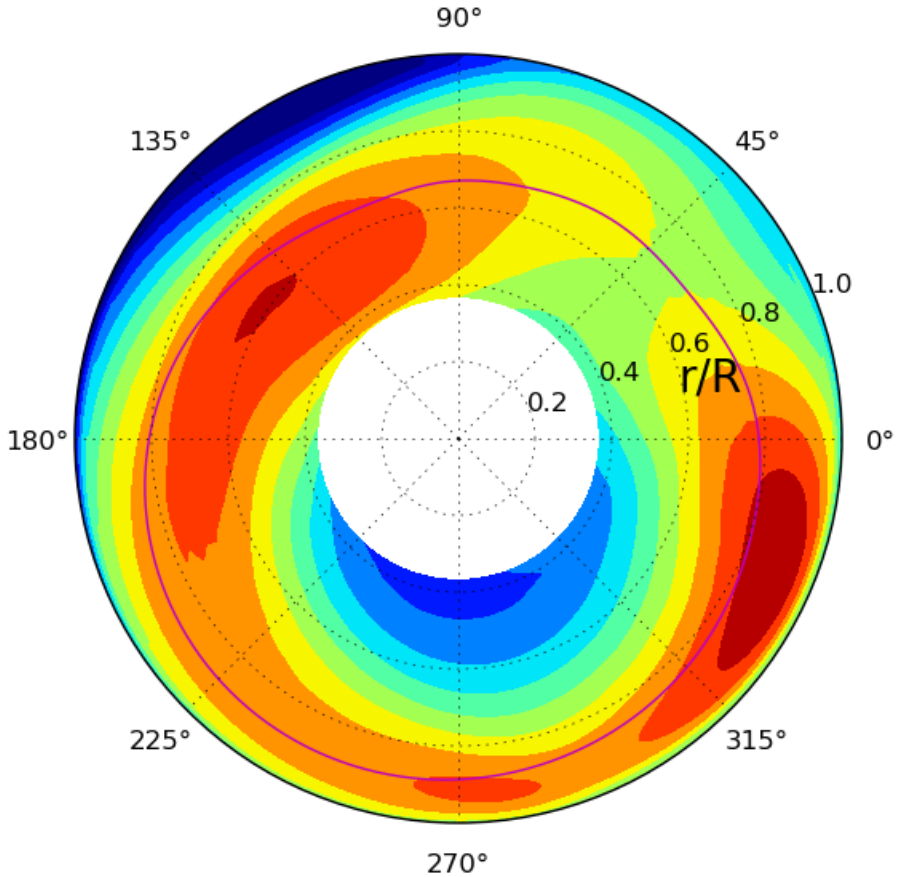
Absolute



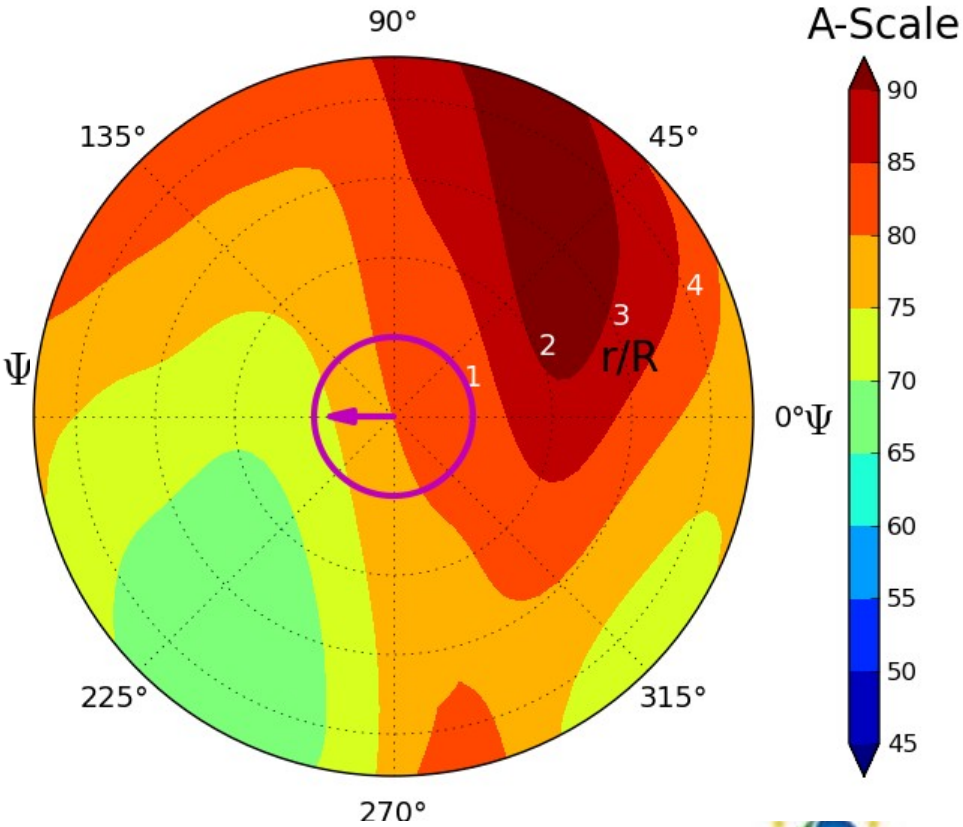
Relative

Acoustics of Reference Blade

Lift

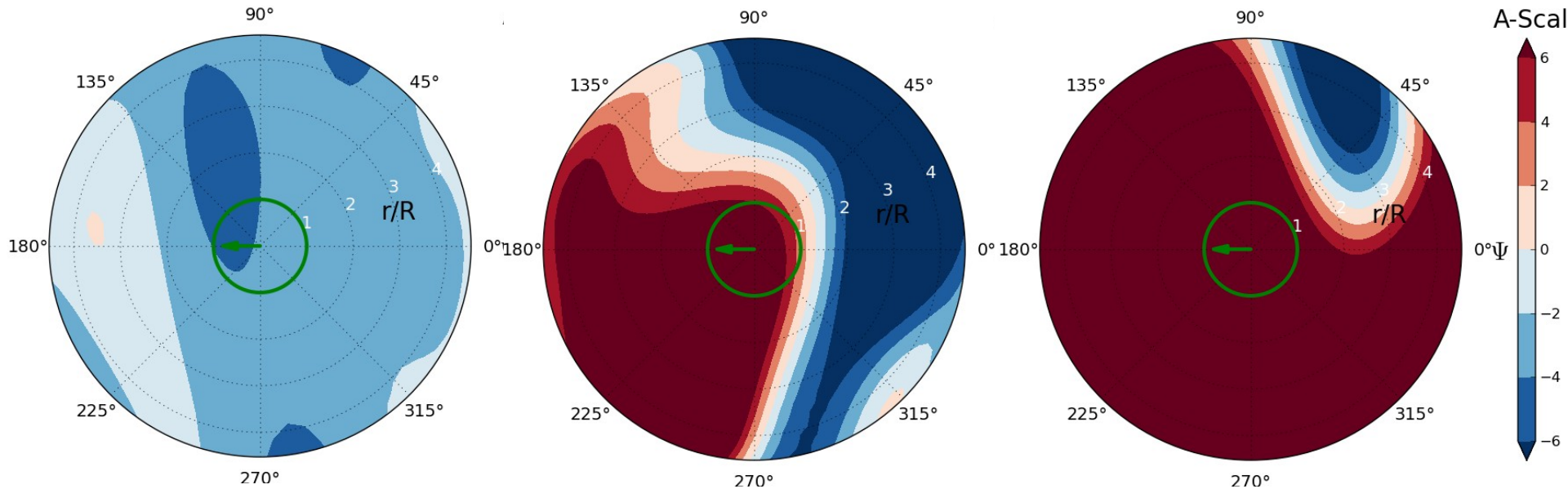


SPL



Acoustics of Selected Blades

Delta SPL



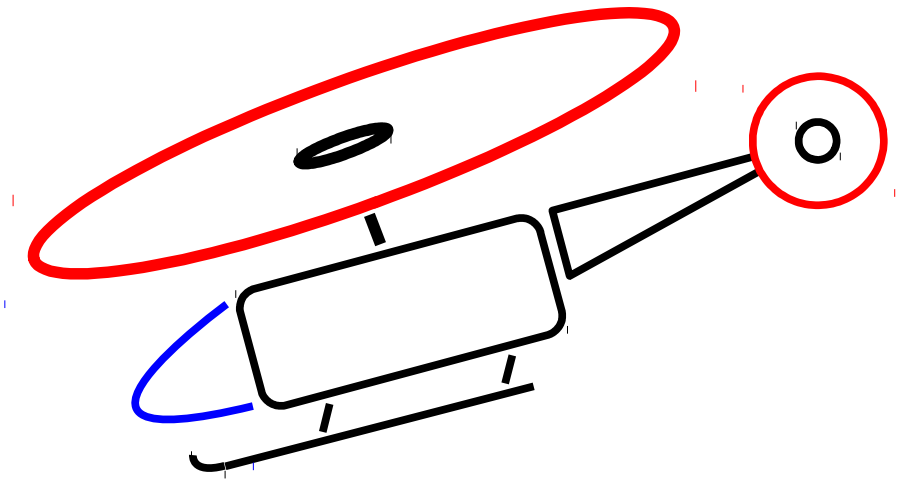
Overflight EPNL

-3.3 dB

-1.1 dB

9.5 dB

Conclusions



Conclusions

- 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!