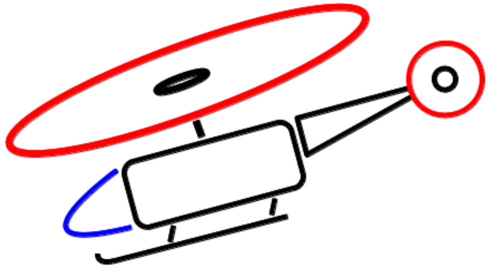
Quieter and Greener Rotorcraft: Concurrent Aerodynamic and Acoustic Optimization



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DLR

Motivation

- Current design cycles are still lengthy
- ERATO → Blue Edge ~ 20 years
- Still a need for quieter & greener helicopters
- CleanSky **1** GRC 1 – 5% power reduction + 10 dB noise reduction w.r.t to rotor blades of the year 2000 fleet
- DLR's VicToria aimed at accelerating the aerodynamic and aeroacoustic design through numerical optimization

AirbusHelicopters.com

https://www.cleansky.eu/green-rotorcraft-grc

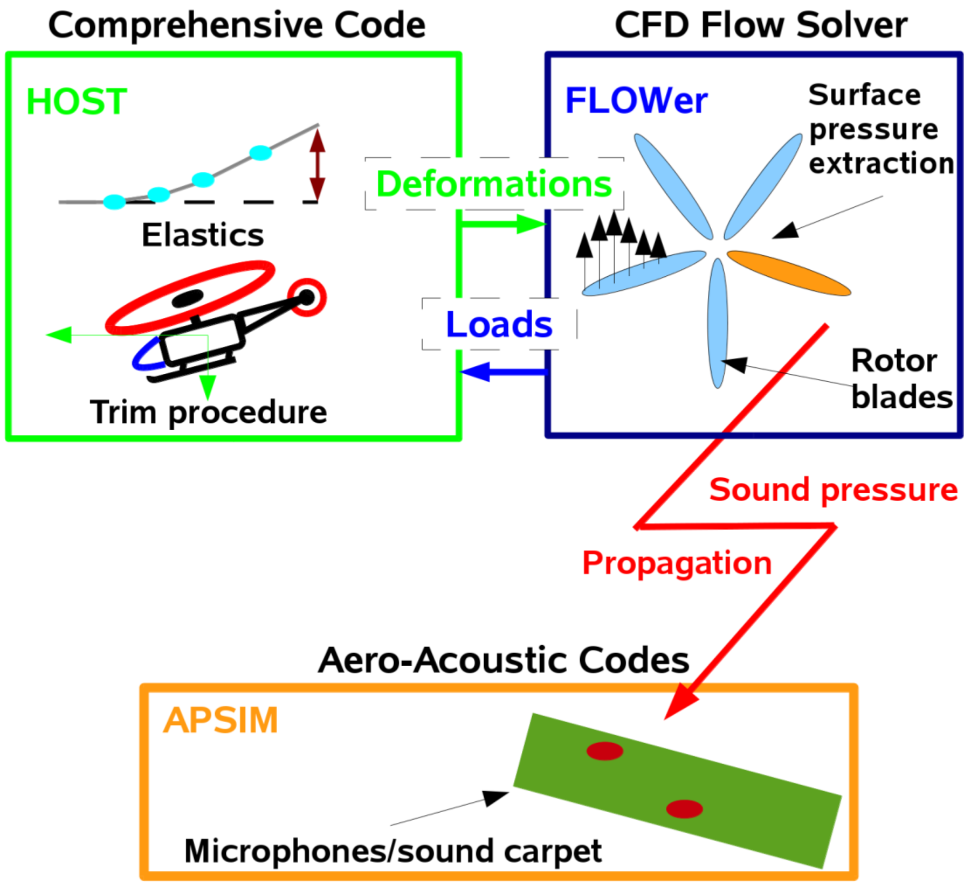
https://www.dlr.de/as/en/desktopdefault.aspx/tabid-11460/20078_read-47033/

Overview

- Simulation Methodology
- Validation
- Surrogate Based Optimization Process
- Optimization Results
- Off-Design analysis
- Summary & Outlook

Simulation Setup

- Fully coupled process: aerodynamics, elastics, flight dynamics & acoustics
- Use of comprehensive code HOST to compute trim settings & deformation
- Use of legacy CFD solver FLOWer for blade loads and acoustic surfaces (use of 4th order method & empirical transition prediction)
- FW-H code APSIM for acoustic “postprocessing”



Validation

- Three flight conditions investigated
  - Hover
  - Forward flight / cruise
  - Descent flight

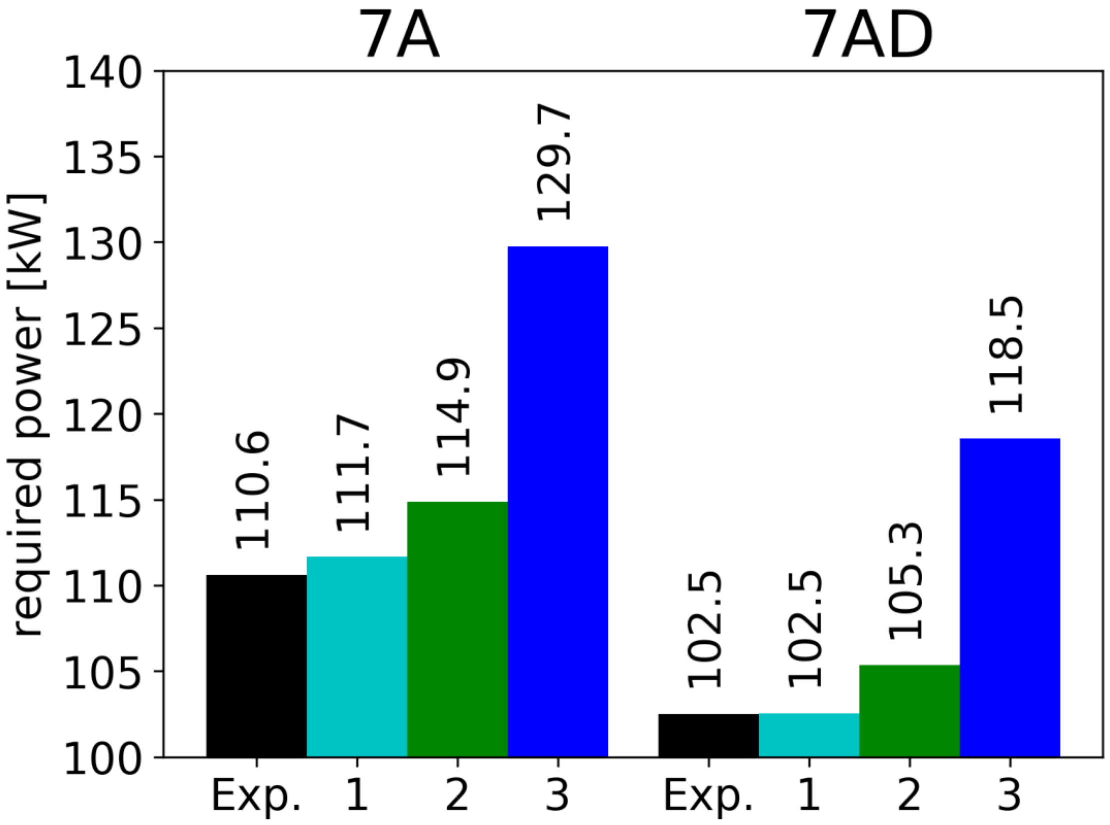
- Use of two mesh setups
  - Periodic mesh in hover with a single blade
  - Chimera setup with four blades and fuselage embedded in a background mesh

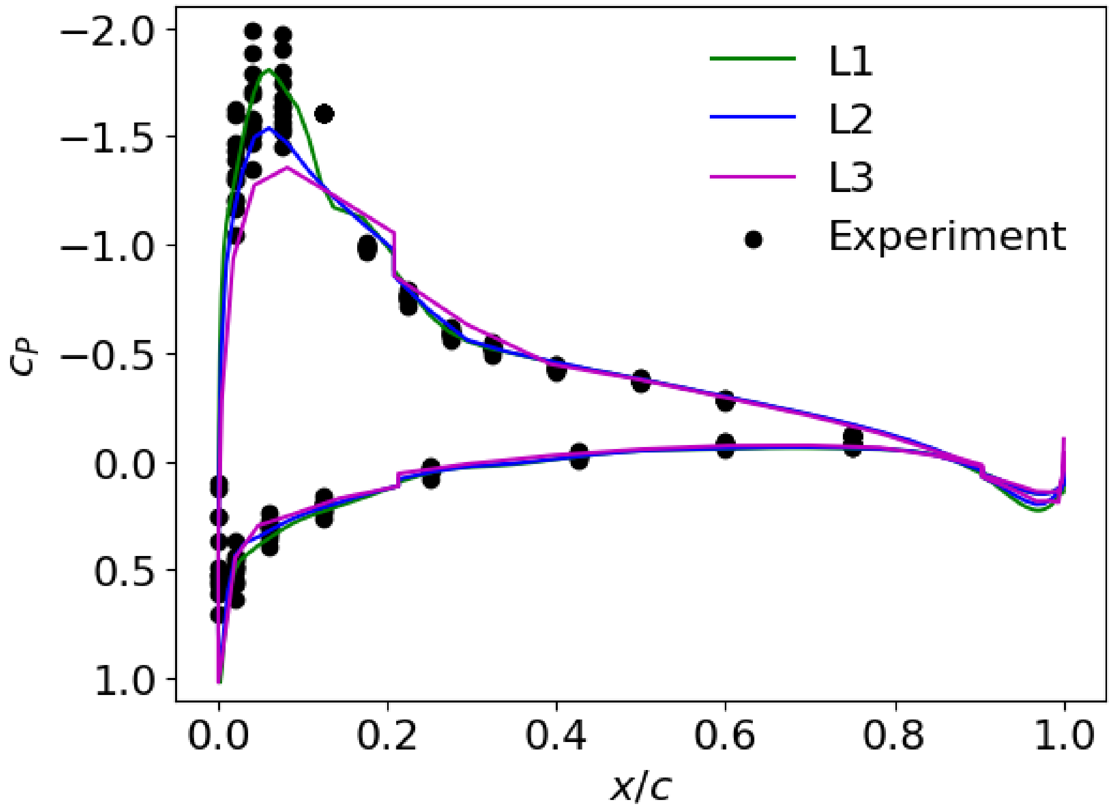
- Validation against various wind tunnel tests with up to three grid sizes

	Hover	Forward / descent flight
Blade	161x161x161 = 4.1e6	129x129x129 = 2.1e6
(embedded) Background	33x33x129 = 1.4e5	161x321x401 = 20e6
Fuselage	-	161x129x129 = 2.6e5
Total	4.4e6	3.2e7

Number of Grid points
On finest mesh (L1)

Validation: Hover

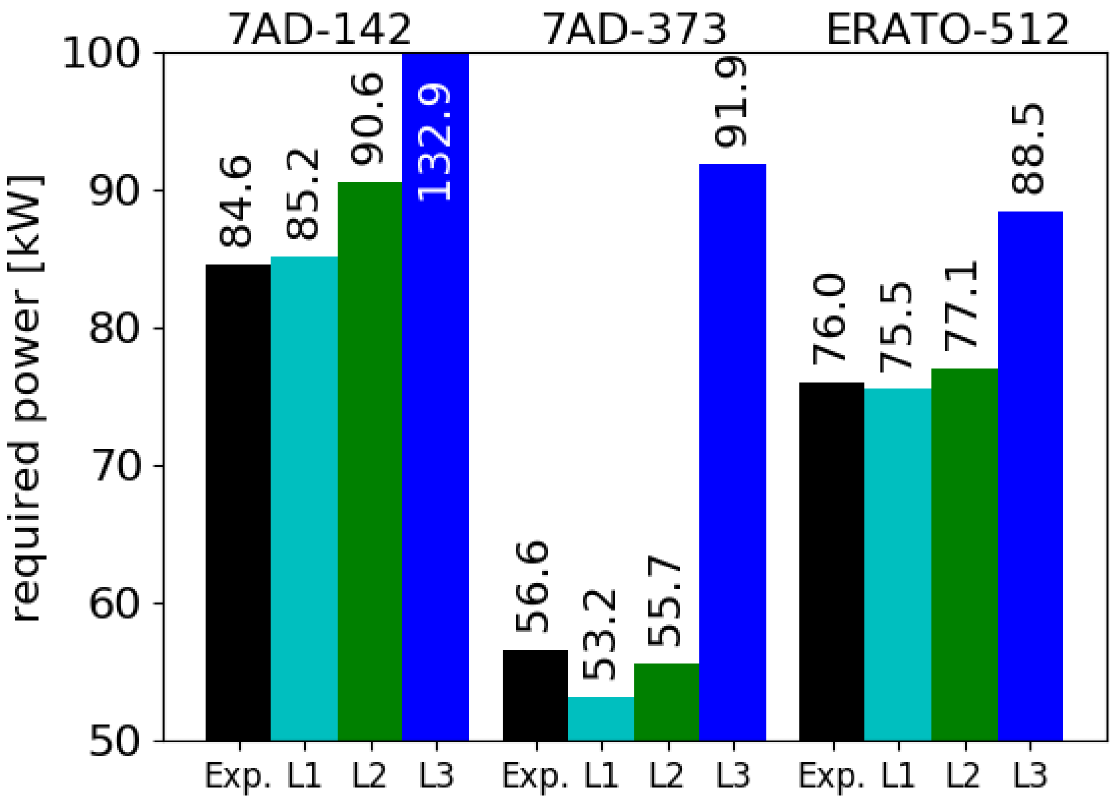




L1 solution match experiment well, L2 yields fair results, L3 too far off (each grid level skips one grid point in each direct w.r.t to the previous grid level)

Validation: Forward flight

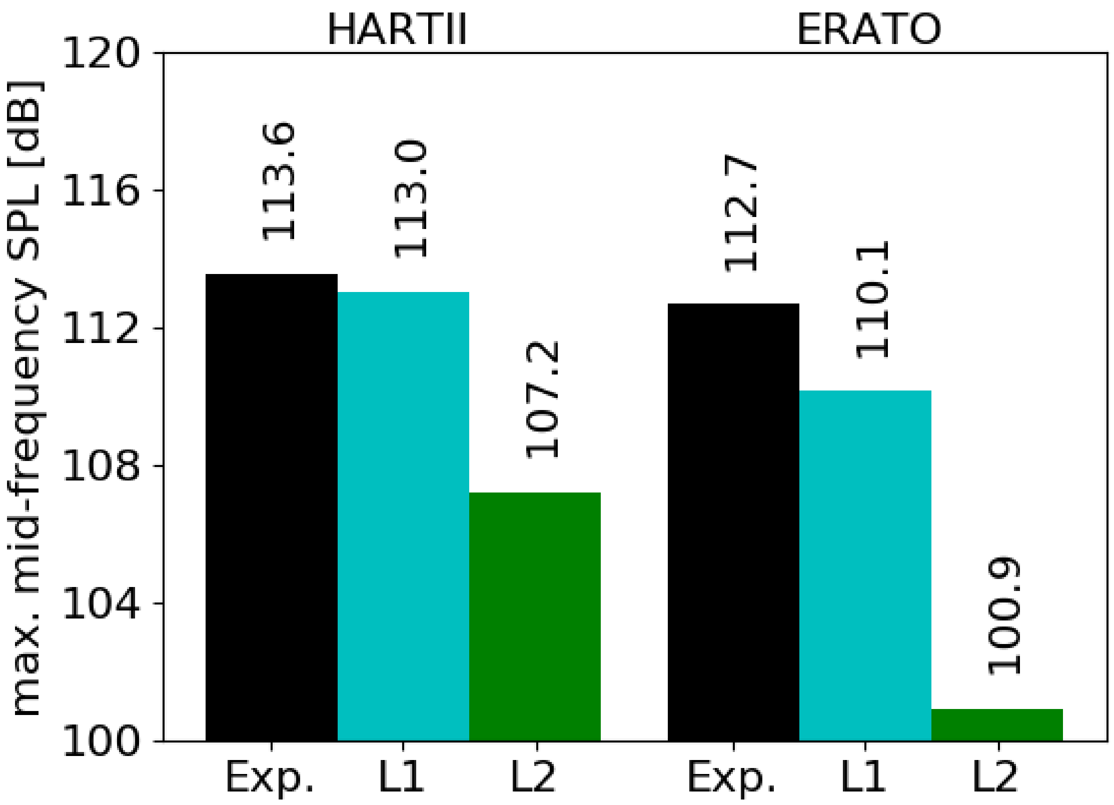
- 2 rotors and 3 flight conditions investigated
- L3 setup also drops the fuselage as not enough Chimera overlap exists anymore
- Again L1 mesh in matches relatively well, with L2 mesh delivering a fair result, L3 is far off



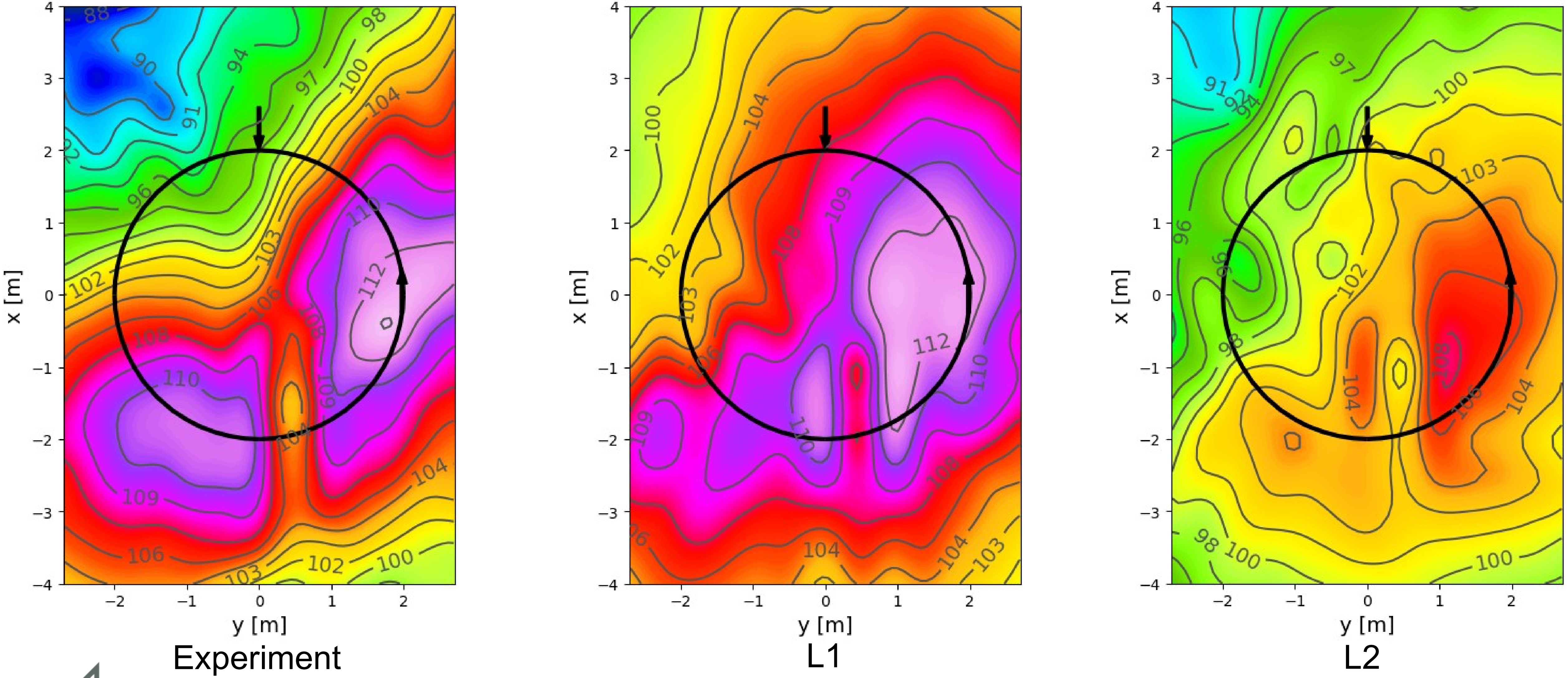
Runtimes: L1 1 week 320 cores, L2 2 days 64 cores, L3 10 hours 64 cores

Validation: Descent Flight

- Most noisy flight condition of current helicopter generations
- Noise is created when the blade pass the previous tip vortices parallel → quick change in AoA → fast pressure fluctuation
- Good vortex preservation necessary
- L3 grid not investigated as L2 grid already far off



Validation: Descent Flight

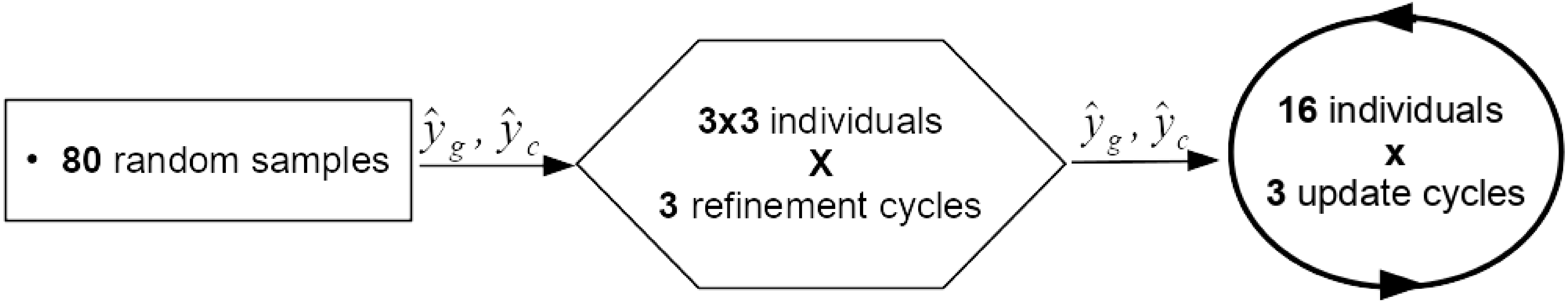


L2 delivers plausible w.r.t to directivity and the acoustic peaks

Surrogate Based Optimization Process

- Use of numerical approximation (surrogate models) to speed up optimizer
- Application of Differential Evolutionary Process to find Pareto front
  (multi-point & multi-objective optimization!)

Design of Experiments | **Goal function refinement** | **Update Cycle**



Parameters and Goals

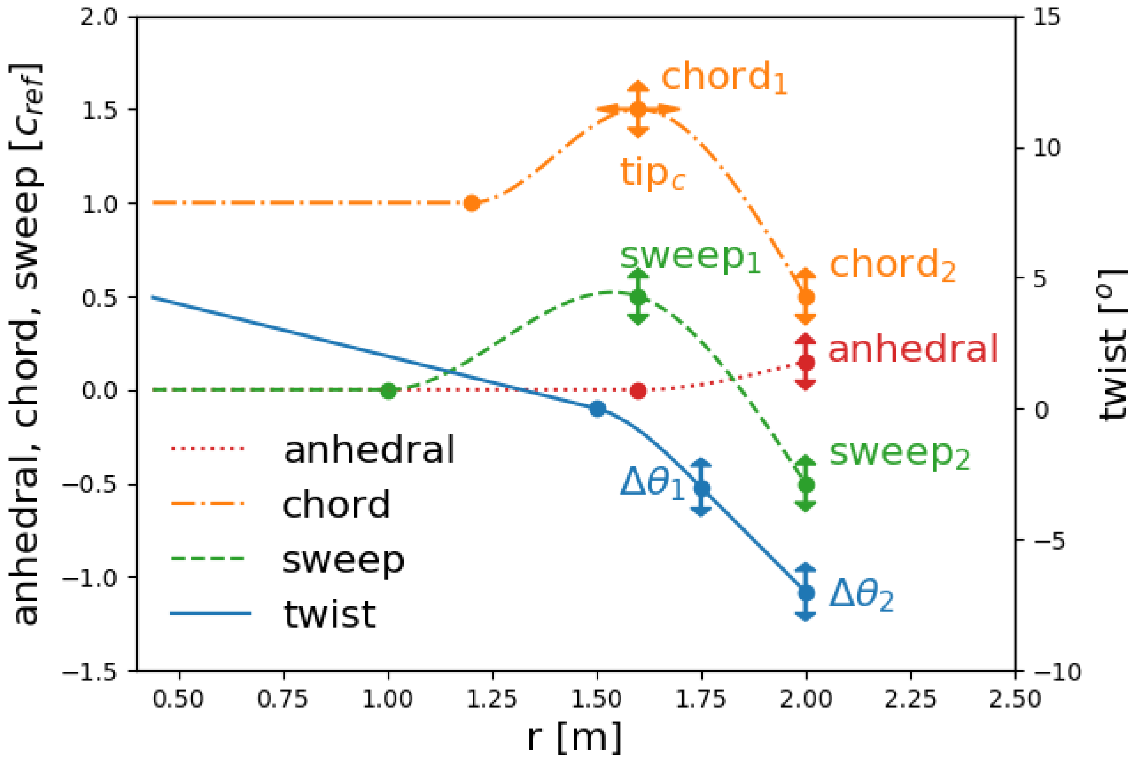
- HARTII rotor as reference blade (rectangular blade with linear twist)

- 8 design variables that determine the planform & twist of the blade

- Cubic spline parameterization

- 3 <u>independent</u> goal functions
  - Required power hover
  - Required power cruise
  - Emitted noise descent

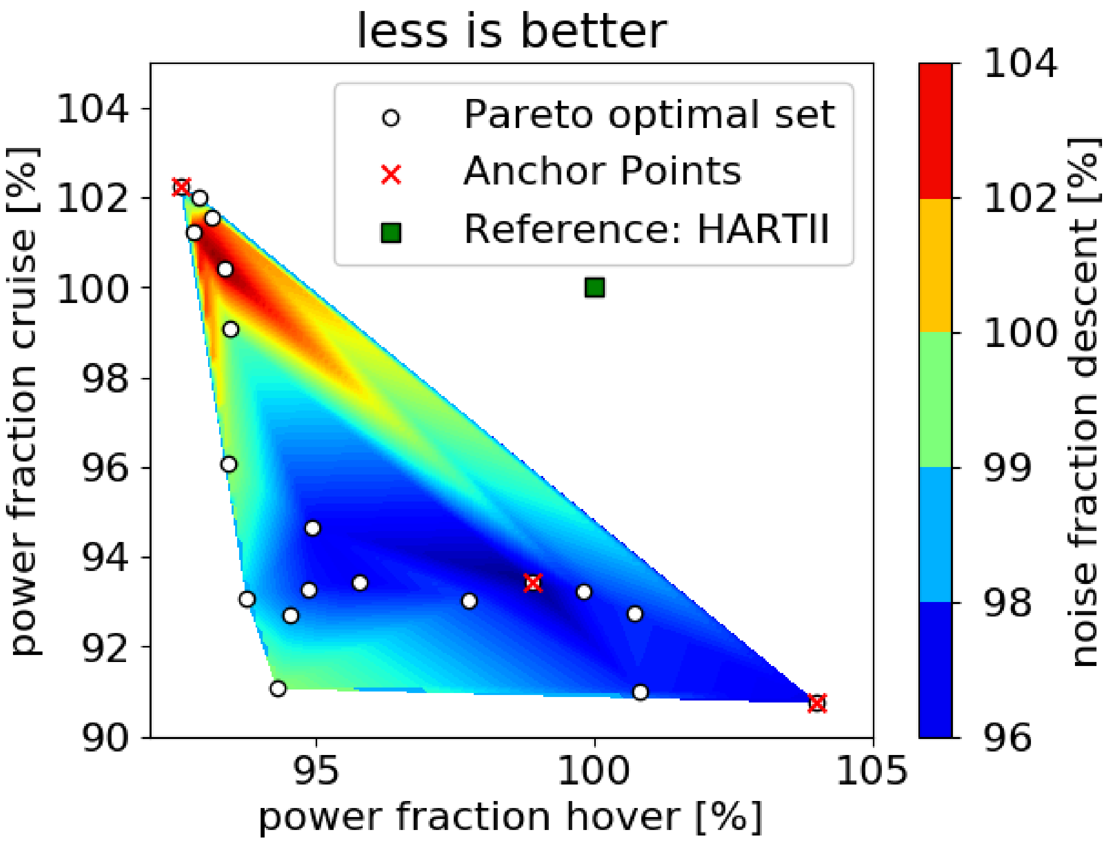
- 3 constraints
  - Eigenfrequencies
  - Noise in cruise
  - Maximal torsion in cruise



Quarter chord line parameterization

Optimization Results

- Evaluated 151 rotors
  - Untrimmable rotors
    - 1 in hover
    - 24 in cruise
    - 2 in descent
- 19 Pareto optimal rotors
  - 12 improve in all goal functions w.r.t to the reference blade
- 5 blades selected from front
  - The 3 anchor points
  - 2 trade-off designs



3D Pareto Front

Optimization Results – Best hover blade

- Recovered a winglet with a high-twist gradient at the tip, moderate forward sweep and taper
- Most improvement in hover, least in forward flight with a good noise reduction in descent flight
- Winglet is from a structural point of view questionable

Merits relative to baseline	Req. Power hover	Req. power cruise	Noise descent flight
	92.6 %	**102 %**	**97.6 %**

top view

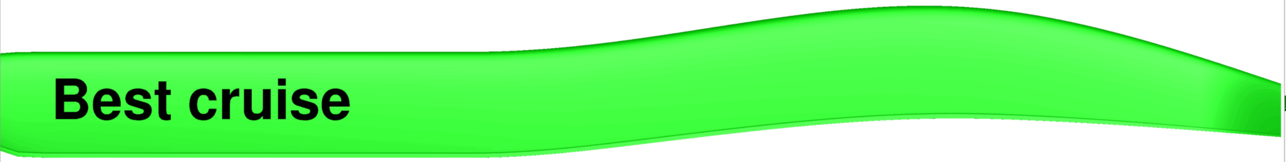
back view

Optimization Results – Best cruise blade

- Strongly reduced twist w.r.t to the hover blade, also the winglet has almost vanished.
  Yet stronger forward sweep and thicker inboard blade. Similar twist to baseline blade

- Best forward flight blade, also improves in descent flight, but sacrifices hover performance

Merits relative to	Req. Power hover	Req. power cruise	Noise descent flight
baseline	**104 %**	**90.2 %**	**96.7 %**



top view

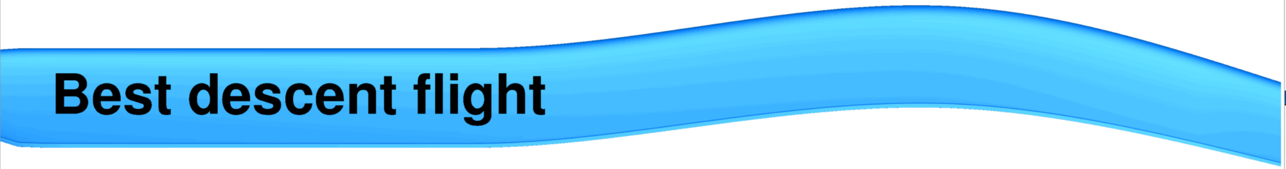
back view

Quietest descent flight blade

- Strong forward-backward swept blade with little change in chord length distribution. Twist in-between the hover and cruise blade – zero gradient at tip

- Quietest blade in descent flight, but also improves in hover and forward flight. Already a good trade-off blade itself

Merits relative to	Req. Power hover	Req. power cruise	Noise descent flight
baseline	**98.9 %**	**92.8 %**	**96.1 %**



top view

back view

Trade-off blades

- Small changes in geometry between them → small changes in goal functions → smooth region of Pareto front

- Improve in both flight conditions

trade-off	Req. Power hover	Req. power cruise	Noise descent flight
hover	**93.8 %**	**92.7 %**	**98.1 %**
cruise	**94.9 %**	**92.5 %**	**97.1 %**

top view

back view

top view

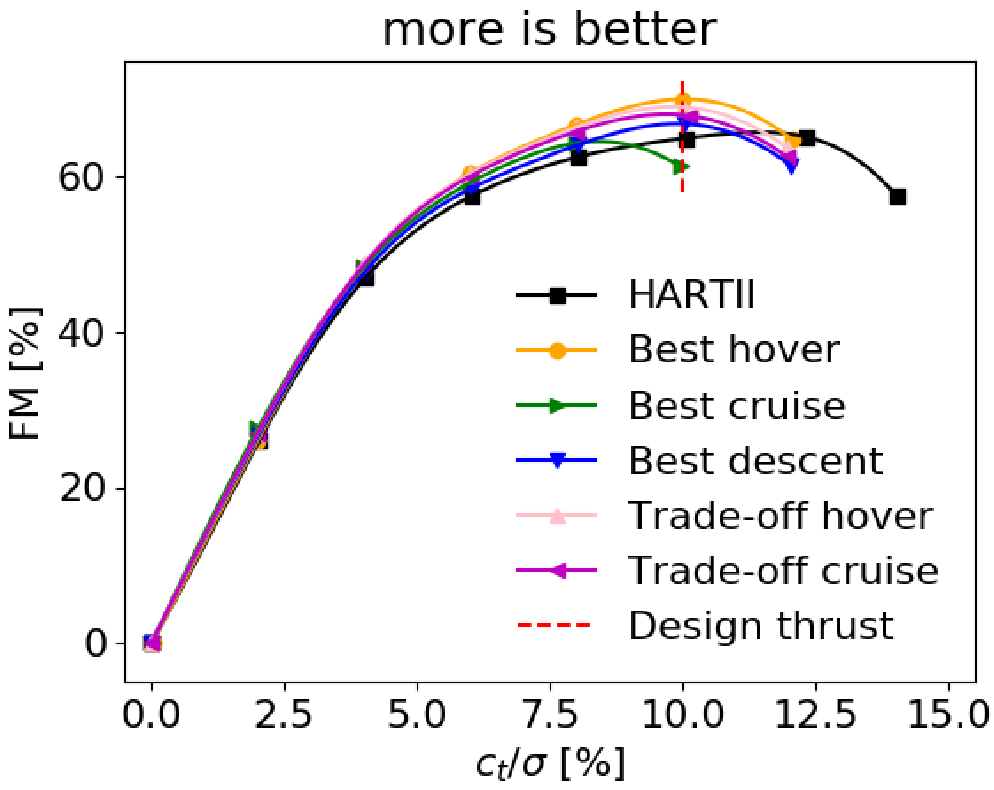
back view

Off-design analysis: Hover

- Except for the cruise blade, all blades improve in hover w.r.t to the baseline blade

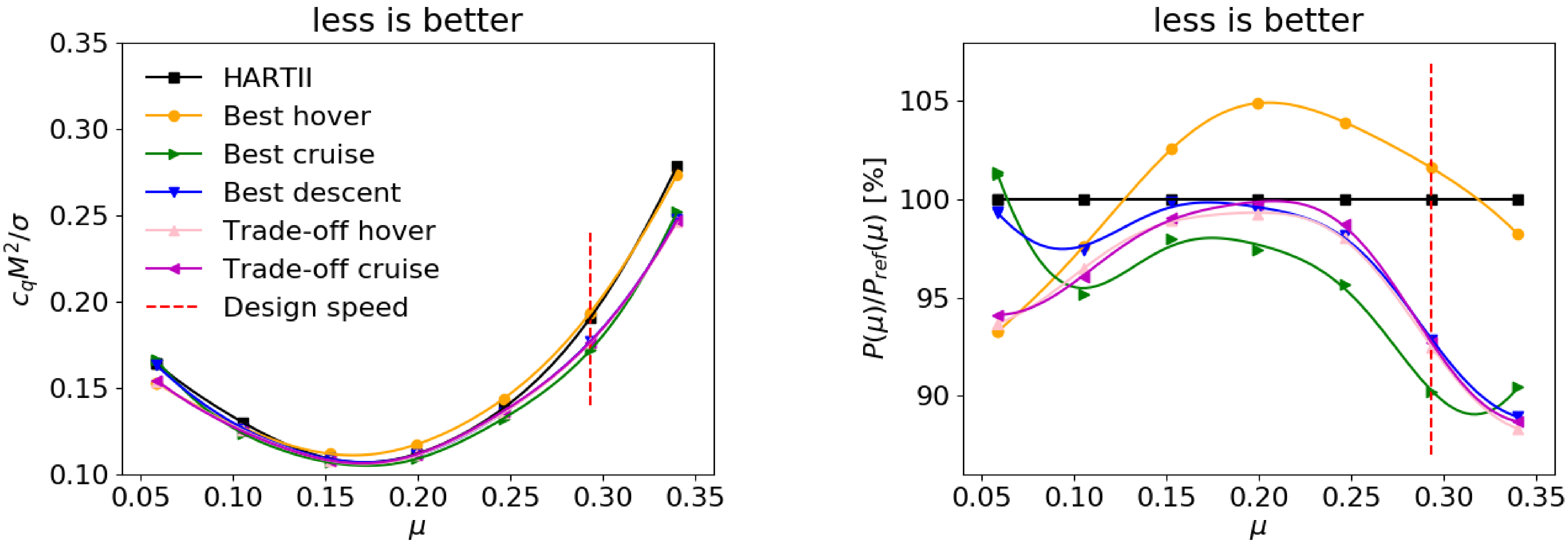
- However, point design, after design thrust they drop-off in performance

- Likely the thrust/weighted solidity 'ensured' this – in GRC it was set free and therefore good hover blades had an increased chord length giving them a wider area of improvement



FM = figure of merit is ideal power requirement over actual power requirement

Off-design Analysis: Cruise



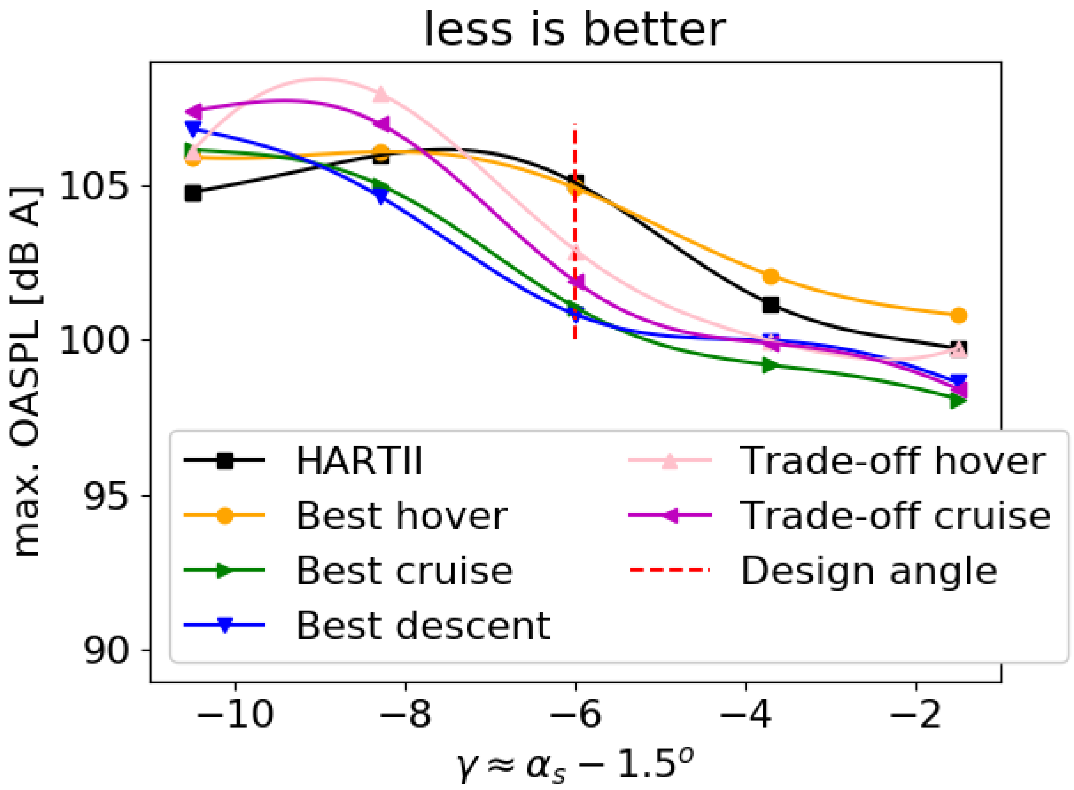
- Except for the hover blades, all blades reduce the power requirement in forward flight
- At intermediate advance ratios, only the cruise blade is superior → better climb capability

Off-Design Analysis: Descent flight

- At the design point, all blades are quieter than the baseline blade

- At lower descent angles, all blades are quieter than the baseline blade

- At the steepest descent angle, the baseline blade becomes the quietest blade



Summary & Outlook

- Successfully validated the optimization setups against various rotors
- Applied a multi-objective surrogate based optimization approach to concurrently optimize 3 goal functions with 3 constraints
- Retrieved 19 Pareto optimal designs – 5 investigated in more detail
- Off-Design analysis revealed that the parameterization might need to be revisited and that more flight conditions need to be included (simple Uncertainty Quantification – the average of 3 variations for each flight condition)
- Inclusion of more disciplines is planed in the next project UrbanRescue:
  dynamics considerations & manufacturability of the blade