New Technologies for Green Rotorcraft
GRDC Symposium 2011
Seoul, 15th November 2011

K. PAHLKE

Head DLR Rotorcraft Programme

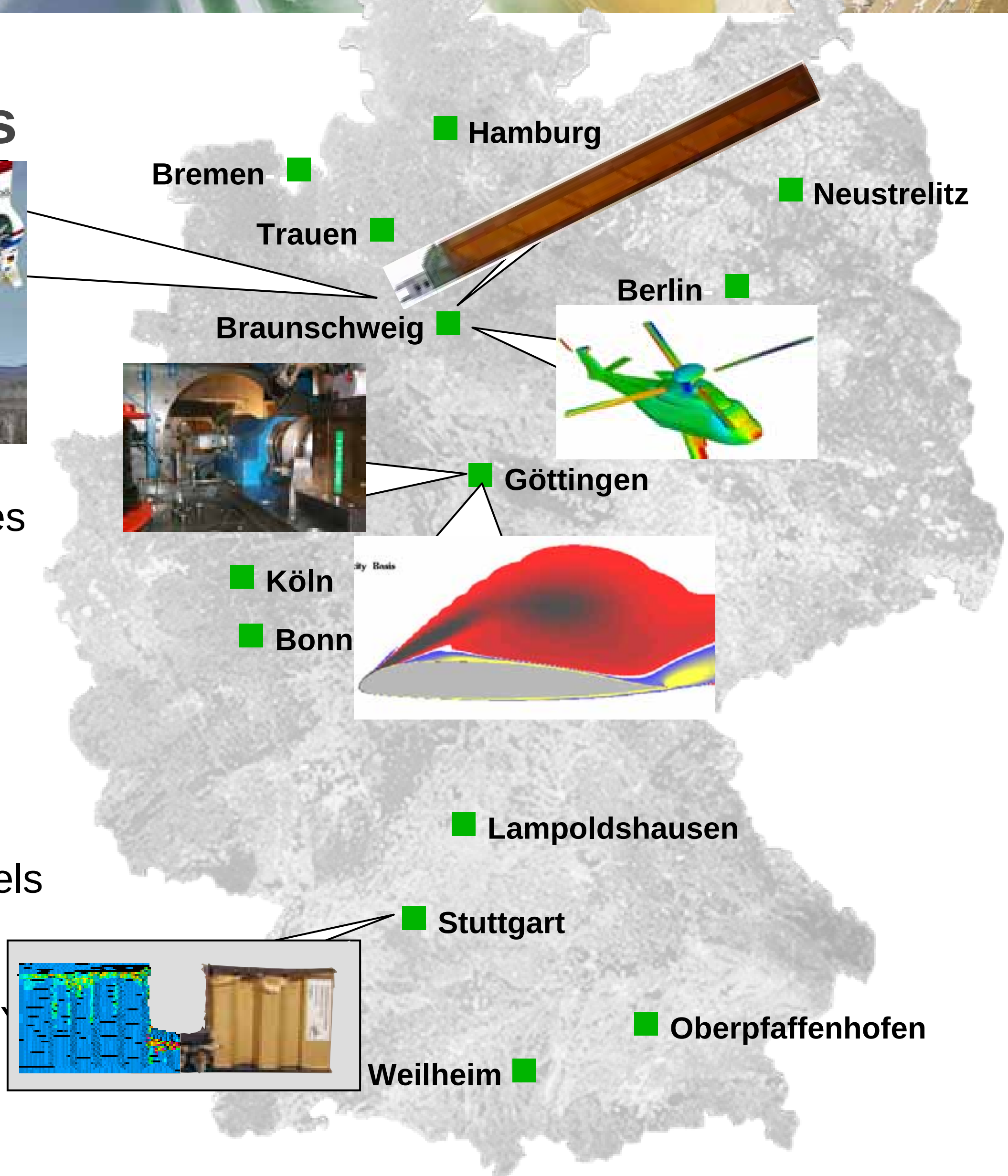
Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Outlook

- Overview on DLR Rotorcraft Research Programme in Cooperation with Onera
- Main Topics for “Greening” Rotorcraft
- Selected Examples of Results
  - Airfoil Design
  - Rotor Optimization
  - Noise Prediction
  - Design of Noise Abatement Flight Procedures
  - Fly by Wire with Active Sidesticks
  - Active Rotor Control (Cooperation with Korea (Konkuk and KARI))
- Conclusion

DLR One of The Two Largest National Aerospace Research Centers in Europe

DLR Research Centers and Helicopter Activities



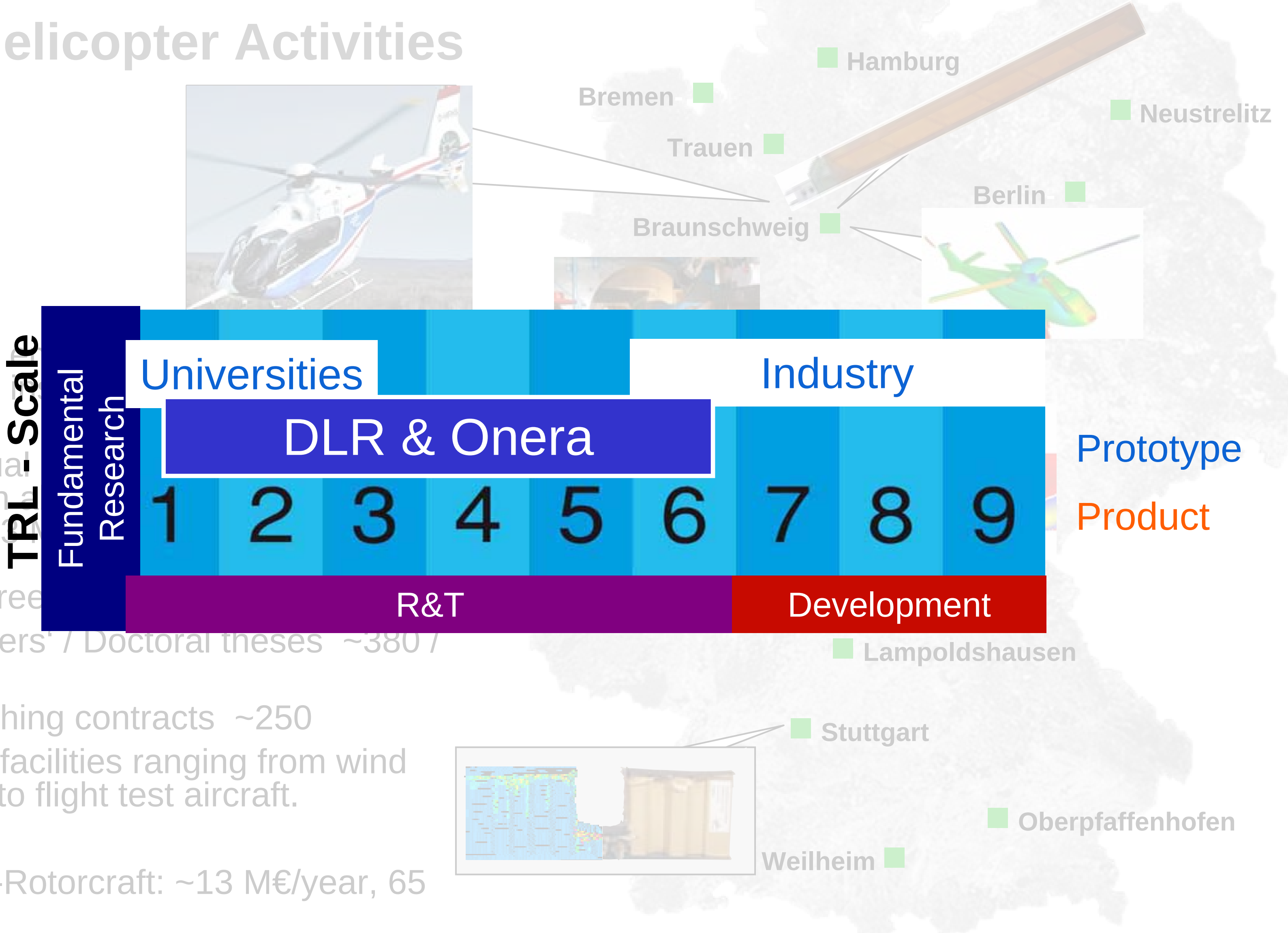
- 6500 employees working in 29 research institutes and facilities at 13 sites
- Annual budget for research and operation about 750 M€, for Aeronautics about 173 M€.

- Referee publications ~500 / year
- Masters' / Doctoral theses ~380 / 90
- Teaching contracts ~250
- Test facilities ranging from wind tunnels to flight test aircraft.

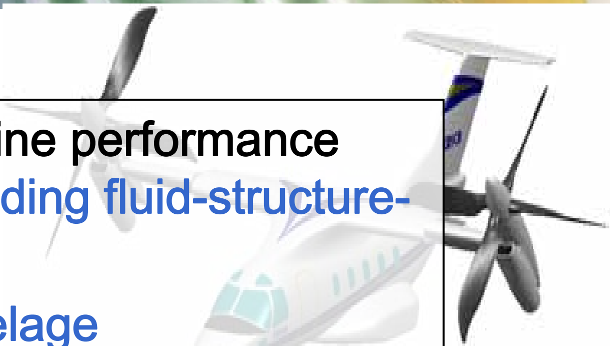
- DLR-Rotorcraft: ~13 M€/year, 65 PY/
- about same volume for Onera.

DLR Research Centers and Helicopter Activities

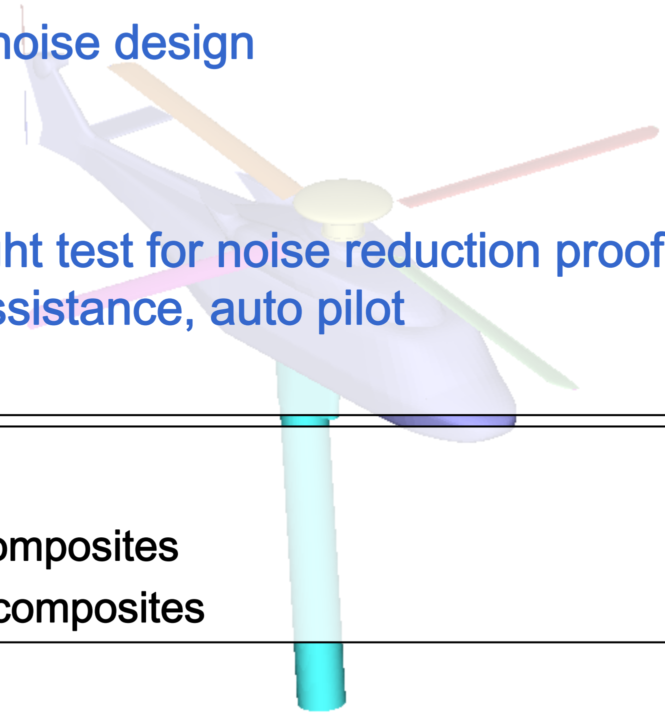
- 6500 ... research ... sites
- Annual ... operation ... about 17...
- Referee...
- Masters' / Doctoral theses ~380 / 90
- Teaching contracts ~250
- Test facilities ranging from wind tunnels to flight test aircraft.
- DLR-Rotorcraft: ~13 M€/year, 65 PY/Y
- about same volume for Onera.



“Greening” Rotorcraft



Fuel Consumption ➔ Aerodynamics, engine performance
Drag reduction using CFD tool chain including fluid-structure-coupling
CFD-based optimization for rotor and fuselage
WT tests for performance proof



Noise, Vibrations ➔ Aeroacoustics, rotor and fuselage dynamics, flight mechanics, pilot assistance
numerical noise prediction methods for low noise design
Active rotor control ➔ active blades
WT test for noise reduction proof
Design of low noise flight procedures ➔ Flight test for noise reduction proof including flight guidance methods for pilot assistance, auto pilot
internal noise reduction (Onera)

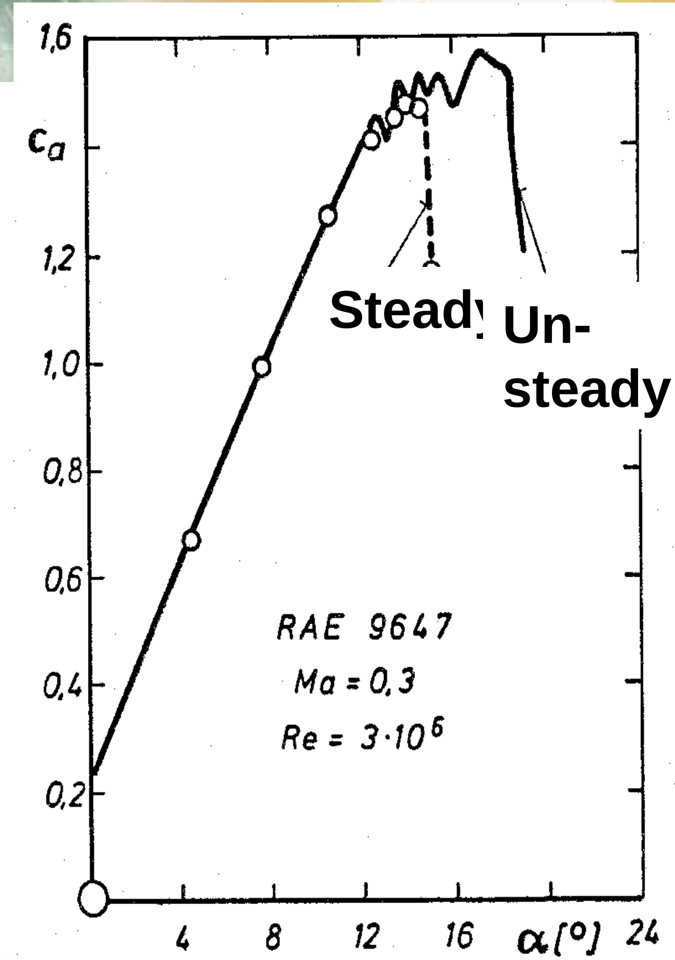
Green production technologies:

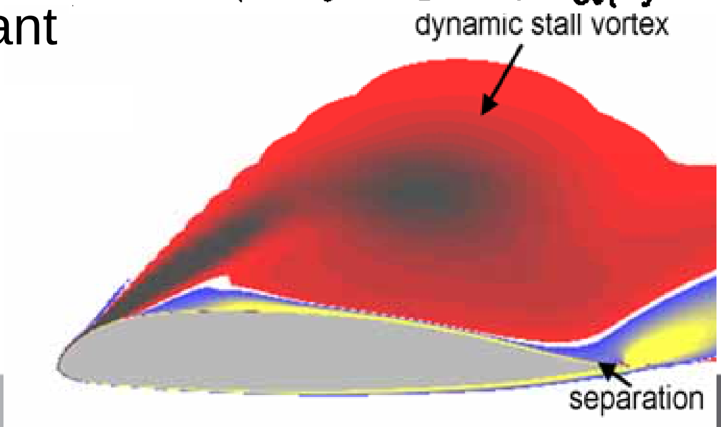
crash modeling tools, composite behavior, new composites
greener and efficient production technologies for composites

Airfoil Design Including Unsteady Criteria

Background:

- All rotors of today’s flying helicopters are based on airfoils which where designed and tested with purely steady criteria.
- During flight test it turned out that some modern airfoils produce extremely high pitching moments which are orders of magnitude higher than the maximum pitching moments in steady flow.
- ➔ Airfoils had to be discarded or significant mods for rotor control system needed resulting in additional weight / costs.





Airfoil Design Including Unsteady Criteria

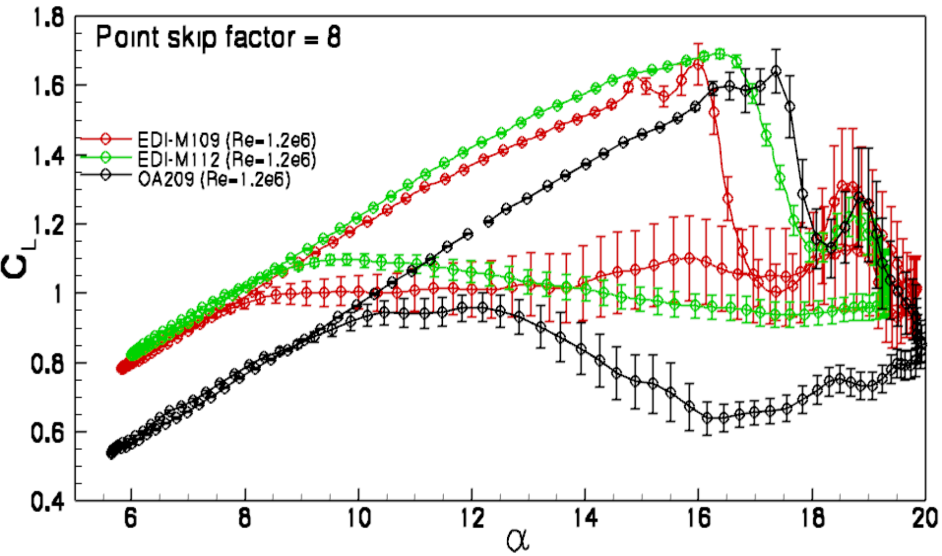
Task:

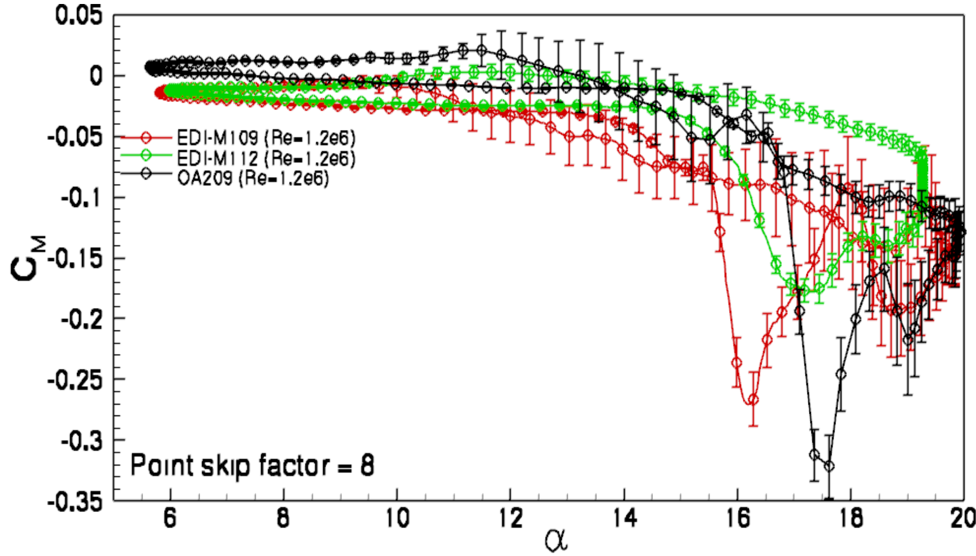
- Design and test a new main rotor airfoil family (EDI-M1XX) in a cooperation between Eurocopter Germany, DLR, and IAG
- As part of the development program, the dynamic stall properties of the new airfoils were considered in the design phase.

Airfoil Design Including Unsteady Criteria

Results:

- EDI-M109 and EDI-M112 were designed with CFD Tools and tested in the Transonic Wind Tunnel of DLR in Göttingen.





EDI-M109 20% increase in lift with 20% reduction in pitching moment peak and reduction in drag (not shown here) compared to OA209.

M=0.31, Re=1.2e6, f =5.7 Hz, $\alpha=13^o \pm 7^o$

Rotor Optimization

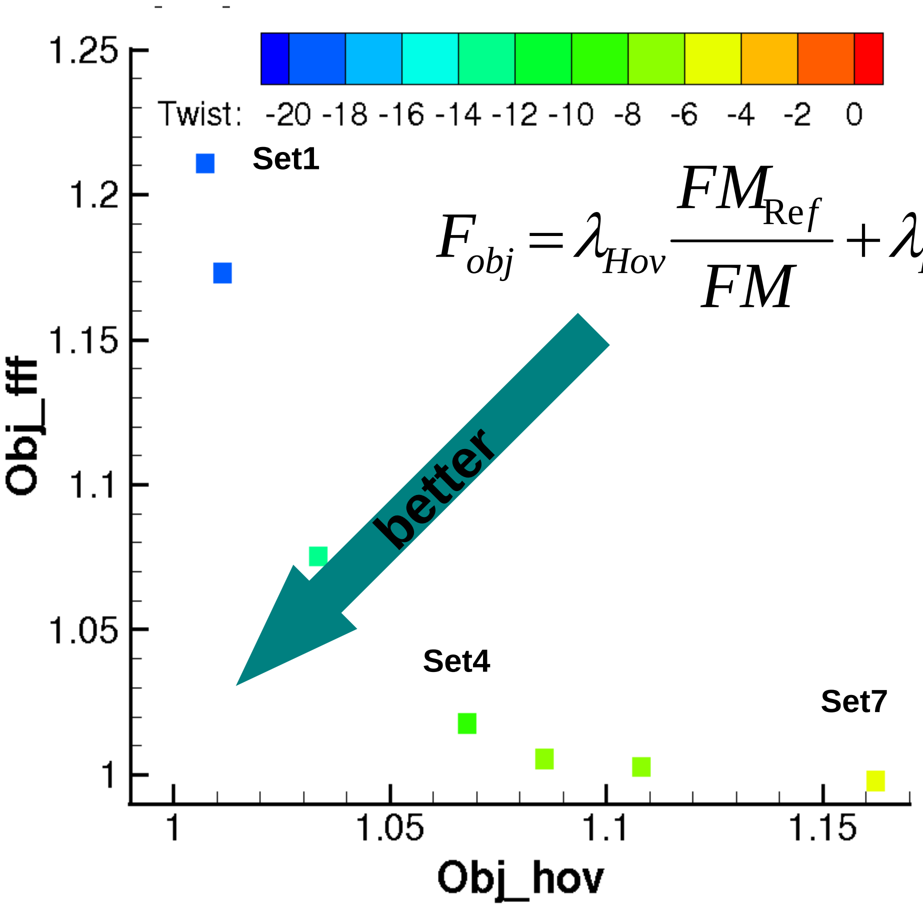
Background:

- **Because of the extremely complex and unsteady flow around a rotor in forw. flight, it was impossible to compute rotor performance with sufficient accuracy based on first principles. In the last decade CFD methods reached a level which allows to apply these methods for rotor optimisation.**

But:

- **What is <u>good for hover</u> is usually <u>bad for forward flight</u>!**
- **High twist ➔ high hover performance**
- **High twist ➔ low forward flight performance and high vibrations and high control loads**

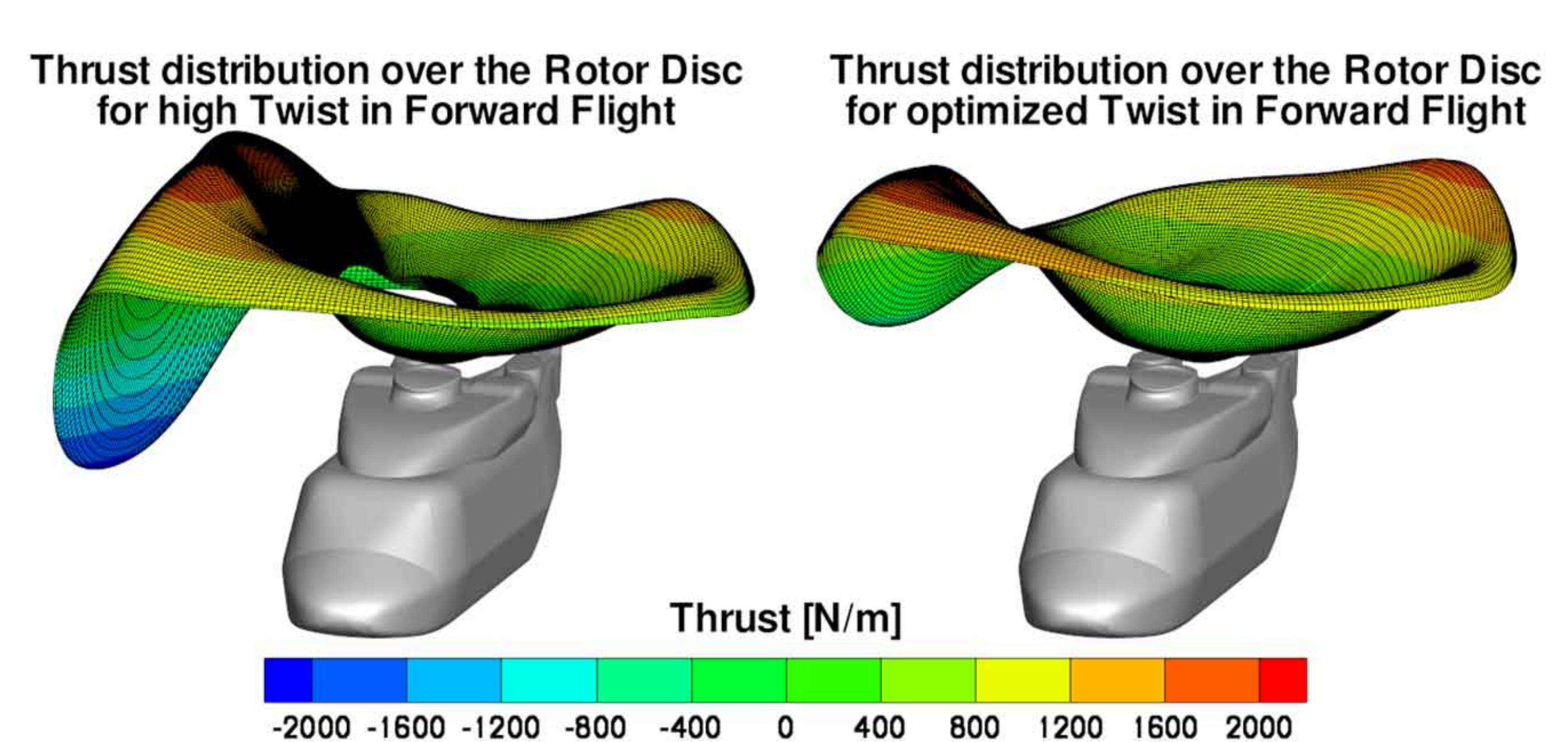
Example: Optimization of Twist in Hover and Forward Flight based on 3D CFD methods including fluid-structure-coupling



$$F_{obj} = \lambda_{Hov} \frac{FM_{Ref}}{FM} + \lambda_{FF} \frac{c_q}{c_{q_{Ref}}}$$

Optimization framework is available and tested. Next step is the application with several design variables (twist, sweep, anhedral, variation of blade chord, etc.).

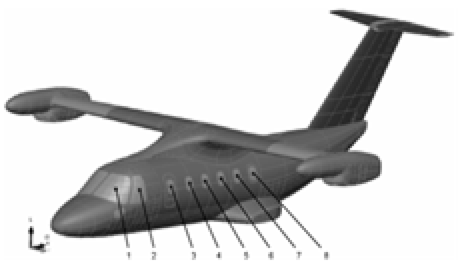
For pure hover and pure forward flight the reference values of -20° and -6° are reached.

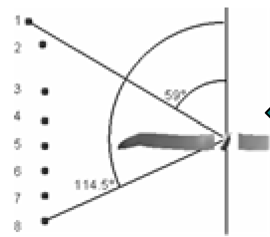


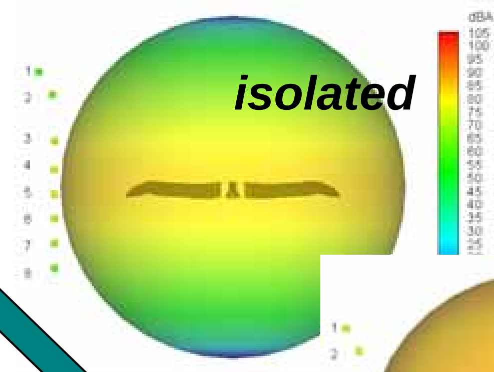
- Performance optimization of a main rotor in forward flight taking into account the fluid-structure interaction and trim
- Thrust distribution shows high loading peaks in case of highly twisted rotor especially on the advancing side
- Performance improvement between high twist (-15.1°/R) and optimized twist (-5.3°/R) makes up 10%

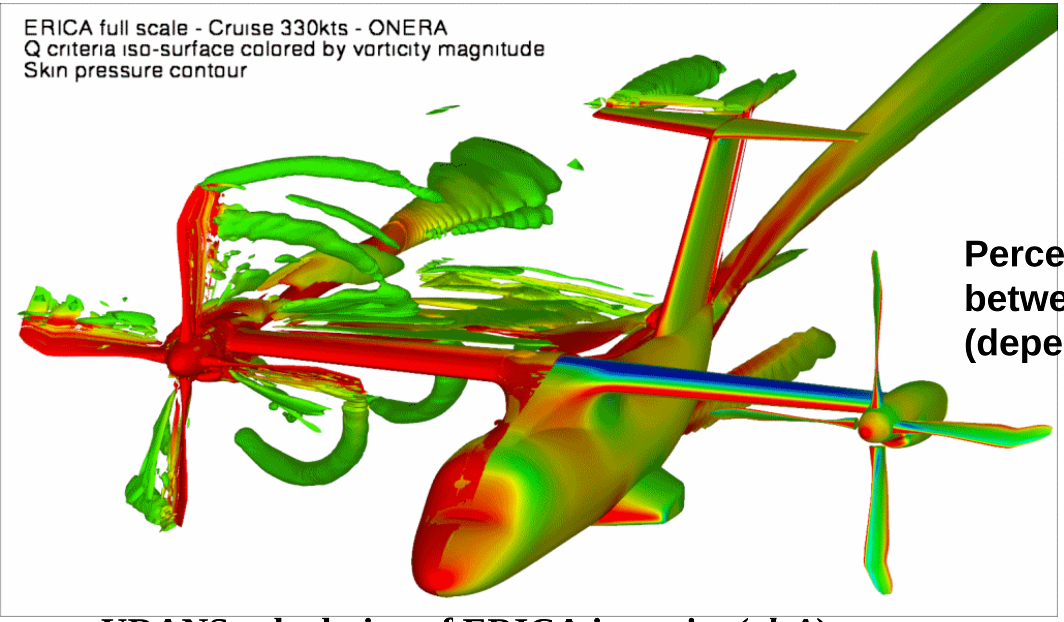
NICETRIP: Novel Innovative Competitive Effective Tilt Rotor Integrated Projekt

- CFD-CAA (FWH) coupling for cabin noise evaluation
- ONERA, *elsA*-KIM approach



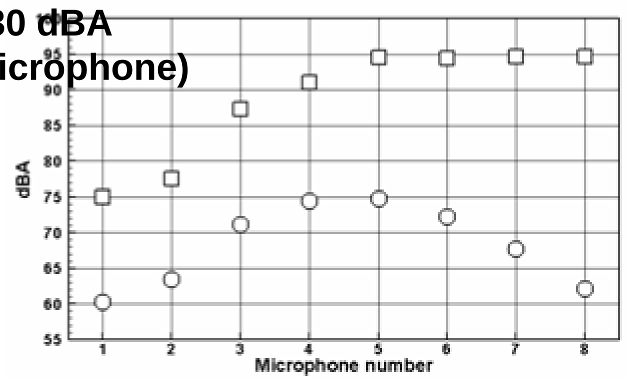




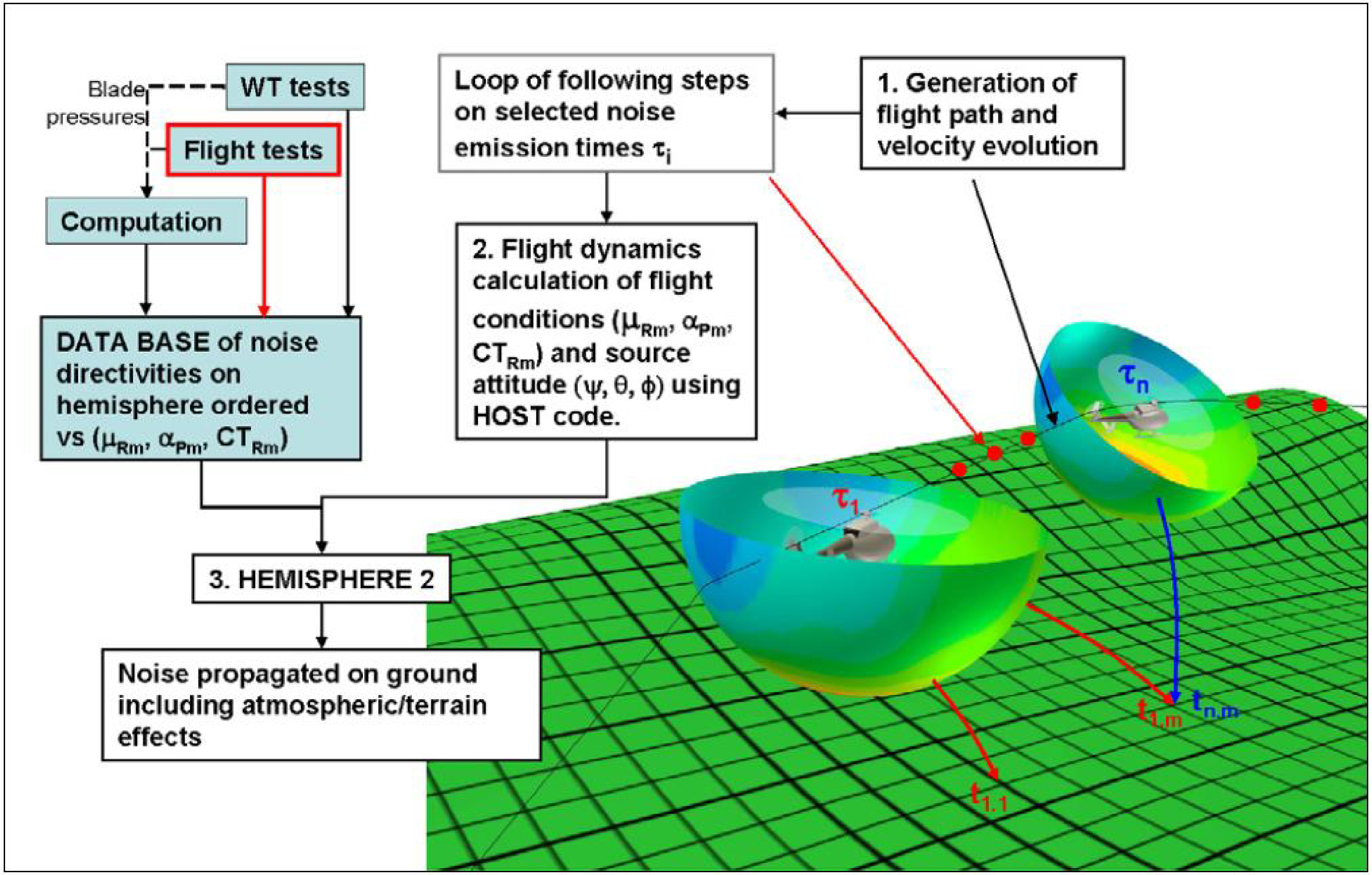


URANS calculation of ERICA in cruise (*elsA*)

Perceived noise increase between 15 and 30 dBA (depending on microphone)



Hybrid Method for Noise Abatement Flight Procedure Design



Le Duc, A., Spiegel, P., Guntzer, F., Lummer, M., Buchholz, H., Götz, J. Simulation of Complete Helicopter Noise in Maneuver Flight using Aeroacoustic Flight Test Database AHS64, May 2008, Montreal, Canada

Sensitivity Analysis of Flight Test Results

5º Pitch variation

Sensitivity: 1.6 dBA/degree

Flight test uncertainty: 5º, 8 dBA

Speed variation

Sensitivity: 0.4 dBA/kt

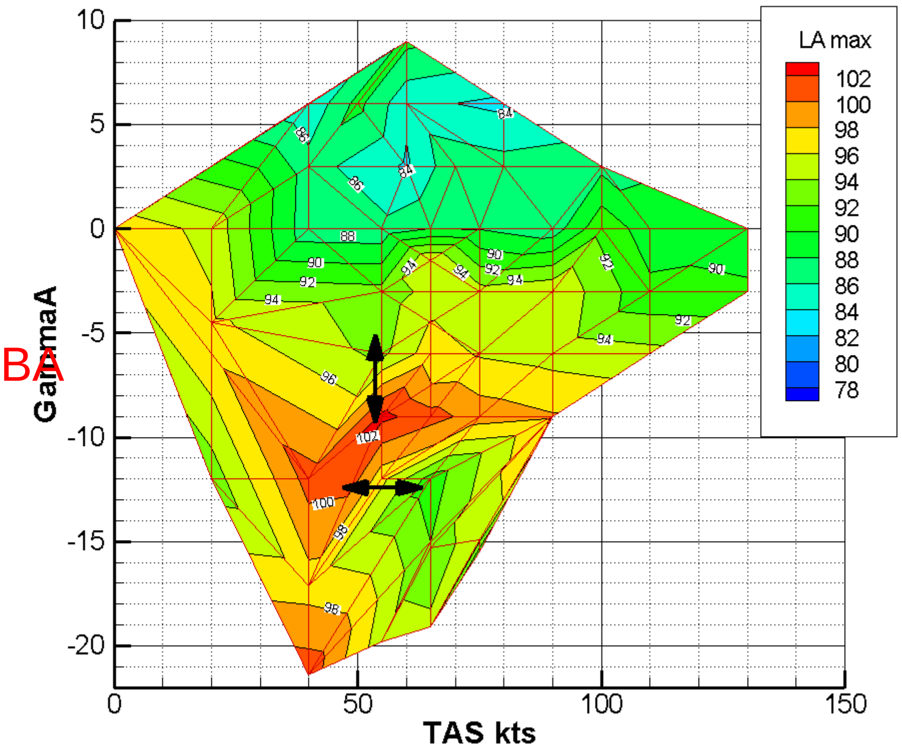
Flight test uncertainty : 4kts, 1.6 dBA

Height variation

8 dBA corresponds to Height / 2.5

Flight test uncertainty :

5% in Height, 0.4 dBA

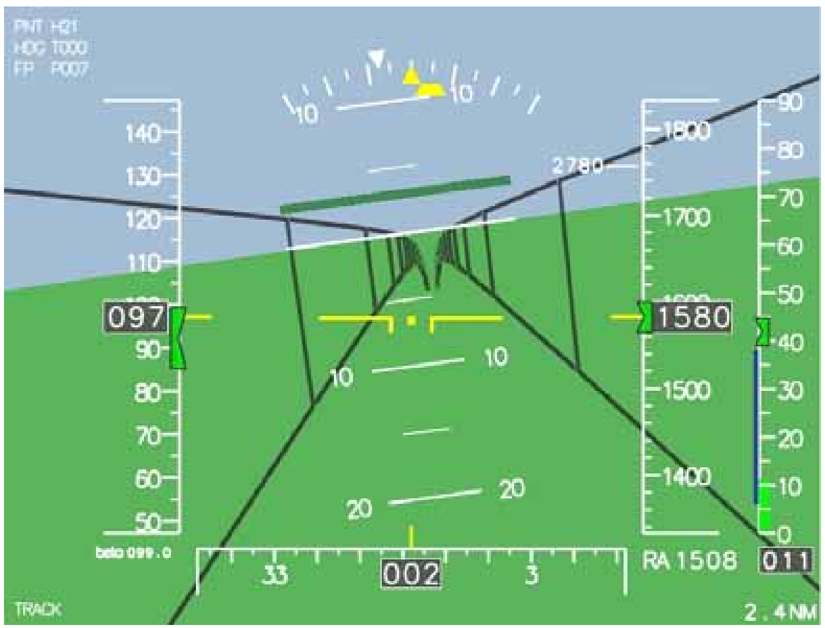


Conclusion: Pitch angle is of highest importance.

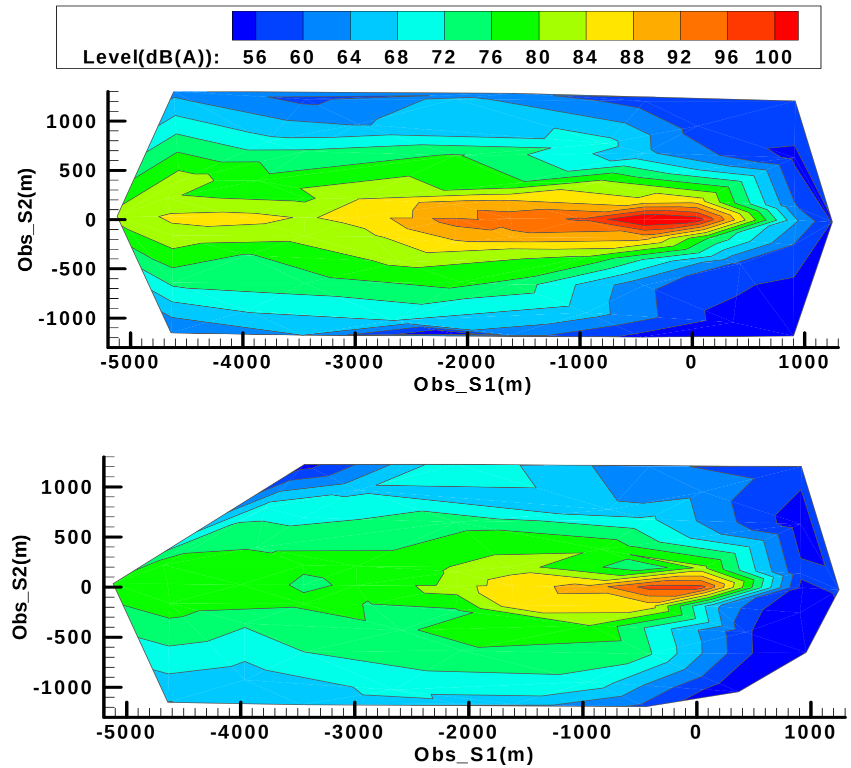
Direct heading cues not useful (Too high pilot workload!)

Main Rotor Noise Reduction

- **Increase of blade-vortex-distance („miss distance“) by noise abatement flight procedures.**
  - Pilot guidance via „Tunnel in the Sky“ (superior to direct bugs in PFD)
  - Alternative: fully automatic flight according to low noise procedures



Noise measured on the ground: -10 dB SEL



Spiegel, P. et al., „Aeroacoustic Flight Test Data Analysis and Guidelines for Noise-Abatement-Procedure Design and Piloting, ERF 2008

Fly by Wire / Active Sidesticks

Background:

Helicopter control is characterised by a strong coupling of most axes (e.g. a simple increase in collective results in a climb and a rotation around the vertical axis and a sideward motion).

State of the Art:

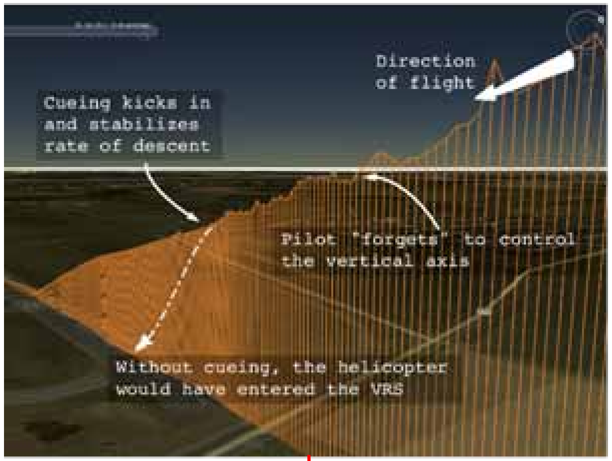
Stability augmentation systems or automatic flight control systems are added to the mechanical control system and achieve a partial decoupling of control inputs/axes. Very modern helicopters feature a fly by wire flight control system which has the potential to achieve a full decoupling of control inputs.

Approach at DLR together with ECD and Liebherr:

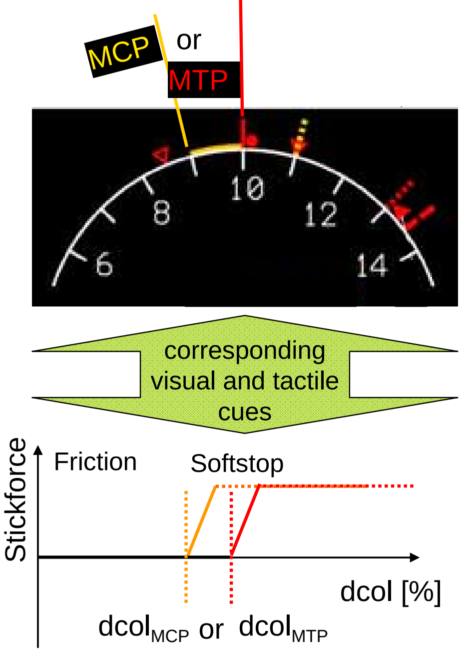
Fly by Wire / Fly be Light with **active** sidesticks.

Active Sidesticks – „Protection“ Functions

- Vortex Ring State Protection (DLR/Onera)
  - Indicated by high sink rates
  - Intuitive counter measures (pull collective) not effective
  - Haptic cue: softstop on collective (lower limit)
  - Workload reduction demonstrated in flight



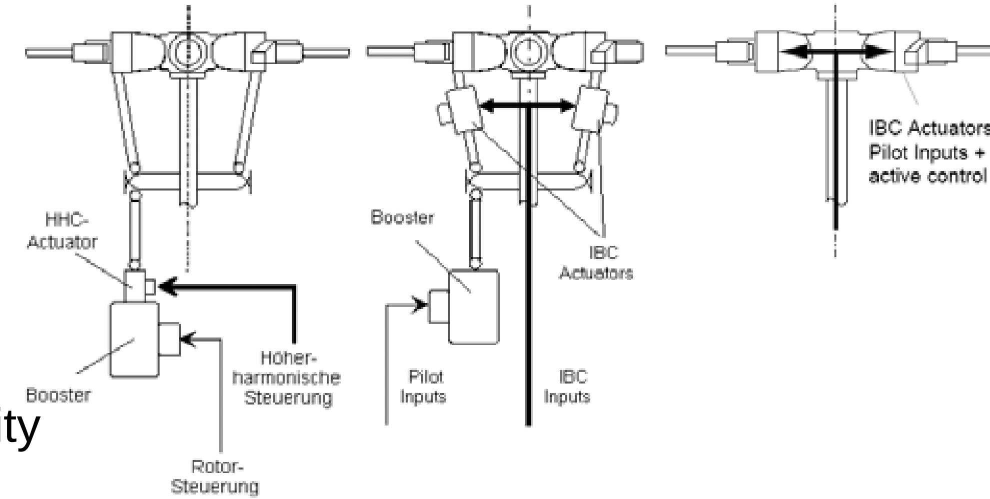
- Haptic „First Limit Indicator (FLI)”
  - Indication of power limits
  - Today: Vehicle and Engine Management Display
  - Haptic cue: softstop on collective (upper limit)
  - Functionality demonstrated in flight



- Decrease pilot workload in order to allow following low noise flight procedures

Active Rotor Control Technologies

Definitions



HHC: actuators in fixed frame
rotor remains as is

IBC: actuators at root in rotating frame
replacing pitch links – IBC authority
eliminating swash plate – full authority

Flaps/tabs: discrete actuators in rotating frame
trailing edge flaps and tabs
leading edge flaps (= nose droop)

Smart materials: distributed actuators
active twist
active camber
soft trailing edge
others …

Active Twist Rotor Control Technology


Active Twist Rotor

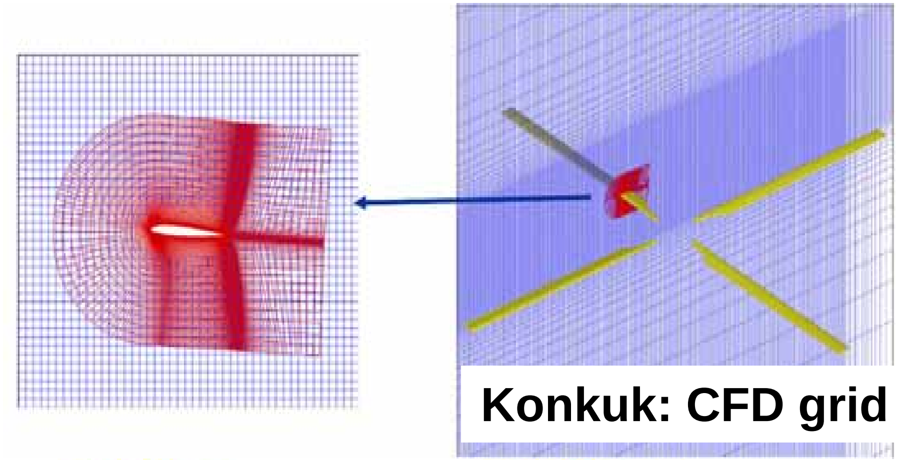
Centrifugal tests at 1043 rpm ($M_{\omega R}$=0.64) proving twist of more than 4^o_{pp} for
1/rev-4/rev. Reduced twist (>3^o) at 5/rev and 6/rev due to 2^{nd} mode shape.

Decision was taken to build WT test rotor with optimized design.

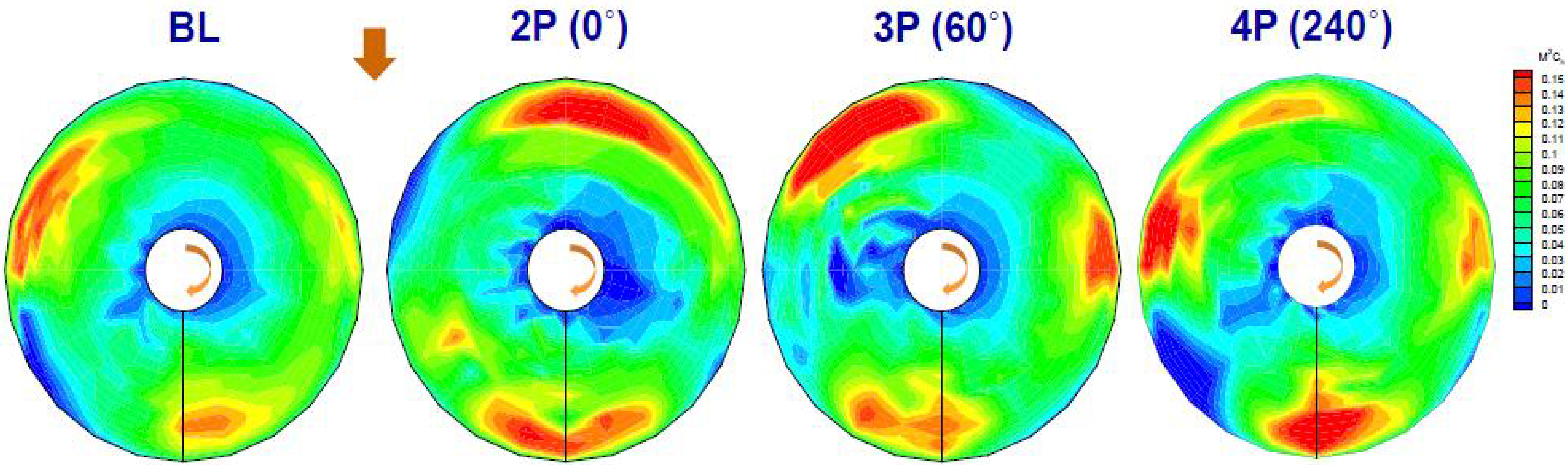
Targets:
-Performance Improvement in Hover: > 2%,
-Performance Improvement in Forw. Flight: 2-3%,
-90% Vibration reduction,
-4-5dB Noise reduction

STAR Cooperation (Smart Twisting Active Rotor)

Partner:
DLR, Onera, US Army, NASA, Konkuk Uni, KARI, JAXA
Ongoing activities:
Manufact of Rotor blades ➔ End 11
Design of control laws for noise, vibration reduction and performance improvement together with Konkuk



Konkuk: CFD grid



Normal forces as a function of control laws (phase/frequenc
Konkuk Universtiy results

Conclusion:

- New design tools for airfoils and rotor planform offer the potential of significant performance improvements in the next years for upgrades or new designs
- Noise abatement flight procedures can provide significant noise reductions for existing helicopters if safe flyable procedures are introduced and accepted by authorities.
- Active sidesticks based on a fly by wire system offer significant improvements in terms of HQ and mission effectiveness paving the way for low exhaust and low noise flight procedures.
- Although still upstream research active twist rotors offer high performance gains in noise, vibrations and power

Contacts

Dr. Klausdieter Pahlke
DLR
Program Directorate Aeronautics
Head of Rotorcraft Program
PCMT
Tel.:+49-531-295-3270
Fax:+49-531-295-3273

Email: Klausdieter.Pahlke@dlr.de