Active Twist Blades – Entwicklung der Hardware für den Windkanal

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Outline

- Motivation / Goals
- Concept for Design and Manufacturing
- Blades for the Wind Tunnel
  - Blade Analysis
- Spinn Offs
  - Shunting – increase of damping
  - De-Icing
- Conclusions

Motivation

Situation:

- Complex aerodynamics cause noise and vibration

Objective:

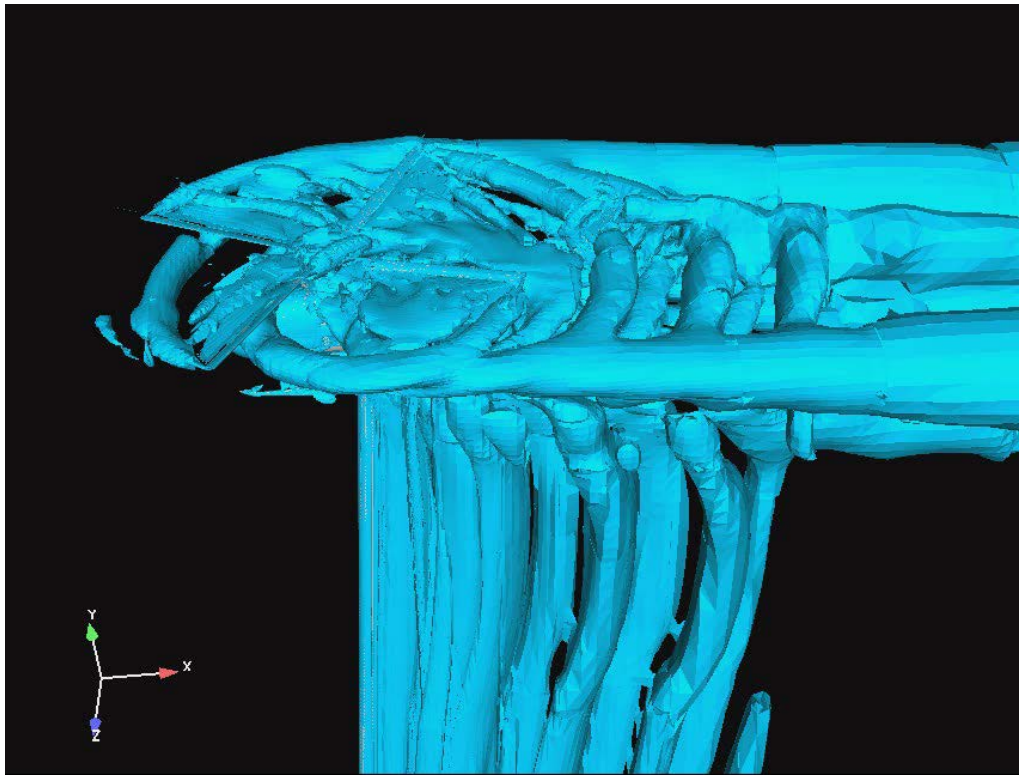
- Vibration reduction 90%
- BVI Noise reduction 6dB
- Shaft power reduction 3%
- Increase of MTOW
- Improvement of figure of merit

Approach:

- IBC: Active twist of the rotor blades: $\pm 2°$ at blade tip

Challenge:

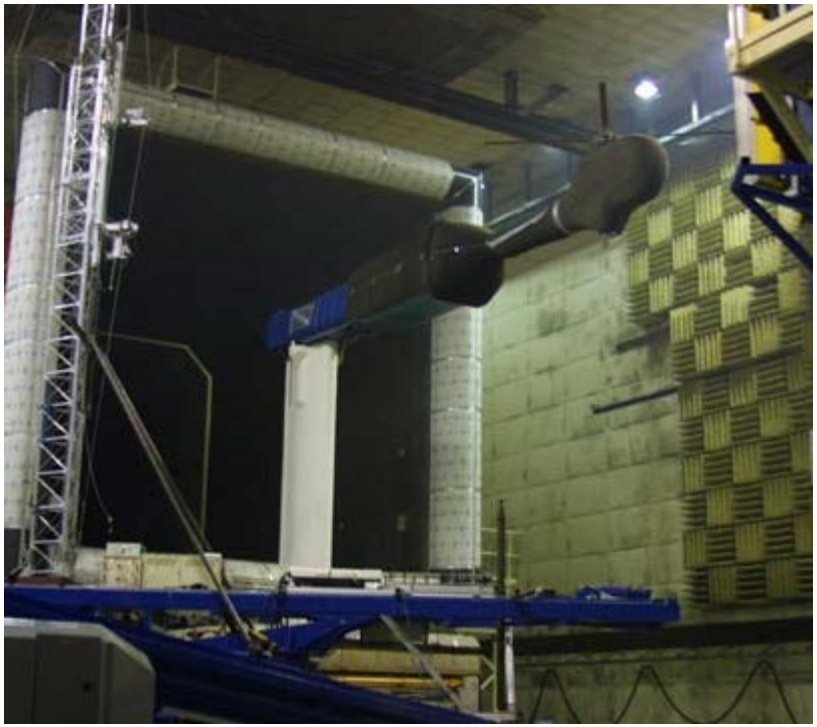
- Highly dynamic morphing



Source: DLR-AS

Goal of current activities

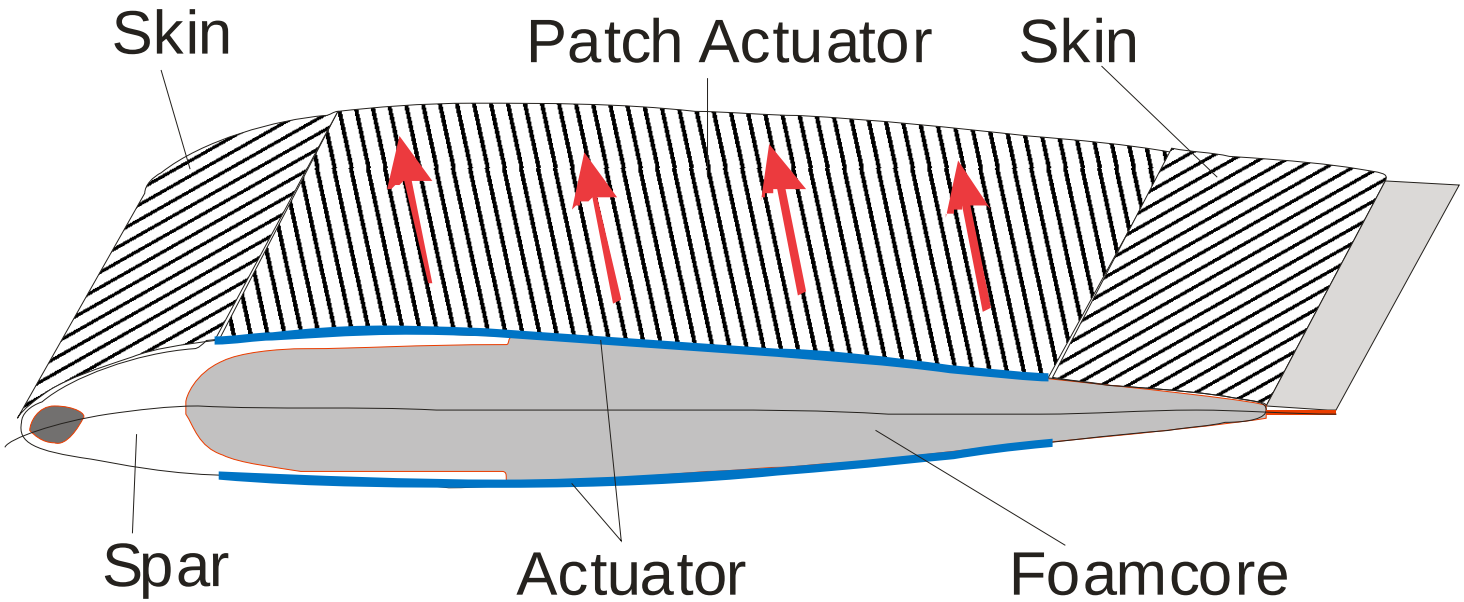
- Design and manufacturing of four bladed rotor
- Wind tunnel test with Active Twist Blade in DNW-LLF
  - Noise measurements
  - Vibration
  - Aerodynamics
  - Deformation
- Test consortium (STAR):
  - DLR; NASA, Onera, Jaxa, DNW, AFDD, Konkuk University



Concept for active twist: Shear-Torsion coupling

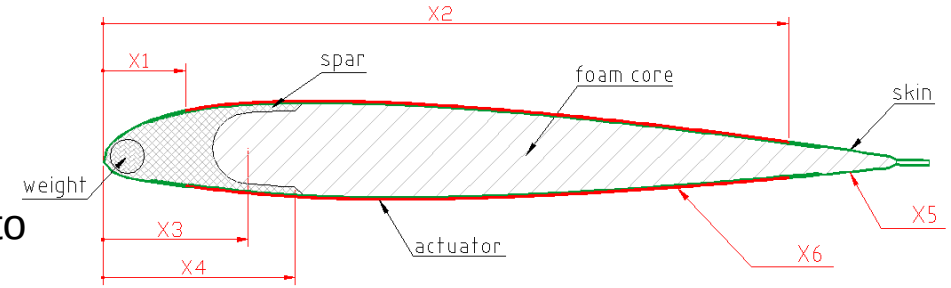
- Skin integrated actuation
- Shear introduction
- Distributed actuation

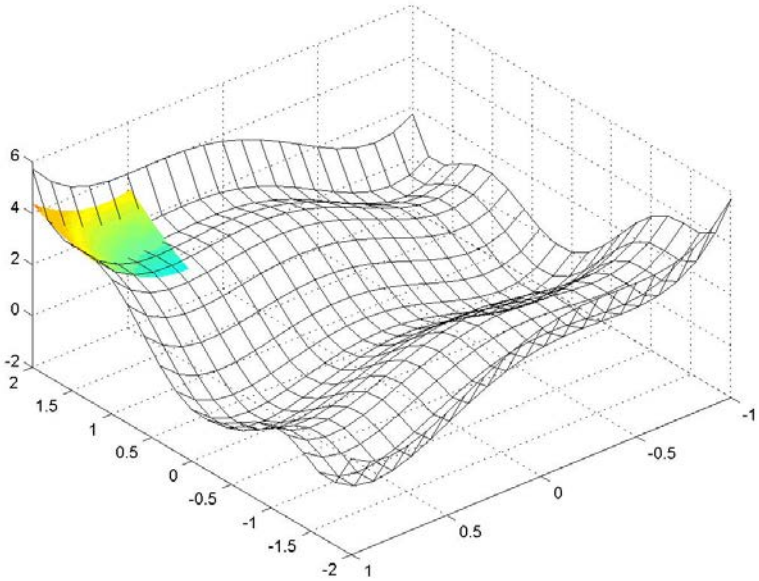
$$\varphi = \frac{M \cdot l}{G \cdot I}$$

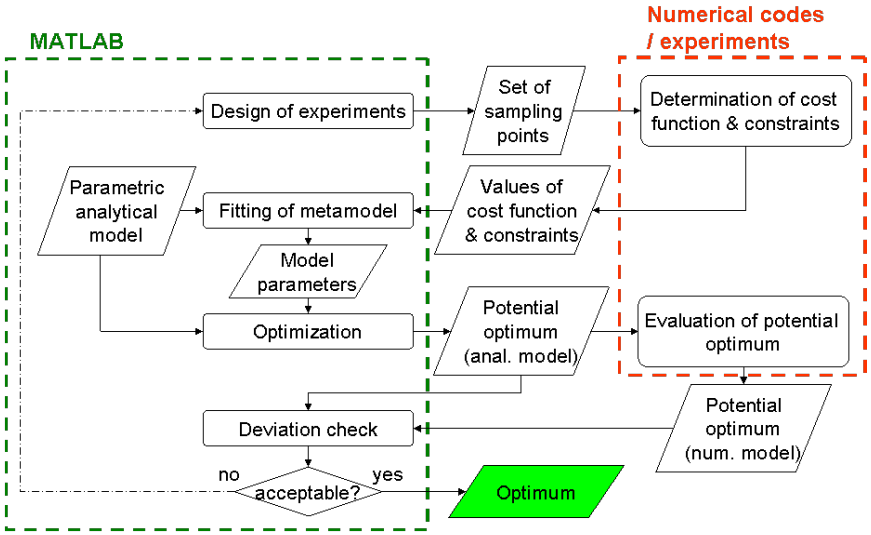


Design: Optimisation of rotor blade

- Parametric FE model of the rotor blade
- Setup of an structural optimization to maximize twist performance
- Geometric design variables

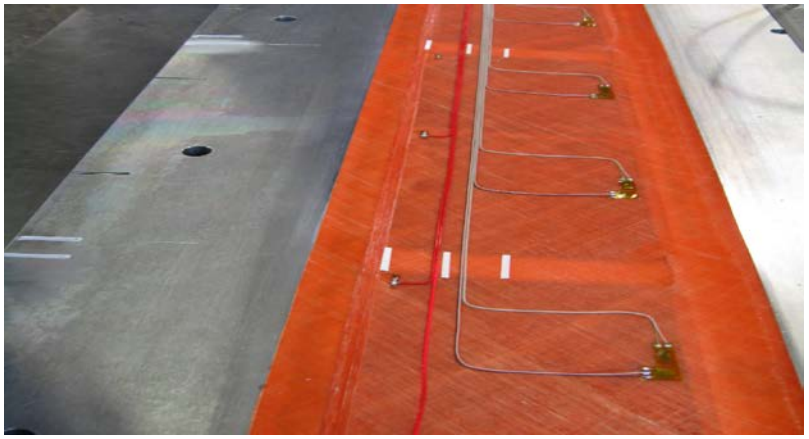


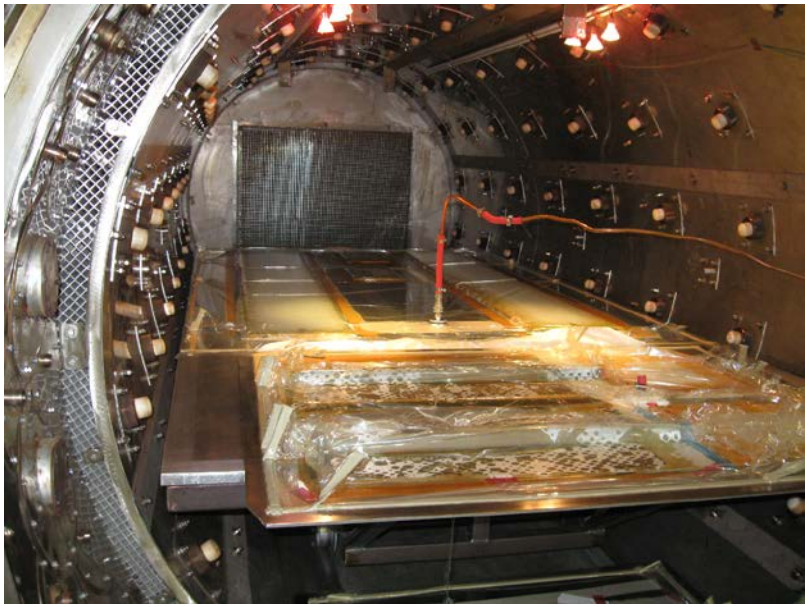




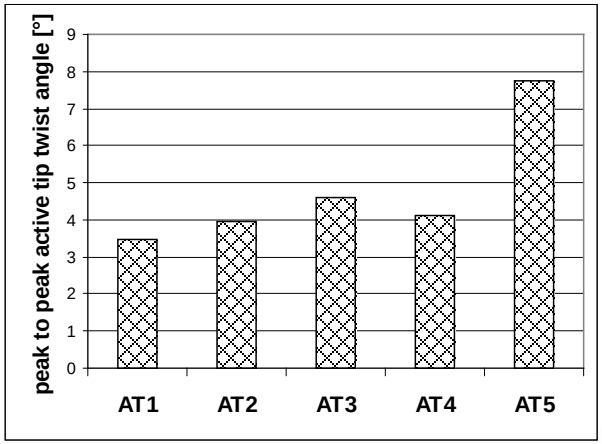
Manufacturing: Function Integration

- Skins are made of GFRP prepreg
- Strain gauges are integrated in skin
- Actuators are integrated in skin
- Wiring is integrated in skin
- Curing in DLR autoclave





Blades built by DLR



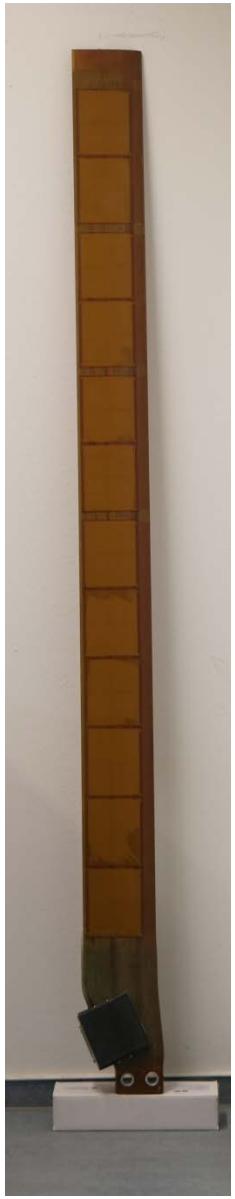
	AT1	AT2	AT3	AT4	AT5
Design goal: max	Momentum	Momentum	Momentum	Momentum	Twist
Skin	orthotropic	orthotropic	isotropic	isotropic	orthotropic
Actuators	standard	customized	customized	standard	customized
Profile	**NACA0012**	**NACA0012**	**NACA23012 / OA209**	**NACA23012**	**NACA23012**

The Wind Tunnel Blades (STAR Blades)

- 5 blades
- Instrumentation
  - Pressure sensors (two fully instr. blades)
  - Strain gauges for **S**train **P**attern **A**nalysis (SPA)
  - Tip pitch sensor
- Active twist at tip:
  - Min: 3° p-p
  - Goal: 4° p-p
- Dynamics:
  - Close to the dynamics of BO105
  - T1 ~ 4/rev

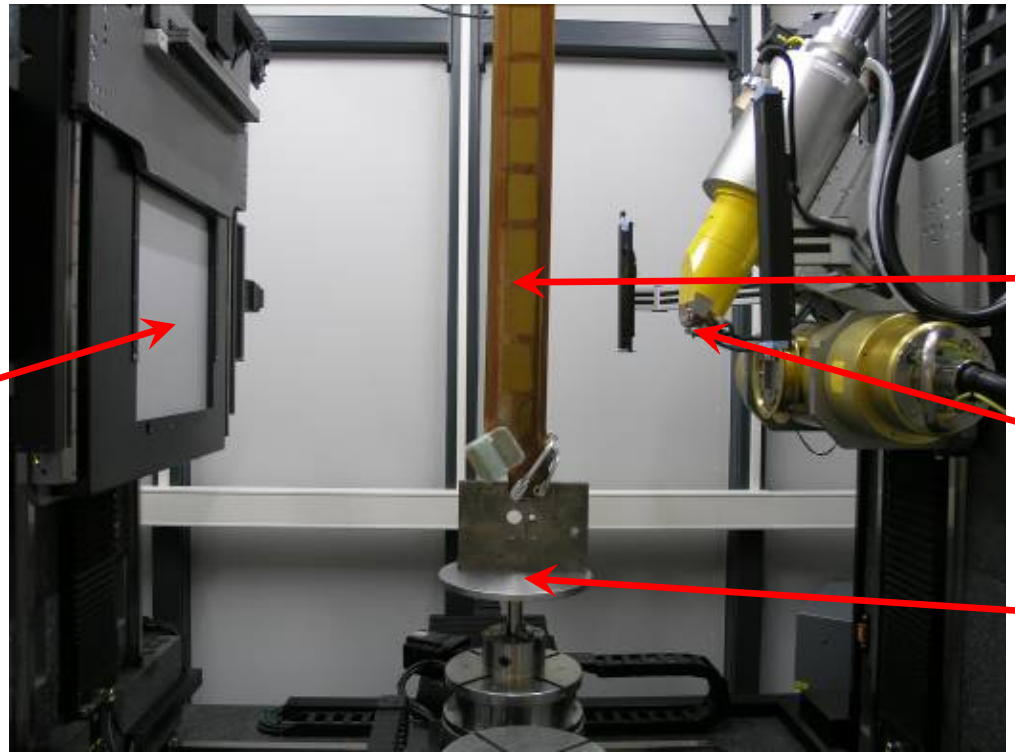
Testing Status STAR-Blades

Action	Status
Test of electrical connections	✓
Lab test stiffness	✓
Lab test frequencies	✓
Lab test actuation	✓
CT scans for mass distribution	✓
Contour scan	✓
Rotating test	Ongoing
Static momentum balancing	✓



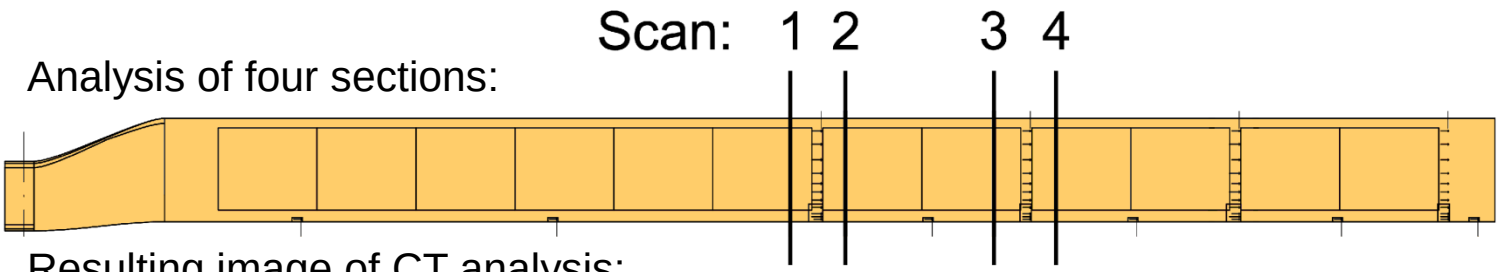
Analysis of Mass Distribution

- Mass distribution is critical for stability (flutter)
- Important to know the actual distribution to validate the design
  - None destructive approach: Computer Tomographic (CT) scans for the geometry of cross section.

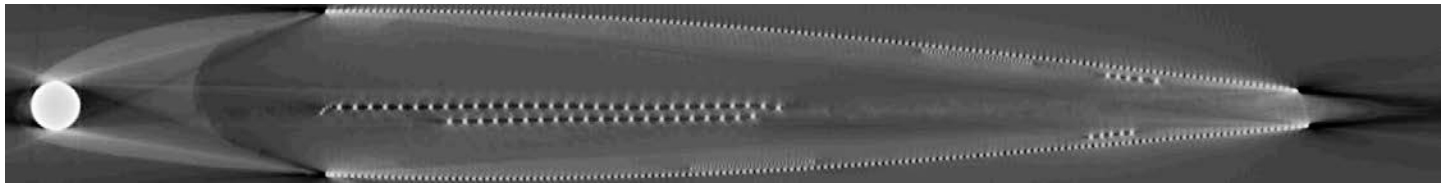


Analysis of mass distribution

- Analysis of four sections:



- Resulting image of CT analysis:

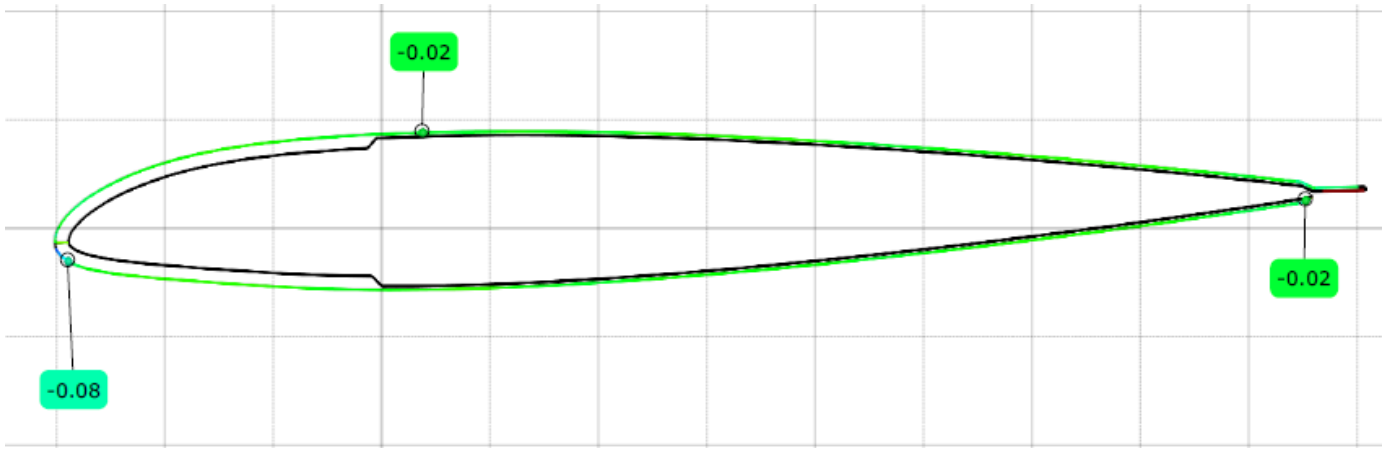


- Image post processing combined with density of the materials leads to cg, inertia and mass
- For validation of CT method a blade was cut in pieces

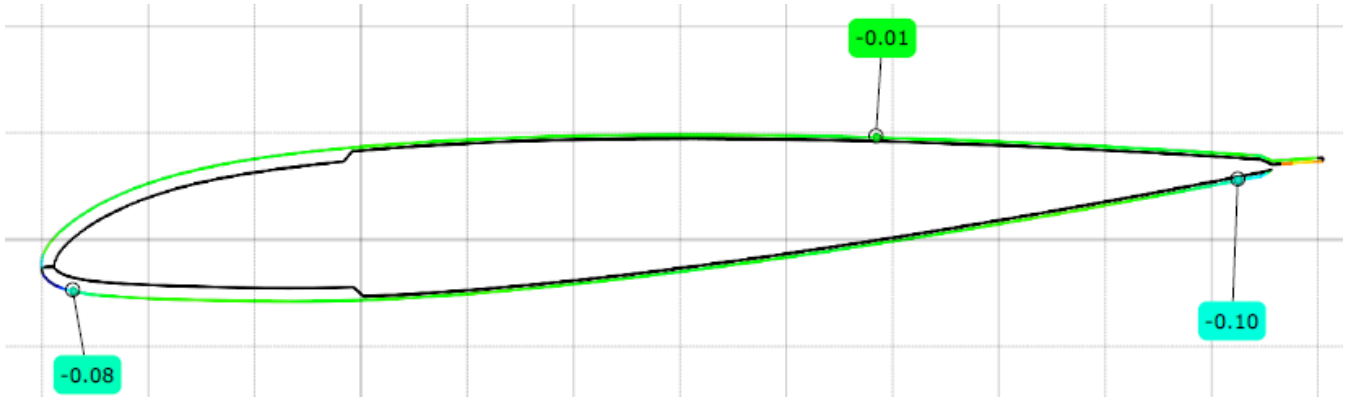
- Experimental analysis of CG with those pieces
- Good agreement of both methods (<0.5%c)

Contour Scan

R = 1010 mm (50,5 %)



R = 1610 mm (80,5 %)



Measurements of all Blades
Flap-Bending Stiffness

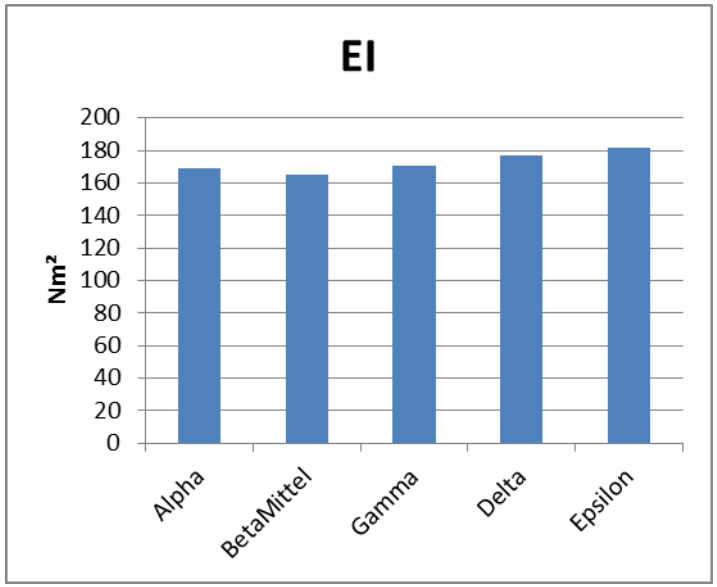
-Initial prediction: 195 Nm²

-Mean value:

173 Nm²

-Standard deviation:

6 Nm²



Two „Groups“ of Blades,

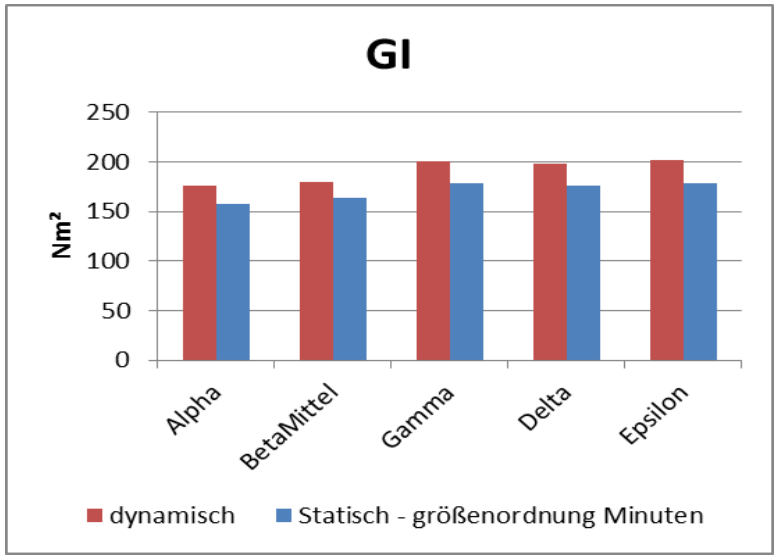
α, β (instrumented with kulites) versus γ, δ, ε (few kulites)

-Initial Prediction: 195 Nm²

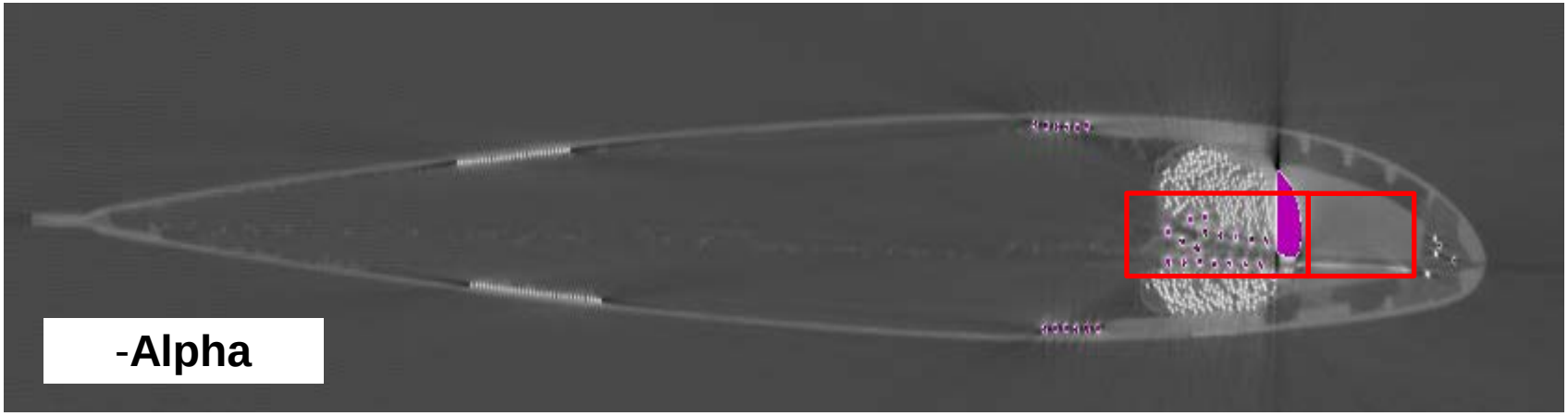
-Mean value:

191 Nm² dyn

171 Nm² stat



CT - Scan



Test of Blade dynamics

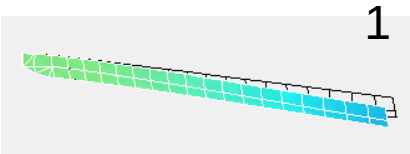
Scanning Vibrometer

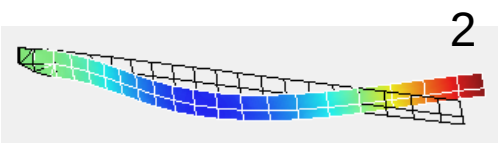
Rotorblade clamped

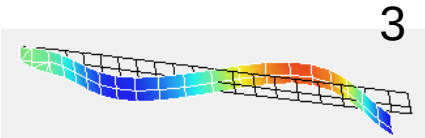
Shaker with
force-transducer

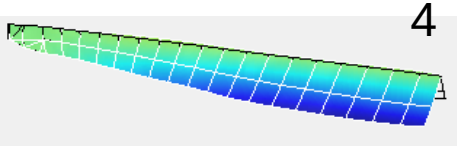
Identified Frequencies

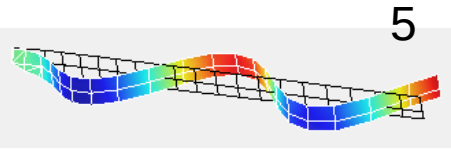
Band	Alpha
	Hz
1	2,8125
2	16,015625
3	45,78125
4	61,5625
5	87,8125
6	141,640625
7	177,890625
8	203,59375

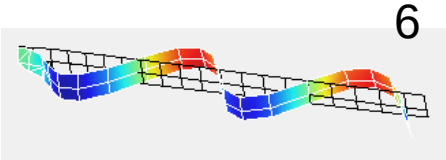


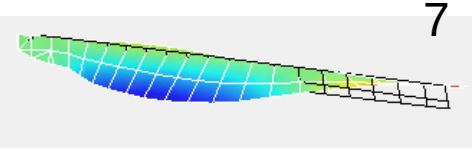


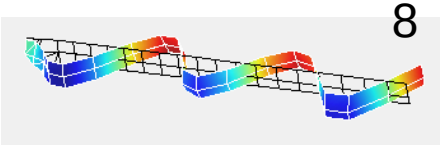












Measurements of all Blades
Active Twist

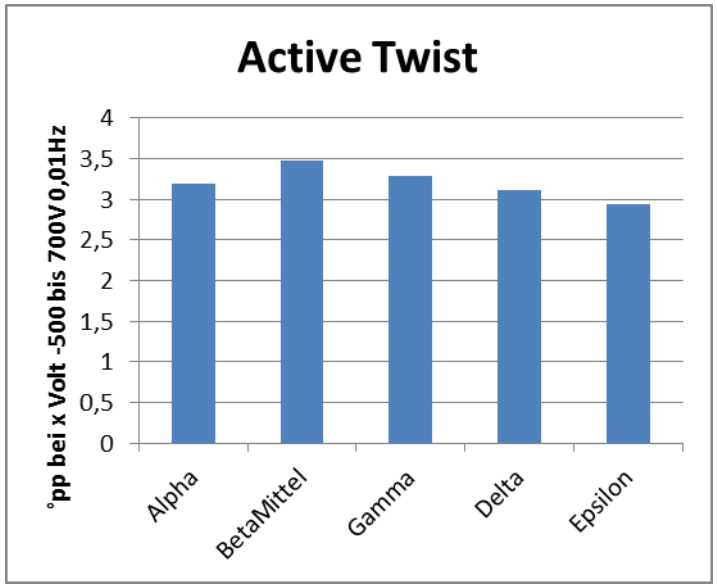
- Measurement at 0.01 Hz
- ¾ of expected voltage for experiment

-Mean value:

3,2°

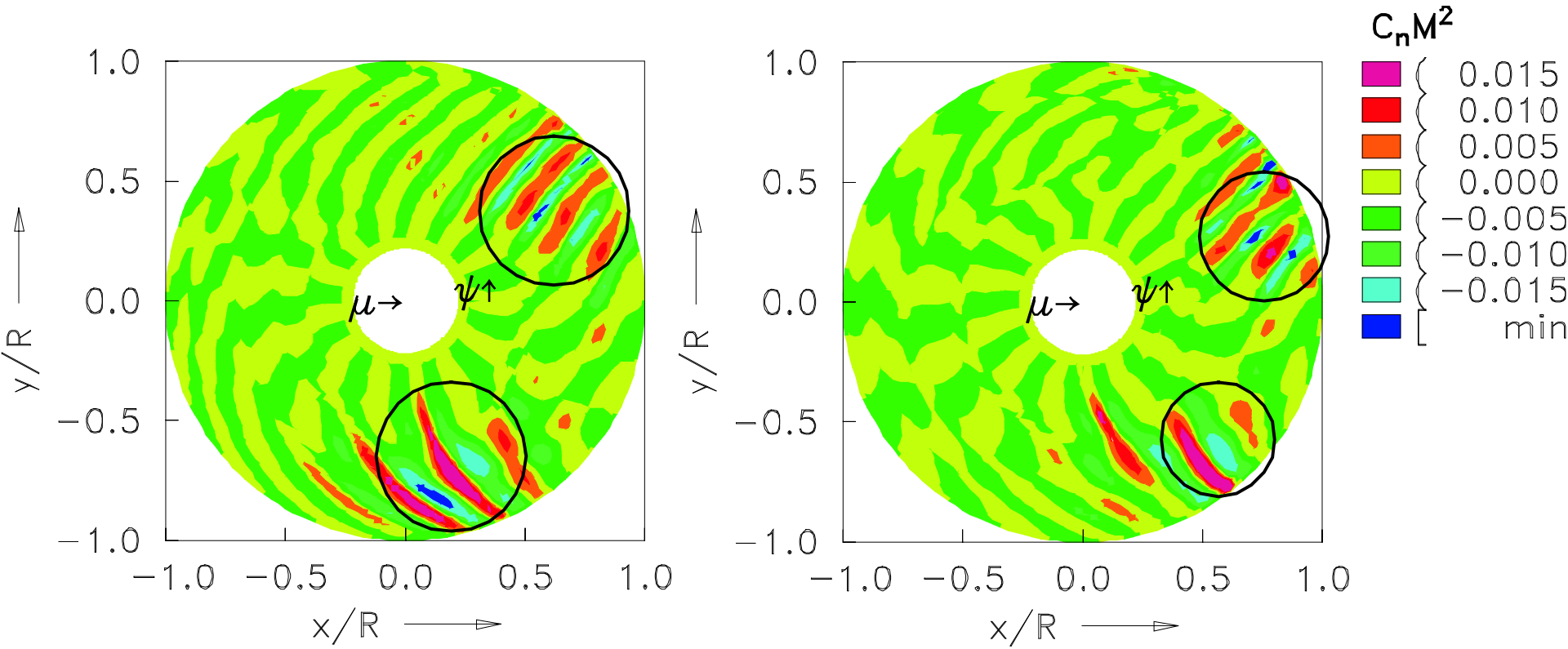
-Standard deviation:

0,18°



Blade testing under centrifugal loads

Normal Force Coefficient



Source: DLR-FT

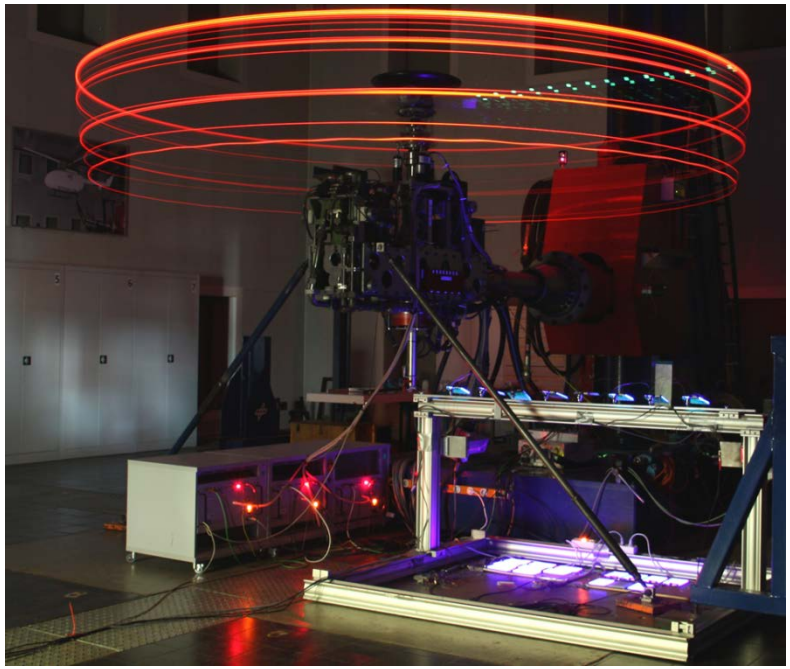
Without Actuation

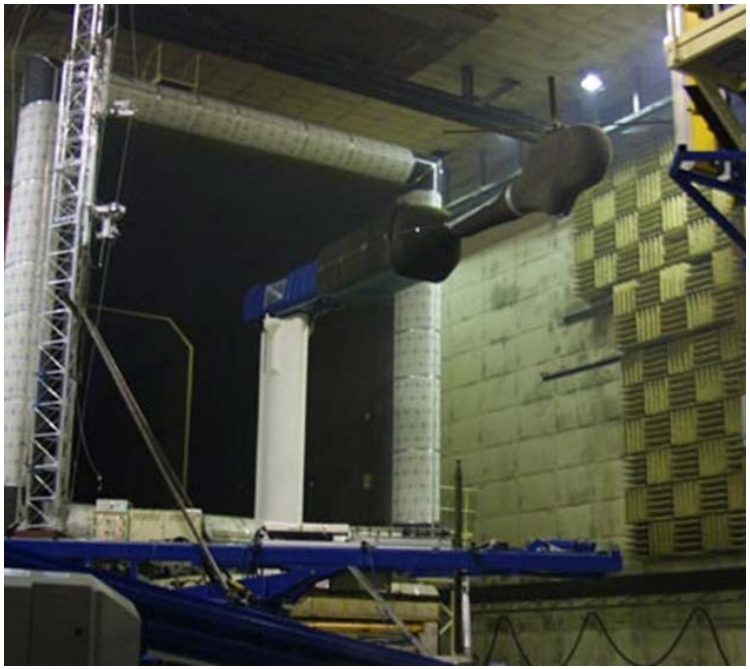
With Actuation

Timeline for Rotating Tests at DLR

- Complete Rotor installed on test rig
- November 2012

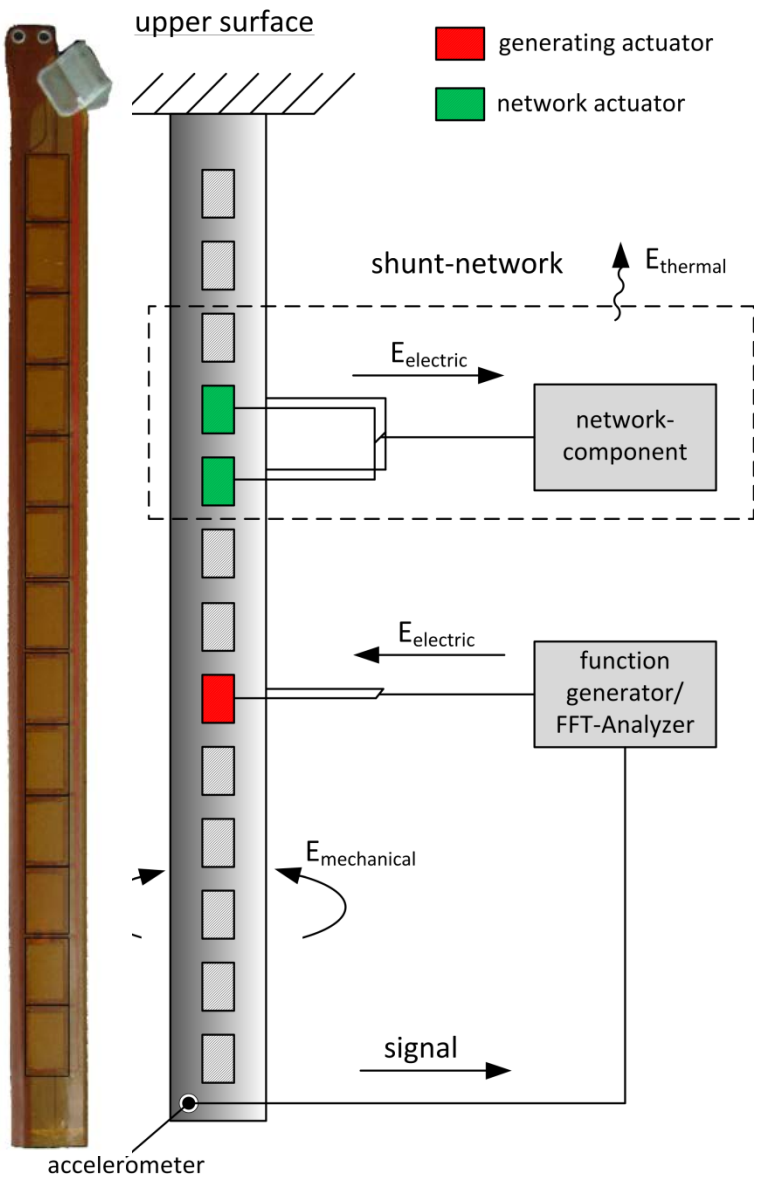
- Wind tunnel test
- Summer 2013



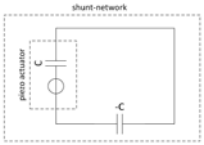


Spinn Off: Shunted networks for increased damping

- AT4 blade clamped
- Excitation by actuators (sweep sinus)
- Vibration measured by accelerometer at blade tip
- Electrical Network connected to different other actuators

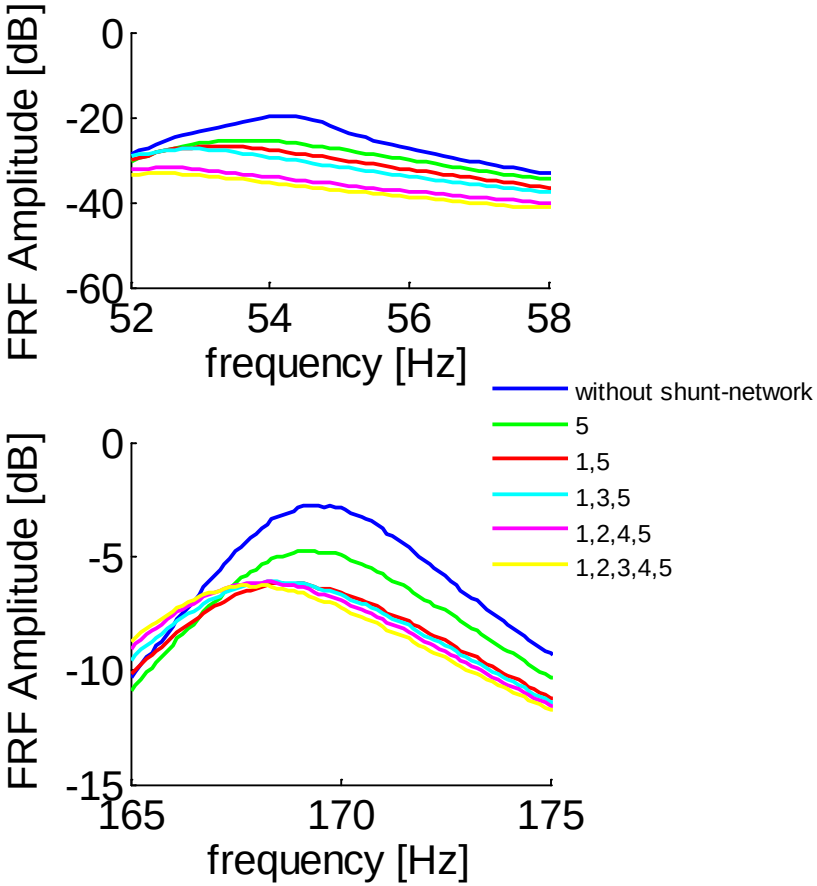


Network: Negative capacitance individual networks



- Significant reduction for T1: more than 12 dB
- Significant reduction for T2: more than 4 dB
- Changes in eigenfrequency do not matter
- Small input energy required (to run OP)

Damping	T 1	T2
Baseline	1.7 %	1.7 %
5 Networks	5.7 %	2.7 %

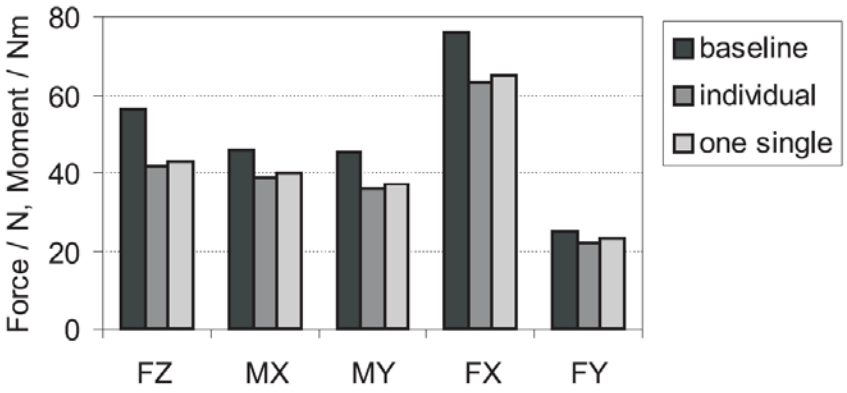


Influence on completer vibration

- Tool: S4 (DLR comprehensive code)
- Mach scaled Bo 105 rotor
- High speed forward flight:
  μ=0.36, C_T/s=0.07
- Tree cases are compared:

Damping	T 1	T2
Baseline	1.7 %	1.7 %
single Network	6.2 %	1.6 %
individual Networks	5.7 %	2.7 %

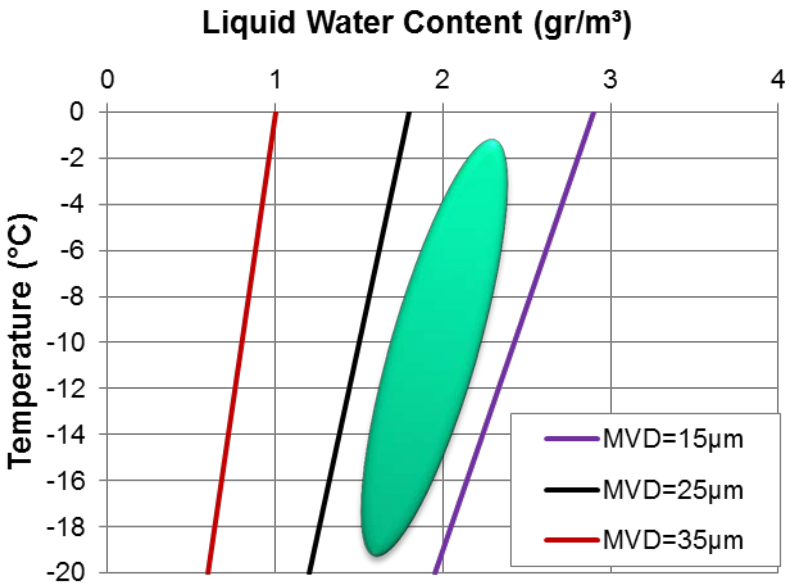
- Rotor vibrations estimated from 4/rev forces and moment in none rotating frame



- Vibration reduction up to 30 %
- Better reduction for individual networks
- Power input just a few Watts

Spinn Off: De-Icing with active twist

- Effect: De-Icing by induced strain and inercia effects
- Icing conditions with super cooled droplets (According to FAR)
- Blade radius: 1,5 m
- Tipmachnumber: 0,25
- Centrifugal Forces: 0,5 of full scale
- Temperature range: -18°C to -7°C
- Icing for 30 sec



Nach FAR Part 25/29

Spinn Off: De-Icing with active twist

- Result:
- De-Icing possible at the outer region
  - Centrifugal forces help
  - De Icing after view seconds
  - Minimum Ice thickness to be shed ~3 mm
- Glace Ice works better than rime ice

- Simulation of this experiment ongoing

PENNSTATE 1855

Conclusions

- Toolchain to design active twist blades established
- 5 blades built
- Individual blade testing still ongoing
- Wind tunnel test scheduled for 2013

- Spinn off:
  - Shunted damping
  - De-Icing

Thank you for your attention !

Contributors:
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