Active Twist Blades – Entwicklung der Hardware für den Windkanal

J. Riemenschneider
Institut für Faserverbundleichtbau und Adaptornik
DLR Braunschweig
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: ±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

\[ \varphi = \frac{M \cdot l}{G \cdot l} \]
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**

![Diagram showing peak to peak active tip twist angle]

<table>
<thead>
<tr>
<th>AT1</th>
<th>AT2</th>
<th>AT3</th>
<th>AT4</th>
<th>AT5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design goal: max</td>
<td>Momentum</td>
<td>Momentum</td>
<td>Momentum</td>
<td>Momentum</td>
</tr>
<tr>
<td>Skin</td>
<td>orthotropic</td>
<td>orthotropic</td>
<td>isotropic</td>
<td>isotropic</td>
</tr>
<tr>
<td>Actuators</td>
<td>standard</td>
<td>customized</td>
<td>customized</td>
<td>standard</td>
</tr>
<tr>
<td>Profile</td>
<td>NACA0012</td>
<td>NACA0012</td>
<td>NACA23012 / OA209</td>
<td>NACA23012</td>
</tr>
</tbody>
</table>
The Wind Tunnel Blades (STAR Blades)

- 5 blades
- Instrumentation
  - Pressure sensors (two fully instr. blades)
  - Strain gauges for Strain Pattern Analysis (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

<table>
<thead>
<tr>
<th>Action</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test of electrical connections</td>
<td>✓</td>
</tr>
<tr>
<td>Lab test stiffness</td>
<td>✓</td>
</tr>
<tr>
<td>Lab test frequencies</td>
<td>✓</td>
</tr>
<tr>
<td>Lab test actuation</td>
<td>✓</td>
</tr>
<tr>
<td>CT scans for mass distribution</td>
<td>✓</td>
</tr>
<tr>
<td>Contour scan</td>
<td>✓</td>
</tr>
<tr>
<td>Rotating test</td>
<td>Ongoing</td>
</tr>
<tr>
<td>Static momentum balancing</td>
<td>✓</td>
</tr>
</tbody>
</table>
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

-Gamma

-Alpha
Test of Blade dynamics

Scanning Vibrometer

Rotorblade clamped

Shaker with force-transducer
Identified Frequencies

<table>
<thead>
<tr>
<th>Band</th>
<th>Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hz</td>
</tr>
<tr>
<td>1</td>
<td>2,8125</td>
</tr>
<tr>
<td>2</td>
<td>16,015625</td>
</tr>
<tr>
<td>3</td>
<td>45,78125</td>
</tr>
<tr>
<td>4</td>
<td>61,5625</td>
</tr>
<tr>
<td>5</td>
<td>87,8125</td>
</tr>
<tr>
<td>6</td>
<td>141,640625</td>
</tr>
<tr>
<td>7</td>
<td>177,890625</td>
</tr>
<tr>
<td>8</td>
<td>203,59375</td>
</tr>
</tbody>
</table>

1
2
3
4
5
6
7
8
Measurements of all Blades
Active Twist

- Measurement at 0.01 Hz
- \(\frac{3}{4}\) of expected voltage for experiment

-Mean value:
  \[3.2^\circ\]

-Standard deviation:
  \[0.18^\circ\]
Blade testing under centrifugal loads
Normal Force Coefficient

Without Actuation

With Actuation

Source: DLR-FT
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)

<table>
<thead>
<tr>
<th>Damping</th>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>1.7 %</td>
<td>1.7 %</td>
</tr>
<tr>
<td>5 Networks</td>
<td>5.7 %</td>
<td>2.7 %</td>
</tr>
</tbody>
</table>
Influence on completer vibration

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

<table>
<thead>
<tr>
<th>Damping</th>
<th>T 1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>1.7%</td>
<td>1.7%</td>
</tr>
<tr>
<td>single Network</td>
<td>6.2%</td>
<td>1.6%</td>
</tr>
<tr>
<td>individual Networks</td>
<td>5.7%</td>
<td>2.7%</td>
</tr>
</tbody>
</table>

- 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 inertia 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

---

[Images of individuals and equipment related to ice simulation and de-icing process]
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:
Steffen Opitz
Martin Schulz
Steffen Kalow
Ralf Keimer
Torsten Medrock
Martin Pohl