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Segmentation technology for large onshore blades

Research by

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Why segment a blade?

Because blade lengths still increase!

>> Transportation can be lengthy, complex and costly – or impossible

>> Erection sites must be big and flat

>> Production requires large buildings
Outline

1. Project Overview
2. State of the art
3. Segmentation position
4. Concepts
5. Conclusion and outlook
Sponsorship from Nordex and DLR

**Objective:**
Investigation and evaluation of joining concepts for segmented rotor blades using the following criteria:
Load bearing capacity, mass, process stability during manufacturing, process stability during assembly on site, quality control and costs.

**Action:**

1st year
- Literature study
- Generate and evaluate joining concepts
- Choice of preferred concept(s)

2nd and 3rd year
- Detailed design of favored concept
- Verification of structural integrity
- Experimental testing of critical components
Overview of past segmented blade activities

- DEBRA-25 [1]
- Megawind [3]
- JOULE III [2]
- Enercon E126 [4]
- Indeol / CENER [7]
- Modular Wind Energy [5]
- Gamesa Innoblade [6]
Classification

**Detachable**
- Bolting in longitudinal direction
  - T-bolts
  - Metallic inserts

**Non-Detachable**
- Bolting in transversal direction
  - Form-fit
  - Force-fit
- Bolting of pieces with a large overlap
  - Connection tubes
  - Bolting of shear web
  - Welding of thermoplasts
  - Bonding of thermosets
  - Single lap
  - Multi lap

**Connection principle**
DEBRA-25

| Company:   | DFVLR Stuttgart (today: DLR) |
| Blade length: | 11,6m (ca. 5,8m + 5,8m) |

- Blade structure similar to modern blades
- **T-bolt**-connection of spar caps
- Extensive static und dynamic tests:
  - Coupon level
  - Static und dynamic flapwise blade test
  - Experimental turbine 18 years in service

Result: **T-bolt connection proofed technical suitability**
JOULE III (1)

**Concept studies**
18 Concepts (bolting and bonding)

**Detailed design** including FE-modelling of 3 concepts: T-bolts, embedded bushings, connection tubes

**Coupon tests** of T-bolts and embedded bushings

- Weak point of embedded bushings: bonding of bushing and laminate
  >> T-bolts are more robust
- Embedded bushings need less space
- Load bearing capacity per unit width of T-bolts and embedded bushings is similar

<table>
<thead>
<tr>
<th>Time span:</th>
<th>1997 – 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Companies:</td>
<td>LM, DLR, TU Delft, …</td>
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<tr>
<td>Blade length:</td>
<td>23,3m (7,3m + 16m)</td>
</tr>
<tr>
<td>Time span:</td>
<td>13,4m (4,5m + 8,9m)</td>
</tr>
</tbody>
</table>
Production and test of segmented **LM23.3** blade with T-bolt connection
- Produced in one piece, cut into segments afterwards
- NC-machine drilled holes
- Passed static und dynamic full-scale blade test, flapwise and edgewise
- Measurements showed higher than calculated load factors for the bolts at the trailing edge.

Reason: 2mm gap between segments

**Economic evaluation** of segmented LM23.3 with T-bolts vs. standard LM23.3
- Extrapolation of results to a 60m blade: *Overall costs for transportation, material and production of segmented rotor blade is 14% higher than of standard blade.*

**Result:** T-bolts proofed technical suitability, but are economically inefficient
JOULE III (3)

Production and test of segmented LM13.4 blade with connection tubes

- Passed static (flap + edge) and dynamic (flap) blade test
  >> minor damages because of bad fit

Result: Connection tubes proofed technical suitability
Megawind

- Design, production and test of segmented **30m-blade with double-row T-bolt connection**
- Production in one piece, then cutting and drilling
- Passed static blade test in flap- and edgewise direction
- Failed dynamic in flapwise direction: At 20% of design life, 9 of 44 bolts were broken
  - No obvious reason
  - Possible cause: irregularities in production

**Result:** Fatigue is a problem for T-bolts in big blades
Enercon E-126

- Segmented blades with T-bolt connection
- L-Flange in root segment
- T-Bolt in tip segment

Time span: since 2007
Blade length: 59m (24 + 35m)
Gamesa Innoblade

Research program „UpWind“
- Concept study (different bolting solutions)
- Detailed design of „channel fittings“

Gamesa Innoblade with „channel fittings“
- Erection of prototype in 2009
- Certification completed in 2011

<table>
<thead>
<tr>
<th>Time span:</th>
<th>since 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade length:</td>
<td>62,5m (30,5 + 32m)</td>
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<tr>
<td>Companies:</td>
<td>Gamesa</td>
</tr>
</tbody>
</table>
Indemodular

- Indemodular is a joining concept for bolting the spar caps
- Component tests

Time span: since 2010

Companies: Indeol, CENER
ModBlade

- Design, production and test of segmented 45m “ModBlade”
- Spar caps made of **pultruded planks (GFRP)**
- Joining of spar caps in a **bonded finger joint**
- Component and full scale blade tests

<table>
<thead>
<tr>
<th>Time span: 2008 - 2013</th>
<th>Company</th>
<th>Modular Wind Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade length</td>
<td>45m (3 segments)</td>
<td></td>
</tr>
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</table>
Summary

**Bolted connections**, in particular T-bolts, have been investigated the most
- Technical suitability
- Economic efficiency
  >> Big extra cost in materials and production

**Bonded connections** have been investigated only in the past few years
- Technical suitability not entirely proven
  >> Validated on-site joining process is still missing
- Economic efficiency is promising

Result: Segmented blades are far away from serial production
Where to cut the blade?

- Bolting
- Bonding

Transportation
- Spar cap loads
- Secondary loads
- Big extra mass = extra cost

Extra mass = dynamic loads
- Little space

Spar cap loads under flapwise bending

Load vs Blade length
Considered concepts

**Connection principle**

- **Detachable**
  - Bolting in longitudinal direction
  - Bolting in transversal direction
  - Bolting of pieces with a large overlap

- **Non-Detachable**
  - Welding of thermoplasts
  - Bonding of thermosets

**Concepts**

- **T-bolts**
  - T-bolt connection
  - Direct bolting of metallic inserts
    - Bolting of metallic inserts at an intermediate plate
  - Bolting of metallic inserts
    - Bolting of GFRP
      - Bolting of fibre metal laminate
  - Bolting of shear web
    - Bolting of shear web

**Project Overview**

- [Connection principle](#)
- [Detachable](#)
- [Non-Detachable](#)
- [Bolting in longitudinal direction](#)
- [Bolting in transversal direction](#)
- [Bolting of pieces with a large overlap](#)
- [Welding of thermoplasts](#)
- [Bonding of thermosets](#)
Bolting of fibre metal laminate (FML)

- Local reinforcement of joint with FML
- 20 – 60 % metal volume fraction
- Metal sheet thickness: 0.1 to 1mm
- Material combinations: GFRP-steel, CFRP-steel, CFRP-titanium

**Pros**
- Increased joint strength
- Little/no material thickening needed
- Low weight

**Cons**
- Costly materials (high-strength stainless steel)
- Special surface preparation for metal sheets
- Special tools required to make holes
# Concept evaluation

<table>
<thead>
<tr>
<th>Field</th>
<th>No.</th>
<th>Criteria</th>
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<tbody>
<tr>
<td>Structure</td>
<td>1</td>
<td>Testability</td>
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<tr>
<td></td>
<td>2</td>
<td>Weight</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Costs</td>
</tr>
<tr>
<td>Production</td>
<td>4</td>
<td>Integration in half shell construction</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Standard material and processes</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Production accuracy</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Quality assurance for production</td>
</tr>
<tr>
<td>Assembly</td>
<td>8</td>
<td>Simplicity and quickness</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Positioning accuracy</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Quality assurance for assembly</td>
</tr>
<tr>
<td>Service</td>
<td>11</td>
<td>Inspection during service life</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Repair during service life</td>
</tr>
<tr>
<td>Aerodynamics</td>
<td>13</td>
<td>Disturbance of aerodynamics</td>
</tr>
</tbody>
</table>
Conclusion

- Segmented rotor blades are not yet capable of competing with conventional blades
- Bonding concepts still lack validated on-site joining process
- Bolting concepts need to be well designed to be competitive

Project outlook

- Detailed design of favoured concepts
- Optimisation of critical components
- Mechanical tests from coupon to full scale
MANY THANKS FOR YOUR ATTENTION.

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References


