



Advanced Validation Strategies for Segmented Blades

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PPT-1358 Rev /



AGENDA

1. INTRODUCTION

- Nabrawind Technologies
- Modular Blades Market
- Nabrajoint®

2. VALIDATION STRATEGY

- Goal of the Validation Program
- Certification Approach
- Test Campaign Overview

3. TEST CAMPAIGN

- Material Characterization Testing
- Subcomponent Analysis and Testing
- Substructure Analysis and Testing

4. CONCLUSIONS

- Nabrajoint® Validation Summary

NABRAWIND TECHNOLOGIES

Advanced Wind Technologies



Modular Blade
Joint



Self Erected
Tower

2016

2017

2018

2019

2020

PRODUCTS DEVELOPMENT

COMMERCIAL DISSEMINATION

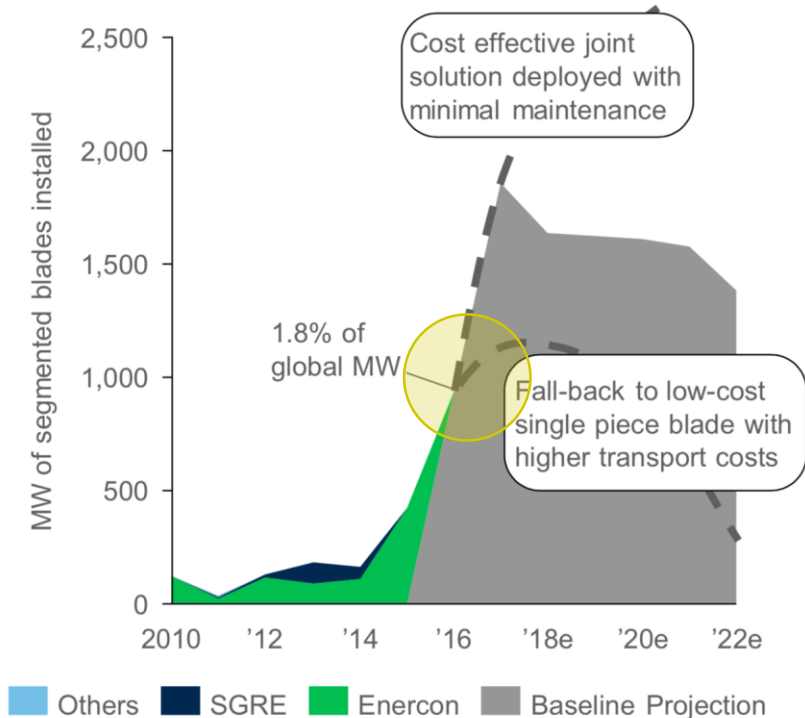
SALES PROCESS

COMMERCIAL PROJ.

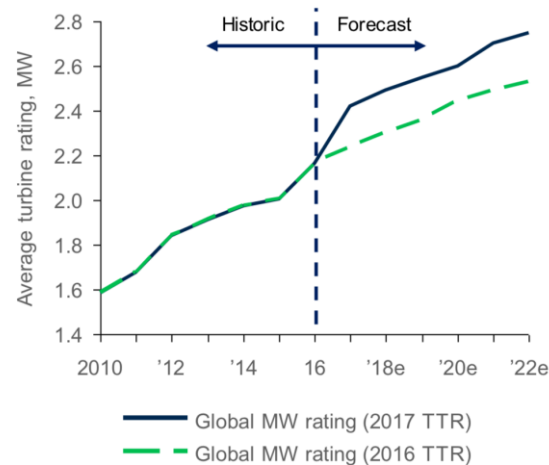
PRESERIAL

Is there a need for modular blades?

2017



Note: Segmented blades refer to blades that are joined on-site
Source: MAKE

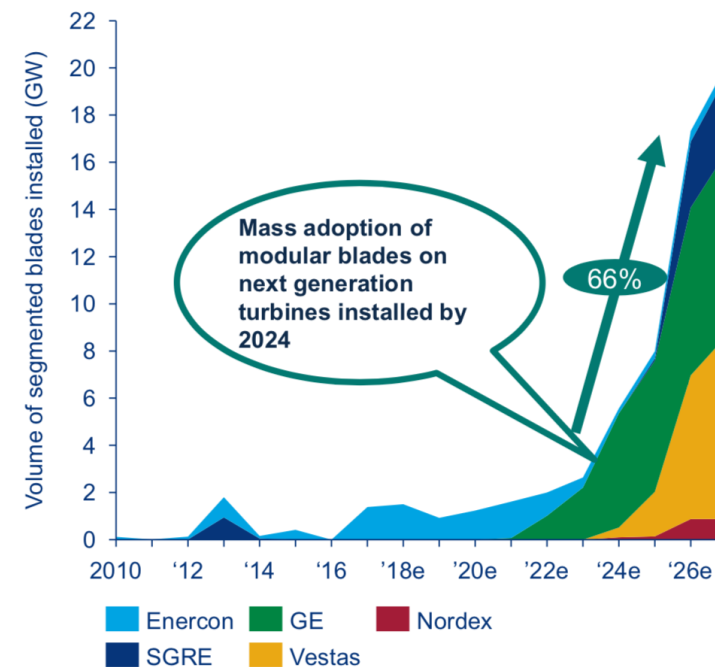


Note: Dotted line is the projection shown in the 2016 version of this report
Source: MAKE



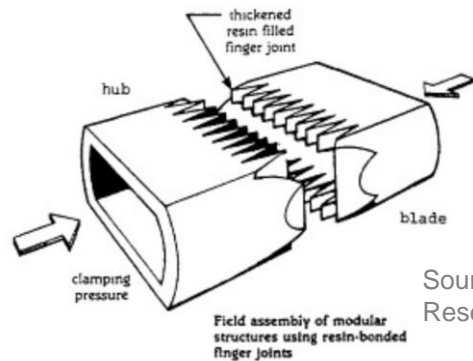
2018

Market forecast for segmented blades 2010-2027e



1 Introduction Modular Blades Market

What is the current state of the art?



Source: National Research Council

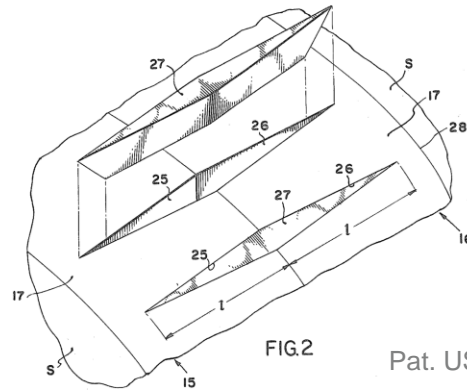


FIG. 2

Pat. US4474536

Bonded Joints

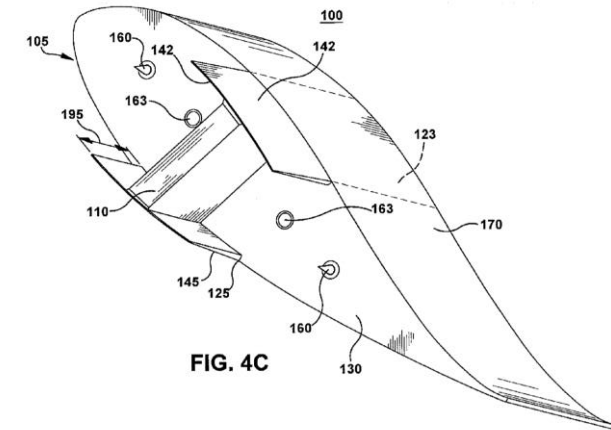


FIG. 4C

Pat. US20100310379A1

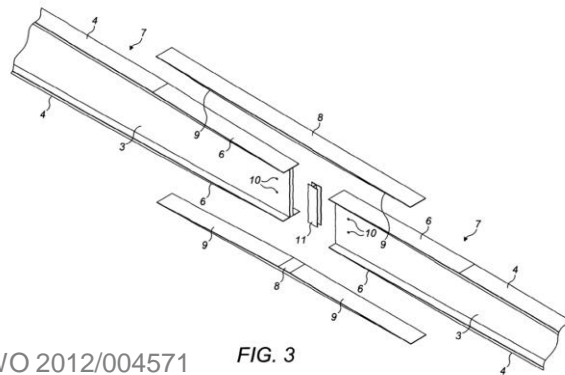


FIG. 3

Pat. WO 2012/004571

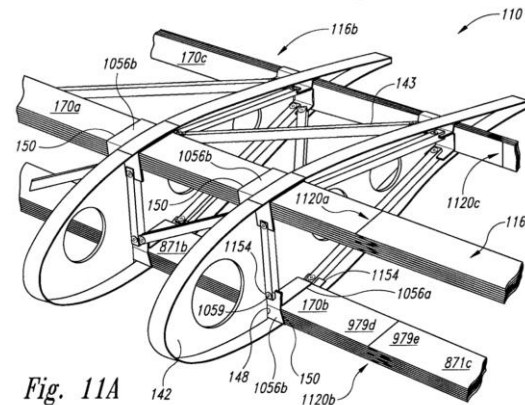


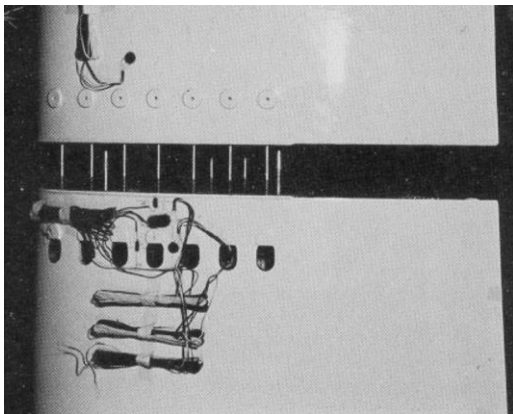
Fig. 11A

Pat. WO 2010/065928

1 Introduction

Modular Blades Market

What is the current state of the art?

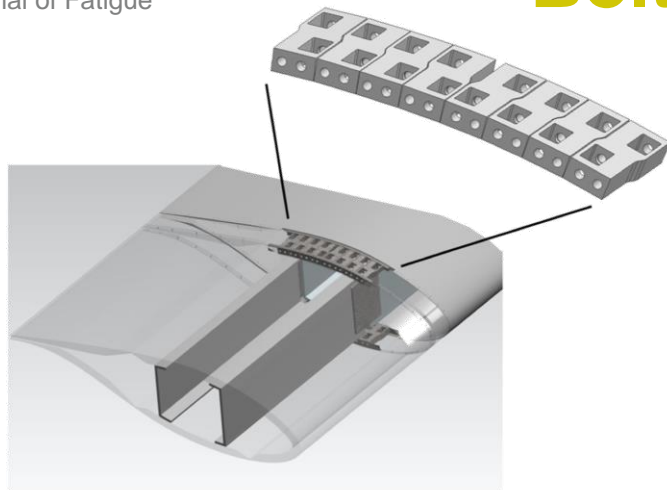


Source: International Journal of Fatigue
28 (2006) 1363-1374



Source: ERU/RAL, LMG, LMGH, DLR, DUT, JOR3-CT97-0167

Bolted Joints



Source: INDEOL



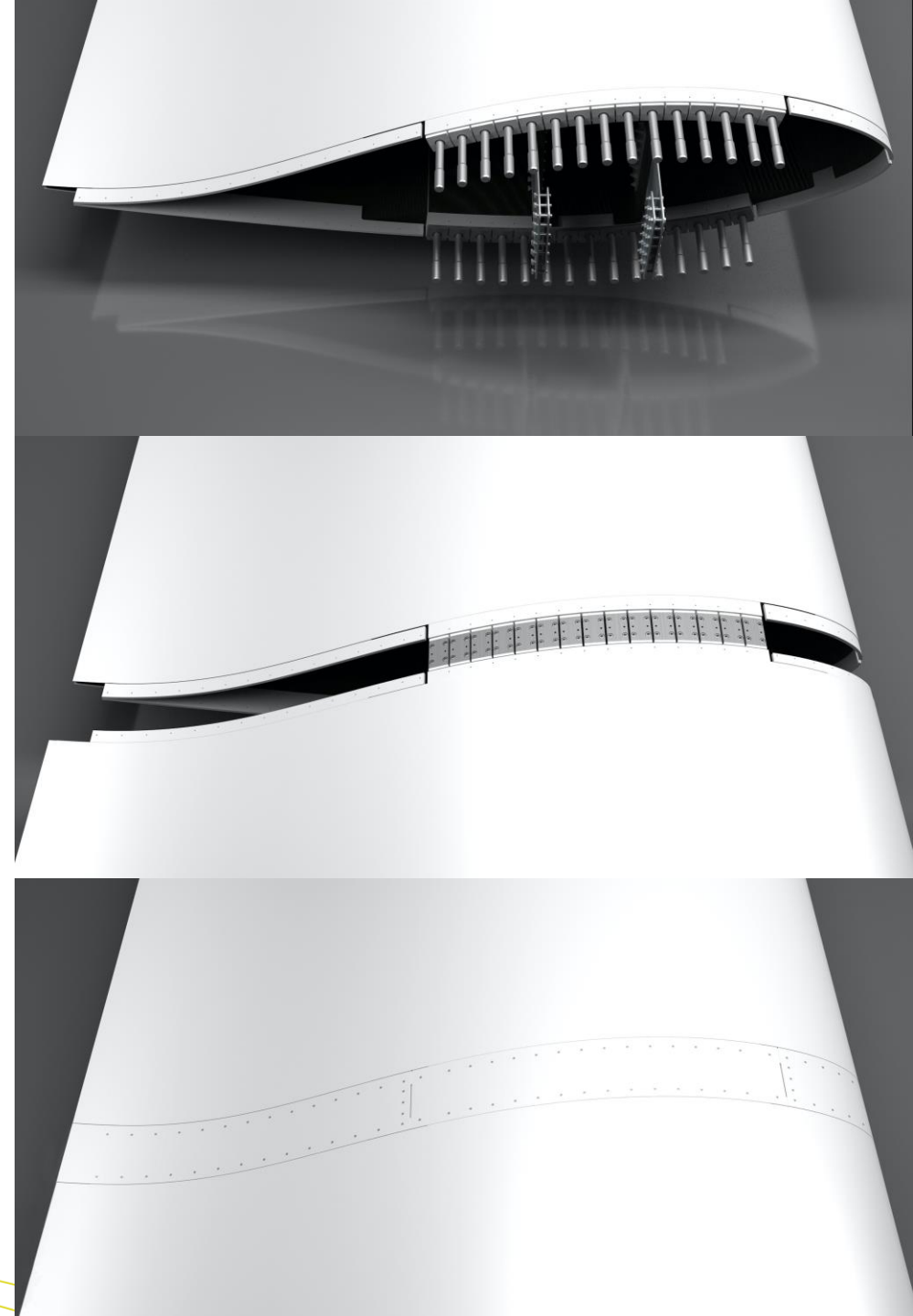
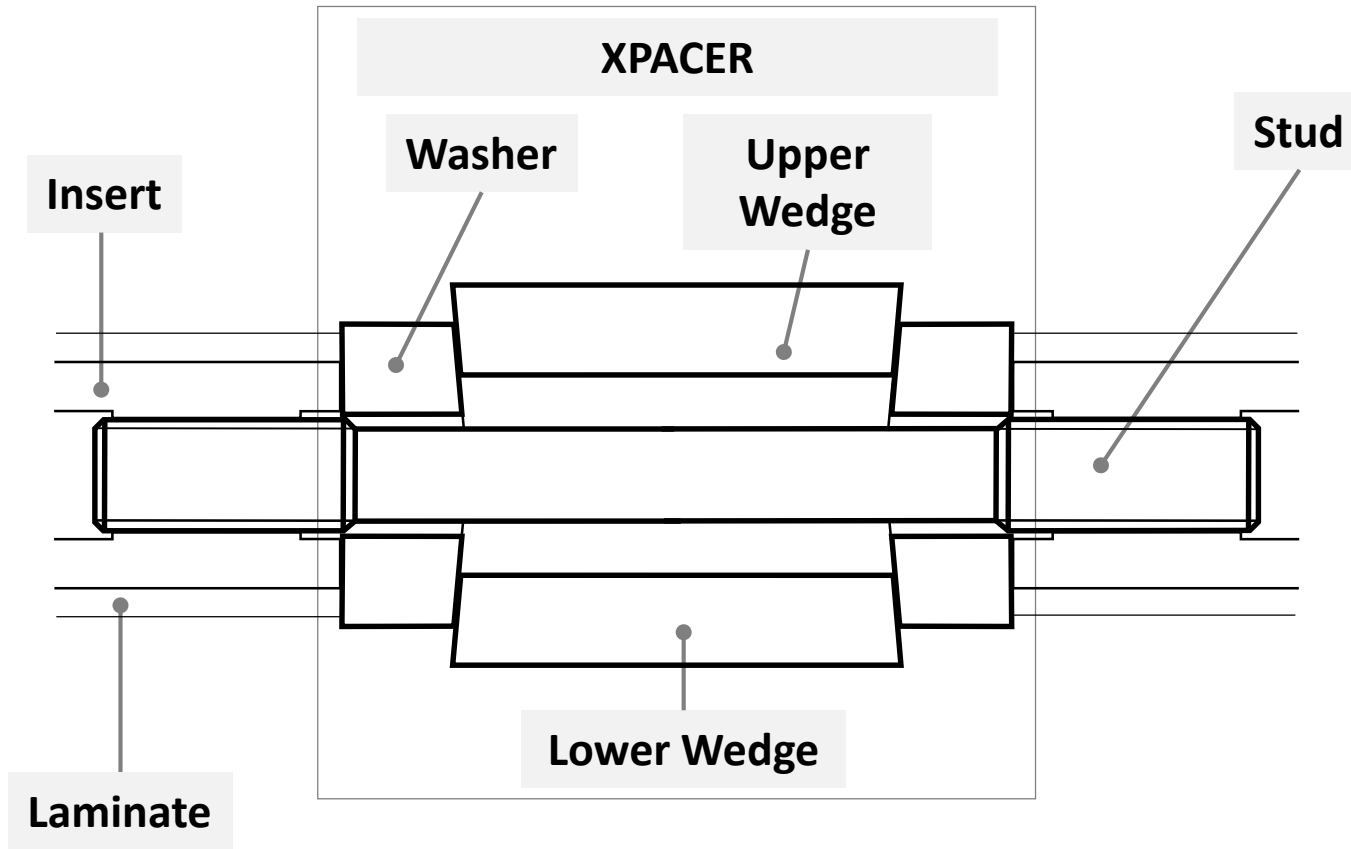
Source: ENERCON



Source: SGRE

1

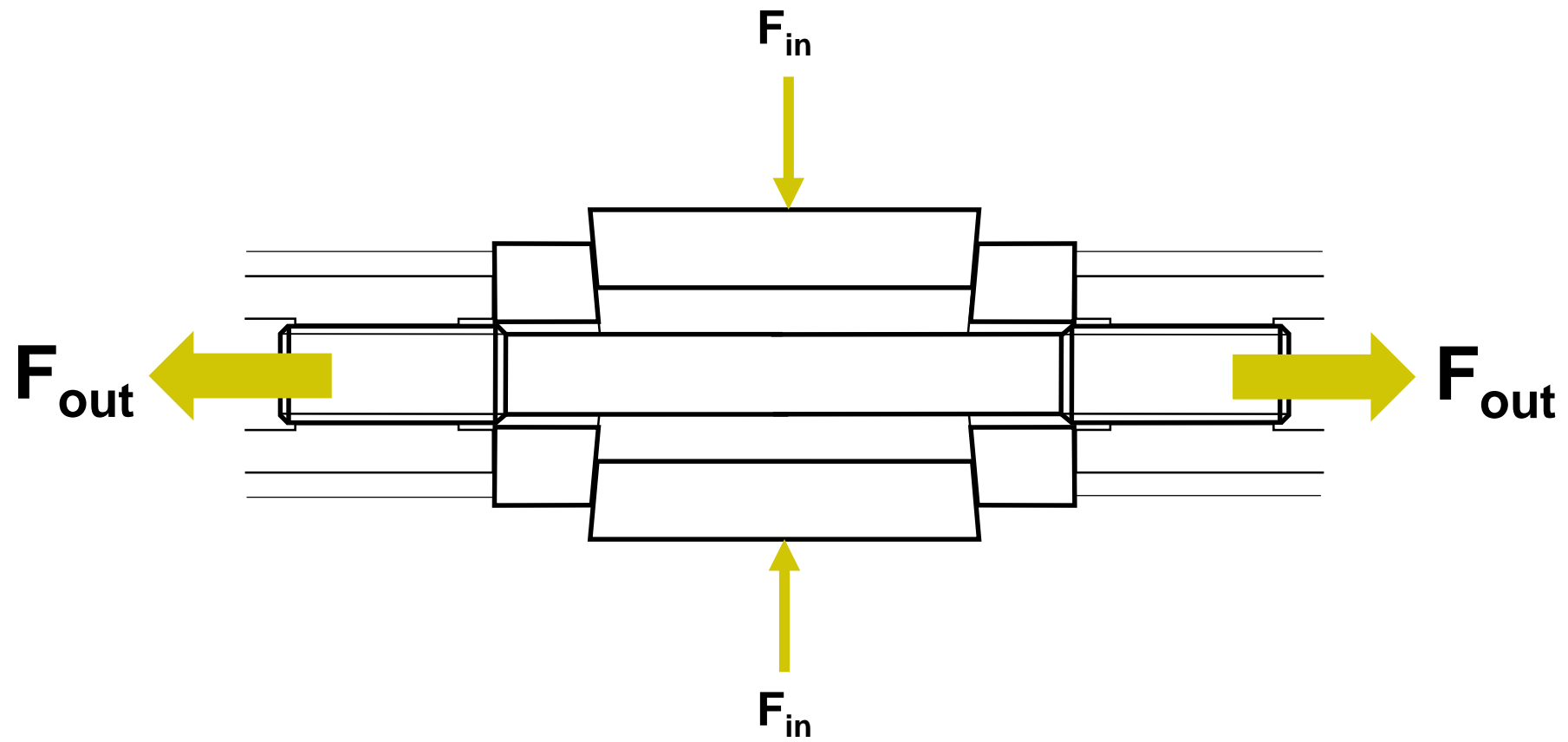
INTRODUCTION Nabrajoint®



1

INTRODUCTION

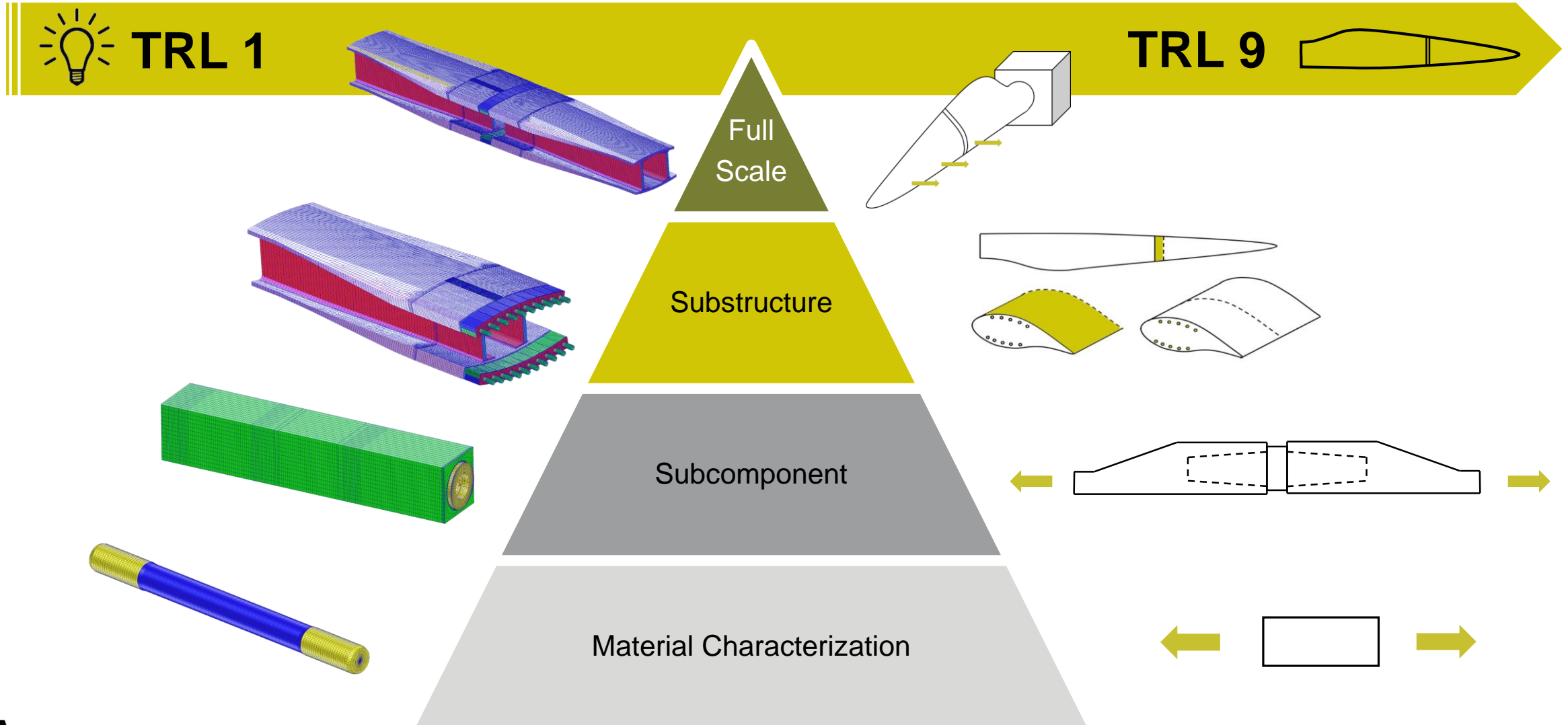
Nabrajoint®



2

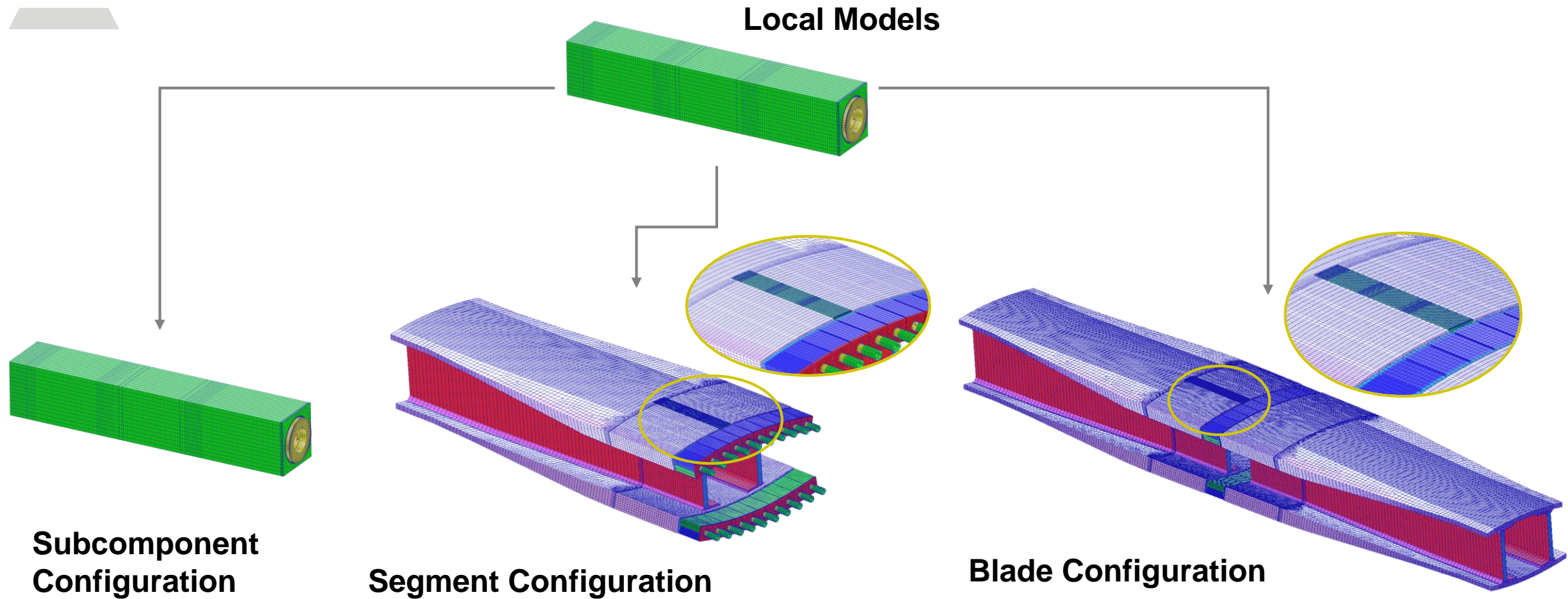
VALIDATION STRATEGY Goal of the Validation Program

Support Technology Readiness Level Through Analysis and Testing





Validation strategy based on Model-Test correlations

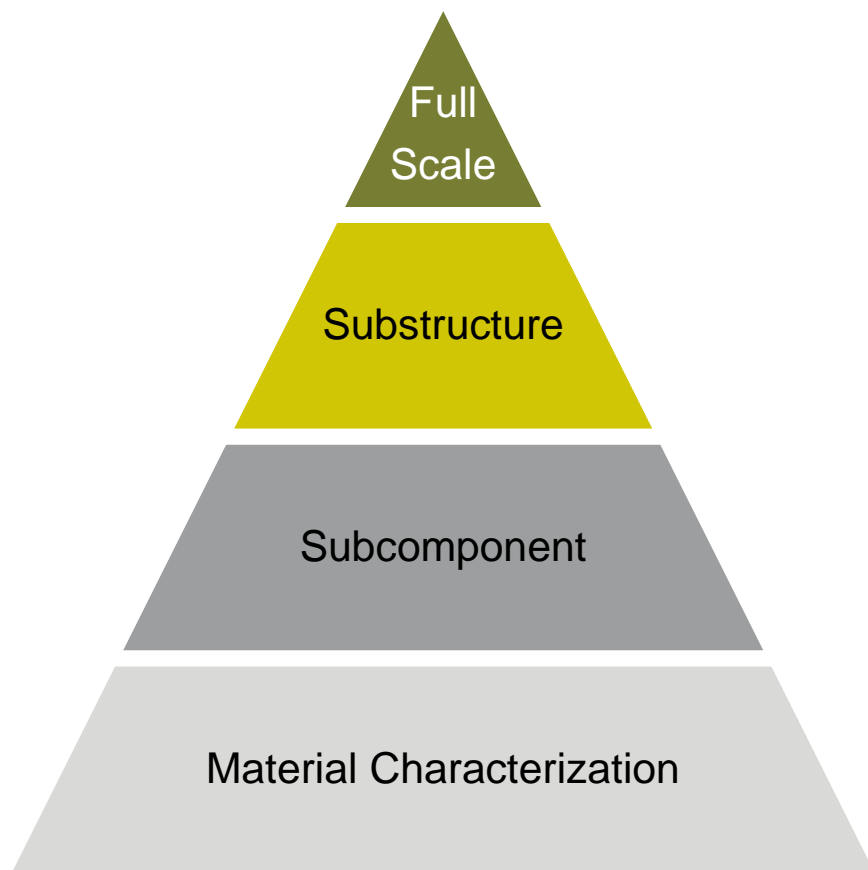




2

VALIDATION STRATEGY Certification Approach

Validation strategy based on Model-Test correlations



Number of Specimens	Boundary Conditions	Load Ratio	Multi-Axial Loading	Ageing
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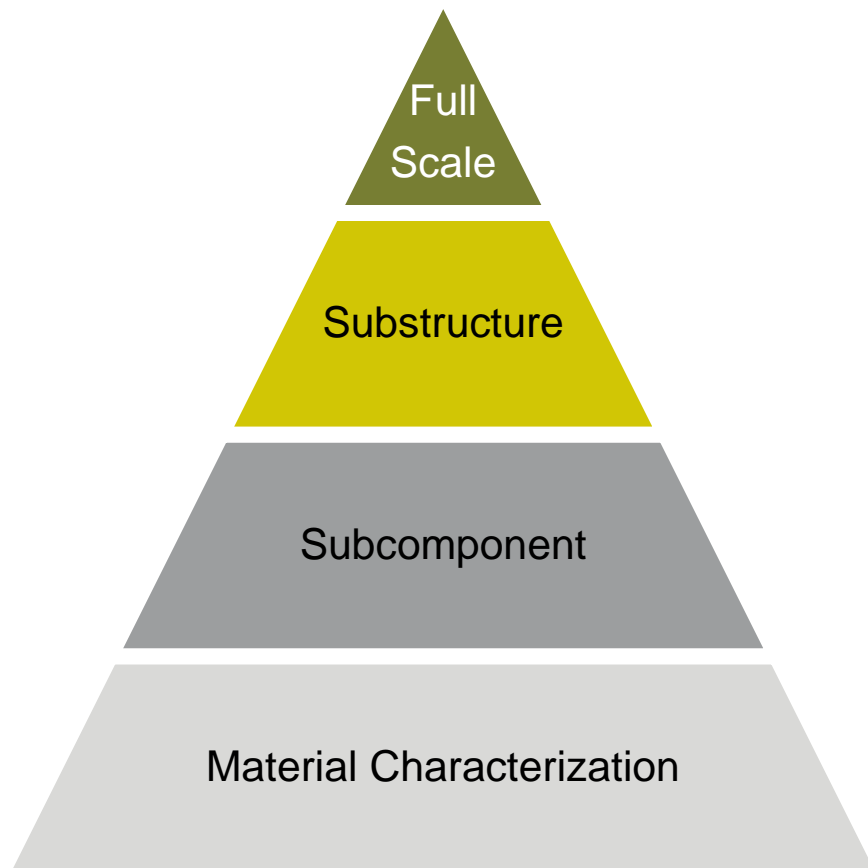
Validation of design assumptions

Obtention of design values



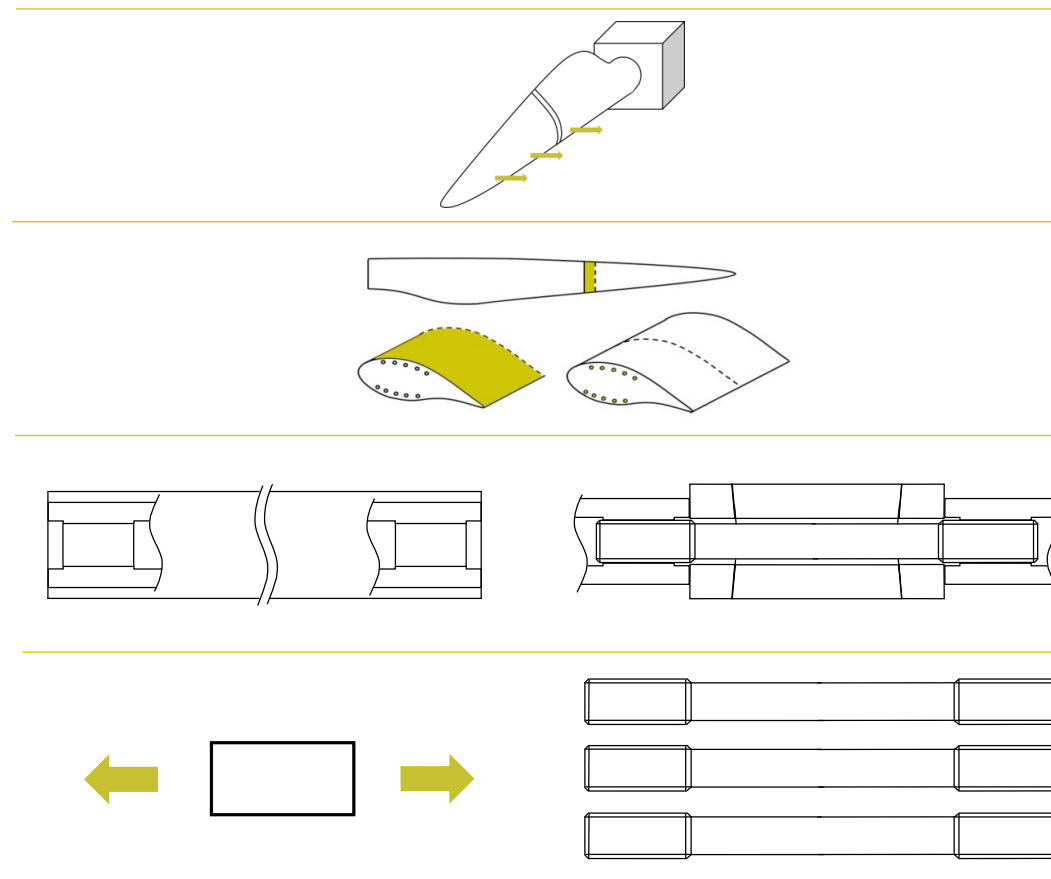
2

VALIDATION STRATEGY Test Campaign Overview



Bonded Joint

Bolted Joint



**Validation of
design
assumptions**

**Obtention of
design values**

3

TEST CAMPAIGN Material Characterization Testing

MAT. CHARACT.

TRL 9

TRL 8

TRL 7

TRL 6

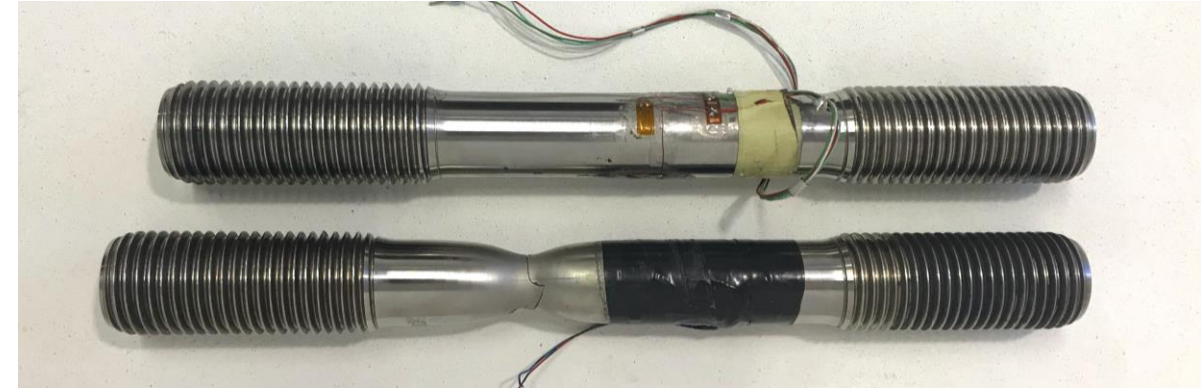
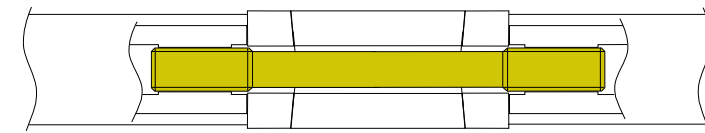
TRL 5

TRL 4

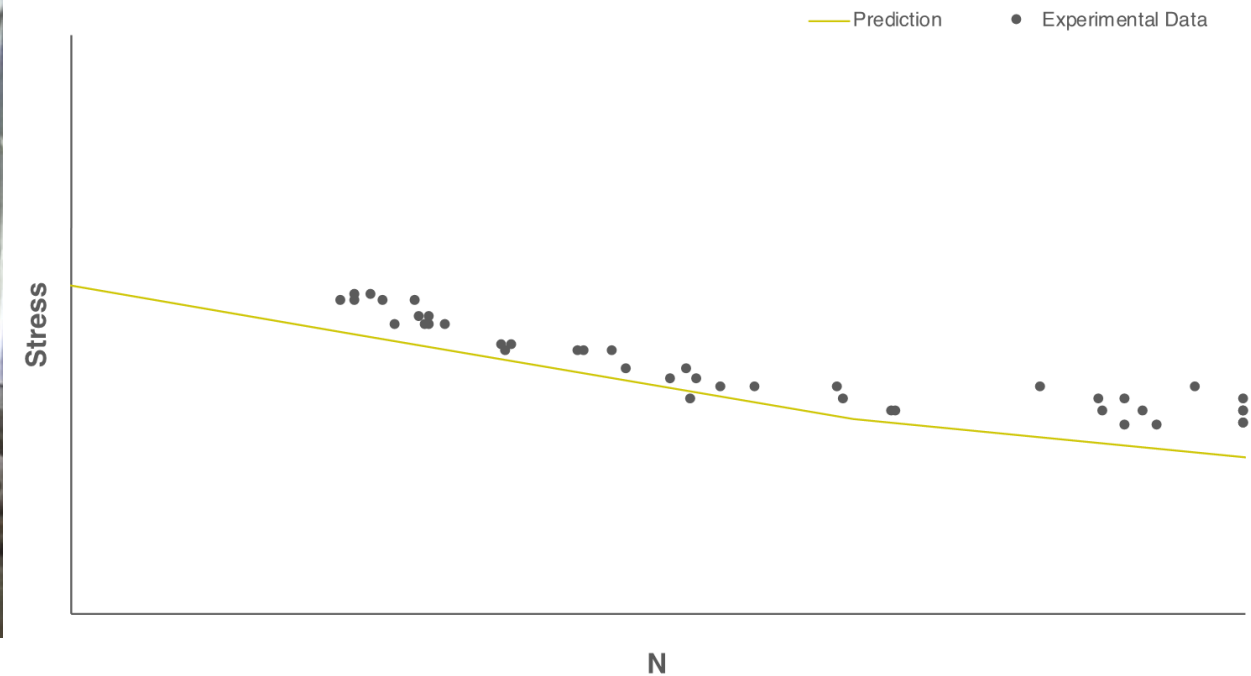
TRL 3

TRL 2

TRL 1



S-N Curve: Prediction & Experimental Data

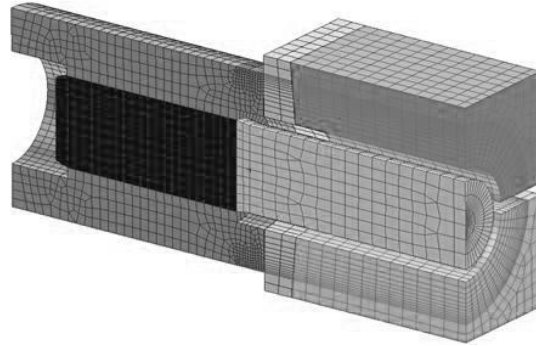




BOLTED JOINT

Validation of Bolted Joint – Correlation Models

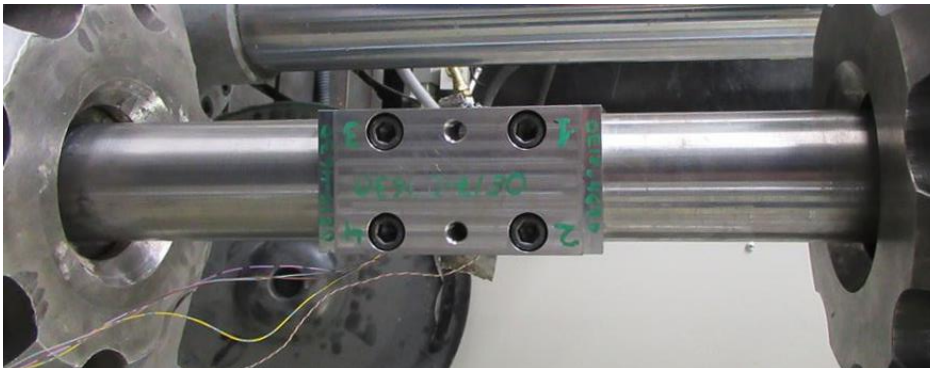
FEM



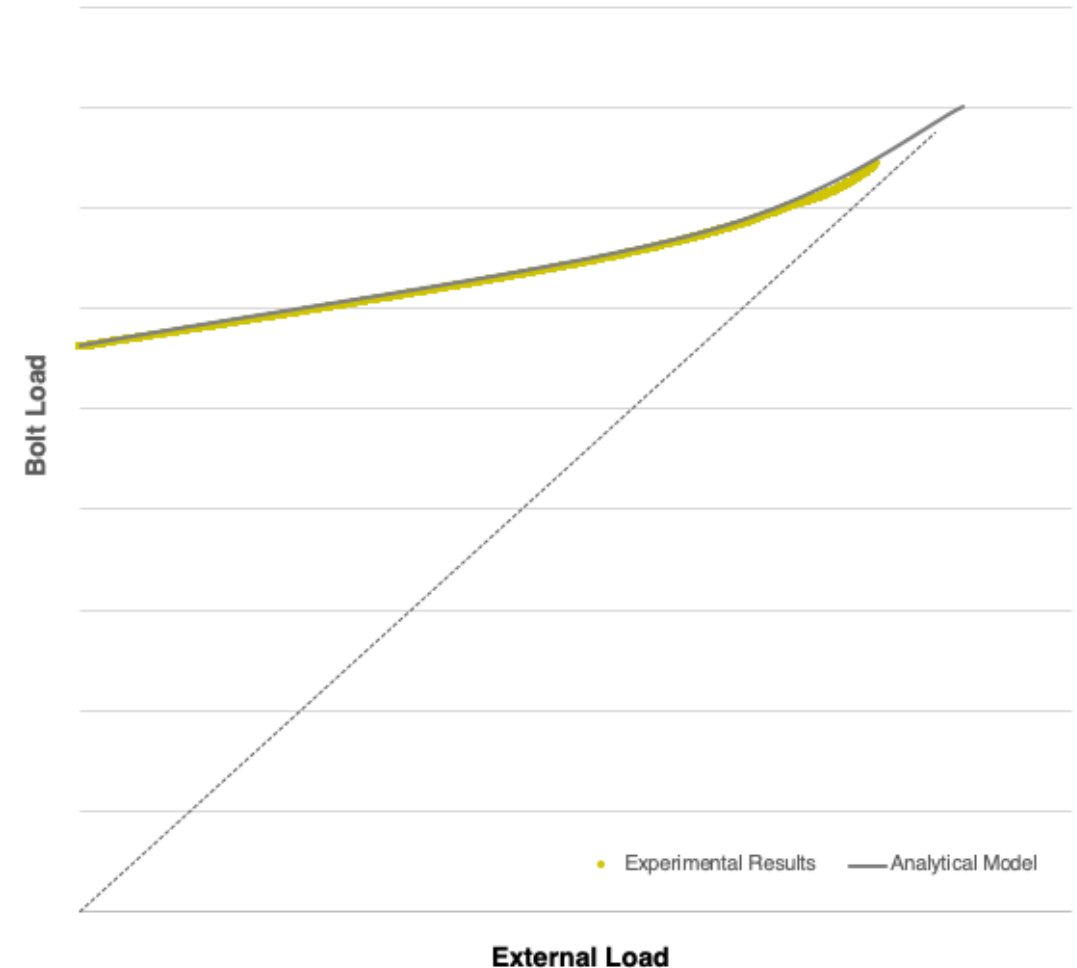
Analytical Model

$$F_{Amax} = \frac{F_{Smax} - \alpha_A \cdot [F_{Kerf} + F_Z + \Delta F'_{Vth}] - \Delta F'_{Vth}}{\alpha_A + (1 - \alpha_A) \cdot \Phi}$$

Test



Nabrajoint® Bolted Joint Response to an External Load



TRL 9

TRL 8

TRL 7

TRL 6

TRL 5

TRL 4

TRL 3

TRL 2

TRL 1

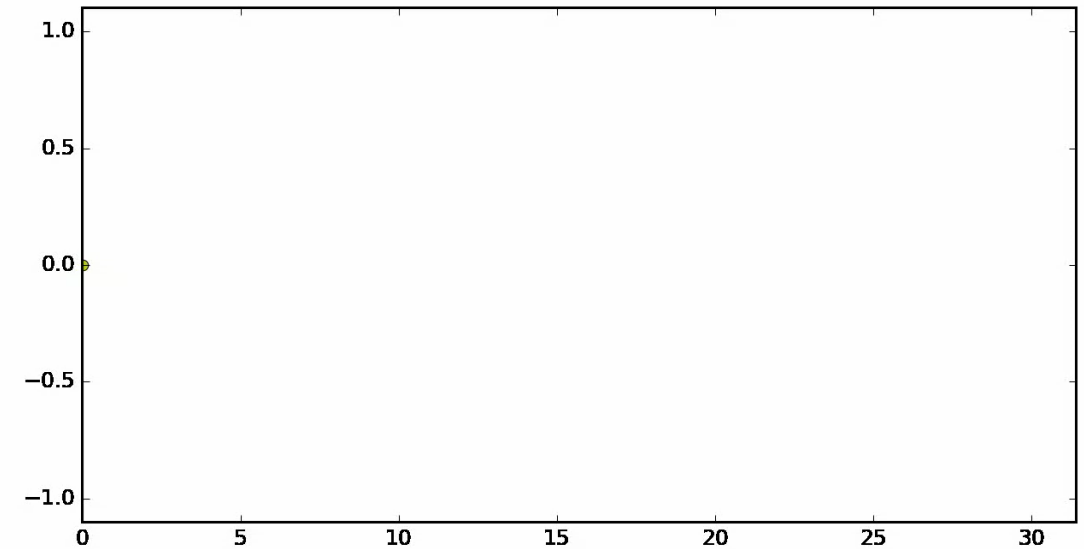
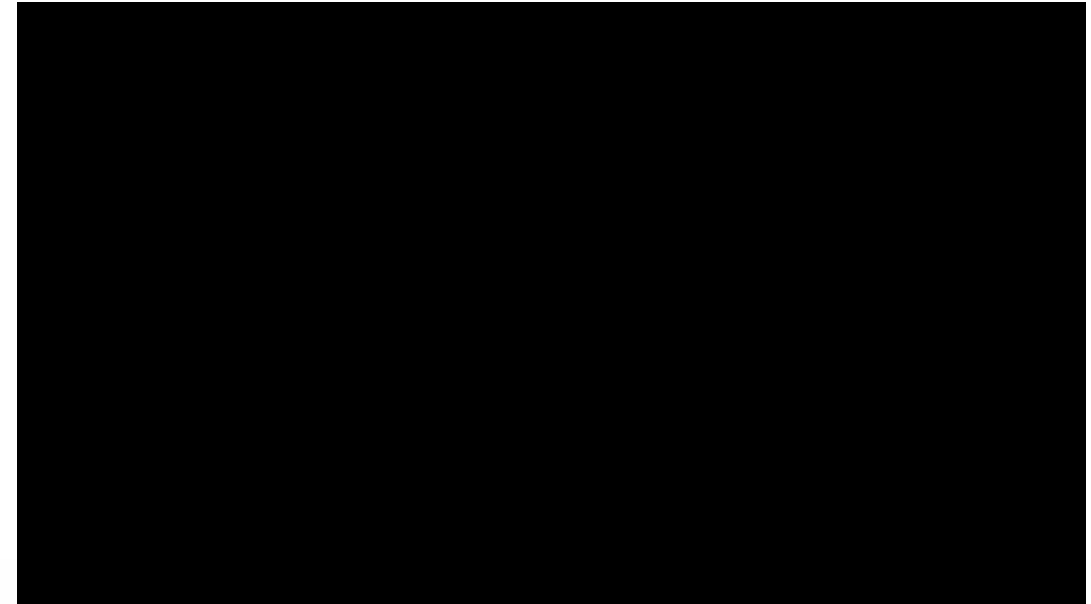
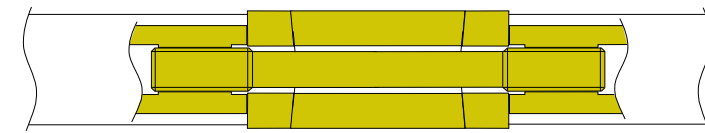
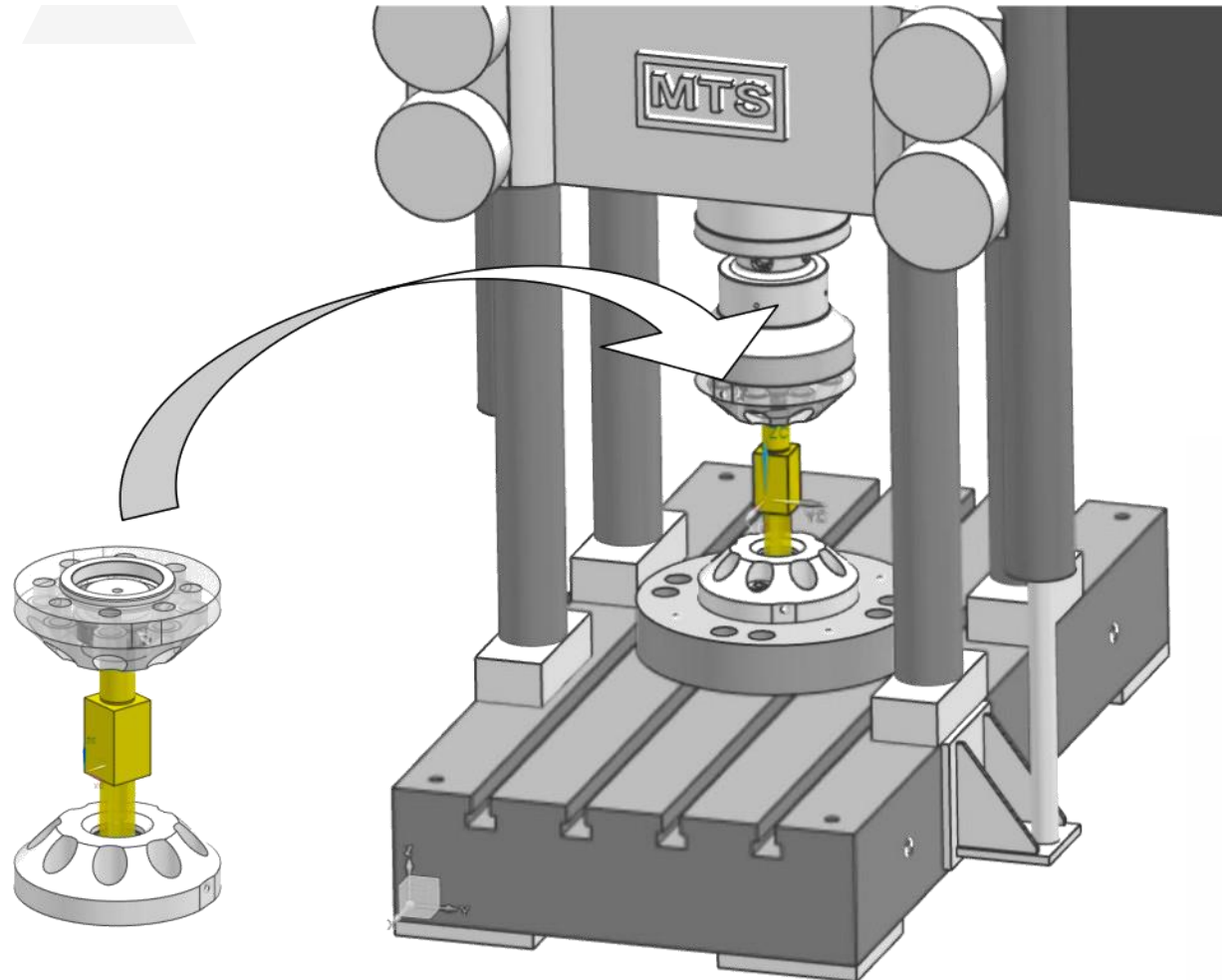
3

TEST CAMPAIGN

Subcomponent Analysis and Testing

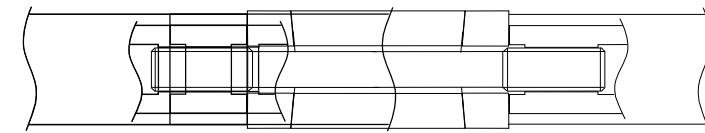
Validation of Bolted Joint - Tests

BOLTED JOINT



3

TEST CAMPAIGN Subcomponent Analysis and Testing



Validation of Bonded Joint – Correlation Models

BONDED JOINT

FEM

Test

TRL 9

TRL 8

TRL 7

TRL 6

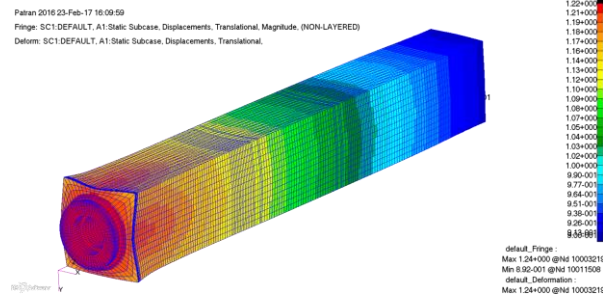
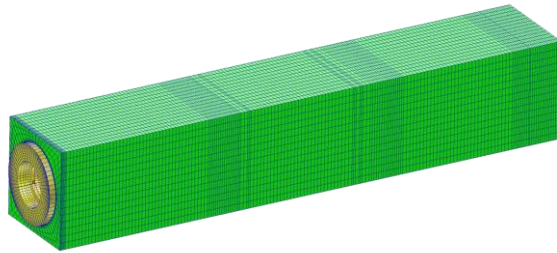
TRL 5

TRL 4

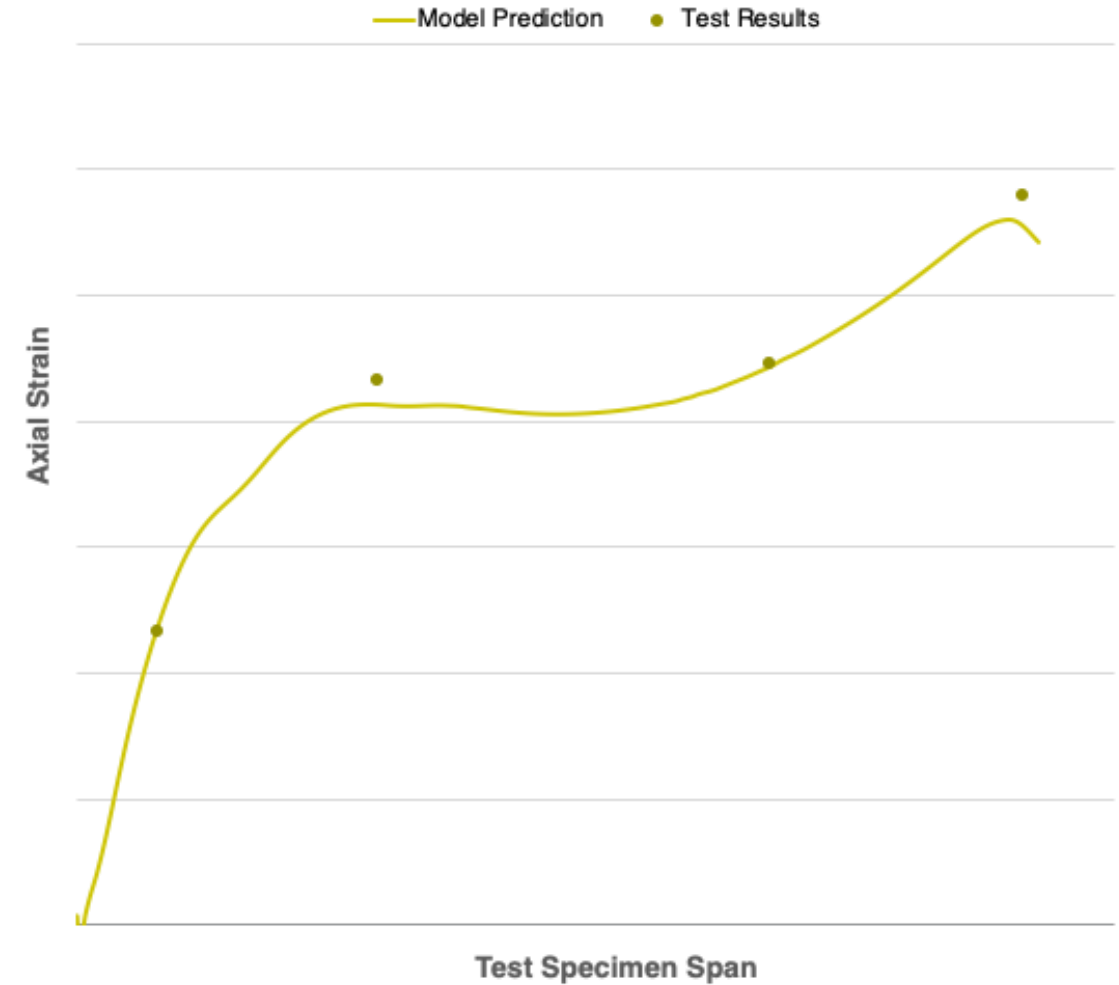
TRL 3

TRL 2

TRL 1



Nabrajoint® Bonded Joint Test Strain Distribution





3

TEST CAMPAIGN

Substructure Analysis and Testing

SEGMENT TEST

Validation of Nabrajoint® Substructure – Correlation Models

TRL 9

TRL 8

TRL 7

TRL 6

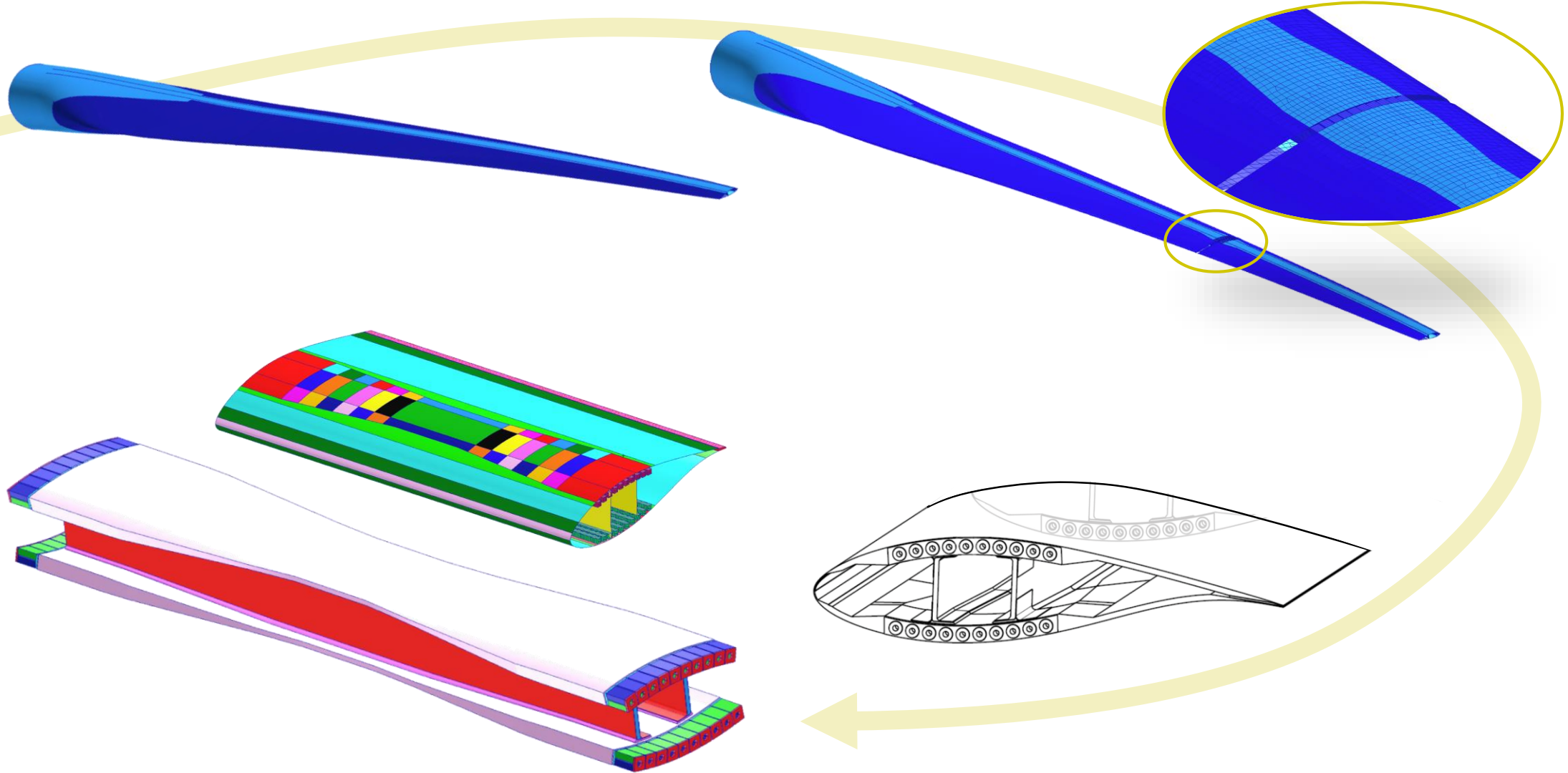
TRL 5

TRL 4

TRL 3

TRL 2

TRL 1



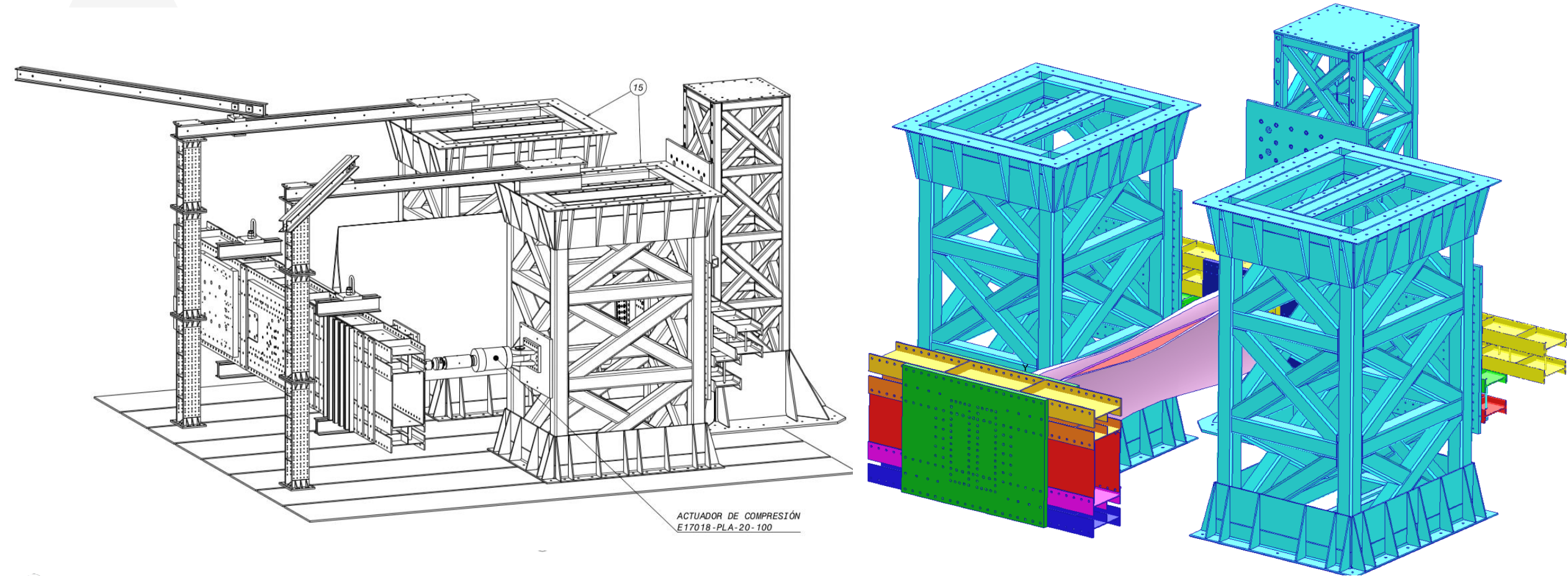
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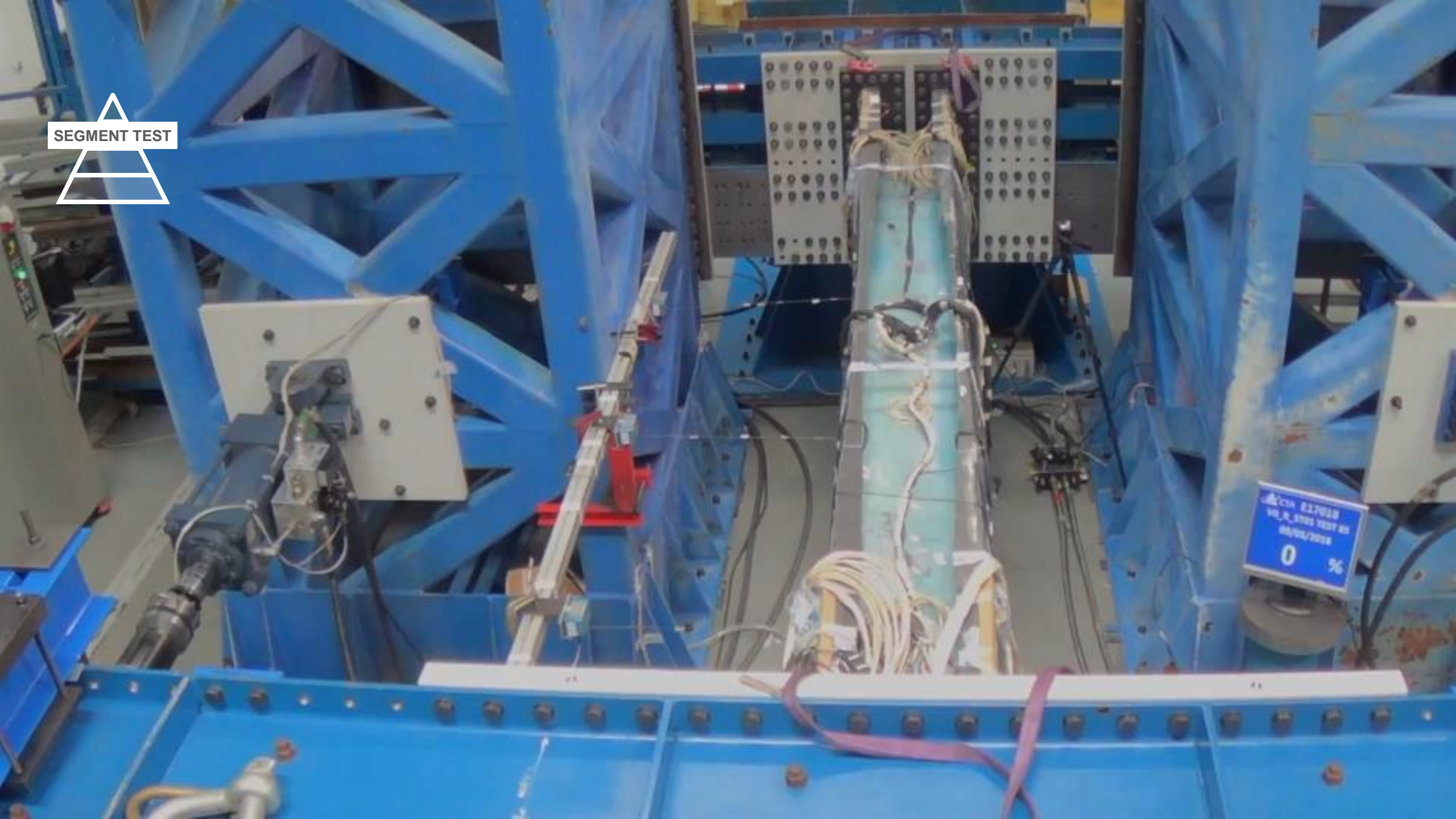
TEST CAMPAIGN

Substructure Analysis and Testing

SEGMENT TEST

Validation of Nabrajoint® Substructure – Test Bench Definition





SEGMENT TEST

nabrajoint®

NA
BRA
WIND

CTA E.17.018
SL ST FLAPMAX
19/12/2018
0 %



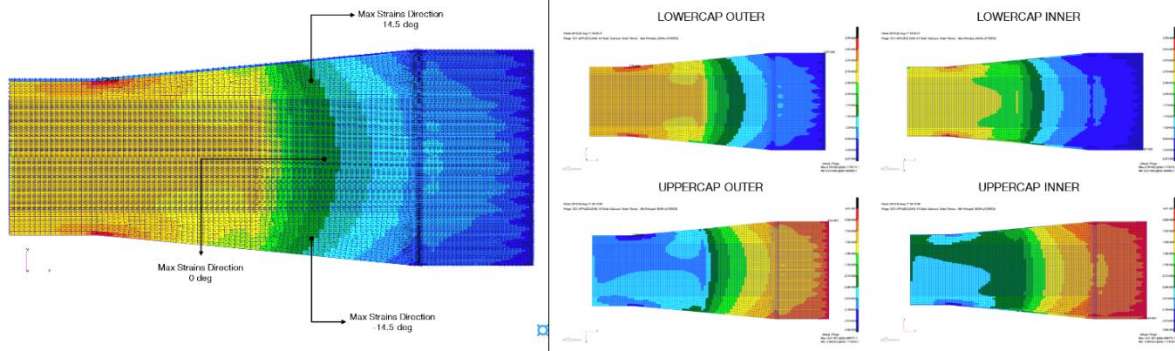
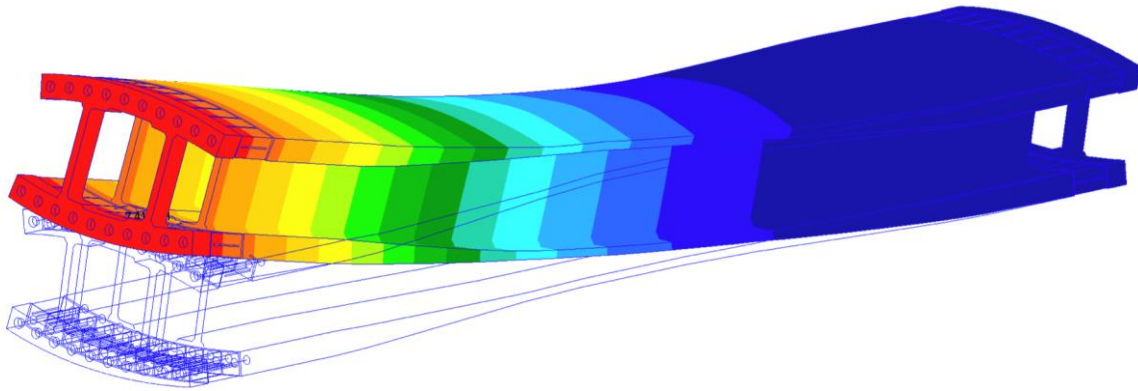
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TEST CAMPAIGN

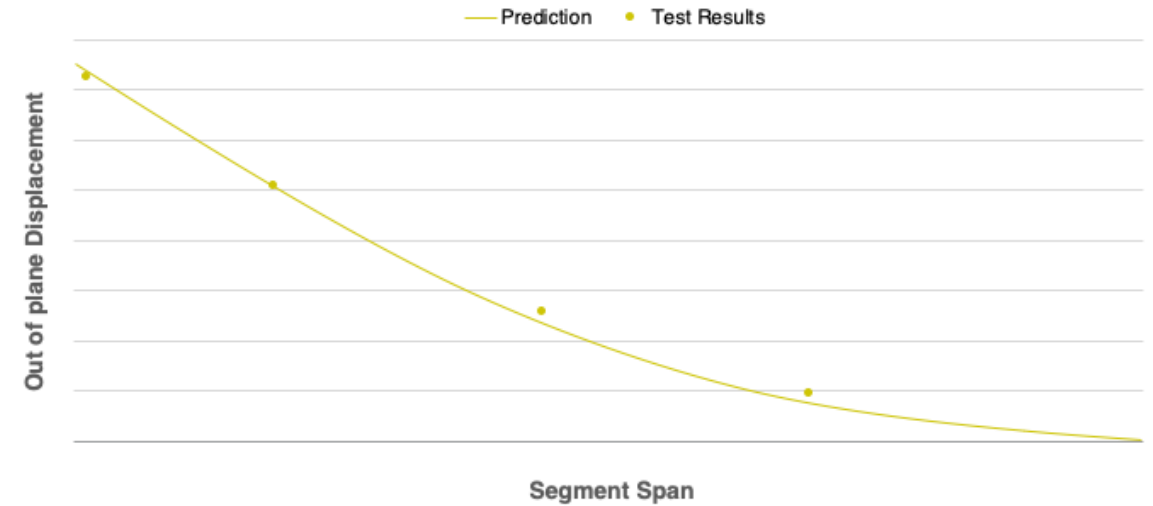
Substructure Analysis and Testing

SEGMENT TEST

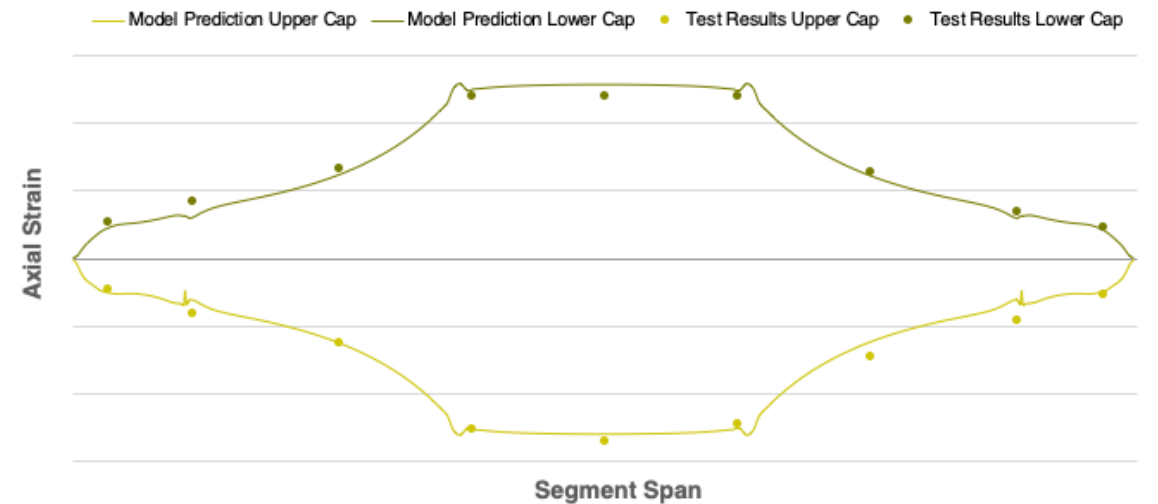
Validation of Nabrajoint® Substructure – Correlation Results



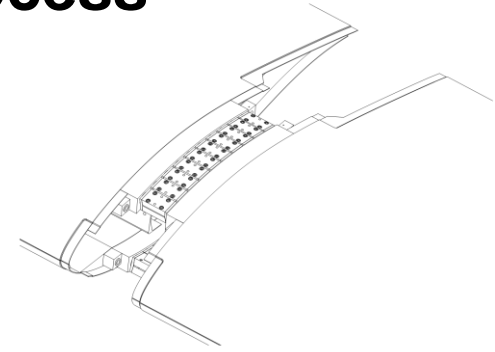
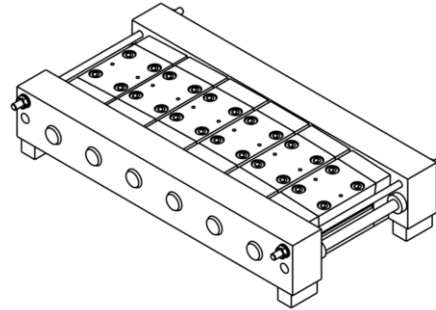
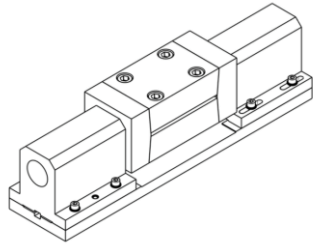
Nabrajoint® Segment Displacement Distribution



Nabrajoint® Segment Strain distribution



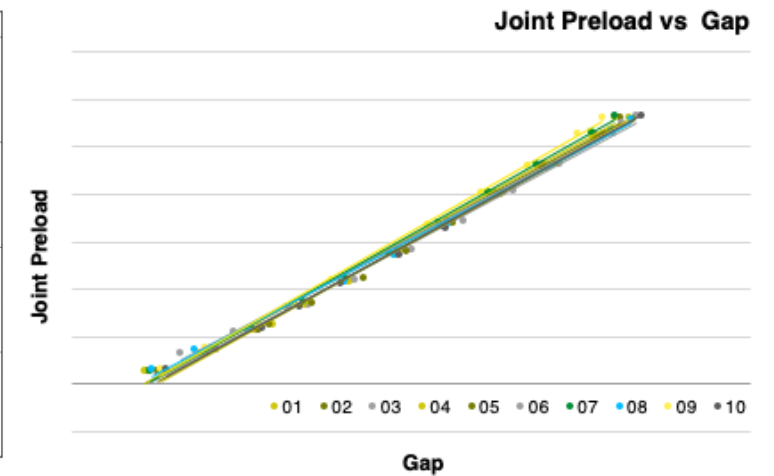
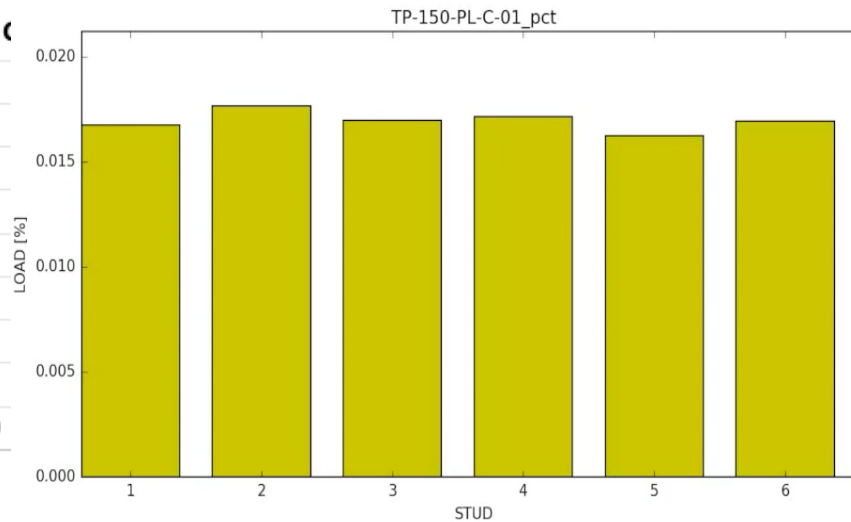
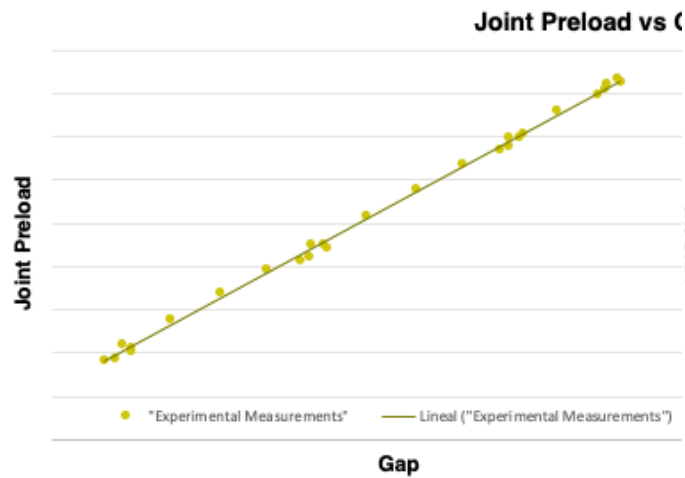
Validation of Novel Assembly and Preloading Process



1D Trials

2D Trials

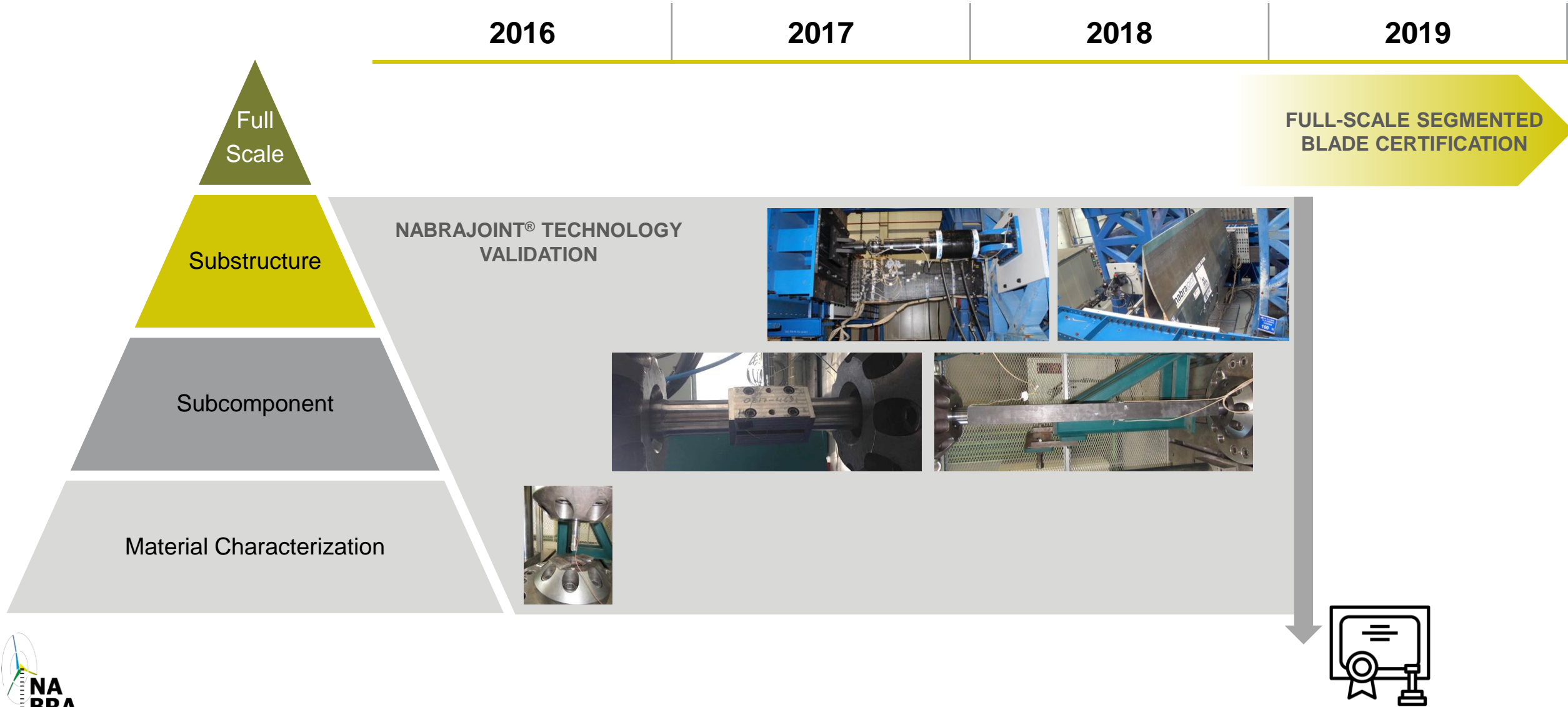
3D Trials





4

CONCLUSIONS Nabrajoint® Validation Summary





THANK YOU!