# Experimental Dynamic Substructuring Coupling and Decoupling

## - Application to Ampair 600 Wind Turbine -

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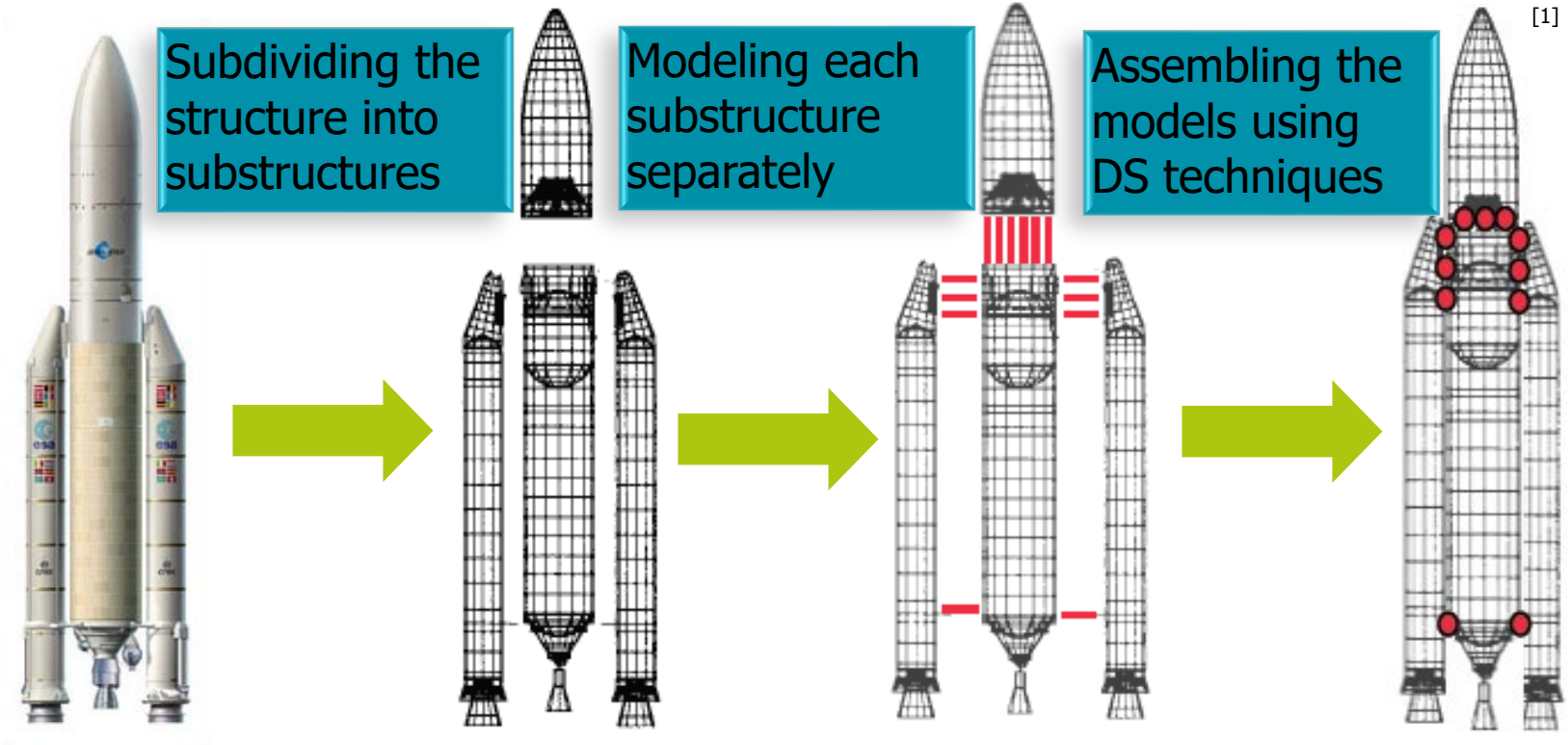
# Introduction

## Presentation outline

# Dynamic Substructuring

## Schematic overview




[1]

[1] Figures from Daniel J. Rixen, Dynamic Substructuring Concepts, Tutorial, IMAC 2010.

# Dynamic Substructuring

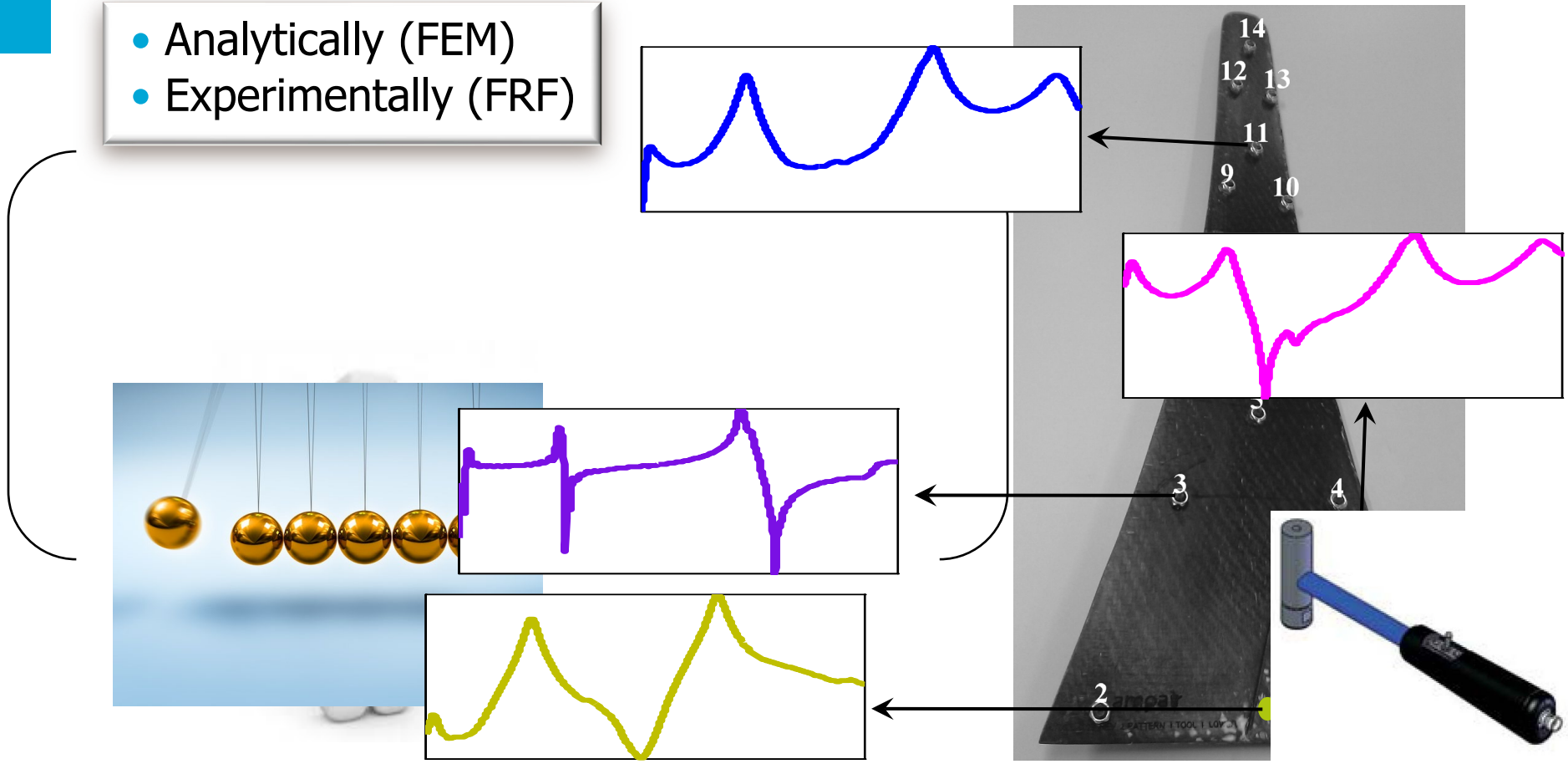
## Advantages of DS

- Local and global structure analyzing and optimizing
- Design groups work independently and exchange information

# Experimental DS

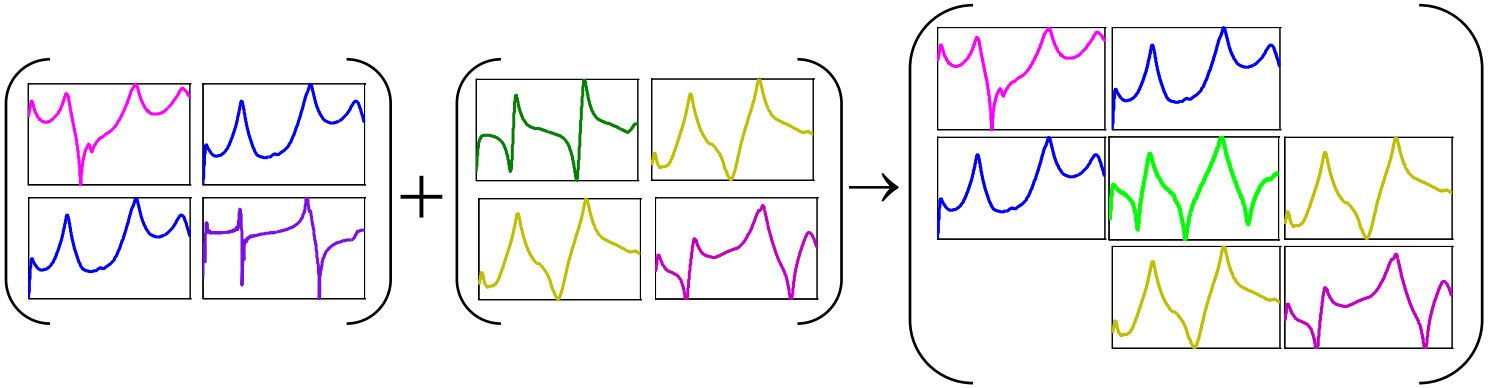
## Substructure modeling

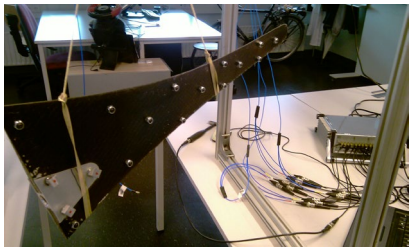
- Analytically (FEM)
- Experimentally (FRF)

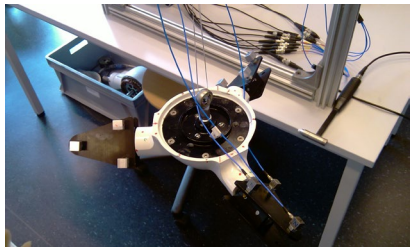


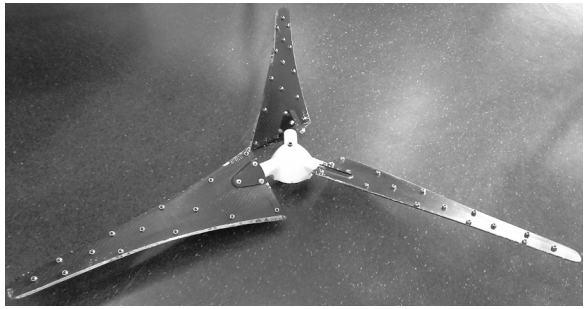
# Experimental DS

## Frequency Based Substructuring (FBS)









# Experimental DS

## Advantages of Experimental DS

- Cheaper and faster for too complex substructures
- Include all structural information such as damping

# Ampair 600 wind Turbine

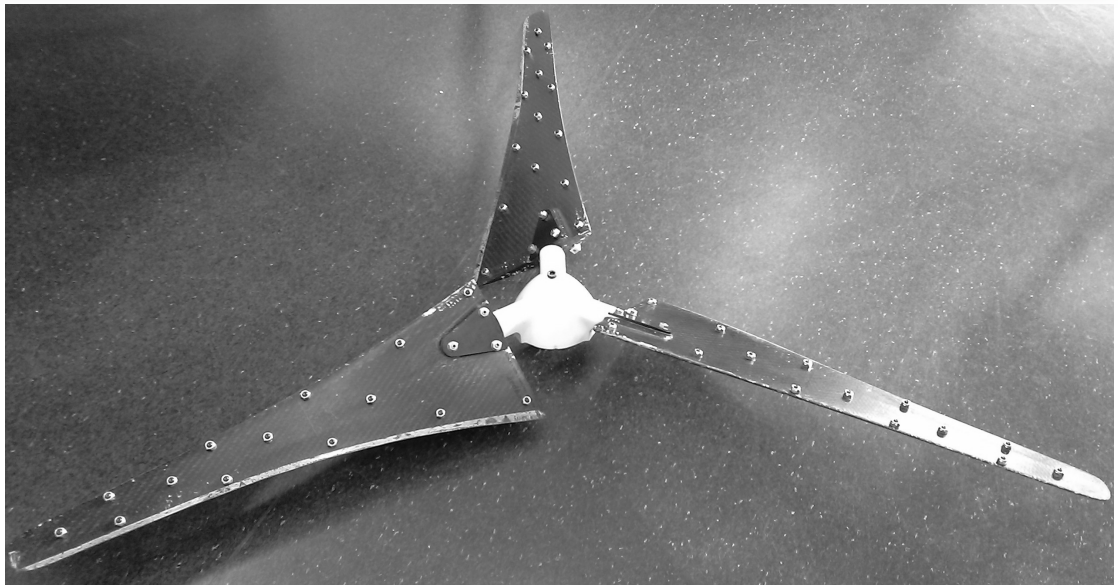
## Experimental DS Test bed initiated by SEM


- Advancing experimental DS
- Studying and evaluating existing methods
- Identifying generalized modeling techniques
- Providing guidance on their use

# Ampair 600 wind Turbine

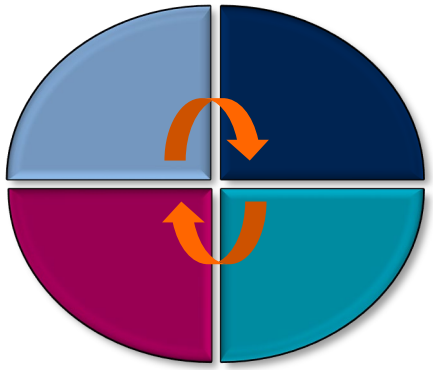
## Here at TU-Delft


- Iterative approach
- First iteration: three blades with the hub



# Ampair 600 wind Turbine

## Blade-Hub Assembly



# Experimental modeling

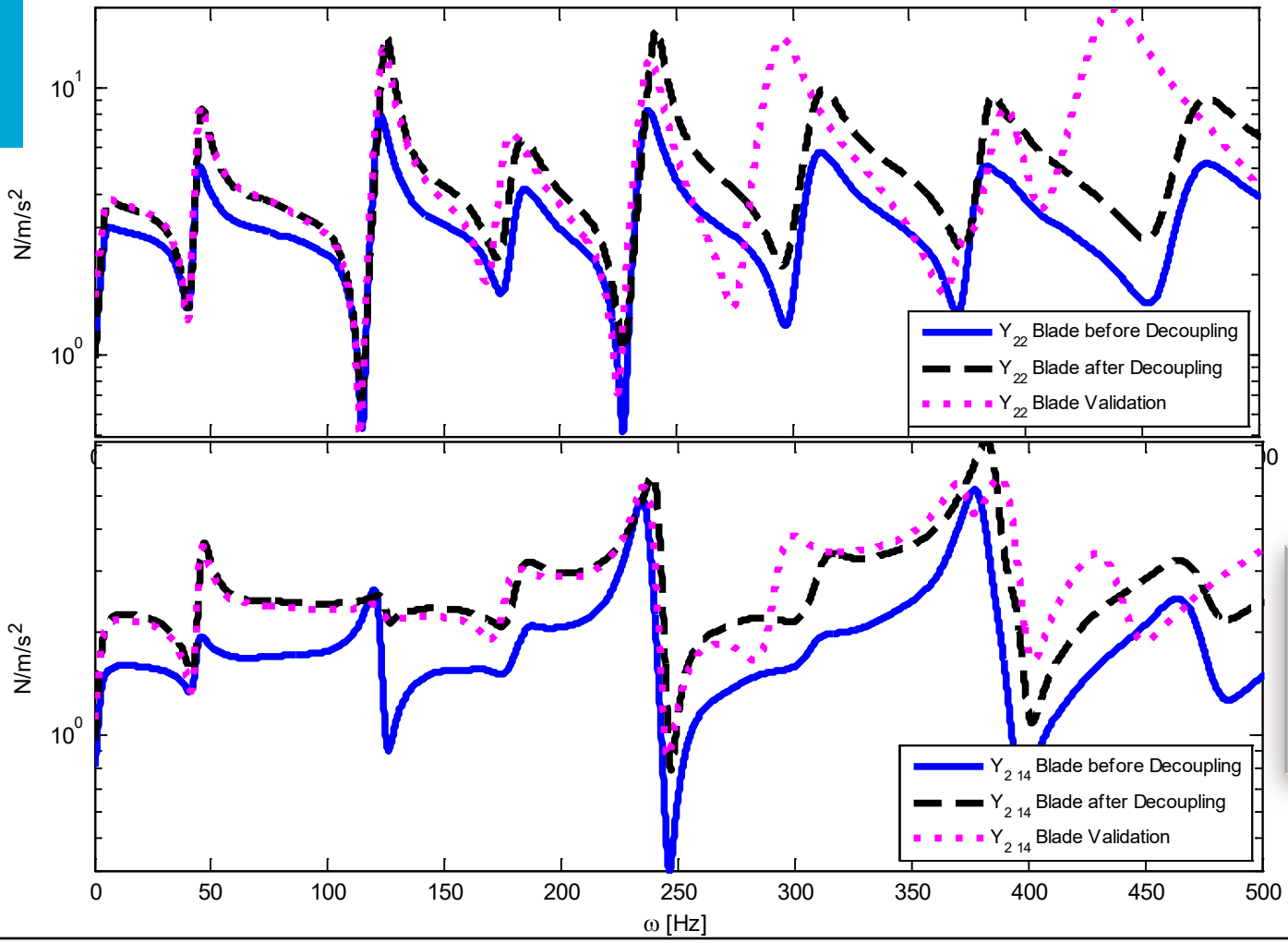
## Blade models

1. **Mass loaded at interface with fixture**
2. **Fully measured at interface**
3. **14 internal nodes are measured**
4. **The blade is decoupled (Fixture is subtracted analytically)**

1. **Blade is locally exercised (worked)**
2. **The joint stiffness and damping are included in the blade model**

# Experimental modeling

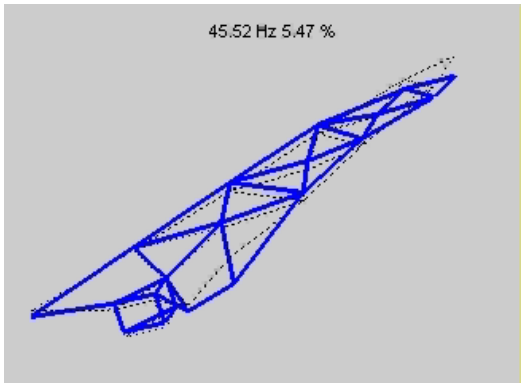
## Blade models

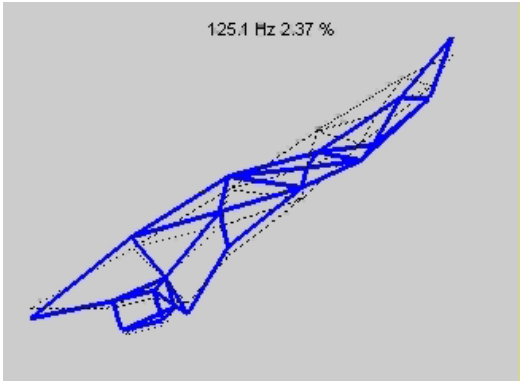


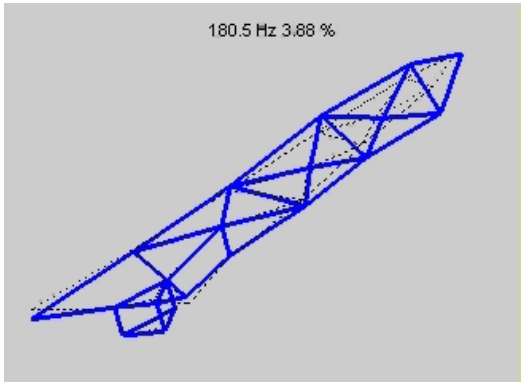

1. **Measured**
2. **Regenerated (Synthesized)**

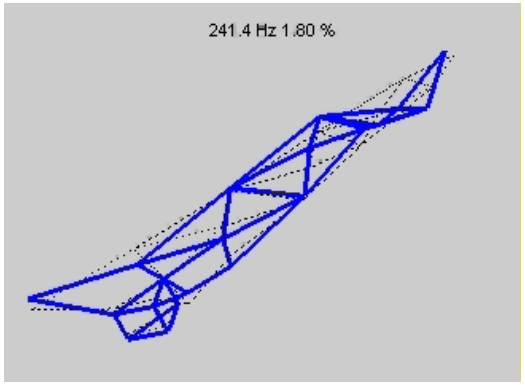
# Experimental modeling

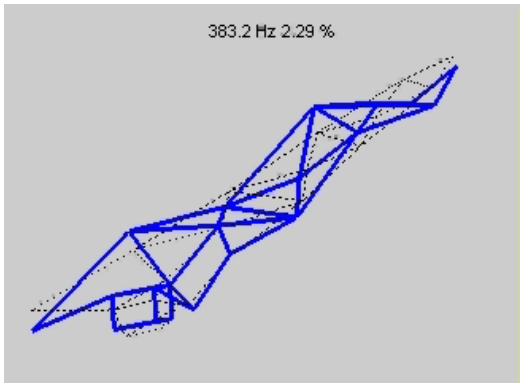
## Several blade modes

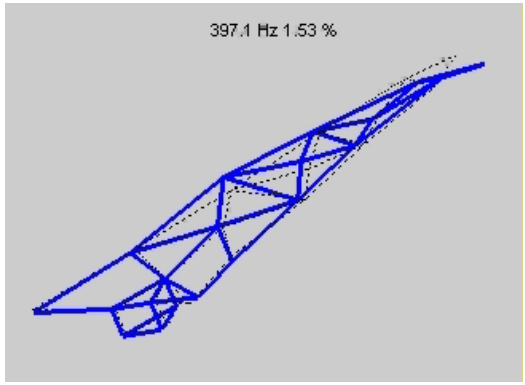


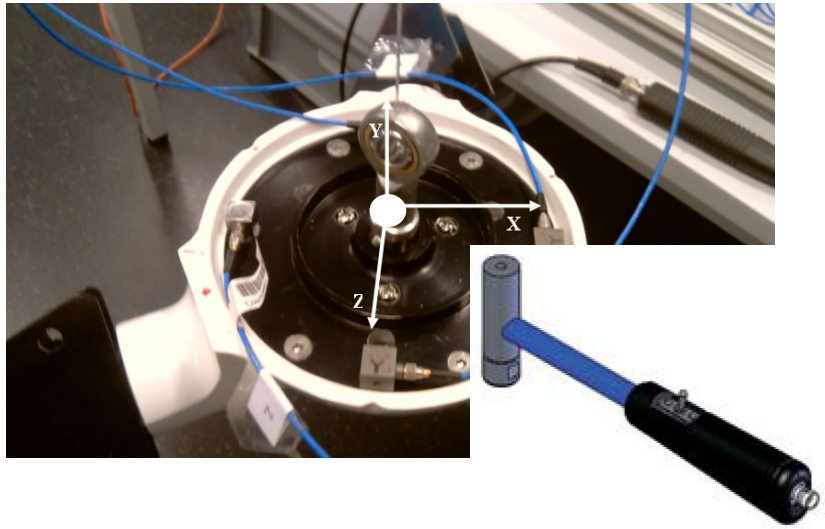



# Experimental modeling

## Lumped Hub model

- Lumped model (rigid body)




| | $m$ | $x_{og}$ | $y_{og}$ | $z_{og}$ | $J_{xx}^{o}$ | $J_{xy}^{o}$ | $J_{xz}^{o}$ | $J_{yy}^{o}$ | $J_{yz}^{o}$ | $J_{zz}^{o}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Hub inertia properties | 3.85 | 0.0014 | - 0.0386 | 0.0 | 0.0201 | 0.0003 | - 0.0002 | 0.0288 | 0.0004 | 0.0212 |

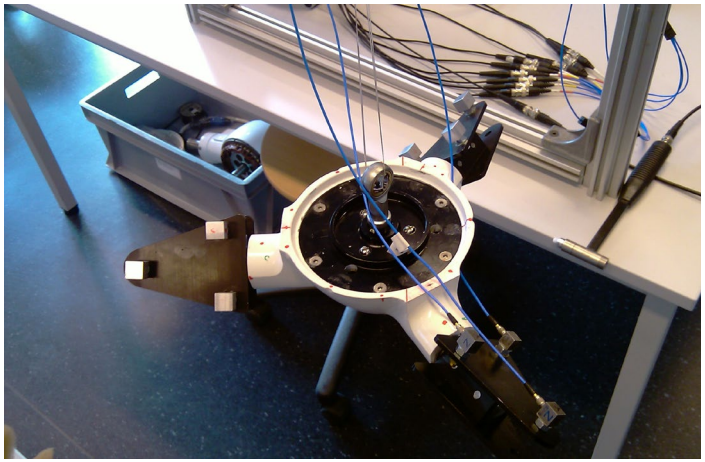
# Experimental modeling

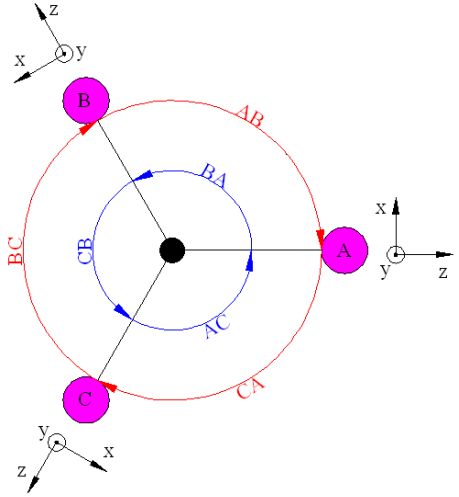
## Full Hub model

- Full model

- Cyclic symmetric

$$Y_{tot} = \begin{bmatrix} \textcircled{$Y_{AA}$} & \textcircled{$Y_{AB}$} & Y_{AC} \\ Y_{BA} & Y_{BB} & Y_{BC} \\ Y_{CA} & Y_{CB} & Y_{CC} \end{bmatrix} \Rightarrow Y_{tot} = \begin{bmatrix} Y_{AA} & Y_{AB} & Y_{BA} \\ Y_{BA} & Y_{AA} & Y_{AB} \\ Y_{AB} & Y_{BA} & Y_{AA} \end{bmatrix}$$

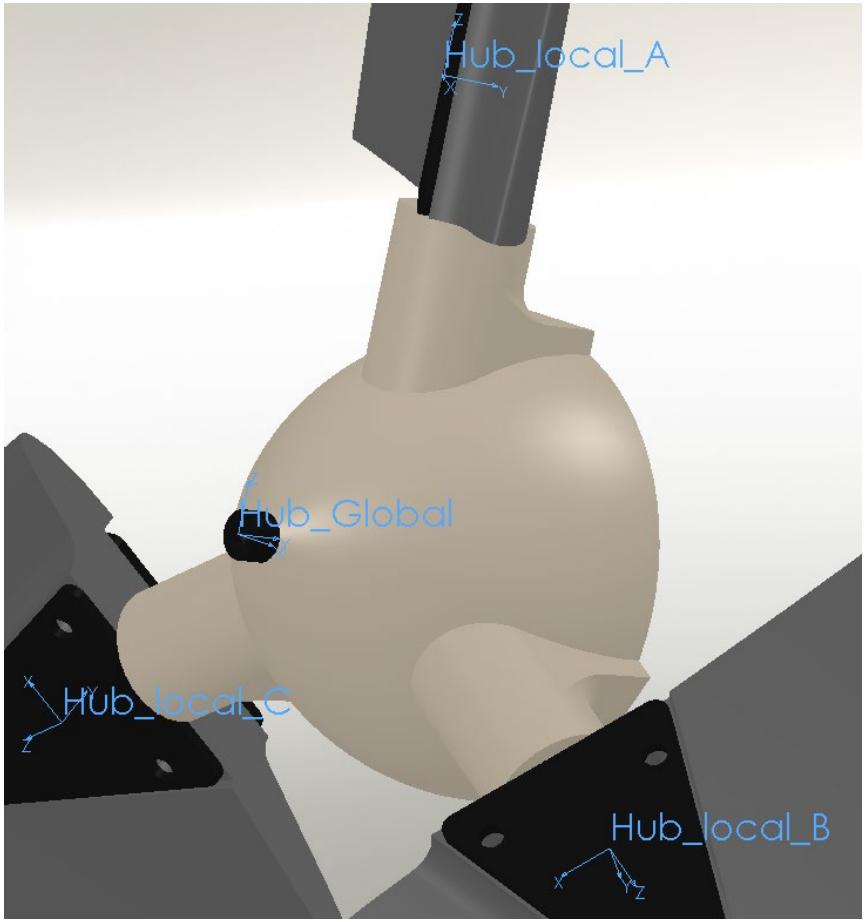




# Assembly results

## Assembly

- One blade model used three times
- In the local coordinates of the hub

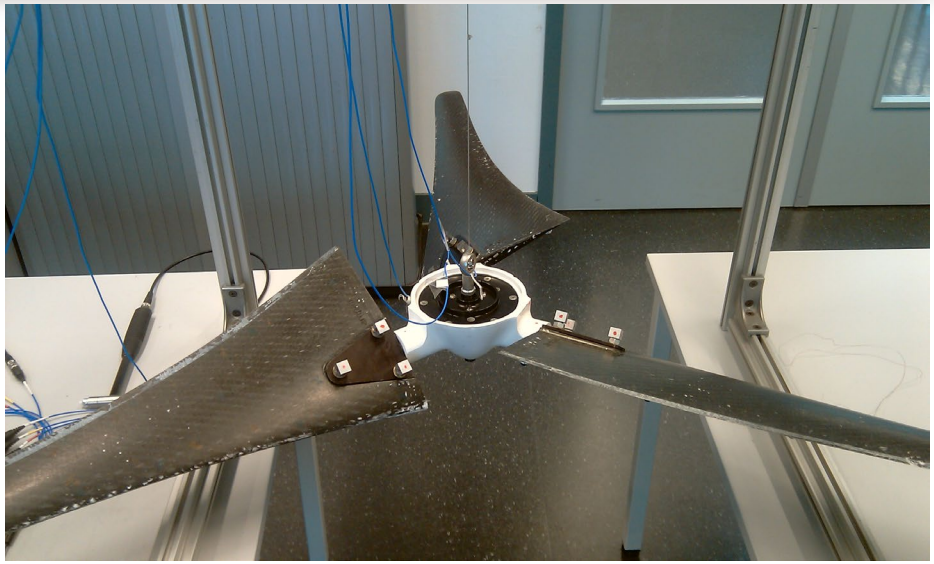


# Assembly results

## Coupling variants

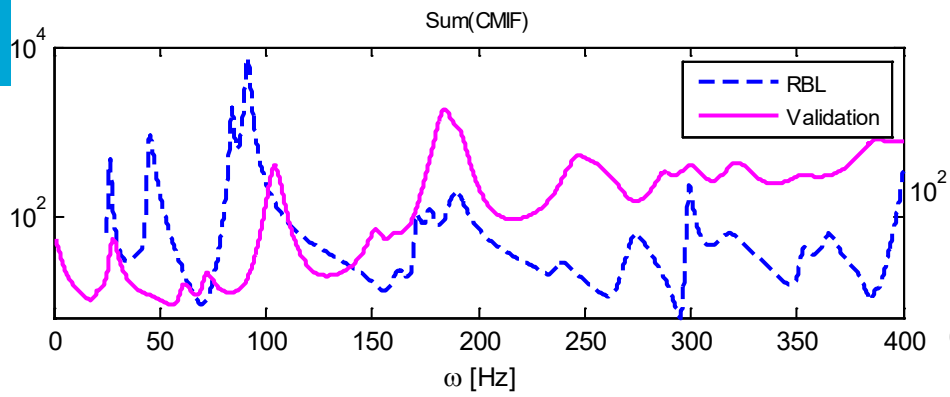
1. Regenerated Blade-Lumped Hub (RBL)
2. Regenerated Blade-Full Hub (RBF)
3. Measured Blade-Lumped Hub (MBL)
4. Measured Blade-Full Hub (MBF)

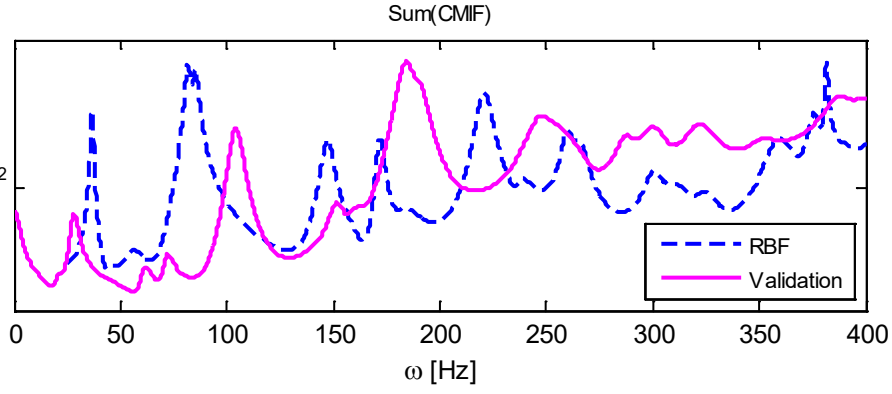
- Validation

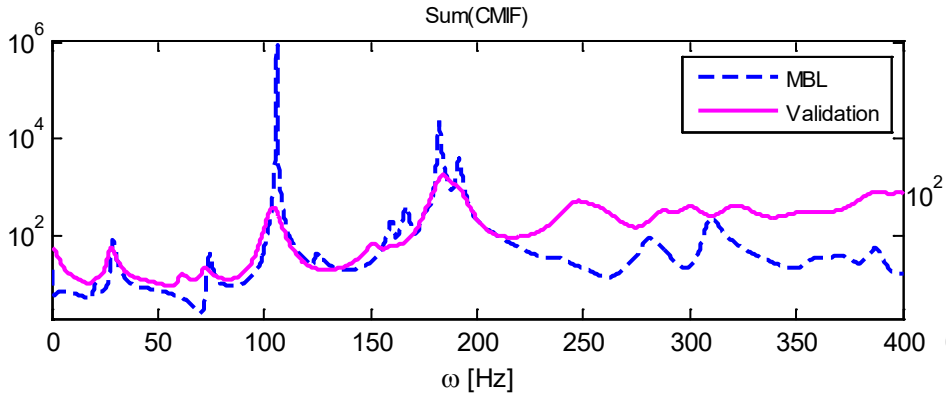


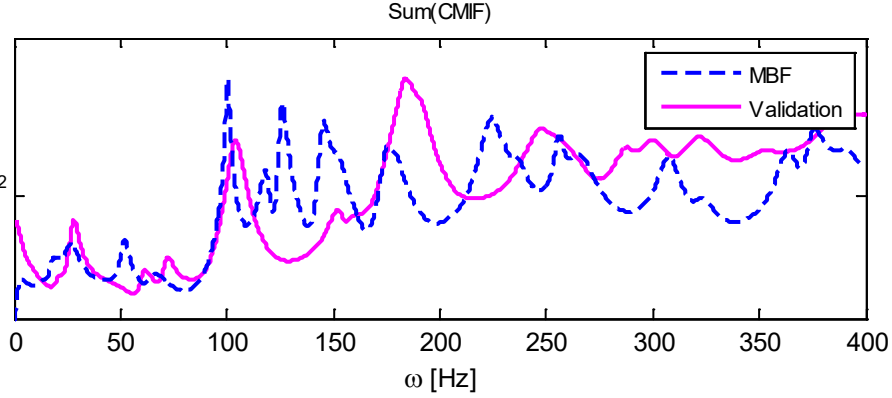
# Assembly results

## Coupling variants CMIF



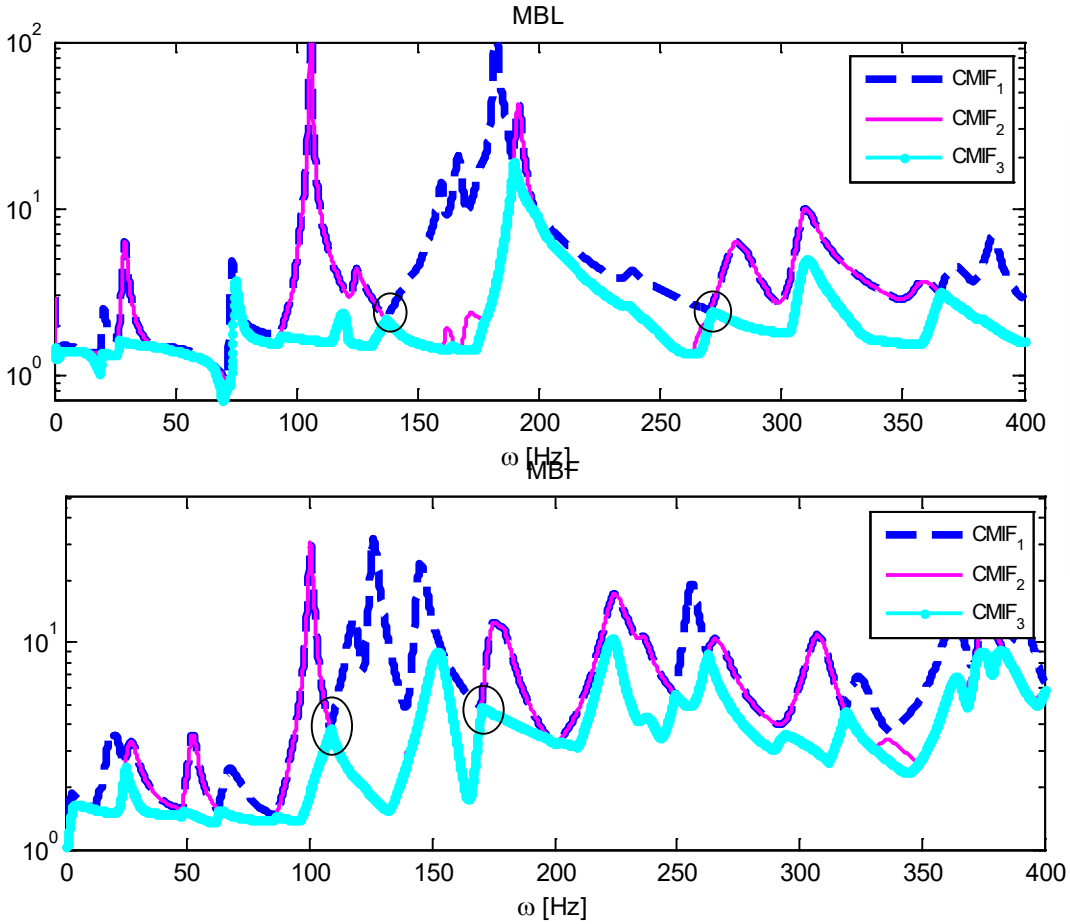



# Assembly results

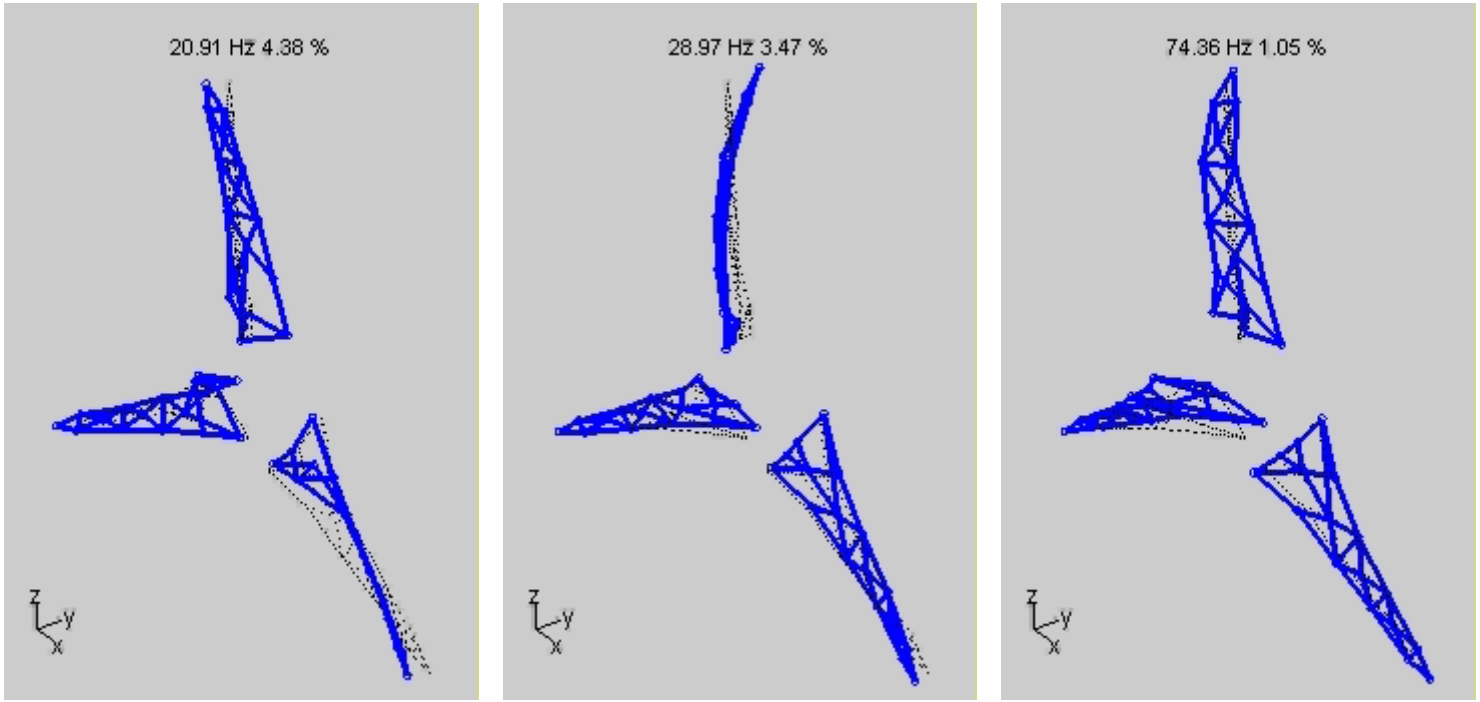
## MBL versus MBF




| | MBF | | MBL | |
|---|---|---|---|---|
| 1st mode | 18.8 [Hz] | 15.64 % | 20.9 [Hz] | 4.4 % |
| 2nd mode | 25.4 [Hz] | 8.1 % | 29.0 [Hz] | 3.5 % |
| 3rd mode | 52.3 [Hz] | 3.41 % | n/a | n/a |
| 4th mode | 65.5 [Hz] | 0.15 % | 74.3 [Hz] | 1.1 % |
| 5th mode | 98.3 [Hz] | -0.55 % | 106.4 [Hz] | 0.2 % |
| 6th mode | 117.0 [Hz] | 1.00 % | 118.0 [Hz] | 2.4 % |
| 7th mode | 125.0 [Hz] | 0.23 % | 123.8 [Hz] | 8.1 % |
| 8th mode | 144.3 [Hz] | 1.43 % | 159.4 [Hz] | 2.4 % |
| 9th mode | 151.6 [Hz] | 0.86 % | 167.6 [Hz] | 0.5 % |
| 10th mode | 178.8 [Hz] | 1.19 % | 182.4 [Hz] | 1.65 % |

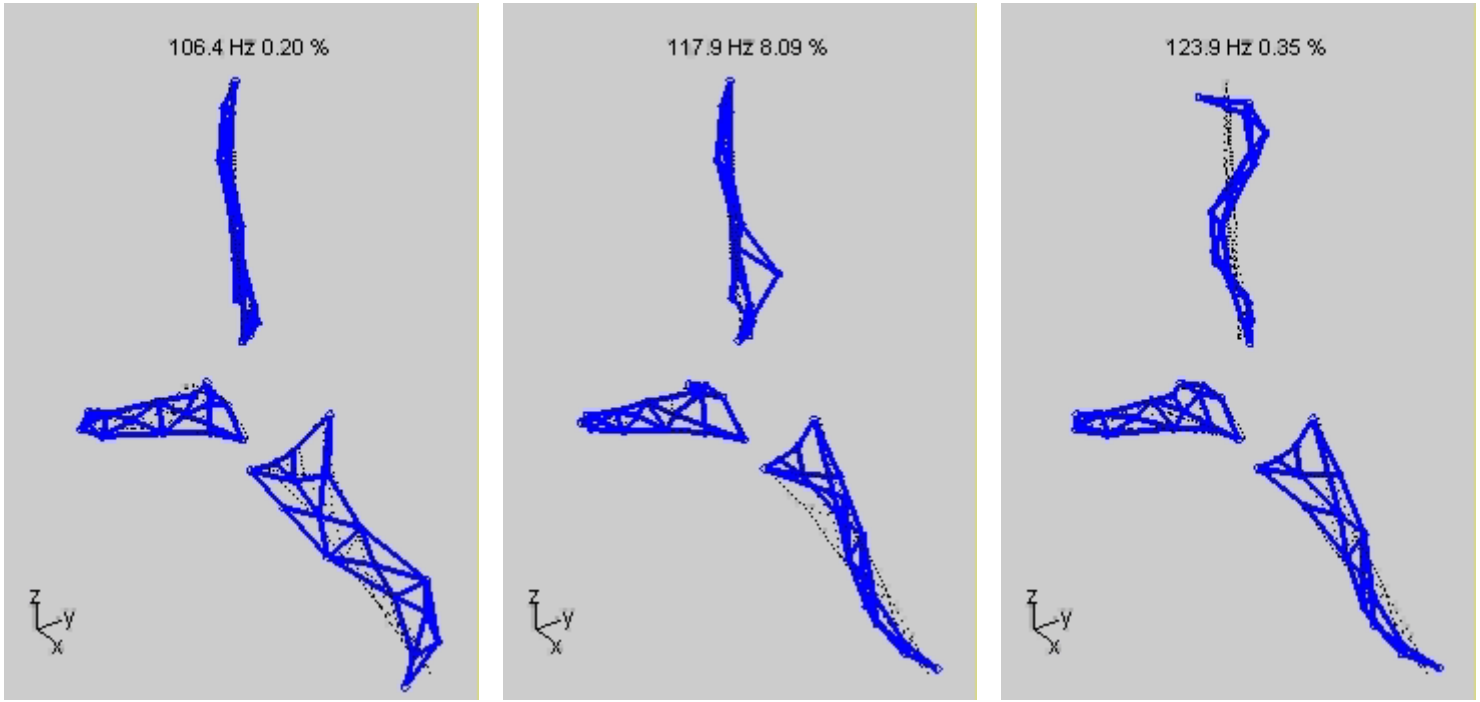
# Assembly results

## MBL Modes



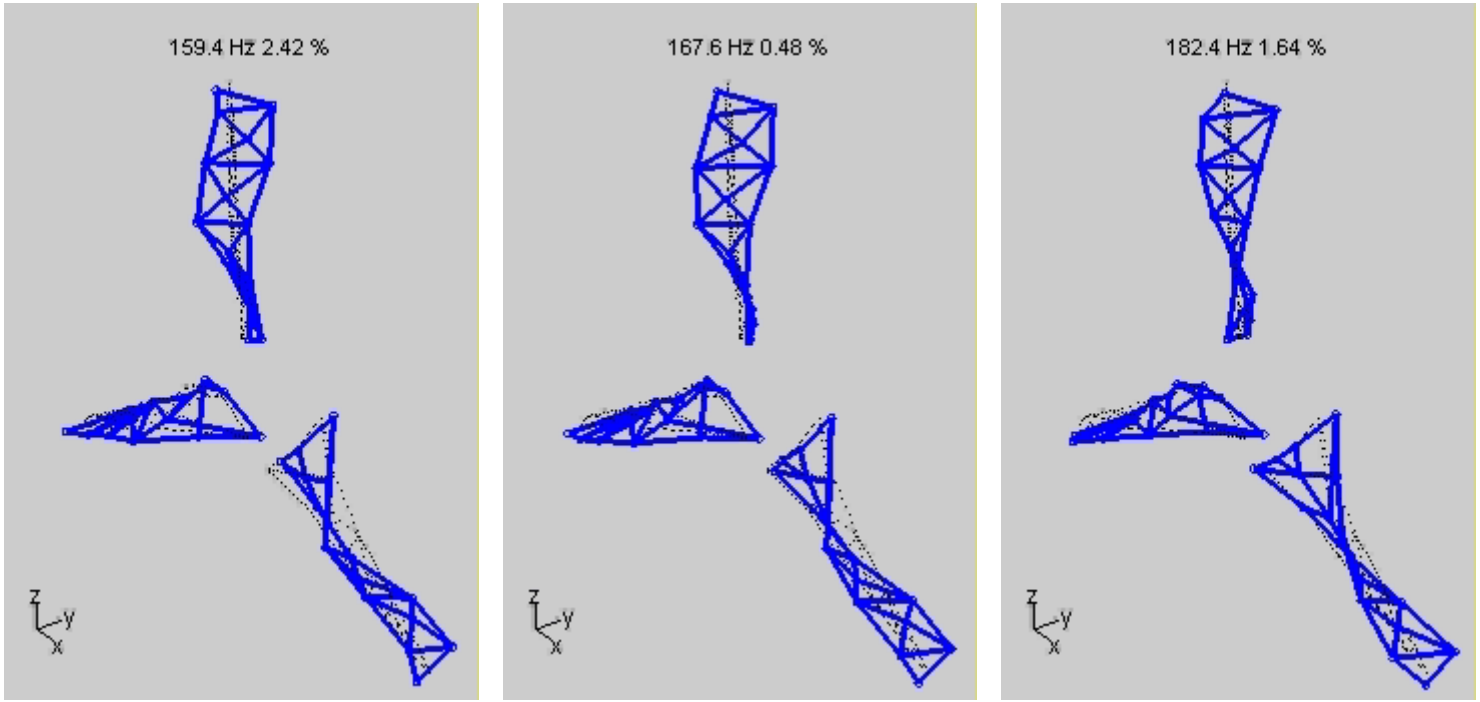
# Assembly results

## MBL Modes



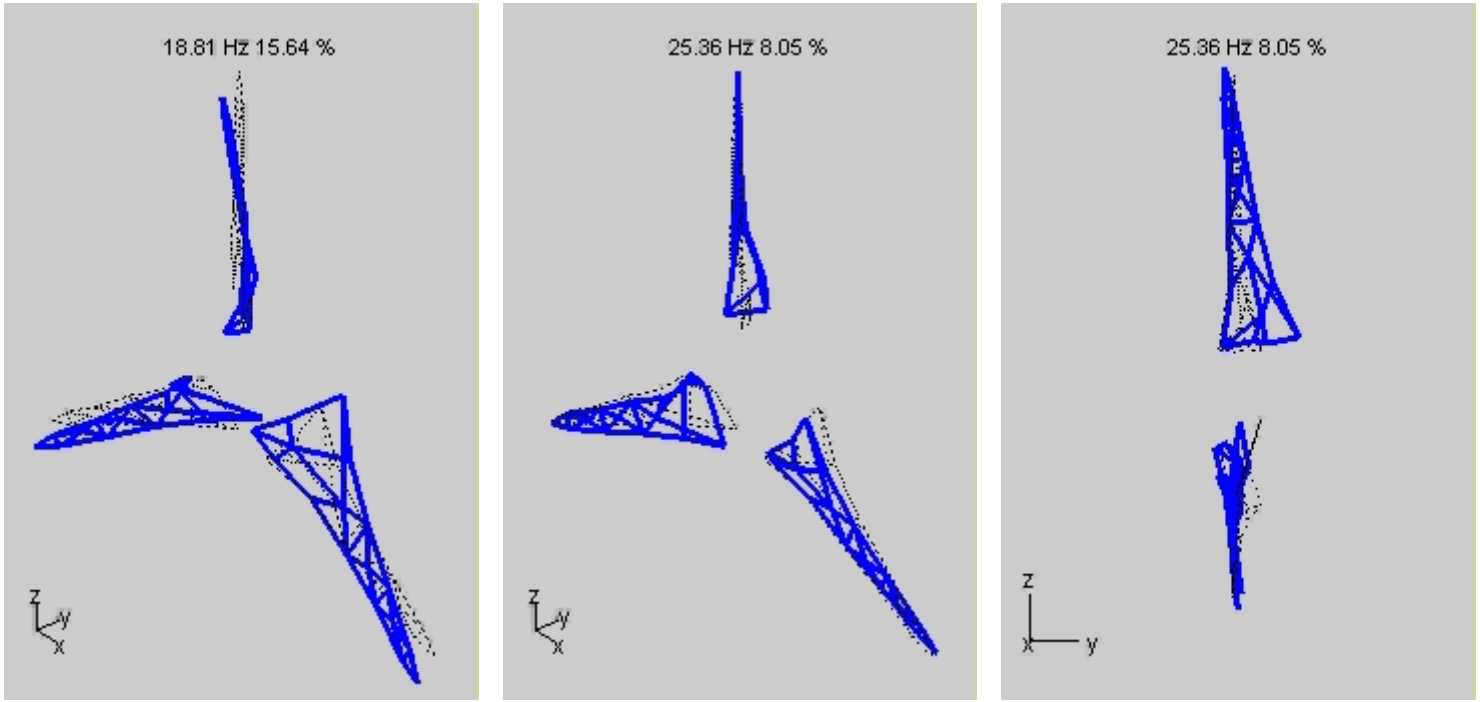
# Assembly results

## MBL Modes



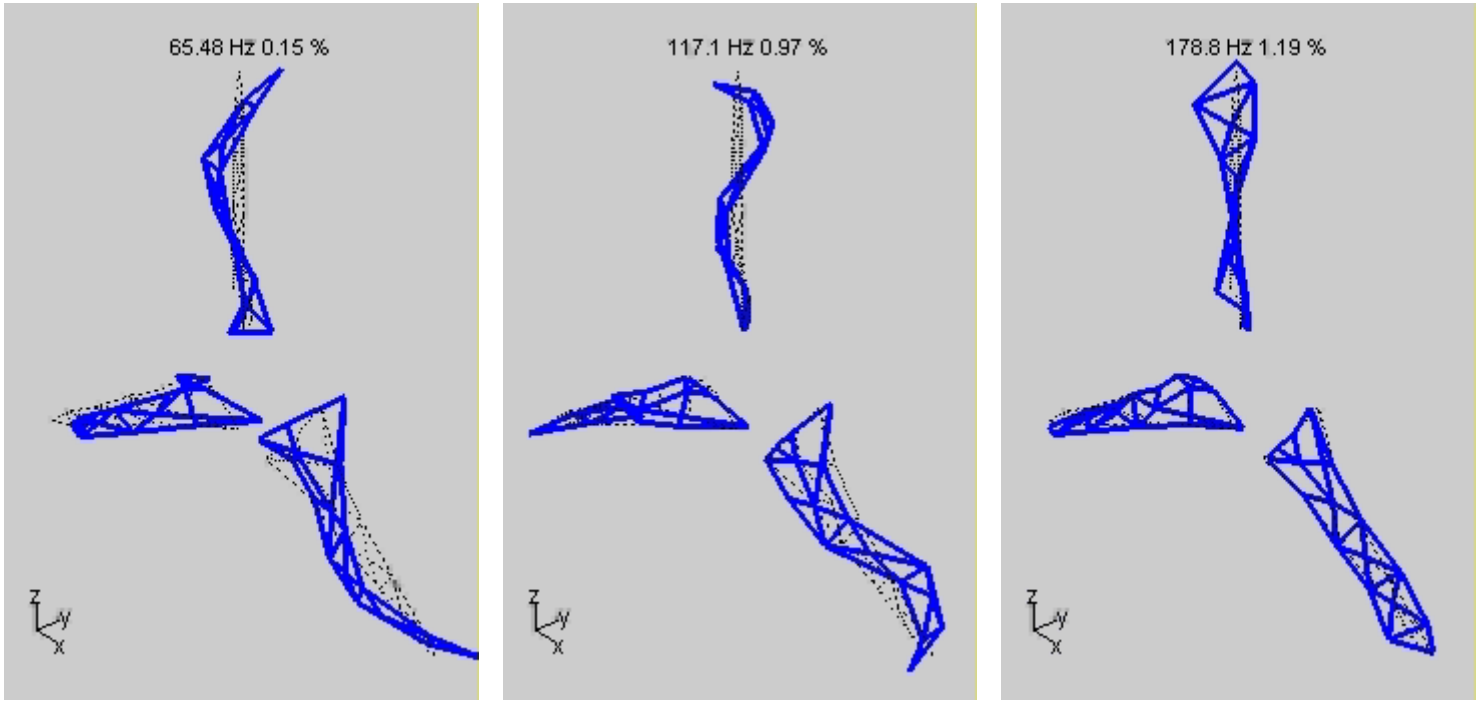
# Assembly results

## MBF Modes



# Assembly results

## MBF Modes



# Conclusion

- Fixture doesn't just mass loads the interface but also rigidifies the connection area.
- The hub mass is very dominant in the low frequency region
- The hub elastic modes are important at the higher region
- The regenerated (synthesized) blade model is not feasible and the experimentally derived model gives a much better result

# Recommendations

## Questions left unanswered

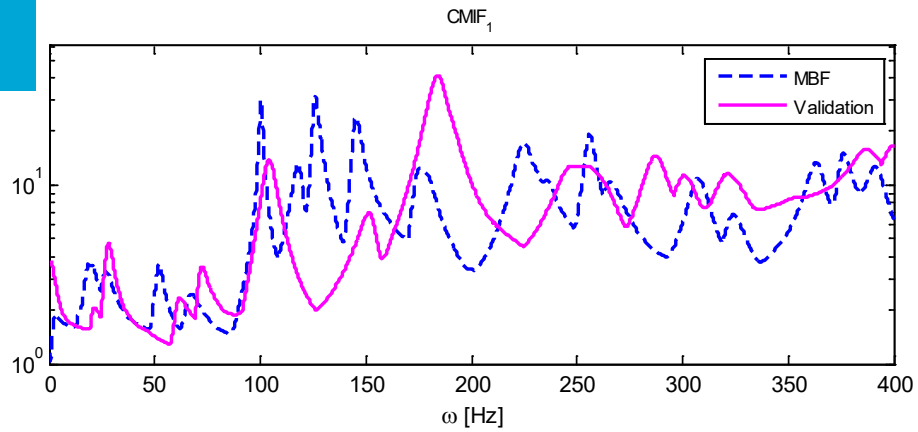
- Would the blade model change if a much heavier fixture was used?
- Were the results still the same if all three blades were modeled and used in the assembly?

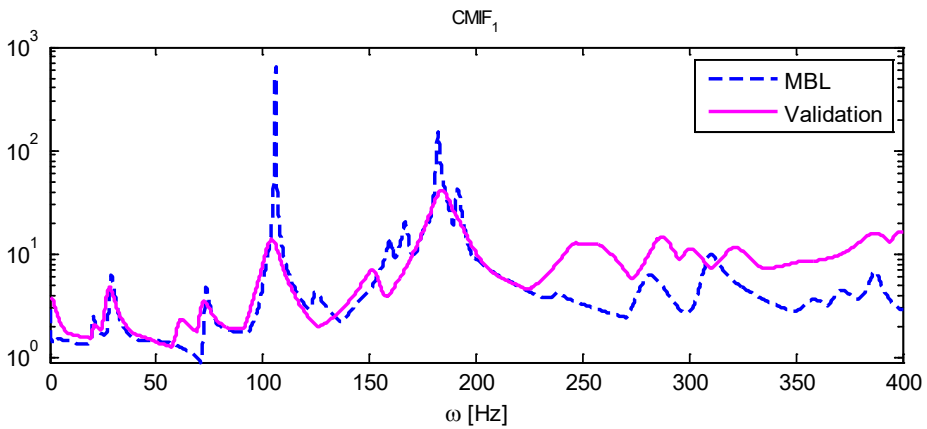
# Thank you

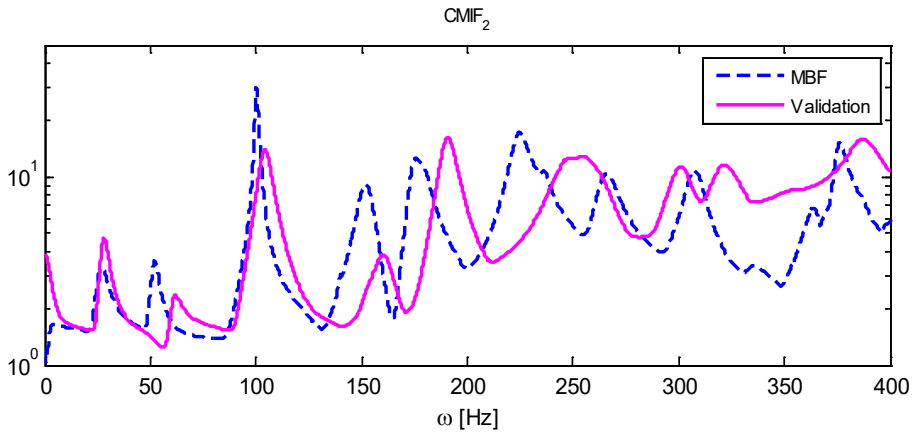
# Thank you

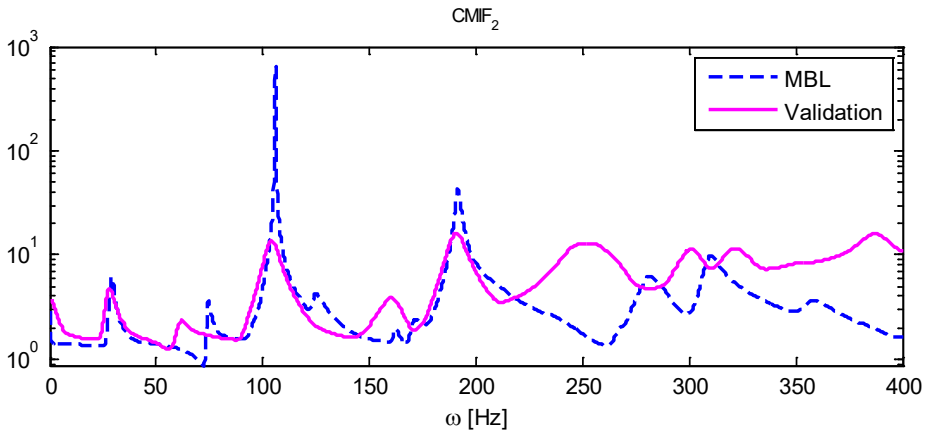
# Assembly results

## MBL versus MBF



# Experimental DS Difficulties

## Rigid Body Dynamic and Noise

- Impact measurement when elastic and rigid body modes are well separated
- Interface Deformation Method (IDM)