HIRENASD structural model

Joint exercise in Aeroelastic Prediction
RTO-203/AVT-067
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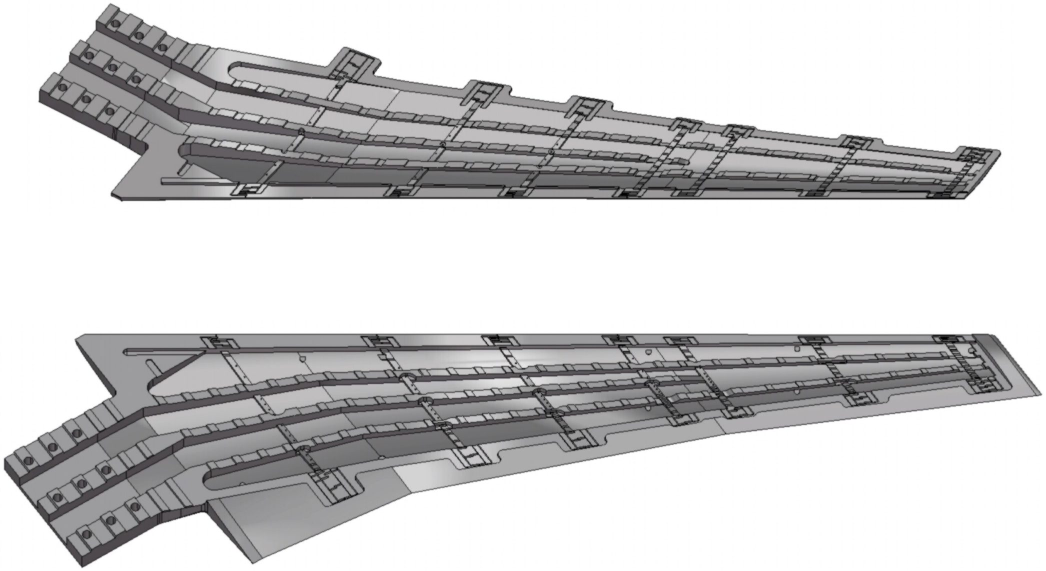
Outline

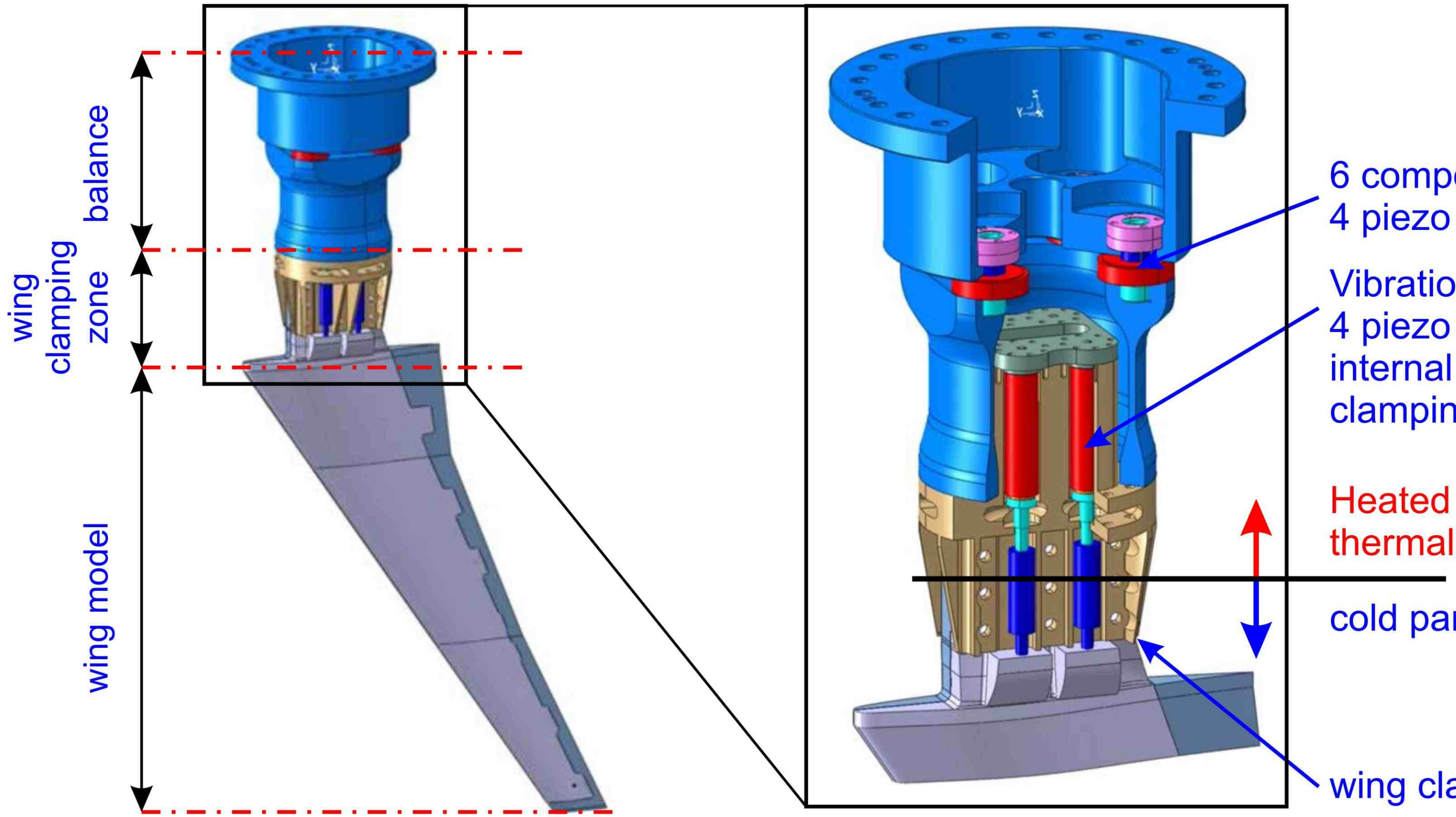
- Closer look at the structures of wing and balance
- Aims and requirements for structural modeling
- Reducing complexity: Beam model
    - Definition of beam properties and potential problems
    - Eigenmodes in comparison with measurements
    - Simulation of excitation

Structures of wing and balance

- Wing: Two complex shaped halves, screwed together
- Wing is exposed to temperature changes in wind tunnel
- Wing clamped to balance and filled with measuring equipment
- Complex balance, mounted in heated enclosure



Detail of balance



6 components balance
4 piezo elements

Vibration excitation by
4 piezo stacks producing
internal force couples in the
clamping device - wing unit

Heated enclosure
thermally conditoned part

cold part (down to 110K)

wing clamping

Positioning in wind tunnel

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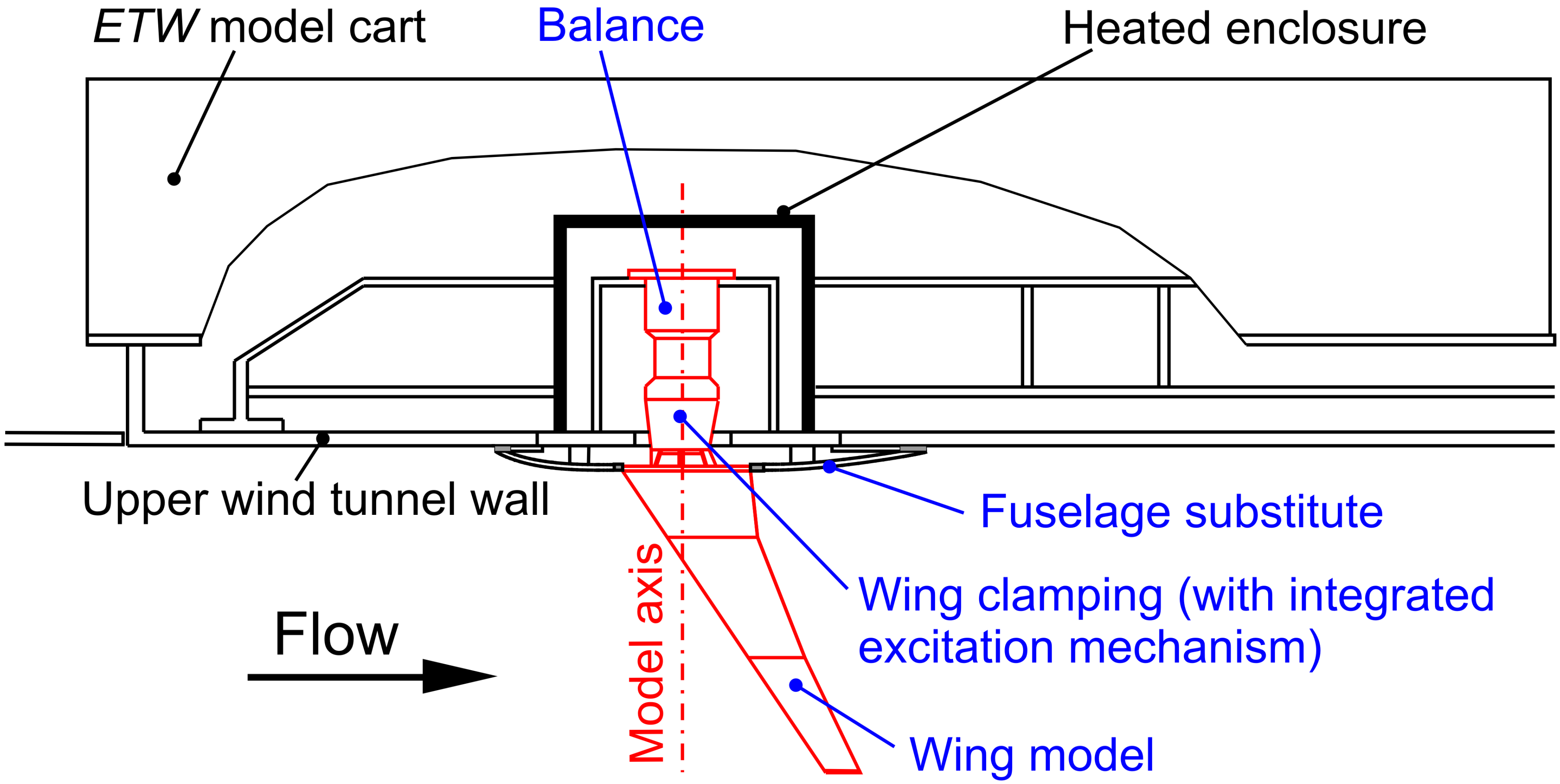
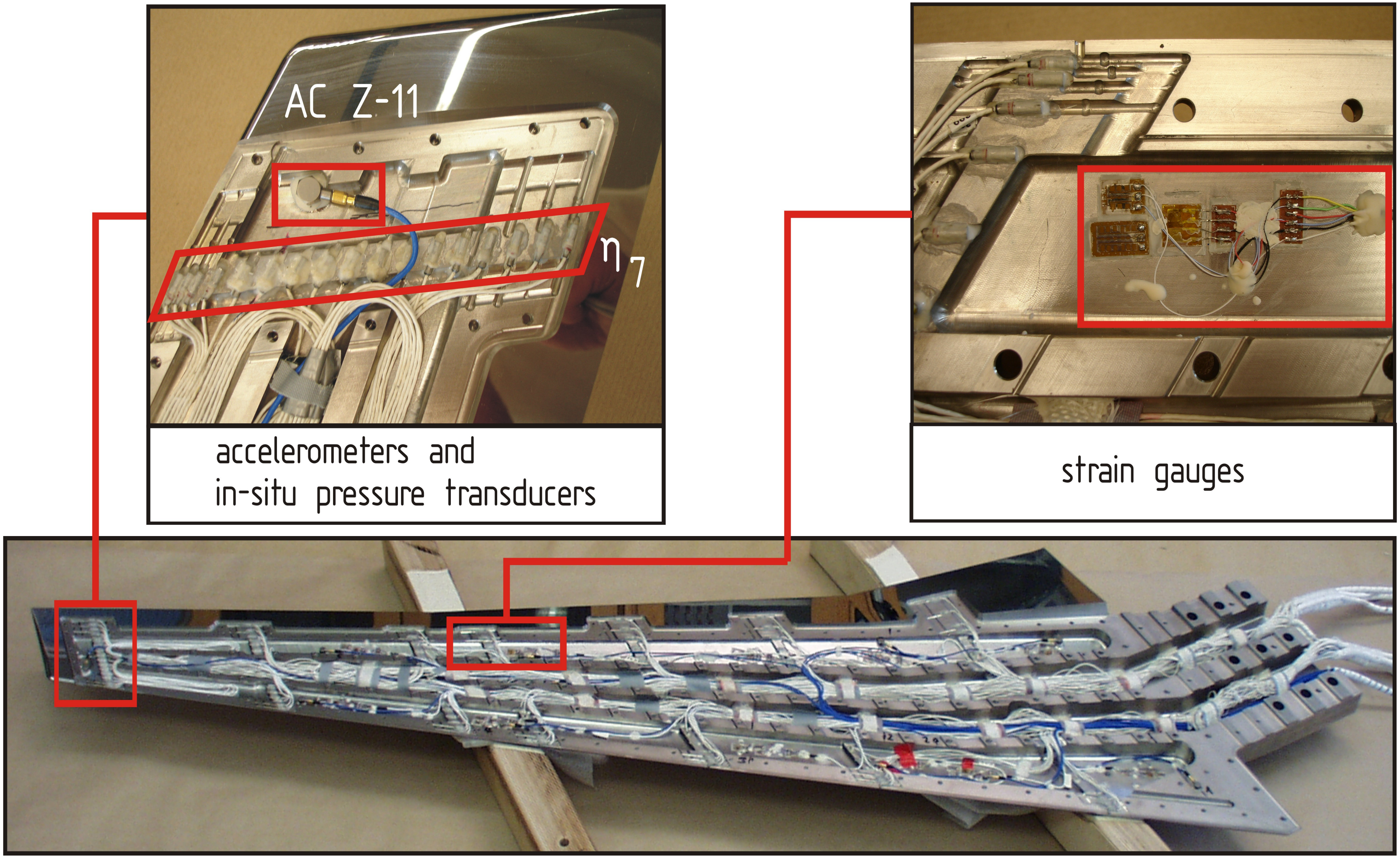


Equipment inside wing



accelerometers and
in-situ pressure transducers

strain gauges

Aims and requirements

- **Aims for this project**:
  - Stationary aeroelastic solution: Correct wing deflection needed; needs fully coupled stationary solver
  - Forced excitation of mode: Can be done using
    - Forced motion of given mode shape: No need for coupled computation; needs good representation of mode shape, frequency given

      → gives unsteady aerodynamic data
    - Simulation of excitation mechanism: Needs fully coupled, non-stationary simulation; needs good representation of mode shapes and frequencies up to a certain mode

      → additional to above: aerodynamic damping
- **Not now**: Frequency shift and aeroelastic damping of modes; needs fully coupled non-stationary solver, good representation of mode shapes and reasonable frequencies.

Possible structural models (1)

Volume models

- “Easy” for coupling to CFD if surfaces match.

Problems for modeling:

- Contact conditions between parts of wind-tunnel model
- Equipment inside wing (extra mass)
- If done: high computation times and possibly non-linear solver needed.
- **Simplification**: Model of wing only as “solid” without extra mass.

→ This will give good deflection results and good mode shapes for low frequencies. Frequencies will not be a good match.

Possible structural models (2)

Reduced order models

- Beam or shell/plate models possible. Shell models pose similar problems to full 3d modeling → Beam model
- Simplifies:
  - Much smaller equation systems
  - Represent total stiffness and mass distribution of cross section in a single value on the “axis”.
  - Quicker to adjust, so that results match with experiments
- Complication:
  - Needs matched data exchange strategy to CFD

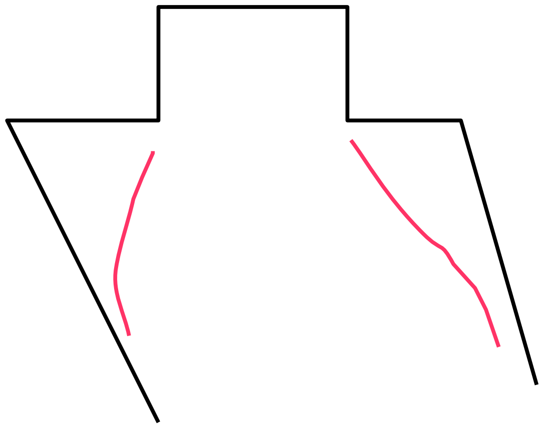
Defining the beam model (1)

- Define the properties of a beam section:
  - Cross section area, mass center
  - Secondary moments of intertia
  - Shear center
- For complex cross sections:
  - Exact solutions may be hard to obtain
  - Reduce complexity by using simplified cross section

    or
  - Use 3D-FEM simulation of long beam with this cross section to get good approximation of properties

Defining the beam model (2)

- Problematic areas for defining beam properties:
  - Strong 3D influence (i.e. near wing root)
  - Non-unitary bodies (contact surfaces)
- Experimental data, special experiments and numerical simulation may be used to get good estimates of equivalent beam.



Beam model – results (1)

Eigen-Frequencies (wind off)

Beam-model vs. experiments

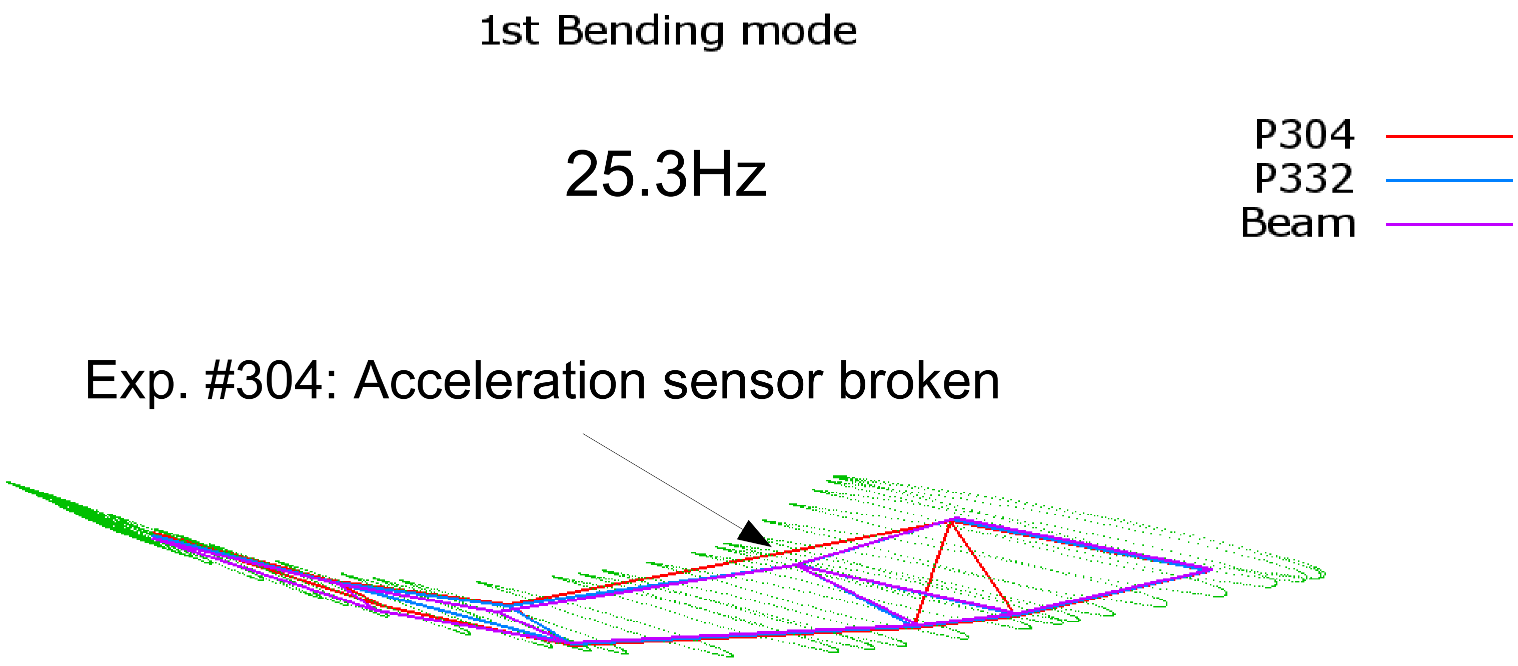
B=Flap bending, T=Torsion dominated

HIRENASD exp. # 304 (M=0) & 332 (M=0.75)

Beam Model	**Mode**	**Experiment** (120K)	
F [Hz]		M=0	M=0.75
25.3	1st B	26.0	27.6
78.6	2nd B	78.6	81.6
158.4	3rd B	166.2	172.6
243.5	4th B	245*	247.1
267.3	1st T	265.8	273.1
342.1	5th B		351.5
424.5	2nd T		435.9

*: multiple of excitation frequency (35Hz)

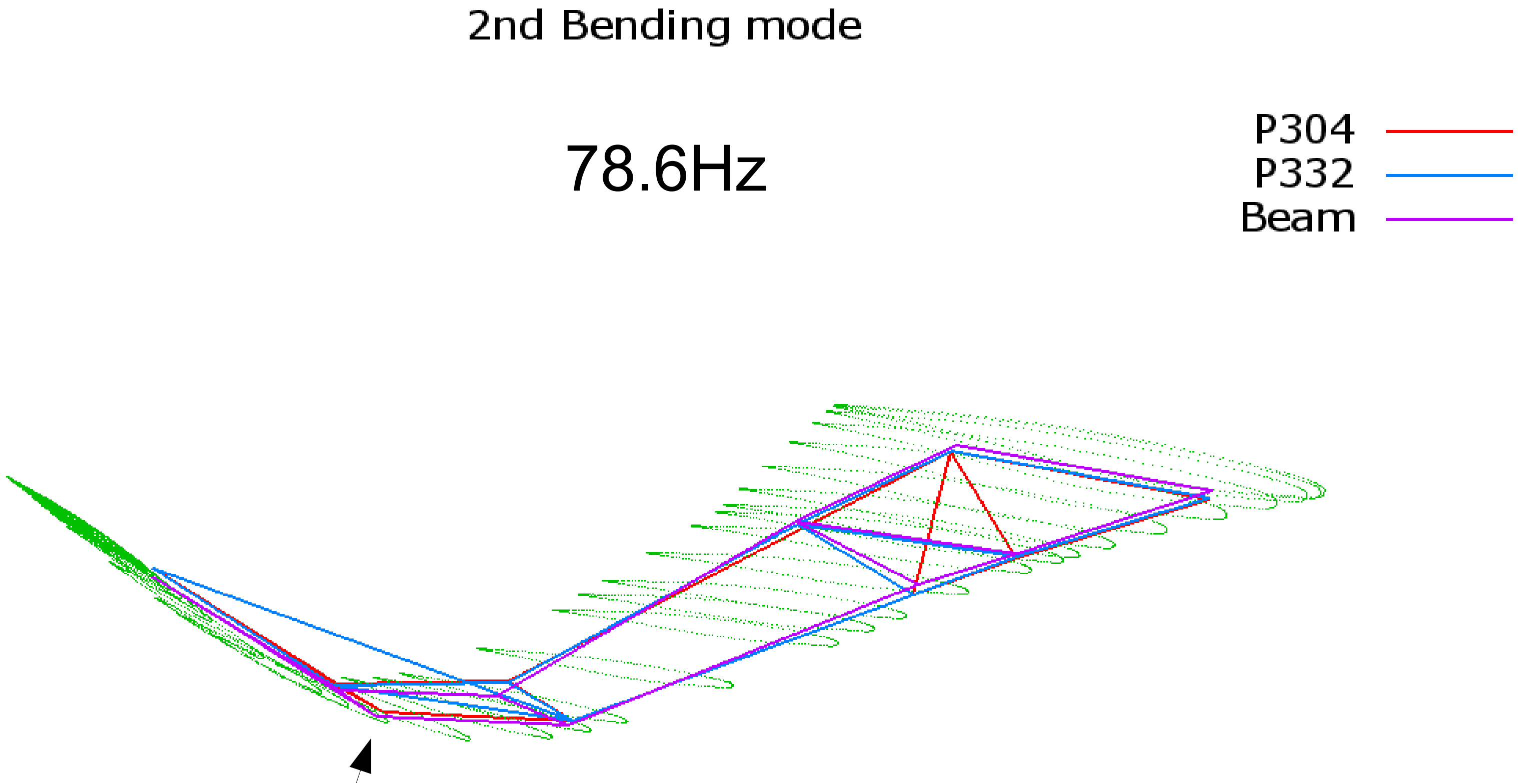
Mode shapes: Beam vs. experiment (1)



Exp. #304: Acceleration sensor broken

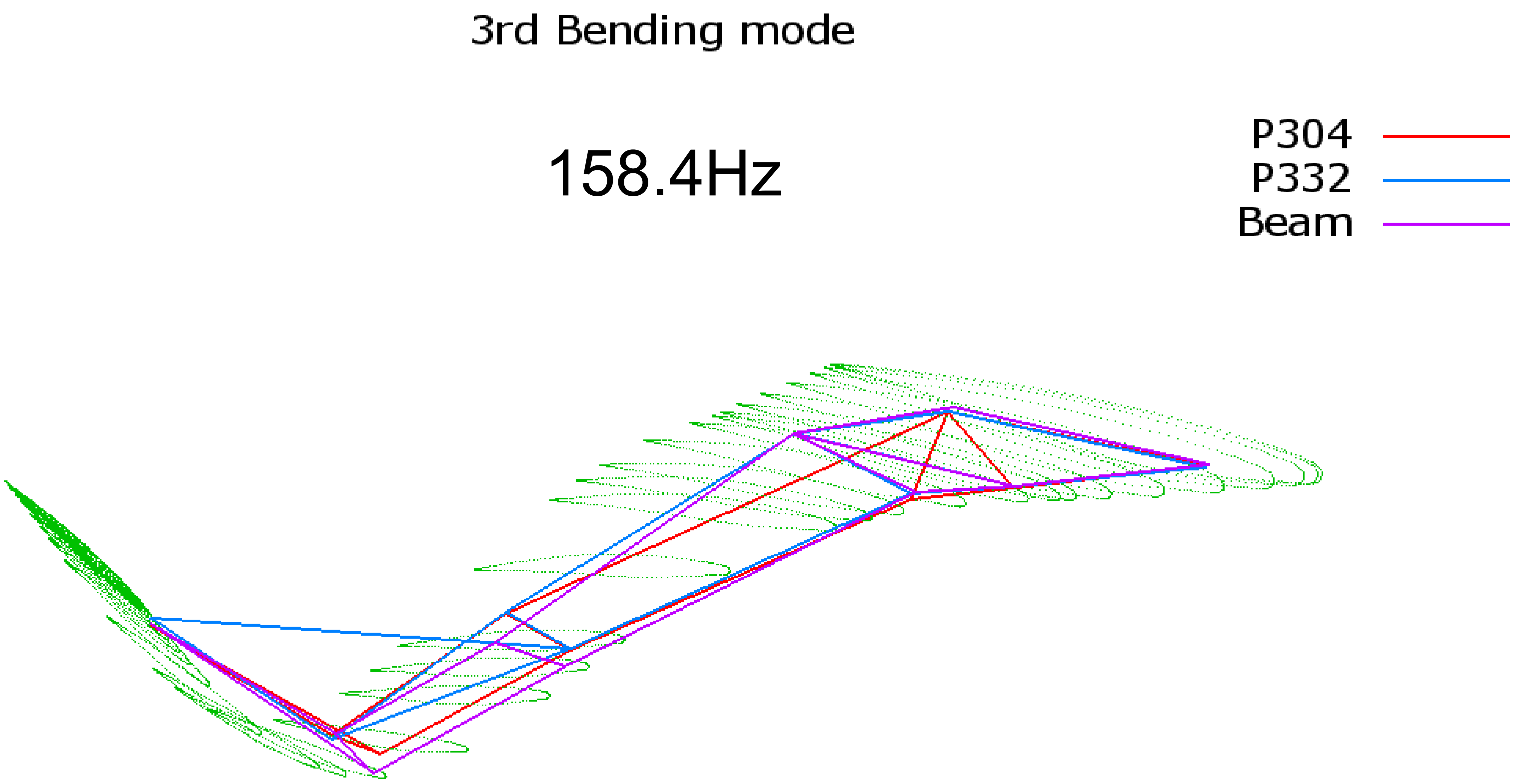
- Experiments: Mode shapes from accelerometers #304 M=0; #332 M=0.75
- Green dots and violet shape: projection from beam model onto wing surface

Mode shapes: Beam vs. experiment (2)



Exp. #332: Acceleration sensor broken

Mode shapes: Beam vs. experiment (3)



Mode shapes: Beam vs. experiment (4)

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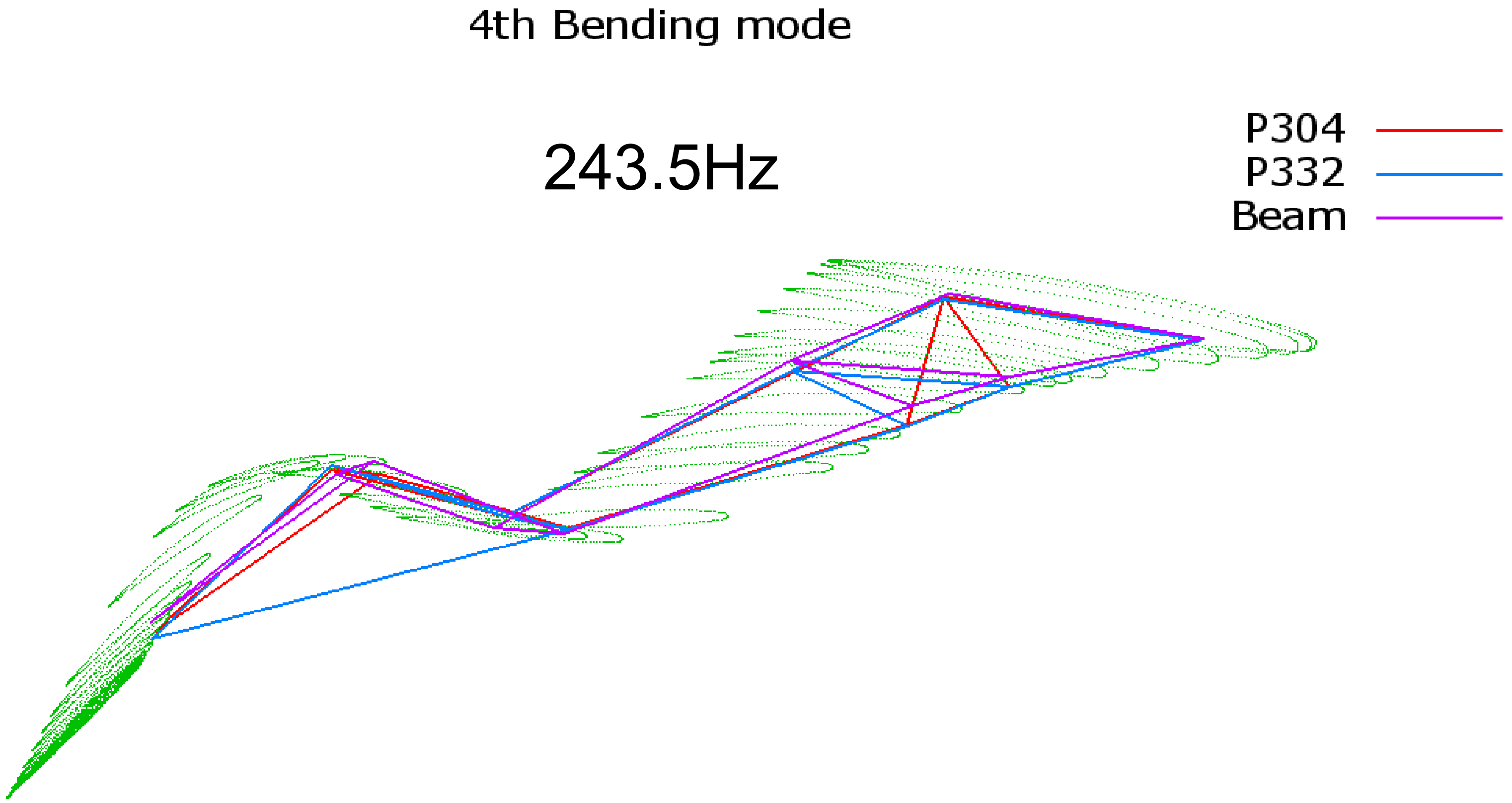
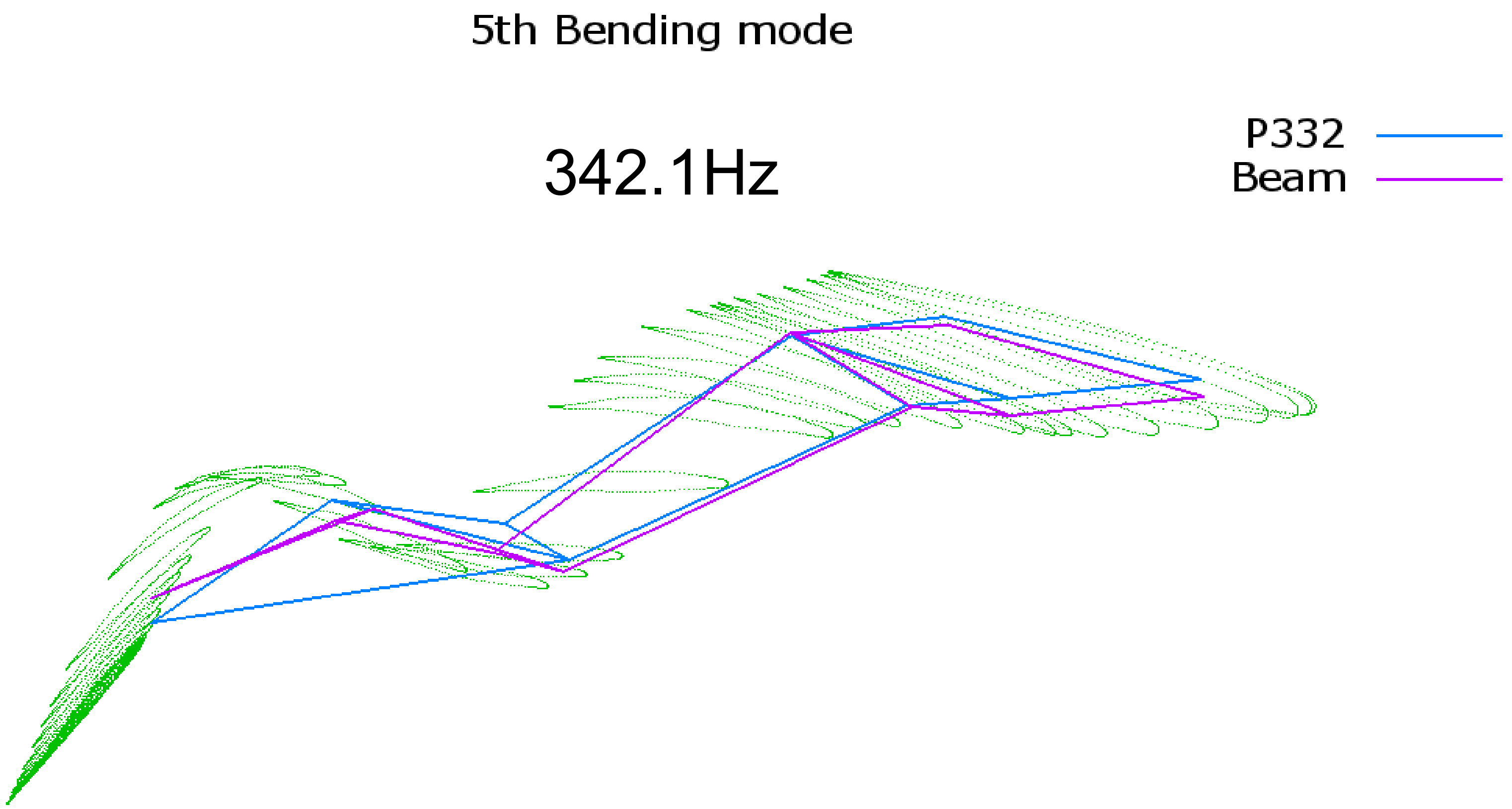


Mode shapes: Beam vs. experiment (5)



- Mode not found in wind-off trial #304
- Shapes of beam and actual wing start to diverge near wing tip

Mode shapes: Beam vs. experiment (6)

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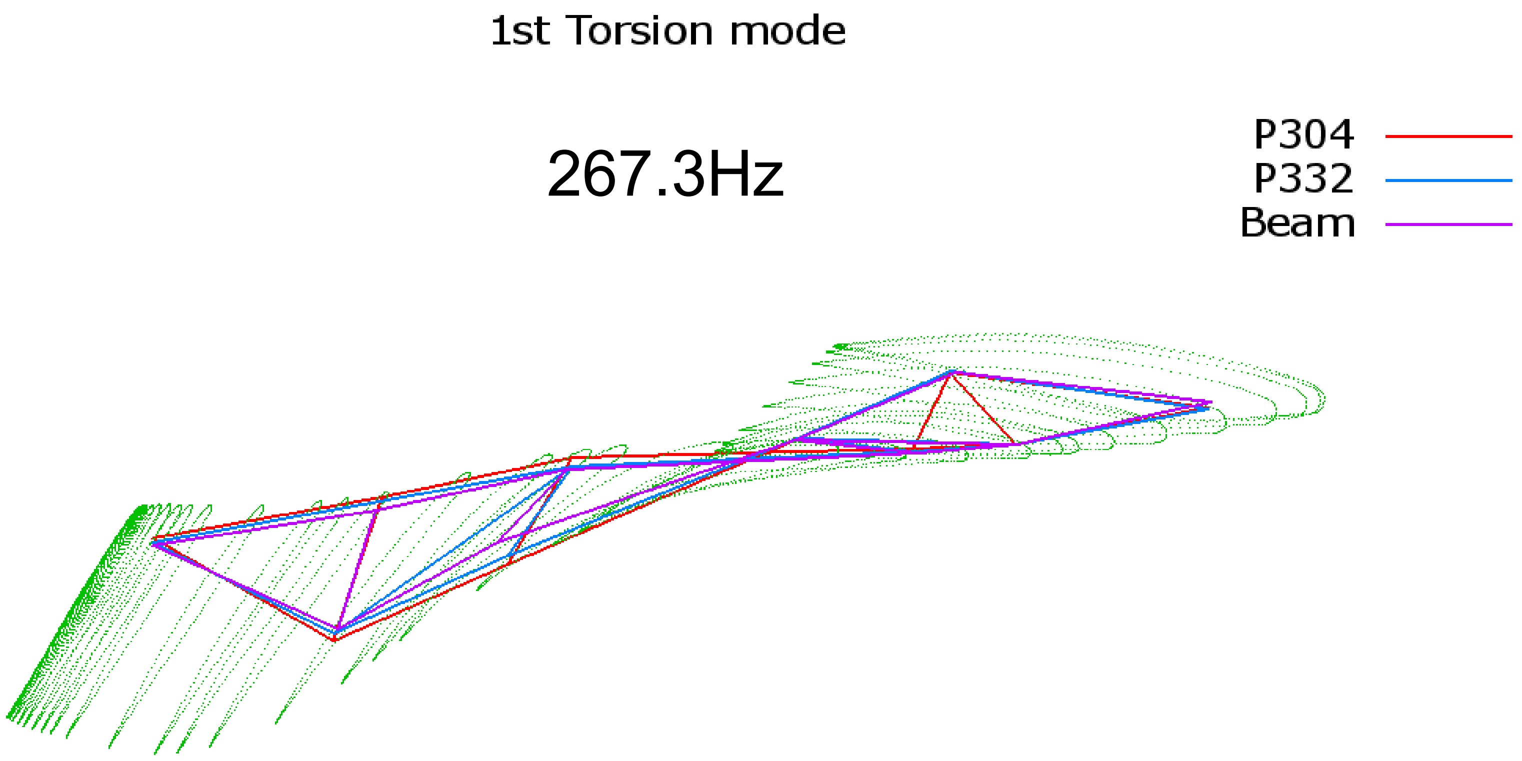

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Mode shapes: Beam vs. experiment (7)

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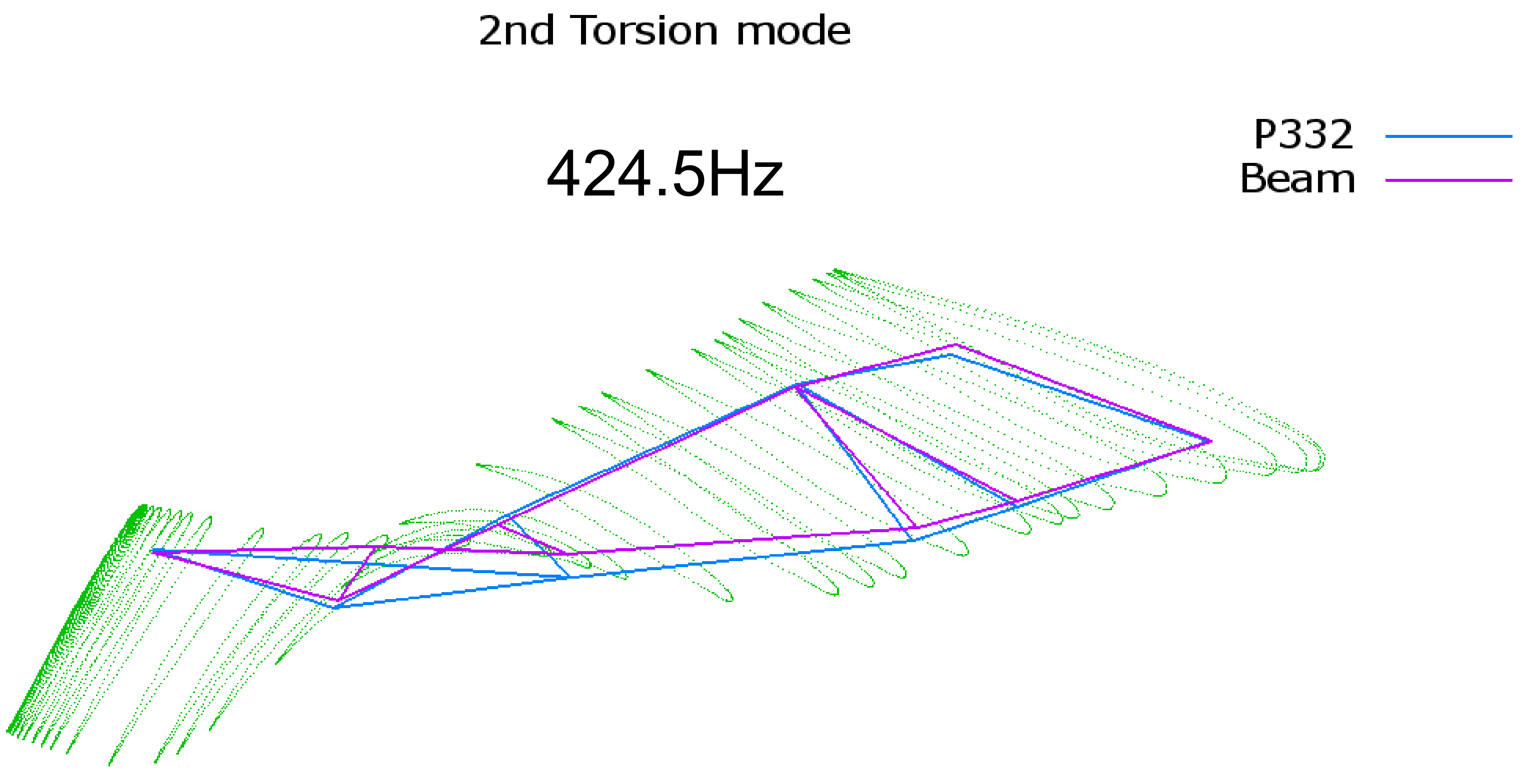


Experimental Eigen-frequencies

Effect of wind on Eigen-frequencies

B=Flap bending, T=Torsion dominated

Experiments at 205K, Re=23.5M, q/E=0.48E-06

- Significant frequency shift for 1st and 2nd bending mode

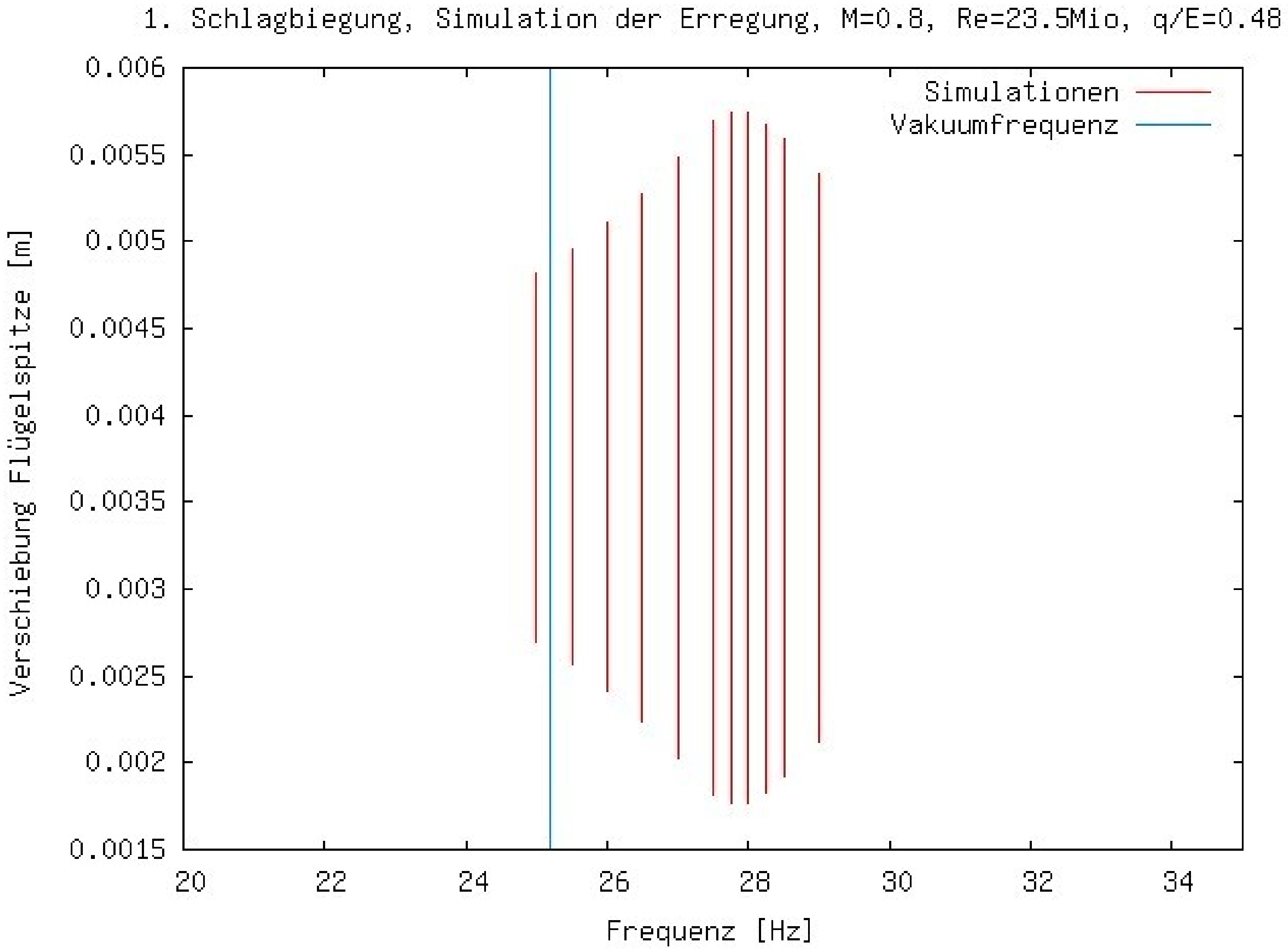
Mode	M=0	M=0.7	M=0.75	M=0.8	M=0.83	M=0.85	M=0.88
1st B	26.1	28.2	28.3	29.3	29.6	29.5	28.7
2nd B	77.6	80.5	81	80.4	80.9	80.7	81.3
3rd B	170	172	171.4	172.5	173	172.2	174.3
4th B	241	243.3	242.5	242.3	242.2	242.4	243
1st T	268	267.7	267.2	268.2	268.1	267.8	268.7

Simulation of frequency shift (1)

Fully coupled simulation using reduced order model (ROM)

- Structure: beam model, but earlier stage as shown before
- Fluid: FLOWer with medium fine grid and no fuselage substitute
- Coupled simulation of forced excitation using a Volterra scheme as a ROM

Simulation of frequency shift (2)



Frequency shift due to wind (M=0.8), 1st flap bending mode

Simulation of frequency shift (3)

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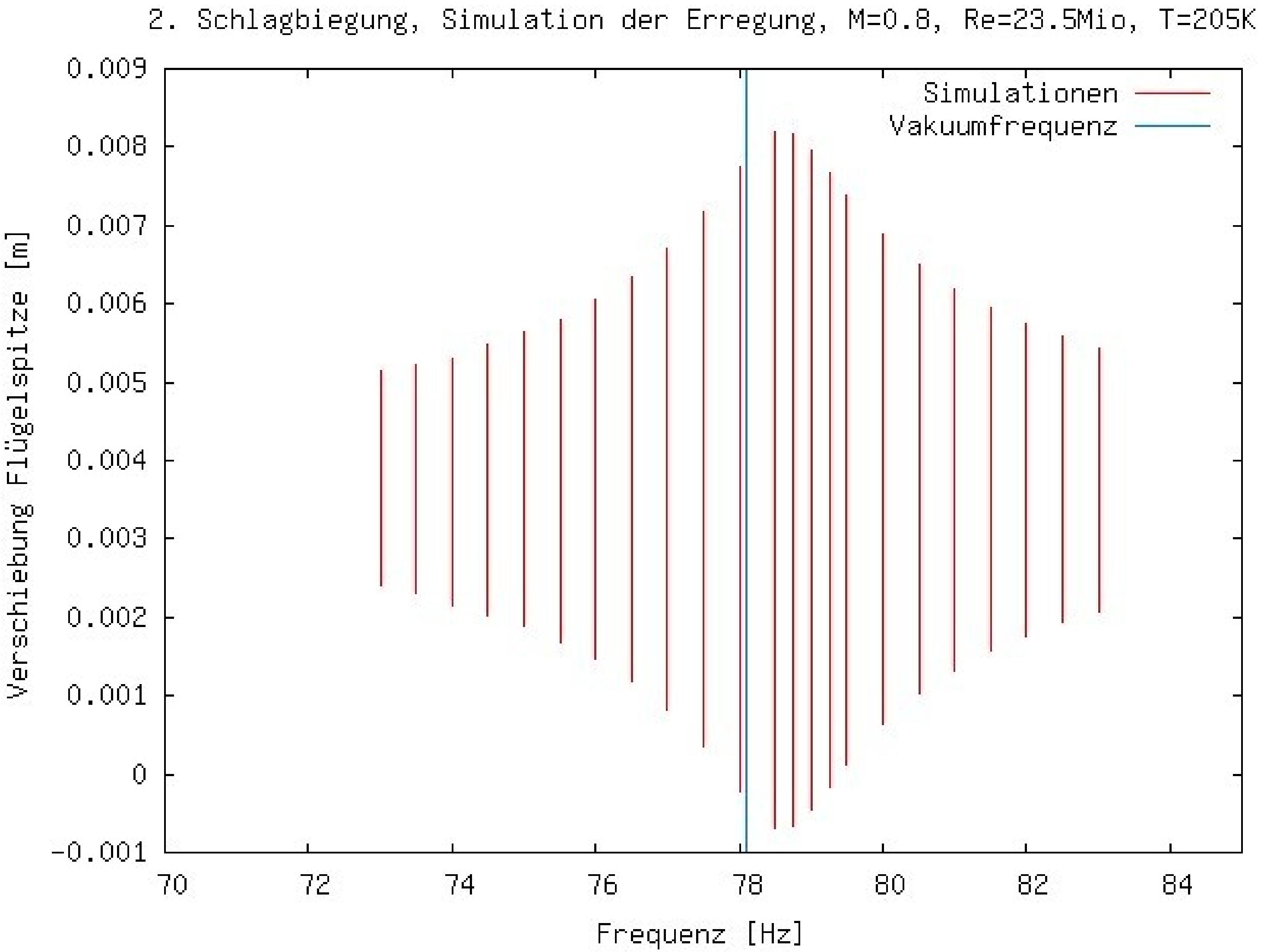

Frequency shift due to wind (M=0.8), 2nd Flap bending mode

Lessons learned

- Beam models allow good approximation of typical commercial aircraft wing structure

  with good representation of
  - Mode shapes and
  - Mode frequencies
- Uncertainty in model can be addressed using comparison with experiments
- Modeling the structure for HIRENASD is a challenge of same complexity and importance as getting good CFD results