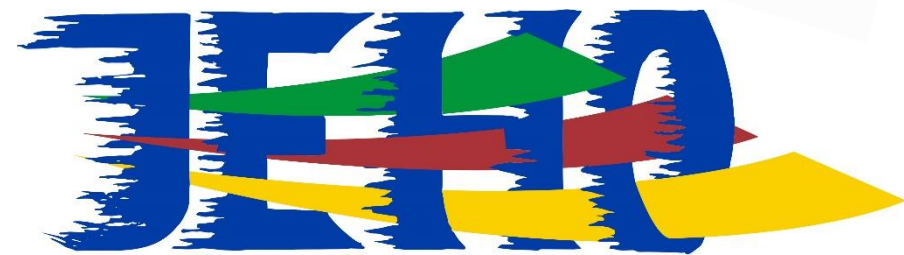
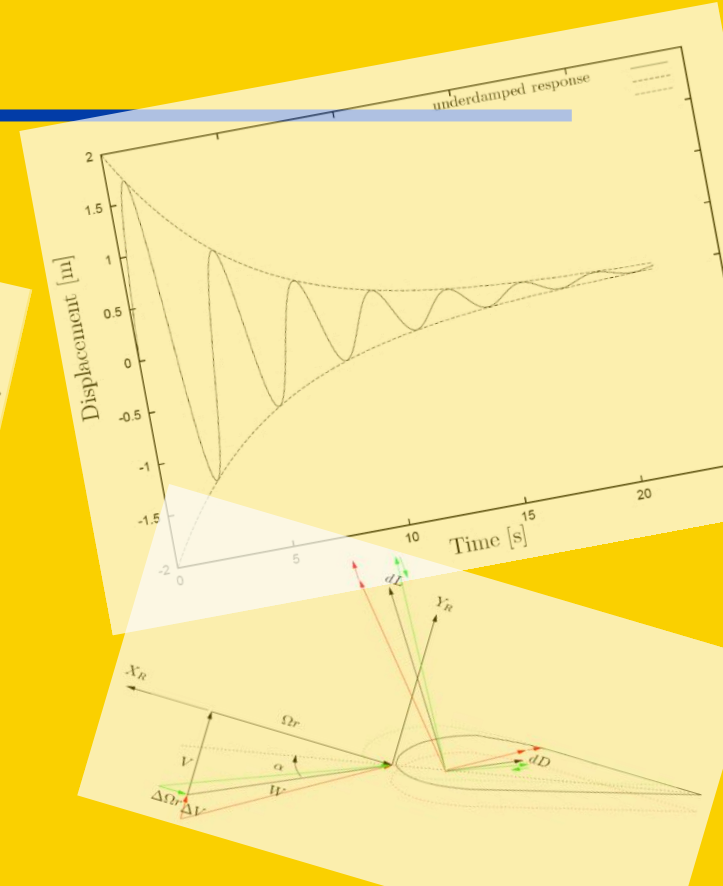
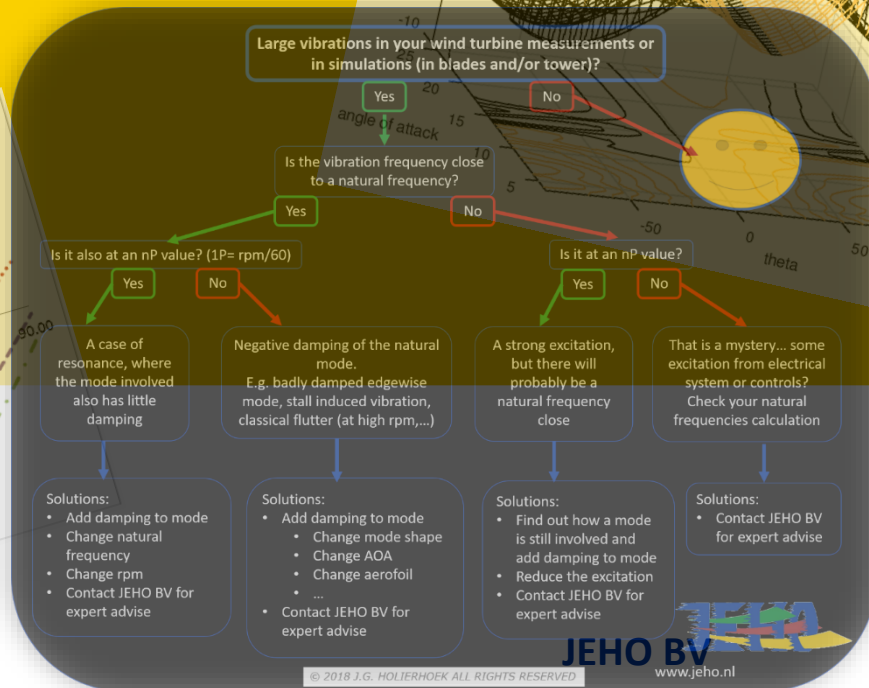
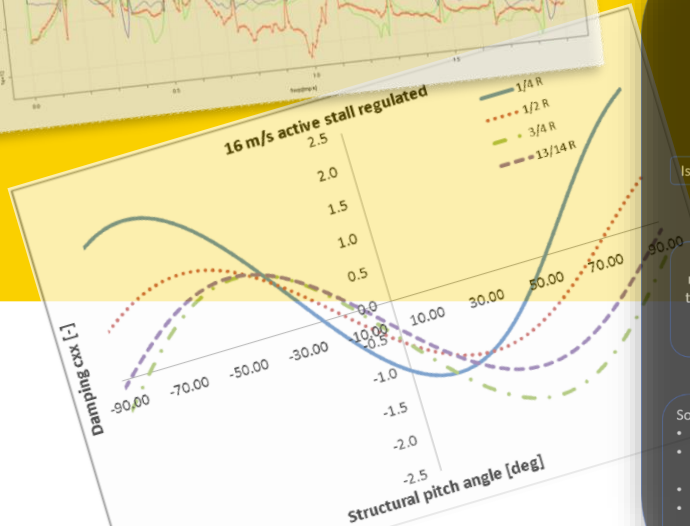
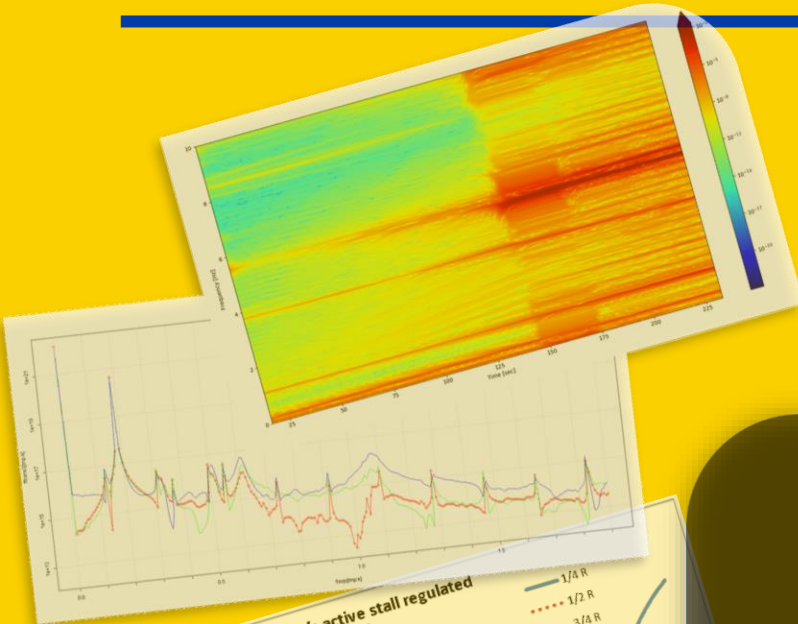


Wind Turbine Aeroelasticity Course



Contents of this leaflet

- This leaflet provides detailed information about an effectively **3-day training course** concerning wind turbine aeroelasticity
- **The course is taught using LIVE [web training](#)** divided over **6 four-hour sessions or 8 three-hour sessions** ([schedule open sessions](#))
- First some general information is provided about the course, [who](#) should attend, [who](#) gives the course, [tools](#), [costs](#), etc.
- Then the contents of the 3-day course are provided in [detail](#) (for the LIVE web training the same subjects will be treated in the same order, but divided over 6 sessions)
- Finally, an overview is given of the [complete training programme](#) we provide



Assume the reaction force to be:

- $F_{xR} = A \sin \omega t$; $F_{yR} = 0$

Transforming to non-rotating frame gives:

- $F_{xNR} = A \sin \omega t \cos \Omega t$
- $F_{yNR} = A \sin \omega t \sin \Omega t$

Using basic mathematics:

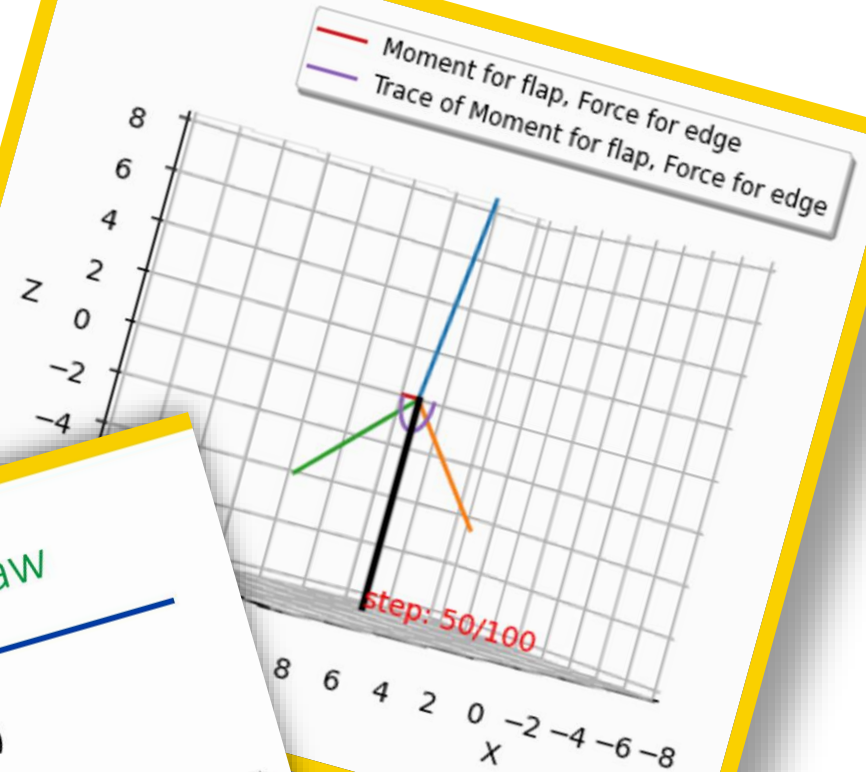
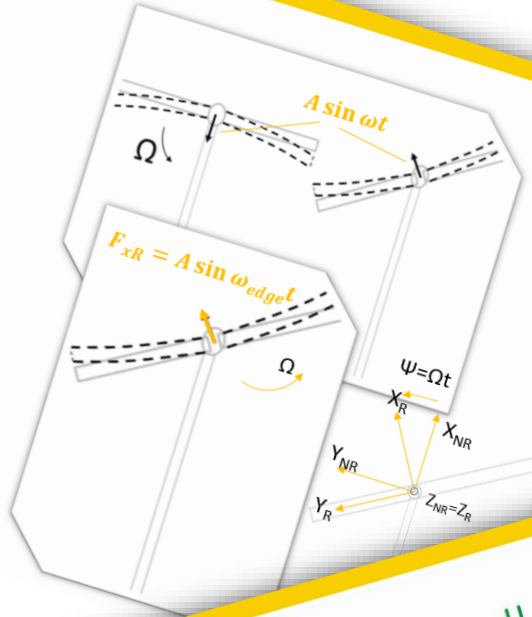
- $F_{xNR} = \frac{1}{2} A \sin((\omega - \Omega)t) + \frac{1}{2} A \sin((\omega + \Omega)t)$
- $F_{yNR} = \frac{1}{2} A \cos((\omega - \Omega)t) - \frac{1}{2} A \cos((\omega + \Omega)t)$

This change in frequency occurs only if the **reaction force is in-plane**

$$\sin(a)\cos(b) = 0.5(\sin(a+b) + \sin(a-b))$$

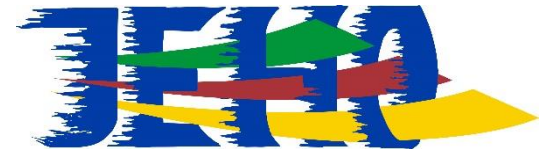
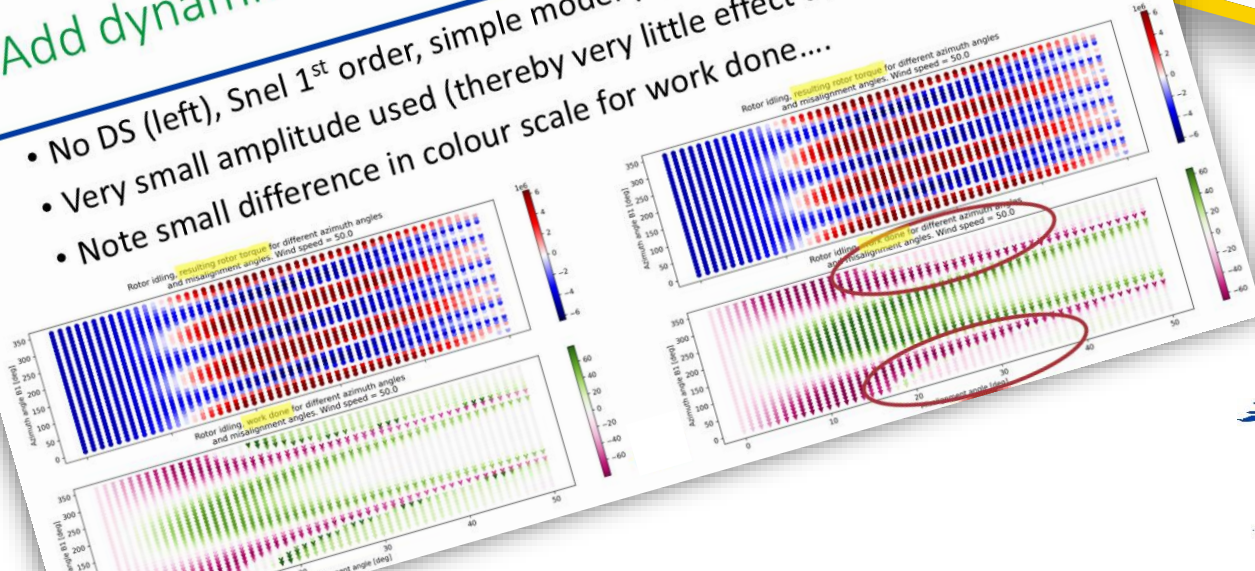
$$\cos(a)\sin(b) = 0.5(\cos(a-b) - \cos(a+b))$$

$$\cos(a)\cos(b) = 0.5(\cos(a+b) + \cos(a-b))$$



Add dynamic stall and smaller steps in yaw

- No DS (left), Snel 1st order, simple model (right)
- Very small amplitude used (thereby very little effect of DS)
- Note small difference in colour scale for work done....



Course content

- The complete content is based on many years of knowledge and experience in aeroelastic analyses and research
- All the experience in teaching courses to students as well as to professionals has been used to continuously improve material and methodology
- The focus of the entire course is on understanding aeroelastic instabilities and resonances and enabling participants to evaluate a design and in case of unexpected vibrations provide an effective solution.
- The course **DOES NOT** concern how to perform certification calculations. Rain flow count will not be discussed, ultimate loads will not be addressed. It really concerns resonances and instabilities and understanding what is happening on a wind turbine from an aeroelastic point of view.



Who should participate?

- The wind turbine aeroelasticity course is designed for engineers that already have some experience in wind energy, specifically wind turbine design or wind turbine loads
- Very basic knowledge of aerodynamics, dynamics and wind energy is expected
- The participants should have a computer at their disposal with internet connection and preferably with a webcam option.
- Software that will be used during the course will be supplied before the course. JEHO software is only to be used during the actual days of the course or workshop.

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Who will give the course?

- Dr. ir. Jessica Holierhoek has over 20 years of experience in wind turbine aeroelasticity, focussing on instability and resonance.
- Currently managing director of JEHO BV specialising in bringing this knowledge to the industry.
- Experience gained at Delft University of Technology (including PhD), at ECN (now TNO) and of course as director of JEHO BV
- Experience in consultancy, research, tool development and teaching/training, always related to the field of wind turbine aeroelasticity

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Three options

- We provide this course in three different ways:
 - OPEN LIVE web training session : for all engineers, so engineers from different companies come and take part in the course. A ready model can be supplied, though it is also possible for the engineers to work on their own design, nothing will be shared with other participants.
 - PRIVATE LIVE web training session: organised for one company only (see next slide).
 - PRIVATE: organised for one company only. In this case the expert can provide more support concerning analyses of the companies own design and discuss it more easily. It is also possible to add a certain focus to the course based on current issues relevant for the company. This also provides the option to provide the course in the offices of the company, preventing travel time and costs for the participants.



Option 1/2: LIVE web training

- LIVE training, **not using video's** that are pre-taped
- This allows for **live discussions**, for direct questions and answers, for always up-to-date material and the instructor can check if the explanation was clear
- The maximum number of participants in these sessions is **six**, otherwise discussions would become too difficult and slow
- As the web training does not require travel, it is possible and practical to spread the course over more days: therefore, six four-hour sessions that do not have to be on consecutive days. Benefits: more time for material to sink in and for participants to repeat material before the next session
- Exact dates and times can also be set in agreement with a small group of participants
- One additional Q&A session can be planned when training is completed (included in the costs for private training)



Tools

- Tools that are used in the course:
 - Either your own licensed tool (e.g. Bladed, FOCUS Phatas,...)
 - Or the open-source tool OpenFAST or FAST from NREL can be used
- Together with a JEHO tool that is specifically developed for illustrational purpose (WAF1C)
- Some open-source tools / free tools will also be required and some recommended, all tools or links to these tools and will be provided well before the course

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Costs for different options (2025)

- OPEN introduction to wind energy course on-line (2 * 4 hours), including lunch: €600 per person (not yet scheduled)
- OPEN Live web training aeroelasticity (six sessions, max 6 participants): €2040 per person ([schedule](#))
- PRIVATE Live web training aeroelasticity (six/eight sessions, max 8 participants): €8150¹
- OPEN Live web workshop aeroelasticity (4 * 4 hours): € 1450 per person (not yet scheduled)
- PRIVATE Live web workshop aeroelasticity for a max 6 participants: € 6800
- Evaluation training, costs depend on your requirements

All prices mentioned are excluding VAT and possible other taxes (e.g. withholding tax). Please contact us if you would like to receive a personal offer for any of these products.

¹ If you would like all participants to pass a test at the end of the training, to check if they have actively and effectively participated, we can provide individual (unique) final tests at €75 each



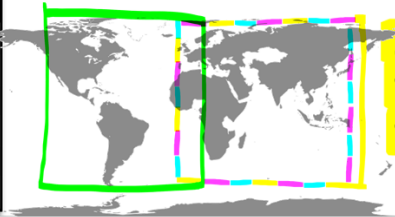
Schedule 2025 open courses ON-LINE

Online live web training sessions **wind turbine aeroelasticity course**. Small groups of participants, allowing pleasant interaction between instructor and participants.

Six times, each week a four-hour training session or eight times twice a week a three-hour training.

Scheduled training times are suitable for different locations, as indicated in the world map

February						
M	T	W	T	F	S	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28		



8x3 hours: Mondays & Thursdays in February
Time: 9-12 CET

April						
M	T	W	T	F	S	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

May						
M	T	W	T	F	S	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

6x4 hours: Tuesdays April 15 – May 20
Time: 18-22 CEST

September						
M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

October						
M	T	W	T	F	S	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

6x4 hours: Thursdays
September 25 – October 30
Time: 9-13 CEST (Sep 25-Oct 23) & 9-13 CET (Oct 30)

November						
M	T	W	T	F	S	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

December						
M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

6x4 hours: Fridays November 14 – December 19
Time: 9-13 CET

Interested in attending?
Contact us: workshop@jeho.nl



Interested?

- If you have any questions or are interested in the course, please get in touch with us: workshop@jeho.nl

Some feed back
from participants:

*This was a great course,
I have learned so much!*

*Thank you very much for
this very interesting course.*

*Thanks again for the great course!
Excellent material provided
and sequencing of the topics!*

*I really enjoyed attending
your course,
I learned a lot!*

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Wind Turbine Aeroelasticity Course



All subjects treated are in connection with vibrations on WT

A far from complete list of what will be discussed during the course:

- Dynamic stall models: which models, how do they work, reliability, effect on damping,...
- Aerodynamic damping: simple models illustrating effects parameters,...
- Structural damping: importance, typical values,...
- Tower and blade modes: which modes exist, which are relevant, whirling modes,...
- Shift of frequency from rotating to stand still frame: when, mathematical & physical explanation,...
- Tower resonances: what to avoid, what is less problematic,...
- Blade resonances: what to avoid, what is less problematic,...
- Rotational sampling: physical and mathematical explanation,...
- Edgewise instability: when, which parameters are important, how to prevent, effect of torsion,...
- Stall induced vibrations: when, which parameters are important, how to prevent,...
- Classical flutter speed: how to calculate, how to increase,...
- Idling instabilities: realistic or not, what are the issues, introduction to vortex induced vibrations ...
- Solutions to instabilities: which instability is it, how is it avoided?
- Aeroelastic analysis: how to perform, what is most important,...
- Tool limitations: what properties should be included, weak points, reliability,...



WT aeroelasticity course set-up

THEORY

- BEM +
- Vibrations
- Aeroelasticity
- Blade modes
- Instabilities
- Resonances

Simulating

- Tools
- Perform aeroelastic analysis
- Post-processing skills

Interactive:

- Damping depending on mode shape
- Find and solve instabilities



WT aeroelasticity course set-up

Session 1

- M1 BEM +
- M2 Vibrations

Session 2

- M3 Aeroelasticity
- M4 Blade modes
- M5 Exercise: damping

Session 3

- M6 Resonances



WT aeroelasticity course set-up

Session 4

- M7 Instabilities
- Return to exercise damping (M5)

Session 5

- M8 Aeroelastic analysis
- M9 Exercise: analysis (homework)
- M10 Tools

Session 6

- M11 Post-processing
- Return to exercise analysis (M9)



Module 1: BEM+

- Short summary of BEM
 - Blade element model
 - Momentum model
 - What is the angle of attack in case of dynamic torsion deformations?
- Wind input (incl. rotational sampling)
- The models added to BEM (and why):
 - 3-D lift correction
 - Dynamic inflow
 - Dynamic stall
 - Yawed flow
 - Tower shadow
 - Tip corrections
 - Turbulent wake state

Always emphasis on validity, possible problems and effect on loads and vibrations



Module 2: vibrations

- Linear vibrations
- What is frequency?
- What is mode?
- What is their relevance?
- Where does damping come from?
- What is resonance?
- When is resonance relevant? Amplification ratio.
- Difference resonance and instability



Module 3: aeroelasticity

- Definition aeroelasticity
- Short history aeroelasticity airplanes
- Short history aeroelasticity of wind turbines
- Why are helicopters relevant for wind turbines?
- Torsion divergence
- Elasticity models
- Aerodynamic models
- Coriolis acceleration



Module 4: blade modes

- What are the main blade modes?
- How are these derived?
- What is the relevance?
- Illustrations of modes and frequencies
- Structural damping
- Where does damping come from? Intro to aerodynamic damping
- Effect of dynamic stall on aerodynamic damping



Module 5: exercise damping

- Use JEHO tool to derive damping for different modes
- Find out effect on damping:
 - Mode shape
 - Angle of attack
 - Phase differences in mode shape



Module 6: resonances

- Modes and frequencies on complete wind turbine
- Centrifugal stiffening effects
- Difference whirling mode frequencies in rotating and stand still frame
- Collective / symmetric modes and interaction with drive train or tower
- Excitation frequencies
 - Sources of excitation
 - Frequencies of these excitations
- Tower resonances
- Drive train resonances
- Blade resonances
- Offshore resonances
- When is it relevant to keep frequencies apart, when is it less of a problem?
- Design guidelines concerning natural frequencies



Module 7: instabilities

- Derive model for edgewise and flapwise instability
- Preventing stall-induced vibrations
- Structural pitch angle
- Stall flutter
- Torsion-edgewise instability
- Classical flutter: flapwise and torsion instability
- Whirl flutter
- Idling instabilities
- Introduction to vortex induced vibrations



With the gained knowledge go back to the exercise M5 and investigate effects



Module 8: aeroelastic analysis

- Why additional analysis? All loads are already calculated in the DLCs...??
- Inspecting results DLCs
- How to perform an aeroelastic analysis
- Campbell diagram: useful but does not include any stability evaluation!
- Excitations: what can you use and what not and why?
- How to find the cause and then the solution
- Measurements: how?
- Eliminate instabilities and resonances
- Differences real world and our simulations
- Future improvements to wind turbine aeroelasticity (tools, designs)



Module 9: exercise aeroelastic analysis

- Several examples need to be investigated
- Perform simulations and try to identify the problem
- If you know the problem, try to resolve the problem in an effective way by changing the input



Module 10: tools

- What are tools based on?
- Different types of tools
- Which tools are available?
- Minimum requirements tools
- Input: definitions, importance, issues
- Time domain and frequency domain
- What are known short-comings / limitations of our tools?
- Linearising: how, when, why? (incl. multi blade coordinate transformations)
- Nonlinearities
- Validation



Module 11: post-processing

- How to use results of simulations
- Frequency domain / time domain
- FFT
- Filtering
- FFT – moving block & spectrograms
- Evaluate damping
- Nonlinear results
- Using measurements
- Try the post-processing techniques on the previous exercise

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Aeroelasticity training overview



Wind turbine aeroelasticity

- Wind turbines are flexible structures that have a strong interaction between elasticity and aerodynamics
- Therefore, aeroelastic instabilities and resonance problems are a real risk
- This is often underestimated, until it happens
- The quickest way to get familiar with the risk, to gain knowledge of the most likely issues and how to prevent them, we provide several specialist courses/activities in this field.



JEHO training: a complete route

- Based on years of experience in wind turbine aeroelasticity as well as providing courses and workshops to the industry, we have set up a complete set of educational activities to effectively train wind turbine design engineers in finding and solving aeroelastic issues
- **The first step is a 3-day course (usually in 6 half day online sessions).** Then, preferably after a few months, this is followed by a 2-day workshop. Finally, during an evaluation training we can perform a full aeroelastic evaluation in close cooperation which will provide significant experience.
- All courses will always be for small groups (no more than 8 participants) to enable good interaction.
- When designing a new wind turbine (blade) a complete aeroelastic evaluation is an absolute must, to prevent many problems that are often not found until the prototype tests are performed.



JEHO Training programme

Wind turbine aeroelasticity (6 sessions)

Introduction course

24 hrs of intensive training

Theory and practise are treated

Also possible to arrange confidential course for your company

The main issues are discussed: types of instabilities, their causes, their solutions as well as resonance issues

Participants will get hands on experience to identify some of the issues presented

Also available as LIVE web training in 6 four hour sessions

Workshop (4 sessions)

Continuation of the initial course

Analyse your own turbine design to find possible issues

Or in an open setting an adjusted public design is evaluated

Step by step it is explained how issues can be found, identified and solved

A perfect course for people that have participated in the WT aeroelasticity course and want to refresh and extend their knowledge

Evaluation training ($\approx$ 4 weeks)

We cooperate with one or more of your engineers and perform a complete aeroelastic evaluation of the design.

The engineers will gain significant experience and the design is checked for possible resonance and stability issues

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Wind turbine aeroelasticity course

- A course of 6 sessions LIVE web training for four hours per session
- Start with the relevant aerodynamics, this includes a discussion of engineering models that are included in many codes, how do they work, are there possible issues with these.
- The whirling of wind turbines will be explained, why does the frequency change its value when measured in rotating frame compared to fixed frame?
- Wind turbine aeroelasticity issues such as resonance and instabilities will be explained, covering all instabilities and resonances currently known to be relevant
- In several interactive sessions participants will try to find and identify issues as well as solve them efficiently by changing design
- Participants will become aware of possible issues, how to find issues and how to solve them
- This can result in significant load reductions as well as preventing loss of prototypes.



Workshop

- A workshop of four sessions
- Wind turbine aeroelasticity issues such as resonance and instabilities will be explained
- Your own wind turbine design can be analysed by the participants under the supervision of an expert
- Participants will become able to find issues and increase their capabilities on identifying the causes. This will allow them to find out how to solve them
- This can result in significant load reductions as well as preventing loss of prototypes.



Evaluation training ($\approx$ 4 weeks)

- Together with one or a few engineers, a full aeroelastic evaluation of your wind turbine design will be performed
- The engineers will learn by closely following the process and by actually helping during the evaluation. At the same time your design will be evaluated and the results presented by JEHO BV in a report or presentation.
- Performing a full aeroelastic analysis of a wind turbine is a typical job that actually requires many years of experience, however by following the process closely, your engineers will become more and more able to do at least large parts of the evaluation themselves.
- JEHO BV also provides the service of performing a full aeroelastic evaluation, please contact us for more information or look on our website: www.jeho.nl



Interested?

- If you have any questions or are interested in any of the training options we provide, please get in touch with us: workshop@jeho.nl
- If you want to receive a more detailed description of any of the other training products at offer, please contact us and we can send you a presentation for that specific product: workshop@jeho.nl
- If you are interested in our other services, please do not hesitate to contact us with your questions: info@jeho.nl



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