Mini-lecture Turbine Whirling Frequencies

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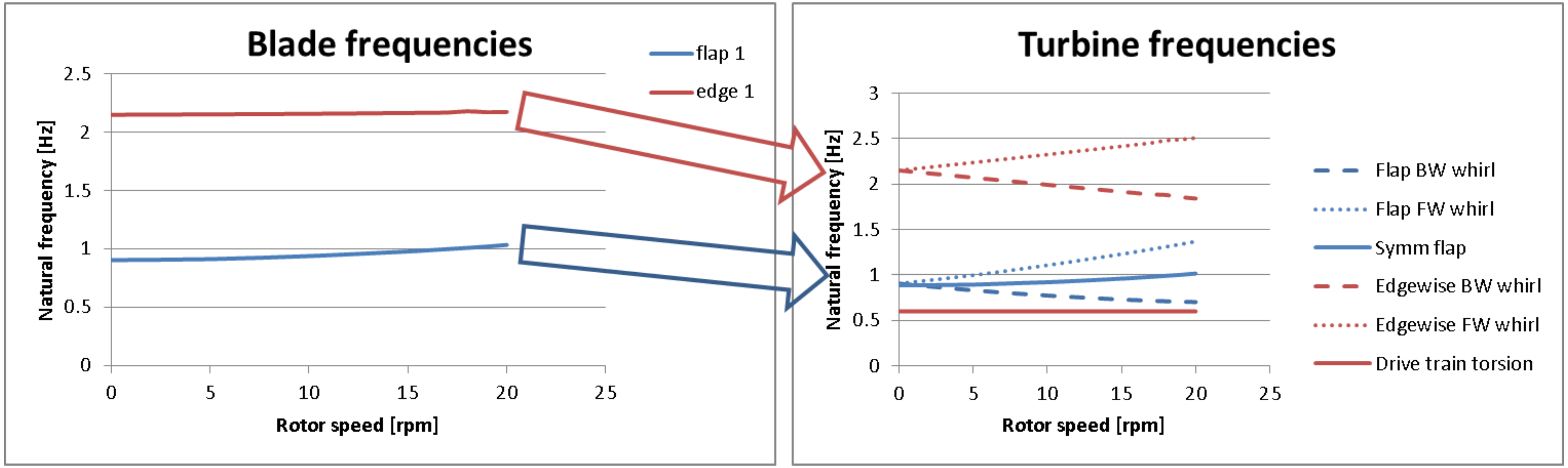
Wondering why this happens?

- If we analyse natural frequencies of a wind turbine, we see this effect when comparing frequencies in the blade to those measured in a frame of reference that does not rotate (e.g. tower)



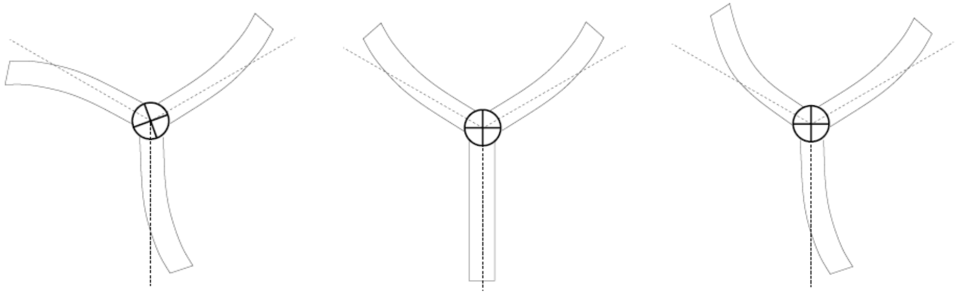
(Frequencies are representative for WT of around 2MW)

Turbine whirling frequencies

- A wind turbine **blade** will have a first flapwise mode, first edgewise mode, first torsion mode, second flapwise mode,… till infinity
- Higher modes are less relevant due to structural damping: there is so much damping that you will not have to take these modes into account
- The lower modes are very important for resonance as well as for aeroelastic stability
- **On a rotating turbine, some frequencies are measured at different values in the tower then in the blade, why?**

Turbine whirling modes

- First, what happens to the blade modes if we put three blades on one turbine?
- We find three different mode shapes in for one blade mode shape:
- For example first edgewise:



- And three similar combinations for first flapwise
- And second edgewise, and second flapwise, and…
- For two-bladed, there will be two combinations: A: both same deformation & B: both same but opposing deformation. Easier to depict, so let's use 2 blades, case B

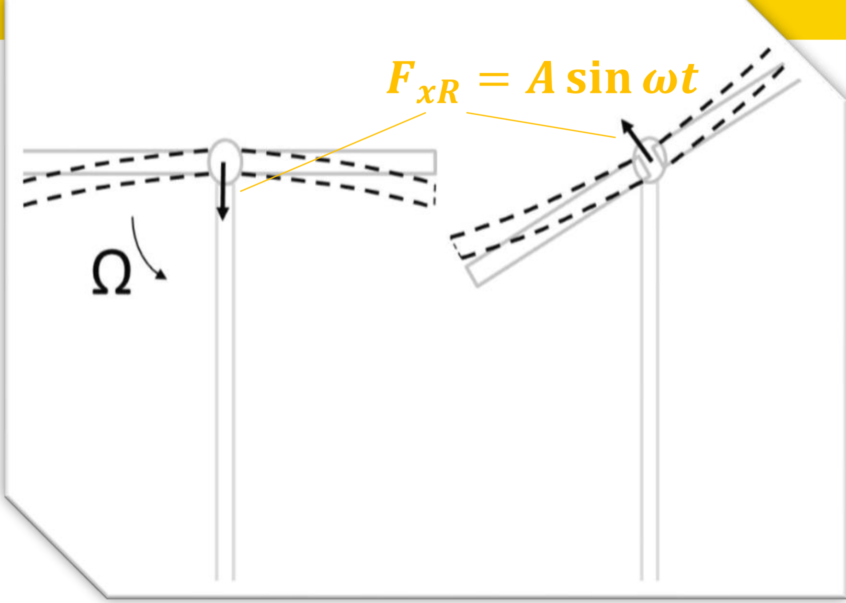
The blades start vibrating in one of the edgewise modes as indicated.

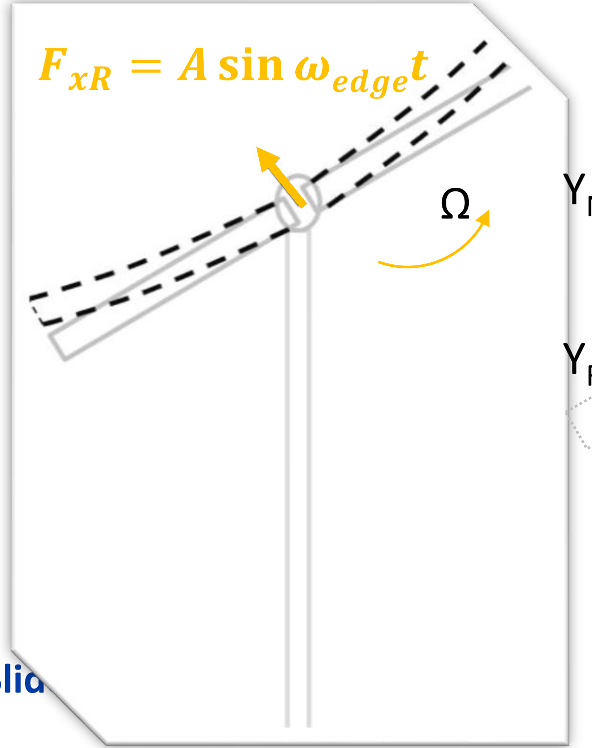
Now you can imagine the reaction force due to this vibration to be (in a rotating frame):

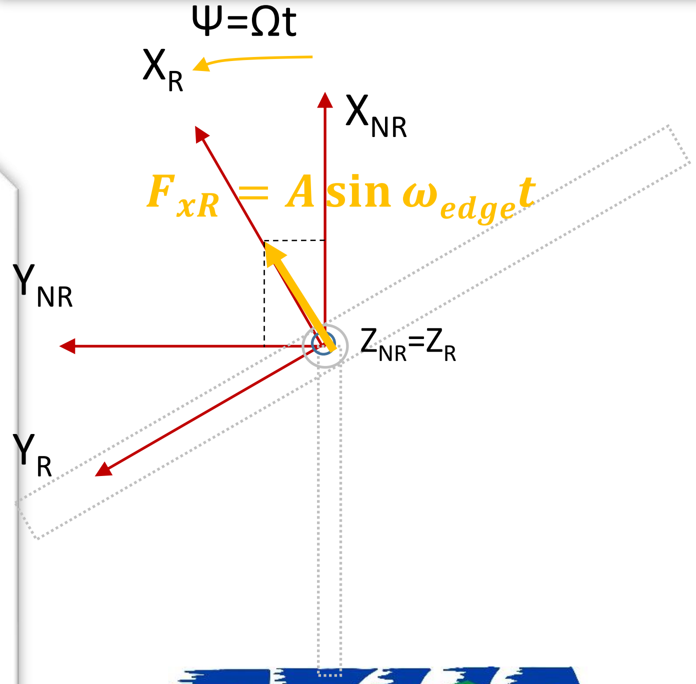
- $F_{xR} = A \sin \omega t$; $F_{yR} = 0$

So the force will increase and decrease at edgewise frequency ω, but the direction rotates with the blades

Now use graph bottom right and find expression for the force F_{xR} in non-rotating frame (X_{NR},Y_{NR},Z_{NR}):







This gives the following expressions in stand still frame:

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

Note that stand still frame refers only to the reference frame, the turbine blades are still rotating, but the frame of reference is fixed, for example in the tower directions

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So we had:

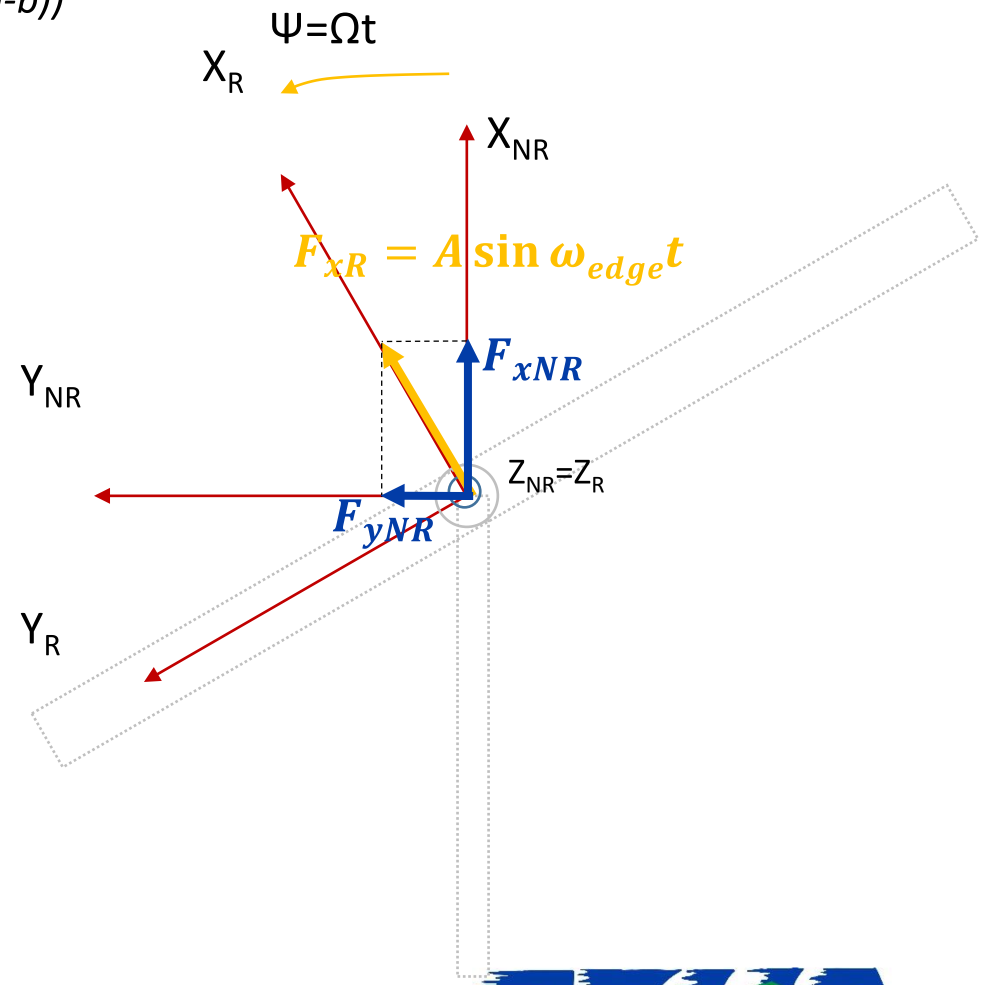
$$F_{xNR} = A \sin \omega t \cos \Omega t$$
$$F_{yNR} = A \sin \omega t \sin \Omega t$$

Some basic mathematics:

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

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

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



Using basic mathematics:

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

So no longer at frequency ω, but at (ω-Ω) and (ω+Ω)!

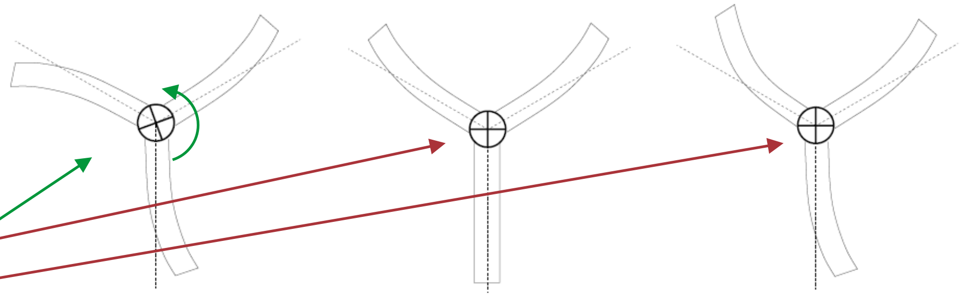
This change in frequency occurs only if the **reaction force or moment is in-plane.**

If the reaction force or moment is in Z-direction (out-of-plane), it will not change from rotating to non-rotating frame.

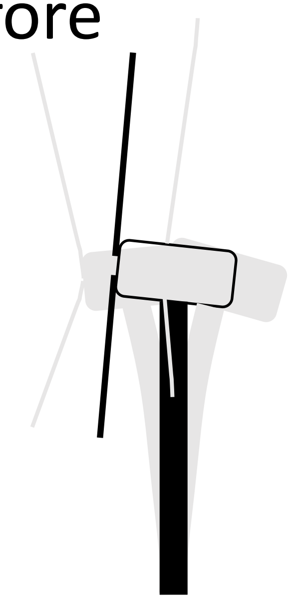
What does this mean? If the force or moment due to the combined modes of the two or three blades are in-plane the frequency of the vibration will be measured in the tower at (ω-Ω) and (ω+Ω) and at ω in the blades…

NOTE: a 2-bladed turbine only has one asymmetric mode, therefore it will be one mode with both frequencies in stand still frame!

Summary:



- Recall there were three modes for each blade mode (3-bladed WT)
- Two asymmetric, one is symmetrical (all blades same deformation)
- Reaction force or moment symmetric mode is out-of-plane, therefore not resulting in whirling mode
- Therefore the symmetric mode **does not change in frequency** if measured in stand still frame
- But there is significant interaction with tower (flapwise) and drive train (edgewise).
- This interaction influences the frequency and the damping



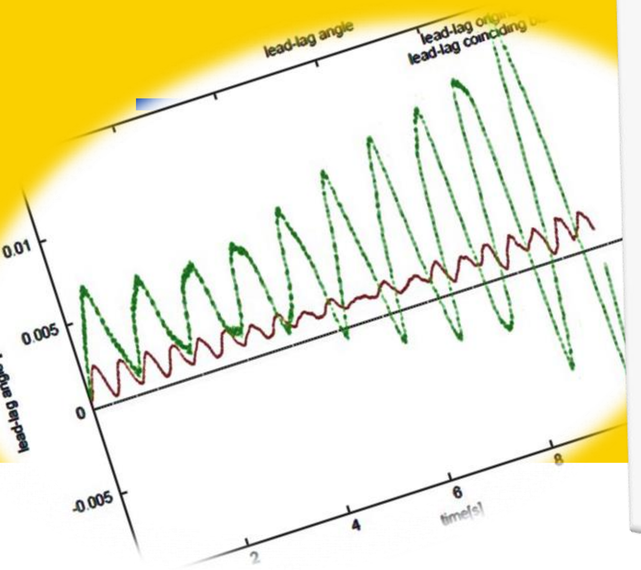
Summary:

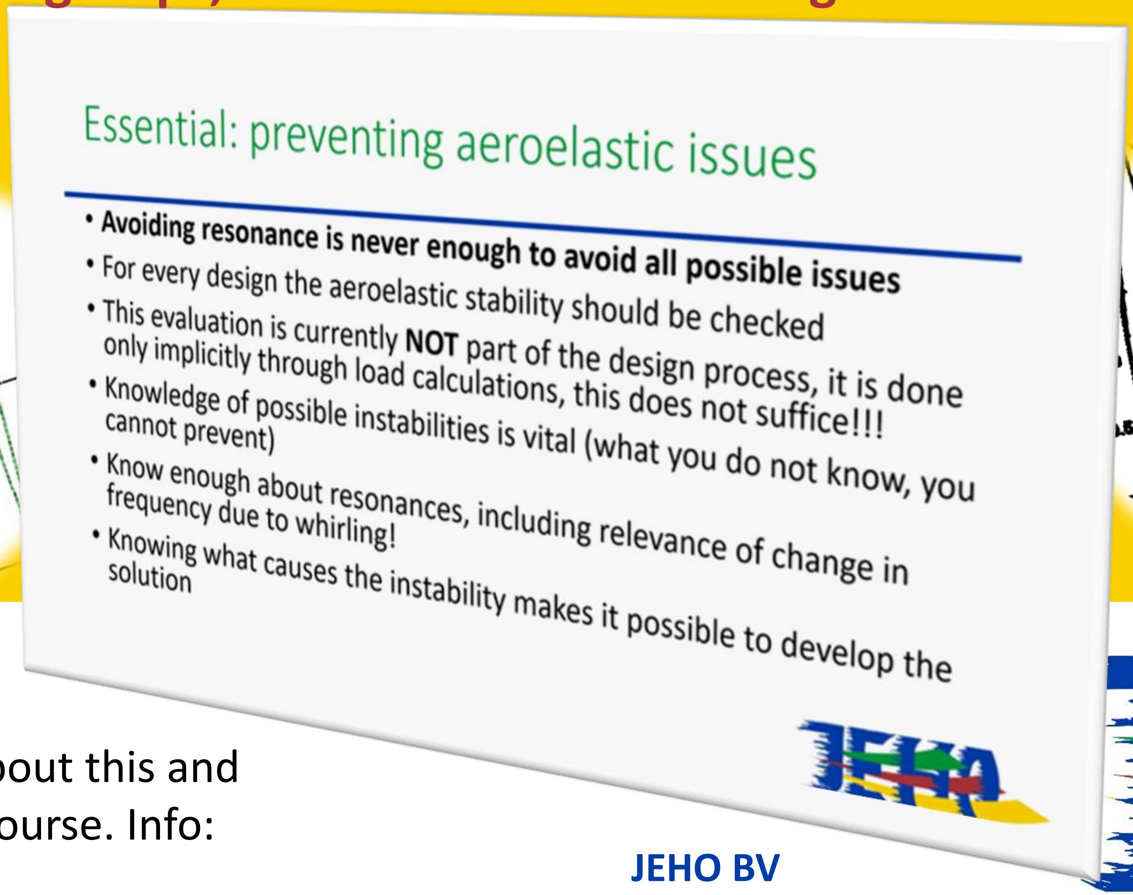
- Flapwise whirling modes: resulting moments that are in-plane (yawing / tilting => vector description of moment will be in-plane!).
- So flapwise asymmetric modes also have different frequency in non-rotating reference frame than in rotating frame
- Note that turbine is rotating in all situations, we only define different reference frames (e.g. measuring at blade root versus in tower)
- Symmetric modes are also called collective modes
- The generator will have significant effect on frequency of symmetric edgewise mode
- The rotor shaft stiffness will also affect the symmetric edgewise mode frequency
- Tower will have effect on frequency of symmetric flapwise modes.
- More reading material can be found at the bottom of our background webpage

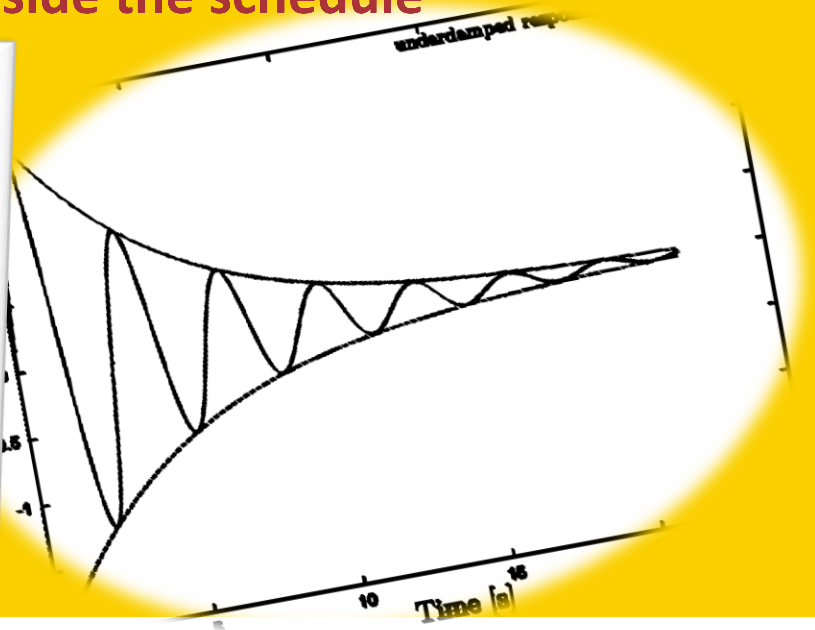
Wind Turbine Aeroelasticity Course

Look at the [leaflets](#) on our website for dates, or contact us

For small groups, we can also make arrangements outside the schedule







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