Aerodynamic forces on a yawed wind turbine rotor

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by

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Background/objectives

• This work has grown out of studies by Kamzin Technology (now GEC) on behalf of Windlite.
• It was also influenced by studies of the mechanics of teetering rotors.
• The forces from the tail vane and from the eccentricity of the thrust are not the only forces affecting the yawed equilibrium.
• the subsequent slides discuss the relevant aerodynamic forces on the yawed rotor.
The model

- An ADAMS model was used, similar to the Windlite 8 kW rotor.
- Output included an integral of the translational and the moment effects on the rotor.
- The rotor was fixed in yaw but the wind direction was changed.
- The rotor speed was kept constant and the wind speed increased stepwise.
Terminology, coordinates

\[ \text{Mass} = 54 \text{ kg} \]
\[ \text{I} = 61 \text{ kg m}^2 \]
\[ H = 1276 \text{ kg m}^2/\text{s} \]
\[ V = 200 \text{ rpm} \]
Aerodynamic forces, yaw angle = 15 deg

Windlite ADAMS results, yaw = 15 deg

- moment, Nm
- lateral force, N

- MYaero
- MZaero
- FYaero

200 rpm rep airfoils
yaw = +15 equilib wake

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Aerodynamic forces, yaw = 45 deg

Windlite ADAMS results, yaw = +45 deg

- Moment, Nm
- Lateral force, N

200 rpm
yaw = +45
equilib wake

M Yaero
MZaero
FYaero

wind speed, m/s

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Aerodynamic forces, yaw = 30 deg

Windlite ADAMS results, yaw = +30 deg

- Moment, Nm
- Lateral force, N

- MYaero
- MZaero
- FYaero

200 rpm
yaw = +30
equilib wake

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Total yawing moments

- $mt$ about yaw axis = $M_{Z\text{aero}} + F_{Y\text{aero}} \times l$

Windlite ADAMS results, total MZ yaw mt

- Wind speed, m/s
- Moment, Nm

- $yaw=15$ deg
- $yaw=30$ deg
- $yaw=45$ deg

- 200 rpm
- rep airfoils
- equilib wake

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Motion and gyroscopic effects

- total mt of inertia about yaw axis = 114 kg m²
- suppose total yaw mt = -200 N m, and MYaero = -400 N m; then, yaw_acceleration = -200/114 = -1.75 rad/s²
- If $\omega_z = -1.0 \text{ rad/s}$
  then $MY_{total} = H \times \omega_z = -1276 \text{ N m}$
- Then moment from bearings is
  $MY_{bearing} = MY_{total} - MY_{aero}$
  $= -1276 + 400$
  $= -876 \text{ N m}$
Some conclusions

• FYaero can change sign and tend to yaw rotor in undesired direction.
• MZaero effect is usually greater than that of Fyaero.
• High yaw rates can lead to high bearing reactions.
• These yawing influences must be added to those from furling mechanisms
• Can the aerodyn routines be believed at high yaw angles?