Wind Turbine Mechanics

$\cos\theta_B = -\cos$

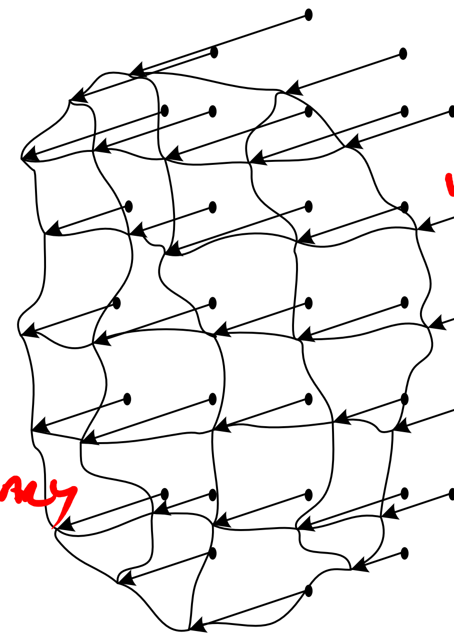
B. Wind Turbine Loads

2. Sources of Load

c. Aerodynamic Loading

TURBULENCE IN WIND INFLOW

- PRODUCES VARYING LOADS AT FREQUENCIES AND LENGTH SCALES OF THE ATMOSPHERIC BOUNDARY LAYER



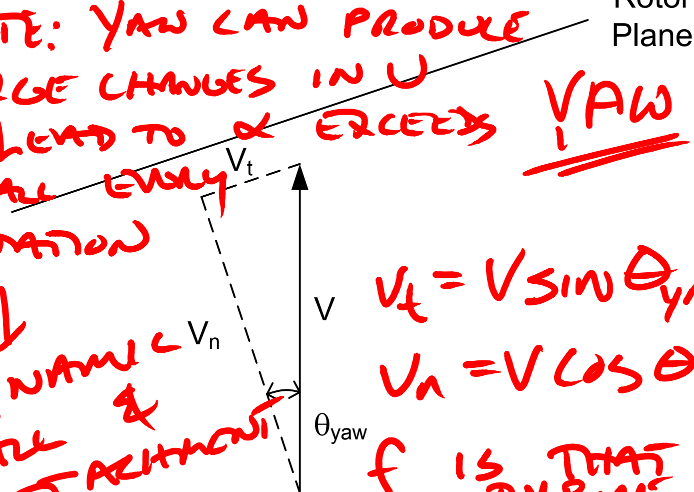
NOTE THAT TURBULENCE MOTIONS CAN EFFECT ENTIRE ROTOR OR JUST A PORTION

NOTE: YAW CAN PRODUCE LARGE CHANGES IN U → LEAD TO α EXCEEDS STALL EVERY ROTATION

↓

DYNAMIC STALL & REATTACHMENT

YAW



$V_t = V\sin\theta_{yaw}$

$V_n = V\cos\theta_{yaw}$

f IS THAT OF TURBINE ROTATION

CHANGE IN U DEPENDENT ON ROTOR ANGLE

IF THE ROTOR PLANE IS YAWED TO INCOMING WIND

- RELATIVE ROTATION SPEED IS ALTERNATELY INCREASE & DECREASED DUE TO COMPONENT V_t IN THE ROTOR PLANE

$\Omega r(1+a') = V\sin\theta_{yaw}\cos\theta_b$

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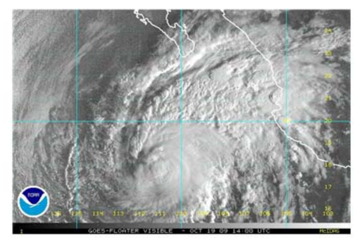
Extreme Events



FOR EXTREME EVENTS ASSUME THAT THE BLADES HAVE BEEN PARKED

$$F_{ext}(r) = q\, C_f\, c(r) \qquad q = \tfrac{1}{2}\rho V^2$$

UNDISTURBED WIND SPEED

$C_f \rightarrow$ REPRESENTATIVE OF WORST LIFT/DRAG CASE ~ 1.5

CONSIDER 60 m/s COMPARED A HIGH OPERATING WIND SPEED 20 m/s

$$\frac{F_{60}}{F_{20}} = \frac{\frac{1}{2}\rho V_{60}^2\, C_f\, c(r)}{\frac{1}{2}\rho V_{20}^2\, C_f\, c(r)} = \frac{(60\,\frac{m}{s})^2}{(20\,\frac{m}{s})^2} = 9$$

Wind Turbine Mechanics

B. Wind Turbine Loads

3. Cyclic Loads and Fatigue

AS DISCUSSED, WIND TURBINES ARE SUBJECT TO CYCLIC LOADING FROM VARIOUS SOURCES

WIND SHEAR
YAW
GRAVITY } → TURBINE ROTATION & BLADE PASSAGE FREQUENCIES & HARMONICS

TURBULENCE &
TRANSIENT } → RANGE OF FREQUENCIES ASSOCIATED WITH DIFFERENT PHENOMENA

RESONANCE-INDUCED LOADS } → RESONANCE FREQUENCIES

Wind Turbine Mechanics

B. Wind Turbine Loads

3. Cyclic Loads and Fatigue

FATIGUE – INCREASING INABILITY TO WITHSTAND LOADS APPLIED MULTIPLE TIMES

FATIGUE IS PHYSICALLY REALIZED AS CRACKS THAT GROW SLOWLY IN TIME

THE LOWER THE MAGNITUDE OF THE CYCLIC LOADS, THE LONGER THE COMPONENT CAN SURVIVE

IMPORTANT TO WIND TURBINES IS THE NUMBER OF CYCLES THEY EXPERIENCE

$$\text{TOTAL CYCLES} = n_{rotor}\left(\frac{rev}{min}\right) T(\text{YEARS}) \frac{60 \times 24 \times 365 \text{ min}}{1 \text{ year}} k$$

$k \equiv$ EVENTS/REV

$n_{rotor} = 20$ rpm

$T = 20$ YEARS

	$k=1$	$k=5$	$k=10$
TOTAL CYCLES	2×10^8	1×10^9	2×10^9