Learning from the Experts Webinar Series

Offshore Wind Resiliency Planning

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July 7, 2021

Meeting Procedures

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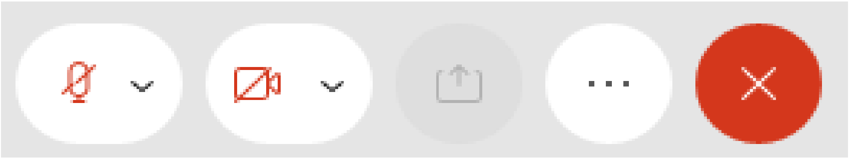

You'll see  **when your microphone is muted**

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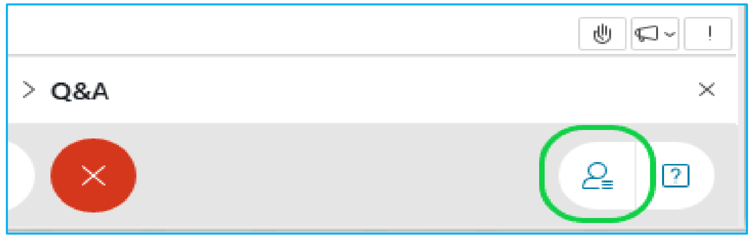

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Learning from the Experts

This webinar series is hosted by NYSERDA's offshore wind team and features experts in offshore wind technologies, development practices, and related research.

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Offshore Wind Adaptation and Resiliency

07/07/2021

- Meet your presenters and ICF
- The role of offshore wind in meeting climate goals
- Offshore wind basics
- How climate impacts offshore wind performance and reliability
- Projected changes to climate by mid-century
- Building resilience of offshore wind systems

Agenda

Your Presenters

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Who is ICF?

Washington, DC area
corporate headquarters

70
offices worldwide

7,000+
employees

$1.4+ billion
revenue

Energy

Environment

Transportation

Technology & Cybersecurity

Health

The NYS Climate Leadership and Community Protection Act (CLCPA), passed in 2019, sets ambitious goals to decarbonize the electric grid, heating and transportation systems while improving energy resilience, affordability and supporting the New York economy.

2025	6,000 MW Solar
2030	70% Renewable Energy 3,000 MW Energy Storage
2035	9,000 MW Offshore Wind
2040	100% Zero-emission Electricity
2050	85% Reduction in GHG Emissions

→ The NYS CLCPA advances ambitious climate goals

- Carbon free source of energy that help mitigate climate change
- Higher energy output than onshore wind because of stronger offshore winds
- Improves local air quality by reducing emissions from fossil units
- Easier to site and less disruptive to communities than onshore wind
- Generates economic growth – estimated at 100,000 jobs and billions in investment to NYS

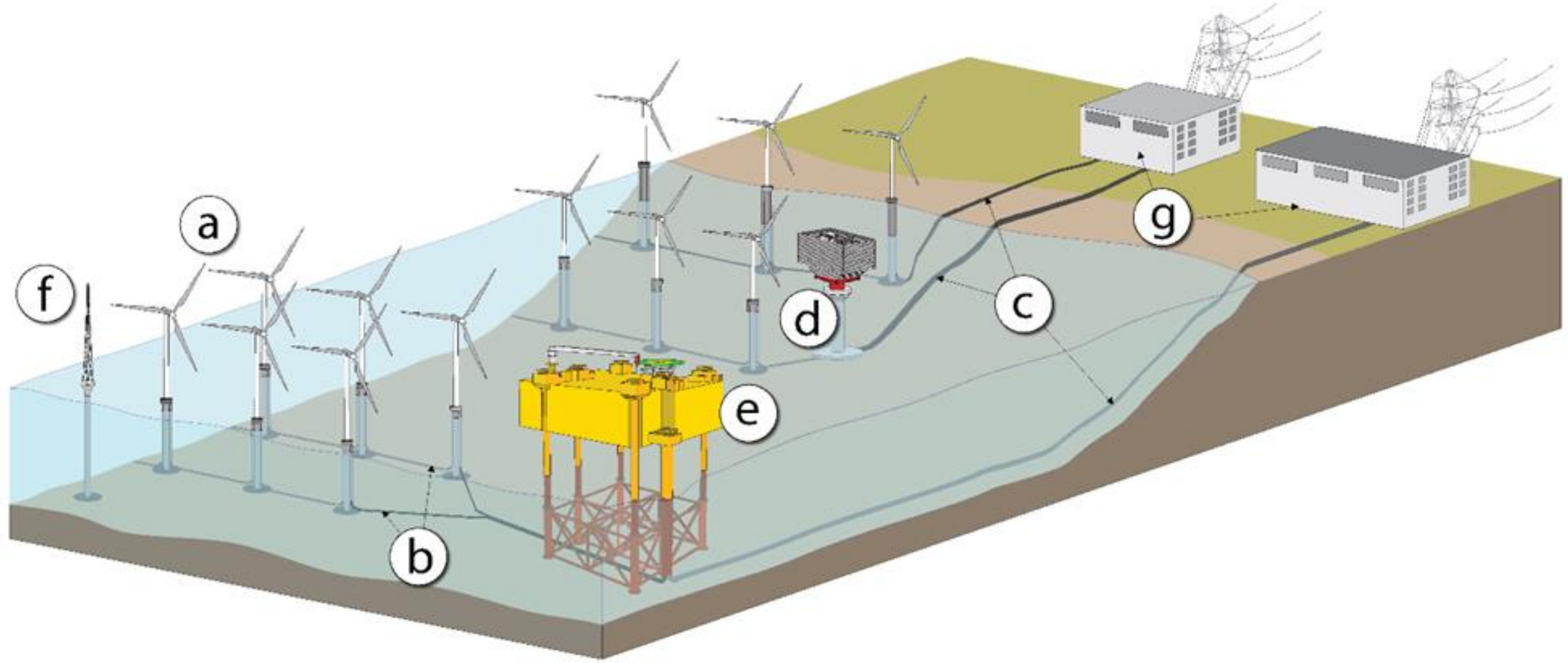
Benefits of Offshore wind

East coast offshore wind potential is greatest from the New Jersey coast to the Gulf of Maine

Source: DOE EERE, 2016

a) Wind turbine generator and fixed support structures
b) Submarine cable collecting array
c) Export cables
d) Transformer stations – increase voltage
e) Offshore stations - may include A.C. to D.C. conversion
f) Meteorological masts
g) Onshore stations – transmit energy to grid, may include D.C. to A.C. conversion.

* Port infrastructure to facilitate staging assembly and installation of Offshore Wind (OSW) systems (not shown)

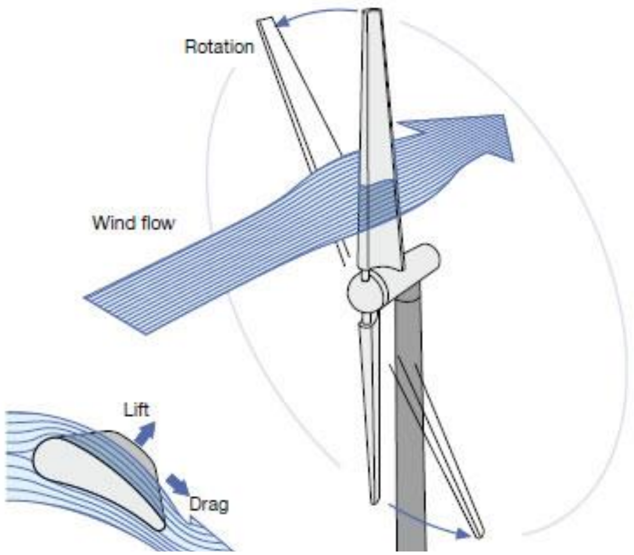


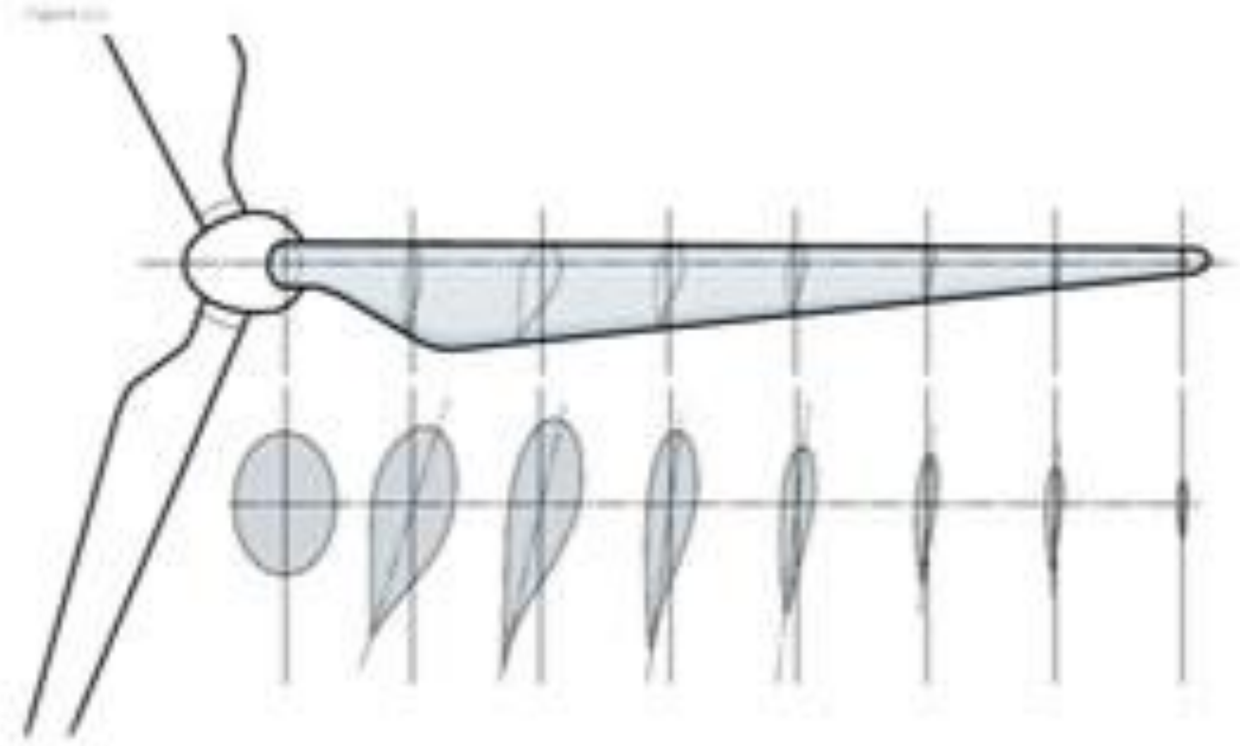
Offshore Wind System

Source: Rodriguez, et. al., 2016

How Does a Turbine Work?

- Blades have lifting body shape (airfoil)
- Air flow over airfoil creates lift on suction side
- Lift rotates the rotor, which is rigidly connected to the drivetrain
- In geared systems, the drivetrain torque is up-converted in gearbox to high-speed rotation for generator, which makes electricity
- Direct drive generators, often used in offshore wind turbines, can generate electricity at much lower rotational speeds than geared systems





Ref: http://www.cleanenergybrands.com/shoppingcart/knowledgemanager/questions/157/101+renewable+-+small+wind+turbines

Ref: http://www.cleanenergybrands.com/shoppingcart/knowledgemanager/questions/157/101+renewable+-+small+wind+turbines

Climate Stressor		Wind Turbine Generators	Support structures*	Collecting and export cables	Onshore stations	Ports
Wind	Low velocity	Low risk	Low risk	Low risk	Low risk	Low risk
	High velocity	Medium risk	Low risk	Low risk	Low risk	Low risk
	Turbulence	Medium risk	Low risk	Low risk	Low risk	Low risk
	Shear	Medium risk	Low risk	Low risk	Low risk	Low risk
	Geographic distribution	Medium risk	Low risk	Low risk	Low risk	Low risk
Air	Temperature	Low risk	Low risk	Low risk	Low risk	Low risk
	Moisture	Low risk	Low risk	Low risk	Low risk	Low risk
Ocean	Waves	Medium risk	Medium risk	Medium risk	Medium risk	Medium risk
	Sea level rise	Low risk	Low risk	Low risk	Medium risk	Medium risk
Precipitation	Rain	Low risk	Low risk	Low risk	Low risk	Low risk
	Ice / frozen	Medium risk	Low risk	Low risk	Medium risk	Medium risk
Extreme storms	Extreme wind	High risk	Low risk	Low risk	Medium risk	Medium risk
	Storm surge	Medium risk	Low risk	Low risk	High risk	High risk
Human stressors	Hacking	Medium risk				
	Vandalism	Medium risk				

*Includes support structures for wind turbine generators and offshore stations

Green	Low risk
Yellow	Medium risk
Red	High risk

Summary of Climate Risk Factors to OSW

- Wind Class I, II, III based on reference wind speed
  - $V_{ref} \approx 5 * V_{ave}$
- I_{ref} is the reference turbulence intensity
- $V_{ref,T}$ is the reference wind speed for a tropical cyclone, typhoon, or hurricane

Wind Class	I	II	III
V_{ref} (m/s)	50	42.5	37.5
V_{ave} (m/s)	10	8.5	7.5
$V_{ref,T}$ (m/s)	**57**		
A I_{ref}	0.16		
B I_{ref}	0.14		
C I_{ref}	0.12		

IEC 61400-1 Wind Classes

IEC 61400-3 Offshore Turbine Design

- Addresses all marine-related design considerations
- Hydrodynamic loading is accounted for
  - Wind + Wave and Current

Table 1 - Design load cases

Design situation	DLC	Wind condition	Waves	Wind and wave directionality	Sea currents	Water level	Other conditions	Type of analysis	Partial safety factor
1) Power production	1.1a	NTM $V_{in} < V_{hub} < V_{out}$ RNA	NSS $H_s = E[H_s \mid V_{hub}]$	COD, UNI	NCM	MSL	For extrapolation of extreme loads on the RNA	U	N (1,25)
	1.1b	NTM $V_{in} < V_{hub} < V_{out}$ Support structure	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, UNI	NCM	NWLR	For extrapolation of extreme loads on the support structure	U	N (1,25)
	1.2	NTM $V_{in} < V_{hub} < V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, MUL	No currents	NWLR or ≥ MSL		F	*
	1.3	ETM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s \mid V_{hub}]$	COD, UNI	NCM	MSL		U	N
	1.4	ECD $V_{hub} = V_r - 2$ m/s, V_r, $V_r + 2$ m/s	NSS (or NWH) $H_s = E[H_s \mid V_{hub}]$	MIS, wind direction change	NCM	MSL		U	N
	1.5	EWS $V_{in} < V_{hub} < V_{out}$	NSS (or NWH) $H_s = E[H_s \mid V_{hub}]$	COD, UNI	NCM	MSL		U	N
	1.6a	NTM $V_{in} < V_{hub} < V_{out}$	SSS $H_s = H_{s,SSS}$	COD, UNI	NCM	NWLR		U	N
	1.6b	NTM $V_{in} < V_{hub} < V_{out}$	SWH $H = H_{SWH}$	COD, UNI	NCM	NWLR		U	N

Factors Impacting OSW Performance

Climate Factor	Considerations	Relative impact
Wind speed and consistency	• Turbine output varies with the cube of wind speed so small changes in speed significantly impact output	●
Wind direction	• Consistent direction improves efficiency and capacity factor • Shifting winds can increase wear and tear on components	◕
Turbulence intensity and wind shear	• Smoother, less turbulent wind improves output • Vertical shear has a small impact on output, depending on surface roughness	◑
Air temperature	• Increases in air temperature can reduce turbine power output due to reduced density of air • A 5-degree increase would result in a 1 – 2% decrease in turbine output	◔
Air moisture and precipitation	• Moisture has the potential to increase the erosion on the leading edges of turbine blades, requiring more frequent maintenance	◔

Factors Impacting OSW Reliability

Climate Factor	Considerations	Relative impact
Winds above operating limit	• High winds above design operating limit may require turbines to shut down	◕
Ocean waves	• Can affect undersea cables and mooring lines • Waves directly impact foundation and support structures	◑
Frozen precipitation	• Build up on blades can cause weight imbalances requiring shutdown • May directly damage turbine blades	◔
Extreme storms	• Accounted for in design standards but storms outside of standards have caused shutdowns and damaged turbines in the past • May also damage undersea infrastructure due to wave action • May impact coastal onshore infrastructure such as substations and ports	●
Sea level rise	• Could cause water damage and corrosion of components • May exceed mooring line or tether tension limits • May impact vertical wind profile and turbine shear loading, increasing wear and tear • May impact coastal onshore infrastructure such as substations and ports	◔

Climate Factor	Outlook	Considerations
Wind speed, shear and geographic distribution	Uncertain	• Global wind speeds declined after the 1970's but increased beginning in 2010. Current thinking points to decadal variations in speed
Temperature	Increase	• The projected increase of 3-5.5 degrees would reduce turbine output • Temperature increases may however invigorate sea breezes, counteracting output reductions
Hurricanes	The same number but Increase in intensity	• Warming waters hold more energy, supporting an increase in hurricane intensity • The number of hurricanes in the North Atlantic is projected to remain the same or slightly diminish but the frequency of the strongest hurricanes is projected to increase • Hurricane tracks may move offshore, more directly impacting OSW.
Nor'easters	Increase in frequency and intensity	• Potential 10% to 40% increase in frequency of very strong storms and greater concentration of storms along the coast.
Precipitation	Increase in frequency and magnitude	• Projected 20% to 40% increase in the amount of precipitation during heaviest events • Projected decrease in the frequency of frozen precipitation but the increases in storm strength may result in an overall increase in icing
Sea level rise and storm surge	Increase	• Up to 30 inches of sea level rise by mid-century • Hurricane tracks shifting further off-shore may moderate increases in storm surge.

Projected Changes to Northeast Climate Factors by Mid-Century

Offshore Wind, Climate Change, and Impacts on Wildlife and Communities

Wildlife Impact	Outlook	Considerations
Avian wildlife	Stable	• Wind power has less than 3% of the avian fatalities per GWh of those associated with fossil fuel generation • The location of the NYS wind farms at greater than 14 miles offshore, significantly reduces the risk to Avian species
Marine wildlife	Stable	• Underwater vibration can disturb wildlife, particularly during construction • No consensus on whether climate change impact on acoustic properties will be meaningful
Turbine sound	No known or identified impact to-date	• Wind farms are far enough offshore to be imperceptible and future increases in ambient temperature are unlikely to change perceptibility

Changing Wind Speeds

- Vortex generations (VGs), gurney flaps, stall strips, aeroelastically tailored blades
- Microtabs, flaps, LIDAR
- More robust designs, increased international design standards

Changing Wind Direction

- Improved and more robust pitch and yaw systems
- Blades designed to operate in a larger range of angles of attack
- Increased O&M

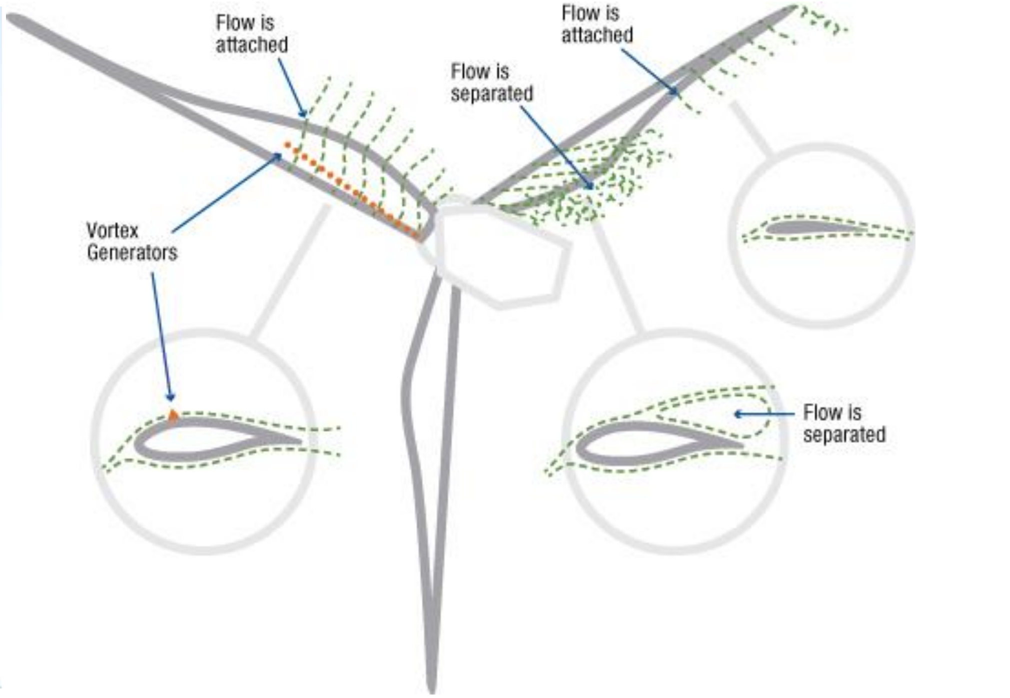
Changing Wind Shear

- Taller towers (vertical shear)
- LIDAR with robust pitch and yaw systems (horizontal shear)

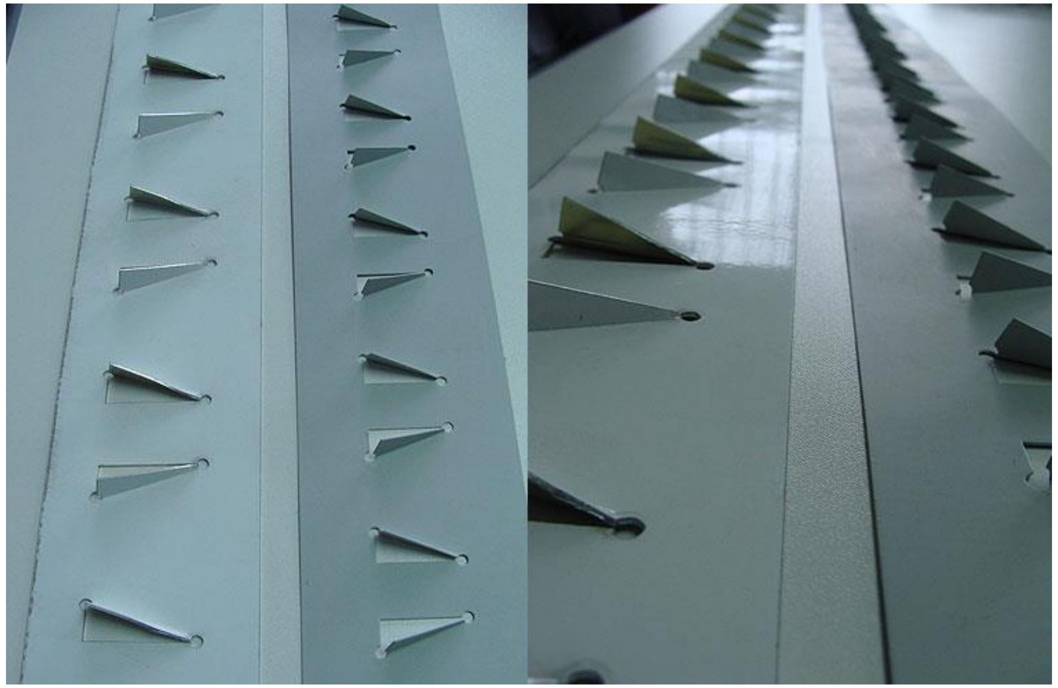
Turbine Resiliency to Changing Wind Speed, Direction, and Shear

- Ridges or fins on suction side of blade (top) to maintain flow attachment along blade chord
- Used to boost power and improve performance, but results in increased loads

Ref: http://powercurve.dk/our-technology/



Ref: https://en.wikipedia.org/wiki/Vortex_generator#/media/File:Wind_Turbine_Vortex_Generator.jpg



Ref: https://www.sparesinmotion.com/wind-turbine-parts/blade-parts/vortex-generator-for-different-technologies-lm-aerpac-vestas-siemens

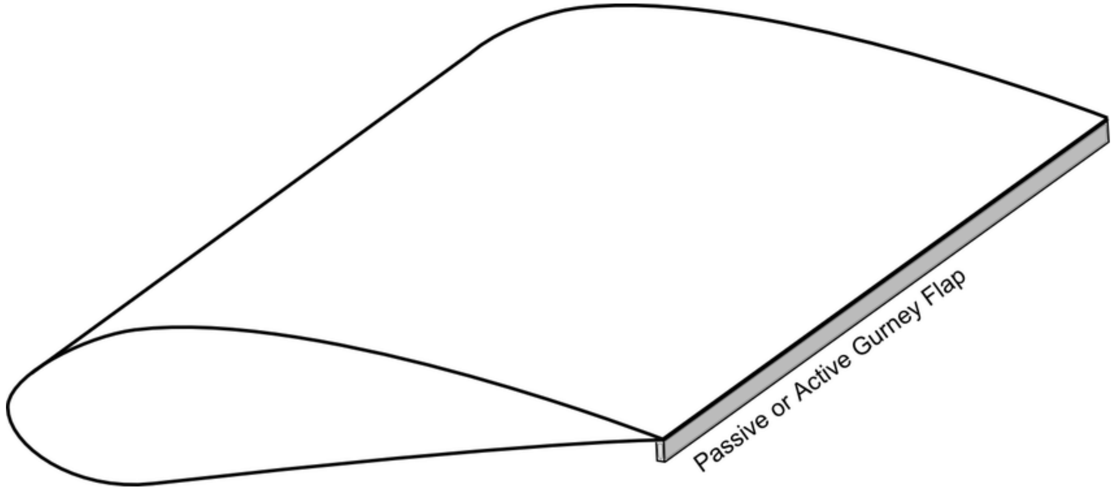
Vortex Generators

Gurney Flaps

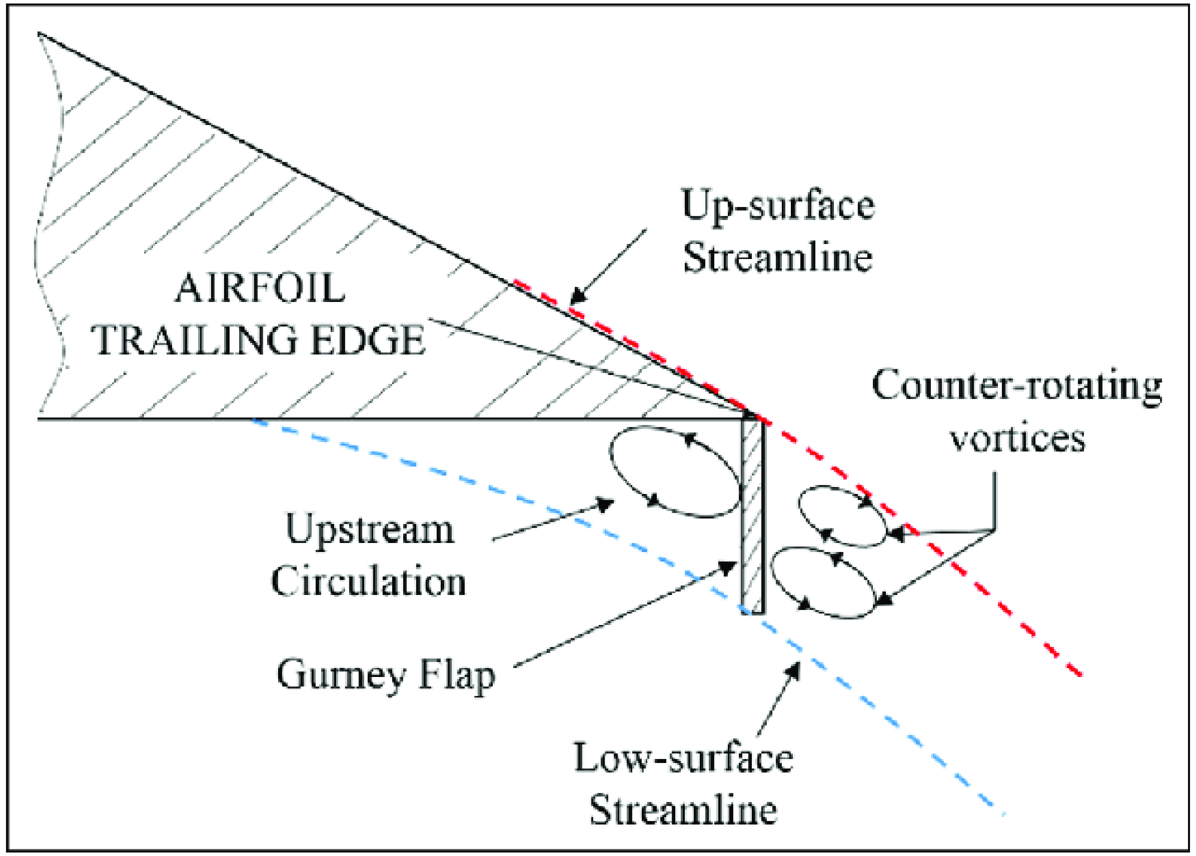
- Added to the trailing edge of the blade
  - Increases pressure on the suction side of the blade
  - Decreases pressure on the low-pressure side
  - Helps maintain boundary layer attachment to trailing edge

- Act as chord extenders on inboard span, working to improve aerodynamic performance

- Can also delay stall

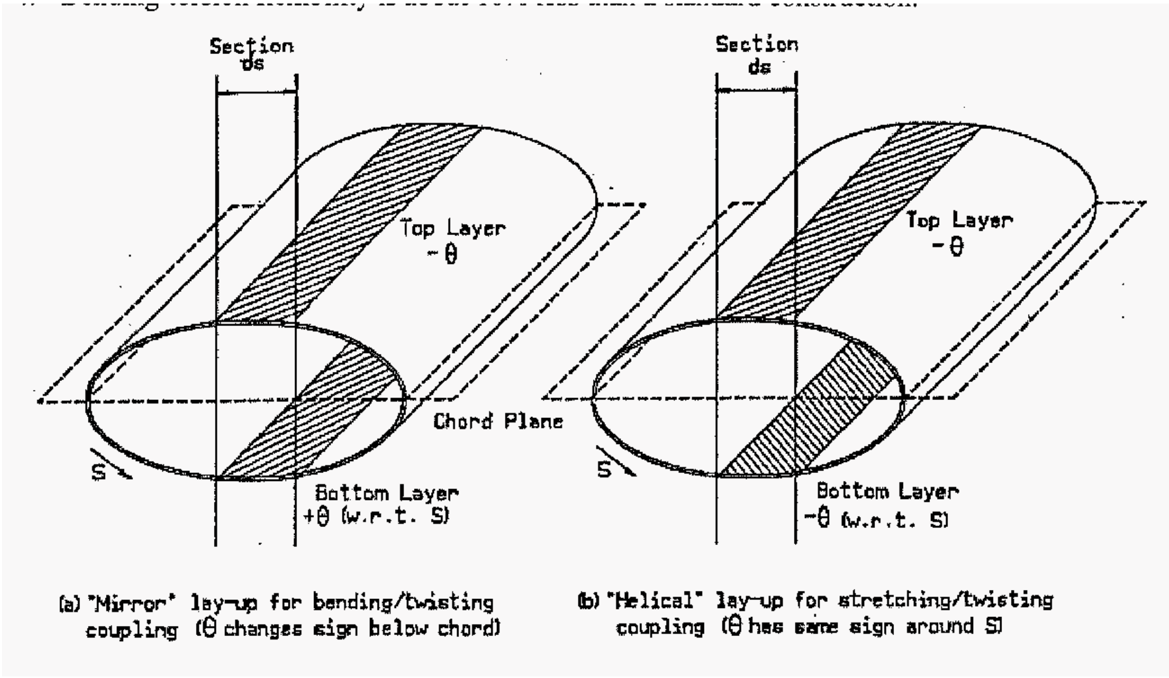


Ref: https://www.researchgate.net/figure/Active-Gurney-Flap-or-Micro-Tab-for-load-alleviation_fig28_307960051

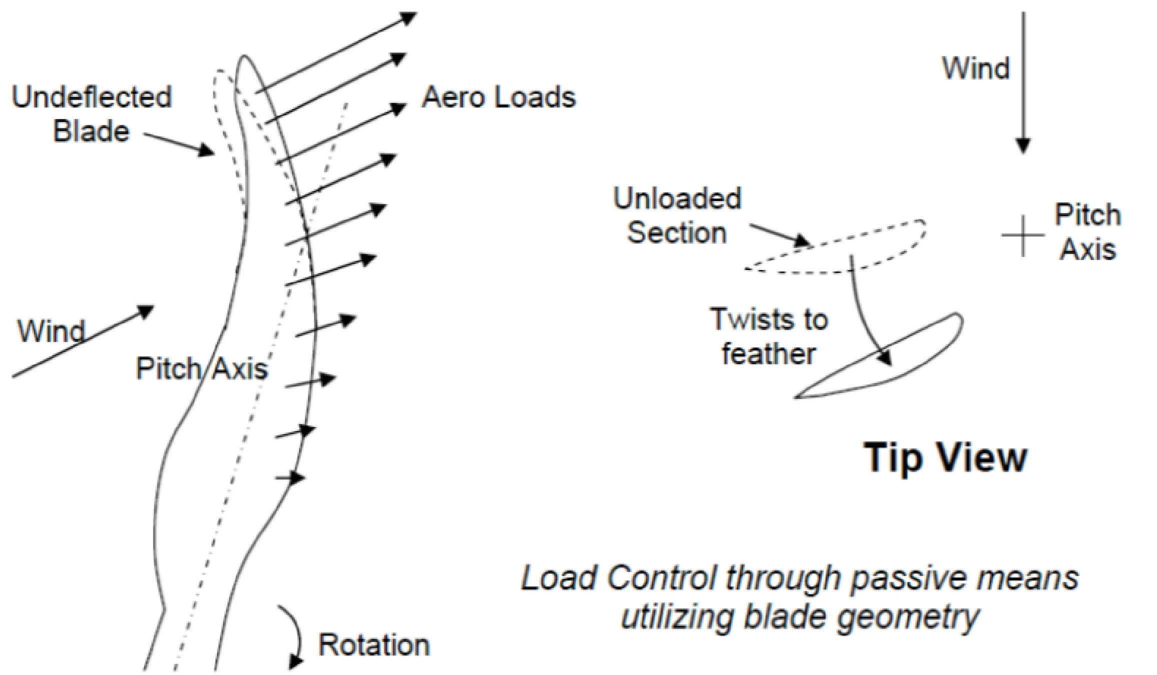


Ref: https://www.researchgate.net/figure/Schematic-showing-the-physical-effect-of-the-Gurney-flap-on-the-trailing-edge-region_fig1_328329783

- Couples flap or edge DOF with torsion
- Two main methodologies
  - Physical sweep curvature
  - Material coupling through off-axis fiber orientations



Ref: https://www.semanticscholar.org/paper/AEROELASTIC-TAILORING-IN-WIND-TURBINE-BLADE-1-co-4-Veers-Gunjit/ddca71e6ddf1462d6ebd1af62dc42b1930e1291c



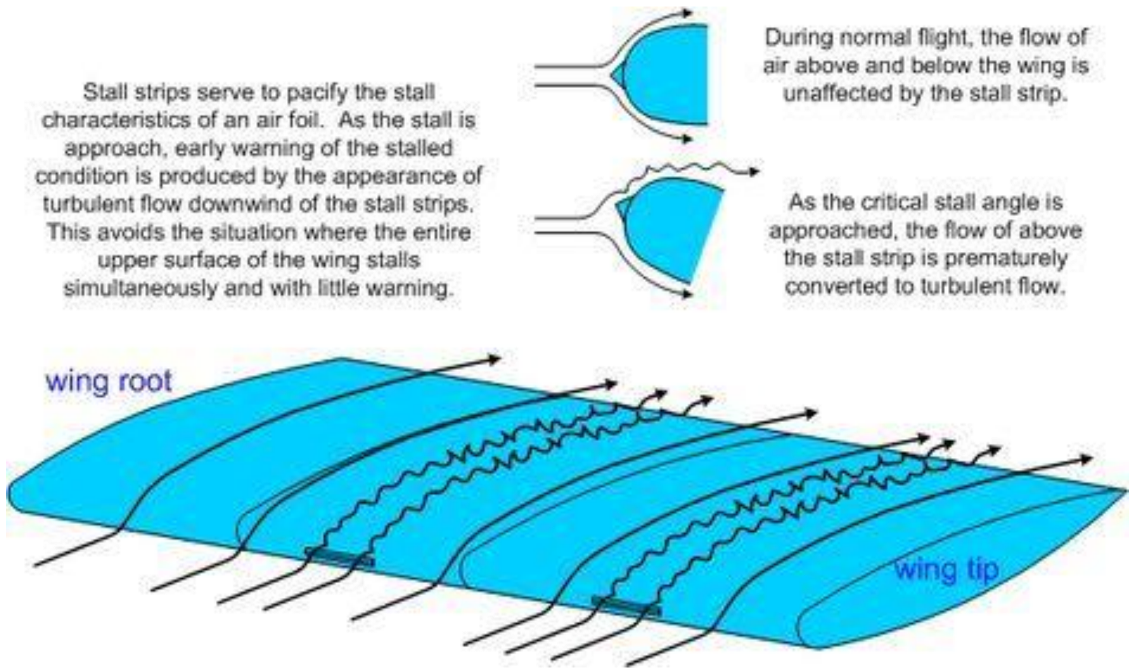
Ref: http://pnwaiaa.org/wp-content/uploads/2013/11/UW_16Oct13_5.pdf

Ref: https://www.sciencedirect.com/science/article/abs/pii/S0960148114003115

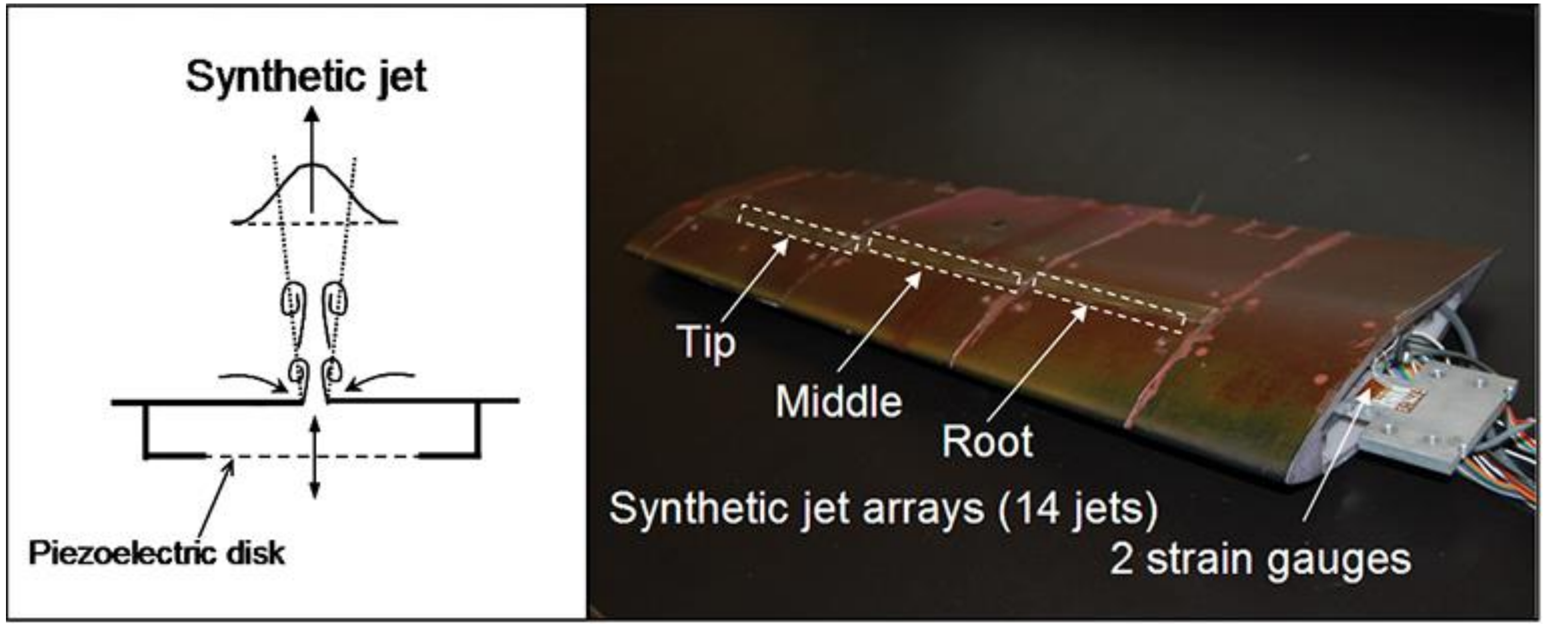
Aeroelastic Tailoring

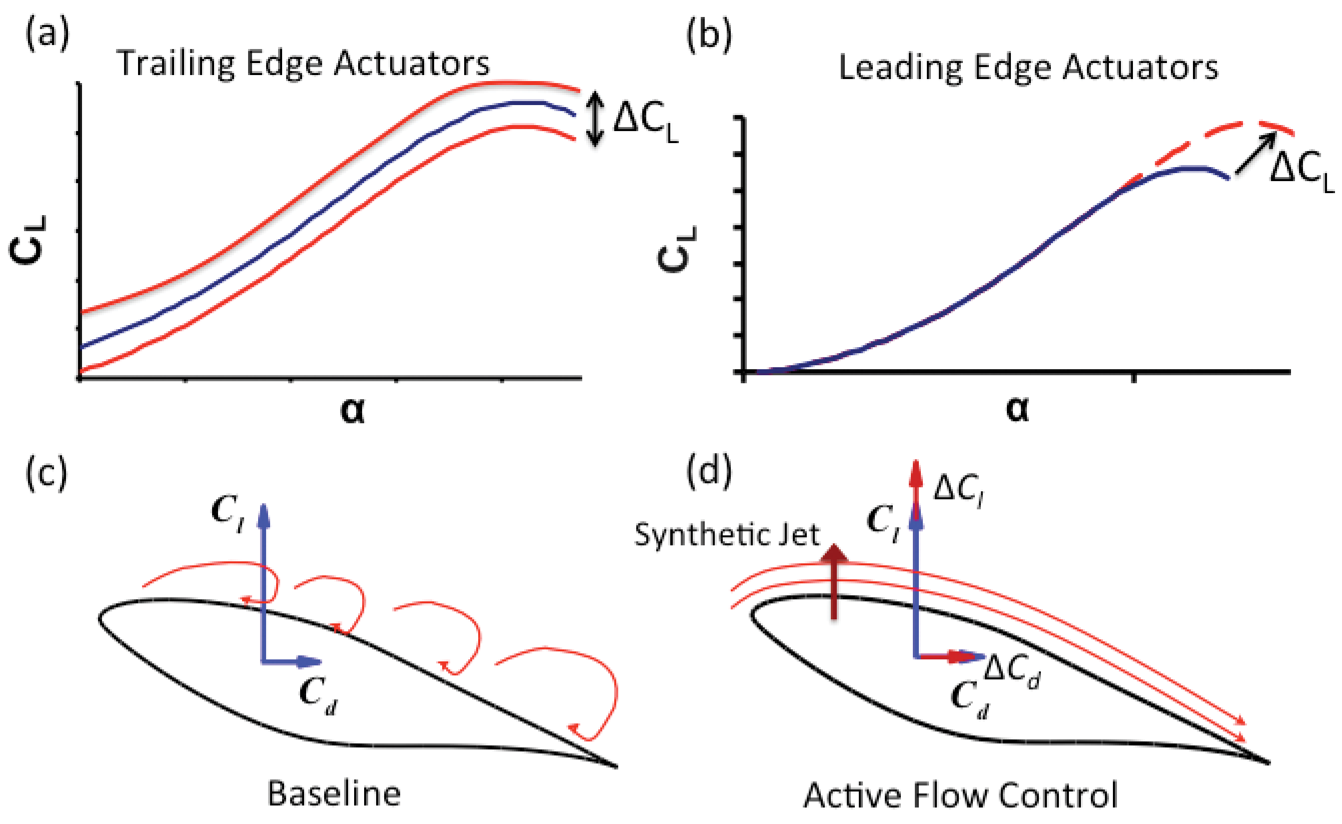
Active Load Control

- Technologies to actively adjust the air flow over the blade
  - Microtabs
  - Synthetic jets
  - Stall strips



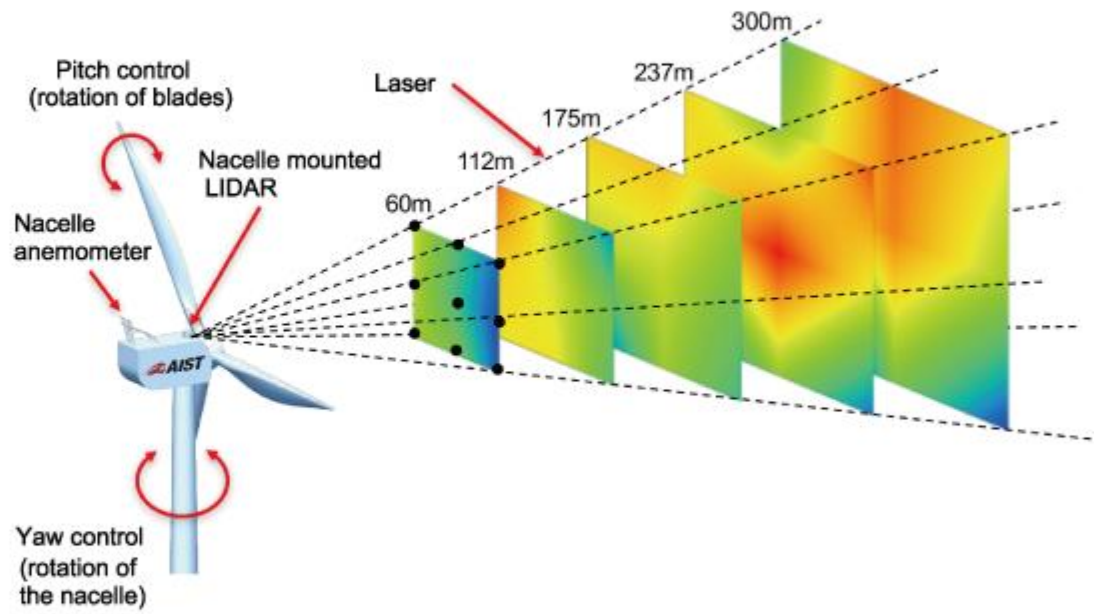
Ref: https://www.pinterest.com/pin/781022760356163549/





Ref: https://www.intechopen.com/books/wind-turbines-design-control-and-applications/active-flow-control-of-wind-turbine-blades

- LIDAR allows the turbine to “see” the wind up-stream and make corrective actions before the wind crosses the rotor disk
  - Part of a feed-forward control loop
- Becoming more common



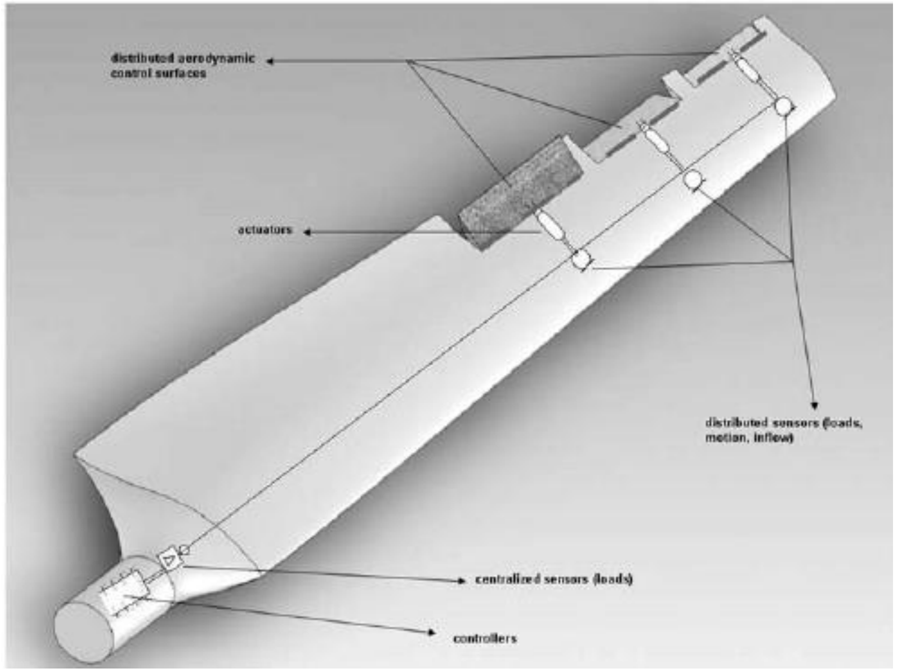
Ref: https://www.aist.go.jp/fukushima/en/unit/WPT_e.html

Ref: https://www.researchgate.net/figure/left-Ground-Doppler-lidar-system-installed-in-a-wind-farm-right-Taking-advantage_fig3_316715802

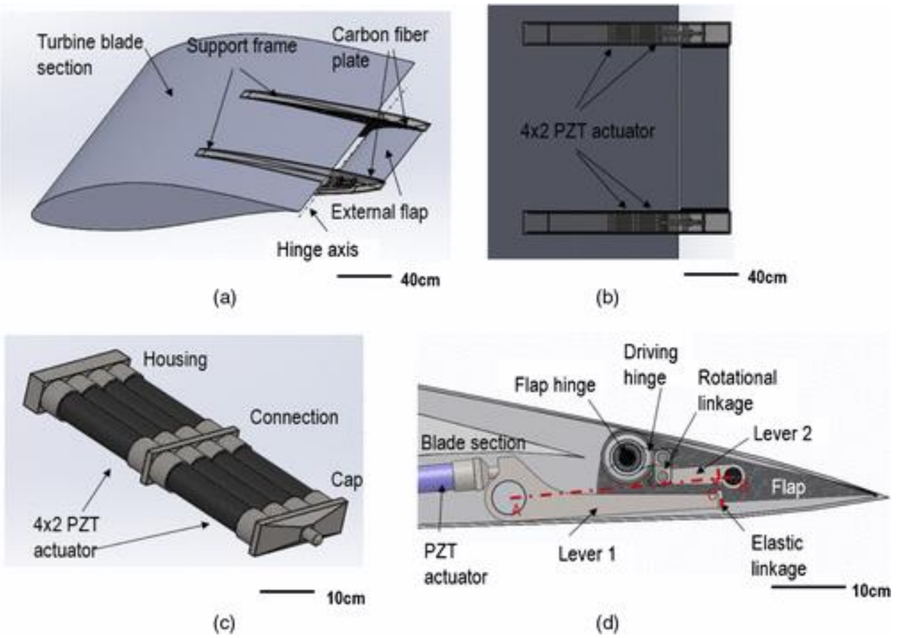
LIDAR (Light Detection And Ranging)

Active Flaps

Ref: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.660.5363&rep=rep1&type=pdf



Ref: https://www.researchgate.net/figure/Conceptual-layout-of-a-smart-wind-turbine-rotor-blade_fig3_231090714



Ref: https://ascelibrary.org/doi/10.1061/%28ASCE%29AS.1943-5525.0000771

- Similar to airplane wing trailing edge flaps, allows the turbine to actively control the loads on individual blades
- Not widely used
  - Requires a lot of maintenance
  - Complex mechanisms that can break

Wave Loading

- Robust fixed foundation designs to withstand potential of increased wave loading
- Heavier and more massive foundations, increased foundation bolts
- Ensure design lengths of cables, tethers, and mooring lines are sufficient for increased sea level and variability

Sea Level Rise

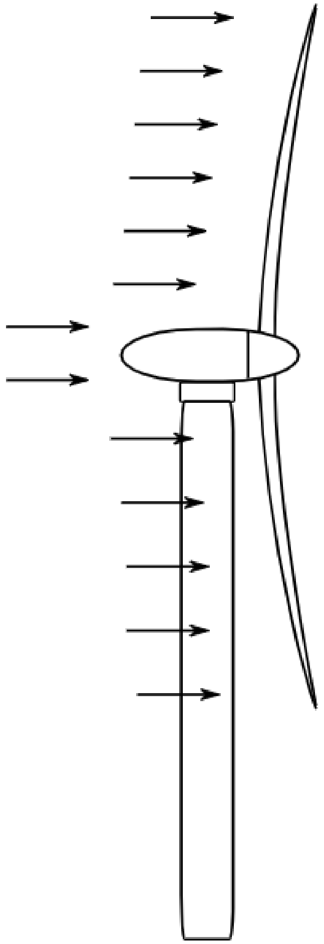
- Likely minimal impact to offshore wind
- Design elevations of future turbines to account for increased sea level and variability

Turbine Resiliency to Sea Level Rise and Wave Loading

Turbine Resiliency to Extreme Weather

- Increased severity and frequency of extreme weather should be incorporated into future international design standards
- Heavier and stiffer blades
- Stronger and more robust pitch and yaw systems
- Split pitch systems
- Two-bladed offshore designs
- Down-wind designs

Ref: https://www.windpowermonthly.com/article/1227512/close-up-envisions-en128-36mw-direct-drive-turbine



Ref: https://en.wikipedia.org/wiki/Yaw_system

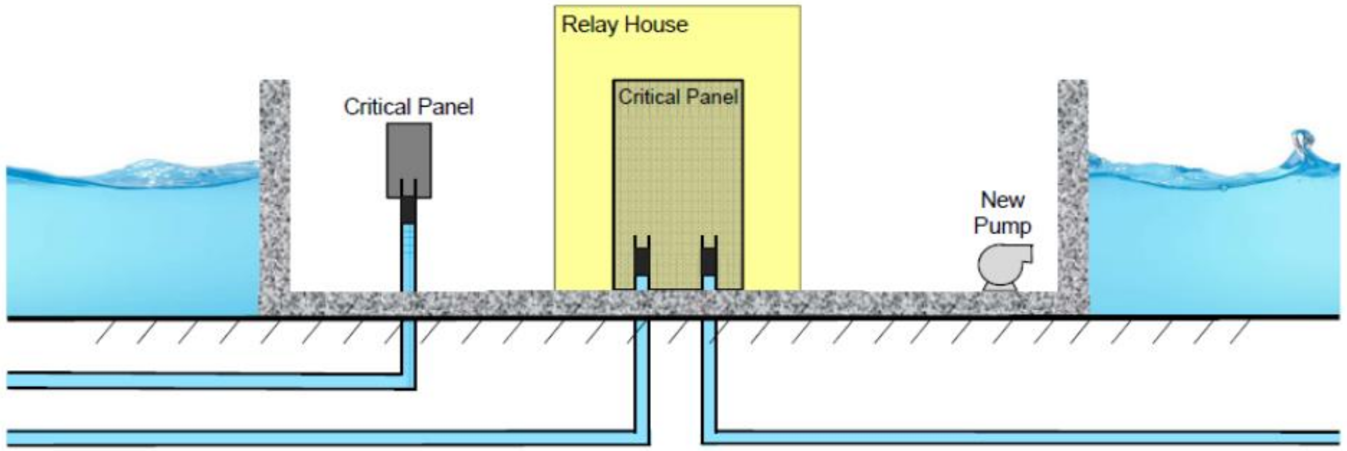
- Hydrophobic blade coatings and paint
- De-icing and anti-icing weatherization technologies
- Real-time health monitoring and remote sensing

Turbine Resiliency to Precipitation

Ref: https://www.researchgate.net/figure/Ice-on-a-wind-turbine-blade-10_fig5_334175712

Ref: https://w3.windfair.net/wind-energy/news/16991-slips-coating-technology-against-ice-build-up-on-offshore-wind-turbines

Climate Factor	Resilience Options
Sea level rise and coastal storms	• Elevating infrastructure • Storm resilient sea walls and piers • Nature based solutions such as wetlands and oyster reefs • Waterproofing facilities
Precipitation	• Drainage systems • Porous paved surface technologies to absorb water • Green infrastructure to help manage rainwater and runoff
Increasing temperature	• Higher temperature materials • Increasing tree and vegetation cover to reduce surface temperature • Green and reflective roofs • Cool pavements
High winds	• Upgrade existing structures consistent with expected peak winds • Incorporate future wind projections into the design of new structures



Building the Resilience of Coastal Infrastructure

Source: http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={C73D6658-896D-4AE0-B909-ADB468421421}

Summary of Climate Risk Factors to OSW and Conclusions

- Offshore wind systems are currently designed to withstand many climate hazards, including extreme winds and storm surge
- Climate change has the potential to stretch design and operational limits
- Designers and operators have a range of options to build resilience of OSW systems
- Some of these options are commercially available today, while others will require continued development
- By monitoring emerging climate science and technologies, designers can incorporate appropriate resilience options into future OSW systems

Climate Stressor		Wind Turbine Generators	Support structures*	Collecting and export cables	Onshore stations	Ports
Wind	Low velocity	Low	Low	Low	Low	Low
	High velocity	Medium	Low	Low	Low	Low
	Turbulence	Medium	Low	Low	Low	Low
	Shear	Medium	Low	Low	Low	Low
	Geographic distribution	Medium	Low	Low	Low	Low
Air	Temperature	Low	Low	Low	Low	Low
	Moisture	Low	Low	Low	Low	Low
Ocean	Waves	Medium	Medium	Medium	Medium	Medium
	Sea level rise	Low	Low	Low	Medium	Medium
Precipitation	Rain	Low	Low	Low	Low	Low
	Ice / frozen	Medium	Low	Low	Medium	Medium
Extreme storms	Extreme wind	High	Low	Low	Medium	Medium
	Storm surge	Medium	Low	Low	High	High
Human stressors	Hacking	Medium				
	Vandalism	Medium				

*Includes support structures for wind turbine generators and offshore stations

(green)	Low risk
(yellow)	Medium risk
(red)	High risk

Backup Slides

- IEC 61400-1 – Onshore turbine design spec
- IEC 61400-3 – Offshore turbine design spec
- And many others…

- Many companies issue turbine certifications
  - DNV GL
  - Lloyd’s Register
  - Technischer Uberwachungsverein (TUV)
  - UL
  - CGC (China)
  - And more…

Design Specifications and Requirements

Ref: https://twitter.com/dnvgl

Ref: https://en.wikipedia.org/wiki/International_Electrotechnical_Commission

- Design Load Cases
  - DLC 1.X – Power production
  - DLC 2.X – Power production with faults
  - DLC 3.X – Start up
  - DLC 4.X – Shut down
  - DLC 5.X – Emergency stop
  - DLC 6.X – Parked and idle
  - DLC 7.X – Parked and idle with faults
  - DLC 8.X – Transportation and erection
- Extreme (ULS) and Fatigue (FLS)
- DLCs consider 1 fault deep failure

IEC 61400-1 – Onshore Turbine Design

Design Situation	DLC		Wind conditions	Type of analysis	Partial Safety Factor	Other conditions
1. Power production	1.1	NTM	$V_{in} < V_{hub} < V_{out}$	U	N	For extrapolation of extreme events
	1.2	NTM	$V_{in} < V_{hub} < V_{out}$	F	*	
	1.3	ETM	$V_{in} < V_{hub} < V_{out}$	U	N	
	1.4	ECD	$V_{hub} = V_r \pm 2.0m/s$ and $= V_r$	U	N	
	1.5	EWS	$V_{in} < V_{hub} < V_{out}$	U	N	
2. Power production plus occurrence of fault	2.1	NTM	$V_{in} < V_{hub} < V_{out}$	U	N	Control system fault or loss of electrical network
	2.2	NTM	$V_{in} < V_{hub} < V_{out}$	U	A	Protection system or preceding internal electrical fault
	2.3	EOG	$V_{hub} = V_r \pm 2.0m/s$ and $= V_{out}$	U	A	External or internal electrical fault including loss of electrical network
	2.4	NTM	$V_{in} < V_{hub} < V_{out}$	F	*	Control, protection, or electrical system faults including loss of electrical network
3) Start up	3.1	NWP	$V_{in} < V_{hub} < V_{out}$	F	*	
	3.2	EOG	$V_{hub} = V_{in}$ $V_{hub} = V_r \pm 2.0m/s$ and $= V_{out}$	U	N	
	3.3	EDC	$V_{hub} = V_{in}$ $V_{hub} = V_r \pm 2.0m/s$ and $= V_{out}$	U	N	
4. Normal shut down	4.1	NWP	$V_{in} < V_{hub} < V_{out}$	F	*	
	4.2	EOG	$V_{hub} = V_r \pm 2.0m/s$ and $= V_{out}$	U	N	
5. Emergency shut down	5.1	NTM	$V_{hub} = V_r \pm 2.0m/s$ and $= V_{out}$	U	N	
6. Parked (standing still or idling)	6.1	EWM	50-year recurrence period	U	N	
	6.2	EWM	50-year recurrence period	U	A	Loss of electrical network connection
	6.3	EWM	1-year recurrence period	U	N	Extreme yaw misalignment
	6.4	NTM	$V_{hub} < 0.7 V_{ref}$	F	*	
7. Parked and fault conditions	7.1	EWM	1-year recurrence period	U	A	
8. Transport, assembly, maintenance and repair	8.1	NTM	V_{maint} to be stated by the manufacturer	U	T	
	8.2	EWM	1-year recurrence period	U	A	

where:

DLC	Design load case	$V_r \pm 2m/s$	Sensitivity to all wind speeds in the range should be analyzed
ECD	Extreme coherent gust with direction change		
EDC	Extreme direction change	F	Fatigue
EOG	Extreme operating gust	U	Ultimate strength
EWM	Extreme wind speed	N	Normal
EWS	Extreme wind shear	A	Abnormal
NTM	Normal turbulence model	T	Transport and erection
ETM	Extreme turbulence model	*	Partial safety for fatigue
NWP	Normal wind profile model		

Coming Next:

July 28, 1:00 p.m. ET
Offshore Wind Stakeholder Engagement
Kris Ohleth, Special Initiative on Offshore Wind

August 11, 1:00 p.m. ET
Offshore Wind COP Review Process
Michelle Morin and
Jessica Stromberg, BOEM

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