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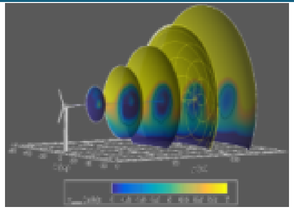
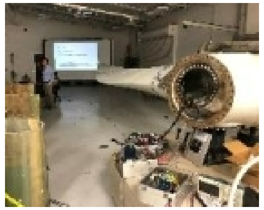
Sandia National Laboratories

SAND2021-6403C

Preliminary Design of a Bi-Wing Wind Blade with Partial Span Pitch Control





PRESENTED BY

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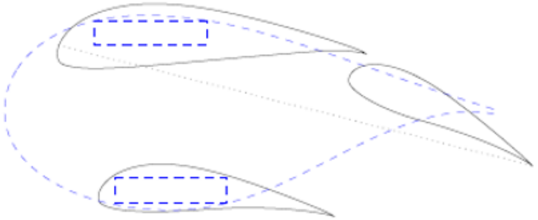
Motivation and Background

100+ m blades are:
- Both max-chord (4.75m) and length (~75m) constrained for transportation, and approaching root constraint
- Pitch rate limited to 1-2 deg/s, creating load/power control problems
- Pre-bend limited to 4m, creating tip clearance problems

Bi-wing blade design with partial-span pitch control could potentially solve all three problems

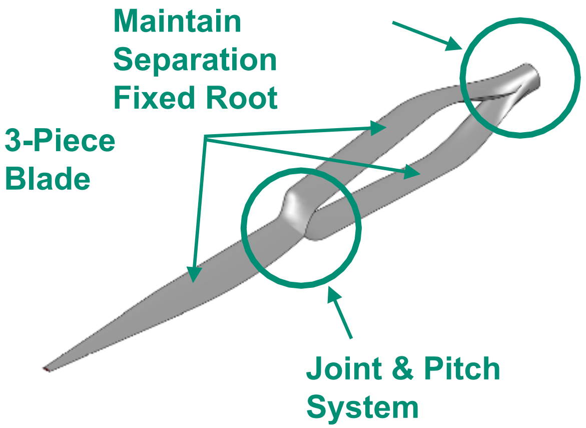
Previous/Current Studies:
- Ragheb & Selig found Cl/Cd increases of 40-60% as compared to conventional airfoil
- Chu found potential for 46% reduction in blade mass, and Roth-Johnson found 25%-35% lower tip deflections
- Roth-Johnson et al. found optimal joint placement at 50% span, while Chu found shortest transition to be most optimal
- NASA Mod2 and later, Argwala & Ro found partial span pitch of 30% was effective to control in high winds, but requires larger pitch motions
- NASA/Boeing Subsonic, Ultra-Green, Aircraft Research (SUGAR) is looking at partial bi-wing design

Challenges
- Lower edge stiffness from reduced chord
- Beam-buckling of long, unsupported section
- Higher inertial loads from pitch system



Ragheb & Selig, 2011

NASA Mod-2 Turbine, 1984



Chu, 2017

NASA Boeing SUGAR Volt, 2019

Method

Aerodynamics

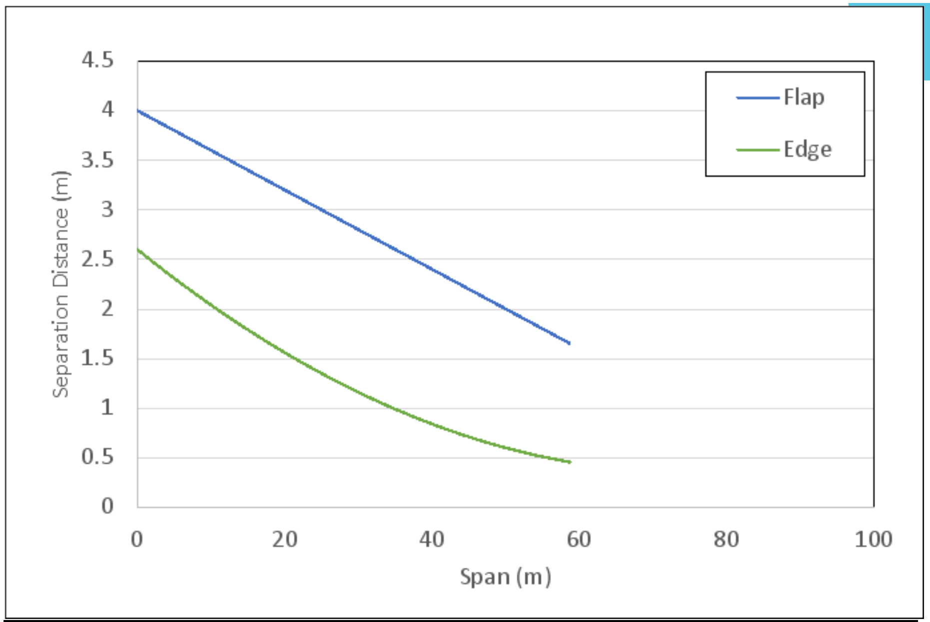
- Prandtl/Glauert interference lift reduction
- Increased drag and decreased lift from the joint was not examined

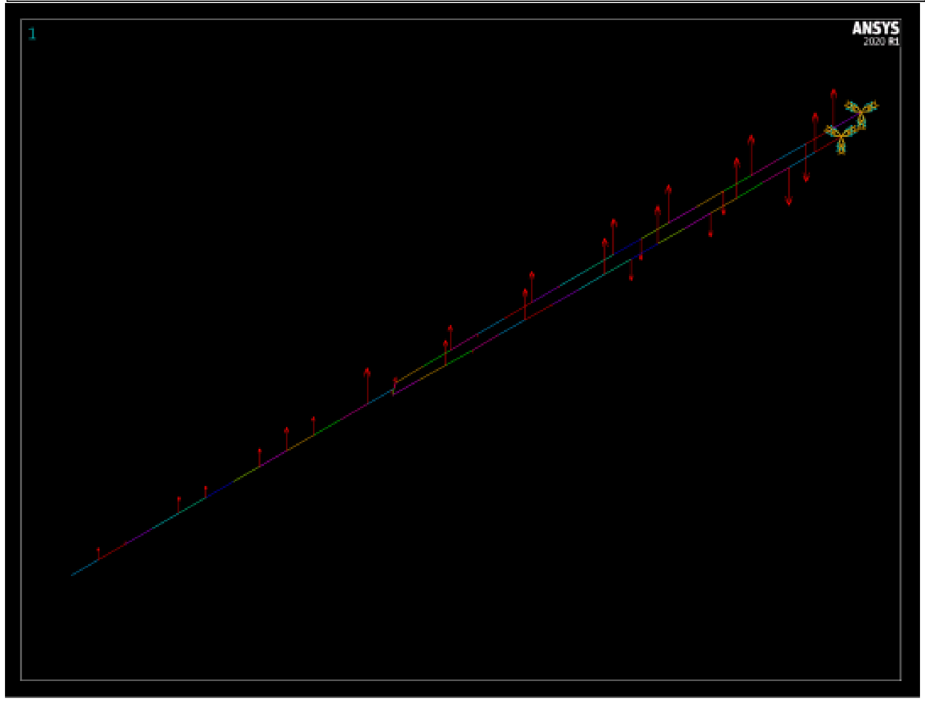
Structures

- Assume rigid joint connecting bi-plane sections to outboard section
- Glass design
- Panel buckling not accounted for, typically addressed with lightweight core materials
- Stiffnesses targeted to be at least matched
- Simplified structural model for optimization using ellipses to approximate stiffness and mass
- ANSYS BEAM188 model with properties from NREL Precomp

System

- Pitch system mass according to NREL “Wind Turbine Design Cost Scaling Model”





Design

Initial Design

- 21% thick airfoils for biwing section
- Laminates are assumed to be constant thickness from 0-80% chord
- Joint placed at approximately 60% based on previous studies

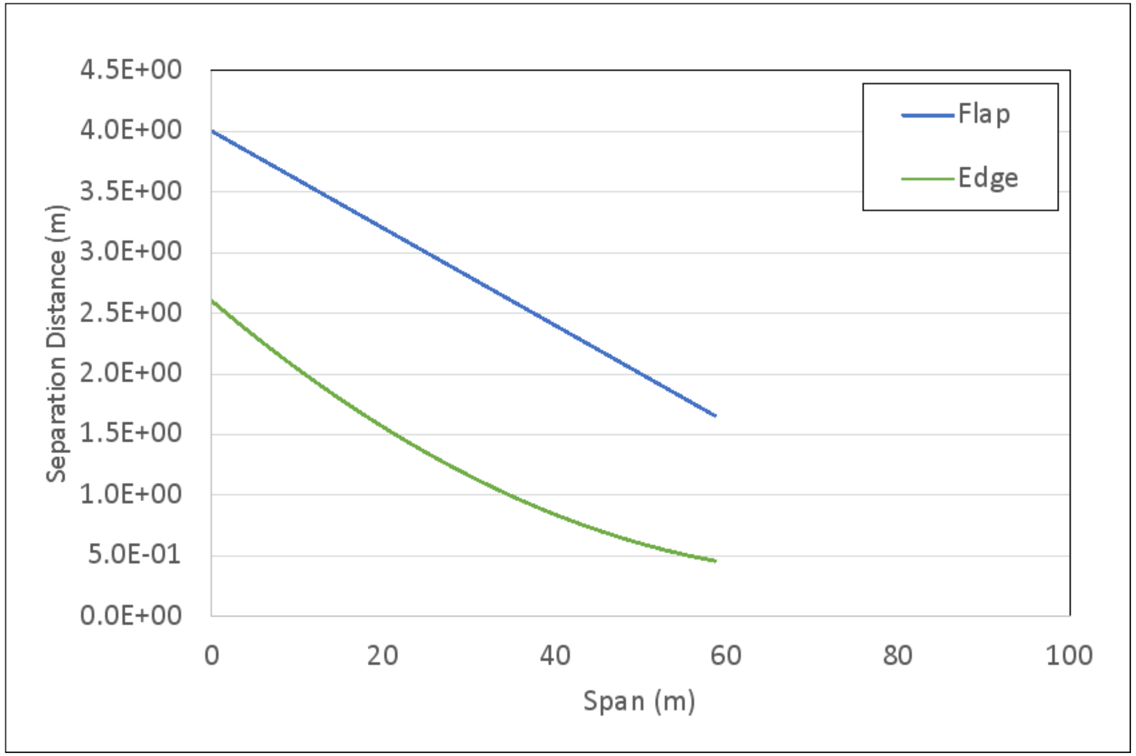
Separation distance and laminate thickness was optimized to match stiffness and minimize mass

Flap and edge stiffness are dominated by total amount of material and offset distance

Larger separation allows for less material

Final Design

- 36% thick airfoils to prevent beam buckling
- Constant laminate thickness of 30mm

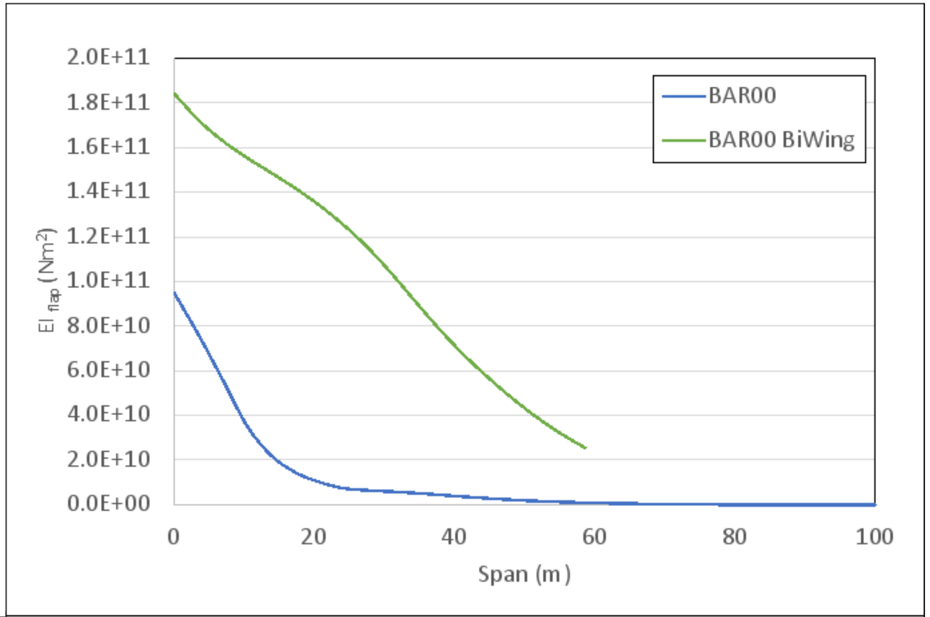


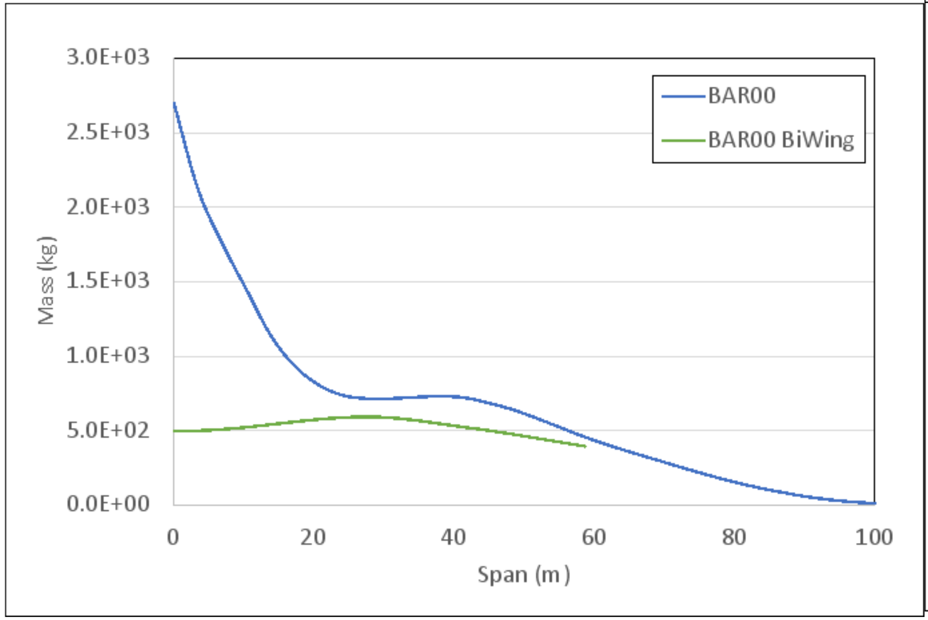
Stiffness and Mass

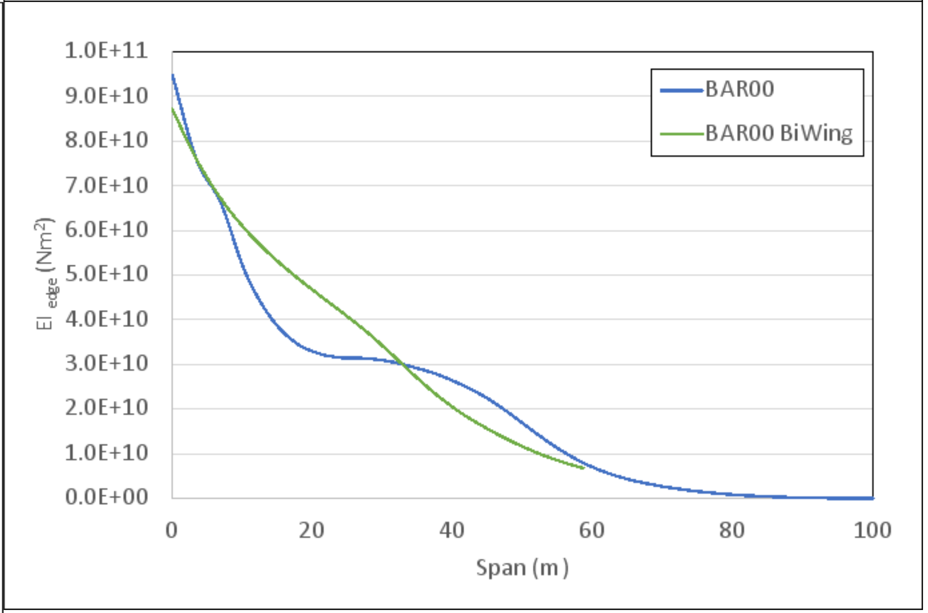
Design is very stiff in flap direction

Significant mass savings inboard

Found design able to approximate edge stiffness



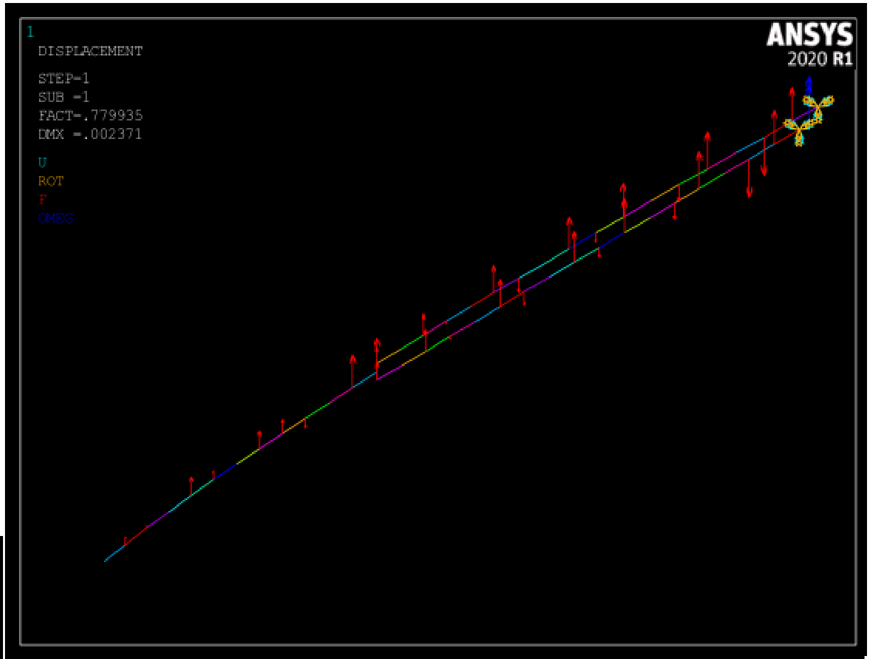




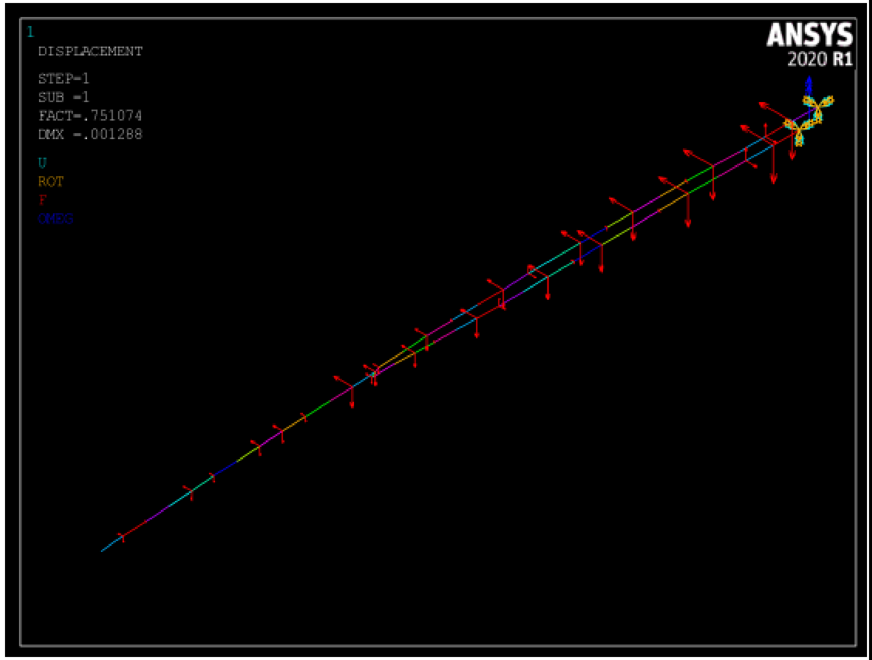
Structural Stability

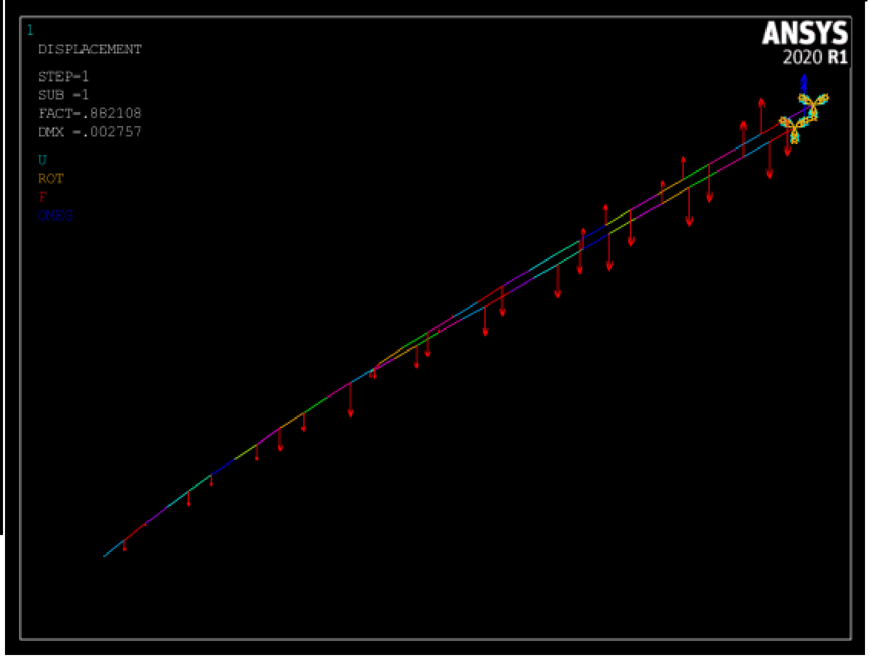
Used loads from BAR00 blade

Buckling occurs at ~75% of max load in flap and combined flap/edge



Loading Direction (deg)	Buckling Factor
0	1.55
45	0.75
90	0.88
135	1.72
180	1.77
225	1.21
270	0.78
315	1.25



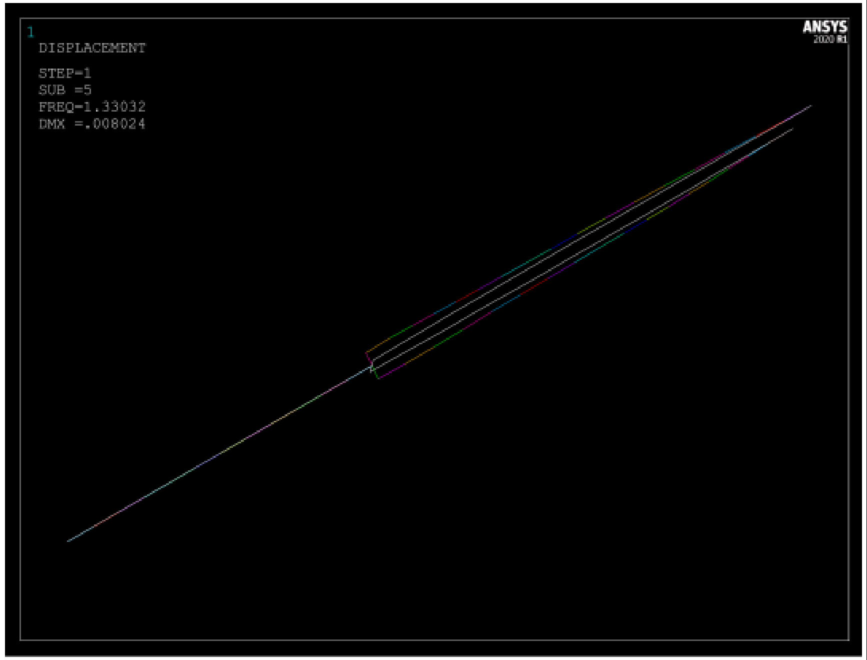


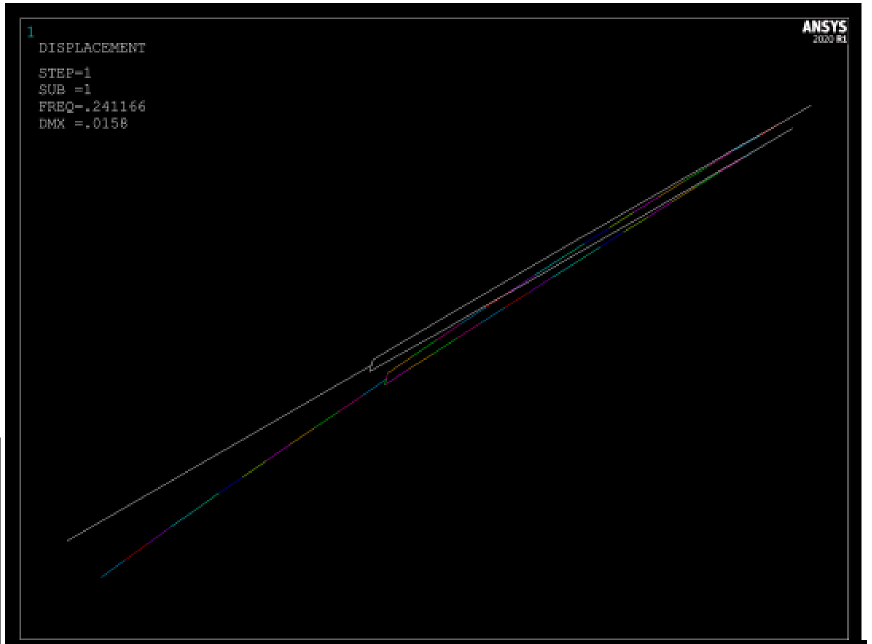
Structural Dynamics

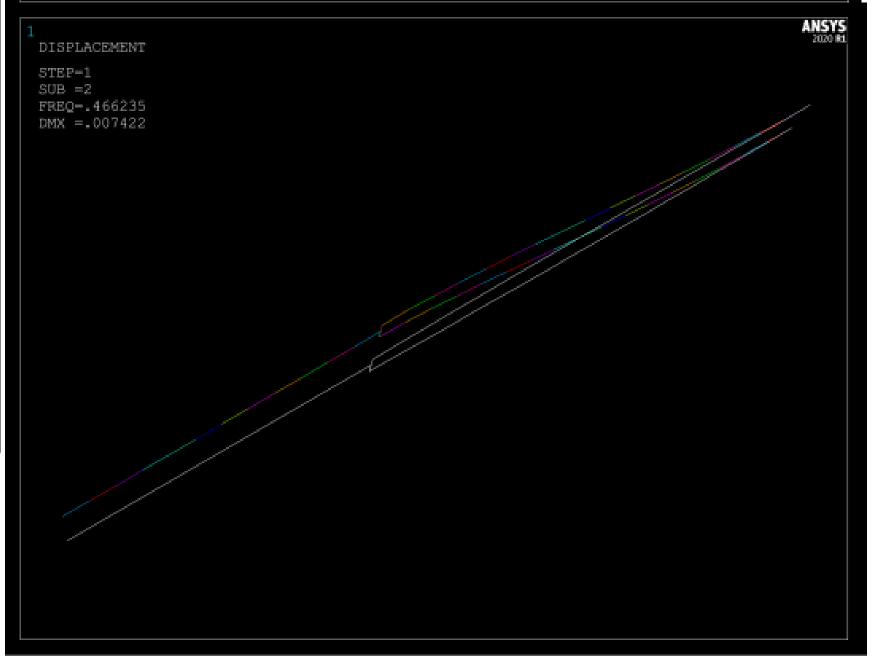
Edge dominated modes starting at 0.24 Hz (~2P for BAR turbine), soft blade

5th mode is a torsional mode at 1.33 Hz

Mode	Frequency (Hz)
1st Edge	0.24
1st Flap	0.47
2nd Edge	0.78
3rd Edge	1.29
1st Torsion	1.33







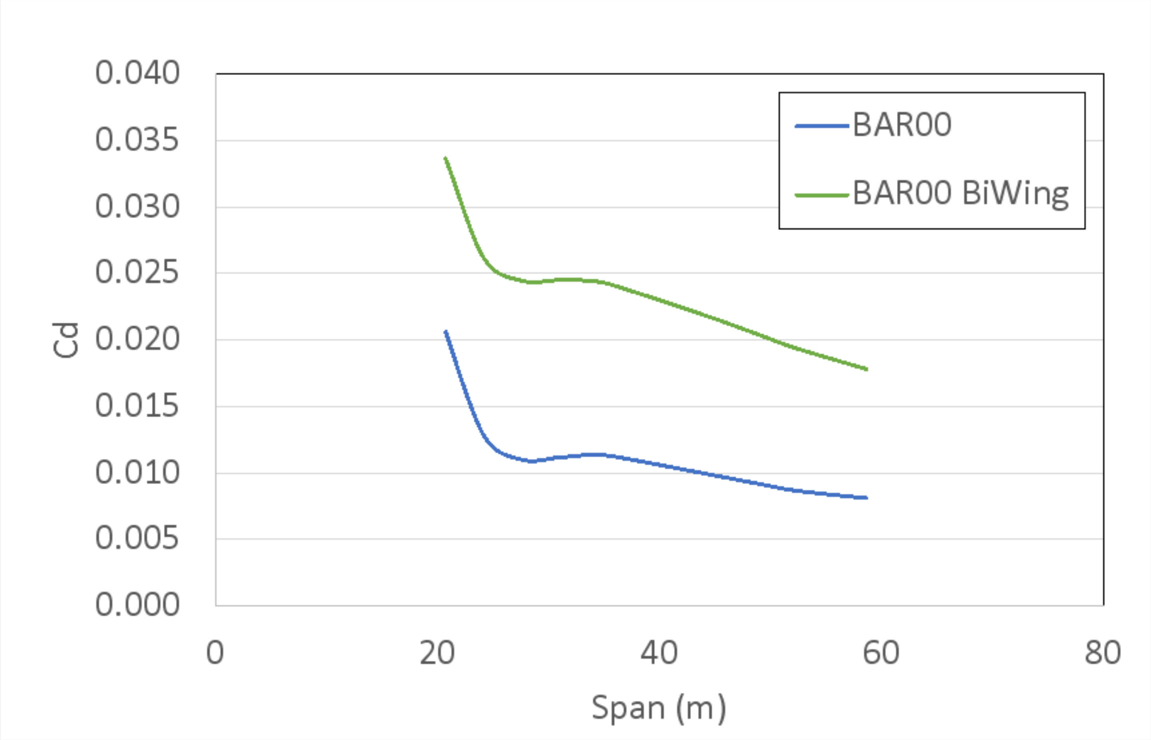
Aerodynamic Performance

No lift penalty

Significant drag increase, 2X

Could be reduce with larger separation distance

Span (m)	Lift Penalty	Drag Increase
0.000	1	0.0106
3.448	1	0.0108
6.897	1	0.0112
10.345	1	0.0116
13.793	1	0.0121
17.241	1	0.0126
20.690	1	0.0130
24.138	1	0.0133
27.586	1	0.0135
31.034	1	0.0133
34.483	1	0.0130
37.931	1	0.0126
41.379	1	0.0122
44.828	1	0.0118
48.276	1	0.0113
51.724	1	0.0108
55.172	1	0.0102
58.621	1	0.0097



Conclusions

Bi-wing design showed ability to greatly increase flap stiffness, reducing tip deflection by ~30%

Mass was reduced from 65 to 35 tons

Edge stiffness with two inboard elements is difficult to maintain

Due to increase in flap stiffness, modes become heavily edge dominated

Beam buckling was avoided, but required thicker airfoils, which would lower aerodynamic performance

Larger downwind cross-section, smaller upwind cross-section might increase buckling resistance

Calculated pitch system mass ~15% of DNV-GL estimated joint mass in Super-Sized Blade study

Drag penalty appears to be significant, but higher fidelity modeling is warranted

Small amount of twist bend coupling found, but could be increased with larger edge separation

Questions