Vertical Axis Wind Turbine (VAWT) Fin Optimization

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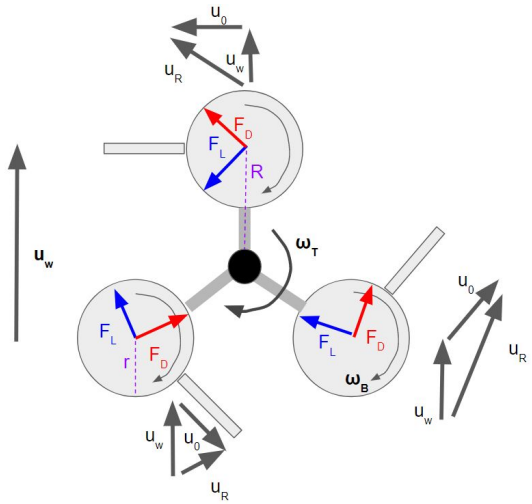
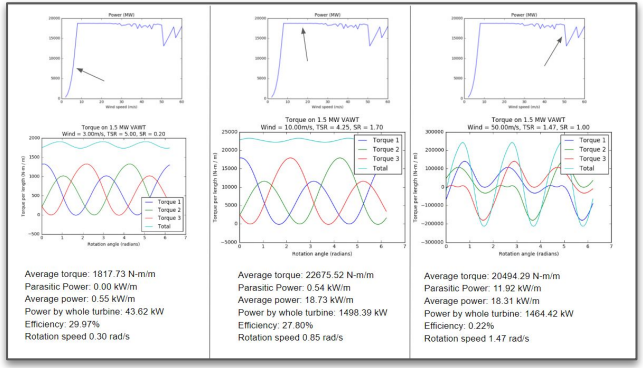
Outline

- Motivation
- Literature Validation
- The Model
- Optimization Setup
  - 50 DPs → 2 DPs
- Lift and Drag Curves
- FSI from Selections
- Conclusions

Motivation

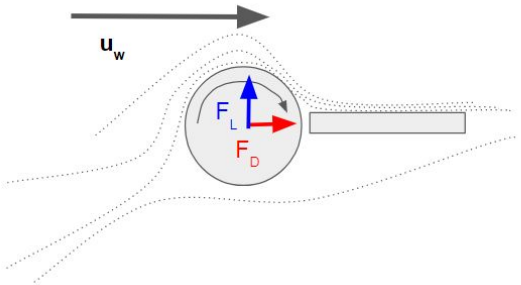
- VAWTs are less efficient, but can operate in higher wind speeds
- Challenergy: Japanese wind energy startup
- ME 262: Physics of Wind Energy final project



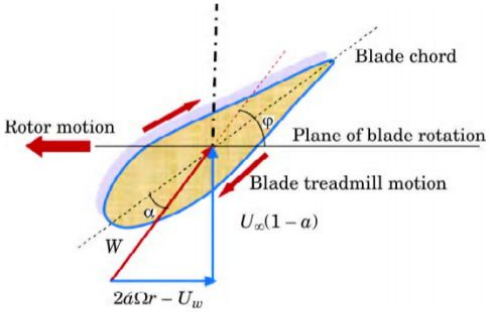


We want our own lift and drag curves!

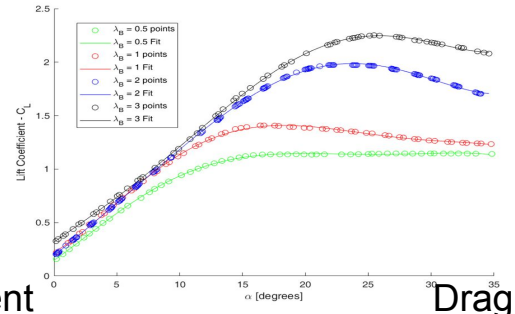
What our airfoil looks like...



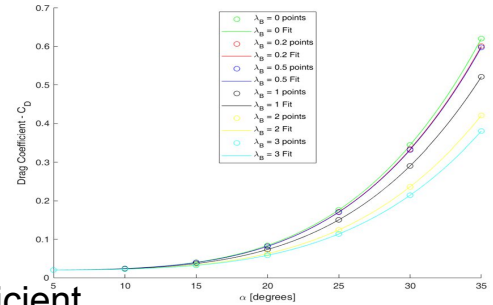
How we modeled it then...



Sedaghat et al.,"Progress in Magnus Type Wind Turbine Theories"



Lift Coefficient



Drag Coefficient

Validation

“The effect of a wake-mounted splitter plate on the flow around a surface-mounted finite height circular cylinder.” A. Igbalajobi, J.F. McClean, D. Sumner, D.J. Bergstrom. 2012.

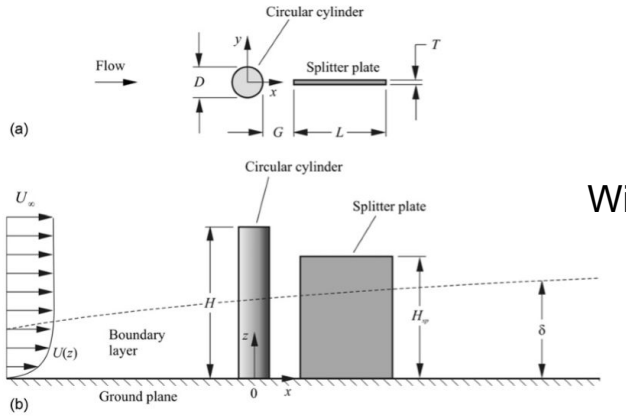
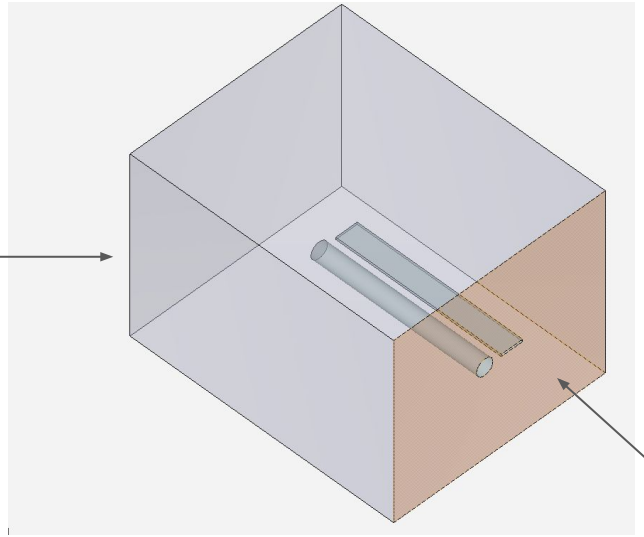


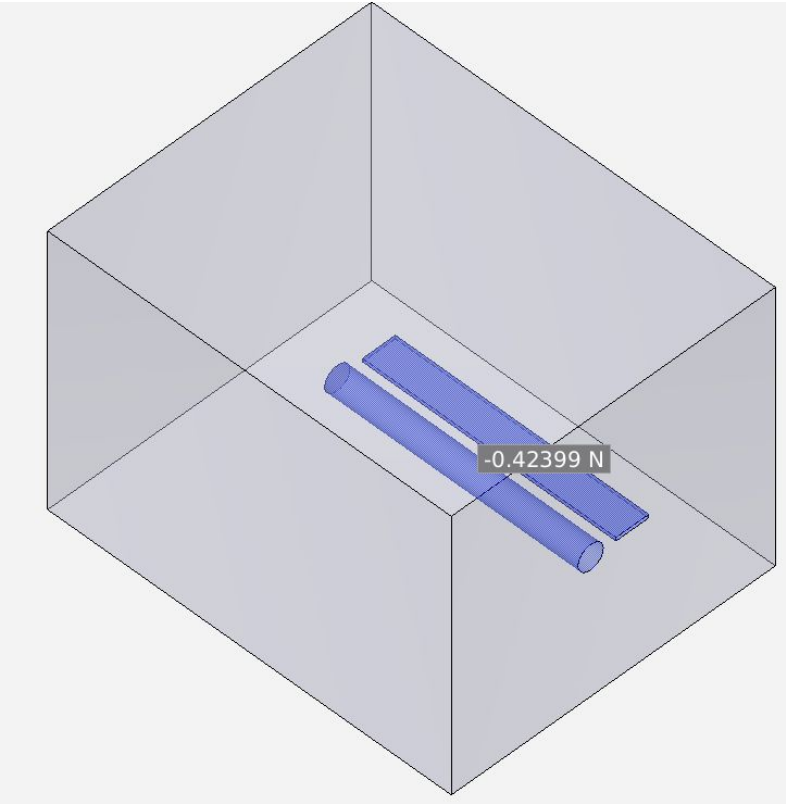
Fig. 1. Flow around a surface-mounted, finite-height circular cylinder (of diameter, D, and height, H) with a splitter plate (of length, L, height, H_{sp}, thickness, T, and gap distance, G) located vertically on the wake centreline: (a) top view; (b) side view.

Wind



Wall

Validation



$$C_D = \frac{F_{z,1} + F_{z,2}}{\frac{1}{2} * \rho * A * V^2} \qquad C_L = \frac{F_{y,1} + F_{y,2}}{\frac{1}{2} * \rho * A * V^2}$$

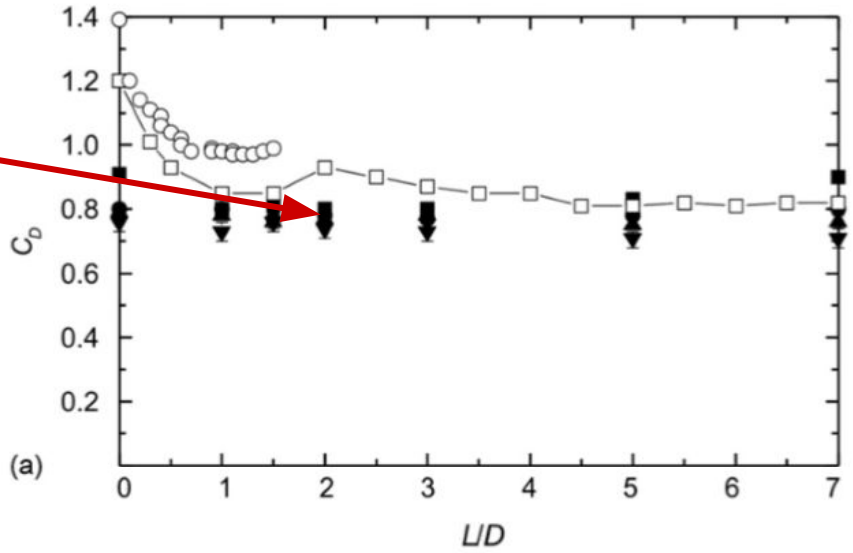
Drag = 0.42399 N
Cd = 0.42399N / (0.5 * 1.225 kg/m^3 * 0.05m*0.01m * (30m/s)^2) = **0.77**

Validation

Cd = 0.77

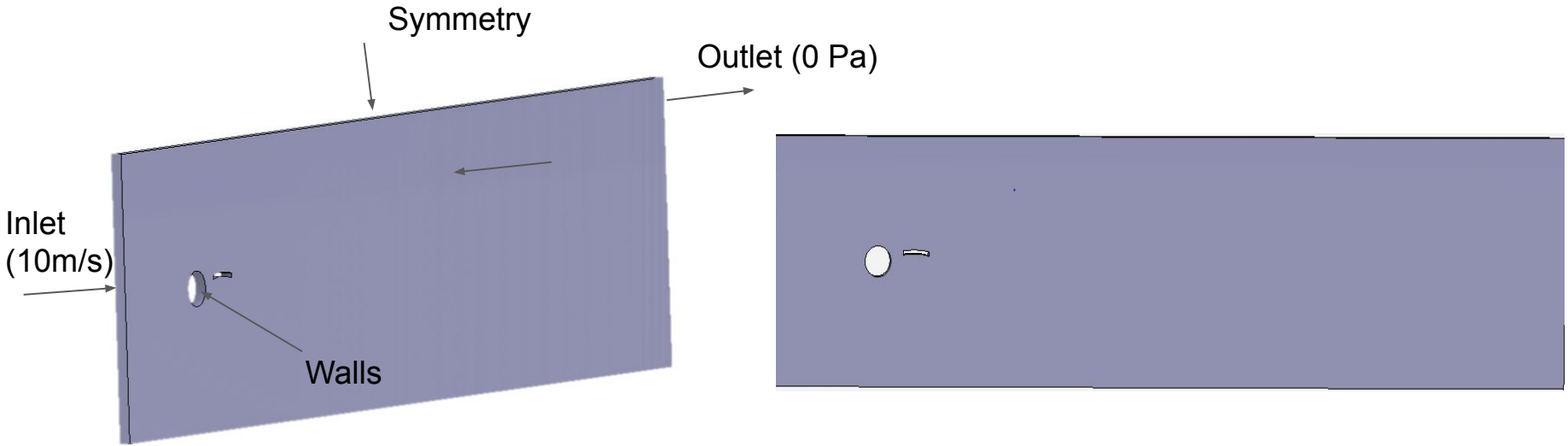
L/D = 2

Good enough!



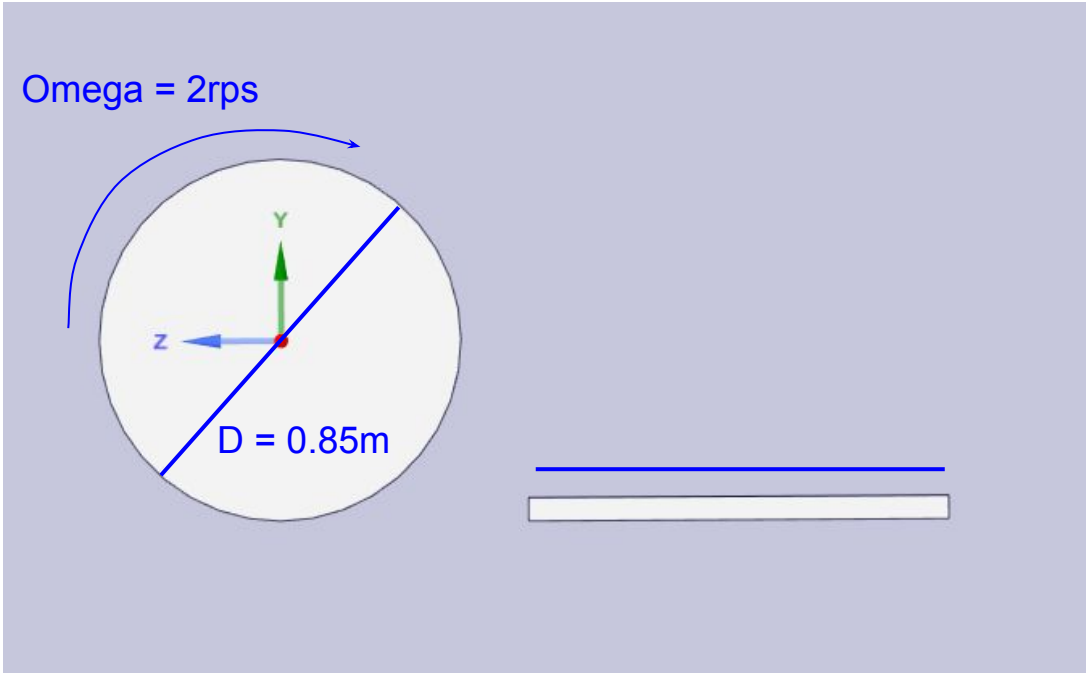
"The effect of a wake-mounted splitter plate on the flow around a surface-mounted finite height circular cylinder." A. Igbalajobi, J.F. McClean, D. Sumner, D.J. Bergstrom. 2012.

The Model



Boundary Layer
First Layer Height: 0.001m
Maximum Layers: 10
Growth Rate: 1.5
Element Shape: Hexahedrons

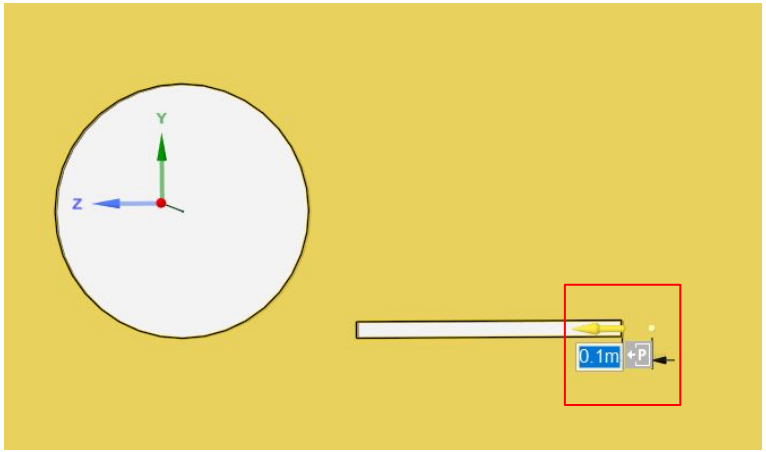
The Model



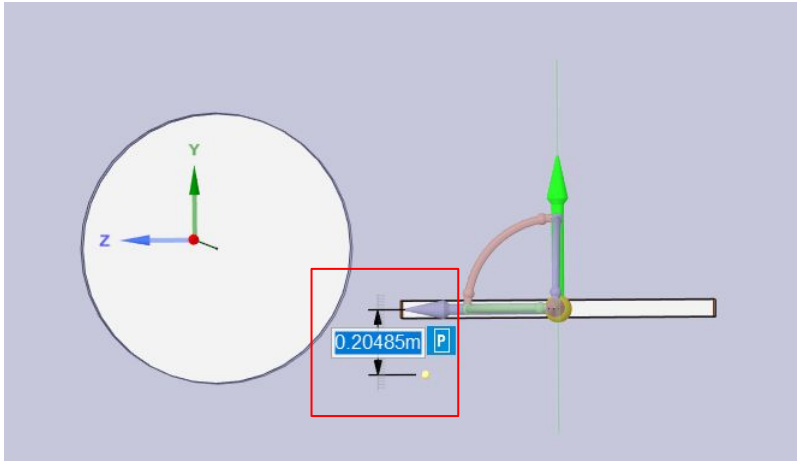
Optimization

Maximize lift coefficient and minimize drag coefficient by changing **vertical position** and rear fin **length**.

Removed Length

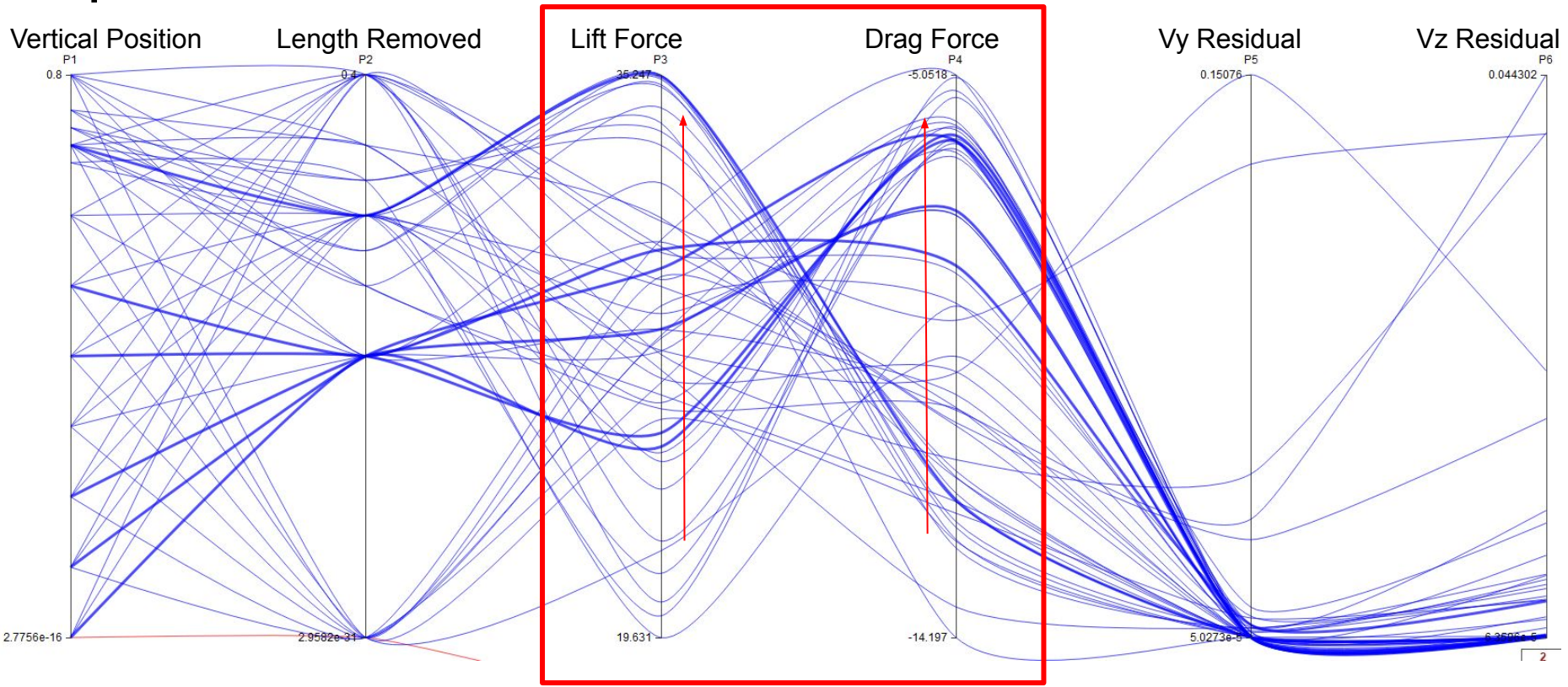


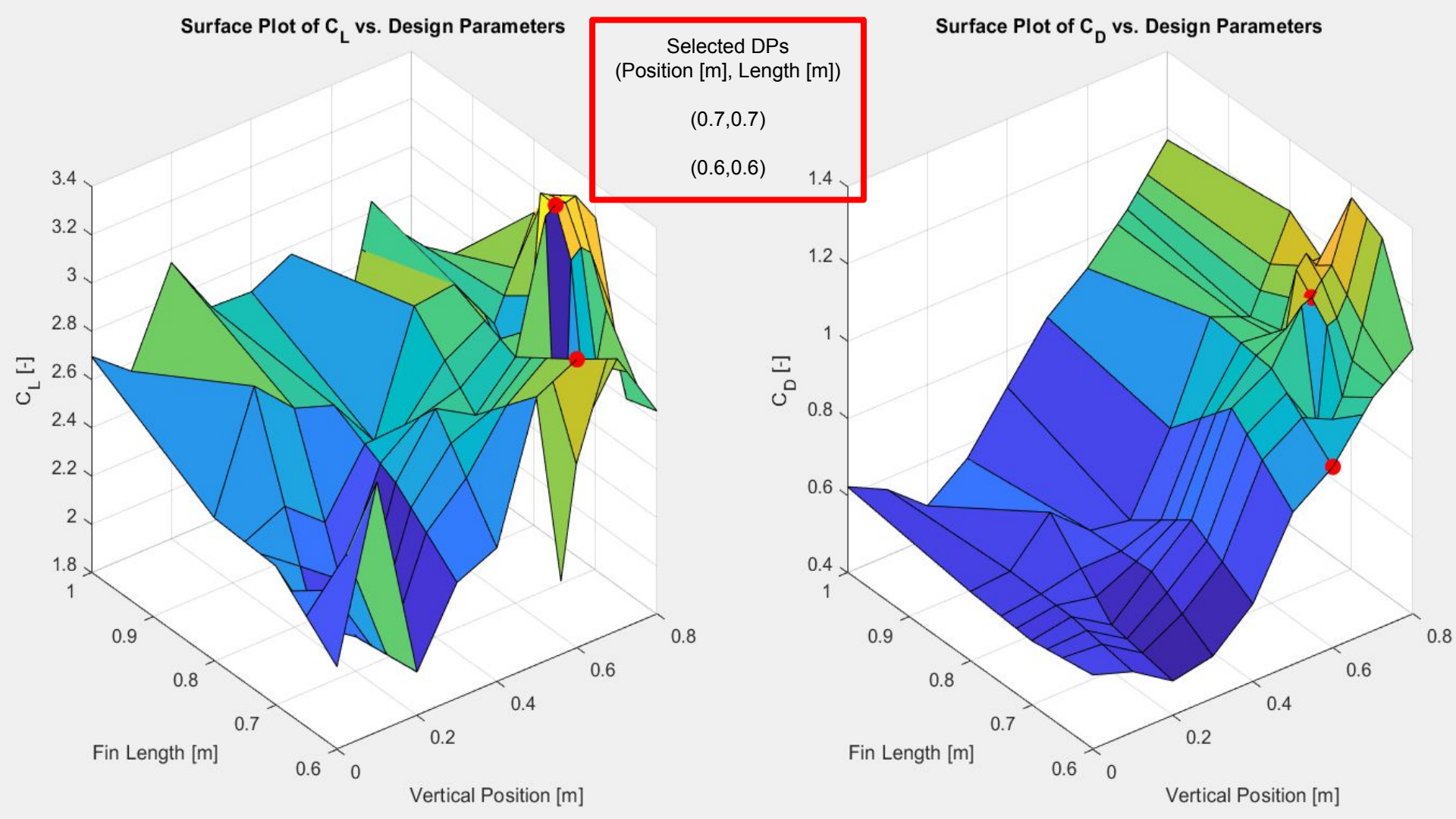
Vertical Position



Wind direction

Optimization Results




Surface Plot of C_L vs. Design Parameters
Selected DPs
(Position [m], Length [m])
(0.7,0.7)
(0.6,0.6)
Surface Plot of C_D vs. Design Parameters
C_L [-]
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
Fin Length [m]
1
0.9
0.8
0.7
0.6
Vertical Position [m]
0
0.2
0.4
0.6
0.8
C_D [-]
1.4
1.2
1
0.8
0.6
0.4
Fin Length [m]
1
0.9
0.8
0.7
0.6
Vertical Position [m]
0
0.2
0.4
0.6
0.8

Selected Design Points

Design 1

Vertical Position: 0.7m

Length Removed: 0.7m

CL = 3.38

CD = 1.15

Design 2

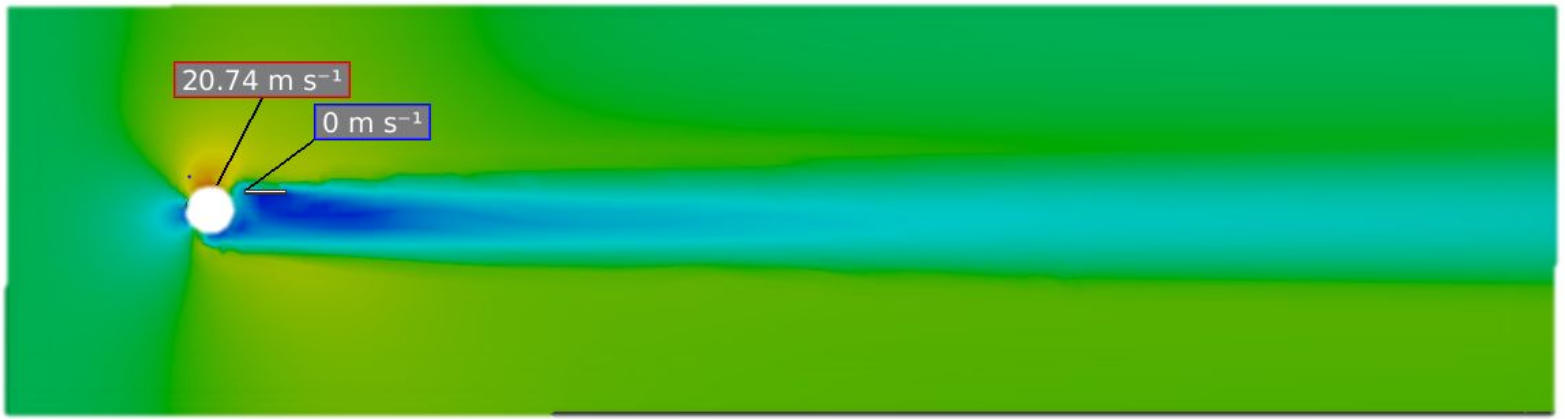
Vertical Position: 0.6m - more similar to original design

Length Removed: 0.6m

CL = 3.00

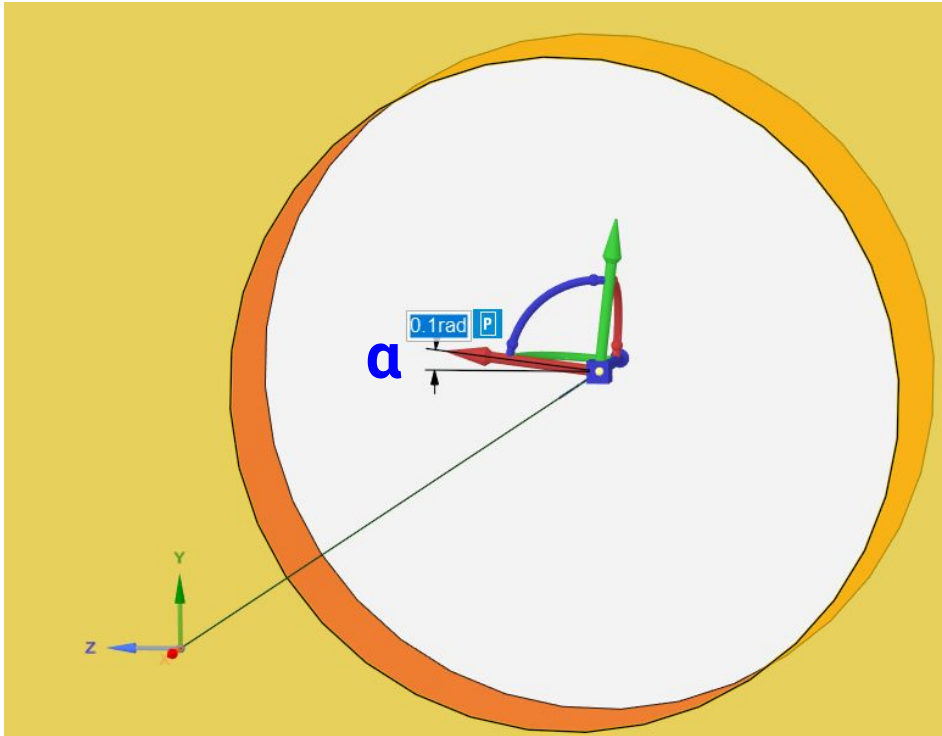
CD = 0.87

Design 1: Flow Visualization (Velocity)



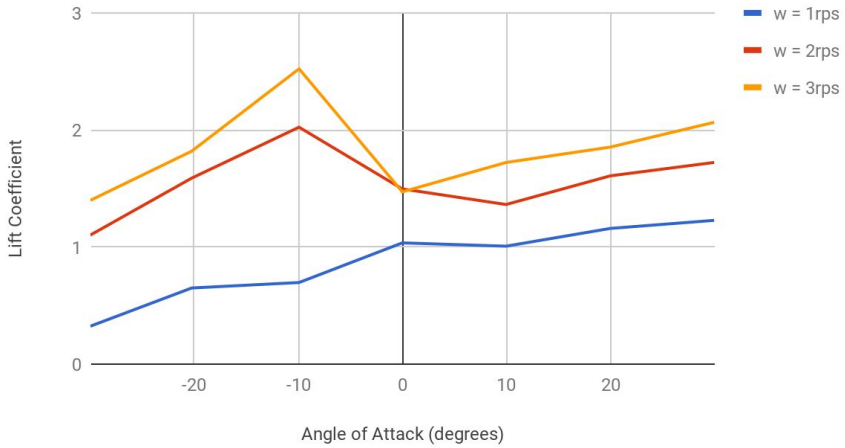
Design 1: Flow Visualization (Pressure)

Lift and Drag - defining Angle of Attack

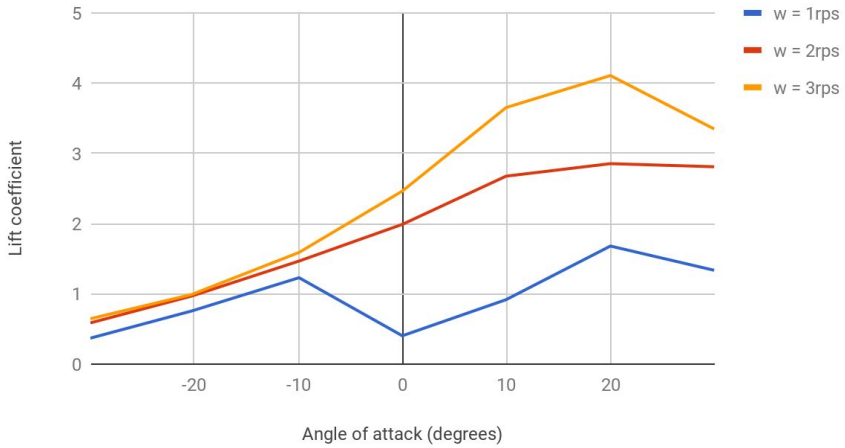


Alpha (deg)	Alpha (rad)	Alpha (rad)
-30	-0.523	5.757
-20	-0.349	5.931
-10	-0.174	6.106
0	0.000	0.000
10	0.174	0.174
20	0.349	0.349
30	0.523	0.523

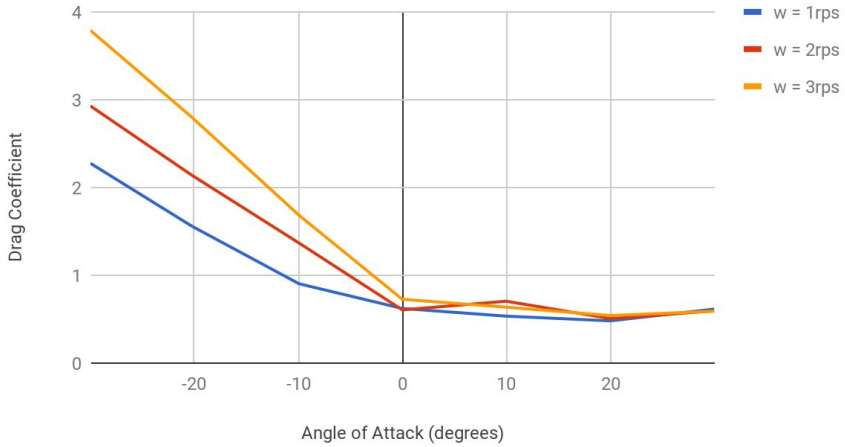
Design 1 Lift Curve



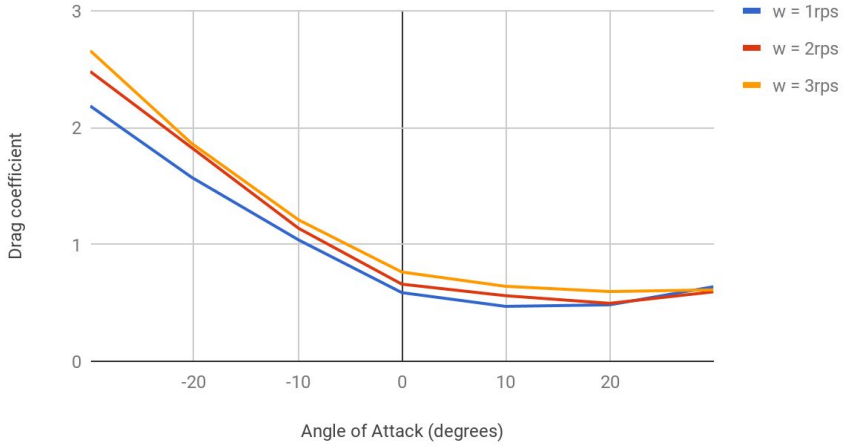
Design 2 Lift Curve



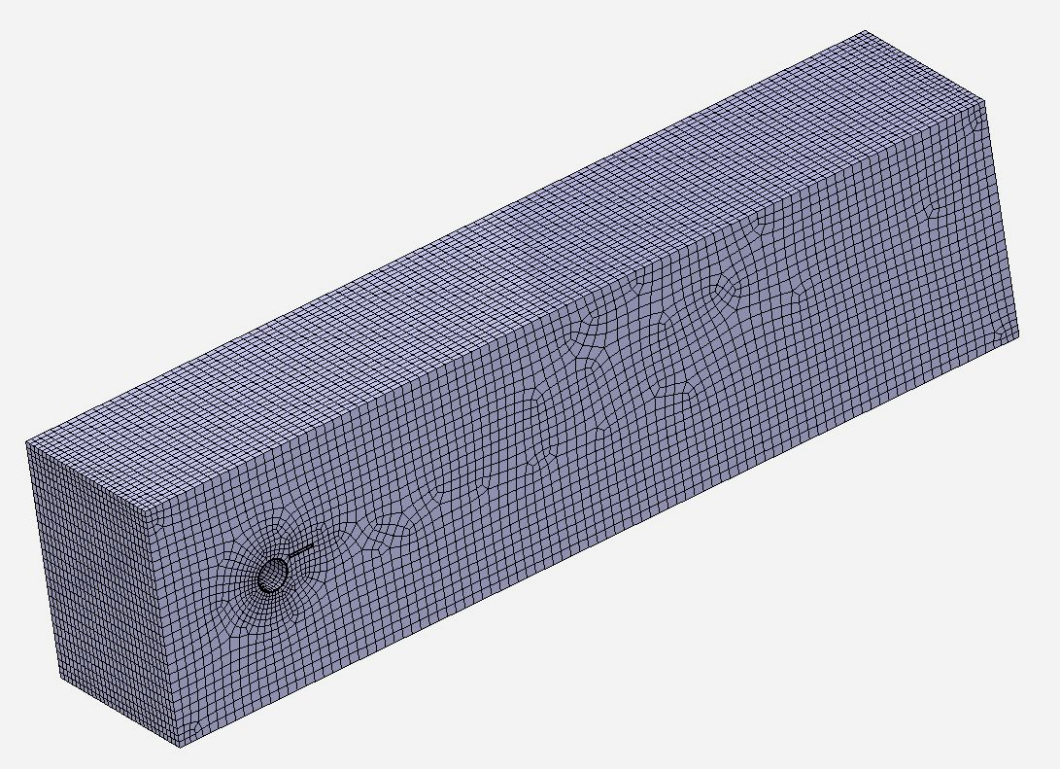
Design 1 Drag Curve



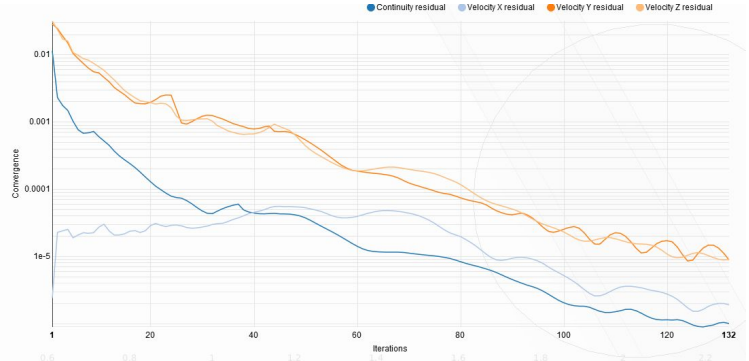
Design 2 Drag Curves

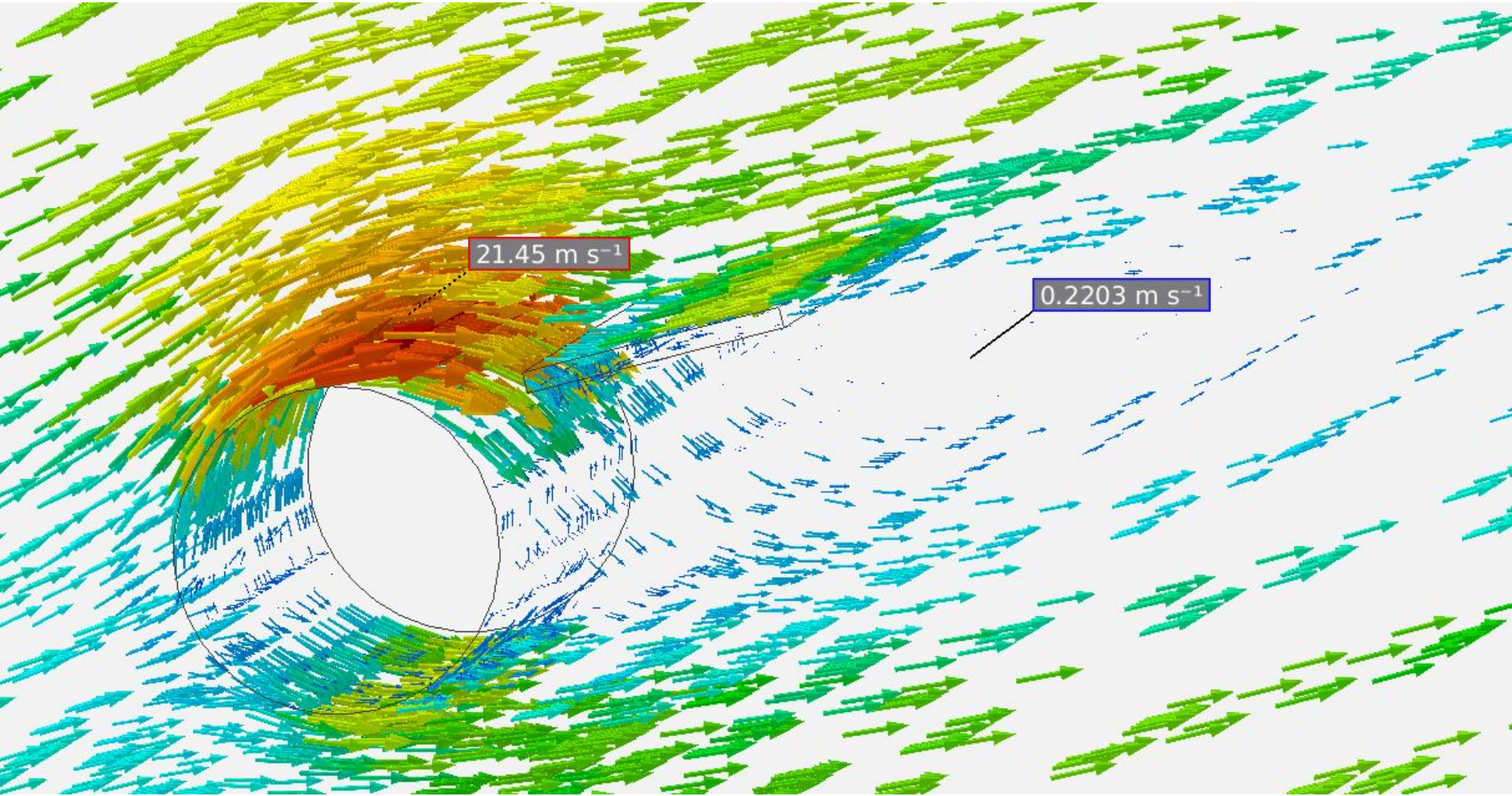


Fluid-Structural Analysis - Design 1

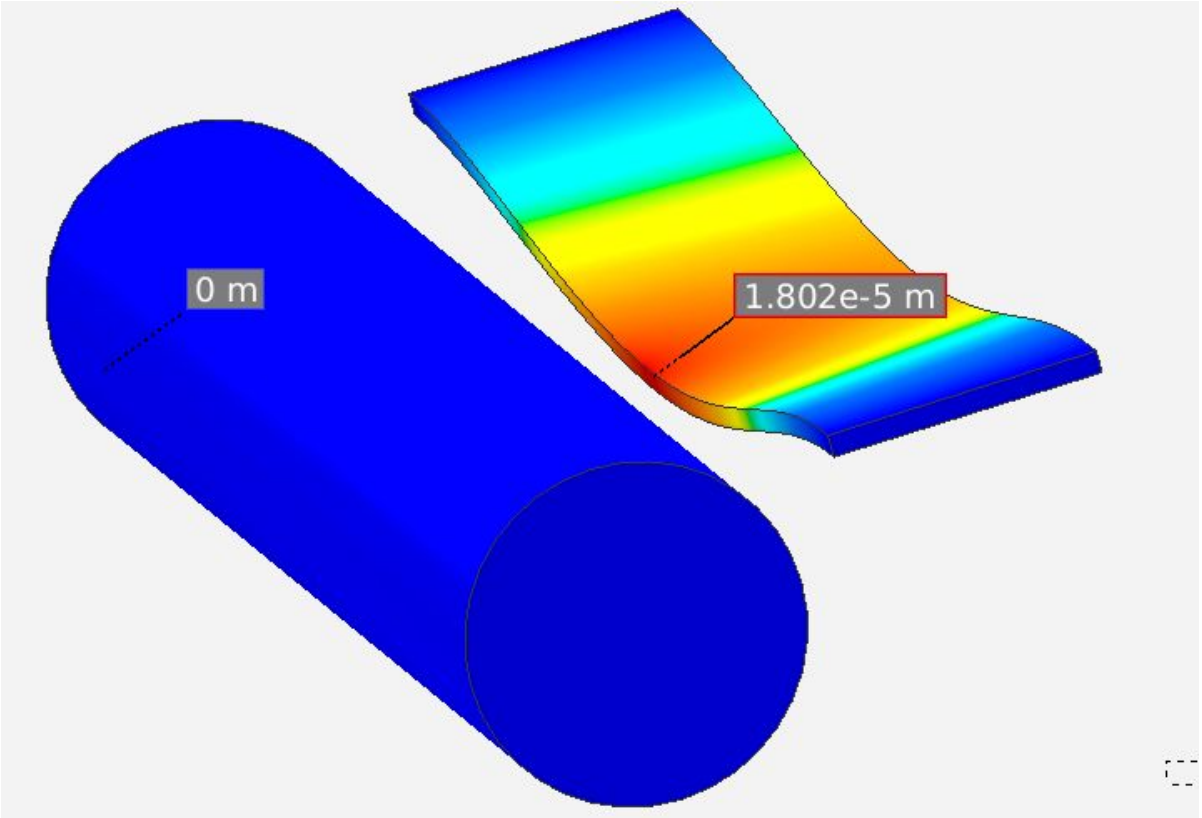


20 edges along length
High resolution
BL with 5 max layers, 1.2 GR, and 0.005m first layer thickness
Hexahedrons

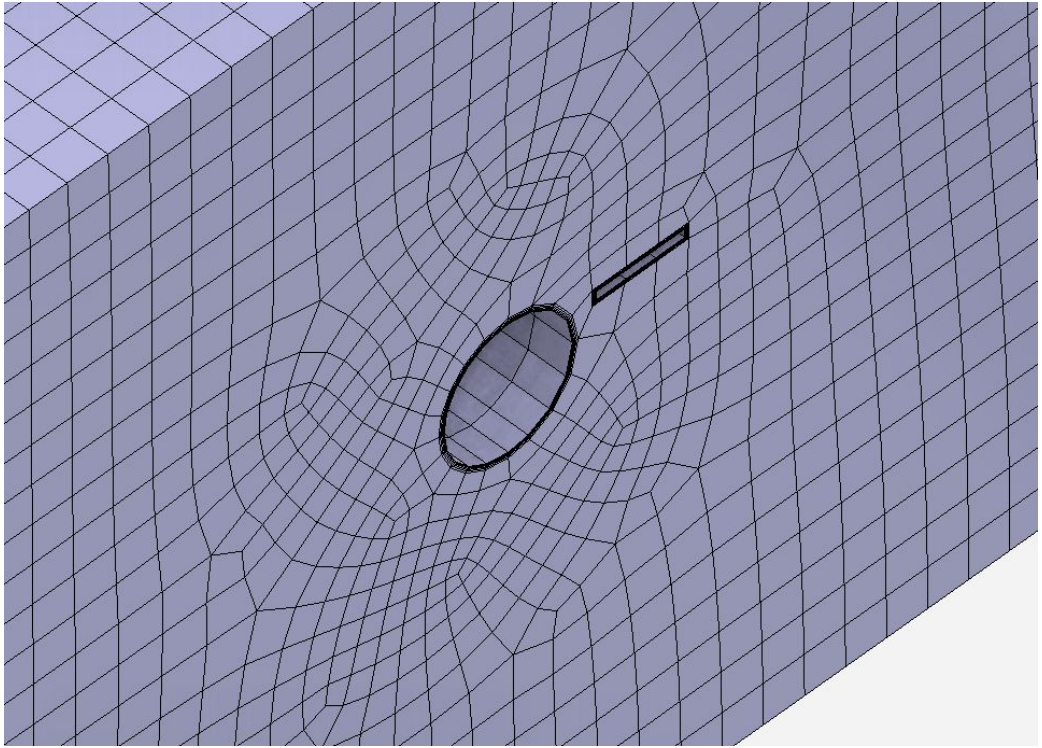



21.45 m s⁻¹
0.2203 m s⁻¹

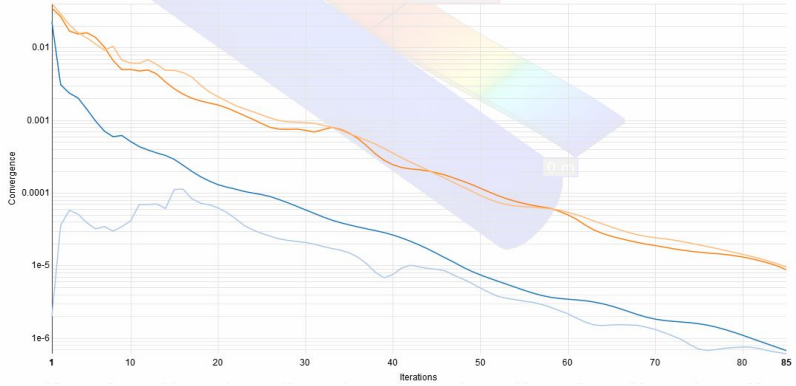
Deformation Analysis - Design 1



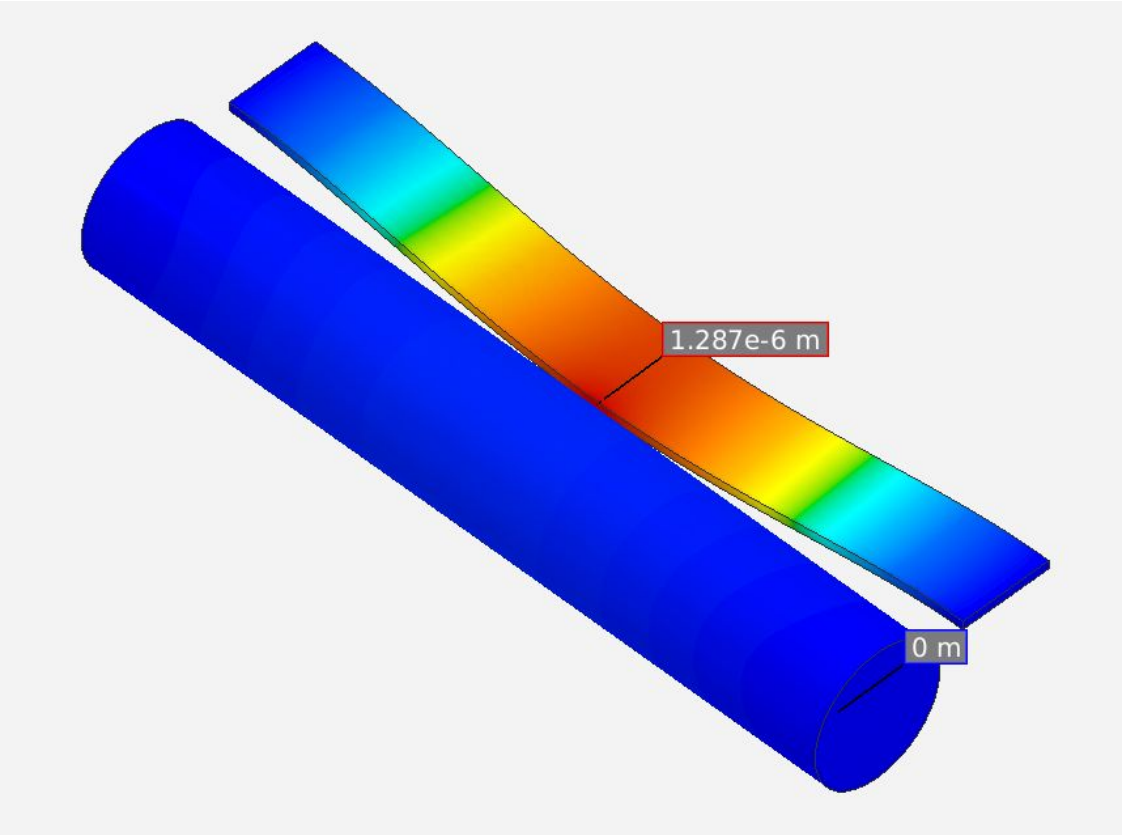
Fluid-Structural Analysis - Design 2



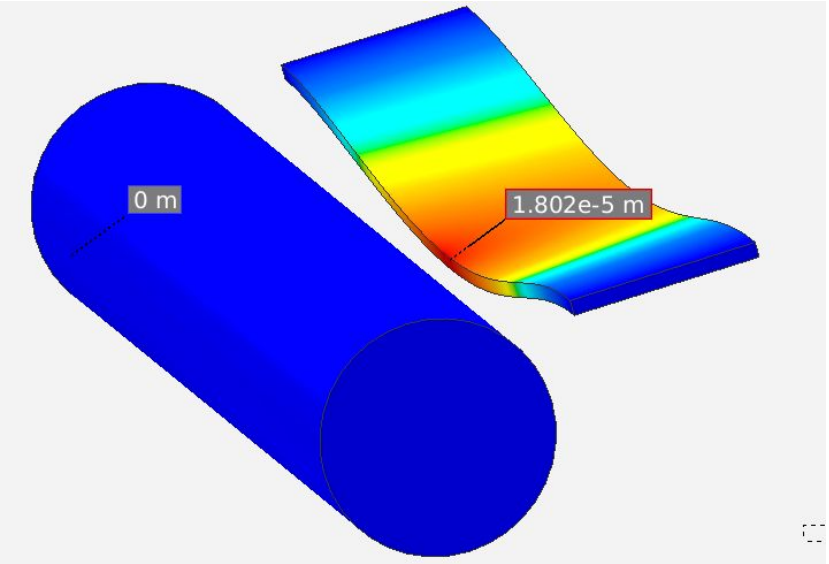
Same mesh parameters as design 1



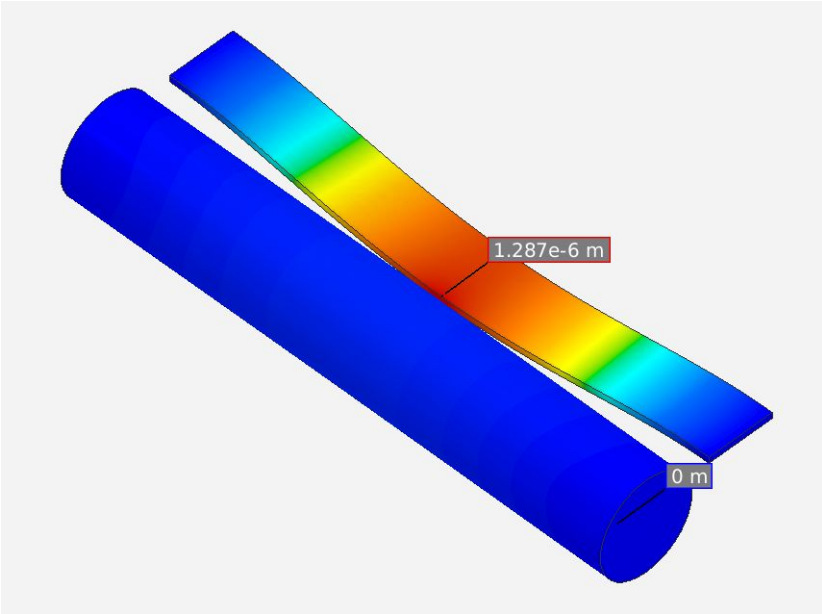
Deformation Analysis - Design 2



Design 1



Design 2



Conclusions

- Optimize for fin-shape and position
- Selected two design points
  - One was better but appeared less stable
- With both design points:
  - Lift and drag curves
    - Inconsistencies
  - FSI
- Recommend design 2
- These extra analyses amplified initial suspicion about instability.

← Comparison with true design

Vertical Axis Wind Turbine (VAWT) Fin Optimization

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Thank you!

Appendix A - raw results

Link to Manual Optimization, Lift and Drag Results

Includes spreadsheets for calculating CD and CL from ANSYS exported data

Appendix B - convergence residuals