F50 Analysis

Ben Jackson

Background

SailGP

SailGP

- Monthly races around the world.
- Powered by Nature

Sailing

- Wind = energy
- Foils reduce drag ➔ Race Catamarans

F50 Specs

50 knot top speed

5 Crew Members

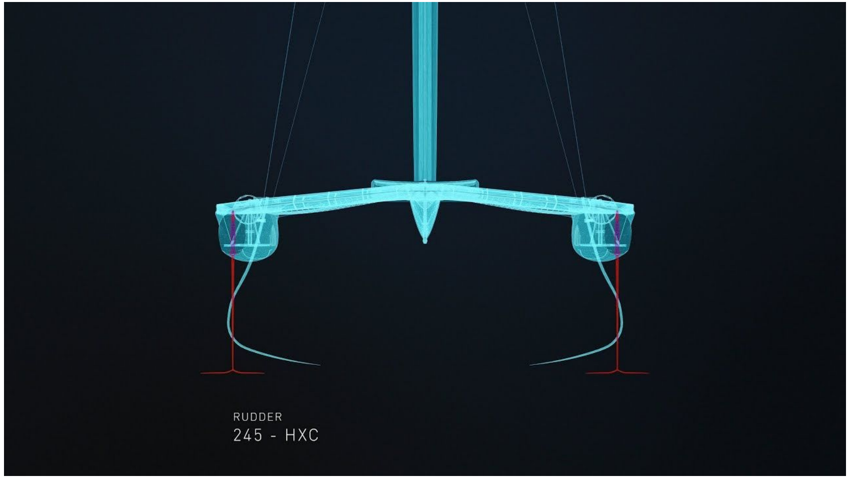
Wingsail Design Change:
18m heavy air, 28m light air

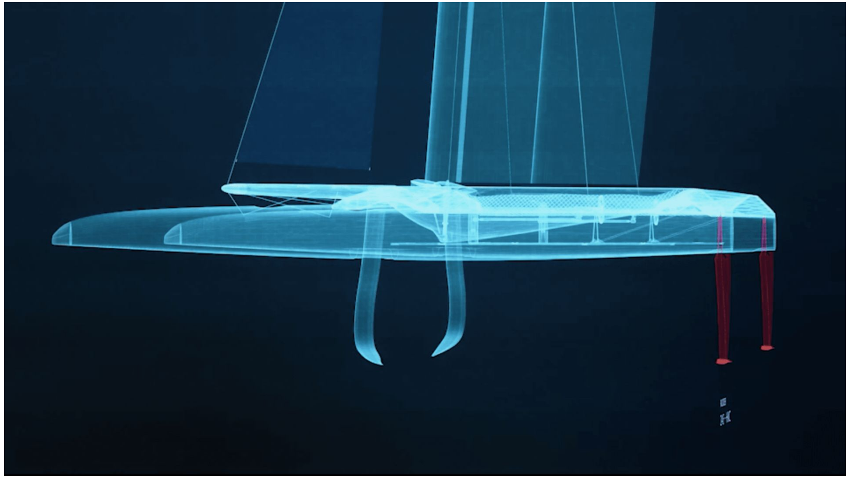
24m Wingsail

15m length

8.8m width

https://www.google.com/search?q=sailgp+hydrofoil&rlz=1C5CHFA_enUS855US858&sxsrf=ALiCzsar2f4sTtJ8FNKsOQd_tToY5S89Vg:1670684571866&source=lnms&tbm=isch&sa=X&ved=2ahUKEwiC-L-Dqe_7AhX0knIEHdNIAUAQ0pQJegQIBxAC&biw=1920&bih=969&dpr=1#imgrc=LKqcHqssFrEMKM





https://www.marine-events.co.uk/sailgp-the-boat-techy-bits/

Control Panel Changing AoA

Research Question

What range hydrofoil attack angles produces the necessary lifting and righting forces on the SailGP F50 Catamaran?

The
Model

A Closer Look

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.sail-world.com%2Fnews%2F236421%2FDenmark-SailGP-first-onto-the-water-in-Bermuda&psig=AOvVaw0YDoz9ILflICzAdxtSWC1v&ust=1670900662337000&source=images&cd=vfe&ved=0CBAQjRxqFwoTCLDC0ZWM8_sCFQAAAAAdAAAAABA i

Wing

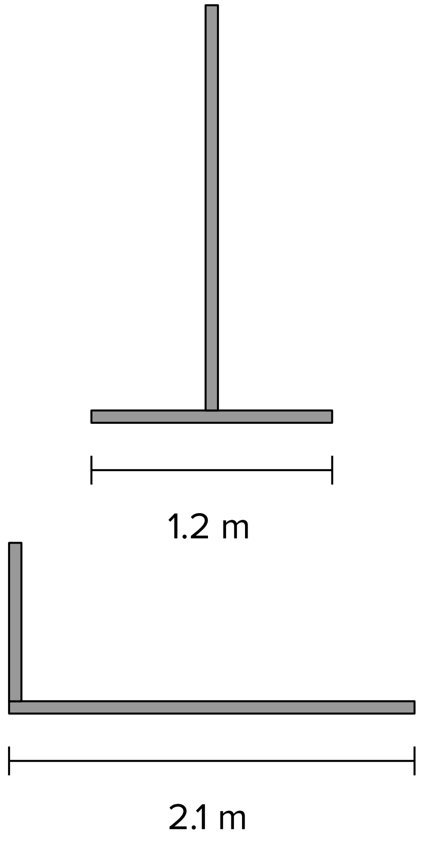
Hydrofoil

Model Assumptions

- Geometries: constant 2D Cross section
- Daggerboard and Hydrofoil: equivalent shape

- Water: incompressible
- Water: minimal viscosity

- Air: inviscid



Governing Equations

Coefficient of Lift C_L

$$C_L = \frac{2L}{\rho v^2 A}$$

Reynolds Number

$$\mathrm{Re} = \frac{\rho L \cdot |V|}{\mu}$$

Navier Stokes Equation

$$\rho\left(\frac{dv}{dt}\right) = \rho g - \nabla p + \mu \nabla^2 V$$

Coefficient of Drag C_D

$$C_d = \frac{D}{A\frac{1}{2}\rho v^2}$$

Turbulence Model Equations K-Omega

Turbulence Kinetic Energy

$$\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial x_j} = P_k - \beta^* k\omega + \frac{\partial}{\partial x_j}\left[(\nu + \sigma_k \nu_T)\frac{\partial k}{\partial x_j}\right]$$

Specific Dissipation Rate

$$\frac{\partial \omega}{\partial t} + U_j \frac{\partial \omega}{\partial x_j} = \alpha S^2 - \beta\omega^2 + \frac{\partial}{\partial x_j}\left[(\nu + \sigma_\omega \nu_T)\frac{\partial \omega}{\partial x_j}\right] + 2(1 - F_1)\sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i}$$

https://knowledge.autodesk.com/support/cfd/learn-explore/caas/CloudHelp/cloudhelp/2014/ENU/SimCFD/files/GUID-0F5C4828-9F91-46B6-A16A-2578D72DCFCC-htm.html

Foil Physical Description

C-Mesh Domain

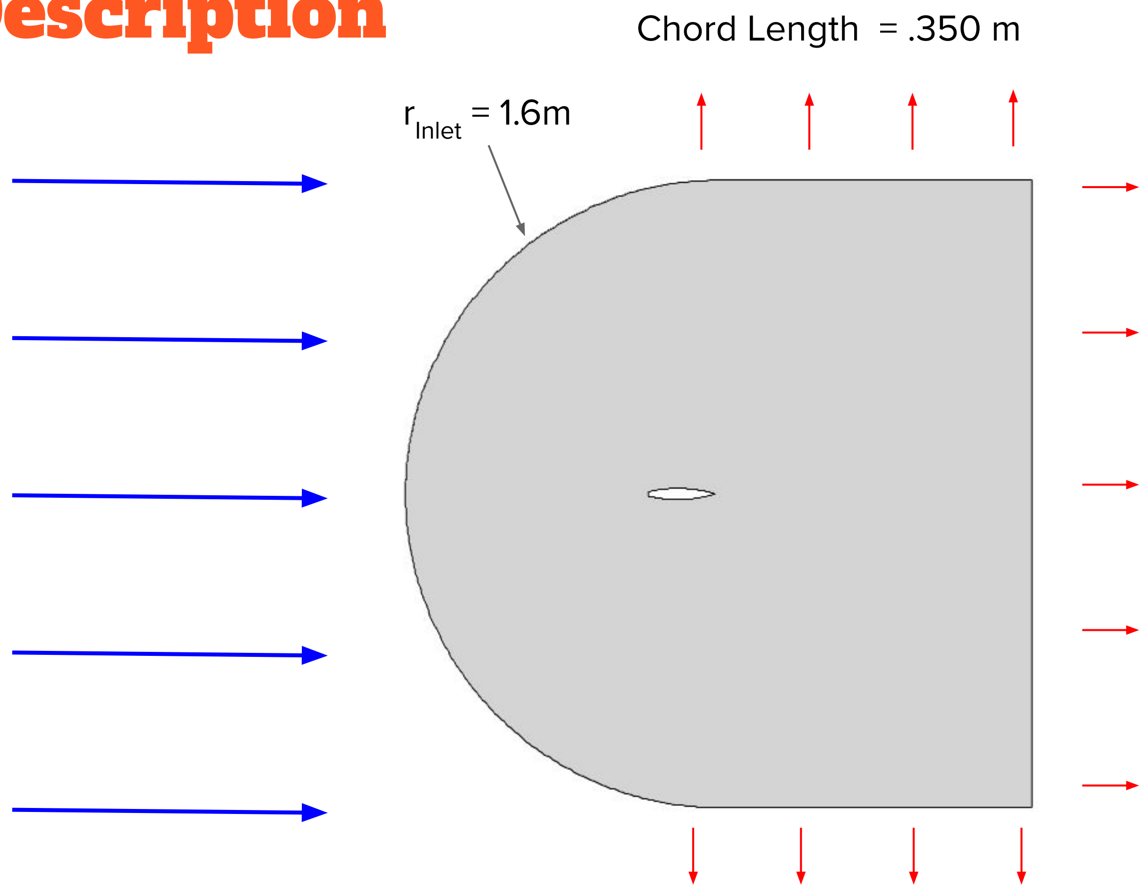
Velocity Inlet

Re = 3.5e+06

α = 0°, 2°, 4°, 6°, 8°, 10°, 20°, 30°

Pressure Outlet

Gauge Pressure = 0 Pa

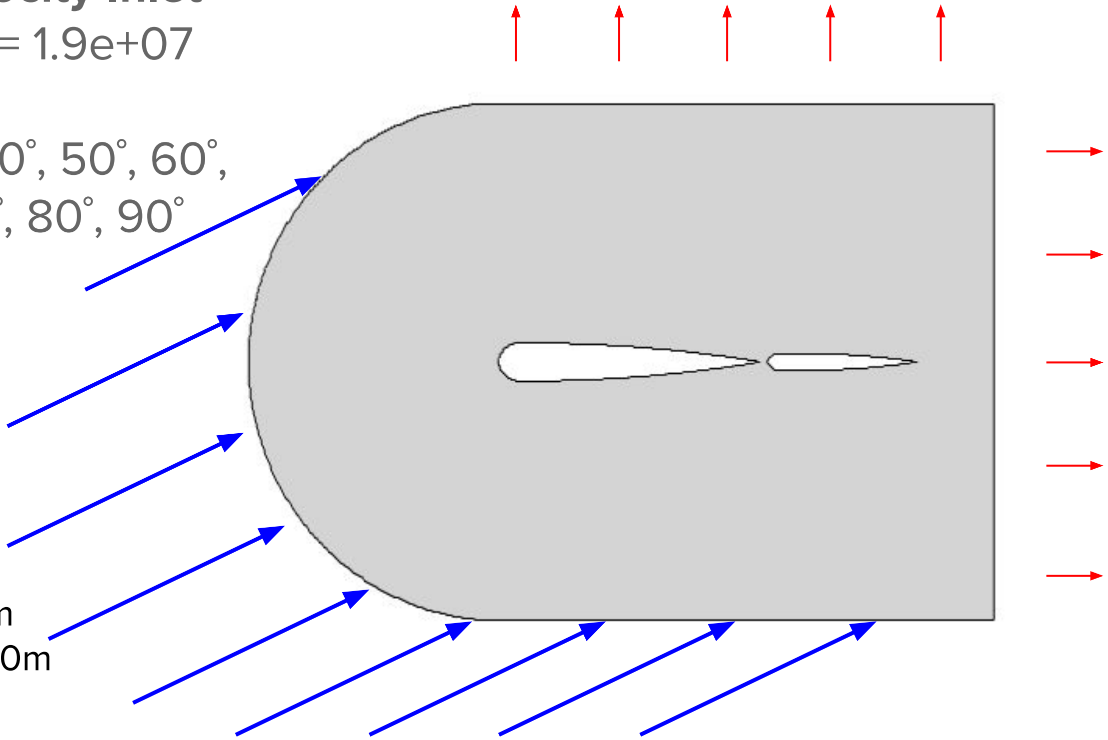


Wing Physical Description

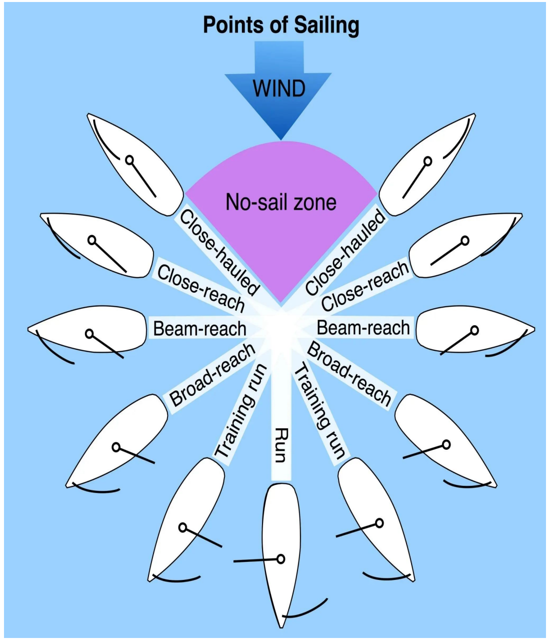
Velocity Inlet

Re = 1.9e+07

α = 40°, 50°, 60°, 70°, 80°, 90°



r_{Inlet} = 40m
L_{domain} = 40m
C_1 = 21m
C_2 = 12m



http://safe-skipper.com/wp-content/uploads/2019/06/36.1_Points-of-sail-1.jpg

Numerical Models & Methods

Wing

- Density Based
- Steady (One Transient)
- Inviscid
- Energy Off
- Implicit: Second Order Upwind
- Working fluid = Air

Hydrofoil

- Pressure Based
- Steady
- K-Omega
- Energy Off
- Implicit: Second Order Upwind
- Working fluid = Water

Transient Ramp Up: Velocity Inlet

Wing

$V_x = \cos(.69813 + .17453t)$

$V_y = \sin(.69813 + .17453t)$

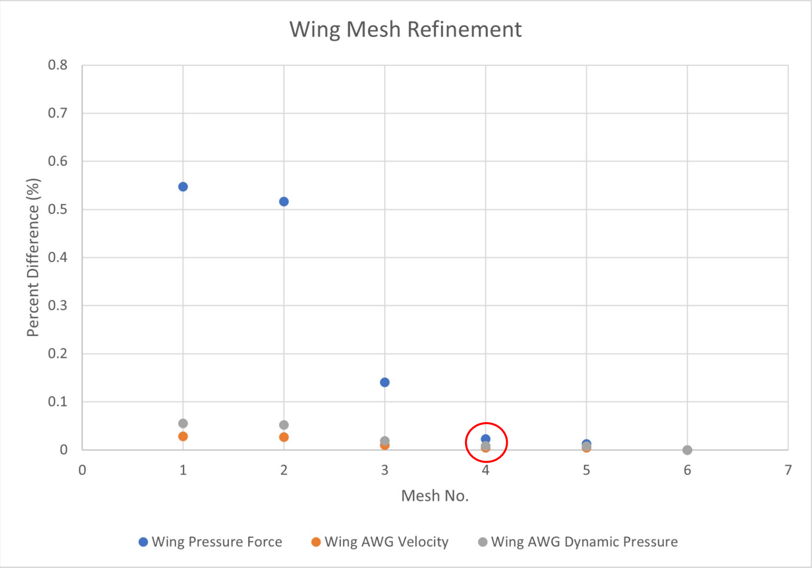
$\Delta t = 1$

$t_{steps} = 5$

$\alpha = 50°, 60°, 70°, 80°, 90°$

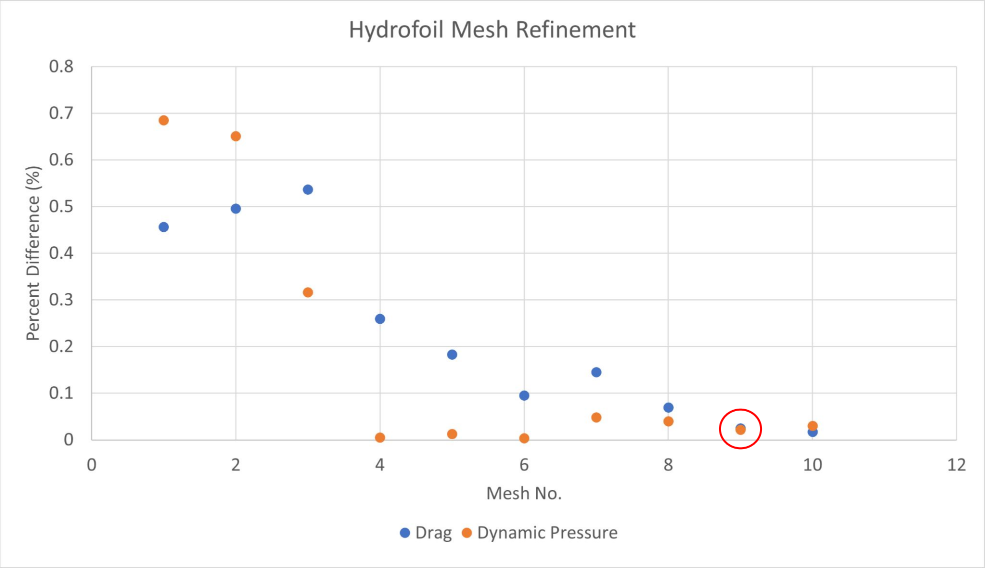
Grid Sensitivity Study

Wing



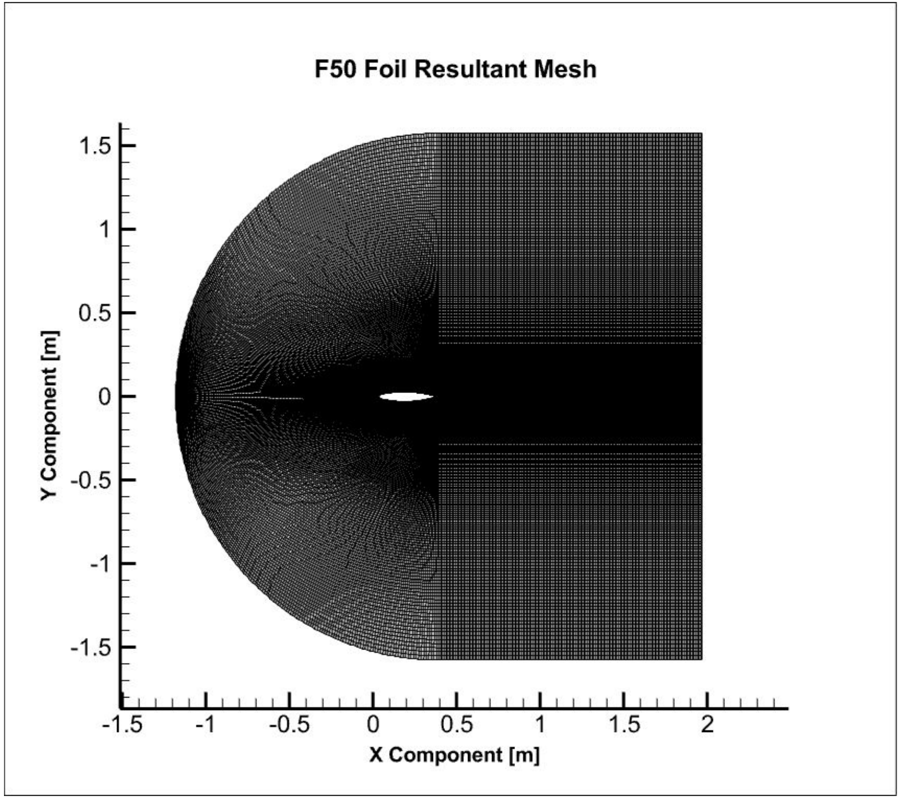
Result FV = 96000

Hydrofoil



Result FV = 102400

Resultant Mesh: Foil

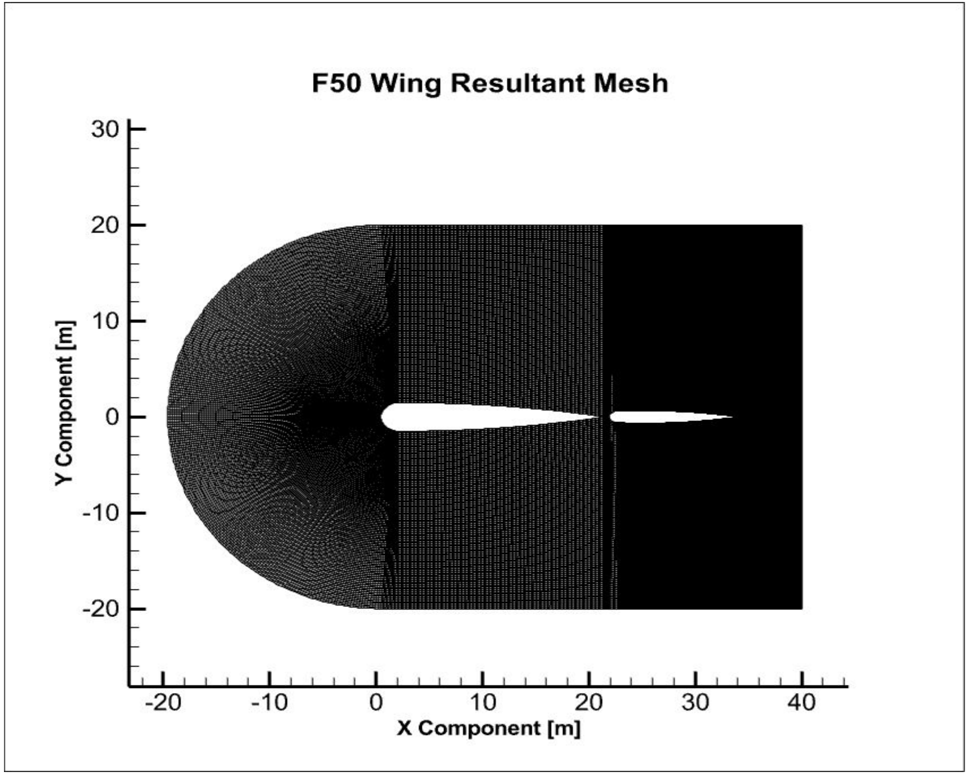


Nodes: 102960

FV: 102400

Bias: Factor 5, away from foil

Resultant Mesh: Wing



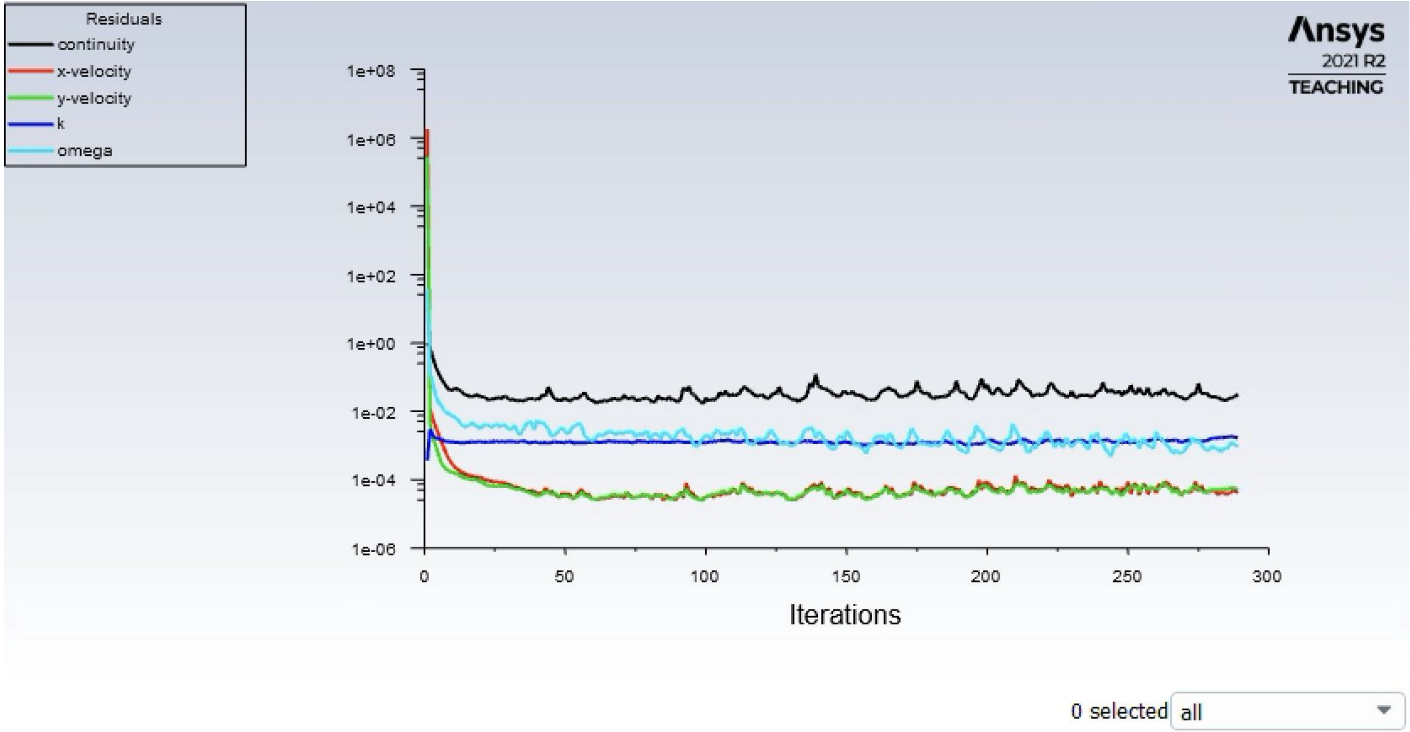
Nodes: 96974

Elements: 96000

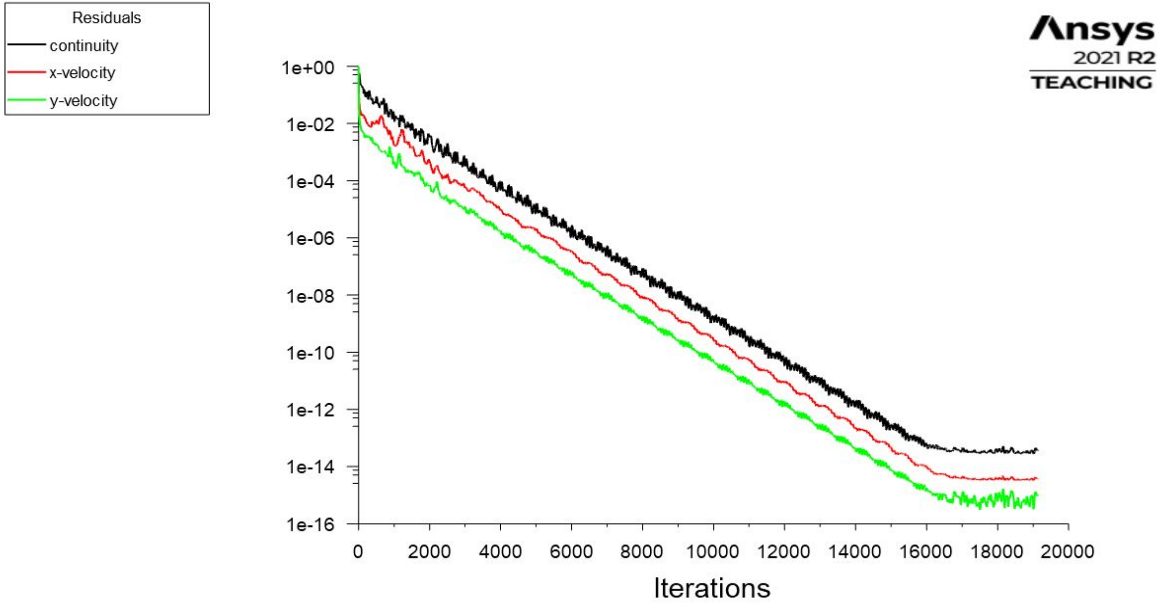
Bias: None

Results

Numerical Convergence: Foil

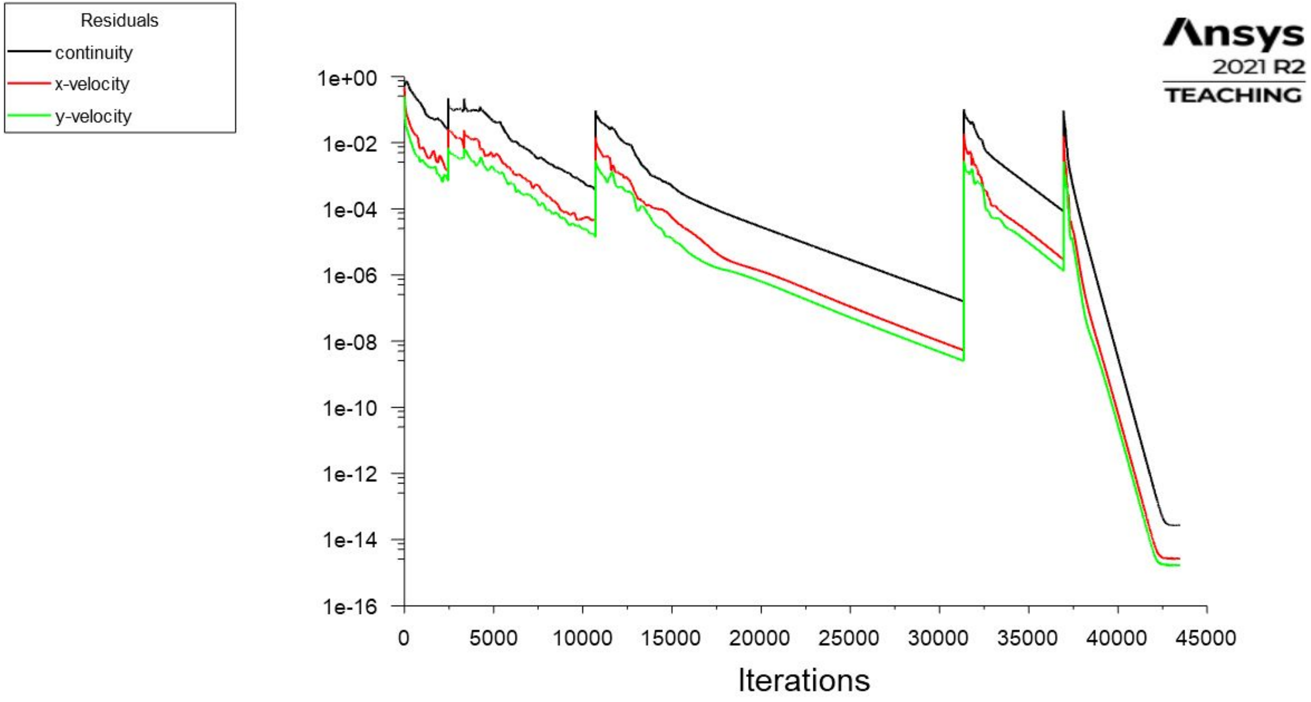


Numerical Convergence: Wing

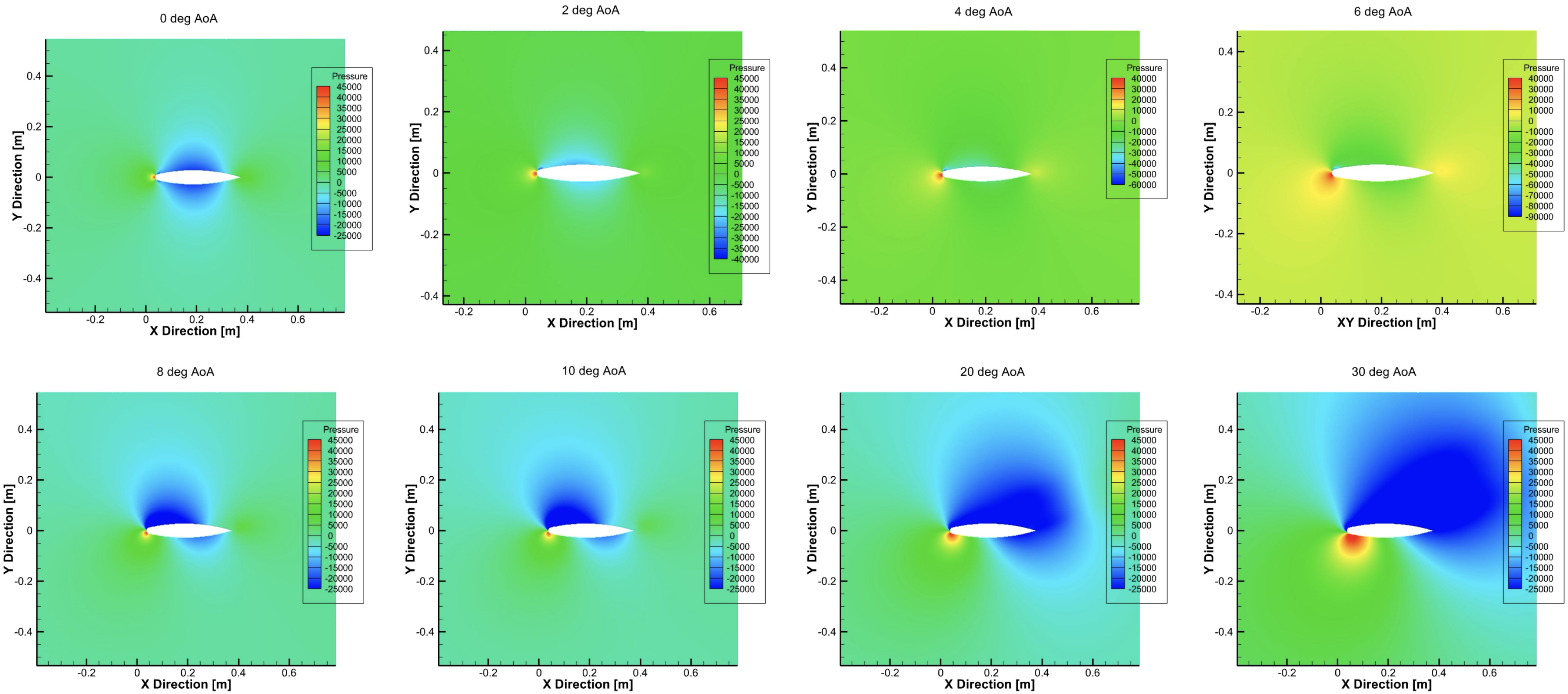


Steady State

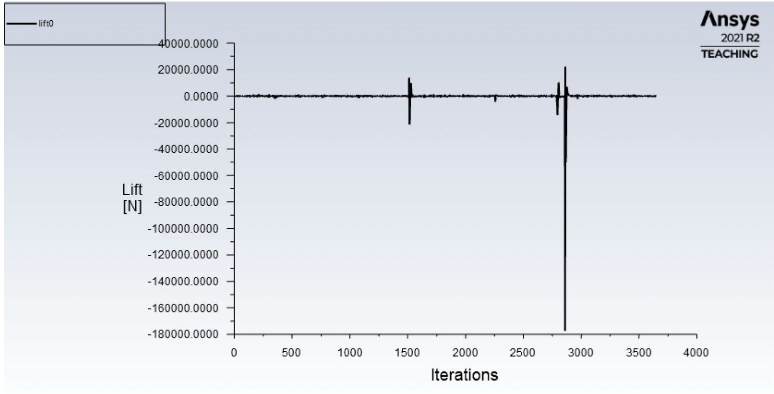
Transient Ramp Up

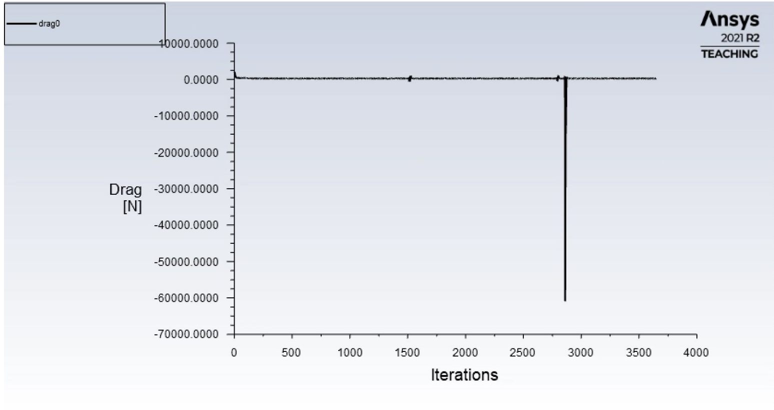


Foil Pressure Contours



Lift & Drag on Foil

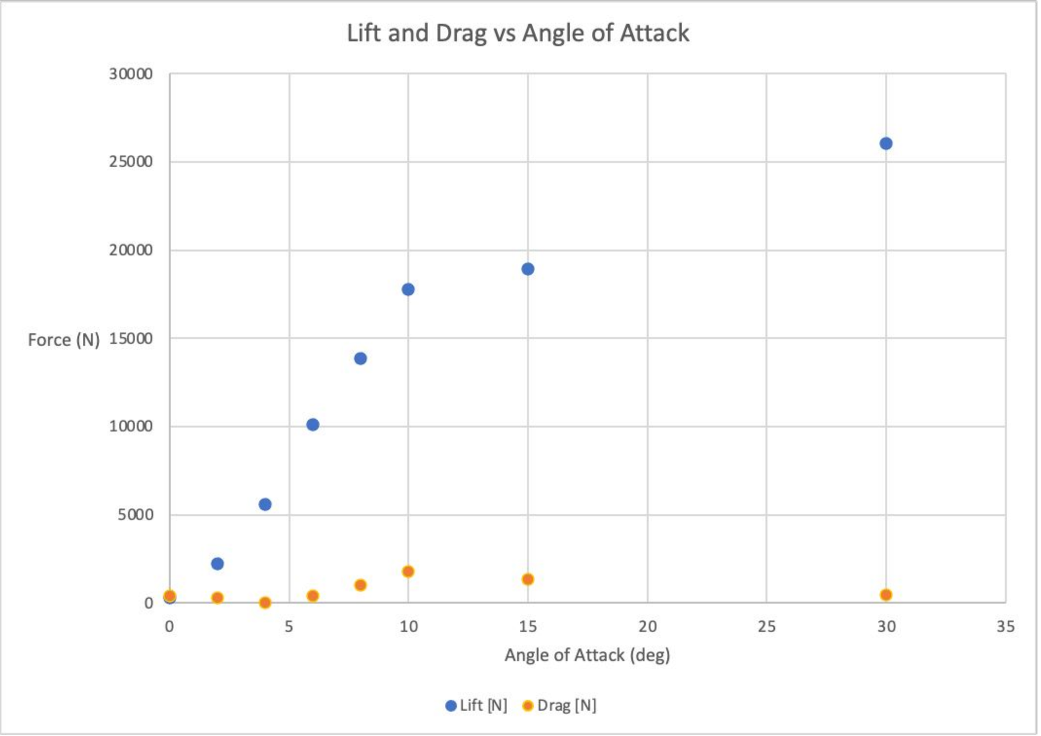




α (°)	Lift (N/m)	Drag (N/m)
0	146.33622	196.43053
2	1071.6655	135.62641
4	2675.4131	16.159412
6	4808.7537	205.73495
8	6587.1219	487.76934
10	8475.0767	841.57815
15	9010.5615	641.51
30	12405.385	225.61513

Lift & Drag on the Hydrofoil

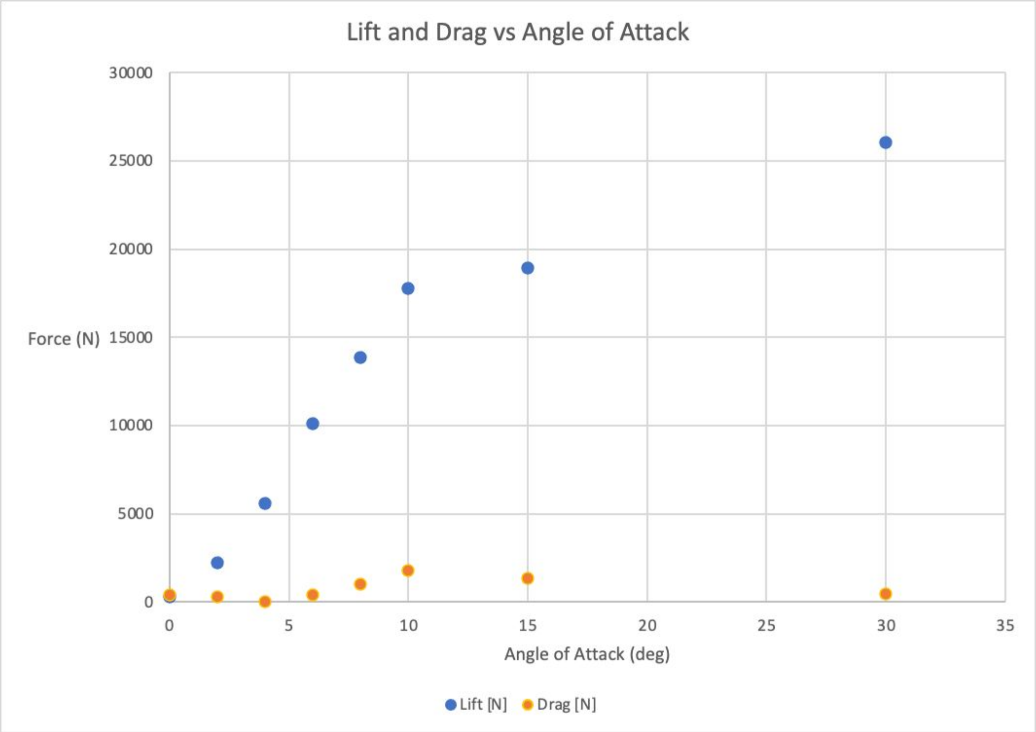
Lift [N]	Drag [N]
307.3061	412.5041
2250.498	284.8155
5618.368	33.93477
10098.38	432.0434
13832.96	1024.316
17797.66	1767.314
18922.18	1347.171
26051.31	473.7918



Foil Length = 2.1m

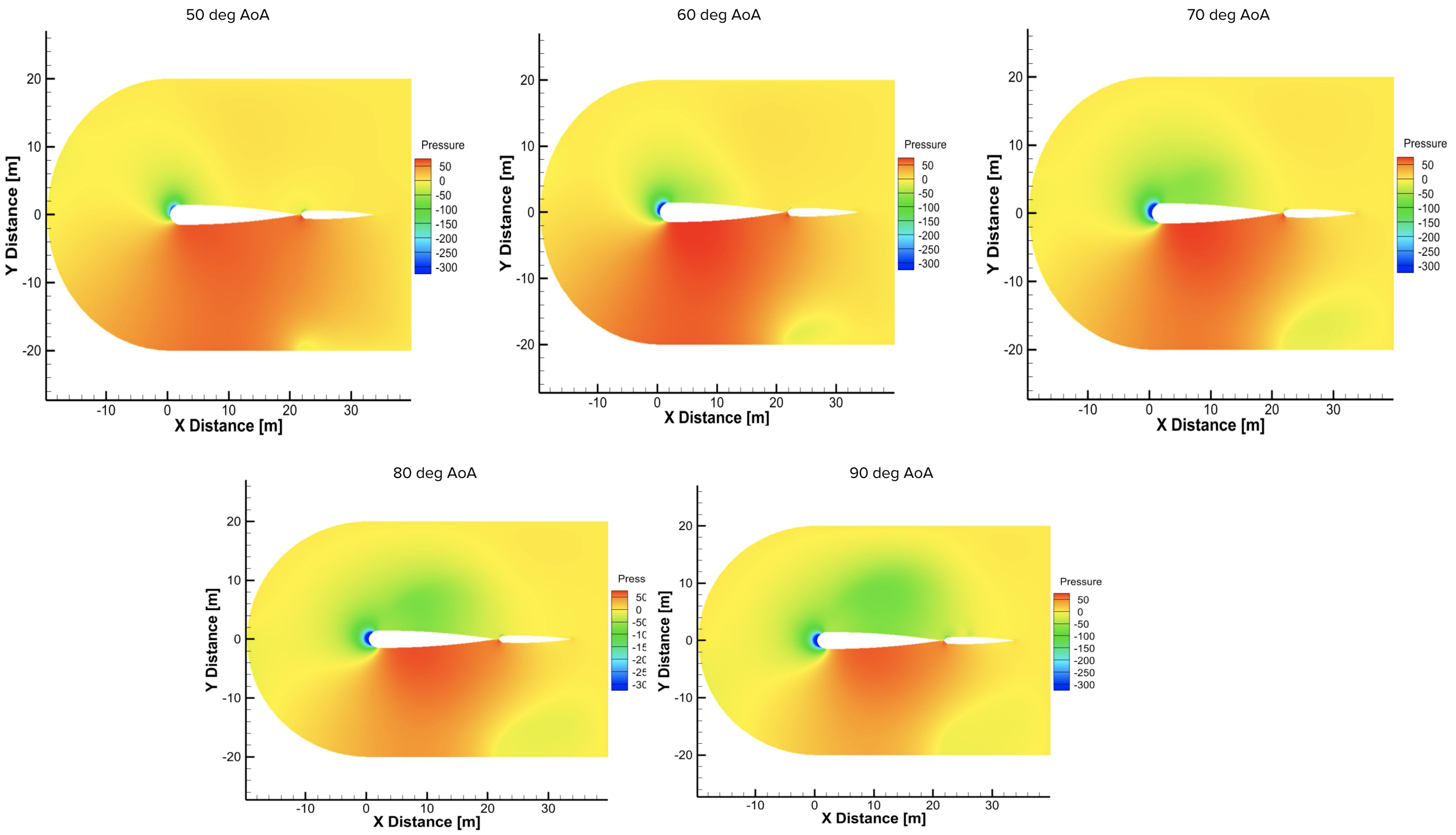
Lift & Drag on the Daggerboard

Lift [N]	Drag [N]
175.6035	235.7166
1285.999	162.7517
3210.496	19.39129
5770.504	246.8819
7904.546	585.3232
10170.09	1009.894
10812.67	769.812
54707.75	994.9627



Dagger Length = 1.2m

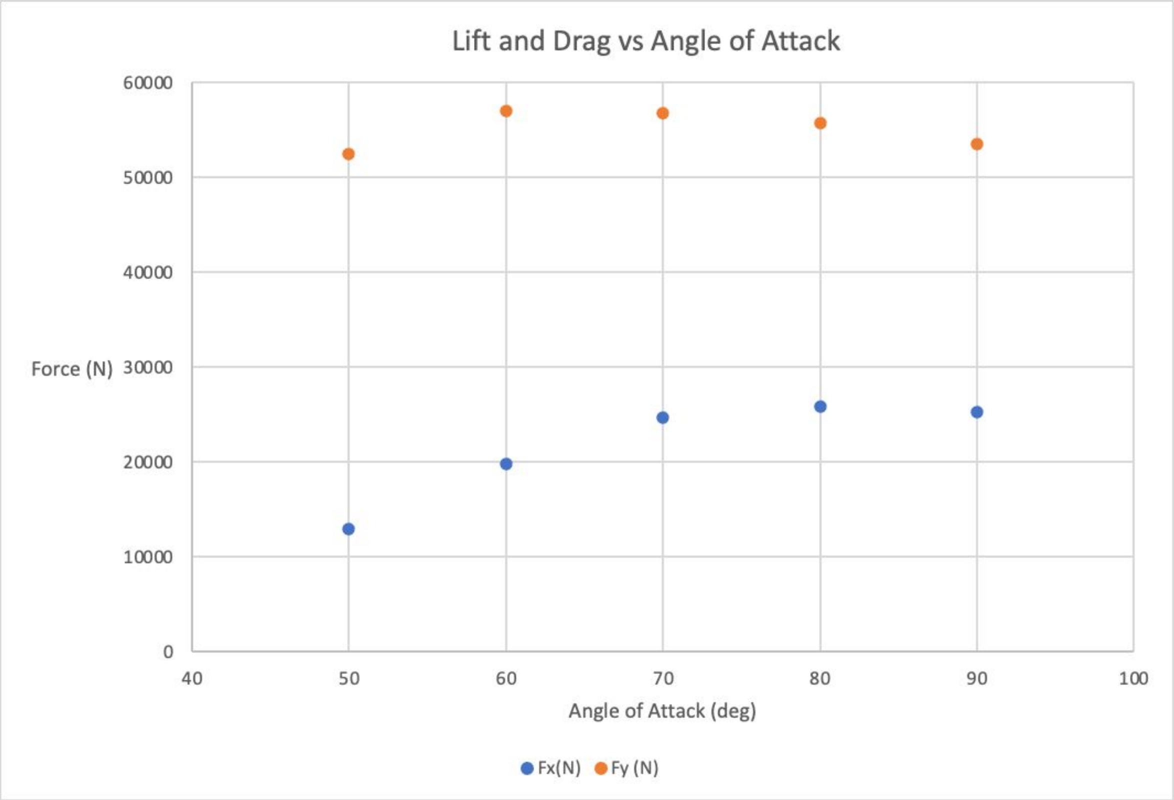
Wing Pressure Contours



Wing Lift and Drag

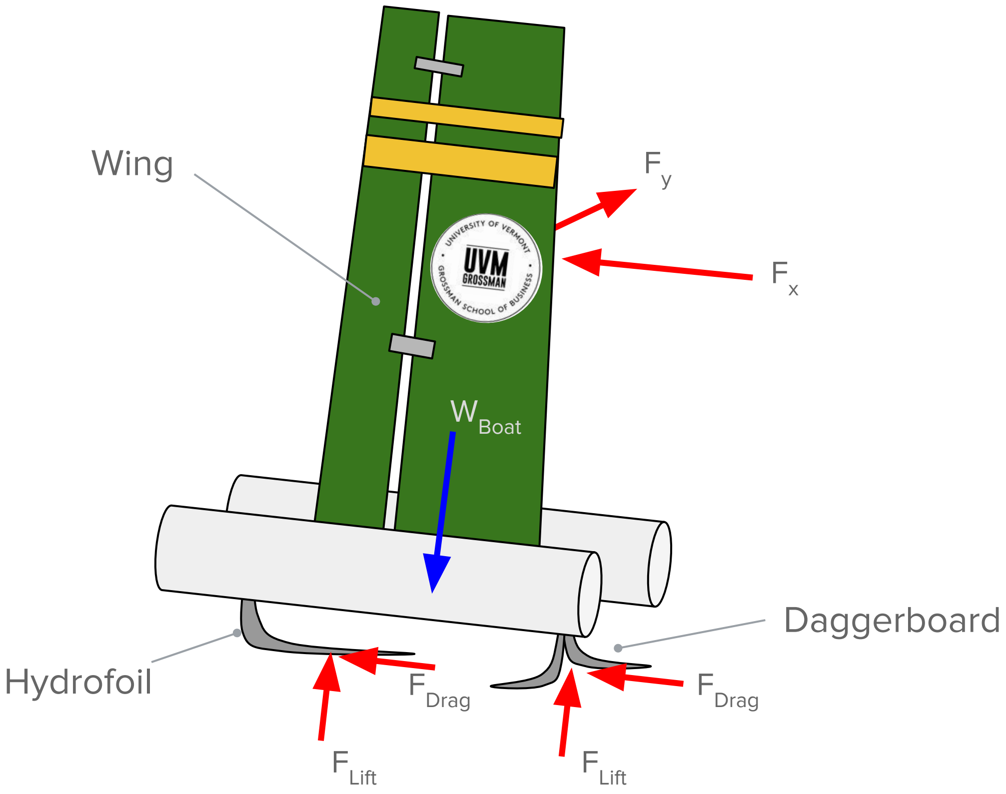
AoA	Fx [N]	Fy [N]
50	12963.1126	52413.332
60	19845.1188	57050.644
70	24695.662	56719.854
80	25862.716	55696.614
90	25243.474	53503.052

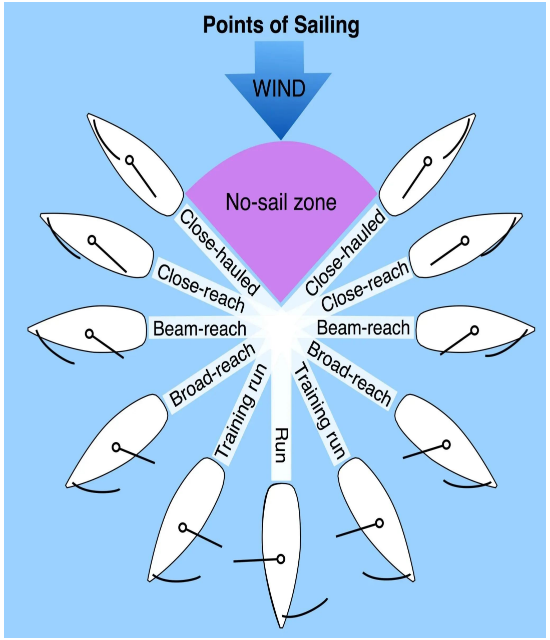
Wing height = 20m



Conclusion

Reminder of Problem





http://safe-skipper.com/wp-content/uploads/2019/06/36.1_Points-of-sail-1.jpg

Boat = 2400 kg

W_{Boat} = 23520 N

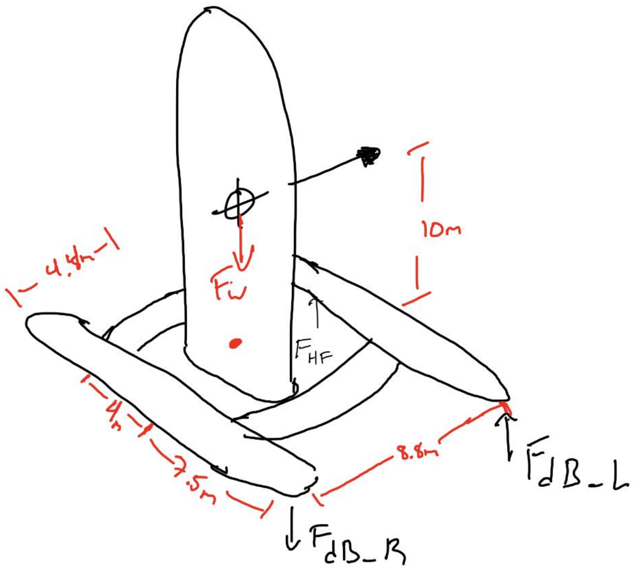
Boat Specs Via: https://sailgp.com/general/sailgp-f50 /

F50 Flight

When traveling at a speed of 10m/s, the skipper must have hydrofoil at $\alpha > 15^\circ$.

Recommendations for Sailors:

- Right Daggerboard ➜ $6 < \alpha < 8^\circ$
- Left Daggerboard ➜ $-8 < \alpha < -6^\circ$
- Hydrofoil ➜ $\alpha \sim 30^\circ$



Future Changes

- Wing offset angle
- Wing twist
- Geometry differences
- Weight of Athletes

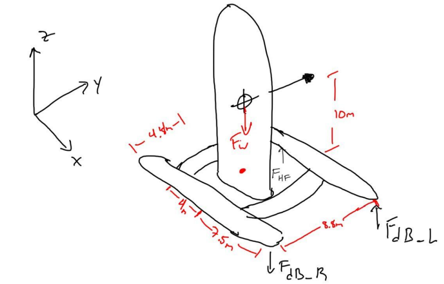
Appendix

Fluent Calculated Values

Wing

AoA (deg)	Fx (N/m)	Fy (N/m)
50	648.15563	2620.6666
60	992.25594	2852.5322
70	1234.7831	2835.9927
80	1293.1358	2784.8307
90	1262.1737	2675.1526

Moment Analysis



$$F_z = F_{HF} + F_{dB\_L} - F_{dB\_R} - F_w = 0$$

$$F_{HF} = F_{dBR} - F_{dBL} + 23520 = 0$$

$$M_x = 0 = (52410N)(10m) - (F_{dB\_L})(4.4m) - (F_{dB\_R})(4.4m) - (F_{HF})(4.4)$$

$$524{,}100 = 4.4(F_{dB\_L} + F_{dB\_R} + F_{HF})$$

$$11{,}911.36 = F_{dB\_L} + F_{dB\_R} + F_{HF}$$

$$11{,}911.36 = F_{dBL} + F_{dBR} + (F_{dBR} - F_{dBL} + 23520) = 0$$

$$11608.64 = 2F_{dBR}$$

$$F_{dBR} = -5804.72\,N \rightarrow 6° \rightarrow 8°$$

$$F_{HF} = -F_{dBL} + 17{,}715.68$$

$$11{,}911.36 = F_{dB\_L} + F_{dB\_R} + F_{HF}$$

$$F_{HF} = -F_{dBL} + 17{,}715.68$$

$$11{,}911.36 = F_{dB\_L} + F_{dB\_R} + F_{HF}$$

$$11{,}911.36 = F_{dBL} + 1$$

$$\Sigma M_y = 0 = F_{BL} - F_{HF} - F_{dBR}$$

$$F_{BL} - (-F_{dBL} + 17{,}715.68) + 5804.72$$

$$2F_{BL} = -11{,}911.36$$

$$F_{BL} = -5{,}955.68\,N$$

$$11911.36 = F_{HF} - 5955.68 - 5804.72$$

$$23{,}671.04\,N$$