Propeller Analyses and the Sensitivity of y+

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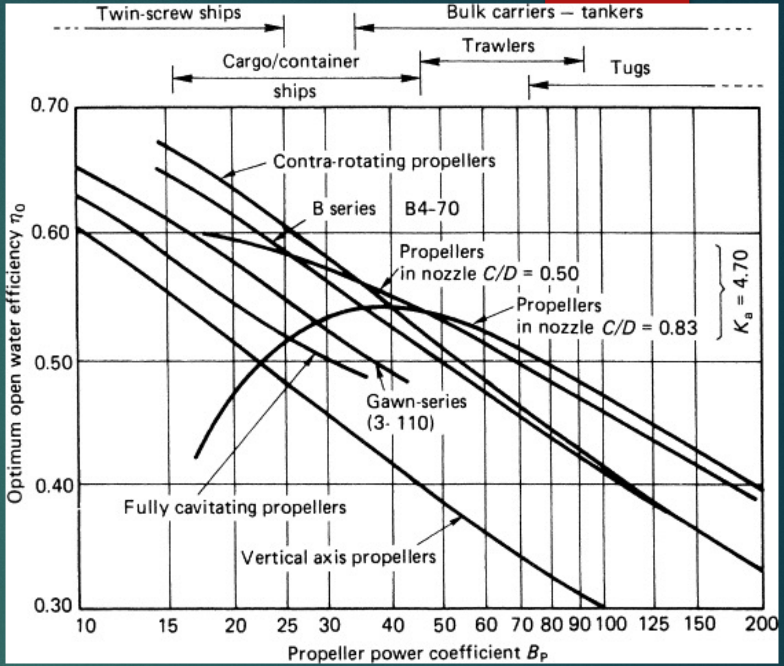
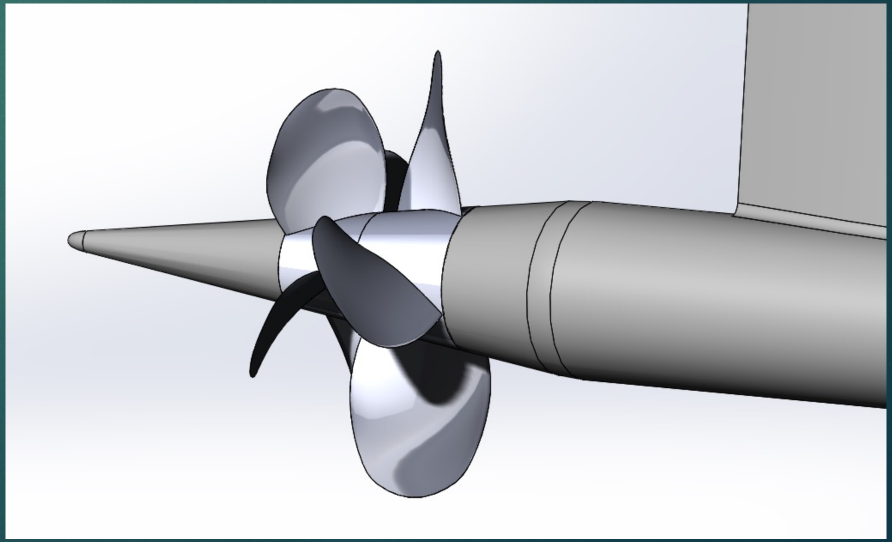
2.290 FINAL PROJECT

CLASS OF 2022

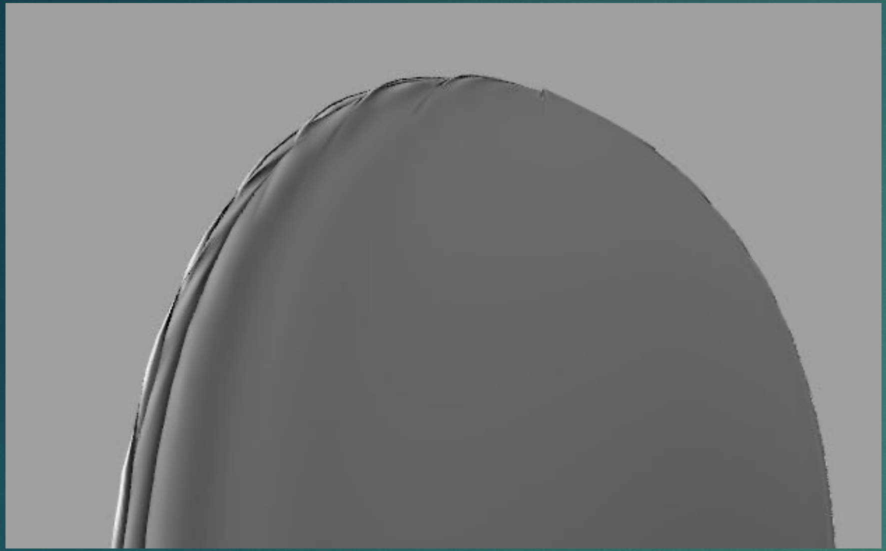
Motivation

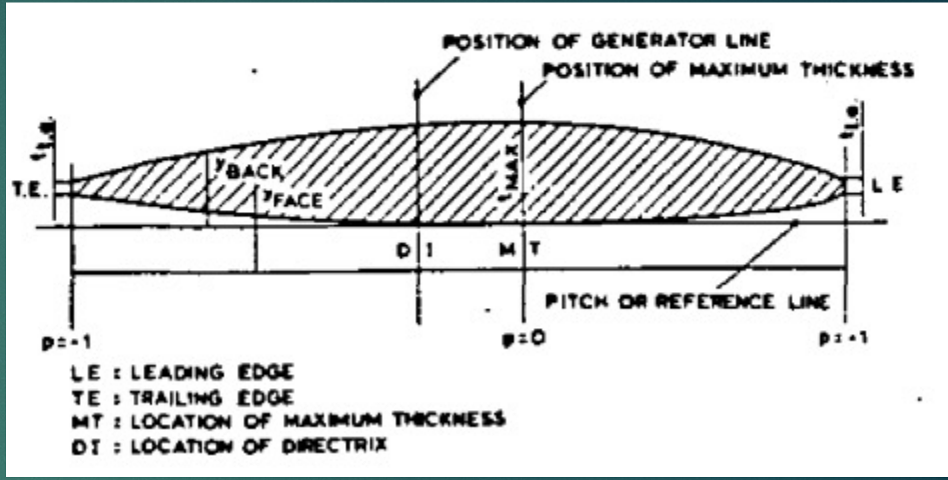
- Modeling Propellers is Hard! No option is perfect.
  - Regression (B Series, Gawn Burrill, Rolla Series, etc.)
    - Steady state, open water only, often proprietary
  - VLM Lifting Line Codes (OpenProp)
    - Steady state, no viscous analysis, open water only
  - Reynold Averaged Navier Stokes Solvers
    - Time and cost consuming but all encompassing
    - Multiple Reference Frames
      - Steady state, computationally easy
    - Sliding Mesh
      - Transient, computationally difficult





Geometry

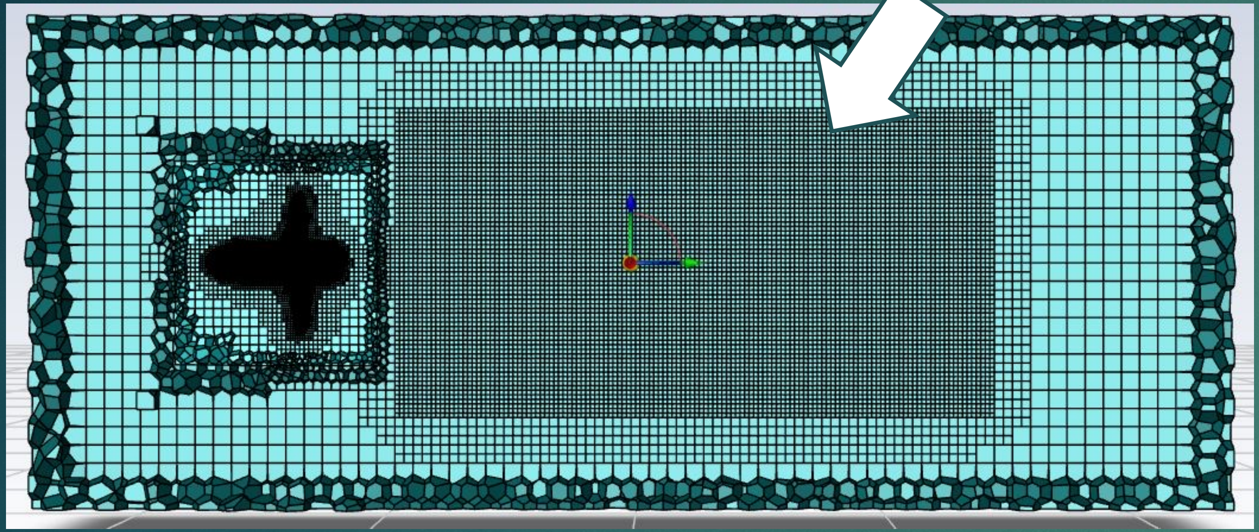


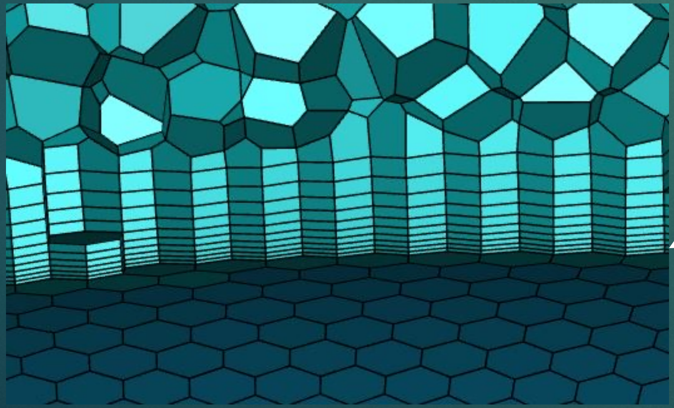

POSITION OF GENERATOR LINE
POSITION OF MAXIMUM THICKNESS
T.E.
L E
BACK
FACE
MAX
D I
M T
PITCH OR REFERENCE LINE
LE : LEADING EDGE
TE : TRAILING EDGE
MT : LOCATION OF MAXIMUM THICKNESS
DI : LOCATION OF DIRECTRIX

Meshing

Fluent Meshing

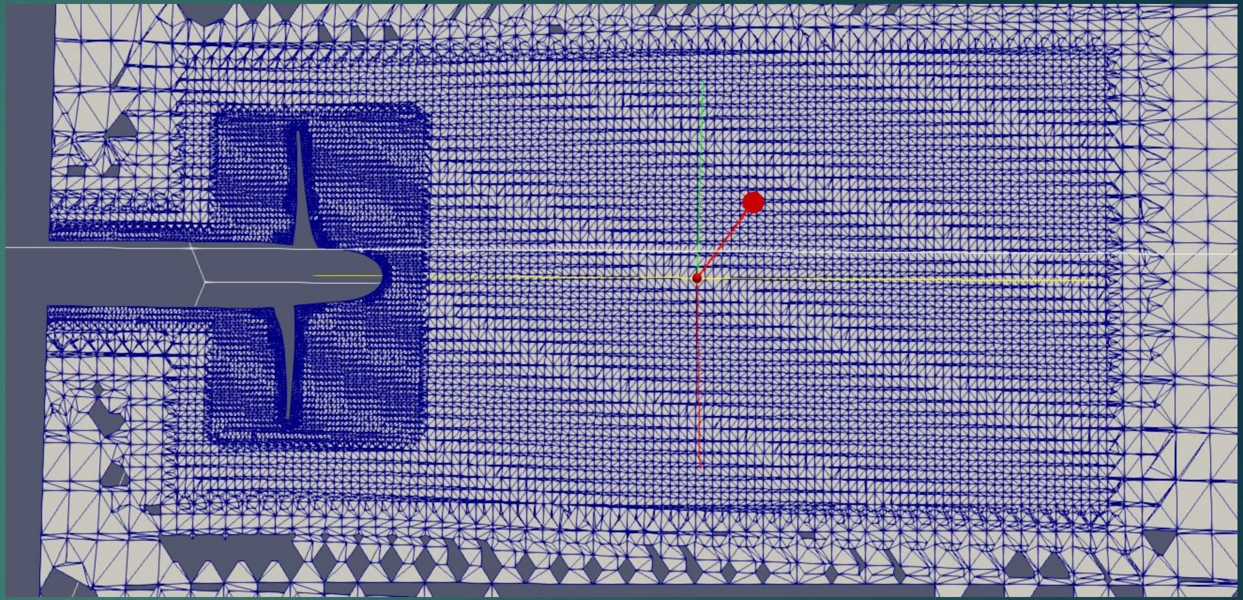
Increased wake resolution

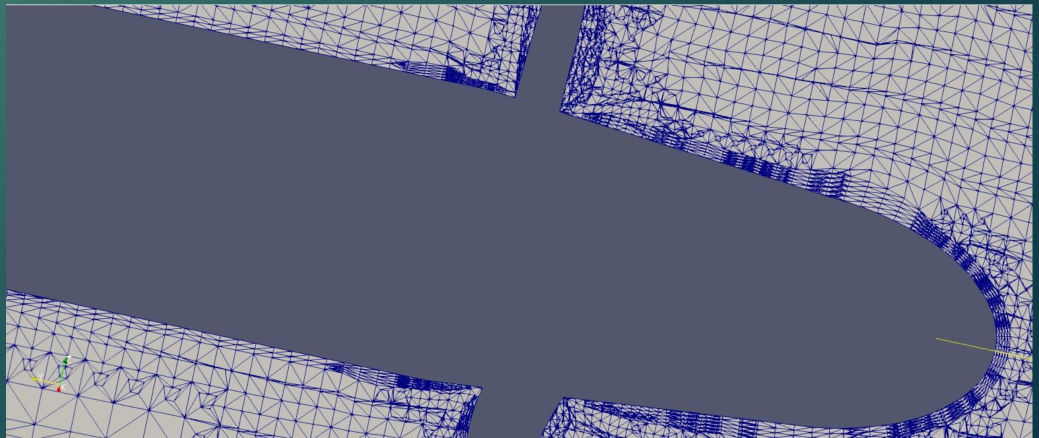




Δy=0.0007

Snappy Hex Mesh





Boundary Layers and Turbulence

Continuity Equation:

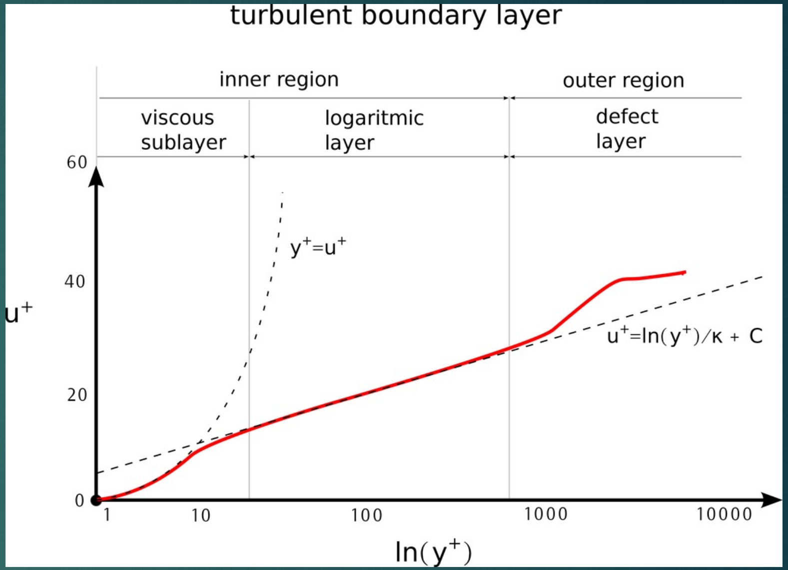
$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} = 0$$

Momentum Equation:

$$\rho\left(\frac{\partial u}{\partial t} + u\cdot\frac{\partial u}{\partial x} + v\cdot\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} + \mu\cdot\frac{\partial^2 u}{\partial y^2}$$

Energy Equation:

$$\rho_c\left(\frac{\partial T}{\partial t} + u\cdot\frac{\partial T}{\partial x} + v\cdot\frac{\partial T}{\partial y}\right) = k\cdot\frac{\partial^2 T}{\partial x^2} + \mu\cdot\left(\frac{\partial u}{\partial y}\right)^2$$



- RANS needs a turbulence modeler
- Using K Omega SST (shear stress transport)
  - Very simply: K-ω near the wall, K-ϵ in the free stream
  - Capable with y+ values < 300

$$\frac{\partial(\rho k)}{\partial t} + \nabla\cdot(\rho \boldsymbol{U} k) = \nabla\cdot\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\nabla k\right) + P_k - \rho\epsilon$$

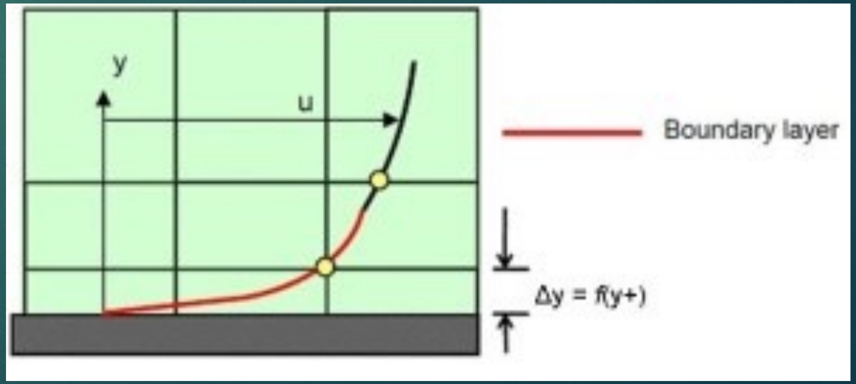
$$\frac{\partial(\rho\omega)}{\partial t} + \nabla\cdot(\rho \boldsymbol{U}\omega) = \nabla\cdot\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\nabla\omega\right) + \frac{\gamma}{\nu_t}P_k - \beta\rho\omega^2$$

$$\underbrace{+\,2(1-F_1)\frac{\rho\sigma_{\omega 2}}{\omega}\nabla k : \nabla\omega}_{\text{Additional Term}}$$

$$\underbrace{\mu_t = \frac{\rho k}{\omega}}_{\text{Original}} \qquad \underbrace{\mu_t = \frac{a_1 \rho k}{\max(a_1\omega, SF_2)}}_{\text{SST Model}}$$

$$F_2 = \tanh\left(\arg_2^2\right)$$

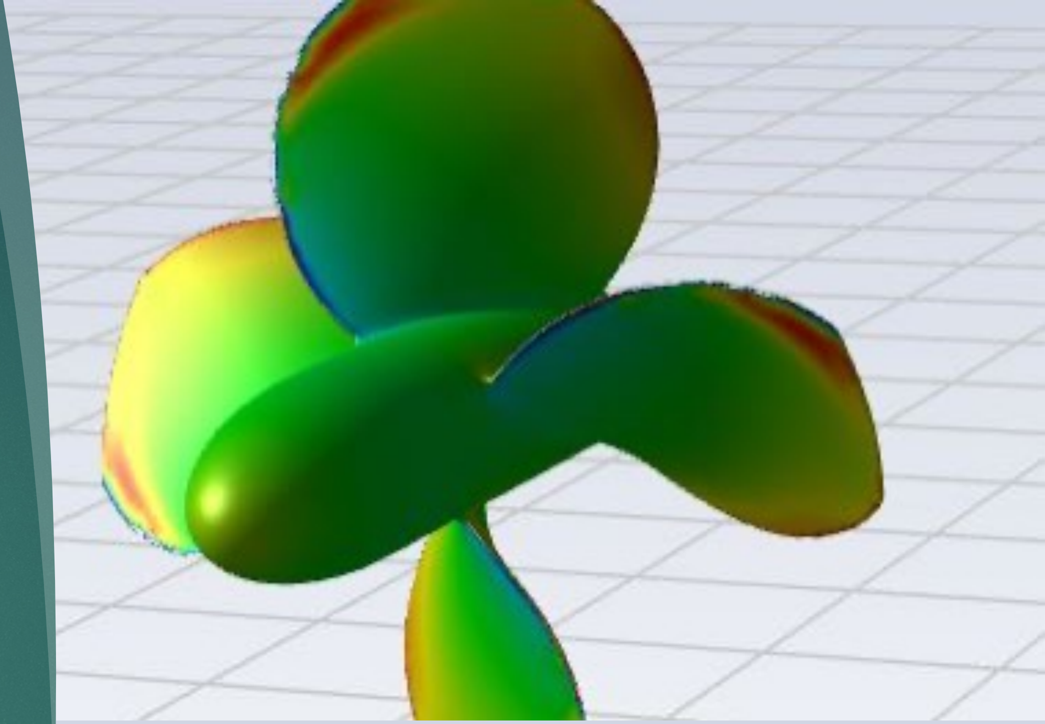
$$\arg_2 = \max\left(\frac{2\sqrt{k}}{\beta^\star \omega d}, \frac{500\nu}{\omega d^2}\right)$$

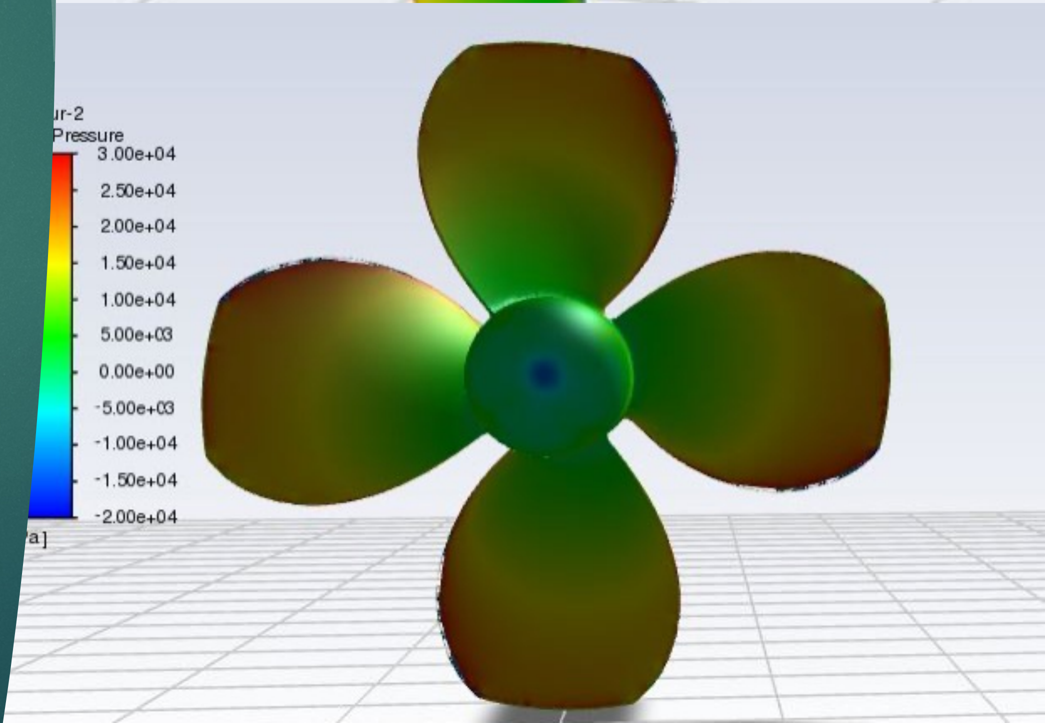


MRF Modeling in Fluent

	8 Layers	3 Layers	No Boundary Layer Mesh
Force (N)	3713	3663	3489
Torque (N-m)	1080.5	1053	1004.5
Y+ Mode	22.5	20	31

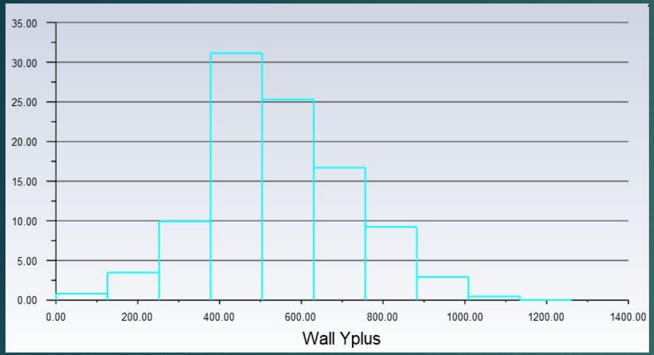
- Unfortunate 512k cell limit in Fluent prevents further resolution
- Mostly second order upwind discretization's



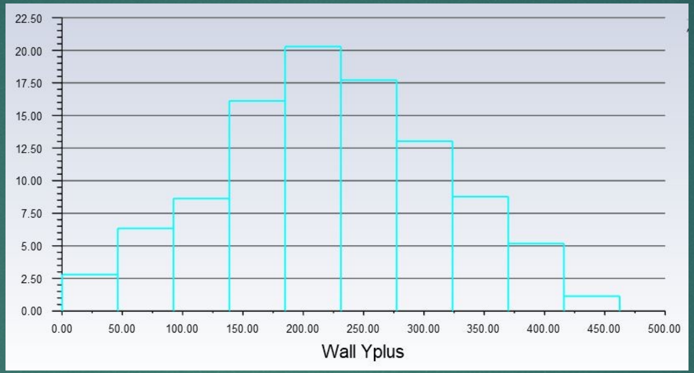


MRF Models & Y+

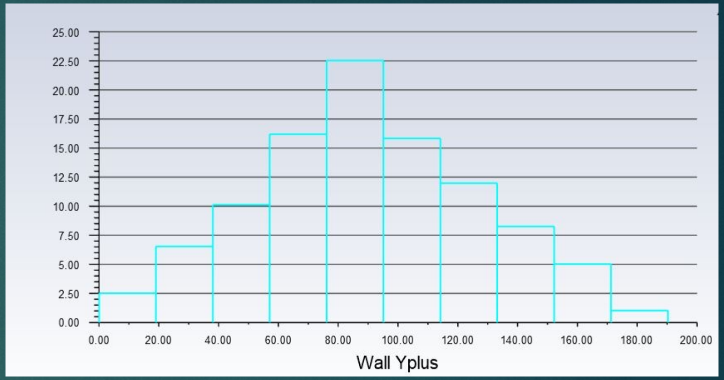
No Mesh Boundary Layers

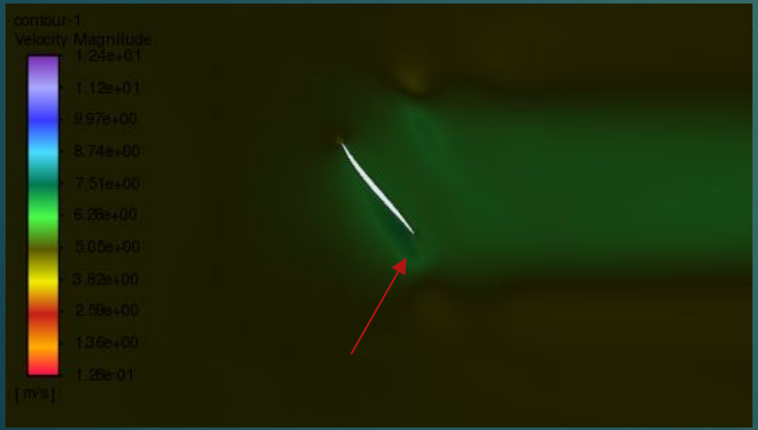


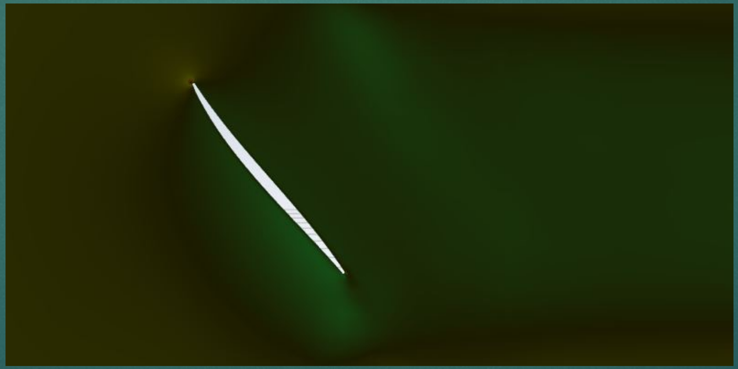
3 Mesh Boundary Layers

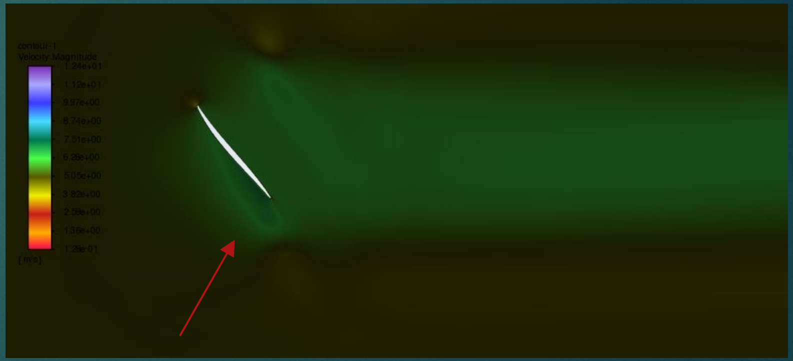


8 Mesh Boundary Layers

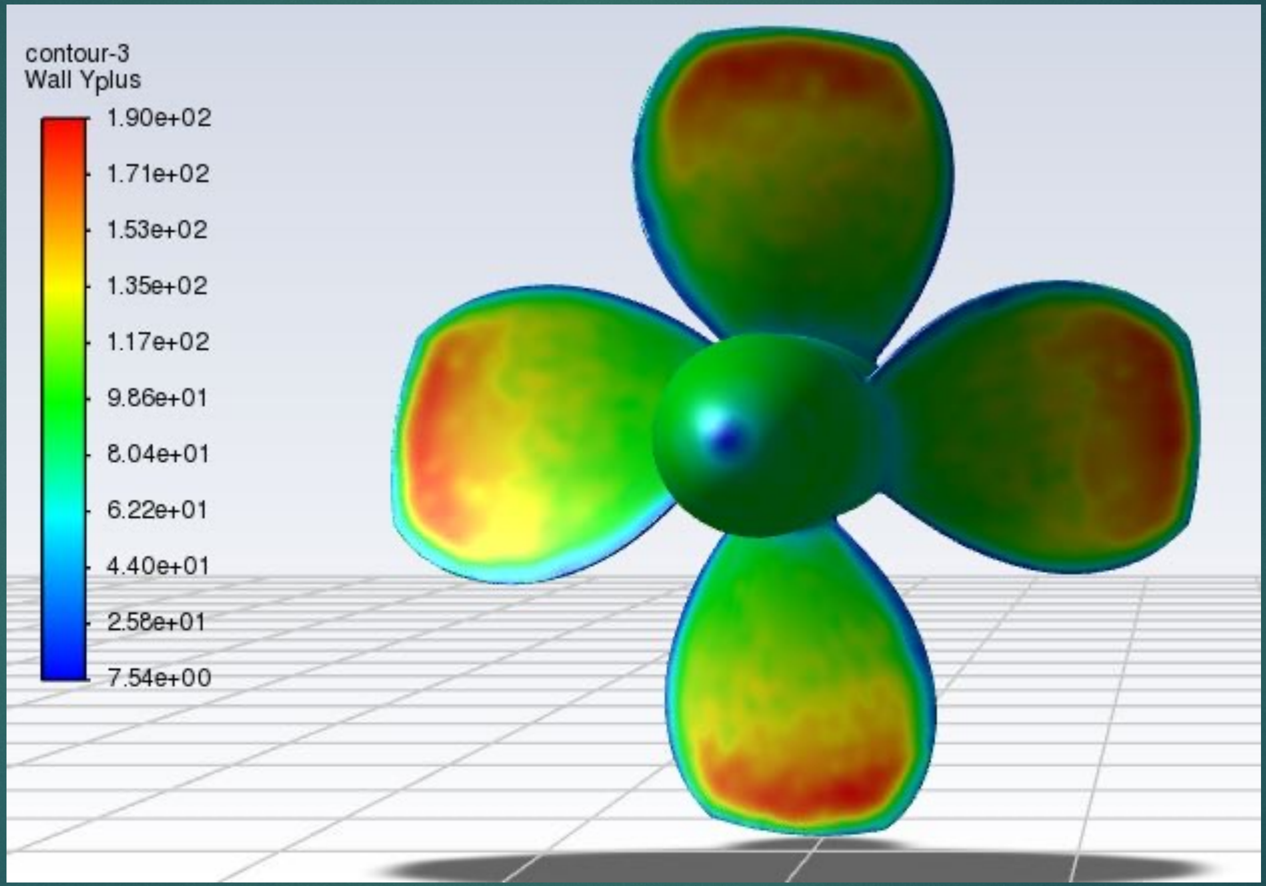








MRF Models & Y+ cont.

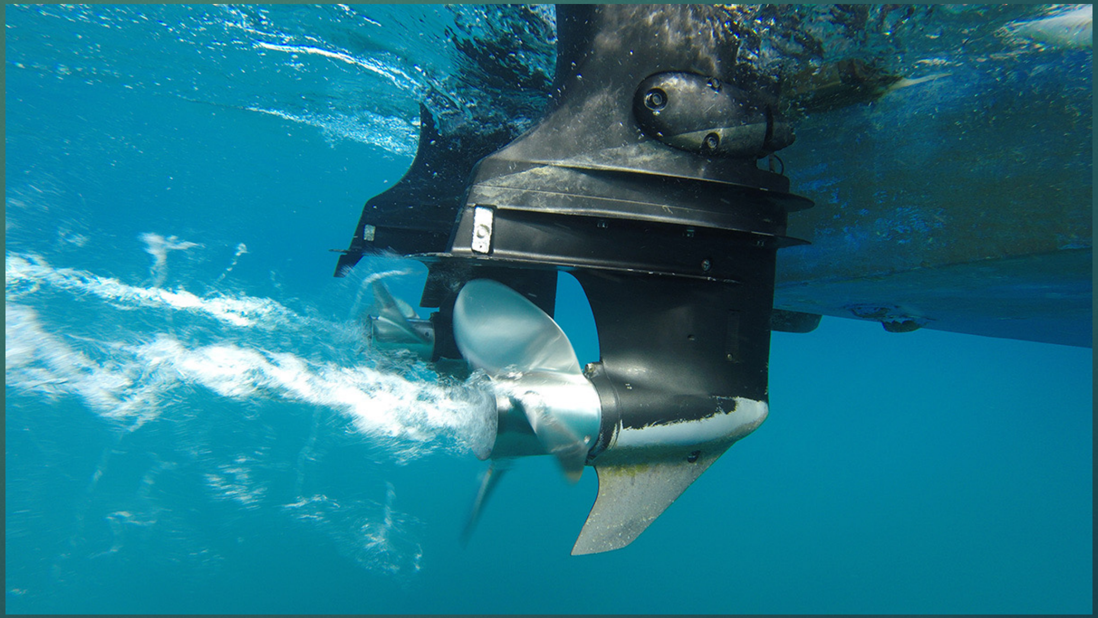


Sliding Mesh

- Keep Courant number down with a small $\Delta t = 10^{-5}$, $C = \frac{|U| * \Delta t}{\Delta x}$ even when implicit
- Using PIMPLE, a SIMPLE-PISO hybrid

Next Steps

- Improved meshing of more complex geometries
- Cell allowance
- Sliding mesh y+ sensitivity study
- Coupled CRP model!
- Multiphase



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