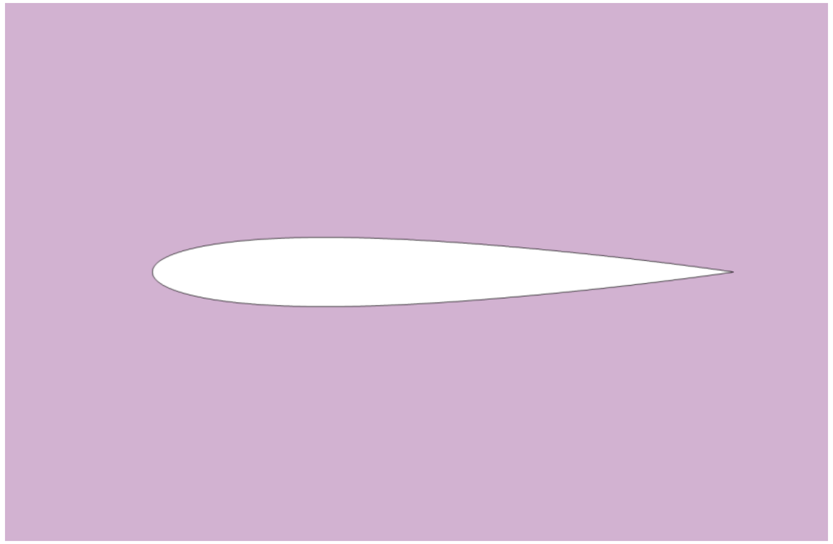
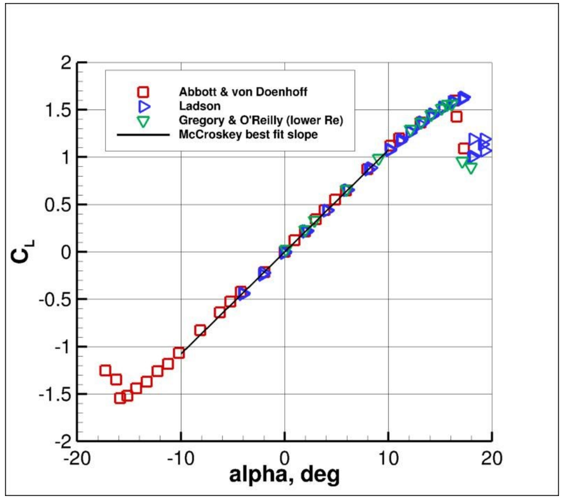
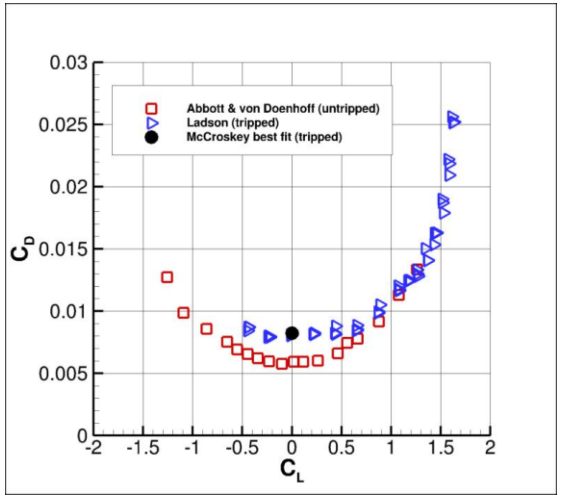
Problem definition

2D NACA 0012 Airfoil Validation Case



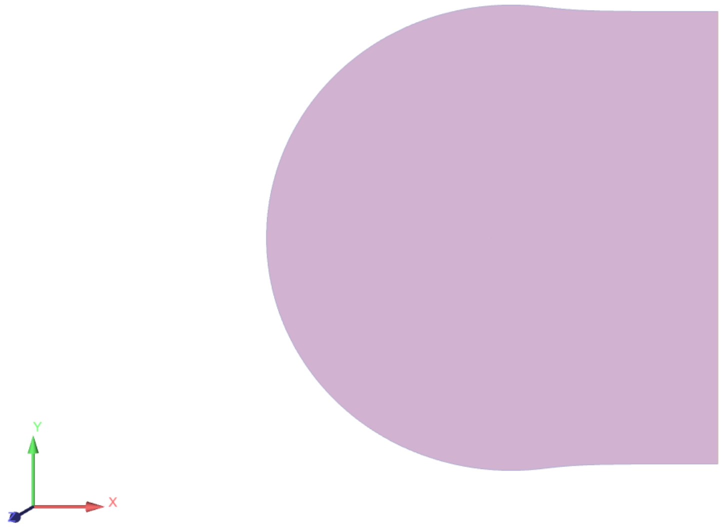


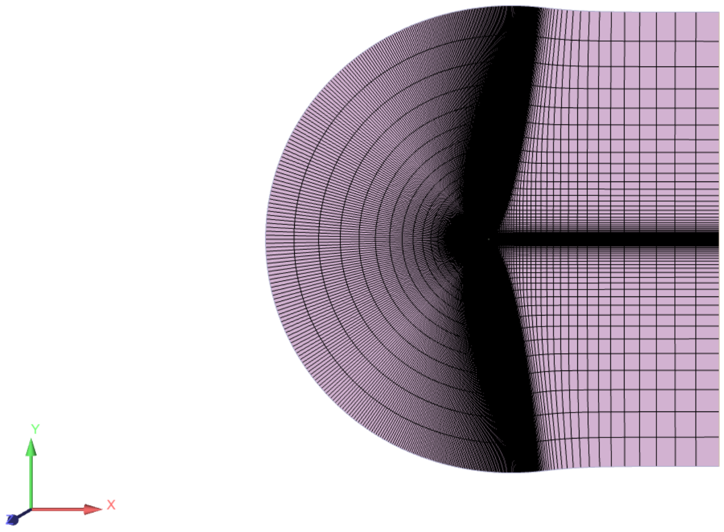


- Flow past airfoils (and wings) are classical validation cases in turbulence modeling.
- There is plenty of experimental and numerical data available for different airfoils at different Reynolds number and Mach number.
- **A few references:**
  - https://turbmodels.larc.nasa.gov/naca0012_val.html
  - C. Ladson. Effects of Independent Variation of Mach and Reynolds Numbers on the Low-Speed Aerodynamic Characteristics of the NACA 0012 Airfoil Section. NASA TM 4074, October 1988.
  - W. McCroskey. A Critical Assessment of Wind Tunnel Results for the NACA 0012 Airfoil, NASA TM 100019, October 1987.

Problem definition

Geometry and mesh

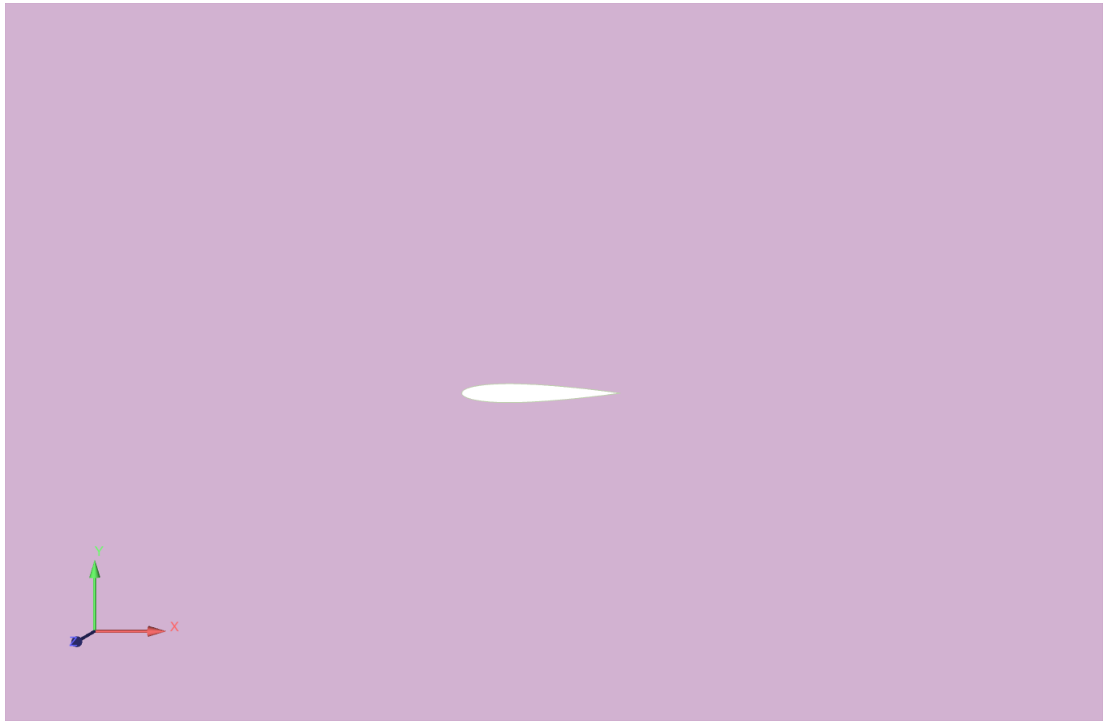


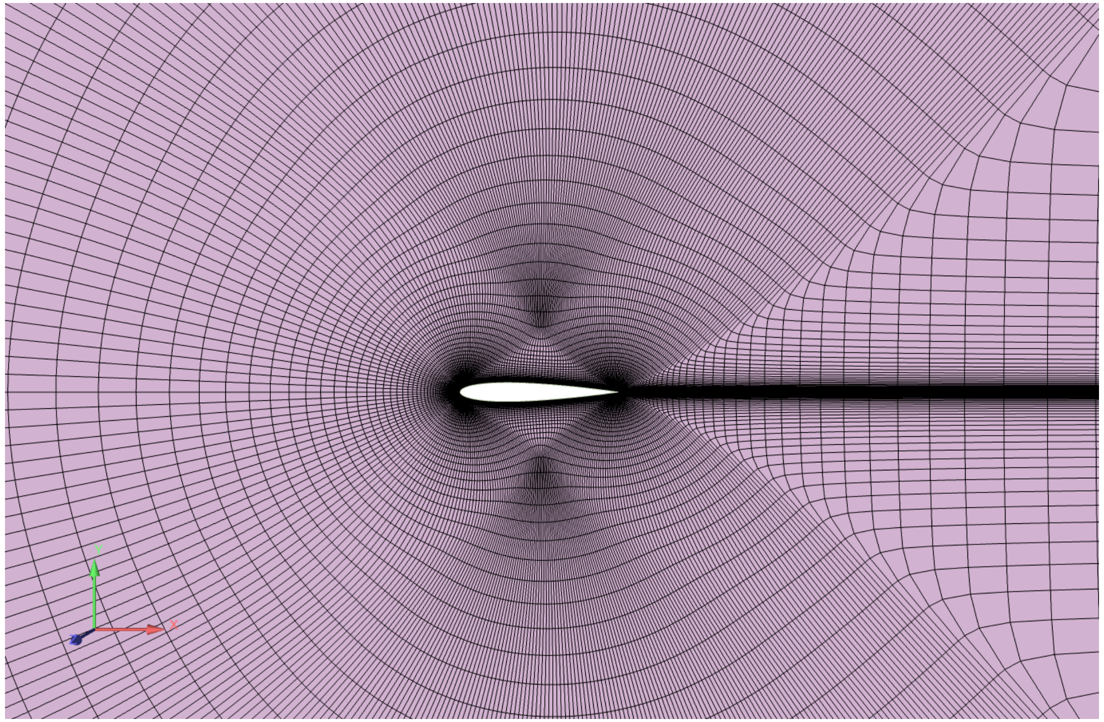


- The mesh illustrated is a structured one.
- It is called a C-type topology.
- This is a wall resolving mesh.

Problem definition

Geometry and mesh





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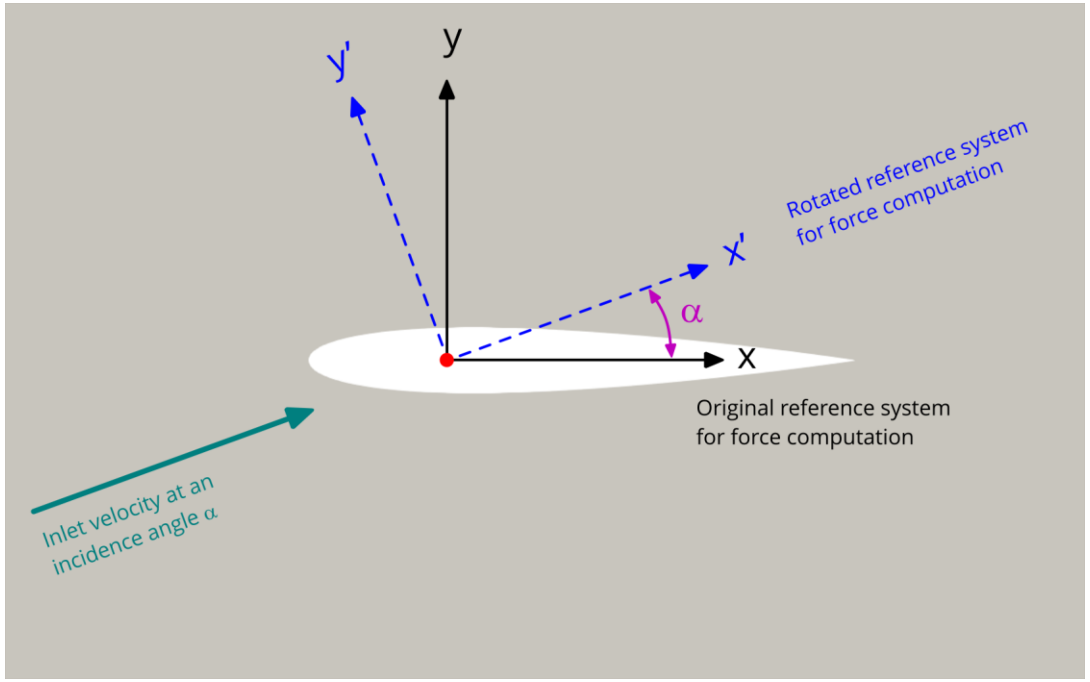
Problem definition

Reference axes to compute the lift and drag coefficients



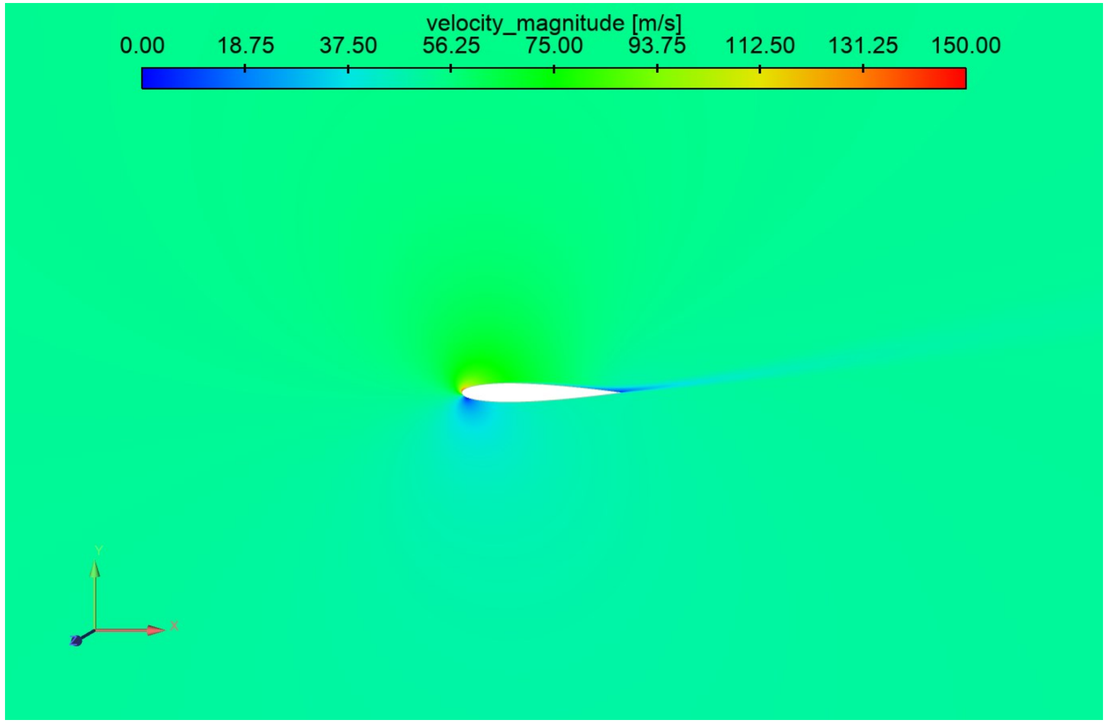
$$\text{liftDir } (-\sin(\alpha), \cos(\alpha), 0)$$

$$\text{dragDir } (\cos(\alpha), \sin(\alpha), 0)$$

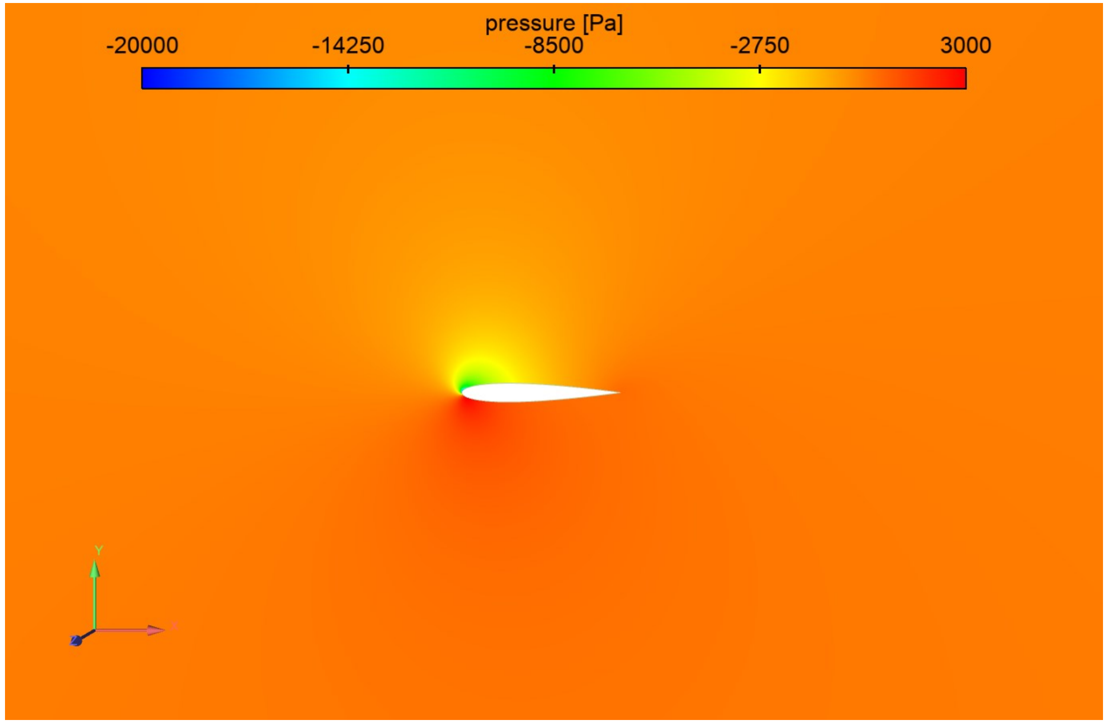
- Remember, lift and drag are perpendicular and parallel to the incoming flow, respectively.
- So, if the inlet velocity is entering at a given angle, you should adjust the vectors **liftDir** and **dragDir** so they are aligned with the incoming flow (rotation matrix).
- Personally speaking, I prefer to rotate the geometry instead of changing the angle of incoming flow.
  - But this requires updating the geometry and mesh.
- **In this case, we will change the angle of the incoming flow, so it is required to adjust the reference axes.**

Qualitative and quantitative results

NACA 0012 Airfoil – Re = 6 000 000 – Ma = 0.15 – AOA = 12°



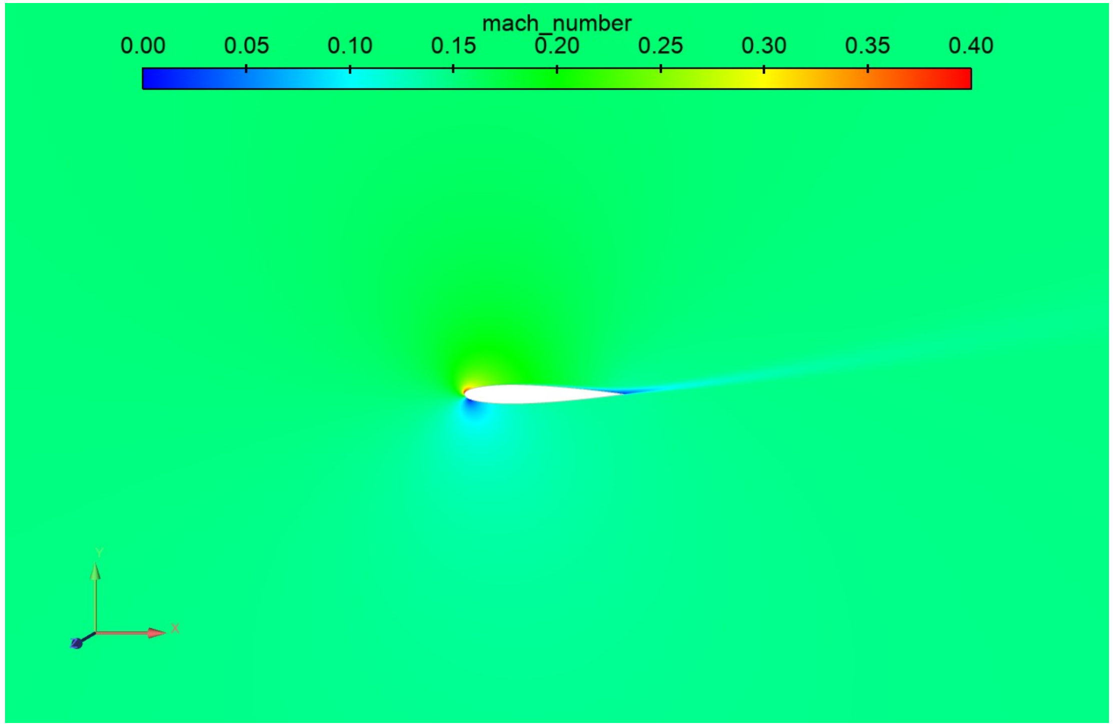
Contours of velocity magnitude



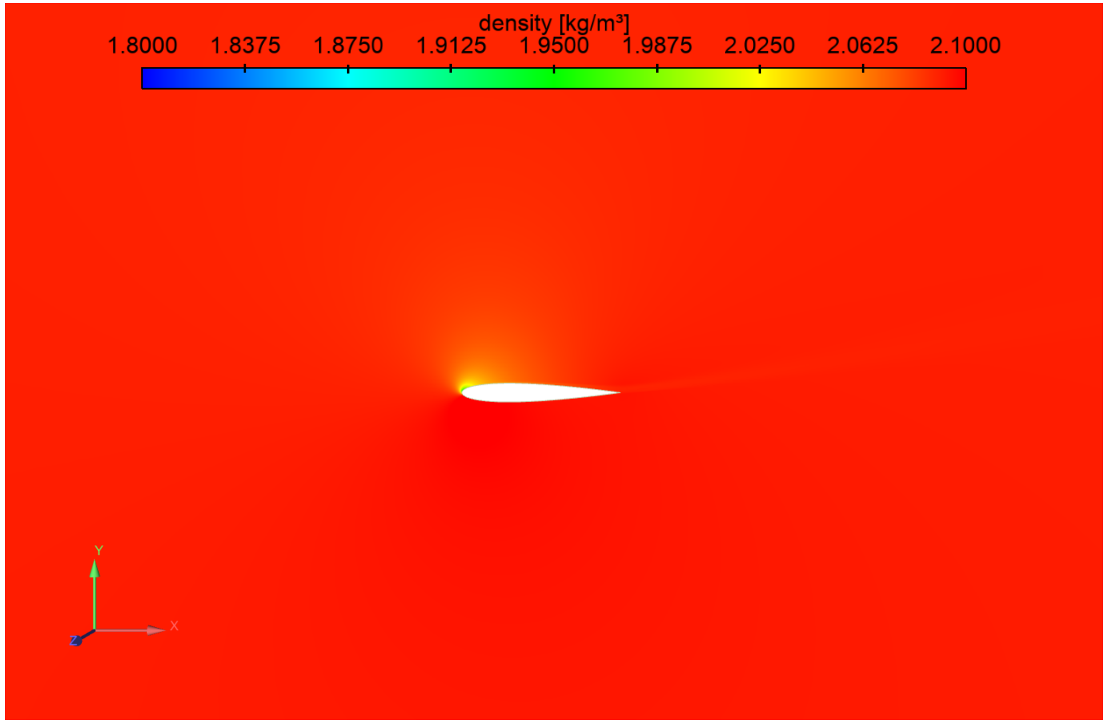
Contours of pressure

Qualitative and quantitative results

NACA 0012 Airfoil – Re = 6 000 000 – Ma = 0.15 – AOA = 12°



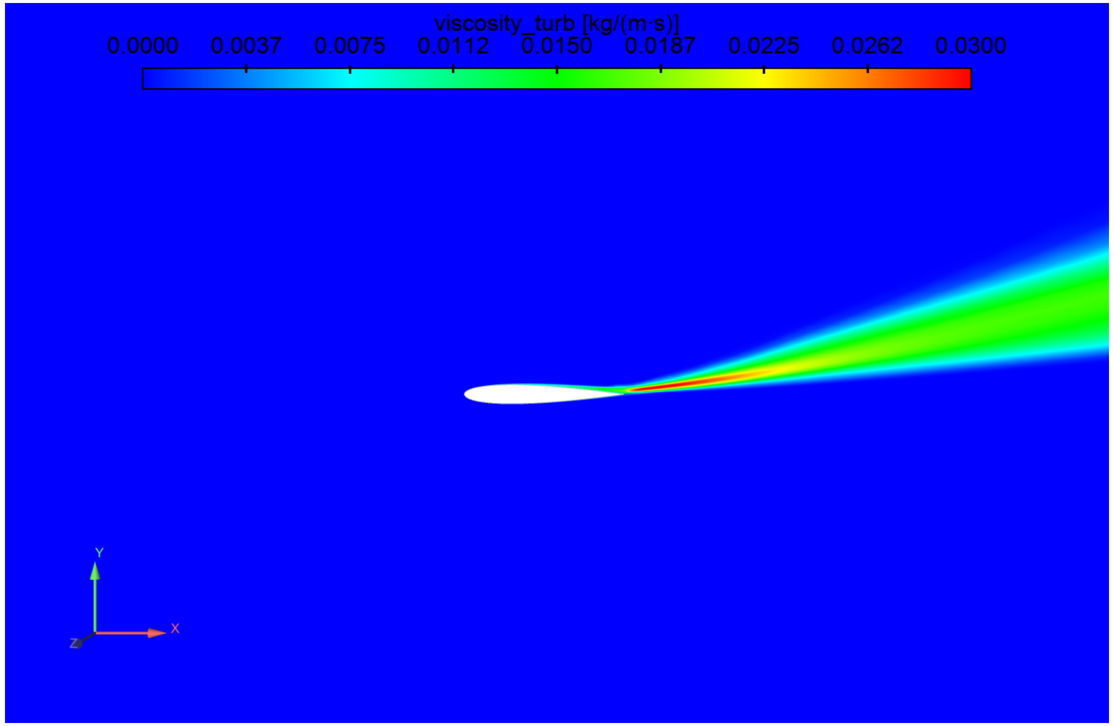
Contours of Mach number



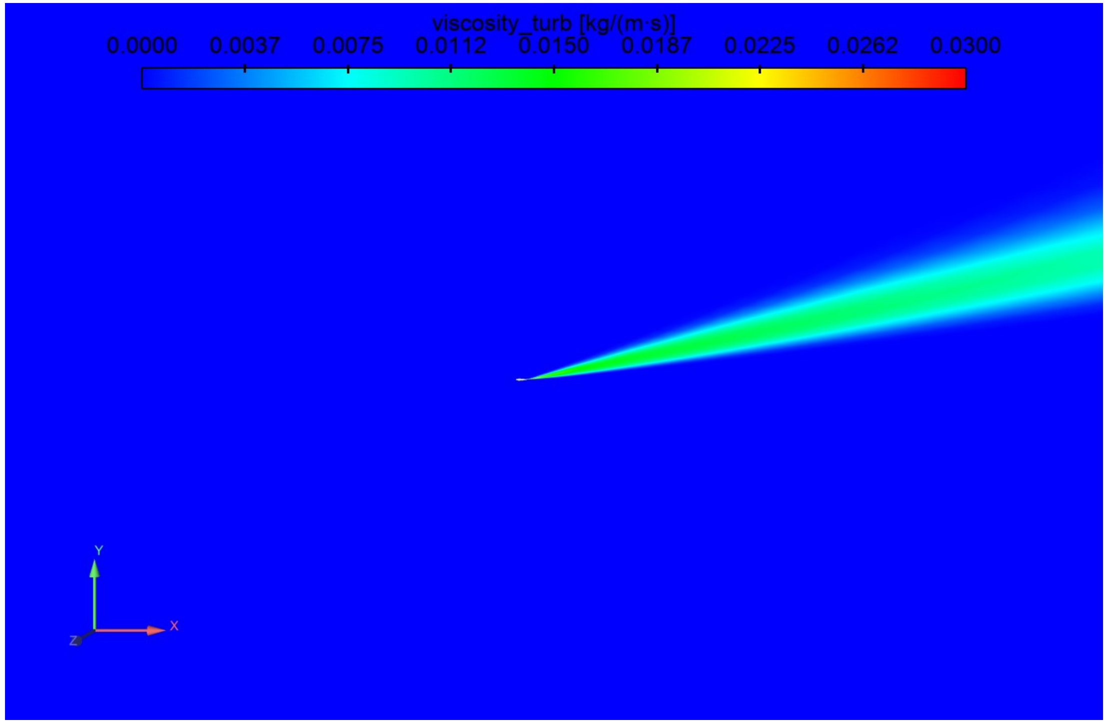
Contours of density

Qualitative and quantitative results

NACA 0012 Airfoil – Re = 6 000 000 – Ma = 0.15 – AOA = 12°



Contours of turbulent viscosity

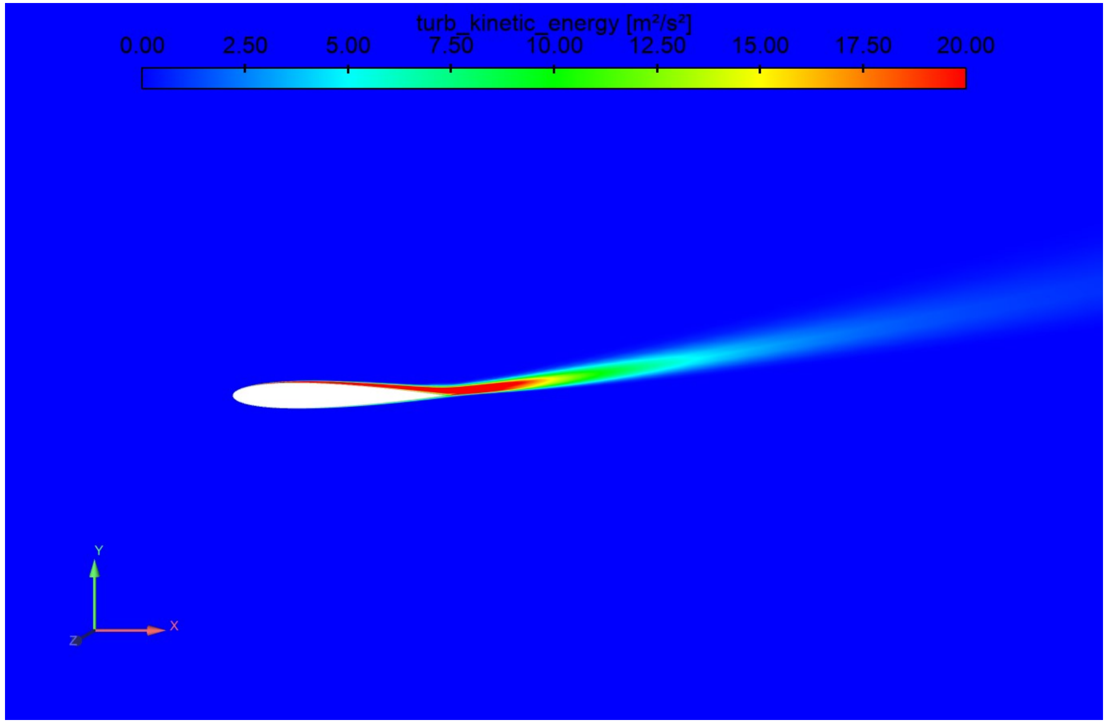


Contours of turbulent viscosity

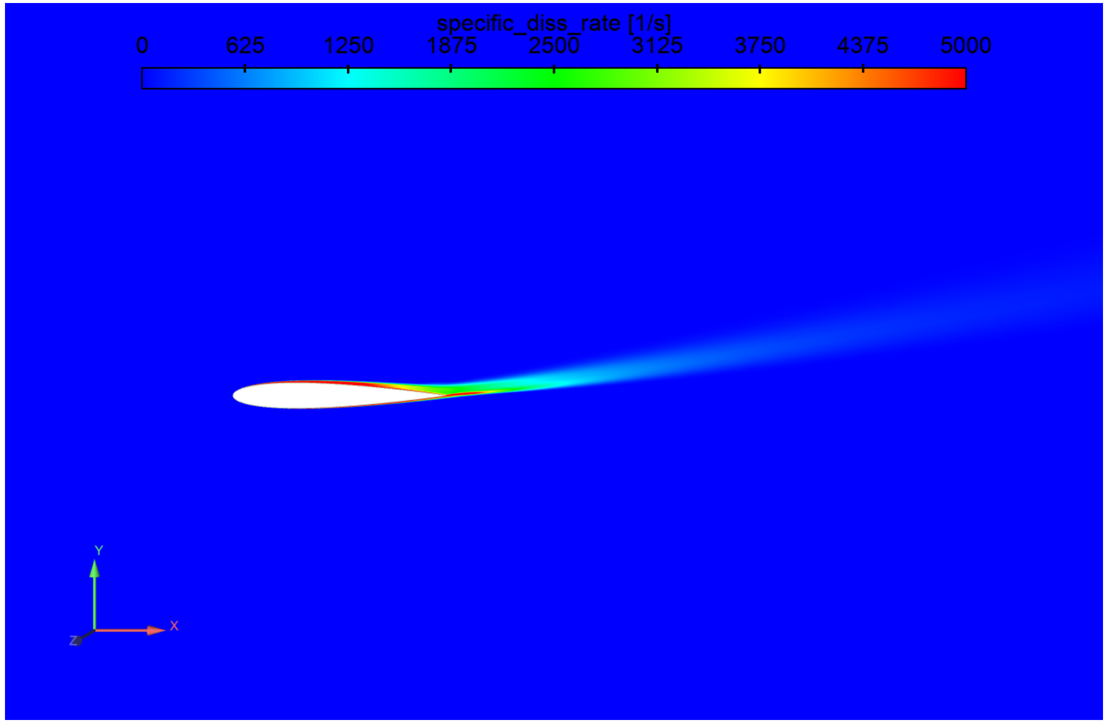
- Notice that the turbulence viscosity is orders of magnitude larger than the molecular viscosity

Qualitative and quantitative results

NACA 0012 Airfoil – Re = 6 000 000 – Ma = 0.15 – AOA = 12°



Contours of TKE



Contours of specific dissipation rate

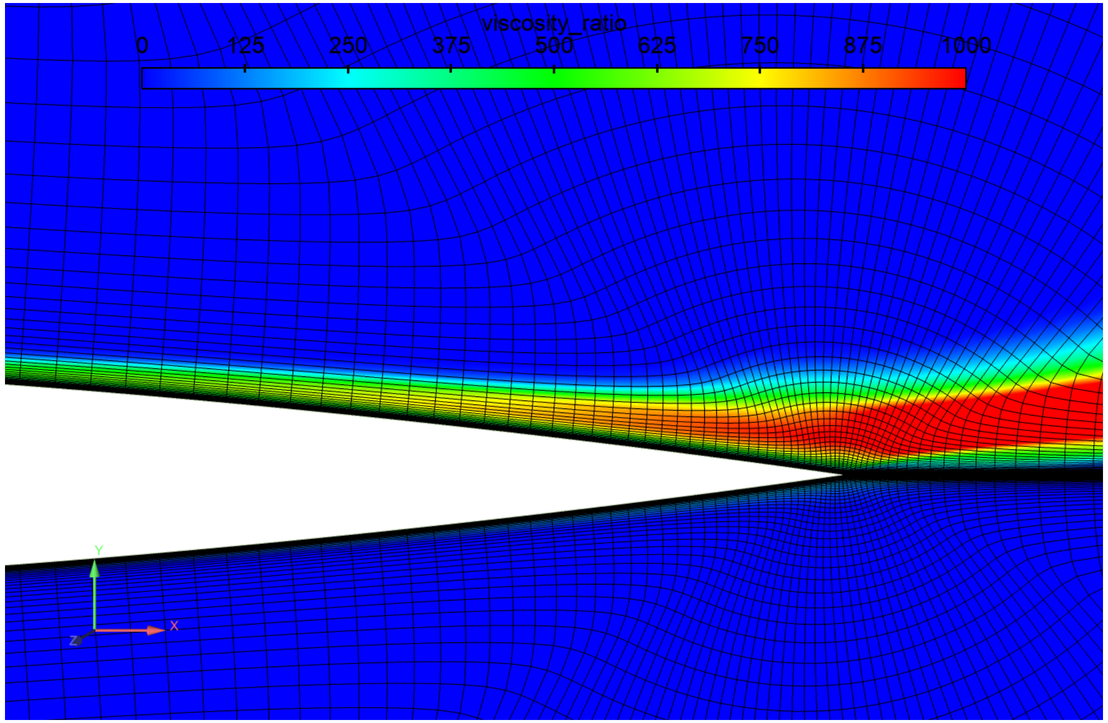
- Recall that in the $k-\omega$ turbulence models, the turbulent viscosity is computed as follows,

$$\nu_t = \frac{k}{\omega}$$

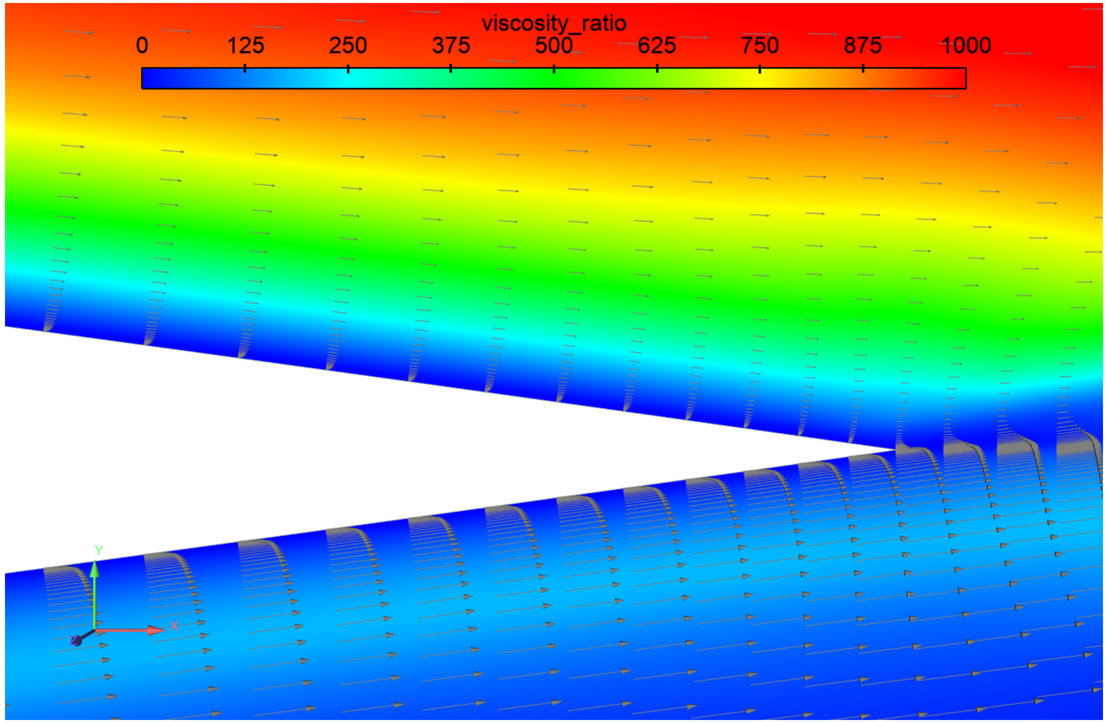
- Using the turbulent quantities, you can also compute the integral length scales and time scales (as we did for the Kolmogorov scales).

Qualitative and quantitative results

NACA 0012 Airfoil – Re = 6 000 000 – Ma = 0.15 – AOA = 12°



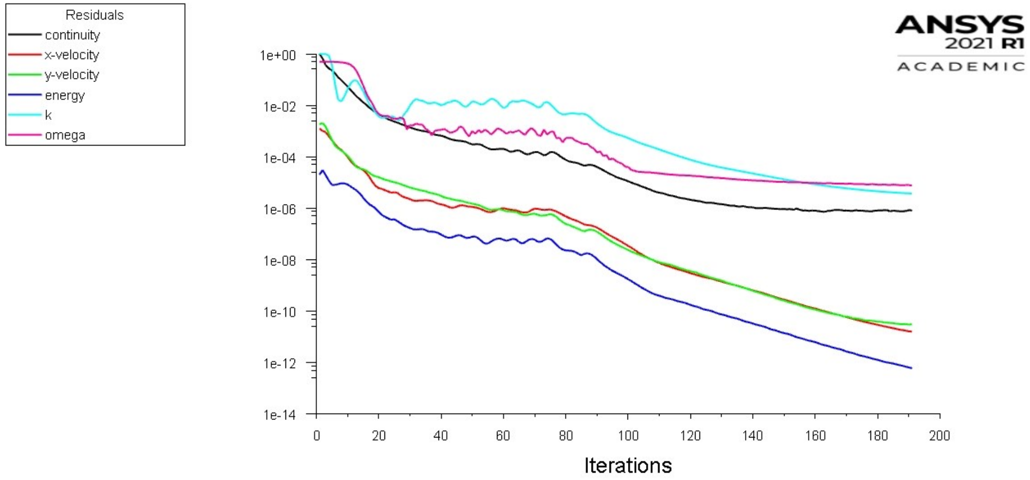
Contours of viscosity ratio

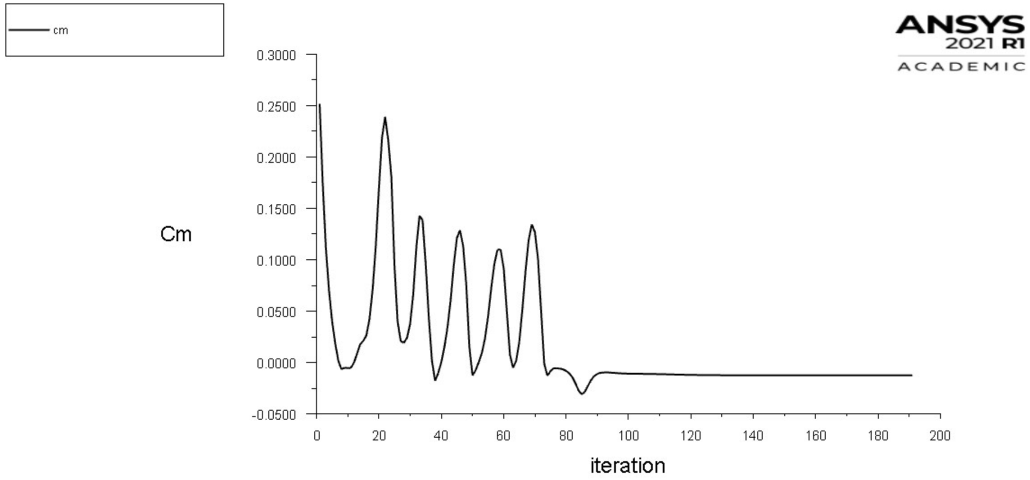


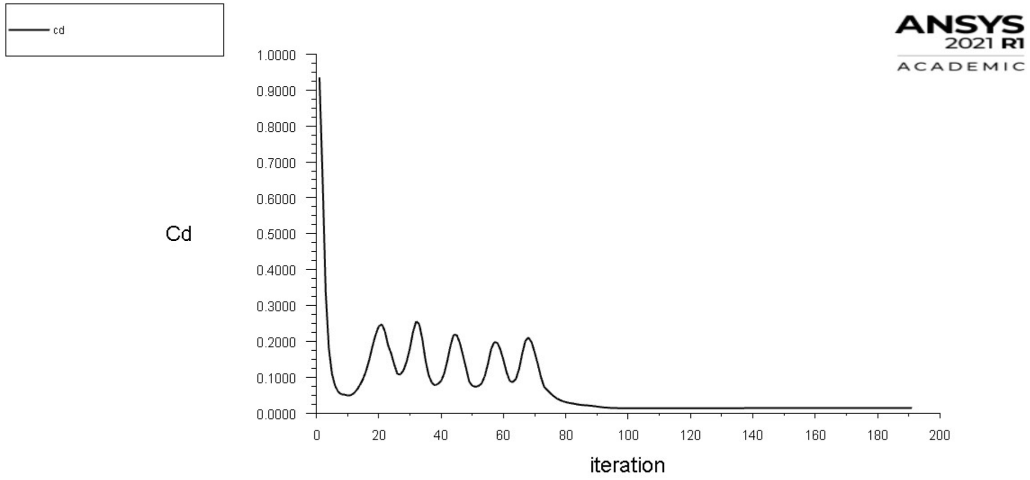
Contours of viscosity ratio and velocity vectors

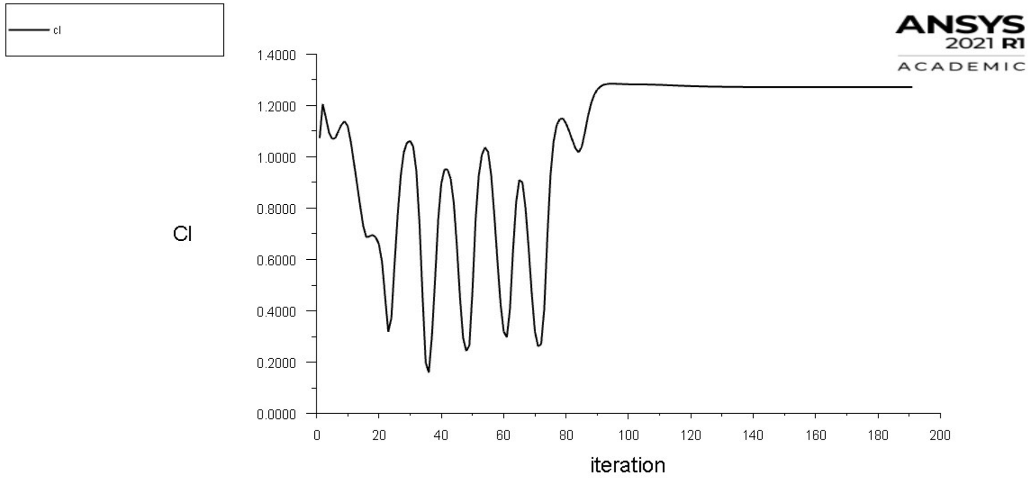
Qualitative and quantitative results

NACA 0012 Airfoil – Re = 6 000 000 – Ma = 0.15 – AOA = 12°





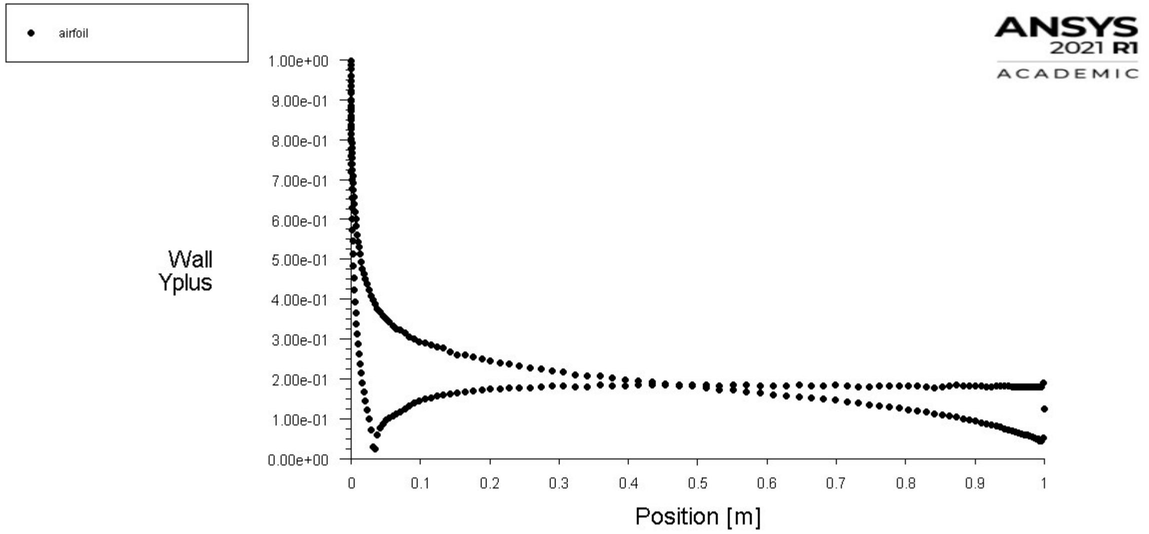




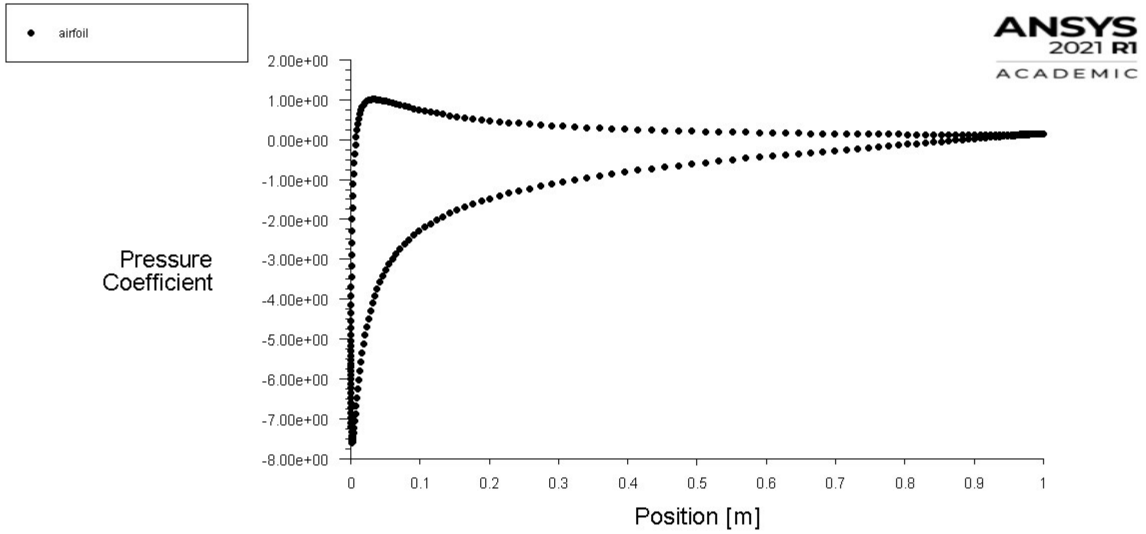
- In this case, the iterative convergence shows some oscillations during the starting. This can be due to many factors.
- The oscillations were damped without user intervention after approximately 100 iterations.

Qualitative and quantitative results

NACA 0012 Airfoil – Re = 6 000 000 – Ma = 0.15 – AOA = 12°



y^+ distribution on the airfoil wall



C_p distribution on the airfoil wall

Qualitative and quantitative results

NACA 0012 Airfoil – Re = 6 000 000 – Ma = 0.15 – AOA = 12°

	AOA	c_d	c_l
Experimental values	12°	0.01332	1.2605
Numerical values	12°	0.014539	1.2704

← The actual measured angle was 12.12°

Experimental data from NASA TM 4074 [1]
Re=6 million, with transition tripped – 80 grit – M=0.15

- Remember, experiments are not the absolute truth, they are also subject to uncertainty.
- When comparing results, you should be sure to capture definite and clear trends.
- Usually, it is fine to be within a 5% margin of error.
- But this is not a rule, can be more, can be less.

[1] C. Ladson. Effects of Independent Variation of Mach and Reynolds Numbers on the Low-Speed Aerodynamic Characteristics of the NACA 0012 Airfoil Section. NASA TM 4074, October 1988.