Advanced Gas Turbine Theory

Project-2

Intake Design

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Subsonic Intake

Airflow and Pressure

Subsonic aerodynamics deals with airflow at speeds below the speed of sound. Understanding the behavior of air at these speeds, including airflow patterns, pressure distribution, and drag forces, is crucial for efficient intake design.

Flow Separation

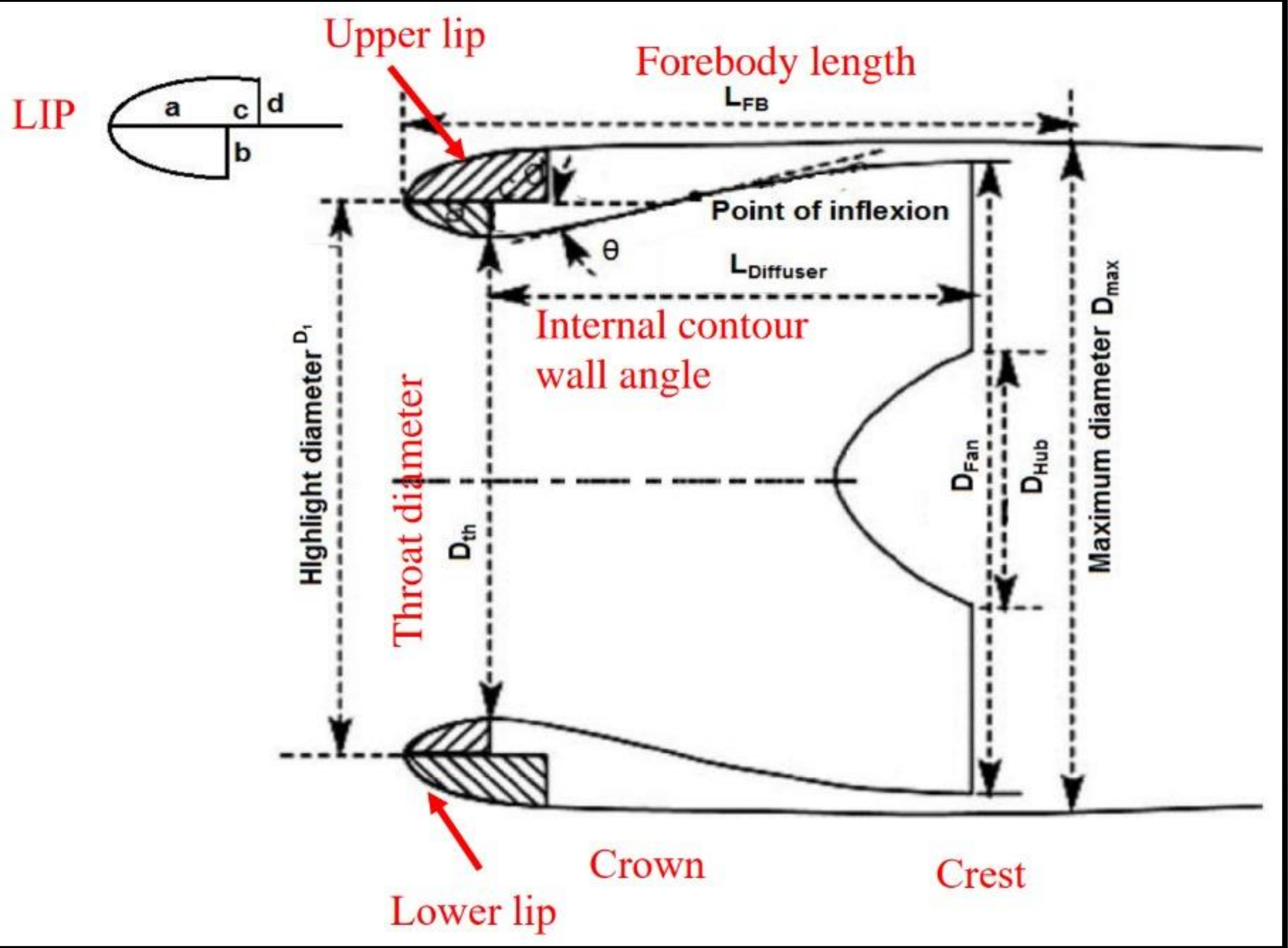
In subsonic flow, airflow can separate from surfaces due to adverse pressure gradients. Understanding flow separation and its effects on intake performance is essential for optimizing intake geometry.

Pod-mounted Subsonic Inlet Duct

A streamlined structure designed to deliver airflow efficiently to an engine operating at subsonic speeds. Mounted externally on an aircraft, this inlet system minimizes drag while ensuring uniform airflow to the engine. Key features include:

- **Streamlining for Low Drag**: The pod shape reduces flow separation and minimizes drag, enhancing overall aerodynamic performance.
- **Shock-Free Operation**: At subsonic speeds, the duct geometry avoids shock formation, ensuring smooth airflow.
- **High-Pressure Recovery**: Designed to maintain a high-pressure recovery coefficient, it delivers air with minimal losses, optimizing engine performance.
- **Minimal Distortion**: The duct ensures a uniform airflow profile, reducing turbulence that can affect engine efficiency.

Pod-mounted Subsonic Inlet Duct and notations



D_1 = highlight diameter; the forward most point of the nacelle.
D_{TH} = throat diameter; the minimum cross-sectional area of the intake geometry
$D_{Tip} = D_{fan}$ = the tip of the fan (supplied by the engine manufacturer)
D_{Hub} = rotor-hub diameter (supplied by the engine manufacturer)
D_{MAX} = maximum external nacelle diameter
L_{diff} = diffuser length, from throat to fan face
L_{FB} = nacelle forebody length; the distance from the highlight to the maximum diameter, D_{MAX}
a = semi-major axis of the internal lip
b = semi-minor axis of the internal lip
c = semi-major axis of the external lip
d = semi-minor axis of the external lip
θ = internal contour wall angle (below 10 deg; better at 6 deg)
L_{hub}/D_{hub} =Ratio of length to diameter….0.75

The throat area is sized from the Lip Contraction Ratio (LCR) = A_1/A_{TH} (typically, from 1.05 to 1.20).
LCR = 1.0 represents a sharp lip and 1.2 represents a well-rounded lip.
D_1 is typically 0.9 to 0.95 times the fan-face diameter.
$L_{diffuser}$ = 0.6 at 1 time D_{fan}
L_{FB} = 1 to 2 times D_{fan} (it must conform with the lip contour).

At the crown cut:
internal-lip fineness ratio, (a/b) = from 2 to 5 (typically 1.5 to 3.0)
external-lip fineness ratio, (c/d) = from 3 to 6 (typically 3 to 5)
b is 1.5 to 2 times d.

Inflection point (at around 0.5 to 0.75 L_{diff}).
the maximum wall angle θ should not exceed 8 or 9 deg.

- An analytic expression that has had wide use in recent years for inlet lips is the Bi-super ellipse.

$$(x/a)^p + (y/b)^q = 1.0$$

- 24The curvature distribution is controlled by the exponents p and q. The fineness ratio is a/b. The lip thickness is b but the contraction ratio, CR, is the more commonly used measure of lip thickness and is given by where r_t is the throat radius and is assumed to be fixed before the lip optimization is performed. In the case of the diffuser the bi-super ellipse can be used provided one of the exponents is less than 1.0 and the other is greater than 1.0.

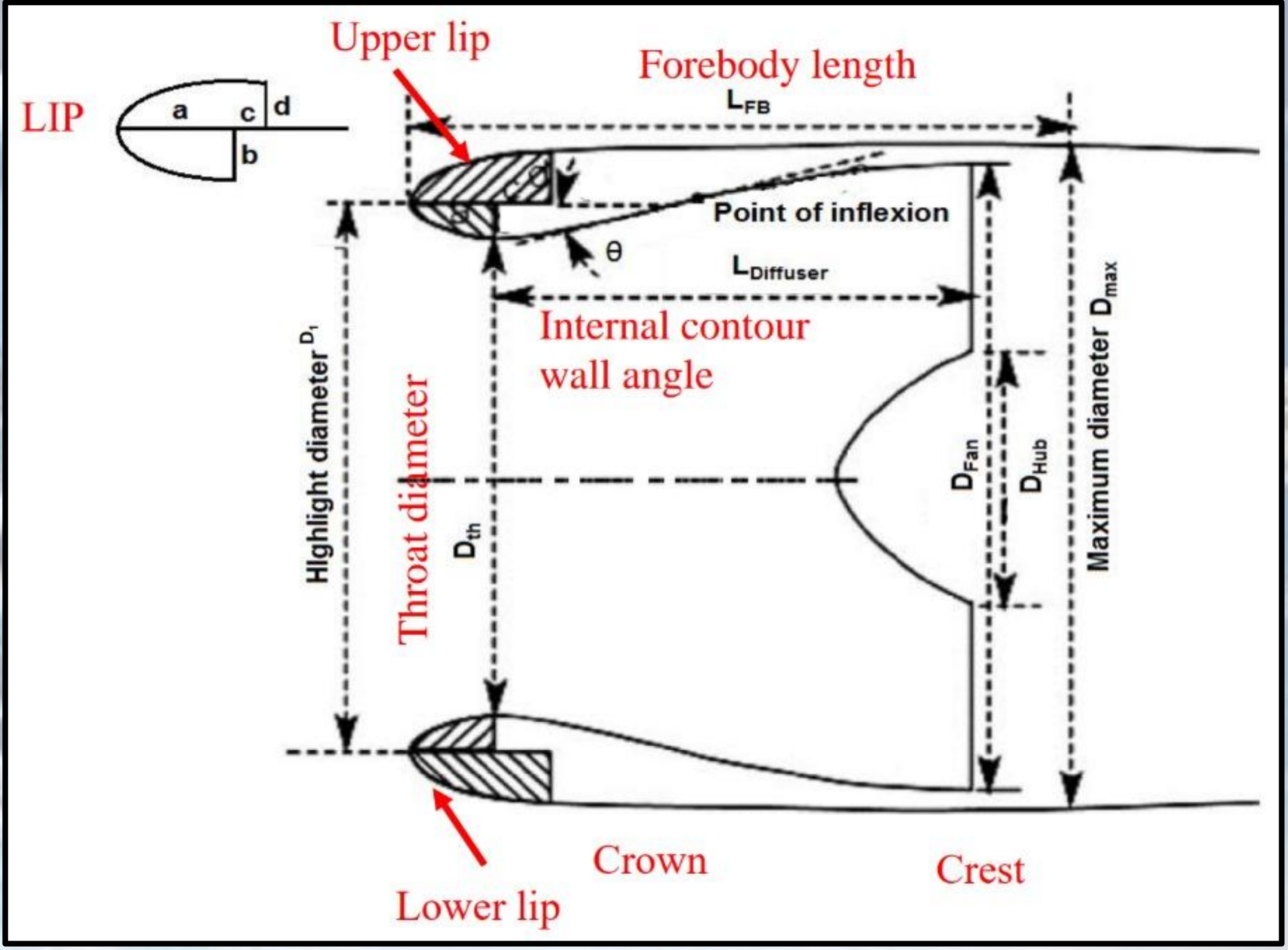
$$CR = A_{h\ell}/A_t = r_{h\ell}^2/r_t^2 = (r_t + b)^2/r_t^2$$

- The diffuser height is determined by the diffuser area ratio -

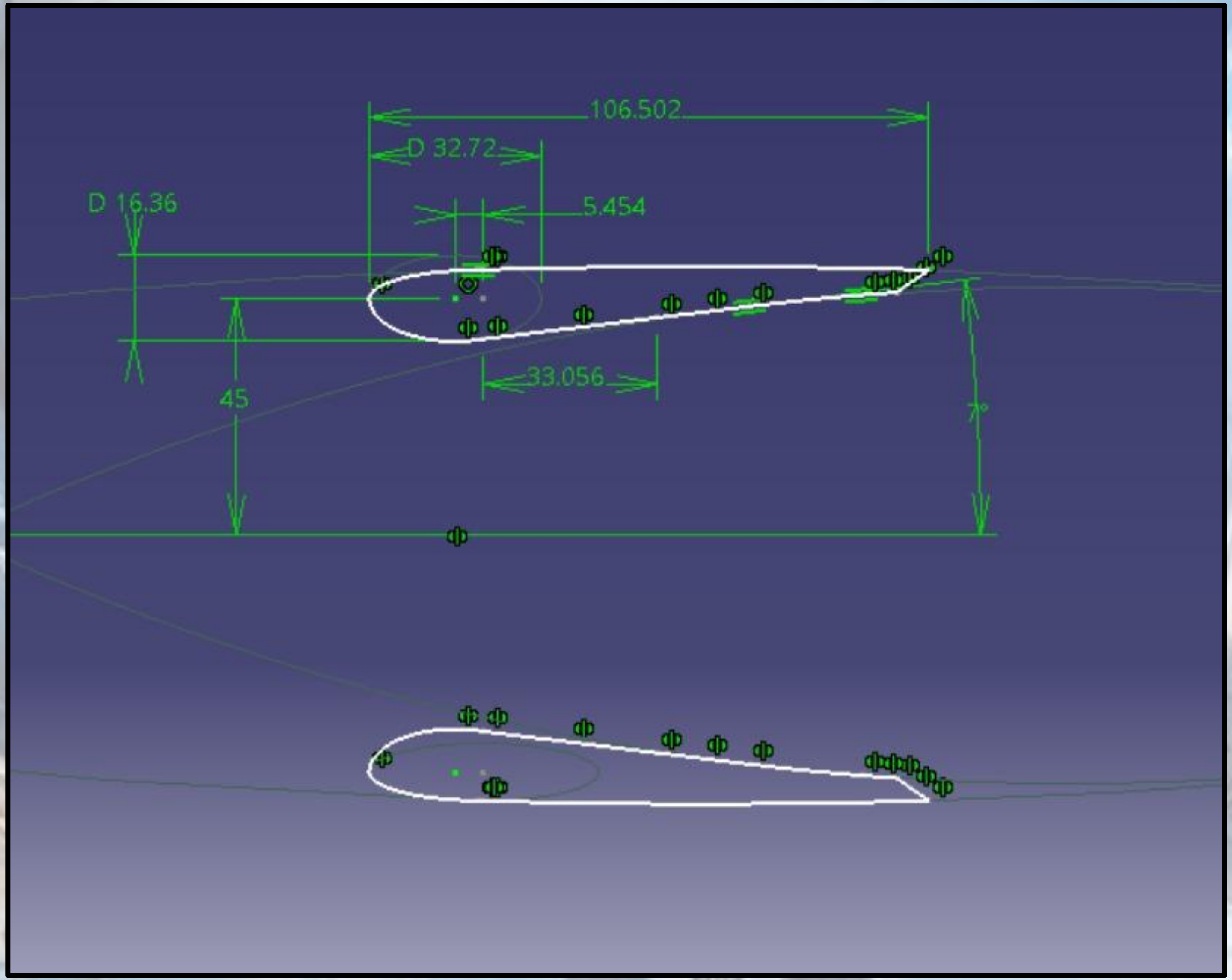
$$A_{de}/A_t = \left(r_{de}^2 - r_{cb}^2\right)\Big/r_t^2 = \left[(r_t + h)^2\right]\Big/r_t^2$$

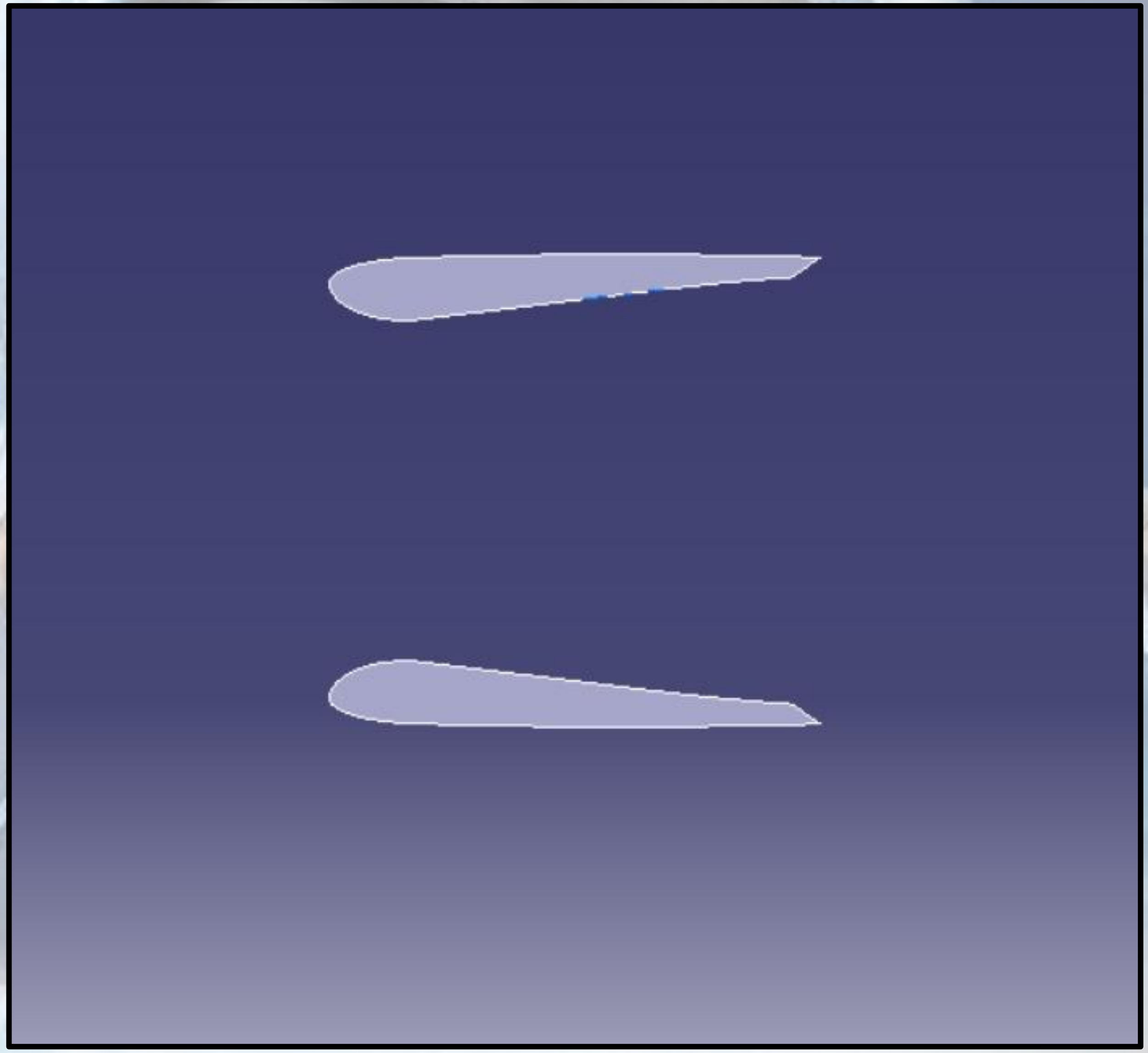
Inlet Parameters

- $a/b = 2$
- $c/d = 4$
- $b = 3d/2$
- $A_1/A_{th} = 1.1$
- $L_{diff} = 0.9*D_{fan}$
- $L_{fb} = 1.2*D_{fan}$
- $L_{hub} = 0.75*D_{hub}$
- $\theta = 7$ deg
- Assumption: Scale down calculations-
  1. $D_{fan} = 100mm$
  2. $D_1 = 90mm$
  3. $D_{hub} = 0.4*D_{fan}$

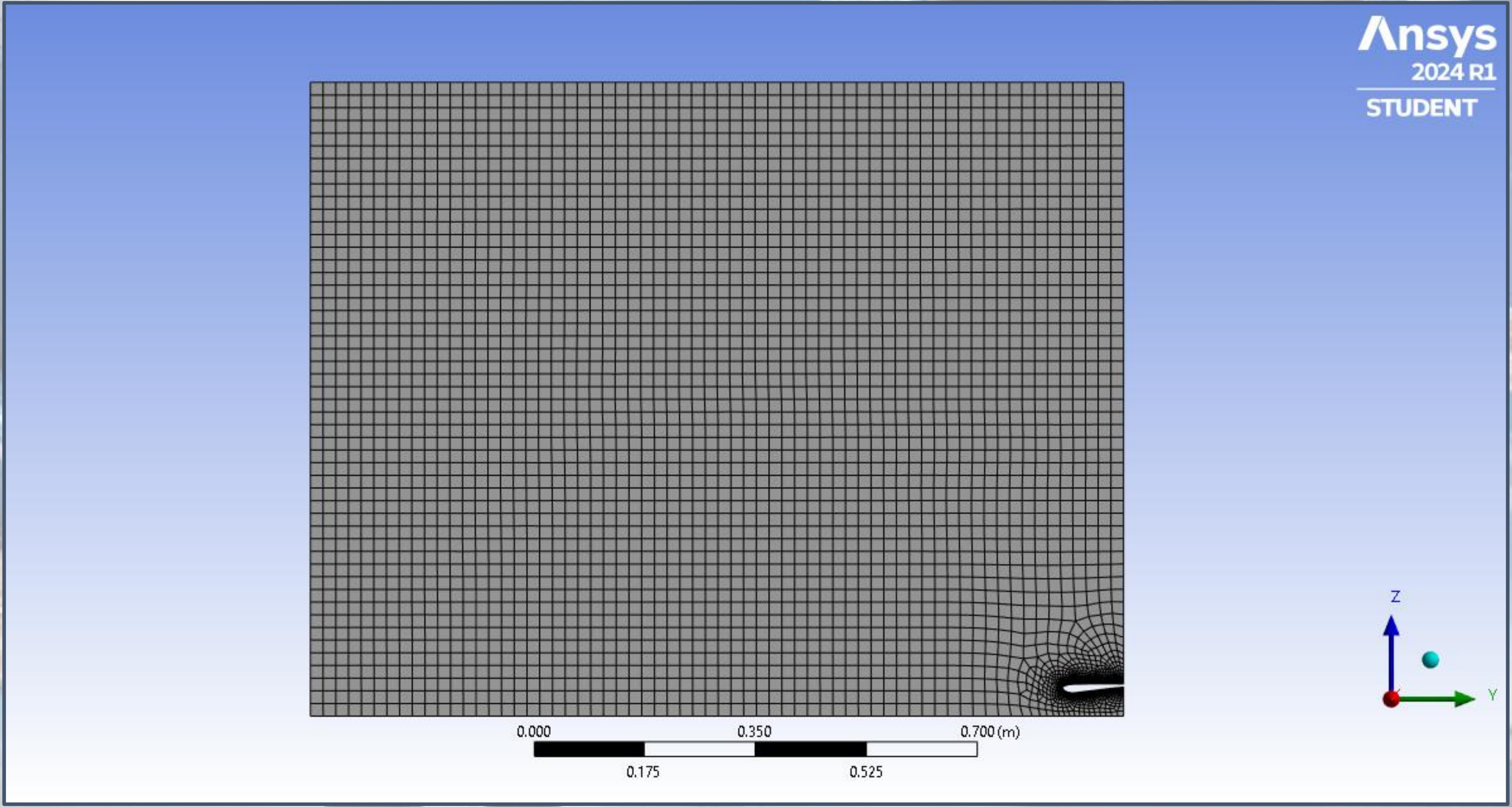


CAD MODEL With Dimensions

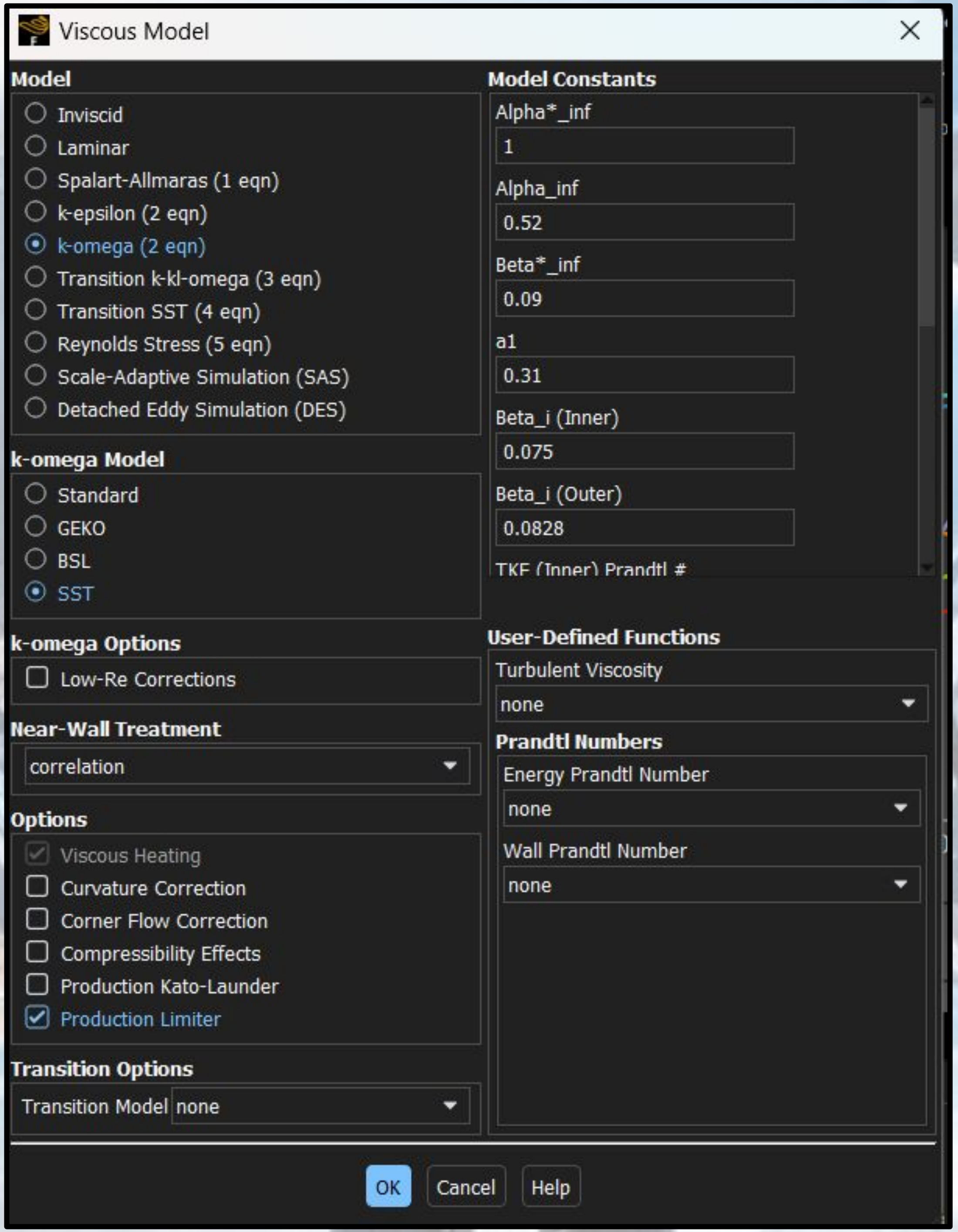


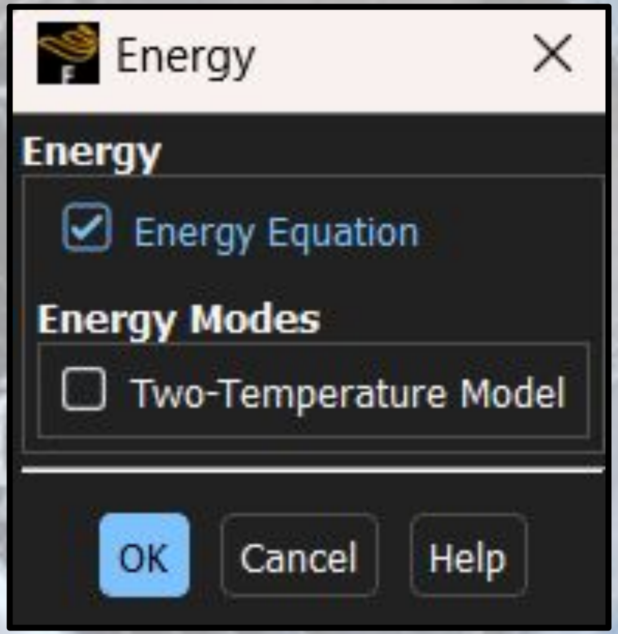


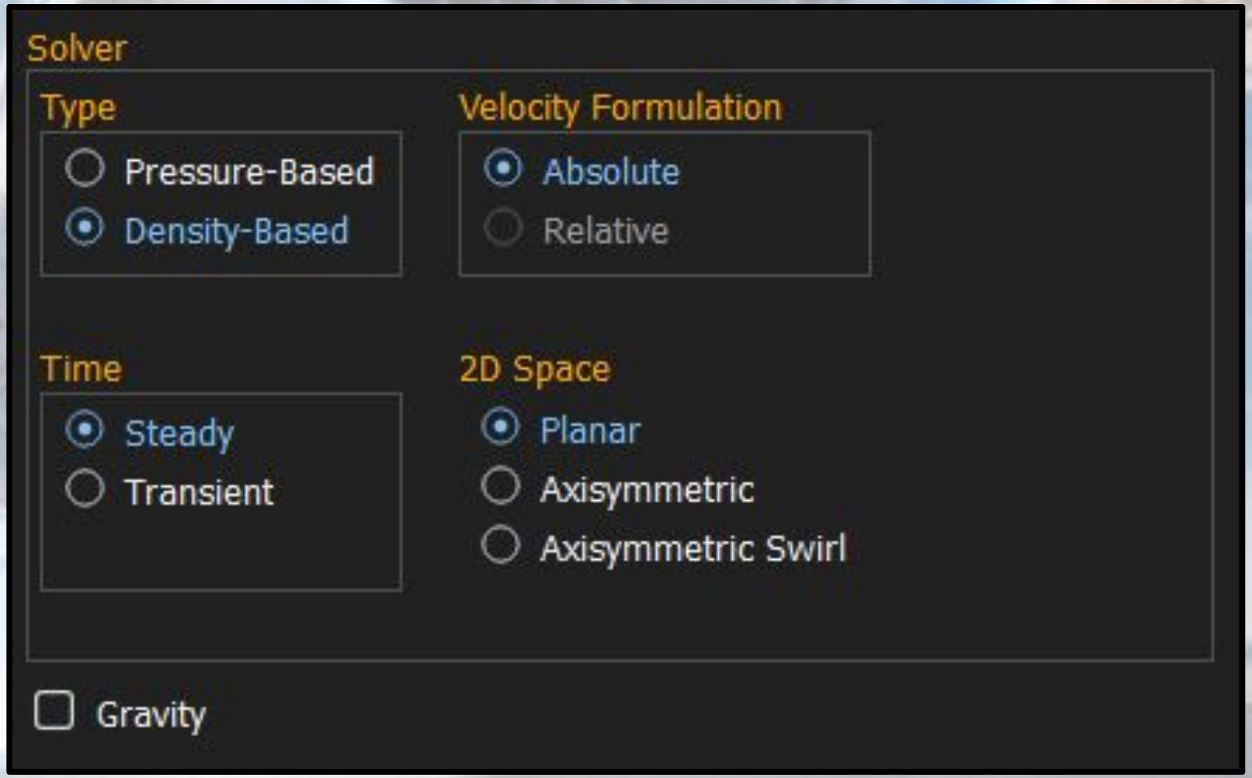
Meshed Flowfield



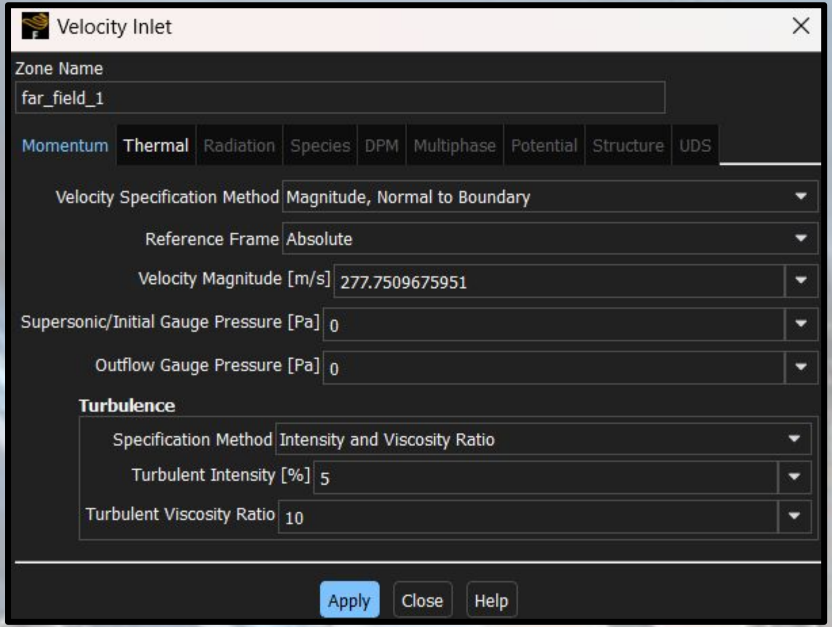
Fluent Solver Model Settings

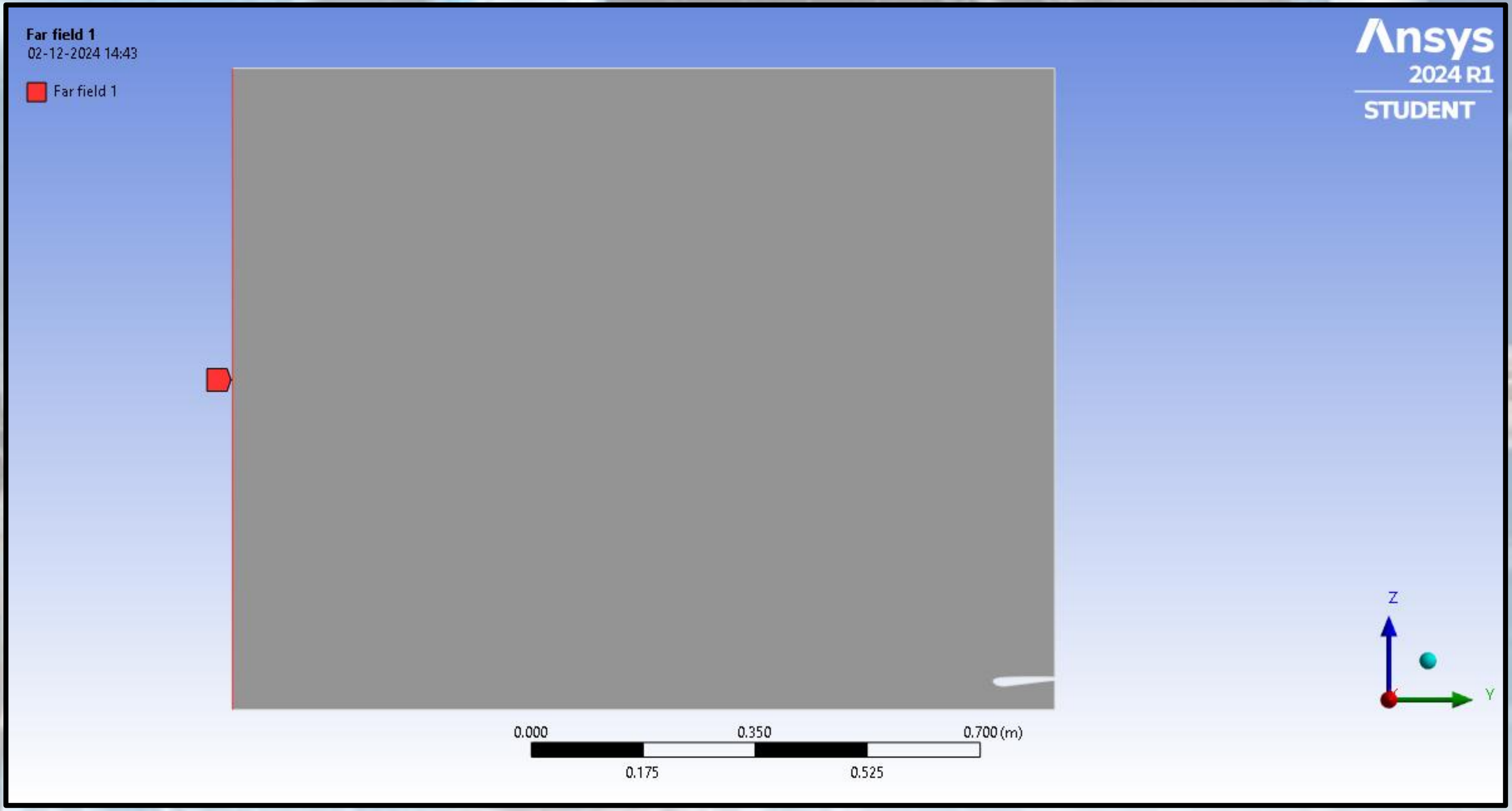






Boundary conditions





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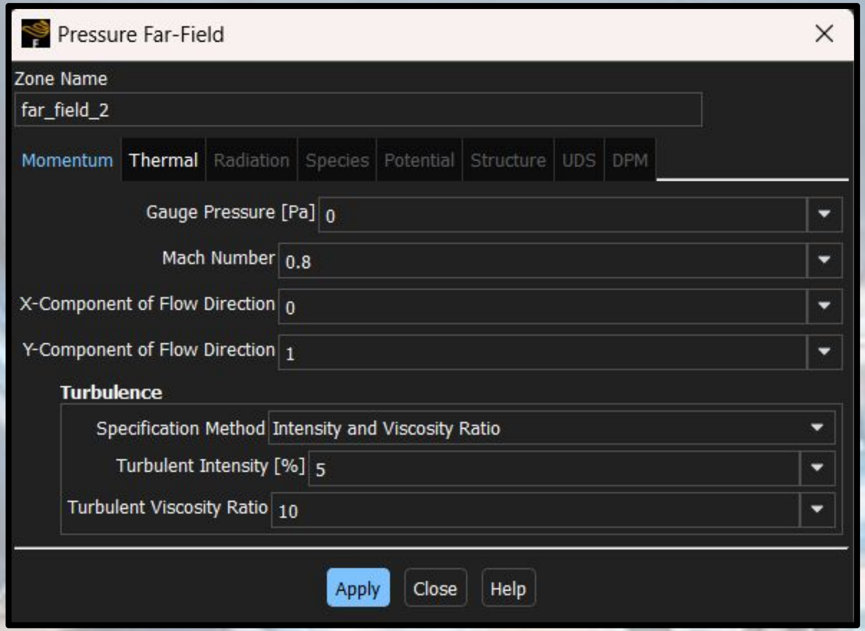
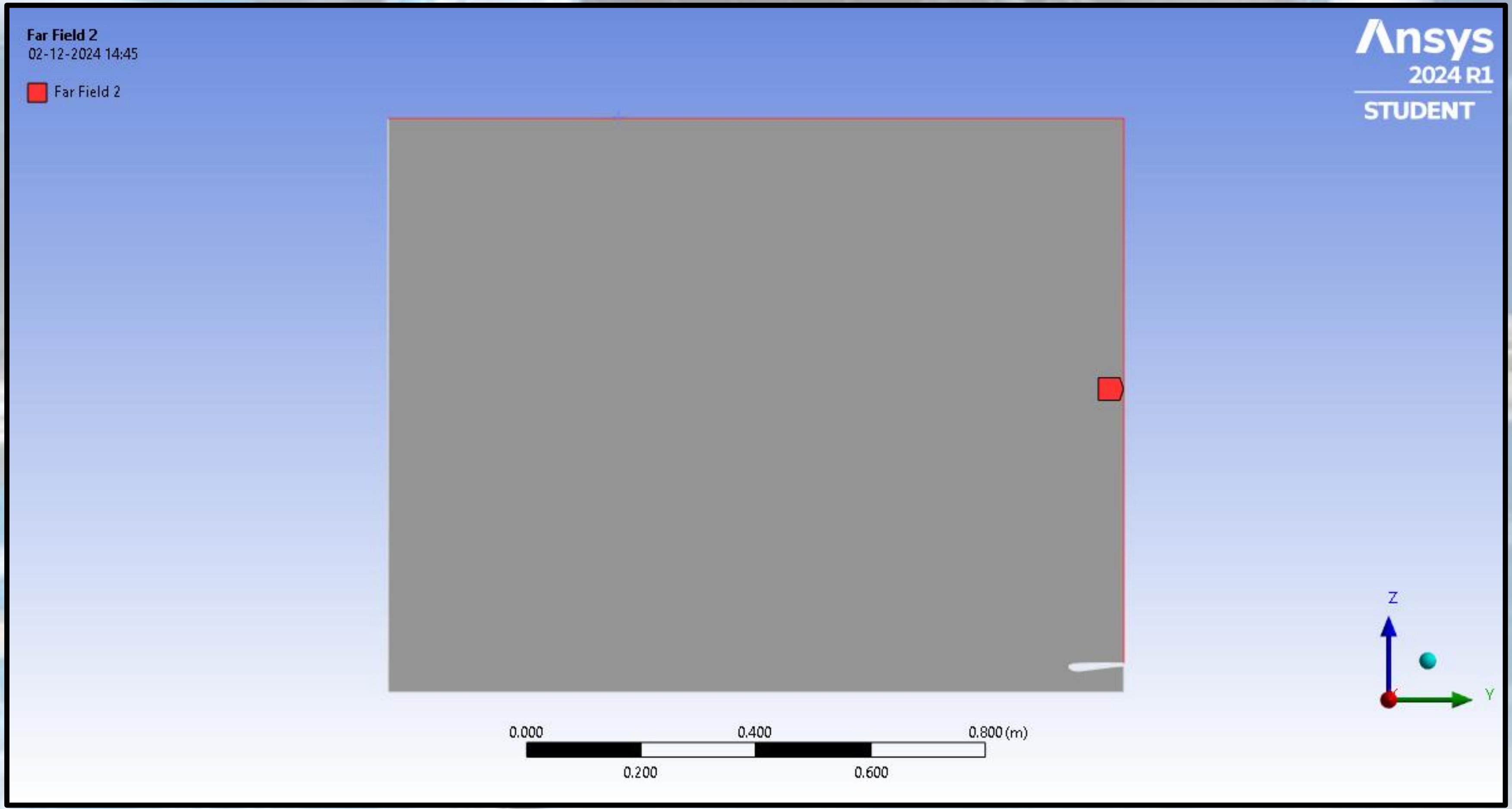


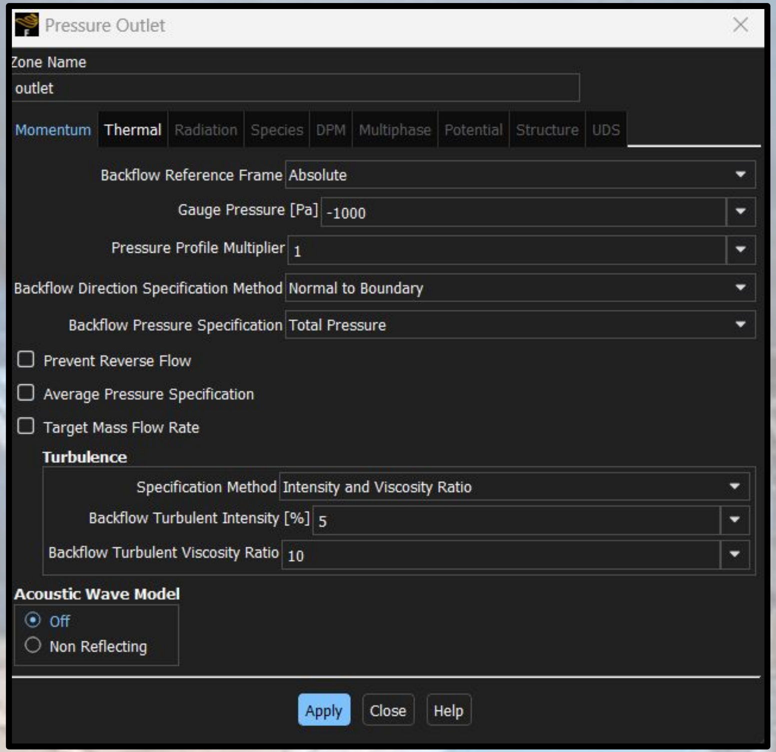


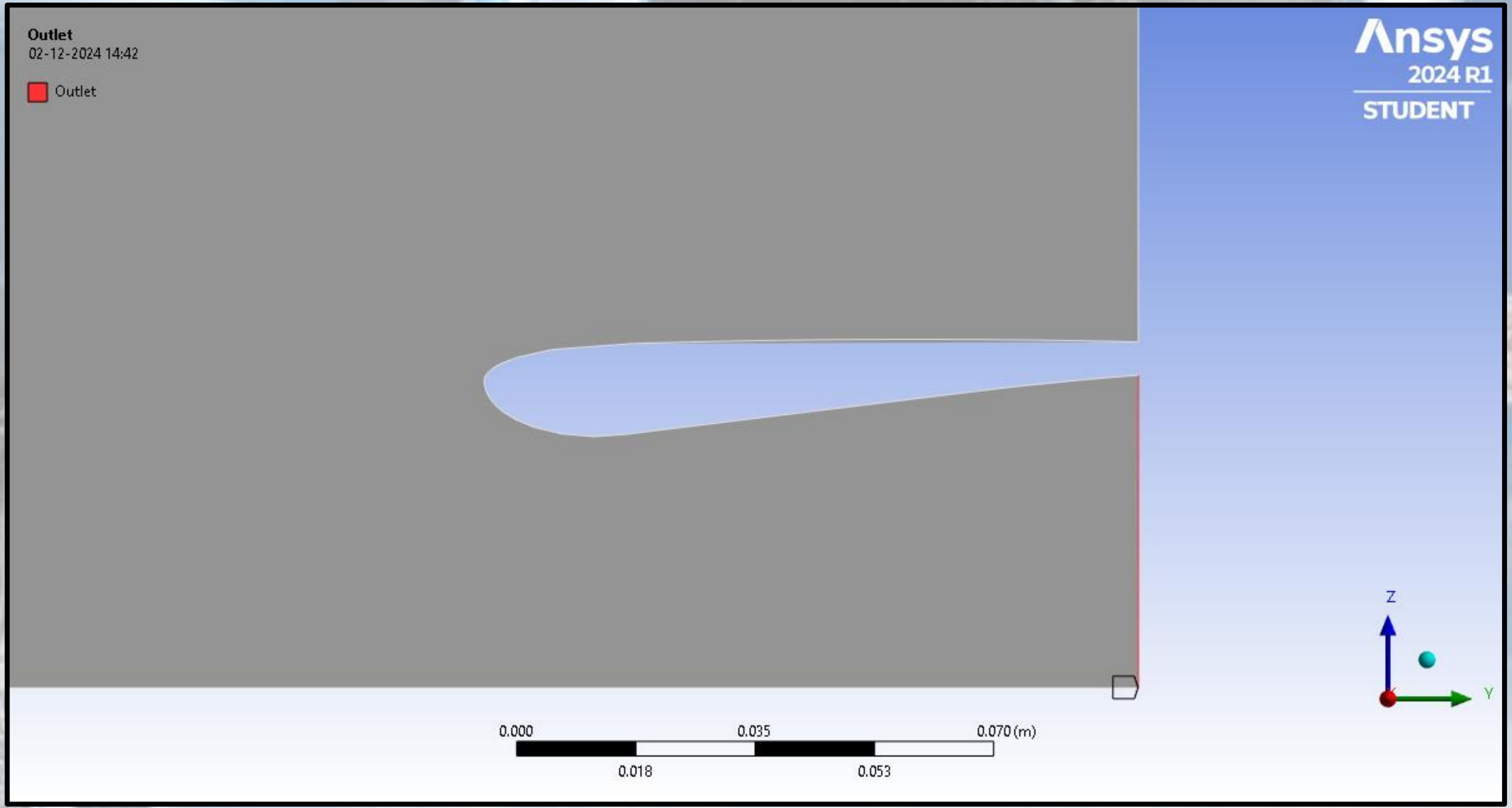
[Ground Condition Analysis]

$P_\infty = 101325$ Pa

$T_\infty = 300$ K

Boundary conditions





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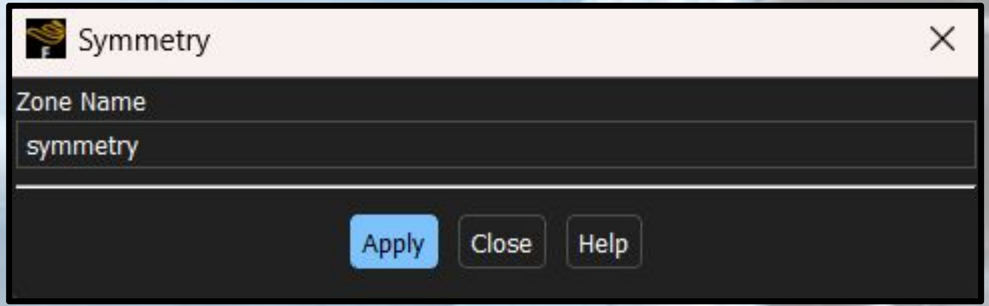

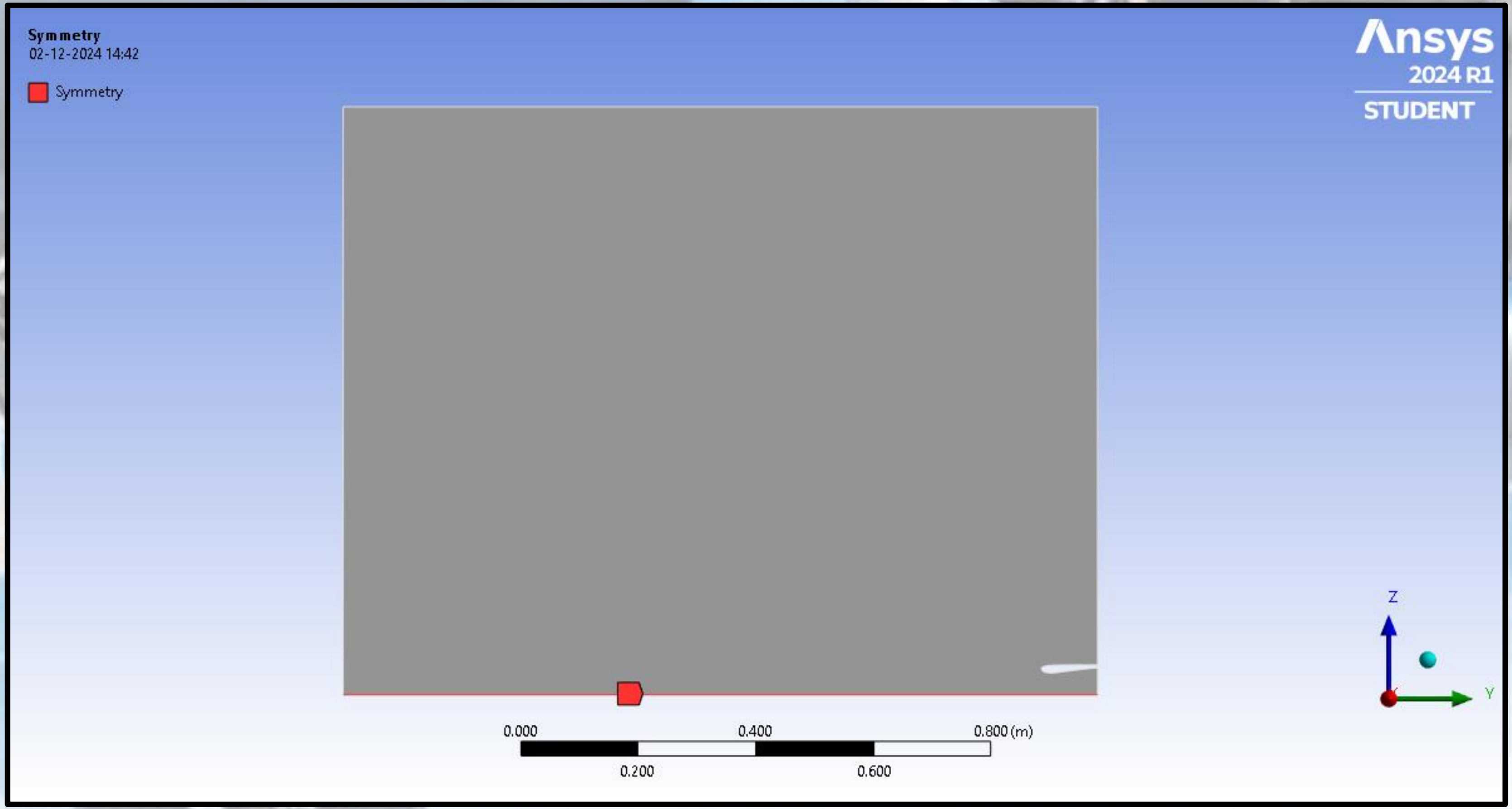

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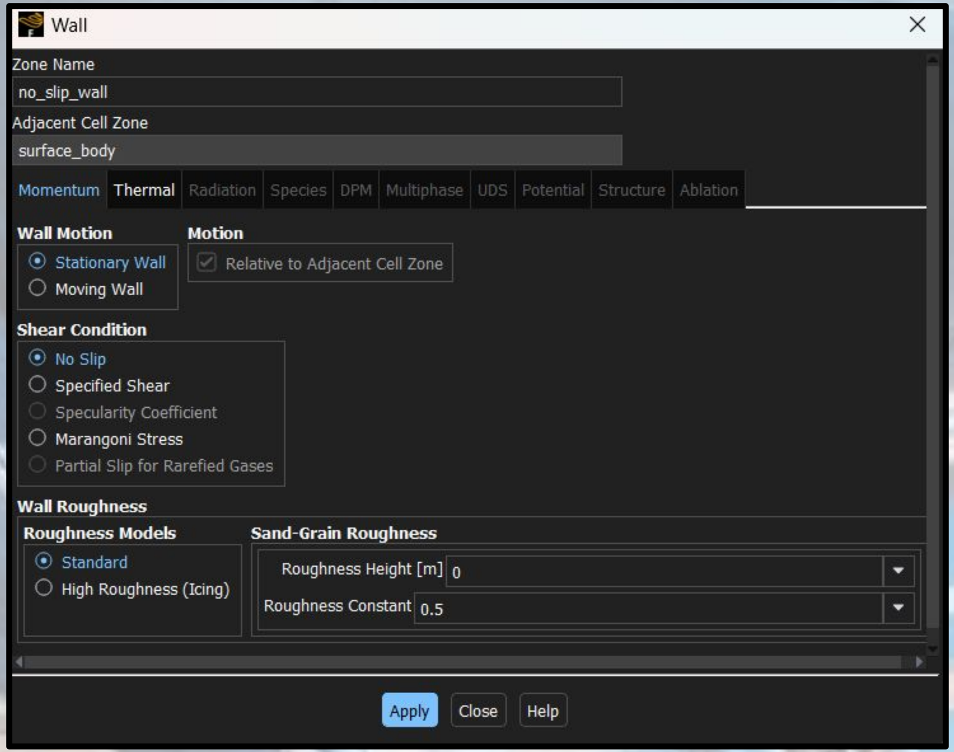
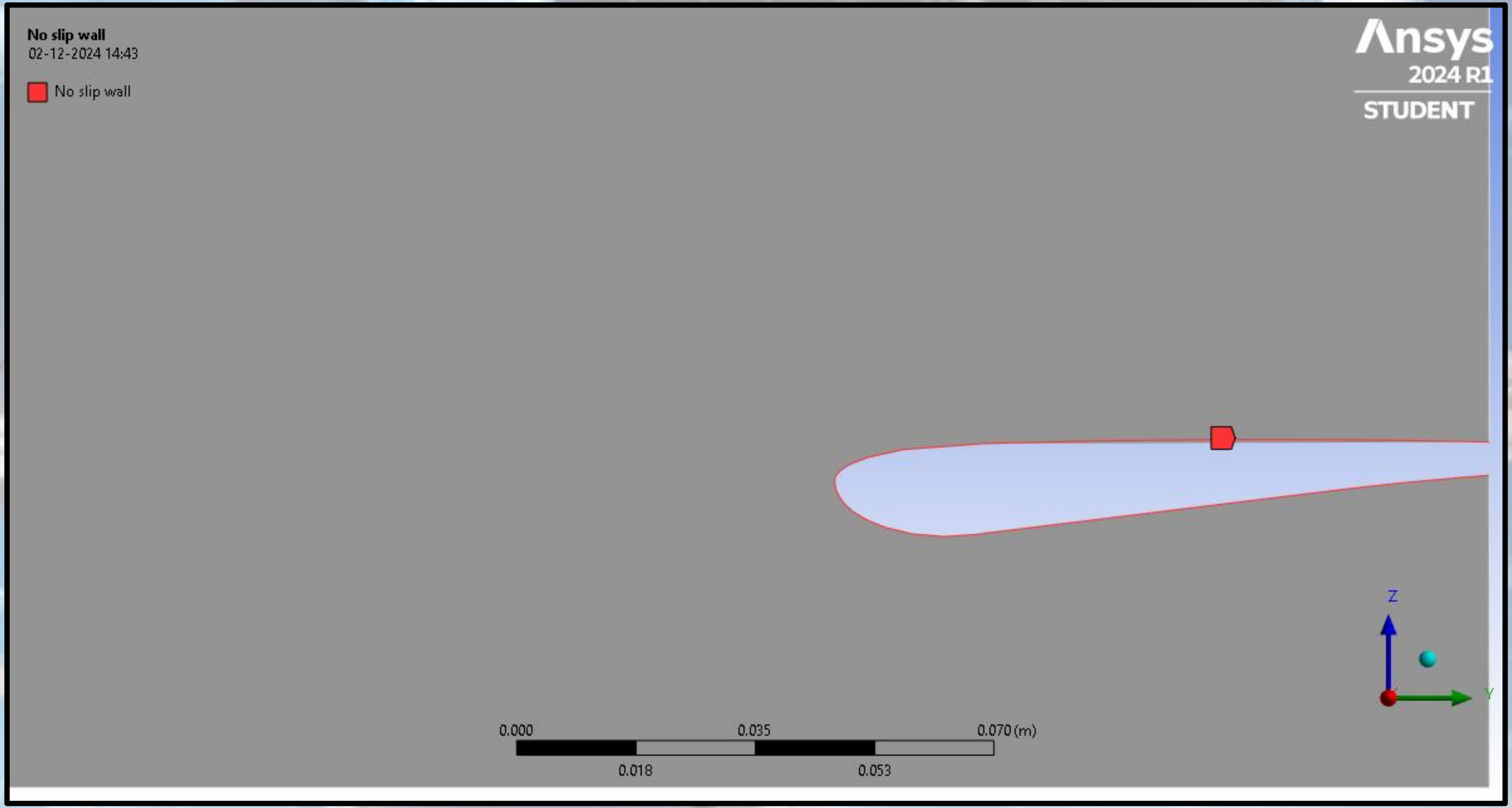
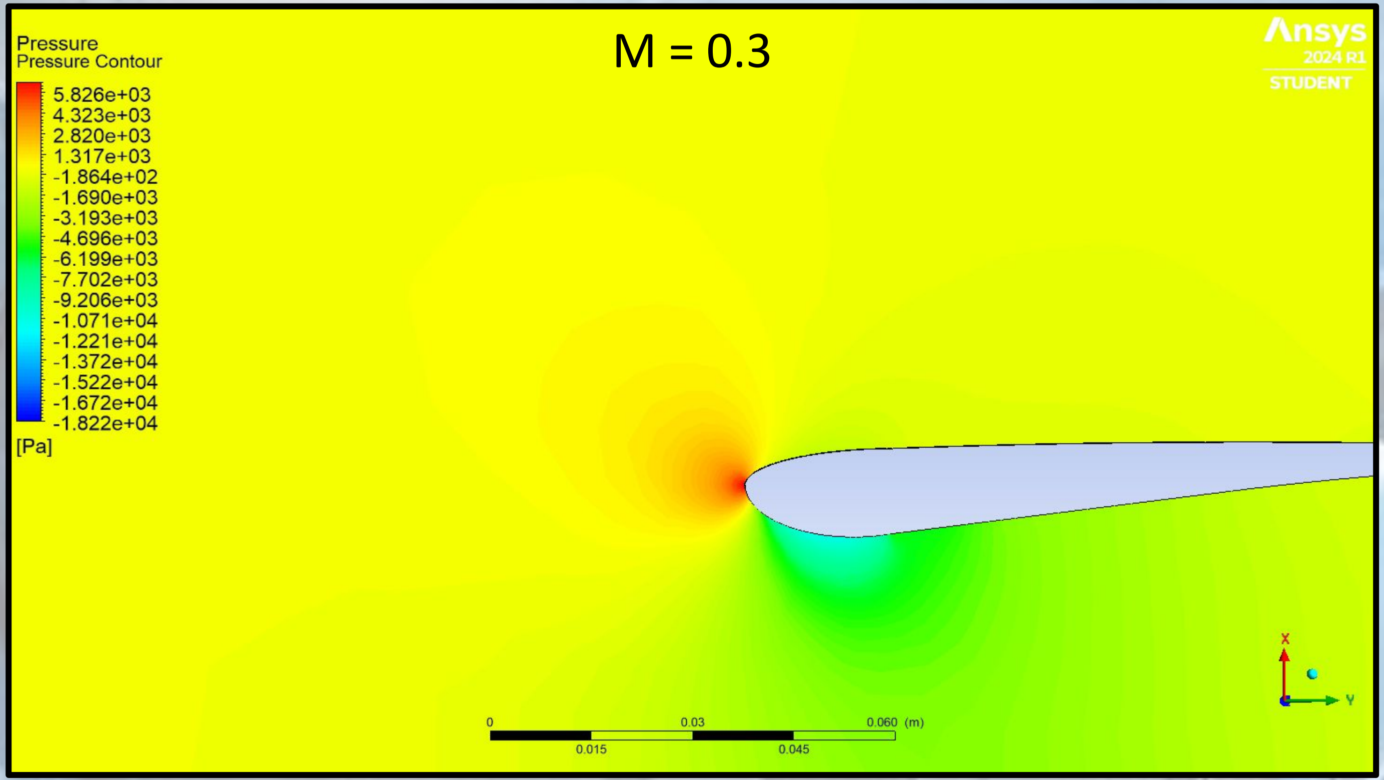
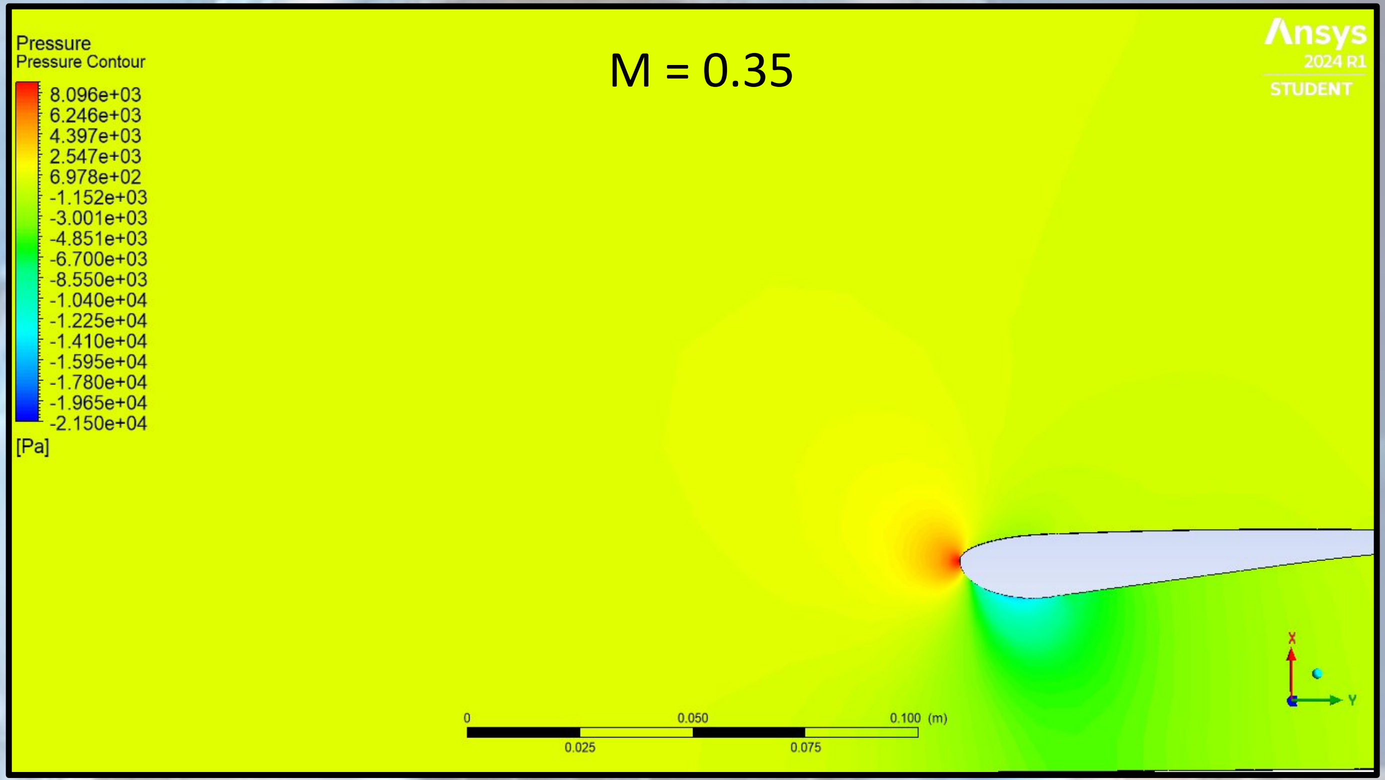
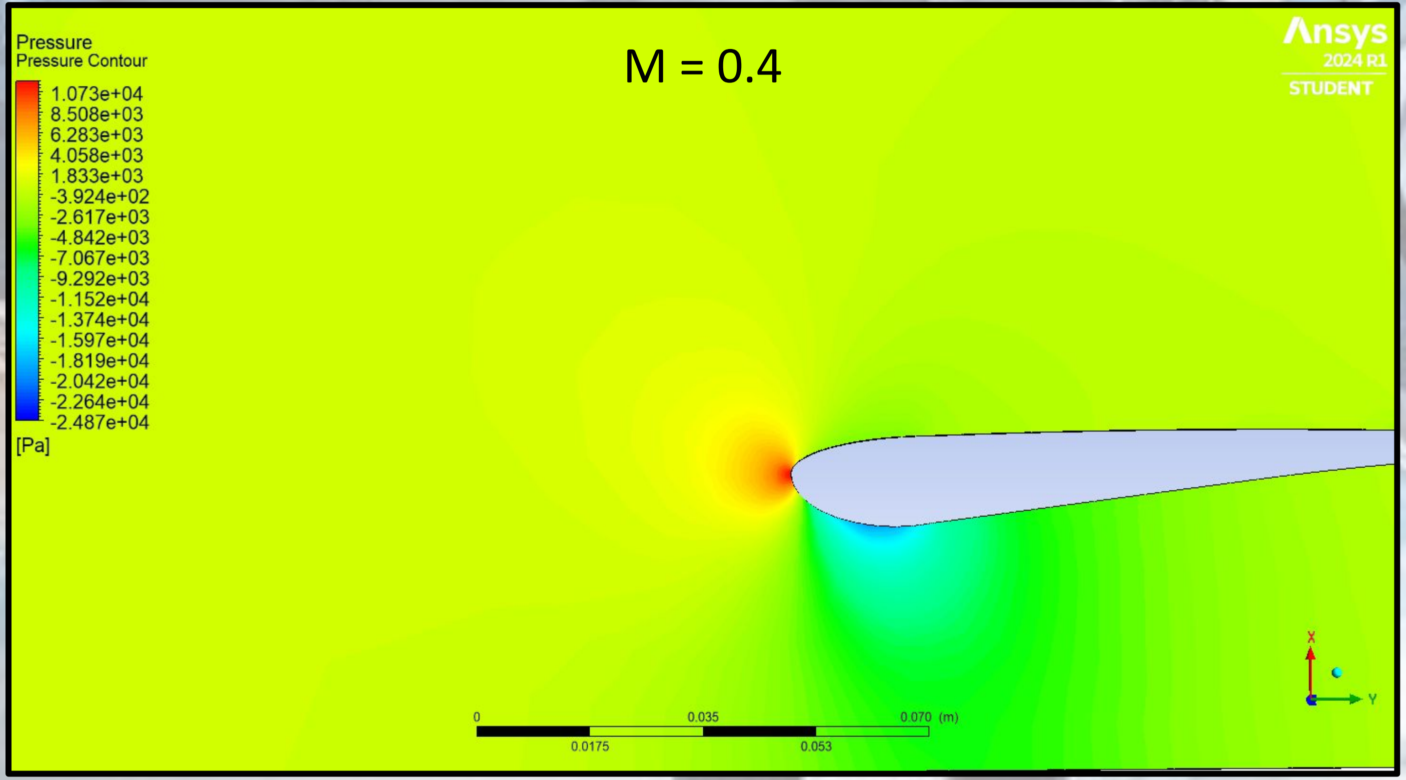


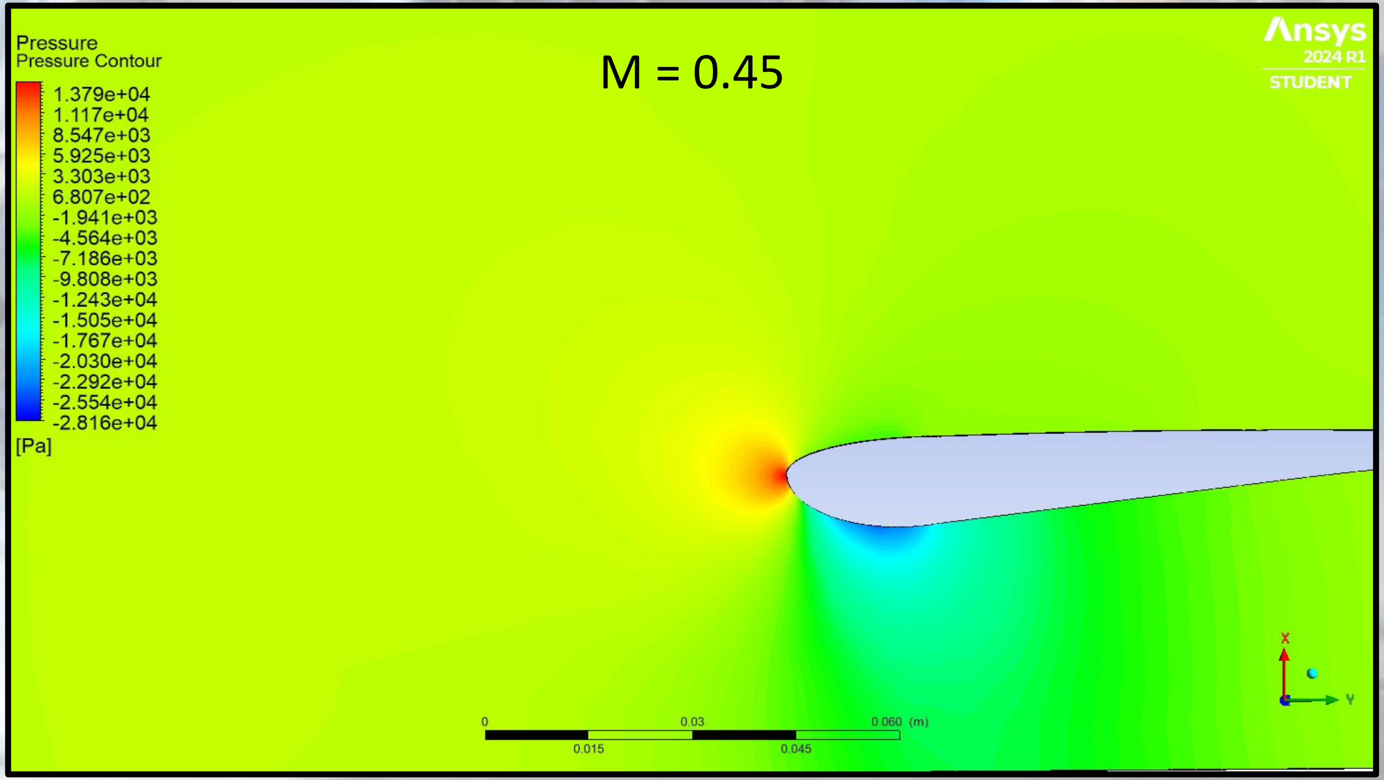


Pressure Contours









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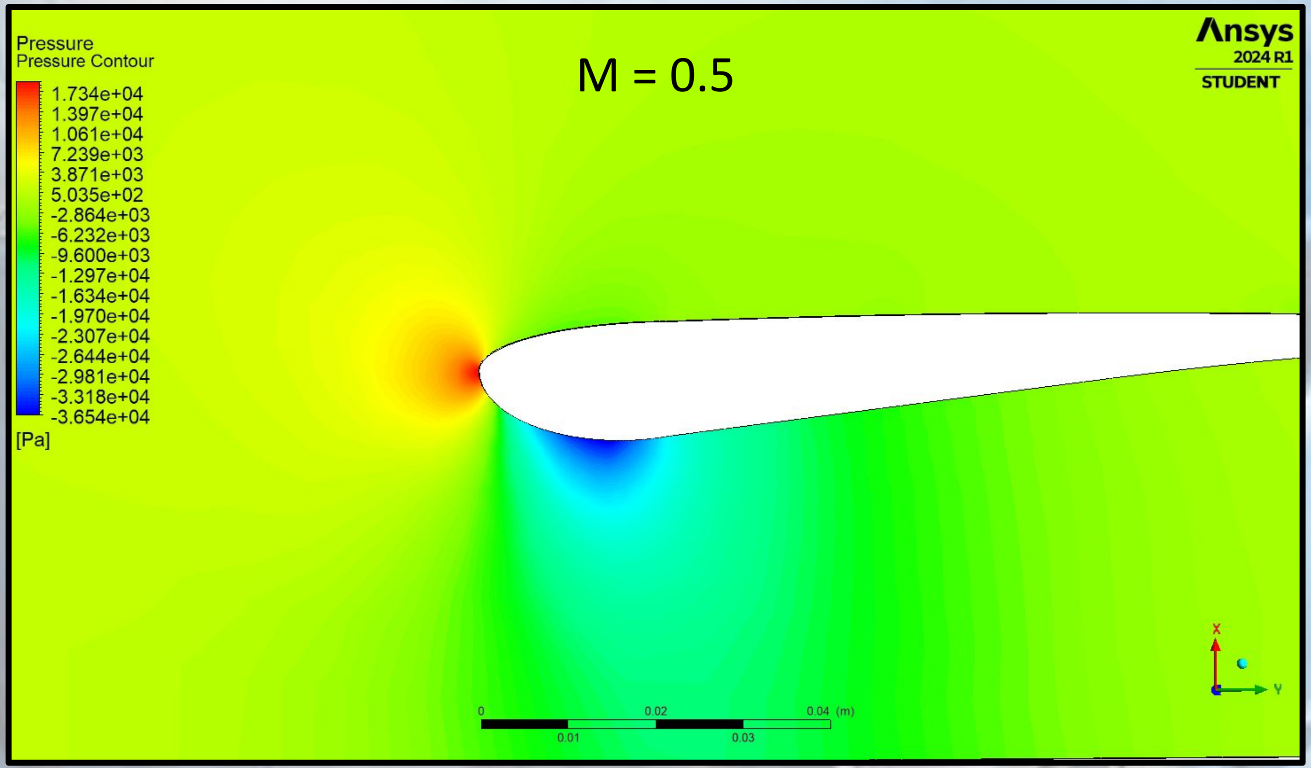

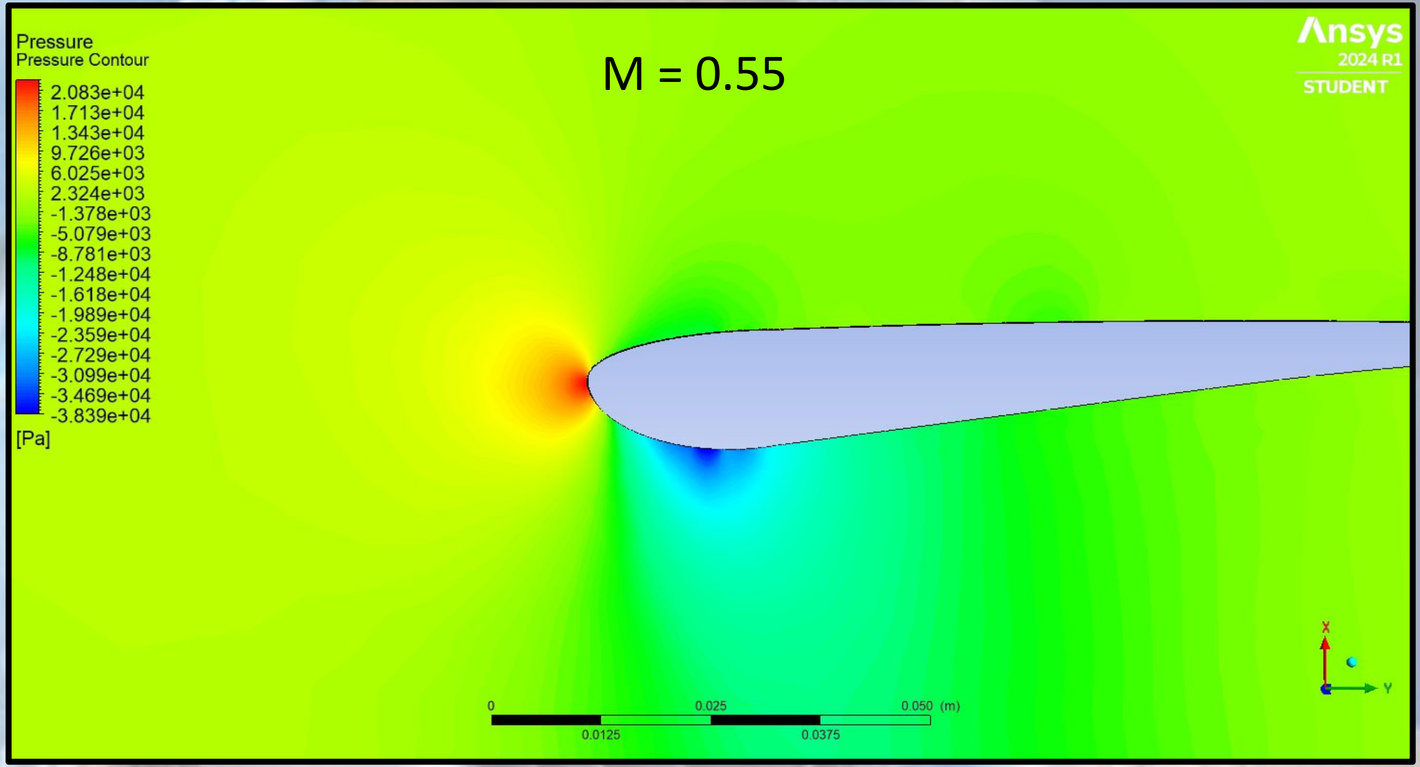

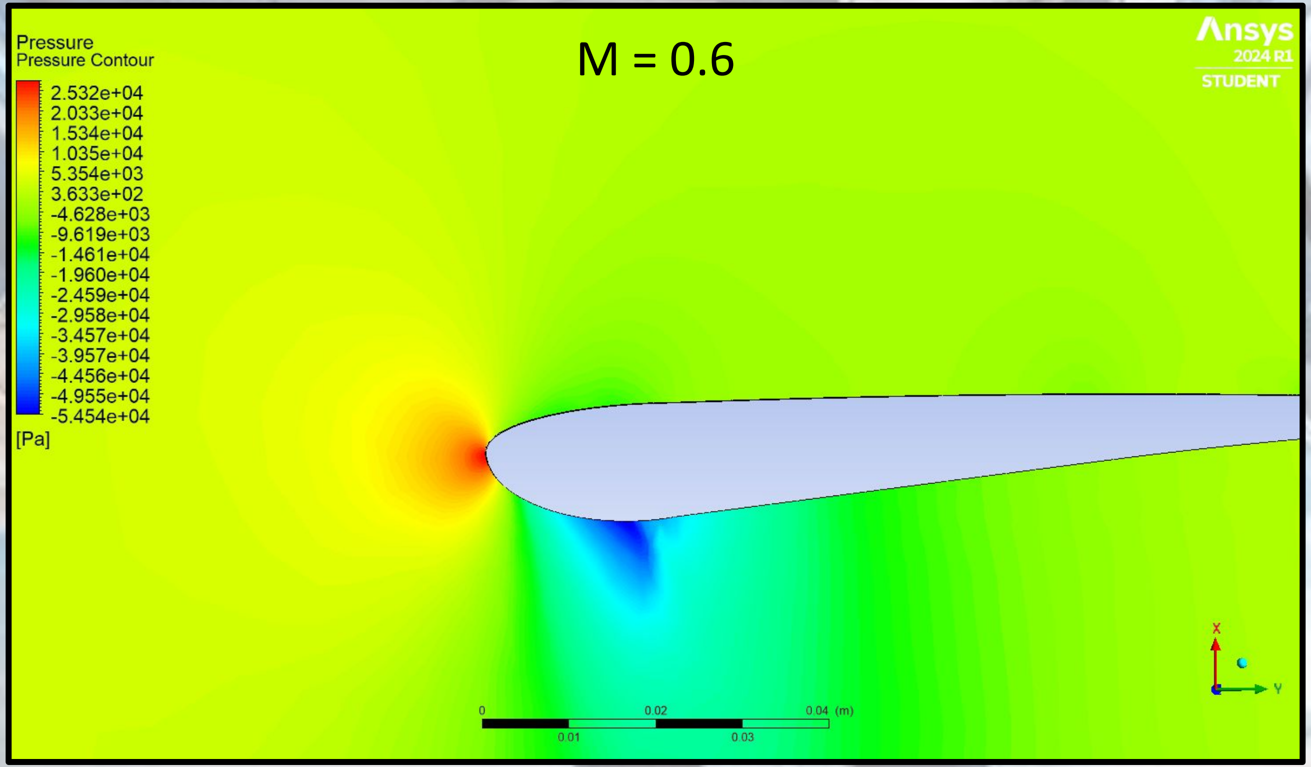

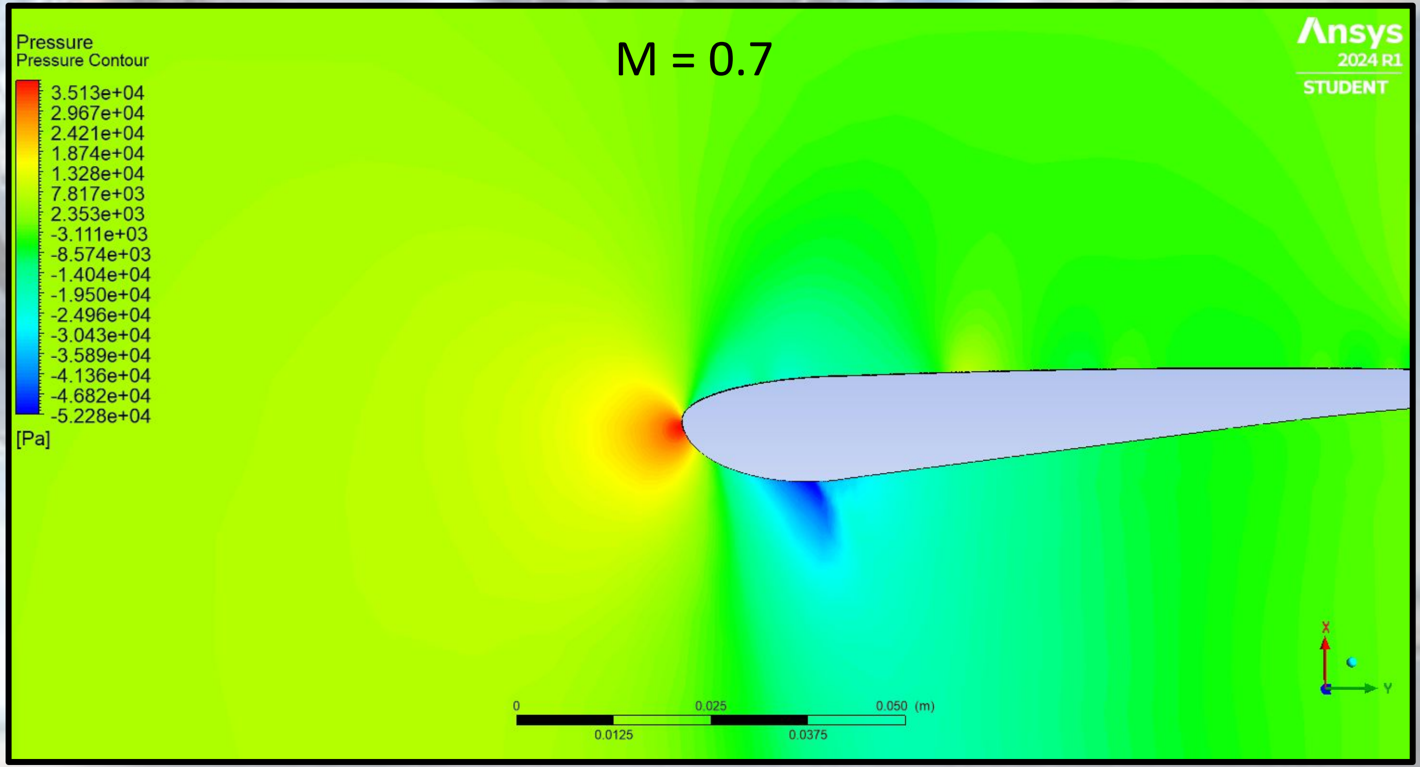

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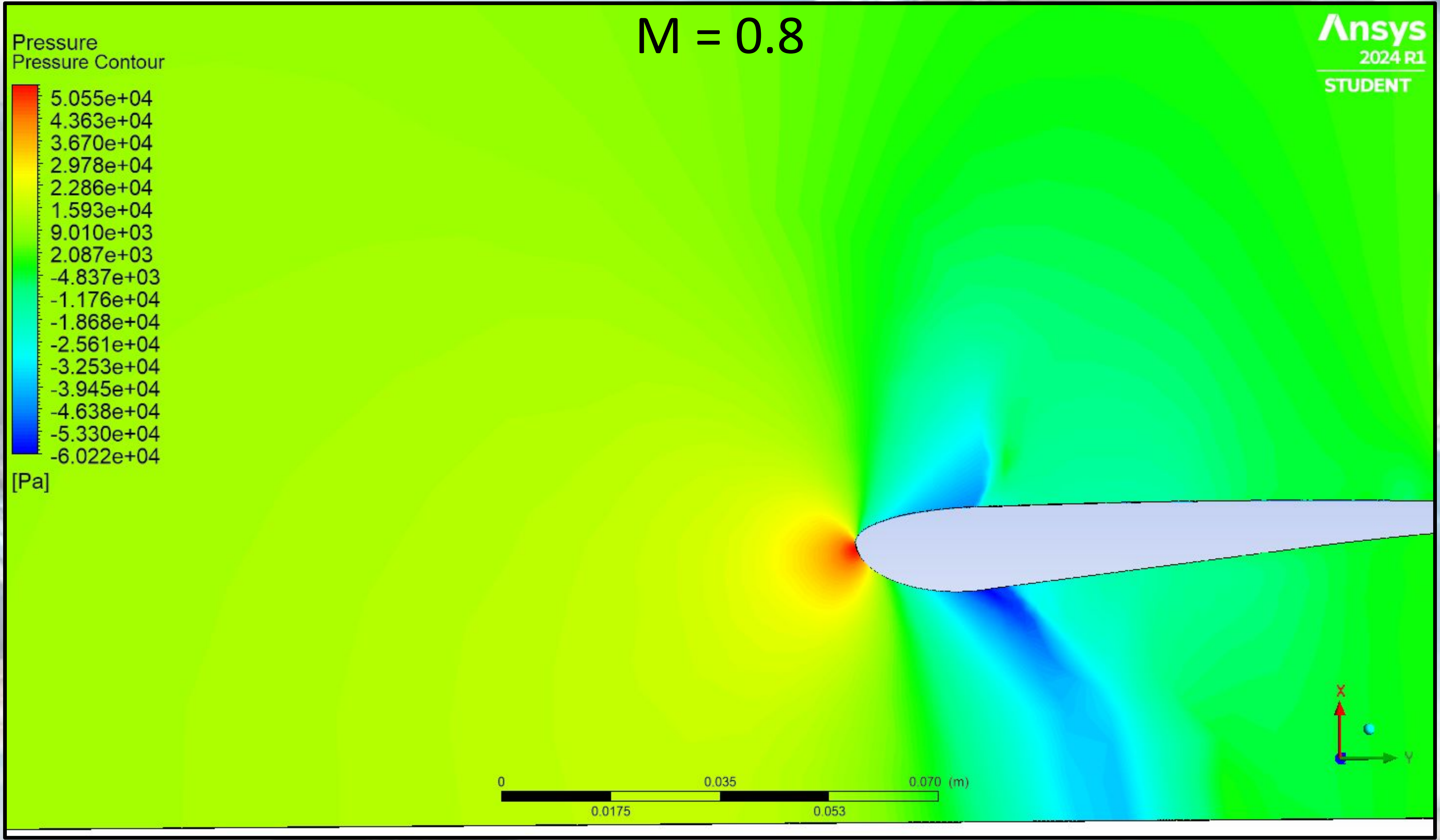
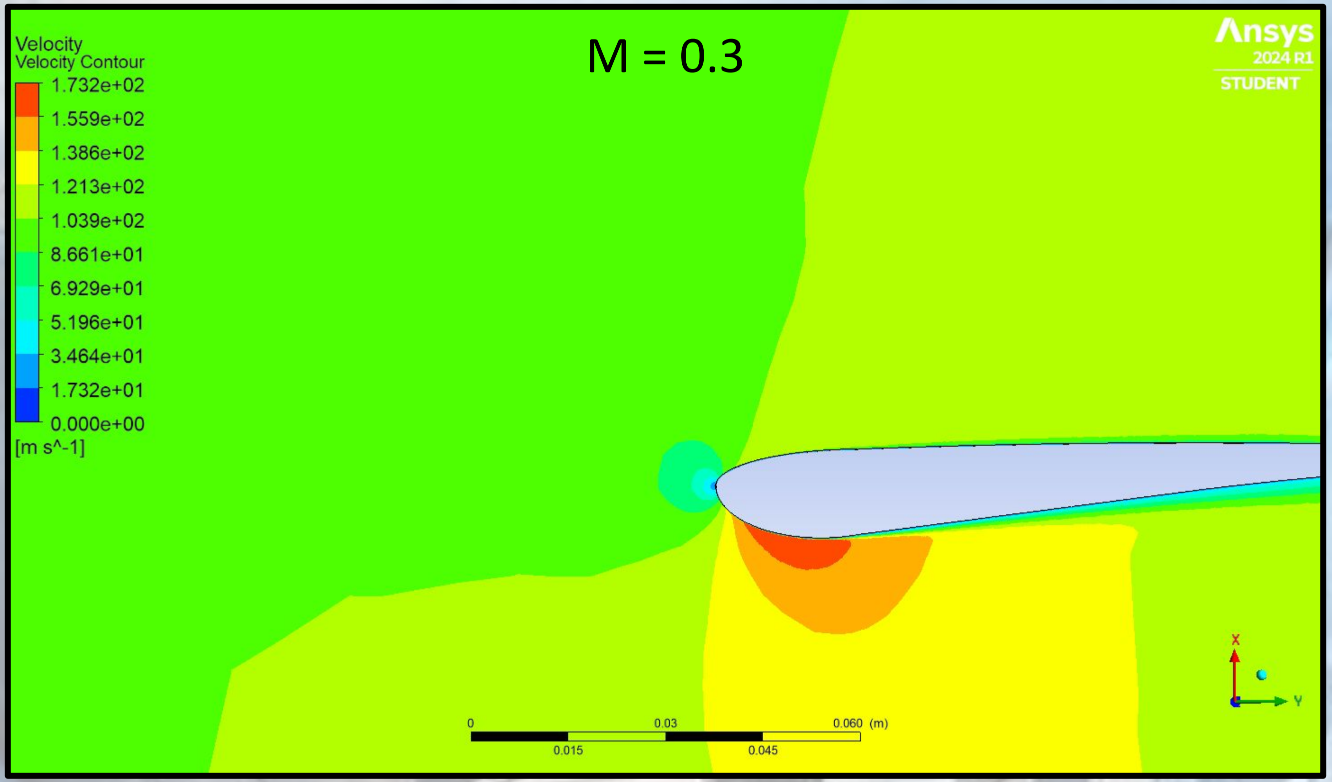
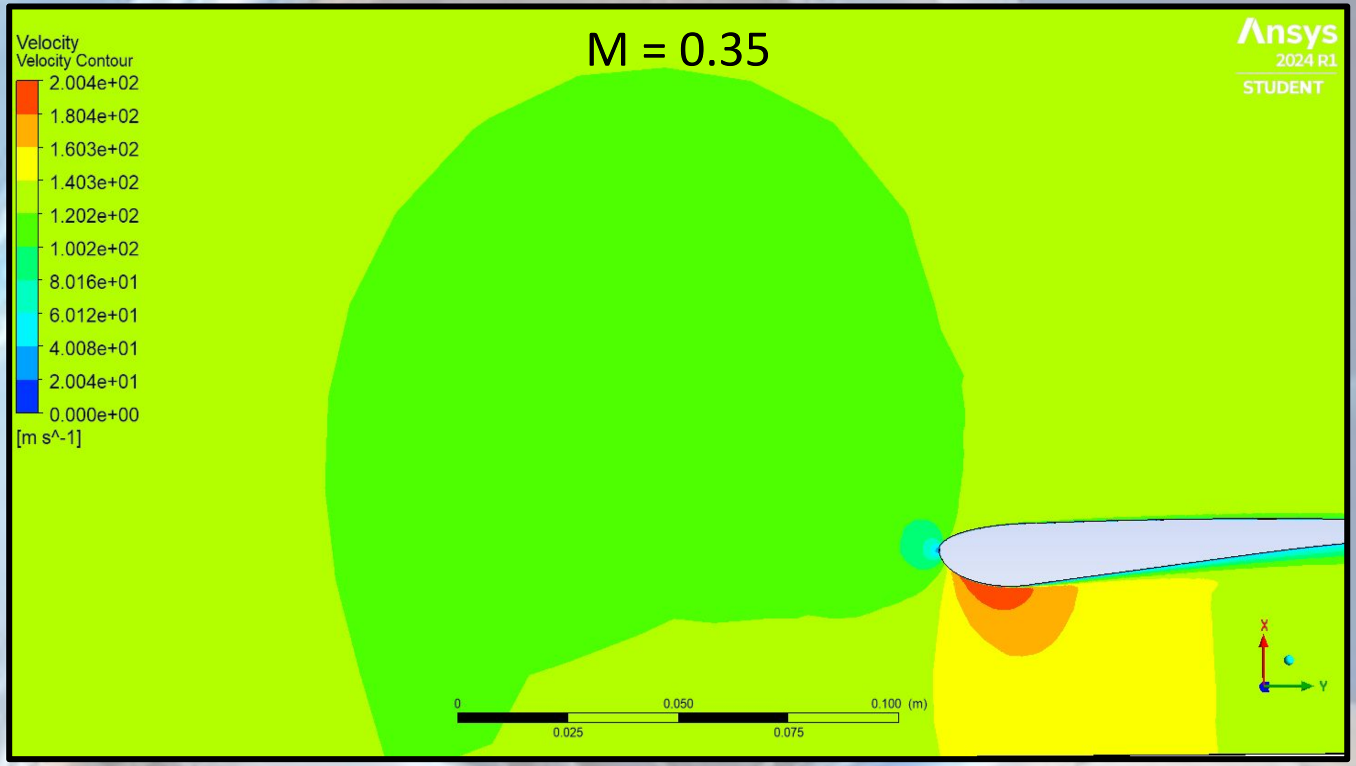
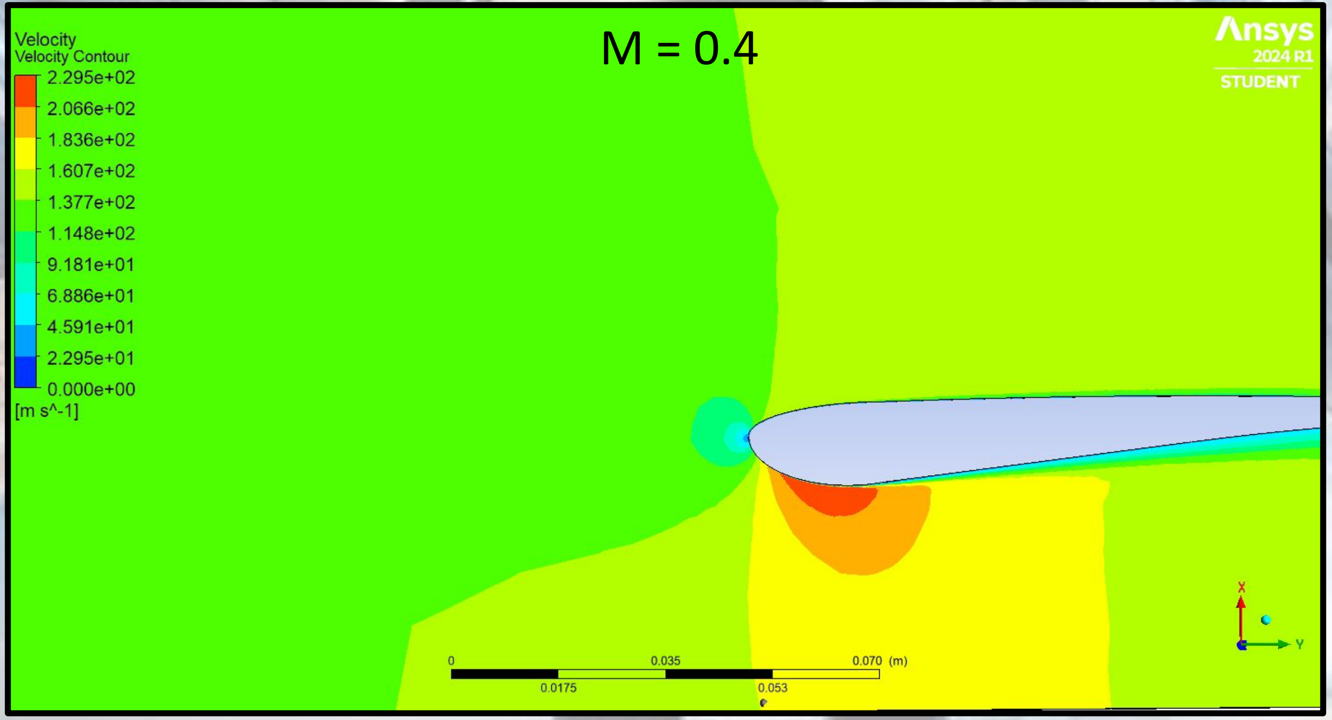
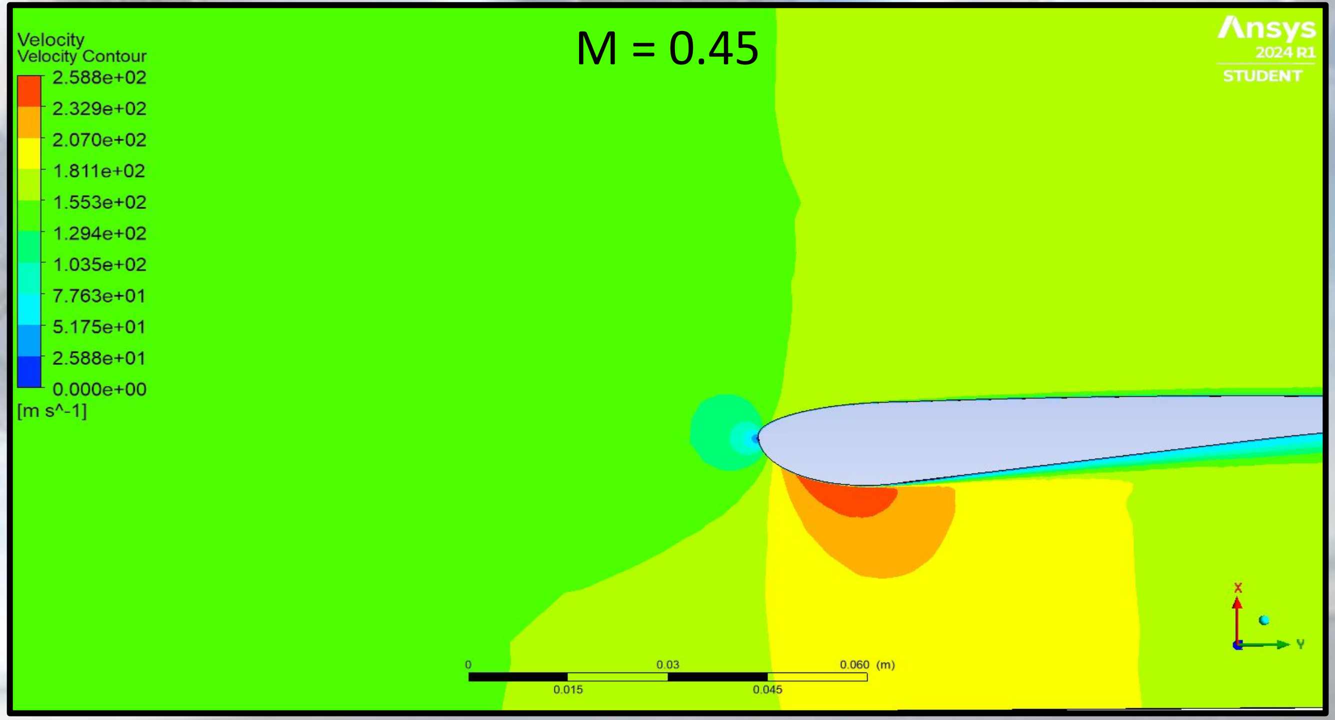


Velocity Contours









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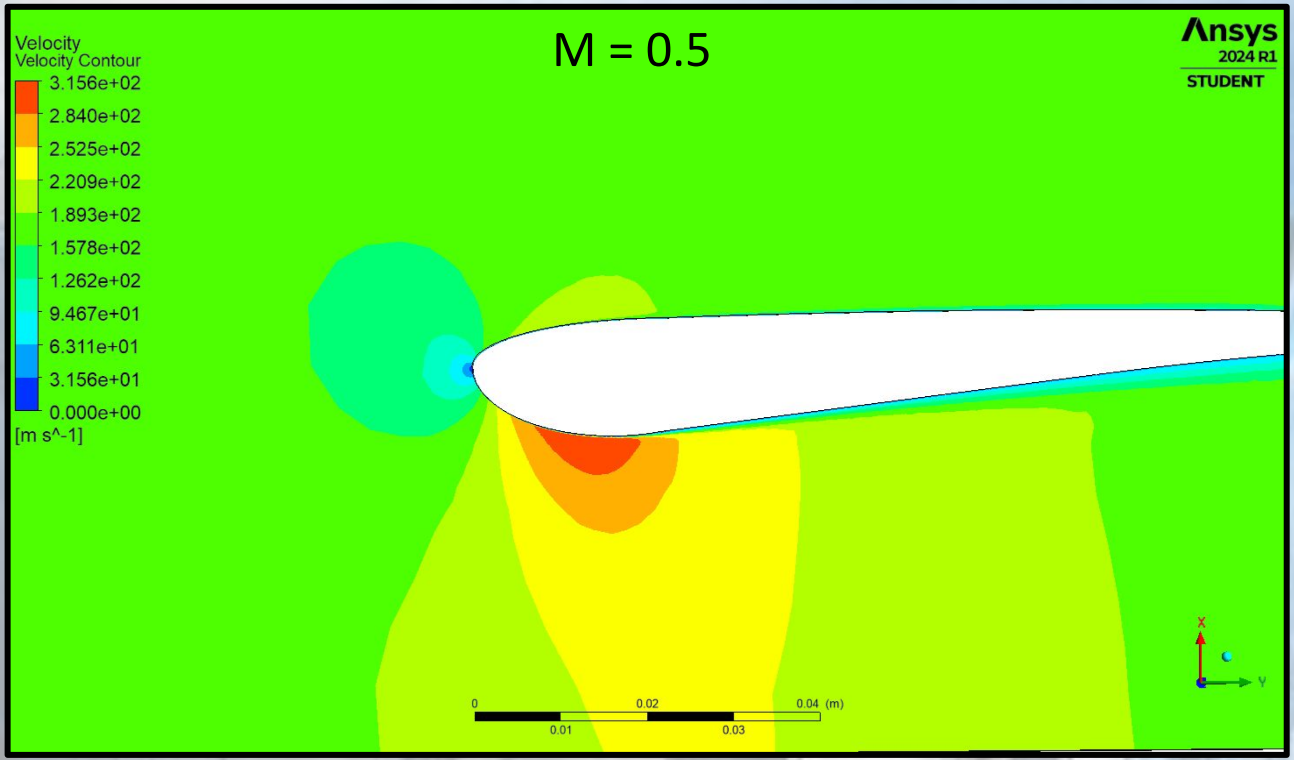

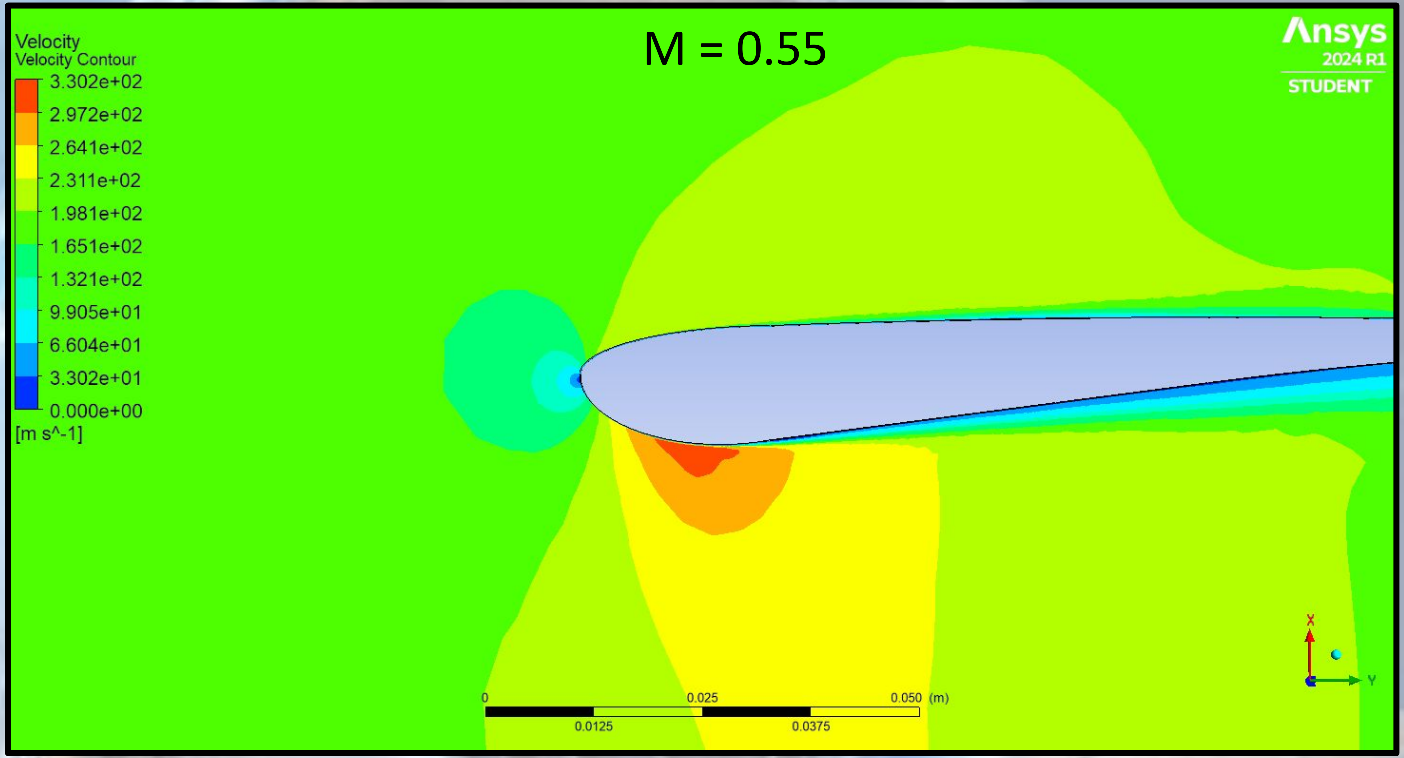

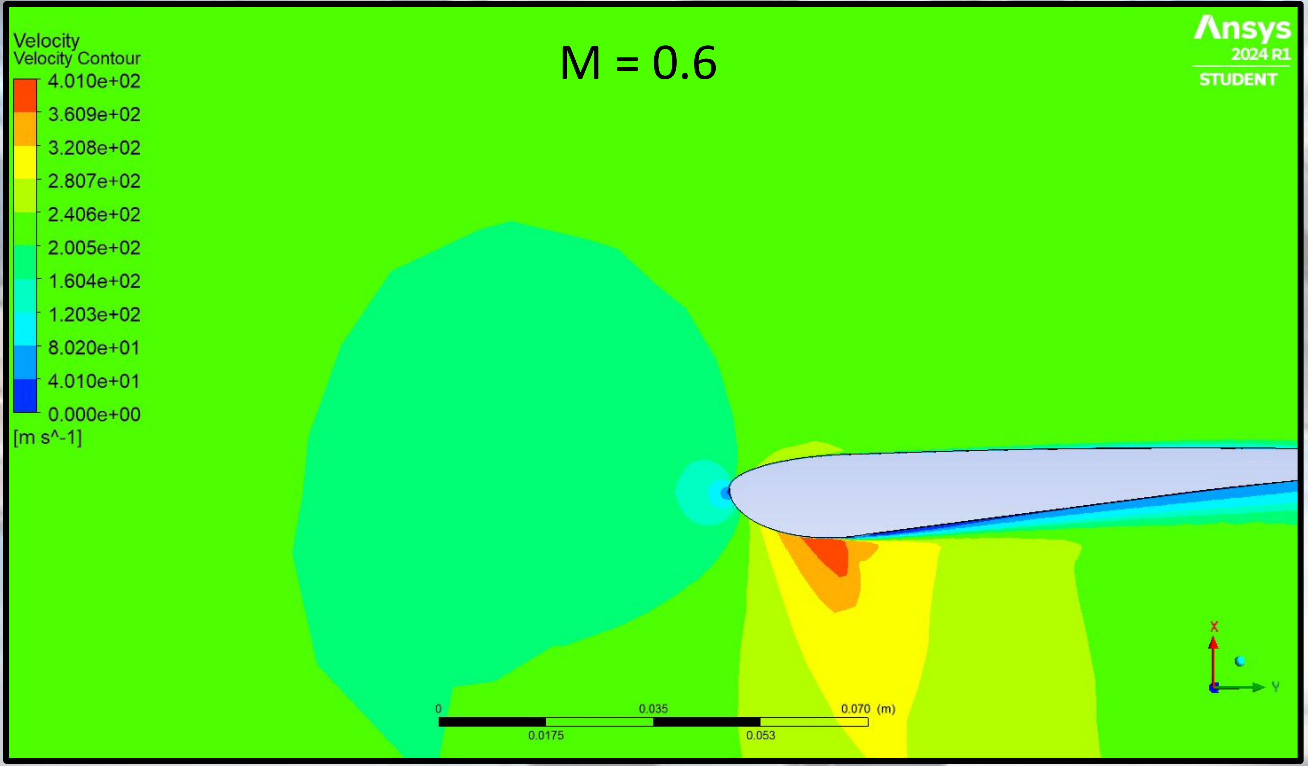

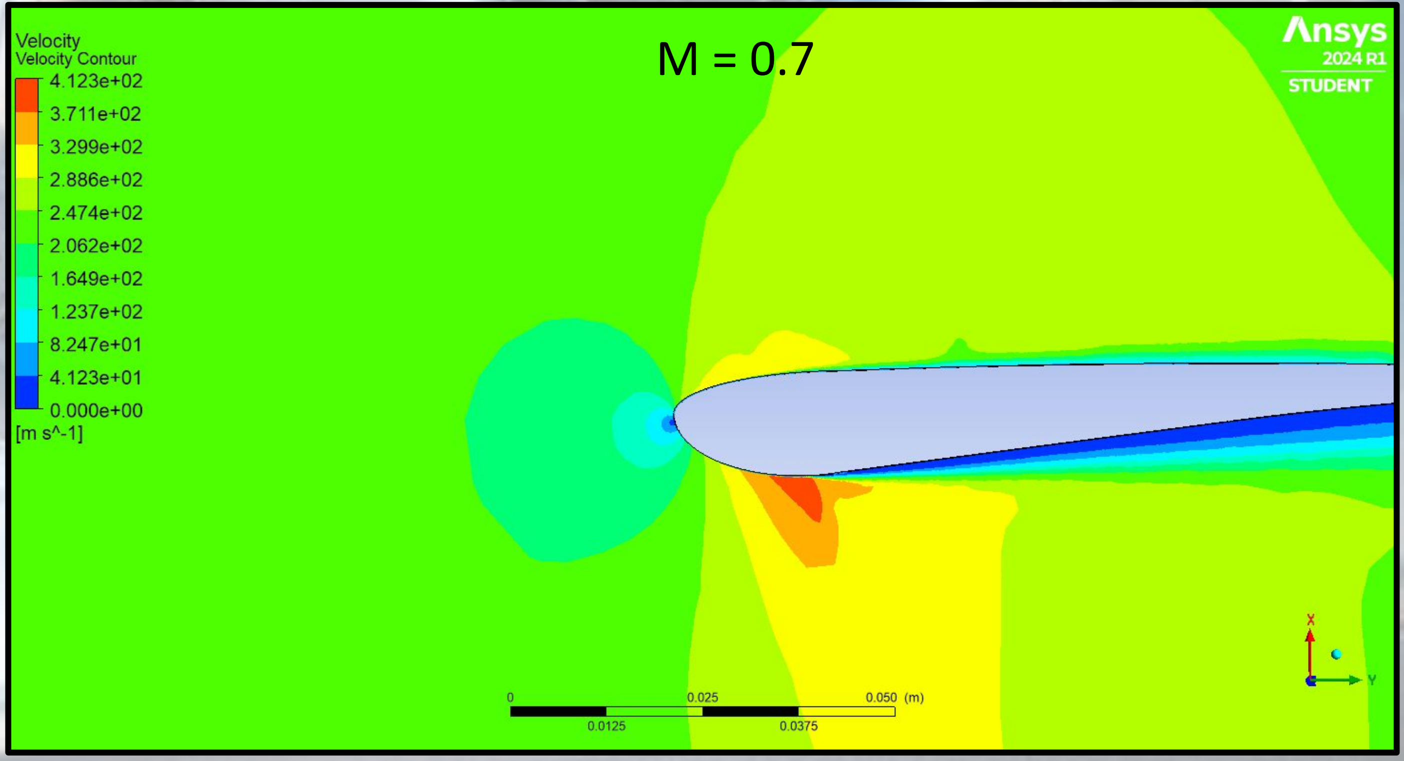

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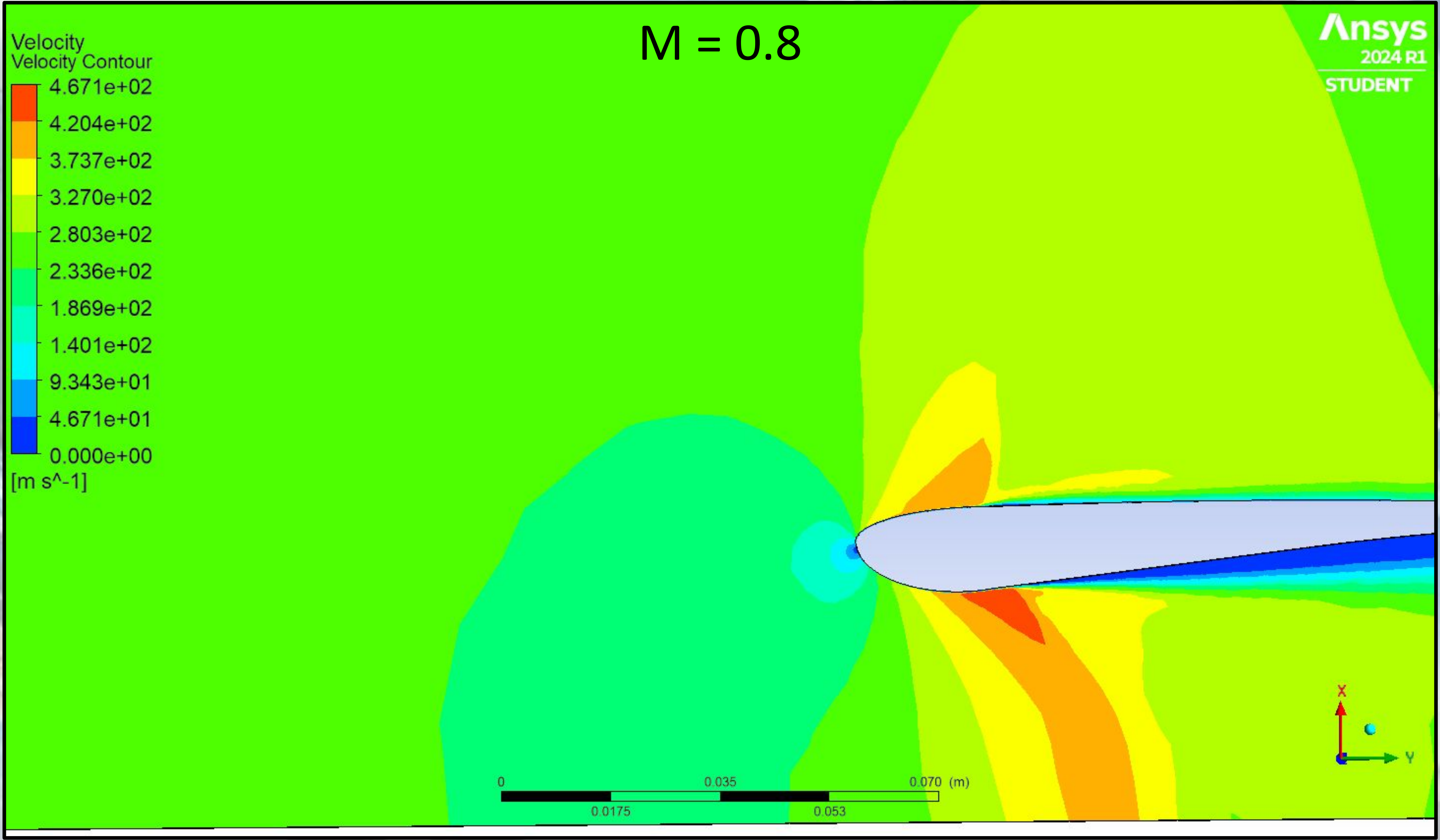
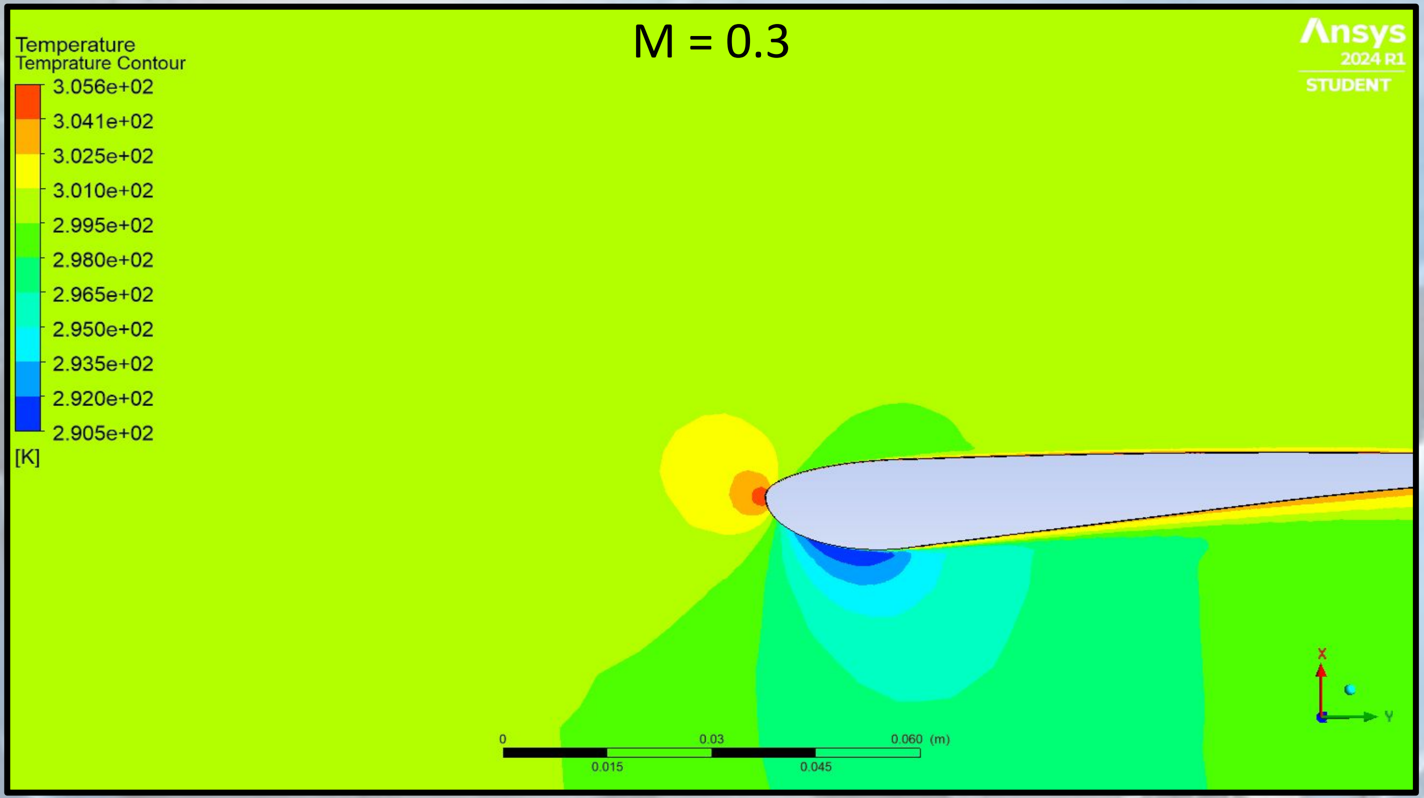
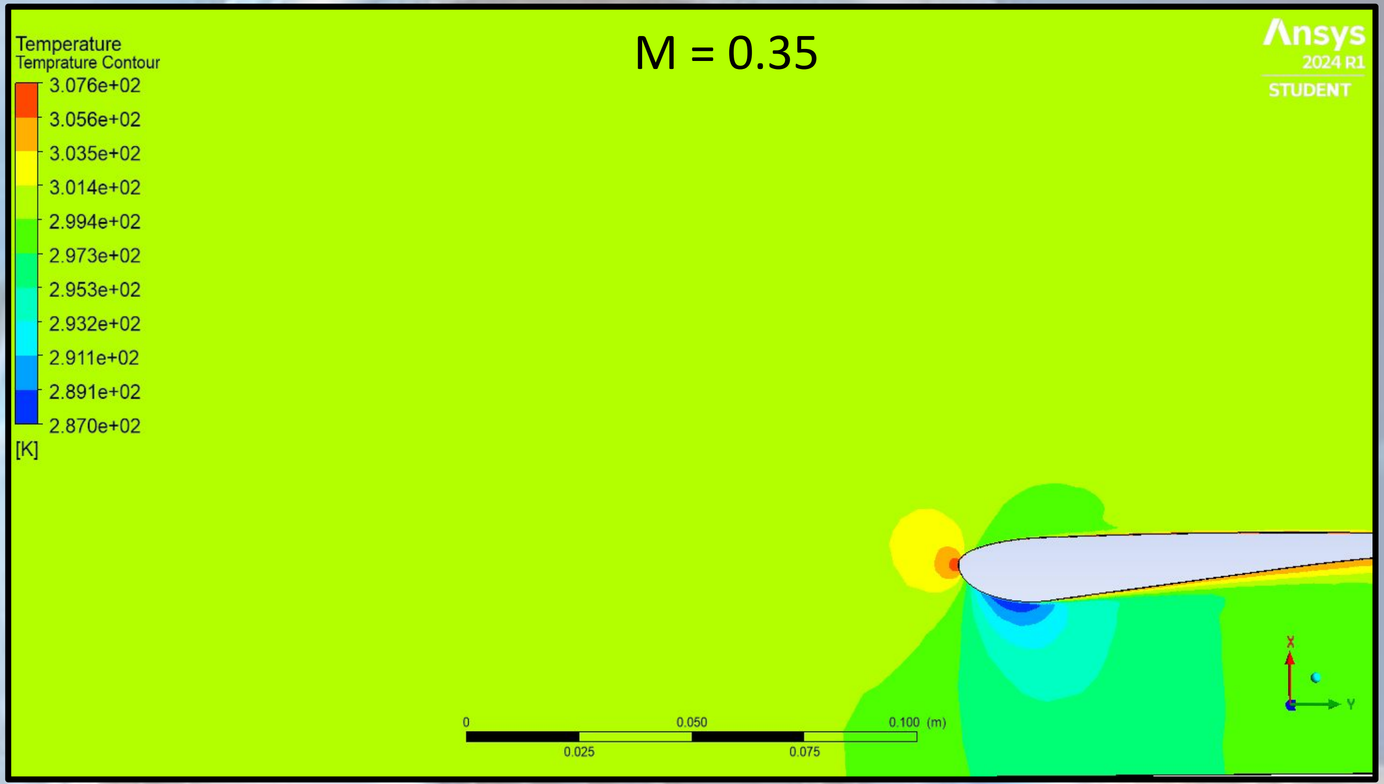
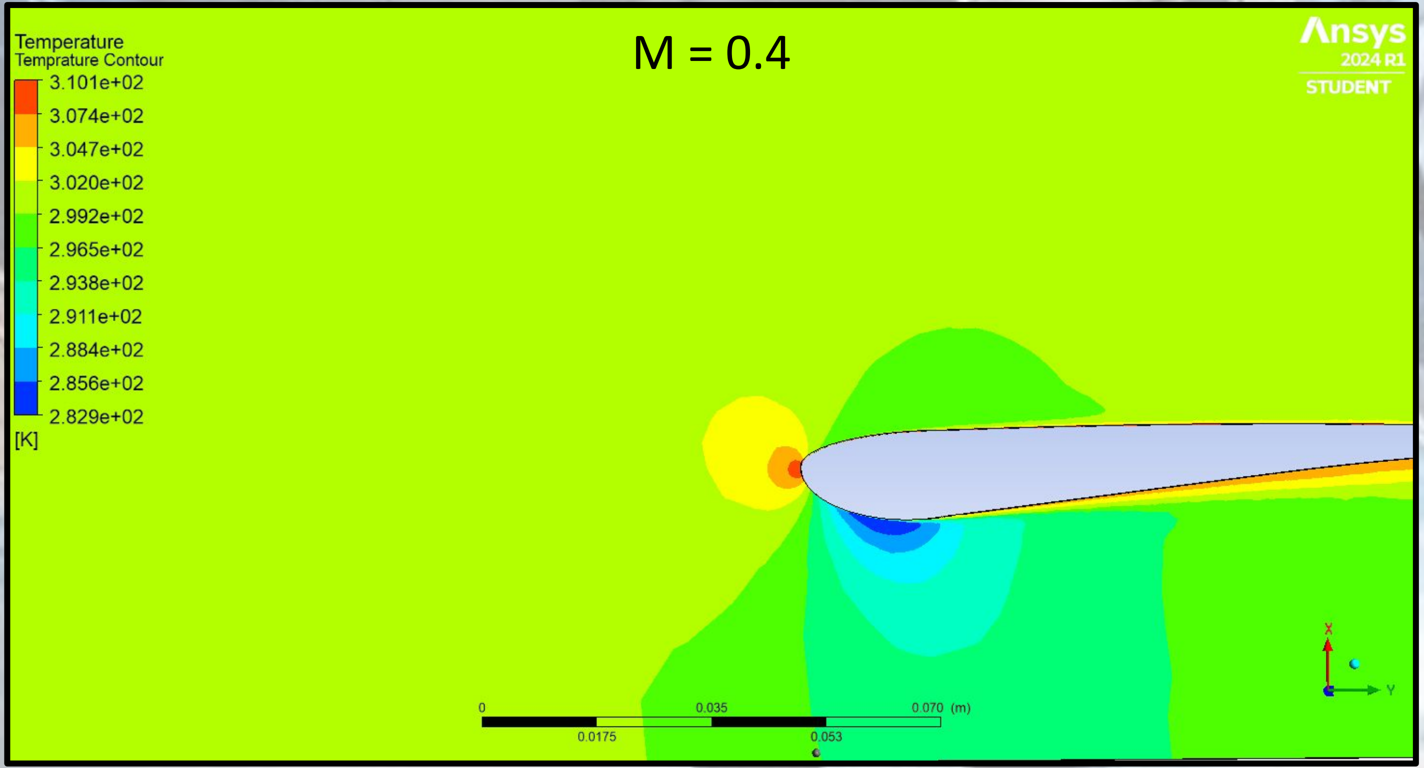
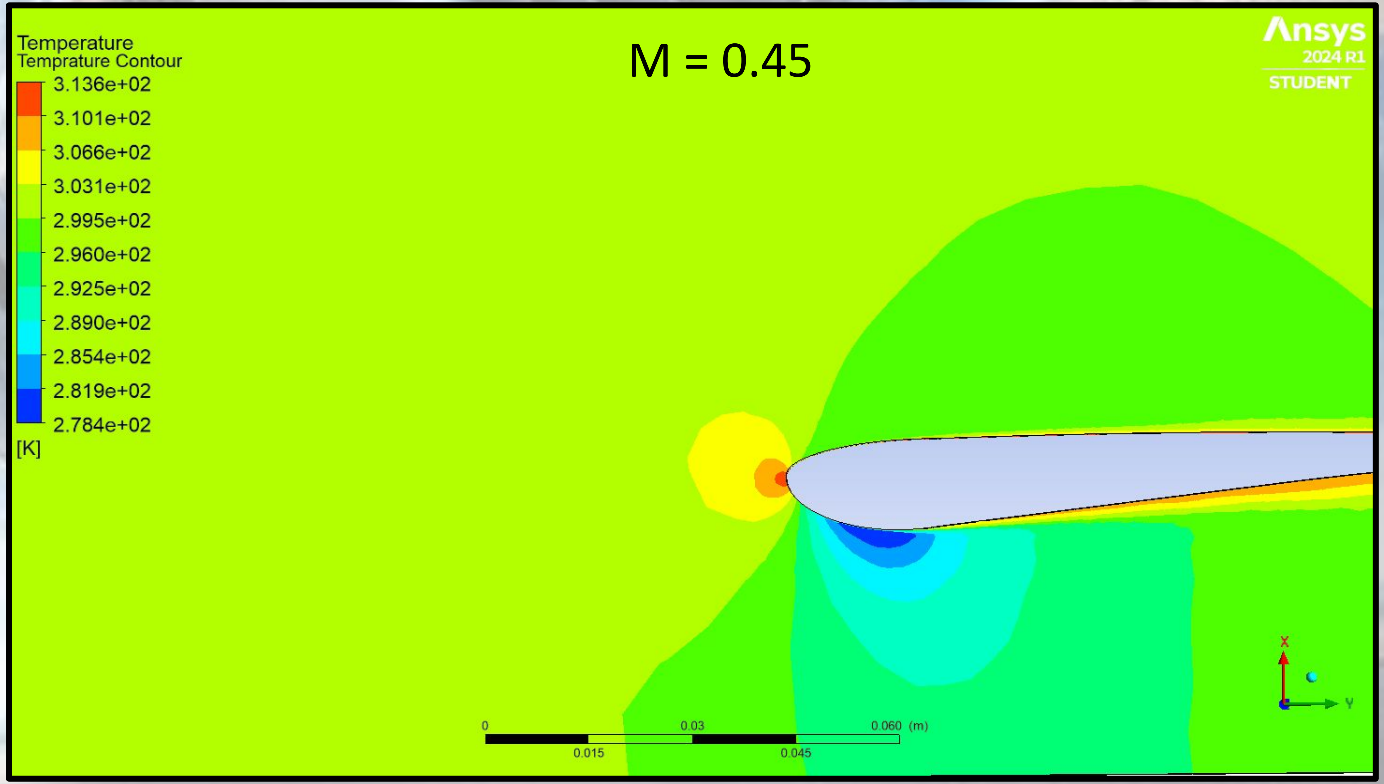


Temperature Contours









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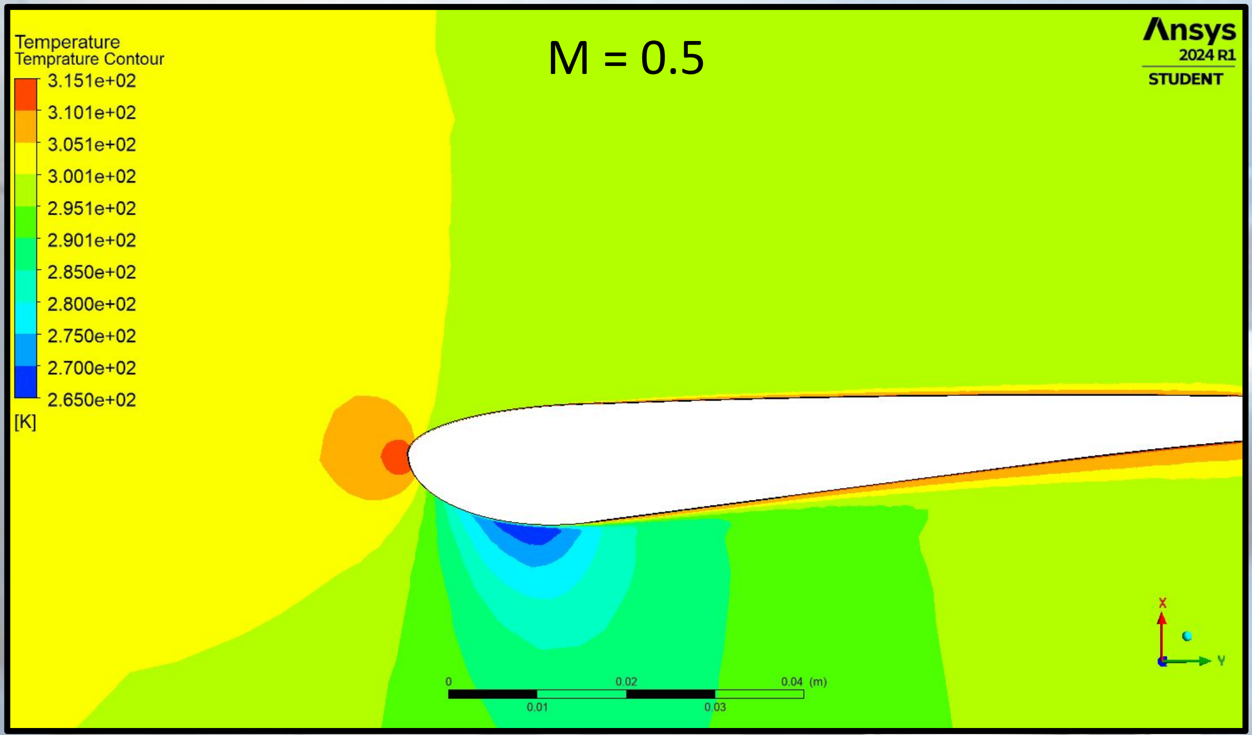

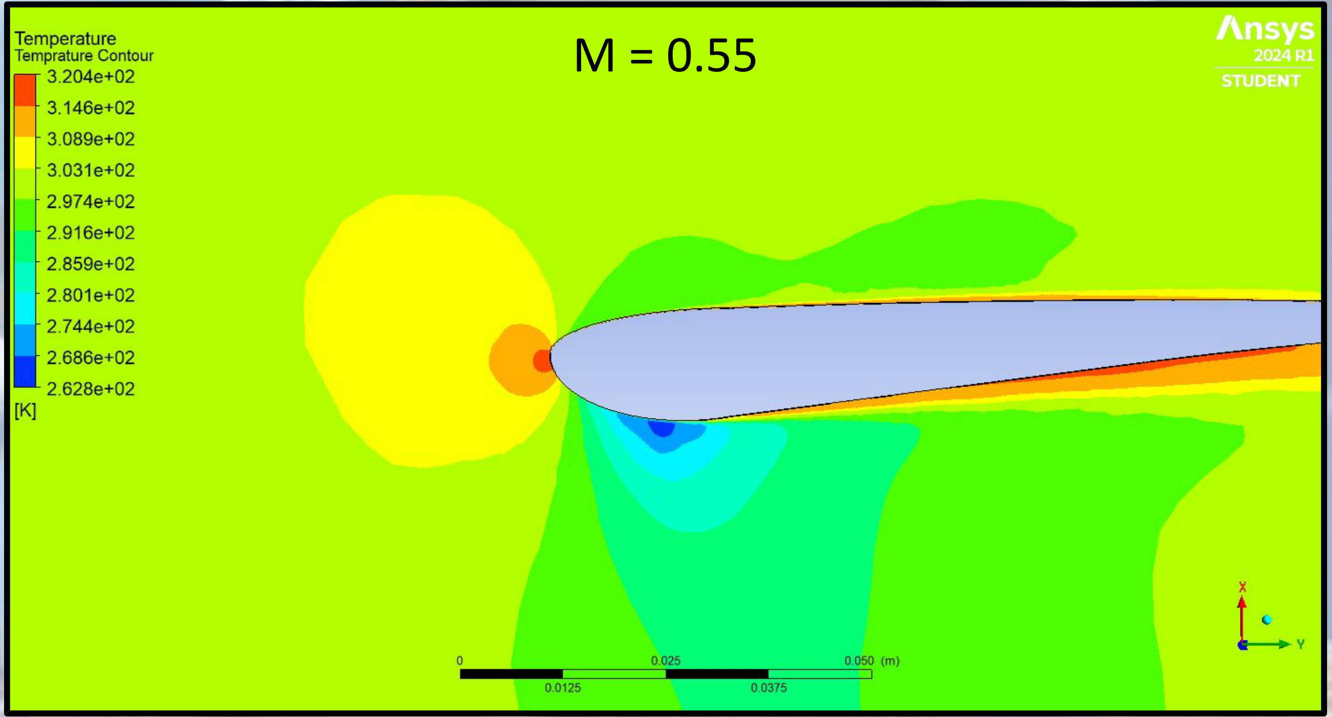

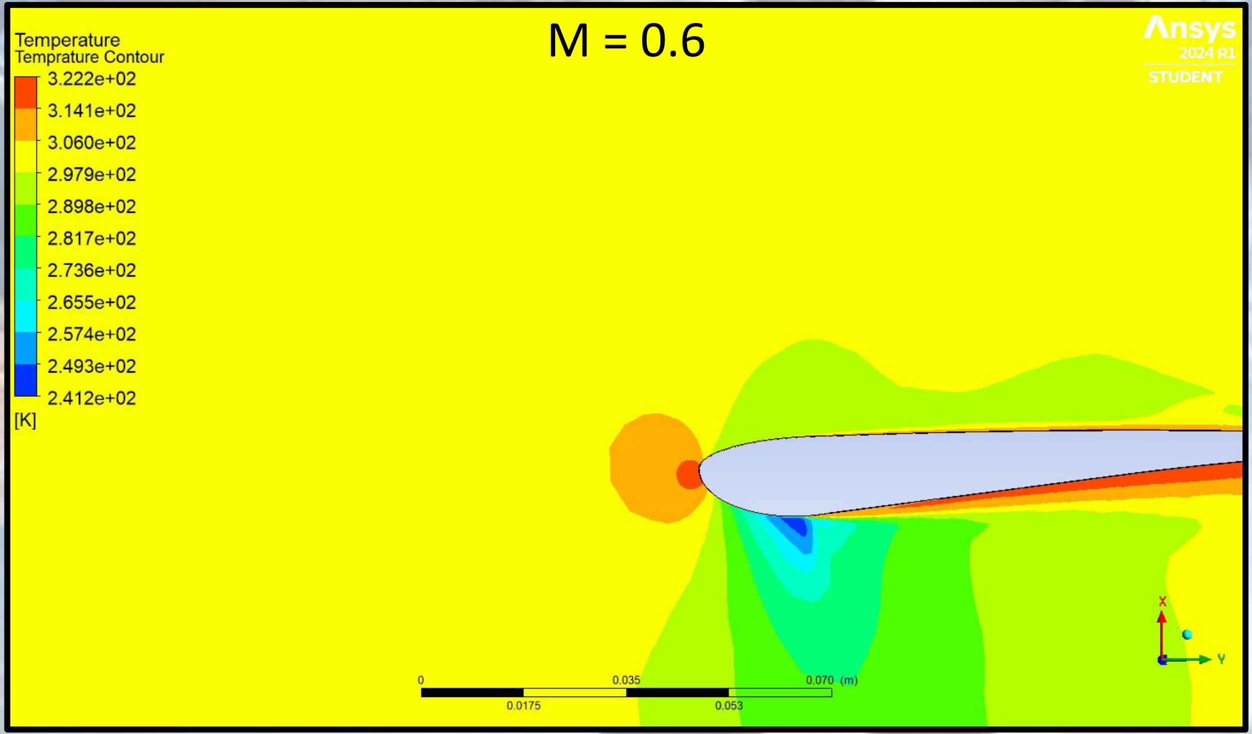

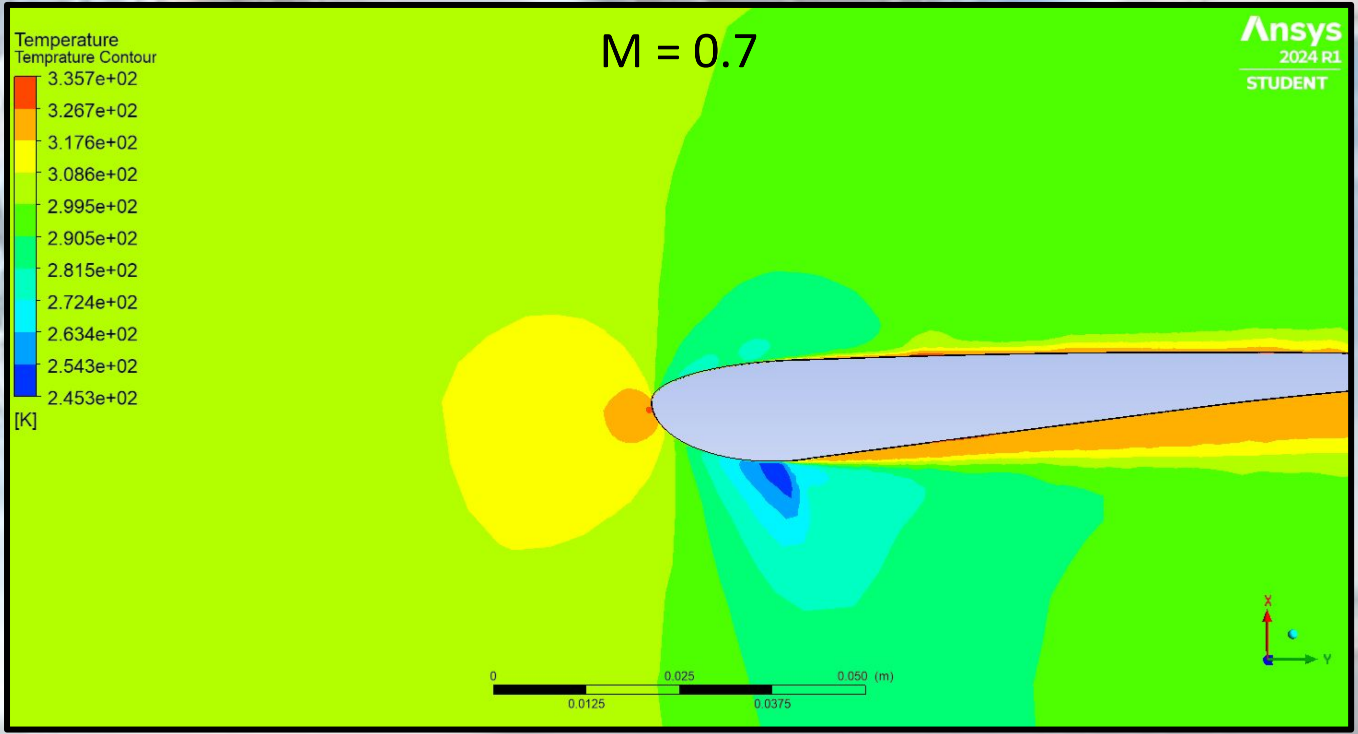

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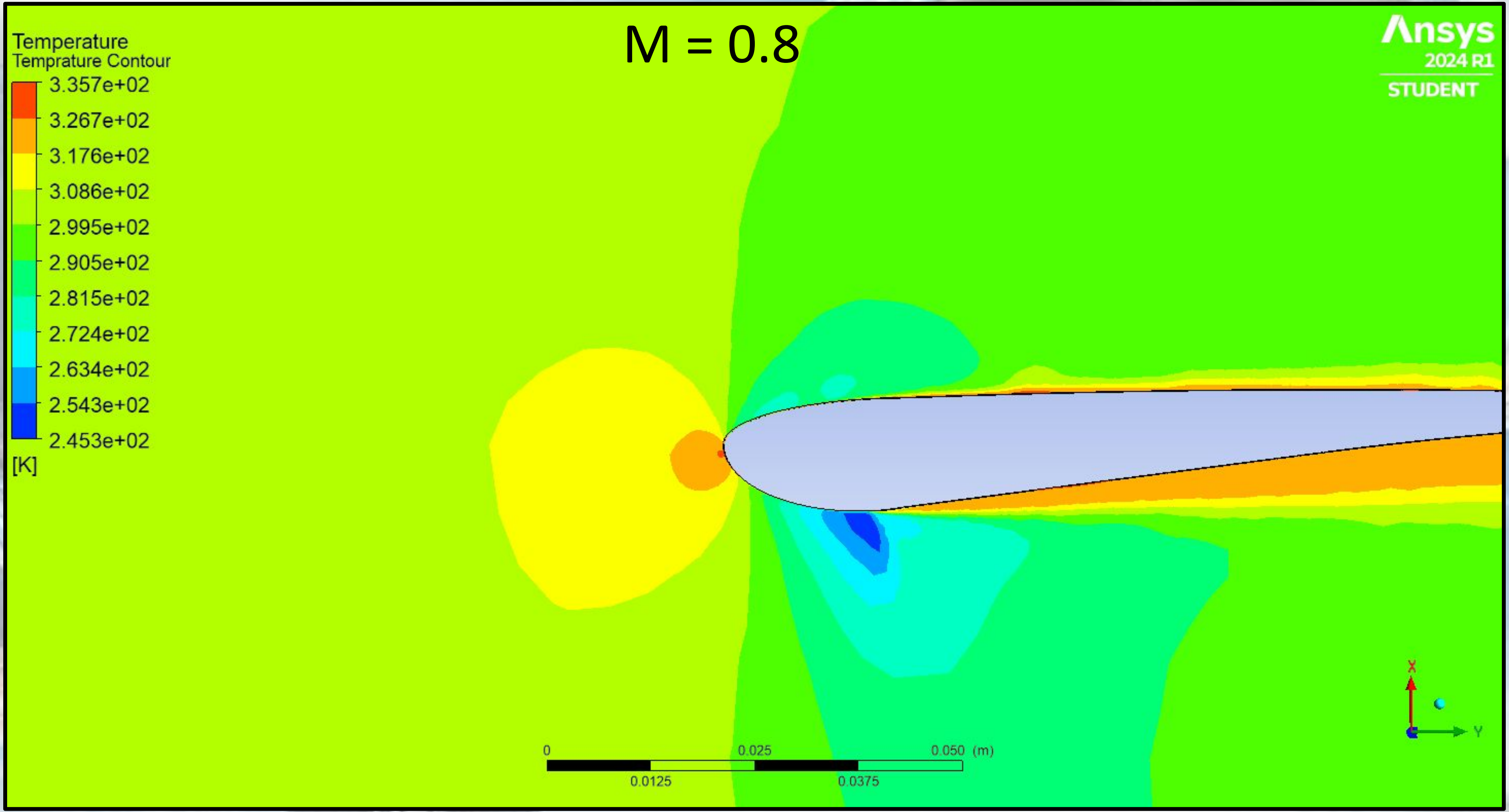
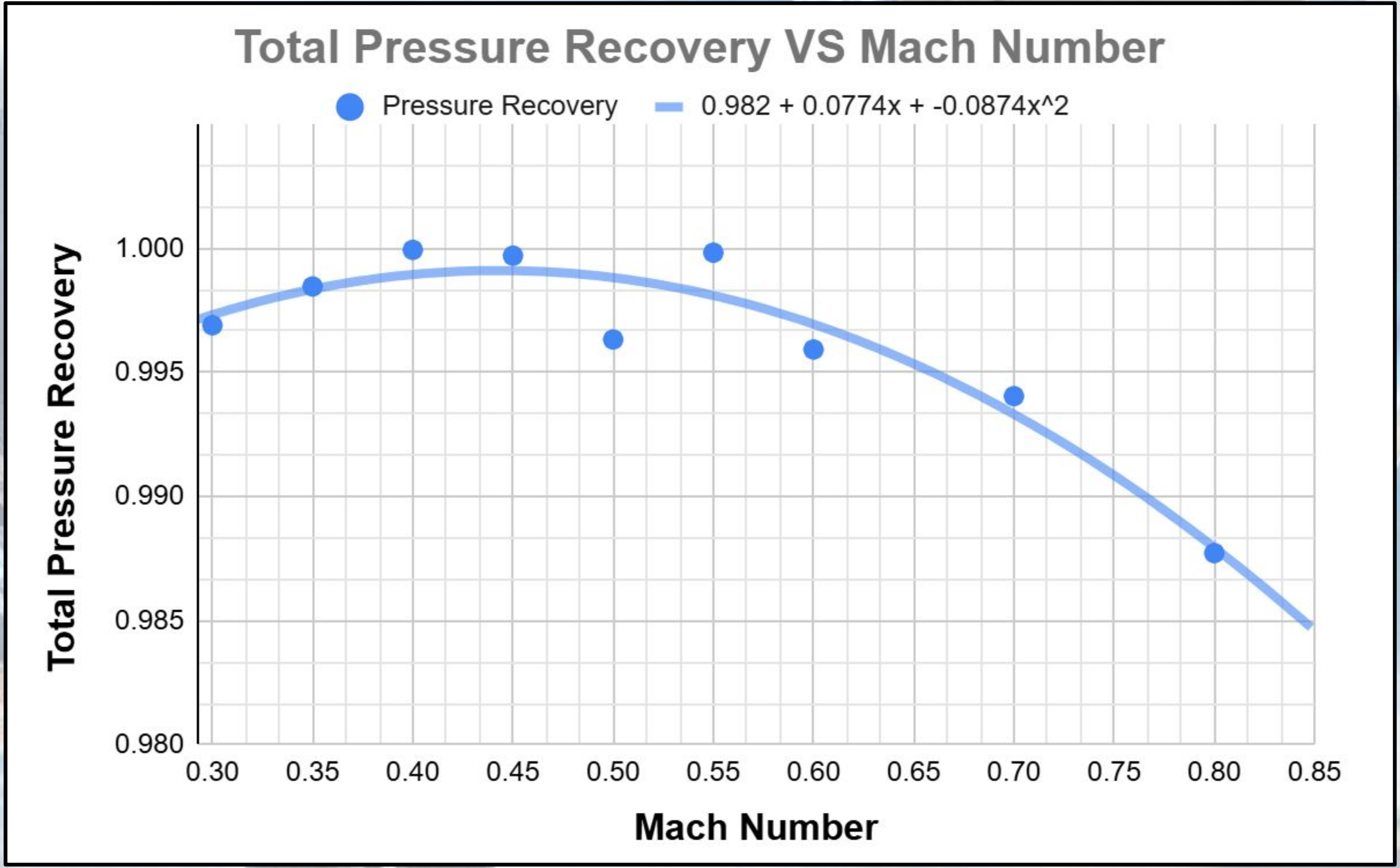


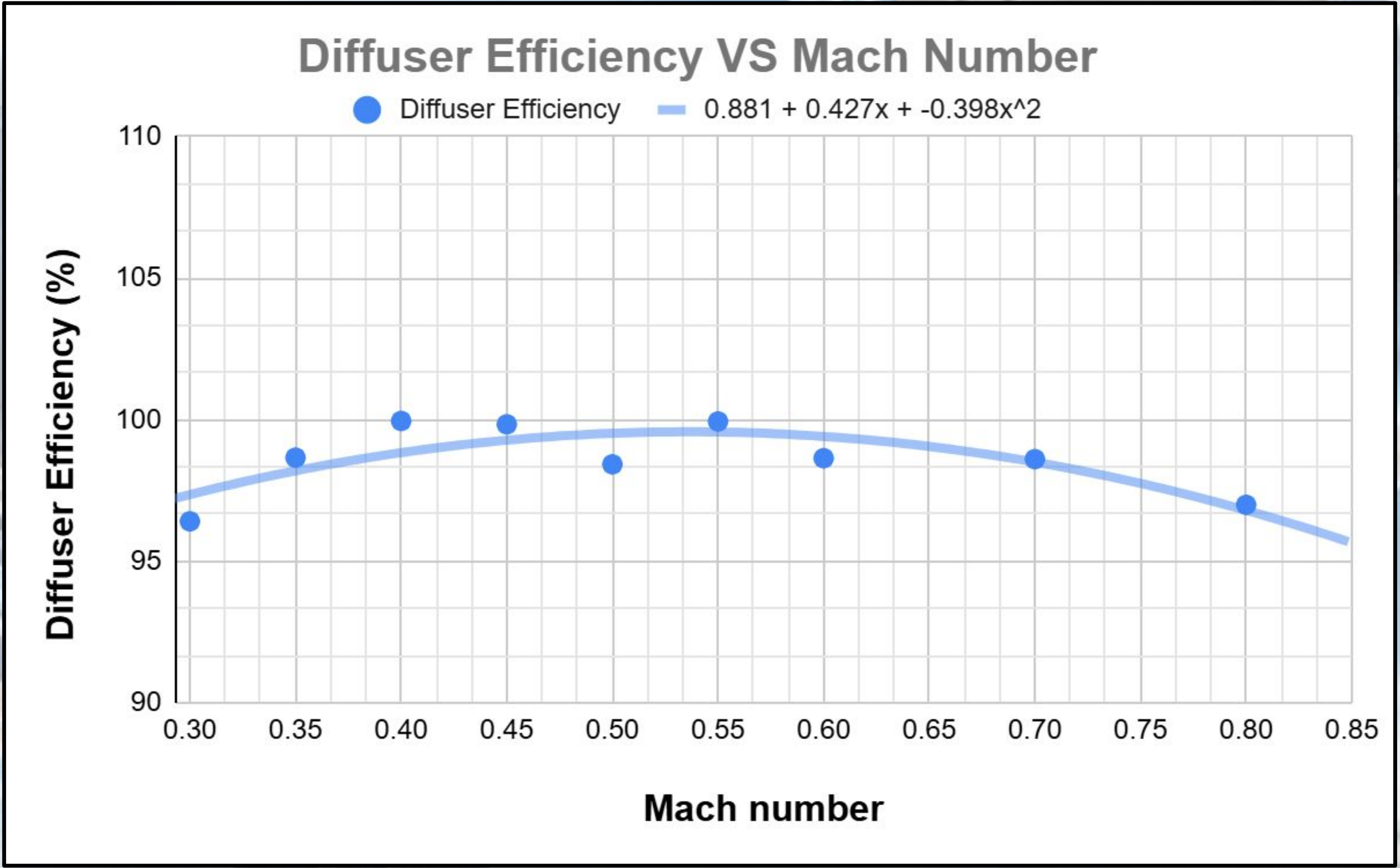
RESULTS

M	Diffuser Efficiency	Pressure Recovery (P02/P01)
0.3	0.9641252081	0.9969015015
0.35	0.9866071235	0.9984620369
0.4	0.9995666275	0.9999365874
0.45	0.9983831794	0.9997030845
0.5	0.9842501367	0.9963283697
0.55	0.9993918352	0.999823652
0.6	0.9864167887	0.9959252479
0.7	0.9860886583	0.9940470188
0.8	0.9699478036	0.9877270698

Total Pressure Recovery VS Mach number Plot



Diffuser Efficiency VS Mach Number Plot



References

- https://sci-hub.se/https://doi.org/10.1115/79-GT-51
- Lecture Slides

Future Work

1. Performance Optimization

- **Flow Uniformity**: Investigate and enhance the uniformity of the flow at the outlet of the inlet.
- **Pressure Recovery**: Optimize the geometry to achieve higher pressure recovery and lower total pressure losses.
- **Noise Reduction**: Study the aeroacoustic performance of the inlet and implement design modifications to minimize noise.

2. Extended Operating Conditions

- **Off-Design Performance**: Analyze the inlet's performance at off-design conditions (e.g., varying angles of attack, different Mach numbers, or under distorted flow conditions).
- **Environmental Conditions**: Test the inlet under extreme conditions such as icing, high-altitude low-density air, or turbulent inflows.


THANK YOU