

# 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.



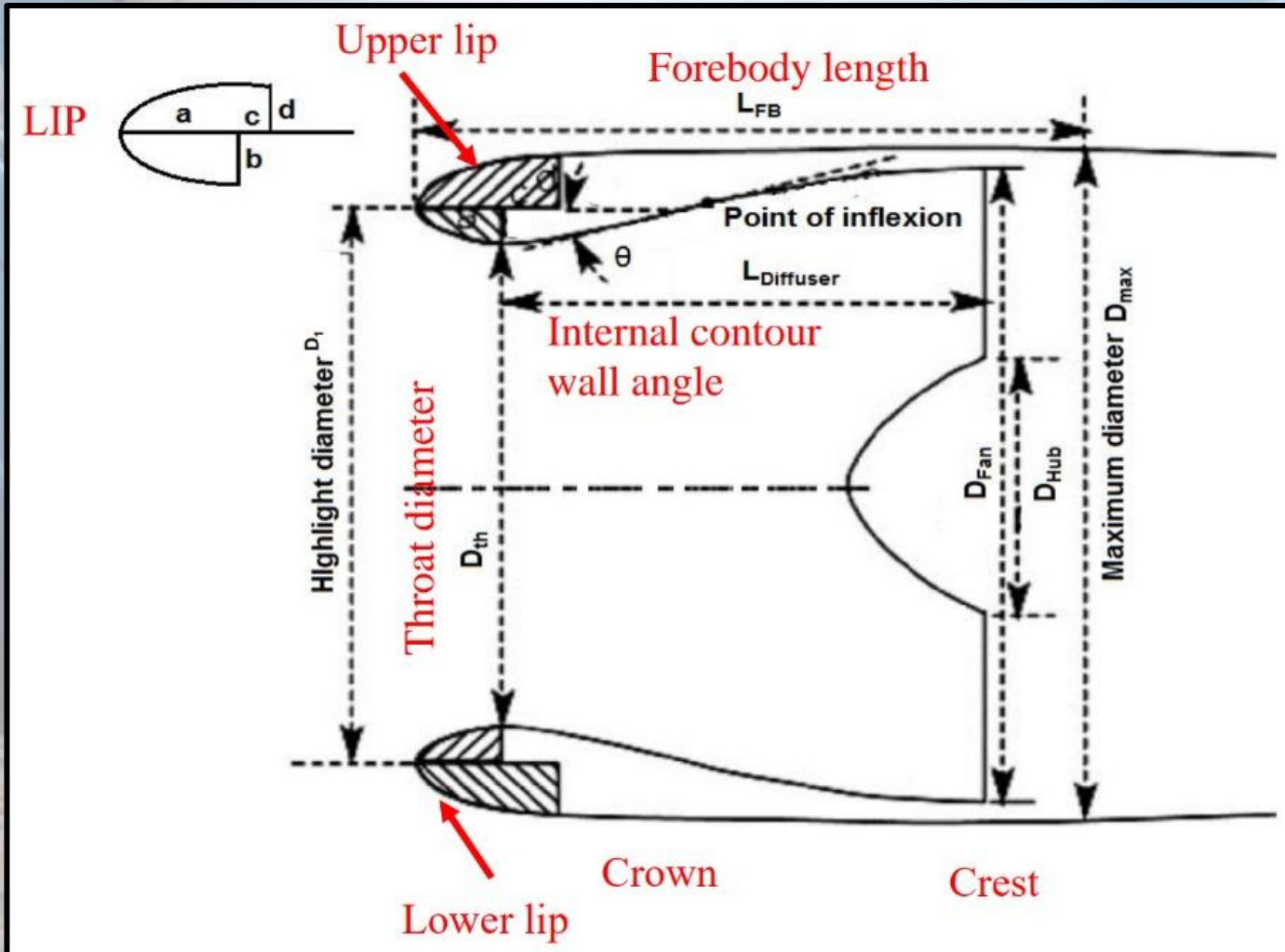
# Pod-mounted Subsonic Inlet Duct

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



$D_i$  = 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

$\theta$  = 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) =  $A_i/A_{TH}$  (typically, from 1.05 to 1.20).

LCR = 1.0 represents a sharp lip and 1.2 represents a well-rounded lip.

$D_i$  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  $\theta$  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.

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

- ❖ The 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.

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

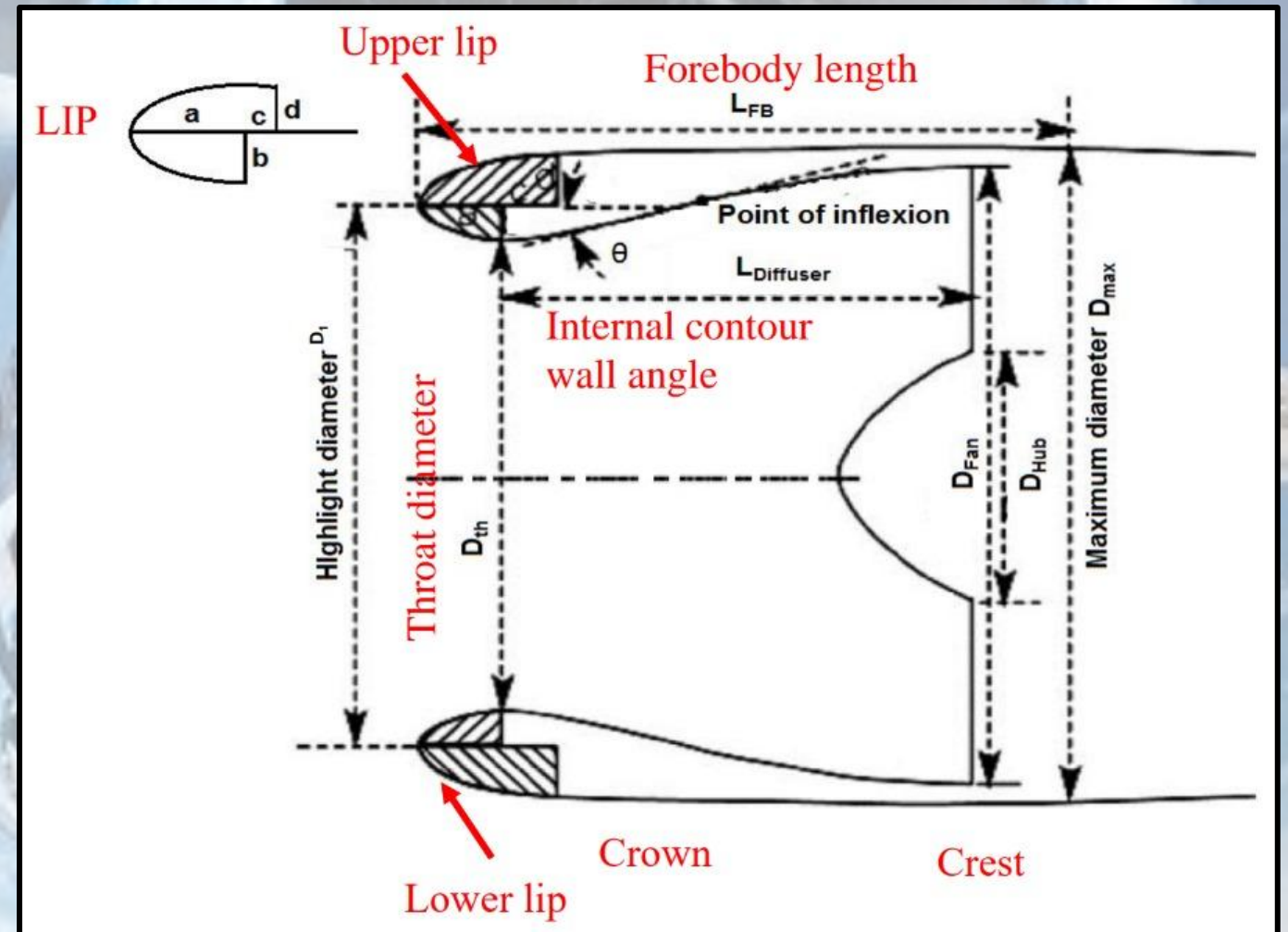
- ❖ The diffuser height is determined by the diffuser area ratio -

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

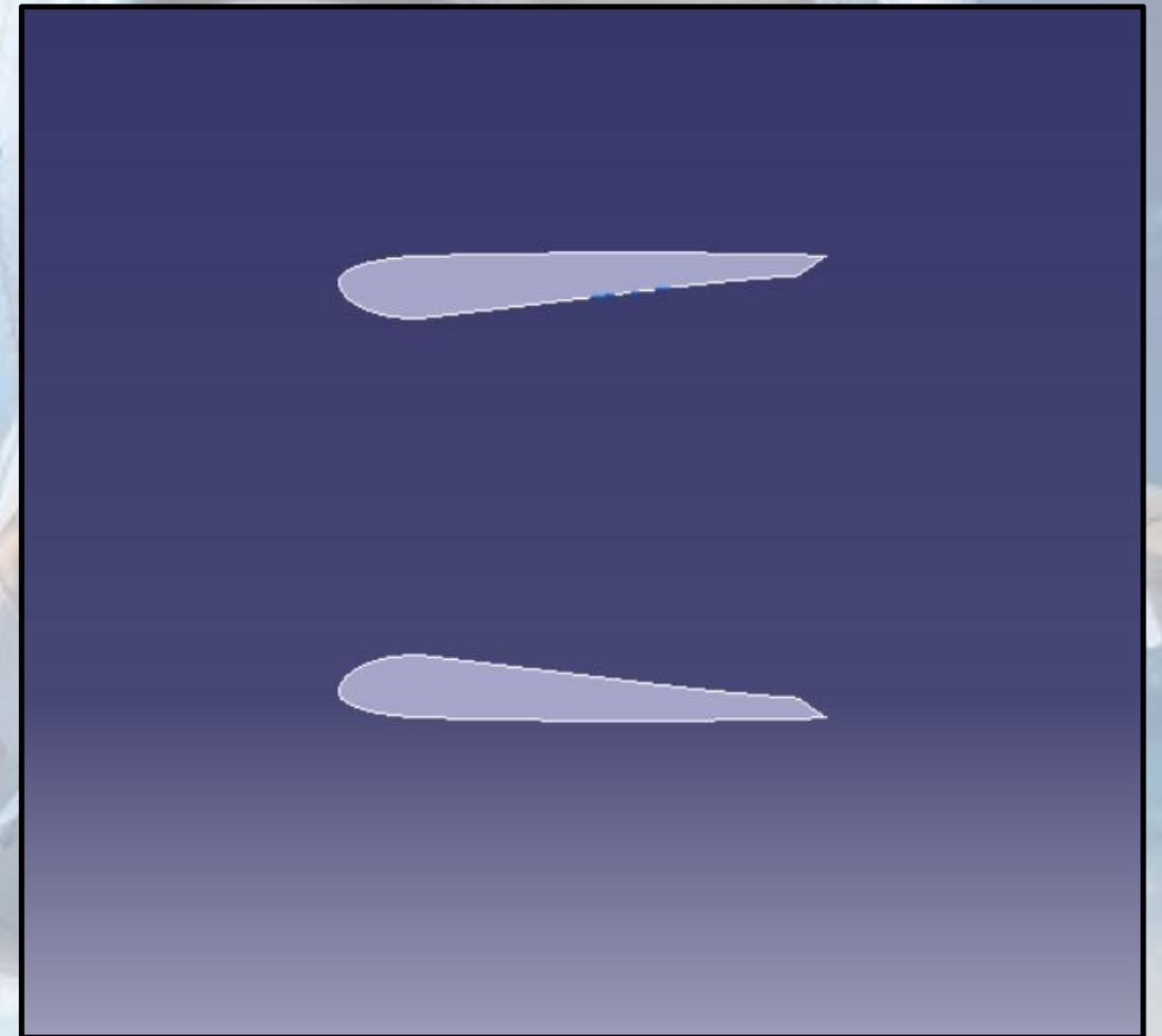
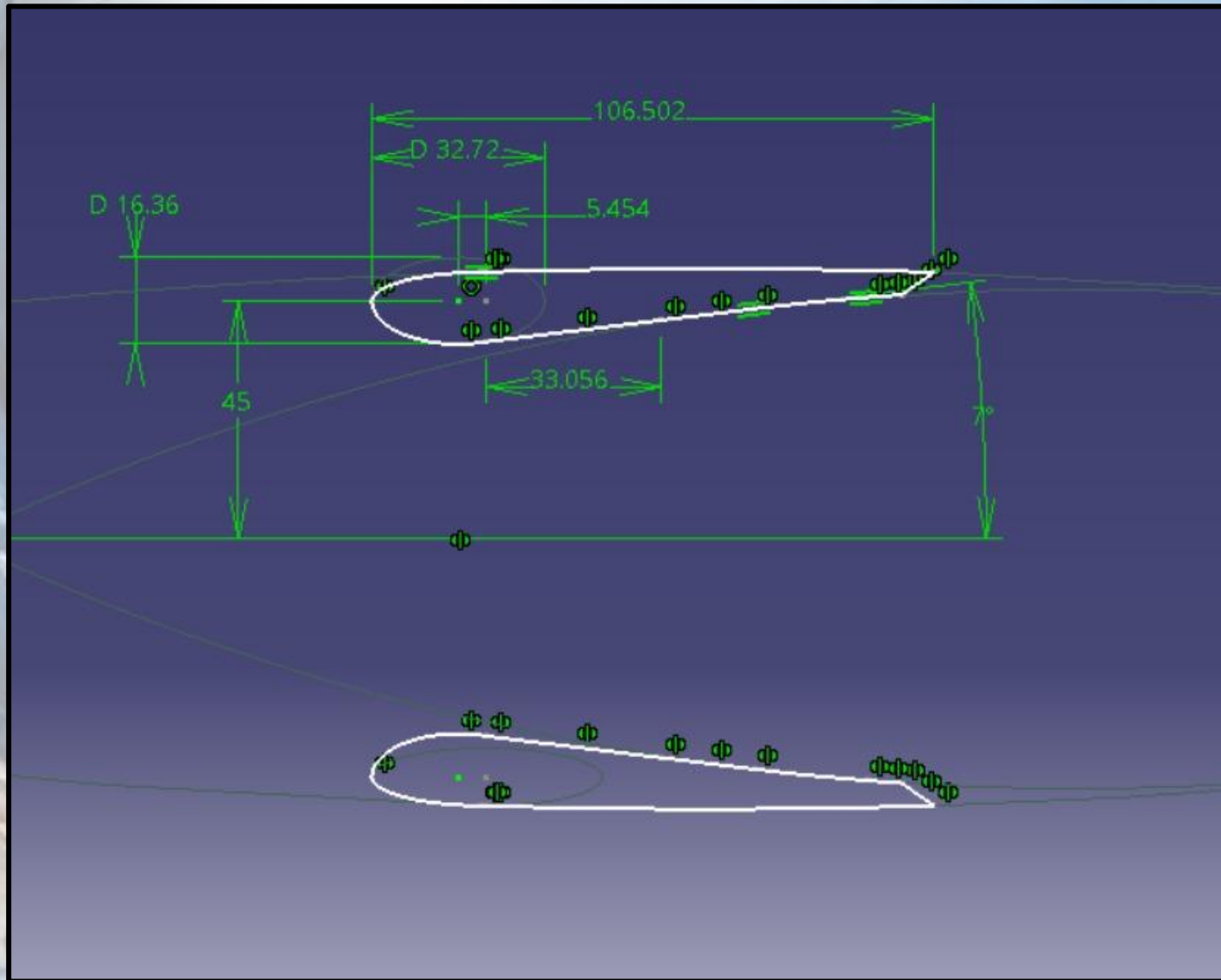


# Inlet Parameters

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



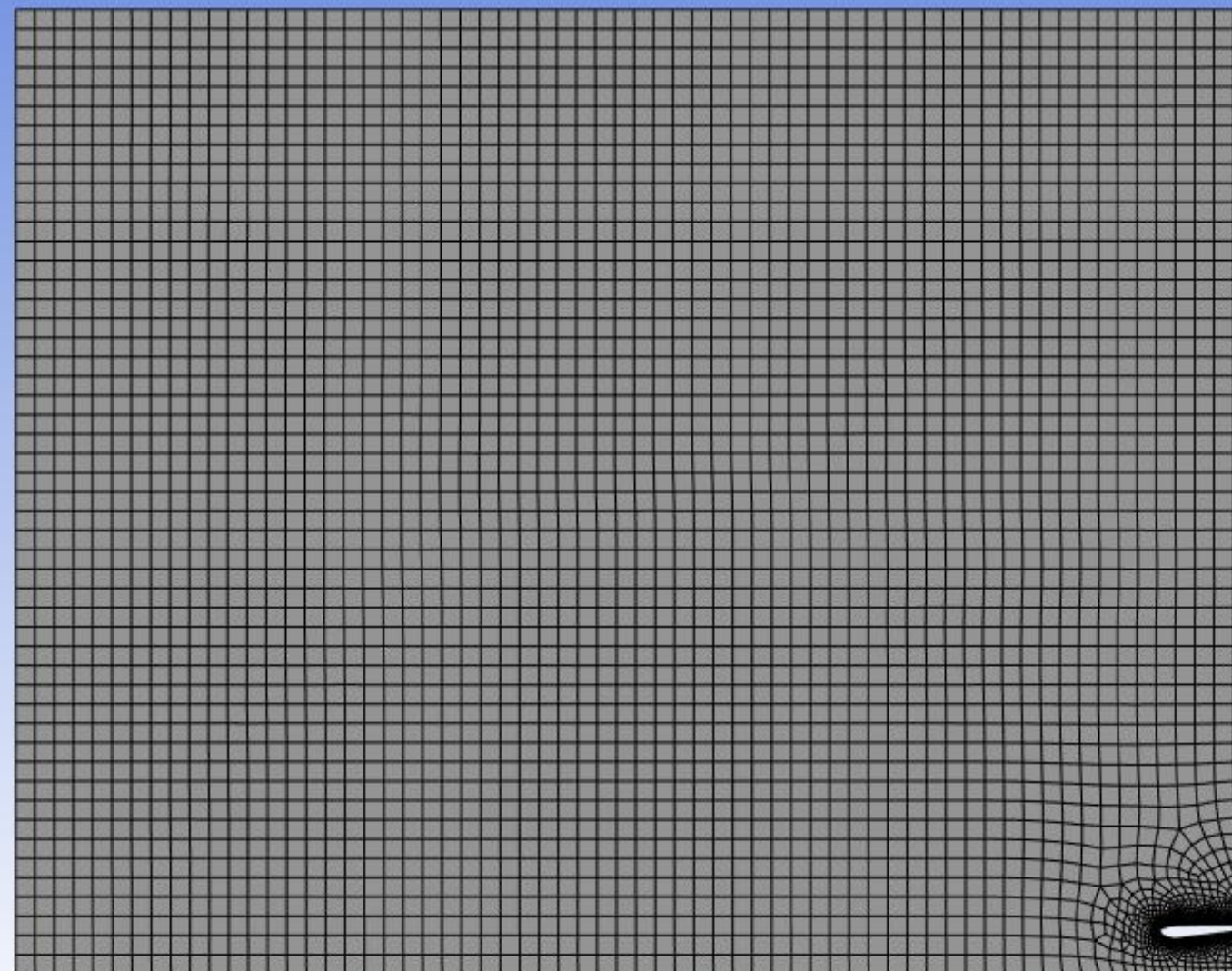
# CAD MODEL With Dimensions



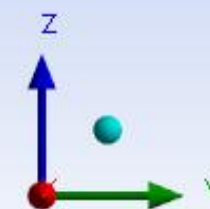


# Meshed Flowfield

**Ansys**  
2024 R1  
STUDENT



0.000 0.350 0.700 (m)  
0.175 0.525





# Fluent Solver Model Settings

Viscous Model

Model

☐ Inviscid

☐ Laminar

☐ Spalart-Allmaras (1 eqn)

☐ k-epsilon (2 eqn)

☒ k-omega (2 eqn)

☐ Transition k-kl-omega (3 eqn)

☐ Transition SST (4 eqn)

☐ Reynolds Stress (5 eqn)

☐ Scale-Adaptive Simulation (SAS)

☐ Detached Eddy Simulation (DES)

k-omega Model

☐ Standard

☐ GEKO

☐ BSL

☒ SST

k-omega Options

☐ Low-Re Corrections

Near-Wall Treatment

correlation

Options

☒ Viscous Heating

☐ Curvature Correction

☐ Corner Flow Correction

☐ Compressibility Effects

☐ Production Kato-Launder

☒ Production Limiter

Transition Options

Transition Model none

Model Constants

Alpha\*\_inf

1

Alpha\_inf

0.52

Beta\*\_inf

0.09

a1

0.31

Beta\_i (Inner)

0.075

Beta\_i (Outer)

0.0828

TKF (Inner) Prandtl #

User-Defined Functions

Turbulent Viscosity none

Prandtl Numbers

Energy Prandtl Number

none

Wall Prandtl Number

none

OK

Cancel

Help

Energy

Energy

☒ Energy Equation

Energy Modes

☐ Two-Temperature Model

OK

Cancel

Help

Solver

Type

☐ Pressure-Based

☒ Density-Based

Velocity Formulation

☒ Absolute

☐ Relative

Time

☒ Steady

☐ Transient

2D Space

☒ Planar

☐ Axisymmetric

☐ Axisymmetric Swirl

Gravity

☐ Gravity



# Boundary conditions

**Velocity Inlet** [X]

Zone Name  
far\_field\_1

**Momentum** Thermal Radiation Species DPM Multiphase Potential Structure UDS

Velocity Specification Method: Magnitude, Normal to Boundary

Reference Frame: Absolute

Velocity Magnitude [m/s]: 277.7509675951

Supersonic/Initial Gauge Pressure [Pa]: 0

Outflow Gauge Pressure [Pa]: 0

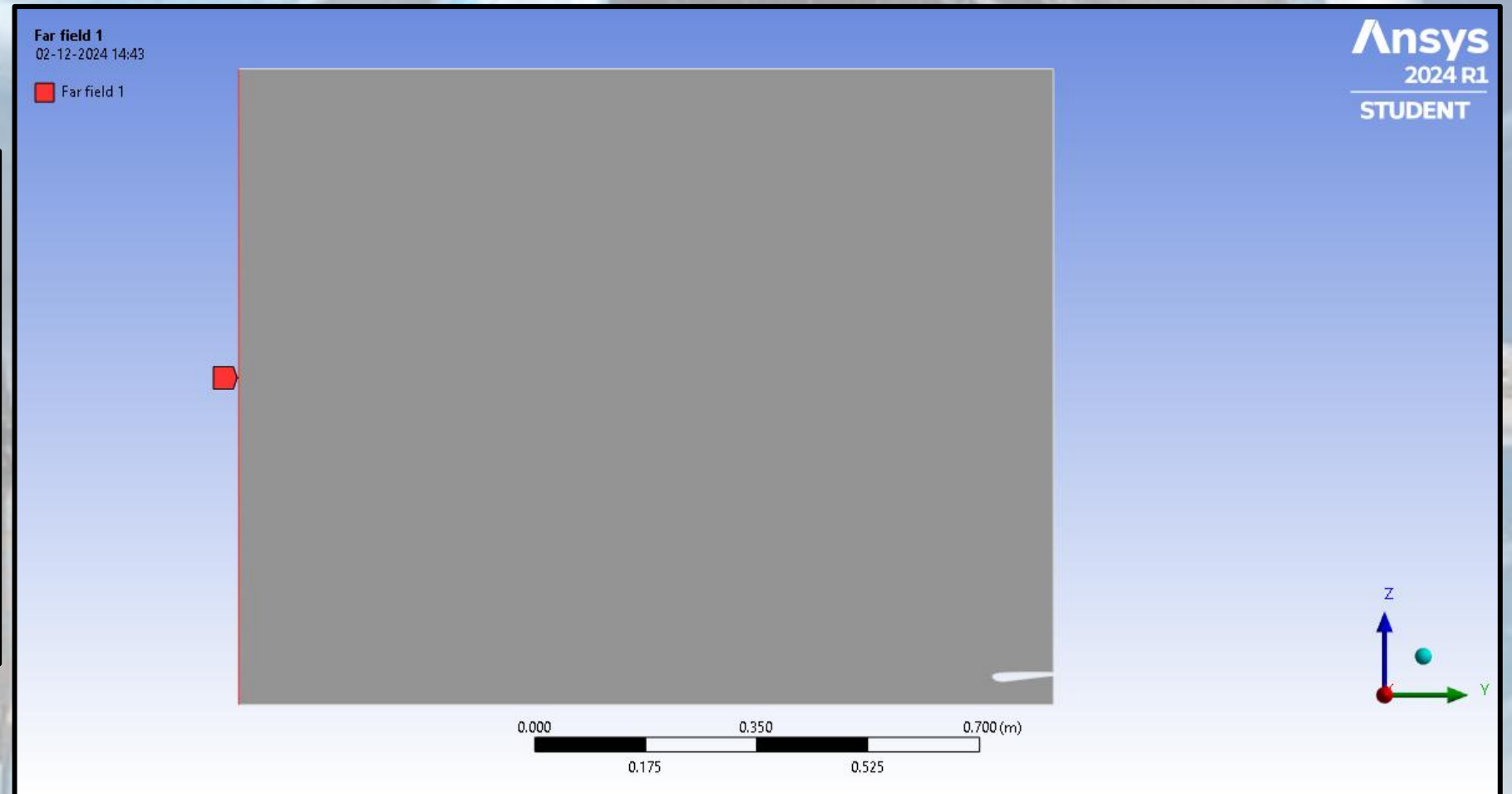
**Turbulence**

Specification Method: Intensity and Viscosity Ratio

Turbulent Intensity [%]: 5

Turbulent Viscosity Ratio: 10

Apply Close Help





# Boundary conditions

**Pressure Far-Field**

Zone Name  
far\_field\_2

Momentum Thermal Radiation Species Potential Structure UDS DPM

Gauge Pressure [Pa] 0

Mach Number 0.8

X-Component of Flow Direction 0

Y-Component of Flow Direction 1

**Turbulence**

Specification Method Intensity and Viscosity Ratio

Turbulent Intensity [%] 5

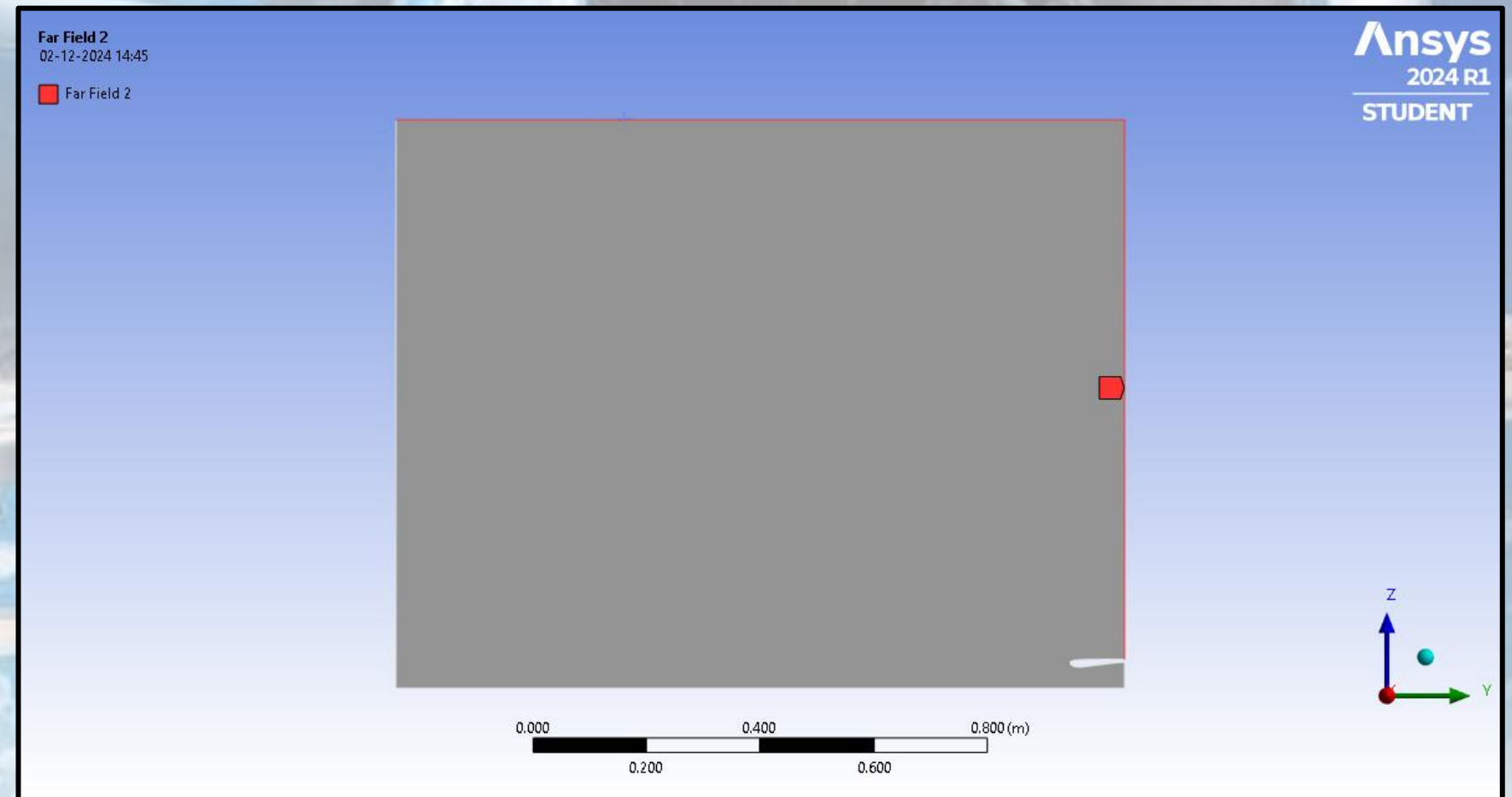
Turbulent Viscosity Ratio 10

Apply Close Help

[Ground Condition Analysis]

$$P_{\infty} = 101325 \text{ Pa}$$

$$T_{\infty} = 300 \text{ K}$$





# Boundary conditions

Pressure Outlet

Zone Name

outlet

Momentum

Thermal

Radiation

Species

DPM

Multiphase

Potential

Structure

UDS

Backflow Reference Frame

Absolute

Gauge Pressure [Pa]

-1000

Pressure Profile Multiplier

1

Backflow Direction Specification Method

Normal to Boundary

Backflow Pressure Specification

Total Pressure

☐ Prevent Reverse Flow

☐ Average Pressure Specification

☐ Target Mass Flow Rate

Turbulence

Specification Method

Intensity and Viscosity Ratio

Backflow Turbulent Intensity [%]

5

Backflow Turbulent Viscosity Ratio

10

Acoustic Wave Model

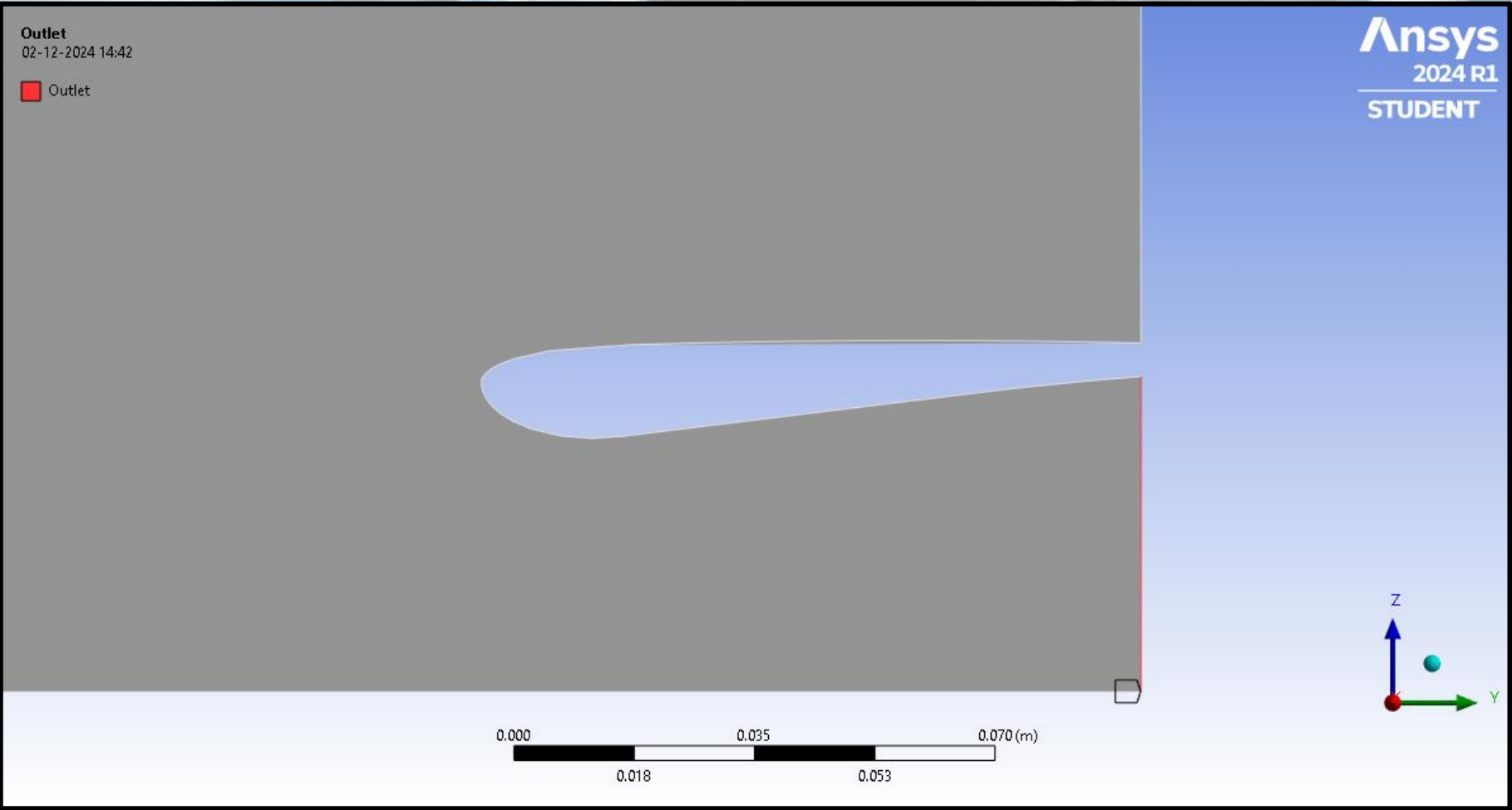
☒ Off

☐ Non Reflecting

Apply


Close

Help





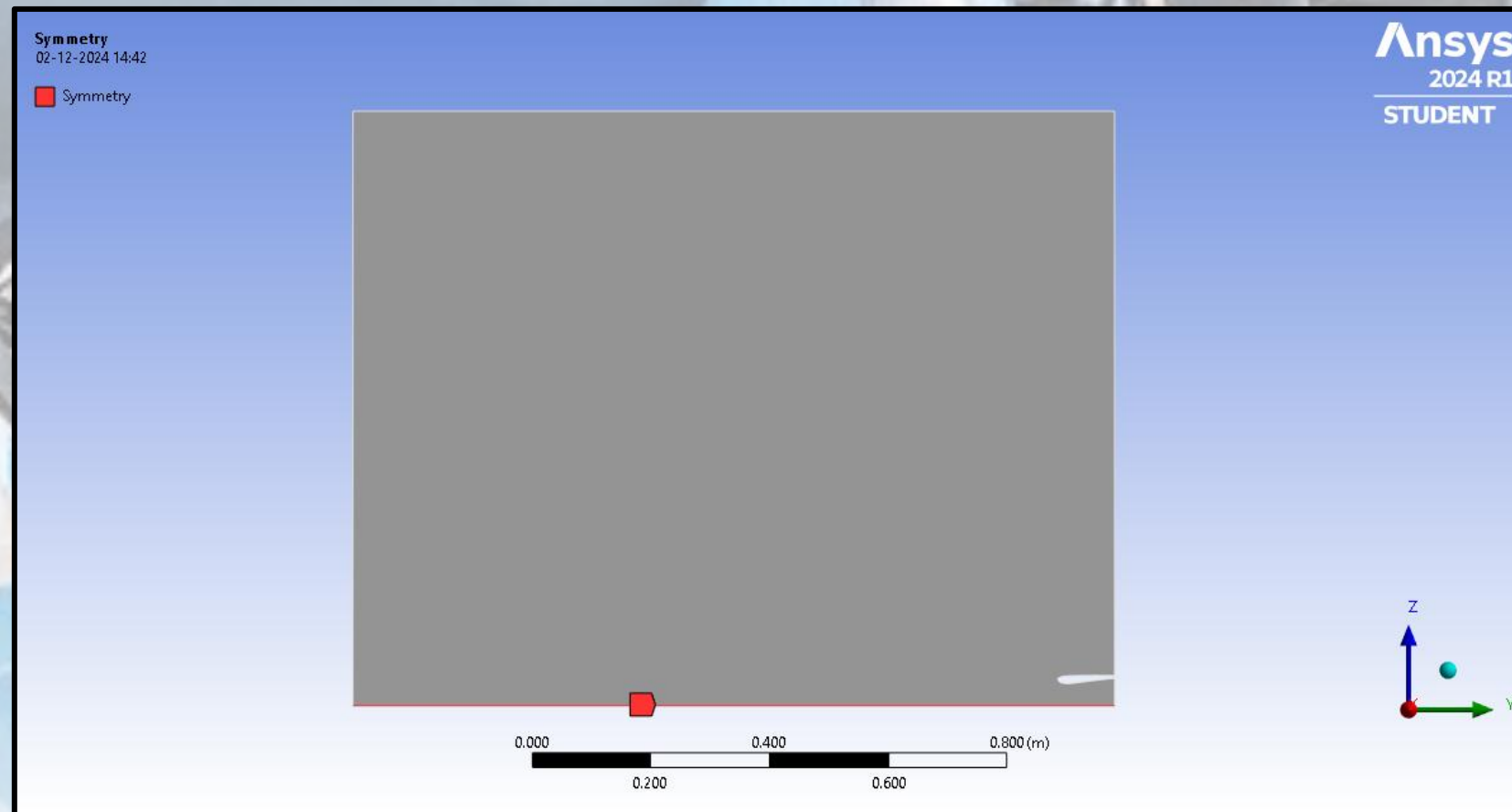
# Boundary conditions

 Symmetry ✕

Zone Name

symmetry

Apply Close Help





# Boundary conditions

Wall

×

Zone Name

no\_slip\_wall

Adjacent Cell Zone

surface\_body

Momentum

Thermal

Radiation

Species

DPM

Multiphase

UDS

Potential

Structure

Ablation

Wall Motion

Motion

☒ Stationary Wall

☐ Moving Wall

☒ Relative to Adjacent Cell Zone

Shear Condition

☒ No Slip

☐ Specified Shear

☐ Specularity Coefficient

☐ Marangoni Stress

☐ Partial Slip for Rarefied Gases

Wall Roughness

Roughness Models

Sand-Grain Roughness

☒ Standard

☐ High Roughness (Icing)

Roughness Height [m]

0

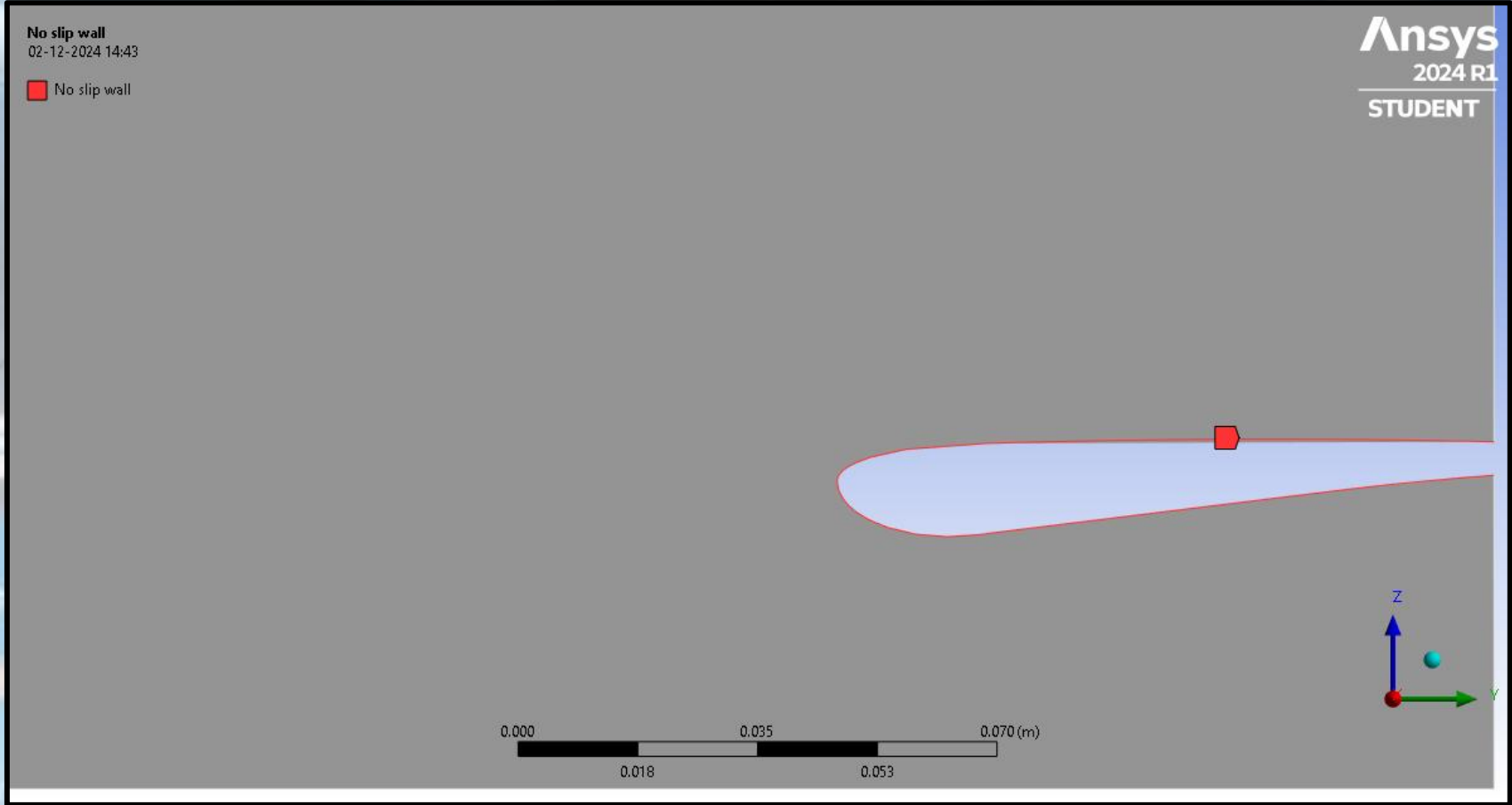
Roughness Constant

0.5

Apply

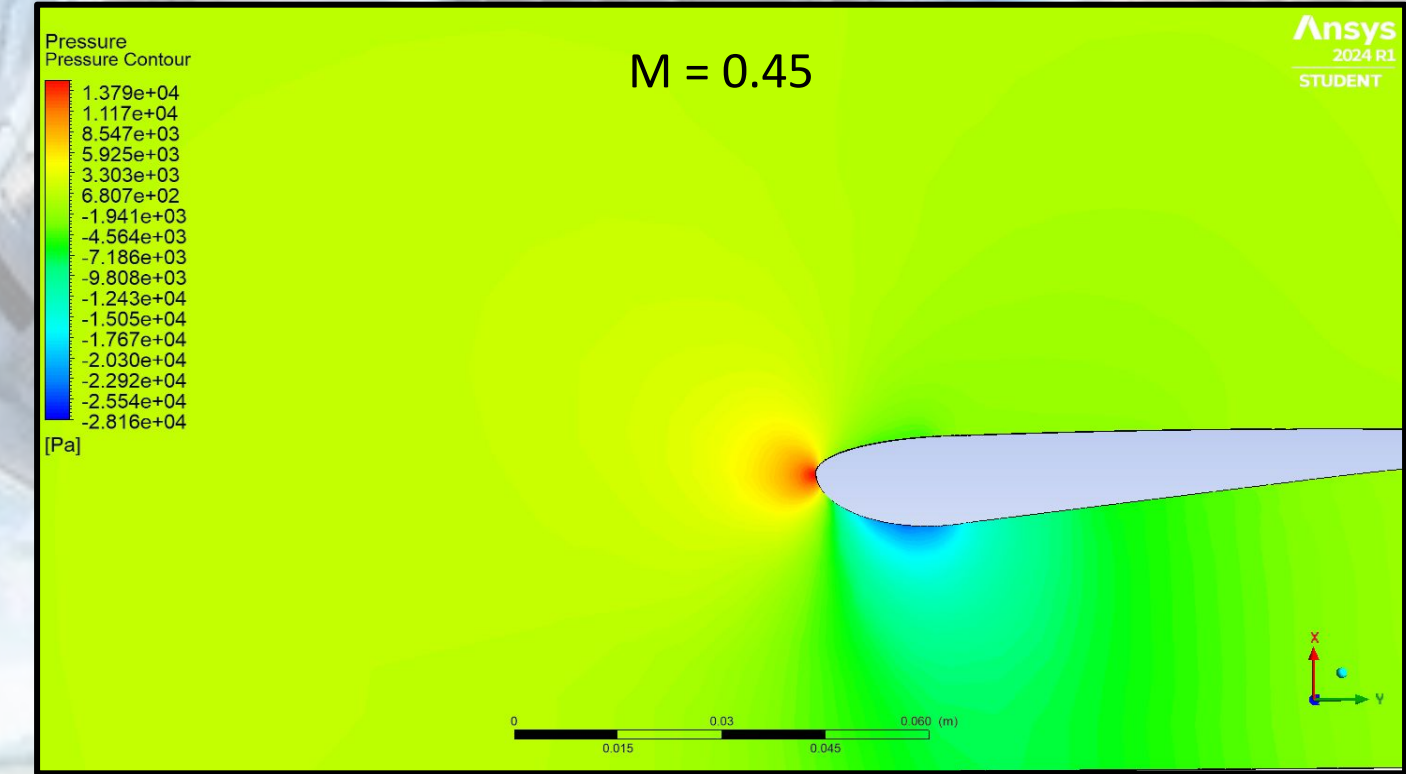
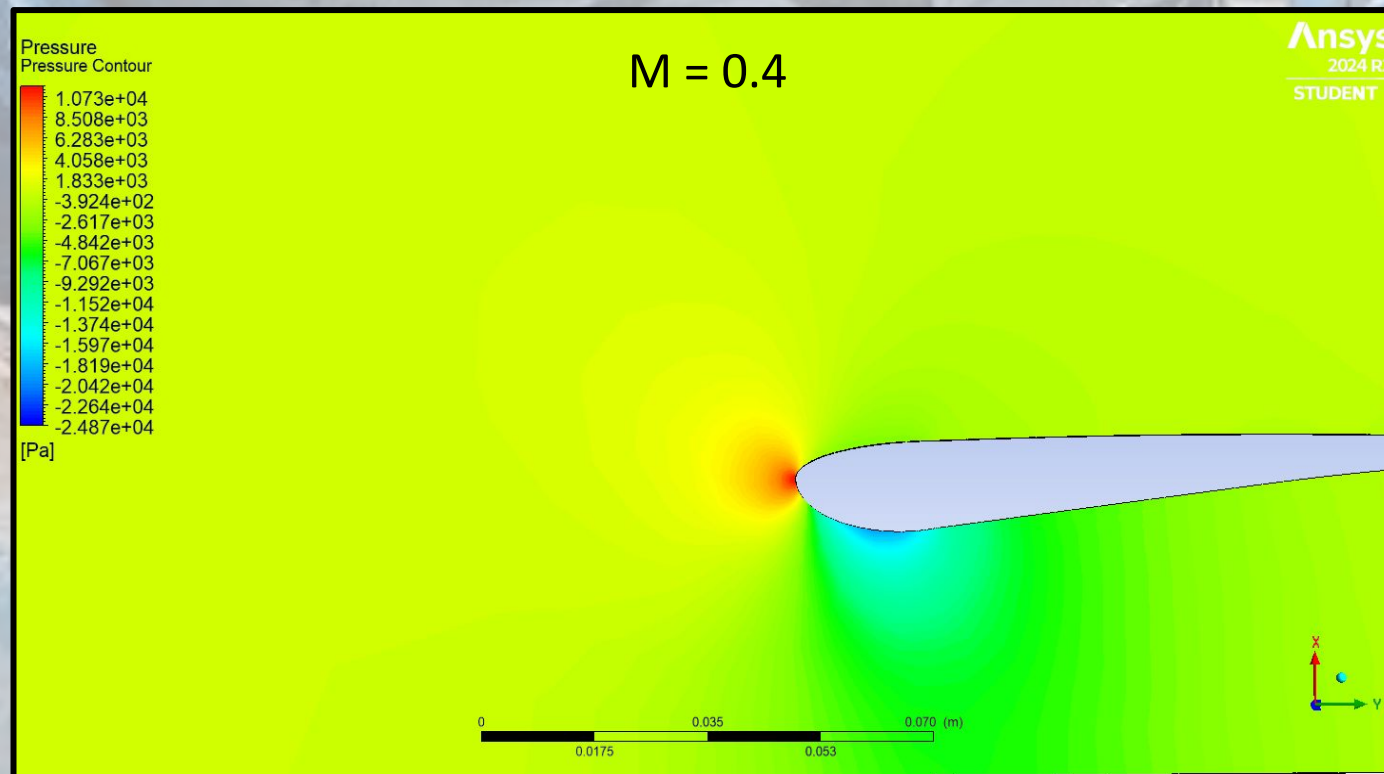
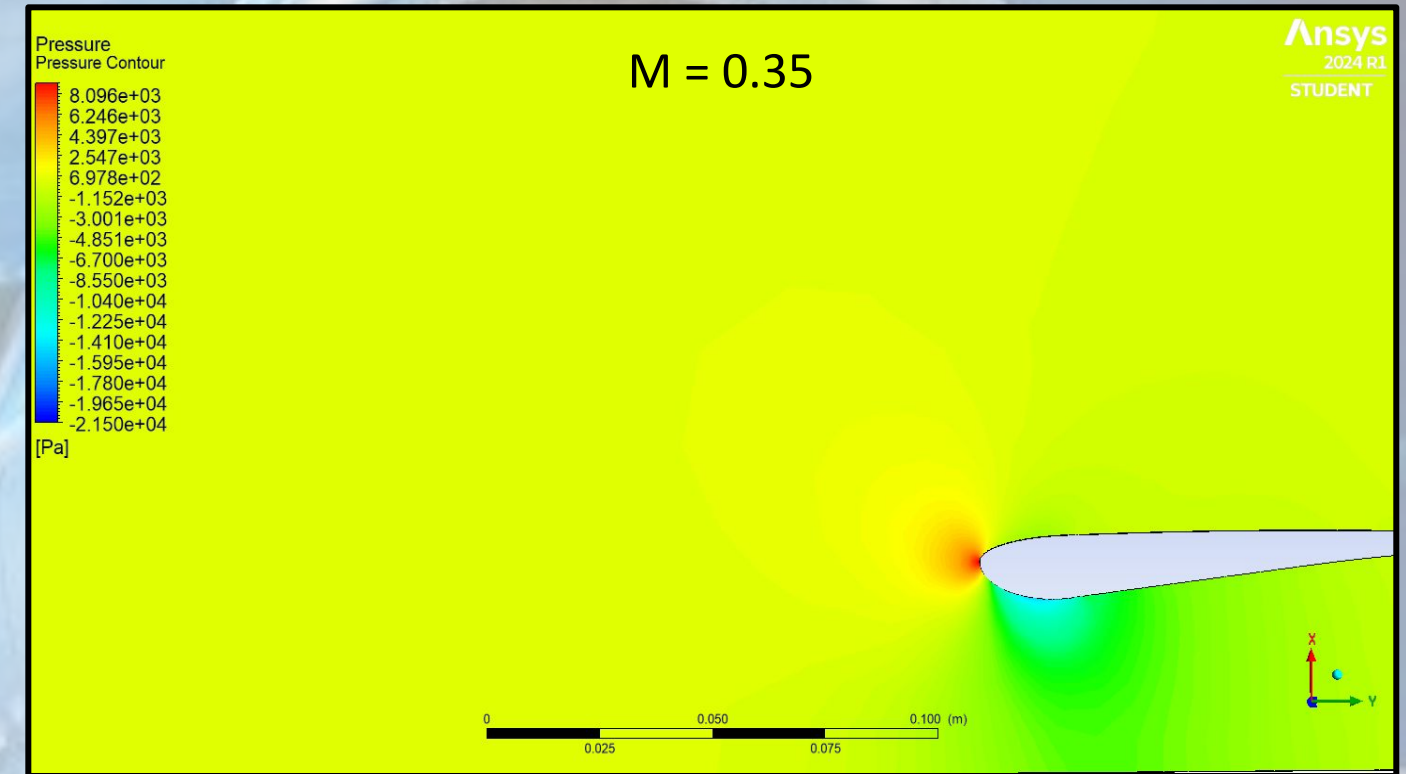
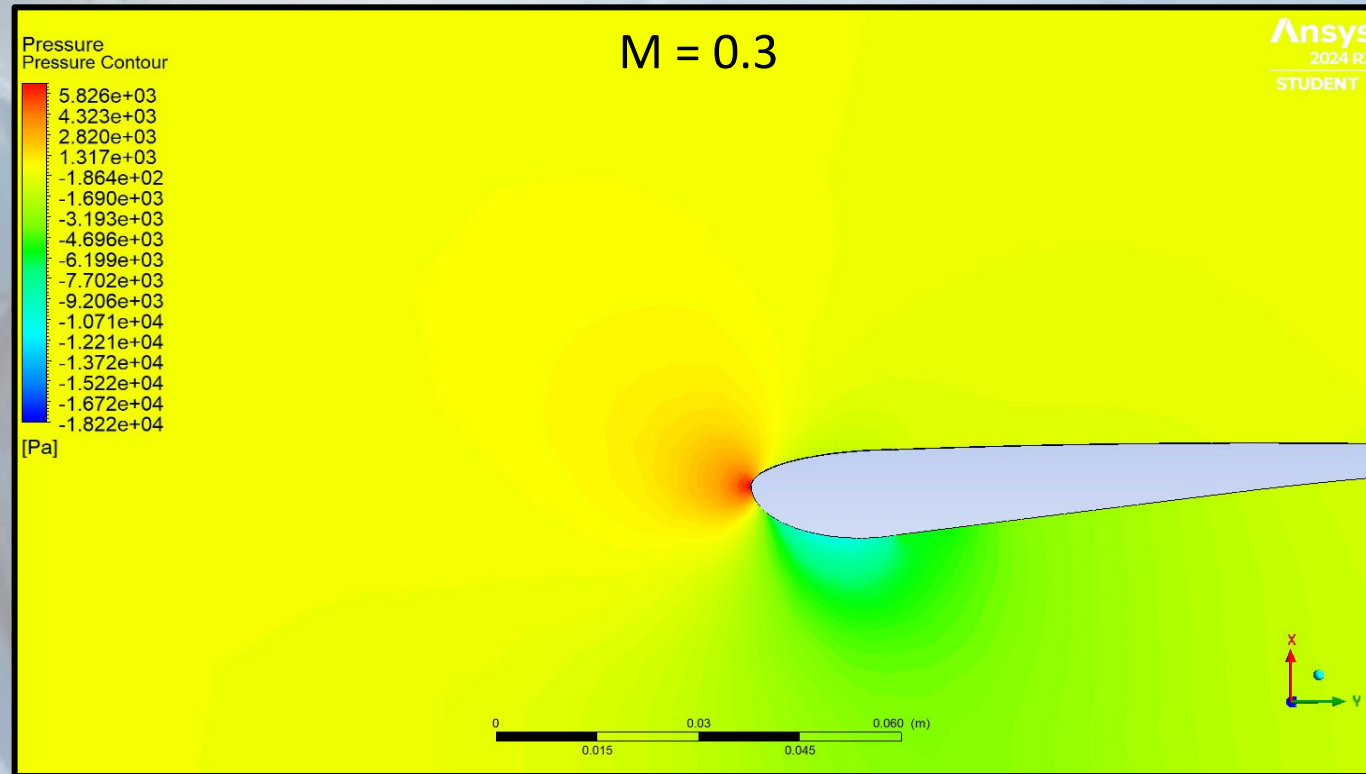
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Help



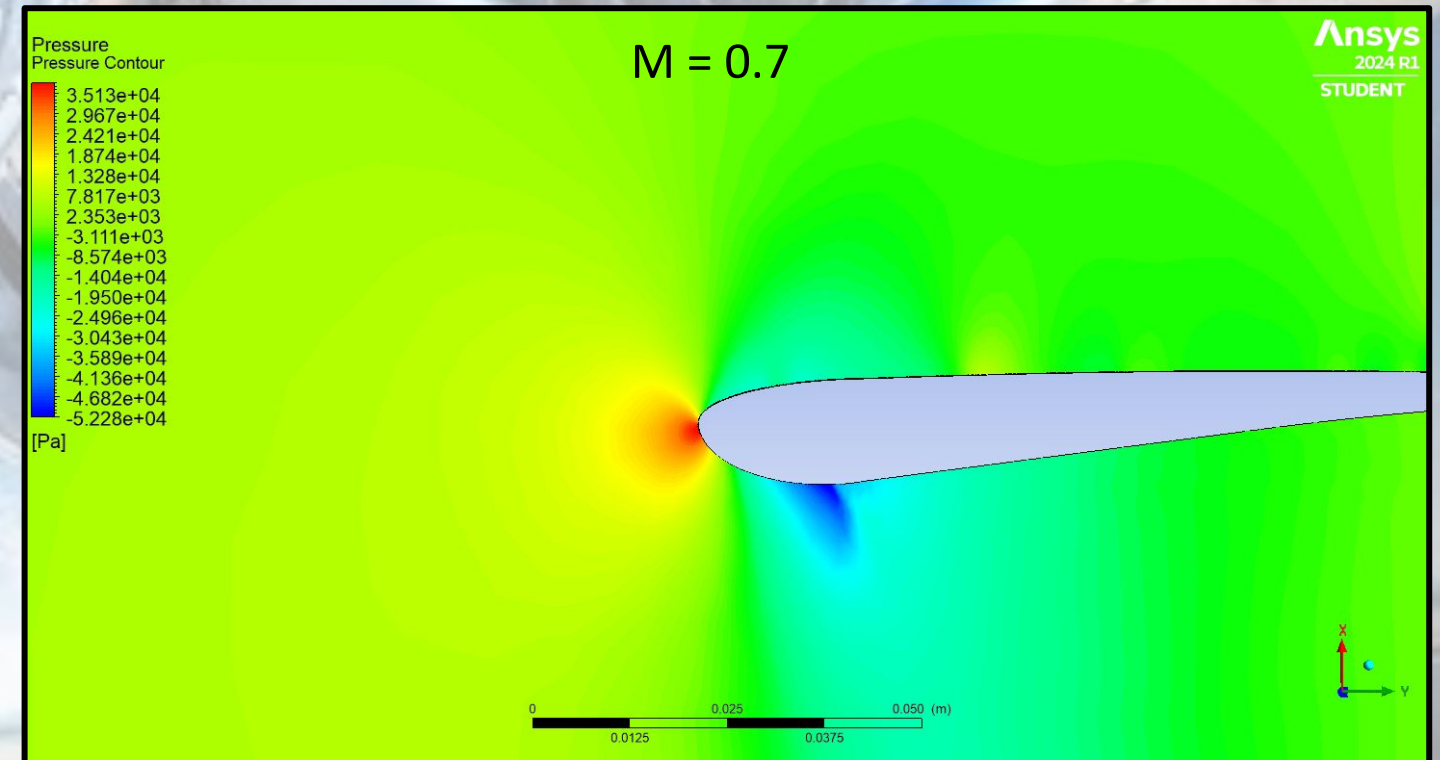
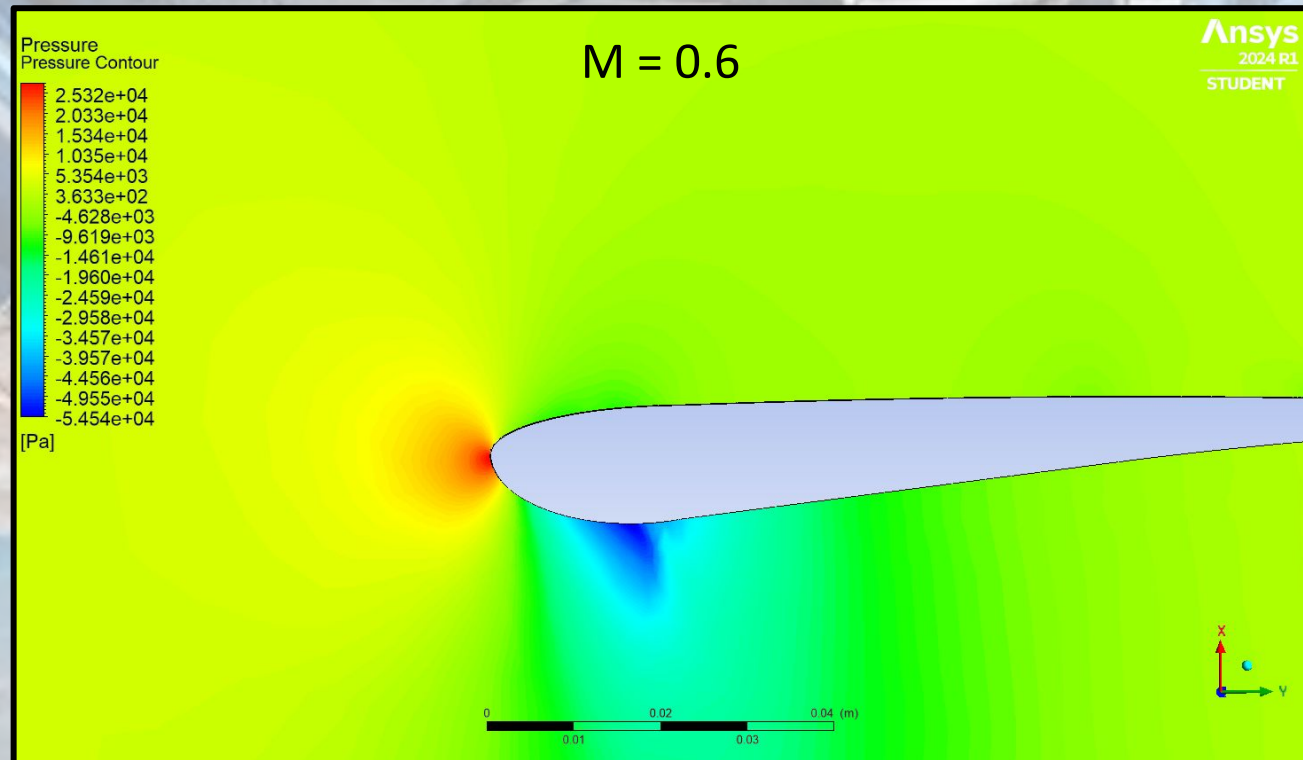
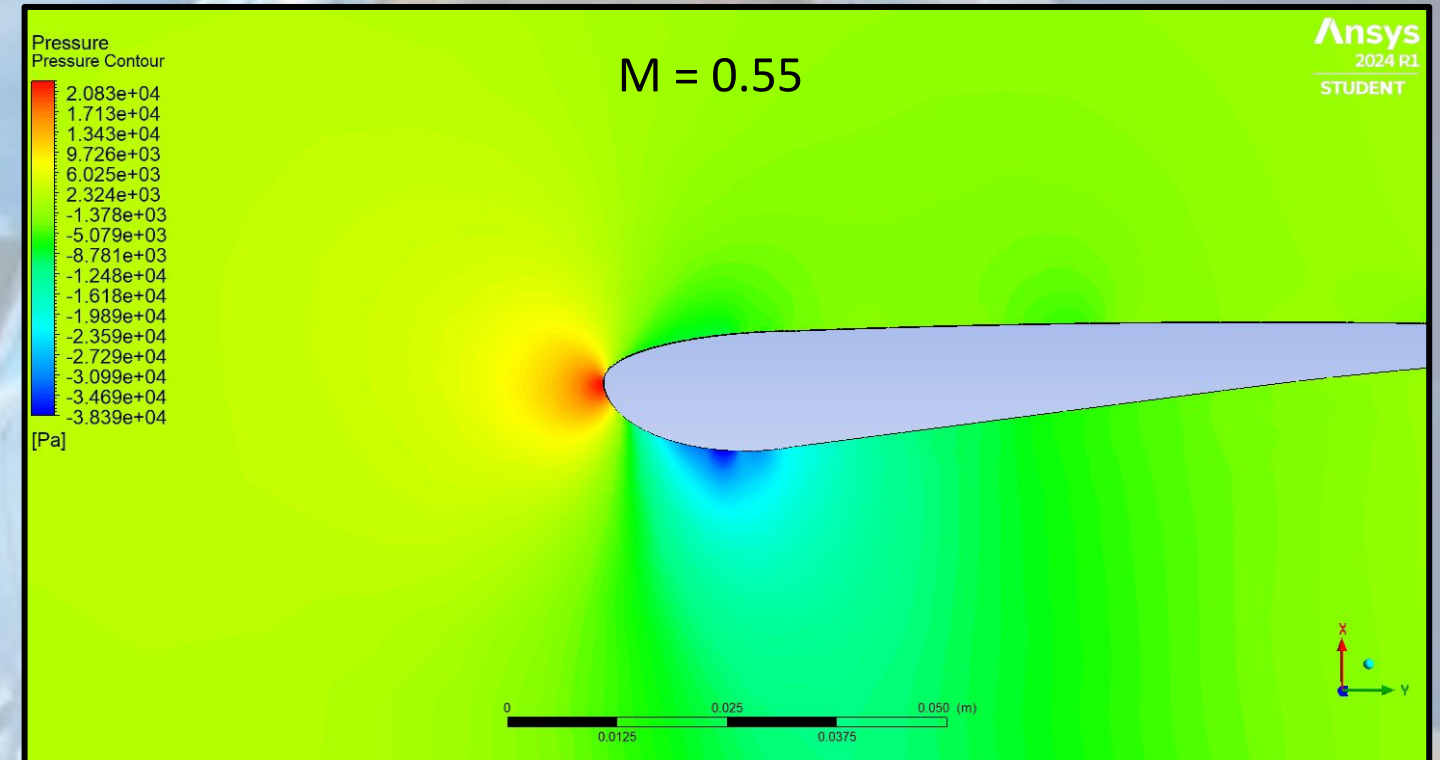
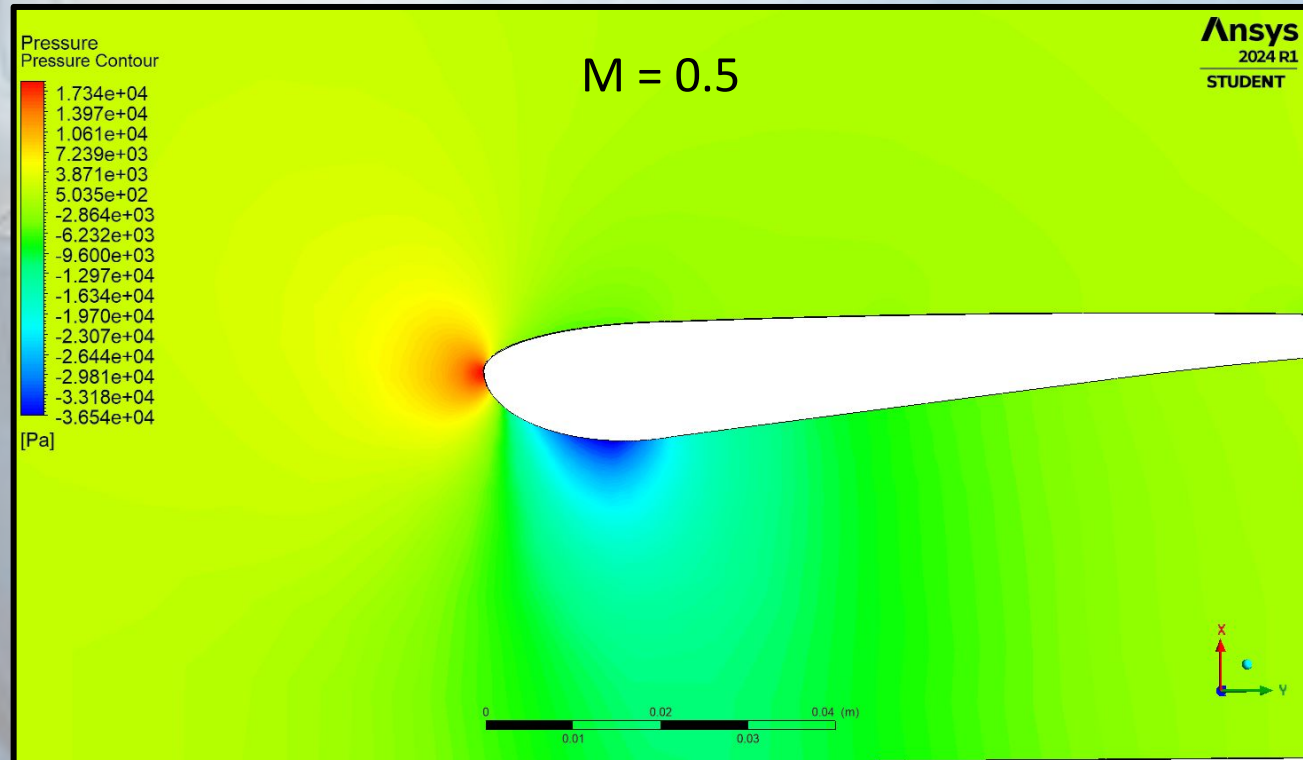


# Pressure Contours



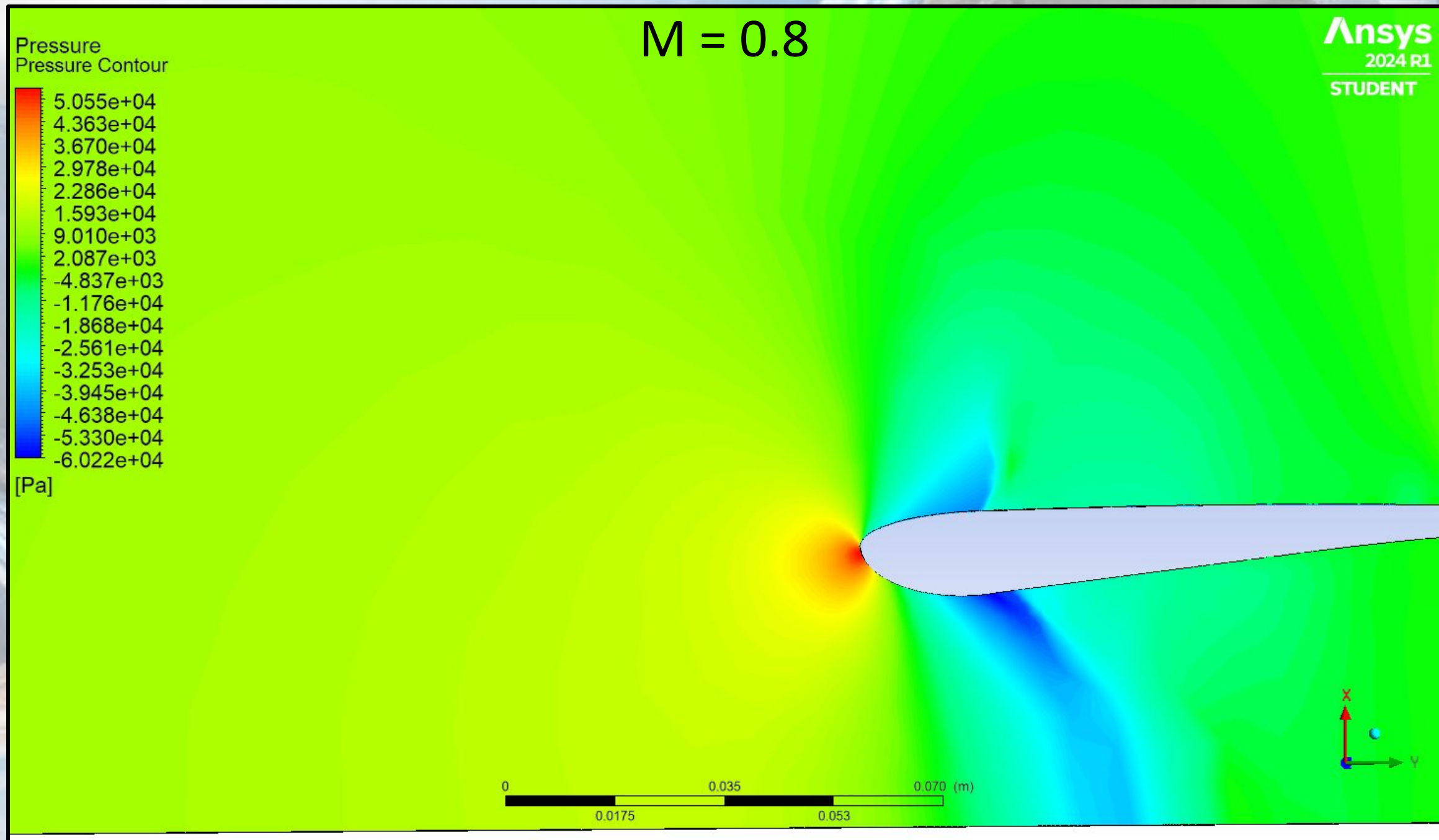


# Pressure Contours



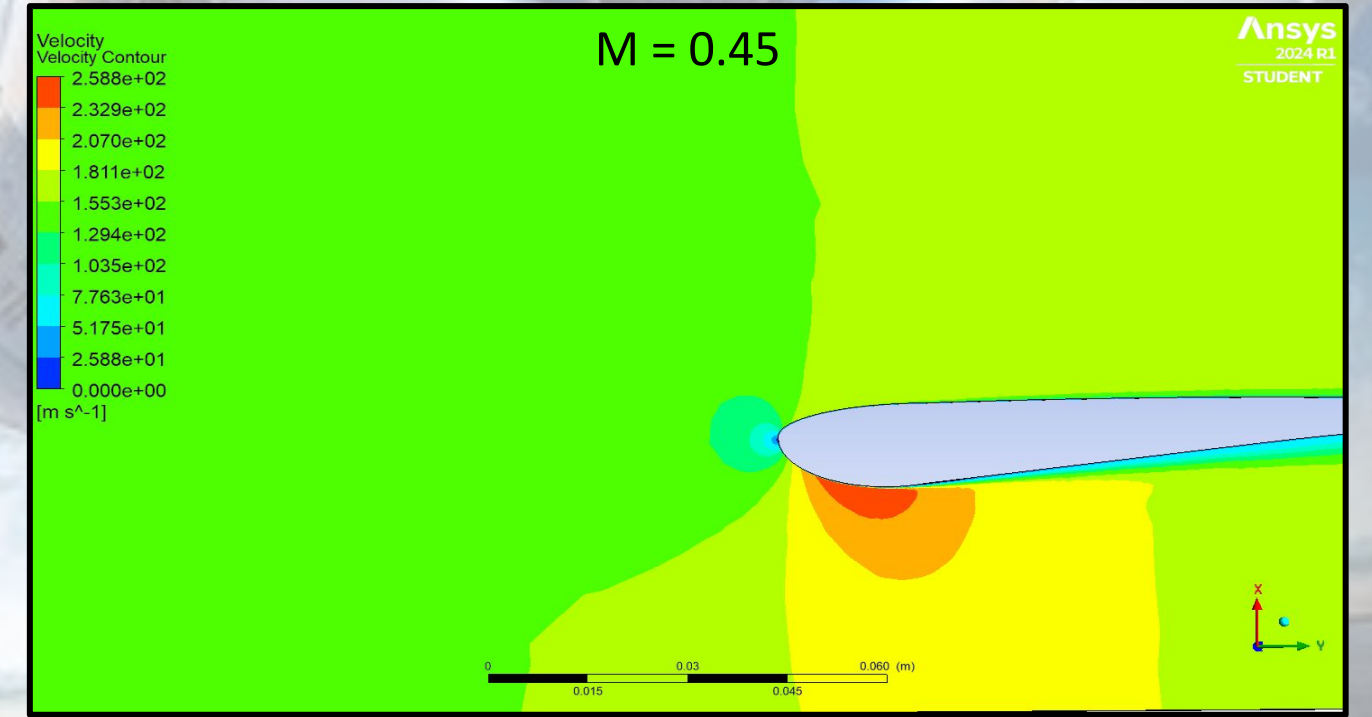
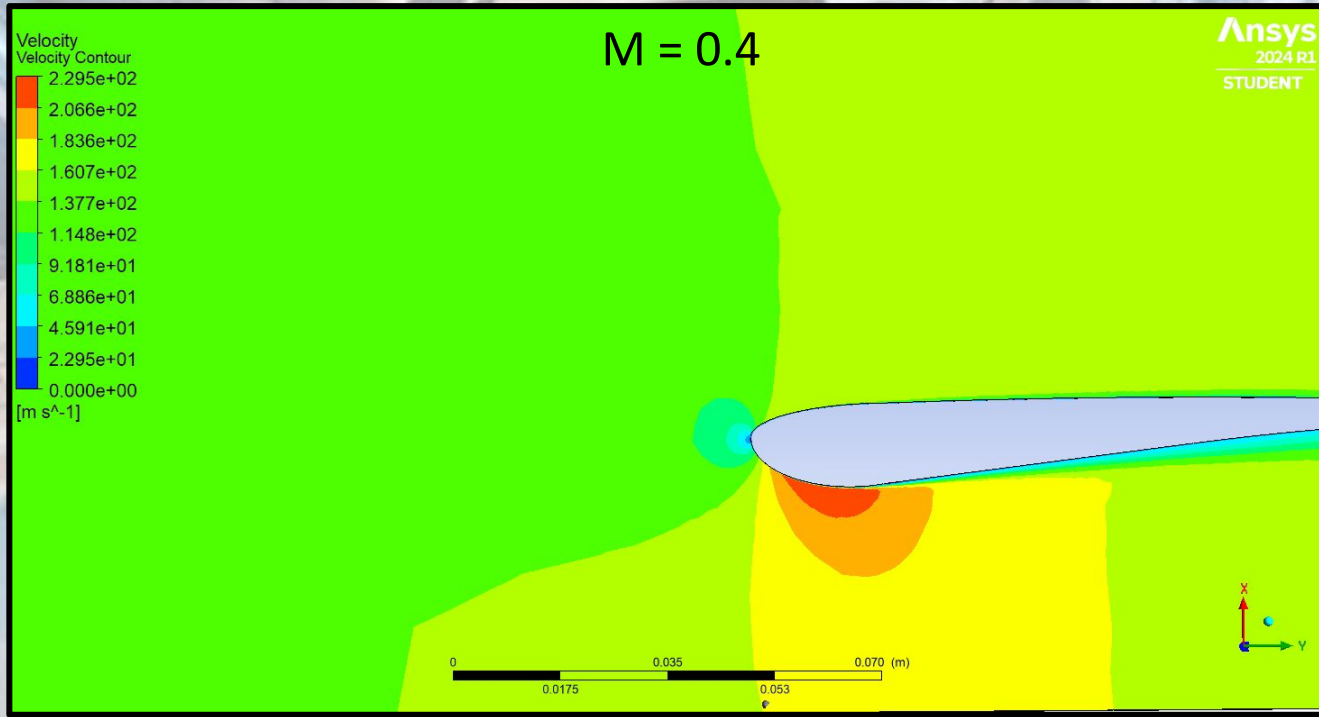
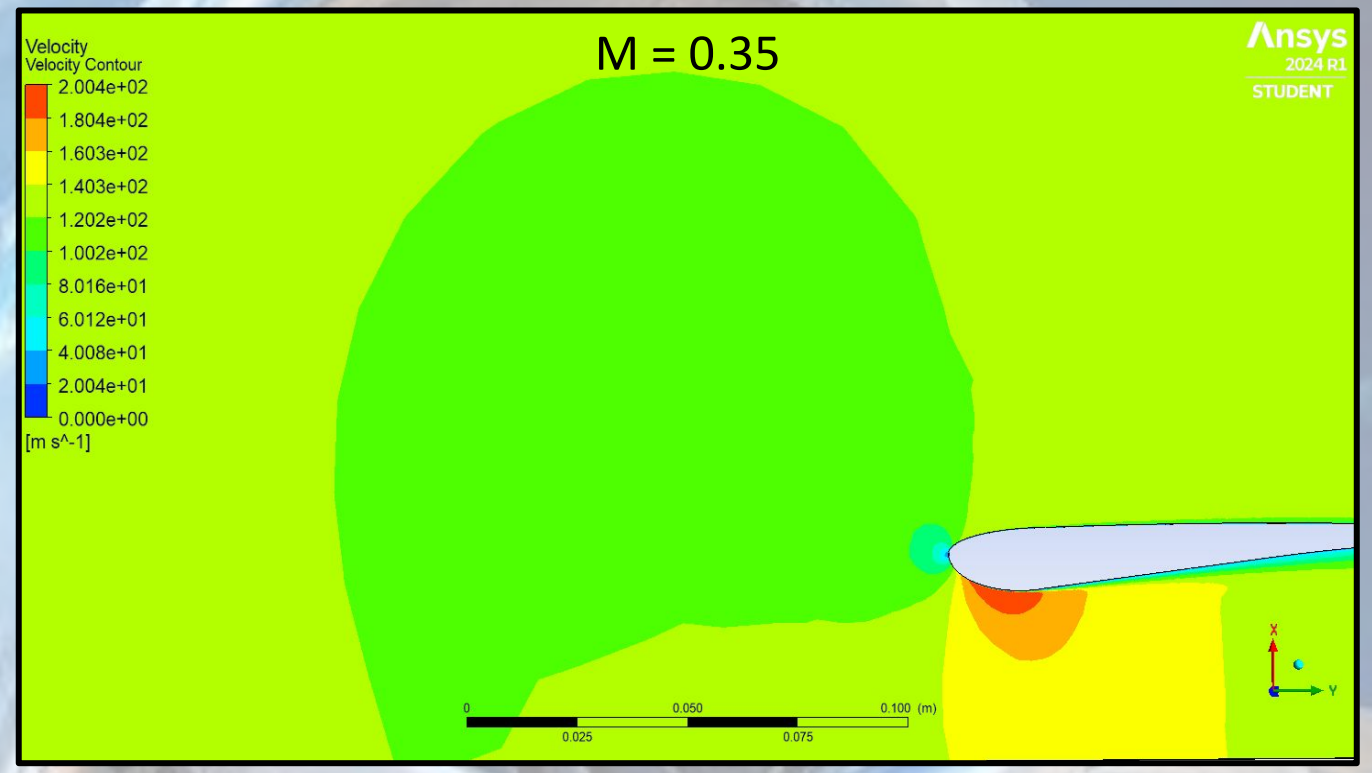
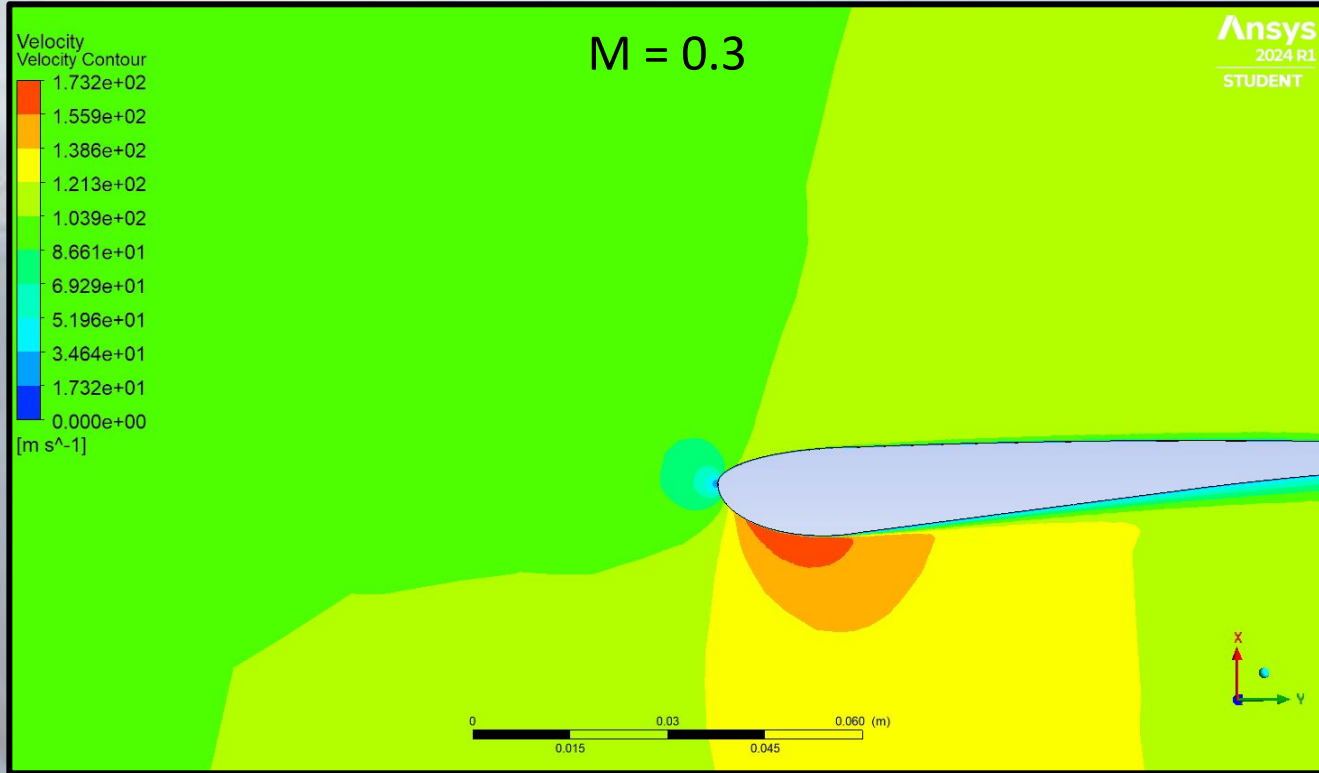


# Pressure Contours



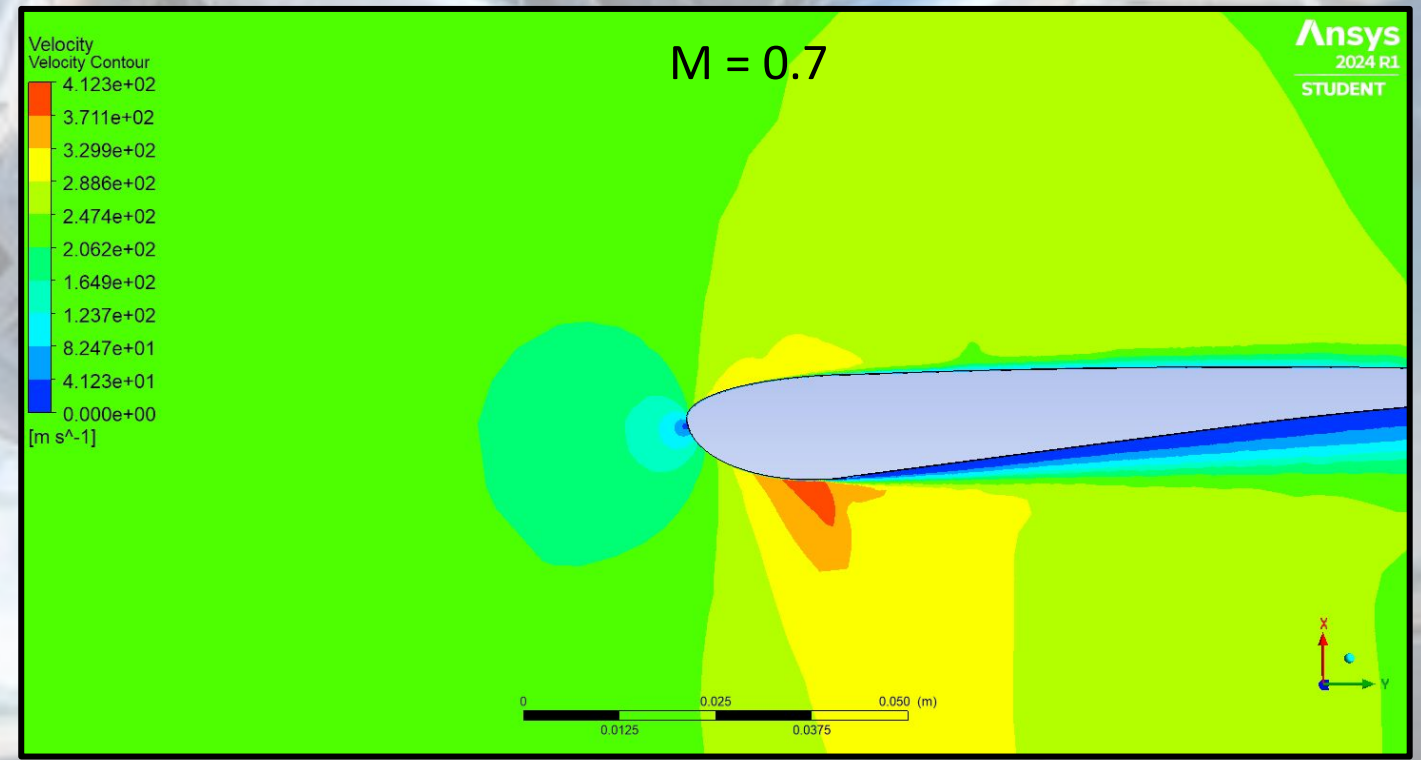
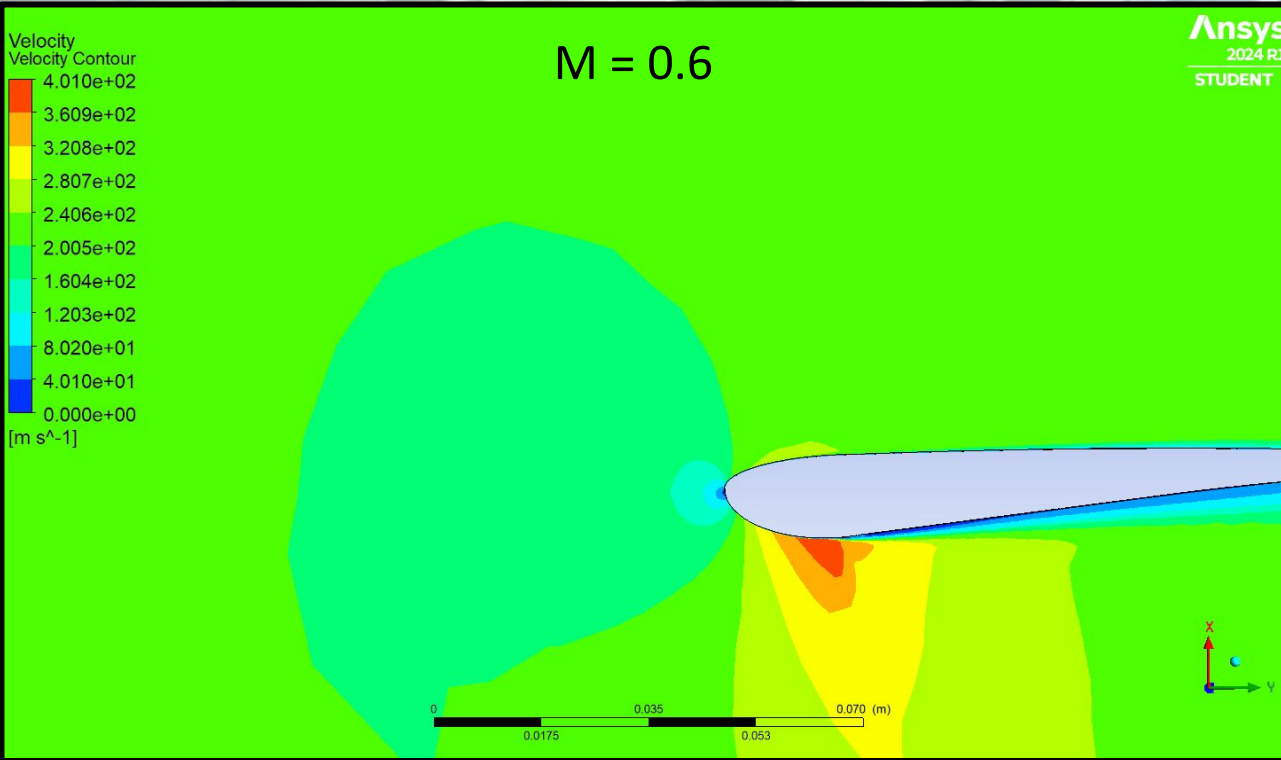
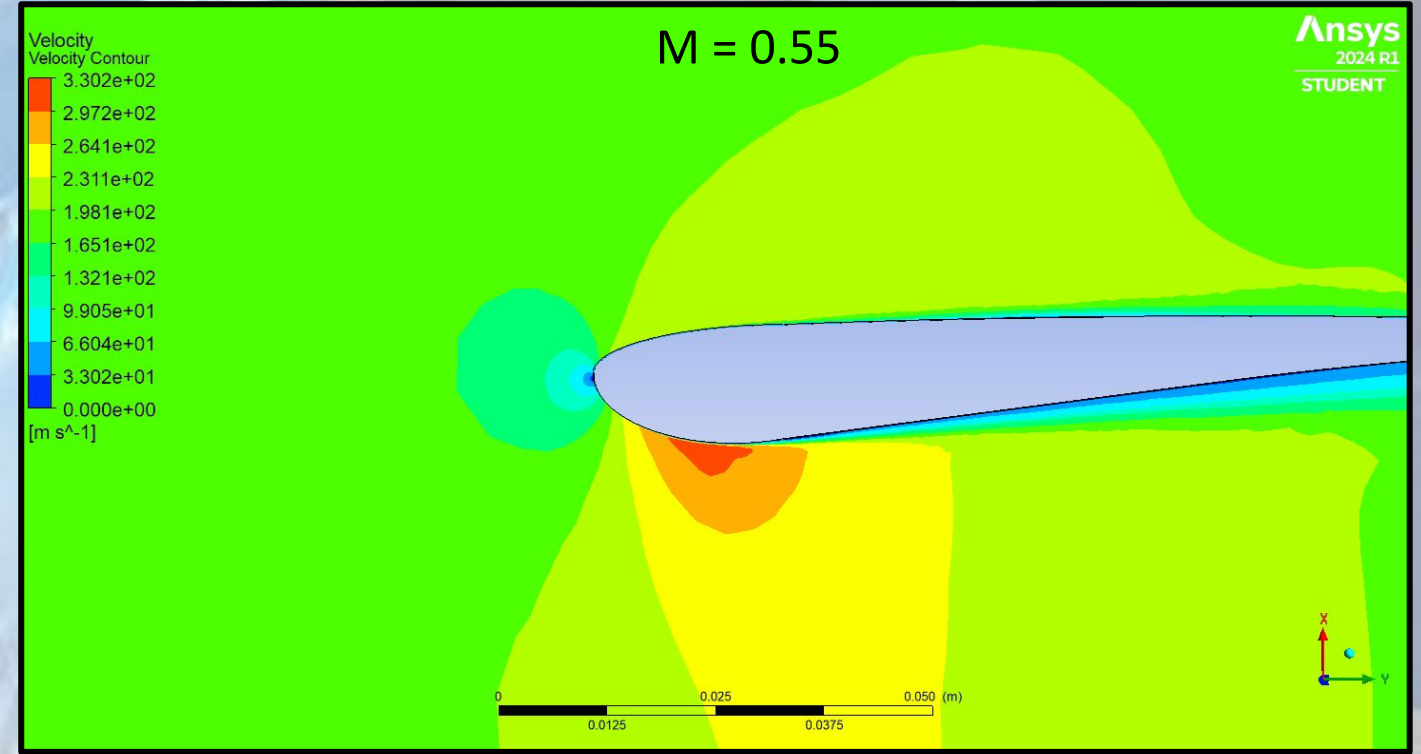
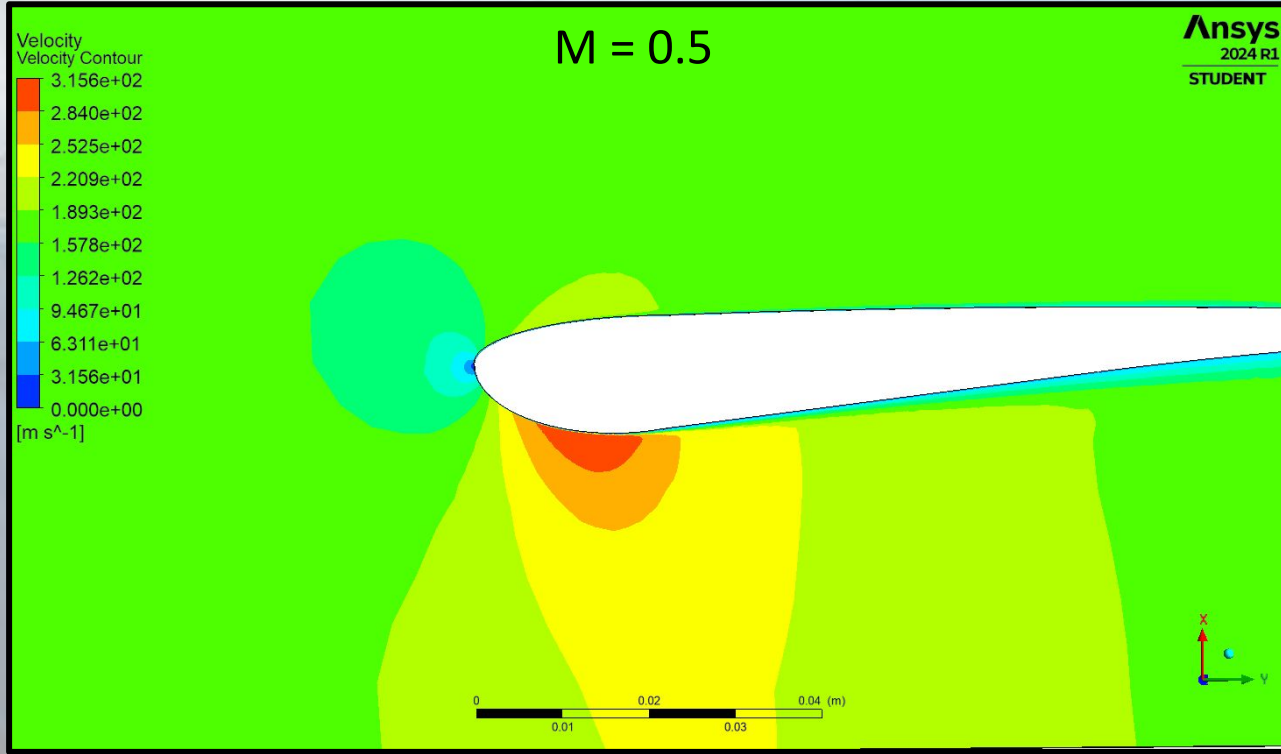


# Velocity Contours



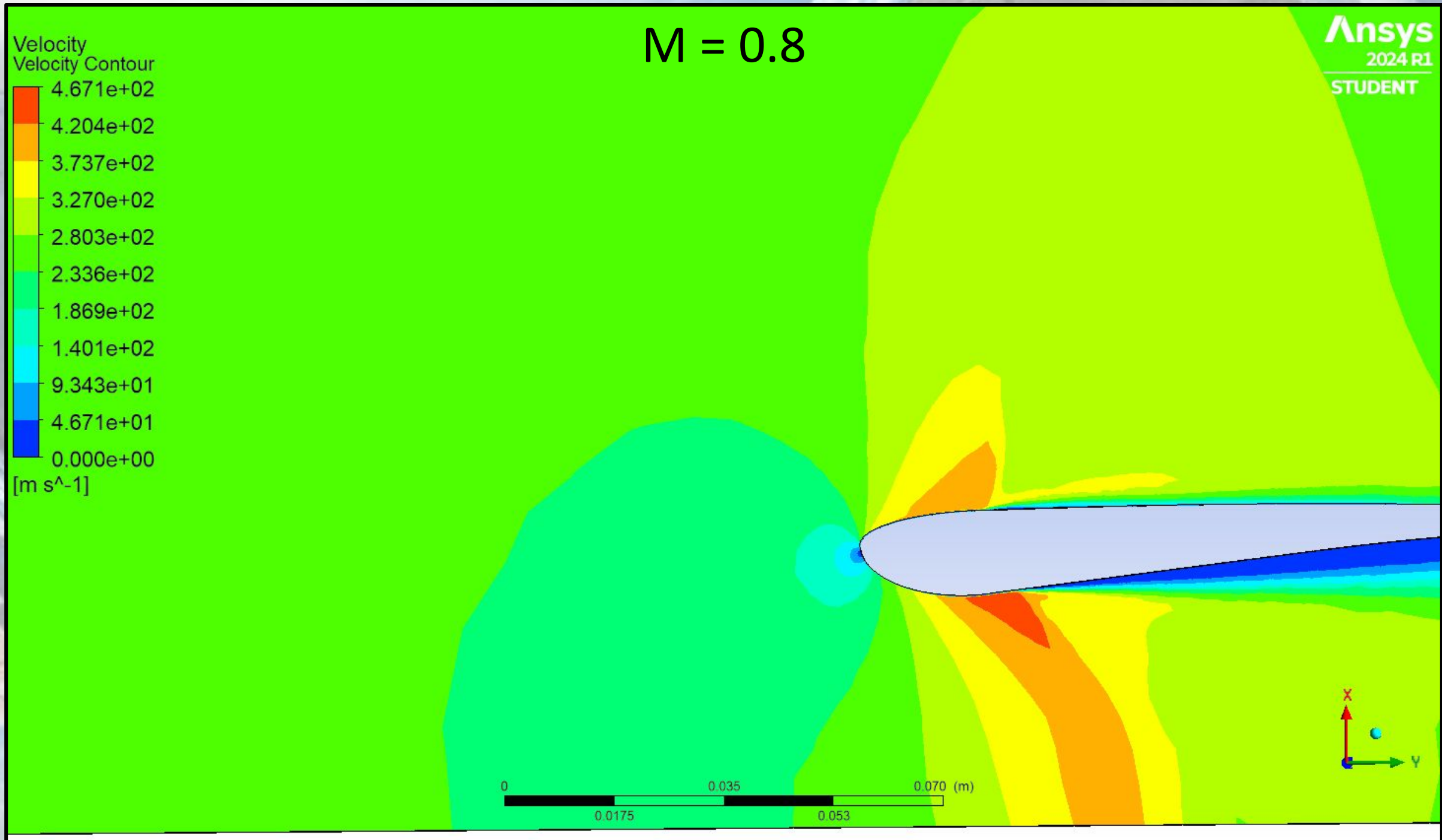


# Velocity Contours



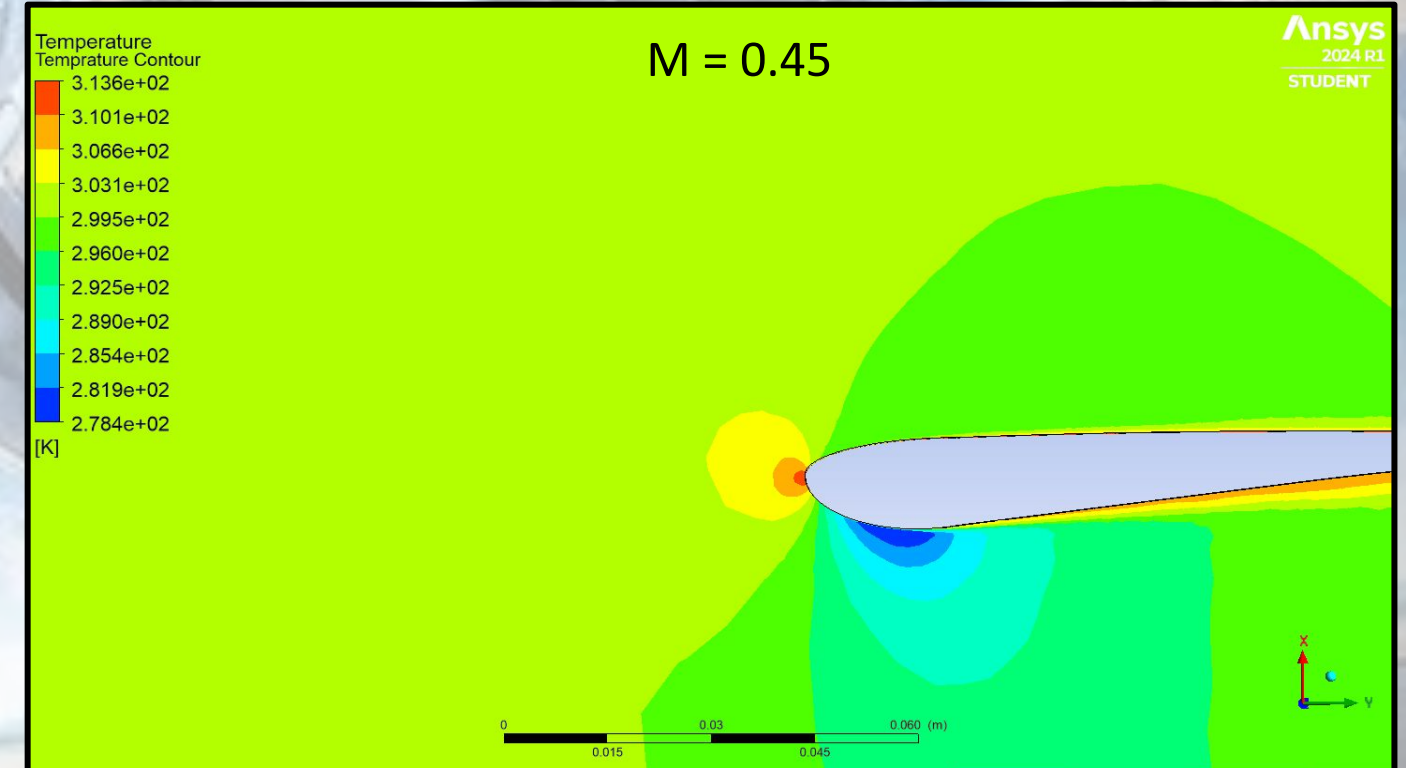
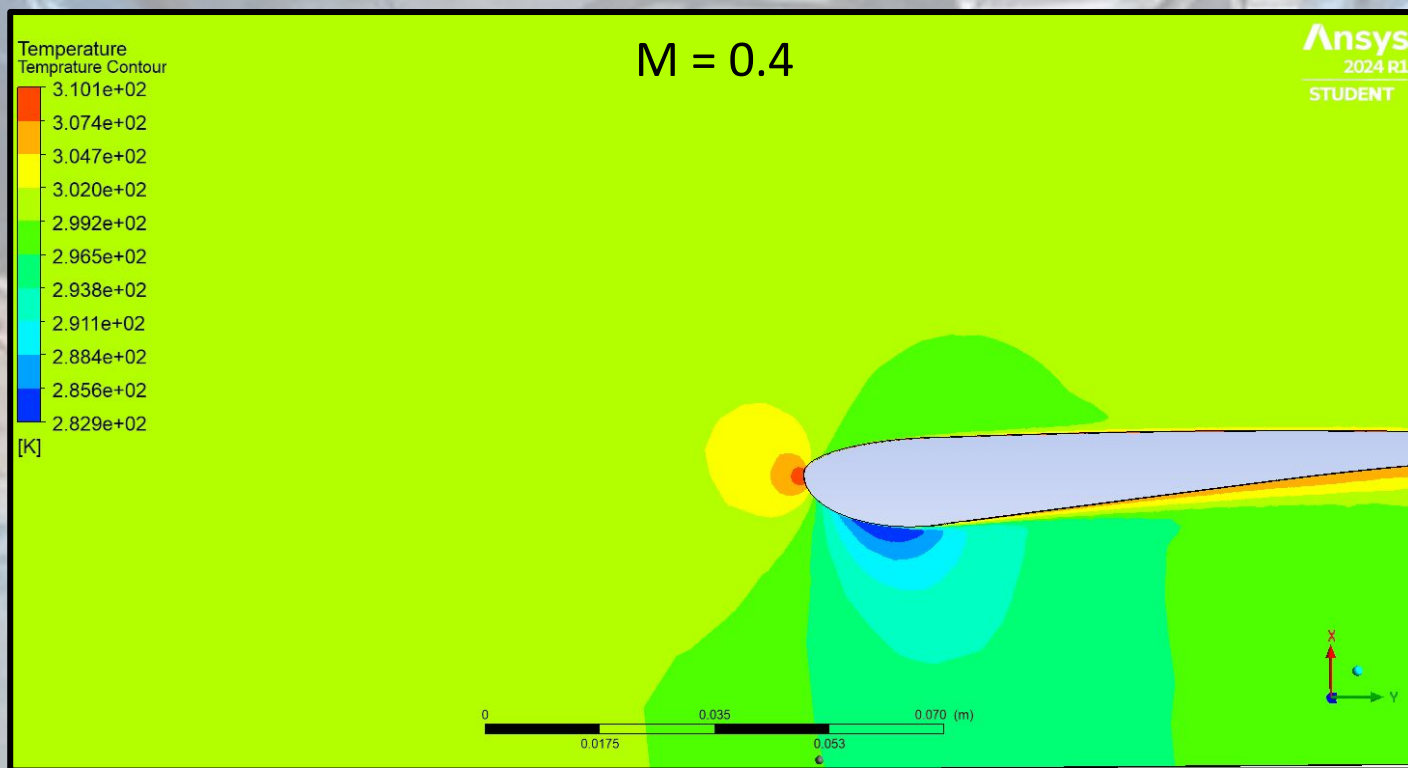
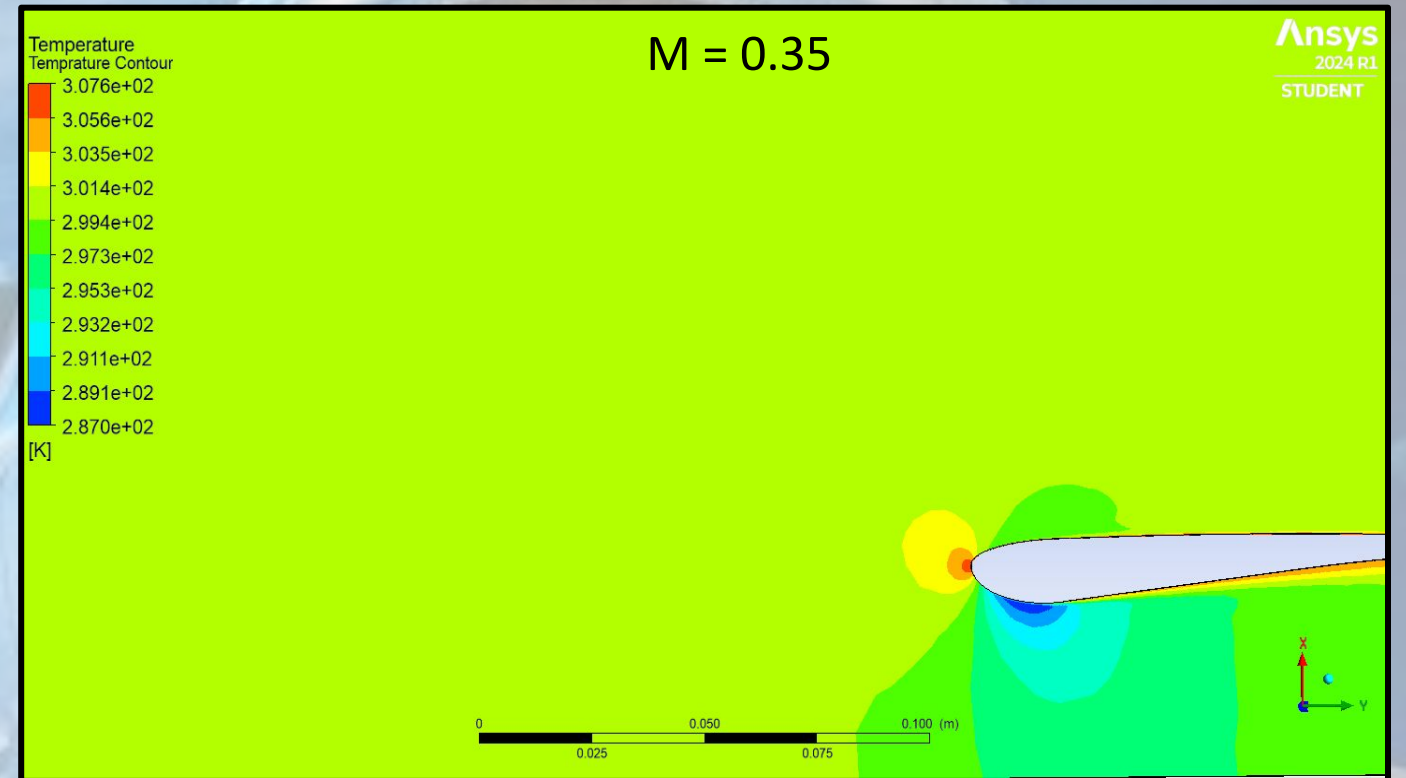
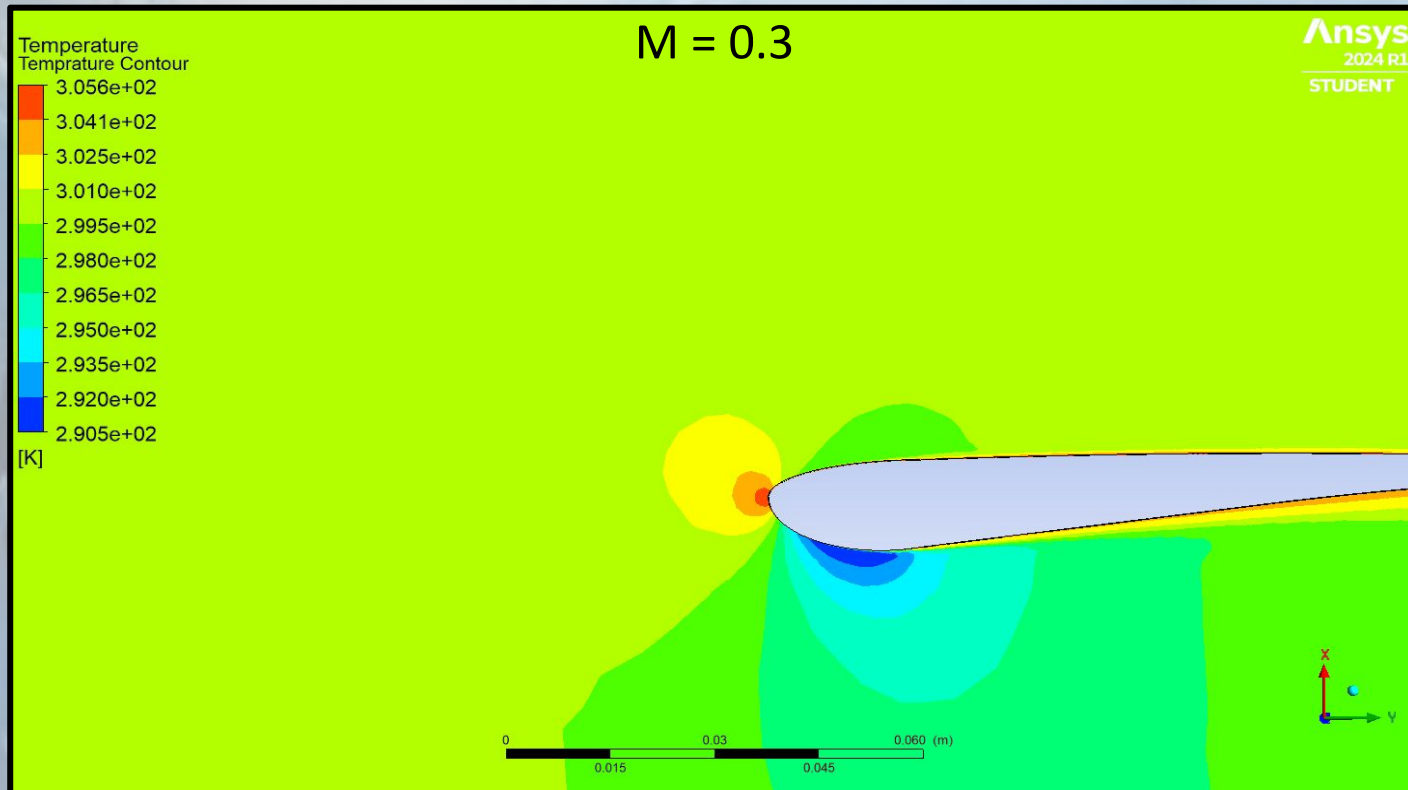


# Velocity Contours



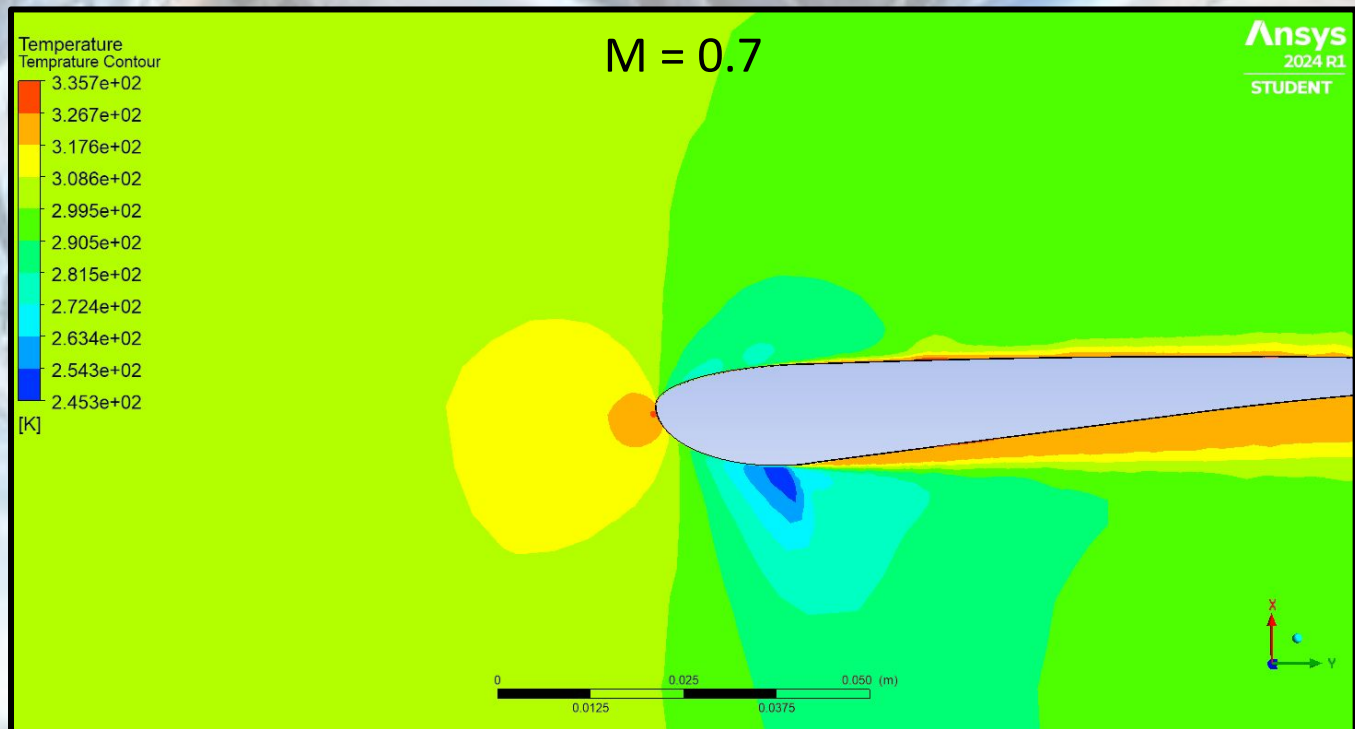
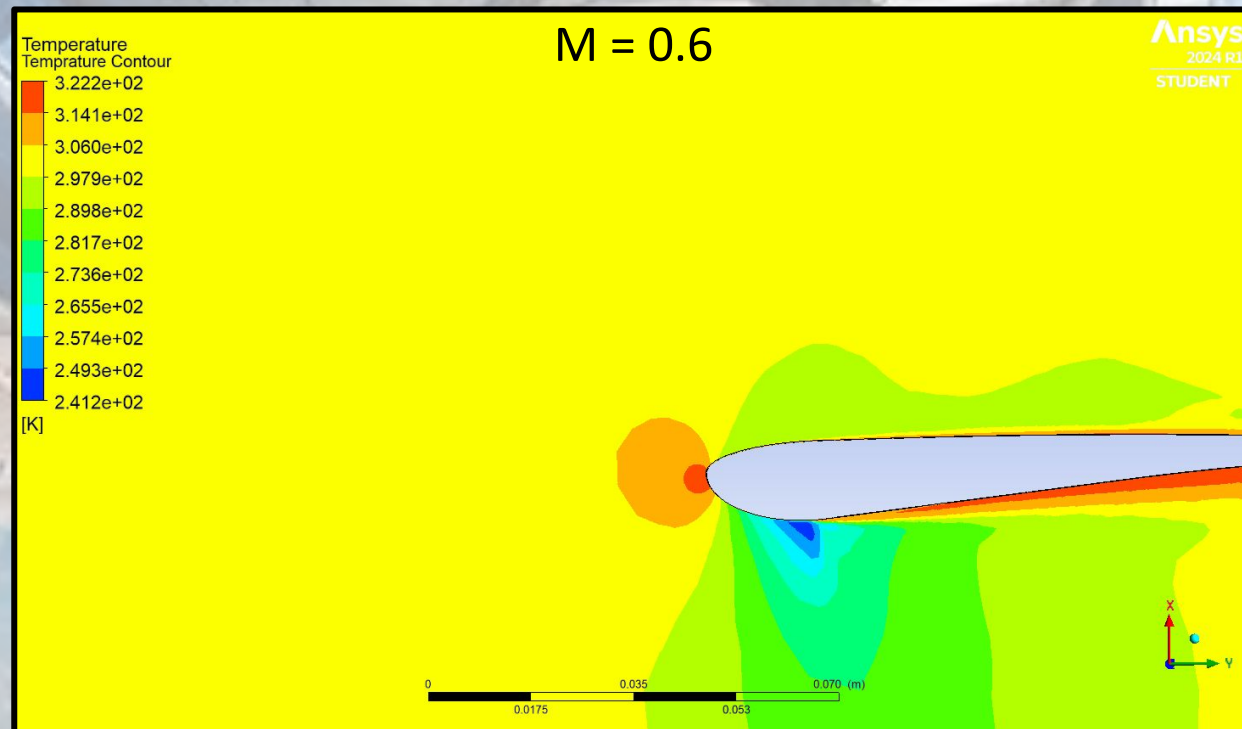
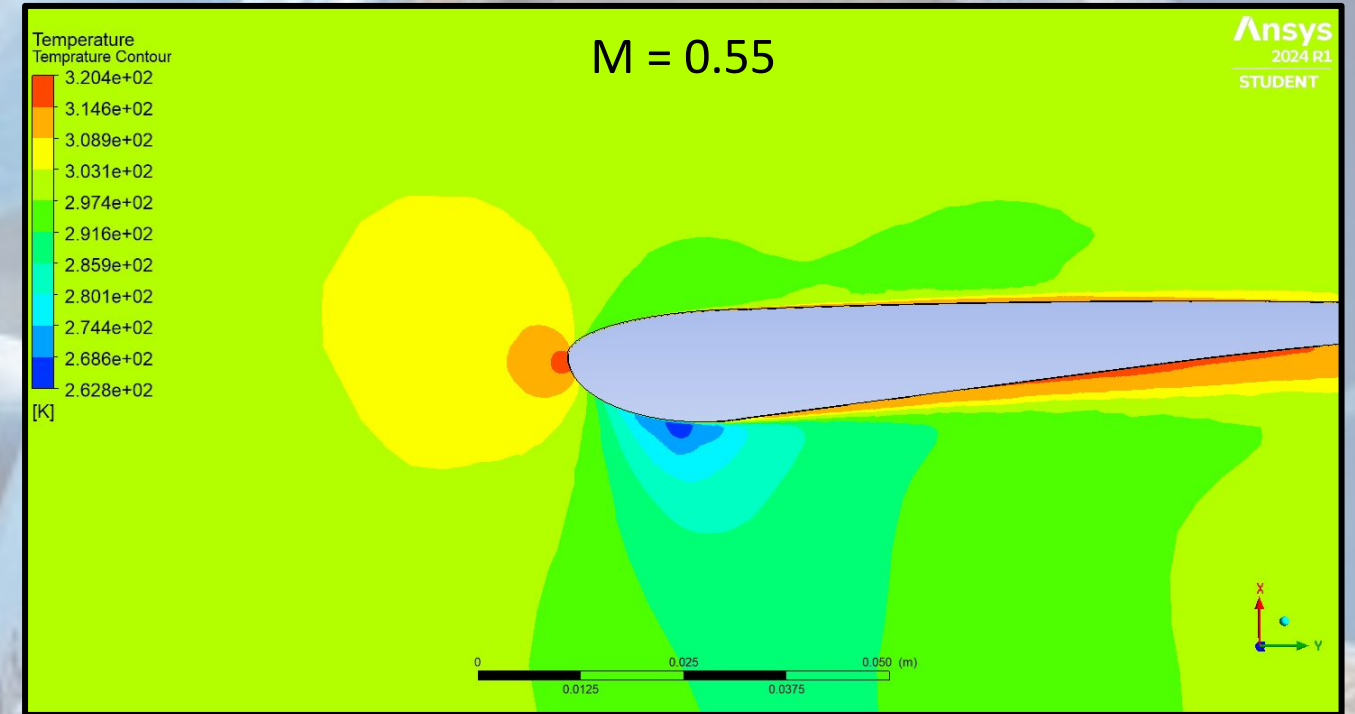
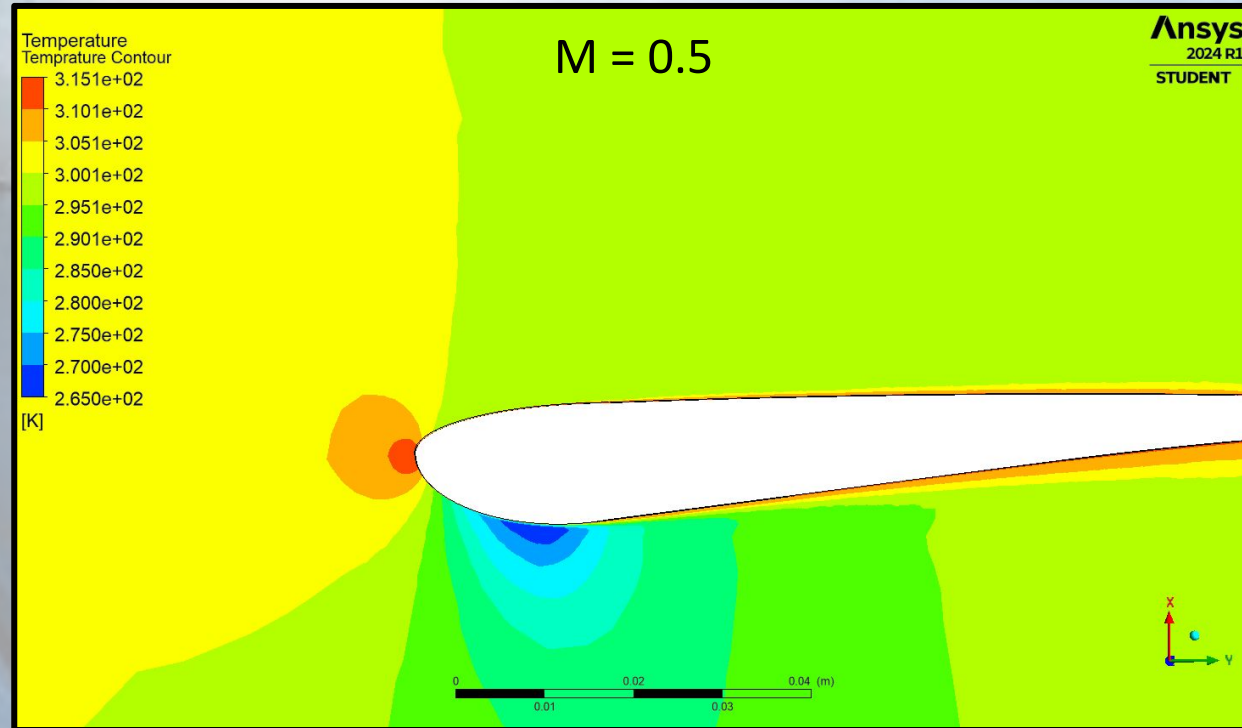


# Temperature Contours



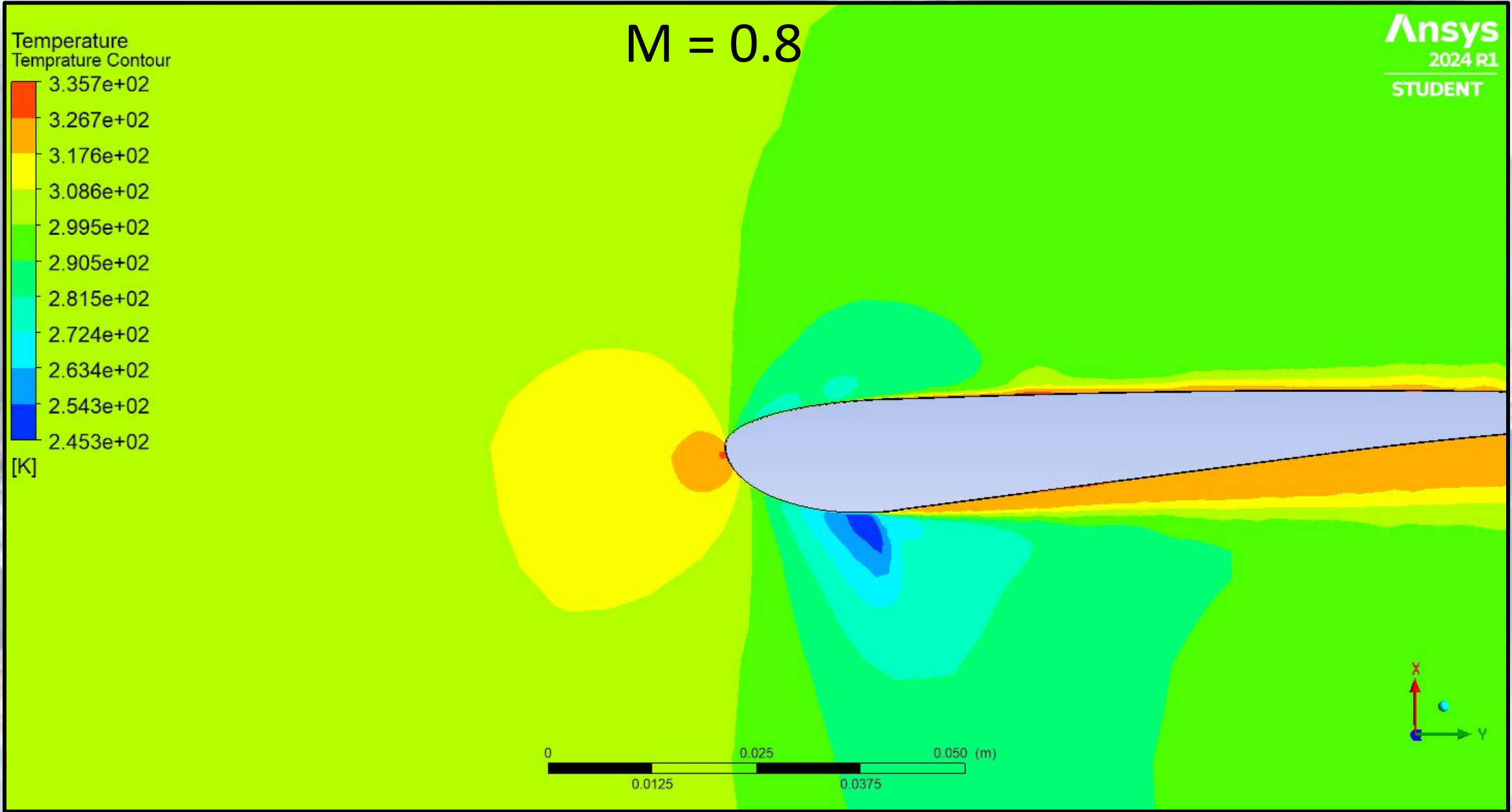


# Temperature Contours





# Temperature Contours



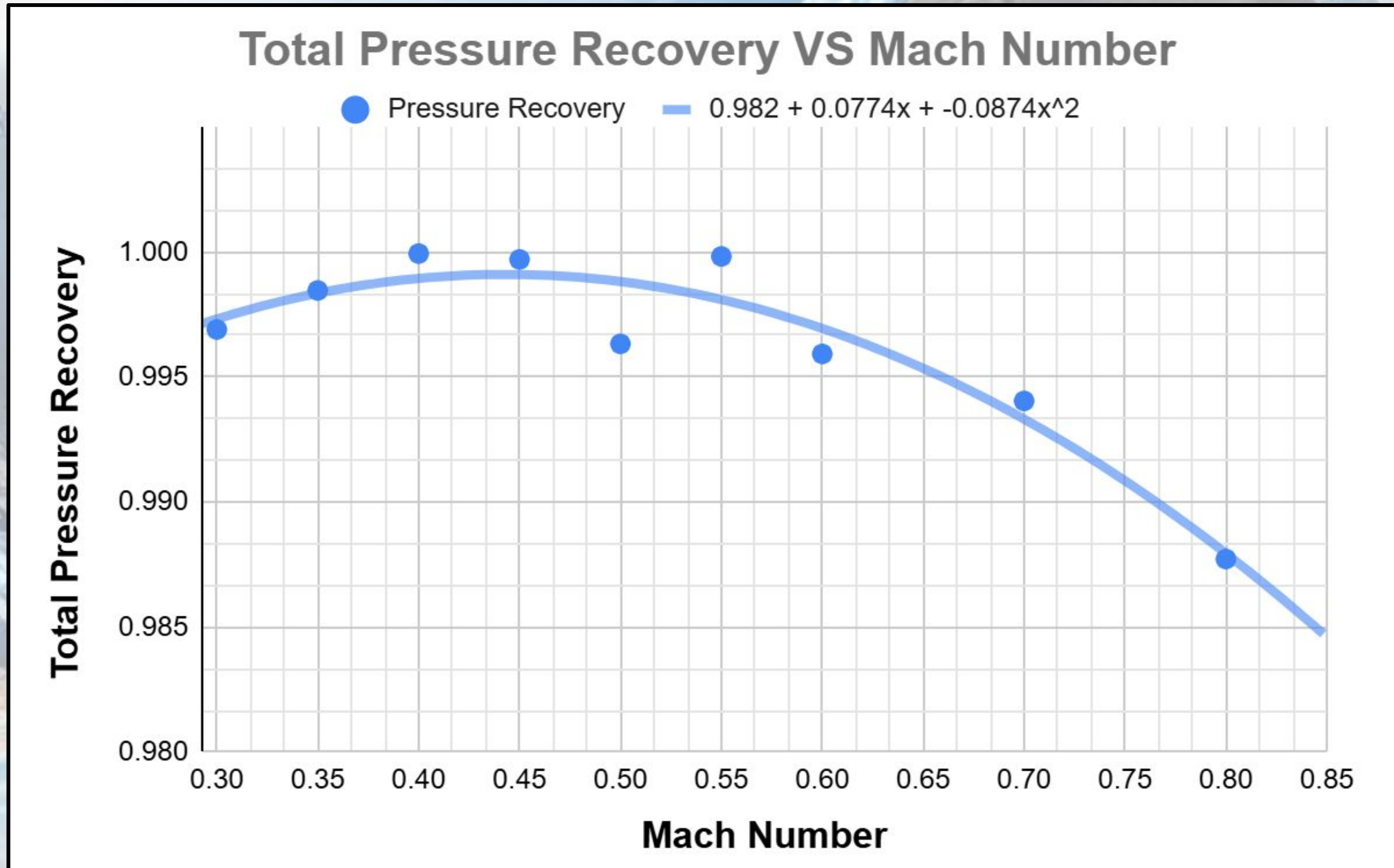


# RESULTS

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

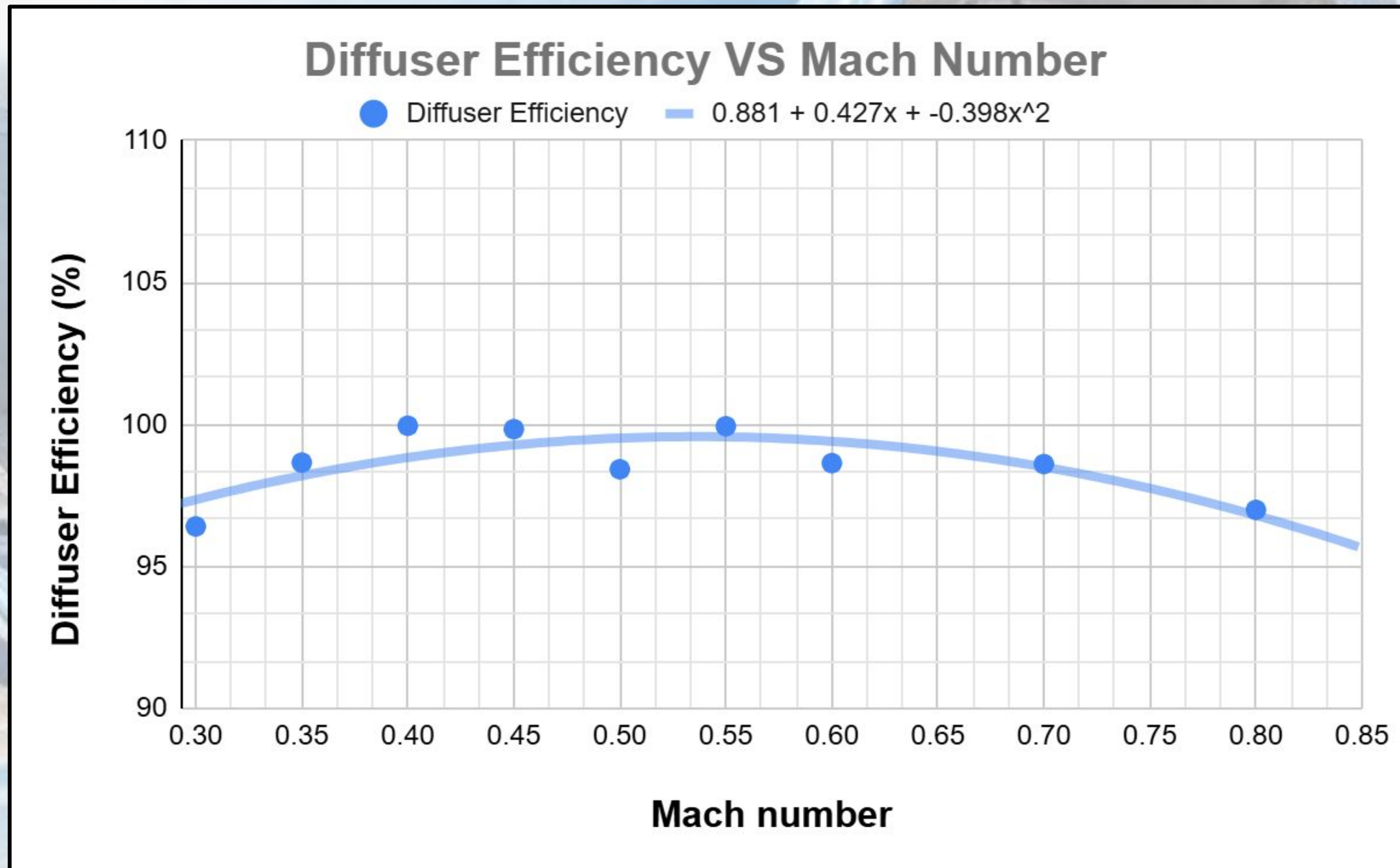


# Total Pressure Recovery VS Mach number Plot





# 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***