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# Computational Fluid Dynamics Study Of Boundary Layer Behaviour In Laminar Flow Over Inclined Plates

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Received: 7/10/2026 Revised: 20/10/2026 Accepted: 25/10/2026 Published: 31/10/2026

## ABSTRACT

Fluid dynamics is the branch of fluid mechanics that studies the movement of fluids, and the finding are widely applied in various industries. Despite numerous studies that have examined the impact of inclined plates inclined plates on boundary layer behaviour, the influence of inclination angles on hydrodynamics and thermal characteristics in laminar air flow remains less explored. This study investigates the hydrodynamics and thermal characteristics of air flow over inclined plates using the Computational Fluid Dynamics simulation. The laminar model is used in the simulation model. Besides, the research study focuses on the flow and heat transfer in laminar flow over inclined plates. The inclined plates used in the simulation model are inclined at specific angles, which are 15°, 30°, and 45°. The effects of the different angles of inclination on the heat transfer and fluid flow characteristics are obtained and discussed. The impacts of angles of inclination angles on the velocity profile, temperature profile, heat transfer rate, and skin friction coefficients are presented in tables and figures. The observations indicate that heat transfer increases with the increase in inclination angles. Meanwhile, the skin friction coefficient experiences a decrease when the angles of inclination increase from the horizontal plate, 0° to 45°. The research study recommends future studies on hydrodynamics and thermal characteristics of laminar flow over inclined plates using water as a fluid type or using two-dimensional (2-D) simulation model. Moreover, the simulation will provide insight into boundary layer behaviour in laminar flow over inclined plates. The findings of this research study can contribute to engineering applications, such as solving real-world problems related to inclined surfaces.

**Keywords:** Computational fluid dynamics, heat transfer, hydrodynamics, inclined plate, laminar flow

## INTRODUCTION

Computational Fluid Dynamics (CFD) is known as the practice of using computer devices or software to do analysis regarding the movement of fluid by solving the governing equations. The governing equations that are solved in the analysis are the governing equations of the conservation of mass, momentum, and energy. Solving the equations allows to do analysis and prediction regarding the flow of the fluid in Computational Fluid Dynamics (CFD). Besides, the applications of Computational Fluid Dynamics (CFD) analysis or simulation can be seen and have been applied in various industries such as in combustor designs, aerodynamic simulations, power plant simulations, and for solving environmental problems (Khalil, 2012). Next, the improvements in computational technology have made CFD as one of the best methods to solve the complex problems of fluid flow. For example, the usual problems that are solved by CFD are problems that are impractical and cannot be solved with the analytical solutions. Besides, CFD simulation allows the engineers to foresee how the fluids behave under various conditions by solving the governing equations of fluid dynamics. The governing equations of fluid dynamics also refers to the Navier-Stokes equation. Additionally, the CFD simulations also offer important information of velocity and temperature profiles, the formation of the boundary layer, and overall dynamics that can contribute to more accurate and well design engineering practice (Sahar et al., 2025).

The purpose of this study is to investigate the behaviour of the boundary layer in laminar flow over inclined flat plates at different angles which is done by using a simulation. The CFD simulation of the laminar flow over inclined plates at different angles will be performed using the computer software, the Ansys Fluent R2 2025 (Student Version). The CFD simulation process of laminar flows over inclined plates have four steps, including the creation of a computational domain or geometry, generating a mesh, choosing the suitable boundary conditions, and solving the equations of fluid flows using numerical solvers. In this research, the impact of fluid flows over plates that are inclined at various angles, specifically $15^O$, $30^O$, and $45^O$ will be investigated. Moreover, this study aims to obtain valuable information of the behaviour of the boundary layer in laminar flow conditions as influenced by various inclinations of the plates. The impact of inclination plates can be seen in a previous study by Alhendal et al. that studied the airflow characteristics over inclination of the plates that is heated at varying angles, $0^O$ to $90^O$. Based on the study, the results show that the average Nusselt number and the coefficient of friction increase with increasing inclination angles (Alhendal et al., 2023).

The previous study by Guha et al. investigated the convection that occurs naturally around the inclined plates that are heated, where the inclination of the plate changes between a horizontal to vertical, especially in thermo-fluid dynamics. In the research paper, Guha et al. aims to learn the effect of the inclination angles specifically from $0^O$ to $90^O$ on the thermo-fluid dynamics. For example, the thermo-fluid dynamics that are analyzed in the study include velocity, temperature, and pressure distributions. Thus, the study by Guha et al. shows an increase in average Nusselt number (Guha et al., 2019). Other than that, a previous study by Alhendal et al. determined the impact of rate of transfer of heat which was influenced by the Rayleigh number, non-dimensional width of the plate, and various rotation angles from $0^O$ to $90^O$. The results of the study obtained the changed in average Nusselt number causes by Rayleigh number at all the rotation angles. For instance, the average Nusselt number increases as the Rayleigh number increases (Alhendal et al., 2024).

In conclusion, this study will utilize the computer software, Ansys Fluent R2 2025 (Student Version) to check the effect of inclination angles within the range $15^O$ to $45^O$ of the plates based on the formation of the boundary layer in laminar flow. There are four CFD simulation processes which are setting the geometry or computational domain, specifying the most suitable boundary conditions, refining the mesh, and solving equations to ensure the accuracy of fluid flow behaviour that will be captured in the simulation. Furthermore, the results from the simulation of laminar flow over different angles of inclination of plates will be compared with other data such as the analytical data to check the accuracy of the simulation. Overall, this research will help to give a better understanding of how the plate inclination will influence the boundary layer and the characteristics of fluid flow.

## METHODOLOGY

### Model Description

The computational domain created in this study is a two-dimensional (2-D) domain, as illustrated in Figure 1 and Figure 2. Figure 1 illustrates the flow configuration of the computational domain of the flat plate. In this research study, the inclined plates are also taken into account as the study aim to investigate the effects of inclination angles on boundary layer behaviour in laminar flow conditions. For example, three inclination angles used in this study such as 15°, 30°, and 45°. The flow configuration of these inclined plates is illustrated in Figures 2. The length of each plate is identical, which is 2 meters long and parallel to the x-axis. Besides, the heights of boundaries AB and CD are 0.5 meters across the y-axis. Based on the figures, the boundary AB is known as the inlet where the fluid flows to the boundary CD or the outlet via the surface of the plate. As illustrated in the figures below, the boundary BC represents the surface of the plate while the boundary AD is known as the symmetry. The ambient fluid velocity $U_\infty$ and the ambient temperature $T_\infty$ are assumed to be 1 and 300K respectively.

***Figure 1***

*The flow configuration of the flat plate*

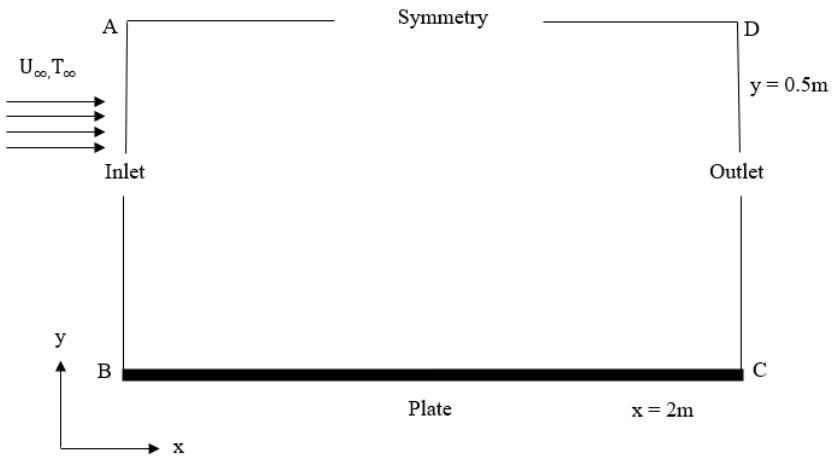
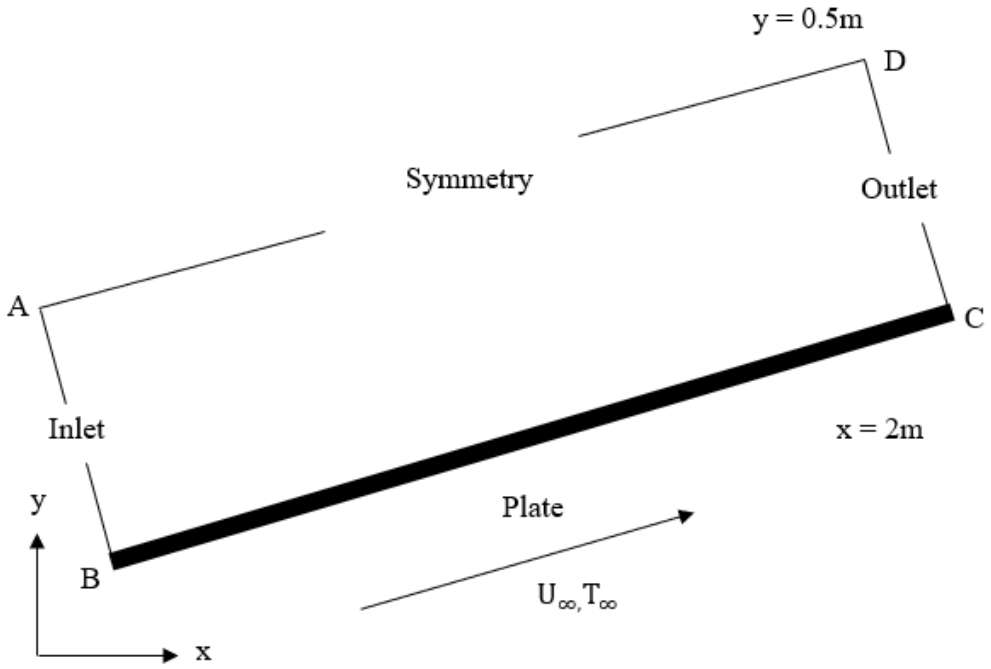


***Figure 2***

*The flow configuration of the inclination angle*




**Meshing Generation and Grid Independence Test**

The second step in Computational Fluid Dynamics (CFD) simulation is a mesh generation. The step is crucial since mesh generation is the geometrical restriction that satisfies the equations for heat transfer and momentum (Mirdrikvand et al., 2012). In this study, the validity of the Computational Fluid Dynamics (CFD) results was directly evaluated by comparing the velocity out of three different element size of meshing. The flow area is divided into smaller elements or quadrilaterals in order to analyze the flow of the fluid more accurately as shown in Figure 3 and Figure 4. Three different element size of meshing that are used in this study are sizes of 10,000, 20,000, and 30,000. The Figure 4 below shows the mesh generation for the horizontal flat plate. Based on the figure, it shows the significant difference between the three elements size of meshing for the horizontal flat plate. From the Figure 3, we can see that the curve moves closer towards the free stream, indicating that the velocity out is increase as the element size for the meshing increases. This method achieves a maximum velocity value of 1.03467 m/s. Besides, the Figure 5, Figure 6, and Figure 7 show the mesh generation for plate with vary inclinations angles including 15°, 30°, and 45°, respectively. Based on all the figures, it can be seen that the graph shows insignificant differences as the element size of meshing increases. For example, there a slight difference of the curves for Meshing 1, 2 and 3. This method achieves a maximum velocity value of 1.041 m/s, 1.0409 m/s, and 1.0408 m/s respectively. In conclusion, the 20,000 sizes of element prove to be effective in this study. For instance, it shows that the results converge as the size elements of meshing increases. Thus, this indicates that the numerical solution already reached mesh independent state at 20,000 sizes of elements.

***Figure 3***

*Generated Meshing in DesignModeler for flat plate*

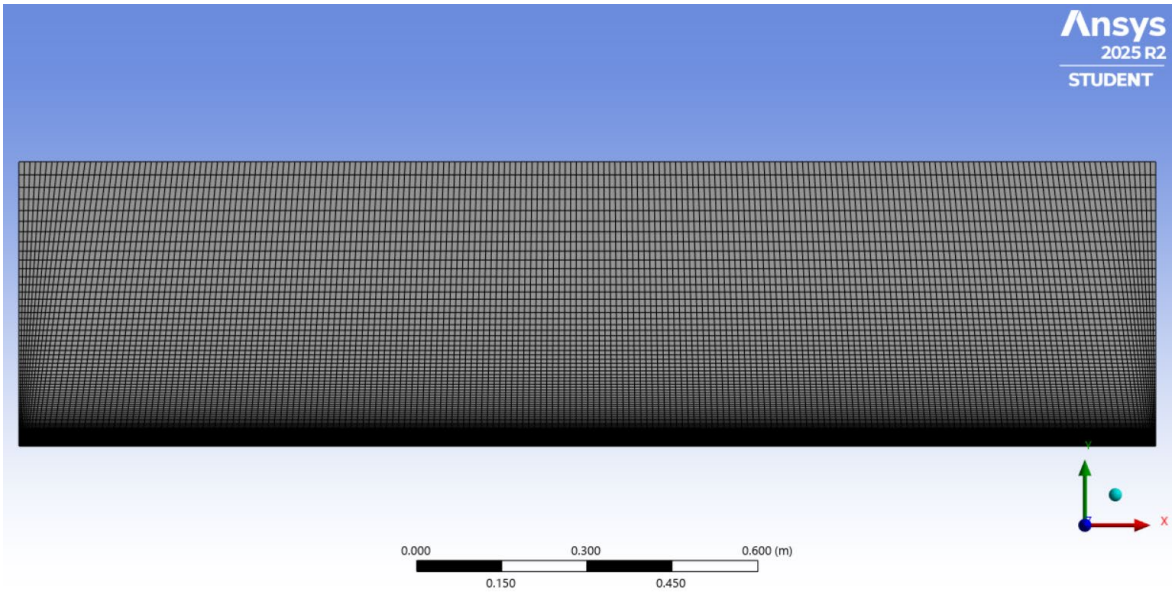



***Figure 4***

*Generated Meshing in DesignModeler for inclined plate*

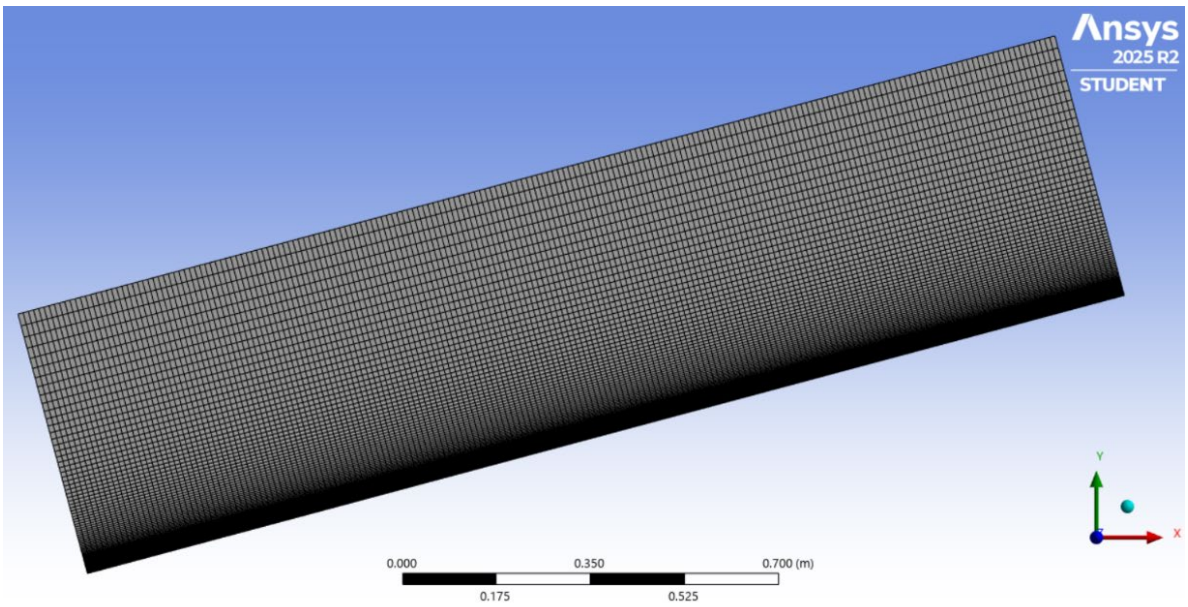


***Figure 4***

*Mesh Sensitivity for 0°*

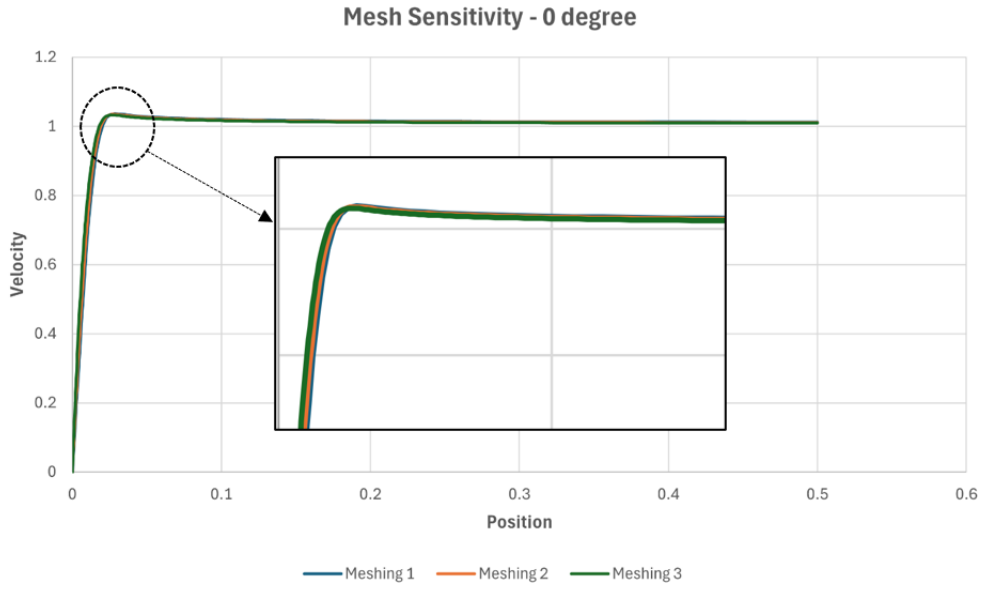



***Figure 5***

*Mesh Sensitivity for 15°*

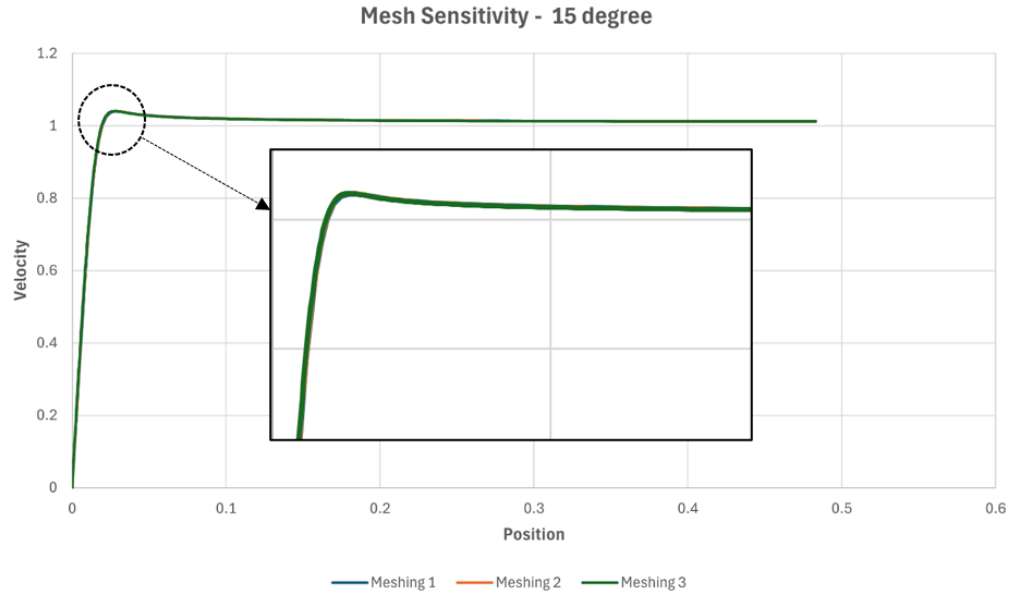


***Figure 6***

*Mesh Sensitivity for 30°*

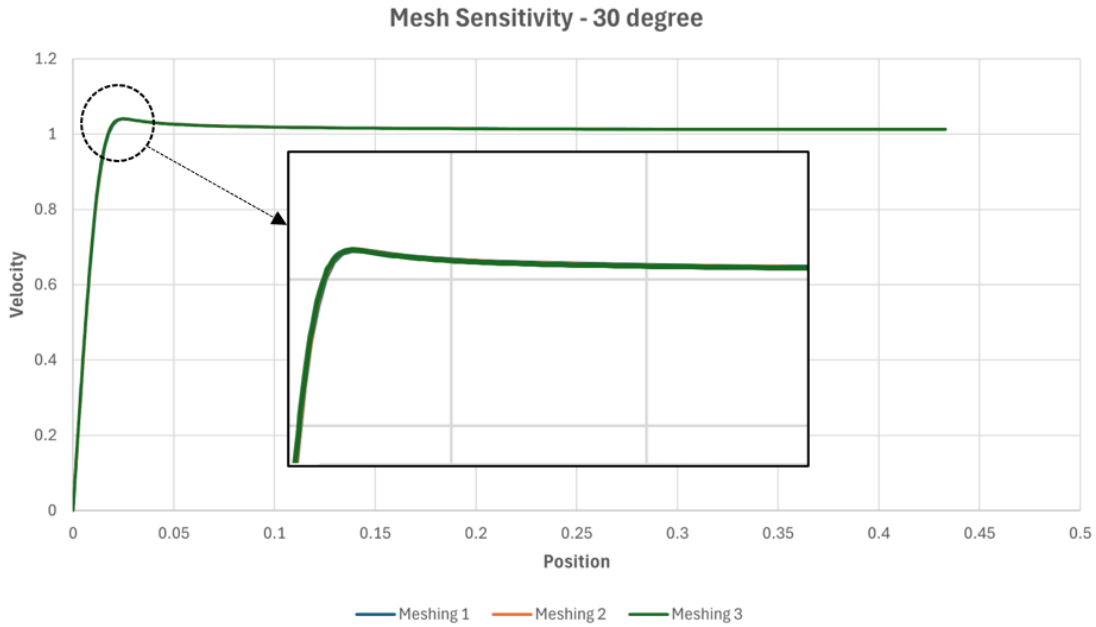
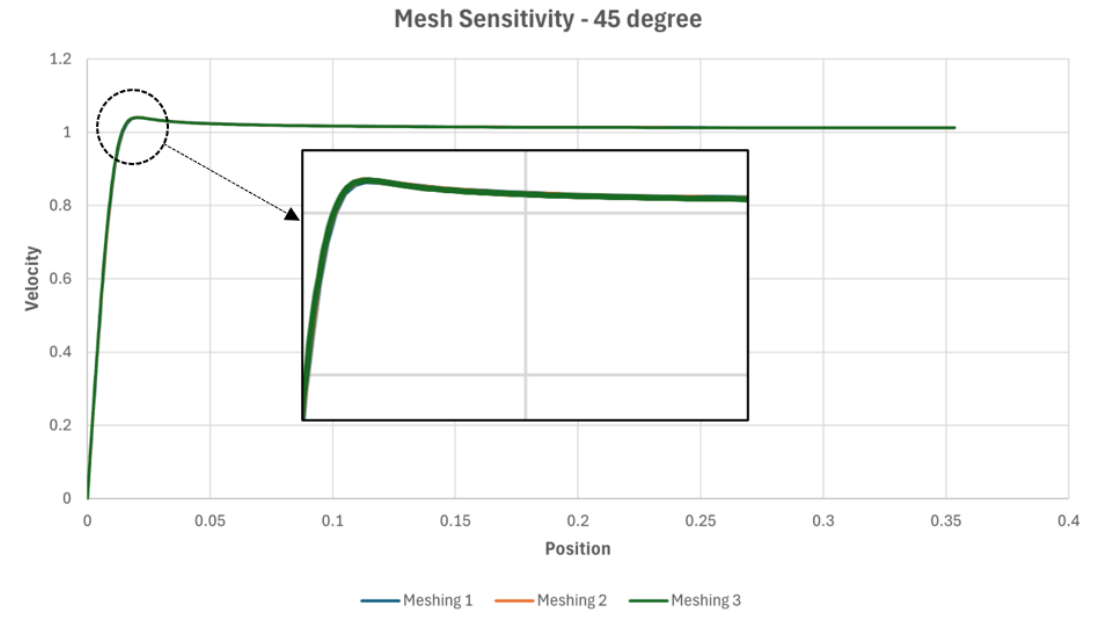



***Figure 7***

*Mesh Sensitivity for 45°*



**Numerical Method**

The computations in this research study were performed using the software package Ansys Fluent R2 2025 (Student Version). In this research study, the method chosen for solving the pressure-velocity coupling is the SIMPLE scheme while the discretization method is the second-order upwind scheme. The second-order upwind scheme is used to solve the equations of the flow of momentum and energy. The calculations in this study were done with high precision, and the solutions were tracked using a residual monitor with a set of convergence criteria of $10^{-6}$. The type of fluid used in this simulation is air and the physical properties of air was tabulated in the Table 1.

**Table 1**

*The physical properties of air*

| Name | Fluid properties | Value (air) |
|---|---|---|
| Density | $\rho$ | 1.225 |
| Specific Heat Capacity | $C_p$ | 1005 |
| Dynamic Viscosity | $\mu$ | $1.7894 \times 10^{-5}$ |
| Length | $L$ | 2 |
| Ambient fluid velocity | $U_\infty$ | 1 |
| Ambient fluid temperature | $T_\infty$ | 300 |
| Wall temperature | $T_w$ | 400 |
| Thermal Conductivity of the Fluid | $k$ | 0.0242 |
| Prandtl number | $Pr$ | 0.744176 |

## RESULTS AND DISCUSSION

**Local Nusselt Number**

The present numerical study of this simulation has been carried out using a commercial package in the Ansys Fluent R2 2025 (Student Version). Local Nusselt number is a dimensionless parameter that measures the rate of convective heat transfer. In this research study, the obtained local Nusselt numbers from the simulation were compared with the existing analytical solution in order to check the accuracy of the simulation results. Table 2 shows the comparison between the local Nusselt numbers obtained from the present simulation and the existing analytical solution. The prediction of the analytical solutions for local Nusselt number, $Nu_x$ is given as (Sahar et al., 2025):

$$Nu_x = 0.332 Re_x^{\frac{1}{2}} \mathrm{Pr}^{\frac{1}{3}} \tag{1}$$

$$Re_x = \frac{\rho U_\infty x}{\mu} \tag{2}$$

where $Re_x$ is the Reynolds number at distance x, and $Pr$ is the Prandtl number.

**Table 2**

*Calculated values of local Nusselt number at the plate*

| x | Air | | |
|---|---|---|---|
| | **Analytical** | **Fluent (CFD)** | **Error %** |
| 0.1 | 25.0307 | 26.1562 | 0.9570 |
| 0.2 | 34.7857 | 36.0675 | 0.9645 |
| 0.3 | 43.1091 | 44.5090 | 0.9685 |
| 0.4 | 43.1091 | 51.5785 | 0.8358 |
| 0.5 | 55.5900 | 57.2177 | 0.9716 |
| 0.6 | 61.1441 | 62.9438 | 0.9714 |
| 0.7 | 65.7428 | 67.7596 | 0.9702 |
| 0.8 | 70.5015 | 72.8474 | 0.9678 |
| 0.9 | 74.5250 | 77.2524 | 0.9647 |
| 1.0 | 78.7549 | 81.9973 | 0.9605 |
| 1.1 | 82.3763 | 86.1564 | 0.9561 |
| 1.2 | 86.2215 | 90.6708 | 0.9509 |
| 1.3 | 89.9028 | 95.0880 | 0.9455 |
| 1.4 | 93.0916 | 98.9890 | 0.9404 |
| 1.5 | 96.5111 | 103.2483 | 0.9347 |
| 1.6 | 99.4880 | 107.0165 | 0.9297 |
| 1.7 | 102.6948 | 111.1452 | 0.9240 |
| 1.8 | 105.4977 | 114.8161 | 0.9188 |
| 1.9 | 108.5270 | 118.8812 | 0.9129 |
| 2.0 | 111.3250 | 121.9174 | 0.9131 |

Based on Table 2 above, the local Nusselt number along the plate for analytical and Fluent solutions increases as it goes further downstream. This indicates that there exists better heat transfer due to the growth in thermal boundary layer. As stated by Ganie et al. (2022) in a previous study, the enhancement in local Nusselt number shows that the convection process occurs faster than the conduction process (Ganie et al., 2022). Besides, the local Nusselt number for the analytical solution is lower than the local Nusselt number in the CFD simulation. As shown in Table 2 above, the highest local Nusselt number for the analytical solution is 111.3250, while the highest local Nusselt number obtained from the CFD simulation is 121.9174.

**Table 3**

*Average value of Local Nusselt number at the plate*

| Pr | Air | | |
|---|---|---|---|
| | **Analytical** | **Fluent (CFD)** | **Error %** |
| 0.744176 | 73.07049 | 77.52759 | 0.94251 |

Table 3 above illustrates the average local Nusselt number of air for the flat plate in both analytical and CFD solutions. Based on the Table 3, the average analytical solution of the local Nusselt number of air is significantly lower than the average local Nusselt number in the CFD. For example, the average local Nusselt number for analytical solutions is 73.07049, and the average local Nusselt number obtained from the simulation is 77.52759. Besides, Table 3 also demonstrates that the CFD result is in good agreement with the analytical solution, with an error of around 1%. Figure 8 illustrates the good agreement between the average local Nusselt number of analytical and CFD solutions at the flat plate.

***Figure 8***

*Local Nusselt number at flat plate*

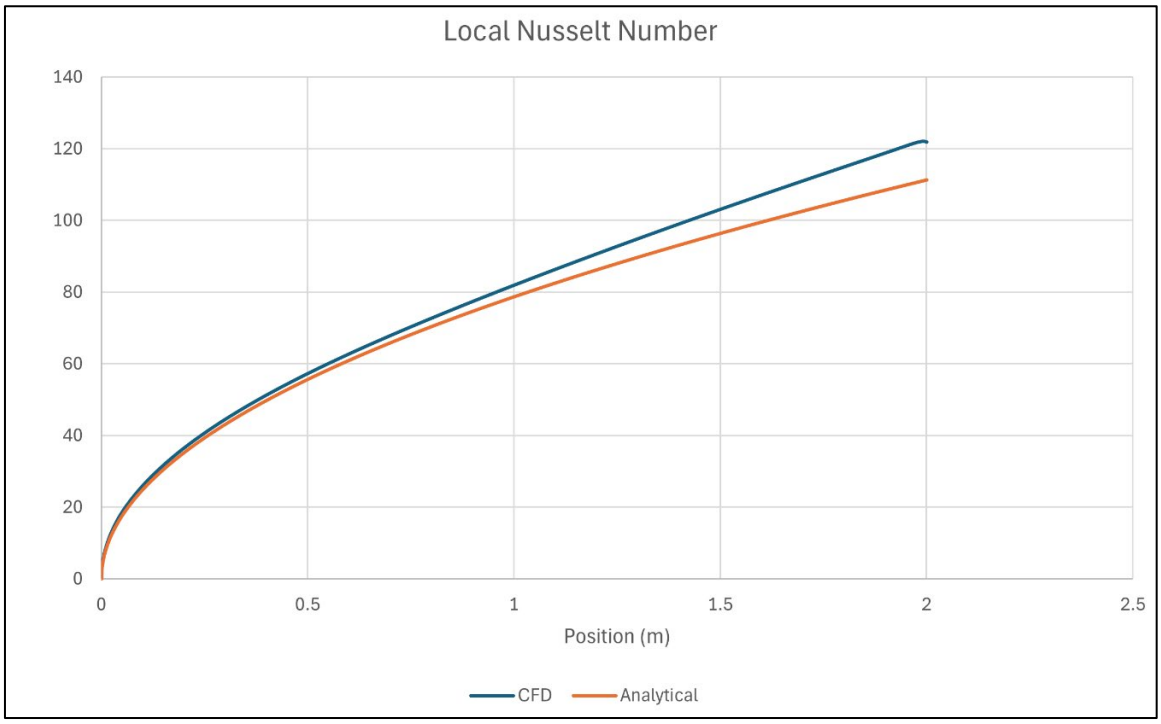



**Table 4**

*Local Nusselt number at the flat and inclined plates*

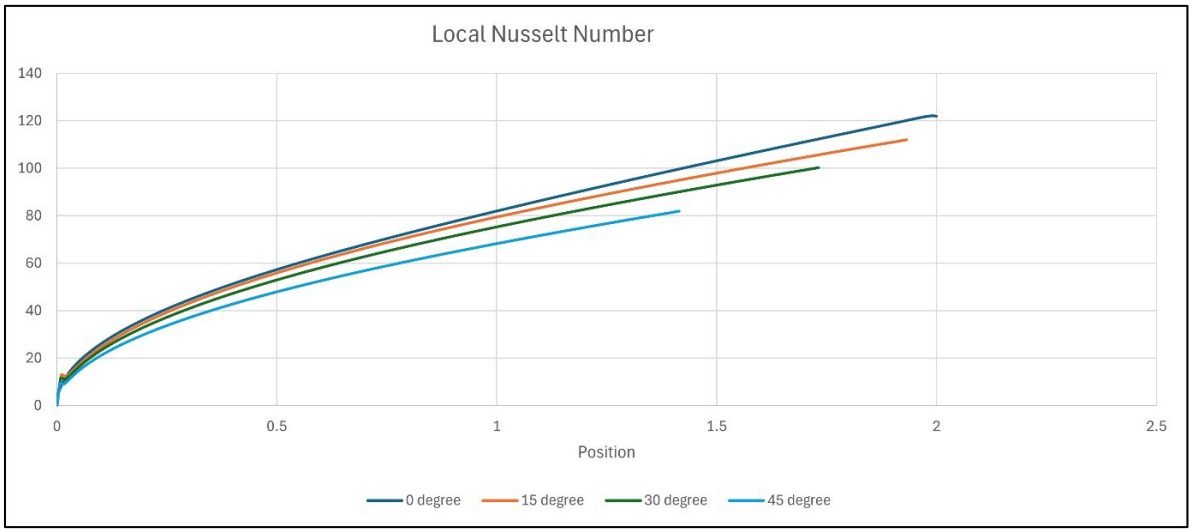
| Angles | Fluent (CFD) |
|---|---|
| 0° | 77.52759 |
| 15° | 73.69462 |
| 30° | 66.06716 |
| 45° | 53.94286 |

Table 4 above demonstrates the local Nusselt number at the flat and inclined plates. As shown in Table 4 above, the local Nusselt number decreases as the inclination angle increases. The decrease in local Nusselt number due to an increase in inclination angles indicates that the transfer of heat along the plate is slower. For example, the local Nusselt number for the flat plate is 77.52759, and it decreases to 53.94286 as the inclination angle increases to 45°. Thus, this indicates that the heat transfer experiences

a decrease when the angles of inclination increase from a horizontal flat plate to the inclined plates (Baskaya et al.(1999). Figure 9 illustrates the local Nusselt number at various locations, including the flat and inclined plates.

***Figure 9***

*Local Nusselt number at flat and inclined plates*




**Skin Friction Coefficient**

The present numerical study of this simulation has been carried out using Ansys Fluent R2 2025 (Student Version). Skin friction coefficient is a dimensionless parameter that measures the frictional resistance that is exerted by fluid when it flows over the surface. In this research study, the obtained skin friction coefficients from the simulation were also compared with the existing analytical solution in order to check the accuracy of the simulation results. Table 5 shows the comparison between the skin friction coefficient obtained from the present simulation and the existing analytical solution. The prediction of the analytical solutions for skin friction coefficient $C_{fx}$ is given as (Sahar et al., 2025):

$$C_{fx} = 0.664 Re_x^{-\frac{1}{2}} \tag{3}$$

$$Re_x = \frac{\rho U_\infty x}{\mu} \tag{4}$$

where $Re_x$ is the Reynolds number at distance x.

**Table 5**

*Calculated values of skin friction coefficient at the plate*

| x | Air | | |
|---|---|---|---|
| | **Analytical** | **Fluent (CFD)** | **Error %** |
| 0.1 | 0.007981 | 0.009706 | 0.8223 |
| 0.2 | 0.005743 | 0.006806 | 0.8438 |
| 0.3 | 0.004634 | 0.005412 | 0.8562 |
| 0.4 | 0.003990 | 0.004623 | 0.8631 |
| 0.5 | 0.003594 | 0.004149 | 0.8662 |
| 0.6 | 0.003267 | 0.003770 | 0.8666 |
| 0.7 | 0.003039 | 0.003517 | 0.8640 |
| 0.8 | 0.002834 | 0.003303 | 0.8579 |
| 0.9 | 0.002681 | 0.003154 | 0.8499 |
| 1.0 | 0.002537 | 0.003024 | 0.8388 |
| 1.1 | 0.002425 | 0.002931 | 0.8273 |
| 1.2 | 0.002317 | 0.002848 | 0.8135 |
| 1.3 | 0.002222 | 0.002781 | 0.7990 |
| 1.4 | 0.002146 | 0.002732 | 0.7856 |
| 1.5 | 0.002070 | 0.002686 | 0.7707 |
| 1.6 | 0.002008 | 0.002652 | 0.7572 |
| 1.7 | 0.001945 | 0.002620 | 0.7425 |
| 1.8 | 0.001894 | 0.002597 | 0.7292 |
| 1.9 | 0.001841 | 0.002578 | 0.7141 |
| 2.0 | 0.001794 | 0.002493 | 0.7197 |

Based on Table 5 above, the value for the skin friction coefficient of air along the plate for analytical and CFD solutions decreases as it goes further downstream. The decrease in the skin friction coefficient of air along the plate indicates an increase in boundary layer thickness. Besides, the value for the skin friction coefficient for the analytical solution is lower than the CFD results. As shown in Table 5 above, the lowest skin friction coefficient for the analytical solution is 0.001794, while the lowest skin friction coefficient obtained from the CFD simulation is 0.002493.

**Table 6**

*Average value of skin friction coefficient*

| Air | | |
|---|---|---|
| **Analytical** | **Fluent (CFD)** | **Error %** |
| 0.0045588 | 0.0068981 | 0.66088 |

Table 6 above shows the value for the skin friction coefficient of air for the flat plate in both analytical and CFD solutions. Based on the Table 6, the average value of analytical solution of skin friction coefficient of air is significantly lower than the average value of skin friction coefficient in the CFD

simulation. For example, the average value of the skin friction coefficient in analytical solution is 0.0045588 and the average value of the skin friction coefficient for the simulation is 0.0068981. Besides, Table 6 also demonstrates the average percentage differences of the CFD result and the analytical solution, with an error of about 34%. The higher percentage of errors indicates that there exist discrepancies in skin friction coefficients obtained from the simulation with the analytical solution. The existence of the discrepancy in skin friction coefficients may occur due to insufficient mesh resolution used in this research study. Figure 10 illustrates the skin friction coefficient of the analytical and CFD solutions at the flat plate.

***Figure 10***

*Skin Friction Coefficient at flat plate*

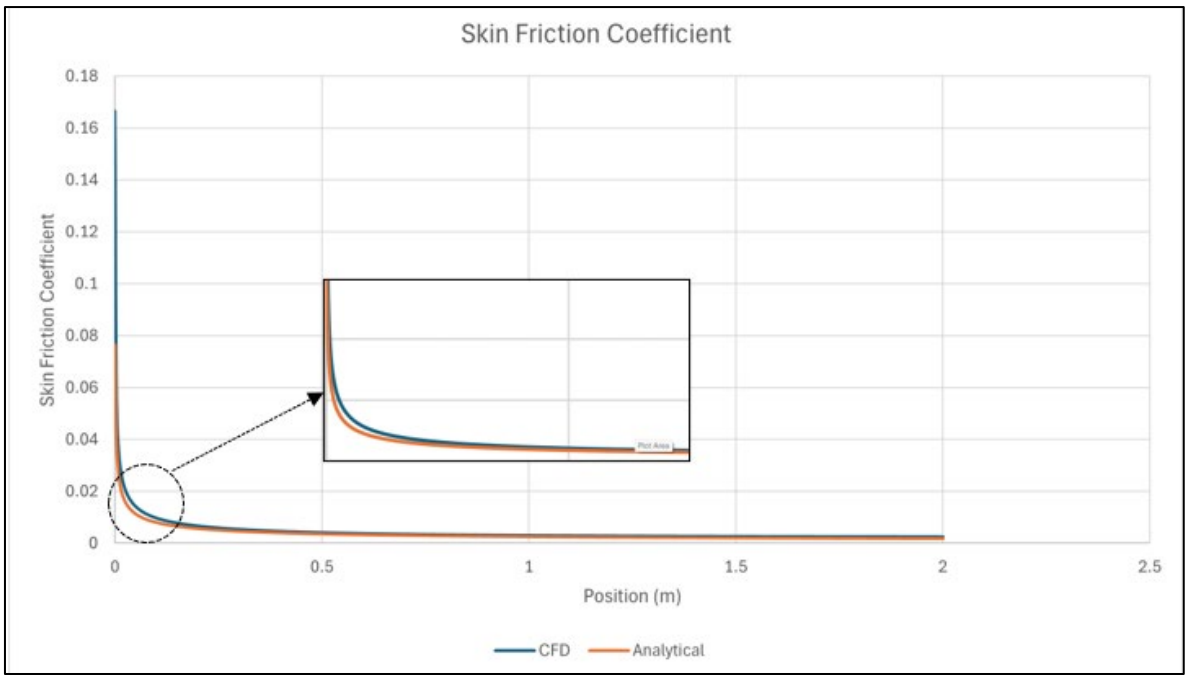



**Table 7**

*Skin friction coefficient at the flat and inclined plates*

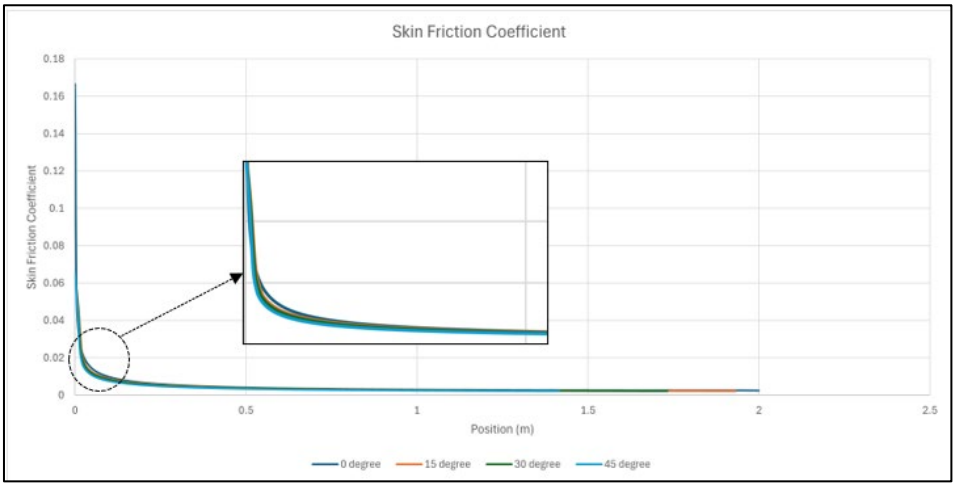
| Angles | Fluent (CFD) |
|---|---|
| 0° | 0.00690 |
| 15° | 0.00426 |
| 30° | 0.00426 |
| 45° | 0.00426 |

Table 7 above demonstrates the value for the skin friction coefficient of air at the flat and inclined plates. As shown in Table 7 above, the value for the skin friction coefficient decreases as the angle of inclination of the plate increases. For example, the skin friction coefficient of air for the flat plate is 0.00690, and it decreases to 0.00426 as the inclination angle increases from 0° to 15°. Besides that, the value of the skin friction coefficient remains constant as the inclination angle of the plate rises from 15°

to 45°. Thus, this shows that the increase in inclination angles of the plate does not significantly affect the skin friction coefficient. Figure 11 illustrates the value for the skin friction coefficient at various locations, including the flat and inclined plates.

***Figure 11***

*Skin Friction Coefficient at flat and inclined plates*

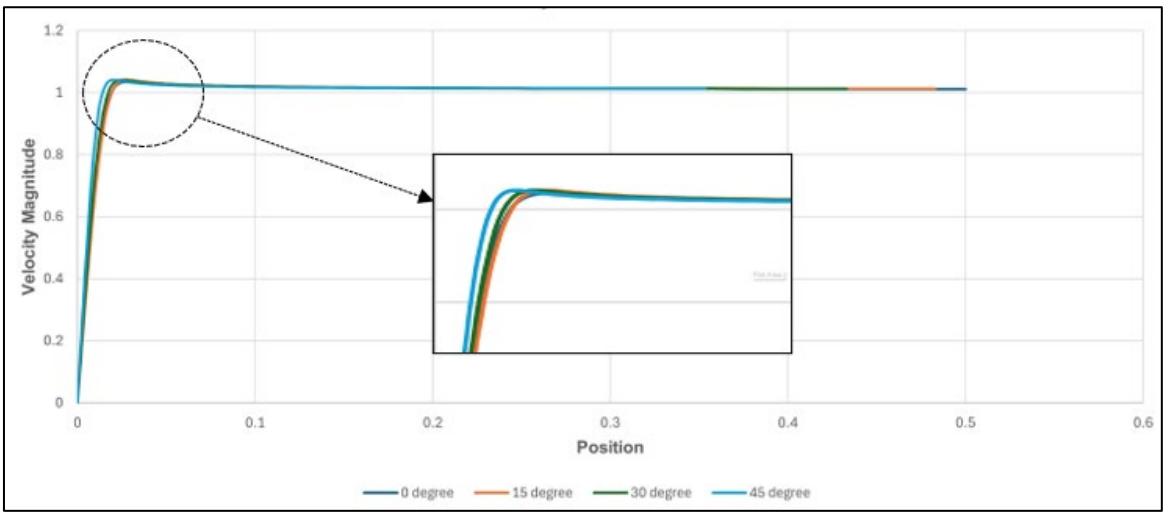



**Velocity Profiles**

In this section, the velocity or hydrodynamics profiles of air were discussed. The Figure 12 below shows the velocity profile for air at various angles of inclinations including 0°, 15°, 30°, and 45°. The velocity starts from zero at the wall (no-slip condition) and increases to the free stream velocity as the inclination angle increases. For example, the velocity gradient at the 45° plate is steeper as compared to the velocity gradient at the flat plate. Thus, this shows that the increases or differences in inclination angles influence the velocity to increase.

***Figure 12***

*Velocity profile of air at flat and inclined plates*



Figures 13, 14, 15, and 16 illustrate the velocity contours of air at different inclination angles of the plates. The colour scale in the figures indicates the range of the velocity of the air. For example, blue in the colour scale ranges indicates the lowest velocity, while red colour indicates the highest velocity. As shown in the figures, the velocity is lowest at the surface of the plate and is represented by the blue colour. Next, the blue colour changes to red colour, which means that the velocity at varying angles of inclination increases until it becomes uniform.

***Figure 13***

*Velocity profile of air at flat plate*

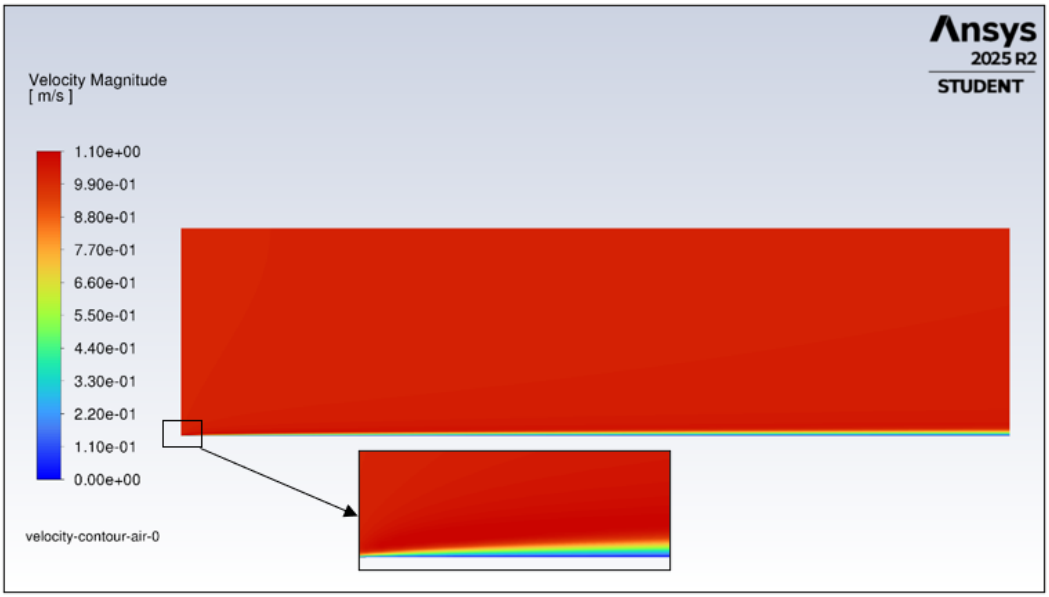



***Figure 14***

*Velocity profile of air at 15°*

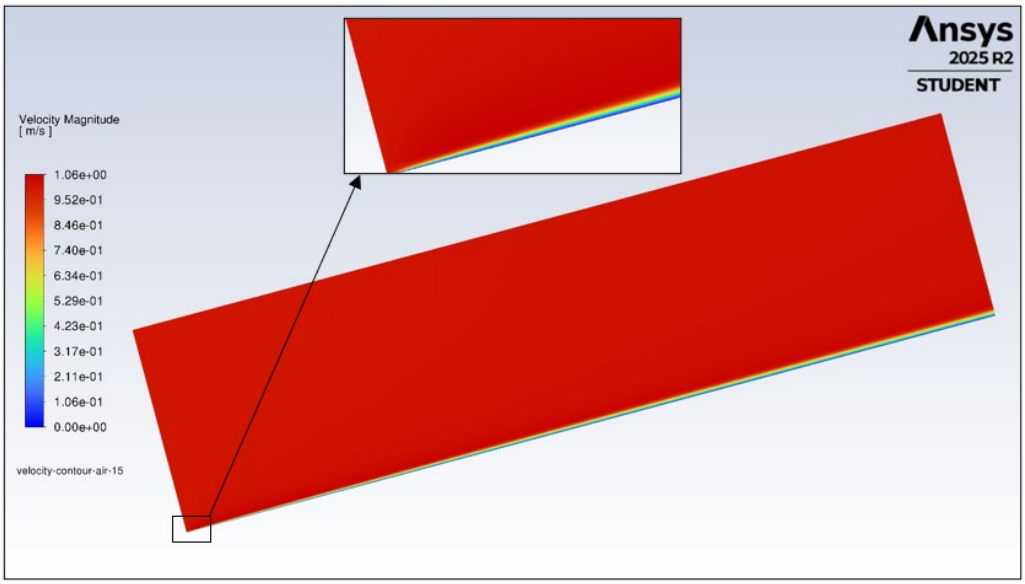


***Figure 15***

*Velocity profile of air at 30°*

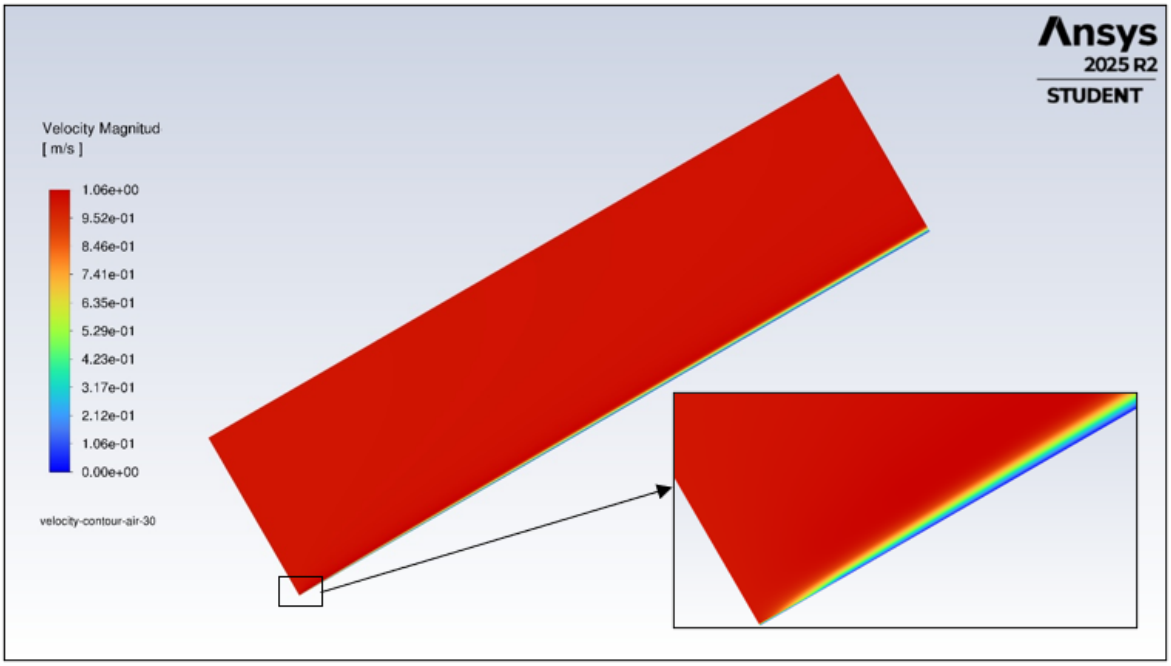
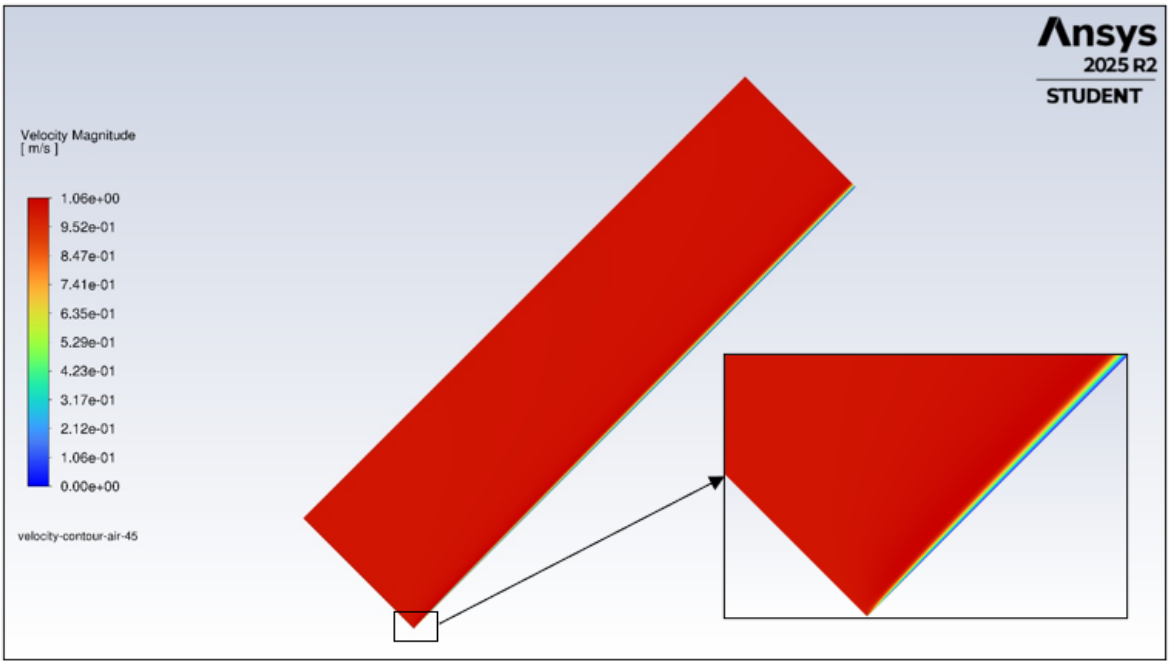



***Figure 16***

*Velocity profile of air at 45°*




**Boundary Layer Thickness**

The boundary layer thickness, $\delta$ is defined as the distance y from the surface of the plate at which $y =$

$(u/u_\infty) = 0.99$. In this research study, the boundary layer thickness is determined and observed based on the value of velocity magnitude.

$$y = (u/u_\infty) = 0.99 \tag{5}$$

**Table 8**

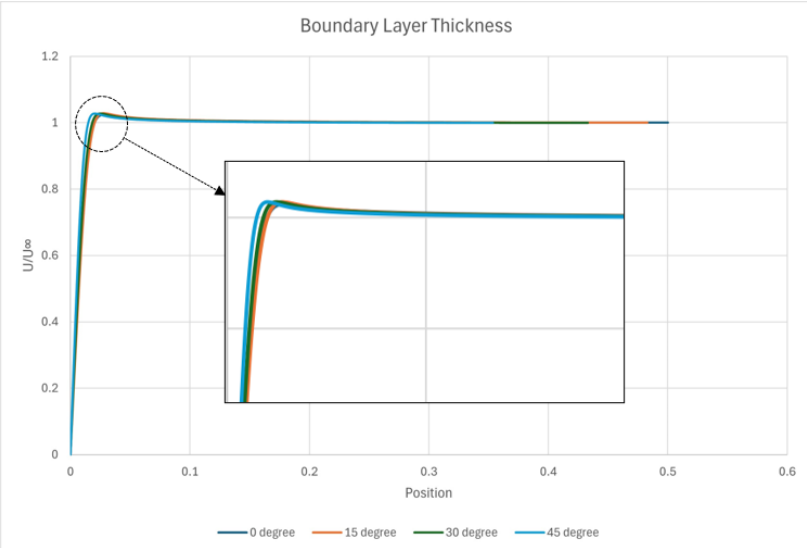
*Calculated value of* $\boldsymbol{\delta}$ *when y = 0.99 at the flat and inclined plates*

| Angles | y | Boundary Layer Thickness, $\delta$ |
|---|---|---|
| 0° | 0.99 | 1.00606 |
| 15° | 0.99 | 1.01058 |
| 30° | 0.99 | 1.02189 |
| 45° | 0.99 | 1.03007 |

Based on Table 8, the data shows the boundary layer thickness based on the velocity magnitude when the distance y from the surface is y = 0.99. The data obtained shows that the boundary layer thickness of the velocity becomes thicker when the inclination angles rise from 0° to 45°. Figure 17 demonstrates the boundary layer thickness at various angles of the plates. As shown in Figure 17, the velocity gradient at an angle of 45° is steeper compared to the other angles when inclination angles rise from 0° to 45°. The development of boundary layer thickness can be influenced by the viscosity of the fluid, a measure of fluid resistance to flow. For instance, air has a higher kinematic viscosity, which leads to a thicker boundary layer of air (Sahar et al., 2025).

***Figure 17***

*Boundary Layer Thickness at flat and inclined plates*

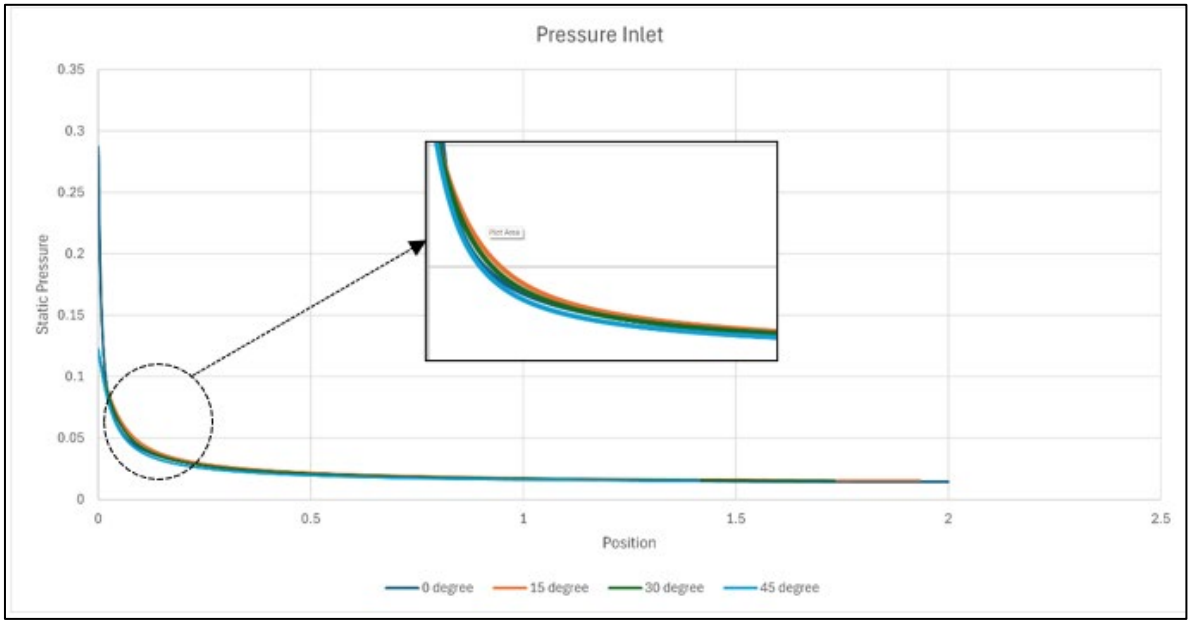


**Pressure Profiles**

In this section, the pressure distribution air was discussed. The Figure 18 illustrates the pressure distribution in the air flow at varying inclination angles such as 0°, 15°, 30°, and 45°. The pressure distribution in the air flow starts from zero at the wall, then gradually decreases as the inclination angles of the plate increases. For example, the pressure gradient at the 45° plate is steeper compared to the pressure gradient at the flat plate. Thus, this show that the pressure distribution of the air flow will experience a decrease when the angles of inclination increase from 0° to 45°.

***Figure 18***

*Pressure profile of air at flat and inclined plates*




Figures 19, 20, 21, and 22 illustrate the pressure contours of air at different inclination angles of the plates. The colour scale in the figures indicates the range of the pressure distribution of the air. For example, blue in the colour scale ranges indicates the lowest pressure, while red colour indicates the highest pressure. As shown in the figures, the pressure is highest at the surface of the plate and is represented by the red colour. Next, the red colour changes to blue colour, which means that the pressure distribution at varying angles of inclination decreases until it becomes uniform.

***Figure 19***

*Pressure contour of air at flat plate*

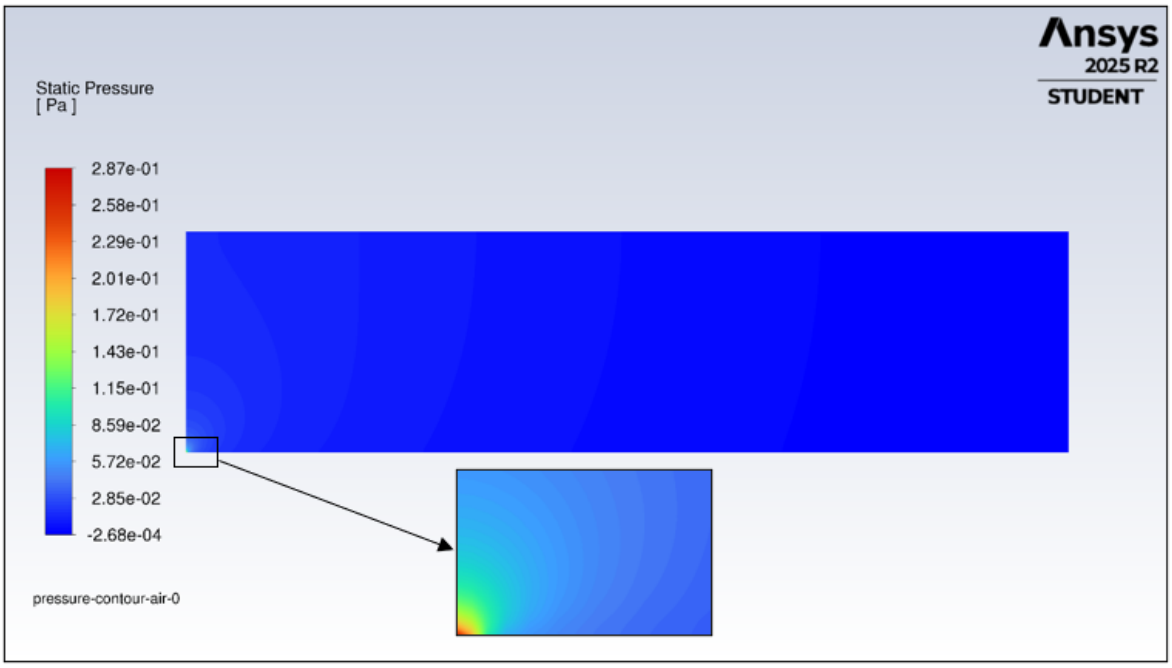



***Figure 20***

*Pressure contour of air at 15°*

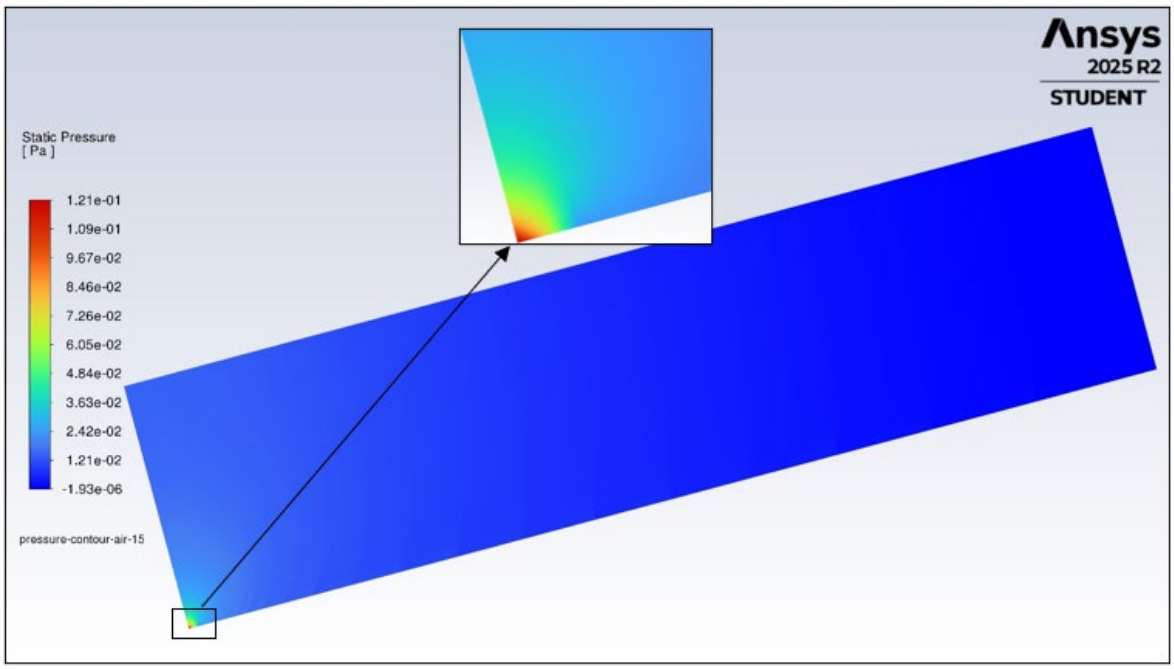


***Figure 21***

*Pressure contour of air at 30°*

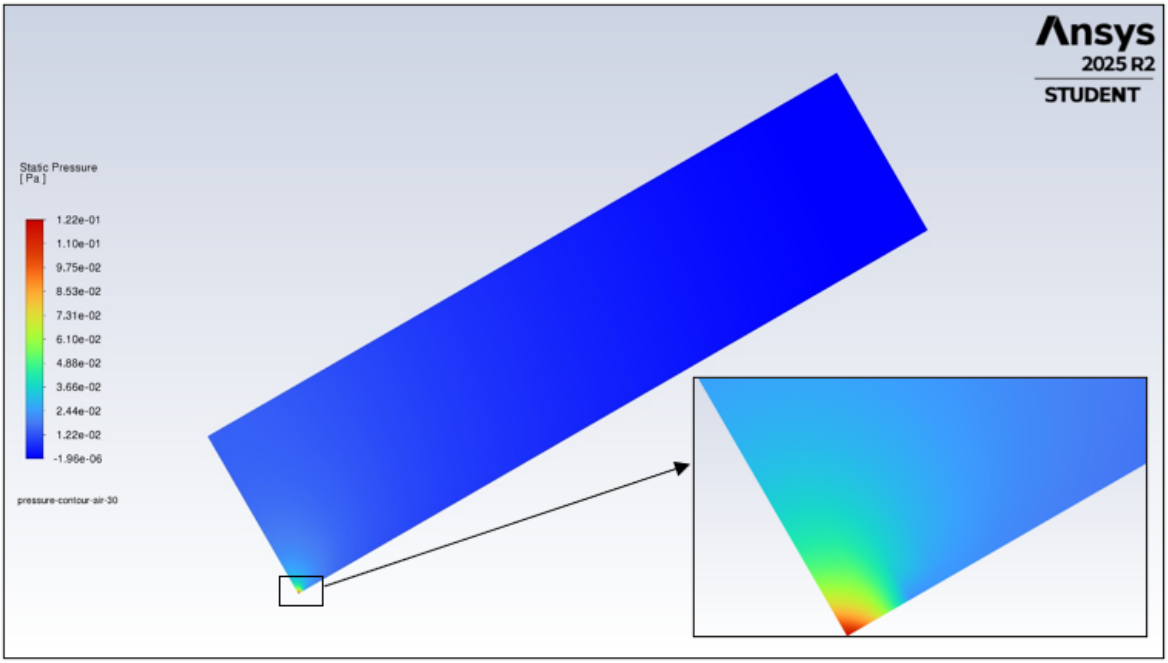
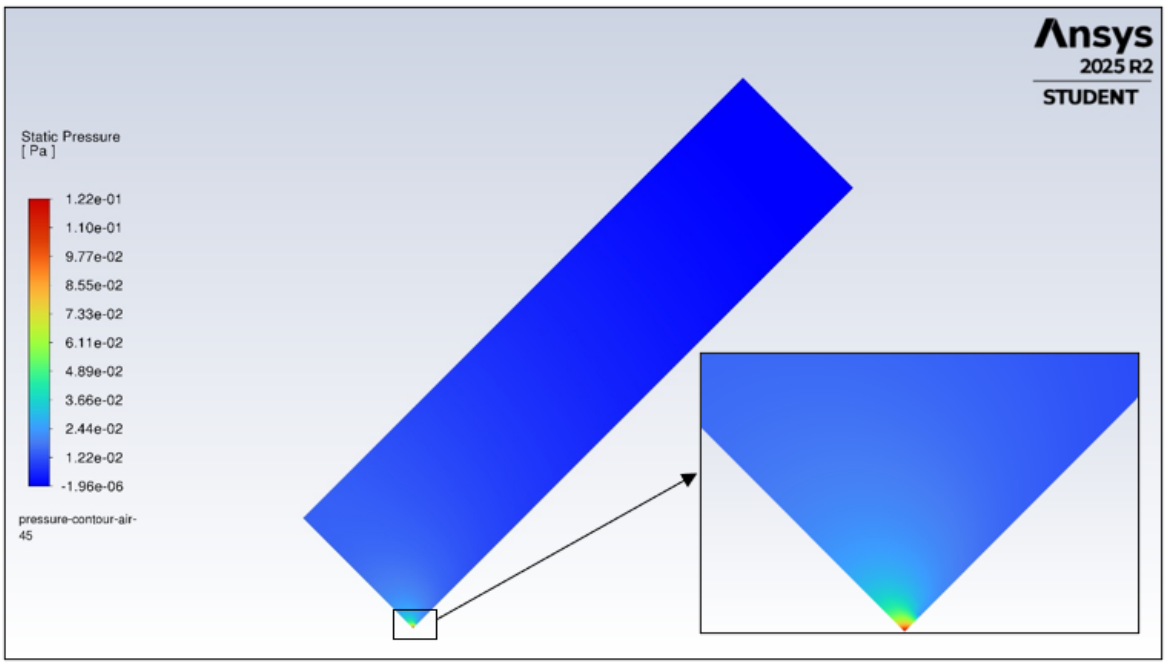



***Figure 22***

*Pressure contour of air at 45°*

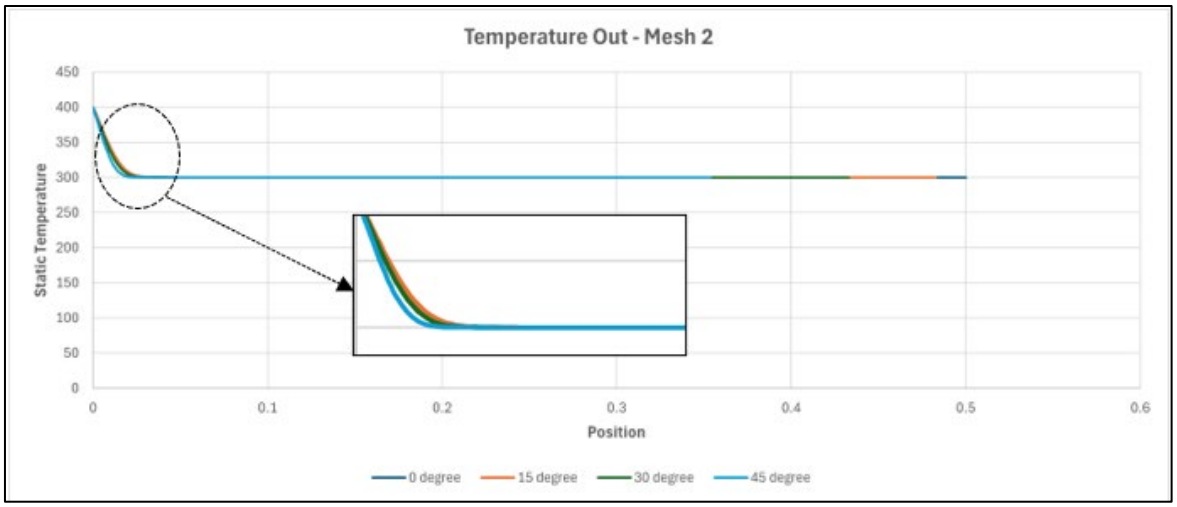


**Temperature Profiles**

In this section, the temperature profiles or thermal characteristics of air were discussed. The Figure 23 above shows the temperature profile for air at various angles of inclinations including 0°, 15°, 30°, and 45°. The temperature profile for air illustrates a sharp gradient near the horizontal flat plate or at 0°, then gradually decreases as the inclination angles of the plate increases. Thus, this show that the increases or differences in inclination angles causes the temperature to decrease.

***Figure 23***

*Temperature profile of air at flat and inclined plates*




Figures 24, 25, 26, and 27 illustrate the temperature contours of air at different inclination angles of the plates. The colour scale in the figures indicates the range of the temperature distribution of the air. For example, blue in the colour scale ranges indicates the lowest temperature, while red colour indicates the highest temperature. As shown in the figures, the temperature is highest at the surface of the plate and is represented by the red colour. Next, the red colour changes to blue colour, which means that the temperature distribution at different angles of inclination decreases until it becomes uniform.

***Figure 24***

*Temperature contour of air at flat plate*

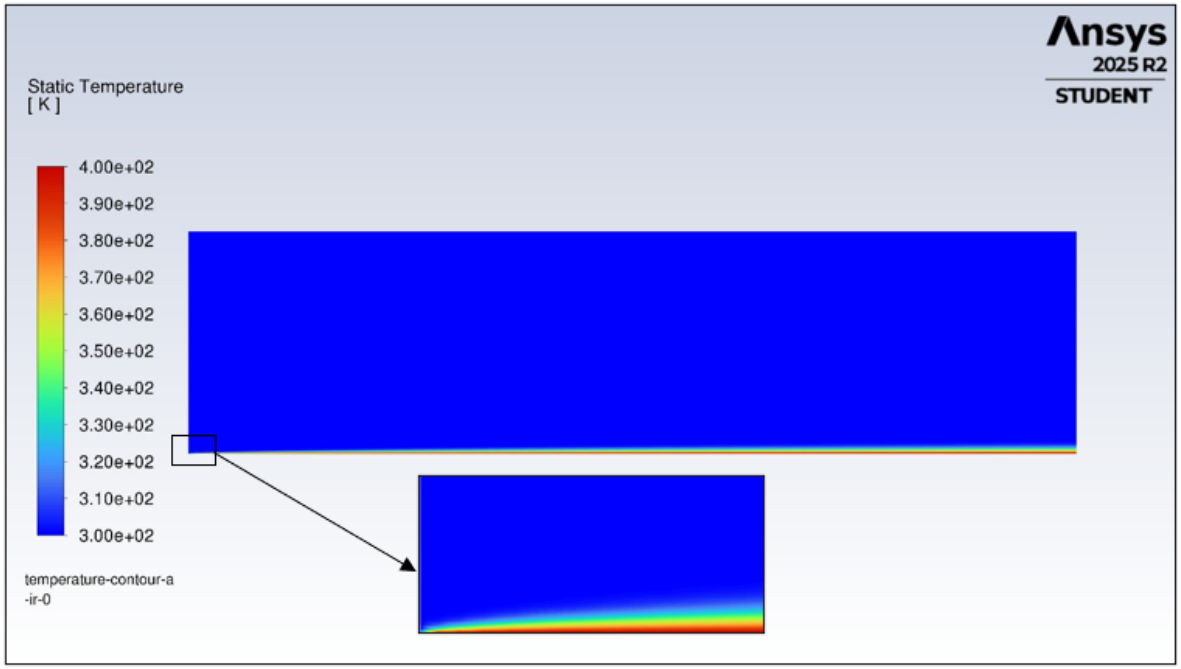



***Figure 25***

*Temperature contour of air at 15°*

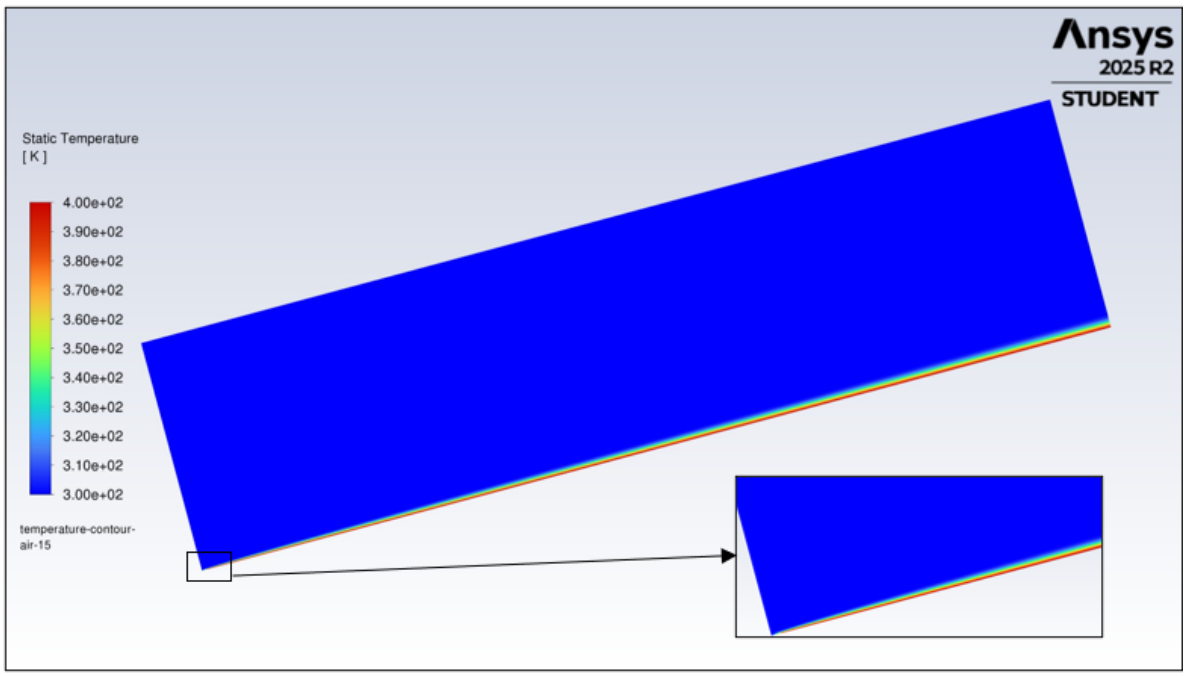


***Figure 26***

*Temperature contour of air at 30°*

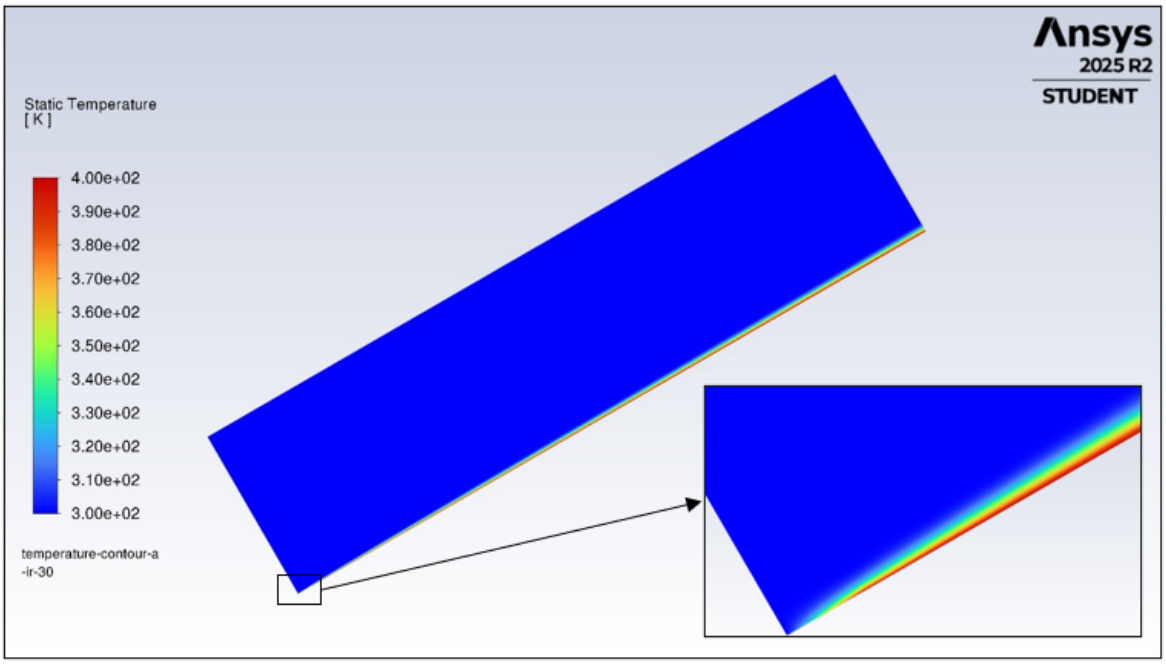
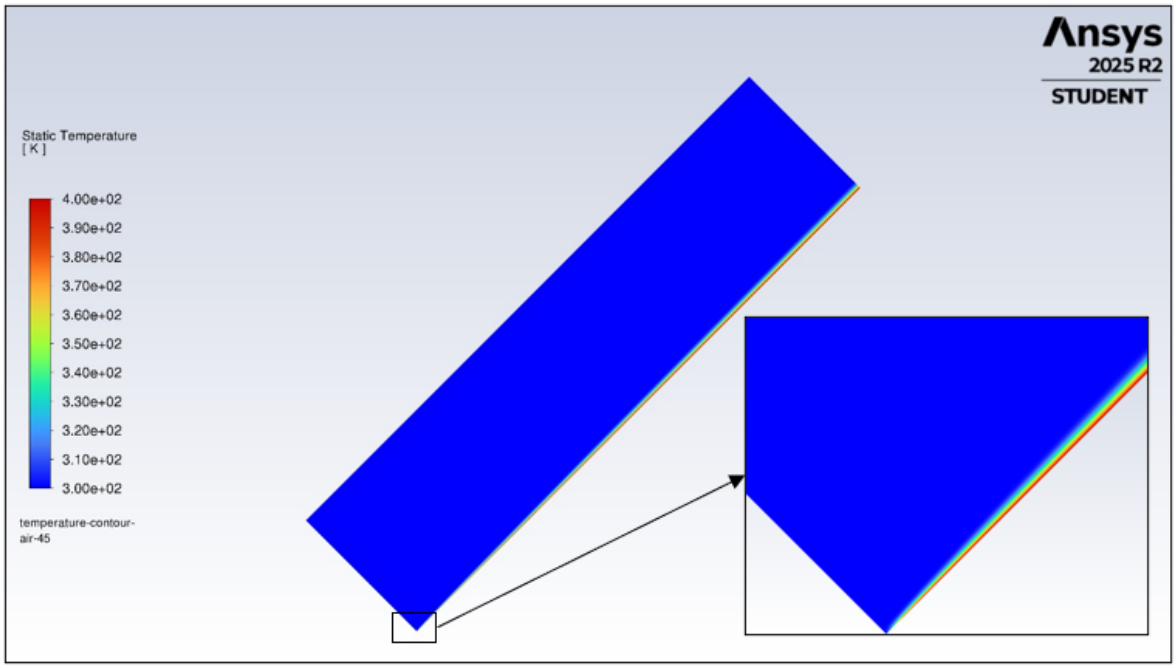



***Figure 27***

*Temperature contour of air at 45°*



## CONCLUSION

The Computational Fluid Dynamics (CFD) simulation was performed to study the hydrodynamics and thermal characteristics of laminar flow for air over inclined plates laminar flow dynamics. Air is the type of fluid that is used and observed in the study. In this research study, the plates used are inclined or tilted at specific angles, including angles of 15°, 30°, and 45°. The Computational Fluid Dynamics (CFD) simulation of laminar flow over various inclination angles is performed using the computational software, Ansys Fluent R2 2025 (Student Version). Besides, the velocity and temperature profiles of air are determined by taking into account the local Nusselt number, skin friction coefficient, and various plate positions. The numerical results of velocity and temperature obtained from the simulation, such as local Nusselt number and skin friction coefficient, were compared with the existing analytical solutions. Additionally, the numerical results observed in the study include the results for a flat plate and plates with various angles of inclination. The comparison of the simulation results and existing analytical are crucial in order to validate the simulation results and check the accuracy of the Computational Fluid Dynamics method for fluid flow analysis. Based on the obtained results, there were significant differences in air behaviour, particularly in their velocity and temperature profiles at the flat and inclined plates. The analysis of air fluid dynamics in laminar flow over different angles of plate and heat transfer mechanisms led to the following conclusions:

a) The obtained results for heat transfer showed good agreement with analytical solutions and validated the accuracy of the numerical methods employed in the simulation.
b) As the inclination angles for the plate increase, the local Nusselt number increases.
c) There exist discrepancies in skin friction coefficient obtained in this research study as compared to the analytical solutions for air, showing that the mesh resolution used for simulation may be insufficient.
d) As the inclination angles for the plate increase, the skin friction coefficient decreases.
e) The meshing strategy or refining mesh was crucial in the simulation process to ensure the accuracy of fluid flow characteristics captured in the simulation. The obtained simulation results showed that finer mesh resolution is needed in order to resolve the boundary layers and obtain more accurate values of the skin friction coefficient.
f) coefficient.
g) The increase in inclination angles of the plate causes an increase in velocity, a decrease in pressure, and a decrease in temperature.

In conclusion, the current research study has focused on boundary layer behaviour in laminar flow over inclined plates, and the type of fluid chosen is air. Besides, the simulation also uses a two-dimensional (2-D) computational domain. There are some suggestions for further improvements that can be made in future studies. For example, future studies can expand these findings by exploring the hydrodynamics and thermal characteristics of laminar flow for water over inclined plates. By expanding these findings, future studies can make comparisons for the boundary layer behaviour involving the air and water fluid dynamics. Other than that, future studies can also expand these findings by exploring more complex scenarios of inclined plates, such as using a three-dimensional (3-D) computational domain. Thus, this research study is beneficial as it helps to gain new fundamental knowledge and improve the understanding of the behaviour of the boundary layer over inclined plates or surfaces.

## ACKNOWLEDGEMENT

This research has been supported by the Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA

**Conflict of Interest**
The authors have no conflicts of interest to declare.

**Non-funded**
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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