Numerical simulation of flow over EPPLER 387 at low Reynolds number and comparison with experiment

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Abstract- This paper presents the numerical simulations of low-Reynolds-number flow past an Eppler 387 airfoil at Re=20,000, 30,000, 60,000, 100,000 and 300,000 where transition takes place through a laminar separation bubble. The analysis is carried out using ANSYS FUENT. Two turbulence models, trans-SST and k-kl-Ꞷ models were used for investigation. The lift coefficient, drag coefficient, point of separation and the point of reattachment were established. The numerical results of the aerodynamic coefficients are validated against wind tunnel results available in the literature.

Index Terms- Low-Reynolds number Eppler 387, laminar separation bubble, Trans-SST, K-kl-Ꞷ models.

I. INTRODUCTION

Over the past decade, Micro Air Vehicles (MAVs) have received an increasing amount of attention in military and civilian markets. With a characteristic length not longer than 15 cm (6 in.), MAVs are barely detectable to the naked eye at 100 yards. This stealth capability makes MAVs a prime candidate for surveillance, detection, and reconnaissance missions. Often, prototype MAVs have been outfitted with cameras with the ability to send and receive data. MAV research generally falls into three vehicle classes: fixed wing, rotary wing, and flapping wing. Each class of MAVs has unique benefits and problems because the aerodynamics of each class is different, due to the different range of operating Reynolds number.

Flows with a chord Re < 1, 00, 000 are typically considered low Reynolds number flows.

LAMINAR SEPARATION BUBBLE:

Bubbles occur when the laminar boundary layer separates from the body and reattaches downstream. Low *Re* flows tend to separate before transition. Figure 1 shows a schematic view of an ideal separation bubble.

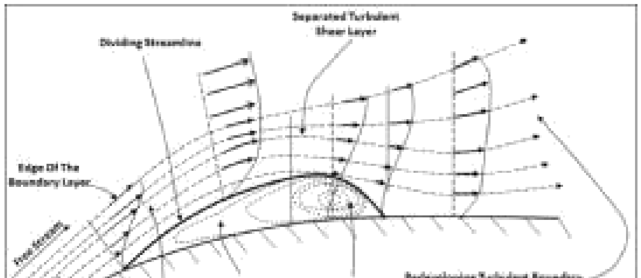

Figure 1: Laminar Separation Bubble Schematic

As discussed above, the bubble tends to create a turbulent transition and thus a velocity jump.

Figure 2 shows the momentum and velocity distributions across a bubble.

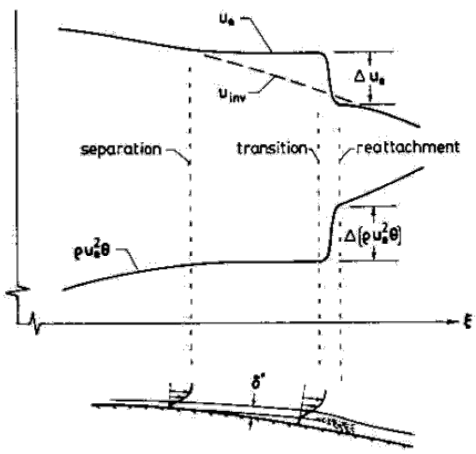

Figure 2: Laminar Separation Profile

Several studies have been made to predict the airfoil performance and LSB characteristics using transition models, but very few studies have been carried out over a thick airfoil at low Reynolds number. In the present study, numerical simulation of EPPLER 387 airfoil has been carried out for Reynolds number viz. 20,000, 30,000, 60,000 100,000 and 300,000. The angle of attack has been varied from 0 to 12 deg. which is below the stall angle and at an interval of 2 deg. In this study, the flow simulation has been carried out with low Reynolds number correction, trans- SST model and k-kl-ω turbulence model.

EPPLER 387:

The Eppler 387 airfoil is chosen for a 2-D validation due to its common use in low Reynolds number flow. This airfoil is about 9% thick with 3.87% camber. Though thicker than most MAV airfoils, the Eppler 387 validation shows the usefulness of the flow solver and gives insight into low Reynolds number flow physics.

II. BACKGROUND

Semi-implicit method for pressure linked equations, start with discrete continuity equation and substitute into the discrete ‘u’ and ‘v’ Momentum equations containing the pressure terms resulting in equation for discrete pressures. SIMPLE actually solves for a relative quantity for pressure correction. The set of momentum and continuity equations are coupled and are non-linear so it is solved iteratively. The pressure field is assumed to be known from the previous equation. Using this 'u' and 'v' momentum equation are solved for the velocities. The computation uses third order accurate Second Order upwind Scheme for convective flux discretization with convergence criteria of 10^-5. The second Order Scheme was proposed as a third order accurate scheme with numerical diffusion reduced to minimum. The scheme assumes quadratic upwind interpolation for the face value of the variable by assuming Second Order polynomial through downstream, upstream and one node further upstream node of the cell.

III. METHODOLOGY

A. Use of simulation software

Computational Fluid Dynamics (CFD) is a valuable tool with the ability to investigate fluid flow for MAV airfoils, wings, and rotors. In this work, as in all CFD approaches, the first step is to generate an appropriate mesh system that accurately resolves the geometry and flow features of interest. The second step is to choose the appropriate governing equations for the flow field points as well as the boundary conditions on the aerodynamic surfaces and in the far-field. Finally, the actual flow solvers are chosen to efficiently and accurately solve the governing equations.

IV. RESULTS AND DISCUSSION

Analysis for Reynolds Number 20,000

Figure 3 shows the comparison between experimental [4] and numerical values for Cl vs Angle of Attack

It is seen that both the models shows a higher value at positive angles of attack. Trans-SST numerical values are more closer to experimental [4]values. However, at negative angles of attack, K-Kl-Ꞷ model shows a better agreement than trans-SST.

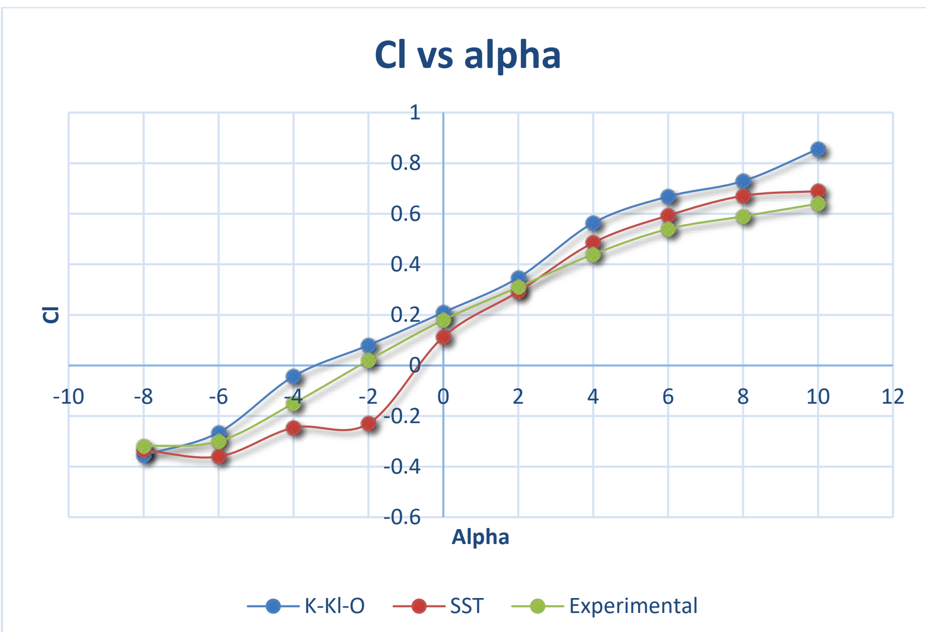

Figure 3

Figure 4 shows the comparison between experimental [4] and numerical values for Cd vs Angle of Attack

It is seen that trans-SST results are more closer to experimental [4]values for various angles of attack.

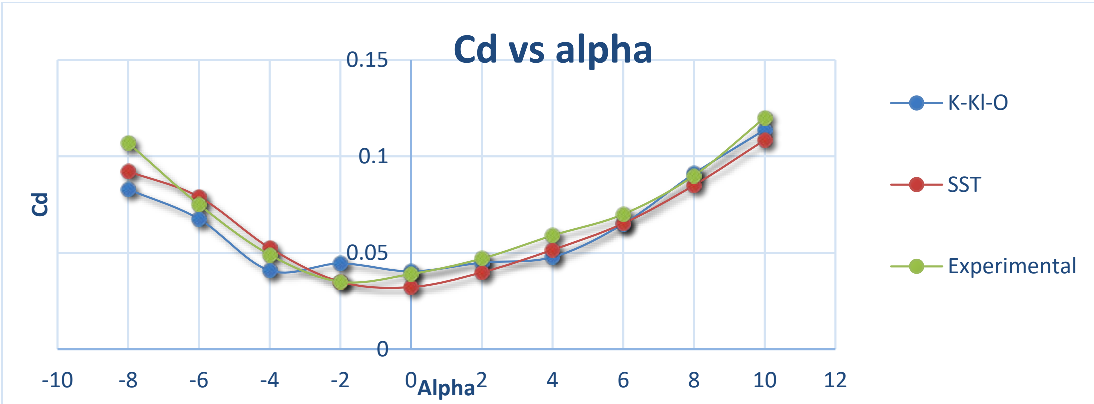

Figure 4

Figure 5 shows the comparison between experimental [4] and numerical values for Cl vs Cd

It is seen that for positive Cl, experimental [4]values are closer to trans-SST model whereas, for negative Cl, experimental [4]values are closer to K-Kl-Ѡ model

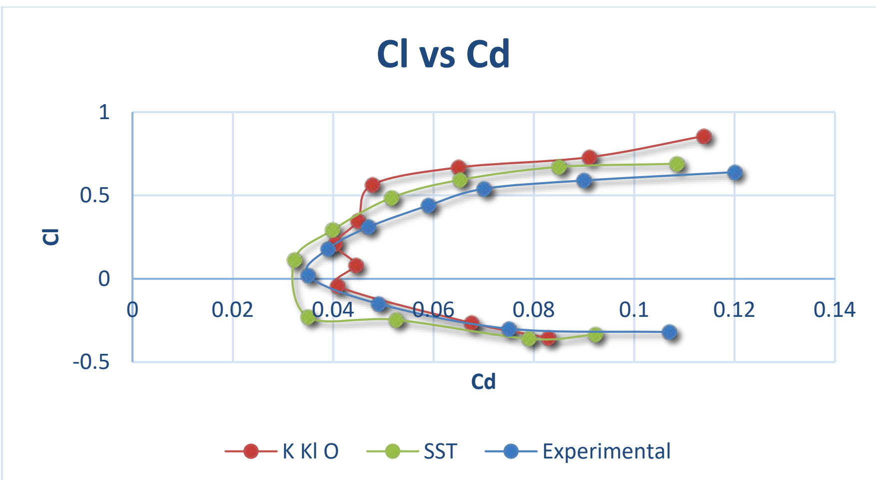

Figure 5

Shear stress distribution

Re=20,000

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Figure 6 shows the results for trans-SST at -8deg

It is evident that the flow separates on the lower surface of the airfoil approximately at 10cm from the L.E and later reattaches close to the trailing edge. The flow on the upper surfaces remains in contact.

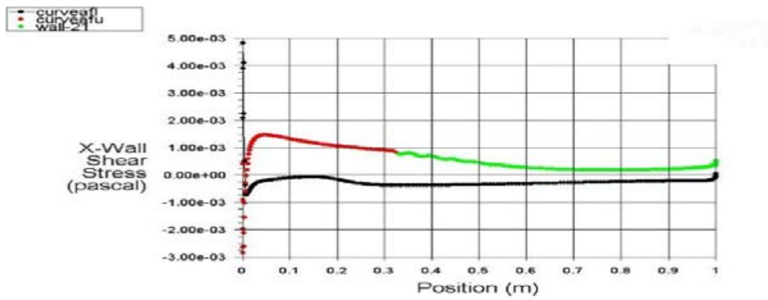

Figure 6

Analysis for Reynolds Number 30,000

Figure 7 shows the comparison between experimental [4] and numerical values for Cl vs Angle of Attack

It is seen that experimental [4]values and trans-SST model are close to each other when compared to K-Kl-ω model.

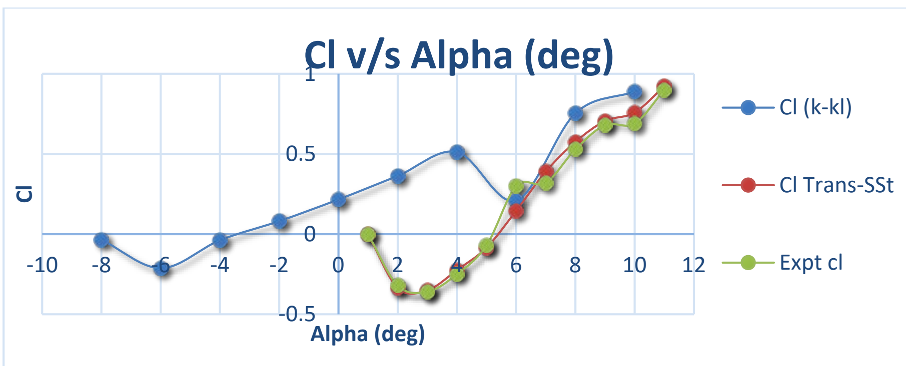

Figure 7

Figure 8 shows the comparison between experimental [4] and numerical values for Cd vs Angle of Attack

It is seen that k-kl-ω model is behaving differently when compared to trans-SST model whose values are closer to experimental [4]values.

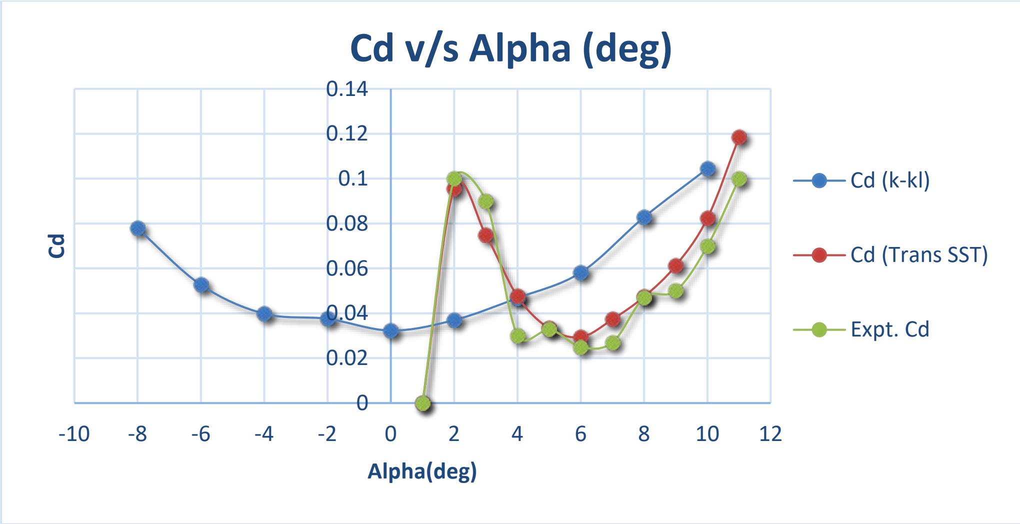

Figure 8

Figure 9 shows the comparison between experimental [4] and numerical values for Cl vs Cd

The figure shows that the there is no correlation seen between the two numerical models. However, experimental [4]values are seen closer to trans-SST model.

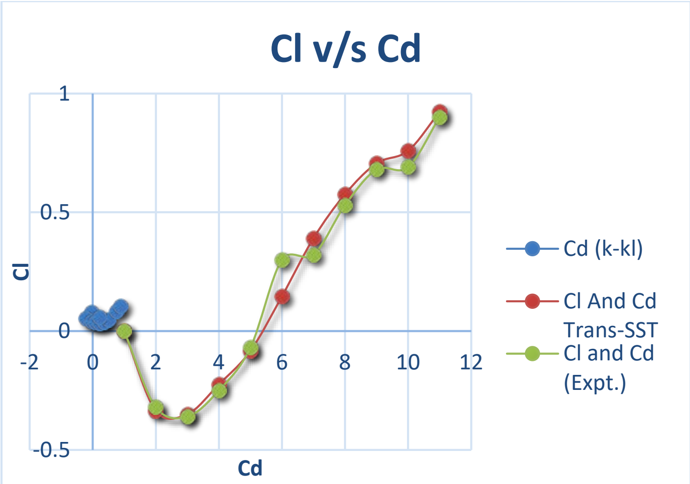

Figure 9

Shear stress distribution

Re 30,000

Figure 10 shows the results for trans-SST at -2 deg.

At this angle, the flow remains attached on the upper surface however the flow on the lower surface separates very close to the leading edge and later reattaches close to 0.57mtrs from the leading edge and remains attached thereafter.

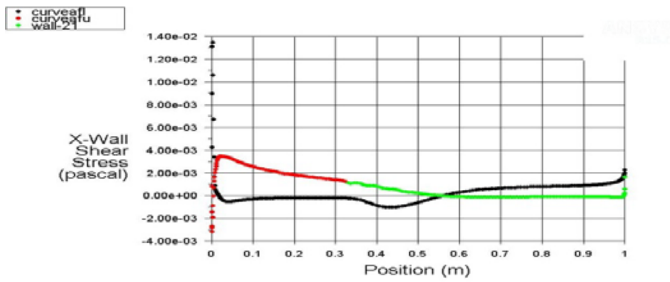

Figure 10

Analysis for Reynolds Number 60,000

Figure 11 shows the comparison between experimental [4] and numerical values for Cl vs Angle of Attack

It can be observed that the distribution using trans-SST model and experimental [4]values are almost matching but K-Kl- ω model over predicts the whole range.

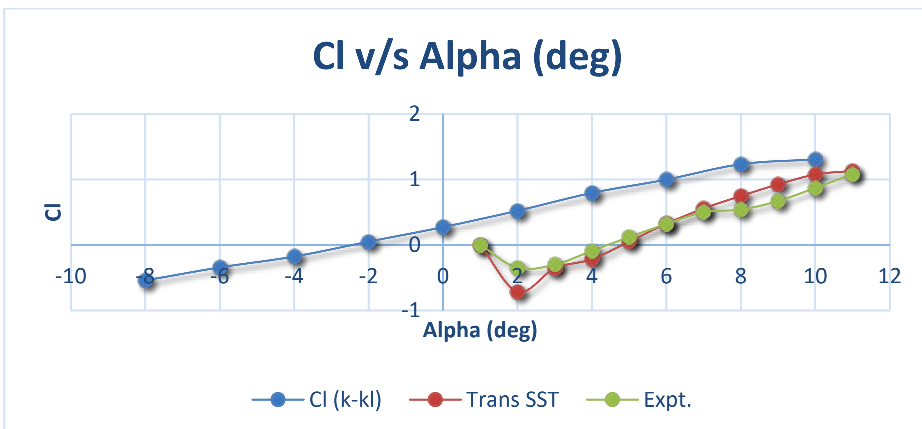

Figure 11

Figure 12 shows the comparison between experimental [4] and numerical values for Cd vs Angle of Attack

It can be observed that the distribution is in agreement with trans-SST model and experimental [4]values except over-predicting between 5 and 7 degrees. But, the Cd variation for K-Kl- ω model is not correlating with the experimental [4]values.

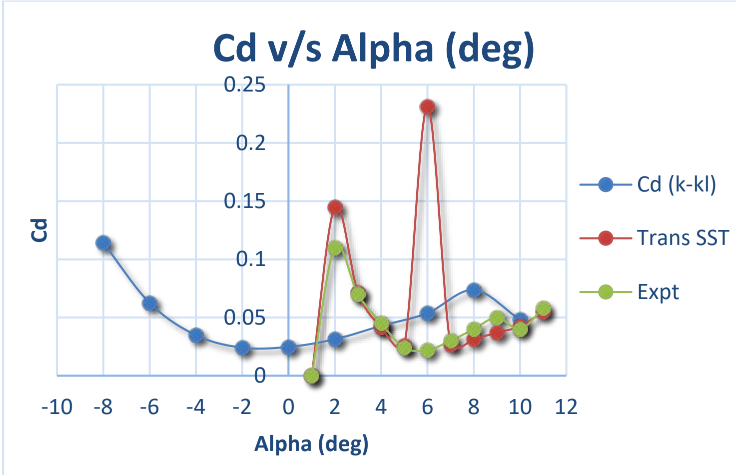

Figure 12

Figure 13 shows the comparison between experimental [4] and numerical values for Cl vs Cd

It is observed that Cd curves using k-kl-Ѡ are not at all in correlation with experimental [4] values. However, trans-SST is in good agreement with experimental [4]values except for 2 deg.

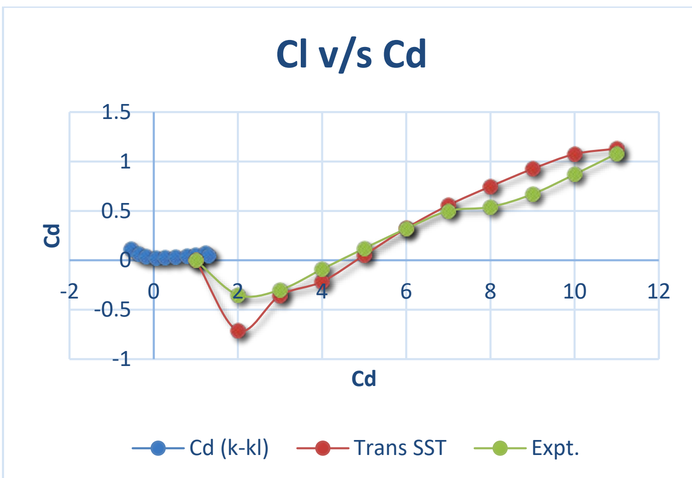

Figure 13

Shear stress distribution

Re 60,000

Figure 14 shows the results for trans-SST at 0 deg.

The flow separates at 0.45m from the leading edge and re-attaches close to the trailing edge.

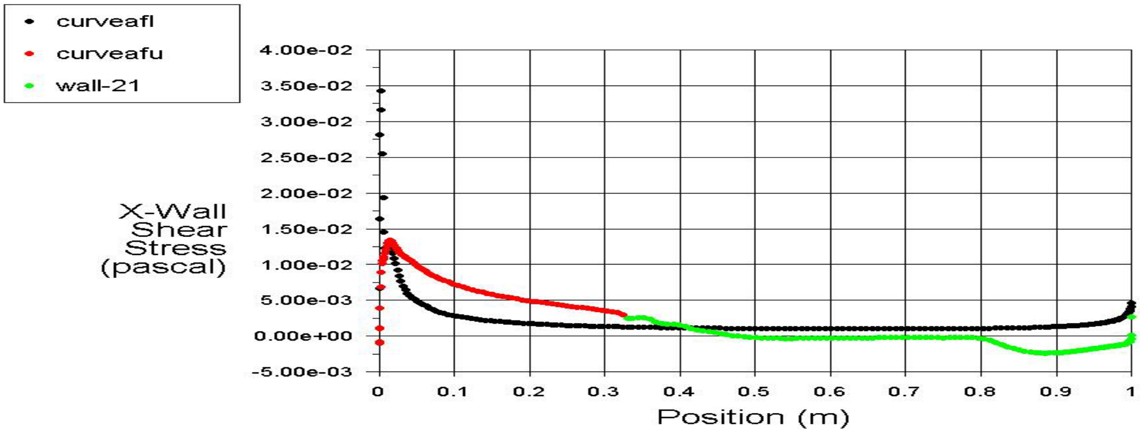

Figure 14

Re 60,000

Figure 15 shows the results for K-kl-Ꞷ at -2deg.

The flow on the upper surface remains attached. However, the flow separates very early and later reattaches at approx. 0.35mtrs from the leading edge.

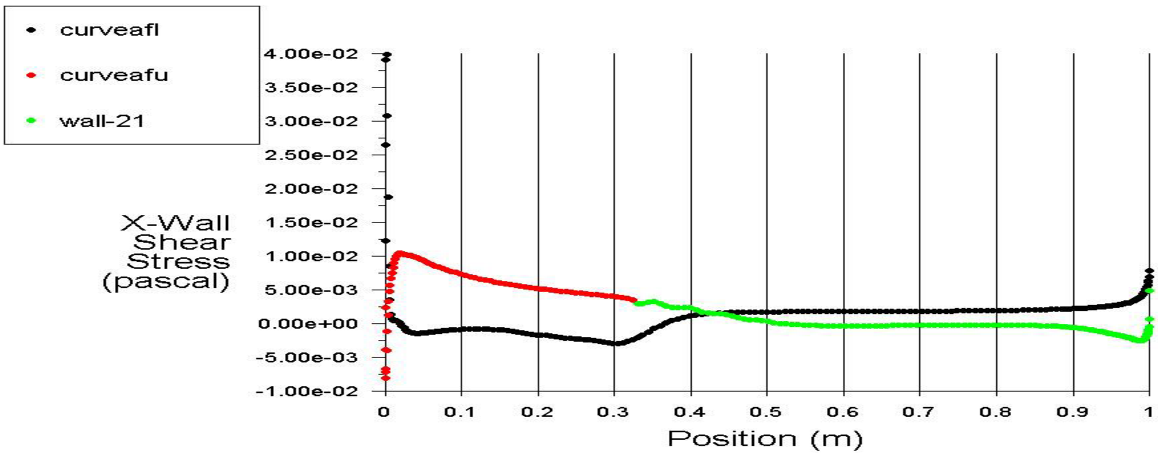

Figure 15

Vector plot representing the Laminar Separation Bubble at Re=60,000 using trans-SST

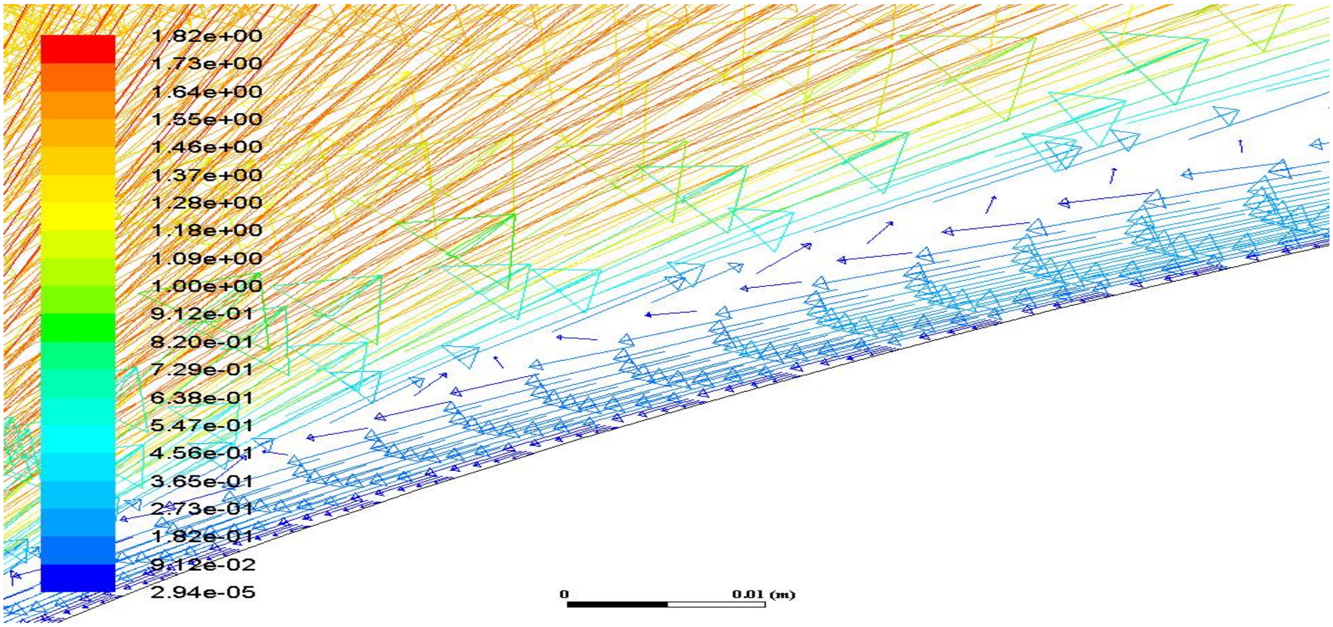

Figure16: Velocity vector showing separation at L.E

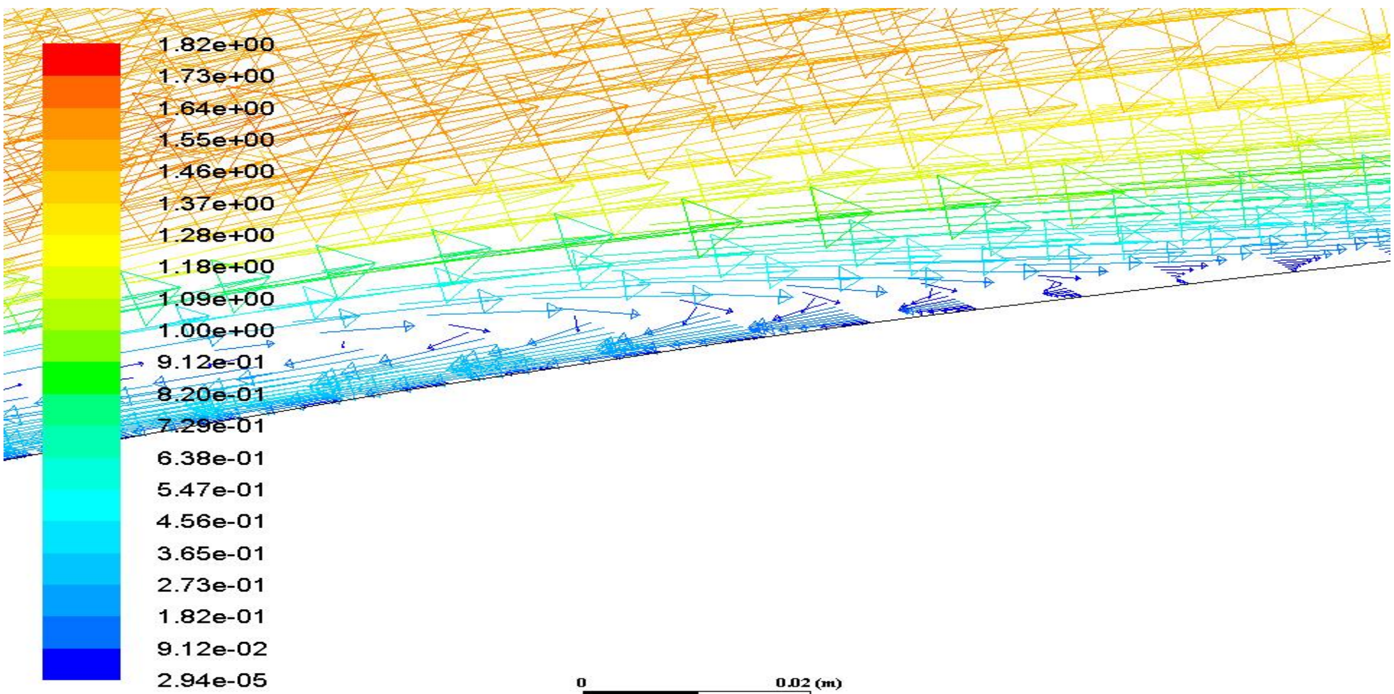

Figure17: Velocity vector showing Reattachment at 0.25m approx. from L.E

Analysis for Reynolds Number 100,000 using trans-SST model

Figure 18 shows the comparison between experimental [4] and numerical values for Cl vs Angle of Attack

It is observed that the values using trans-SST and experimental [4]values are agreeing well.

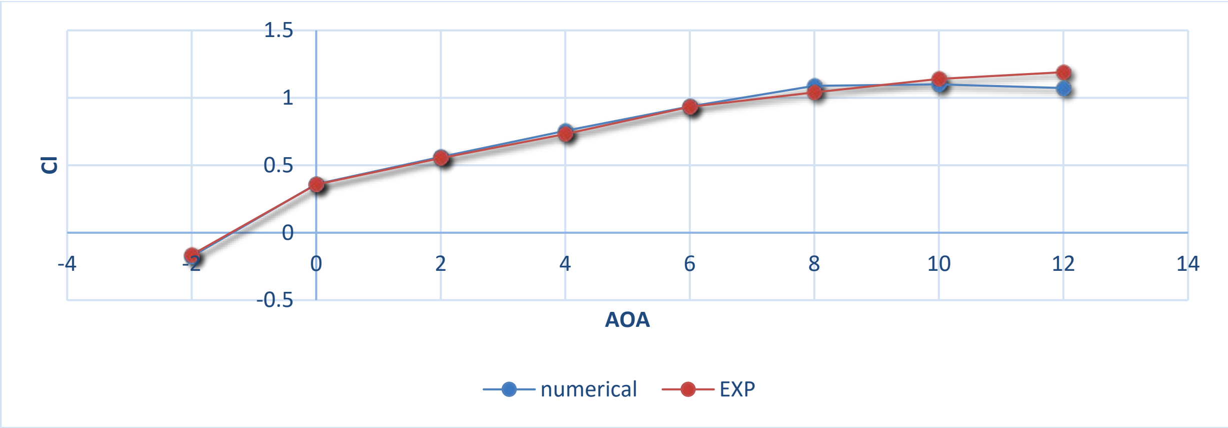

Figure 18

Figure 19 shows the comparison between experimental [4] and numerical values for Cd vs Angle of Attack

It is observed that the distribution obtained using trans-SST and experimental [4]values have some variations.

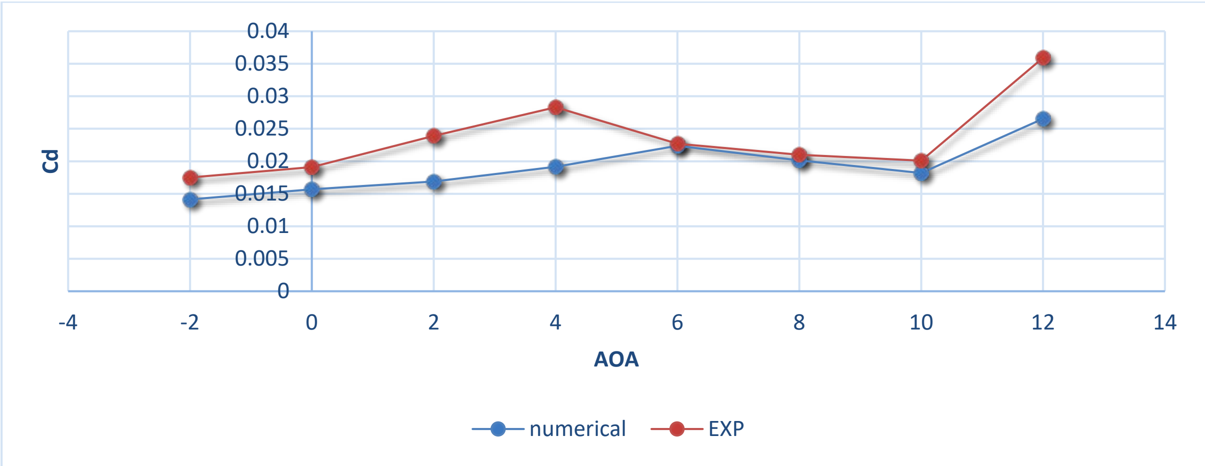

Figure 19

Figure 20 shows the comparison between experimental [4] and numerical values for Cl vs Cd

It is seen that agreement is good except with minor variation.

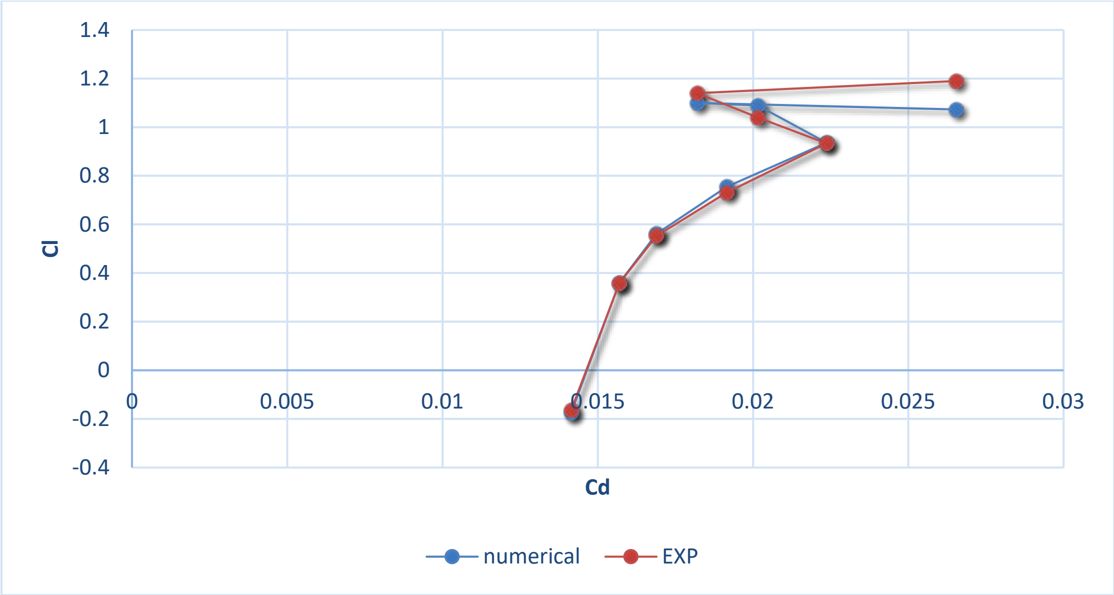

Figure 20

Figure 21 shows the separation plot for Re=100,000

It is seen that the numerical values and experimental [4] values are reasonably in good agreement.

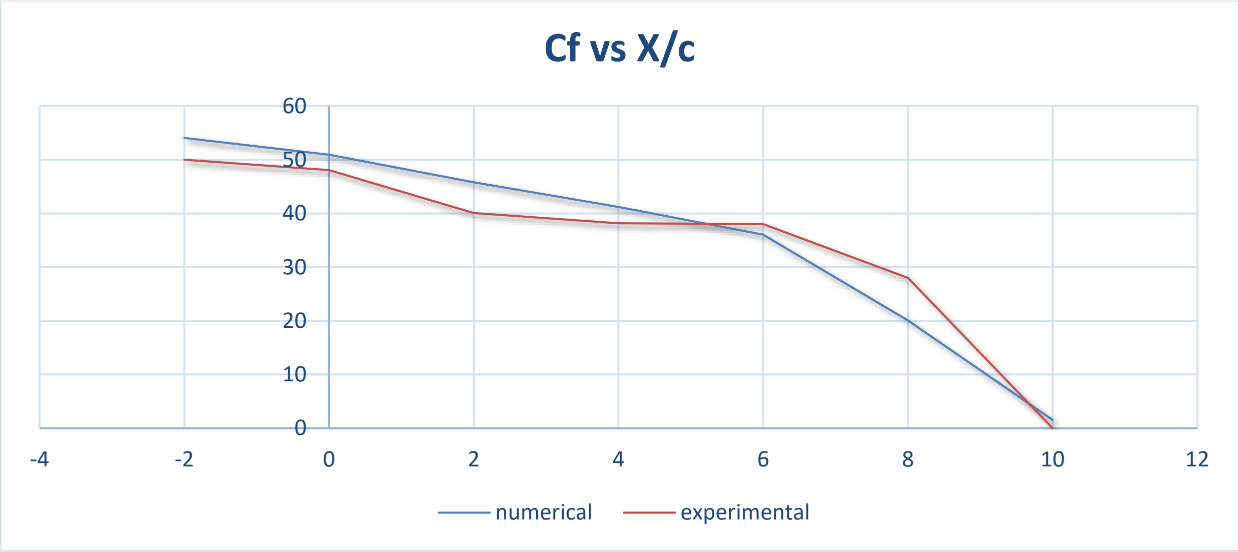

Figure 21

Figure 22 shows the reattachment plot at Re=100,000

It is seen that the numerical values and experimental [4] values are in good agreement with each other.

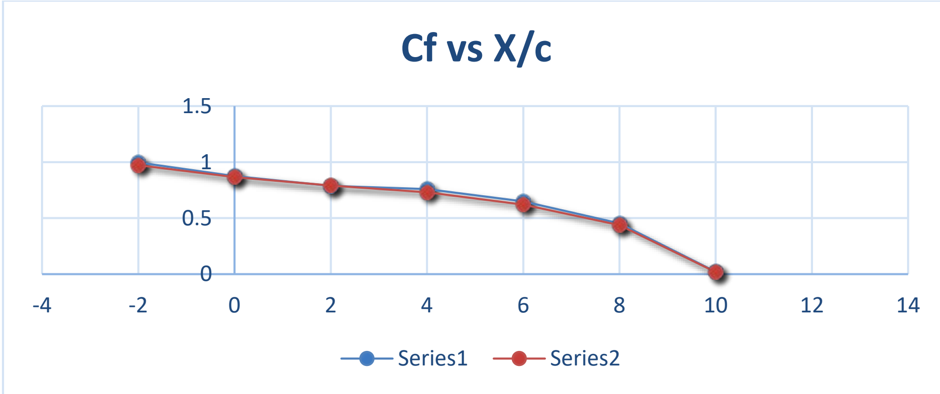

Figure 22

Analysis for Reynolds Number 300,000 using trans-SST

Figure 23 shows the comparison between experimental [4] and numerical values for Cl vs Angle of Attack

It can be observed that both the curves are perfectly correlated.

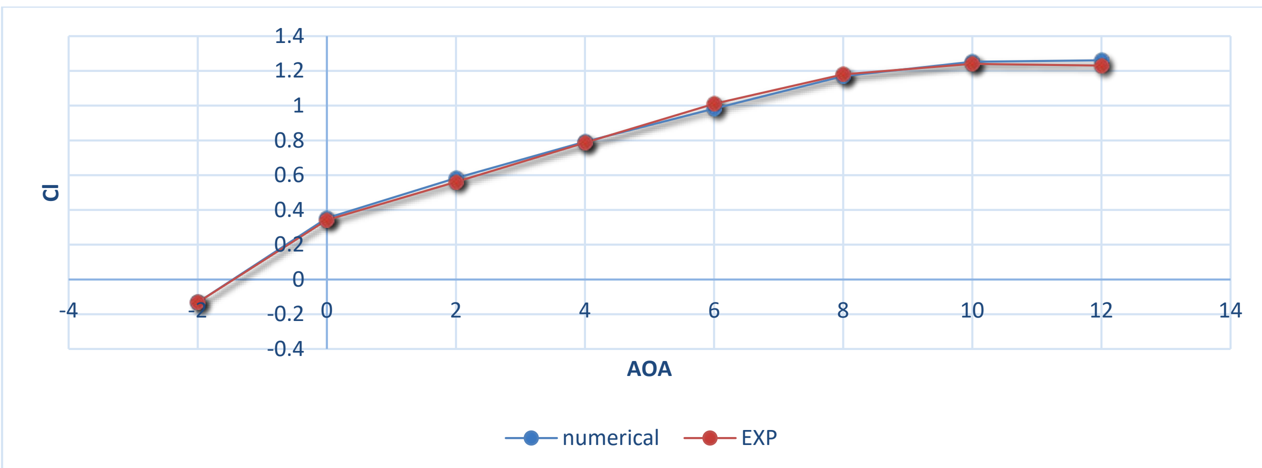

Figure 23

Figure 24 shows the comparison between experimental [4] and numerical values for Cd vs Angle of Attack

It is observed that numerical values almost align with each other.

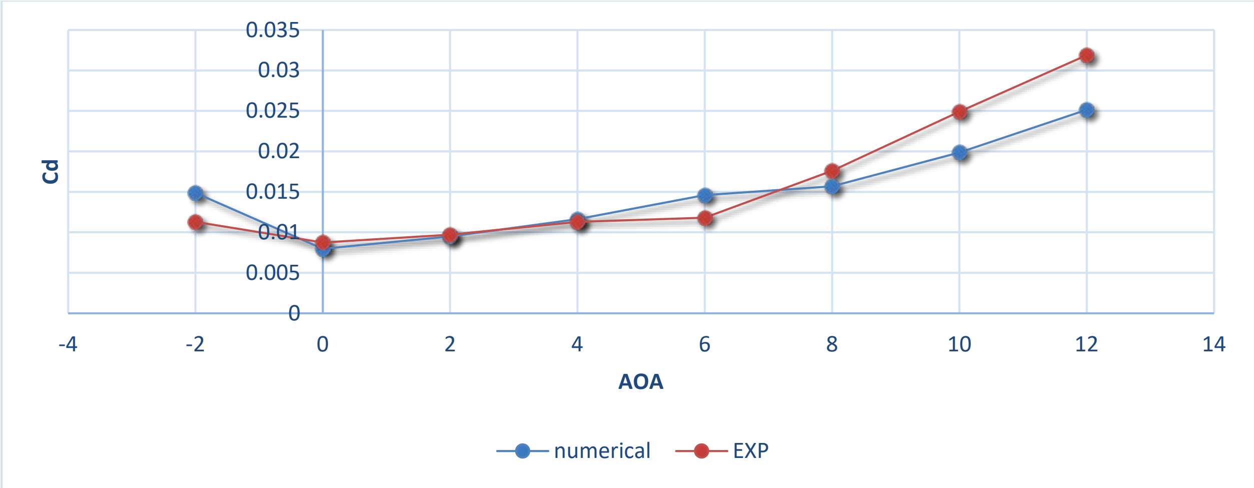

Figure 24

Figure 25 shows the comparison between experimental [4] and numerical values for Cl vs Cd

It can be seen that both the curves are in good agreement with each other.

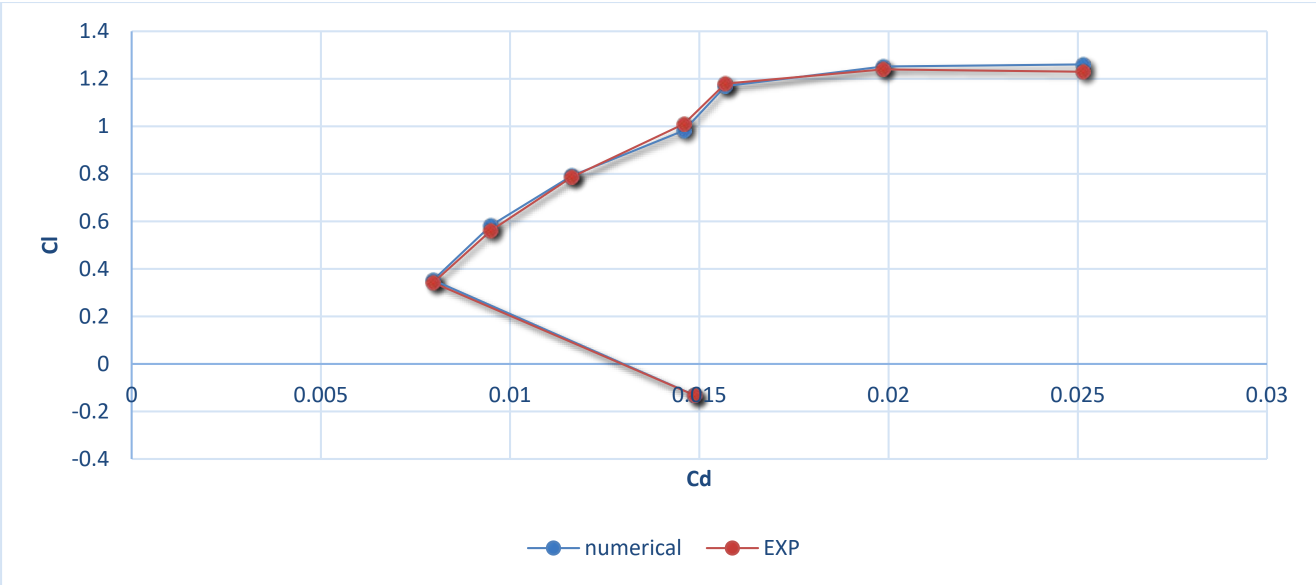

Figure 25

Figure 26 shows the Separation plot at Re=300,000

In the range of experiments, the agreement is good.

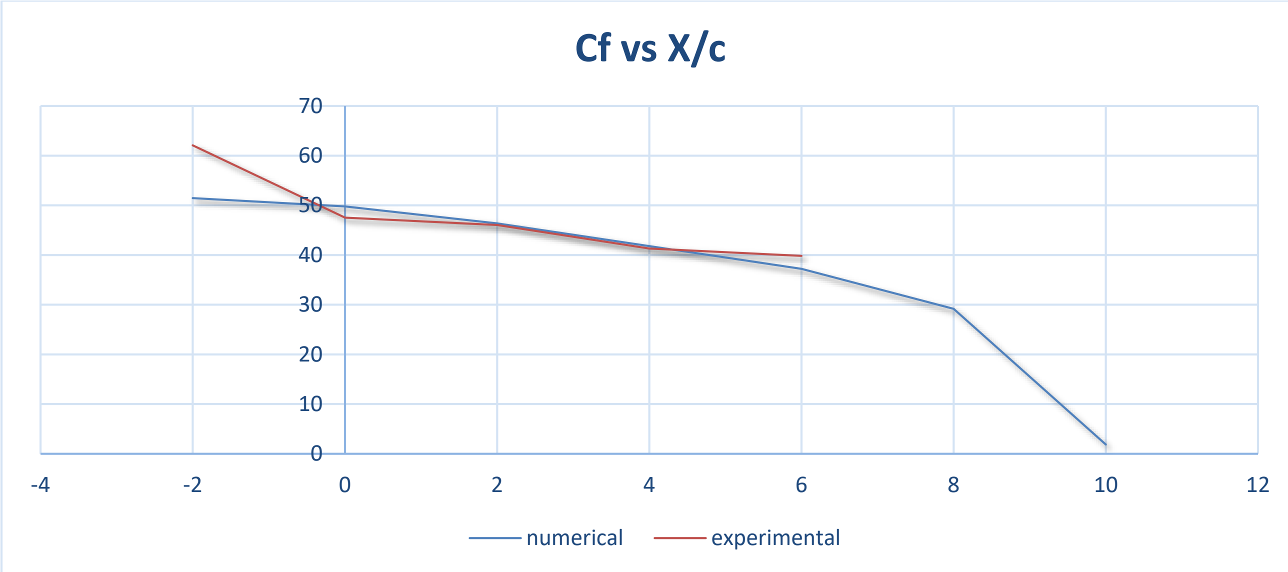

Figure 26

Figure 27 shows the reattachment plot at Re=300,000

By comparing numerical and experimental [4]value, it is seen that good comparison between the two.

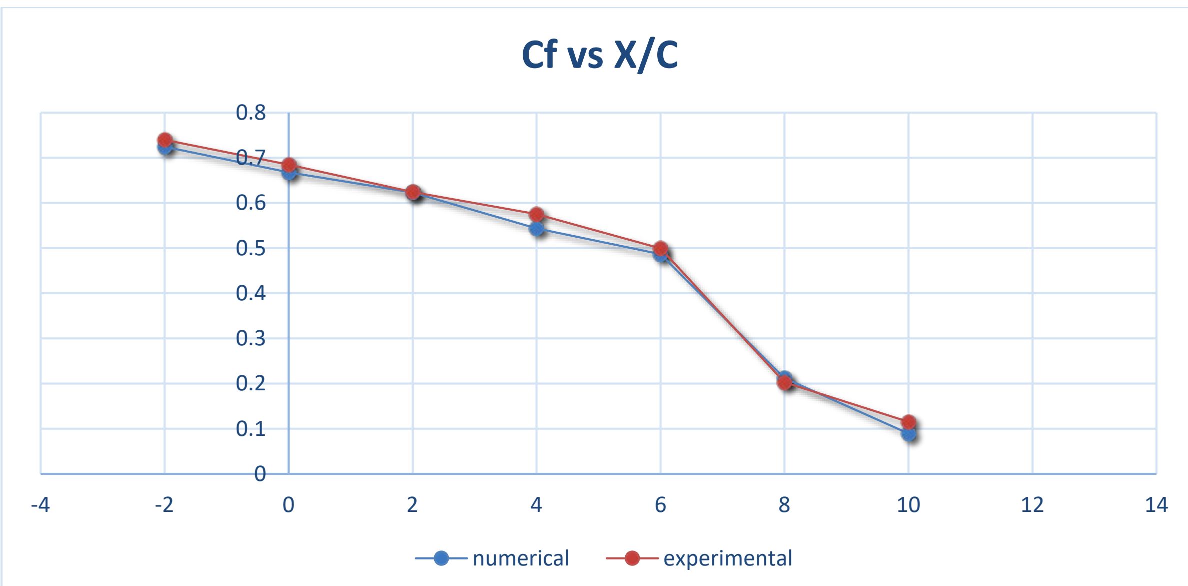

Figure 27

V. CONCLUSION

The simulations and analysis for the Eppler airfoil shows the expected behavior of lift curves at low Reynolds number. The performance of the Eppler airfoil is dominated by laminar separation bubble at Reynolds number below 200,000. At positive angle of attack, a short laminar separation bubble becomes more evident on the upper surface and moves forward whereas the bubble on the lower surface moves aft. The separation increases with increasing angle of attack. Transition SST model shows a better trend when compared to K-Kl-Ꞷ Model.

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