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Simulation of Drag Crisis in flow past a circular cylinder using 3-D computations

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ABSTRACT

The Navier Stokes Equation are solved using LES, using Sigma Model at high Re(2X105,3X105,4X105) to simulate the Drag Crisis in flow past a circular cylinder. At the critical Reynolds Number, the transition point is located very close to the point of separation. As a result shear layer eddies cause mixing of the flows in the boundary layer. This energizes the boundary layer and leads to its reattachment. The delay in flow separation causes narrowing of wake which results in reduction of drag. The mean drag coefficient for various Re are compared with experimental data. It was observed that the flow separates much later for Sigma Model, from the Cylinder. Laminar Separation Bubble was observed for the Sigma Model. Streamlines, surface pressure and Q-criteria was also observed Sigma model.

Keywords

Linux, Cylinder, Wake, Boundary Layer.

1. INTRODUCTION

Flow analysis is an important concern for various engineering fields, as well as in the different areas of science and technology. Many problems are characterized by turbulent flows and various suitable models are necessary to analyze the flow characteristics. Turbulent Flows are characterized by the high Reynolds Number and another important characteristic of turbulent flows is that multiple scales are involved. Consequently, turbulence may be defined as continuous phenomenon. The conservation equation of fluid mechanics forms a mathematical model that is capable of describing the turbulent flows. In Large Eddy Simulation technique, the conservation equations are solved for large flow scales and models are used to represent the effects of sub grid scales. These models are simple from the conventional models because they consider only the effects of small scales. Beyond the critical Re, the shear layer separated from the upper and lower layer of the cylinder. The transition point, beyond which the separated layer becomes unstable, moves upstream with increase in Re. The Reynolds Number at which the boundary layer on the cylinder surface undergoes a transition from laminar to turbulent is 2X105. This transition leads to the delay of separation of flow from cylinder surface causing a substantial reduction in drag force that the cylinder experiences. This is known as Drag crisis.

2. MATHEMATICAL AND NUMERICAL ASPECTS

The spatially filtered Navier Stokes equation can be expressed as

$$\frac{\partial \overline{u_i}}{\partial t} \qquad (1)$$

$$\frac{\partial \overline{u_i}}{\partial t} + \frac{\partial \overline{u_i u_j}}{\partial x} + \vartheta \frac{\partial \text{^} 2\overline{u_i}}{\partial x_{i\ x_j}} + \rho - 1\ \frac{\partial \overline{p}}{\partial x_j} = - \frac{\partial \tau_{ij}}{\partial x_j} \qquad (2)$$

Where $\overline{u}$ and $\overline{p}$ stands for filtered velocity and pressure respectively. ϑ is the kinematic viscosity and ρ is the density of fluid.

In eqn (2) ,τ_{ij} is the subgrid scale (SGS) stress tensor which has to be modeled. Its deviatoric part is given as

$$\tau_{ij-\frac{1}{3}}\tau_{ij}\delta_{ij} = -2\vartheta_{SGS}\overline{S}_{ij} \qquad (3)$$

Where $\bar{S}_{ij}$ is the large scale rate of stress tensor.

3. RESULTS AND DISCUSSIONS

3.1 Cd v/s Re

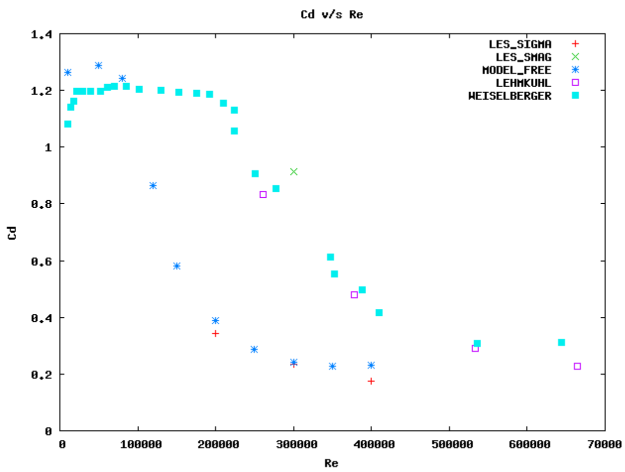

Figure 1: Flow past a cylinder: Variation of time averaged drag coefficient with Re

Figure 1 shows the variation of Cd v/s Re. As we can see from the figure that sigma model at (2e5; 3e5; 4e5). The present study results are compared with computational results from Weiselberger, experimental results from Lehmkuhl and model free results. As the Reynolds Number is increased beyond a critical value, the drag experienced by the cylinder reduces. Results from Sigma model and model free calculations match very well with each other. They predict drag crisis at low Re compared to experiments.

3.2 Streamlines and Formation of LSB

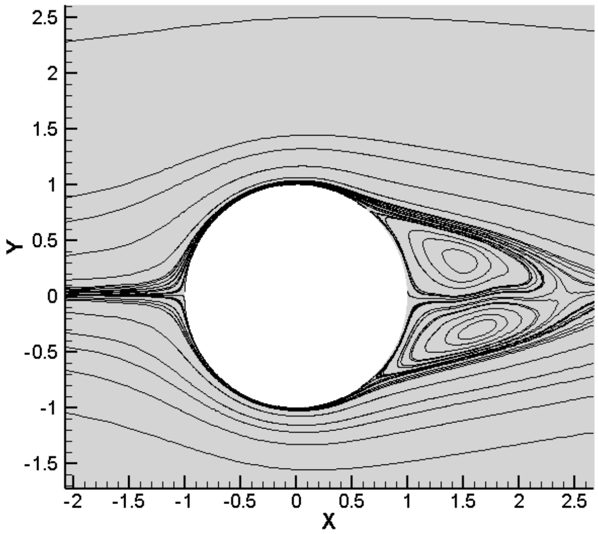

Figure2: Streamlines over flow of cylinder

Figure 2 shows the streamlines of the time averaged flow of Sigma. For Re = 3X105 flow for the sigma model, a long bubble is observed close to the cylinder surface, immediately downstream of the point of separation, this bubble is known as Laminar Separation Bubble(fig3&4). The formation of LSB results in the narrowing of the wake as in case of Sigma Model. Narrowing of the wake for Re = 3X105 flow (Sigma Model). It was also observed that for the sigma model at Re = 3X105 downstream of the separation point, the speed of the flow inthe reverse flow region is quite high very close to the surface of the cylinder. This results in the local peak in the suctionpressure. The time averaged streamlines and pressure distribution for Sigma Model suggests that, it is associated with the recirculatory "Laminar Bubble" close to the cylinder, immediately downstream of the point of flow separation. At higher Re, the shear layer vortices cause the flow to become turbulent and the LSB bursts.

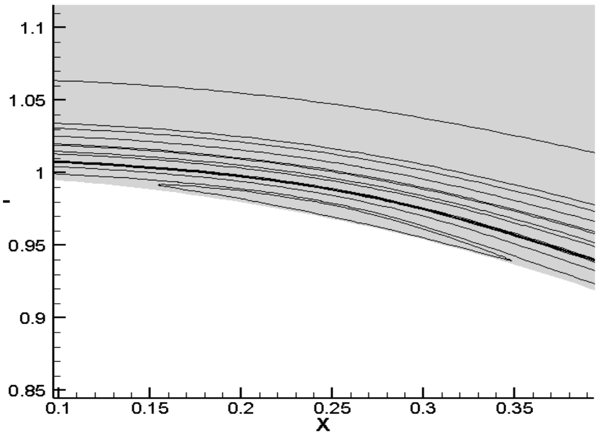

Figure 3: LSB on Upper Side

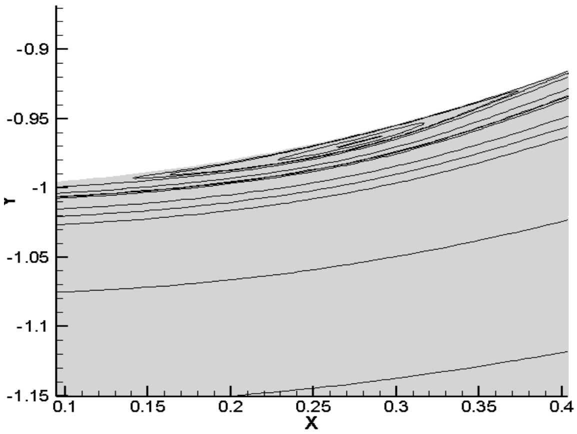

Figure 4: LSBon Lower Side

3.3 Time averaged Pressure coefficient

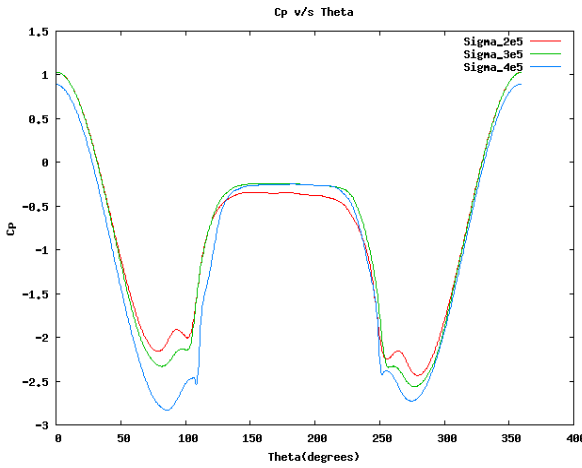

Figure 5: Cp v/s theta variation

Figure 5 shows time averaged Pressure coefficient (Cp) distribution on the surface of the cylinder. Formation of LSB is found near $\theta = 110^{o}$ and $\theta = 250^{o}$ in case of Sigma Model. A plateau corresponds to laminar separation of the flow. This is followed by a turbulent attachment, a local pressure minima and turbulent separation. The LSB lies in the region between laminar separation and turbulent attachment of the flow.

3.4 Contour of ratio of eddy viscosity and molecular viscosity

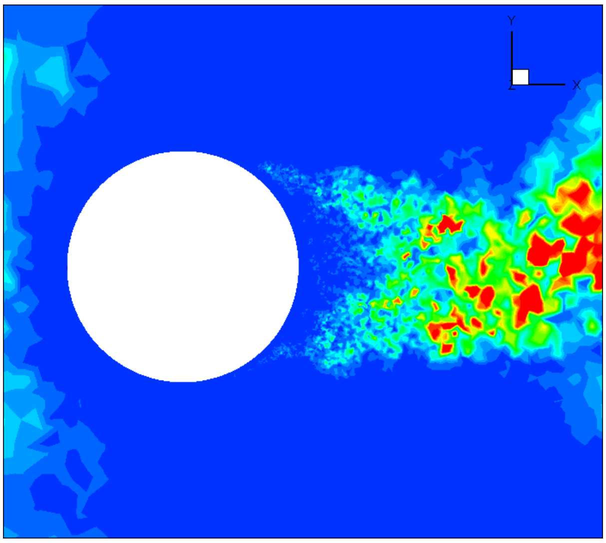

Figure 6: Contour of ratio of eddy viscosity and molecular viscosity

It was observed that the ratio of eddy viscosity and molecular viscosity for the sigma model at Re = 3 X 105 is zero over the surface of cylinder (fig6).

4. CONCLUSION

The flow past a circular cylinder has been numerically investigated by using LES, for both Sigma Model(2e5; 3e5; 4e5). In this range of Re, the cylinder experiences a very significant reduction in drag which is also known as Drag Crisis. Results for computational results from Weiselberger, experimental results from Lehmkuhl and model free have also been presented. It is shown in fig 1 that LES Sigma Model results are closer to Model free results.

This reduction in drag is not sudden but is gradual with increase in Re. The boundary layer from the cylinder separates close to the shoulder leading to large wake and high drag in the sub critical regime. But in critical regime, the separated shear layer reattaches to the surface of cylinder and turbulent separation occurs far downstream. In this case, the wake formed is narrower and the drag is comparatively lower.

5. REFERENCES

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