MANIPULATION OF FLOW OVER BACKWARD STEP

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ABSTRACT

By varying vertical edge to slant edge in a backward step the formation of vortex, reverse flow distance and drag force are analyzed in this paper. The backward step model is incremented by 10 degrees like 0, 10, 20 and 30 degrees. Each step is rotated in anticlockwise direction to make various slant edge step models and flow analysis done at Reynolds no.900 and 1350.Step model of 30degrees shows significant effect at two Reynolds numbers.

Keywords: Backward Step, Reynolds Number, Vortex, Contours, Pressure Gradient

I. INTRODUCTION

The discovery of boundary layer theory by Ludwig Prandtl in the early twentieth century was the beginning to the extensive research on separated Flows. To understand the physics of the separated shear layers and their instability mechanisms characteristics of separated flows has to be study.Besides the academic interests, knowledge of separated flows can also be applied to many practical applications in automobile and aerospace Fuel efficient vehicle design aspects.Developing fuel efficient designs to reduce consumption of the rapidly-depleting non-renewable resource and minimize greenhouse gas emission. In an aerodynamic perspective, drag is considered as one of the major reason for inefficient fuel consumption. There are several types of drag, but in this focus will be on the pressure drag created by the separated flows and the ways to minimize it. Controlling the flow separation, coherent structure characteristics significant influence on drag characteristics[1]. These aspects of the flow make it important to understand the instabilities and coherent structure characteristics for controlling flow to achieve significant drag reduction or lift enhancement. Apart from drag reduction, understanding the fluid-structure interactions of these separated shear layer instabilities can be very useful in controlling the noise and vibration characteristics of such flows[2].

Various geometries, like rib, fence, and bluff body with a splitter plate, suddenly expanding pipes, forward and backward-facing steps, cavities, and bluff bodies with blunt leading edges are taken to be study the flow characteristics separated flows due to their instabilities. The backward-facing step is considered by most as the ideal canonical separated flow geometry because of its single fixed separation point and the wake dynamics unperturbed by the downstream disturbances. An illustration of the wake characteristics behind a backward-facing step is shown in Figure 1.1 the wake of a backward-facing step has unique features mainly in two regions: the free shear layer and the low velocity re-circulating bubble. Due to instabilities, the vortices in the shear layer roll up and pair with the adjacent vortices to form larger coherent structure[3]. These vortices entrain fluid from the region below and trigger the recirculation. Due to the adverse pressure gradient in the wake of the step the free shear layer reattaches at the bottom wall.

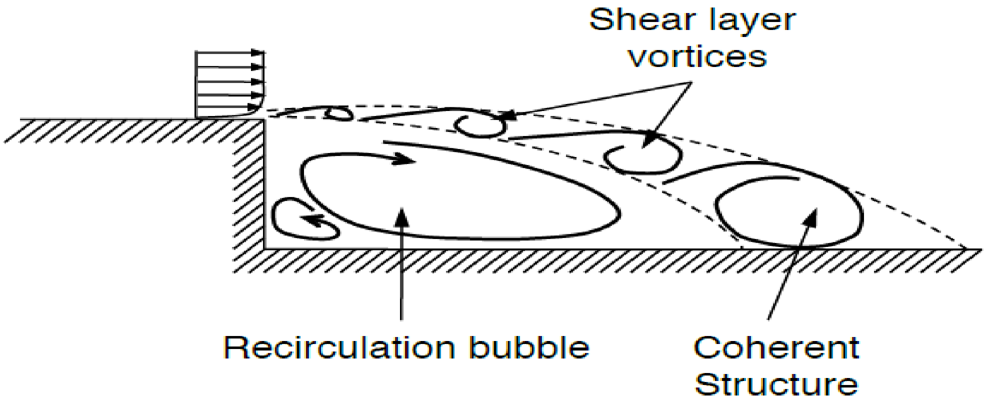

Figure 1.1: Backward-Facing Step Flow Features

For this backward-facing step flow has received a lot of attention over the past decades, and it has also served as a test case for numerical methods. Separated recirculating flows appear very often in applications. The flow in diffusers as well as over airfoils and obstacles, such as buildings or cars, are examples of these. Flow recirculation is also used as an efficient way to stabilize flames in premixed combustion.

The experimental results show that the various flow regimes are characterized by typical variation of separation length with Reynolds number[4].Also an additional region of flow separation at the downstream of the step is found apart from the primary recirculation region[5]. Experimental investigation for the flow of Reynolds number 100 to 8000 shows the size of the reverse flow region is function of the Reynolds number[6].

Very few literatures are found on the analysis of to be flow over a step having expansion ratios as well as geometry modifications on step inclinations of same expansion ratios. But in spite of all these efforts there is a definite breath of information regarding flow over a backward facing step of different slant edge position. So the present work added the extension Knowledge of back ward facing step flow with different models have modification on slant edge orientation over a two different Reynolds number of 900 and 1350. The objective of this study is analysis of flow characteristics over a back ward facing steps of different models.

II.COMPUTATIONAL METHODOLOGIES

Computational analysis is carried out to solve a flow field in two-dimensional backward facing steps of different models to analyze flow characteristics, and the effect of step inclination on the recirculation of the separated flow. Fig. 2.1 shows the different step models of varying inclination. The modeling is done in 'Gambit' modeling tool for the aforementioned geometries. Pure quadrilateral meshing is used to get structured mesh. The following table shows the description of model and meshing details.

Standard $k{-}\varepsilon$ model is used to predict the flow field Flow past the step involves recirculation (swirl) and the effect of swirl on turbulence is included in the Standard model, due to which accuracy of the model further increases. A UN steady state based implicit solver is used to achieve convergence. Second-order upwind scheme was used for the discretization of all the equations to achieve higher accuracy in results. Velocity-pressure coupling is established by pressure-velocity correlation using a PISO algorithm. Under-relaxation factors are used for all equation to satisfy Scarborough condition. Residuals are continuously monitored for continuity, *x*-velocity, *y*-velocity, *z*-velocity, *k*, and *ε*. Convergence of the solution is assumed when the values of all residuals goes below 10^{-6} Enhanced wall treatment is used to solve for the near wall treatment, as *y*+ is more than 30 in the whole domain.

III. RESULT AND DISCUSSION

Velocity vectors, contours of pressure and velocity and coefficient of drag have taken to analyze the flow over a backward step of different models at Reynolds no. 900 and 1350. Vortex size is normalized by dividing vortex size to mean hydraulic diameter. Snaps of velocity vectors and contours of pressure and velocity taken for each and every model to give detailed view of the flow.

3.1 Flow Over a Backward Facing Step of 0^0 Model

Figure 3.1 (a, b, &c) shows the velocity vectors, contours of velocity and pressure at Reynolds no. 900. Figure 3.2 (a, b, &c) shows the velocity vectors, contours of velocity and pressure at Reynolds no 1350.

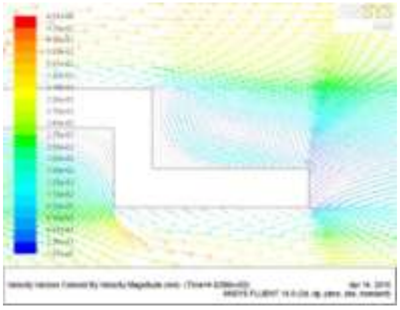

Fig 3.1(a) Velocity vectors

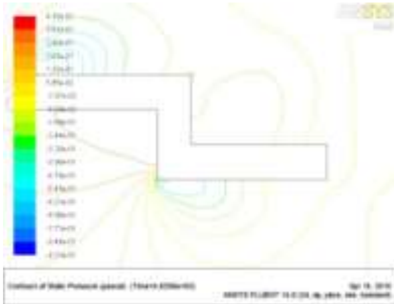

Fig 3.1(b) Velocity contours

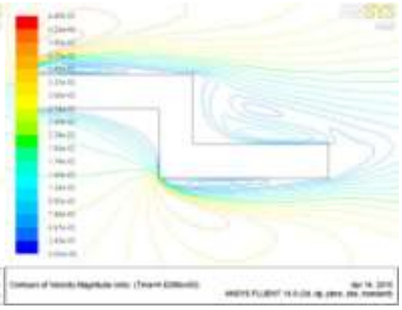

Fig 3.1(c) Pressure contours

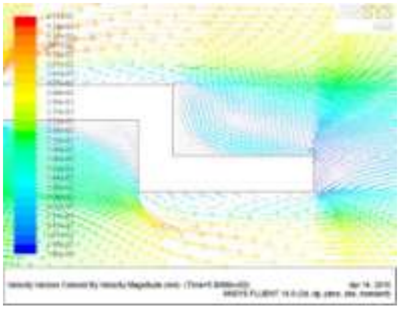

Fig 3.2(a) Velocity vectors

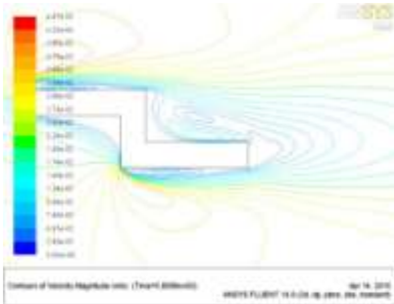

Fig 3.2 (b) Velocity contours

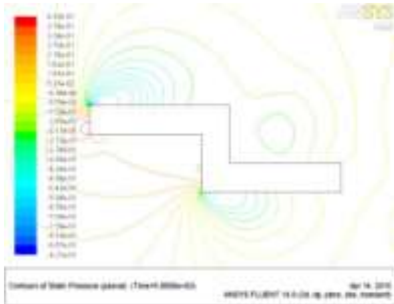

Fig 3.2(c) Pressure contours

At Reynolds number 900 the step effected zone beside the extreme end of the step has a horizontal distance of 39.69mm , maximum height of 20.41mm , behind the plate 4.71 mm and vortex size of 20.23mm and at Reynolds no. 1350 step effected zone beside the extreme end of the step has a horizontal distance of 39.3mm , maximum height of 19.87mm , behind the plate 4.12 mm and vortex size of 18.40mm as increase Reynolds number no significant effect is there in this model. No effect shown by this model as increasing the Reynolds no.

3.2 Flow Over a Backward Facing Step of 10^0 Model

Figure 3.3 (a, b, &c) shows the velocity vectors, contours of velocity and pressure at Reynolds no. 900. Figure 3.4 (a, b, &c) shows the velocity vectors, contours of velocity and pressure at Reynolds no 1350.

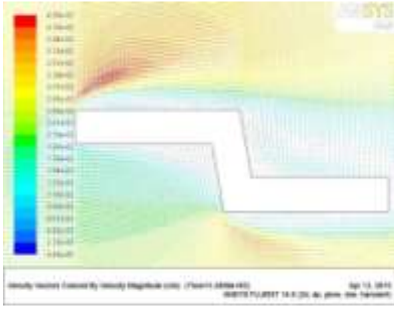
Fig 3.3(a) Velocity vectors

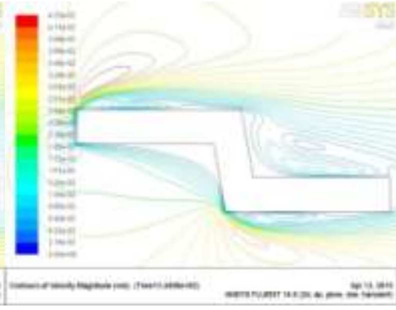
Fig 3.3(b) Velocity contours

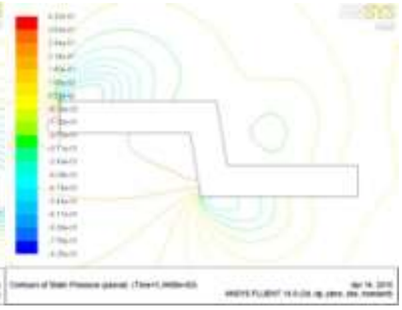
Fig 3.3(c) Pressure contours

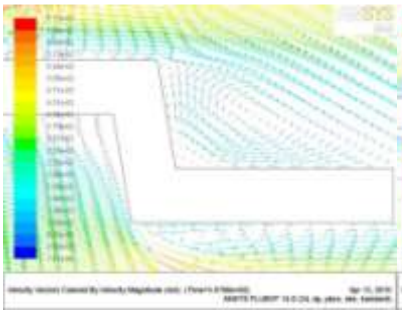
Fig 3.4(a) Velocity vectors

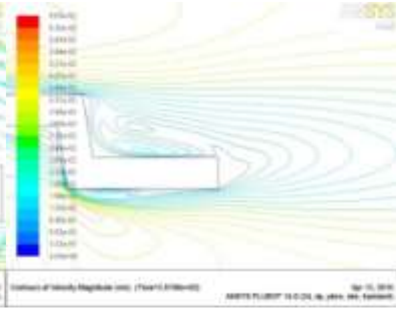
Fig 3.4(b) Velocity contours

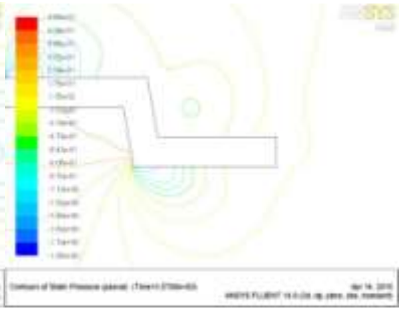
Fig 3.4(c) Pressure contours

At Reynolds number 900 the step effected zone beside the extreme end of the step has a horizontal distance of 37.50 mm , maximum height of 19.39 mm , behind the plate 4.09 mm and vortex size of 23 mm . At Reynolds number 1350 the step effected zone beside the extreme end of the step has a horizontal distance of 46.31 mm , maximum height of 20.78 mm , behind the plate 2.89 mm and vortex size of 21.42mm. As increase in Reynolds number this model shown significant effect in flow past from the model.

3.3 Flow Over a Backward Facing Step of 20^0 Model

Figure 3.5 (a, b, &c) shows the velocity vectors, contours of velocity and pressure at Reynolds no. 900. Figure 3.6 (a, b, &c) shows the velocity vectors, contours of velocity and pressure at Reynolds no 1350.

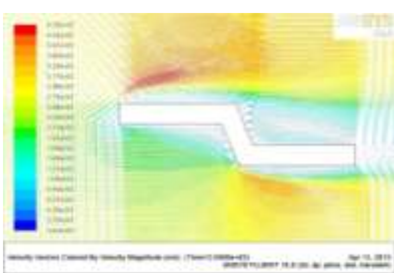
Fig 3.5(a) Velocity vectors

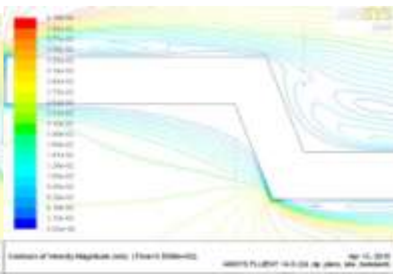
Fig 3.5(b) Velocity contours

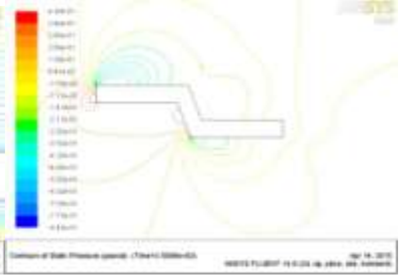
Fig 3.5(c) Pressure contours

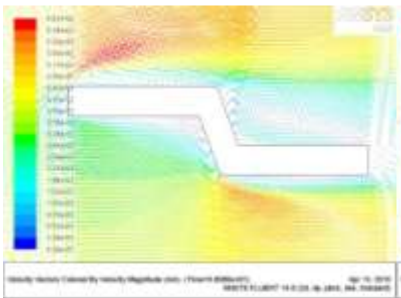
Fig 3.6(a) Velocity vectors

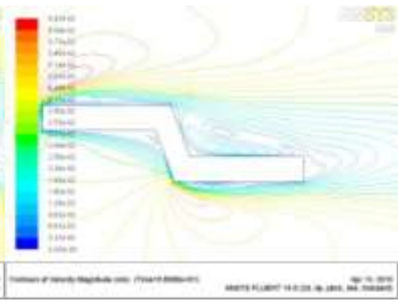
Fig 3.6(b) Velocity contours

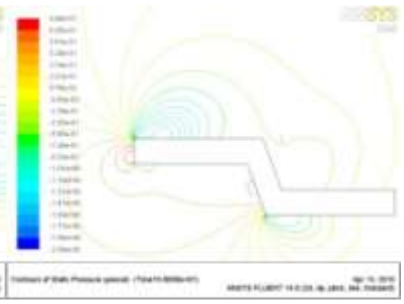
Fig 3.6(c) Pressure contours

At Reynolds number 900 the step effected zone beside the extreme end of the step has a horizontal distance of 34.02 mm , maximum height of 17.75 mm , behind the plate 2.95 mm and vortex size of 25mm. At Reynolds number 1350 the step effected zone beside the extreme end of the step has a horizontal distance of 44.26 mm , maximum height of 15.30 mm , behind the plate 2.73 mm and vortex size of 18.96mm. . As increase in Reynolds number this model shown significant effect in flow past from the model.

3.3 Flow Over a Backward Facing Step of 30^0 Model

Figure 3.7 (a, b, &c) shows the velocity vectors, contours of velocity and pressure at Reynolds no 900. Figure 3.8 (a, b, &c) shows the velocity vectors, contours of velocity and pressure at Reynolds no 1350.

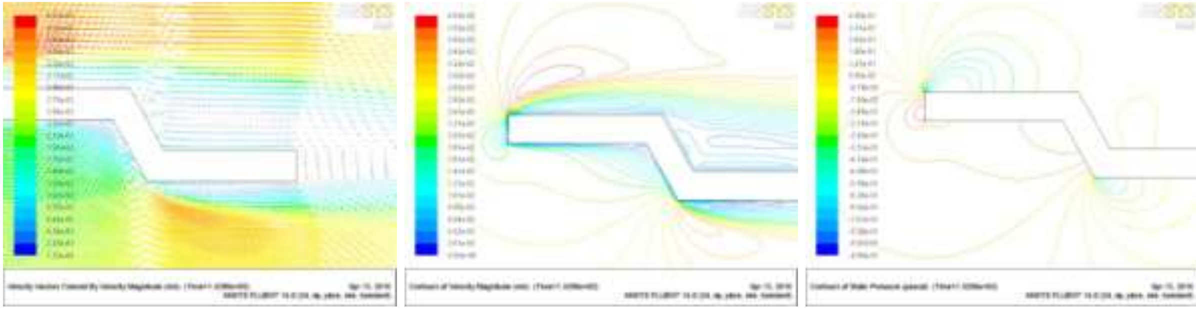

Fig 3.7(a) Velocity vectors **Fig 3.7(b) Velocity contours** **Fig 3.7 (c) Pressure contours**

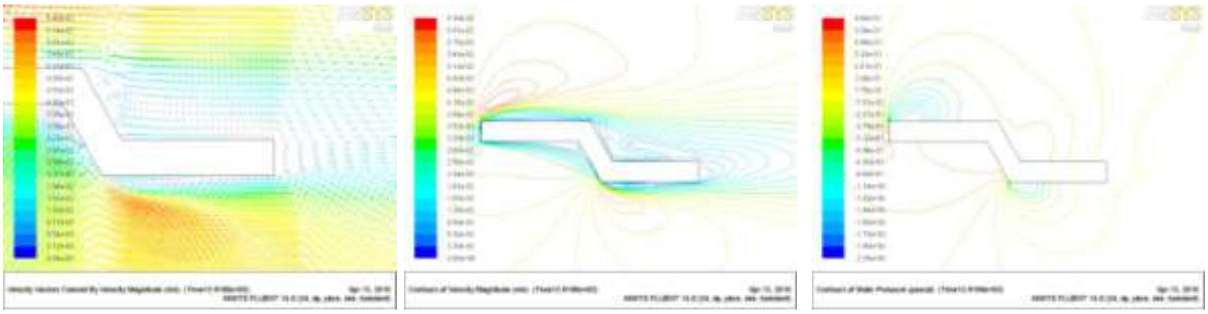

Fig 3.8(a) Velocity vectors **Fig 3.8(b) Velocity contours** **Fig 3.8 (c) Pressure contours**

At Reynolds number 900 the step effected zone beside the extreme end of the step has a horizontal distance of 39.69 mm , maximum height of 20.41 mm , behind the plate 24.71 mm and vortex size of 25.75mm. At Reynolds number 1350 the step effected zone beside the extreme end of the step has a horizontal distance of 39.30 mm , maximum height of 19.87 mm , behind the plate 4.12 mm and vortex size of 21.25 mm. . As increase in Reynolds number this model shown significant effect in flow past from the model in reverse manner.

3.4 Effect of Coefficient of Drag

The fig 3.9 shows the plot of Coefficient of drag at Reynolds number 900of different models. The model of 10^0 has highest drag and model of 30^0 has lowest drag at starting flow time. As flow time increases all the models as show almost same co efficient drag of 30.

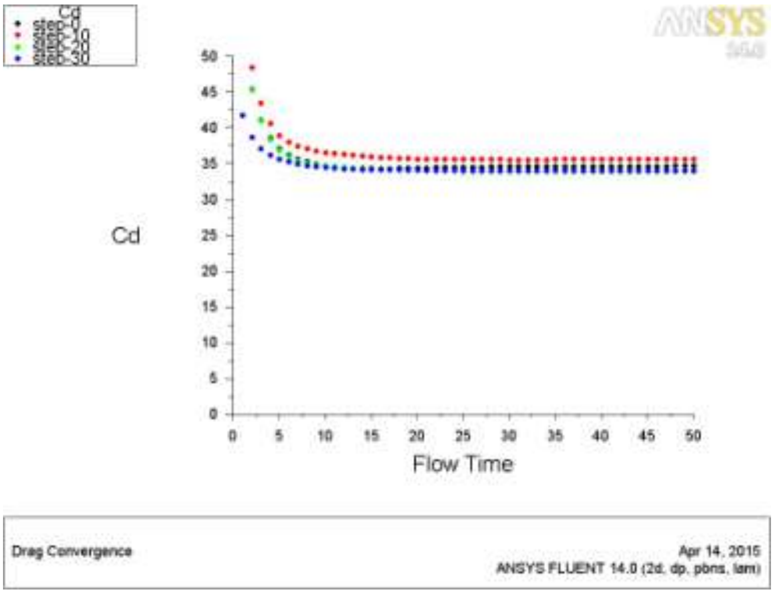

Fig 3.9 Plot of Coefficient drag w.r.to Flow time.

3.5 Effect of Coefficient of Drag

The fig 3.9 shows the graph of Normalized vortex size to the different models at different Reynolds numbers. As the Reynolds number increase vortex size is reducing. And step model of 20^0 has show significant effect comared to rest of models as increasing Reynolds number.

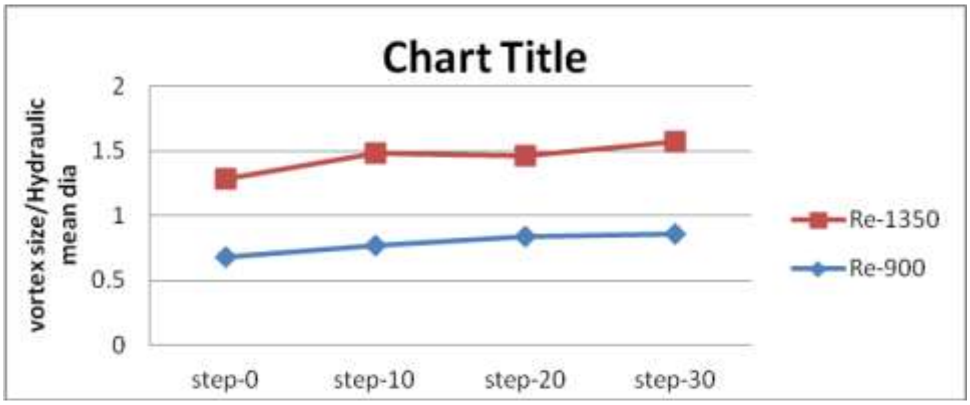

Fig 3.9 Graph of Normalized Vortex Size to Different Models

IV. CONCLUSION

Back ward facing step Models of different orientation has show significant effects at two different Reynolds number. Comparison has to done on different models at same Reynolds number and Flow analysis on a model at two different flows.

4.1 Flow Analysis at Different Reynolds Number

Back ward facing step model 0^0 has no significant effect on flows at two Reynolds numbers. Back ward facing step model 30^0 has significant effects on flows at two Reynolds numbers compared to the other models. Has Reynolds number increases all the rest models have less effect with increase in Reynolds number. The maximum effect zone on vertical direction is shown by step model of 30^0, and minimum effect zone on vertical direction is shown by step model of 20^0.

4.2 Flow analysis of different Step Models:

At Reynolds number 900 except Step 30^0 model rest of all models shows almost same flow behavior. Step 30^0 has significant effect on flow at this Reynolds number. At Reynolds number 1350 the 10^0 step model has significant effect compared to the other models. Step model of 30^0 has highest vortex size at two different Reynolds numbers.

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