NUMERICAL SIMULATION OF THE 3D FLOW AROUND JUNCTURES

by: VŨ MINH TU  N

Outline

1) Introduction
2) The studied problem
3) Choosing the best grid and turbulence model
4) The solution of steady simulation
5) The solution of unsteady simulation
6) Conclusion and future work
Introduction

- Junction flow is characterized by the horseshoe vortex and the boundary layer separation caused by the adverse pressure gradient. The circular cylinder mounted on the plate is the most popular representative juncture.
- Many studies have been conducted for recent decades, but, there is no established method to understand the 3D flow around the cylinder mounted on the curved plate.
- Primary objective: The 3D flow around the inclinded cylinder mounted the flat and curved plate at $Re=3900$ and $Re=10^6$.

Rear view of the horseshoe vortex at $Re=3,900$ and $Re=10^6$.

The studied problem

- The radius of cylinder is 0.1m
- The depth of cylinder is 1m.
- The plate is either flat or curved (convex or concave)
- The three different curvature radii of the plate: 30D, 40D, 50D, where D is the diameter of cylinder.
- The cylinder is inclined at every 10 degrees, from $0^\circ$ to $30^\circ$ laterally, downstream and upstream

140 configurations to cover all the combinations
Choosing the best grid and turbulence model

FVM used to discretize the equations in space,
H-O type grids are used for the PDE discretization,
Re=3,900 and Re = 1,000,000,

The number of cells in each Grid

<table>
<thead>
<tr>
<th>Type of grid</th>
<th>2D</th>
<th>3D</th>
<th>First cell size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid 1</td>
<td>15,068</td>
<td>1,356,120</td>
<td>0.0001</td>
</tr>
<tr>
<td>Grid 2</td>
<td>21,492</td>
<td>1,934,280</td>
<td>0.0005</td>
</tr>
<tr>
<td>Grid 3</td>
<td>16,964</td>
<td>1,526,760</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Which is the best mesh?

The S-A model is the most suitable turbulent model and the Grid 3 is the best mesh which will be used to simulate the next complex cases.

The drag coefficient of an upright circular cylinder at Re=10^6

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Turbulence models</th>
<th>$C_d$ in Simulation</th>
<th>$C_d$ in Experiment [75]</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid 1</td>
<td>k-epsilon RNG</td>
<td>0.3518399</td>
<td>0.35  (5%)</td>
<td>12.0402</td>
</tr>
<tr>
<td></td>
<td>k-epsilon Realizable</td>
<td>0.34843775</td>
<td></td>
<td>12.38585</td>
</tr>
<tr>
<td></td>
<td>k-omega SST</td>
<td>0.45771024</td>
<td></td>
<td>14.42756</td>
</tr>
<tr>
<td>Grid 2</td>
<td>k-epsilon RNG</td>
<td>0.41781925</td>
<td>0.41  (5%)</td>
<td>20.8772</td>
</tr>
<tr>
<td></td>
<td>k-epsilon Realizable</td>
<td>0.36106899</td>
<td></td>
<td>4.454807</td>
</tr>
<tr>
<td></td>
<td>k-omega SST</td>
<td>0.53113265</td>
<td></td>
<td>9.732715</td>
</tr>
<tr>
<td>Grid 3</td>
<td>S-A</td>
<td>0.590606025</td>
<td>0.59  (5%)</td>
<td>2.348495</td>
</tr>
<tr>
<td></td>
<td>k-epsilon RNG</td>
<td>0.35814081</td>
<td></td>
<td>10.3888</td>
</tr>
<tr>
<td></td>
<td>k-epsilon Realizable</td>
<td>0.36169231</td>
<td></td>
<td>8.826908</td>
</tr>
<tr>
<td></td>
<td>k-omega SST</td>
<td>0.46612037</td>
<td></td>
<td>16.53019</td>
</tr>
</tbody>
</table>
The solution of steady simulation

- The upright cylinder mounted on the flat plate:

- From simulation at Re = 3,900
- From Baker’s test with Re = 4370
- The vortex structure in front of the cylinder

NUMERICAL SIMULATION OF THE 3D FLOW AROUND JUNCTURES

Flow topology around the cylinder in front of cylinder

Flow topology around the cylinder in the rear side of cylinder

Re=3,900
Re=10^6
- The solution of steady simulation
- The inclined cylinder mounted on the flat plate:

Pressure fields around a cylinder inclined longitudinally, \( Re = 3,900 \)
Pressure fields around a cylinder inclined laterally

Pressure fields around a cylinder inclined longitudinally, \( Re = 10^6 \)
Pressure fields around a cylinder inclined laterally
The solution of steady simulation

- The upright cylinder mounted on the curved plate:

Pressure fields in concave plate case \( Re = 3,900 \)
Pressure fields in convex plate case

\( Re = 10^6 \)
The solution of steady simulation

- The inclined cylinder mounted on the curved plate:

Transversal streamlines around the cylinder inclined at 20°

Curvature influence on the drag coefficient of the cylinder
The solution of steady simulation

- The inclined cylinder mounted on the curved plate:

- Concave case
- Convex case

The drag coefficient of the cylinder
Inclined downstream Velocity fields

The solution of unsteady simulation

- The circular cylinder is inclined laterally with an angle of 30° and mounted on the convex plate that has the curvature radius of 50D.
- Re=3,900
- The turbulence model: Spalart-Allmaras model
- Computational time: time step of 0.005s, number of time steps of 50,000, residuum of $10^{-6}$
The solution of unsteady simulation

Velocity contours at the different time

The velocity vectors existing near the cylinder

<table>
<thead>
<tr>
<th></th>
<th>Unsteady</th>
<th>Steady</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drag coefficient of the cylinder</td>
<td>0.95035344</td>
<td>0.956929</td>
</tr>
<tr>
<td>Drag coefficient of the plate</td>
<td>1.0544992</td>
<td>1.115424</td>
</tr>
</tbody>
</table>

The unsteady simulation shows that the total drag coefficient of the cylinder is reduced comparing with the steady simulation.

The pressure contour around the cylinder
- Conclusion

- The direction of cylinder inclination affects the juncture flow. The stronger pressure gradients reveals at the root of the cylinder inclined longitudinally towards to upstream.
- The smaller curvatures determine the larger pressure. This leads to an increase of the total drag coefficient.
- At Re = 3,900, the total drag coefficients decrease when the inclination angle of cylinder increases, regardless the direction of the cylinder inclination as well as the plate curvature.
- At Re = 10^6, the total drag coefficient mostly increases along with the increase of cylinder inclination angle in upstream and downstream cases, except for the case of 10° angle in downstream for all convex and concave cases.

- Future work

- Carrying out the experiments with the circular cylinder mounted on the curved plate.
- The simulation of free surface.

Thank You For Your Attention!