Geometrical Approach to the Grid System in the KOPEC Pilot Code

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1. Introduction

KOPEC has been developing a pilot code to analyze two phase flow. The earlier version of the pilot code adopts the geometry with one-dimensional structured mesh system. As the pilot code is required to handle more complex geometries, a systematic geometrical approach to grid system has been introduced. Grid system can be classified as two types; structured grid system and unstructured grid system. The structured grid system is simple to apply but is less flexible than the other. The unstructured grid system is more complicated than the structured grid system. But it is more flexible to model the geometry. Therefore, two types of grid systems are utilized to allow code users simplicity as well as the flexibility [1].

2. Structured Grid System

There are two types of structured grid system. One type of the structured grid system accompanies coordinate transformation. The other type is based on fixed coordinate system. The former is more complicated than the later. But it has more flexibility to model the geometry. Body fitted coordinate approach is one of them. However, fixed Cartesian as well as cylindrical coordinate systems are adopted.

3. Unstructured Grid System

An unstructured grid is a tessellation of a part of the Euclidean plane or Euclidean space by simple shapes, such as triangle, tetragon in 2 dimensions or tetrahedron, hexahedron, prism, or wedge in 3 dimensions, in an irregular pattern. Grids of this type may be used in finite volume analysis when the domain to be analyzed has an irregular shape.

An unstructured mesh is a mesh that has irregular arrangement of its cells. Each cell has a set of vertices with positions determined by the topological shape of the cell and its order. A connection between cells is deduced, if cells have common vertices, and each cell and its connections to adjacent cells are defined separately. Unlike structured grids, unstructured grids require a list of the connectivity which specifies the way a given set of vertices make up individual elements.

Also, an unstructured mesh has some advantages such as flexibility in fitting complicated domains, rapid grading from small to large elements, and relatively easy refinement and de-refinement.

3.1 Points

A point is a location in 3-D space, defined by a position vector in units of meter (m). The points are compiled into a list and each point is referred to by a label, which represents its position in the list, starting from zero. The point list cannot contain two different points at an exactly identical position nor any point that is not part at least one face.

3.2 Faces

A face is an ordered list of points, where a point is referred to by its label. The ordering of point labels in a face is such that each two neighboring points are connected by an edge, i.e. you follow points as you travel around the circumference of the face. Faces are compiled into a list and each face is referred to by its label, representing its position in the list.

Inner faces that connect two cells (and it can never be more than two). For each inner face, the ordering of the point labels is such that the face normal points into the cell with the larger label.

Boundary faces belongs to one cell since they coincide with the boundary of the domain. A boundary face is therefore addressed by one cell and has three types of boundary conditions which are for wall, pressure, and flow. The ordering of the point labels is such that the face normal points outside of the computational domain.

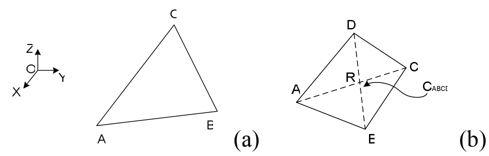


Figure 1 The shape of faces (a) triangle (b) tetragon

Face area vector is calculated by following equations.

$$\mathbf{S}_{\mathbf{ABC}} = \frac{1}{2}\left(\mathbf{X}_{\mathbf{AB}} \times \mathbf{X}_{\mathbf{AC}}\right) \text{ for triangle} \quad (1)$$

$$\mathbf{S}_{\mathbf{ABCD}} = \frac{1}{2}\left(\mathbf{X}_{\mathbf{AC}} \times \mathbf{X}_{\mathbf{BD}}\right) \text{ for tetragon} \quad (2)$$

Face centroid is calculated by following equations.

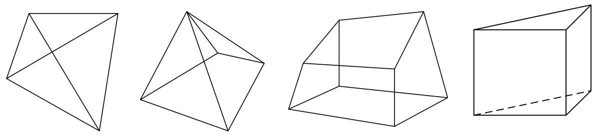
$$\mathbf{C}_{\mathbf{ABC}} = \frac{\mathbf{X}_{\mathbf{A}} + \mathbf{X}_{\mathbf{B}} + \mathbf{X}_{\mathbf{C}}}{\mathbf{3}} \text{ for triangle} \quad (3)$$

$$\mathbf{C}_{\mathbf{ABCD}} = \frac{\mathbf{C}_{\mathbf{ABR}}\left|\mathbf{S}_{\mathbf{ABR}}\right| + \mathbf{C}_{\mathbf{BCR}}\left|\mathbf{S}_{\mathbf{BCR}}\right| + \mathbf{C}_{\mathbf{CDR}}\left|\mathbf{S}_{\mathbf{CDR}}\right| + \mathbf{C}_{\mathbf{DAR}}\left|\mathbf{S}_{\mathbf{DAR}}\right|}{\left|\mathbf{S}_{\mathbf{ABR}}\right| + \left|\mathbf{S}_{\mathbf{BCR}}\right| + \left|\mathbf{S}_{\mathbf{CDR}}\right| + \left|\mathbf{S}_{\mathbf{DAR}}\right|}$$

for tetragon (4)

3.2 Cells

In three dimensions, the mesh space can be divided into hexahedron, tetrahedron, pyramid, or wedge (prism) shaped cells.



(a)Tetrahedron (b) Pyramid (c) Hexahedron (d) Prism

Figure 1 The shape of various cells

Cell volume is calculated by following equations.

$$V_{PABC} = \frac{1}{3}\mathbf{X}_{\mathbf{PA}} \cdot \mathbf{S}_{\mathbf{ABC}} \quad \text{for tetrahedron cell} \qquad (5)$$

$$V_{PABCD} = \frac{1}{3}\mathbf{X}_{P(ABCD)} \cdot \mathbf{S}_{\mathbf{ABCD}} \quad \text{for pyramid cell} \qquad (6)$$

Also, cell centroid is calculated by following equations.

$$\mathbf{C}_{\mathbf{PABC}} = \frac{\mathbf{3C}_{\mathbf{ABC}} + \mathbf{X}_{\mathbf{P}}}{\mathbf{4}} \quad \text{for tetrahedron cell} \qquad (7)$$

$$\mathbf{C}_{\mathbf{PABCD}} = \frac{\mathbf{3C}_{\mathbf{ABCD}} + \mathbf{X}_{\mathbf{P}}}{\mathbf{4}} \quad \text{for pyramid cell} \qquad (8)$$

In the way of estimating general hexahedron, different equations can be applied to obtain the volume of the hexahedral cell. The hexahedral cell is divided into six(6) pyramid and calculation is expressed in the followings[3].

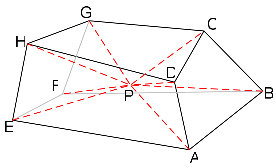


Figure 2 Subdivision of hexahedron into six pyramids

$$V_{HEX} = V_{PABCD} + V_{PBFGC} + V_{PGFEH} + V_{PADHE} + V_{PDCGH} + V_{PBAEF}$$

$$\mathbf{C}_{\mathbf{ABCDEHFG}} = \frac{\begin{pmatrix} \mathbf{C}_{\mathbf{PABCD}}\left|V_{PABCD}\right| + \mathbf{C}_{\mathbf{PCBFG}}\left|V_{PCBFG}\right| + \mathbf{C}_{\mathbf{PGFEH}}\left|V_{PGFEH}\right| \\ + \mathbf{C}_{\mathbf{PDHEA}}\left|V_{PDHEA}\right| + \mathbf{C}_{\mathbf{PDCGH}}\left|V_{PDCGH}\right| + \mathbf{C}_{\mathbf{PBAEF}}\left|V_{PBAEF}\right| \end{pmatrix}}{\left(\left|V_{PABCD}\right| + \left|V_{PCBFG}\right| + \left|V_{GFEH}\right| + \left|V_{PDHEA}\right| + \left|V_{PDCGH}\right| + \left|V_{PBAEF}\right|\right)}$$

4. Results

The geometry drawn up using Gambit, consists of 384 vertices and 160 unstructured hexahedrons. Input data for pilot code, face and cell data, are calculated by above equations and transfer to the main solver.

Figure 4 shows the pressure distribution and velocity vector in case of single phase. The inlet boundary condition is given at the lower left position, and the outlet boundary condition is given at the upper right position on the opposite side of inlet: the inlet flow velocity is 5 m/s(x-dir), and the outlet pressure is 10 bar.

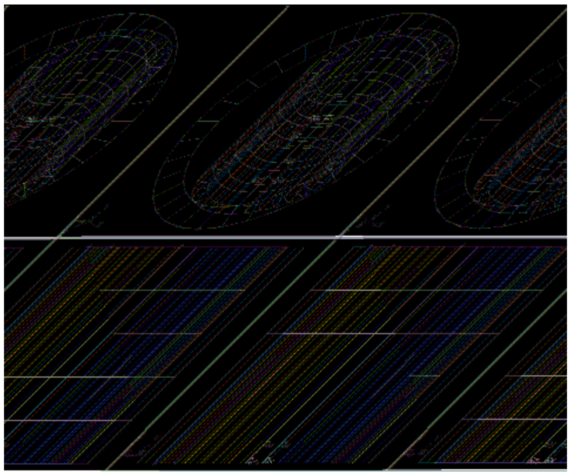


Figure 3 Geometry of the test problem

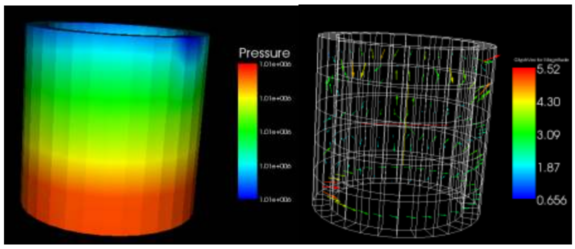


Figure 4 Pressure distributions and velocity vector

5. Conclusion

The grid system of the pilot code can handle various complicated multi-dimensional geometry.

Acknowledgment

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