# Numerical Heat Transfer

# (数值传热学)

## Chapter 12 How to Use ANSYS FLUENT

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# 数值传热学

## 第12章 ANSYS FLUENT软件学习和应用

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# Chapter 12 How to Use ANSYS FLUENT

## 12.1 Introduction to NHT software

## 12.2 NHT Modeling Overview

## 12.3 Simple Examples of Using ICEM/FLUENT

## 12.4 Procedure of Using FLUENT

## 12.5 Introduction to ICEM and Meshing with ICEM for structural grid

# 12. 1. Numerical Heat Transfer Software

**FLUENT, CFX, COMSOL, STAR-CD, ABAQUS, PHOENICS, ADINA, NASTRAN…..**

**Market share: Fluent>CFX> others**

**Accuracy: case-dependent**

**Technical documentation available:**

**Fluent>CFX> others**

## Advantage of commercial NHT Software:

**Easy to use!**

**However, it can not solve all the problems!**

## Advantage of Self-programming for NHT:

**It is rather important for research!**

**We can understand the basic procedures and mechanisms in NHT.**

# 12.1.2 ANSYS Fluent software

Fluid flow

Conduction/Convection/Radiation
Heat Transfer

Turbulence Modeling

Multiphase Flow

Fluid-Structure Interaction

Combustions/Pollution Distribution

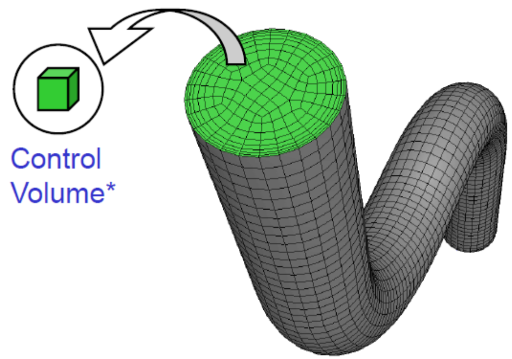
# 12.1.3 How Does NHT Software Work?

**Fluent solvers are based on the finite volume method.**

**1) Domain is discretized into a finite set of control volumes.**

**2) General conservation equations for mass, momentum, energy, etc. are solved on this set of volumes.**

**3) Partial differential equations are discretized into a system of algebraic equations.**




**4) All algebraic equations are then solved numerically to render the solution field.**

**Fluid region of pipe flow is discretized into a finite set of control volumes**

# 12.2. NHT Modeling Overview

## Solver

### Pre-Processing

- Modeler
- Mesh Generator

- Solver Settings

- Post-Processing

### Equations solved on mesh

- **Transport Equations**
  - **mass**
  - **momentum**
  - **energy**
- **Supporting Physical Models**

- Physical Models
  - Turbulence
  - Combustion
  - Radiation
  - Multiphase
  - Phase Change
  - Moving Zones
  - Moving Mesh

- **Material Properties**
- **Boundary Conditions**
- **Initial Conditions**

# 12.2.1 NHT Analysis: Basic Steps

- Problem Identification and Pre-Processing

1. Define your modeling goals.
2. Identify the domain you will model.
3. Design and create the grid.(网格生成)

- Solver Execution

4. Set up the numerical model.(算法和格式选择)
5. Compute and monitor the solution.(方程求解)

- Post-Processing

6. Examine the results.
7. Consider revisions to the model.

# 1. Define Your Modeling Goals

## 1) What results are you looking for, and how will they be used?

- What are your modeling options?
- What physical models will need to be included in your analysis?
- What simplifying assumptions do you have to make?
- What simplifying assumptions can you make?
- Could you use user-defined functions (written in C)?

## 2) What degree of accuracy is required?

## 3) How quickly do you need the results?

**(4)How will you isolate a piece of the complete physical system?**

**(5)Where will the computational domain begin and end?**

- **Do you have boundary condition information**
- **Can the boundary condition types accommodate that information?**
- **Can you extend the domain to a point where reasonable data exists?**

**(6) Can it be simplified or approximated as a 2D or axi-symmetric problem?**

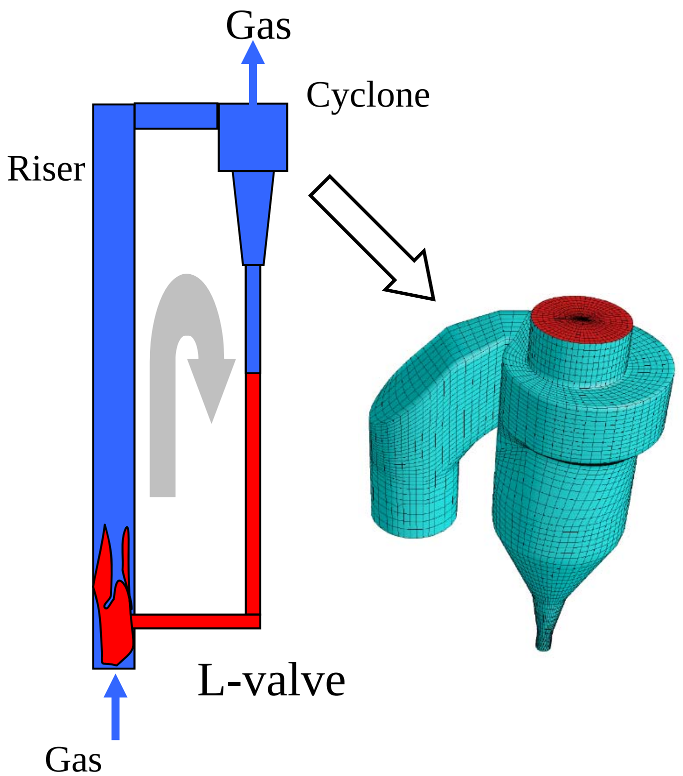
# 2.Identify the Domain You Will Model

1) How will you isolate a piece of the complete physical system?

2) Where will the computational domain begin and end?

- Are the boundary condition types appropriate?
- Do you have boundary condition information at these boundaries?
- Is the domain appropriate?

3) Can it be simplified or approximated as a 2D or axisymmetric problem?

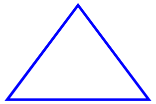



**Example: Cyclone Separator**

# 3.Design and Create the Grid

**1) Can you use a quad/hex (四边形的/六面体的) grid or should you use a tri/tet (三角形/四面体) grid or hybrid grid?**

- **How complex is the geometry and flow?**

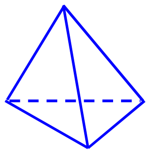


Triangle

三角形

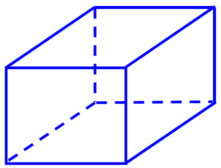
**Quadrilateral**

四边形



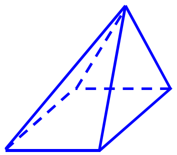
Tetrahedron

四面体



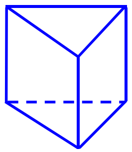
**Hexahedron**

六面体



**Pyramid**

金字塔



**Prism/wedge**

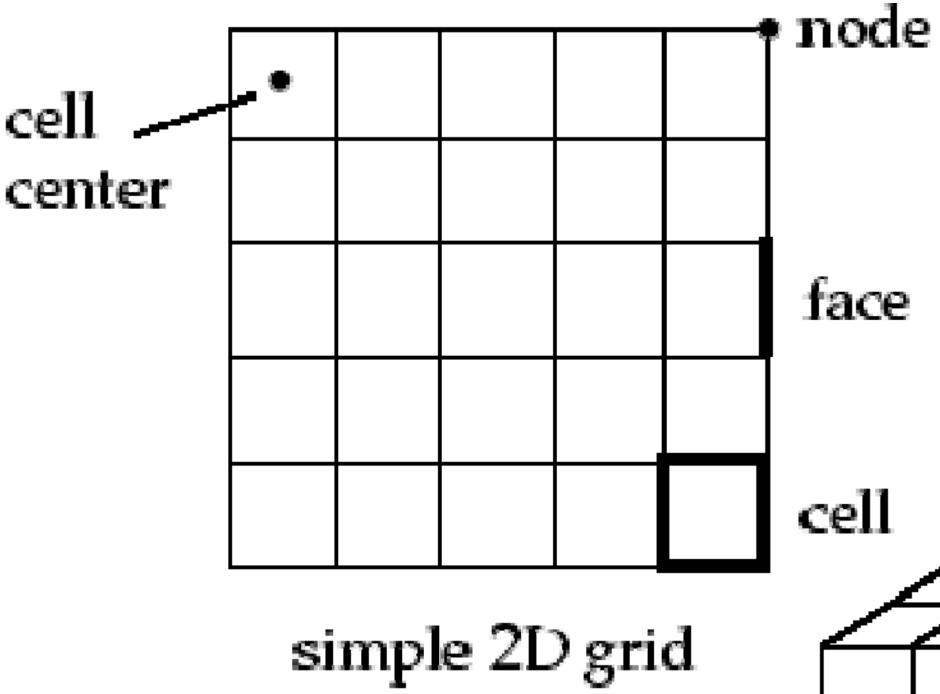
五面体

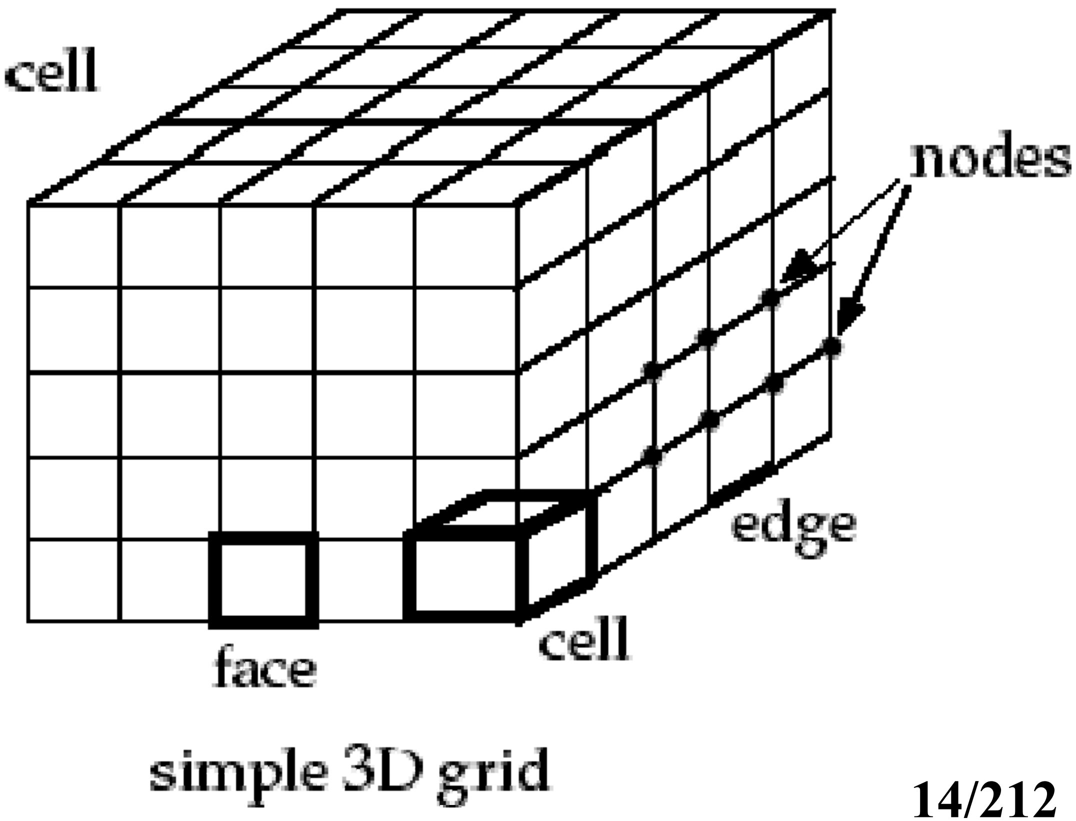
**2) What degree of grid resolution is required in each region of the domain?**

- **Is the resolution sufficient for the geometry?**
- **Can you predict regions with high gradients?**
- **Will you use adaption to add resolution?**

**3) Do you have sufficient computer memory?**

- **How many cells are required?**
- **How many models will be used?**



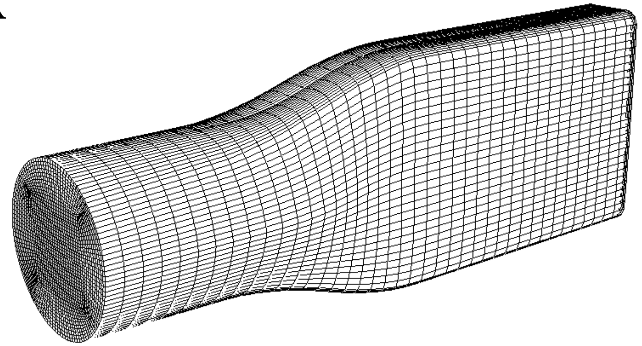

**Some basic grid terminology**

# Mesh Terminology

| | |
|---|---|
| Cell | Control volume into which domain is broken up |
| Cell center | Location where cell data is stored |
| Face | Boundary of a cell (2D or 3D) |
| Edge | Boundary of a face (3D) |
| Node | Grid point |
| Cell thread | Grouping of cells |
| Face thread | Grouping of faces |
| Node thread | Grouping of nodes |
| Domain | A grouping of node, face, and cell threads |

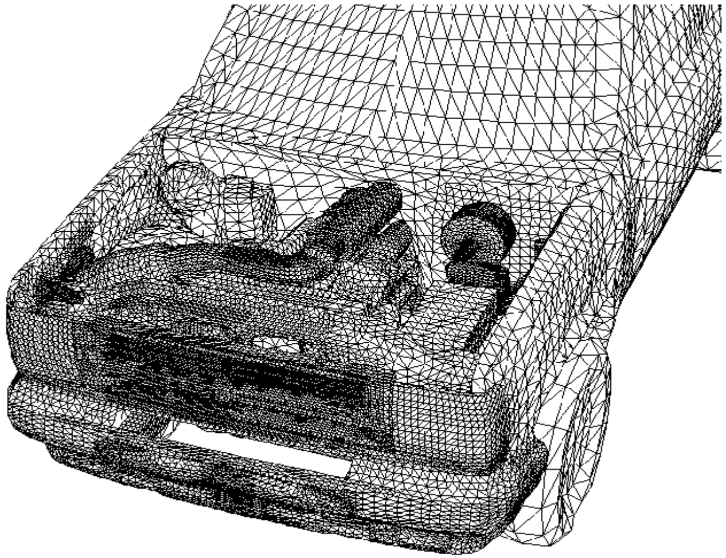
# Tri/Tet vs. Quad/Hex Meshes

1) For simple geometries, quad/hex meshes can provide higher-quality solutions with fewer cells than a comparable tri/tet mesh.



**Align the gridlines with the flow.**

2) For complex geometries, quad/hex meshes show no numerical advantage, and you can save meshing effort by using a tri/tet mesh.



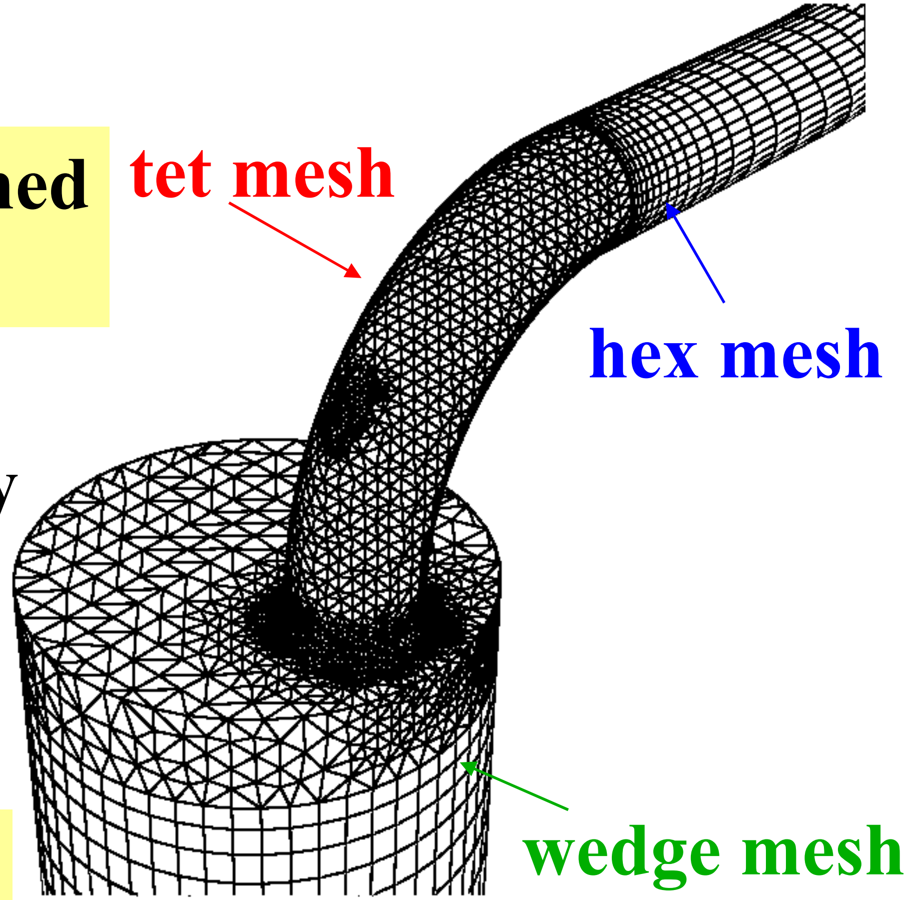
# Hybrid Mesh Example

- Valve port grid

1)Specific regions can be meshed with different cell types.

2)Both efficiency and accuracy are enhanced relative to a hex or tet mesh alone.

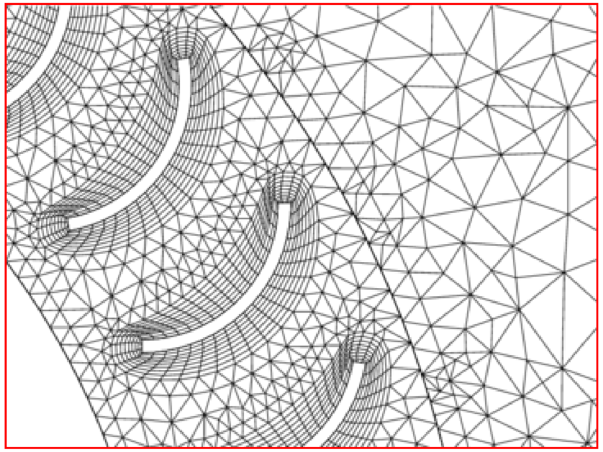
3)Tools for hybrid mesh generation are available in Gambit and ICEM.

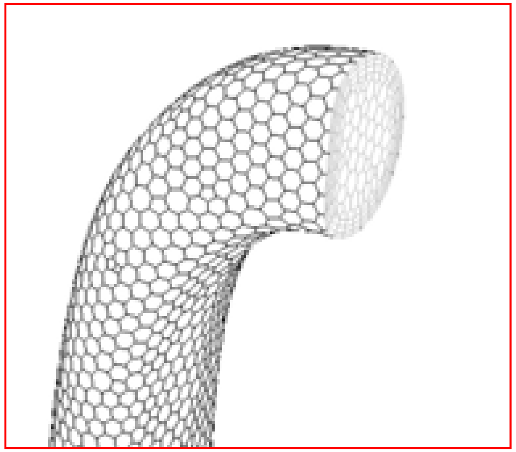



Hybrid mesh for an engine valve port

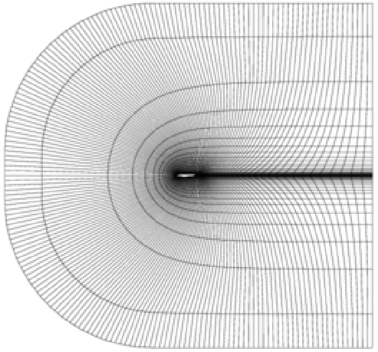
**Fluent is an unstructured solver. It uses internal data structures to assign an order to the cells, faces, and grid points in a mesh and to maintain contact between adjacent cells.**

**Therefore, it does not require i, j, k indexing to locate neighboring cells. This gives you the flexibility to use the best mesh topology for your problem, as the solver does not force an overall structure or topology on the mesh.**

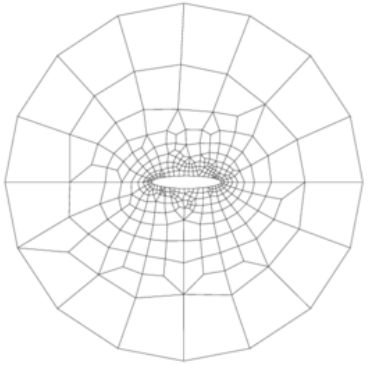




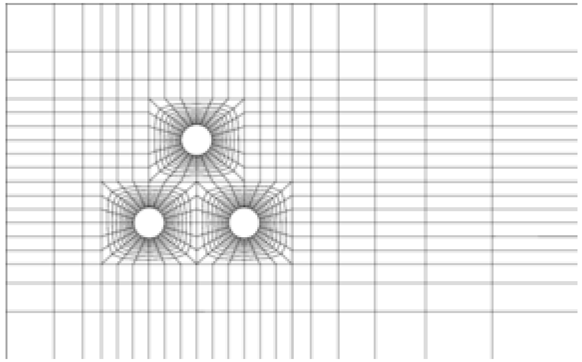
# ◆ Examples of Acceptable Mesh Topologies



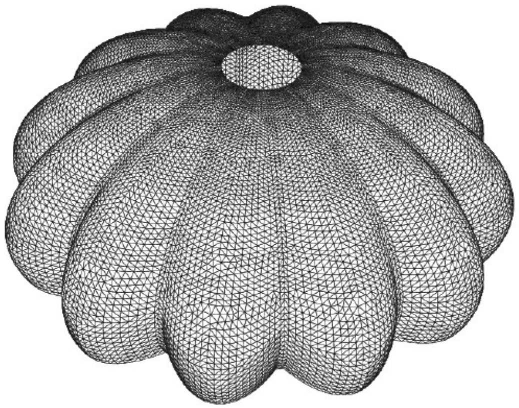
Structured Quad Mesh for an Airfoil



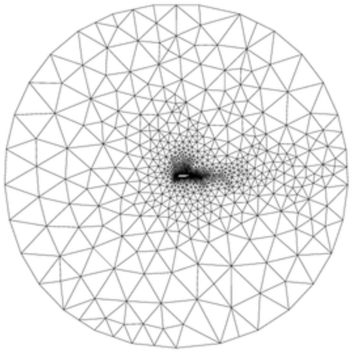
Unstructured Quad Mesh



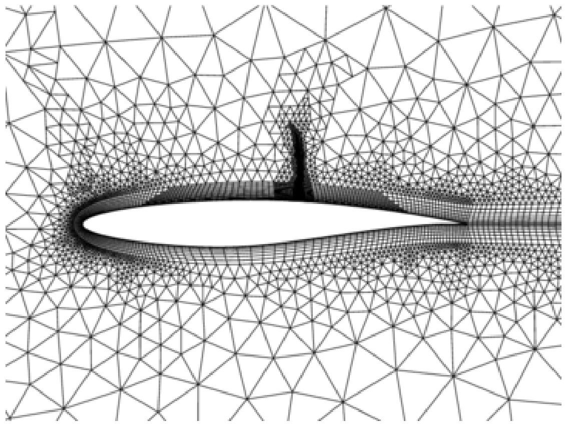
Multiblock Structured Quad Mesh



Parachute Modeled With Zero-Thickness Wall



Unstructured Triangular Mesh for an Airfoil



Hybrid Tri/Quad Mesh with Hanging Nodes

## ◆ Choosing the Appropriate Mesh Type

**Fluent can use meshes comprised of triangular or quadrilateral cells (or a combination of the two) in 2D domain, and tetrahedral, hexahedral, polyhedral, pyramid, or wedge cells (or a combination of these) in 3D domain.**

**The choice of which mesh type to use will depend on the actual application. When choosing mesh type, consider the following issues:**

① **Setup time**

② **Computational expense**

③ **Numerical diffusion(false diffusion)**

## ① Setup Time

Many flow problems solved in engineering practice involve complex geometries. The creation of structured or block-structured meshes (consisting of quadrilateral or hexahedral elements) for such problems can be extremely time-consuming.

Therefore, setup time for complex geometries is the major motivation for using unstructured meshes employing triangular or tetrahedral cells. However, if the geometry is relatively simple, there may be no saving in setup time with either approach.

**Other risks of using structured or block-structured meshes with complicated geometries include the oversimplification of the geometry, mesh quality issues, and a less efficient mesh distribution(for example, fine resolution in areas of less importance) that results in a high cell count.**

## ② Computational Expense

**When geometries are complex or the range of length scales of the flow is large, a triangular/tetrahedral mesh can be created with far fewer cells than the equivalent mesh consisting of quadrilateral/hexahedral elements.**

**Structured quadrilateral/hexahedral meshes will generally force cells to be placed in regions where they are not needed. Unstructured quadrilateral/hexahedral meshes offer many of the advantages of triangular/tetrahedral meshes for moderately-complex geometries.**

**A characteristic of quadrilateral/hexahedral elements that might make them more economical in some situations is that they permit a much larger aspect ratio than triangular/tetrahedral cells.**

**A large aspect ratio in a triangular/tetrahedral cell will invariably affect the skewness of the cell, which is undesirable as it may impede accuracy and convergence.**

**Therefore, if it is a relatively simple geometry in which the flow conforms well to the shape of the geometry, such as a long thin duct, use a mesh of high-aspect-ratio quadrilateral/hexahedral cells. The mesh is likely to have far fewer cells than if you use triangular/tetrahedral cells.**

**The following practices are generally recommended:**

**① For simple geometries, use quadrilateral/hexahedral meshes.**

**② For moderately complex geometries, use unstructured quadrilateral/hexahedral meshes.**

**③ For relatively complex geometries, use triangular/tetrahedral meshes with wedge elements in the boundary layers.**

**④ For extremely complex geometries, use pure triangular/ tetrahedral meshes.**

## ◆ Numerical diffusion(False Diffusion)

**A dominant source of error in multidimensional situations is false diffusion. Its effect on a flow calculation is analogous to that of increasing the real diffusion coefficient.**

**The following comments can be made about false diffusion:**

① **All practical numerical schemes for solving fluid flow contain a finite amount of false diffusion. This is because false diffusion arises from truncation errors (截断误差) that are a consequence of representing the fluid flow equations in discrete form.**

**② The second-order and the MUSCL discretization scheme used in Fluent can help reduce the effects of false diffusion on the solution.**

**③ The amount of false diffusion is inversely related to the resolution of the mesh. i.e. a coarser mesh will have more false diffusion than a more refined mesh. Therefore, one way of dealing with false diffusion is to refine the mesh.**

**④ False diffusion is minimized when the flow is aligned with the mesh.**

- **False diffusion is minimized when the flow is aligned with the mesh.**

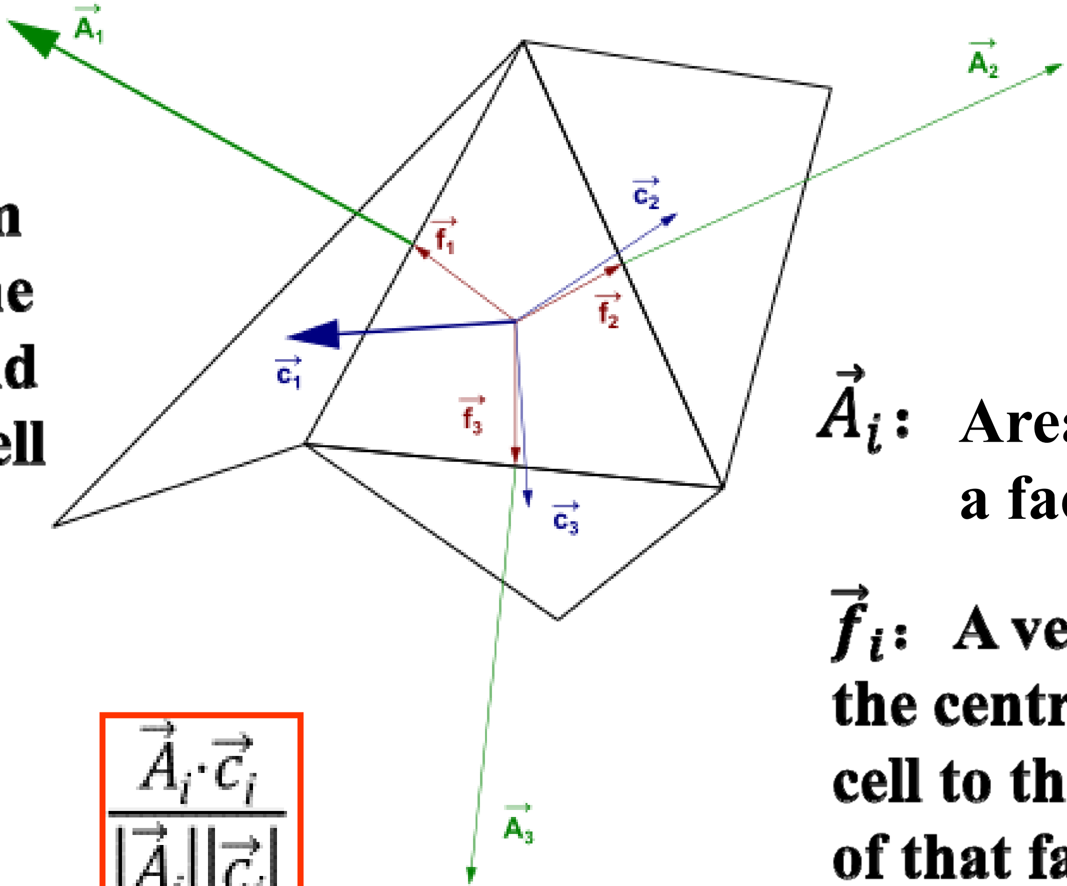
**If you use a quadrilateral/hexahedral mesh, this situation might occur, but not for complex flows. It is only in a simple flow, such as the flow through a long duct, in which you can rely on a quadrilateral/hexahedral mesh to minimize false diffusion.**

**In such situations, it is advantageous to use a quadrilateral/hexahedral mesh, since you will be able to get a better solution with fewer cells than if you were using a triangular/tetrahedral mesh.**

# Mesh Quality- Orthogonal quality

The quality of the mesh plays a significant role in the accuracy and stability of the numerical computation. Regardless of the type of mesh used in your domain, checking the quality of your mesh is essential. One important indicator of mesh quality that Fluent allows to check is a quantity referred to as the **orthogonal quality(正交质量)**.

**The worst cells will have an orthogonal quality closer to 0 and the best cells will have an orthogonal quality closer to 1.**




**$\vec{c}_i$: A vector from the centroid of the cell to the centroid of the adjacent cell that shares that face**

**$\vec{A}_i$: Area vector of a face**

**$\vec{f}_i$: A vector from the centroid of the cell to the centroid of that face**

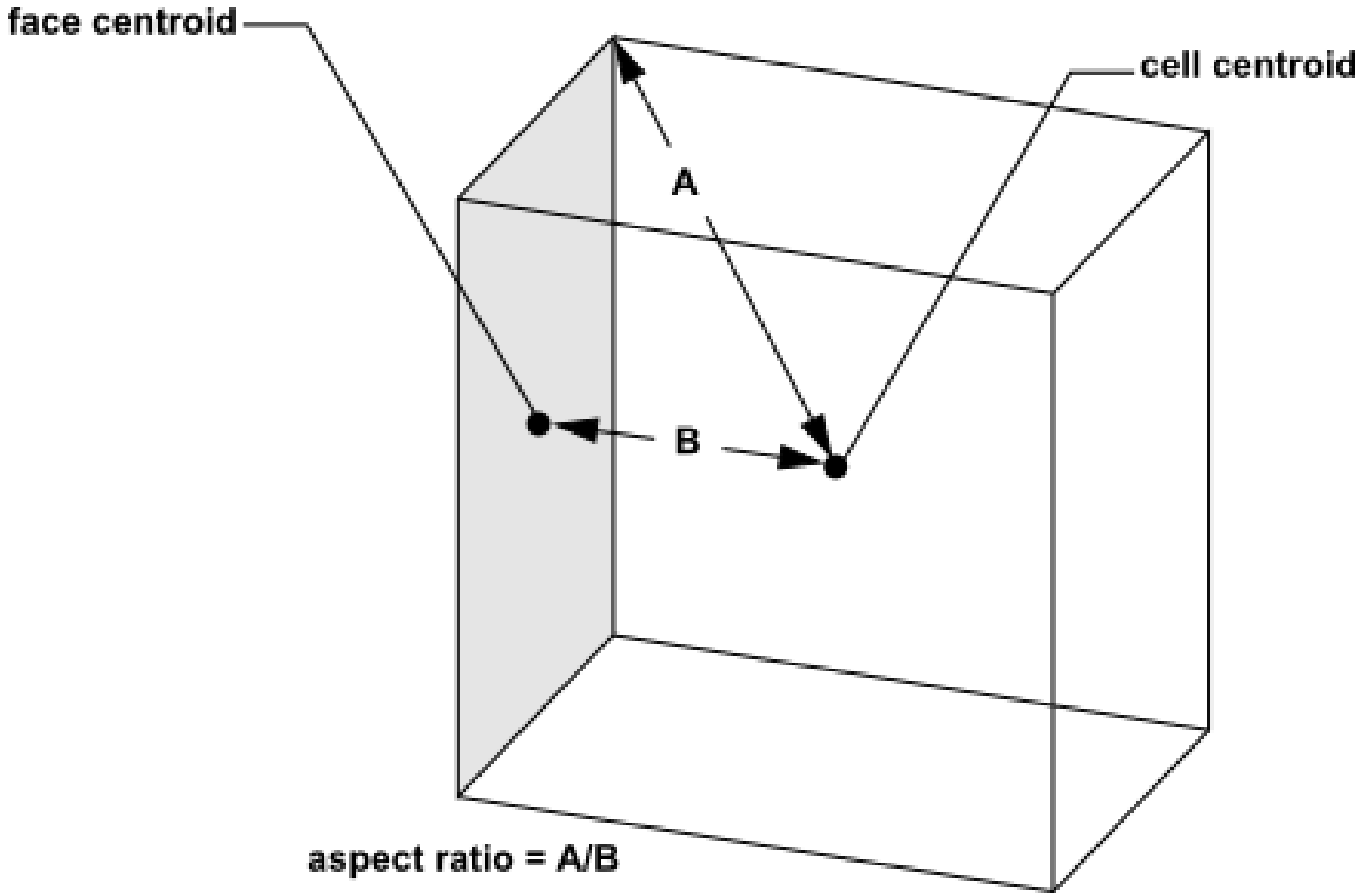
$$\boxed{\frac{\vec{A}_i \cdot \vec{f}_i}{|\vec{A}_i||\vec{f}_i|}} \qquad \boxed{\frac{\vec{A}_i \cdot \vec{c}_i}{|\vec{A}_i||\vec{c}_i|}}$$

**The minimum value of the two above equations for all of the faces is defined as the orthogonal quality for the cell.**

# Mesh Quality- Aspect ratio

**Another important indicator of mesh quality is aspect ratio(长宽比). The aspect ratio is a measure of the stretching of a cell.**

**It is computed as the ratio of the maximum value to the minimum value of any of the following distances: the normal distances between the cell centroid and face centroids (computed as a dot product of the distance vector and the face normal), and the distances between the cell centroid and nodes.**


face centroid
cell centroid
A
B
aspect ratio = A/B

## ◆ Mesh Element Distribution

**Since it is discretely defining a continuous domain, the degree to which the salient features of the flow (such as shear layers, separated regions, shock waves, boundary layers, and mixing zones) are resolved depends on the density and distribution of mesh elements.**

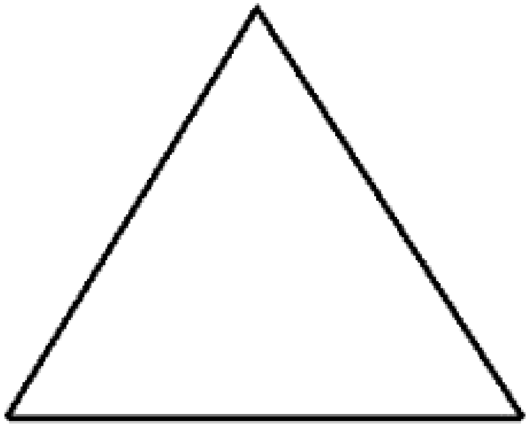
**In many cases, poor resolution in critical regions can dramatically affect results. For example, the prediction of separation due to an adverse pressure gradient depends heavily on the resolution of the boundary layer upstream of the point of separation.**

**In general, no flow passage should be represented by fewer than 5 cells. Most cases will require many more cells to adequately resolve the passage. In regions of large gradients, as in shear layers or mixing zones, the mesh should be fine enough to minimize the change in the flow variables from cell to cell.**

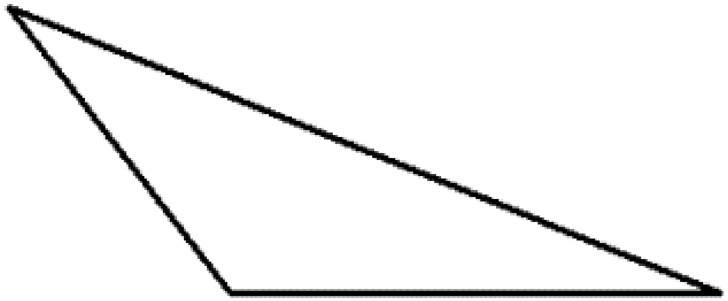
## Cell Quality

**The quality of the cell (including its orthogonal quality, aspect ratio, and skewness) also has a significant impact on the accuracy of the numerical solution.**

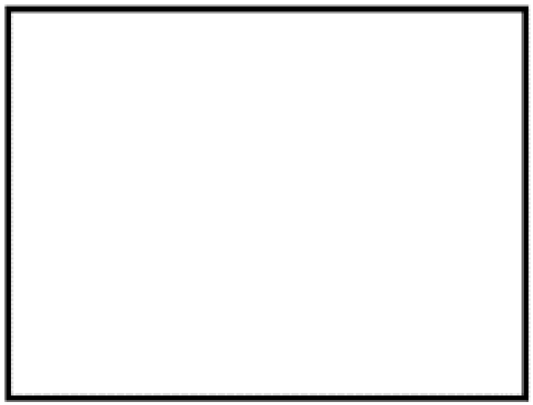
**Skewness is defined as the difference between the shape of the cell and the shape of an equilateral cell of equivalent volume. Highly skewed cells can decrease accuracy and destabilize the solution. A general rule is that the maximum skewness for a triangular/tetrahedral mesh in most flows should be kept below 0.95, with an average value that is significantly lower. A maximum value above 0.95 may lead to convergence difficulties and may require changing the solver controls, such as reducing under-relaxation factors and/or switching to the pressure-based coupled solver.**



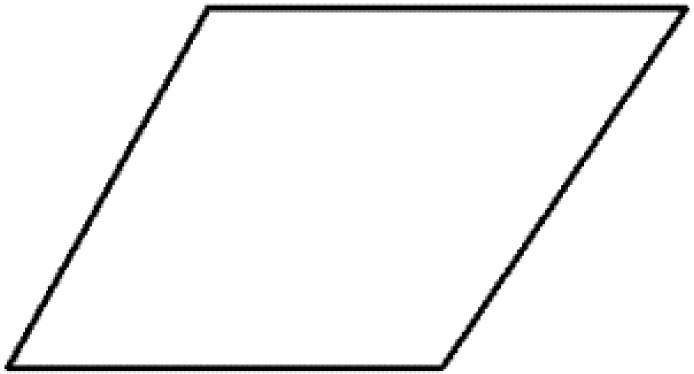
Equilateral Triangle



Highly Skewed
Triangle



Equiangular
Quad



Highly Skewed
Quad

| Value of Skewness | Cell Quality |
|---|---|
| 1 | degenerate |
| 0.9 — <1 | bad (sliver) |
| 0.75 — 0.9 | poor |
| 0.5 — 0.75 | fair |
| 0.25 — 0.5 | good |
| >0 — 0.25 | excellent |
| 0 | equilateral |

## Equilateral-Volume-Based Skewness

$$\text{Skewness} = \frac{\text{Optimal Cell Size - Cell Size}}{\text{Optimal Cell Size}}$$

Mesh Quality（2D）:

**Orthogonal Quality ranges from 0 to 1, where values close to 0 correspond to low quality.**

Minimum Orthogonal Quality = 6.07960e-01

Maximum Aspect Ratio = 5.42664e+00

Mesh Quality（3D）:

Minimum Orthogonal Quality = 5.09565e-01

(Orthogonal Quality ranges from 0 to 1, where values close to 0 correspond to low quality.)

Maximum Ortho Skew = 4.90435e-01

(Ortho Skew ranges from 0 to 1, where values close to 1 correspond to low quality.)

Maximum Aspect Ratio = 5.51406e+01

## ◆ Smoothness

Rapid changes in cell volume between adjacent cells translate into larger truncation errors.

Fluent provides the capability to improve the smoothness by refining the mesh based on the change in cell volume or the gradient of cell volume.

## ◆ Flow-Field Dependency

The effect of resolution, smoothness, and cell shape on the accuracy and stability of the solution process is dependent on the flow field being simulated. For example, very skewed cells can be tolerated in benign(平缓的) flow regions, but can be very damaging in regions with strong flow gradients.

Since the locations of strong flow gradients generally cannot be determined before the simulation, we should strive to achieve a high-quality mesh over the entire flow domain.

# 4. Set Up the Numerical Model

- **For a given problem, you will need to:**

① **Select appropriate physical models.**
- **Turbulence, combustion, multiphase, etc.**

② **Define material properties.**
- **Fluid/Solid/Mixture**

③ **Prescribe operating conditions.**

④ **Prescribe boundary conditions at all boundary zones.**

⑤ **Provide an initial solution.**

⑥ **Set up solver controls.**

⑦ **Set up convergence monitors.**

***Solving initially in 2D will provide valuable experience with the models and solver settings for your problem in a short amount of time.***

# 5. Compute the Solution

①The discretized conservation equations are solved iteratively.

A number of iterations are usually required to reach a converged solution.

② Convergence is reached when:

Changes in solution variables from one iteration to the next are negligible.

Residuals provide a mechanism to help monitor this trend.

Overall property conservation is achieved.

③ The accuracy of a converged solution is dependent upon:

Appropriateness and accuracy of physical models.

Grid resolution and independence

Problem setup

# 6. Examine the Results

- Examine the results to review solution and extract useful data.

1) Visualization Tools can be used to answer such questions as:

- What is the overall flow pattern?
- Is there separation?
- Where do shear layers form?
- Are key flow features being resolved?

2) Numerical Reporting Tools can be used to calculate quantitative results:

- Forces and Moments
- Average heat transfer coefficients
- Surface and Volume integrated quantities
- Flux Balances

*Examine results to ensure property conservation and correct physical behavior. High residuals may be attributable to only a few cells of poor quality.*

# 7. Consider Revisions to the Model

## 1) Are physical models appropriate?

- Is flow turbulent? Is flow unsteady?
- Are there compressibility effects? Are there 3D effects?

## 2) Are boundary conditions correct?

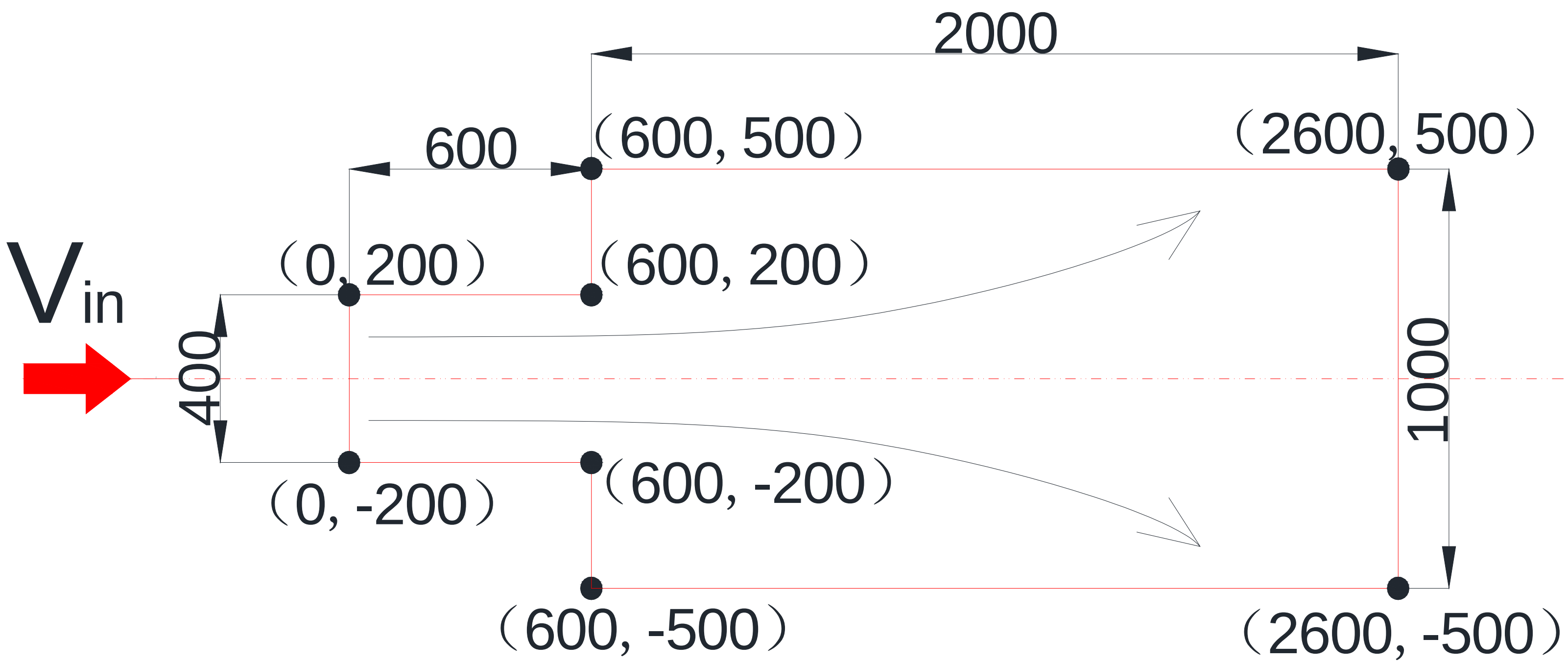
- Is the computational domain large enough?
- Are boundary conditions appropriate?
- Are boundary values reasonable?

## 3) Is grid adequate?

- Can grid be adapted to improve results?
- Does solution change significantly with adaption, or is the solution grid independent?
- Does boundary resolution need to be improved?

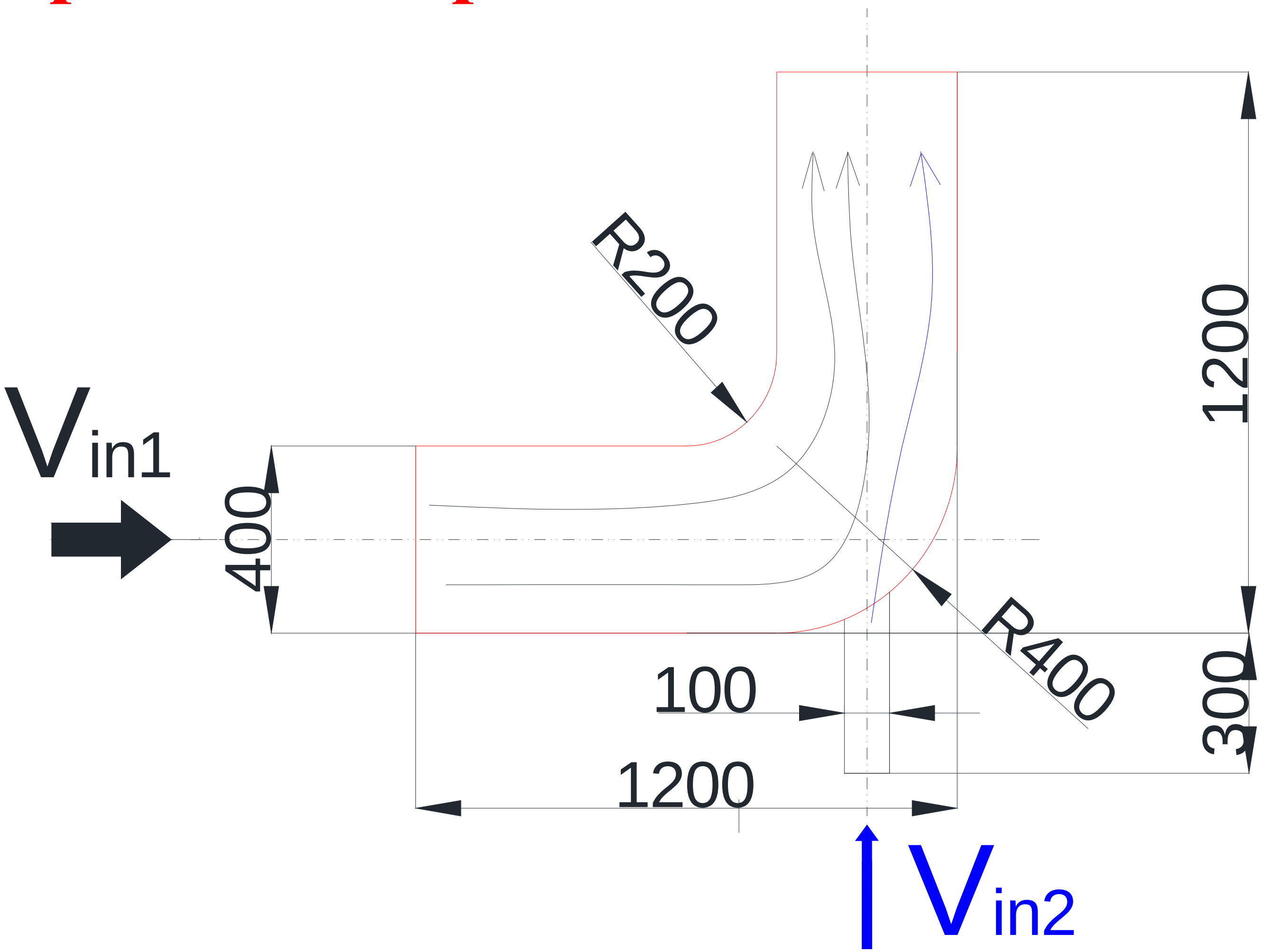
# 12.3.Simple Examples to Using FLUENT

## Example 1: Sudden expansions of a circular tube



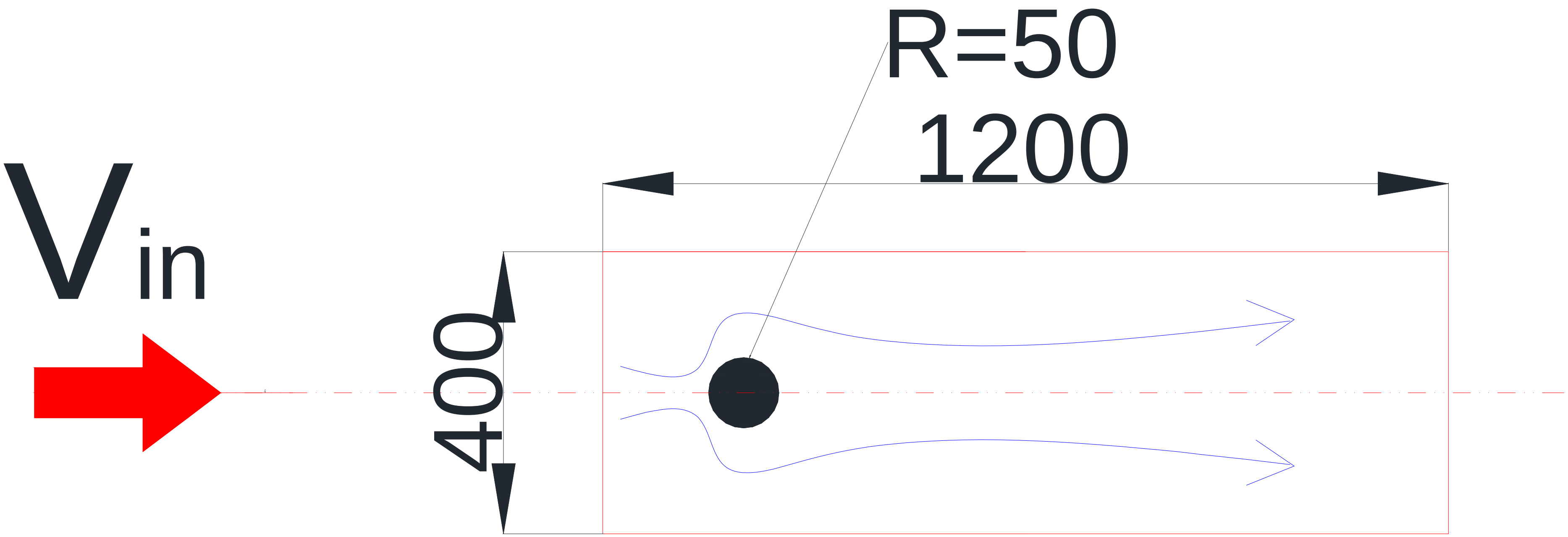

**$V_{in}$=2m/s**

# Example 2: 2D Pipe Junction



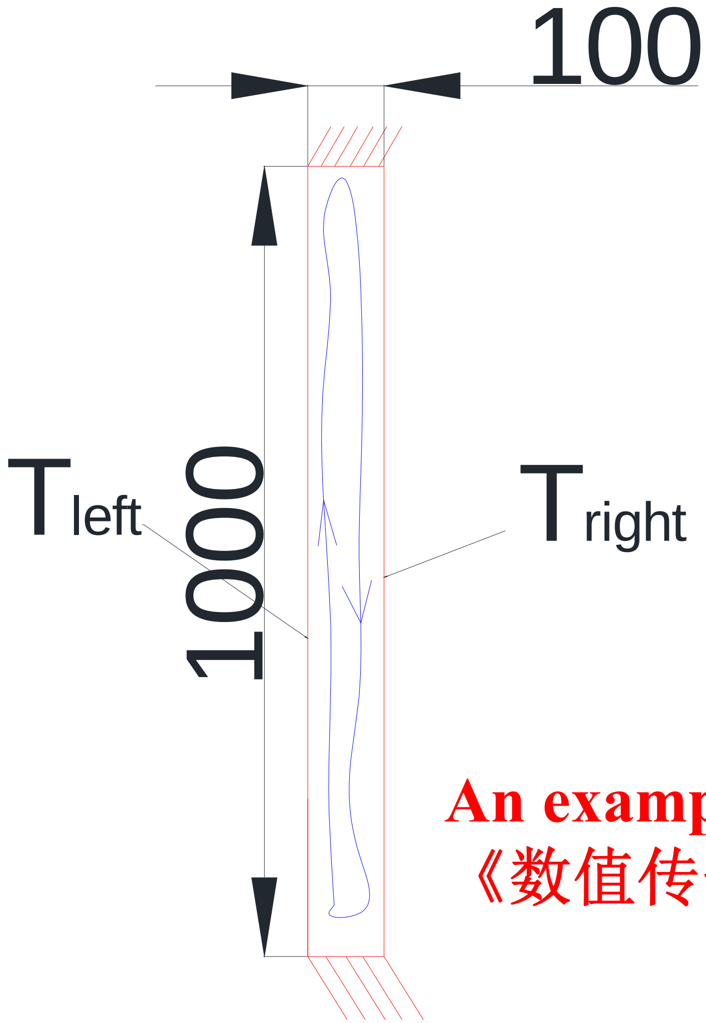

$T_{in1}$=300K $V_{in1}$=1m/s $T_{in2}$=360K $V_{in1}$=5m/s

# Example 3: Flow over a cylinder




$V_{in1}$=0.01m/s

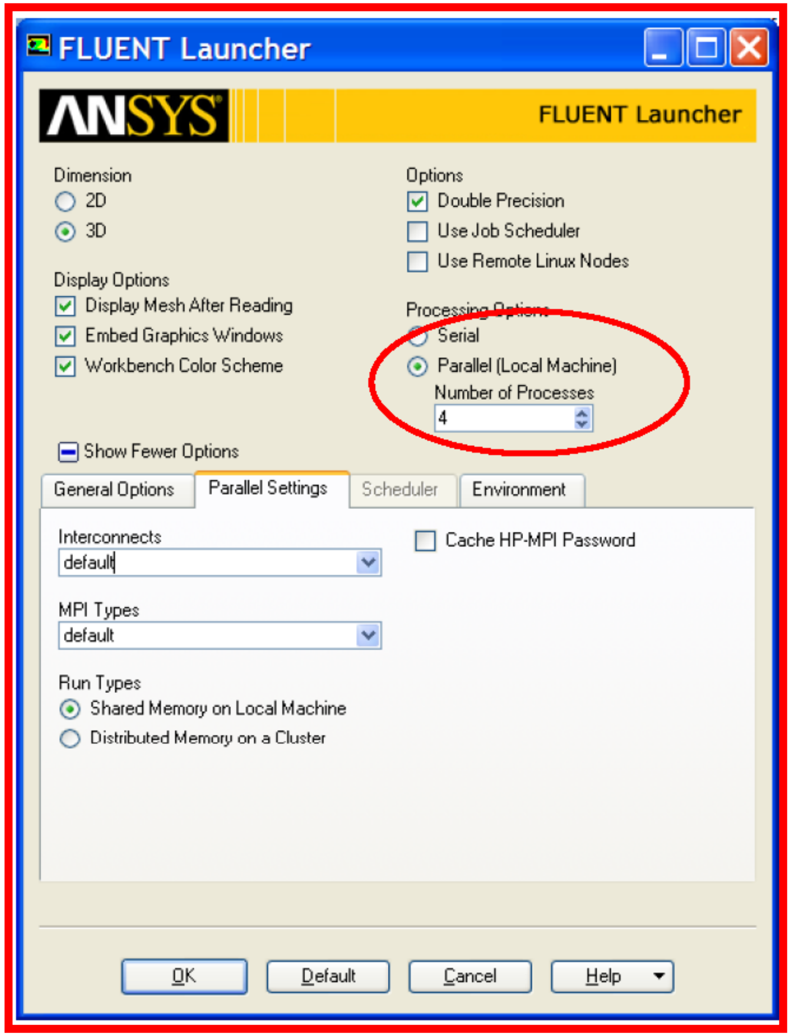
# Example 4: Natural convection in a slot




An example from text book(P161)
《数值传热学》第161页例题

$T_{left}$=320K, $T_{right}$=300K

# 12.4.Procedures of Using FLUENT




Fluent launcher interface

## ◆ Parallel Processing（并行处理）

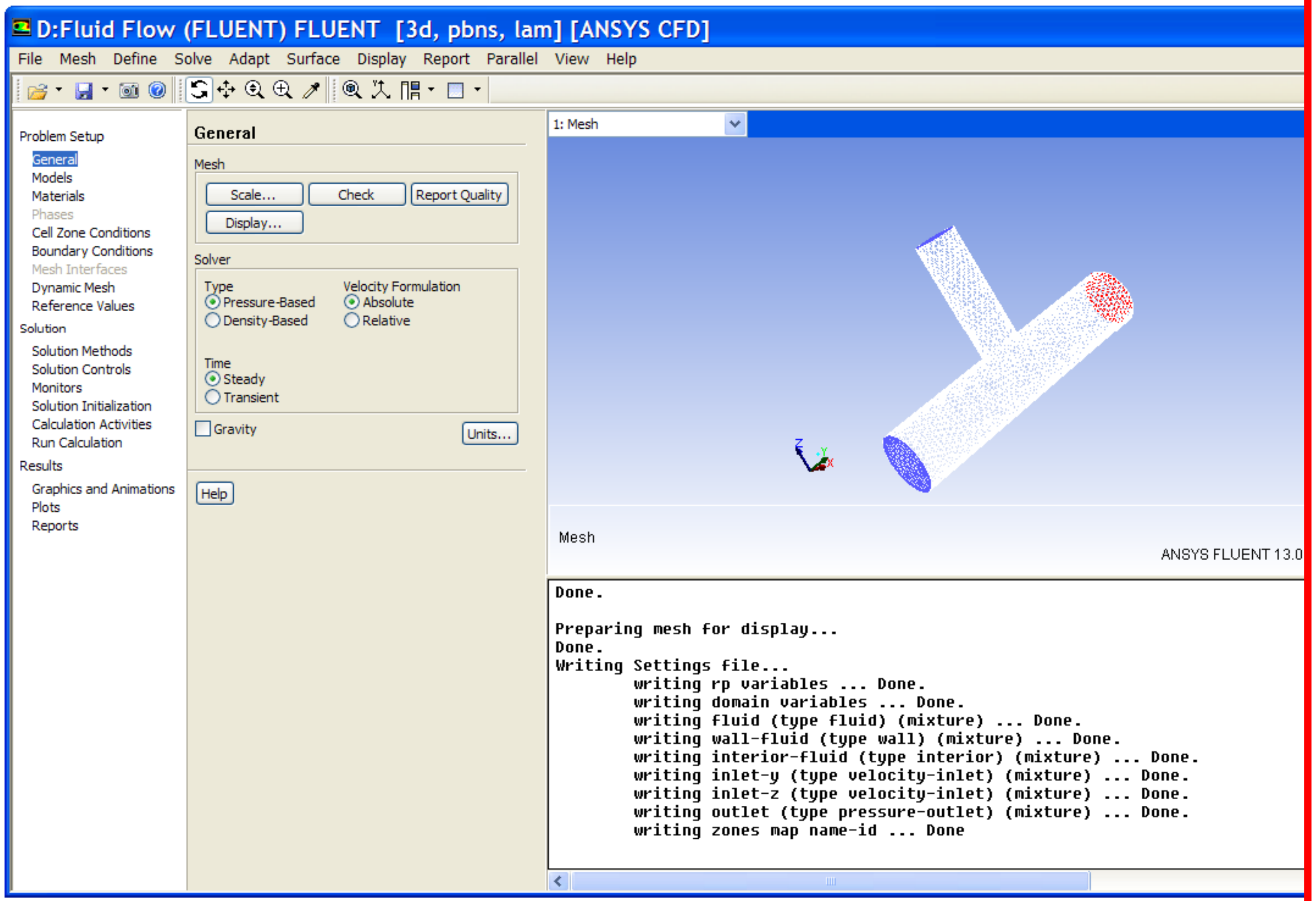
**FLUENT can readily be run across many processors in parallel. This will greatly speed up the simulation time.**

**1) It is common for modern computers to have several processors, or 'cores' per processor. Each one of these can be a "node(节点)" for the FLUENT simulation.**

**2) The mesh is automatically partitioned, and different blocks of the mesh are assigned to the different compute nodes.**

**3) Alternatively a distributed parallel cluster(集群) can be set up, and the simulation can run across many machines simultaneously.**

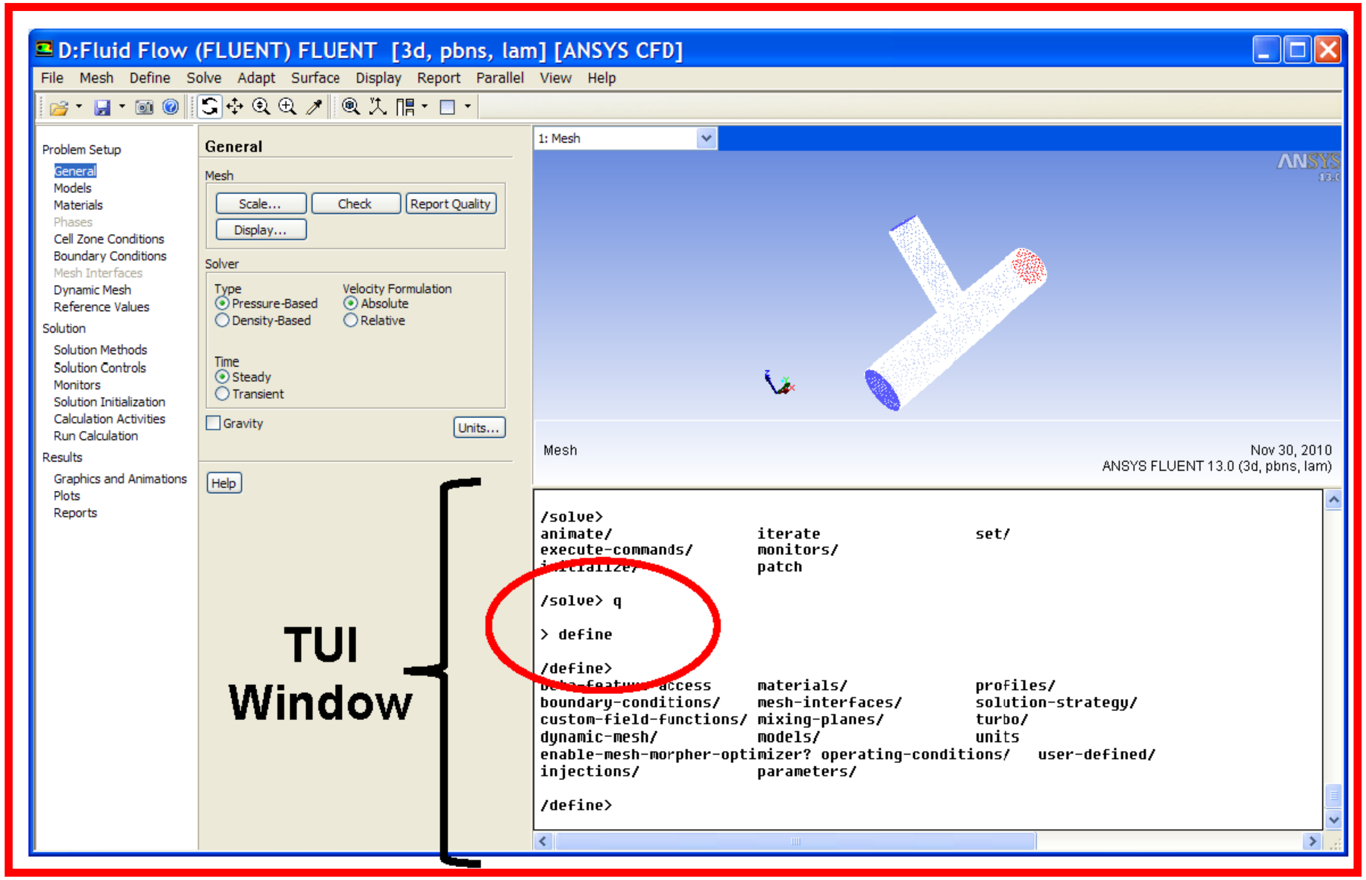
• **The FLUENT Graphical User Interface (GUI,图形界面) is arranged such that the tasks are generally arranged from top to bottom in the project setup tree.**



# ◆ Text User Interface

**Most GUI commands have a corresponding TUI command.**

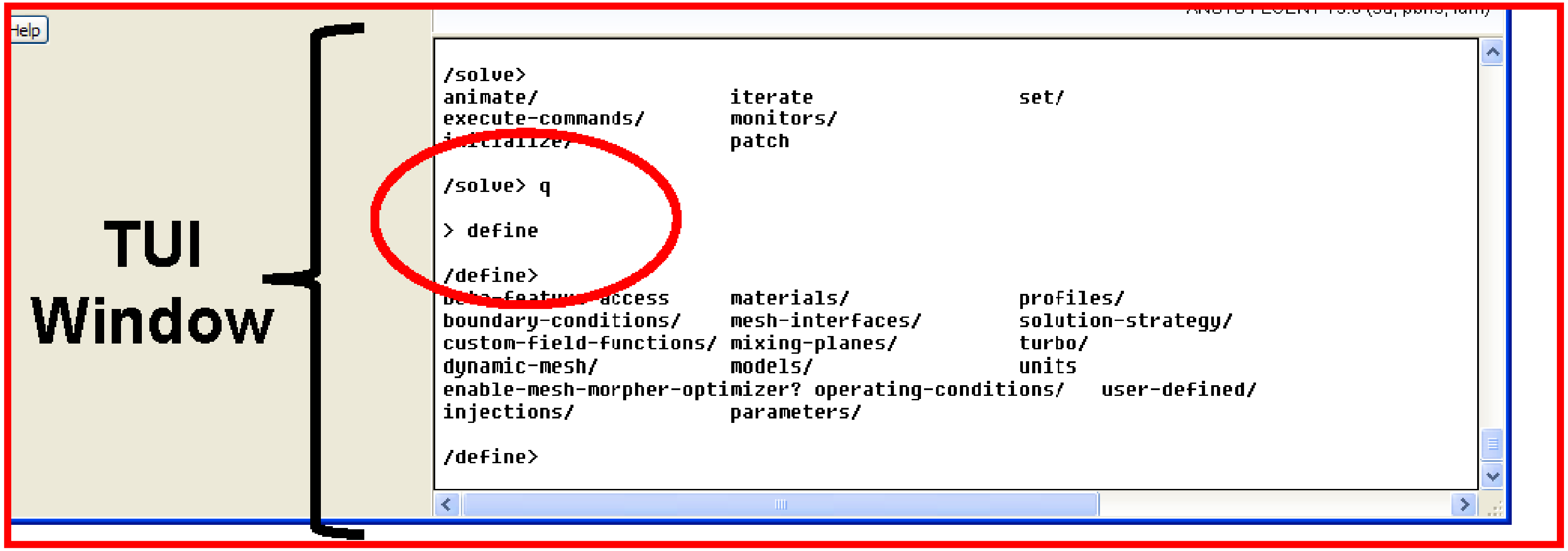
**1) Press the Enter key to display the command set at the current level.**
**2) Some advanced commands are only available through the TUI.**



# The TUI offers many valuable benefits:

1) Journal files can be constructed to automate repetitive tasks.

2) FLUENT can be run in batch mode(批处理模式), with TUI journal scripts set to automate the loading/modification/solver execution and post processing.



- **A journal file is a text file which contains TUI commands which FLUENT will execute sequentially.**

- **Note that the FLUENT TUI accepts abbreviations of the commands for example,**
  - **rcd: Reads case and data files**
  - **wcd: Writes case and data files**

**Sample Journal File**

```
; Read case file
rc example.cas.gz
; Initialize the solution
/solve/initialize/initialize-flow
; Calculate 50 iterations
it 50
; Write data file
wd example50.dat.gz
; Calculate another 50 iterations
it 50
; Write another data file
wd example100.dat.gz
; Exit FLUENT
exit
yes
```

# • FLUENT 16 GUI Navigation

**Selecting an item in the tree opens the relevant input items in the center pane.**

① **General**

② **Models**

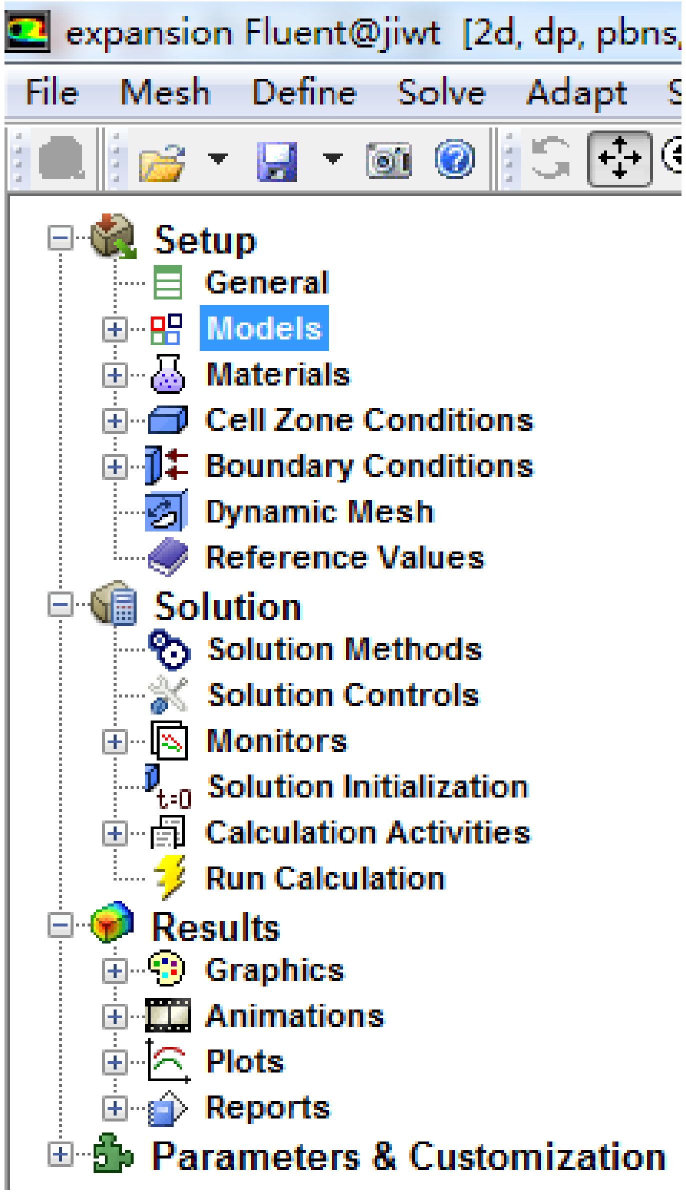
③ **Materials**

④ **Boundary Conditions**

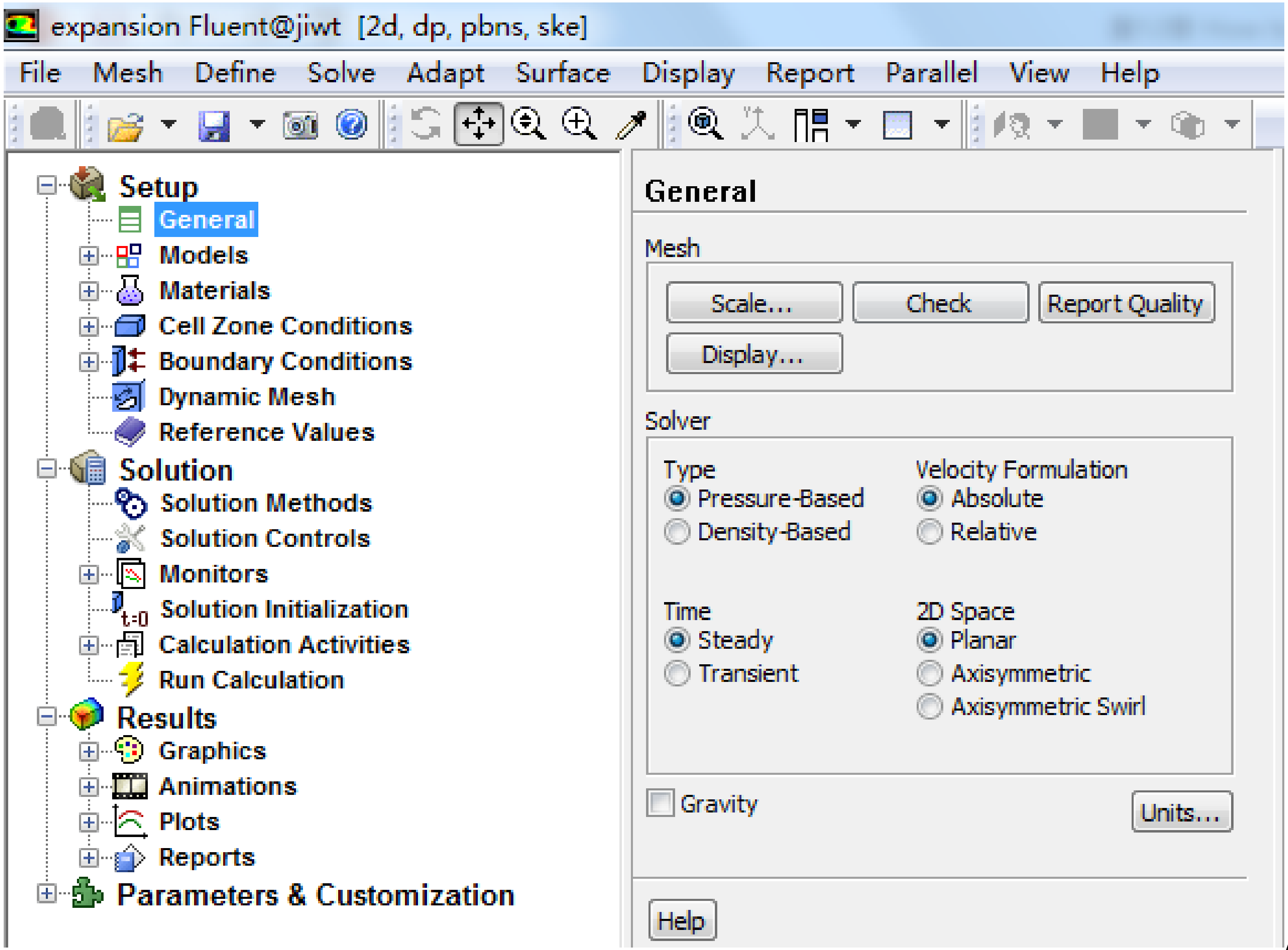
⑤ **Solver Settings**

⑥ **Initialization and Calculation**

⑦ **Post-processing**



# 1. General setting



# ◆Mesh Check Report

```
 Mesh Check

 Domain Extents:
   x-coordinate: min (m) = -4.000000e-002, max (m) = 2.550000e-001
   y-coordinate: min (m) = 0.000000e+000, max (m) = 2.500000e-002
 Volume statistics:
   minimum volume (m3): 2.463287e-009
   maximum volume (m3): 4.508038e-007
    total volume (m3): 4.190433e-004
   minimum 2d volume (m3): 3.000589e-007
   maximum 2d volume (m3): 3.019523e-006
 Face area statistics:
   minimum face area (m2): 4.199967e-004
   maximum face area (m2): 2.434403e-003
 Checking mesh......................
Done.
```

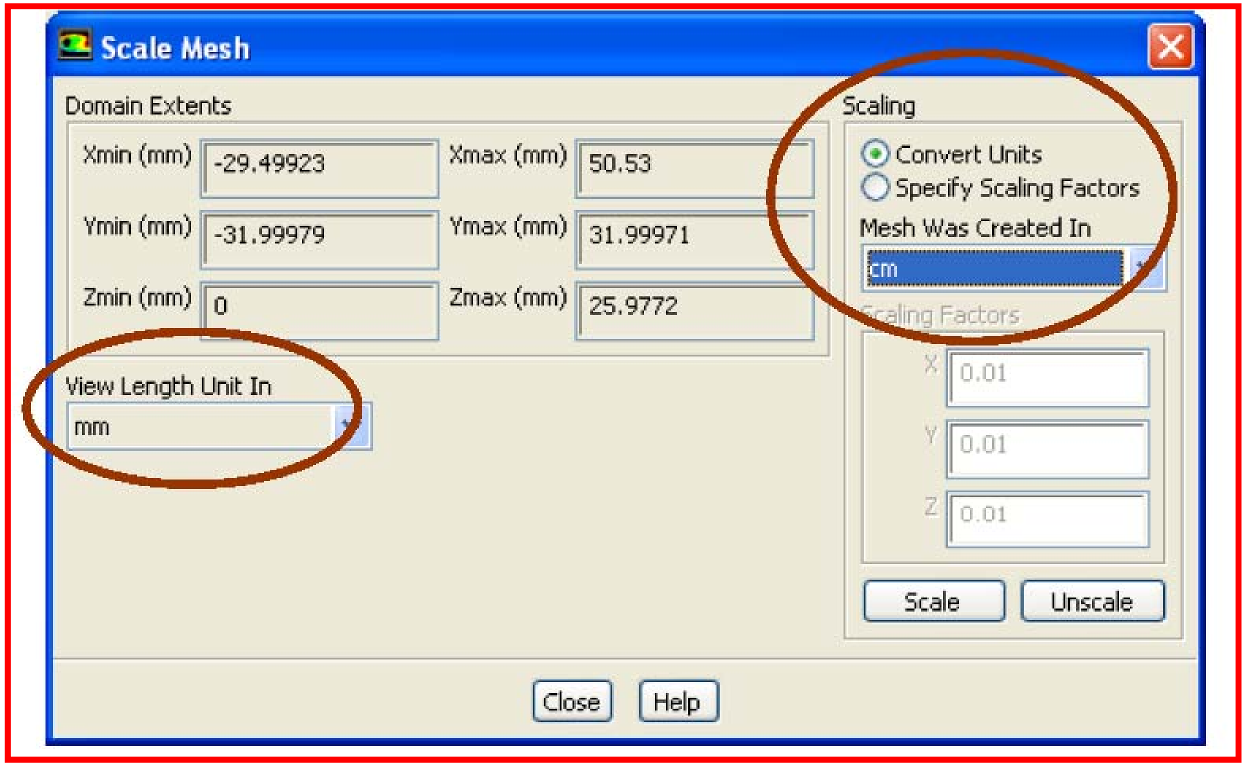
① **The mesh check report begins by listing the domain extents. The domain extents include the minimum and maximum x, y, and z coordinates in meters.**

② **It also display warnings based on the results of the checks previously described.**

③ **Then the volume statistics are provided, including the minimum, maximum, and total cell volume in $m^3$. A negative value for the minimum volume indicates that one or more cells have improper connectivity. Cells with a negative volume can often be identified using the Iso-Value Adaption dialog box to mark them for adaption and view them in the graphics window.**

④ **Next, the mesh report lists the face area statistics, including the minimum and maximum areas in $m^2$. A value of 0 for the minimum face area indicates that one or more cells have degenerated. As with negative volume cells, such faces must be eliminated. It is also recommended to correct cells that have non-zero face areas, if the values are very small.**

# ◆Scaling the Mesh and Selecting Units

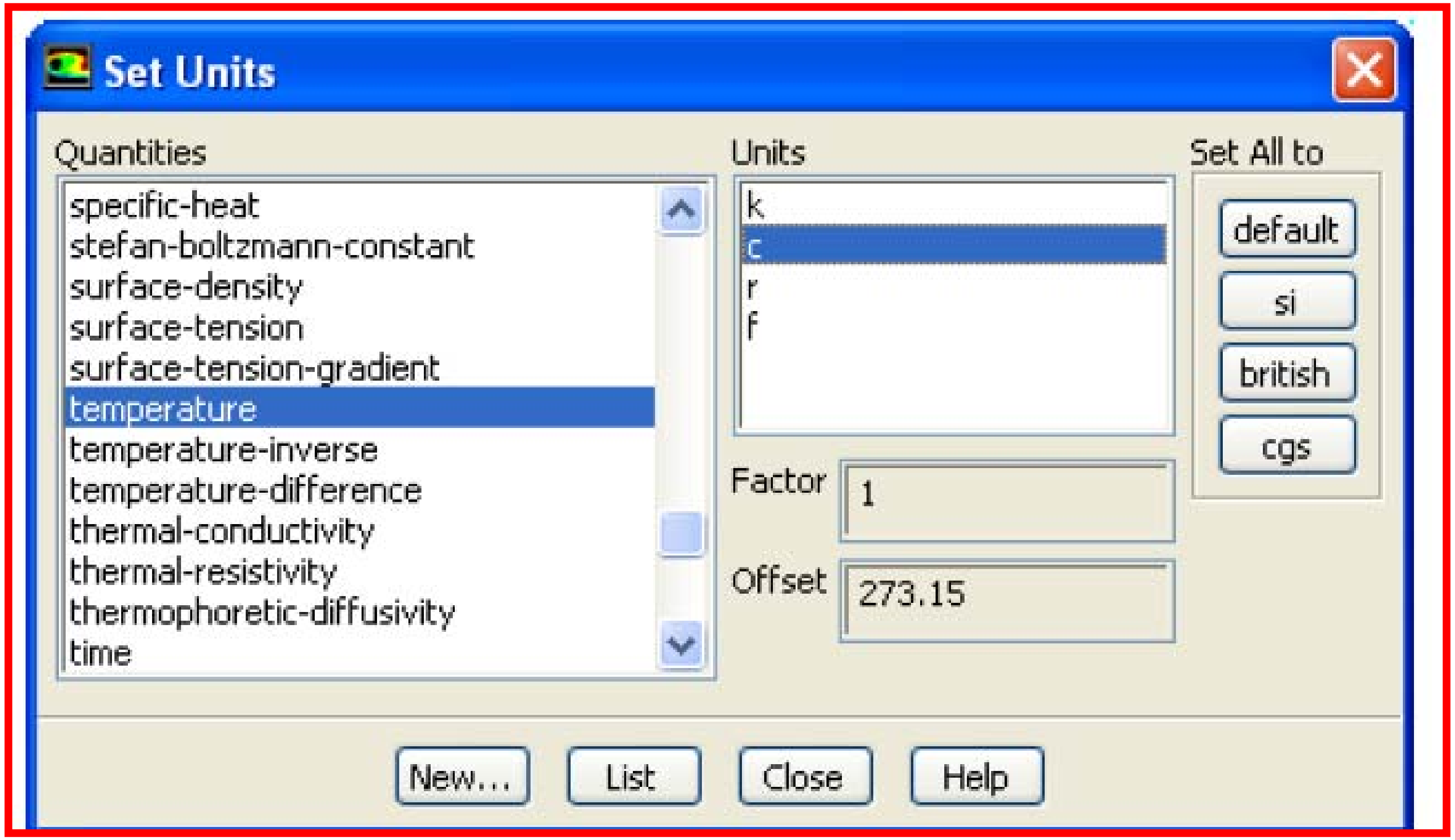



- **When FLUENT reads a mesh file(.msh), all dimensions are assumed to be in units of meters.**

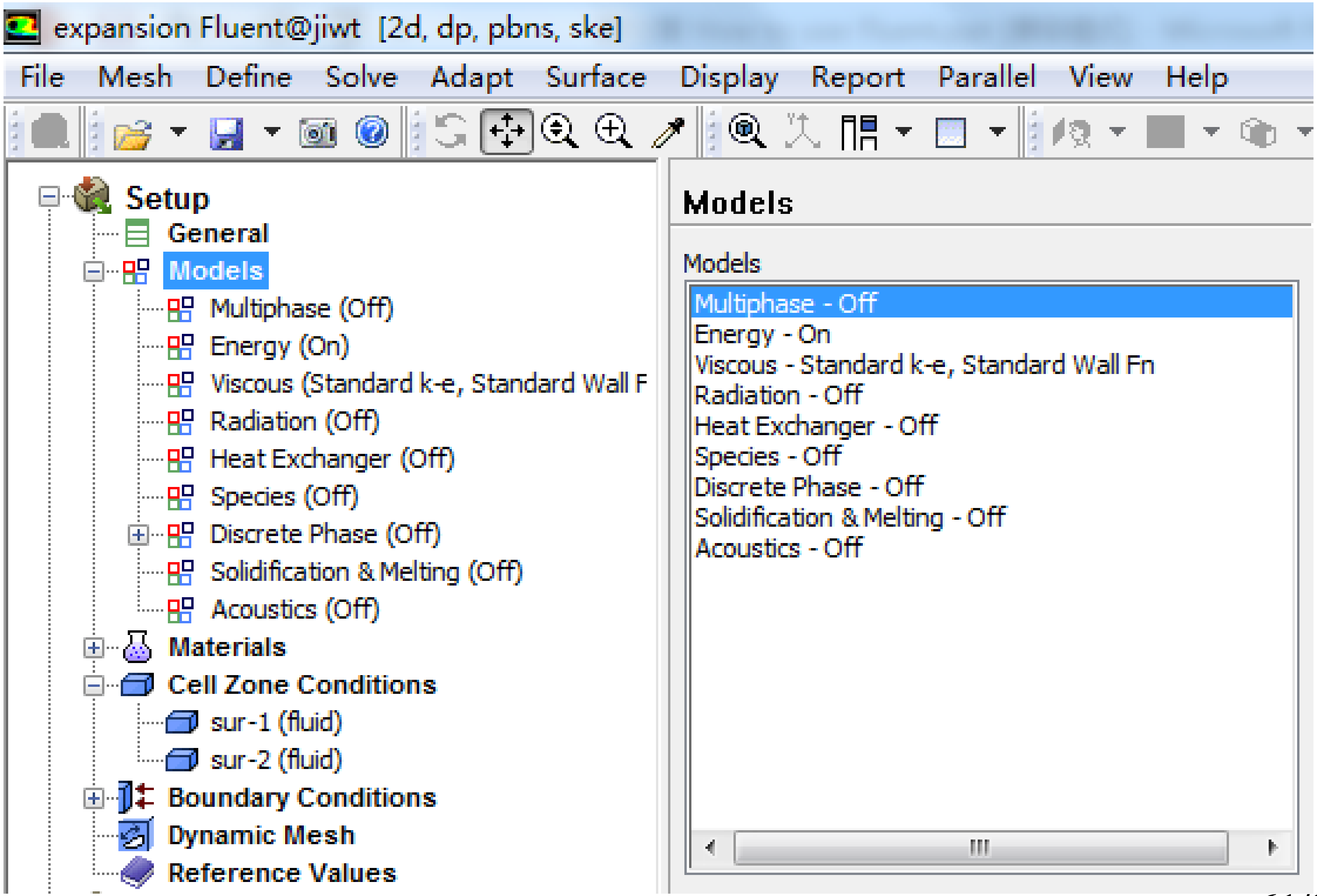
**① If your model was not built in meters, then it must be scaled.**
**② Always verify that the domain extents are correct.**

# Any "mixed" units system can be used if desired.

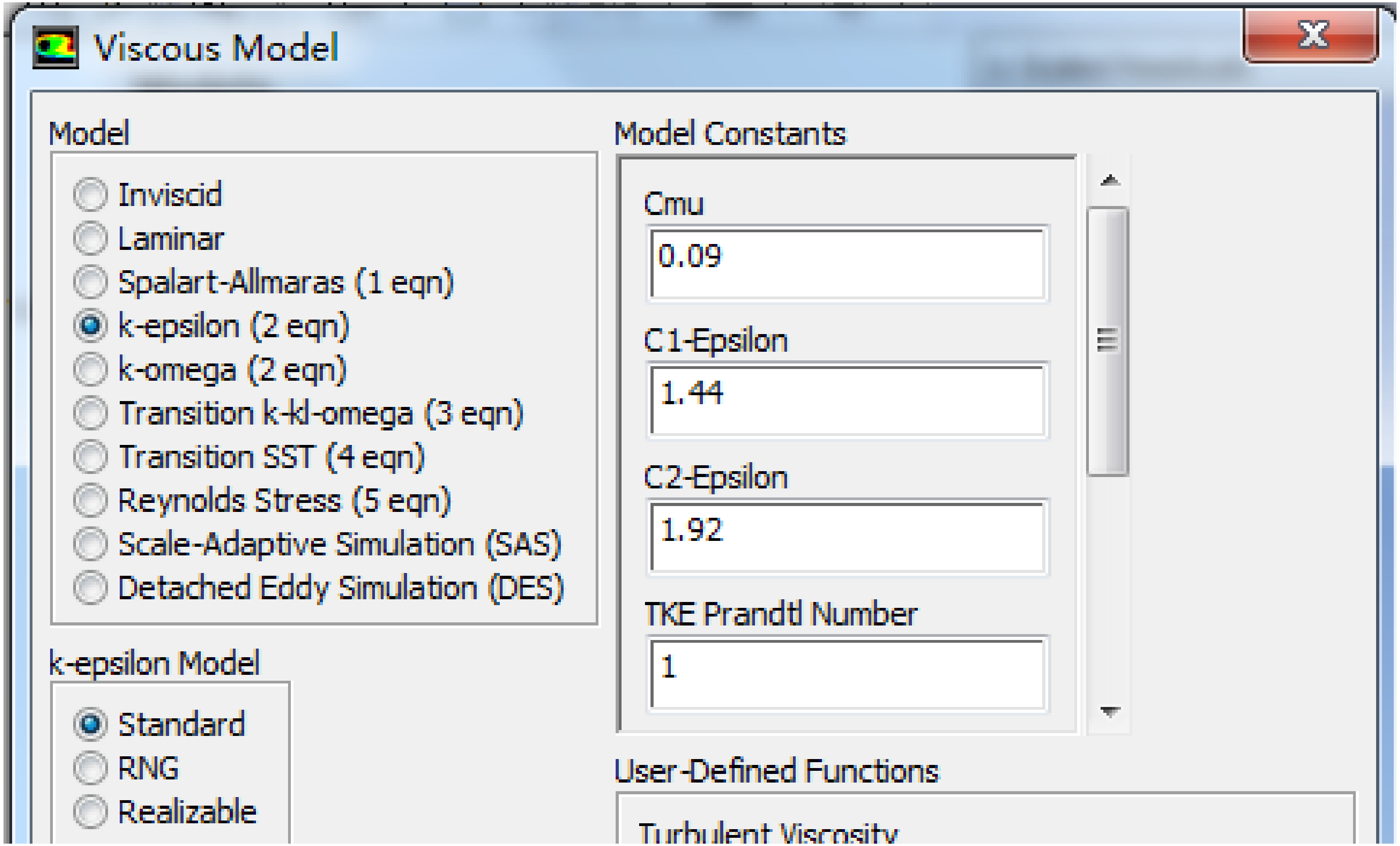
① By default, FLUENT uses the international system of units (SI).
② Any units can be specified in the Set Units panel, accessed from the top menu.



# 2. Setup the Models



# ◆Turbulence Models Available in FLUENT(Chapter 9)



**RANS based models**

| |
|---|
| One-Equation Model<br>Spalart-Allmaras |
| Two-Equation Models<br>Standard k–ε<br>RNG k–ε<br>Realizable k–ε |
| Standard k–ω<br>SST k–ω |
| 4-Equation v2f * |
| Reynolds Stress Model |
| *k–kl–ω* Transition Model<br>SST Transition Model |

Detached Eddy Simulation

Large Eddy Simulation

Increase in Computational Cost Per Iteration

# 3. Material Properties

1） Material properties need to be defined for all fluids and solids to be simulated.

2） The parameters depend on the models selected for the simulation.

3） Many common materials are already defined in the 'FLUENT Database' and can easily be copied to the model.

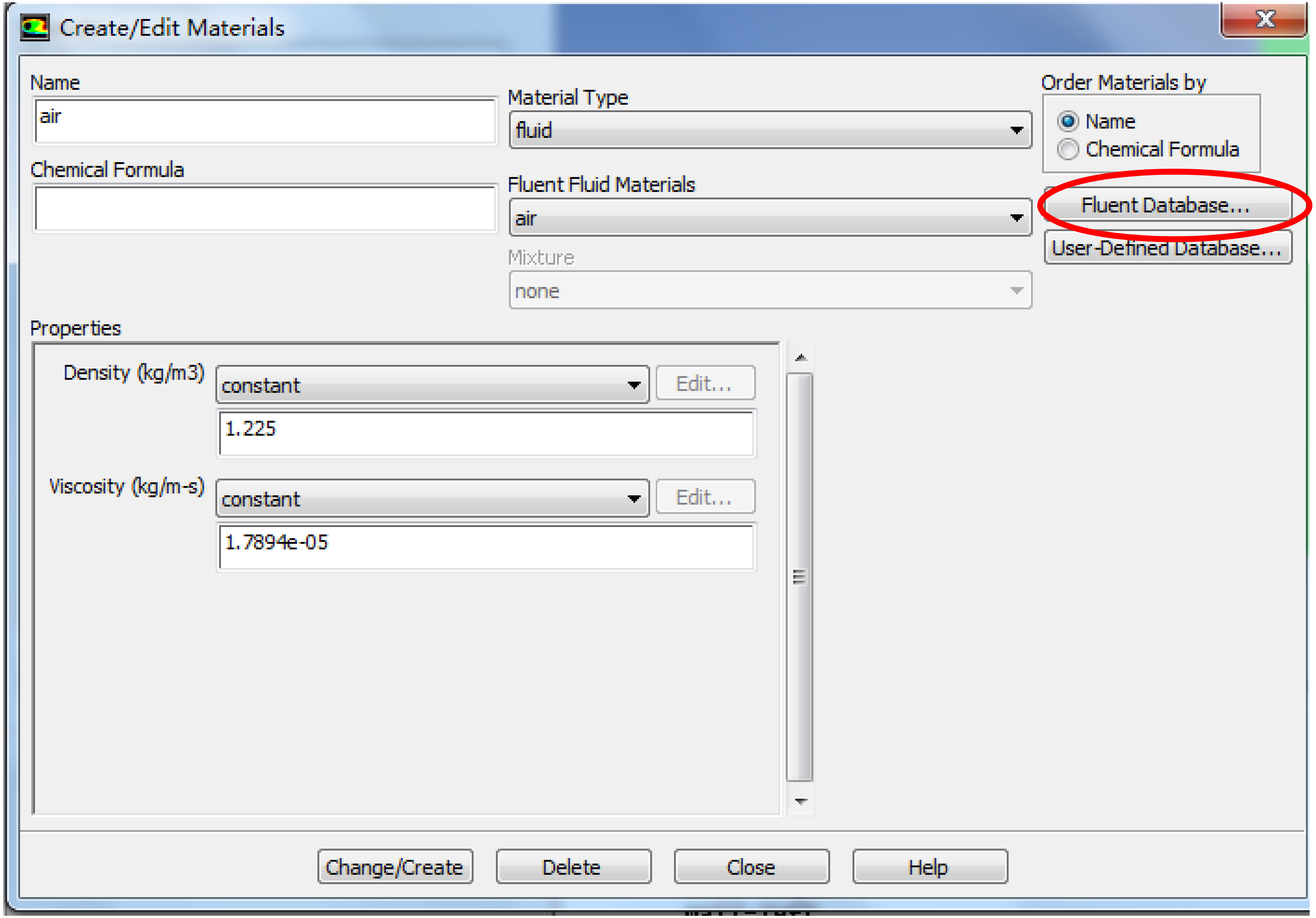
Note that these values may be either:

① Constants

② Functions of temperature

③ Other built in functions following common relationships

④ Defined by the user in a UDF.


Create/Edit Materials
Name
air
Chemical Formula
Material Type
fluid
Fluent Fluid Materials
air
Mixture
none
Order Materials by
Name
Chemical Formula
Fluent Database...
User-Defined Database...
Properties
Density (kg/m3)
constant
Edit...
1.225
Viscosity (kg/m-s)
constant
Edit...
1.7894e-05
Change/Create
Delete
Close
Help

# These properties may include:

① Density and/or molecular weights

② Viscosity

③ Heat capacity

④ Thermal conductivity

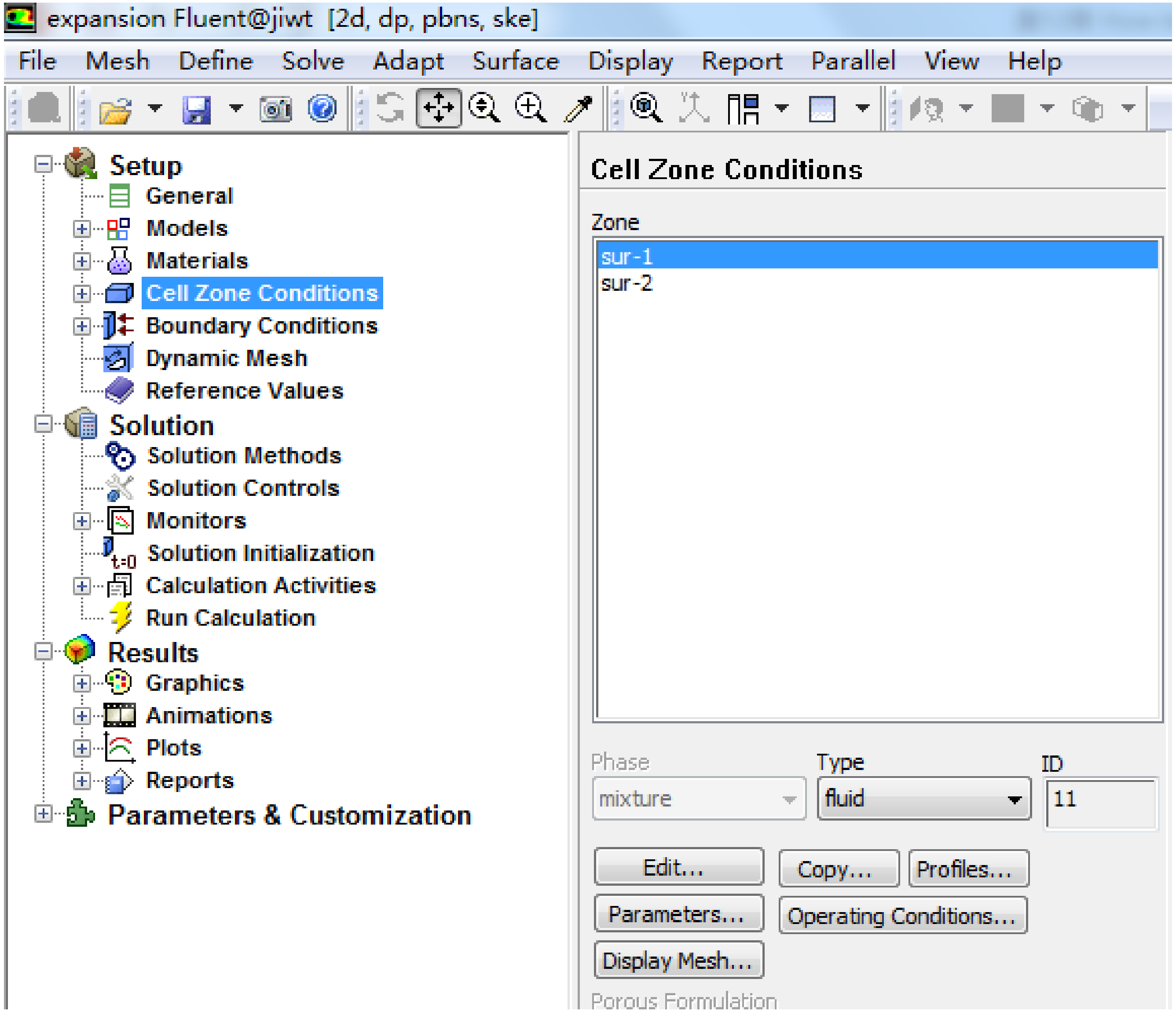
⑤ User-defined scalar diffusivity

⑥ Mass diffusion coefficients

⑦ Standard state enthalpies

⑧ Kinetic theory parameters

# 4.Cell Zone Conditions

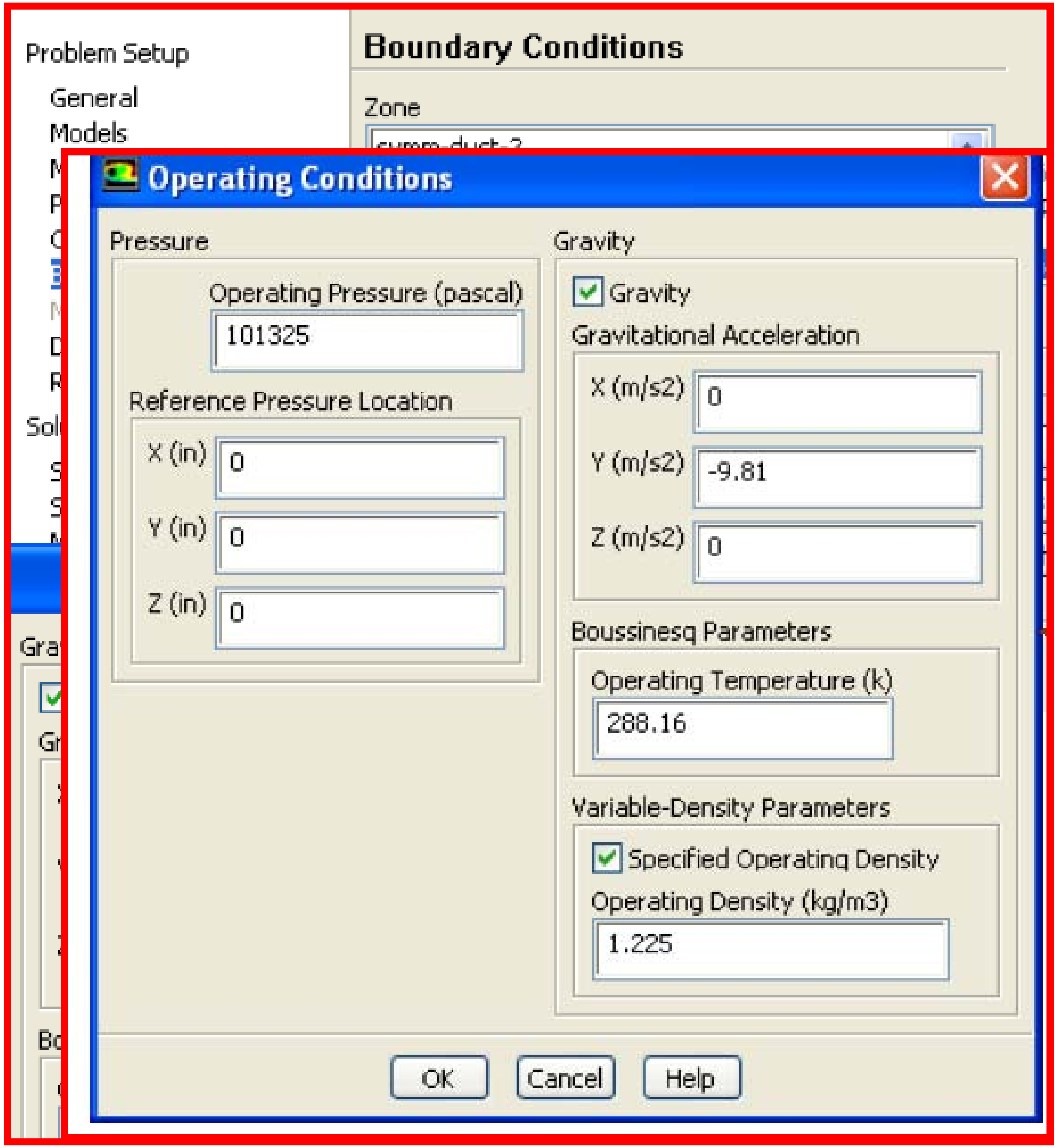


## ◆Operating Conditions

① The Operating Pressure with a Reference Pressure Location sets the reference value that is used in computing gauge pressures.

② The Operating Temperature sets the reference temperature (used when computing buoyancy forces).

• **Specified Operating Density** sets the reference value for flows with widely varying density.


Problem Setup
General
Models
Boundary Conditions
Zone
Operating Conditions
Pressure
Operating Pressure (pascal)
101325
Reference Pressure Location
X (in)
0
Y (in)
0
Z (in)
0
Gravity
Gravity
Gravitational Acceleration
X (m/s2)
0
Y (m/s2)
-9.81
Z (m/s2)
0
Boussinesq Parameters
Operating Temperature (k)
288.16
Variable-Density Parameters
Specified Operating Density
Operating Density (kg/m3)
1.225
OK
Cancel
Help

## Zone Types Listed by Category

| Category | Zone Types |
|---|---|
| Faces | Axis, Outflow, Mass Flow Inlet, Pressure Far-field, Pressure Inlet, Pressure Outlet, Symmetry, Velocity Inlet, Wall, Inlet Vent, Intake Fan, Outlet Vent, Exhaust Fan |
| Double-Sided Faces | Fan, Interior, Porous Jump, Radiator, Wall |
| Periodic | Periodic |
| Cells | Fluid, Solid |

# ◆Defining Cell Zones and Boundary Conditions

**To properly define any NHT problem, you must define:**

**1）Cell zones**

**① These relate to the middle of the grid cells**

**② Typically this always involves setting up which material (fluid) is in that cell**

**③ Other values（heat sources， etc)**

**2）Boundary conditions**

**①Where fluid enters or leaves the domain, the conditions must be set (velocity/pressure/temperature)**

**②Other boundaries also need declaring, like walls (smooth /rough, heat transfer?)**

**③There may also be symmetry, periodic or axis boundaries.**

**3）The data required at a boundary depends upon the boundary condition type and the physical models employed.**

## ◆ Cell Zones – Fluid

① A fluid cell zone is a group of cells for which all active equations are solved.

② The material in the cell zone must be declared.

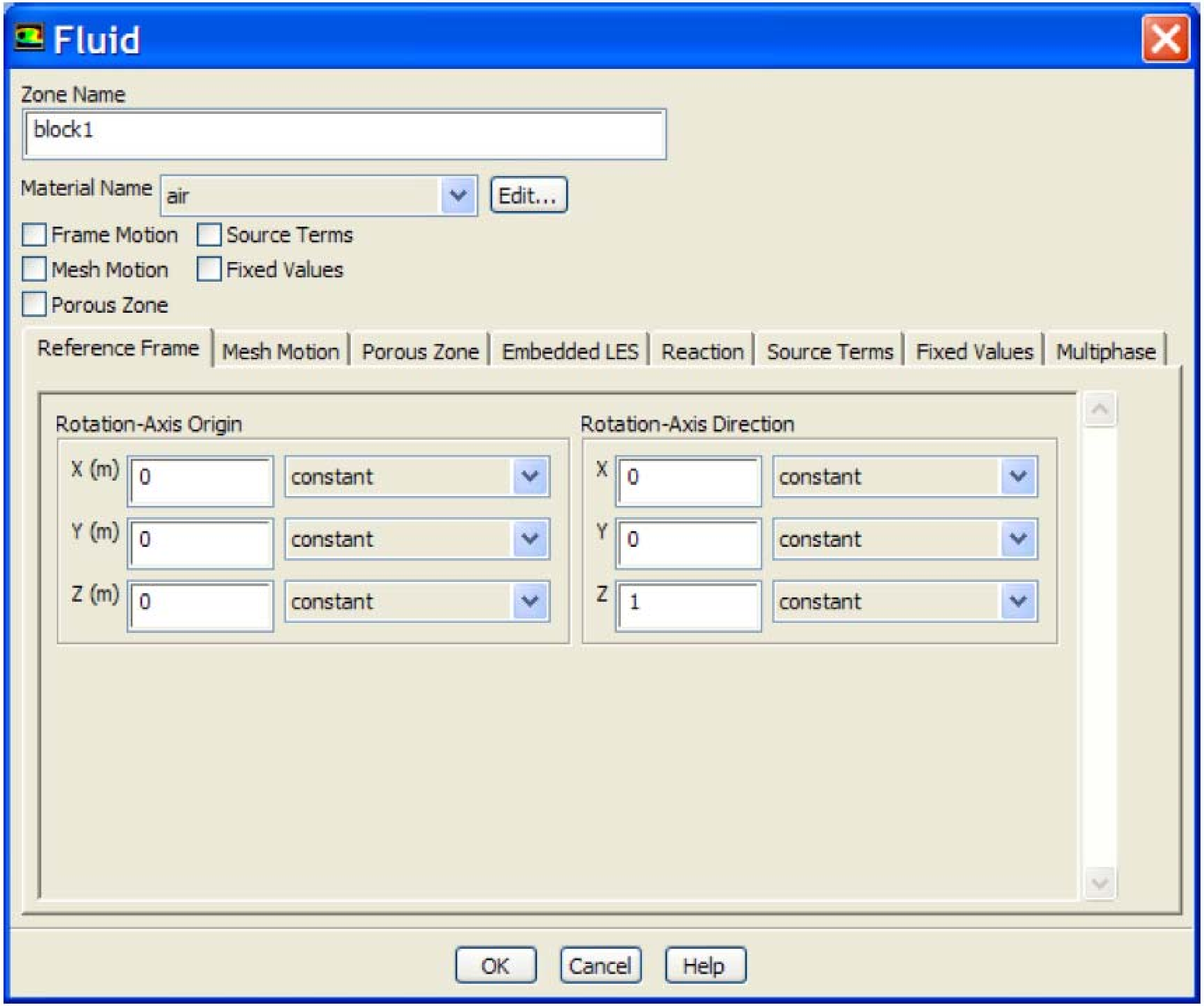
- Optional inputs

① Moving zones

② Porous region

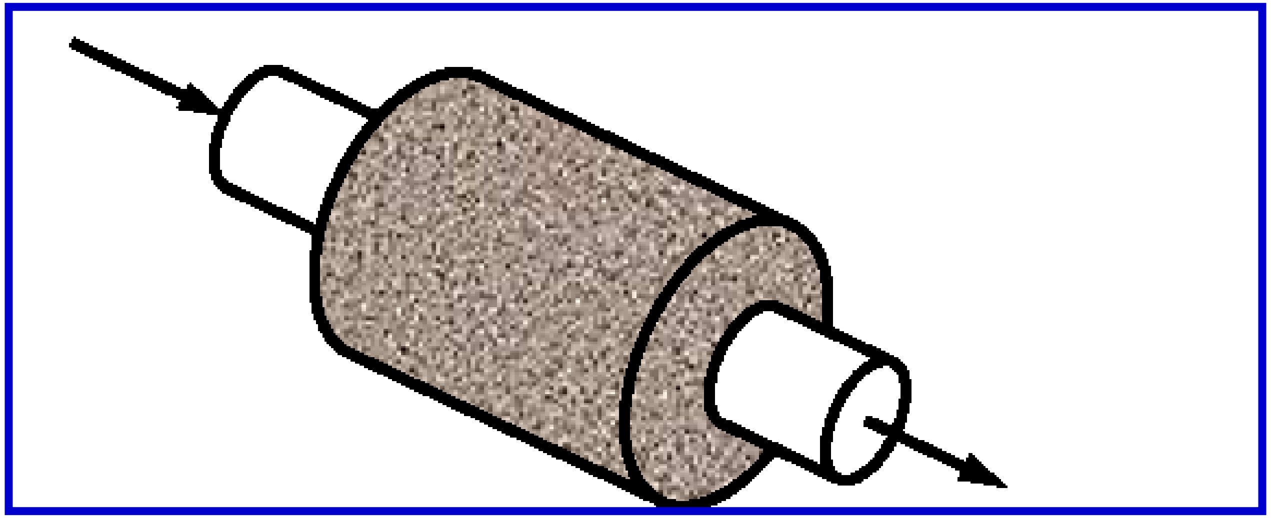
③ Source terms

④ Fixed Values


Fluid
Zone Name
block1
Material Name
air
Edit...
Frame Motion
Source Terms
Mesh Motion
Fixed Values
Porous Zone
Reference Frame
Mesh Motion
Porous Zone
Embedded LES
Reaction
Source Terms
Fixed Values
Multiphase
Rotation-Axis Origin
X (m)
0
constant
Y (m)
0
constant
Z (m)
0
constant
Rotation-Axis Direction
X
0
constant
Y
0
constant
Z
1
constant
OK
Cancel
Help

## ◆Cell Zones - Porous Media

- Some fluid regions are obviously porous and impossible to resolve exactly in a mesh:
  - Packed beds， metal foam



## Cell Zones – Solid

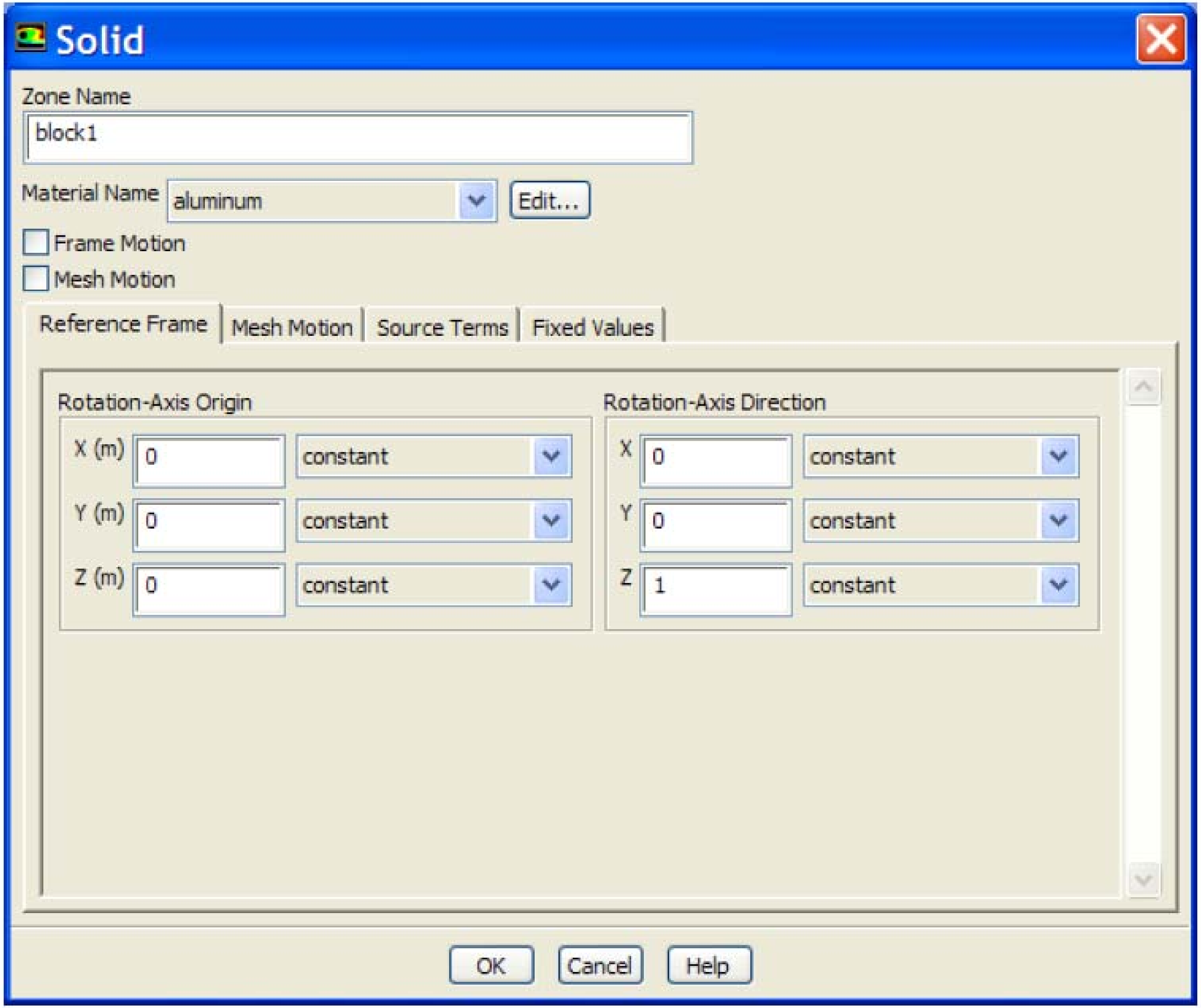
1) A solid zone is a group of cells for which only the energy equation is solved.

2) Only required input is the material name (defined in the Materials panel).

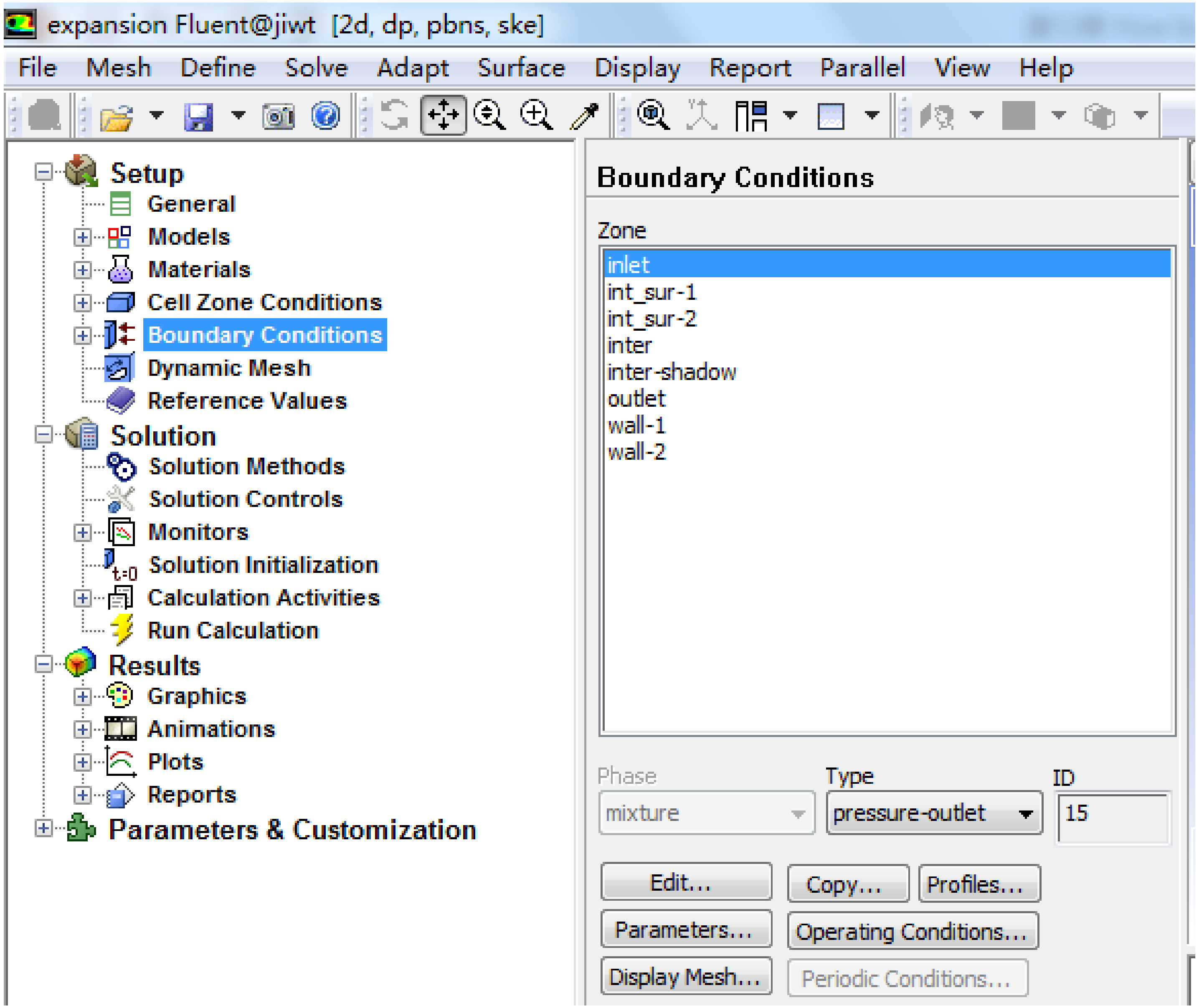
3) Optional inputs allow you to set volumetric heat generation rate(heat source).

4) Need to specify rotation axis if rotationally periodic boundaries adjacent to solid zone.

5) Can define motion for a solid zone


Solid
Zone Name
block1
Material Name
aluminum
Edit...
Frame Motion
Mesh Motion
Reference Frame
Mesh Motion
Source Terms
Fixed Values
Rotation-Axis Origin
X (m) 0 constant
Y (m) 0 constant
Z (m) 0 constant
Rotation-Axis Direction
X 0 constant
Y 0 constant
Z 1 constant
OK
Cancel
Help

# 5. Boundary Conditions



# Defining Boundary Conditions

① To define a problem that results in a unique solution, you must specify information on the dependent (flow) variables at the domain boundaries

- Specifying fluxes of mass, momentum, energy, etc. into domain.

② Defining boundary conditions involves:

- Identifying the location of the boundaries (e.G., Inlets, walls, symmetry)
- Supplying information at the boundaries

③ **The data required at a boundary depends upon the boundary condition type and the physical models employed.**

④ **Be aware of the information that is required of the boundary condition, and locate the boundaries where the information on the flow variables are known or can be reasonably approximated**

- **Poorly defined boundary conditions can have a significant impact on the solution**

- **General guidelines:**

① **If possible, select boundary location and shape such that flow either goes in or out.**

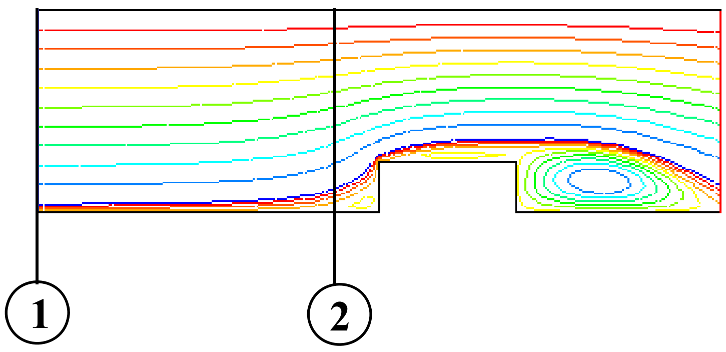
- **It will typically observe better convergence.**

② **Should not observe large gradients in direction normal to boundary.**

**Indicates incorrect set-up.**

③ **Minimize grid skewness near the boundary.**

**Otherwise it would introduce error early in calculation.**



# Boundary Conditions - Available Types

## External Boundaries

**1）General**

- Pressure Inlet
- Pressure Outlet

**2）Incompressible**

- Velocity Inlet
- Outflow

**3）Compressible**

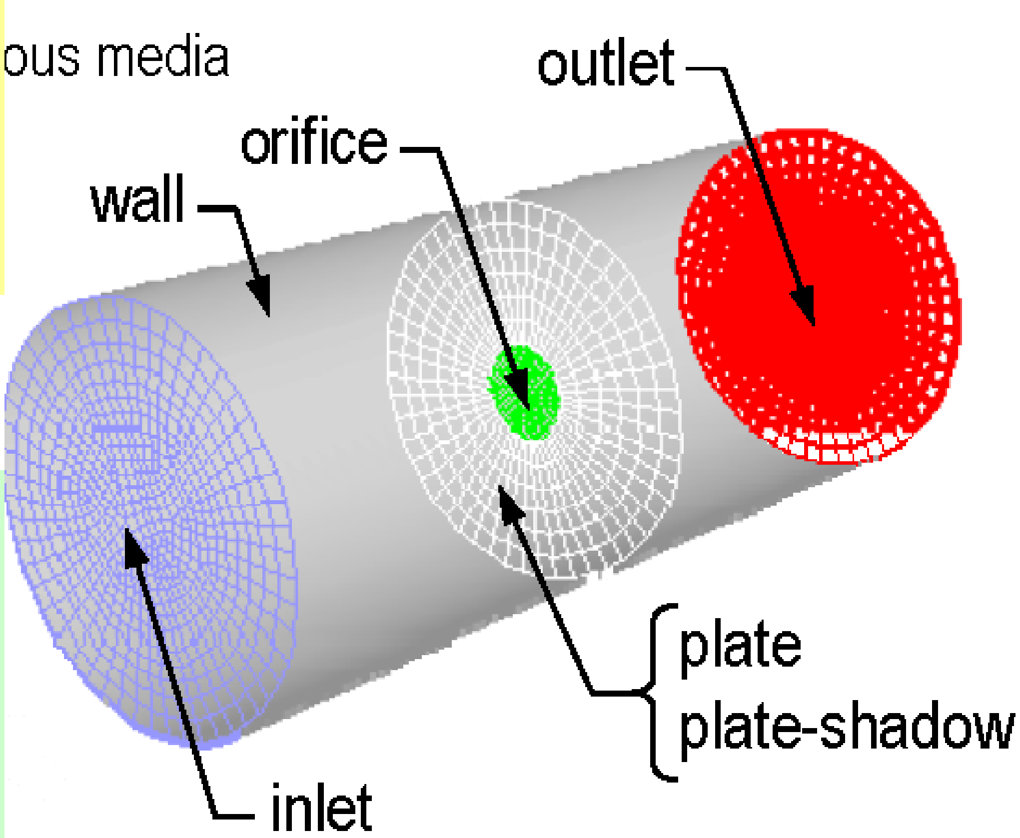
- Mass Flow Inlet
- Pressure Far Field

**4）Other**

- Wall
- Symmetry
- Axis
- Periodic

- **Internal Boundaries**
  - **Fan**
  - **Interior**
  - **Radiator**
  - **Wall**

**Cell (Continuum) zones**
- **Fluid**
- **Solid**
- **Porous media**



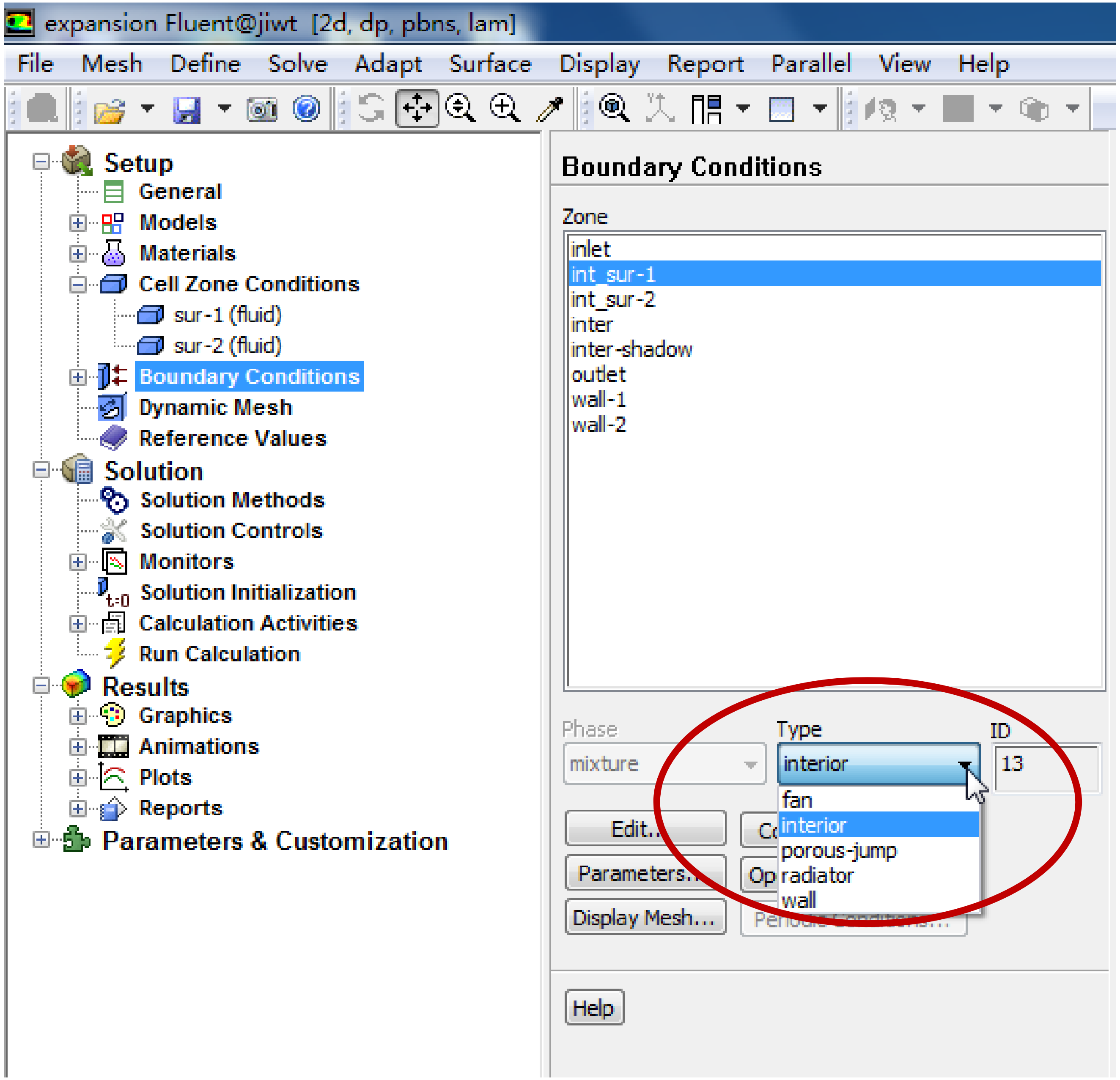
## ◆Boundary Conditions – Changing the Types

• Zones and zone types are initially defined in the pre-processing phase(eg.ICEM).

• To change the boundary condition type for a zone:

① Choose the zone name in the Zone list.

② Select the type you wish to change it to in the Type pull-down list.


expansion Fluent@jiwt [2d, dp, pbns, lam]
File Mesh Define Solve Adapt Surface Display Report Parallel View Help
Setup
General
Models
Materials
Cell Zone Conditions
sur-1 (fluid)
sur-2 (fluid)
Boundary Conditions
Dynamic Mesh
Reference Values
Solution
Solution Methods
Solution Controls
Monitors
Solution Initialization
Calculation Activities
Run Calculation
Results
Graphics
Animations
Plots
Reports
Parameters & Customization
Boundary Conditions
Zone
inlet
int_sur-1
int_sur-2
inter
inter-shadow
outlet
wall-1
wall-2
Phase
mixture
Type
interior
ID
13
fan
interior
porous-jump
radiator
wall
Edit...
Parameters...
Display Mesh...
Help

# ◆Boundary Conditions - Velocity Inlet

1) Velocity Specification Method

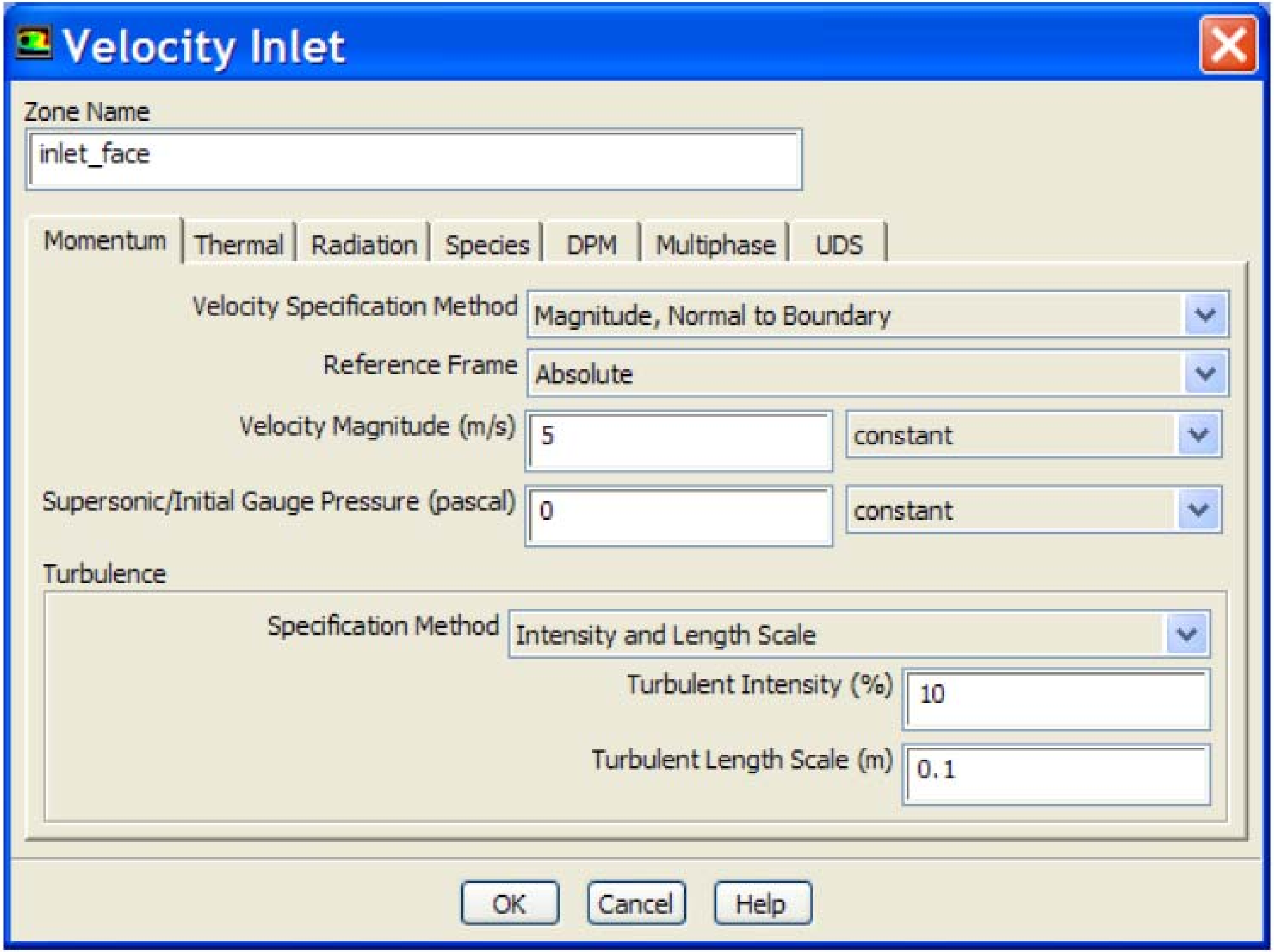
– Magnitude, Normal to Boundary

– Magnitude and Direction

2) Applies a uniform velocity profile at the boundary, unless UDF or profile is used.

3) Velocity inlets are intended for use in incompressible flows and are not recommended for compressible flows.

4) Velocity Magnitude input can be negative, implying that you can prescribe the exit velocity.


Velocity Inlet
Zone Name
inlet_face
Momentum
Thermal
Radiation
Species
DPM
Multiphase
UDS
Velocity Specification Method
Magnitude, Normal to Boundary
Reference Frame
Absolute
Velocity Magnitude (m/s)
5
constant
Supersonic/Initial Gauge Pressure (pascal)
0
constant
Turbulence
Specification Method
Intensity and Length Scale
Turbulent Intensity (%)
10
Turbulent Length Scale (m)
0.1
OK
Cancel
Help

# ◆Boundary Conditions - Pressure Inlet

**1) Pressure inlets are suitable for both compressible and incompressible flows.**

**– FLUENT calculates static pressure and velocity at inlet (Dynamic pressure)**

**2) Required inputs**

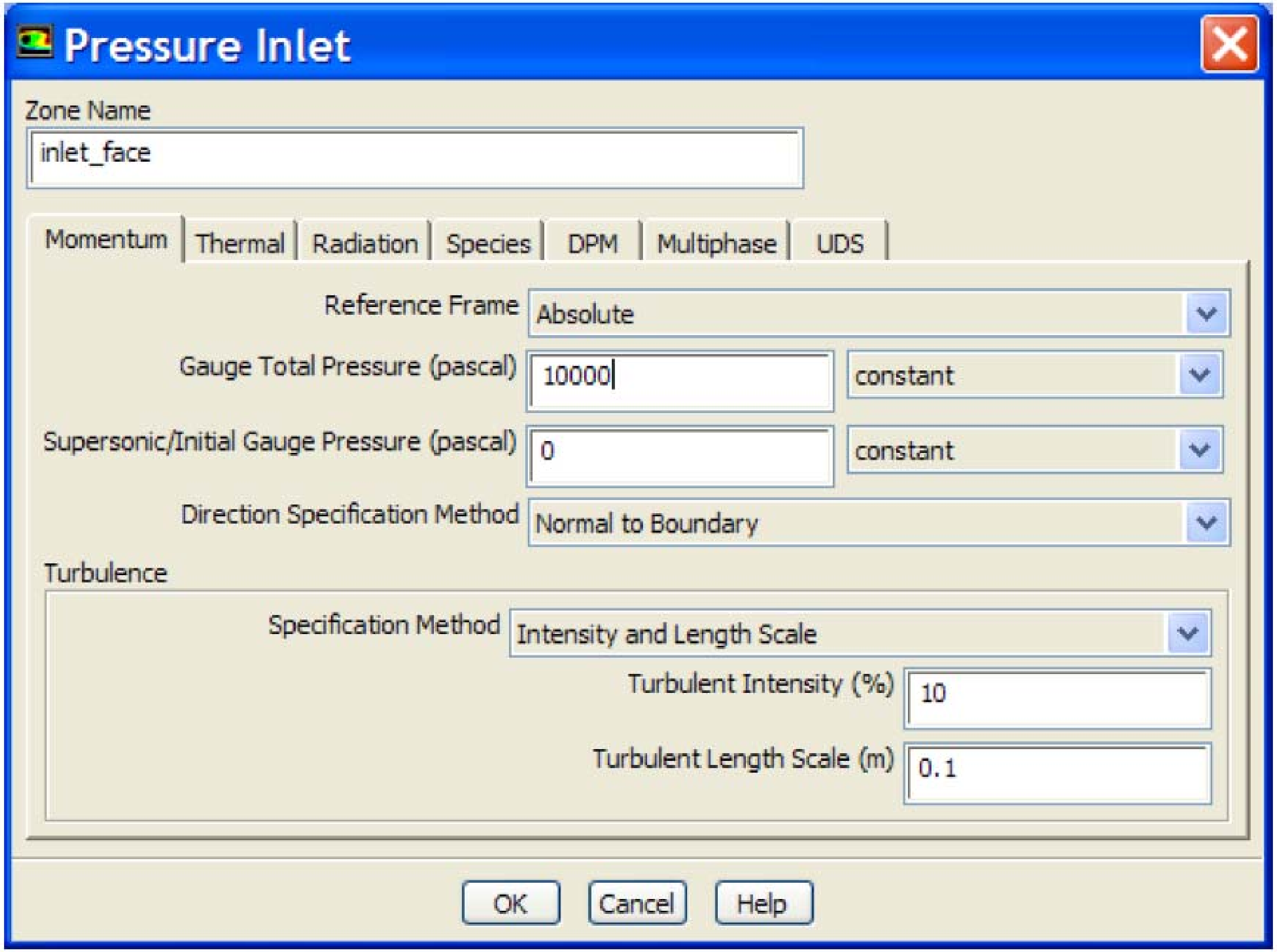
① **Gauge Total Pressure**

② **Supersonic/Initial Gauge Pressure**

③ **Inlet flow direction**

④ **Turbulence quantities( if applicable)**

⑤ **Total temperature (heat transfer or compressible).**




**Incompressible:** $p_{\text{total}} = p_{\text{static}} + \dfrac{\rho V^2}{2}$

# ◆Boundary Conditions - Mass Flow Inlet

1) Mass flow inlets are intended for compressible flows; however, they can be used for incompressible flows.

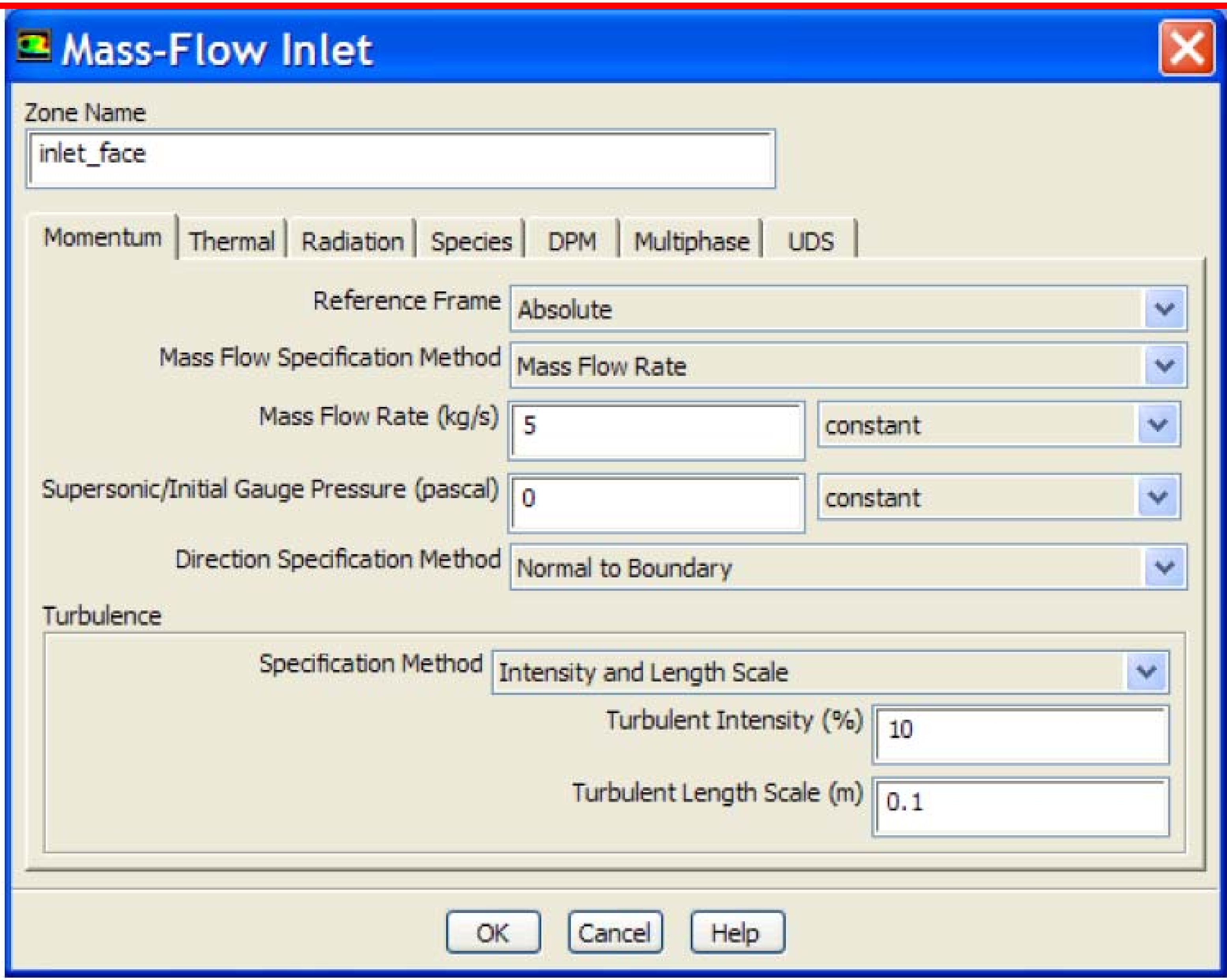
① Total pressure adjusts to accommodate mass flow inputs.

② More difficult to converge than pressure inlet.

**2) Required information**

① Mass Flow Rate or Mass Flux

② Supersonic/Initial Gauge Pressure


Mass-Flow Inlet
Zone Name
inlet_face
Momentum
Thermal
Radiation
Species
DPM
Multiphase
UDS
Reference Frame
Absolute
Mass Flow Specification Method
Mass Flow Rate
Mass Flow Rate (kg/s)
5
constant
Supersonic/Initial Gauge Pressure (pascal)
0
constant
Direction Specification Method
Normal to Boundary
Turbulence
Specification Method
Intensity and Length Scale
Turbulent Intensity (%)
10
Turbulent Length Scale (m)
0.1
OK
Cancel
Help

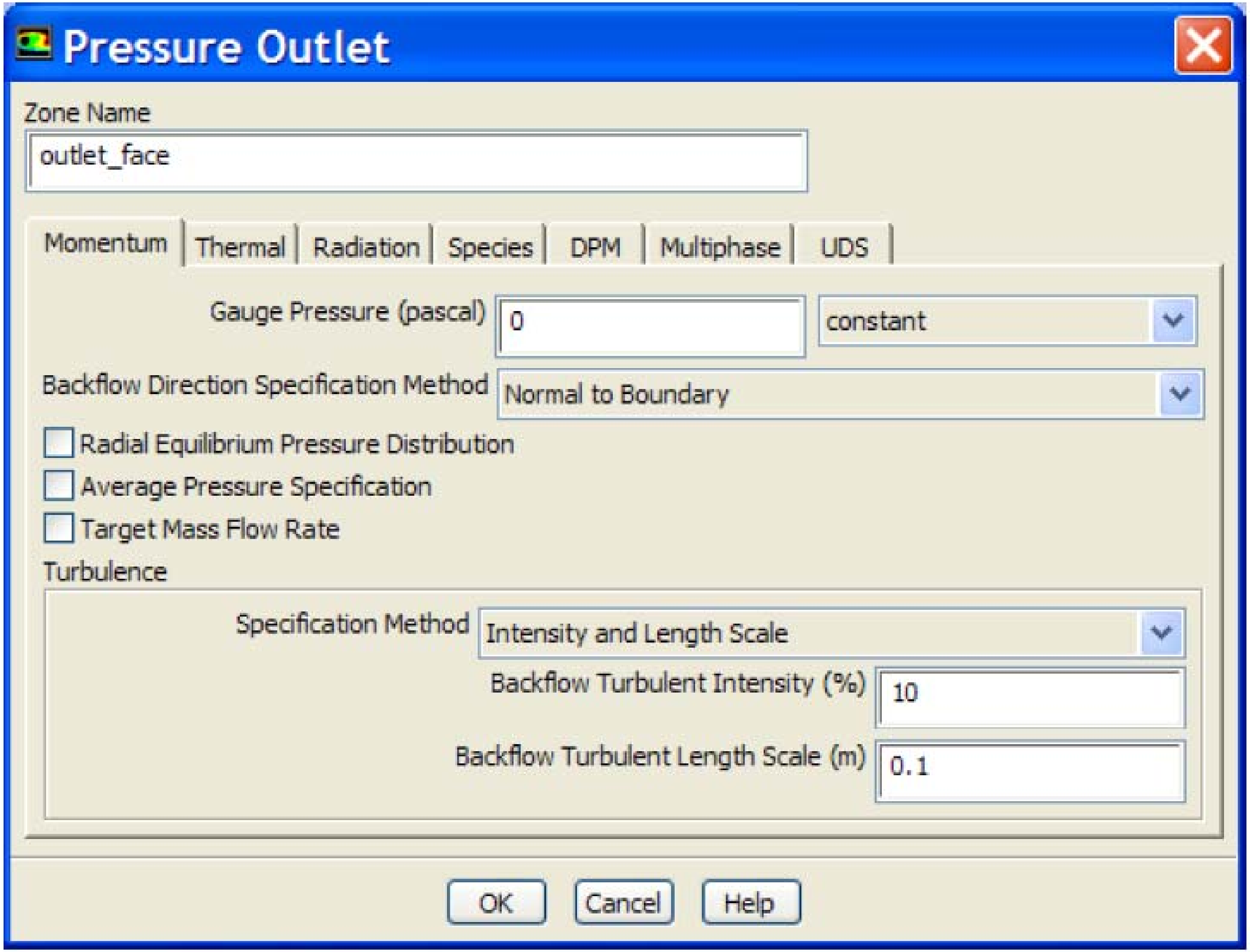
# ◆Boundary Conditions - Pressure Outlet

**1) Suitable for compressible and incompressible flows.**

**2) Required information**

**① Gauge Pressure (static)–static pressure of the environment into which the flow exits.**

**② Backflow quantities–Used as inlet conditions when backflow occurs (outlet acts like an inlet).**

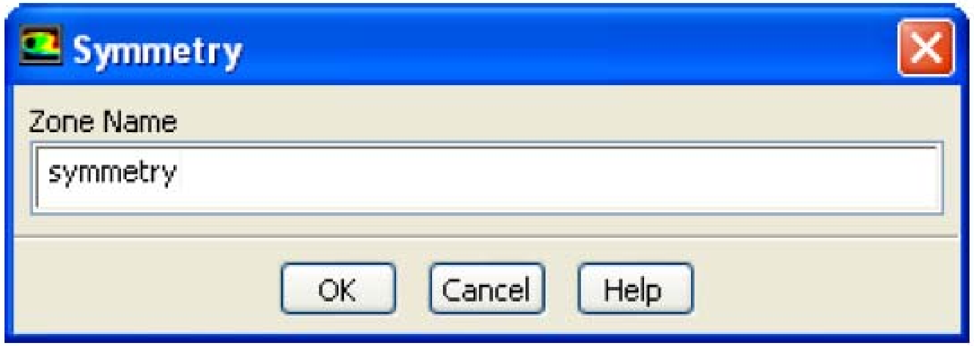

Pressure Outlet
Zone Name
outlet_face
Momentum
Thermal
Radiation
Species
DPM
Multiphase
UDS
Gauge Pressure (pascal)
0
constant
Backflow Direction Specification Method
Normal to Boundary
Radial Equilibrium Pressure Distribution
Average Pressure Specification
Target Mass Flow Rate
Turbulence
Specification Method
Intensity and Length Scale
Backflow Turbulent Intensity (%)
10
Backflow Turbulent Length Scale (m)
0.1
OK
Cancel
Help

# ◆Boundary Conditions - Symmetry and Axis

- **Symmetry Boundary**

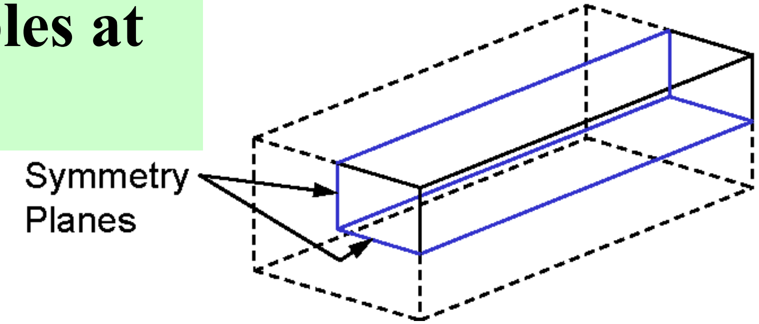
**① No inputs are required.**

**② Flow field and geometry must be symmetric:**




**③ Zero normal velocity at symmetry plane**

**④ Zero normal gradients of all variables at symmetry plane**




- **Axis Boundary**

**①The center axisymmetric problems used at line for problems.**

**② No user inputs required.**

## ◆Boundary Conditions - Periodic Boundaries

1) Used to reduce the overall mesh size.

2) Flow field and geometry must contain either rotational or translational periodicity.

3) Rotational periodicity

- $\Delta P$=0 across periodic planes.
- Axis of rotation must be defined in fluid zone.

4) Translational periodicity

$\Delta P$ can be finite across periodic planes.

5) Rotationally periodic planes

Models fully developed conditions.

Specify either mean $\Delta P$ per period or net mass flow rate.

## ◆Boundary Conditions - Internal Faces

① **Defined on the cell faces only:**

– **Thickness of these internal faces is zero**

– **These internal faces provide means of introducing step changes in flow properties.**

② **Used to implement various physical models including:**

– **Fans**

– **Radiators**

③ **Preferable over porous media for its better convergence behavior.**

– **Interior walls**

④ **The "interior" type of internal face zone does not require any input.**

## ◆Boundary Conditions - Outflow

① No pressure or velocity information is required.

– Data at exit plane is extrapolated from interior.

– Mass balance correction is applied at boundary.

② Flow exiting outflow boundary exhibits zero normal diffusive flux for all flow variables.

– Appropriate where the exit flow is fully developed.

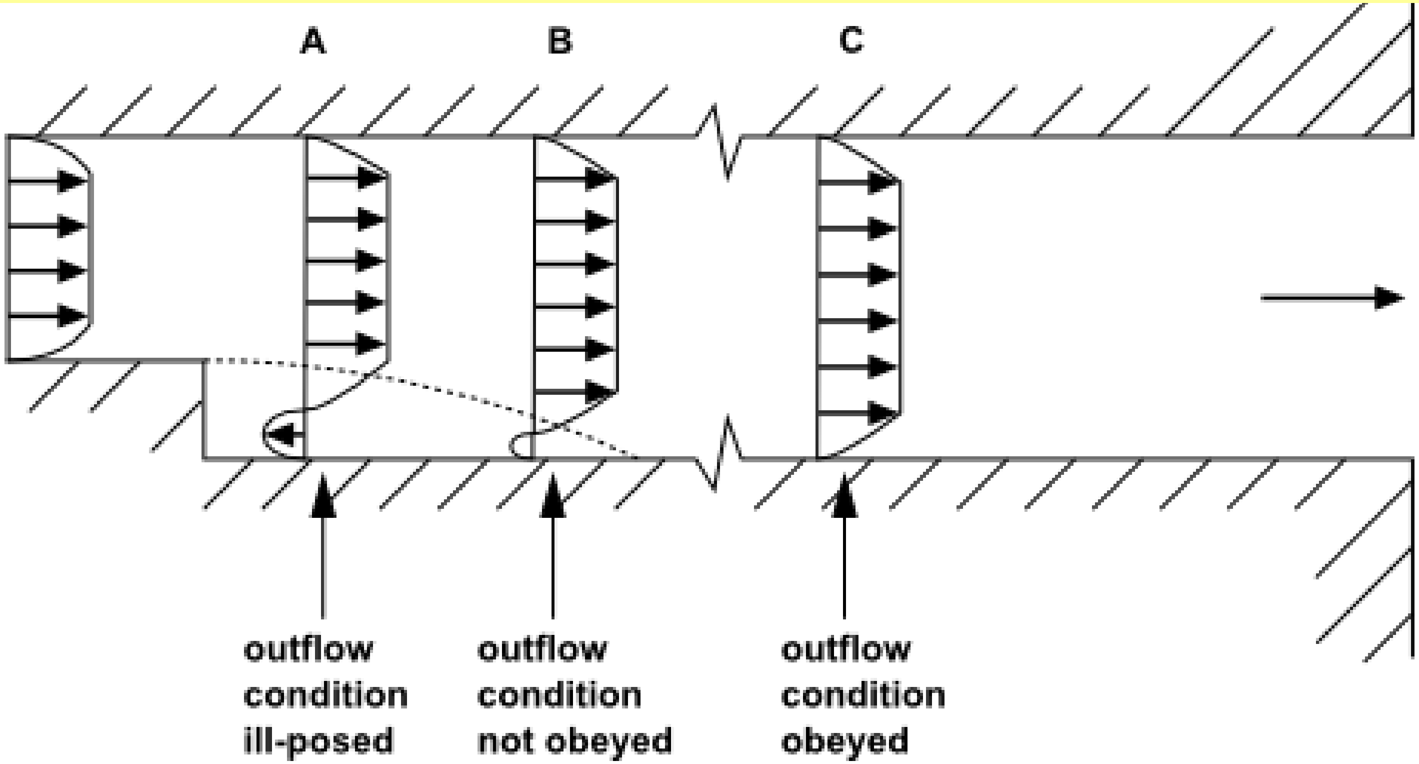
③ The outflow boundary is intended for use with incompressible flows.

– Cannot be used with a pressure inlet boundary (must use velocity-inlet).

④ **Cannot be used for unsteady flows with variable density.**

⑤ **Poor rate of convergence when backflow occurs during iterations.**

**Cannot be used if backflow is expected in the final solution.**



## ◆Wall Boundary Conditions

### • Five thermal conditions

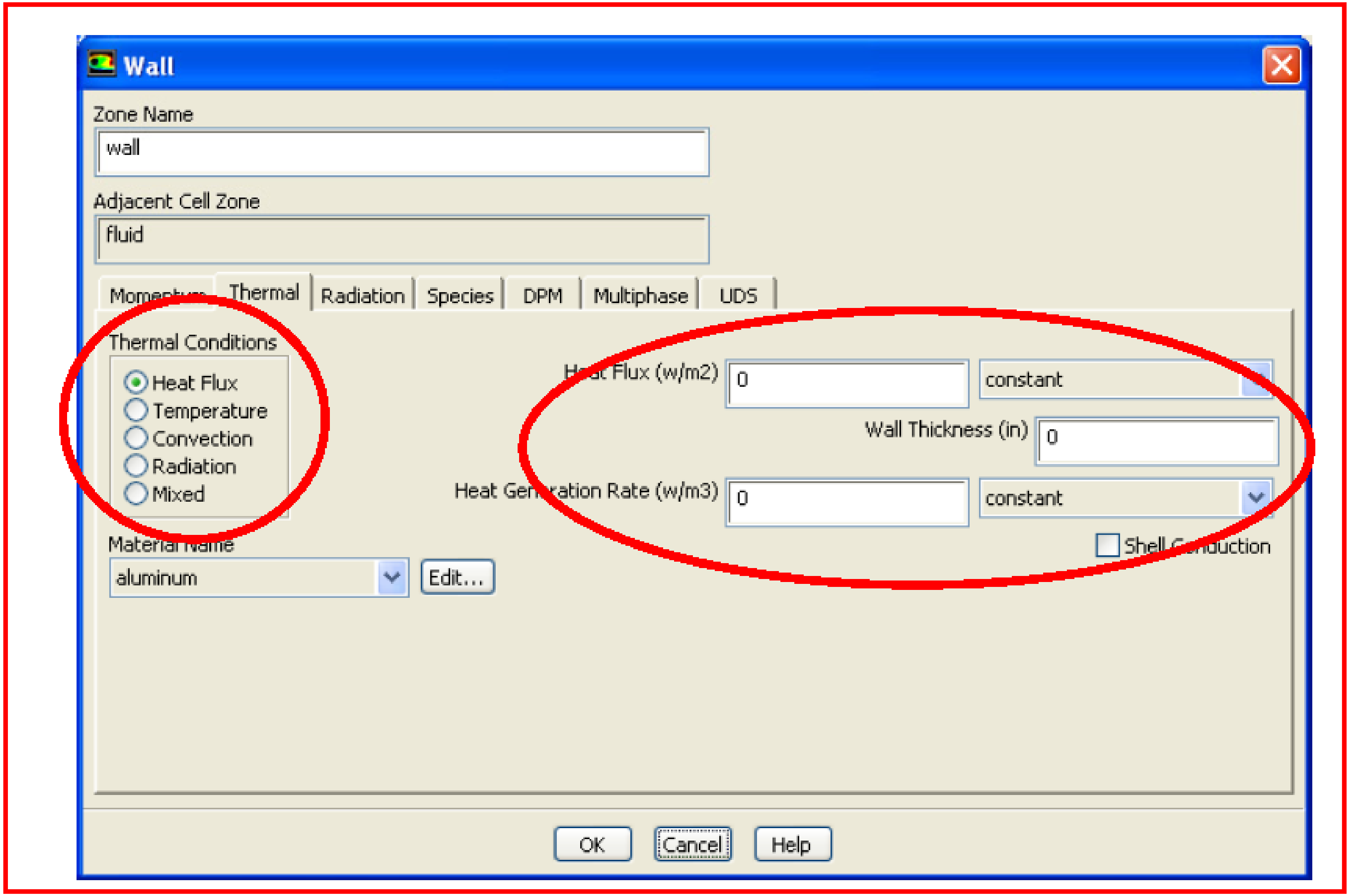
① **Heat Flux**

② **Temperature**

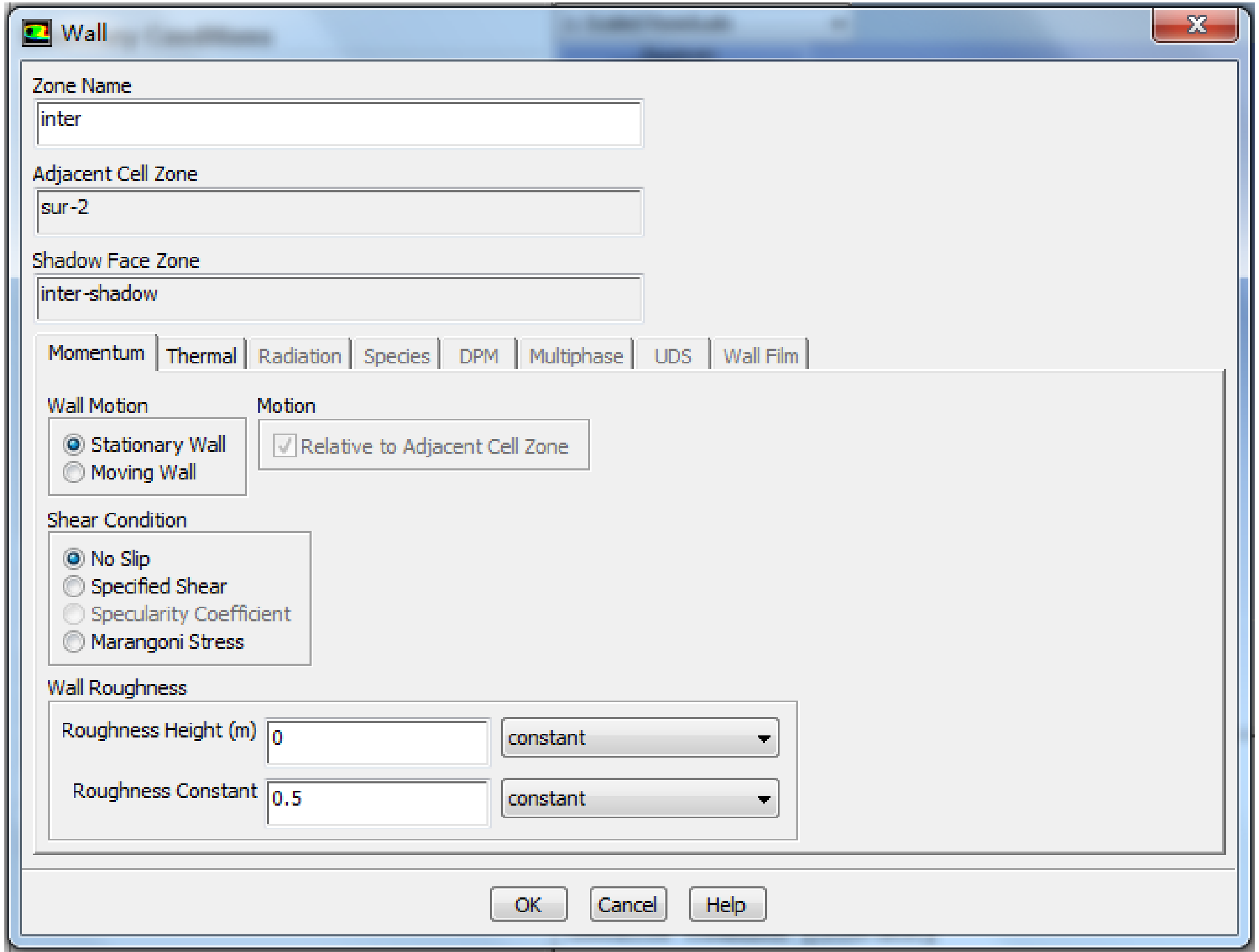
③ **Convection–simulates an external convection environment which is not modeled (user-prescribed heat transfer coefficient).**

④ **Radiation – simulates an external radiation environment which is not modeled (user-prescribed external emissivity and radiation temperature).**

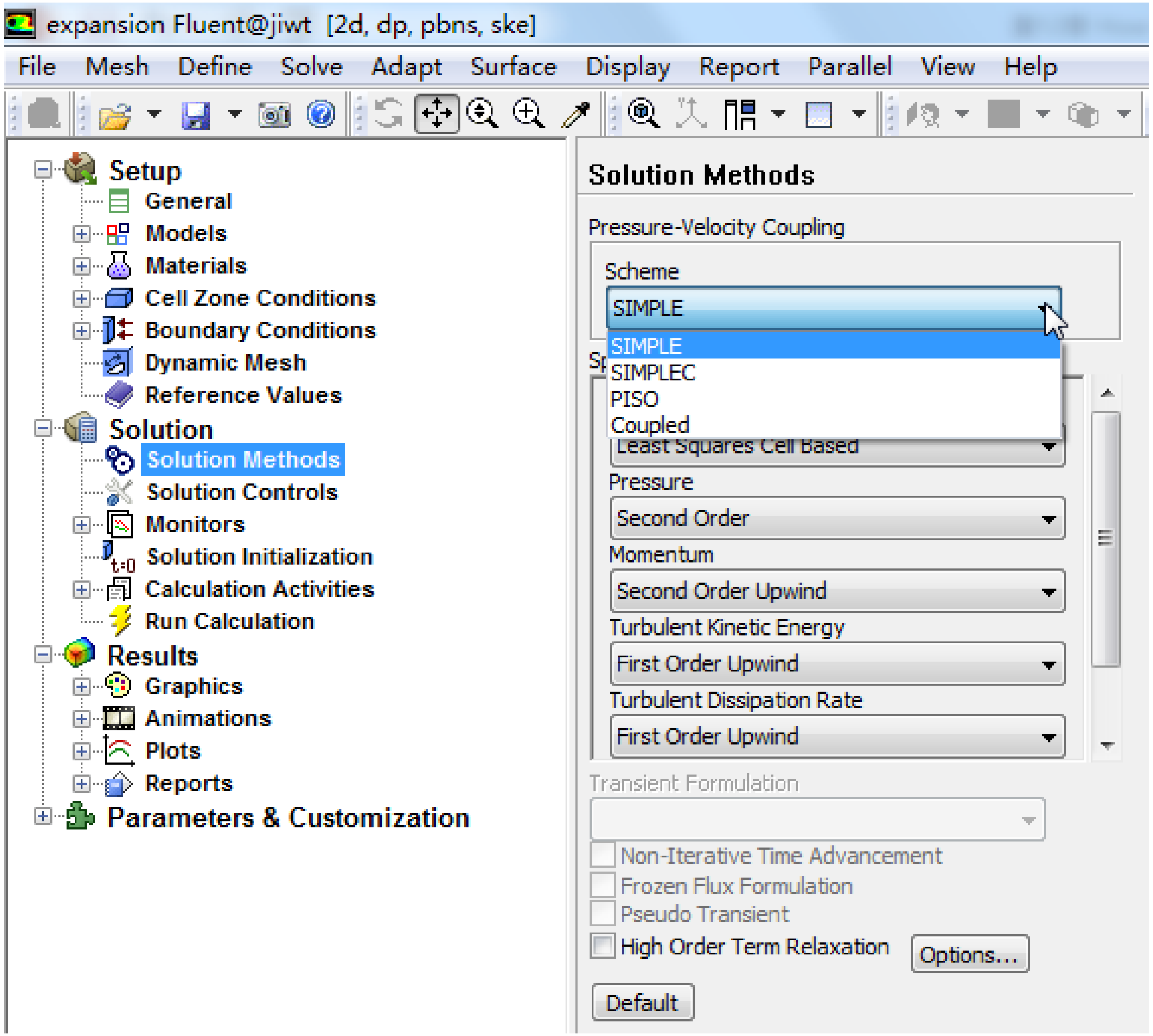
⑤ **Mixed– Combination of Convection and Radiation boundary conditions.**


Wall
Zone Name
wall
Adjacent Cell Zone
fluid
Momentum
Thermal
Radiation
Species
DPM
Multiphase
UDS
Thermal Conditions
Heat Flux
Temperature
Convection
Radiation
Mixed
Heat Flux (w/m2)
0
constant
Wall Thickness (in)
0
Heat Generation Rate (w/m3)
0
constant
Shell Conduction
Material Name
aluminum
Edit...
OK
Cancel
Help

# Momentum conditions



# 6. Solution Methods



# Solution Procedure Overview

① Select the solution parameters

- Choosing the Solver
- Discretization Schemes

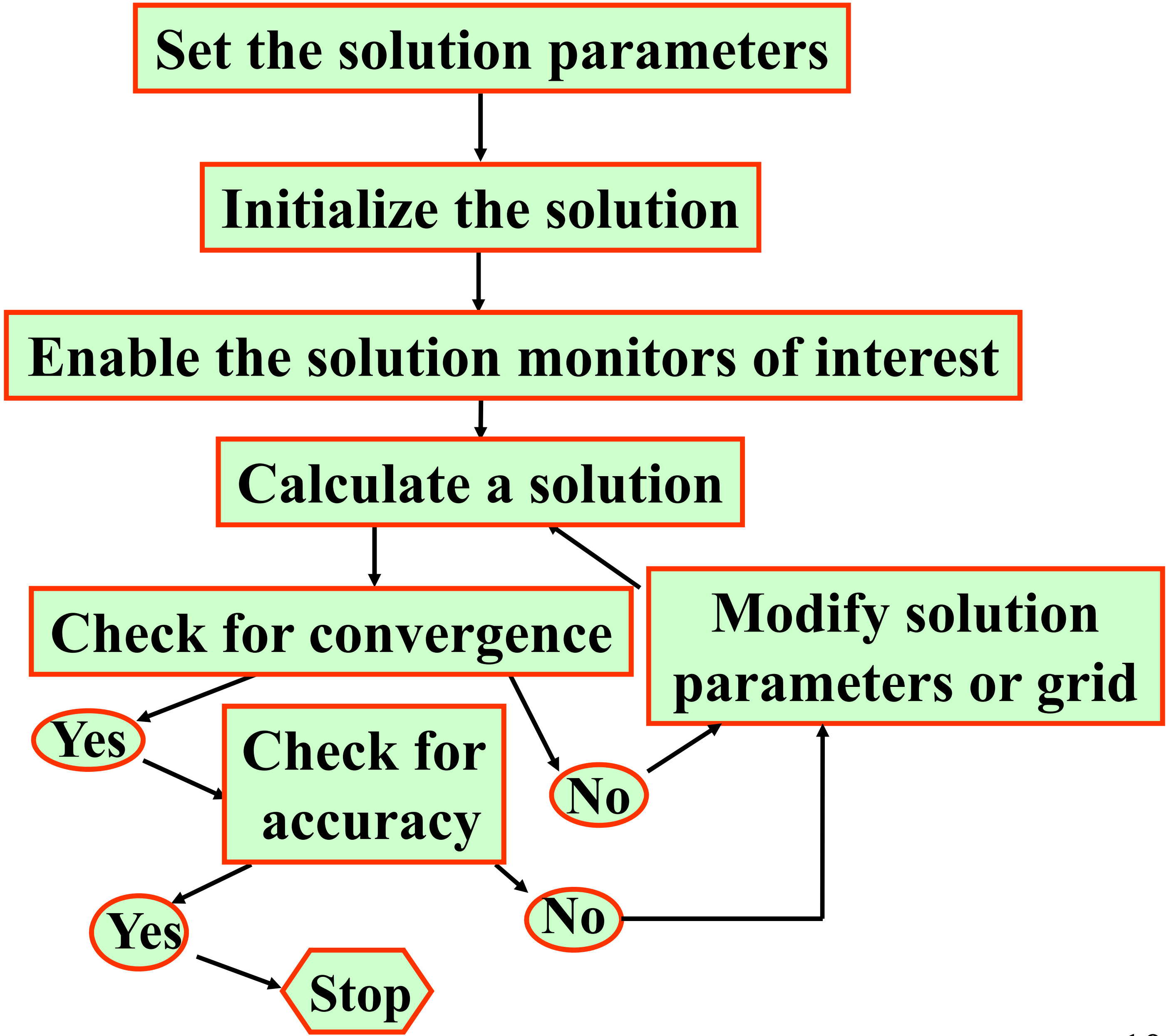
② Initialization

③ Check the convergence behavior

- Monitoring Convergence Stability
  - Setting Under-relaxation factor
  - Setting Courant number
- Accelerating Convergence

④ Evaluation the accuracy of computation result

- Grid Independence
- Adaption


Set the solution parameters
Initialize the solution
Enable the solution monitors of interest
Calculate a solution
Check for convergence
Modify solution parameters or grid
Yes
No
Check for accuracy
Yes
No
Stop

# Solver Settings

- **By modifying the solver settings you can improve both:**

**① The rate of convergence of the simulation. (Chapter 6 求解椭圆形流动)**
**② The accuracy of the computed result.(Chapter 5 对流-扩散方程的离散格式)**

**To Consider:**

**① The choice of solver**
**② Discretization schemes**
**③ Checking convergence**
**④ Assessing accuracy**

## ◆Available Solvers

① There are two kinds of solvers available in FLUENT:

– Pressure based
– Density based

② The pressure-based solvers take momentum and pressure (or pressure correction) as the primary variables(such as SIMPLE Algorithm)

③ Two algorithms are available with the pressure-based solvers:

- Segregated solver– Solves for pressure correction and momentum sequentially.(SIMPLE, SIMPLC, PISO)
- Coupled Solver (PBCS) – Solves pressure and momentum simultaneously(COUPLED).

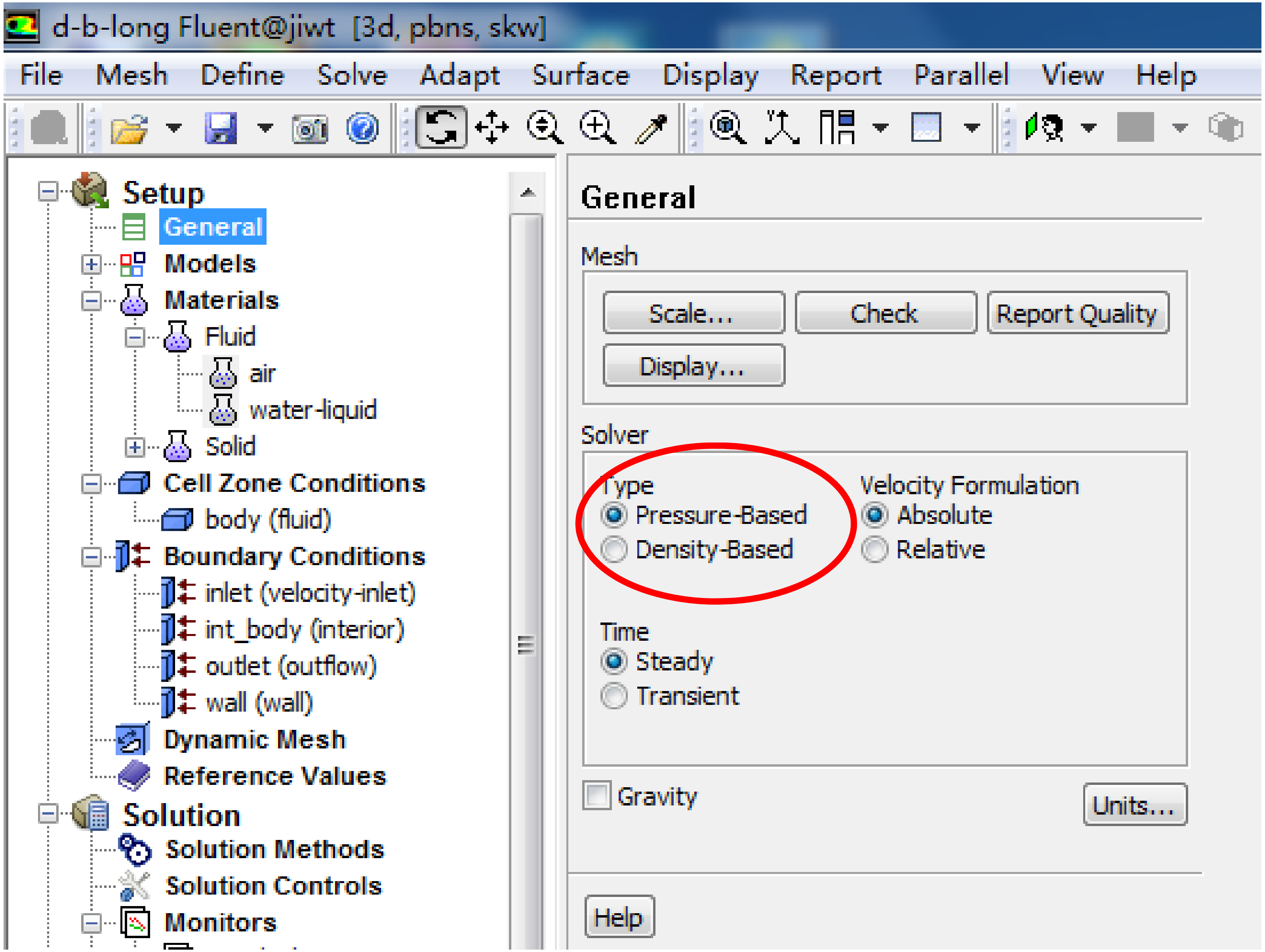
## ④ Density-Based Coupled Solver

– Equations for continuity, momentum, energy and species (if required) are solved in vector form.

– Pressure is obtained through an equation of state.

– Additional scalar equations are solved in a segregated fashion.

• The Density-Based Coupled Solver can be run either explicit or implicit.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air
water-liquid
Solid
Cell Zone Conditions
body (fluid)
Boundary Conditions
inlet (velocity-inlet)
int_body (interior)
outlet (outflow)
wall (wall)
Dynamic Mesh
Reference Values
Solution
Solution Methods
Solution Controls
Monitors
General
Mesh
Scale...
Check
Report Quality
Display...
Solver
Type
Pressure-Based
Density-Based
Velocity Formulation
Absolute
Relative
Time
Steady
Transient
Gravity
Units...
Help

# ◆Choosing a Solver

① The pressure-based solver is applicable for a wide range of flow regimes from low speed incompressible flow to high-speed compressible flow.

– Requires less memory (storage).

– Allows flexibility in the solution procedure.

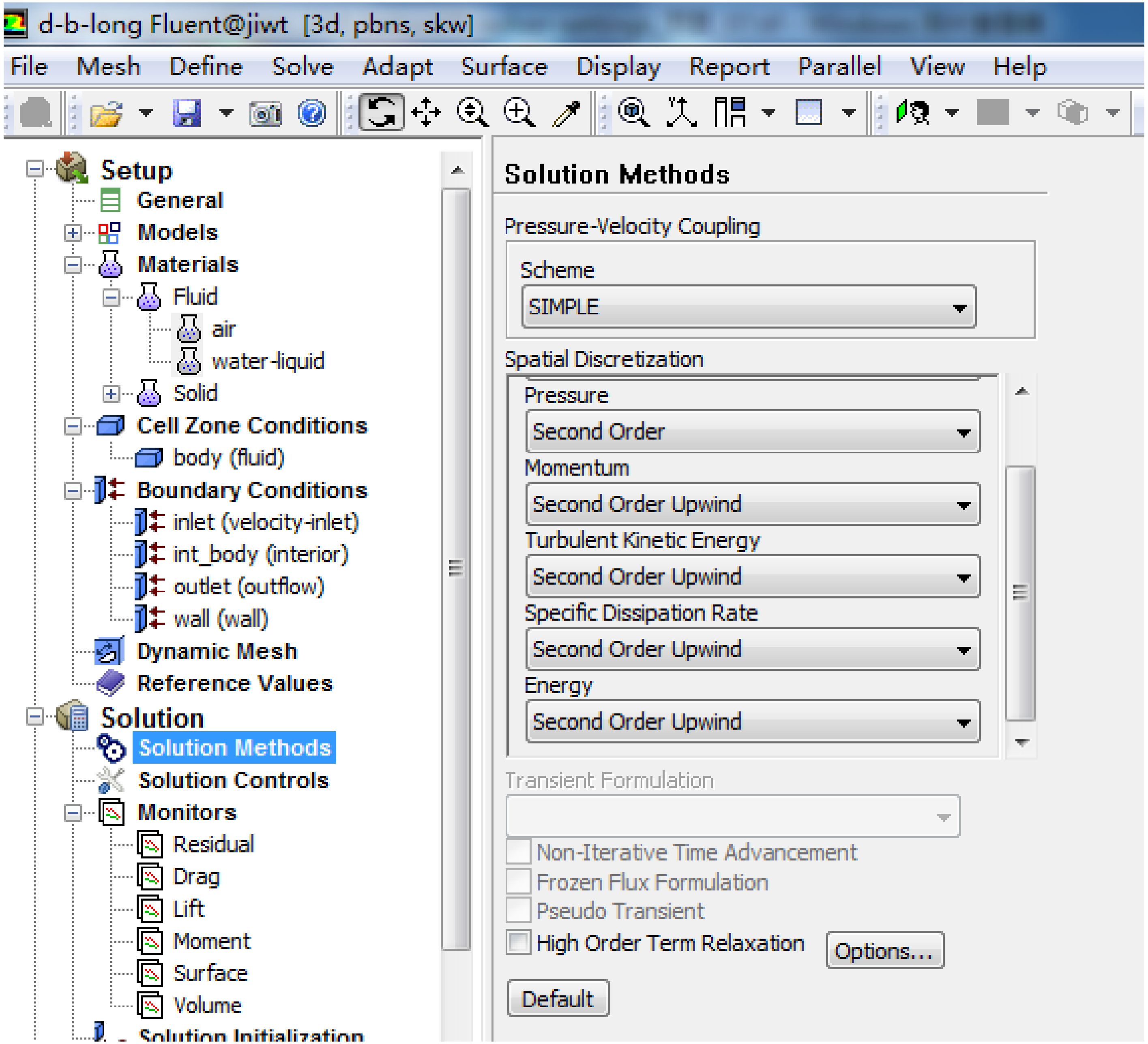
② The pressure-based coupled solver (PBCS) is applicable for most single phase flows, and yields superior performance to the standard pressure-based solver.

– Requires 1.5–2 times more memory than the segregated solver.

③ **The density-based coupled solver (DBCS)** is applicable when there is a strong coupling, or interdependence, between density, energy, momentum, and/or species.

- Examples: High speed compressible flow with combustion, hypersonic flows, shock interactions.
- The implicit option is generally preferred over explicit since it has a very strict limit on time step size
- The explicit approach is used for cases where the characteristic time scale of the flow is on the same order as the acoustic time scale. (e.g. propagation of high-Ma shock waves).

**Note: the pressure-based solvers are implicit**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int_body (interior)
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wall (wall)
Dynamic Mesh
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Solution Methods
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Surface
Volume
Solution Initialization
Solution Methods
Pressure-Velocity Coupling
Scheme
SIMPLE
Spatial Discretization
Pressure
Second Order
Momentum
Second Order Upwind
Turbulent Kinetic Energy
Second Order Upwind
Specific Dissipation Rate
Second Order Upwind
Energy
Second Order Upwind
Transient Formulation
Non-Iterative Time Advancement
Frozen Flux Formulation
Pseudo Transient
High Order Term Relaxation
Options...
Default

## ◆ Interpolation schemes for the convection term(Chapter 5):

① **First-Order Upwind**–Easiest to converge, only first-order accurate.

② **Power Law** – More accurate than first-order for flows when $Re_{cell}$ <5 (typ. low Re flows)

③ **Second-Order Upwind** – Uses larger stencils for 2nd order accuracy, essential with tri/tet mesh or when flow is not aligned with grid; convergence may be slower.

④ **Monotone Upstream-Centered Schemes for Conservation Laws (MUSCL)** – Locally 3$^{rd}$ order convection discretization scheme for unstructured meshes; more accurate in predicting secondary flows, vortices, forces, etc.

⑤ **Quadratic Upwind Interpolation (QUICK)**–Applies to quad/hex and hybrid meshes, useful for rotating/swirling flows, 3rd-order accurate on uniform mesh.

# Interpolation Methods (Gradients)

① **Gradients of solution variables are required in order to evaluate diffusive fluxes, velocity derivatives, and for higher-order discretization schemes.**

② **The gradients of solution variables at cell centers can be determined using three approaches:**

- **Green-Gauss Cell-Based– Least computationally intensive. Solution may have false diffusion.**
- **Green-Gauss Node-Based–More accurate/computationally intensive; minimizes false diffusion; recommended for unstructured meshes.**
- **Least-Squares Cell-Based–Default method; has the same accuracy and properties as Node-based Gradients and is less computationally intensive.**

# Interpolation Methods for Pressure

**Interpolation schemes for calculating cell-face pressures when using the pressure-based solver in FLUENT are available as follows:**

**① Standard: The default scheme; reduced accuracy for flows exhibiting large surface-normal pressure gradients near boundaries**

**② PRESTO!: Use for highly swirling flows, flows involving steep pressure gradients, or in strongly curved domains**

**③ Linear: Use when other options result in convergence difficulties or unphysical behavior**

**④ Second-Order: Use for compressible flows; not to be used with porous media, jump, fans, etc. or VOF/Mixture multiphase models**

**⑤ Body Force Weighted: Use when body forces are large, e.g., high Ra natural convection or highly swirling flows**

## ◆Pressure-Velocity Coupling

Pressure-velocity coupling refers to the numerical algorithm which uses a combination of continuity and momentum equations to derive an equation for pressure (or pressure correction) when using the pressure-based solver.

Five algorithms are available in FLUENT.

① Semi-Implicit Method for Pressure-Linked Equations (SIMPLE)

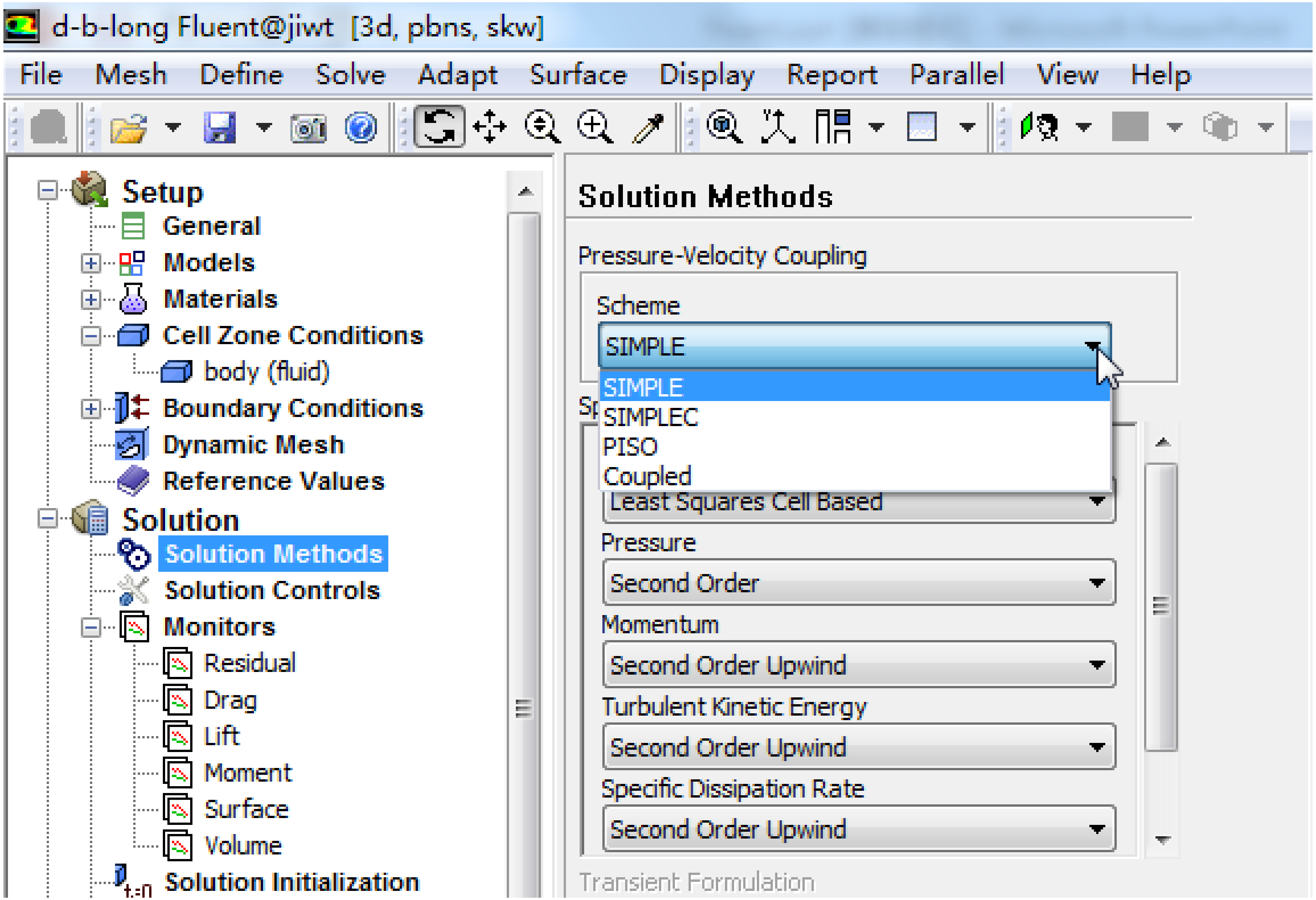
The default scheme, robust

② SIMPLE-Consistent (SIMPLEC)

Allows faster convergence for simple problems (e.g., laminar flows with no physical models employed).

③ Pressure-Implicit with Splitting of Operators (PISO)

Useful for unsteady flow problems or for meshes containing cells with higher than average skewness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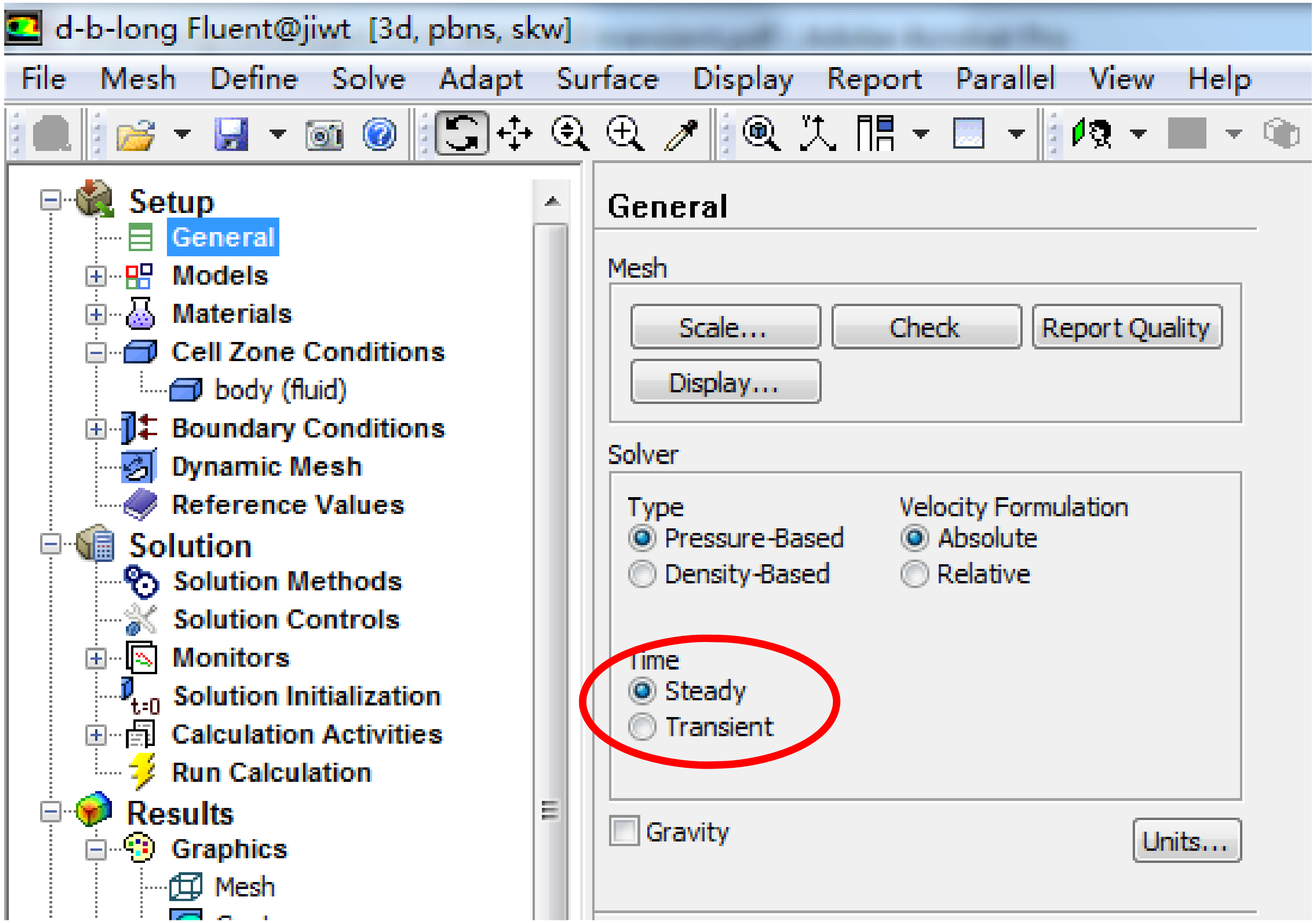
body (fluid)
Boundary Conditions
Dynamic Mesh
Reference Values
Solution
Solution Methods
Solution Controls
Monitors
Residual
Drag
Lift
Moment
Surface
Volume
Solution Initialization
Solution Methods
Pressure-Velocity Coupling
Scheme
SIMPLE
SIMPLE
SIMPLEC
PISO
Coupled
Least Squares Cell Based
Pressure
Second Order
Momentum
Second Order Upwind
Turbulent Kinetic Energy
Second Order Upwind
Specific Dissipation Rate
Second Order Upwind
Transient Formulation

# ◆Enabling the Transient Solver

• To enable the transient solver, select the Transient button on the General problem setup form:



① **Before performing iterations, you will need to set some additional controls.**

- **Solver settings**
- **Animations**
- **Data export/Autosave options**

② **Selecting the Transient Time Step Size**

**Time step size, $\Delta t$, is set in the Run Calculation form.**

- **$\Delta t$ must be small enough to resolve time-dependent features; make sure convergence is reached within the number of Max Iterations per Time Step**
- **The order or magnitude of an appropriate time step size can be estimated as:**

$$\Delta t \approx \frac{\text{Typical cell size}}{\text{Characteristic flow velocity}}$$

**Time step size estimate can also be chosen so that the transient characteristics of the flow can be resolved (e.g. flow within a known period of fluctuations)**

**① A good way to judge the choice of *Δt* is to observe the number of iterations. FLUENT needs to converge at each time step. The ideal number of iterations per time step is 5–10. If FLUENT needs substantially more, the time step is too large. If FLUENT needs only a few iterations per time step, it should be increased.**

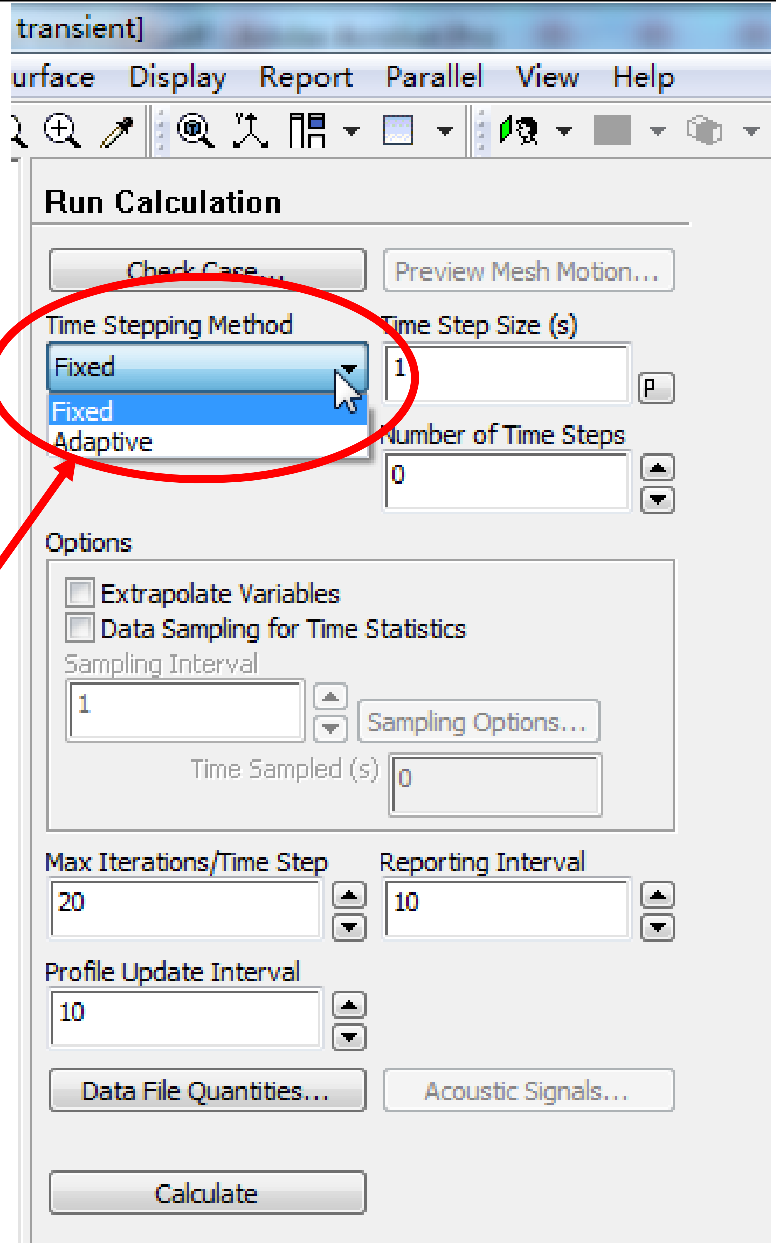
② It is often wise to choose a conservatively small for the first 5–10 time steps. Then gradually increased it as the calculation proceeds.

③ To iterate without advancing in time, specify zero time steps. This will instruct the solver to converge the current time step only.

④ The PISO scheme may aid in accelerating convergence for many transient flows form.

# Transient Flow Modeling Options

- **Adaptive Time Stepping**



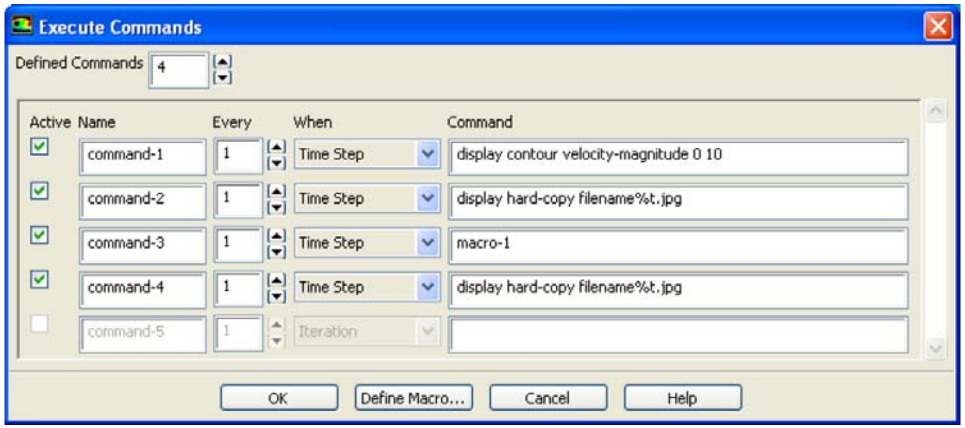

**Automatically adjusts time-step size based on local truncation error analysis**

## Creating Animations

This approach is very useful in creating high-quality animations of CFD results.

– A command is defined which generates an animation frame (contour plot, vector plot, etc.) and then writes that frame to a hard copy file.

– Third-party software can then be used to link the hard copy files into an animation file (AVI, MPG, GIF, etc.)



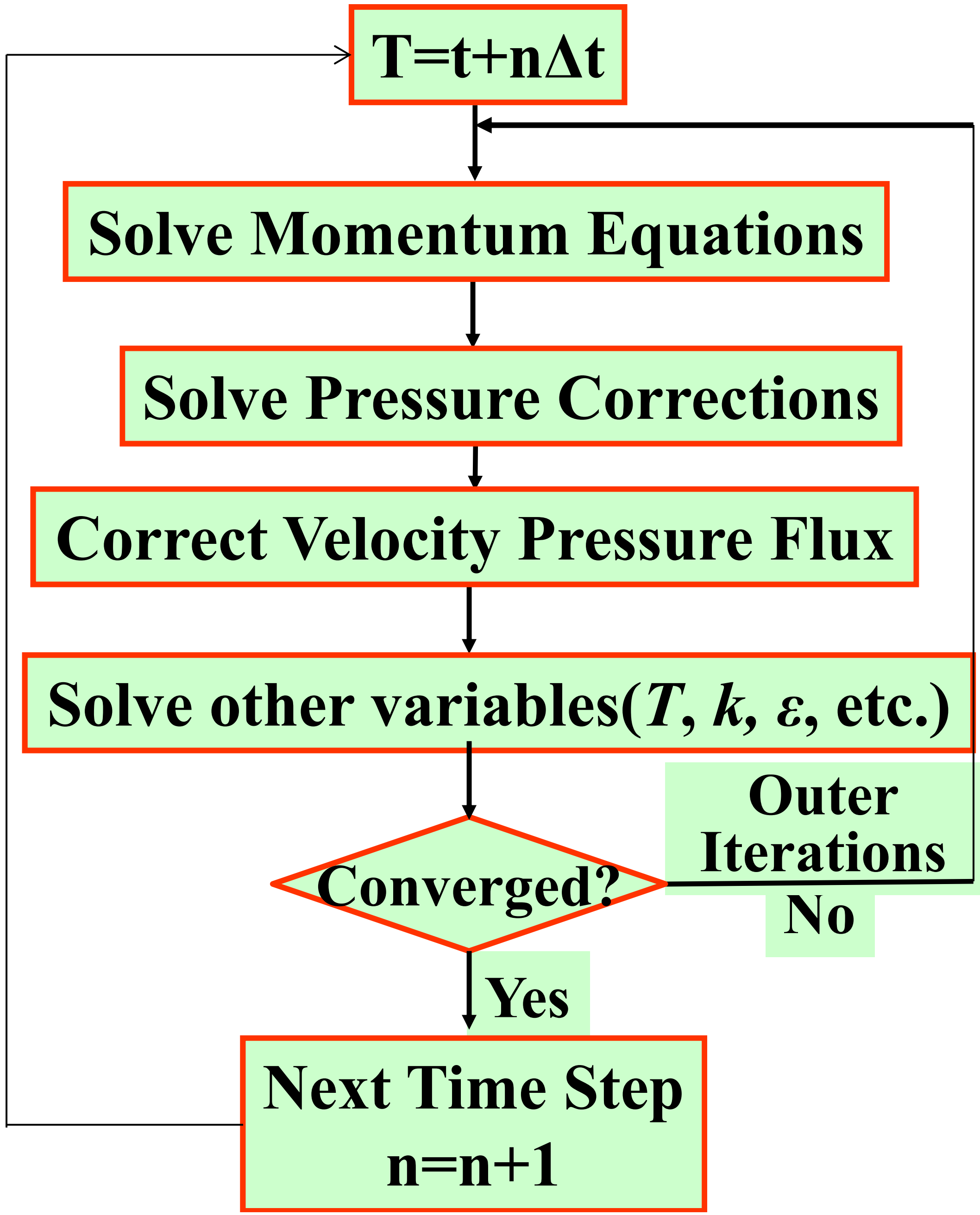
## ◆Performing Iterations

① The most common time advancement scheme is the iterative scheme.

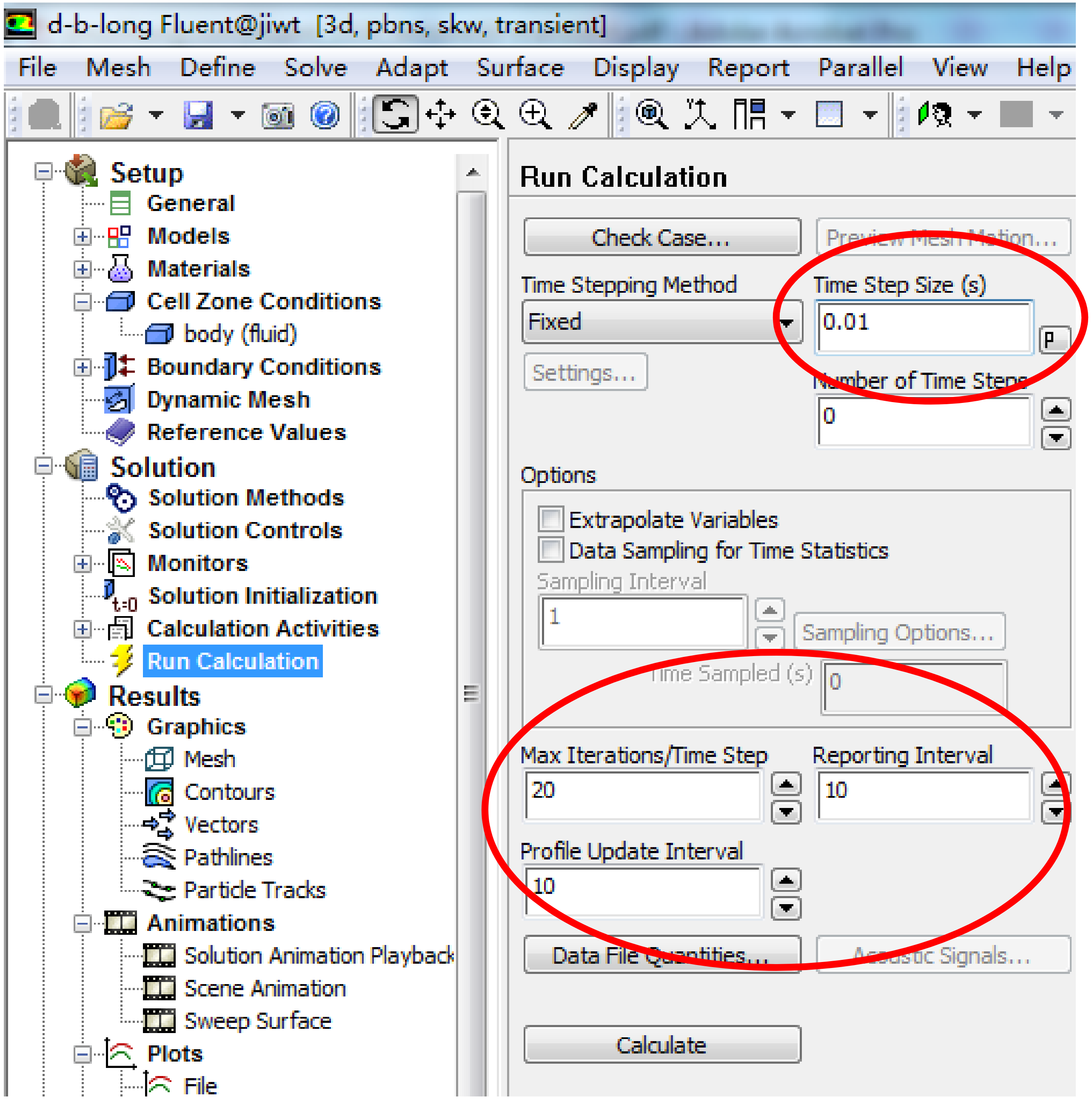
- The solver converges the current time step and then advances time.
- Time is advanced when Max Iterations/Time Step is reached or convergence criteria are satisfied.
- Time steps are converged sequentially until the Number of Time Steps is reached.

② Solution initialization defines the initial condition and it must be realistic.

Sets both the initial mass of fluid in the domain and the initial state of the flow field.




**Overview of the Iterative Time Advancement Solution Method for the Segregate Solver**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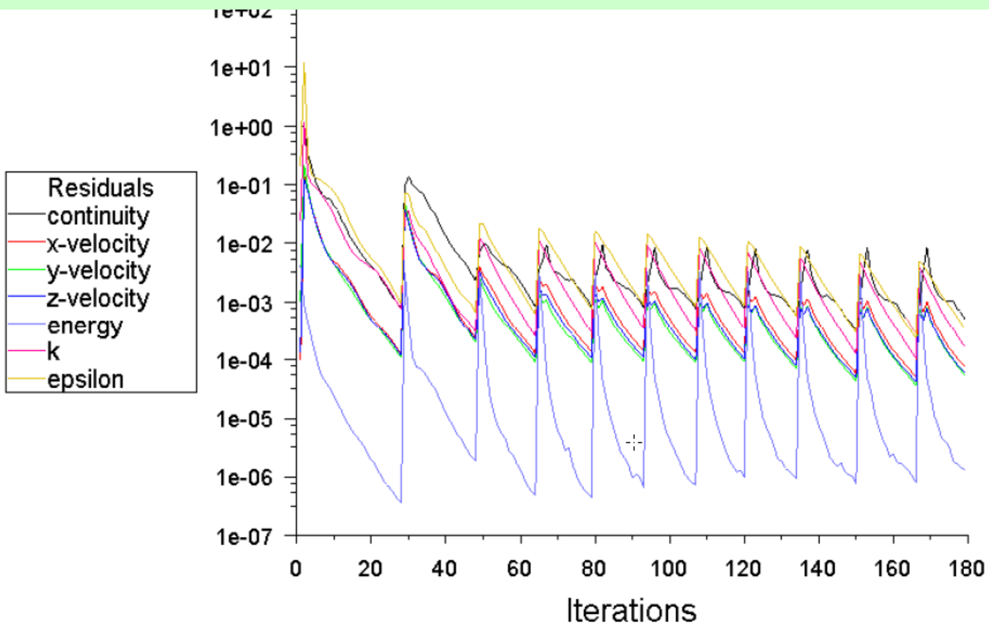
Solution Methods
Solution Controls
Monitors
Solution Initialization
Calculation Activities
Run Calculation
Results
Graphics
Mesh
Contours
Vectors
Pathlines
Particle Tracks
Animations
Solution Animation Playback
Scene Animation
Sweep Surface
Plots
File
Run Calculation
Check Case...
Preview Mesh Motion...
Time Stepping Method
Fixed
Settings...
Time Step Size (s)
0.01
Number of Time Steps
0
Options
Extrapolate Variables
Data Sampling for Time Statistics
Sampling Interval
1
Sampling Options...
Time Sampled (s)
0
Max Iterations/Time Step
20
Reporting Interval
10
Profile Update Interval
10
Data File Quantities...
Acoustic Signals...
Calculate

# ◆Convergence Behavior

① **Residual plots for transient simulations are not always indicative of a converged solution.**

② **You should select the time step size such that the residuals reduce by around three orders of magnitude within one time step.**

**This will ensure accurate resolution of transient behavior.**



# ◆Tips for Success in Transient Flow Modeling

① Use PISO scheme for Pressure-Velocity Coupling-this scheme provides faster convergence for transient flows than the standard SIMPLE approach.

② Select the time step size so that the solution converges three orders of magnitude for each time step(convergence behavior is also problem-specific).

③ Select the number of iterations per time step to be around 20 – it is better to reduce the time step size than to do too many iterations per time step.

④ Remember that accurate initial conditions are just as important as boundary conditions for transient problems – initial condition should always be physically realistic!

⑤ Configure any animations you wish to see before running the calculations.

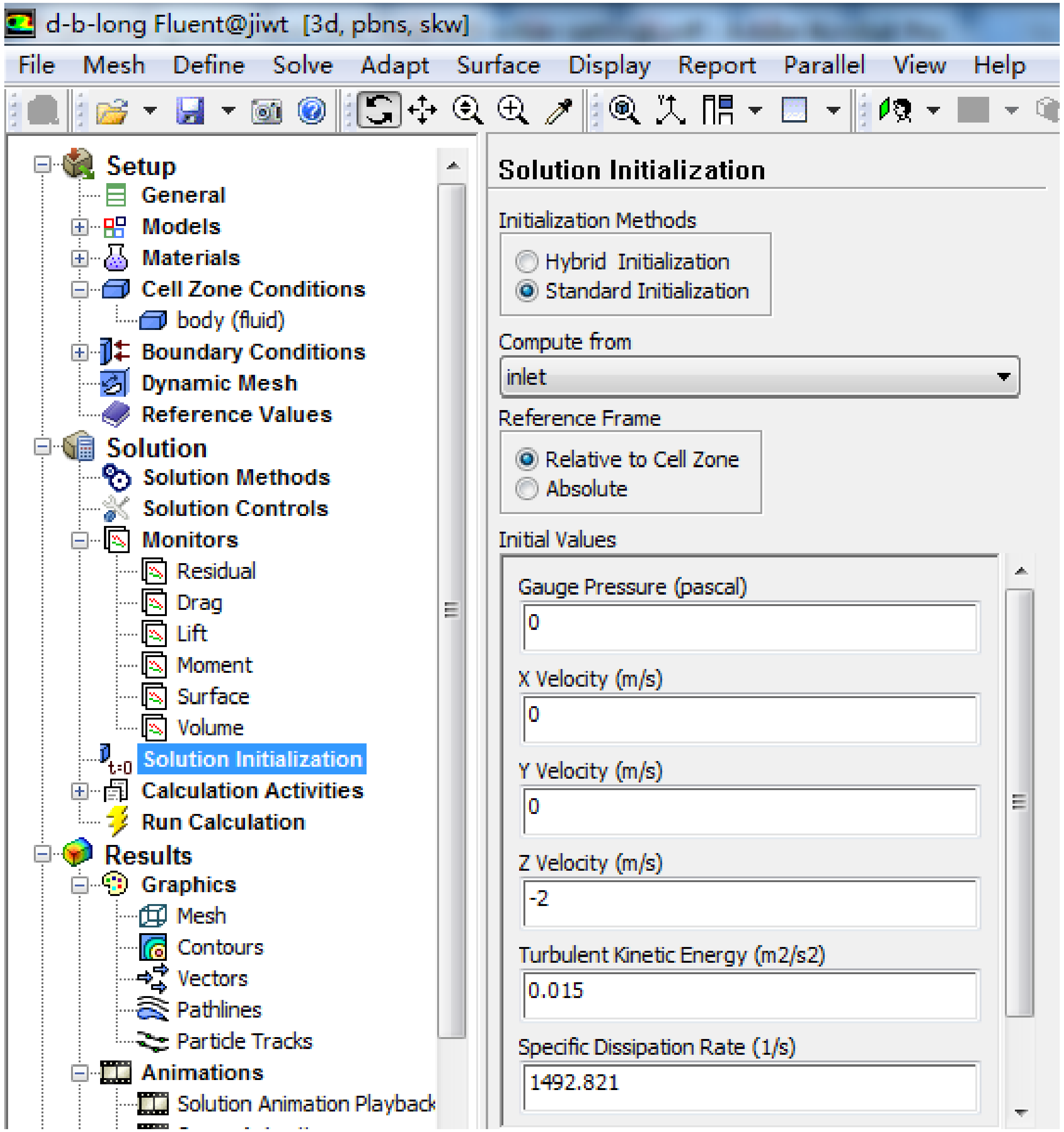
# 7.Solution Initialization

1)The solver works in an iterative manner.

2)Therefore, before the very first iteration, a value must exist for every quantity in every grid cell.

3)Setting this value is called ‘Initialization’

4) The more realistic the value, the better (quicker)convergence will be.

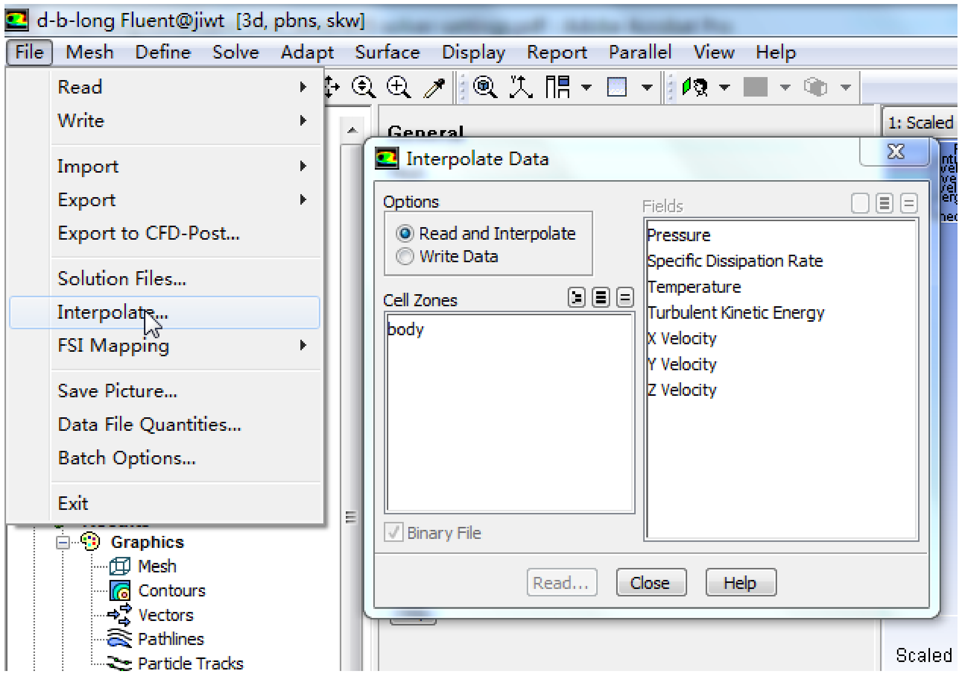


# ◆Starting from a Previous Solution

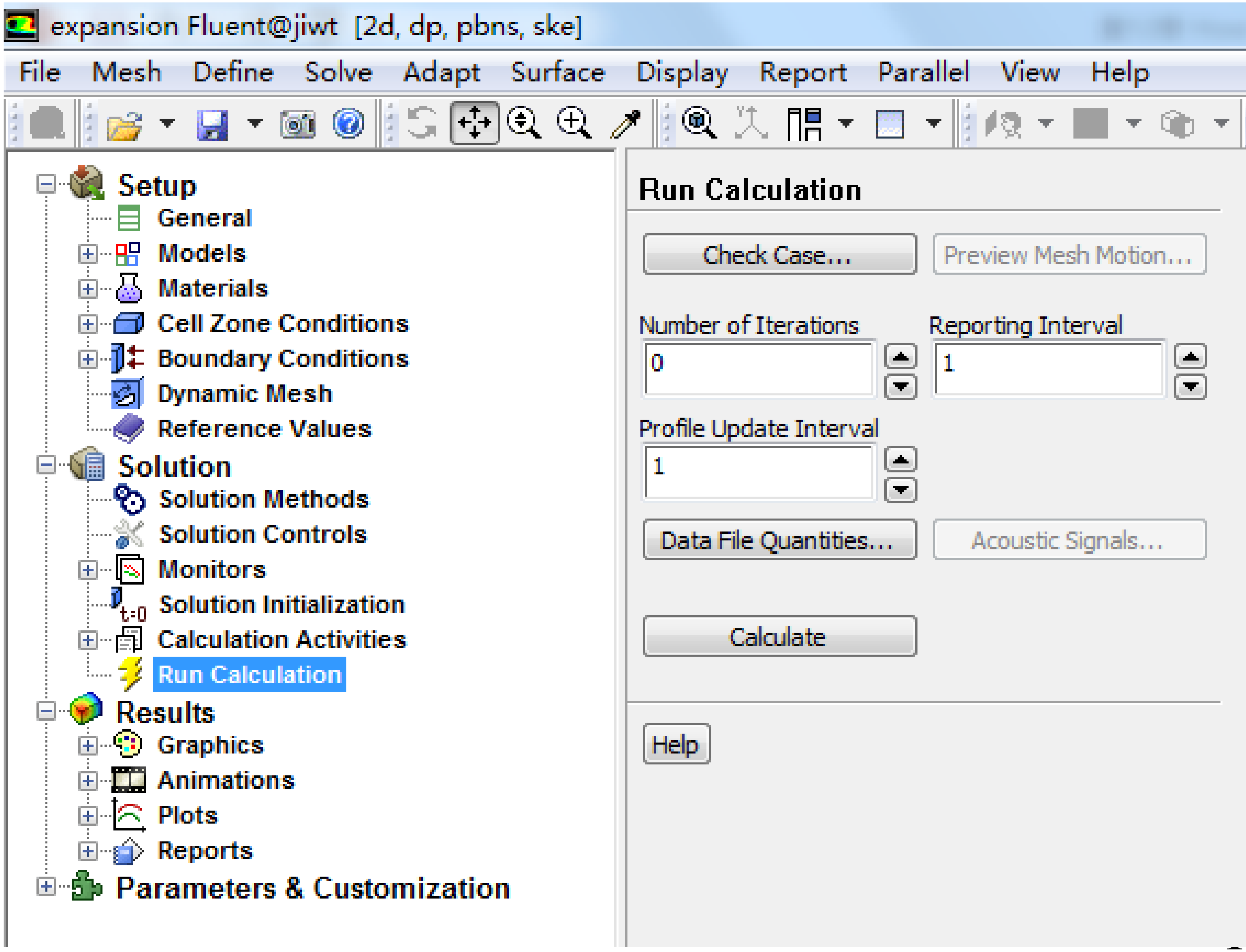
- Convergence rates are dependent on how good the starting point is.

- **Therefore if you already have a similar result from another simulation, you can save time by interpolating that result into the new simulation.**

- Then use the 'Read and Interpolate' option on the new model.



# 8.Run Calculation

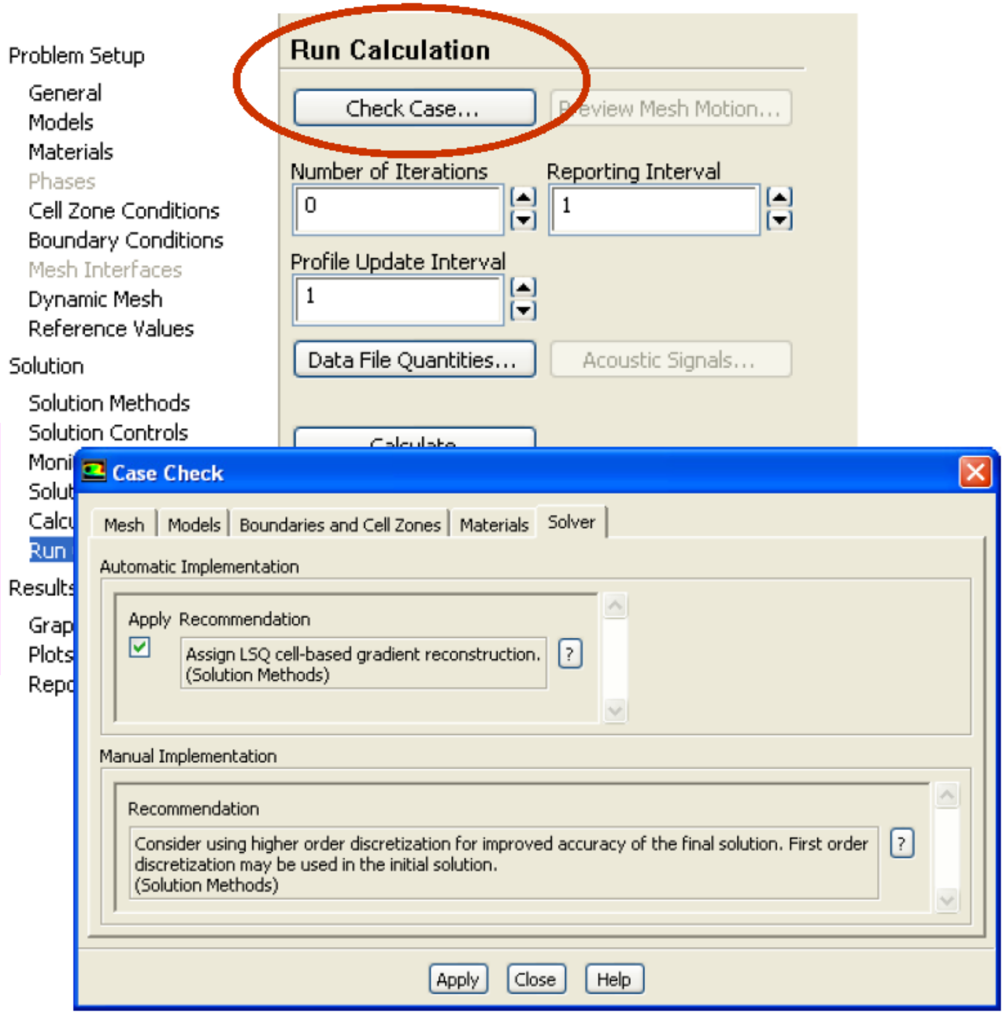


# ◆Case Check

① Case Check is a utility in FLUENT which searches for common setup errors and inconsistencies.

② It provides guidance in selecting case parameters and models.

③ Contain recommendations which the user can optionally apply or ignore.



## ◆Convergence

- The solver should be given sufficient iterations so that the problem is converged.

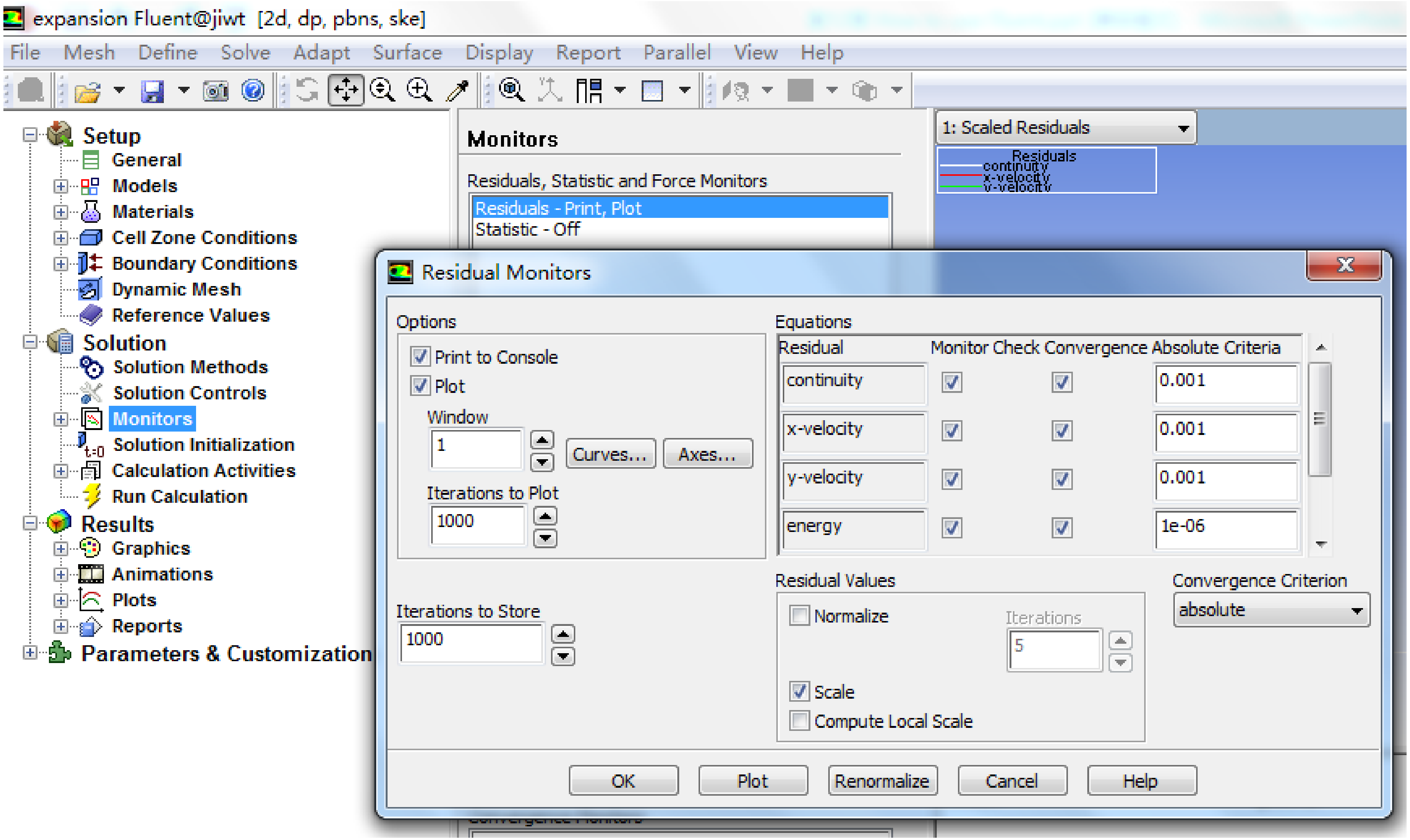
- At convergence, the following should be satisfied:

① The solution no longer changes with subsequent iterations.

② Overall mass, momentum, energy, and scalar balances are achieved.

③ All equations (momentum, energy, etc.) are obeyed in all cells to a specified tolerance

# 9. Monitoring



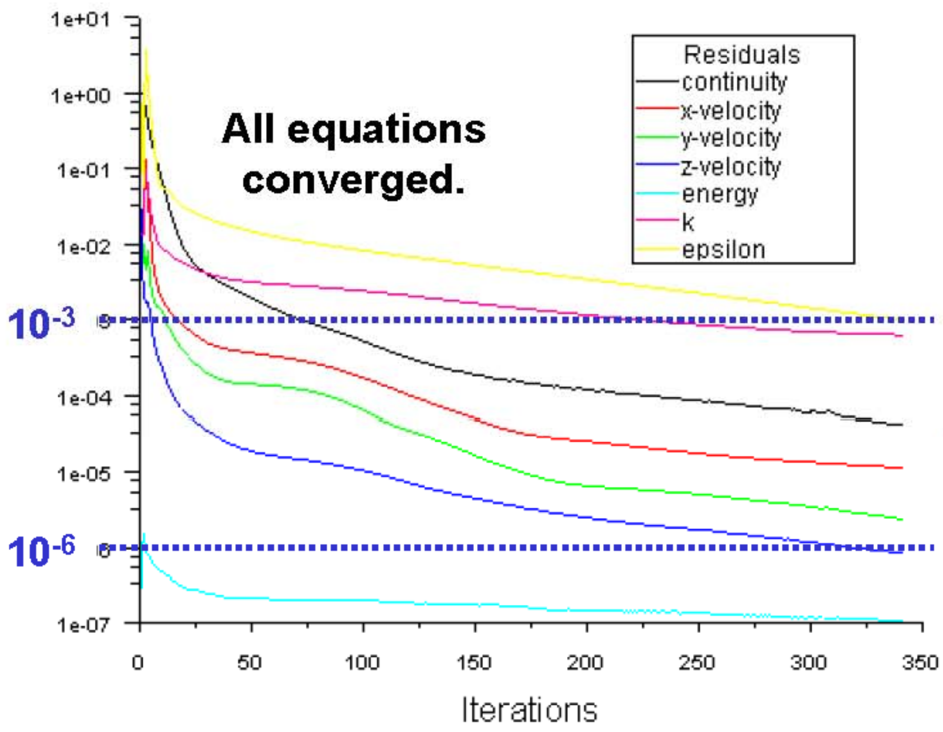
## • Monitoring convergence using residual history:

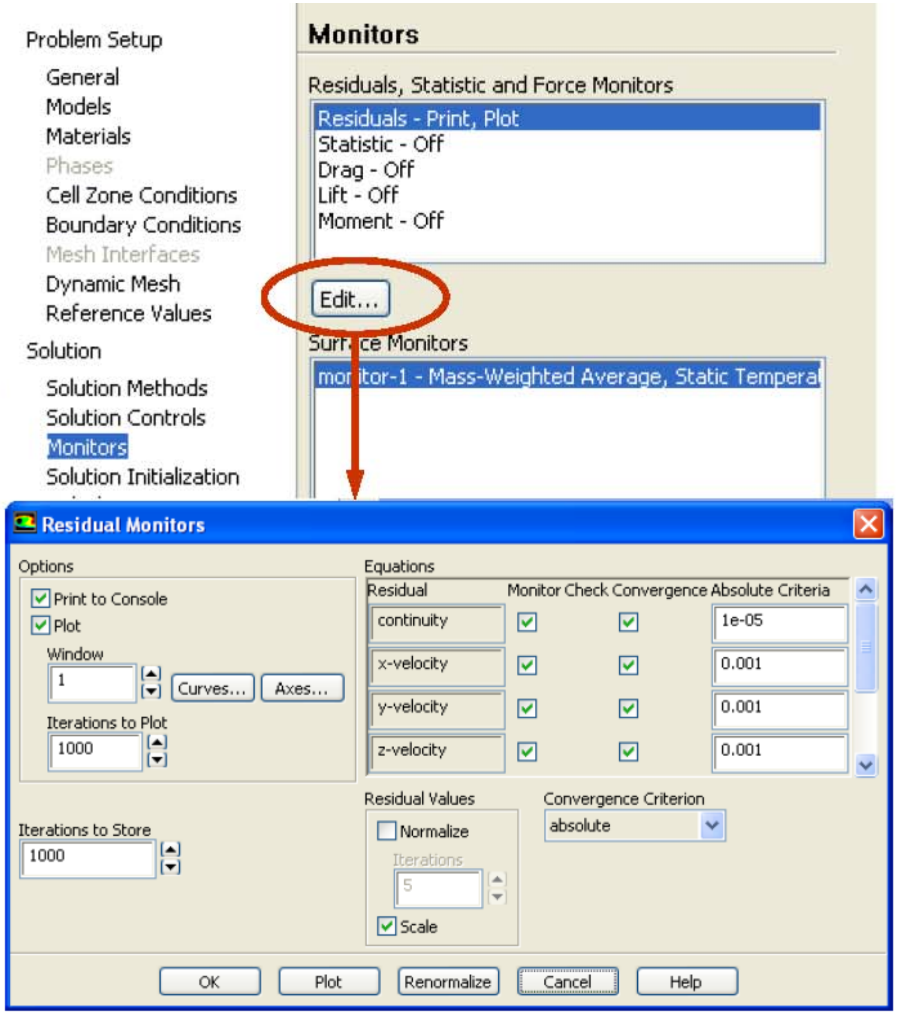
① **Generally, a decrease in residuals by three orders of magnitude indicates at least qualitative convergence. At this point, the major flow features should be established.**

② **Scaled energy residual should decrease to $10^{-6}$ (for the Pressure-based solver).**

③ **Scaled species residual may need to decrease to $10^{-5}$ to achieve species balance.**

# ◆Convergence Monitors – Residuals

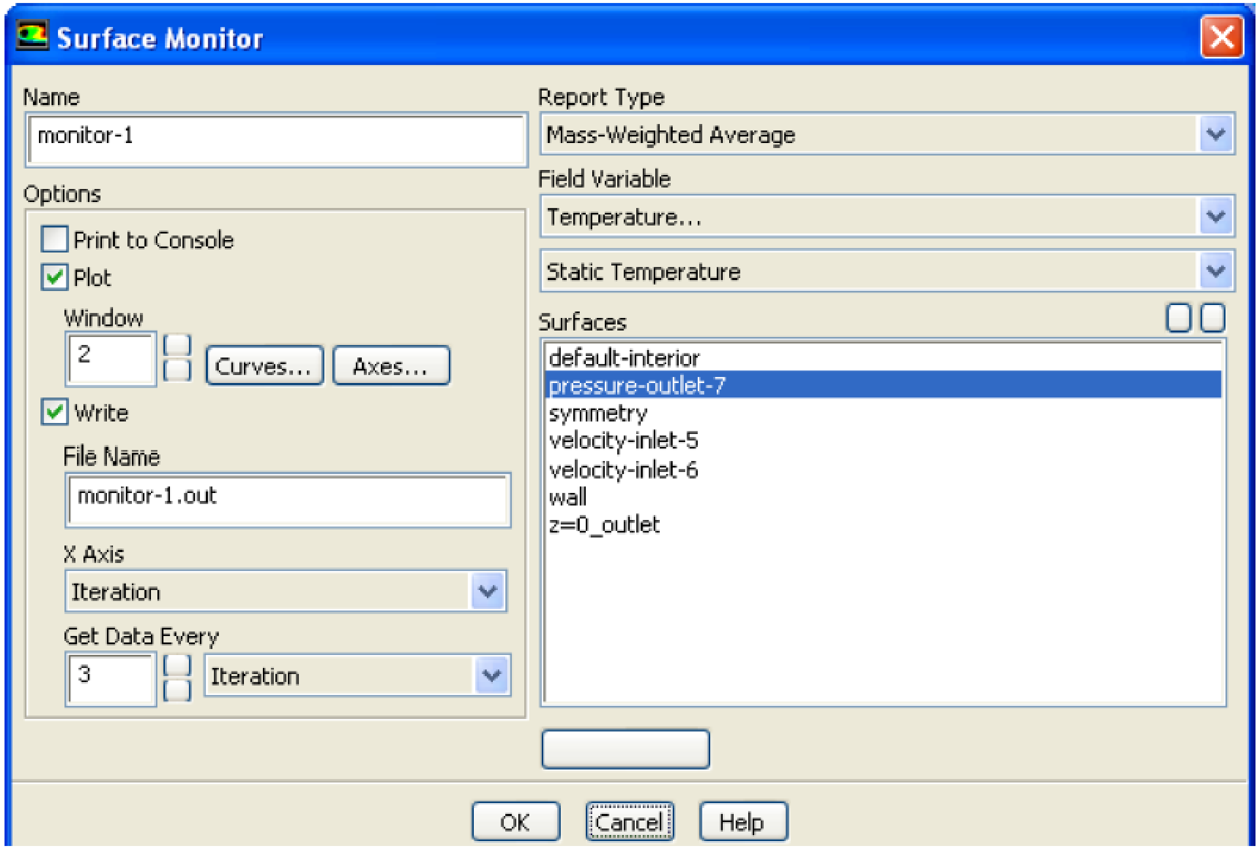



• **Residual plots show when the residual values have reached the specified tolerance.**

# ◆Convergence Monitors – Forces and Surfaces

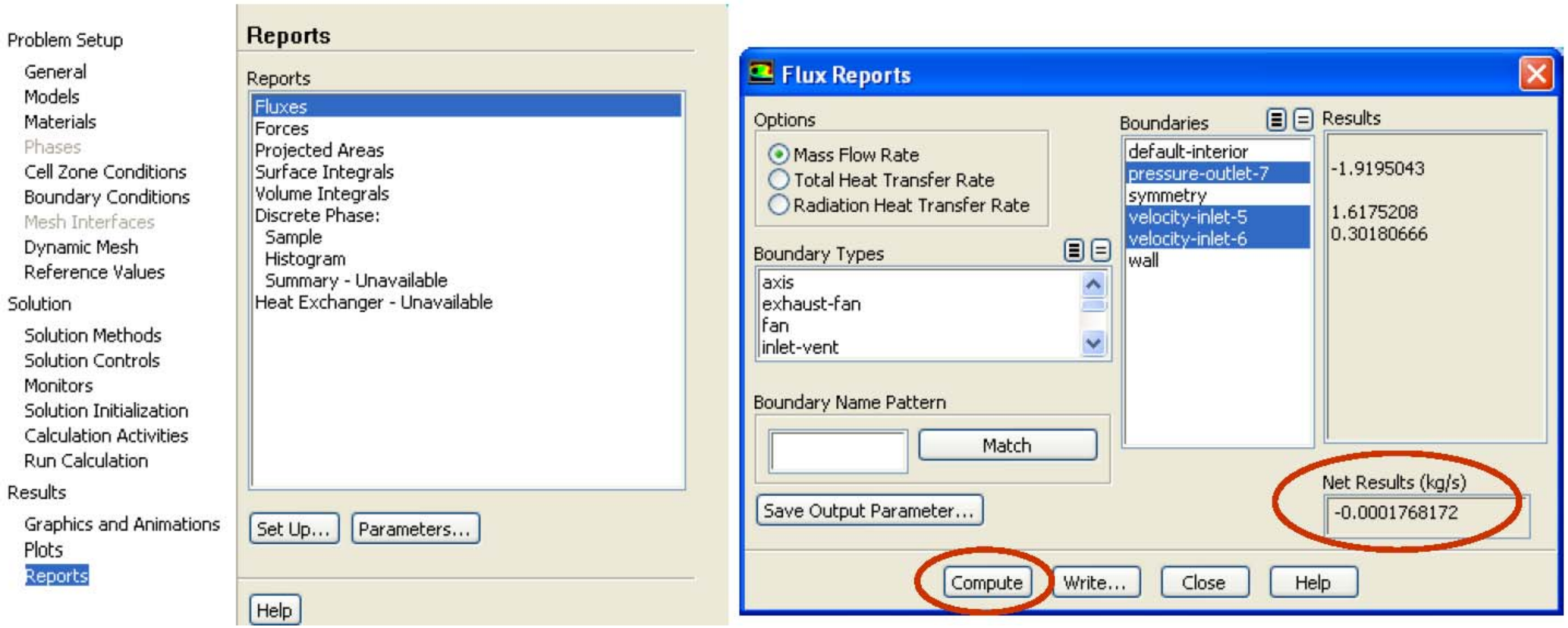
**If there is a particular value you are interested in (lift coefficient, average surface temperature etc), it is useful to plot how that value is converging.**



# Checking Overall Flux Conservation

• Another important metric to assess whether the model is converged is to check the overall heat and mass balance.

• The net flux imbalance (shown in the GUI as Net Results) should be less than 1% of the smallest flux through the domain boundary



## ◆Tightening the Convergence Tolerance

• If solution monitors indicate that the solution is converged, but the solution is still changing or has a large mass/heat imbalance, this clearly indicates the solution is not yet converged.

• In this case, you need to:

– Reduce values of Convergence Criterion or disable Check Convergence in the Residual Monitors panel.

– Continue iterations until the solution converges.

## ◆Convergence Difficulties

① Sometimes running for further iterations is not the answer:

– Either the solution is diverging

– Or the residuals are 'stuck（卡住）' with a large imbalance still remaining.

② Troubleshooting

Continuity equation convergence trouble affects convergence of all equations.

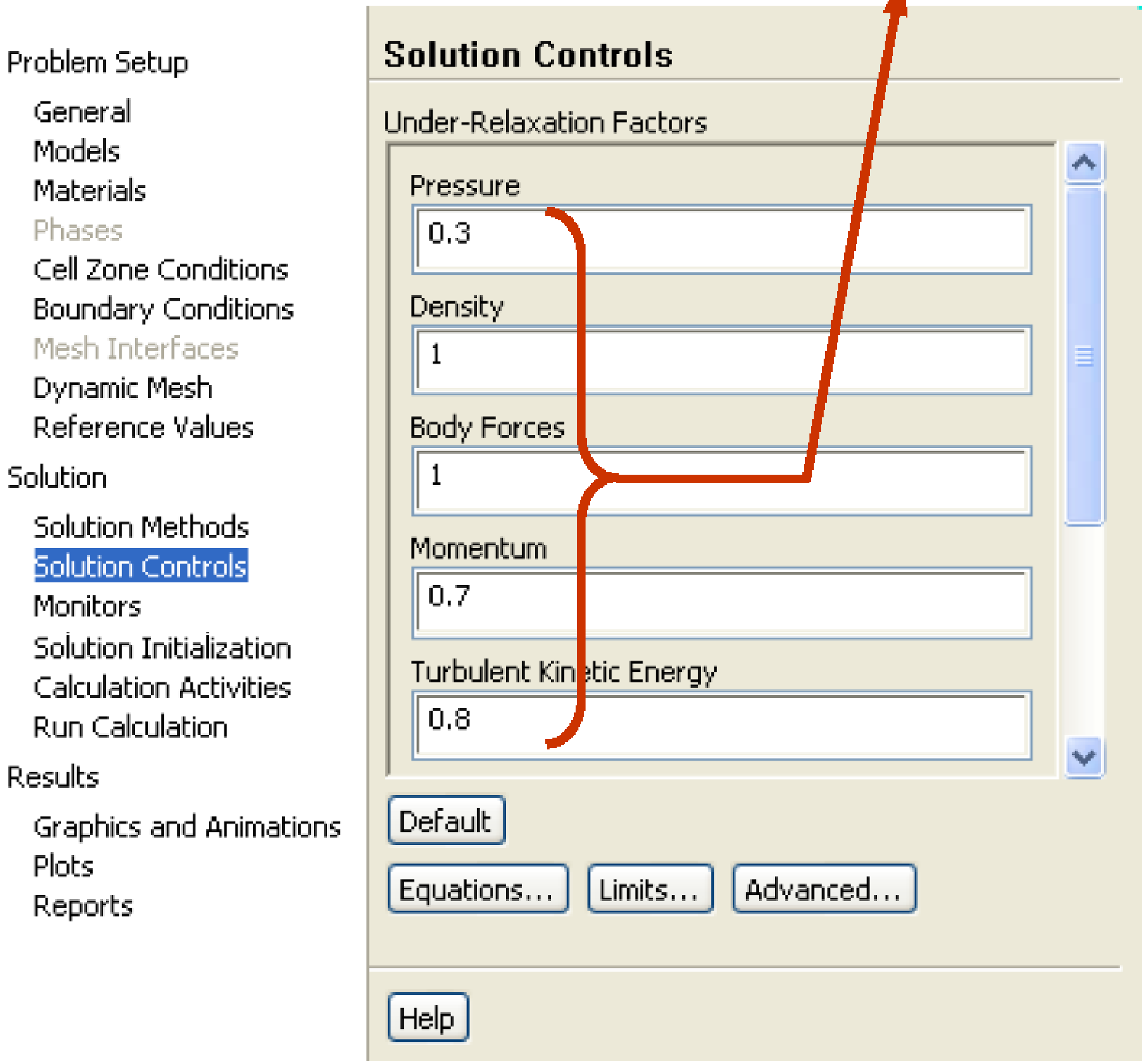
A. Compute an initial solution using a first-order discretization scheme.
B. Alter the under-relaxation or Courant numbers
C. Check the mesh quality. It can only take one very skewed grid cell to prevent the entire solution converging

## ◆Modifying Under-Relaxation Factors

- Under-relaxation factor, $\alpha$, is included to stabilize the iterative process for the pressure-based solver.
- Use default under-relaxation factors to start a calculation.

- If value is too high, the model will be unstable, and may fail to converge
- If value is much too low, it will take longer (more iterations) to converge.
  – Default settings are suitable for a wide range of problems, you can reduce the values when necessary.
  – Appropriate settings are best learned from experience!

$$\phi_P = \phi_{P,\mathrm{old}} + \alpha \Delta \phi_P$$



# Solution Accuracy

## ① Remember, a converged solution is not necessarily a correct one!

A. Always inspect and evaluate the solution by using available data, physical principles and so on.

B. Use the second-order upwind discretization scheme for final results.

C. Ensure that solution is grid-independent

## ② If flow features do not seem reasonable:

A. Reconsider physical models and boundary conditions

B. Examine mesh quality and possibly re-mesh the problem

C. Reconsider the choice of the boundaries' location (or the domain): inadequate choice of domain (especially the outlet boundary) can significantly impact solution accuracy.

# Mesh Quality and Solution Accuracy

① Numerical errors are associated with calculation of cell gradients and cell face interpolations.

② Ways to reduce the numerical errors:

A. Use higher-order discretization schemes (second-order upwind, MUSCL)

B. Attempt to align grid with the flow to minimize the "false diffusion"

③ Refine the mesh

# Refine the mesh

① Sufficient mesh density is necessary to resolve salient features of flow

- Interpolation errors decrease with decreasing cell size

② Minimize variations in cell size in non-uniform meshes

A. Truncation error is minimized in a uniform mesh

B. FLUENT provides capability to adapt mesh based on cell size variation

③ Minimize cell skewness and aspect ratio

A. In general, avoid aspect ratios higher than 5:1 (but higher ratios are allowed in boundary layers)

B. Optimal quad/hex cells have bounded angles of 90 degrees

C. Optimal tri/tet cells are equilateral

## ◆Grid-Independent Solutions

① It is important to verify that the mesh used was fit-for-purpose.

– Even if the grid metrics like skewness are showing the mesh is of a good quality, there may still be too few grid cells to properly resolve the flow.

② To trust a result, it must be grid-independent. In other words, if the mesh is refined further, the solution does not change.

③ Typically you should perform this test once for most your of problems.

# Determining Grid Independence

**Procedure:**

① **Obtain new grid:**

**Adaption**

A. A process by which the mesh is selectively refined in areas that are affected by the adaption criteria specified.

B. If you know where large gradients are expected, you need to have fine grids in the original mesh for that region, e.g., boundary layers.

② **Continue calculation until it converge.**

③ **Compare results obtained with different grids.**

④ **Repeat the procedure if necessary**

# 10. Results and Analysis: Graphics, Animation and Reports

## Reporting Heat Flux

① **Heat flux report:**

– It is recommended that you perform a heat balance check so to ensure that your solution is truly converged.

② **Exporting Heat Flux Data:**

– It is possible to export heat flux data on wall zones (including radiation).

# Available Variables for Heat Transfer

| | |
|---|---|
| Static Temperature | Total Temperature |
| Enthalpy | Relative Total Temperature |
| Rothalpy(滞止焓) | Wall Temperature |
| Wall Temperature (Thin) | Total Enthalpy |
| Total Enthalpy Deviation | Entropy |
| Total Energy | Internal Energy |
| Total Surface Heat Flux | Surface Heat Transfer Coef. |
| Surface Nusselt Number | Surface Stanton Number |

# 12.4.2. Physical models

## Multiphase Flow Modelling

A. Discrete phase model
B. Eulerian model
C. Mixture model
D. Volume-of-Fluid (VOF) model

## Reacting Flow Modelling

A. Eddy dissipation model
B. Non-premixed, premixed and partially premixed combustion models
C. Detailed chemistry models
D. Pollutant formation
E. Surface reactions

## • Modelling Moving Parts

A. Single and multiple reference frames
B. Mixing planes
C. Sliding meshes
D. Dynamic meshes
E. Six-degree-of-freedom solver

## Multiphase Flows

In many flows, there is more than one fluid present in the domain

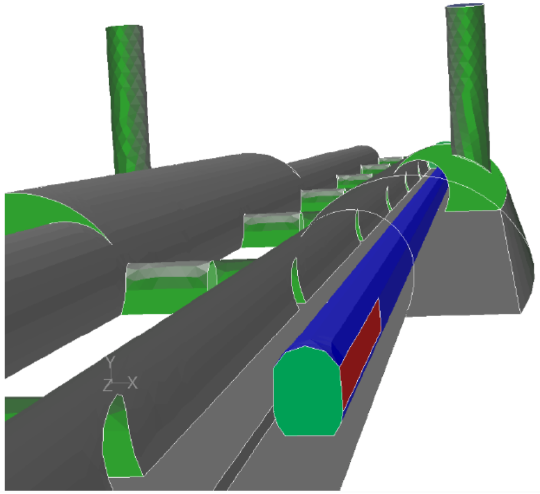
A. Different substances (eg oil&water, or water&air)
B. Different phases of same substance (water & steam)

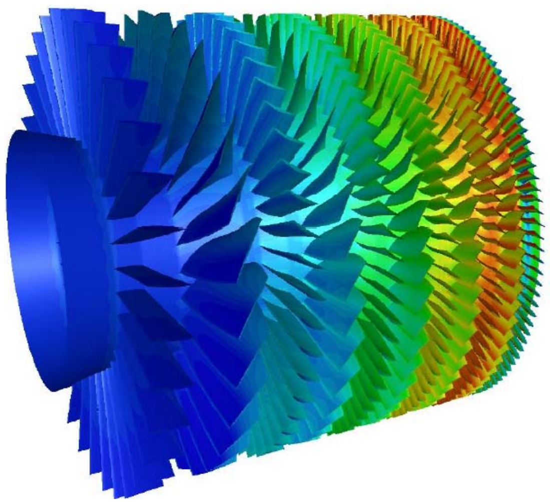
# Modelling Moving Parts

- **Many flow problems involve domains which exhibit forms of motion.**

- **Two types of motion are possible – translational and rotational.**

- **There are two modeling approaches for moving domains:**
  - **Moving Reference Frames(运动参考坐标系)**
  - **Moving/Deforming Domains**





# 12.4.3 User Defined Functions

## What is a User Defined Function?

① A UDF is a function (programmed by the user) written in C which can be dynamically linked with the FLUENT solver.

- Standard C functions

② Trigonometric, exponential, control blocks, do-loops, file i/o, etc.

- Pre-Defined Macros

③ Allows access to field variable, material property, and cell geometry data and many utilities

## Why program UDFs?

**Standard interface cannot be programmed to anticipate all needs:**

① **Customization of boundary conditions, source terms, reaction rates, material properties, etc.**

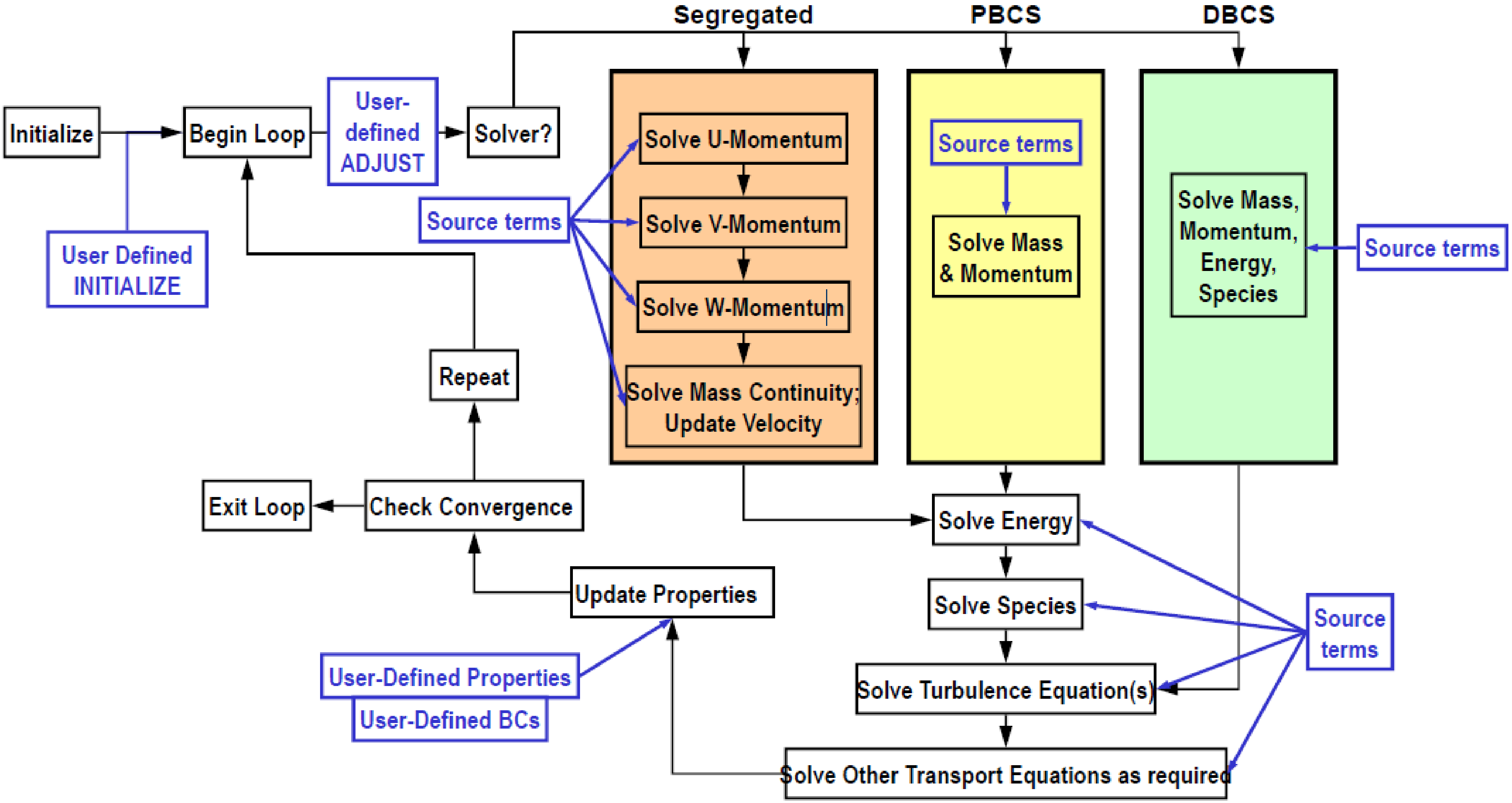
② **Customization of physical models**

③ **User-supplied model equations**

④ **Adjust functions (once per iteration)**

⑤ **Execute on Demand functions**

⑥ **Solution Initialization**

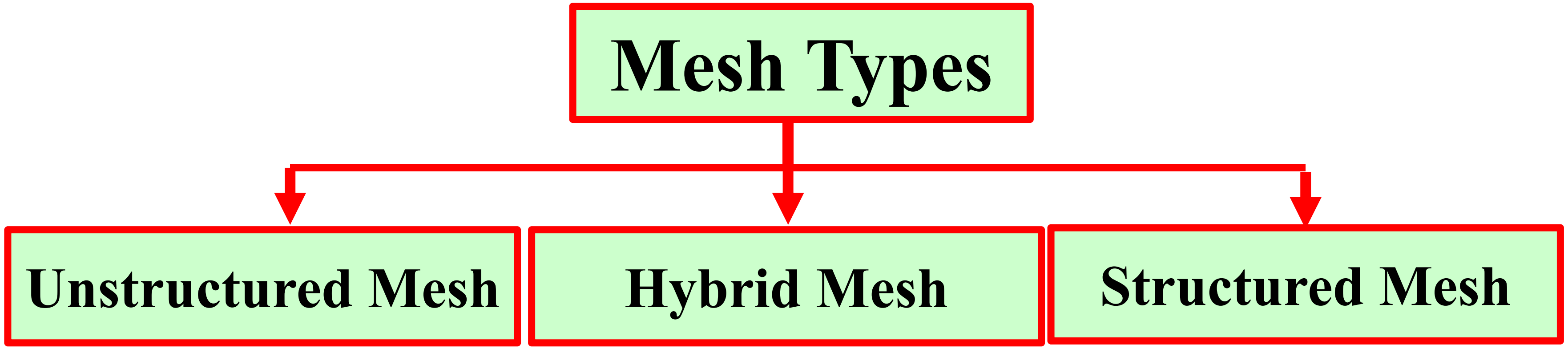



# User Access to the FLUENT Solver

# 12.5 Introduction to ICEM and Meshing with ICEM for structural grid

# 12.5.1 Introduction to ICEM

## ICEM CFD mesh types




ICEM CFD can generate both structured and unstructured meshes using structured or unstructured algorithms which can be given as inputs to structured as well as unstructured solvers.

- **Mesh**

**Volume comprised of elements used to discretize a domain for numerical solution**

  - **Heat Transfer**
  - **Fluid dynamics**
  - **Other**

- **Nodes**
  - **Point locations of element corners**

**2D – Surface/Shell**

① **Quads(四边形)**

② **Tris（三角形）**

**3D-Volume**

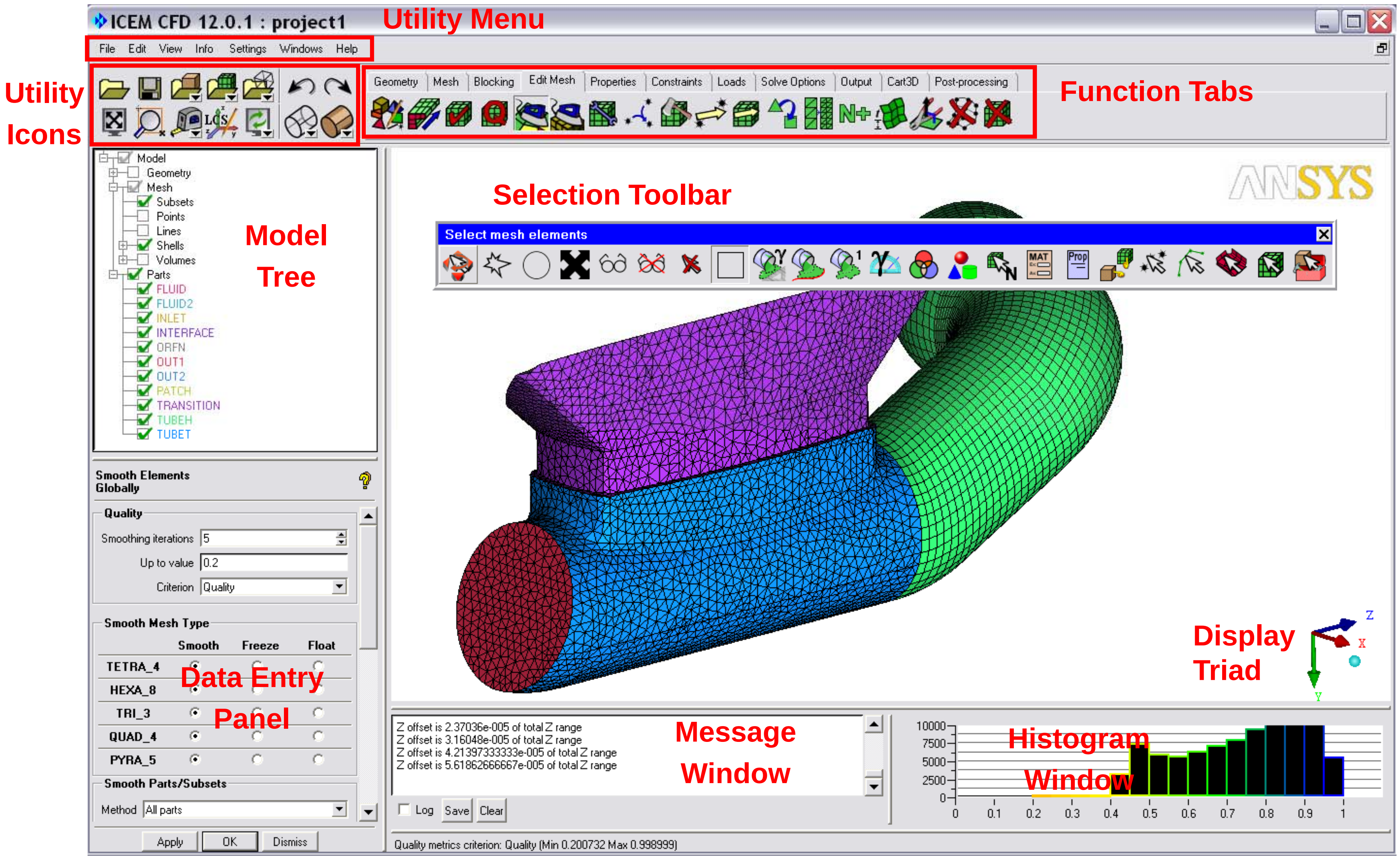
① **Tetra（四面体）**

② **Pyramid（棱锥）**

③ **Prism（棱柱）**

④ **Hexa（六面体）**

# GUI and Layout

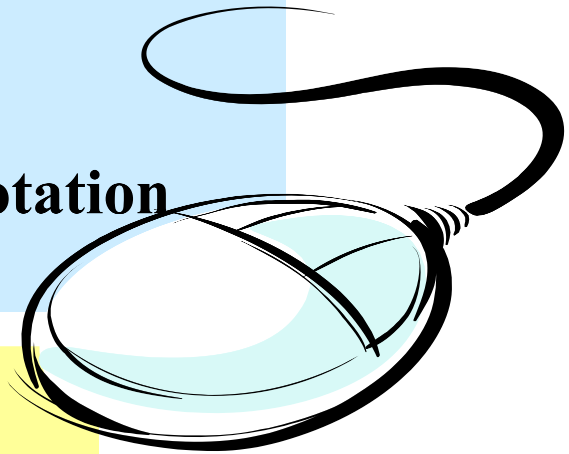


# File and Directory Structure

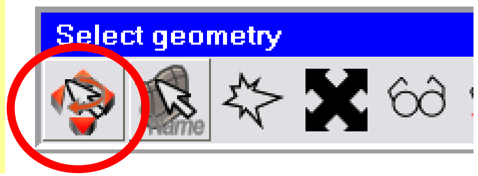
- **Primary file types:**
  - **Tetin (.tin): Geometry**
    - Geometry and material points
    - Part association
    - Global and entity mesh sizes
    - Created in Ansys ICEM CFD or Direct Cad Interface
  - **Domain file (.uns)**
    - Unstructured mesh
  - **Blocking file (.blk)**
    - Blocking topology
  - **Attribute file (.fbc, .atr)**
    - Boundary conditions, local parameters & element types
  - **Parameter file (.par)**
    - solver parameters & element types
  - **Journal and replay file(.jrf, .rpl)**
    - Record of performed operations (echo file)

# Mouse Usage

- **'Dynamic' viewing mode (click and drag)**
  - left: rotate (about a point)
  - middle: translate
  - right: zoom(up-down)/Z-axis rotation
  - Wheel zoom



- **Selection mode (click)**
  - left: select
  - middle: apply operation
  - right: unselect

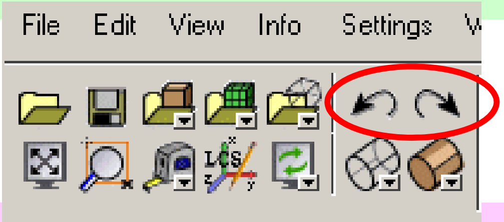



- **F9** toggles the mouse control to Dynamic mode while in Select mode

- Spaceball allows for dynamic motion even while in select mode

# Some Commonly Used Utilities

## ① Edit > Undo/Redo



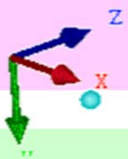

## ② View

–Fit 

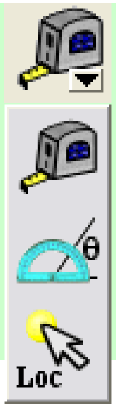
•Fit active entities into screen

–Box Zoom 

–Standard views



## ③ Measure




–Distance

–Angle

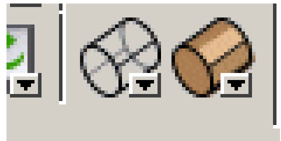
–Location

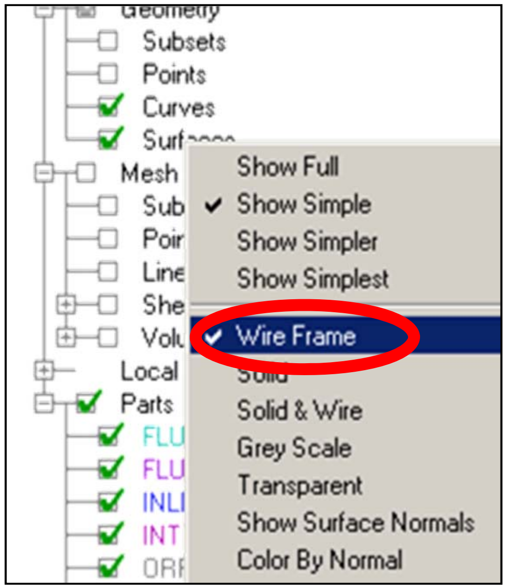
## ④ Surface display

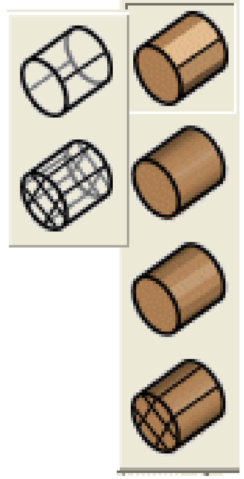
-Wireframe

-Solid

-Transparent

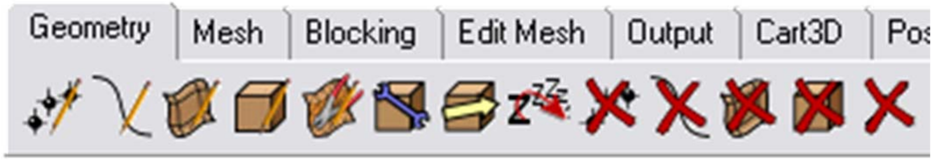




# Function Tabs

**Geometry**




Create/Modify geometry

**Mesh**


Set mesh sizes, types and methods
Set options; Auto create Shell, Volume, Prism meshes

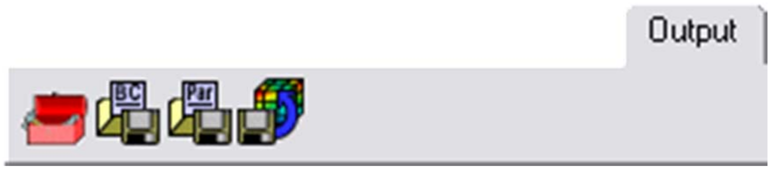
**Blocking**


Initialize a block
Split/modify blocks
Generate structured hexa mesh

**Edit Mesh**


Check, Smooth, Refine/ Coarsen, Merge, Auto repair, Manual edit, Transform, etc.

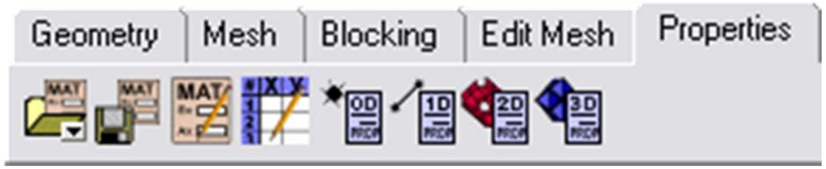
**Output**




Set Boundary Conditions and Parameters；Write mesh for 100+ solvers.

# Primary Function Tabs

**Properties**




Create, read, write out material properties
Apply to geometry/elements

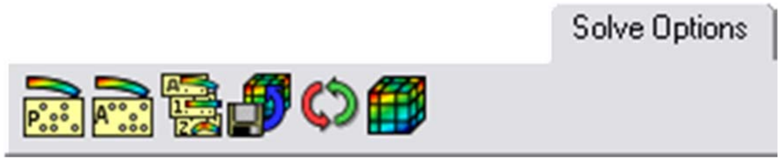
**Constraints**


Set constraints, displacements, define contacts, initial velocity, rigid walls

**Loads**


Set force, pressure and temperature loads

**Solve options**



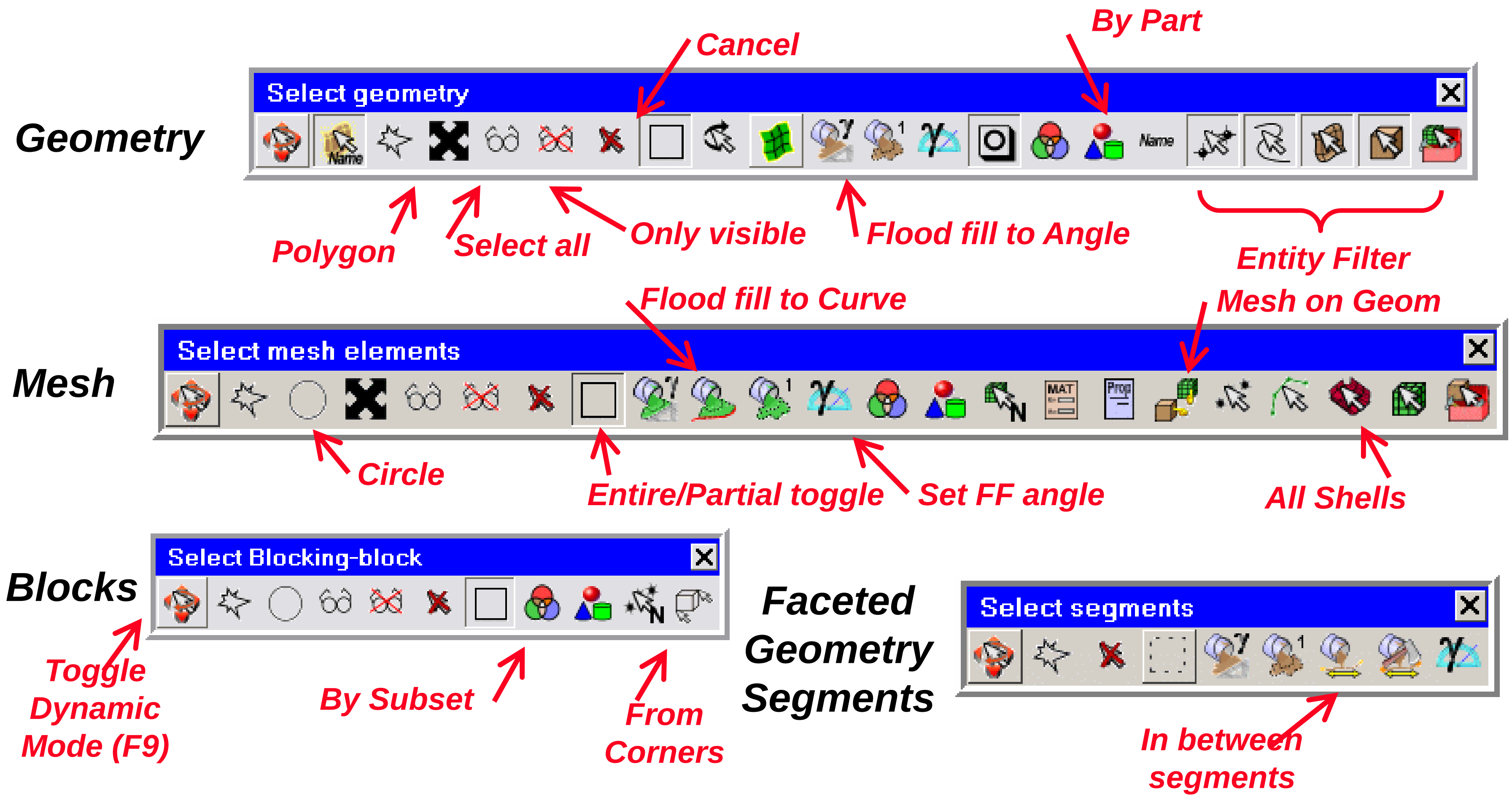

Set parameters, attributes, create subcases, write out input file, run solver

**Post Processing**


Visualize results: cut plane, streams, animation, calculate integral and more.

# Selection Toolbar

- During select mode, selection toolbar appears
  - Filtering of entities
  - Linked to select mode hotkeys



# Workflow

**Typical ICEM Workflow:**

1.Create/open new project

2.Import/Create geometry

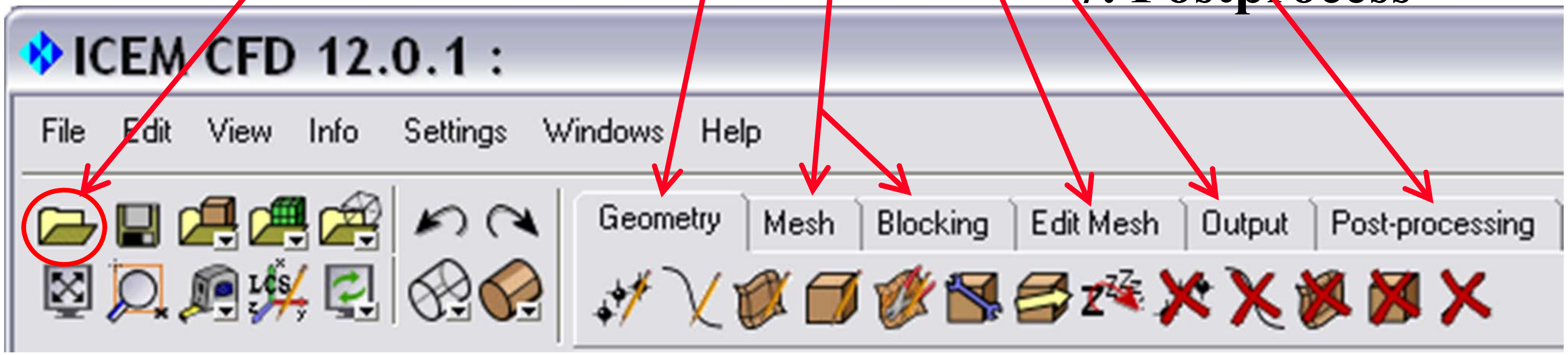
3.Build topology/Clean geometry

4. Mesh model (Possibly Hex Blocking)

5. Check/edit mesh

6. Output to Solver

7. Postprocess




Workflow

## The unstructured mesh generation procedure:

1.Create/Import geometry

2.Repair geometry ensuring a closed volume

3.Determine global meshing parameter

4.Specify part mesh setup

5.Specify curves and surface mesh size

6.Compute mesh

- **ANSYS ICEM CFD was designed to mainly import geometry, not create complicated geometries, although many geometry tools are provided.**

**ICEM CFD provides:**

**Geometry import**

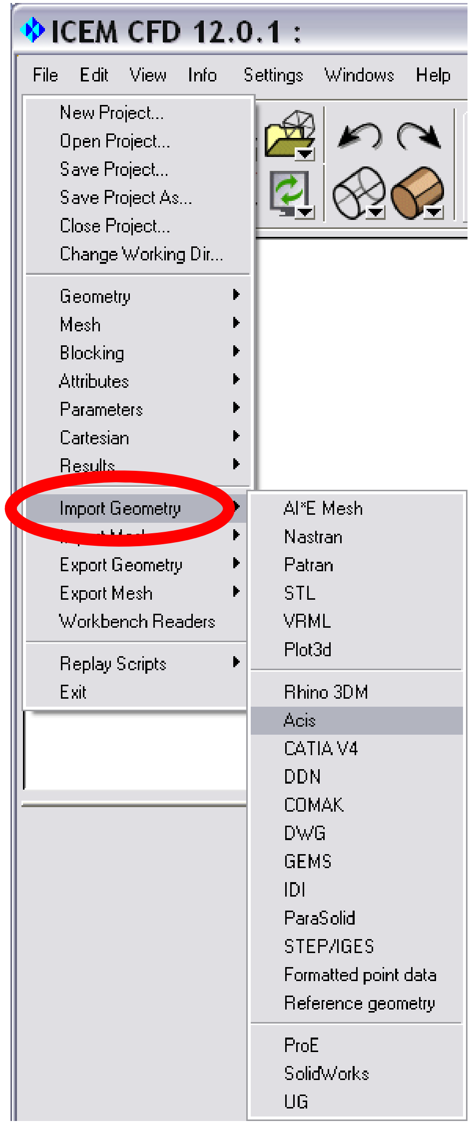
① **Directly from CAD package**

② **3rd party formats (step, acis, etc…)**

③ **Via Workbench/Design Modeler**

- **Surface geometry kernel**
  - **Imported solids are converted to surfaces**
  - **Geometry fixing**

# Geometry Import




**CAD from just about any source**

① **Direct CAD Interfaces**

– Set up ICEM meshing requirements within CAD environment
  - Saved within CAD part
  - Retained for parametric geometry changes

– Directly write out ICEM formatted geometry (tetin file)
  - No 3rd party exchange (clean!)

– ProE, Unigraphics, SolidWorks

② **Direct import**

–ACIS (.sat) -CATIA V4 -DWG/DXF

–Catia V4 -IDEAS -GEMS

–IDEAS (IDI) –Parasolid -STEP/IGES

–Pro/E -Unigraphics

# 12.5.2 Introduction to Shell Meshing with ICEM

**Usages of shell meshing:**

① **2D cross sectional analysis(二维) (CFD)**

② **Input for volume meshing (FEA/CFD)**

③ **Filling a surface mesh is faster than tetra octree but requires well-connected geometry**

# 1.General Procedure

## First need to decide mesh setup parameters

① **Mesh method**

– **Algorithm used to create mesh**

② **Mesh type**

– **quad/tri/mix**

③ **Mesh sizes**

a. **Small enough to capture physics, important features**

b. **Large enough to reduce grid size (number of elements)**

- **Memory limitations**
- **Faster mesh/solver run**

a. **Set mesh sizes on parts, surfaces, and/or curves**

b. **Based on edge length**

**Can have different types/methods set on different surfaces**

# 2. Global Mesh Setup

## *Global Mesh Size*

① **For entire model**

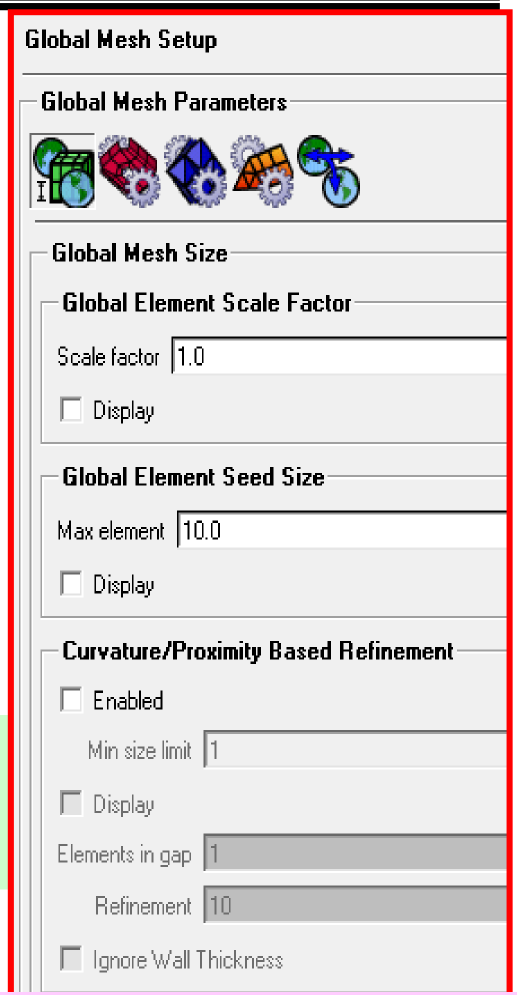
② **Scale factor**

- **Global setting by which many local settings are multiplied**
- **Good for scaling overall mesh**

## ③ *Global Element Seed Size*

- **Maximum possible element size in model**
- **Default size if don't wish set sizes**

## ④ *Curvature/Proximity Based Refinement*




- **Automatically creates smaller element size to better capture geometry**
- **Only for Patch Independent method and tetra octree**

## *Global Mesh Setup Mesh tab*


① To change defaults globally for size, method and type

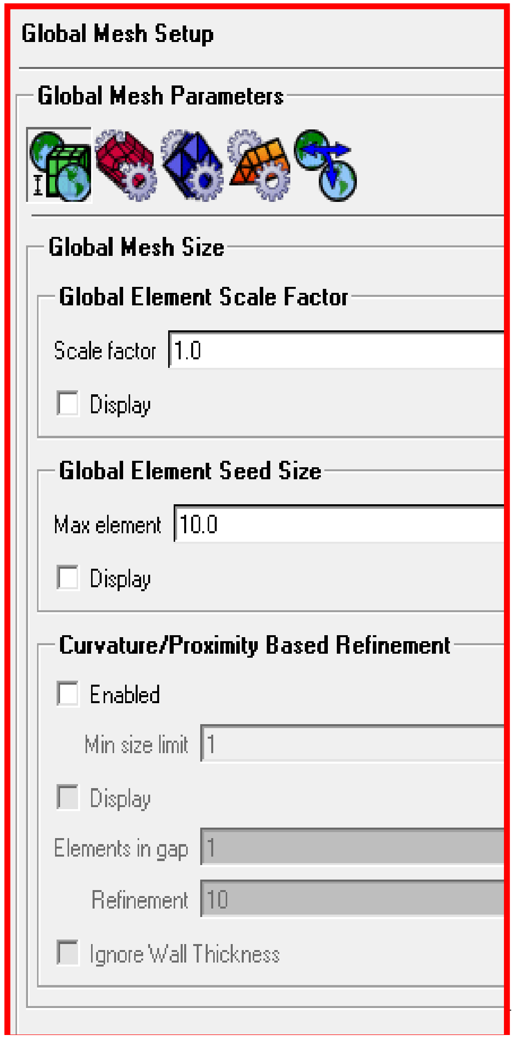
② For entire model

③ For Shells

④ For Volume

⑤ For Prism

⑥ To periodicity




**Parameters relative to scale factor**

– Max size – Min size limit

– Height – Max deviation

# 3. *Global Shell Meshing Parameters*

– **From *Global Mesh Setup* tab**

– ***Set surface mesh parameters globally***

- Defaults for the selected mesh method

– ***Method***

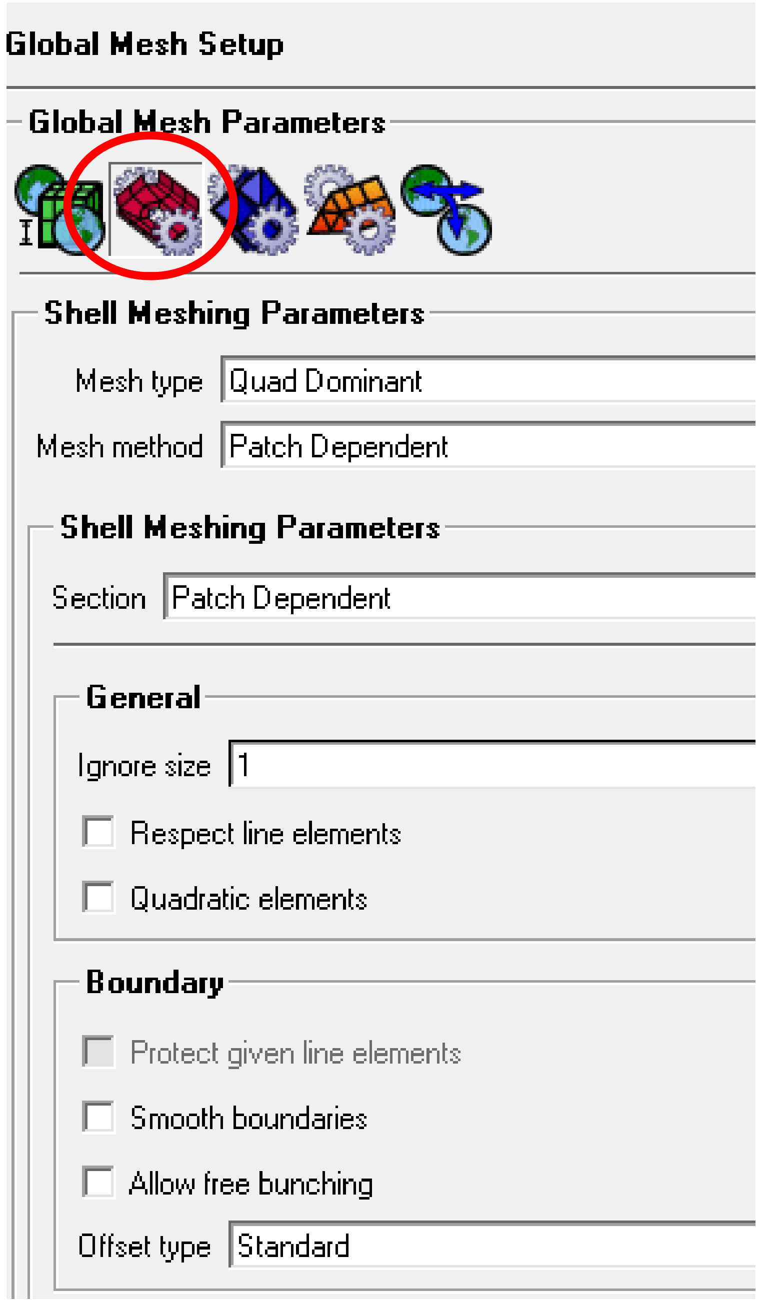
① **Autoblock**

② **Patch dependent**

③ **Patch independent**

④ **Shrinkwrap**

⑤ **Delaunay**



# *Type*

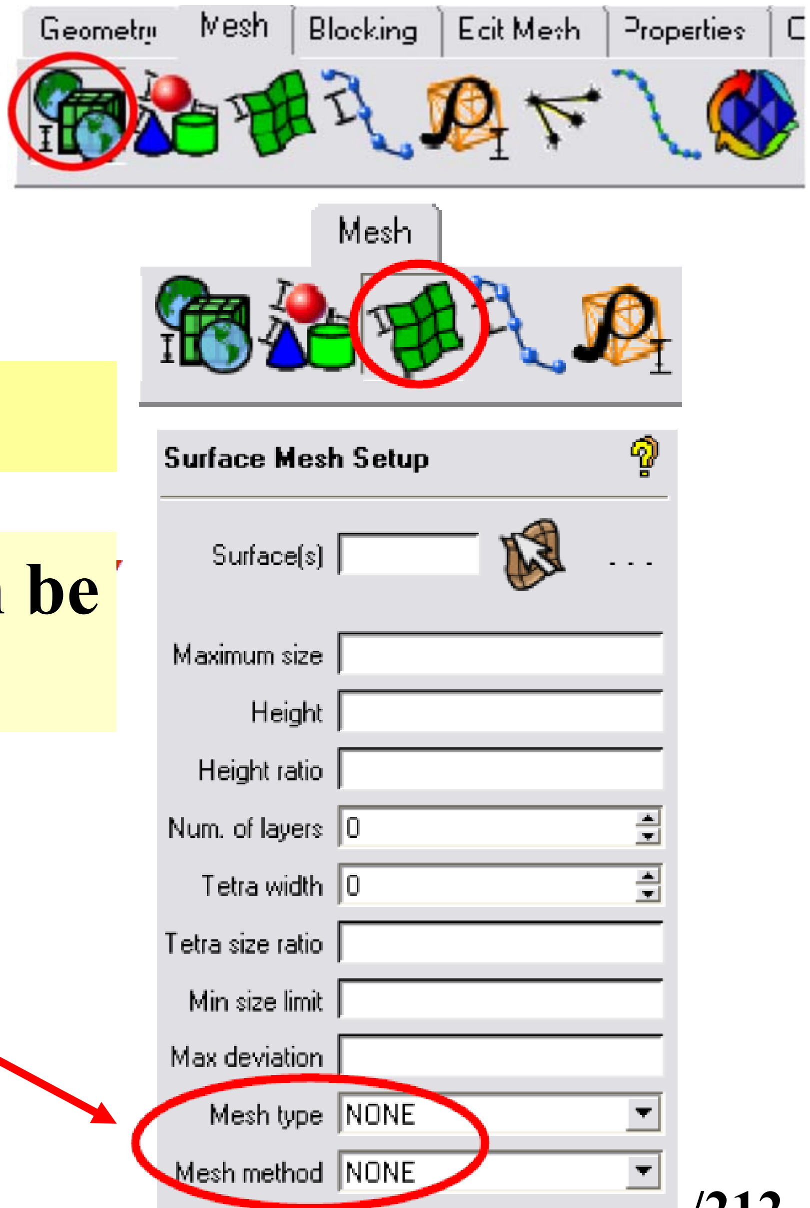
- All Tri, Quad with one tri
- Quad dominant, All quad

– Options for different methods

– Global types and methods can be overridden by:

## Local settings

*In Surface Mesh Setup*

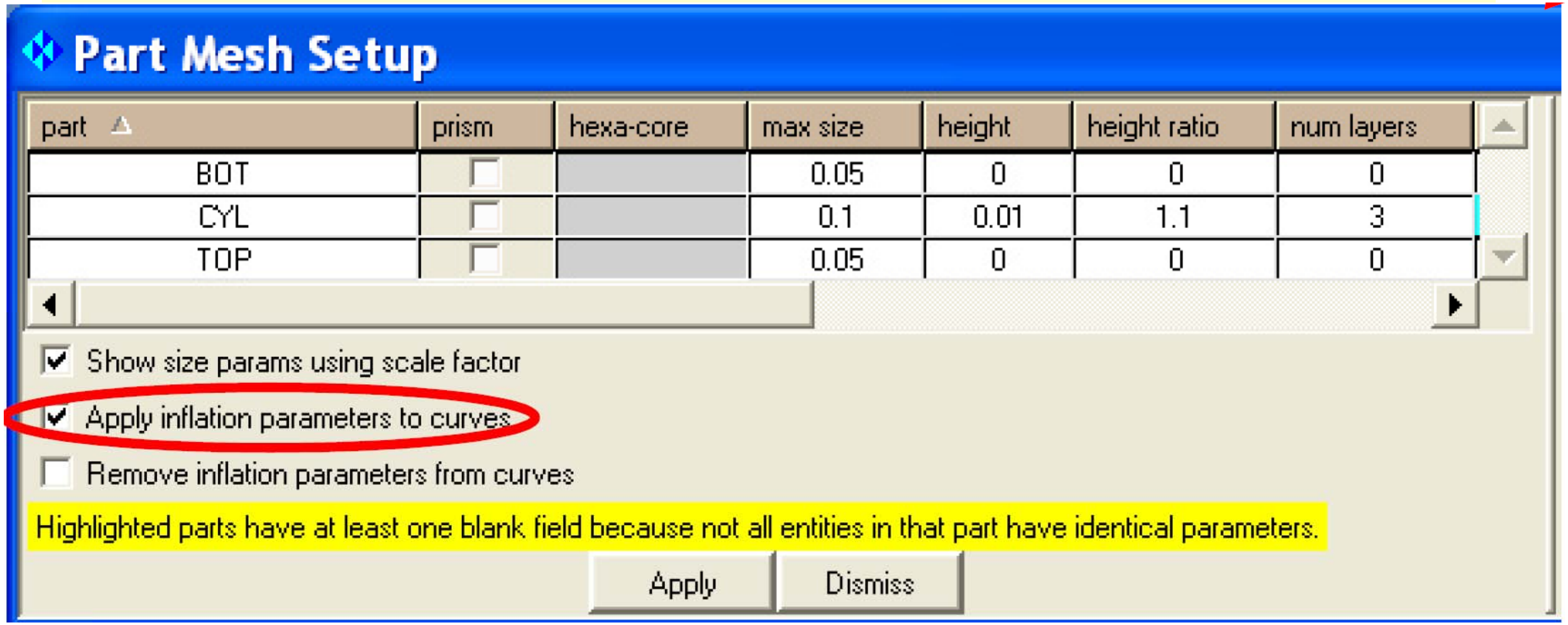


## *4. Part Mesh Setup*


– **Set mesh parameters on all entities within part**

– ***Max. size***

- **Multiplied by global *Scale Factor* = actual size**

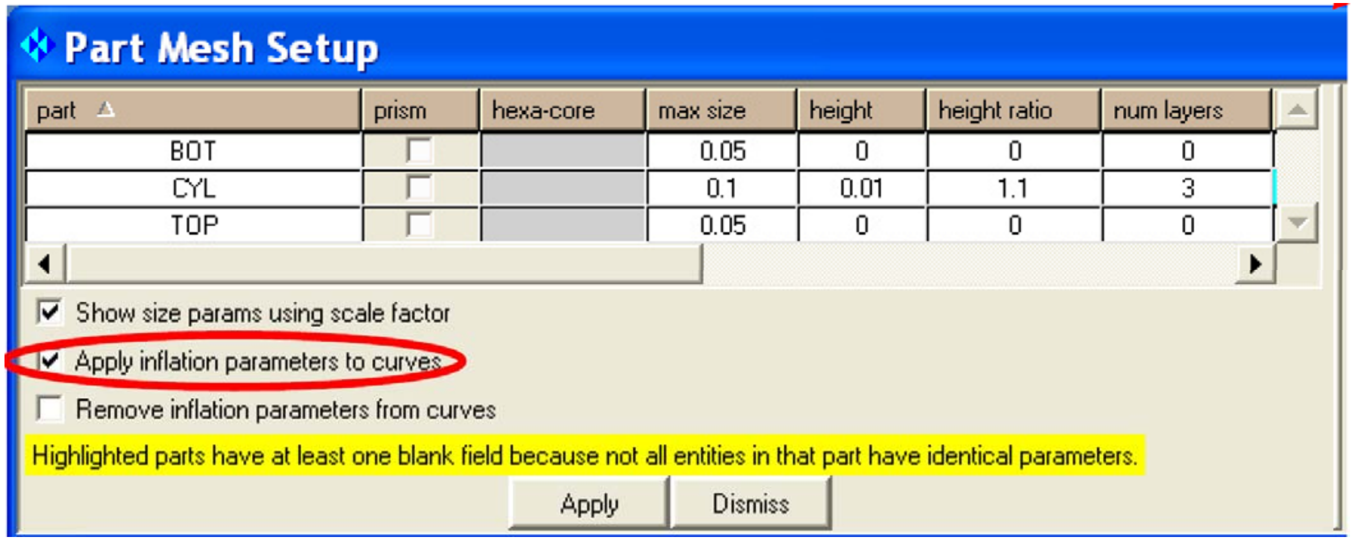


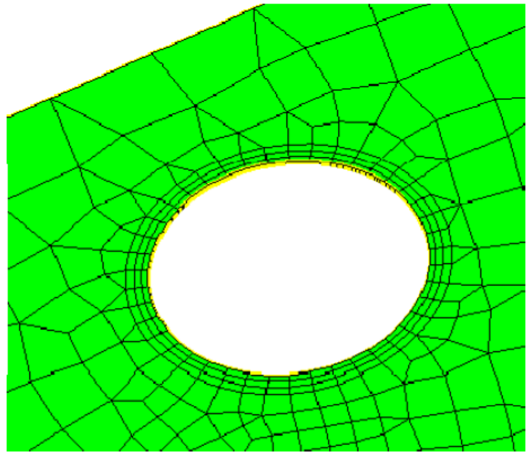
# Quad layers grown from curves (e.g. rings around holes), use these 3 parameters:

– ***Height:*** **First layer quad height on curves**

– ***Height ratio:*** **growth ratio which determines the heights of each subsequent layer**

– ***Num layers:*** **Number of rings/inflation layers**

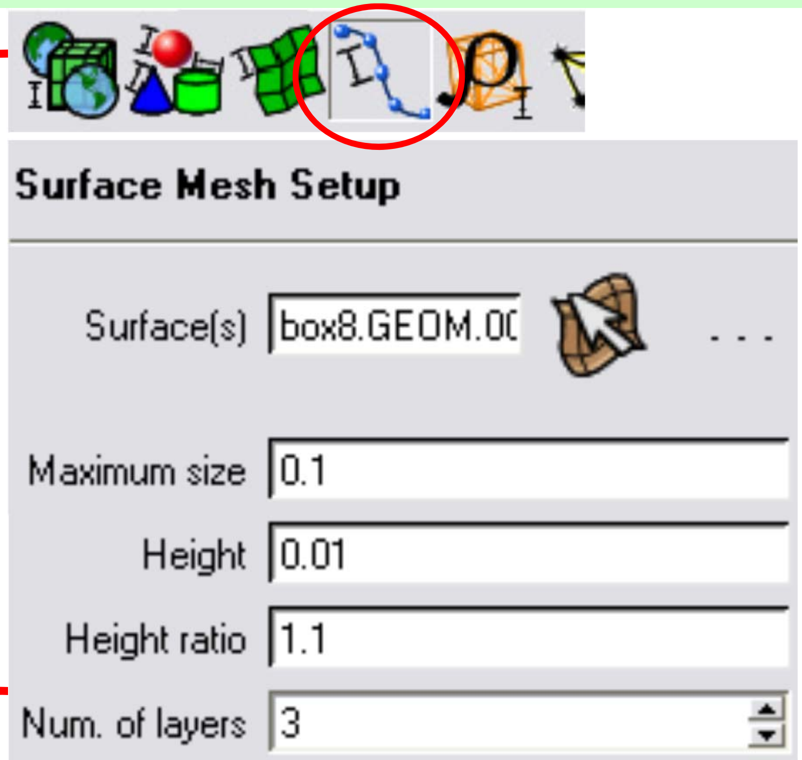


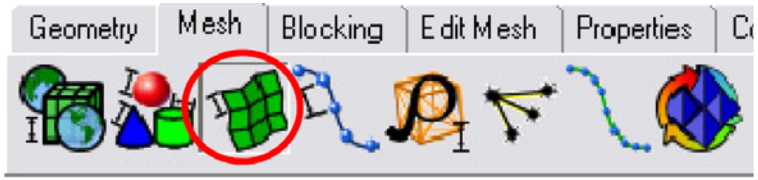
- **For quad layers, the minimum required to be set is *height* (1 layer) or *num layers* (height = max. size)**

- **If done in the *Part Mesh Setup* spreadsheet you must toggle on *Apply inflation parameters to curves***

**Or set on individual curves**



# 5. Surface Mesh Setup



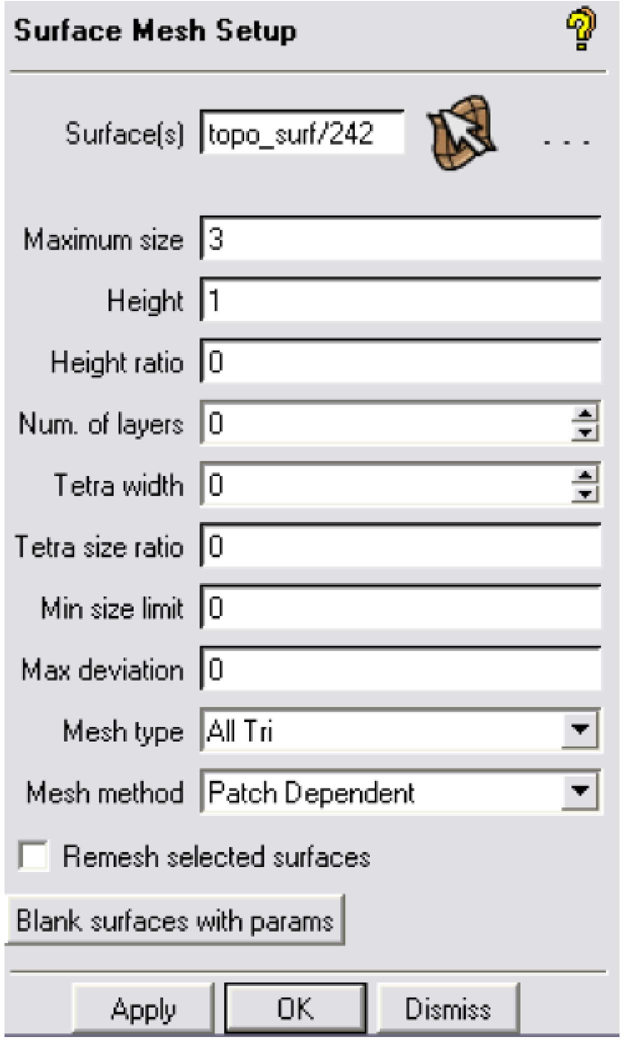

① Same parameters as part mesh setup but also includes:

- *Mesh type*
- *Mesh method*

② Select surfaces first from screen, set sizes/parameters and *Apply*

③ Mesh method/type will override global shell mesh settings for selected surface(s)

④ Will override *Part Mesh Setup* settings if set afterward

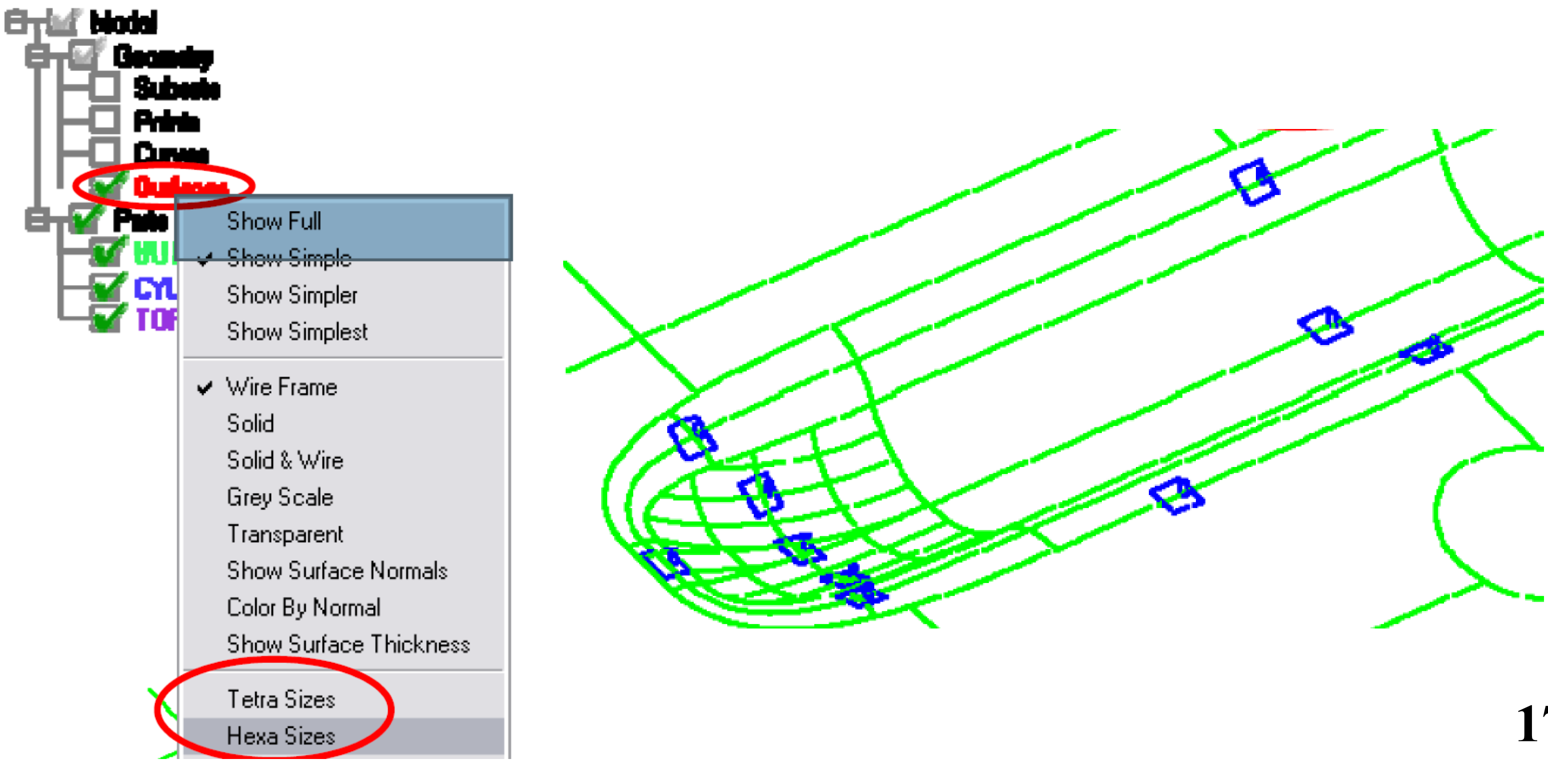


# Display

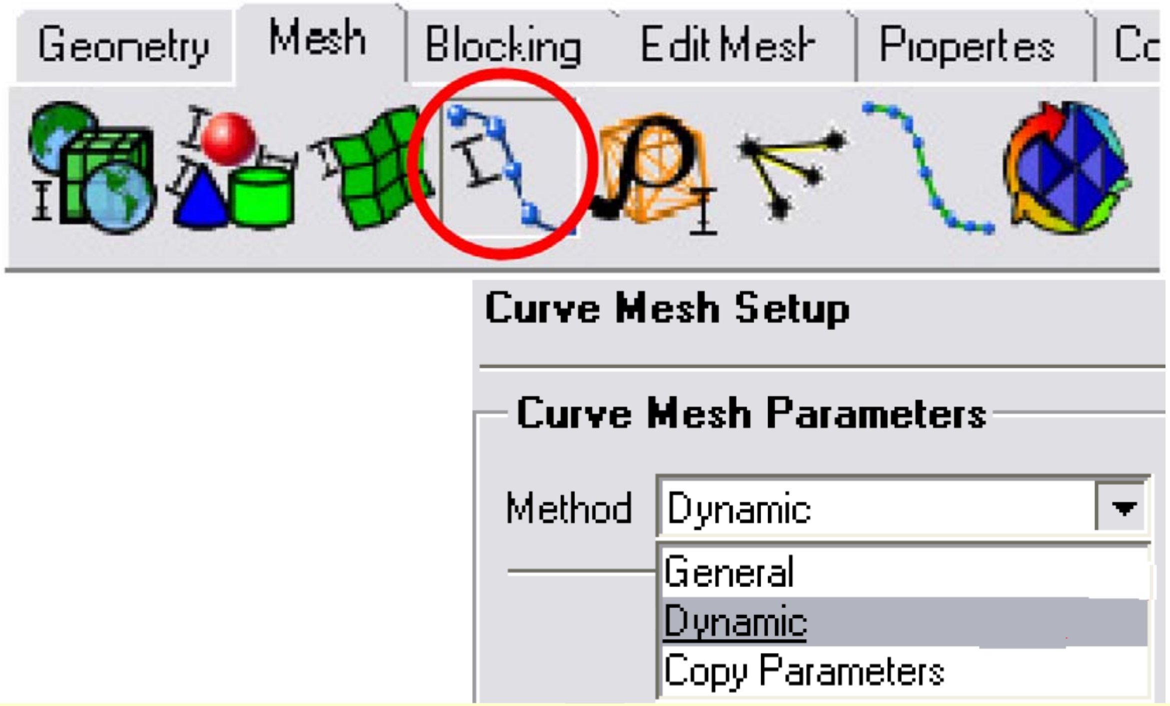
- **Right mouse, select in Model tree on**

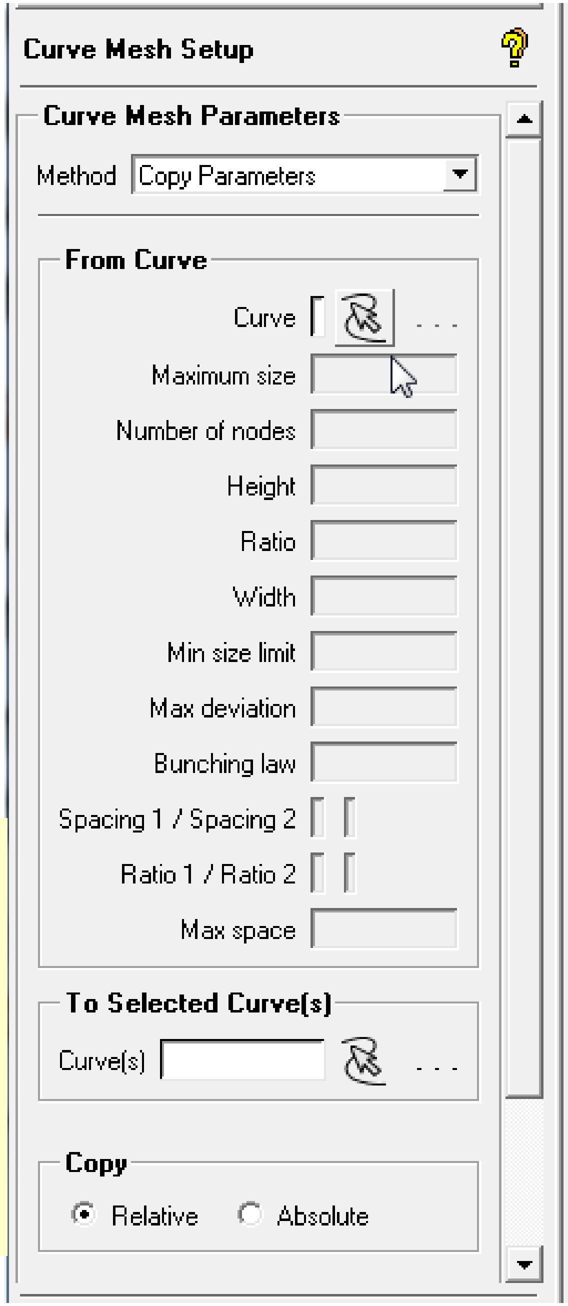
  ***Surfaces > Tetra/Hexa Sizes***

  - **Icon appears for each surface**
  - **Gives you a visual estimate of prescribed max. size**



# 6. Curve Mesh Setup



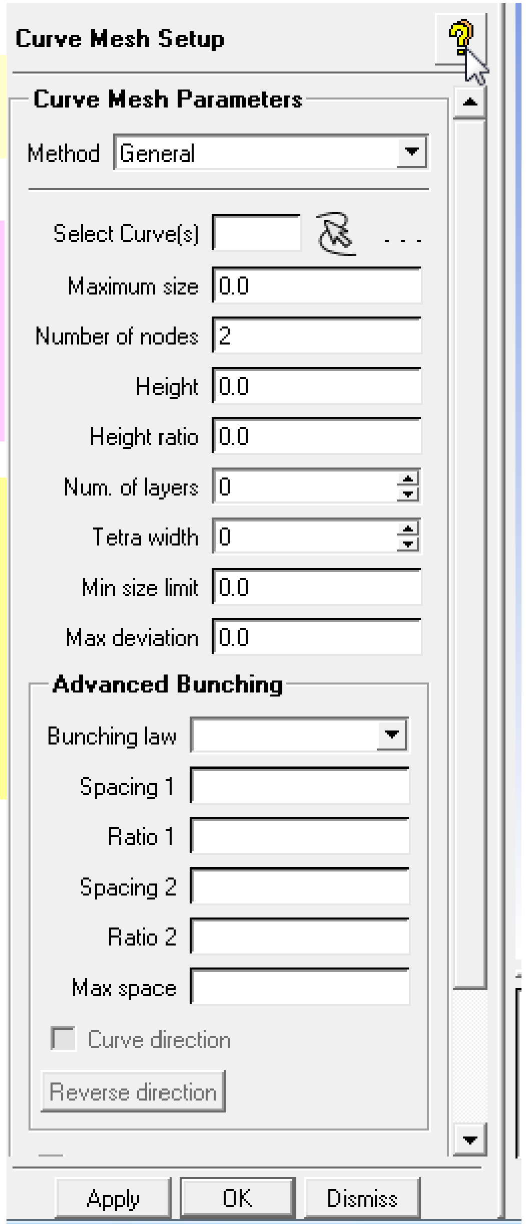




– *General*

- Same as *Surface Mesh Setup*
- But also can prescribe *Number of nodes*
  – Instead of element size

- **Also includes node biasing along curves**
  - **Initial spacing from either curve end**
  - **Bunching laws**
  - **Expansion ratios from either curve end**
  - **Matching of node spacing to adjacent curves**

**Select curves first, middle mouse to accept selection, then type in parameters/sizes - *Apply***



# *Curve Mesh Setup*

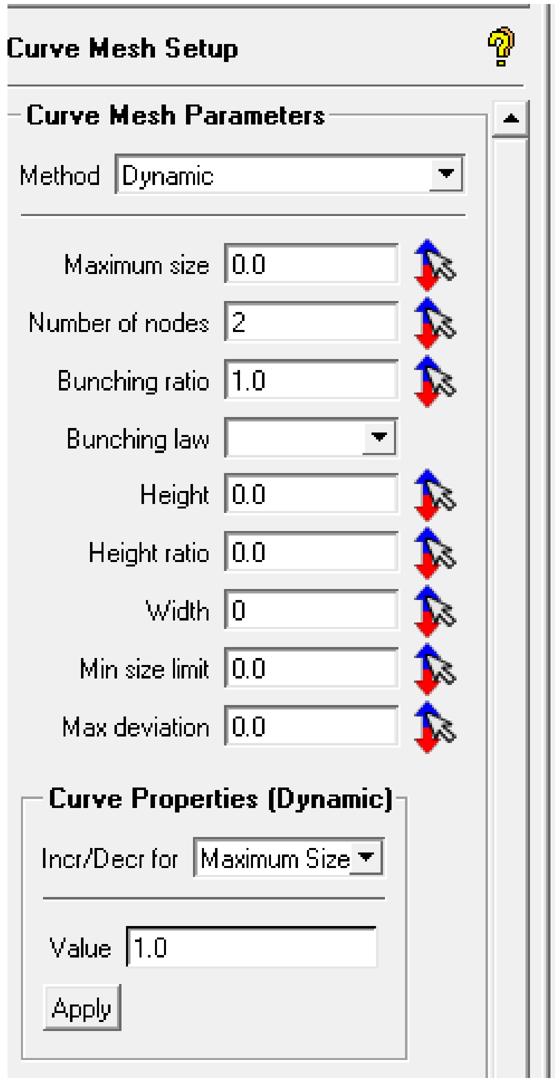
## – *Dynamic Method*

- **Adjust mesh parameters on screen**
- **Interactively toggle displayed values near curve with left (to increase)/right mouse (to decrease) keys**

## – *Copy Parameters*

- **Copy parameters set on curve to one others**
  - **e.g. parallel curves, downstream**

– ***Curve Mesh Setup*** **will override** ***Part Mesh Setup*** **parameters if set afterward**



# *7. Mesh Methods*

## Algorithm used to create mesh

- **Patch Dependent**

– Based on loops of curves surrounding patches

– Best for capturing surface details and creating quad dominant mesh with good quality

- **Patch Independent**

– Robust octree algorithm

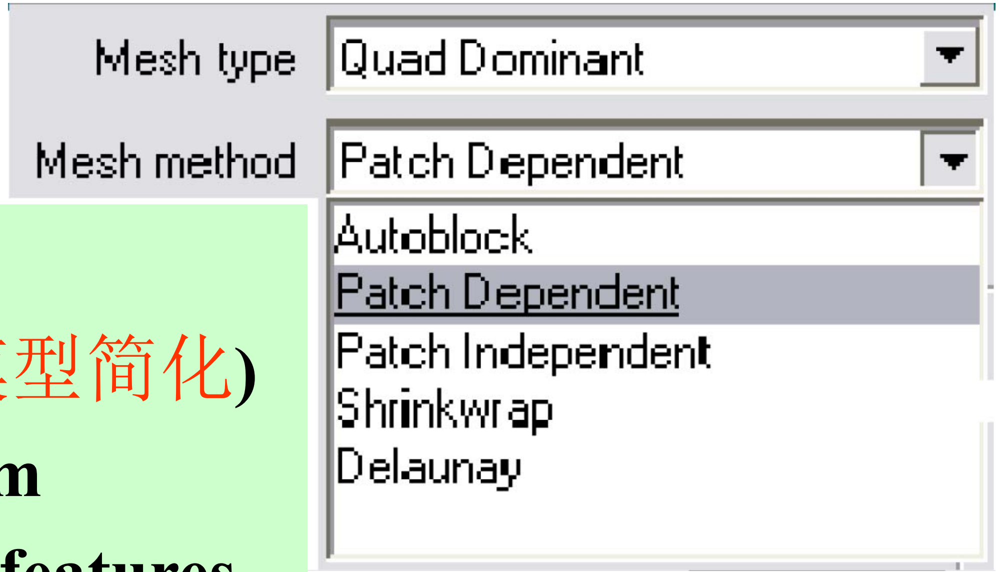
– Good for dirty geometry, ignoring small features, gaps, holes

- **Autoblock**

– Based on 2D orthogonal blocks

– Best for mapped meshing, mesh follows contours of geometry

- **Autoblock**




– **Shrinkwrap(薄膜)**

– **Automatic defeaturing(模型简化)**

– **Quick Cartesian algorithm**

– **Allows ignoring of larger features, gaps and holes**

- **Delauney**

– **Allows for transition in mesh size**

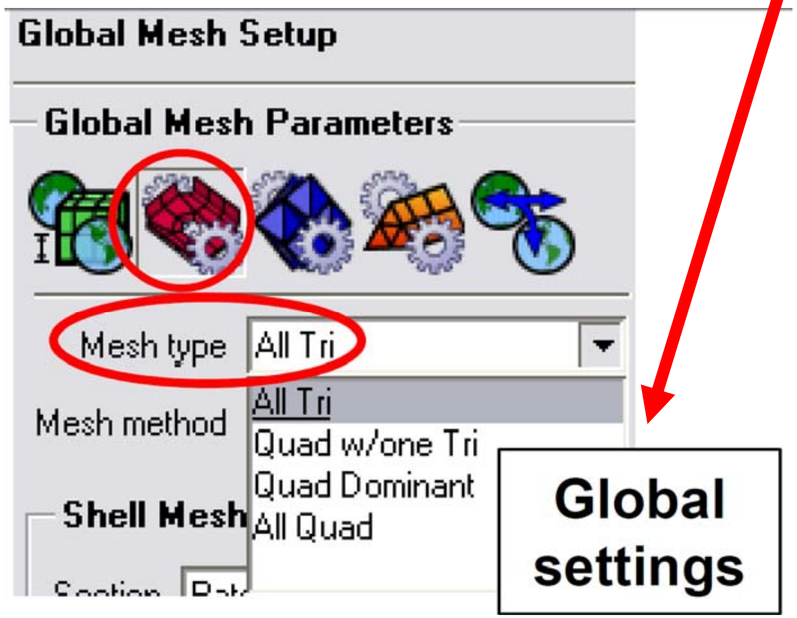
  - **Coarser towards surface interior**

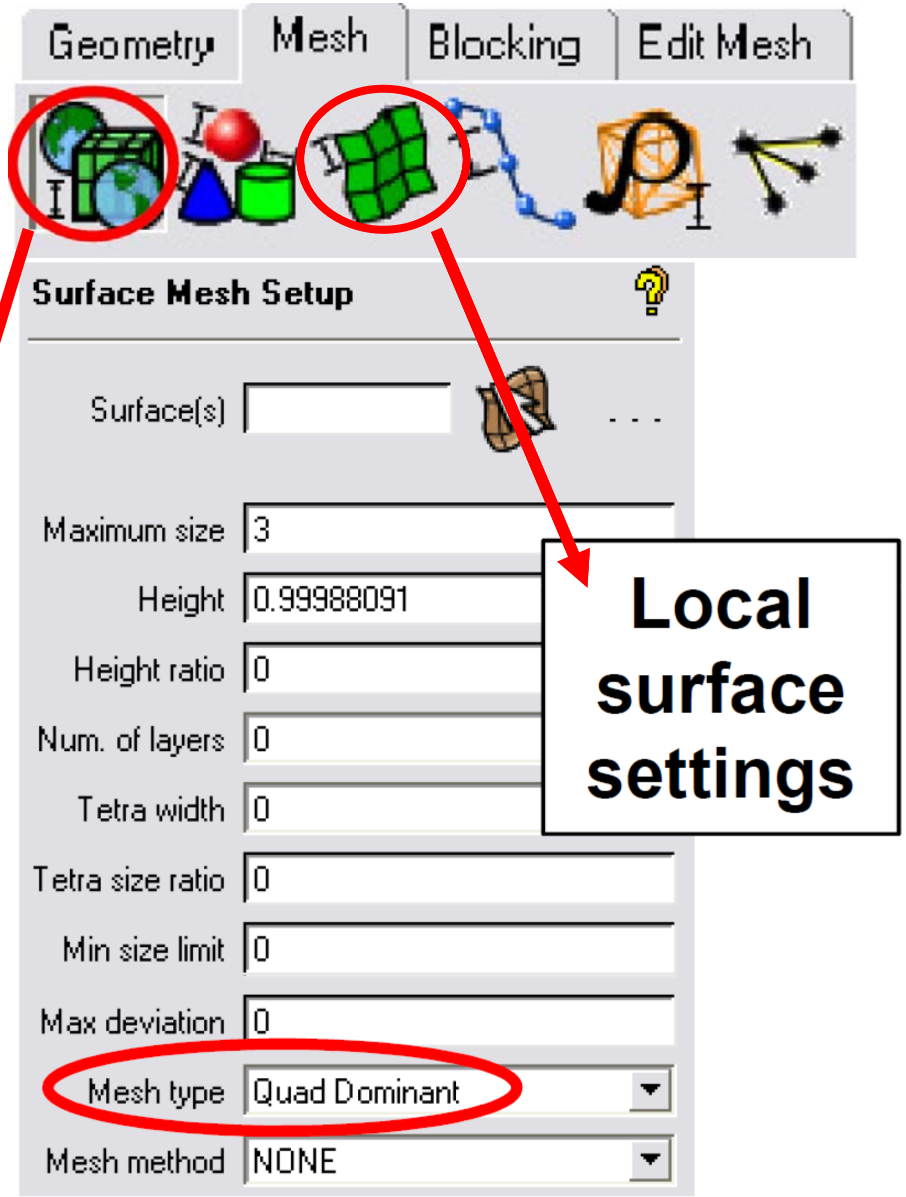
– **Tri only**

# *8. Mesh Types*

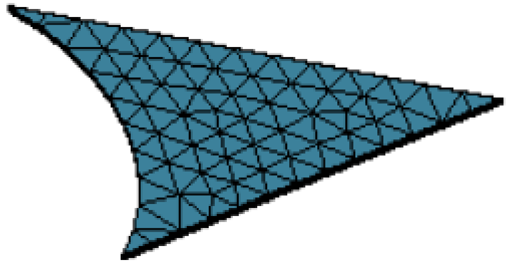
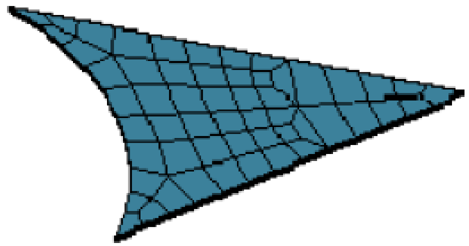
– Set in ***Global Mesh Setup > Shell Mesh Parameters*** **or** ***Surface Mesh Setup*** **(local upon selected surface entities**

- **Global defaults overridden by local settings**

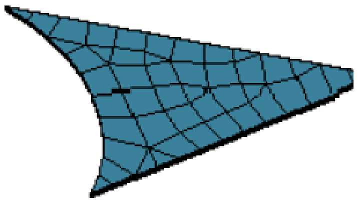


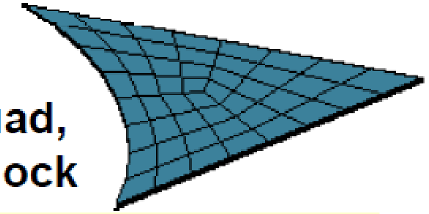
# *Mesh Types*

– *All Tri*
– *Quad with one Tri*
  - **Almost all quad except with one tri per surface**
  - **Single tri allows transition between uneven mesh distribution on loop edges**
  - **Where pure quad will fail**



All quad, autoblock



– *Quad Dominant*
  - **Allows for several transition triangles**
  - **Very useful in surface meshing complicated surfaces where a pure quad mesh may have poor quality**

– *All Quad*

**These mesh types will look different with the different mesh methods**

# 9. Compute Mesh

**Once sizes, methods and types are set – ready to compute!**

- **Select *Mesh > Compute Mesh >Surface Mesh Only***

**– Most of the time can just select *Compute* at bottom of panel which will create shell mesh for entire model *(Input* = *All*)**

**– *Overwrite Surface Preset/Default Mesh Type/Method***
- **To quickly override global and local settings**
- **Avoid going back to other *Mesh Setup* menus to change parameters**

# Input

① **Can mesh *All* (default – entire model)**

② **Visible – only visibly displayed surfaces/geometry**

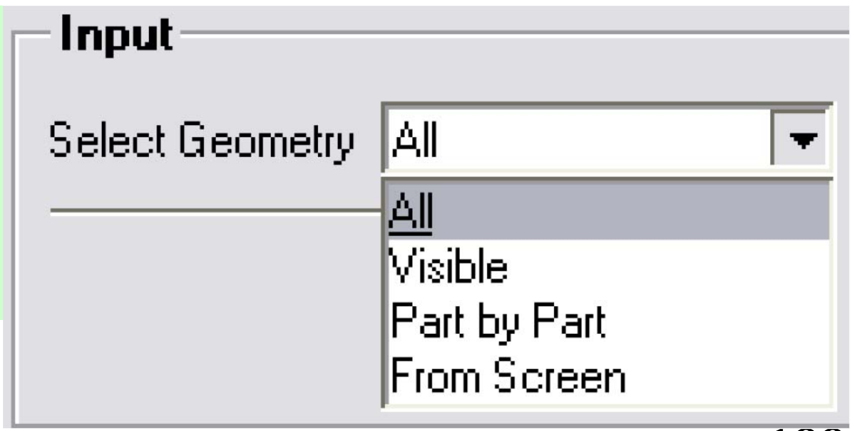
③ **Part by Part**

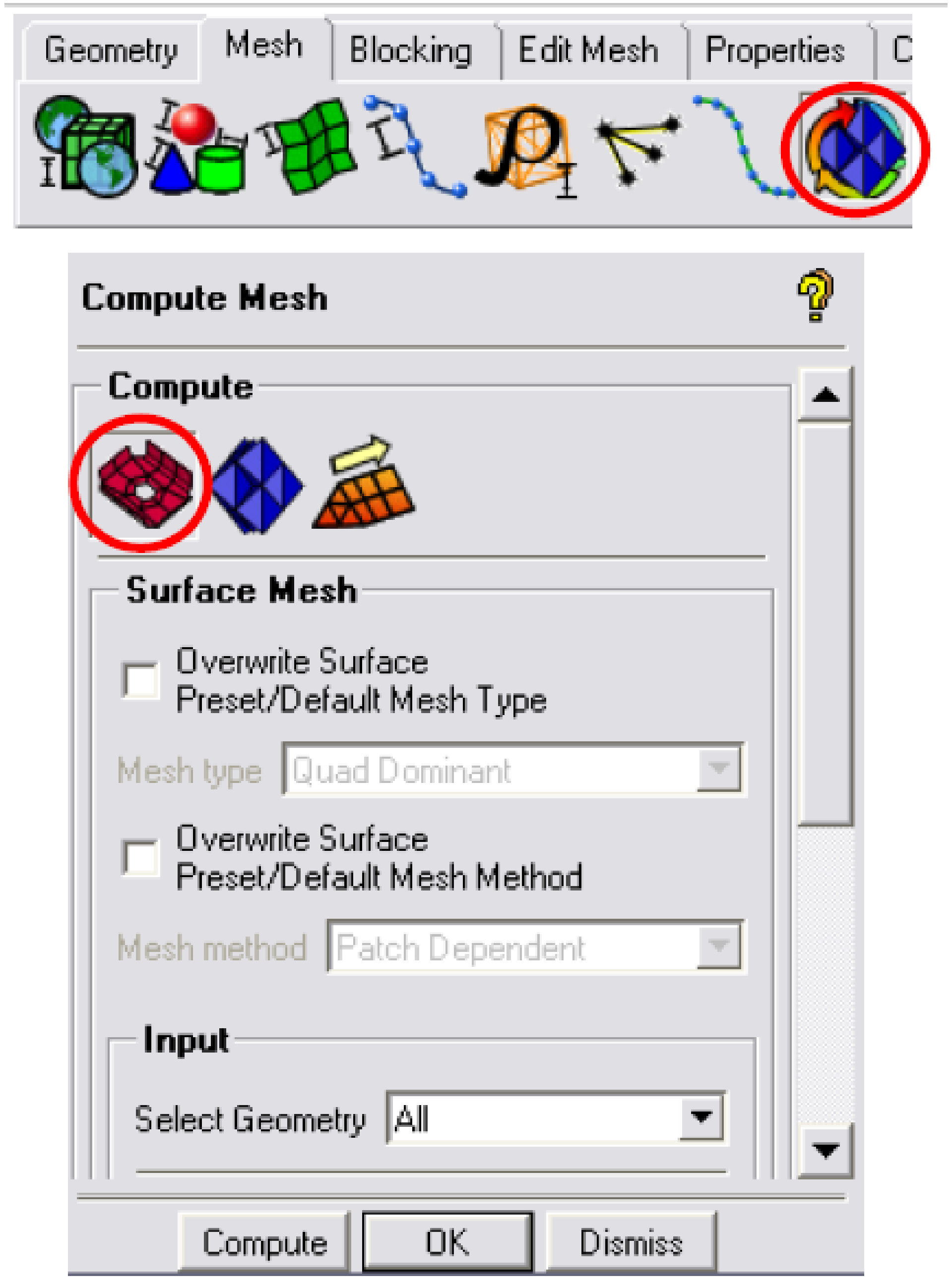
– **Parts meshed separately**

– **Mesh will be non-conformal between parts**

④ **From Screen**

– **Select entities to mesh from screen**




Geometry
Mesh
Blocking
Edit Mesh
Properties
Compute Mesh
Compute
Surface Mesh
Overwrite Surface
Preset/Default Mesh Type
Mesh type
Quad Dominant
Overwrite Surface
Preset/Default Mesh Method
Mesh method
Patch Dependent
Input
Select Geometry
All
Compute
OK
Dismiss

# 12.5.3 Introduction to Volume Meshing with ICEM

## To automatically create 3D elements to fill volumetric domain

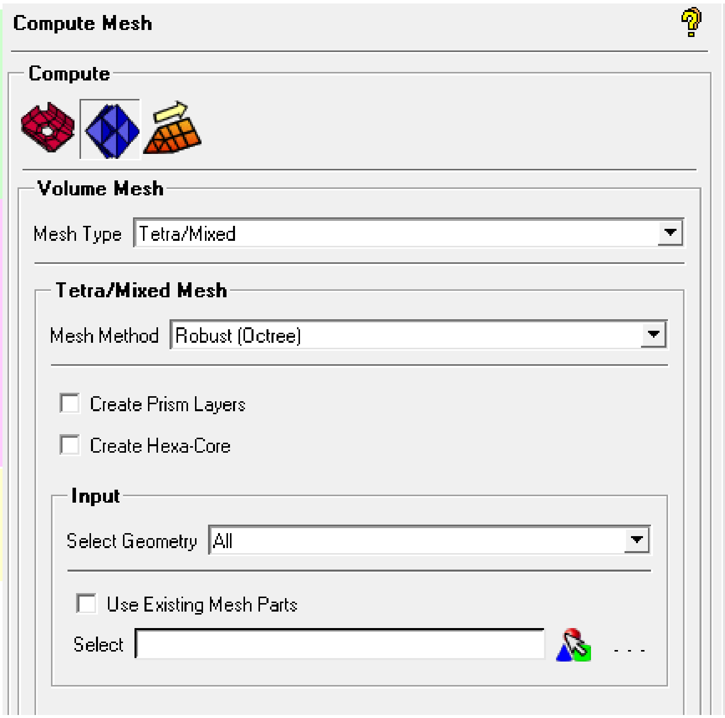
① **Generally termed "unstructured"**
- **Mainly tetra**

② **Full 3D analysis**
- **Where 2D approximations don't tell the full story**

③ **Internal/External flow simulation**

④ **Structural solid modeling**
⑤ **Thermal stress**

} **Finite element analysis**



# 1. Standard procedures

## ① Start from just geometry

- Octree tetra
  - Robust
  - Walk over features
- Cartesian
  - Fastest
- Have to set sizes

## ② Start from existing shell mesh

- Delauney/T-grid
  - Quick
- Advancing Front
  - Smoother gradients, size transition
- Hex Core
- Hex Dominant

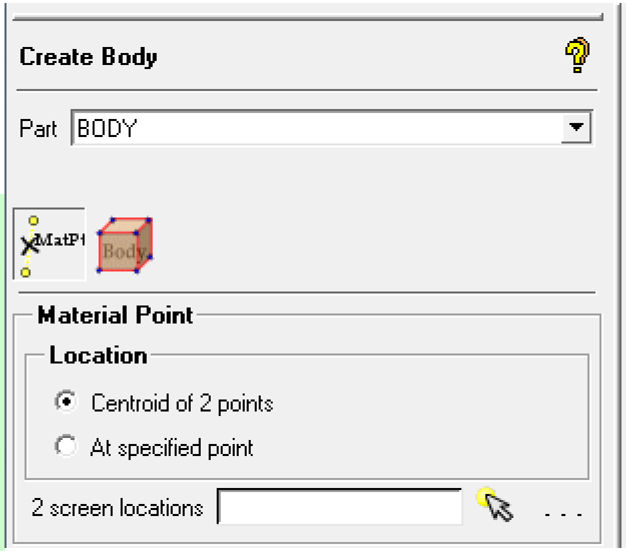
## ③ Start from both geometry and shell mesh

- Potions of model already meshed
  - Inflation layers
- "Prism" sizes

# 2. Define Volumetric Domain

– Optional
- Recommended for complex geometries
- Multiple volumes

– *Geometry -> Create Body– Material Point*

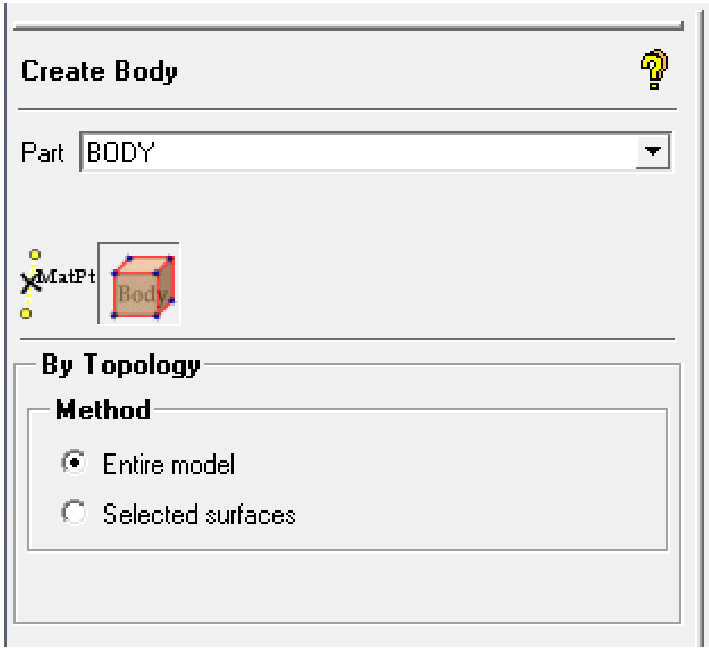



## Material Point

- Centroid of 2 points
  – Select any two locations whose mid-point is within volume
  – Preferred
- At specified point
  – Define volume region by “point” within volume

## *By Topology*

- **Defines volume region by set of closed surfaces**
- **Must first *Build Diagnostic Topology***

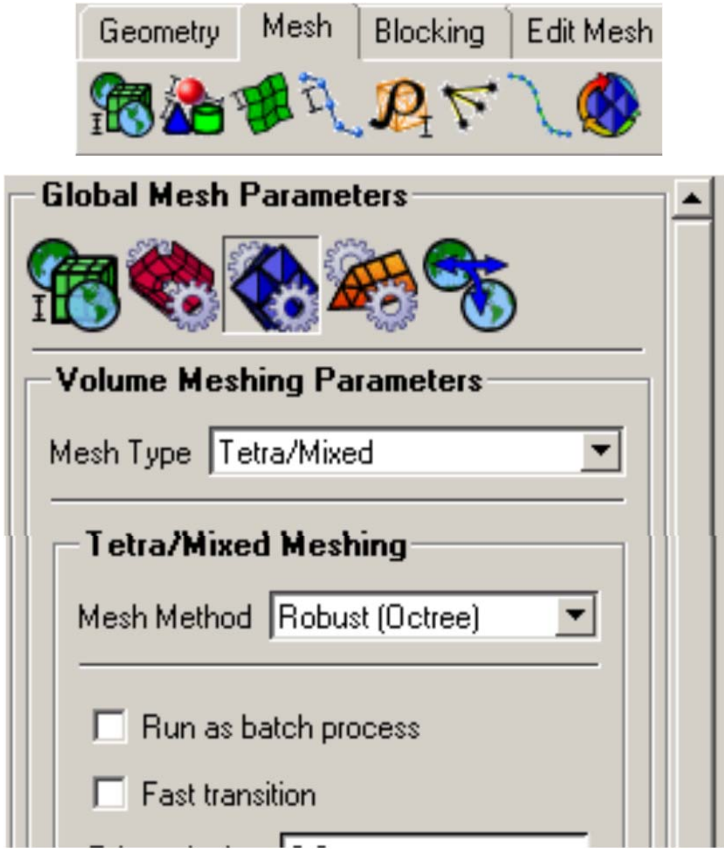



- ***Entire model***
  - **Automatically define all volumes**
- ***Selected surfaces***
  - **User selects surfaces that form a closed volume**

# 3. Volume Meshing General Procedure

## ① First decide volume mesh parameters

- *Global Mesh Setup > Volume Meshing Parameters*
- Select *Mesh Type*
- Select *Mesh Method* for selected *Type*
- Set options for specific *Methods*



## ② Set mesh sizes

- Globally
  - As in *Shell Meshing*
- Locally
  - *Part/Surface/Curve Mesh Setup*
  - As in Shell Meshing
  - For *From geometry* only
    - Octree
    - Cartesian

③ **Load/create surface mesh**

– **As in shell meshing section**

– **For Delauney, Advancing Front, T-grid, Hex-Dominant**

• **Either of these types run from geometry will automatically create surface mesh using global and local Shell Mesh settings without any user input/editing**

• **If in doubt, run Shell Mesh first, then from existing mesh**

## ④ Define volumetric region

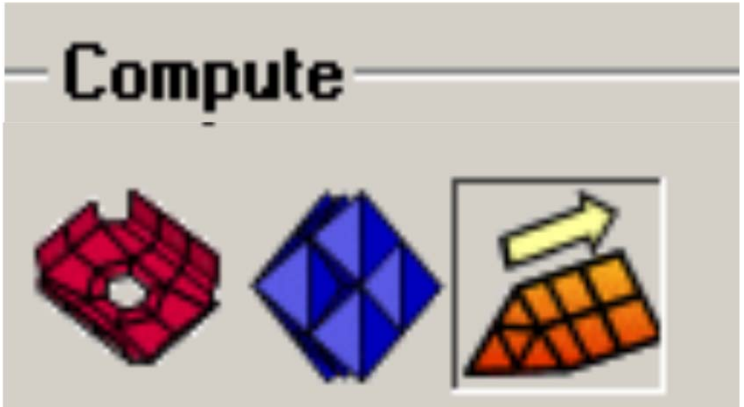
- Typically for octree on complex models
- Multiple volumes

## ⑤ Define density regions (optional)

- Applying mesh size within volume where geometry doesn't exist

## ⑥ Compute Prism (optional)

- As separate process
- Also option to run automatically following tetra creation



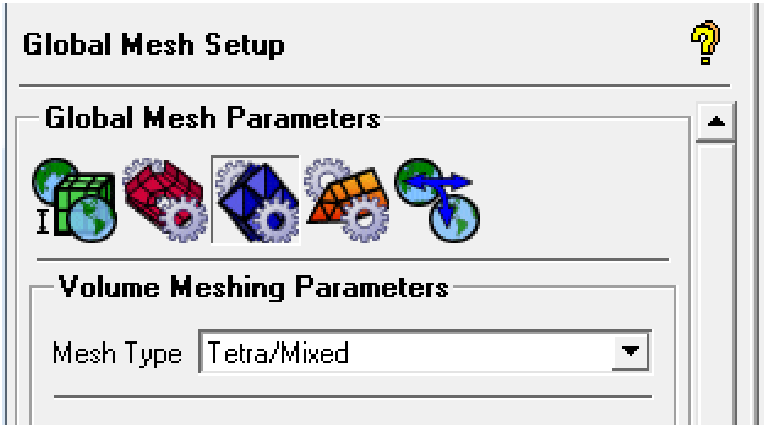
# ⑦ Compute Mesh

– *Mesh> Compute Mesh > Volume Mesh*

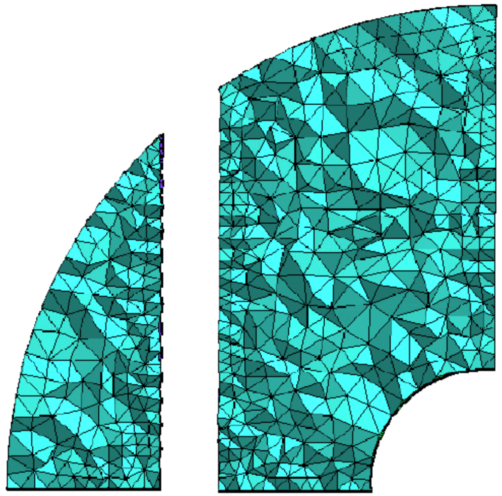
# 4.Mesh Types

## ① Tetra/mixed

- Most used
- Tetra
- With hex core



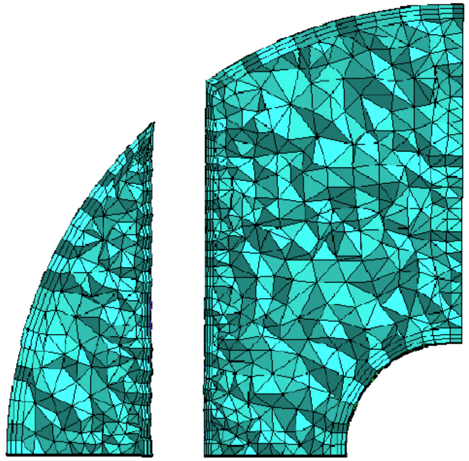

- Hexa (cartesian ) filling majority volume
- Tetra (from delauney algorithm) used to fill between surface or top of inflation layers and hex core
- Pyramids to make conformal between tetra tri and hex quad faces



Pure tetra

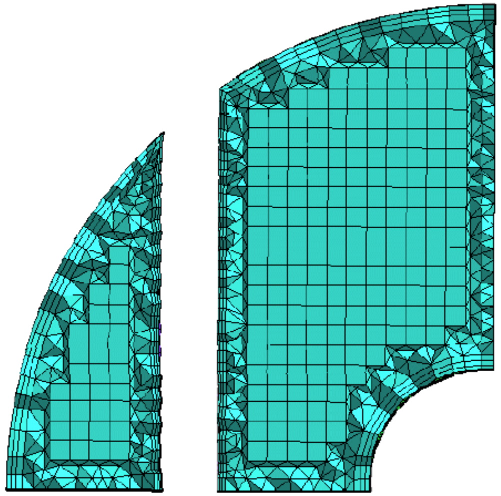
## With inflation layers

- Prisms from tri surface mesh
- Hexas from quad surface mesh
- Tetra and/or hex core filling interior
- Pyramids to cap off any quad faces
  – Of hex core or hex inflation layers



Tetra/Prism

## Merged hybrid with structured hex mesh



Tetra/Prism/Hexcore

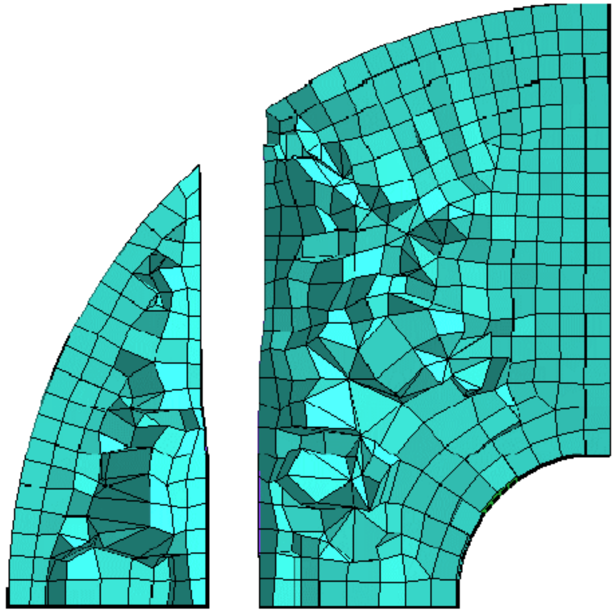
## ② Hexa-Dominant

– From existing quad mesh

– Good quality hex near surface

– Somewhat poor in interior

– Typically good enough for static displacement



# ③ Cartesian

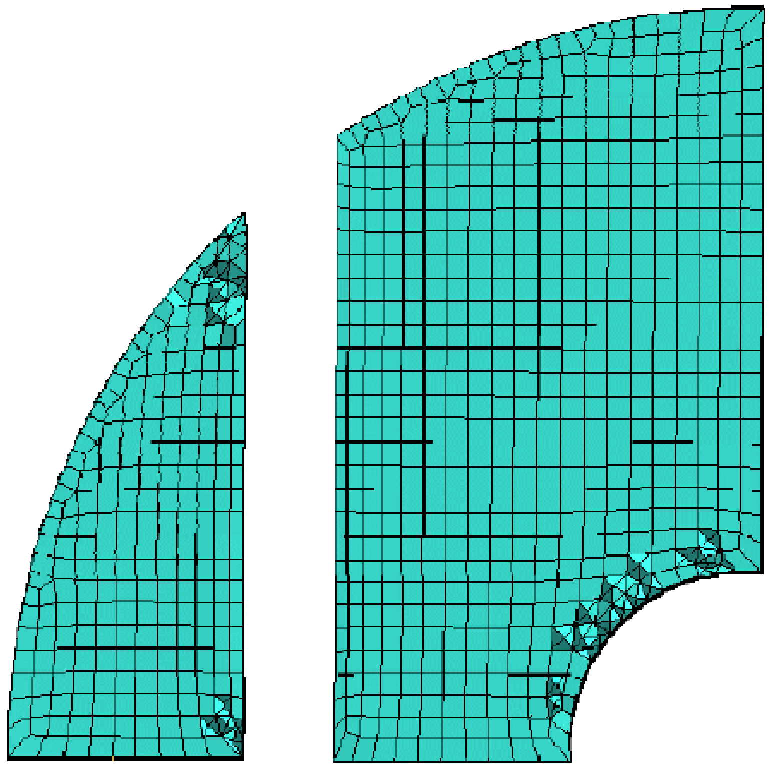
– Automatic pure hexa

– Rectilinear mesh

– Staircase or

– Body fitted

– Fastest method for creating volume mesh



# 5. Set Mesh Sizes

## *Create Mesh Density*

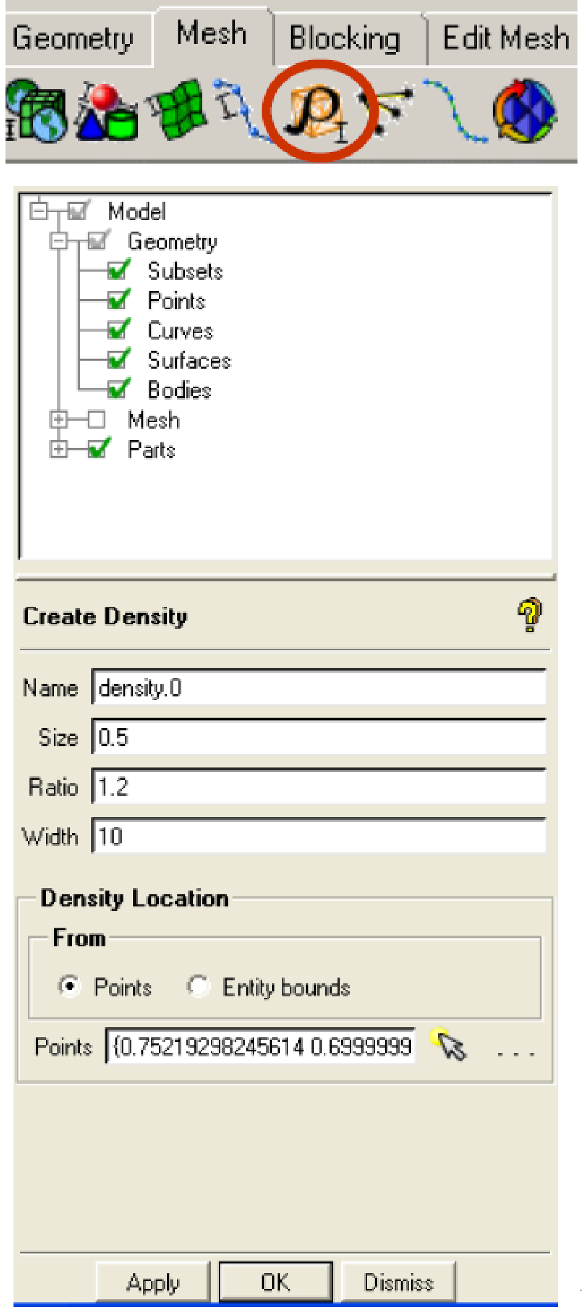
① **Define volumetric region with certain mesh size where no geometry exists, e.g. wake region behind a wing**

② **Not actual geometry!**

- **Mesh nodes not constrained to density object**
- **Can intersect geometry**

③ **Can create densities within densities**

- **Always subdivides to smallest set size**



## Set *Size*

- As for surface/curve – multiplied by global *Scale Factor*
- *Ratio* – expansion ratio away from density object
- *Width* – Number of layers from object

## Type

- *Points* – Select any number of points
  - *Size* and *Width* (number of layers) will determine

"thickness" of volume if number of points selected is 1-3
  - 4-8 creates polyhedral volume
- *Entity bounds* – define region by bounding box

of selected entities

# 12.5.4 Examples to generate structural grid

## The structured mesh generation procedure:

**1.Create/Import geometry.**

**2.Initialize blocking with respect to geometry dimension**

**3.Generate block structure using the split, merge, O-grid definition.**

**4.Associate vertices to points, edges to curve and block faces to geometry face.**

**5.Check block structure quality to ensure the block model meets specified quality threshold.**

**6.Determine edge meshing parameters and using spacing 1 or spacing 2 for increasing mesh density in specific zone.**

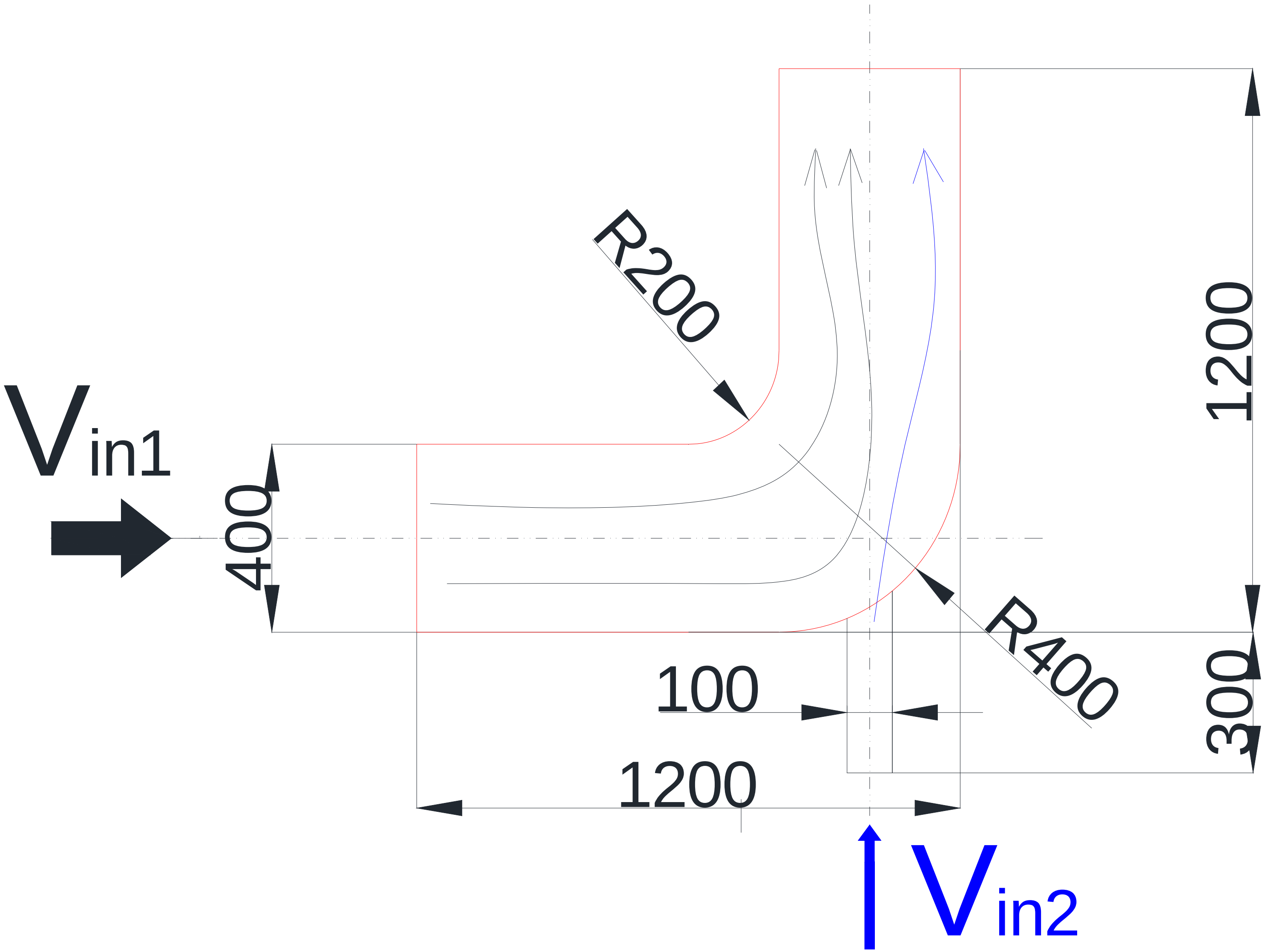
**7.Using pre-mesh to update mesh**

**8.Check the cell quality of the mesh once its generated.**

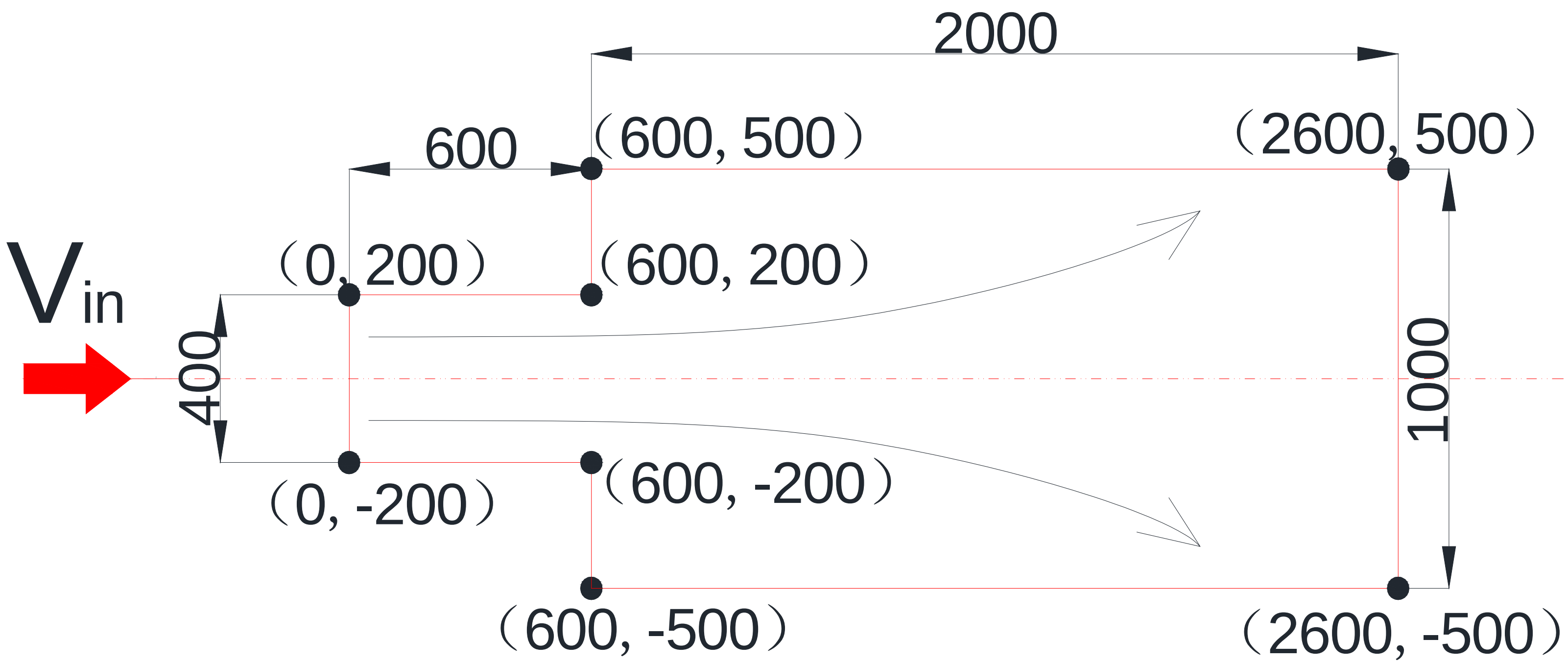
**9.Convert structure mesh to substructure mesh by right click on the re-compute mesh**

**10.Write output files to desired solver like fluent**

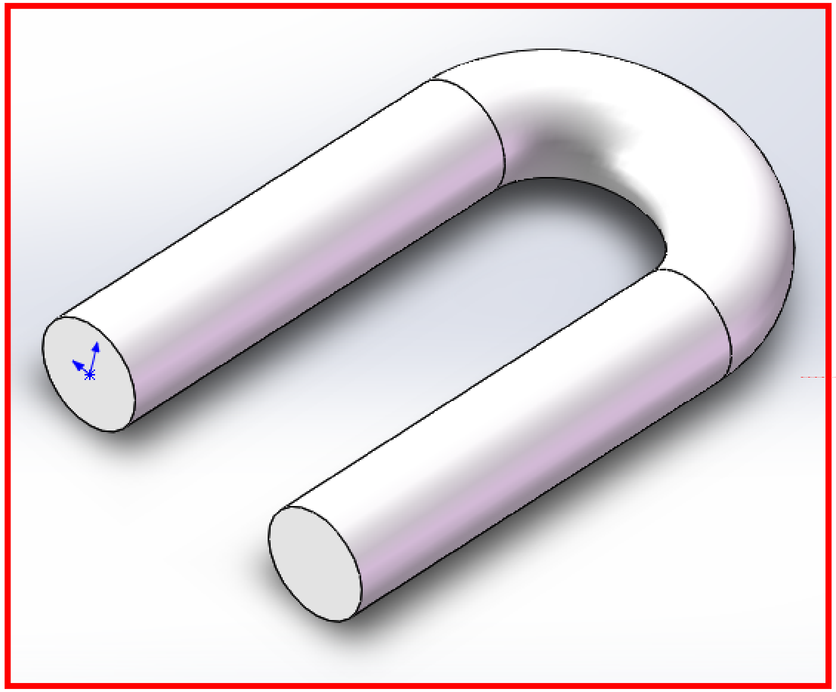
# Example 1: 2D Pipe Junction

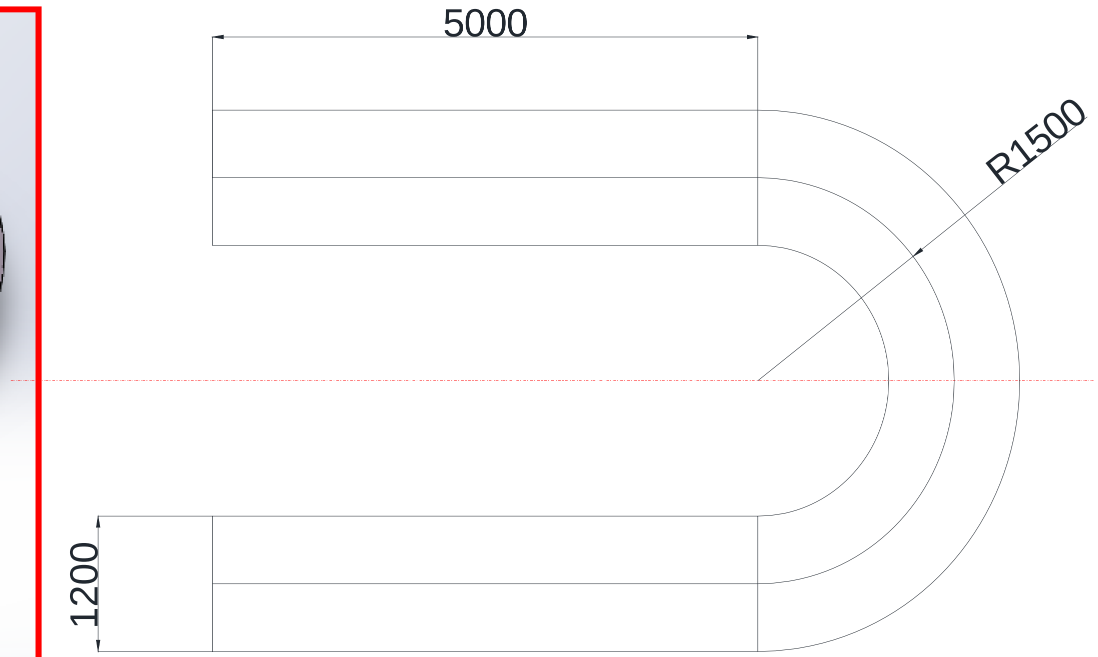


# Example 2: Sudden expansions of a circular tube

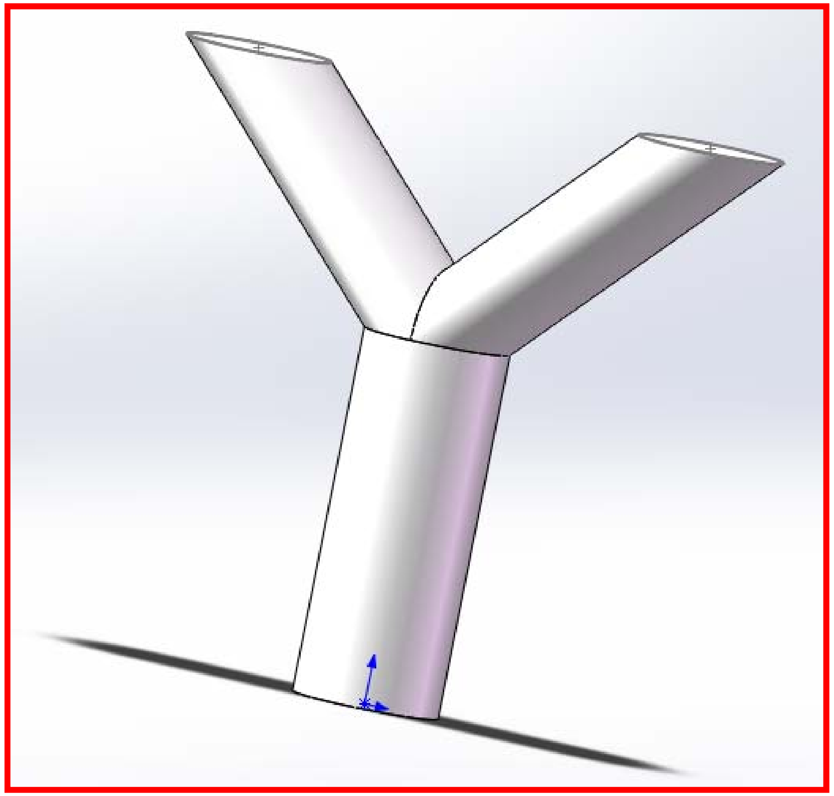


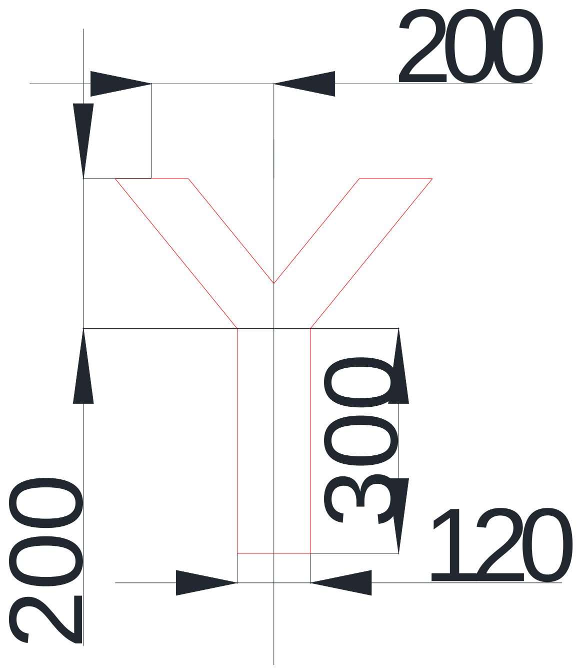
# Example 3: Flow in a U turn



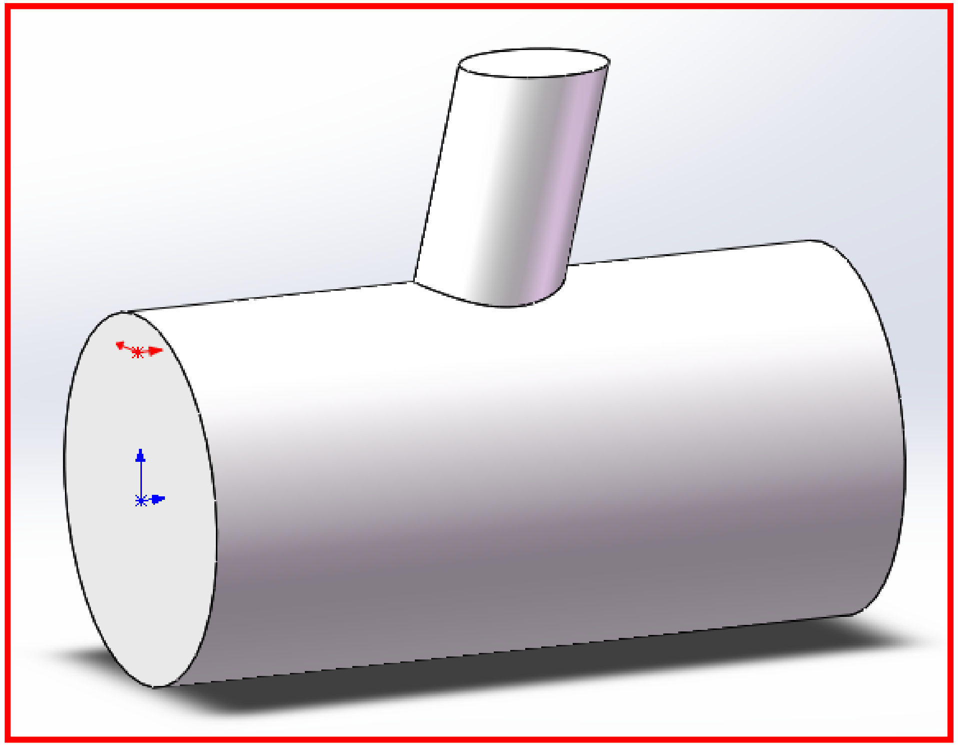


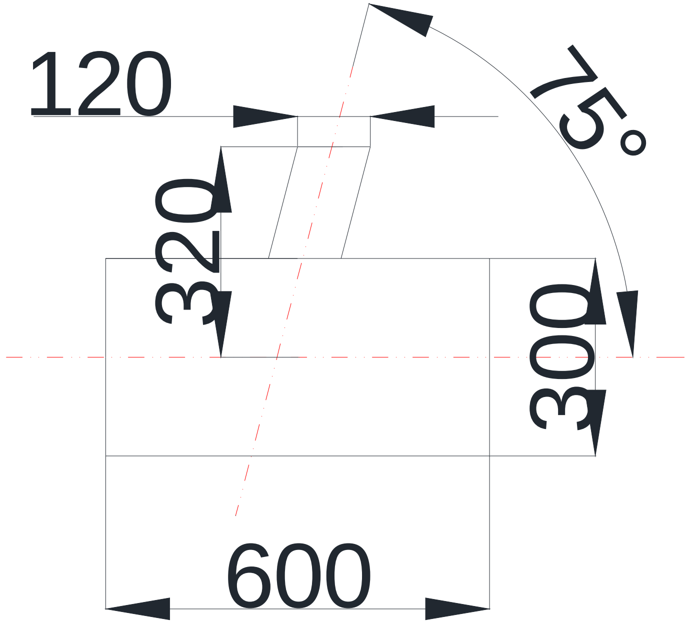
# Example 4: Flow in a “Y” tube





# Example 5: Three pipe junction






Thanks very much!

谢谢各位!

同舟共济

渡彼岸!