弹箭发射模拟的关键问题及解决方法

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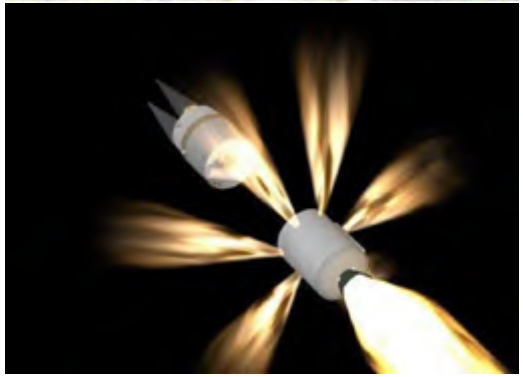
ANSYS China

弹箭发射概述









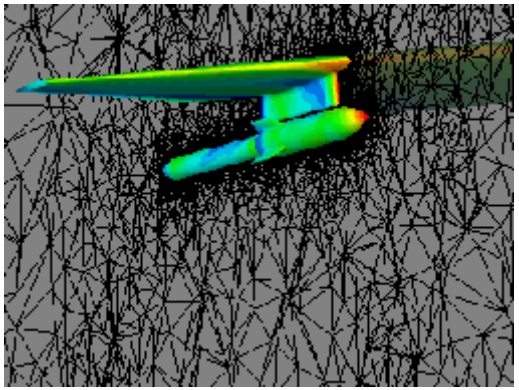
弹箭发射仿真的物理问题

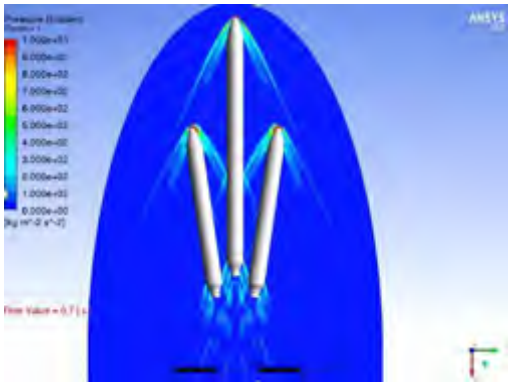
弹箭发射需要考虑的一些因素	仿真需求
▪ 气动分析	√ DBS+湍流模型
▪ 激波捕捉	√ DBS+湍流模型+高精度通量分裂格式
▪ 气动弹性	√ 1 way & 2 way FSI
▪ 气动加热	√ Fluent共轭换热
▪ 弹道轨迹	√ Remeshing/OverSet Mesh + 6DOF
▪ 噪声分析	√ Fluent噪声分析模块
▪ …….	√ ANSYS Modules

弹箭发射模拟的关键问题及解决方法

❑弹箭发射及弹道轨迹设计

- ➢ Remeshing + 6DOF
- ➢ OverSet Mesh + 6DOF

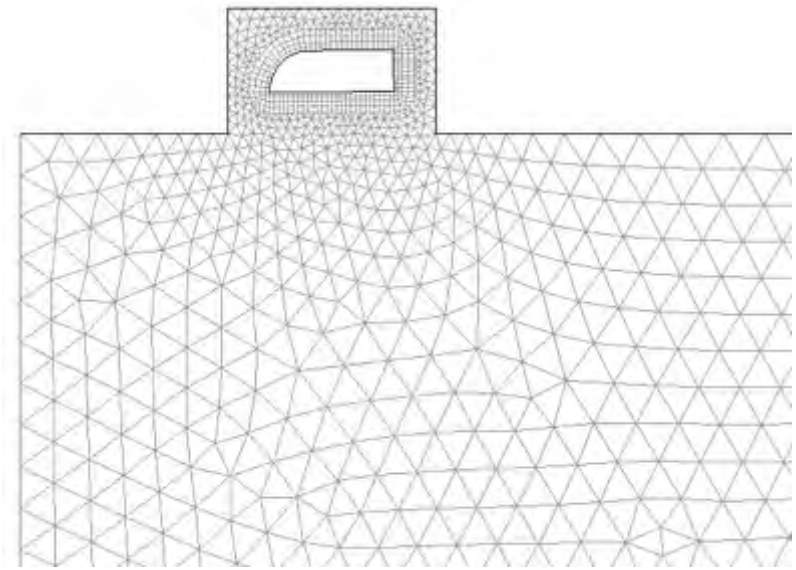




Remeshing

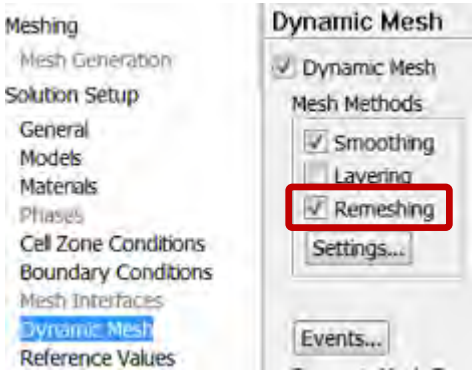
Remeshing Method - Introduction

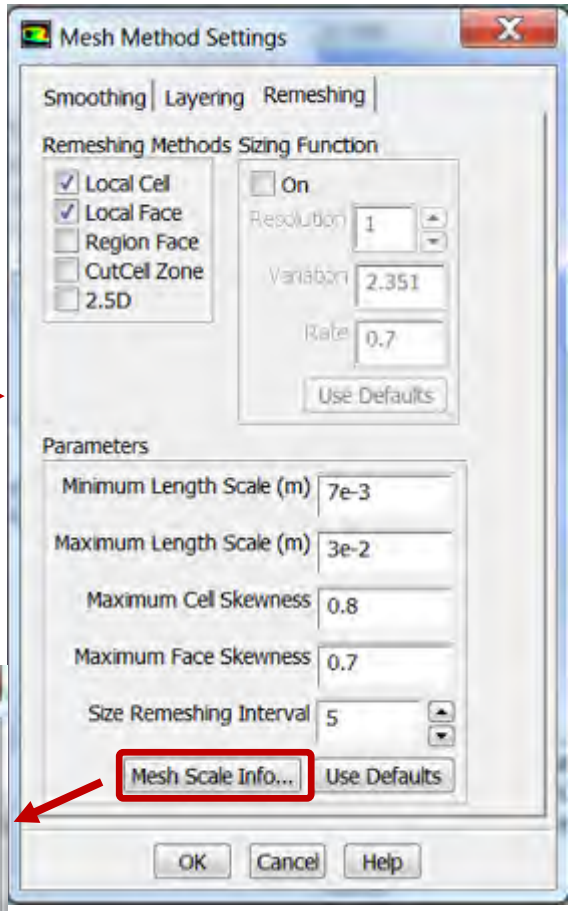
- The remeshing method makes it possible to simulate problems with large relative motion of boundaries
  - ✓ Cells and faces are remeshed when skewness or size exceeds specified limits
  - ✓ The number of nodes and their connectivity changes as cells/faces are added or deleted
- Available for:
  - ✓ tri & tet meshes (with or without prism layers)
    - (i.e. for both 2D and 3D)
  - ✓ 2.5D Prism zones (extruded tri elements)
  - ✓ Cutcell
- Remeshing and smoothing are typically used together
  - ✓ Produces better quality mesh
  - ✓ Allows larger time steps



Remeshing

- **To enable the Remeshing method**
  - Activate Dynamic Mesh
  - Select Remeshing under Mesh Methods
  - Click on settings
    - **Remeshing tab**
  - Select Method
    - **Local cell/ Local Face**
  - View “mesh scale info”
  - Select parameters
    - **A good starting point for the length scales are $0.4L_{min}$, $1.4L_{max}$**

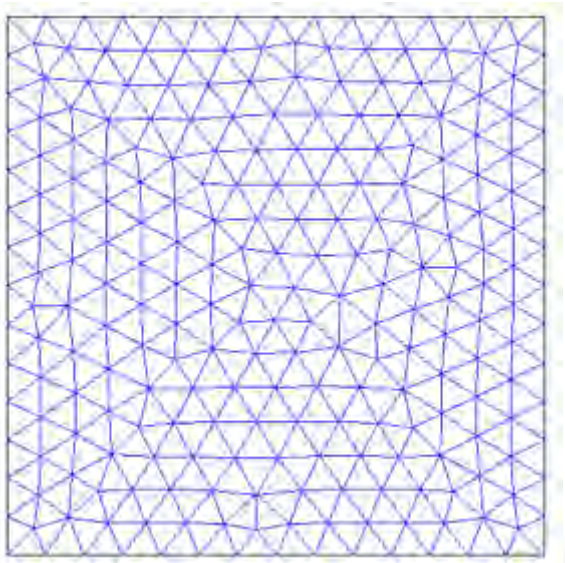




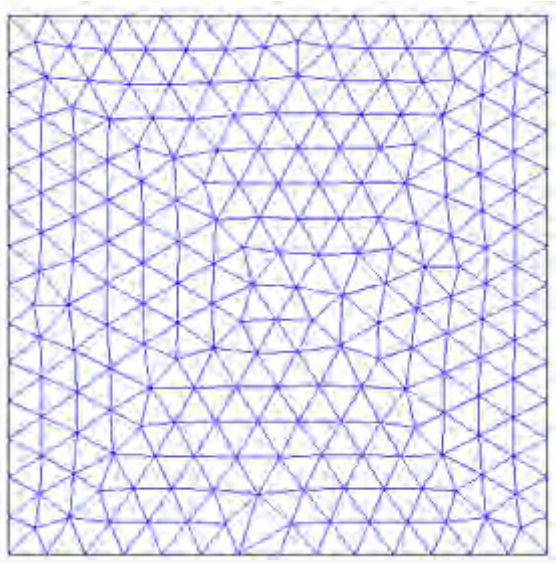
Remeshing

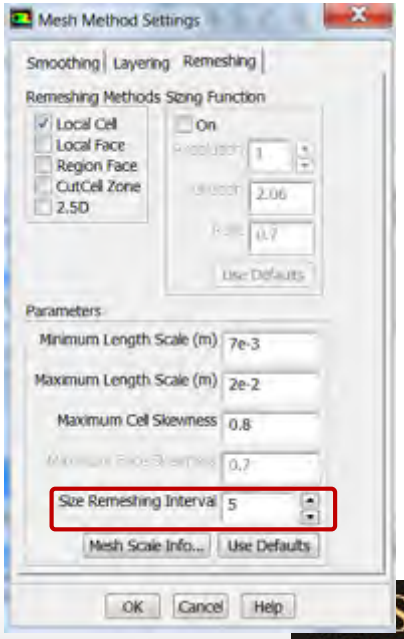
- **Size Remeshing Interval**
  - Size Remesh Interval (SRI) controls how frequently cells are marked for remeshing based on the cell size.
    - If SRI is large, then remeshing interval is dominated by skewness.
    - If SRI is small, then remeshing interval is strongly affected by both cell size and skewness.
    - Setting SRI to 1 is often necessary for larger time steps
      - It is common that the time step size is limited by the remeshing rather then the flow solution

Size Remeshing Interval = 10



Size Remeshing Interval = 1





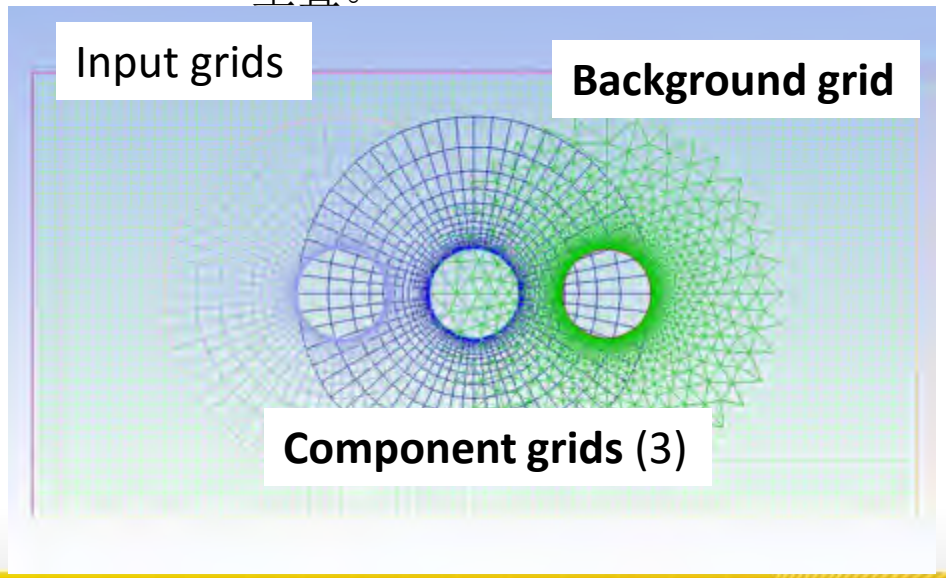
Overset Meshing

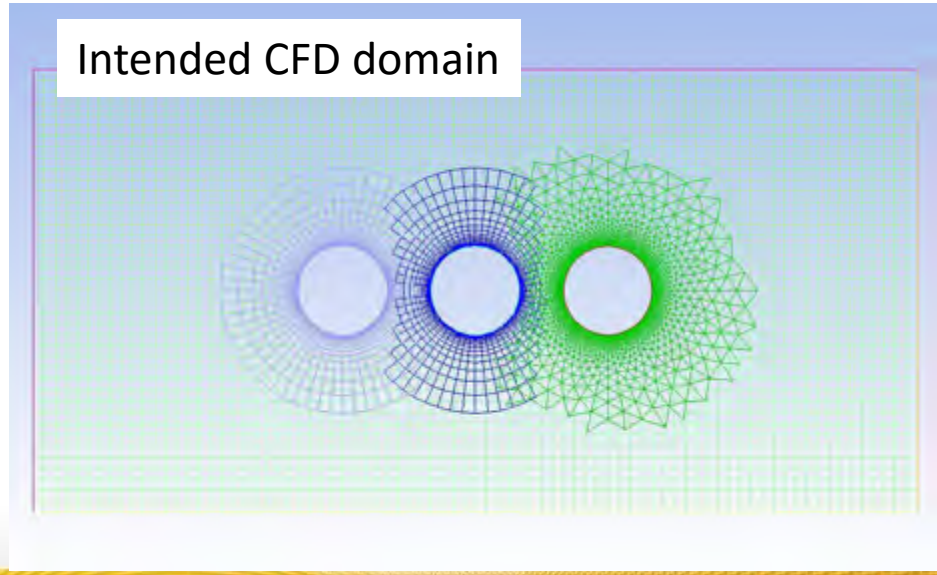
重叠网格概述

- 由部件网格构建计算域的新方法
  - *单域或共节点 连接多区域网格*
  - *匹配面之间的网格连接是通过non-conformal来实现的. 网格之间的连通性是建立在面level上的。*

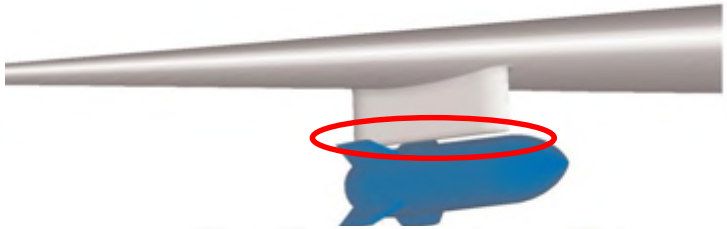
旧的现有方式

  - 通过overset interface连接重叠网格单元区域
    - 单独划分Parts网格，并将其嵌入到背景网格中
    - 重叠区域的连通是通过网格单元数据插值来实现的，网格之间需要有足够的重叠。

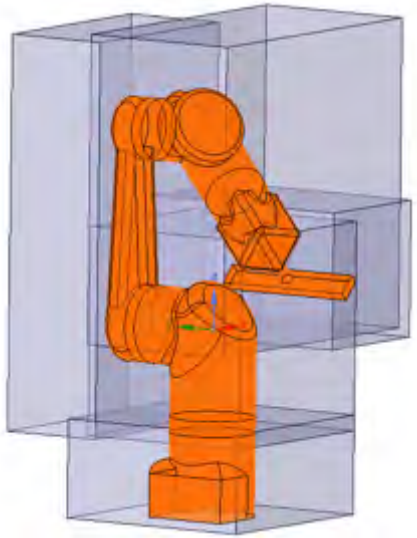




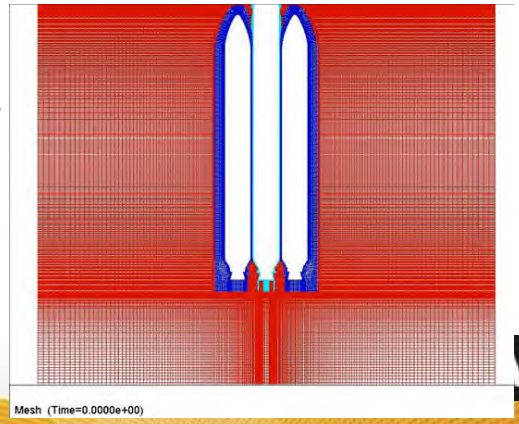
重叠网格特点



- **ANSYS Fluent功能扩展**
  - 克服了动网格的一些限制
    - 可以处理具有小缝隙部件的相对网格运动

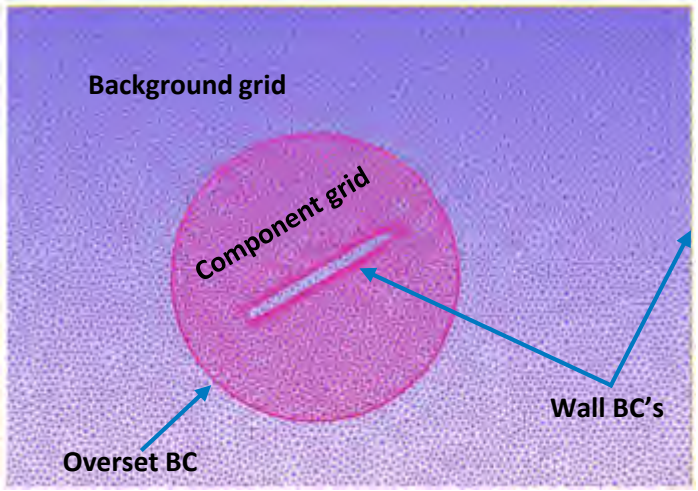


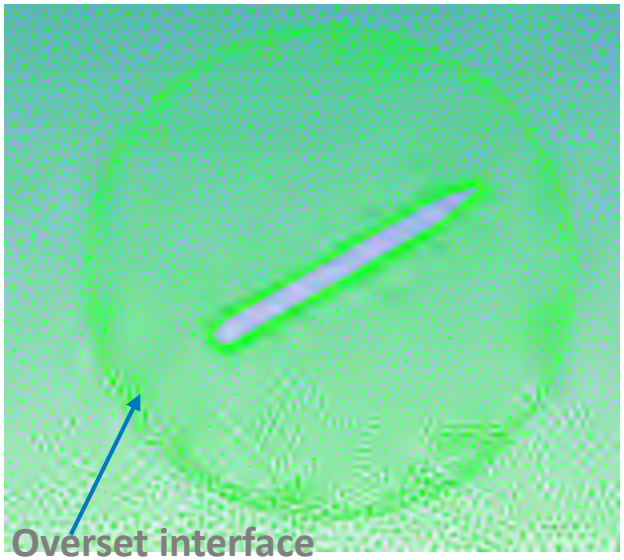
- **易用**
  - 简化了复杂几何的网格生成
  - 避免了动网格应用中网格重构失败和动网格设置的一些问题
  - 更容易的构型变化和组件交换
- **求解质量**
  - 重叠网格在网格运动期间始终可以保持很高的网格质量
  - 局部结构网格在非结构网格中的使用



重叠网格构建条件

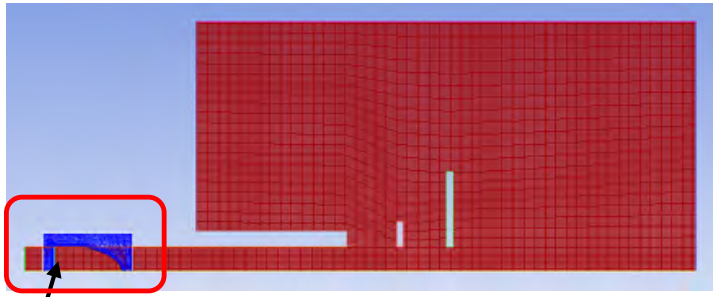
- **背景网格**
  - 网格单元区域内没有重叠类型边界，背景网格必须是共节点的网格
- **组件网格**
  - 网格单元区域至少有一个重叠类型边界，组件网格一定是共节点网格
- **重叠边界**
  - 新的特定的重叠边界条件类型
  - 将组件与其他网格通信的区域指定为重叠边界
- **重叠交界面**
  - 组件网格和背景网格是成对出现的
  - 至少需要一个背景网格和一个组件网格



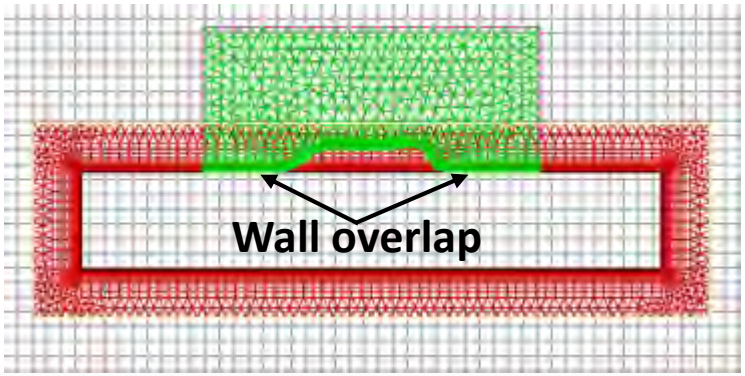


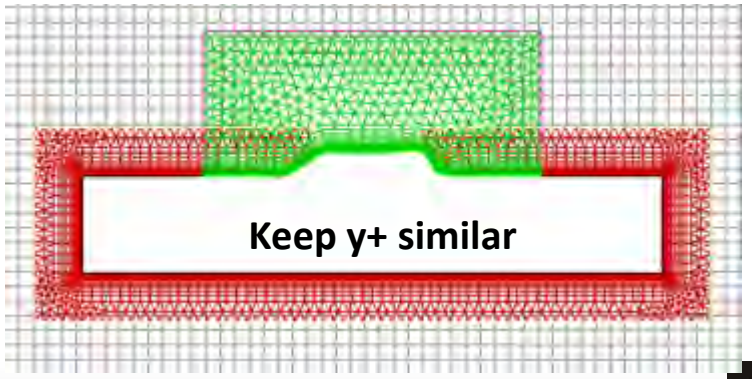
重叠拓扑

- **组件网格可任意重叠**
  - 重叠网格边界是允许的
- **允许边界重叠，但不允许边界交叉**
  - 挖洞过程中自动进行匹配检测/相同边界条件类型的重叠几何 (wall, symmetry, …)
- **交叉壁面边界需要额外 衣领 网格**
  - 衣领网格连接交叉几何
    - 生成边界重叠网格，并去除交叉
  - 生成了孤点（没用衣领网格）



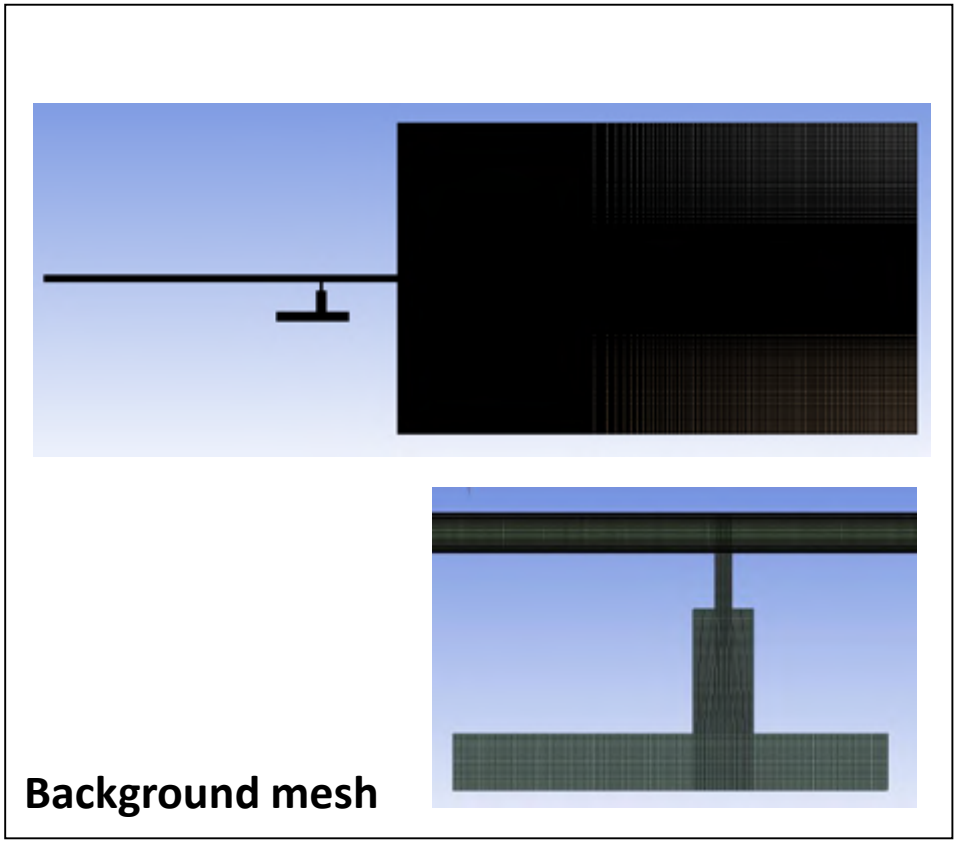
Wall intersections not permissible

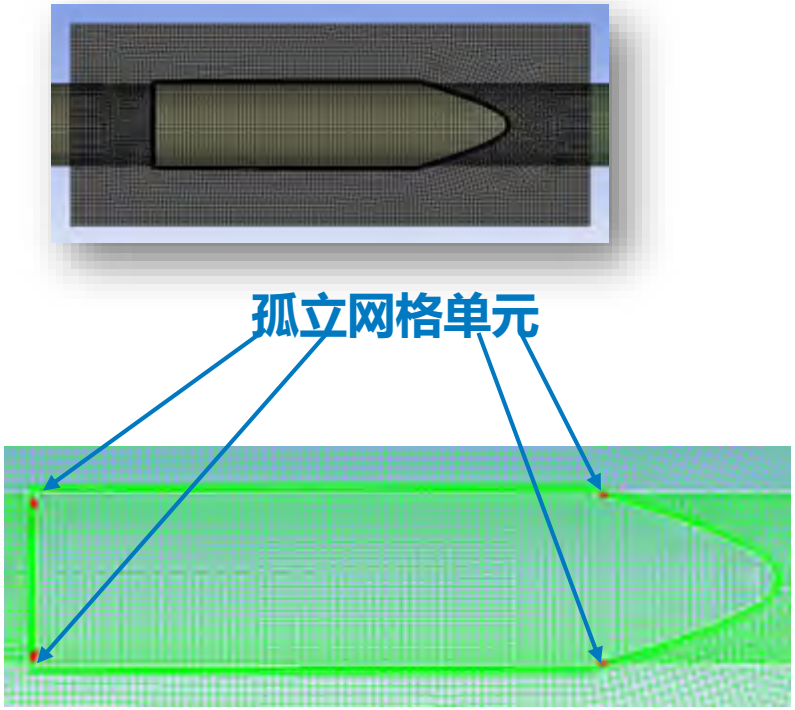




网格拓扑

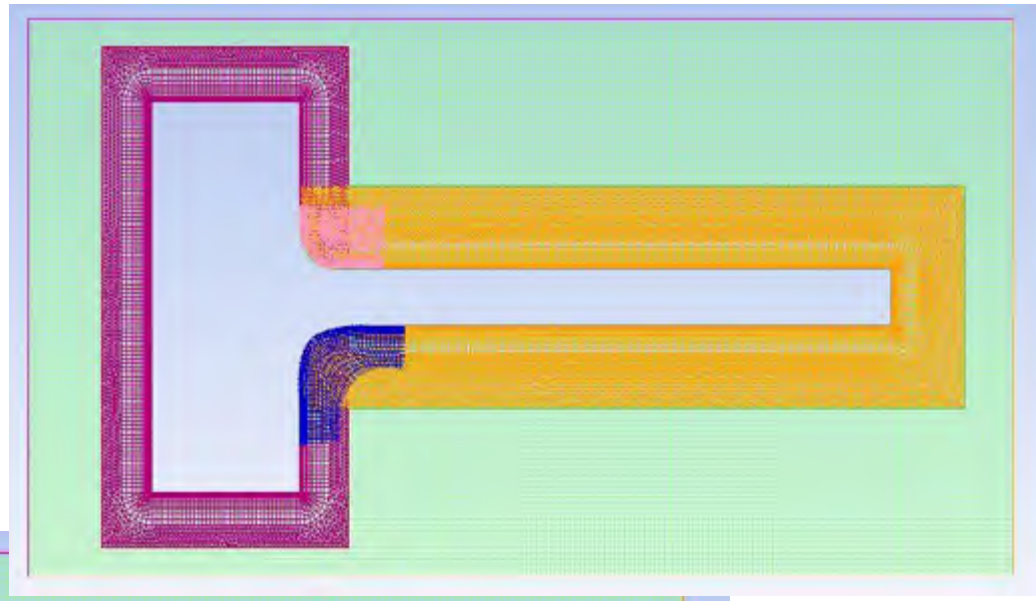
- 没用衣领网格处理的交叉壁面边界

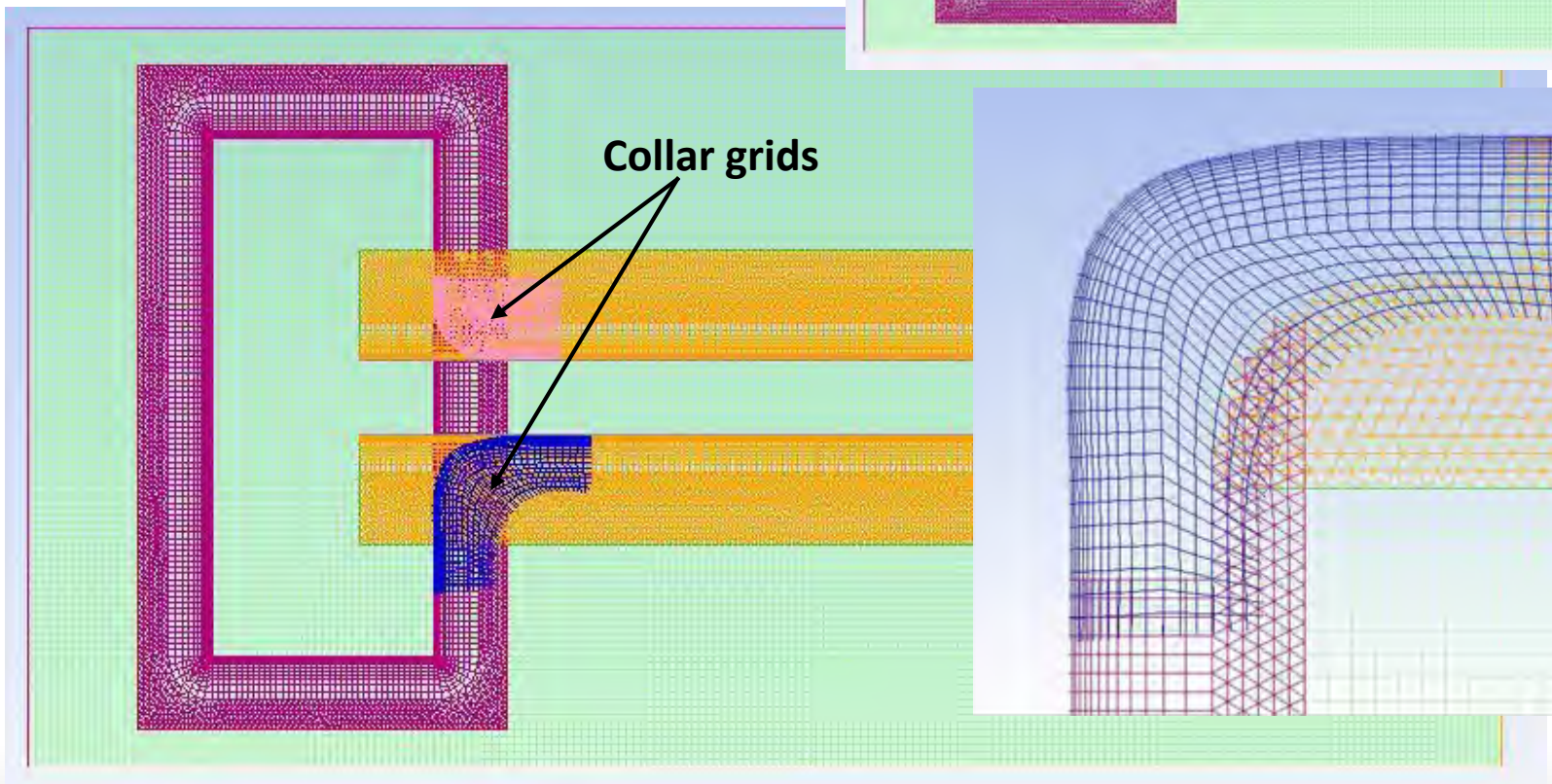




重叠拓扑

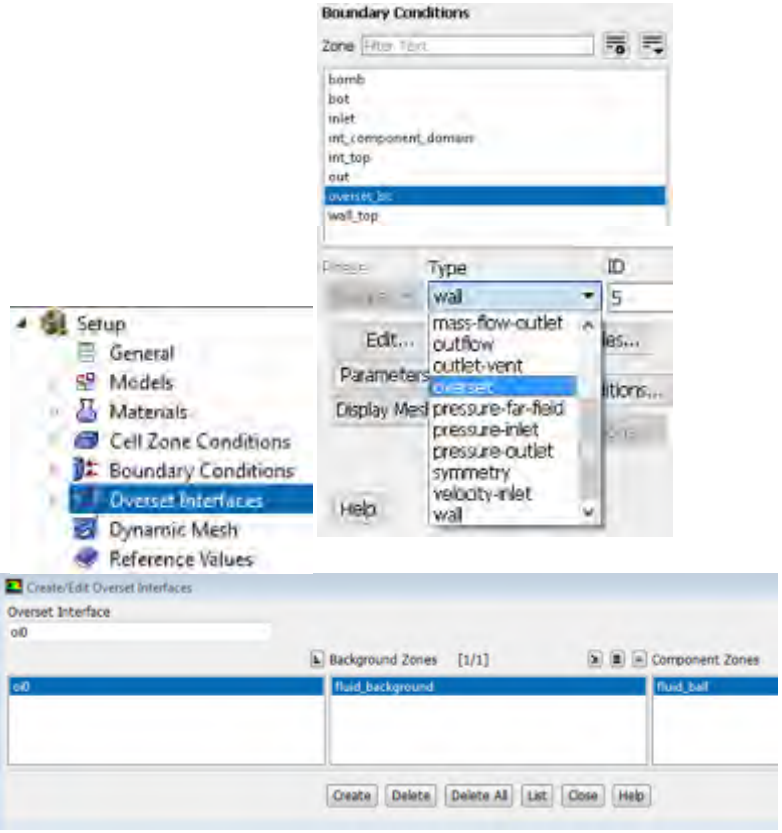
- **用衣领网格处理交叉壁面边界**
  - 消除交叉，并用重叠壁面取代





重叠网格设置

- **Read all related meshes into fluent**
- **Set the overset boundary condition**
- **Create the interface**
  - ✓ Select background and component meshes
- **Define grid priorities if needed**
  - ✓ *define/overset-interfaces/grid-priorities*
- **Initialize to intersect the interface**
  - ✓ Or use TUI command to intersect the interface without initializing the flow field (activate expert options first) *define/overset-interfaces/intersect*
- **An overset interface will automatically be created during initialization if an overset BC is defined but no interface**



注：User interface 与non-conformal interfaces类似, 用最小的用户输入就可以处理所有支持的拓扑

- 不需要连接信息
- 自动检测重叠区域

重叠网格支持的选项&模型@ R18.0

- 压力基耦合求解器 (Planar 2D & 3D)
- 密度基求解器 (Planar 2D & 3D)
- Laminar, standard k-epsilon & standard k-omega，k-omega SST
- Compressible flows, heat transfer
- Volume of Fluid (VOF)
- Dynamic and sliding meshes with the first-order transient formulation
- 与Fluent支持的所有网格单元和类型都兼容
  包括：*polyhedra, hexcore and cutcell meshes*
- 与网格自适应兼容

Coupled 6 DOF (Degree of freedom)

Introduction

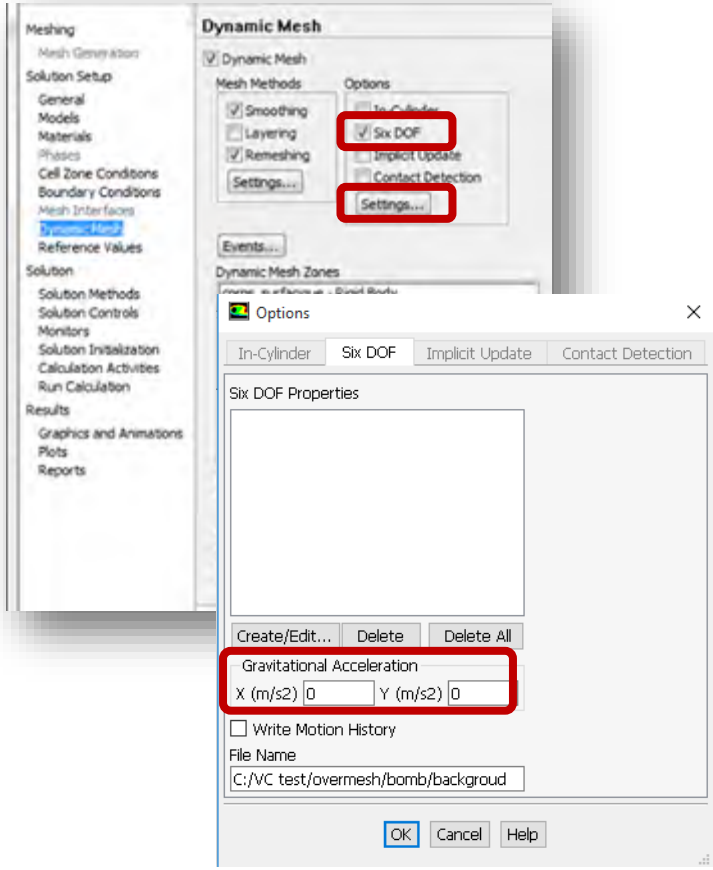
- **The motion of the parts have been explicitly defined**
- **The motion is known at the start of the simulation,**
  - Due perhaps, to parts that are mechanically driven
- **However in some cases the motion of the body is driven by the forces exerted by the fluid**
  - Therefore the motion is dependent on the flow solution
  - This can be solved in Fluent using the "6 Degree of Freedom" option

- **The 6 DOF solver computes the trajectory of the object with respect of the**
  - Aerodynamic forces/moments calculated
  - Additional external or internal forces
    - **Gravity**
    - **Thrust**
    - **Ejector**

    - ***Motion and flow field are thus coupled ➔ coupled motion***

6DOF – Principle

- **6DOF Parameter settings are done in 2 steps**
  - Dynamic Mesh panel
    - **Provides Gravitational forces**
    - **Initial conditions**
      - CG location & orientation
      - CG linear & angular velocity
  - UDF/GUI
    - **Mass**
    - **Momentum of inertia , …**
- **Fluent computes**
  - Aerodynamic forces and moments + New CG location and orientation
    - **The translational acceleration is computed from the overall force balance**
      - integrate to calculate the translational velocity.
    - **The angular acceleration is computed from the overall moment balance**
      - integrate to calculate the angular velocity



6DOF - UDF

- **To specify custom properties to a moving object, use the following macro**
  - ***DEFINE_SDOF_PROPERTIES (***names, properties, dt, time, dtime***)***

```
SDOF_MASS     /* mass */
SDOF_IXX,     /* moment of inertia */
SDOF_IYY,     /* moment of inertia */
SDOF_IZZ,     /* moment of inertia */
SDOF_IXY,     /* product of inertia */
SDOF_IXZ,     /* product of inertia */
SDOF_IYZ,     /* product of inertia */
```

```
SDOF_LOAD_LOCAL,   /* boolean */
SDOF_LOAD_F_X,     /* external force */
SDOF_LOAD_F_Y,     /* external force */
SDOF_LOAD_F_Z,     /* external force */
SDOF_LOAD_M_X,     /* external moment */
SDOF_LOAD_M_Y,     /* external moment */
SDOF_LOAD_M_Z,     /* external moment */
```

```
SDOF_ZERO_TRANS_X,     /* boolean, suppress translation in x-direction */
SDOF_ZERO_TRANS_Y,     /* boolean, suppress translation in y-direction */
SDOF_ZERO_TRANS_Z,     /* boolean, suppress translation in z-direction */

SDOF_ZERO_ROT_X,       /* boolean, suppress rotation around x-axis */
SDOF_ZERO_ROT_Y,       /* boolean, suppress rotation around y-axis */
SDOF_ZERO_ROT_Z,       /* boolean, suppress rotation around z-axis */

SDOF_SYMMETRY_X,       /* normal vector of symmetry plane for half model */
SDOF_SYMMETRY_Y,       /* normal vector of symmetry plane for half model */
SDOF_SYMMETRY_Z,       /* normal vector of symmetry plane for half model */
```

6DOF – UDF example

- **6DOF UDF example case with ejector forces & momentum included**

```
#include "udf.h"

DEFINE_SDOF_PROPERTIES(delta_missile, prop, dt, time, dtime)
{
      real y;

       prop[SDOF_MASS] = 907.185;
       prop[SDOF_IXX] = 27.116;
       prop[SDOF_IYY] = 488.094;
       prop[SDOF_IZZ] = 488.094;
       /* add injector forces, moments */
       {
        y = CURRENT_TIME;
        if (y  <=  0.15)
           {
            prop[SDOF_LOAD_F_Z] = 10676.0;
            prop[SDOF_LOAD_M_Y] = -1920.0;
           }
           else
           {
            prop[SDOF_LOAD_F_Z] = 0;
            prop[SDOF_LOAD_M_Y] = 0;
           }}
      printf ("\ndelta_missile: updated 6DOF properties");
}
```

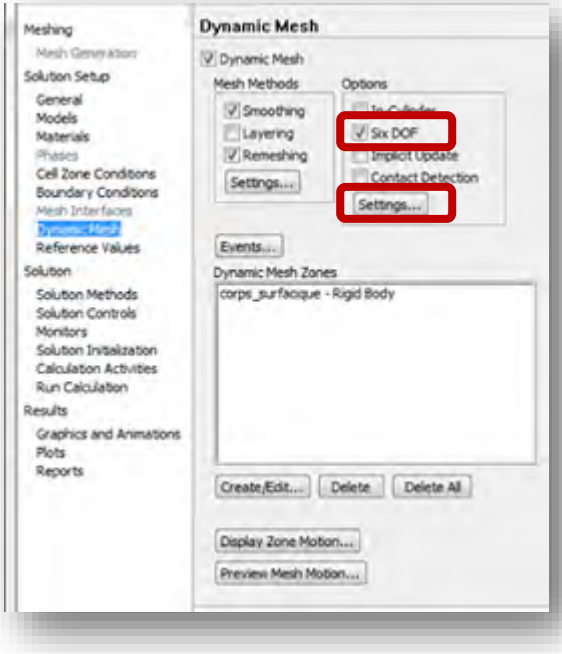
Properties of the delta_missile

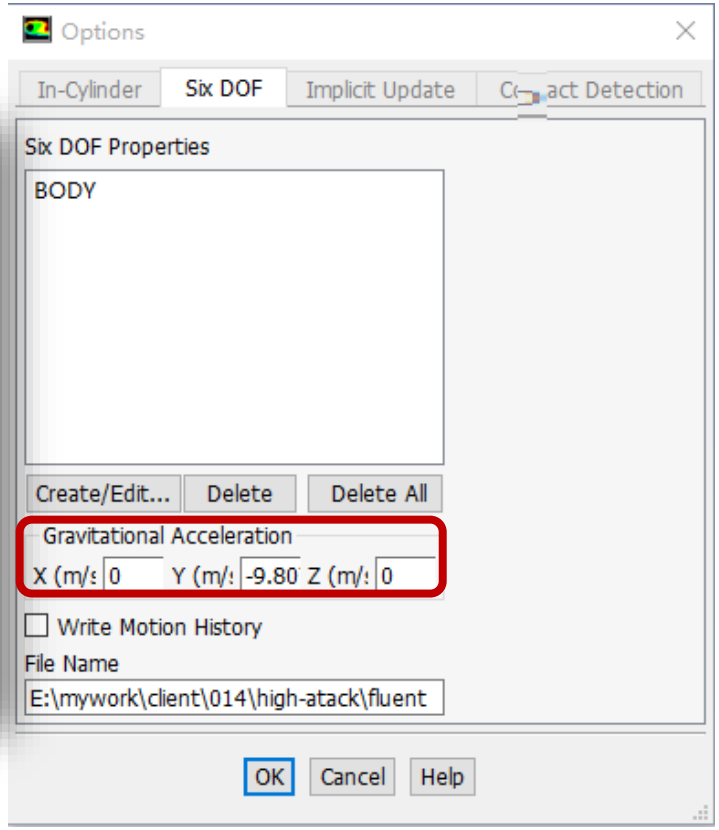
forces & moments depend on the current time

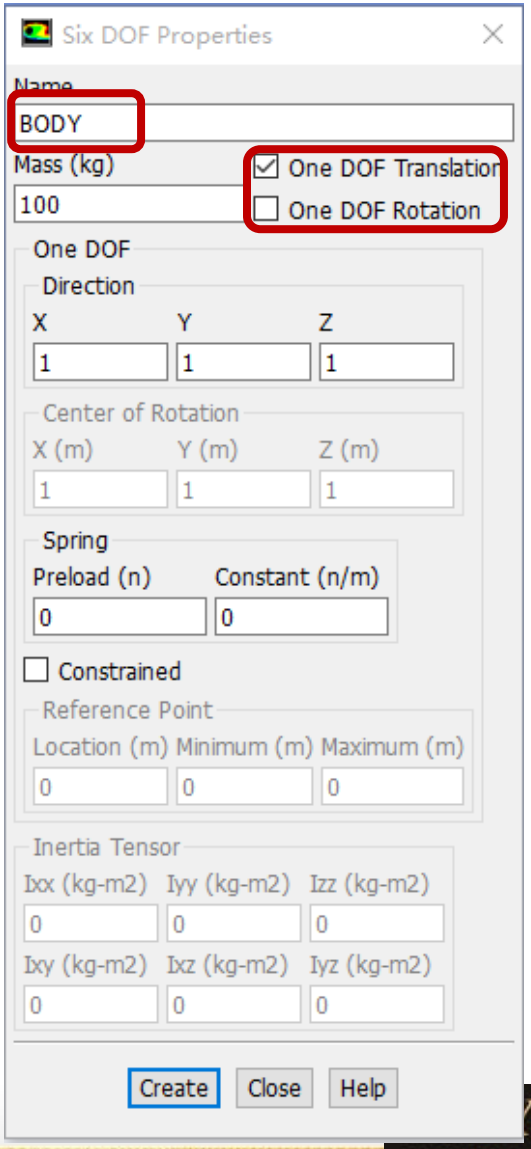
Additional forces & moments load

Removal of forces & moments load

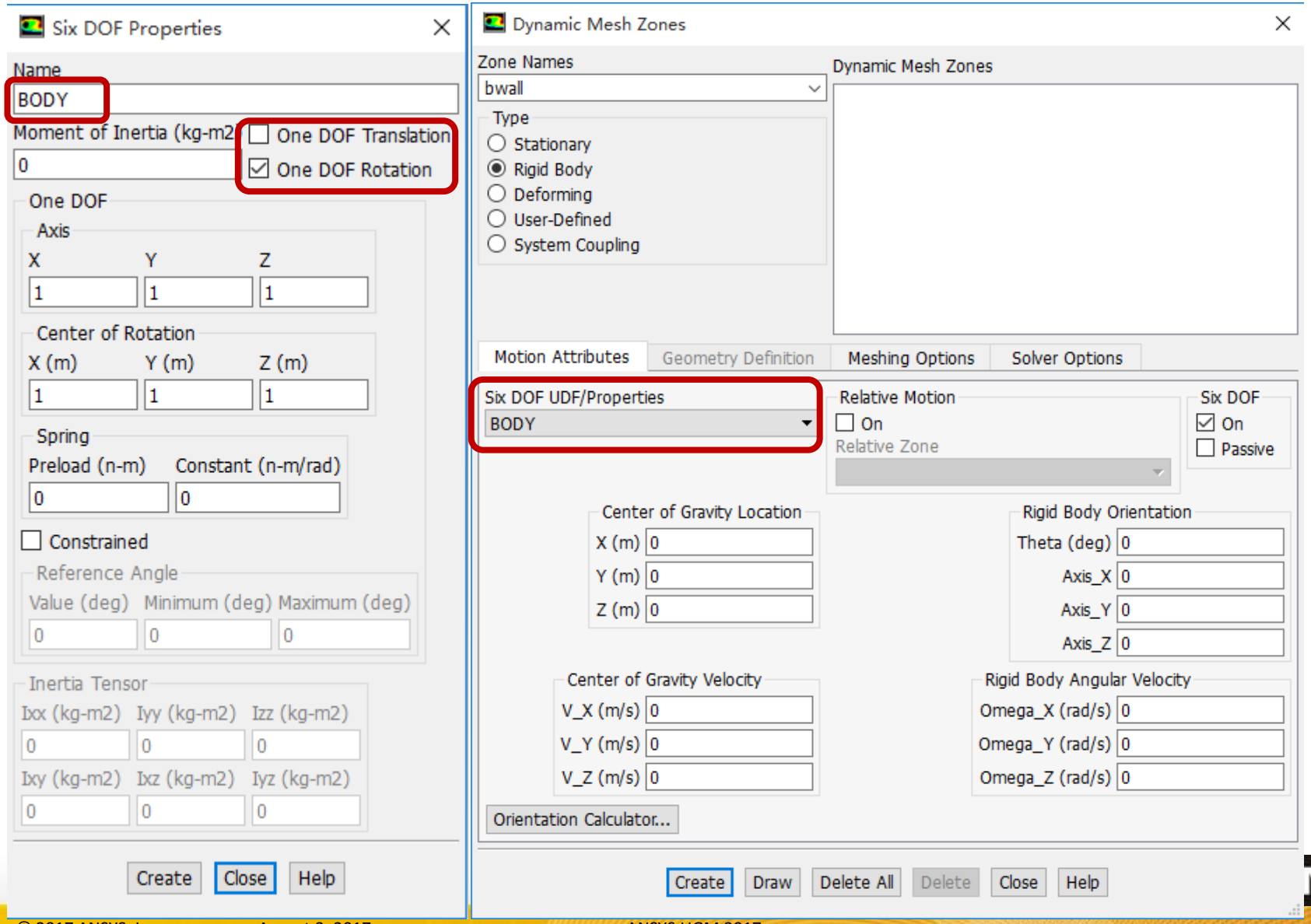
6DOF – GUI


Meshing
Solution Setup
General
Models
Materials
Cell Zone Conditions
Boundary Conditions
Reference Values
Solution
Solution Methods
Solution Controls
Monitors
Solution Initialization
Calculation Activities
Run Calculation
Results
Graphics and Animations
Plots
Reports
Dynamic Mesh
Dynamic Mesh
Mesh Methods
Smoothing
Layering
Remeshing
Settings...
Options
Six DOF
Implicit Update
Contact Detection
Settings...
Events...
Dynamic Mesh Zones
corps_surfacique - Rigid Body
Create/Edit...
Delete
Delete All
Display Zone Motion...
Preview Mesh Motion...


Options
In-Cylinder
Six DOF
Implicit Update
Contact Detection
Six DOF Properties
BODY
Create/Edit...
Delete
Delete All
Gravitational Acceleration
X (m/s 0
Y (m/s -9.80
Z (m/s 0
Write Motion History
File Name
E:\mywork\client\014\high-atack\fluent
OK
Cancel
Help

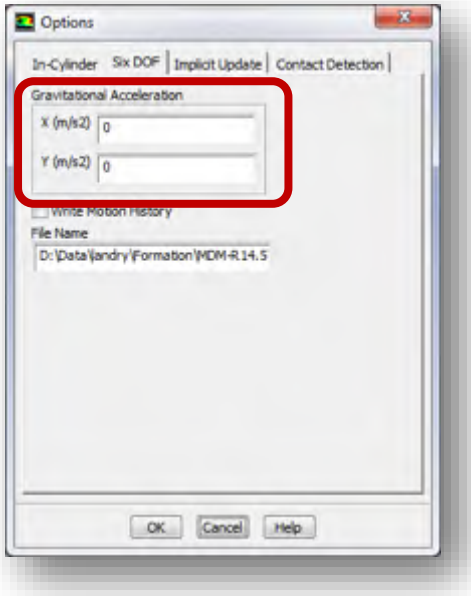

Six DOF Properties
Name
BODY
Mass (kg)
100
One DOF Translation
One DOF Rotation
One DOF
Direction
X
Y
Z
1
1
1
Center of Rotation
X (m)
Y (m)
Z (m)
1
1
1
Spring
Preload (n)
Constant (n/m)
0
0
Constrained
Reference Point
Location (m)
Minimum (m)
Maximum (m)
0
0
0
Inertia Tensor
Ixx (kg-m2)
Iyy (kg-m2)
Izz (kg-m2)
0
0
0
Ixy (kg-m2)
Ixz (kg-m2)
Iyz (kg-m2)
0
0
0
Create
Close
Help

6DOF – GUI


Six DOF Properties
Name
BODY
Moment of Inertia (kg-m2)
0
One DOF Translation
One DOF Rotation
One DOF
Axis
X
Y
Z
1
1
1
Center of Rotation
X (m)
Y (m)
Z (m)
1
1
1
Spring
Preload (n-m)
Constant (n-m/rad)
0
0
Constrained
Reference Angle
Value (deg)
Minimum (deg)
Maximum (deg)
0
0
0
Inertia Tensor
Ixx (kg-m2)
Iyy (kg-m2)
Izz (kg-m2)
Ixy (kg-m2)
Ixz (kg-m2)
Iyz (kg-m2)
Create
Close
Help
Dynamic Mesh Zones
Zone Names
bwall
Type
Stationary
Rigid Body
Deforming
User-Defined
System Coupling
Dynamic Mesh Zones
Motion Attributes
Geometry Definition
Meshing Options
Solver Options
Six DOF UDF/Properties
BODY
Relative Motion
On
Relative Zone
Six DOF
On
Passive
Center of Gravity Location
X (m)
Y (m)
Z (m)
Rigid Body Orientation
Theta (deg)
Axis_X
Axis_Y
Axis_Z
Center of Gravity Velocity
V_X (m/s)
V_Y (m/s)
V_Z (m/s)
Rigid Body Angular Velocity
Omega_X (rad/s)
Omega_Y (rad/s)
Omega_Z (rad/s)
Orientation Calculator...
Create
Draw
Delete All
Delete
Close
Help

Workflow for a 6DOF case

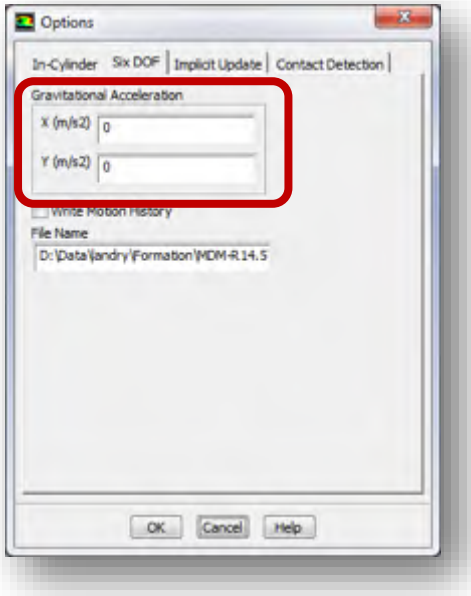
- Write the 6DOF UDF
  - **DEFINE_SDOF_PROPERTIES (**names, properties, dt, time, dtime**)**
  - Set up the flow case
- **Compile & Load the UDF**
  - **Run till convergence (if required)**
- **Read the mesh,**
- **Switch to transient solver**
- **Choose the right Dynamic mesh method(s)**
- **Switch ON the 6 DOF**
  - Settings
    - defined Rigid properties in Fluent 6DOF GUI
    - **Set the gravitational acceleration**
    - define Rigid properties
    - **Set the appropriate Dynamic Mesh Zones**
- **Save case file**
- **Preview mesh motion**



Even if it is a coupled motion (see tips later)

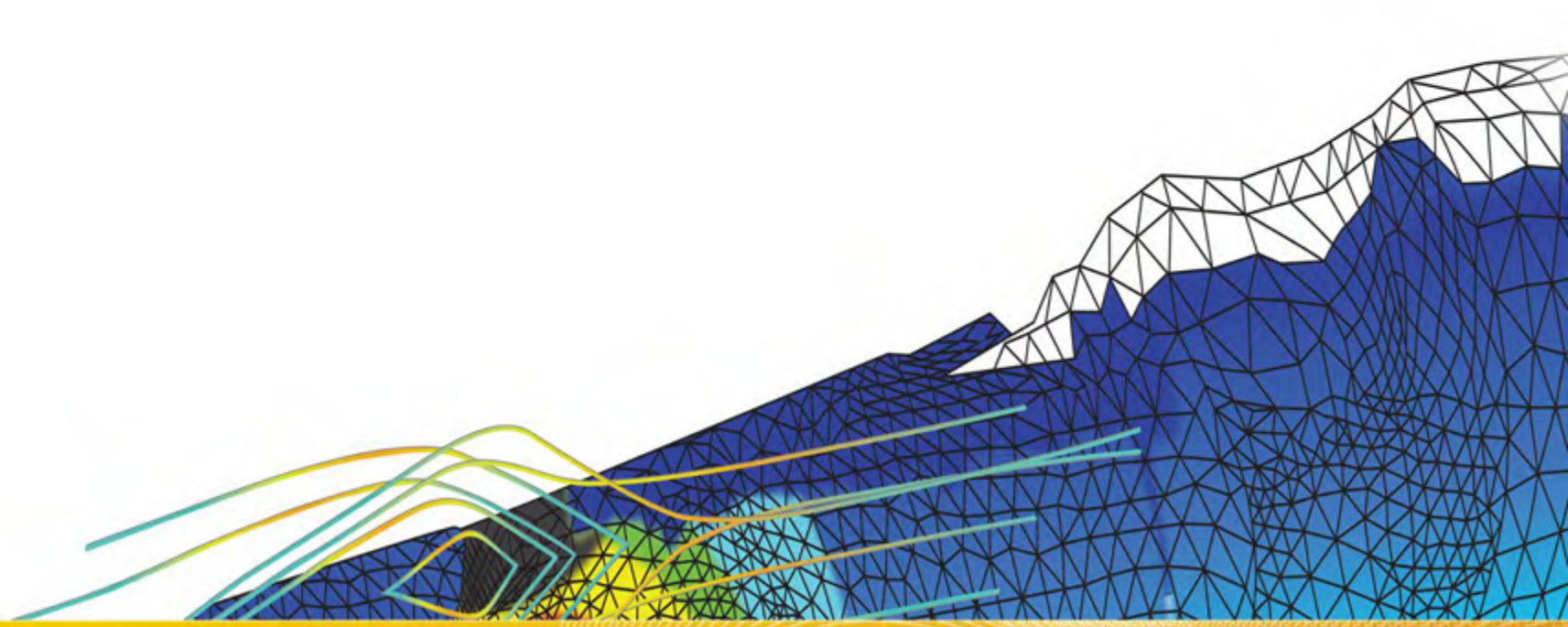
Workflow for a 6DOF case

- **Read the mesh,**
  - Create overset mesh compute domain
  - Set up the flow case
    - **Run till convergence (if required)**
- **Switch to transient solver**
- **Switch ON the 6 DOF**
  - Settings
    - defined Rigid properties in Fluent 6DOF GUI
    - define Rigid Move attributes in dynamic zones
- **Save case file**
- **Preview mesh motion**



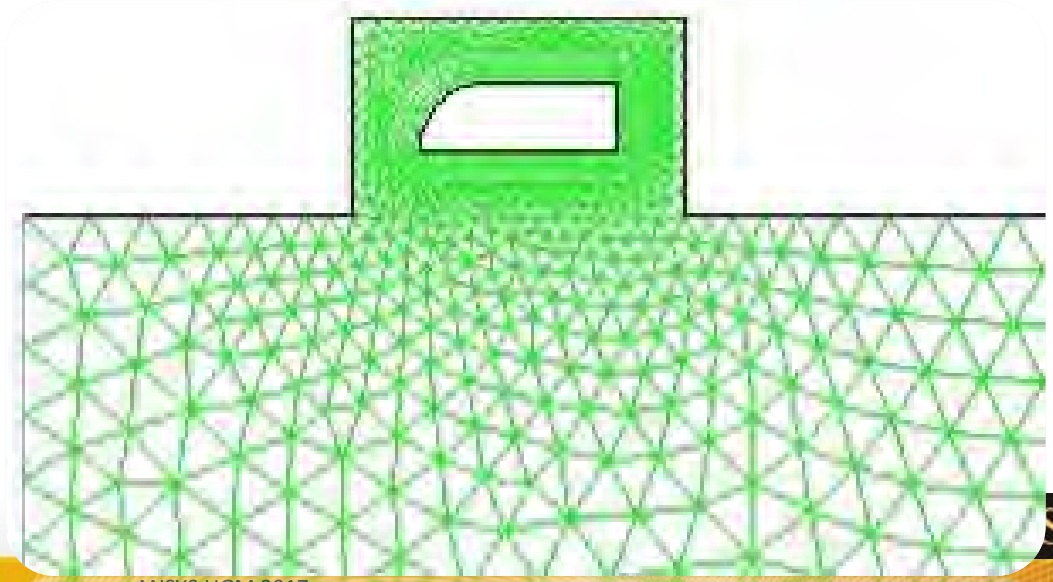
ANSYS

应用案例



Case 1 – Airdrop

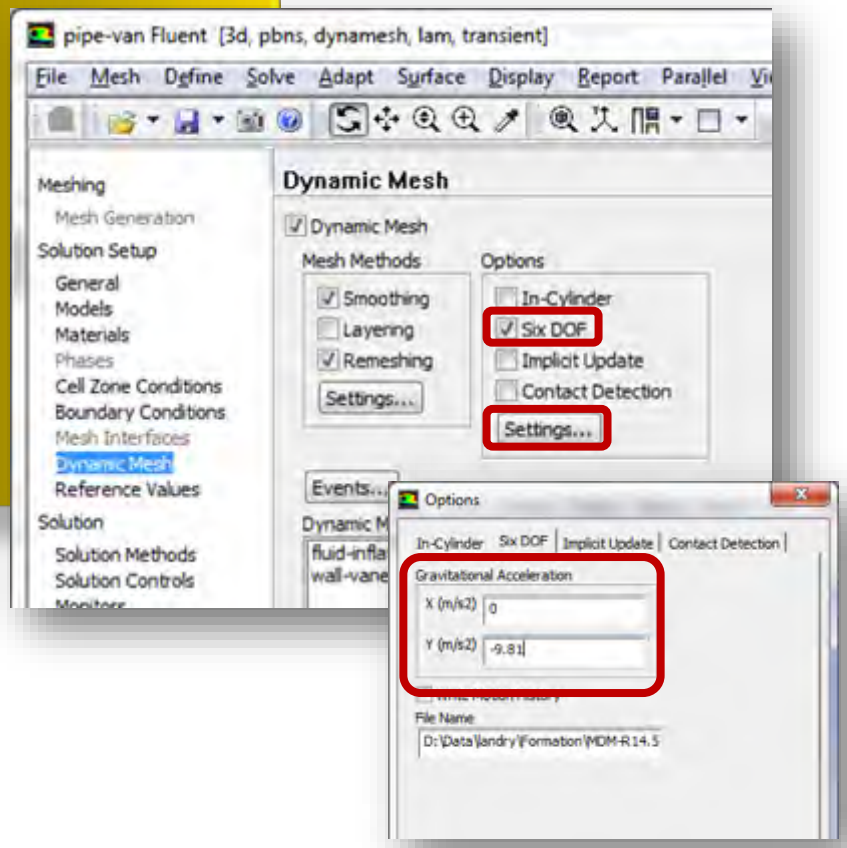
- **The object is not in contact with any external boundary**
- **The fluid domain is composed of 2 fluid zones**
  - One prism cells
    - **Moves with the falling object (to better follow up forces & y+)**
    - **Define as a rigid body**
  - One triangle
    - **Does correspond to the deforming zone**
      - Smoothing method
      - Remeshing method
        - Local cell



Case 1 – Airdrop

- **The 6DOF UDF**

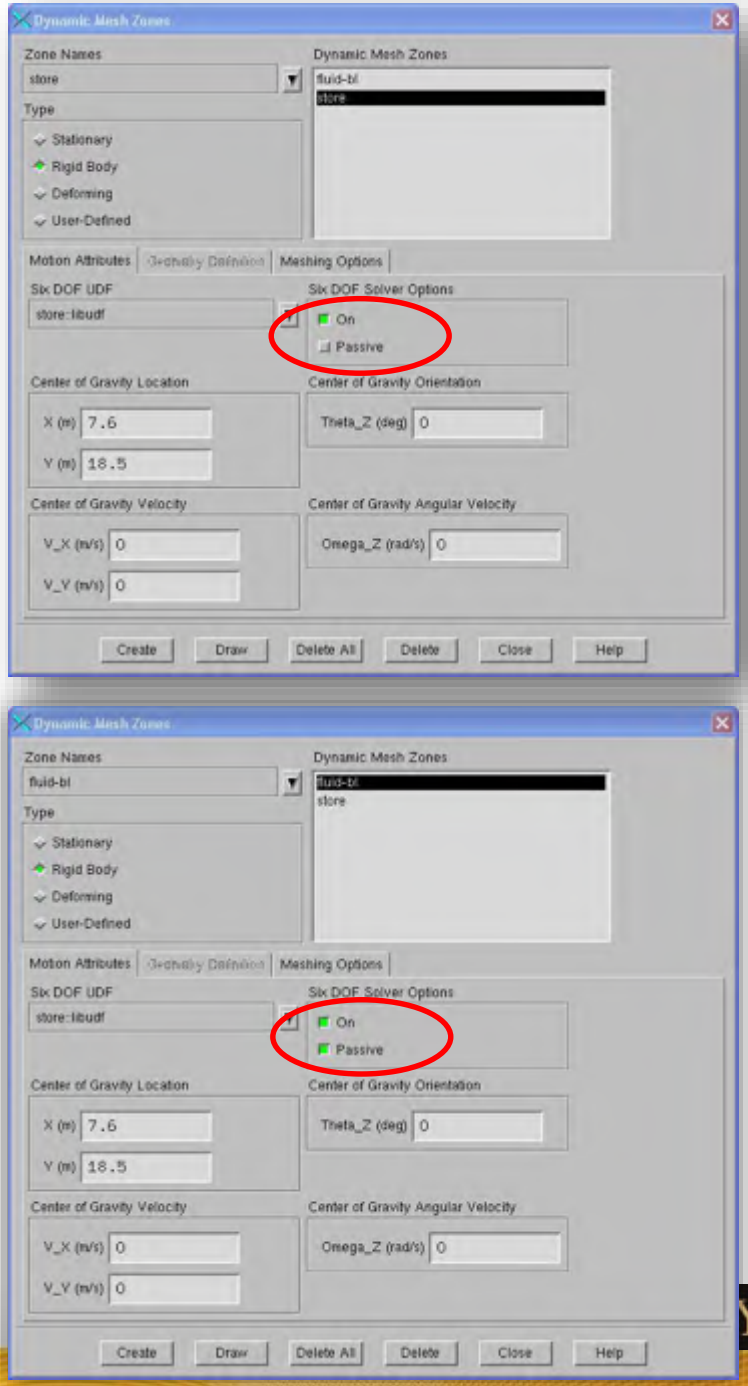
```
#include "udf.h"
DEFINE_SDOF_PROPERTIES(store, prop, dt, time, dtime)
{
 /* Define the mass matrix */
 prop[SDOF_MASS] = 5000.0;
 prop[SDOF_IZZ] = 5e3;
/* add ejector forces, moments */
if (time <= 0.3)
 {
        prop[SDOF_LOAD_F_X] = -40000;
        prop[SDOF_LOAD_F_Y] = -80000;
        prop[SDOF_LOAD_M_Z] = -2200.0;
 }
  Message0("\nUpdated 6DOF properties\n");
}
```



  - Define the gravitational acceleration

Case 1 – Airdrop

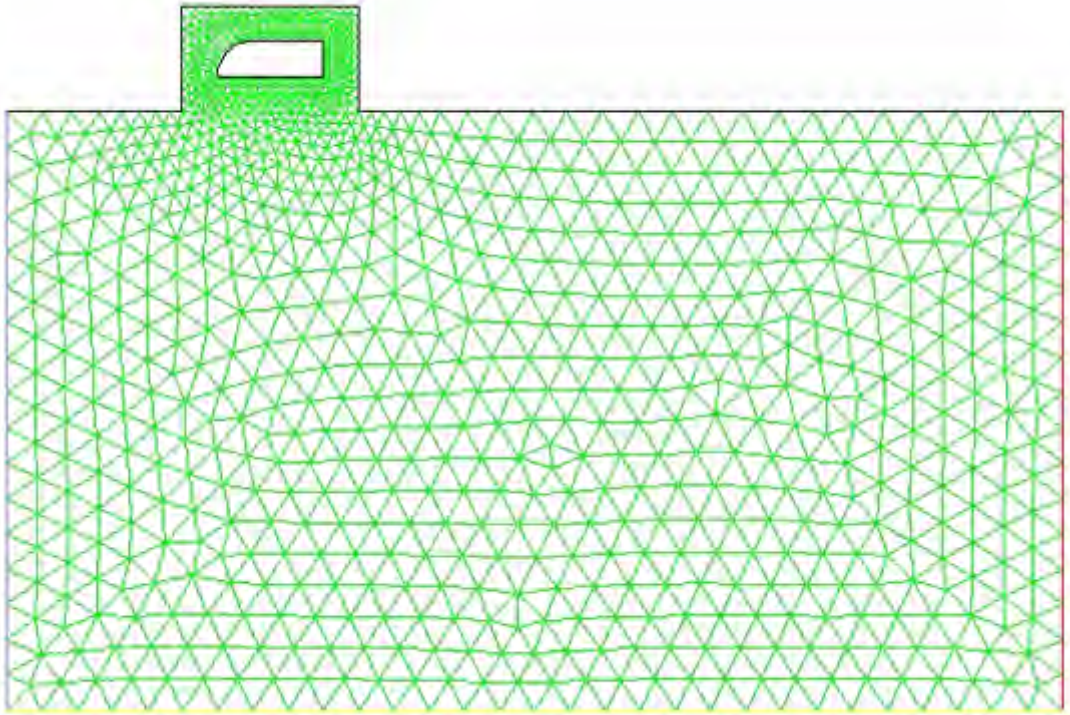
- **2 Dynamic Mesh Zone to define**
  - The wall (store)
    - **Rigid body**
    - **Six DOF UDF + option ON**
    - **Center of gravity location & orientation**
    - **…**
  - The prism cells (fluid-bl)
    - **Rigid body**
    - **Six DOF UDF**
      - Option **ON**
        - Insure store displacement
      - **Passive** activated
        - To not take flow efforts into count
    - **Center of gravity location & orientation**
    - **…**



Case 1 – Mesh Motion

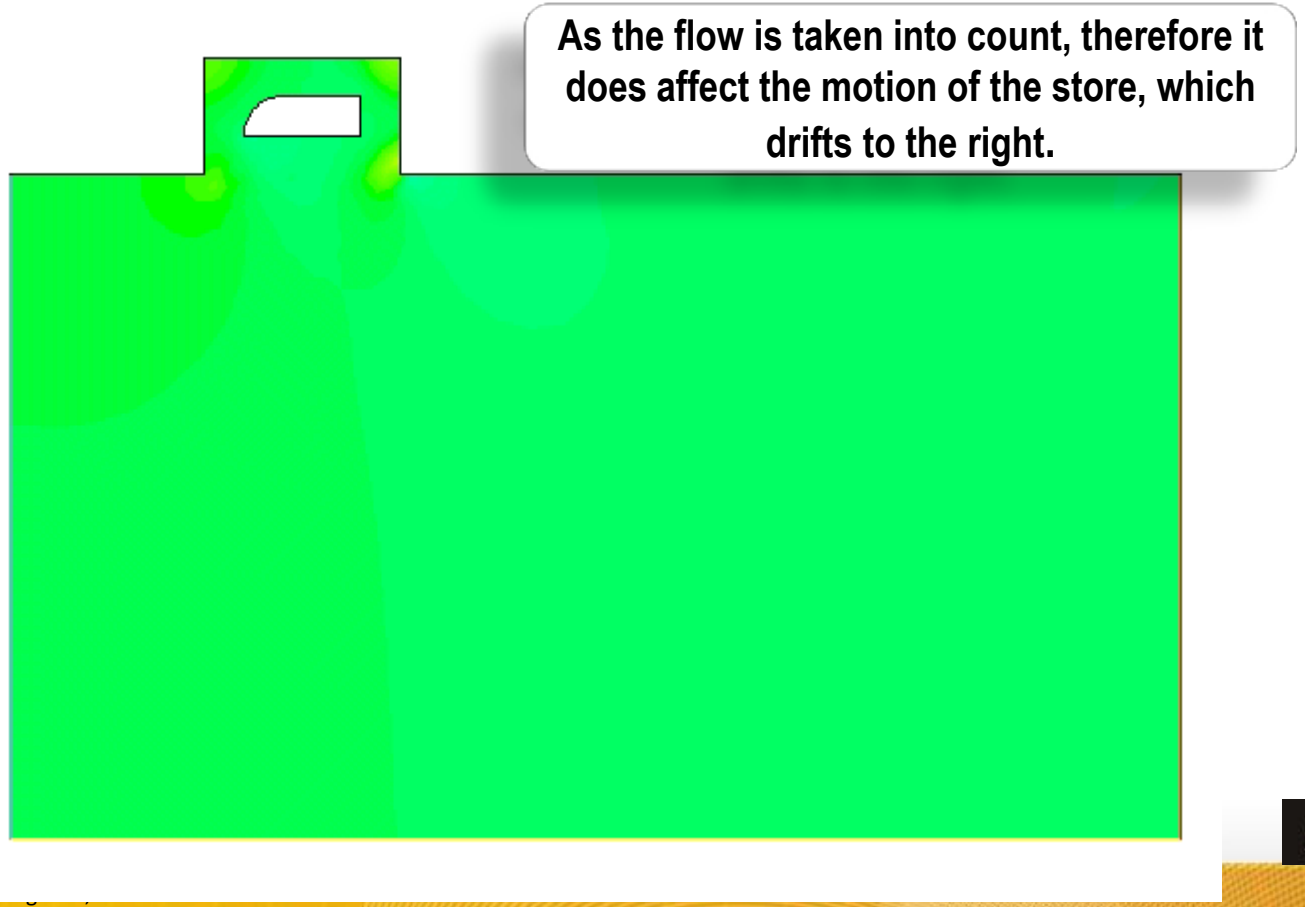
- **Preview mesh motion**
  - Wise to preview the mesh motion before performing the calculations
  - Start without initializing,

- **Object simply drops under the influence of gravity and/or external forces**

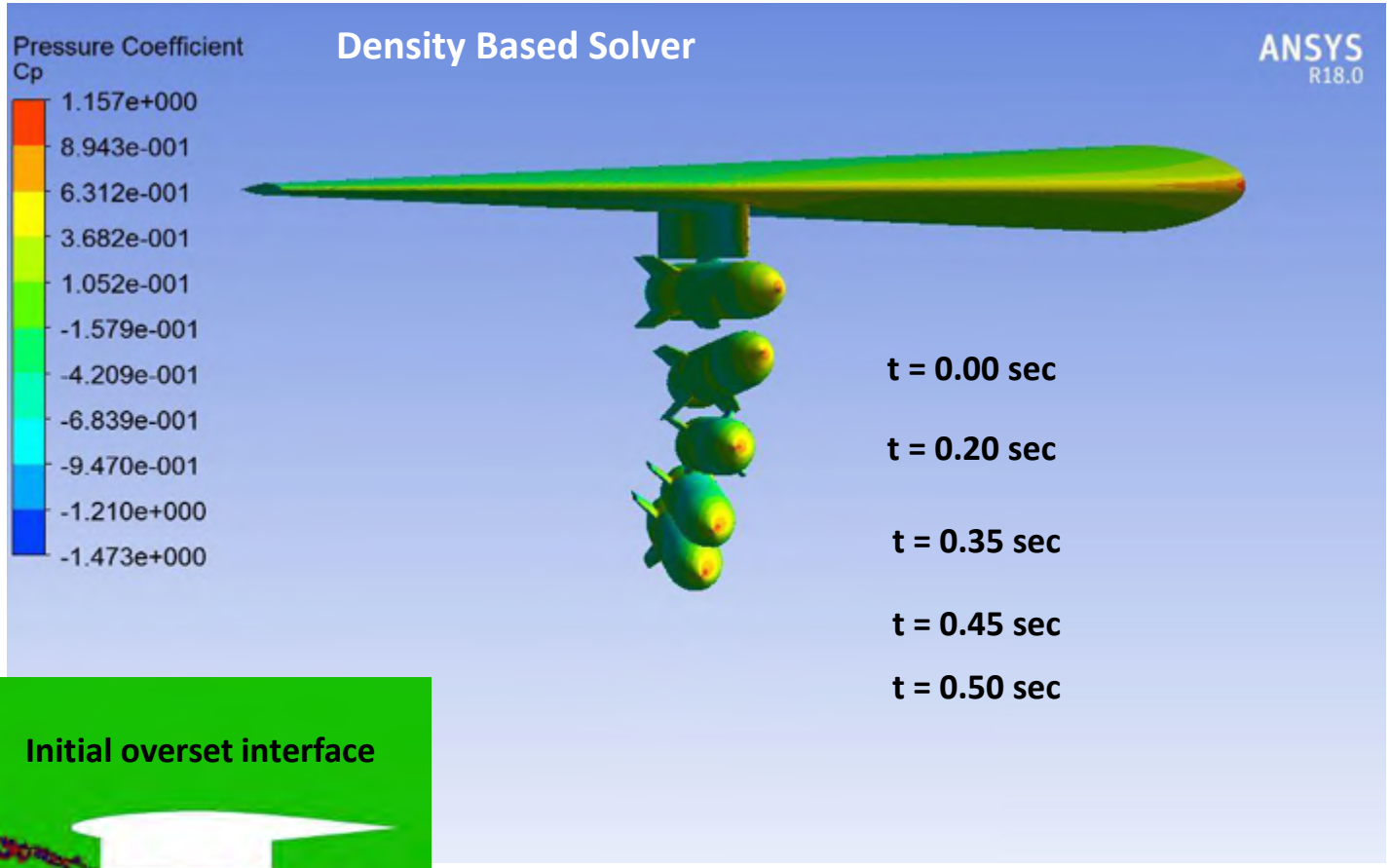


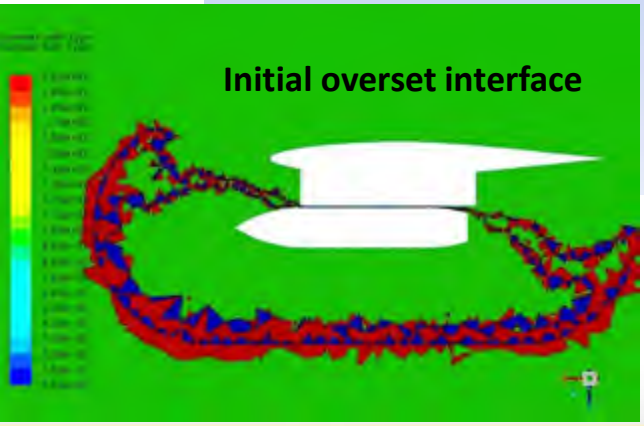
Case 1 – Animation

- **Figure shows pressure contours**
  - Freestream Mach number of 0.8
- **The store goes forward at the start due to ejector force**

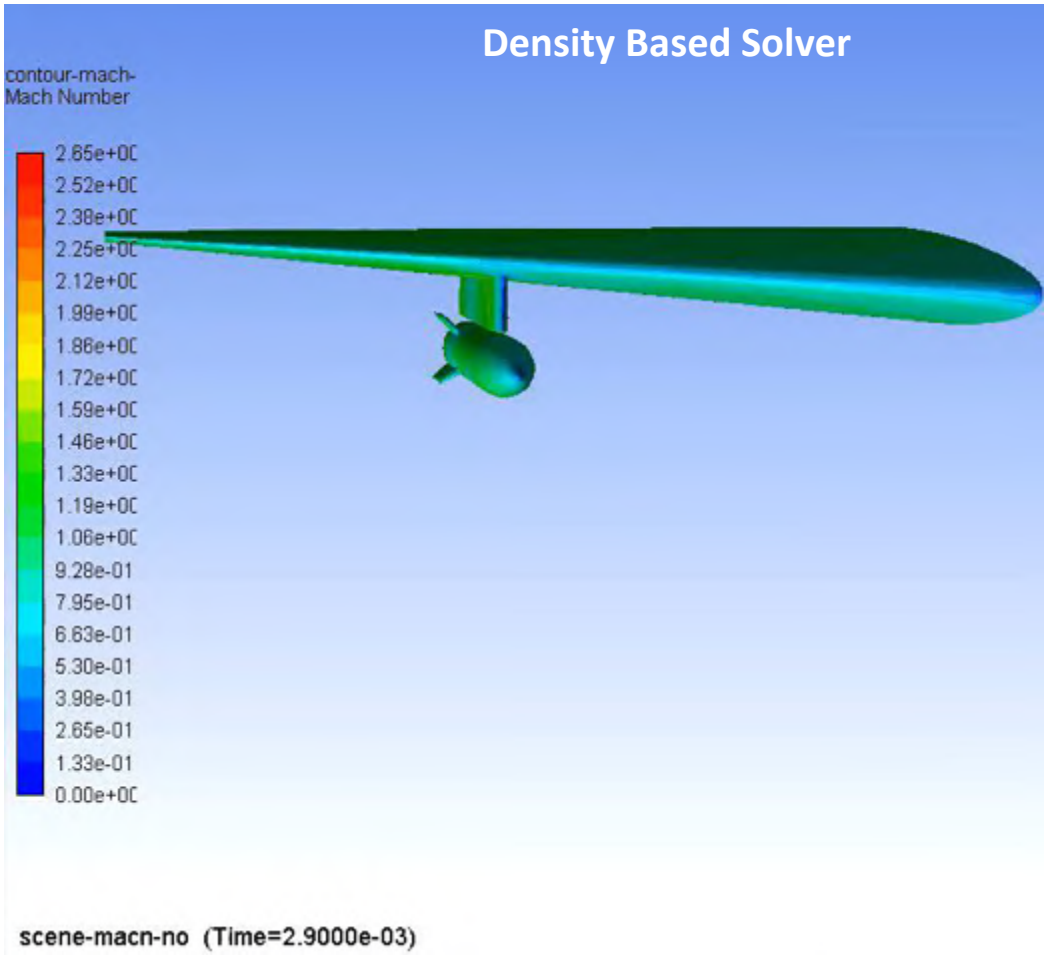


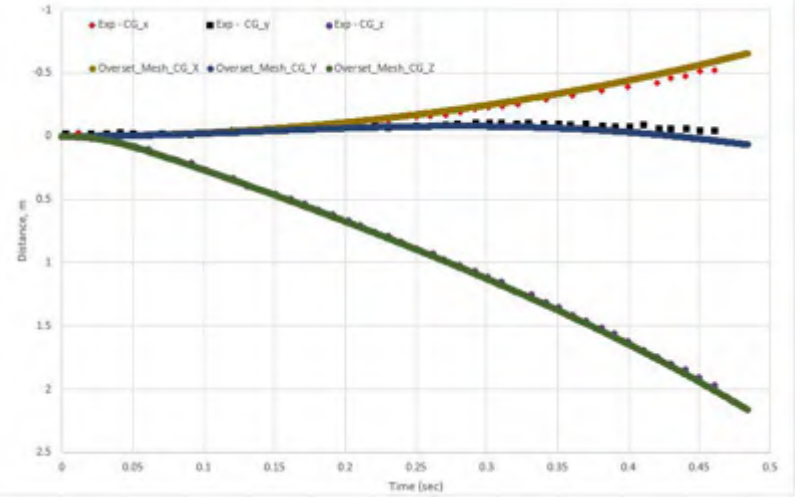
Case2：跨音速投放数值模拟& 密度基求解器

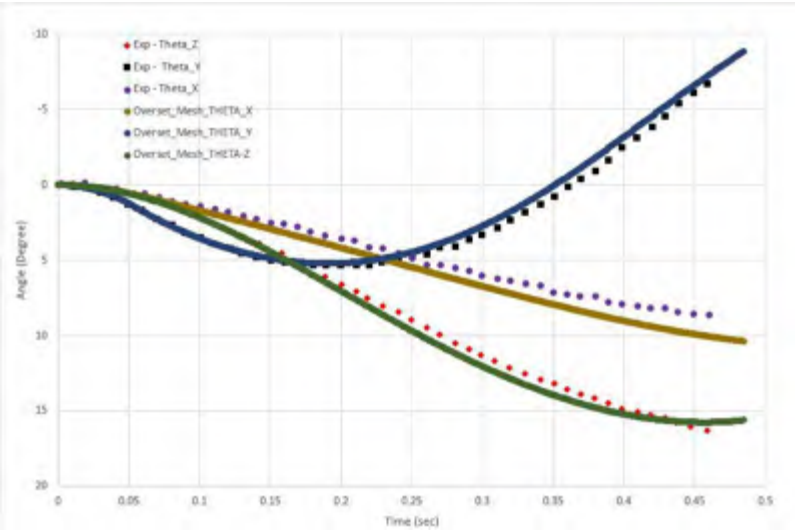




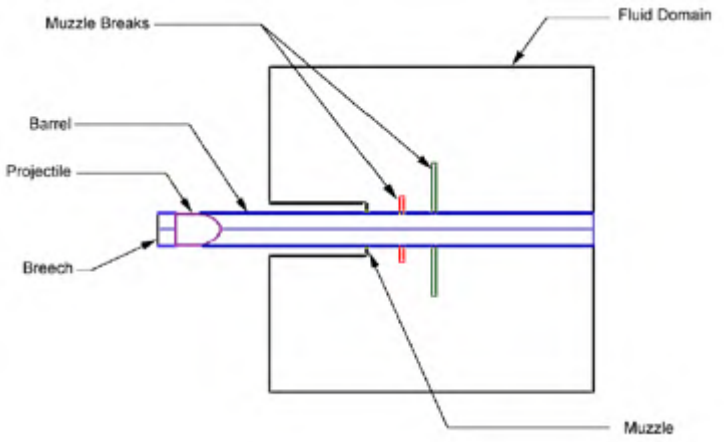
Case2 ： Result





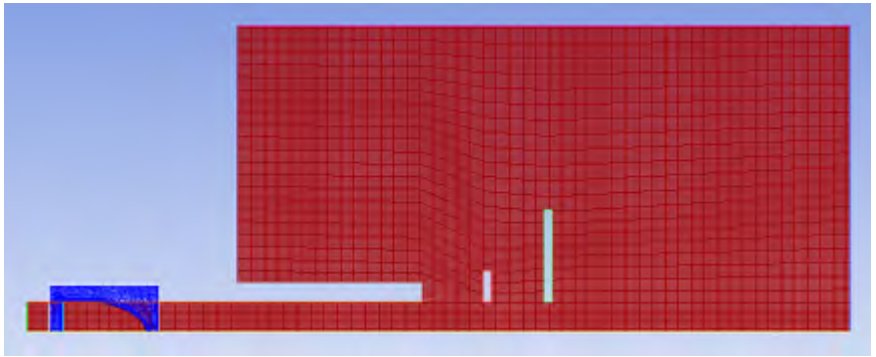


Case3：2D弹丸出膛分析



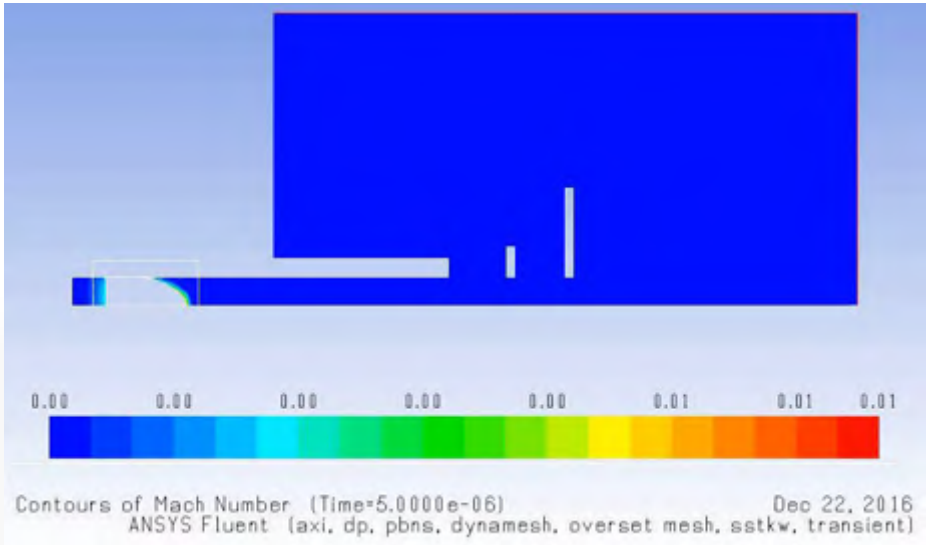
❑ 网格 & 设置

- 与层铺动网格（non-conformal interface）计算结比较果
- Pressure based coupled solver
- SSTk-omega
- Noble-Abel real gas

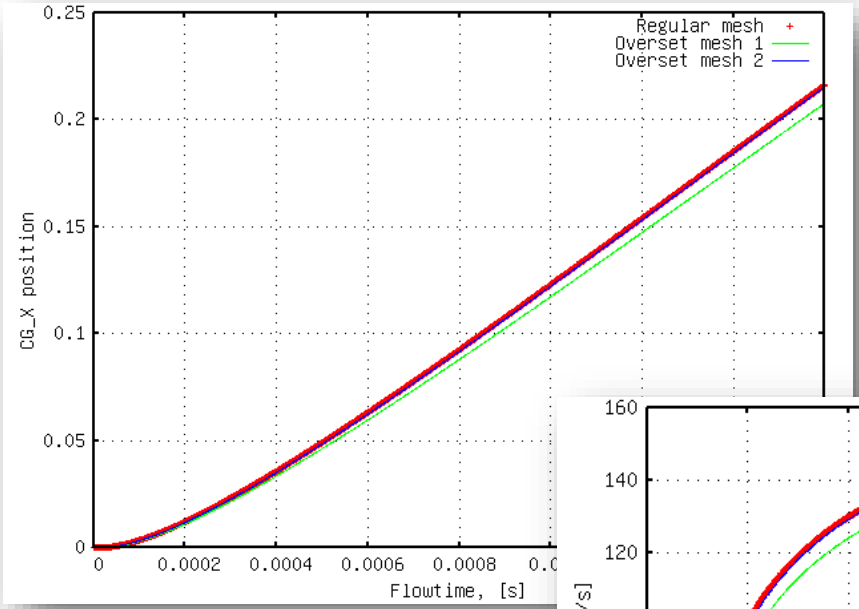


- 弹丸后的初始条件为:
  p=3000 atm, and T=2700K

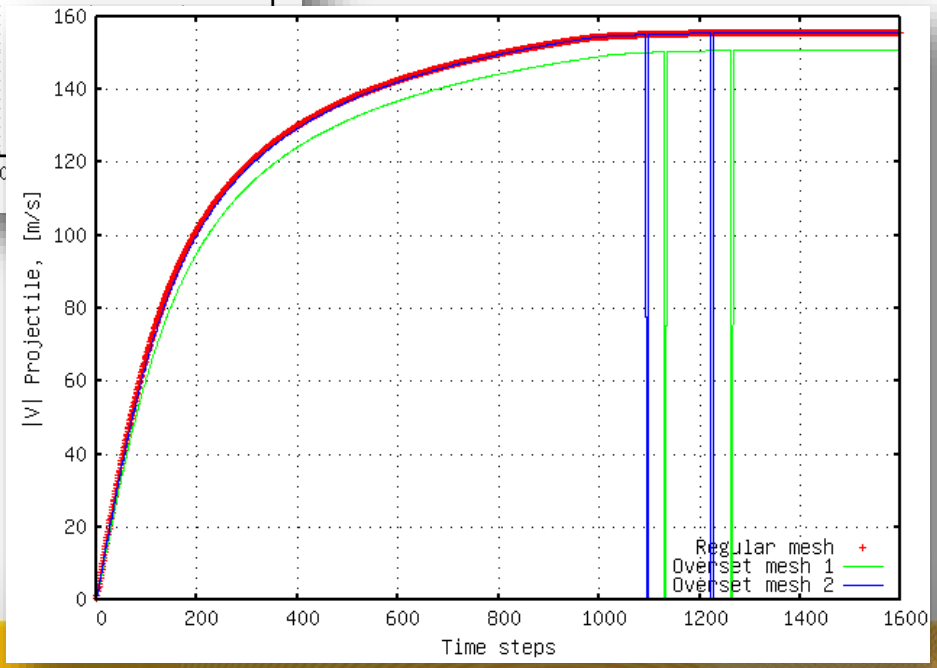
Case3：Result



Projectile position history



Projectile velocity history

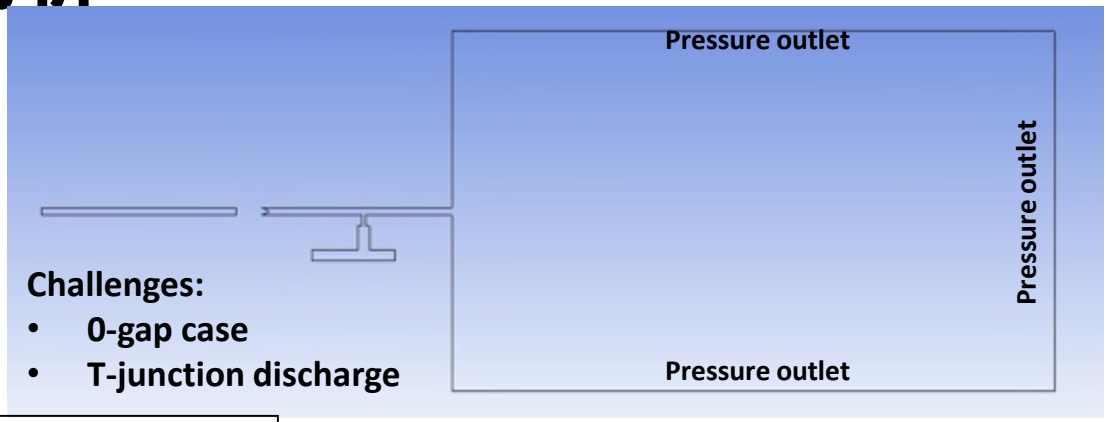


- Orphans，dead cells和弹丸后壁面影响弹丸的驱动力

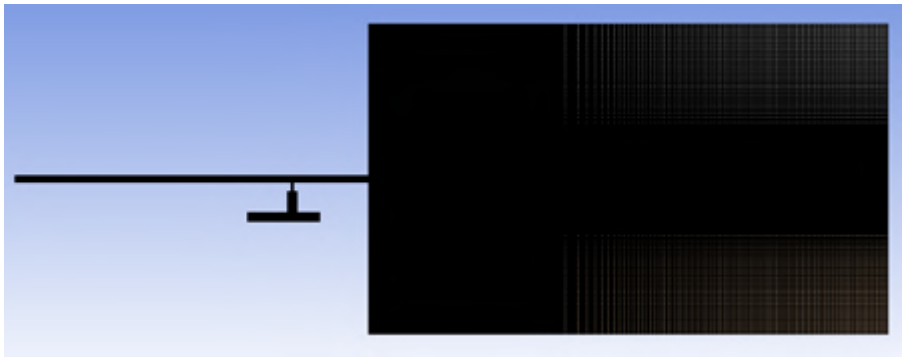
- 由于在muzzle breaks处存在orphans和dead cell导致的后处理问题

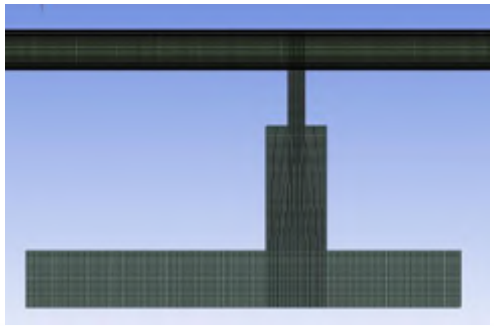
Case4：2D弹头运动分析

- ❑ 网格 & 设置
- PBNS & DBNS
- SST k-omega
- Noble-Abel real gas

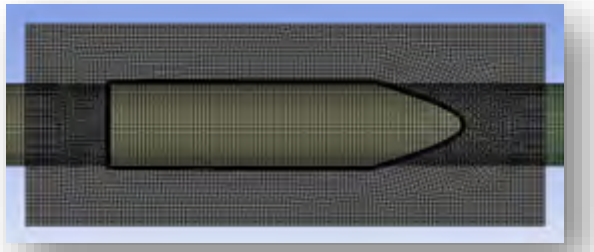


Challenges:
- 0-gap case
- T-junction discharge

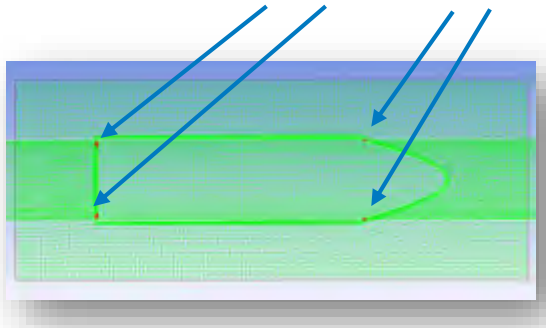




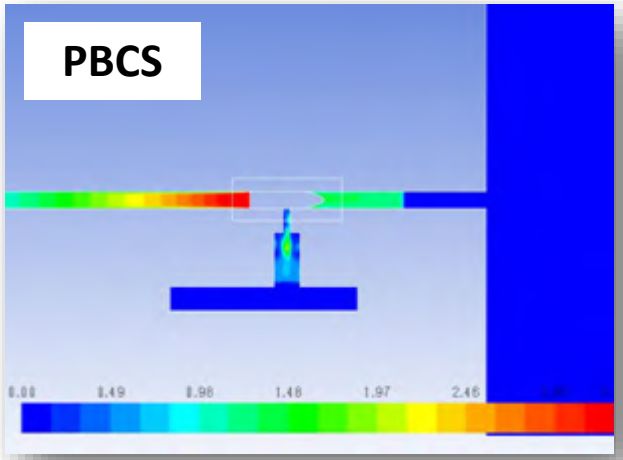
Background mesh

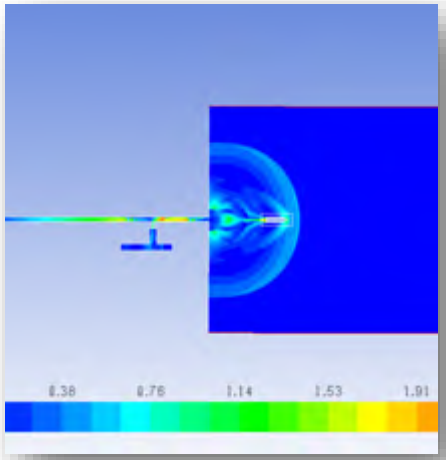


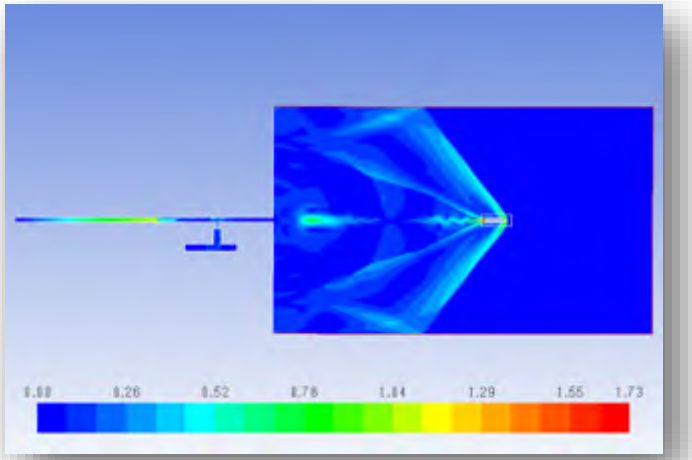
Un-avoidable Orphans

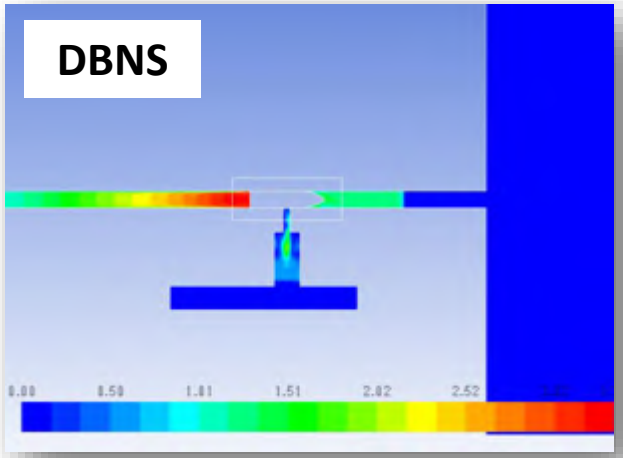


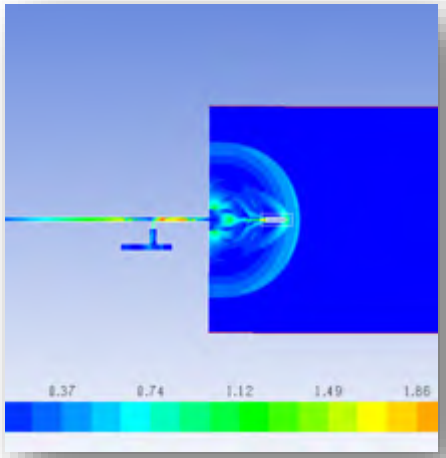
Case4：Result, 马赫数

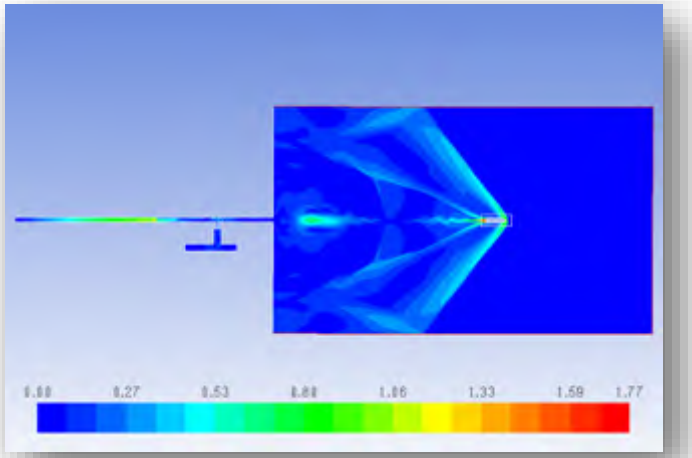




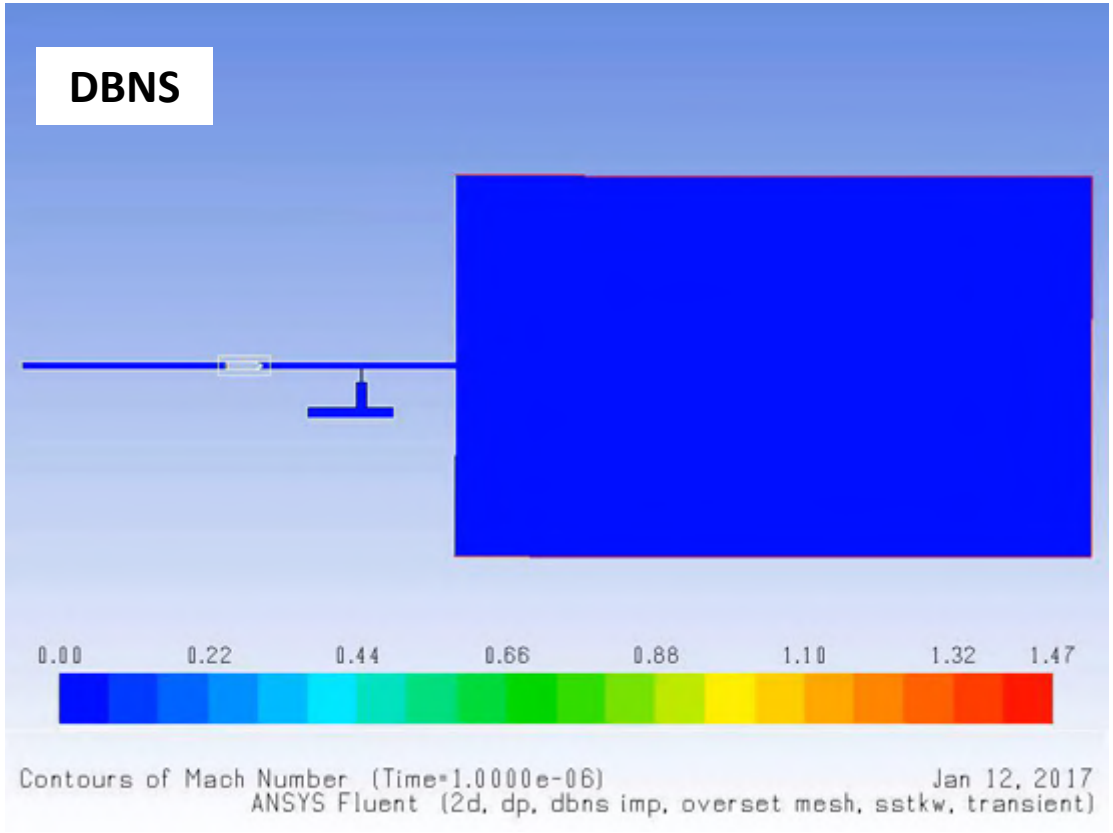


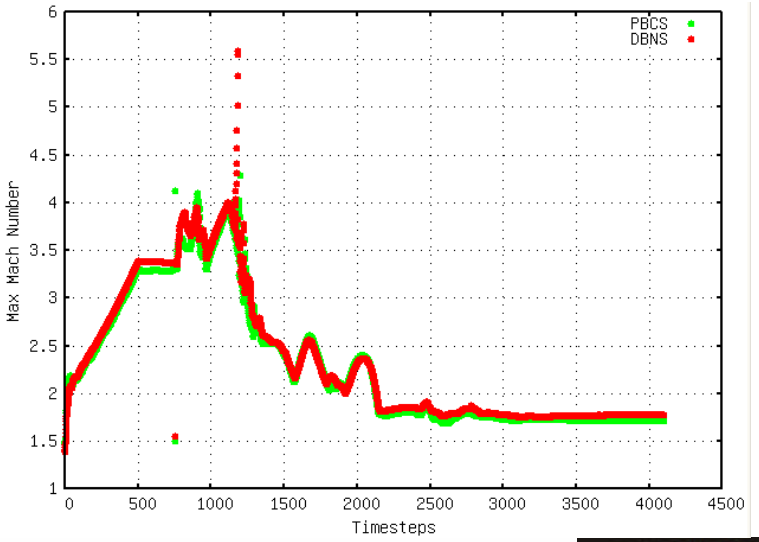






Case4：Result, 马赫数





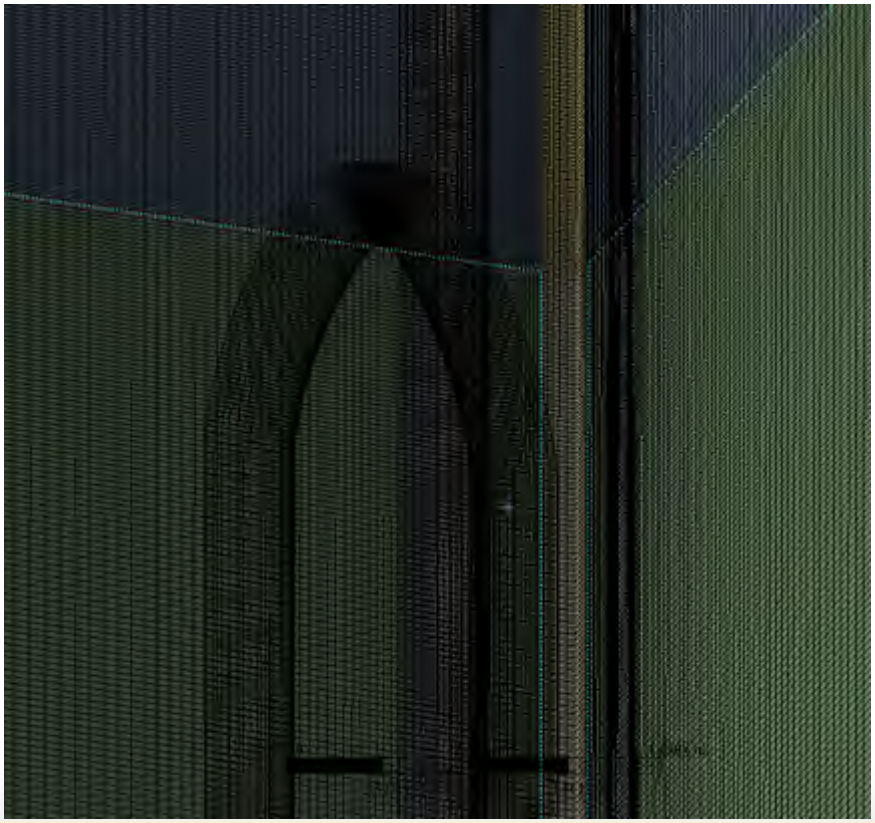
by AnhTuan Le

Case5 : ULA Stage Separation

Free Stream Mach = 3.0 (Note: DBNS is not supported for Overset Mesh at R17.0)

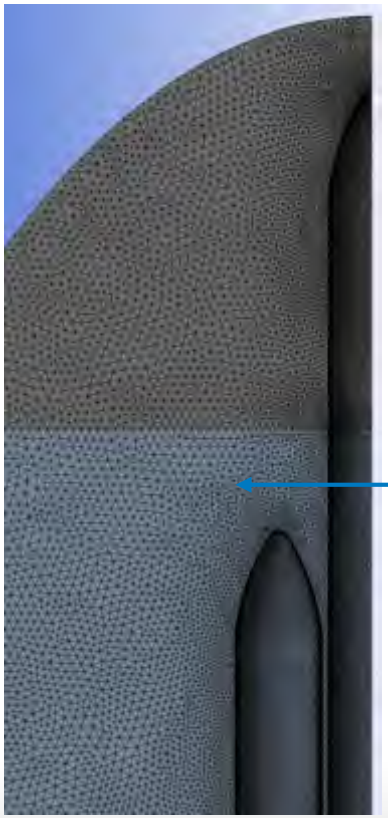
Overset Mesh

Quarter symmetry, hexahedral mesh with inflation, **1.67M cells**

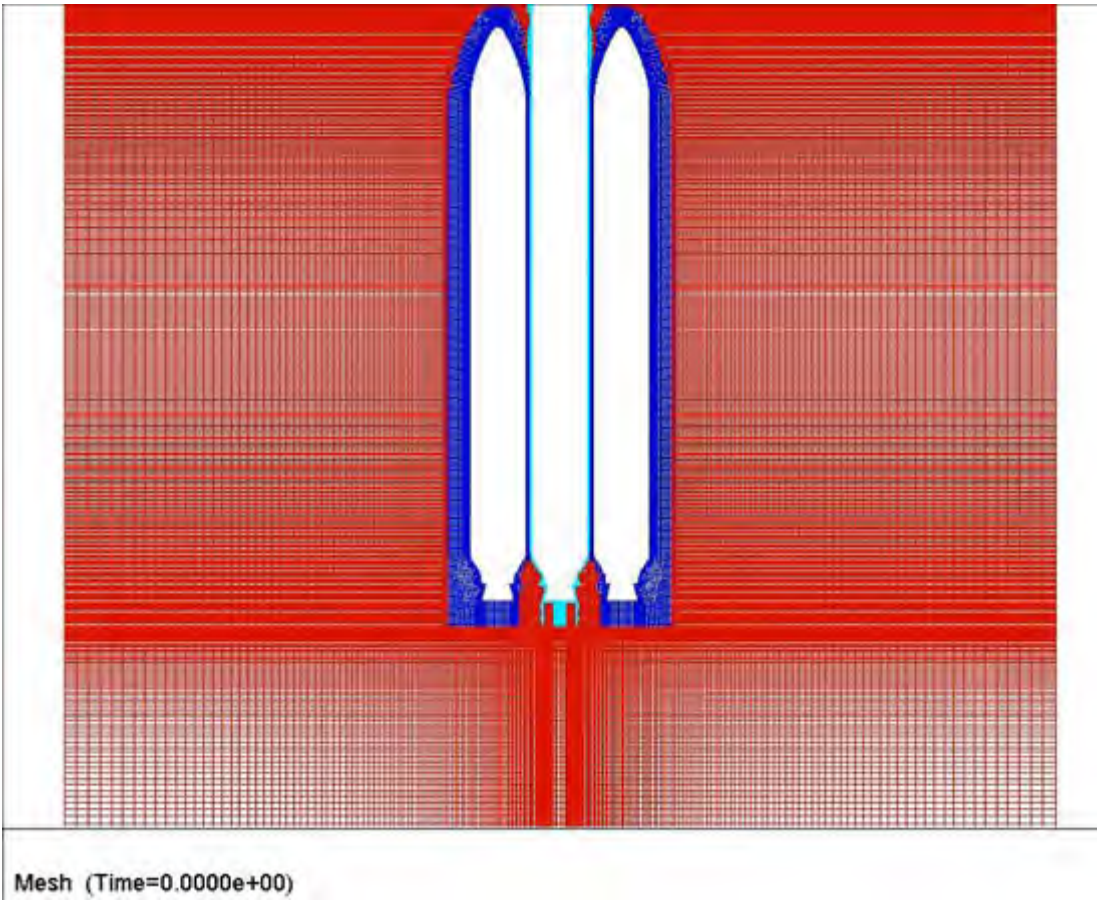


MDM Mesh

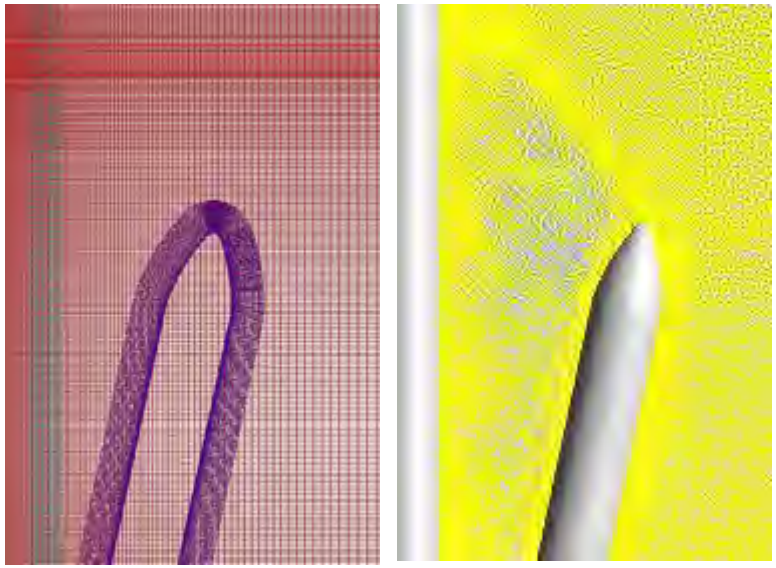
Quarter symmetry, hybrid mesh with inflation, **6M cells**



Case5 : ULA Stage Separation

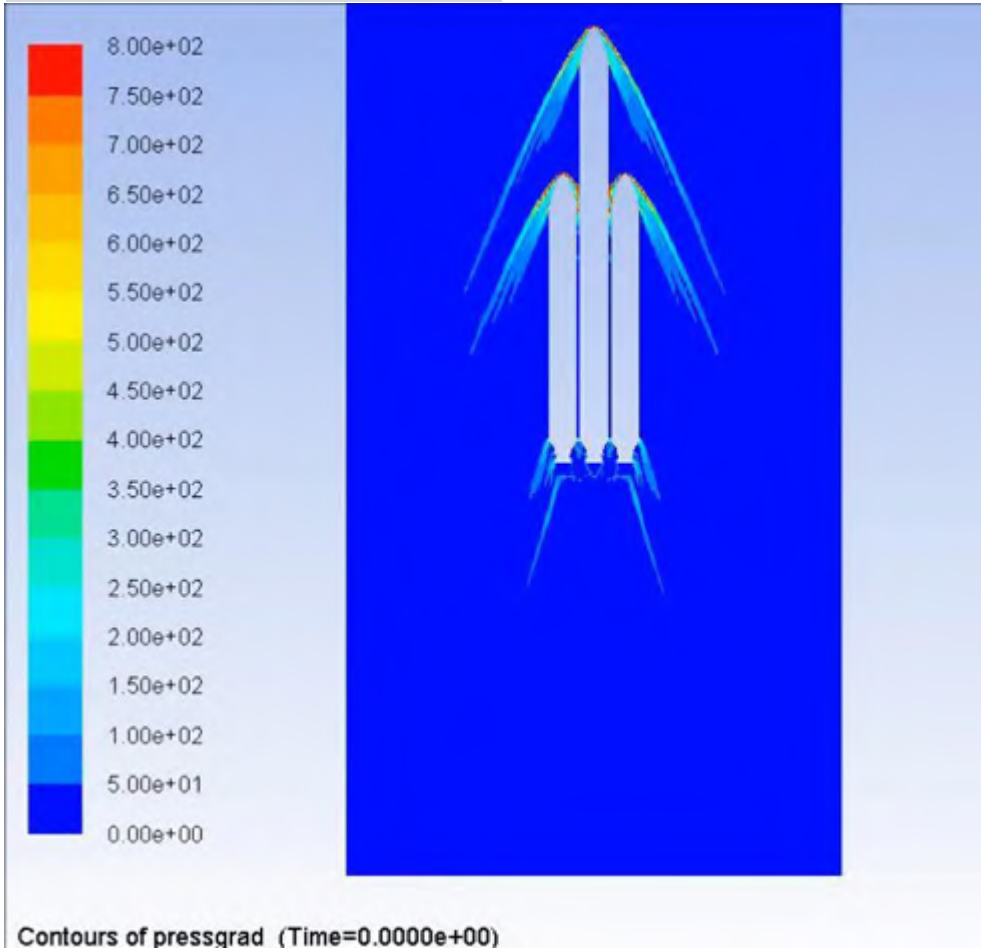


Mesh at 1.0s:
Original mesh quality preserved in overset mesh

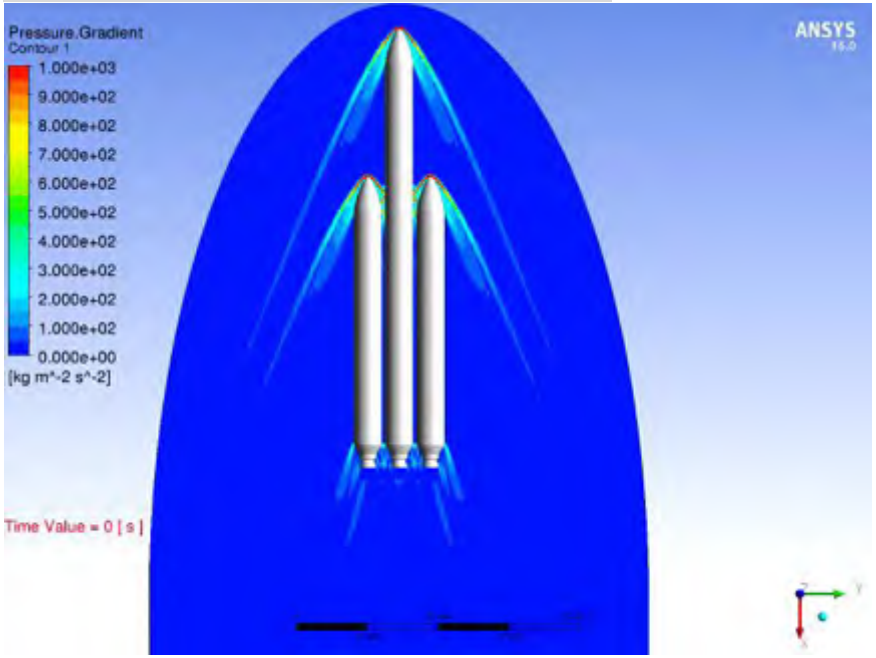


Case5 : ULA Stage Separation

Overset Mesh Solution



MDM (Remeshing) Solution



- **No Mesh Degradation in Overset Mesh and it preserves quality of Shock Capture**

感谢聆听