

# 弹箭发射模拟的关键问题及解决方法

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# 弹箭发射仿真的物理问题







### 口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
  - $\checkmark$  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:
  - $\checkmark$  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 ٠

- Activate Dynamic Mesh \_
- Select Remeshing under Mesh Methods —

- Click on settings \_
  - **Remeshing tab** ٠

- Select Method \_
  - Local cell/ Local Face •
- View "mesh scale info" \_
- Select parameters \_
  - A good starting point for the ٠ length scales are

0.4L<sub>min</sub>, 1.4L<sub>max</sub>

ods		Remeshing Methods	Sizing Function
Meshing Mesh Generation Solution Setup General Models Matenals	Dynamic Mesh Dynamic Mesh Mesh Methods Smoothing Lavering	Local Cel     Local Face     Region Face     CutCel Zone     2.5D	On Resolution 1 * Variabori 2.351 Rate 0.7 Use Defaults
Cell Zone Conditions	Settings	Parameters	1
Mesh Interfaces Dynamic Mesh Reference Values	Events	Minimum Length S Maximum Length S Maximum Cell S Maximum Face S	Scale (m) 7e-3 Scale (m) 3e-2 Skewness 0.8 Skewness 0.7
Mesh S	Scale Info	Size Remeshing	Interval 5
Maximum	Length Scale (m) 0.00735021	Mesh Scale	Info Use Defaults
Maxim	um Cell Skewness 0.8783247	ОК	Cancel Help
Maximul	m Face Skewness 0,7911397		
E	Close Help		

Mesh Method Settings



X



#### • 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







### **Overset Meshing**



- 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。



- 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。





- ・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



Mesh (Time=0.0000e+00)



# 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









#### ・组件网格可任意重叠

- 重叠网格边界是允许的
- ・ 允许边界<u>重叠</u>,但不允许边界<u>交叉</u>
  - 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 <u>衣领</u> 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





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・没用衣领网格处理的交叉壁面边界





・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







- Read all related meshes into fluent
- Set the overset boundary condition
- Create the interface
  - $\checkmark$  Select background and component meshes
- Define grid priorities if needed
  - ✓ <u>define/overset-interfaces/grid-priorities</u>
- Initialize to intersect the interface
  - ✓ Or use TUI command to intersect the interface without initializing the flow field (activate expert options first) <u>define/overset-interfaces/intersect</u>
- 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 
         <u>coupled motion</u>



### 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

Meshing	Dynamic Mesh
Mesh General Solution Setup General Models Materials Phases Cell Zone Conditions Boundary Conditions Mesh Inter faces Processor (Intel Processor (Intel Process	Dynamic Mesh Mesh Methods Options     Smoothing     Layering     Settings      Settings       Events
Solution Solution Methods	Dynamic Mesh Zanes
Solution Controls Monitors Solution Initialization	Options     To Guilador Six DOE Translicit Lipidate Contact Detection
Calculation Activities Run Calculation	
Graphics and Animations Plots Reports	Create/Edit Delete Delete All Gravitational Acceleration X (m/s2) 0 Y (m/s2) 0
	Write Motion History     File Name     C:/VC test/overmesh/bomb/backgroud



### 6DOF - UDF

- To specify custom properties to a moving object, use the following macro
  - DEFINE\_SDOF\_PROPERTIES (names, properties, dt, time, dtime)

SDOF_MASS SDOF_IXX, SDOF_IYY, SDOF_IZZ, SDOF_IXY, SDOF_IXZ, SDOF_IYZ,	/* mass */ /* moment of ine /* moment of ine /* moment of ine /* product of iner /* product of iner /* product of iner	rtia */ rtia */ rtia */ rtia */ rtia */ rtia */	SDOF_LOAD_LOCAL, SDOF_LOAD_F_X, SDOF_LOAD_F_Y, SDOF_LOAD_F_Z, SDOF_LOAD_M_X, SDOF_LOAD_M_Y, SDOF_LOAD_M_Z,	<pre>/* boolean */ /* external force */ /* external force */ /* external force */ /* external moment */ /* external moment */ /* external moment */</pre>
SDOF_ZERO_T	RANS_X,	/* bool	ean, suppress translati	ion in x-direction */
SDOF_ZERO_T	RANS_Y,	/* bool	ean, suppress translati	ion in y-direction */
SDOF_ZERO_T	RANS_Z,	/* bool	ean, suppress translati	ion in z-direction */
SDOF_ZERO_R	OT_X,	/* bool	ean, suppress rotation	around x-axis */
SDOF_ZERO_R	OT_Y,	/* bool	ean, suppress rotation	around y-axis */
SDOF_ZERO_R	OT_Z,	/* bool	ean, suppress rotation	around z-axis */
SDOF_SYMME	TRY_X,	/* norn	nal vector of symmetry	y plane for half model */
SDOF_SYMME	TRY_Y,	/* norn	nal vector of symmetry	y plane for half model */
SDOF_SYMME	TRY_Z,	/* norn	nal vector of symmetry	y 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;
                                                         Properties of the delta_missile
     prop[SDOF | YY] = 488.094;
     prop[SDOF IZZ] = 488.094;
     /* add injector forces, moments */
      y = CURRENT TIME;
                                           forces & moments depend on the current time
      if (y <= 0.15)
         prop[SDOF LOAD F Z] = 10676.0;
                                                       Additional forces & moments load
         prop[SDOF LOAD M Y] = -1920.0;
        else
         prop[SDOF LOAD F Z] = 0;
                                                       Removal of forces & moments load
         prop[SDOF LOAD M Y] = 0;
     printf ("\ndelta missile: updated 6DOF properties");
```





### 6DOF – GUI

			BODY
	La mana de la composición de la composi	In-Cylinder Six DOF Implicit Update Compact Detection	Mass (kg) 🗹 One DOF Translatio
thing Insh Generation	Dynamic Mesh	Six DOF Properties	100 One DOF Rotation
Iton Setup eneral odels aterials Nates el Zone Conditions oundary Conditions esh Interfaces norma (Interfaces norma (Interfaces norma (Interfaces norma (Interfaces norma (Interfaces norma (Interfaces) outon Controls ontors outon Controls ontors outon Controls ontors outon Initialization alculation Activities un Calculation utis raphics and Animations ots eports	Mesh Methods Options Setting: Layering Remeshing Settings Dynamic Mesh Zones Corps_surfaciple - Rigid Body Create,Edit Display Zone Motion Preview Mesh Motion	BODY         Create/Edit       Delete         Delete       Delete         All       Gravitational Acceleration         X (m/!       Y (m/!         -9.80' Z (m/!       0         Write       Wotion         File       Name         E:\mywork\client\014\high-atack\fluent	One DOF Direction X Y Z 1 1 1 1 Center of Rotation X (m) Y (m) Z (m) 1 1 1 1 Spring Preload (n) Constant (n/m) 0 0 Constrained Reference Point Location (m) Minimum (m) Maximum (m)
		OK Cancel Help	Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the system       Image: Construction of the system         Image: Construction of the



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### 6DOF – GUI

Six DOF Properties X	Dynamic Mesh Zones	×
Name BODY Moment of Inertia (kg-m2 One DOF Translation 0 One DOF Rotation One DOF Axis X Y Z 1 1 1 1 Center of Rotation	Zone Names Dynamic Mesh Zone bwall    Type  Stationary  Rigid Body  Deforming  User-Defined  System Coupling  Deforming	25
X (m) Y (m) Z (m)	Motion Attributes Geometry Definition Meshing Options	Solver Options
1     1       Spring       Preload (n-m)       Constant (n-m/rad)	Six DOF UDF/Properties           BODY         Relative Motion           Relative Zone	Six DOF On Passive
0     0       Constrained       Reference Angle       Value (deg)     Minimum (deg)       0     0	Center of Gravity Location X (m) 0 Y (m) 0 Z (m) 0	Rigid Body Orientation Theta (deg) 0 Axis_X 0 Axis_Y 0 Axis_Z 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	Center of Gravity Velocity V_X (m/s) 0 V_Y (m/s) 0 V_Z (m/s) 0 Orientation Calculator	Rigid Body Angular Velocity Omega_X (rad/s) 0 Omega_Y (rad/s) 0 Omega_Z (rad/s) 0
Create Close Help	Create Draw Delete All Delete ANSYS UGM 2017	Close Help



### Workflow for a 6DOF case

- Reise the Preshor
  - 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,
- Switchptoetnansient solver
- Run till convergence (if required).
   Choose the right Dynamic mesh method(s)
- Switch to transient solver
- Envitchten ight Dynamic mesh method(s)
- Swittentionsthe 6 DOF
  - Settlefined Rigid properties in Fluent 6DOF GUI
    - Set the gravitational acceleration

    - define Rigid properties
      Set the appropriate Dynamic Mesh Zones
- Savecesselfile
- Preview meshanotion



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



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#### • Read the mesh,

ONVERGENCE

- 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

In-Cylinder	Six DOF Implicit Update Contact Detection
Gravitationa	al Acceleration
X (m/s2)	0
Y (m/s2)	0
Write Mo	otion History
File Name	and the second se
	OK Cancel Help





# 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





٠ The 6DOF UDF

```
#include "udf.h"
DEFINE_SDOF_PROPERTIES(store, prop, dt, time, dtime)
ł
                                                               pipe-van Fluent [3d, pbns, dynamesh, lam, transient]
 /* Define the mass matrix */
                                                               File Mesh Define Solve Adapt Surface Display Report Parallel Vit
 prop[SDOF_MASS] = 5000.0;
                                                                   📴 • 🚽 • 🗃 🥥 🖾 🔄 电电力 电先 🛄 • 🗆 •
 prop[SDOF_IZZ] = 5e3;
/* add ejector forces, moments */
                                                                                  Dynamic Mesh
                                                                Meshing
if (time <= 0.3)
                                                                 Mesh Generation
                                                                                  V Dynamic Mesh
 Ł
                                                                Solution Setup
                                                                                   Mesh Methods
         prop[SDOF_LOAD_F_X] = -40000;
                                                                 General
                                                                                    ✓ Smoothing
                                                                 Models
         prop[SDOF_LOAD_F_Y] = -80000;
                                                                                    Layening
                                                                 Materials
         prop[SDOF\_LOAD\_M\_Z] = -2200.0;
                                                                                    V Remeshing
                                                                 Phases
 }
                                                                 Cell Zone Conditions
                                                                                    Settings...
                                                                 Boundary Conditions
  Message0("\nUpdated 6DOF properties\n");
                                                                 Mesh Interfaces
                                                                 Bynamic Mesh
                                                                 Reference Values
                                                                                   Events...
                                                                Solution
                                                                                   Dynamic N
                                                                                   fluid-infla
         Define the gravitational acceleration
                                                                 Solution Methods
      -
```



×

Options

In-Cyinder

Implicit Update

Contact Detection

In-Cvinder Six DOF Implicit Update Contact Detection

V Six DOF

Settings....

D:\Data\andry\Formation\MDM-R14.5

Options

wall-vane

Solution Controls Monitore

Gravitational Acceleration

X (m/s2) 0 Y (m/s2) -9.81

File Name



### 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

Zoon Namor	Dupanic Mach Zopps	
store	Buch	
Tune	- Sister	
type		
<ul> <li>Rigid Body</li> </ul>		
~ Deforming		
Vser-Defined		
Motion Attributes Gronality Darini	Meshing Options	
Six DOF UDF	Six DOF Solver Options	
store:libudf	🖉 🖉 On	
	_ Passive	
Contra of Contract of Contract		
Center of Gravity Location	Center of Gravity Orientation	
X(m) 7.6	Theta_Z (deg) 0	
V (m) 18 5	1	
1 44 70.2		
Center of Gravity Velocity	Center of Gravity Angular Velocity	
V X (m/s) 0	Omega Z (rad/s)	
V_Y (m/s) 0		
Create Draw	Delete Alt Delete Close Hel	
Create Draw Dynamic Mirsh Zones Zone Names	Delete Alt Delete Close Heij	- -
Create Draw Dynamic Mirsh Zowes Zone Names Ruid-bi	Delete All Delete Close Her	×
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Create Draw Dynamic Mesh Zones Zone Names Ruid-bi Type Stationary Rigid Body Stationary Rigid Body Deforming User-Defined Motion Attributes Storpe Libud Center of Gravity Location X (m) 7.6	Delete All Delete Close Help	
Create Draw Dynamic Mesh Zores Zone Names Ruid-bi Type Stationary Rigid Body Stationary Rigid Body Deforming User-Defined Motion Attributes Six DOF UDF store: iliuud Center of Gravity Location X (m) 7.6	Delete All Delete Close Help	
Create Draw Dynamic Mesh Zores Zone Names Ruid-bi Type Stationary Rigid Body Stationary Rigid Body Deforming User-Defined Motion Attributes Sto DOF UDF store::likudf Center of Gravity Location X (m) 7.6 Y (m) 18.5	Delete All Delete Close Help	
Create Draw Dynamic Mesh Zores Zone Names Ruid-bi Type Stationary Rigid Body Stationary Rigid Body Deforming User-Defined Motion Attributes Store-fileudf Center of Gravity Location X (m) 7.6 Y (m) 18.5 Center of Gravity Velocity	Delete All Delete Close Help	
Create Draw Dynamic Mesh Zores Zone Names Ruid-bi Type Stationary Rigid Body Stationary Rigid Body Deforming User-Defined Motion Attributes Store-likudf Center of Gravity Location X (m) 7.6 Y (m) 18.5 Center of Gravity Velocity V X Actor	Delete All Delete Close Help	
Create     Draw       Dynamic Mesh Zores       Zone Names       Rigid-bit       Type       Stationary       Rigid Body       Deforming       User-Defined       Motion Attributes       Store-likudf       Center of Gravity Location       X (m)       7.6       Y (m)       18.35       Center of Gravity Velocity       V_X (m/s)	Delete All Delete Close Help Dynamic Mesh Zones Dynamic Mesh Zones Dynamic Mesh Zones Store Store Store Ski DOF Selver Options Ski DOF Selver Options Center of Gravity Orientation Theta_Z (deg) 0 Center of Gravity Angular Velocity Omega_Z (rad/s) 0	
Create     Draw       Dynamic Mesh Zores       Zone Names       Ruid-bit       Type       Stationary       Rigid Body       Deforming       User-Defined       Motion Attributes       Six DOF UDF       store-likudf       Center of Gravity Location       X (m)       7.6       Y (m)       18.5       Center of Gravity Velocity       V_X (m/s)       0       V_Y (mV)	Delete All Delete Close Help Dynamic Mesh Zones Dynamic Mesh Zones Interact store Skr DOF Selver Options Skr DOF Selver Options Center of Gravity Orientation Theta_Z (deg) 0 Center of Gravity Angular Velocity Omega_Z (rad/s) 0	

• ...



### **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



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### Case2 : Result











### Case3:2D弹丸出膛分析

- □ 网格 & 设置
- ・ 与层铺动网格 ( nonconformal 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





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### Case4:2D弹头运动分析





### Case4:Result,马赫数





### Case4:Result, 马赫数





# Case5 : ULA Stage Separation

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

#### **Overset Mesh**

ONVERGENCE

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



#### **MDM Mesh**

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





### **Case5 : ULA Stage Separation**



Mesh (Time=0.0000e+00)

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# 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

