Numerical Heat Transfer

Chapter 13 Application examples of fluent for basic flow and heat transfer problems

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数值传热学

第 13 章 求解流动换热问题的Fluent软件基础应用举例

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2020年12月22日，西安

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13.1 有内热源的导热问题

13.2 非稳态圆球冷却问题

导热问题

13.3 顶盖驱动流动换热问题

13.4 微通道内流动换热问题

混合对流问题

13.5 芯片冷却流动换热问题

微通道问题

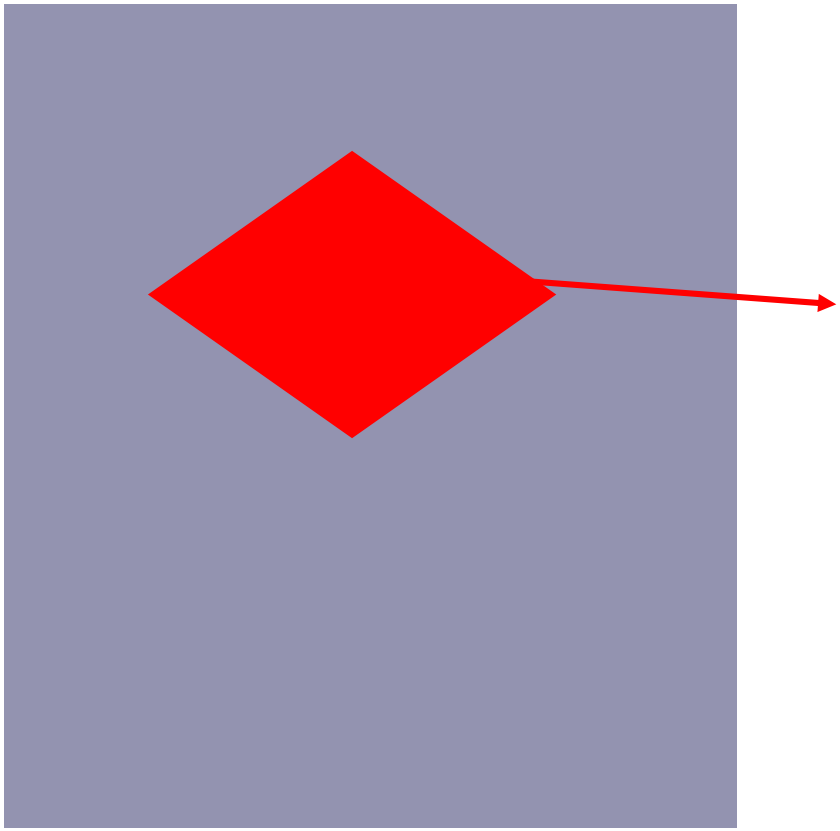
13.6 肋片强化相变材料融化

相变传热

Review

Example 2

Patching (修补) Values in Selected Cells



Domain

Sub-region need to Patch

1. **Define the sub-region**
2. **Use Patch to specify related variables.**

For transient problem you have to

time stepping method, time step size, the max iteration per time step

Max iteration per time step

Inner iteration times

Time step size

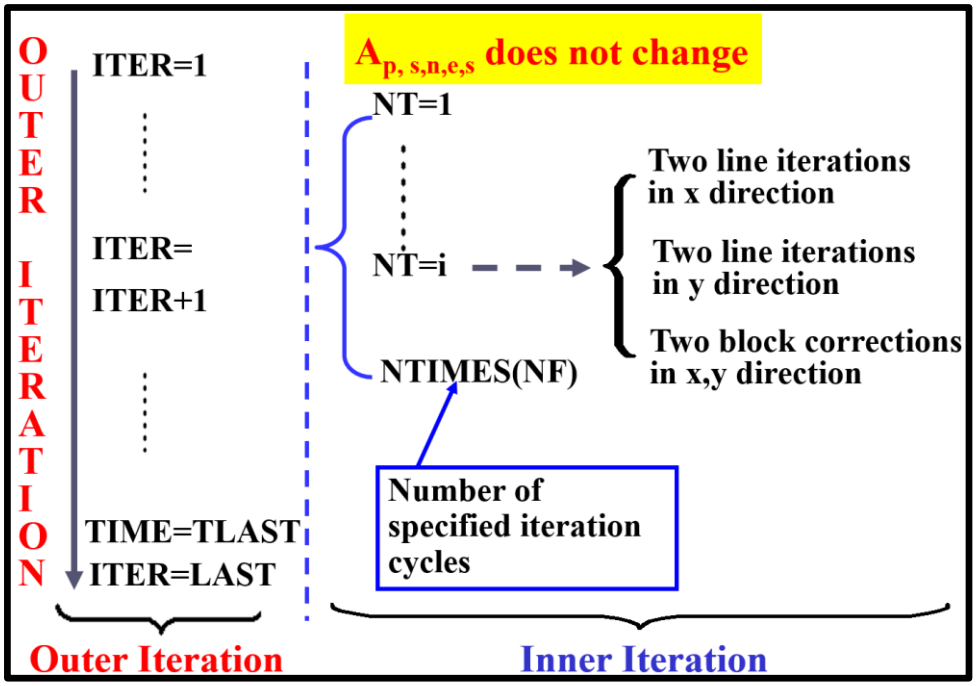
Outer iteration

Time stepping method

Fixed

Adaptive method

Teaching code



For fully implicit scheme, Δt does not affect stability, but will affect the accuracy of the simulation results.

The following way is recommended by Fluent to set Δt:

1. At each time step, the ideal iteration number is 5-10.

2. If Fluent needs more inner iteration step (>10) for convergence at each time step, Δt is too large.

3. If Fluent needs only a few iteration steps, Δt is too small.

13.6 Phase change material melting with fins

肋片强化相变材料融化传热问题

Focus: compared with previous examples, the focus of this example is solid-liquid phase change heat transfer.

13.6 Phase change material melting with fins

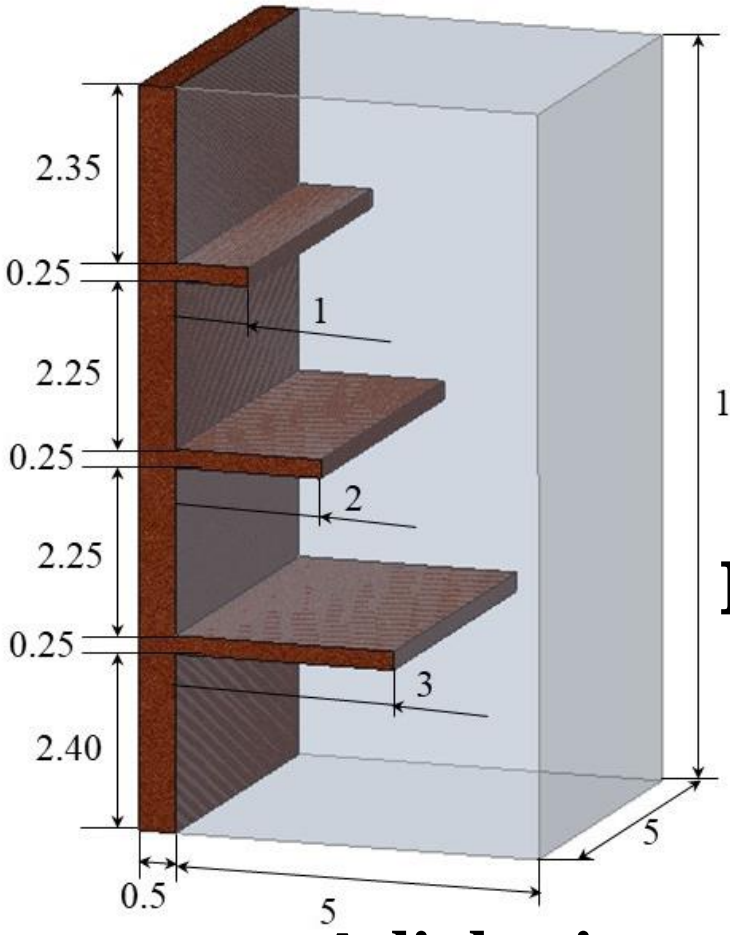
Known: Paraffin RT50 is used as the phase change material, and internal copper fins are used to enhance the solid-liquid phase change inside the 3D square cavity.

Property	Copper	RT50
$\rho\ [kg/m^3]$	8954	880
$C_p\ [J/kg\cdot K]$	383	2000
$k\ [W/m\cdot K]$	400	0.2
$\beta\ [K^{-1}]$	1.67×10^{-5}	1×10^{-3}
$\mu\ [Pa\cdot s]$	–	0.0275
$L\ [kJ/kg]$	–	168
$T_m\ [K]$	–	322

Assumption: (1) laminar flow, (2) incompressible fluid, (3) constant fluid properties except the density ρ , (4) negligible radiation heat transfer

Adiabatic

$T_l = 330\ K$



Adiabatic

Adiabatic

Initial temperature

$T_i = 321.9\ K$

Adiabatic

Fig.1 Computational domain (mm)

Find: **Temperature distribution and liquid fraction distribution in the domain.**

Governing equations:

Continuity equation:

$$\frac{\partial u_i}{\partial x_i} = 0$$

Momentum equations:

$$\rho \frac{D(u_i)}{Dt} = -\frac{\partial p}{\partial x_i} + \mu \frac{\partial^2 u_i}{\partial x_j \partial x_j} + F_i$$

Energy equation for PCM:

$$\frac{\partial(\rho h)}{\partial t}+\frac{\partial(u_i \rho c_{pf} T_f)}{\partial x_i}=k_f\left(\frac{\partial^2 T_f}{\partial x_i^2}\right)$$

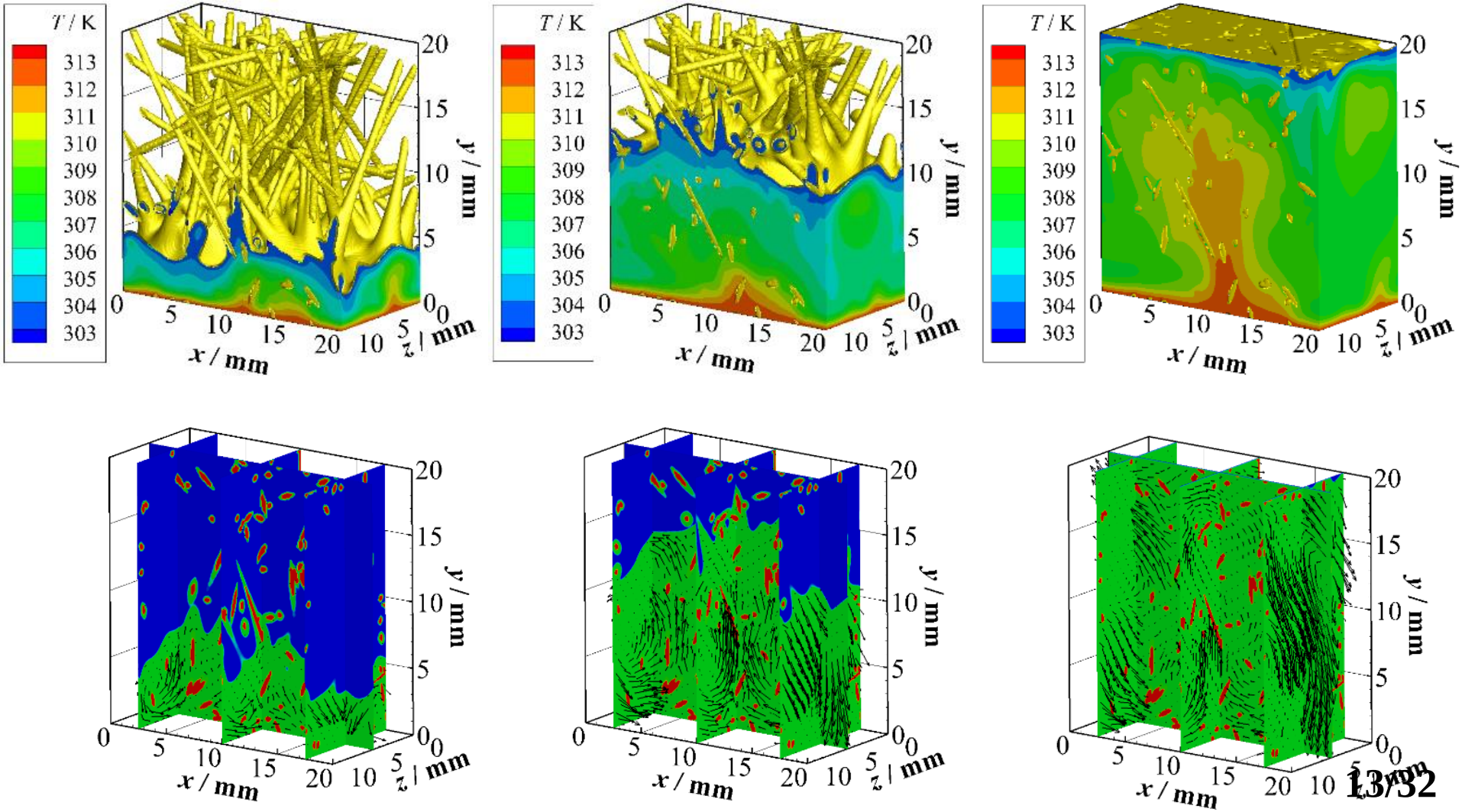
Where h is the enthalpy, T_f is the PCM temperature, c_{pf} is PCM specific heat and k_f is fluid thermal conductivity.

Energy equation for the fins:

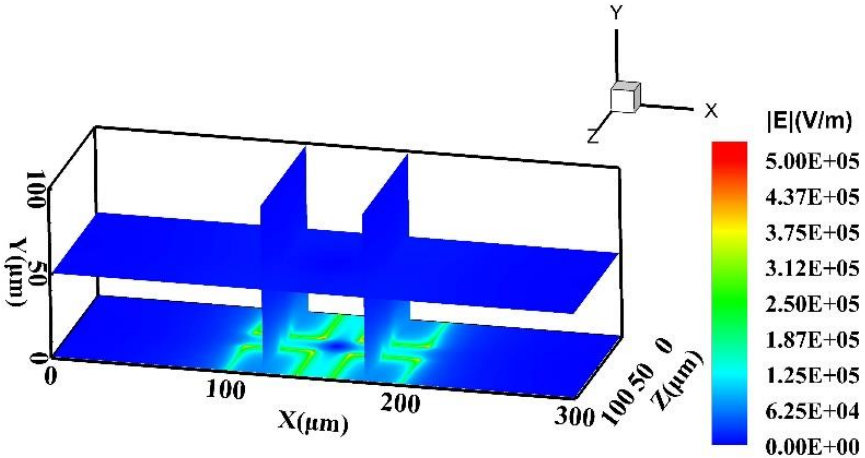
$$\rho_s c_{ps}\frac{\partial T_s}{\partial t}=k_s\left(\frac{\partial^2 T_s}{\partial x_i^2}\right)$$

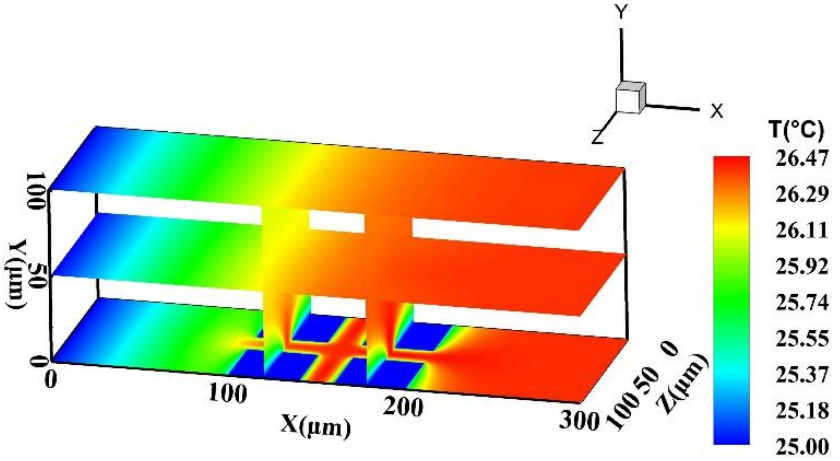
where T_s is fin temperature and k_s is fin thermal conductivity

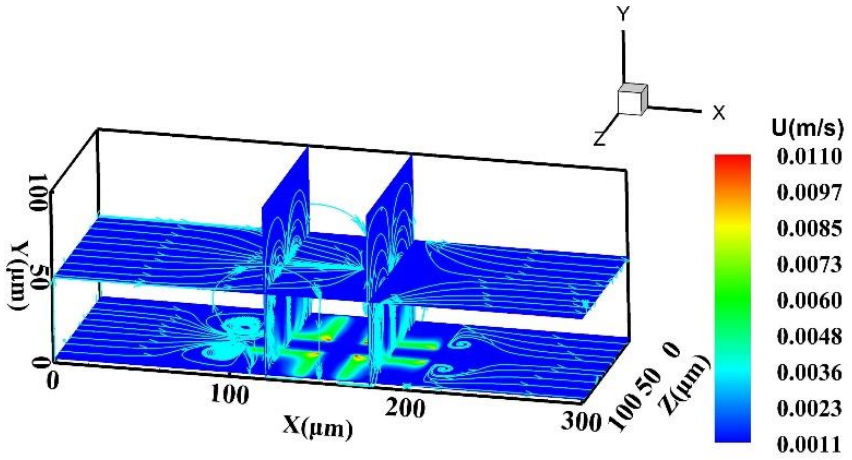
三维多孔金属纤维内固液相变传热（GPU加速LBM）

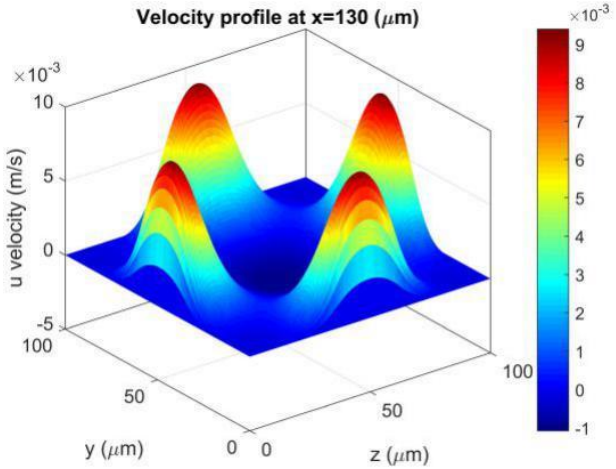


三维多场耦合非牛顿血液电热流动（GPU加速LBM）

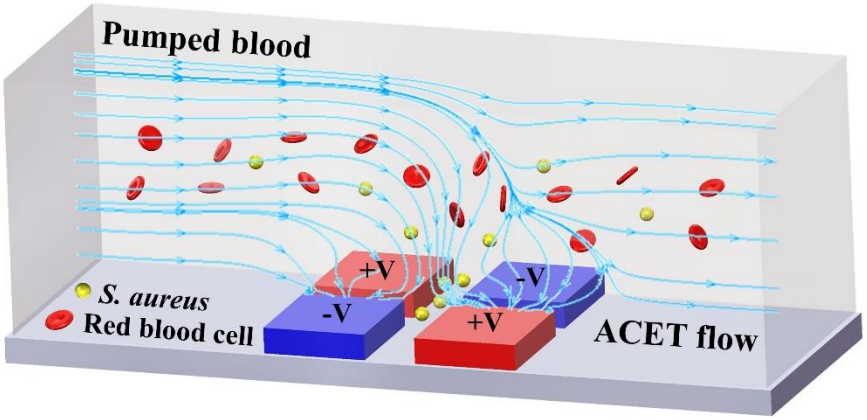


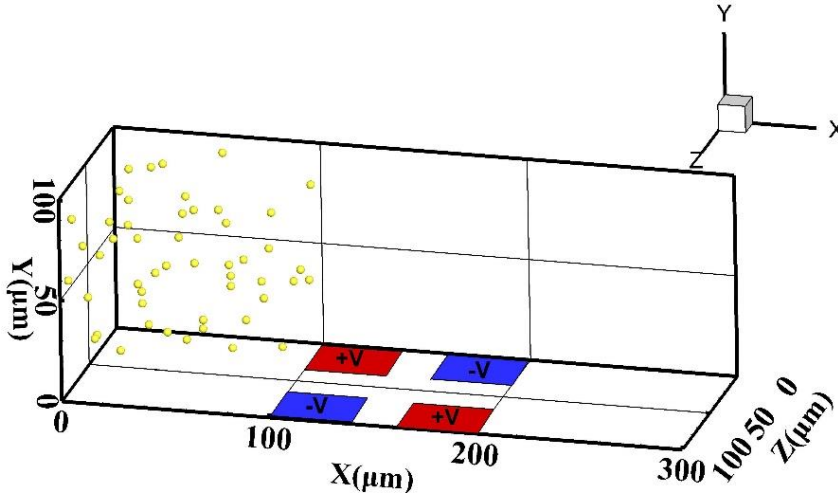


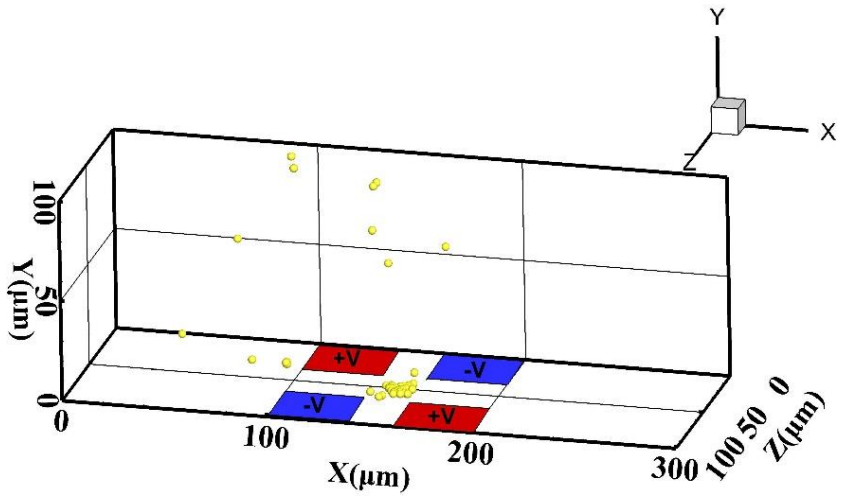


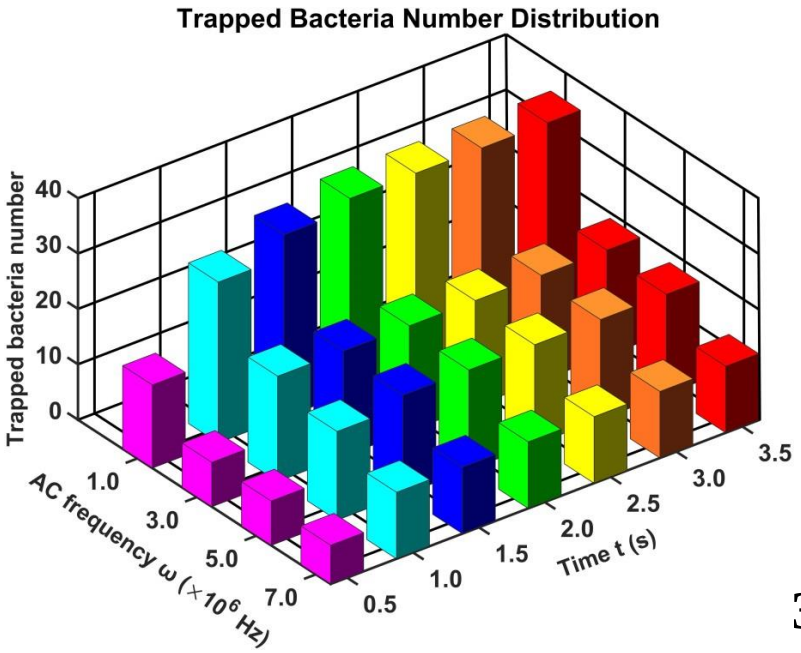


三维微流控芯片血液细菌富集（GPU加速LBM）

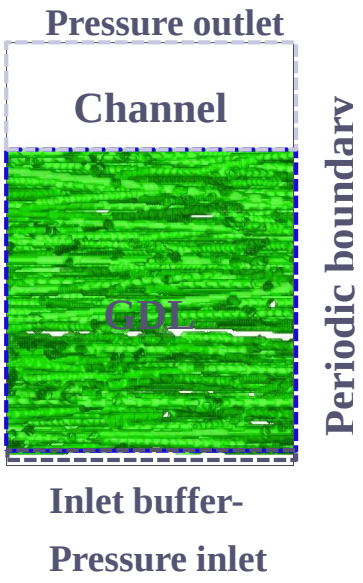


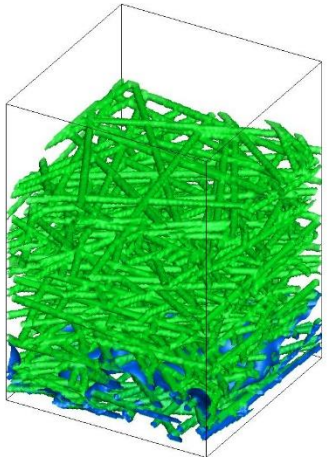




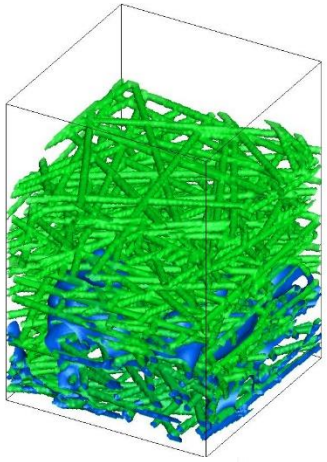


燃料电池扩散层内液态水突破过程（GPU加速LBM）

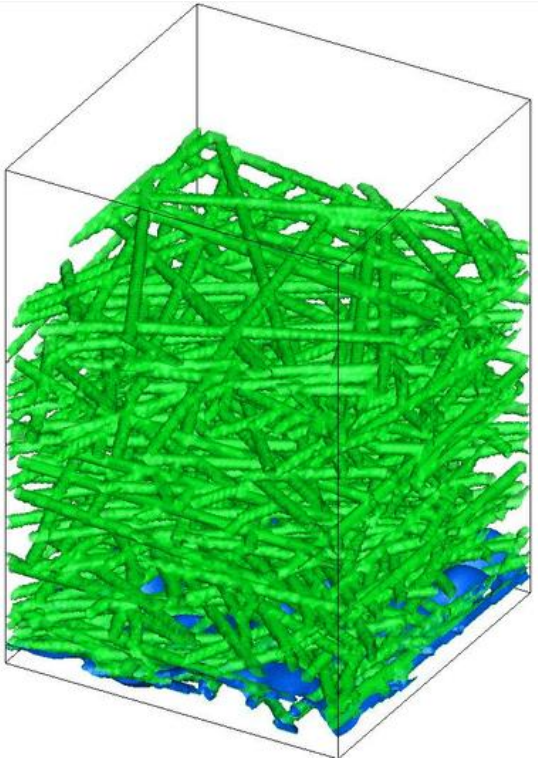


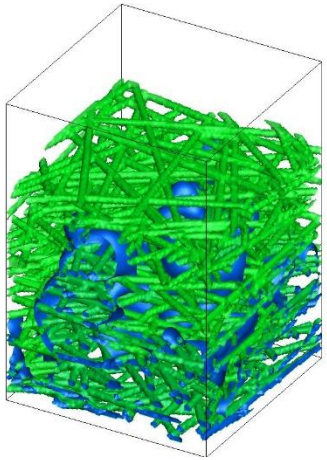


t=1.785 ms

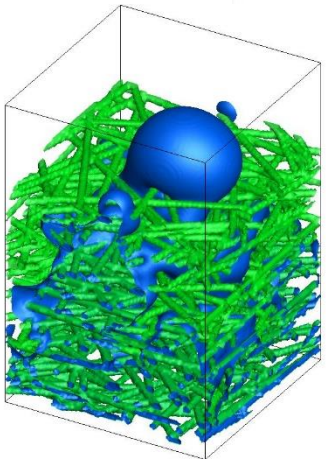


t=3.570 ms



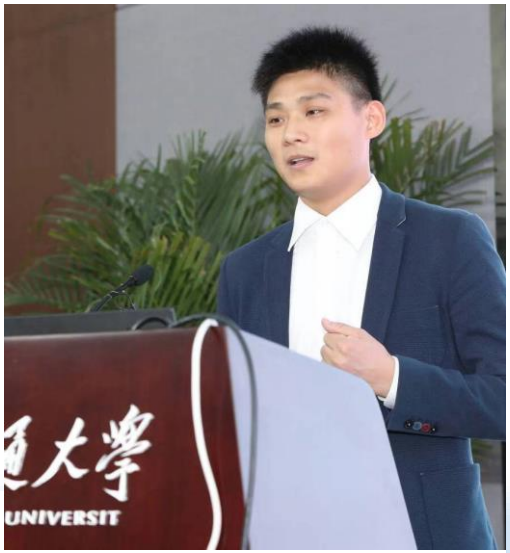


t=5.355 ms



t=6.693 ms

CFD的软件开发是一项典型的复杂工程



Prof. Kong Ling

$$\underbrace{\frac{\partial(\rho_\phi \phi)}{\partial t}}_{\text{Transient}} + \underbrace{\nabla \cdot (\rho_\phi \boldsymbol{u} \phi)}_{\text{Convection}} = \underbrace{\nabla \cdot (\Gamma_\phi \nabla \phi)}_{\text{Diffusion}} + \underbrace{s_\phi}_{\text{Source}}$$

有限容积法的通用输运方程

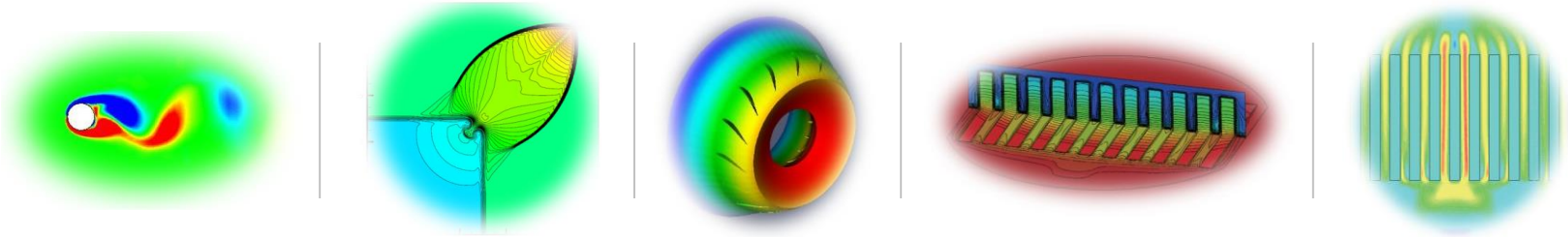
其实这些算子还可以进一步简化

直到形成这样的软件框架

应用层	特定工程问题求解模块
方法层	单一物理问题的求解算法与模型
离散层	控制方程各部分的离散及格式
框架层	计算网格、物理场、代数方程组
基础层	基本代数运算，几何单元

MHT

Multi- { physics / phase / region / scale } Heat Transfer



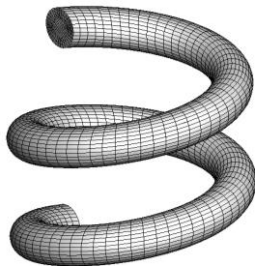
框架层功能：网格支持模块

非结构化网格

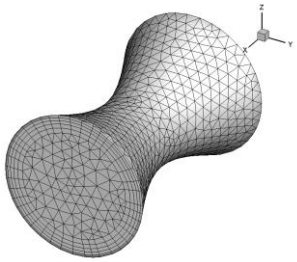
二维与三维统一

支持多种格式的网格文件

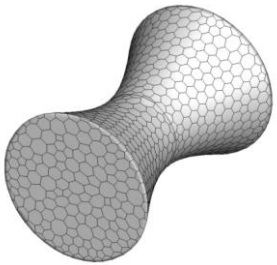
六面体网格



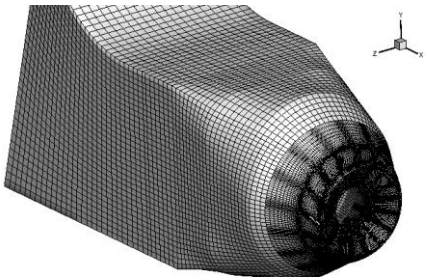
混合网格



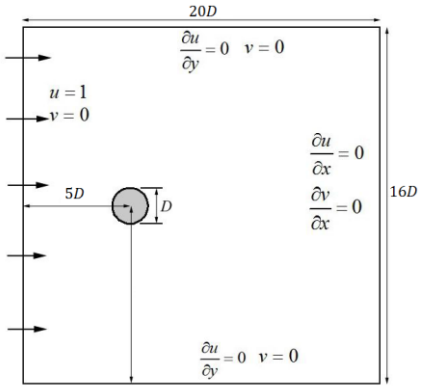
多面体网格

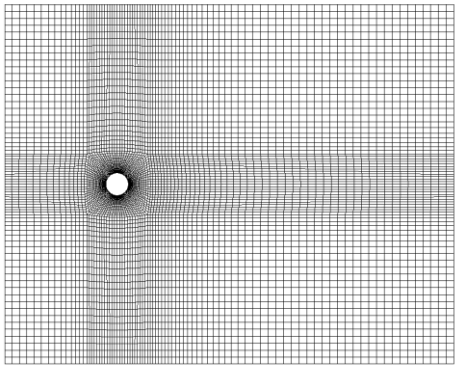


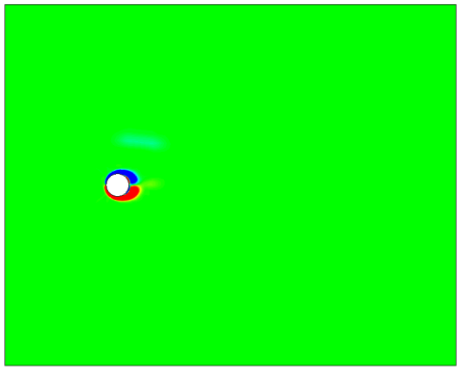
多区域网格

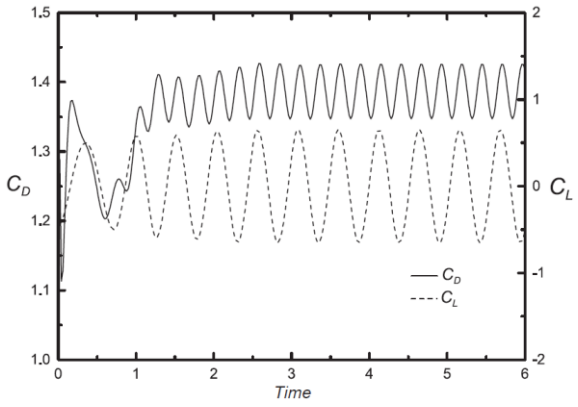


方法层功能：求解不可压缩流动的SIMPLE算法







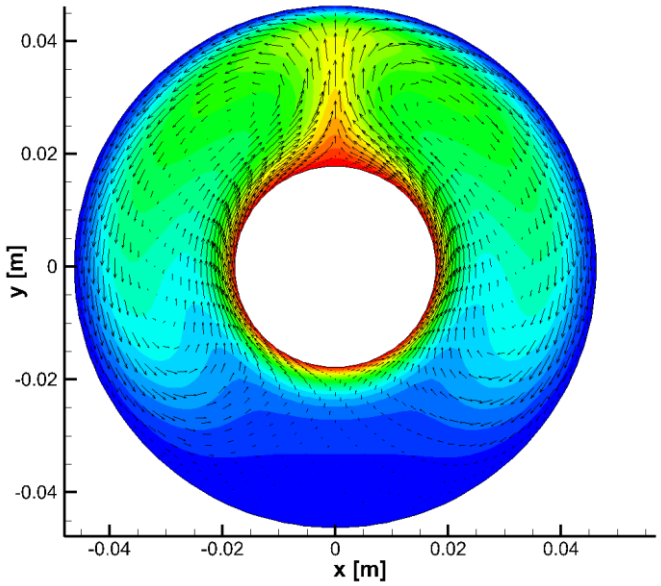


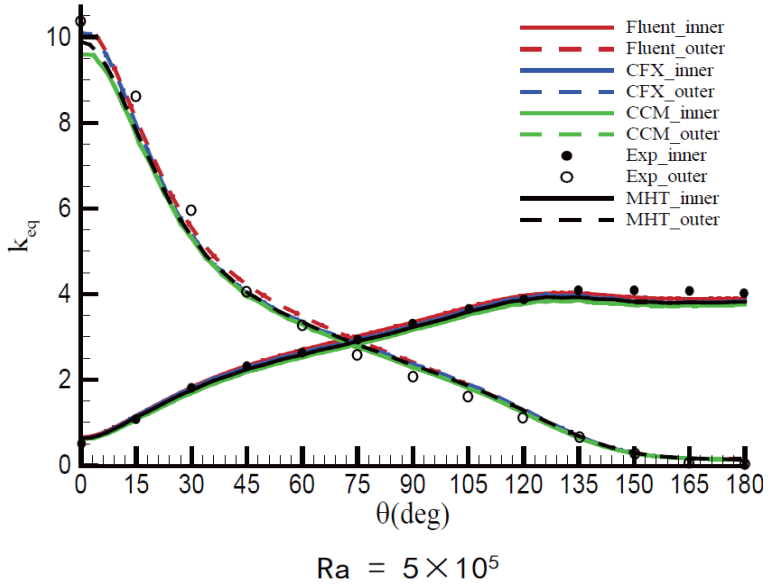
C_D	C_L	St
1.388±0.041	±0.65	0.192

	Re = 200		
Authors	C_D	C_L	S_t
Rosenfeld et al. [47]	1.31 ± 0.04	±0.65	0.20
Liu et al. [48]	1.31 ± 0.049	±0.69	0.192
Wright and Smith [49]	1.33 ± 0.04	±0.68	0.196
Calhoun [50]	1.17 ± 0.058	±0.67	0.202
Russell and Wang [51]	1.29 ± 0.022	±0.50	0.195
Stålberg et al. [52]	–	–	–
Choi et al. [45]	1.36 ± 0.048	± 0.64	0.191
Taira and Colonius [46]	1.34 ± 0.047	±0.68	0.195
Present	1.37 ± 0.051	±0.71	0.198

P.H. Chiu, R.K. Lin, Tony W.H. Sheu, A differentially interpolated direct forcing immersed boundary method for predicting incompressible Navier–Stokes equations in time-varying complex geometries, *Journal of Computational Physics*, 2010, 229, 4476-4500

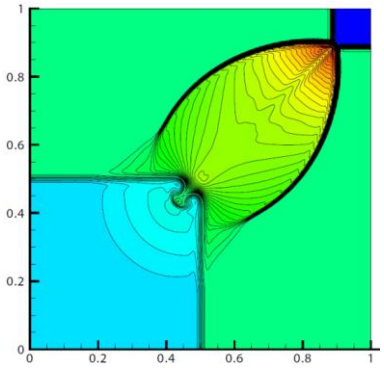
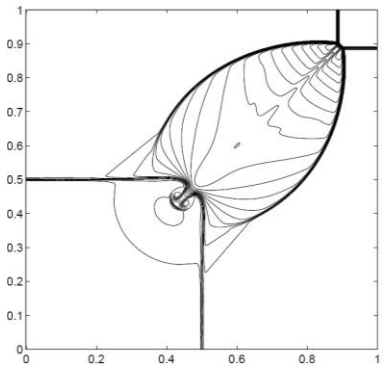
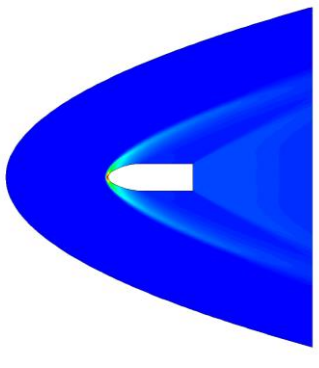
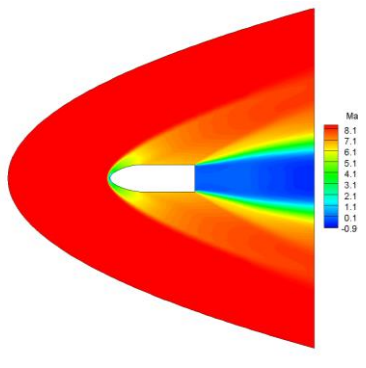
引入求解自然对流的Bossinisque假设



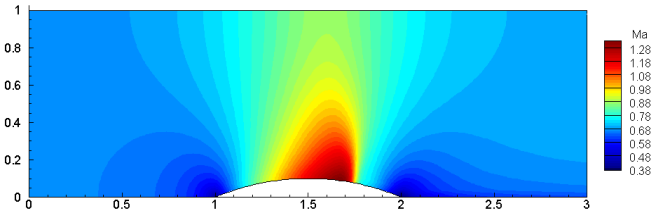


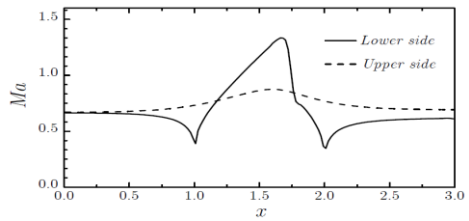
Ra = 5×10^5

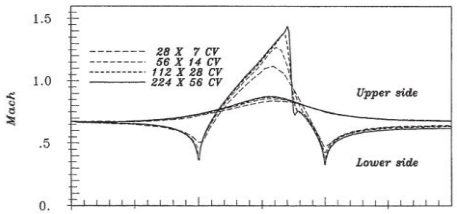
方法层功能：可压缩流动

P.D. Lax, X.D. Liu, Solution of two-dimensional Riemann problems of gas dynamics by positive schemes, *SIAM J. Sci. Comput.*, 1998, 19(2), 319-340





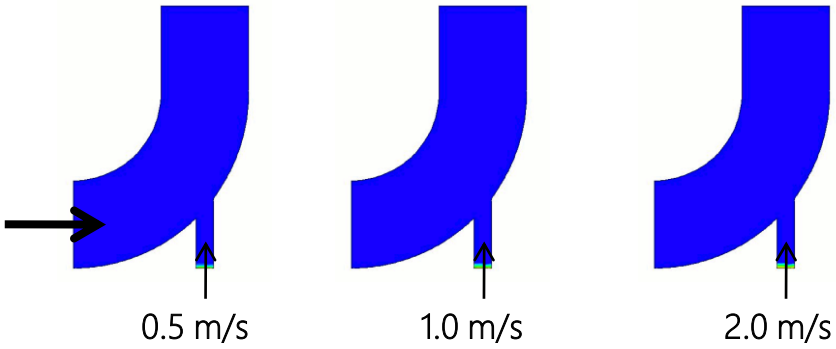


方法层功能：两相流

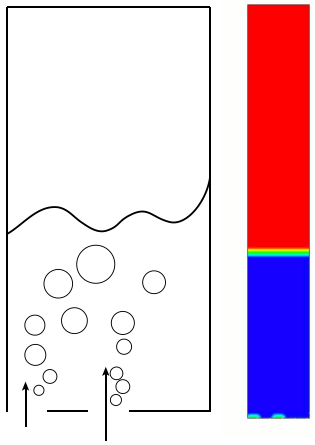
VOSET界面追踪算法

两流体模型

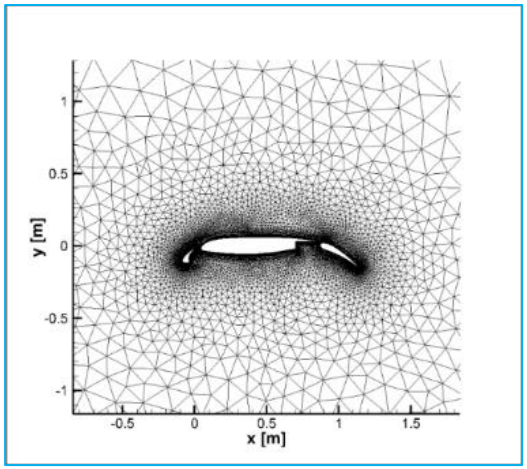
主支管两相混合

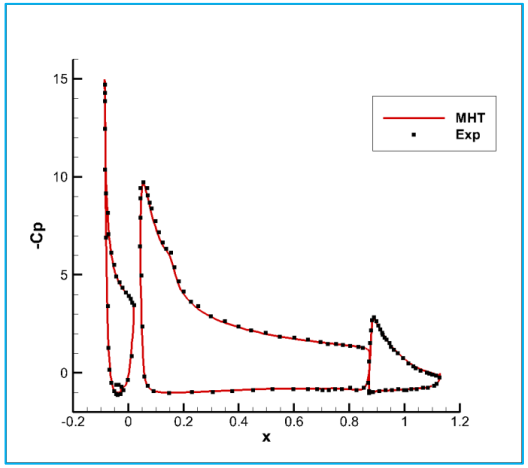


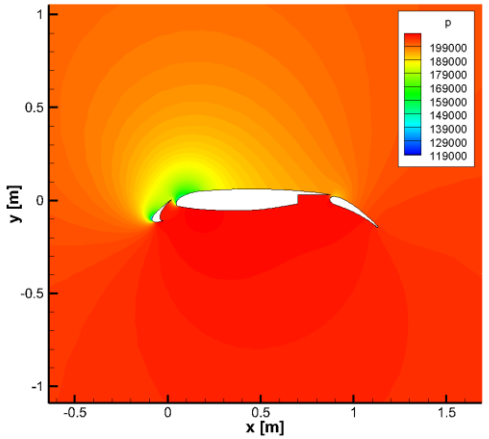
气泡上升流



方法层功能：湍流模型

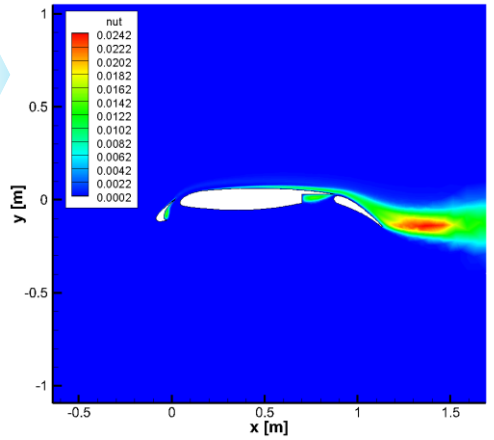




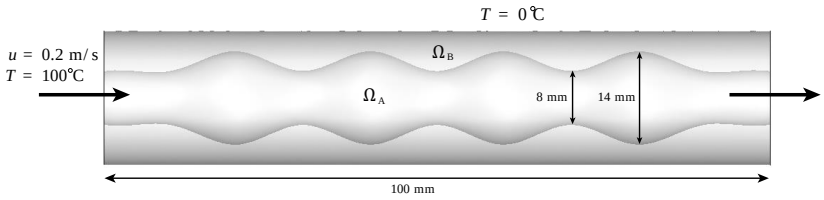


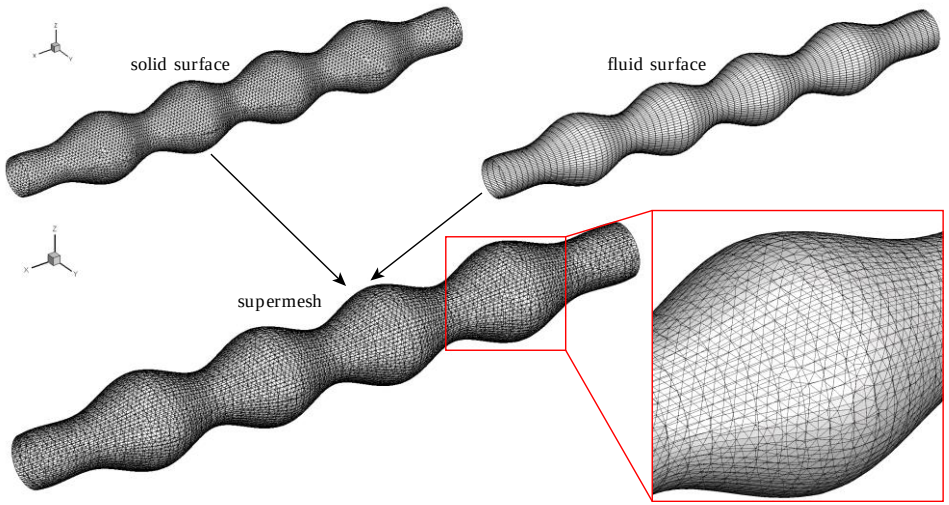
压力

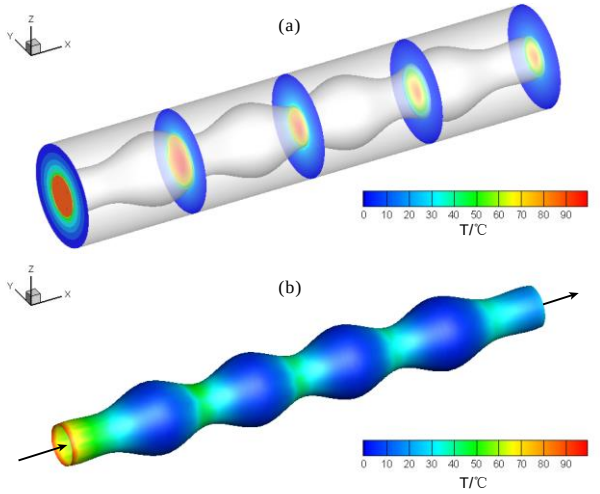
湍流粘性



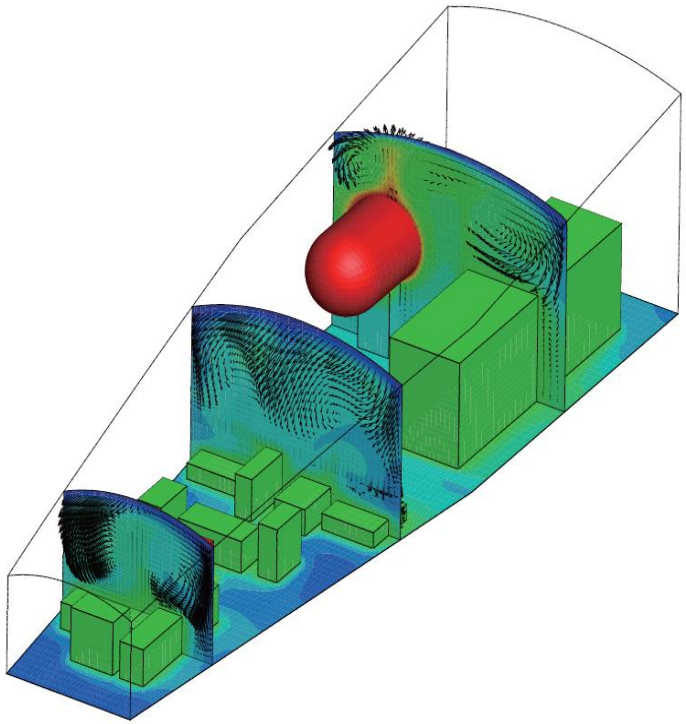
方法层功能：网格的非协调交界面



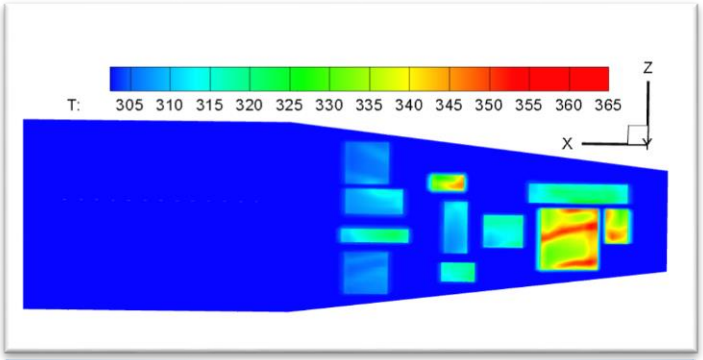




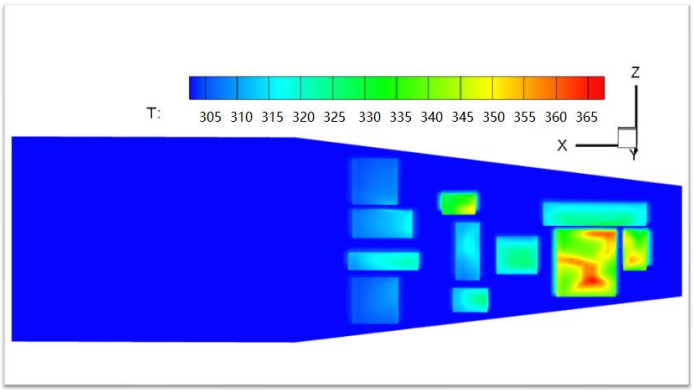
应用举例：某飞行器设备舱自然对流



流场与温度场



FLUENT



MHT

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同舟共济渡彼岸!

People in the same boat help each other to cross to the other bank, where….