第九章　CFD中的图形技术

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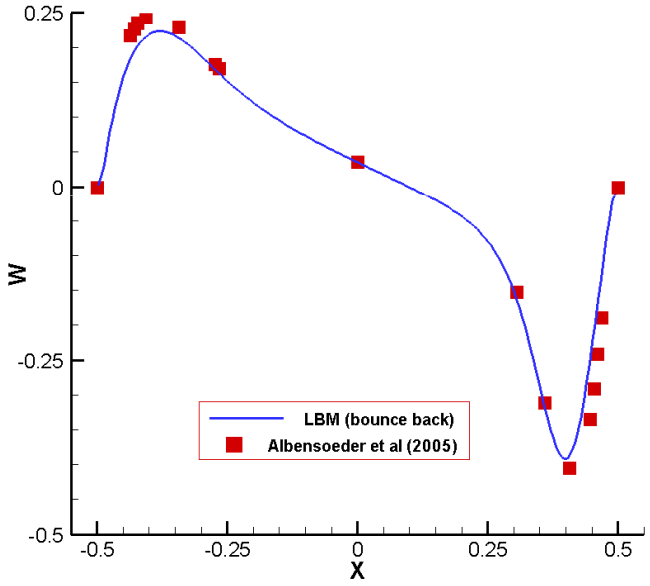
CFD中使用的计算机图形技术

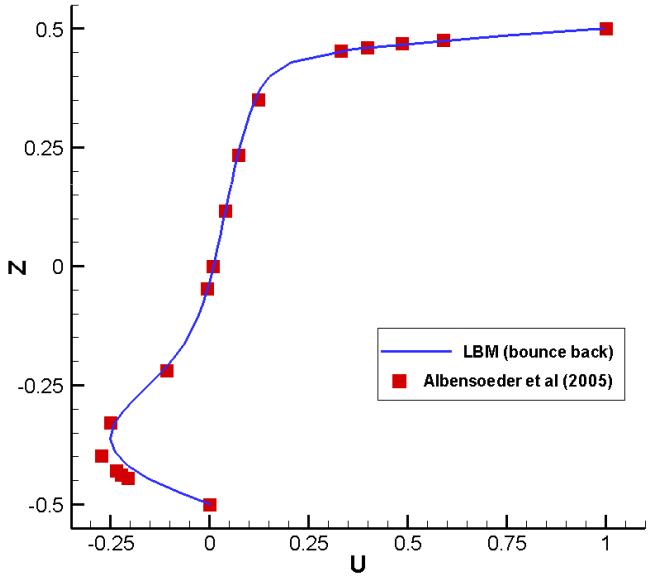
如何使用计算机图形技术来显示CFD的计算结果 ----- 结果的可视化

CFD人员通过计算机图形类软件（可视化软件）来显示结果，而不是自己开发此类程序（非CFD内容）

1. x-y 图

- 二维图，表示因变量随自变量的变化
- 最简单，最直接
- 无法一次性从xy图上看出CFD数据的整体特性





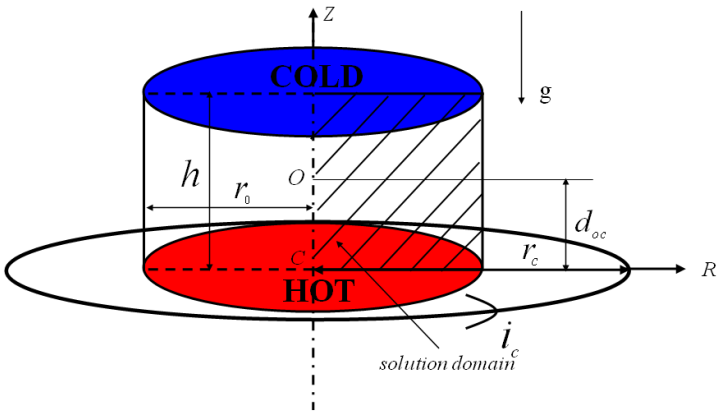
Detailed comparison with *ref** at **Re=1000** :

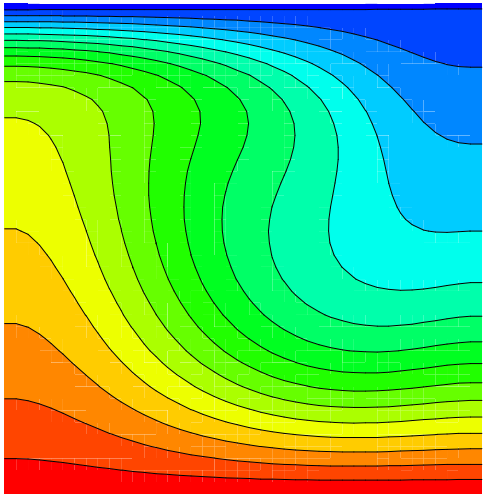
(a) *w* (velocity component in z direction) on the center line (x,0,0)

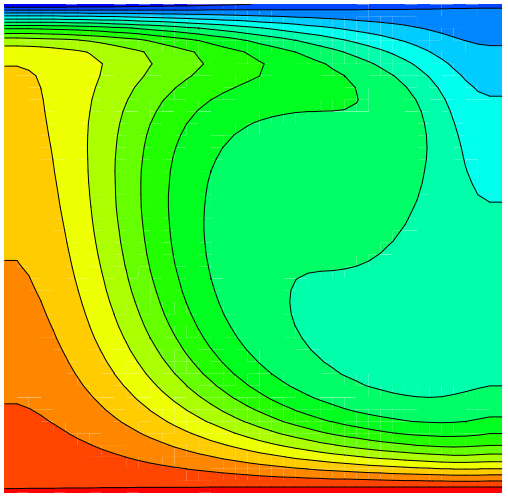
(b) *u* (velocity component in x direction) on the center line (0,0,z)

2. 等值线（面）图

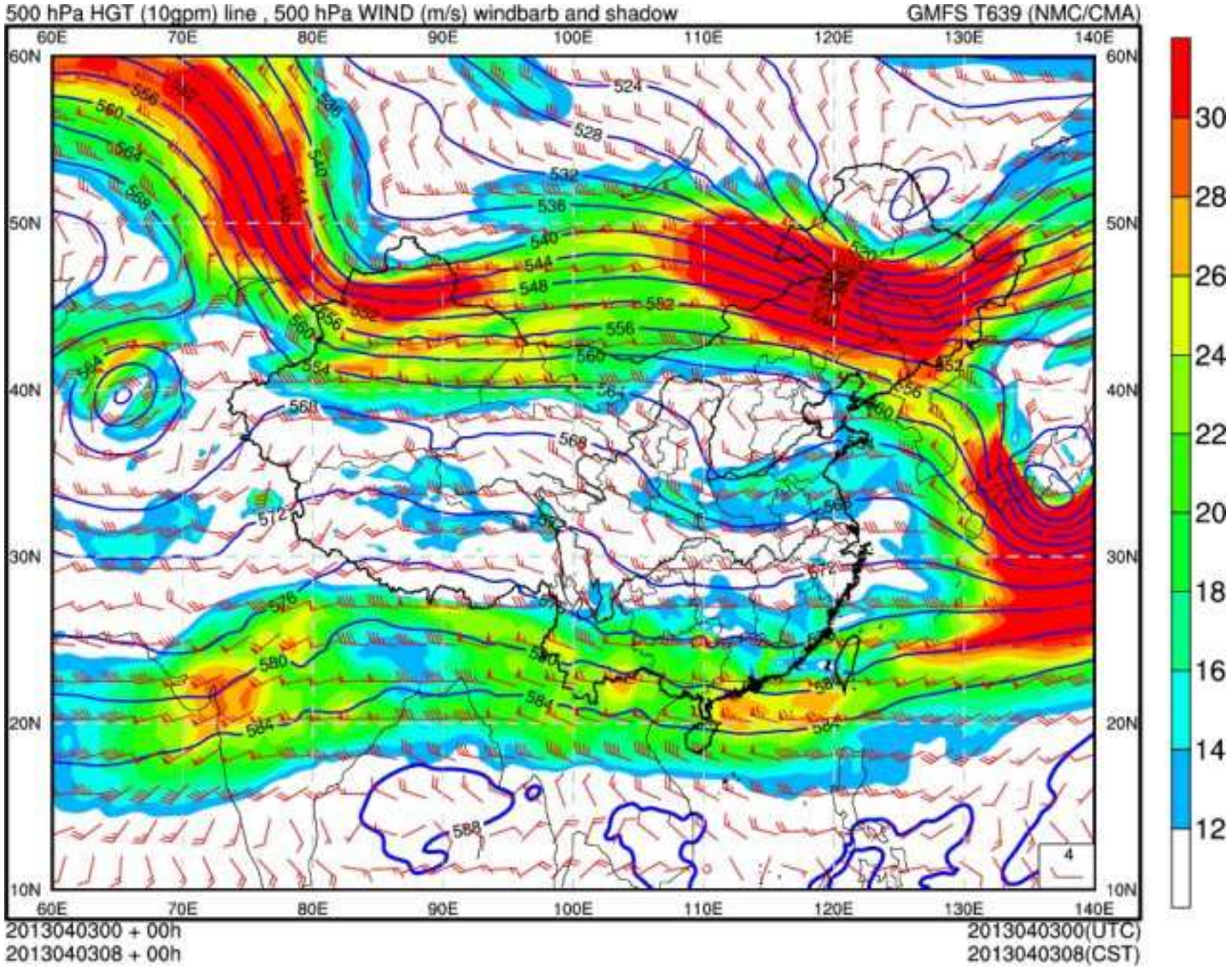
- 等值线：在这条线上所表达的量的值是不变的
- 云图：线条之间的区域被一定强度的色彩所填充
- 三维：等值面
- 可以一次性看出CFD数据的整体特性
- 多相流动的可视化



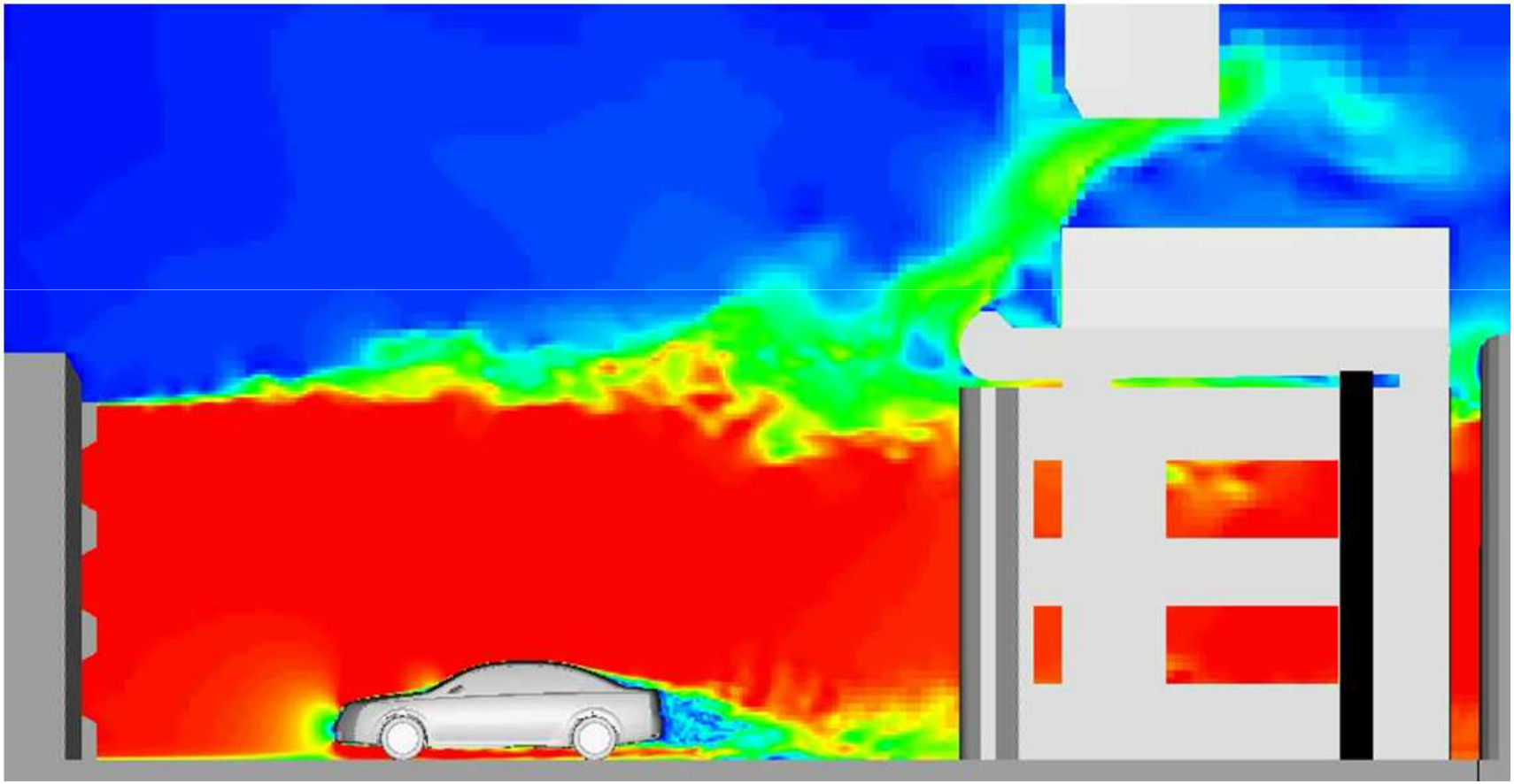




2. 等值线（面）图


500 hPa HGT (10gpm) line , 500 hPa WIND (m/s) windbarb and shadow
GMFS T639 (NMC/CMA)
60E
70E
80E
90E
100E
110E
120E
130E
140E
60N
50N
40N
30N
20N
10N
30
28
26
24
22
20
18
16
14
12
2013040300 + 00h
2013040308 + 00h
2013040300(UTC)
2013040308(CST)

2. 等值线（面）图



2. 等值线（面）图

$$\frac{D\vec{U}_f}{D\tau_f} = -\vec{\nabla}P_f + \nabla^2\vec{U}_f + \frac{Ra}{\mathrm{Pr}}T_f\left[-\gamma_f\vec{\nabla}B^2 + \begin{pmatrix}0\\0\\1\end{pmatrix}\right]$$

$$\frac{DT_f}{D\tau_f} = \frac{1}{\mathrm{Pr}}\nabla^2 T_f$$

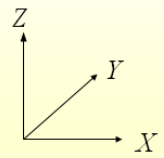
$h = 0.064$ m

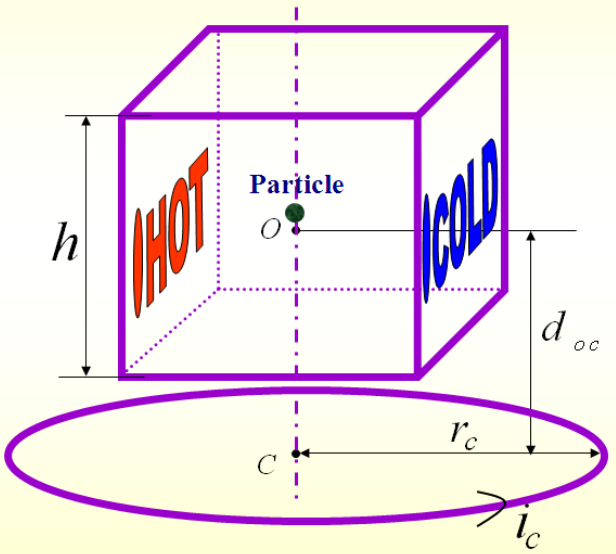
$d_{oc} = 0.05$ m

$r_c = 0.05$ m

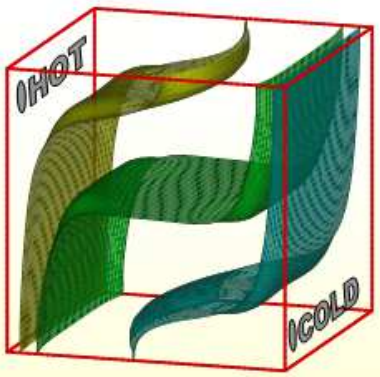
$\rho = 997$ [kg/m^3]

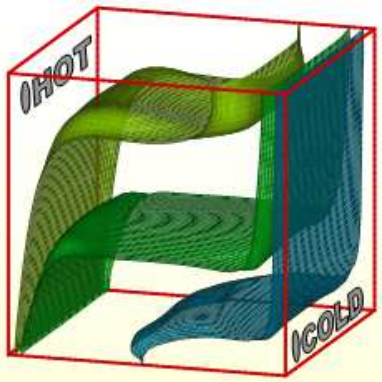
$\chi = -9.05\times10^{-9}$ [m^3/kg]

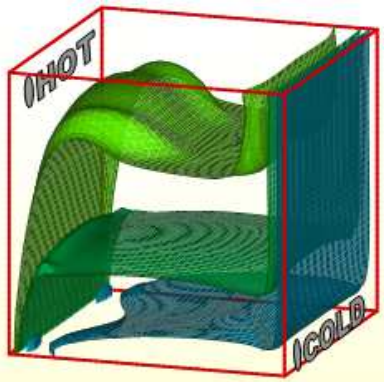




The sketch of the cubical enclosure and coil.







Temperature iso-surface

$\gamma_f = 0$ ($b_o = 0$ T)

$Nu = 4.476$

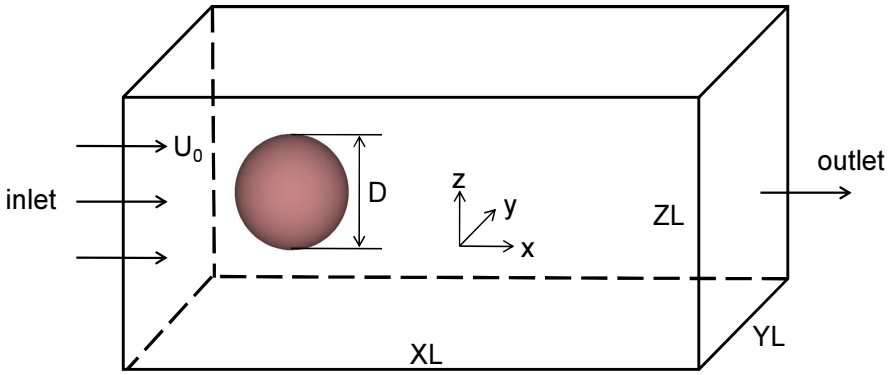
$\gamma_f = 10$ ($b_o = 1.16$ T)

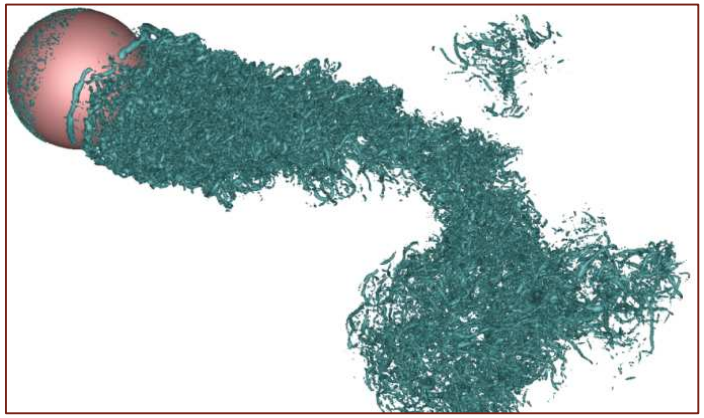
$Nu = 6.974$

$\gamma_f = 100$ ($b_o = 3.67$ T)

$Nu = 12.98$

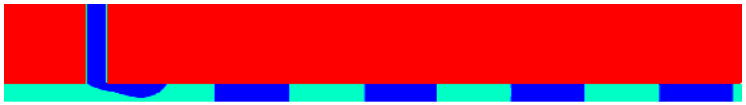
2. 等值线（面）图

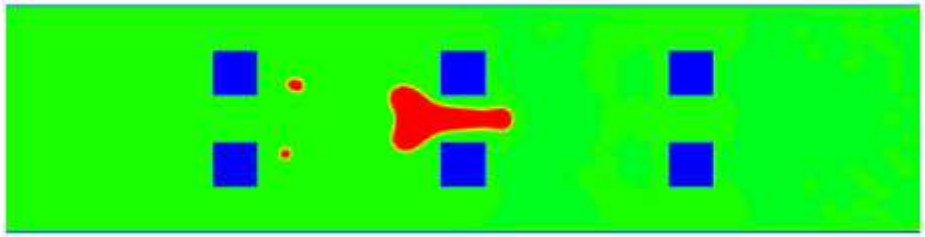




iso-surface of second invariant of velocity gradient tensor at Re=13000

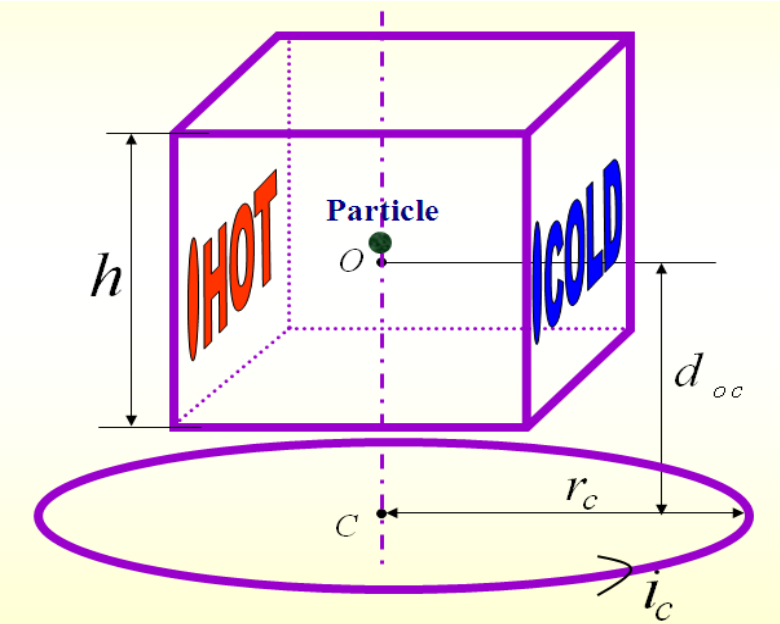
两相流





3. 矢量图和流线图

- 矢量图：显示的是各个离散网格点上的一个矢量（CFD中通常指速度矢量）
- CFD中流线图是观察流动性质的一个出色的工具
- 粒子跟踪图像



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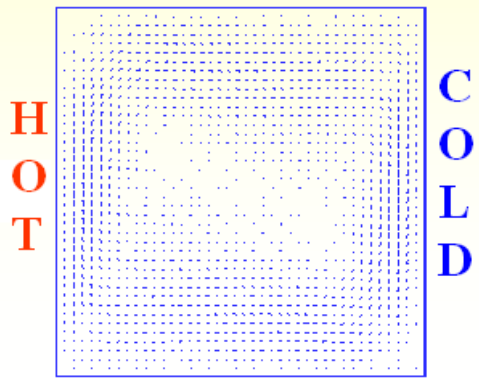
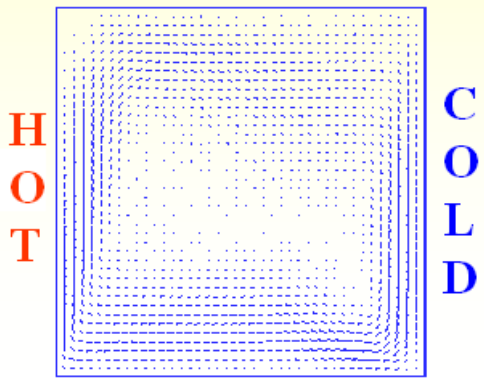
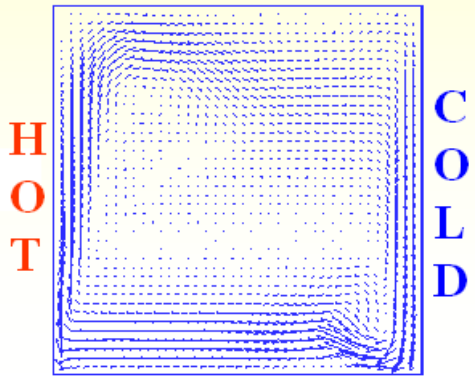
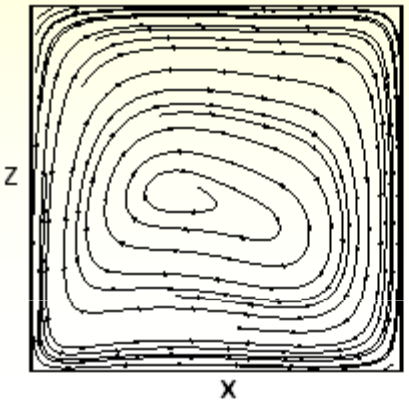
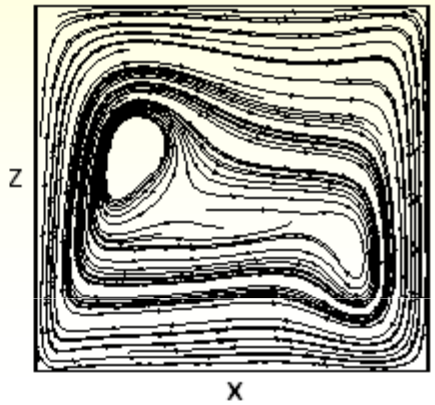


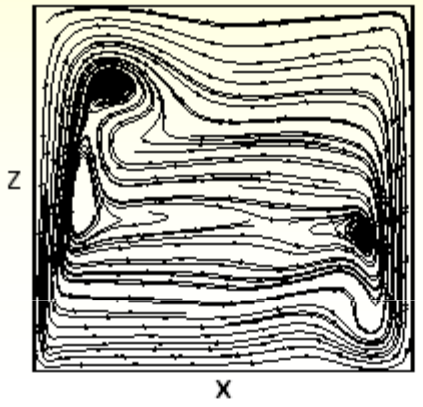




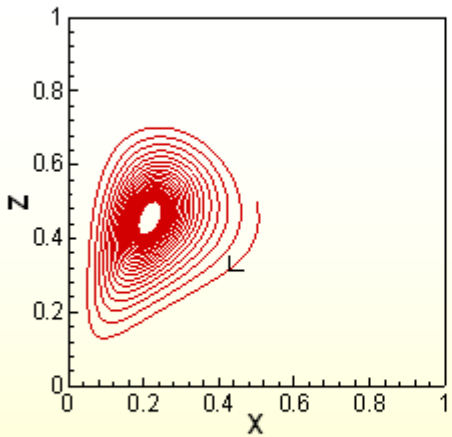
Air velocity vectors

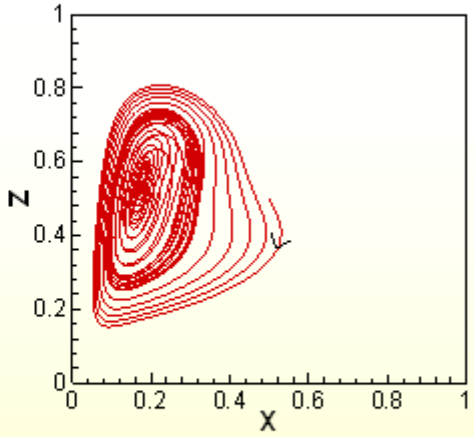


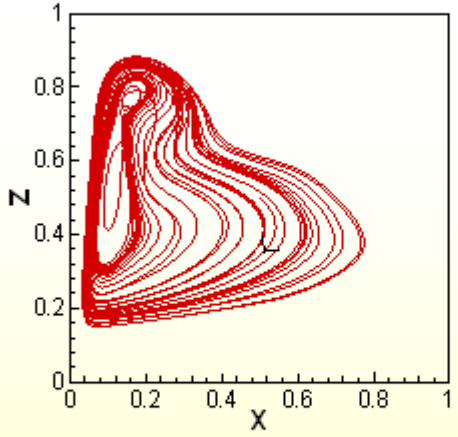




Fluid streak lines





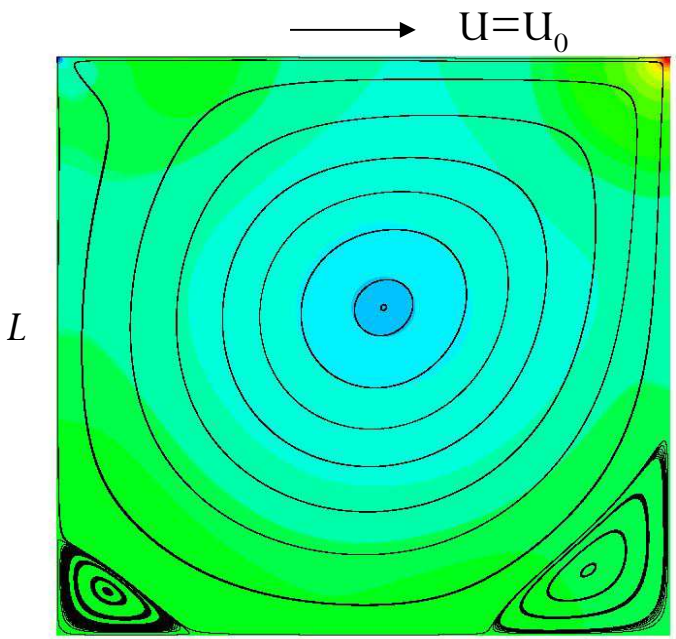


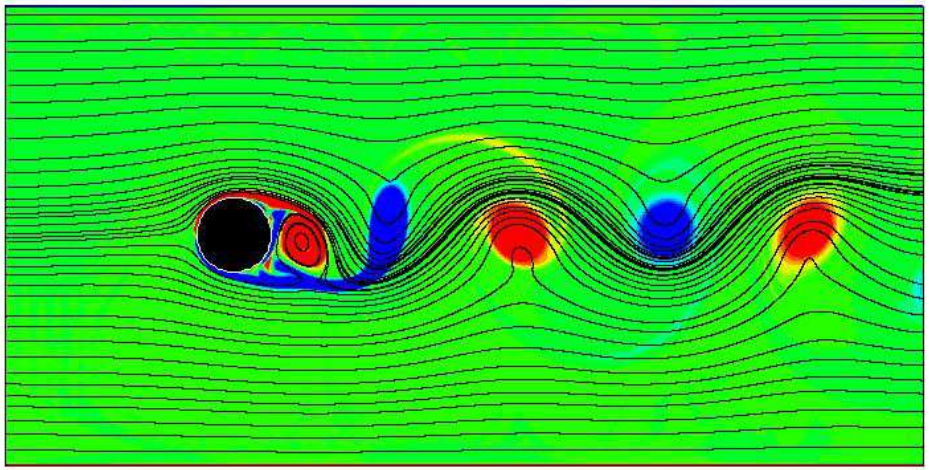
Particle trajectory

$Ra = 10^4$ $Ra = 10^5$ $Ra = 10^6$

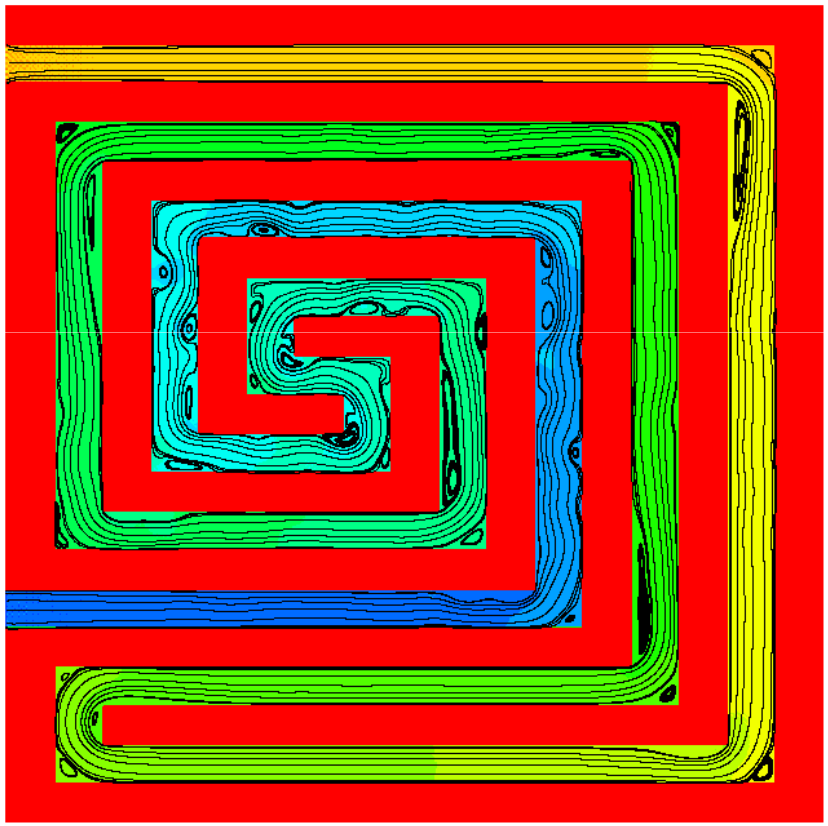
b_0=1.16T, d=1.28×10^{-5}m, (X_0,Y_0,Z_0)=(0.5,0.5,0.5), (U_0,V_0,W_0)=(0,0,0).

3. 矢量图和流线图

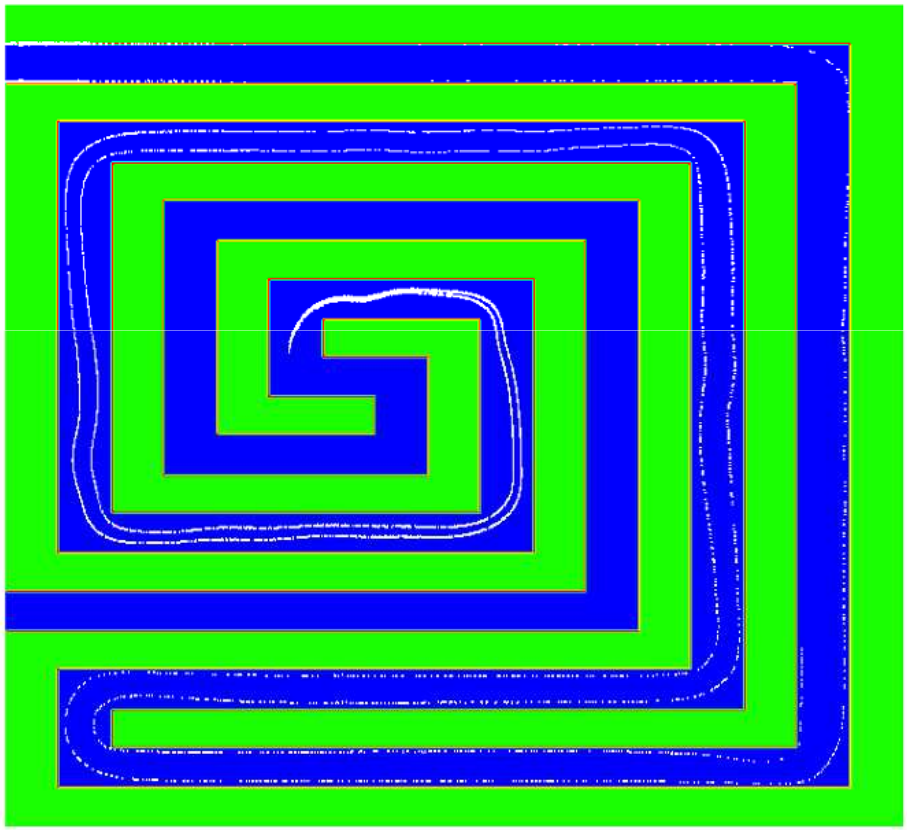




3. 矢量图和流线图

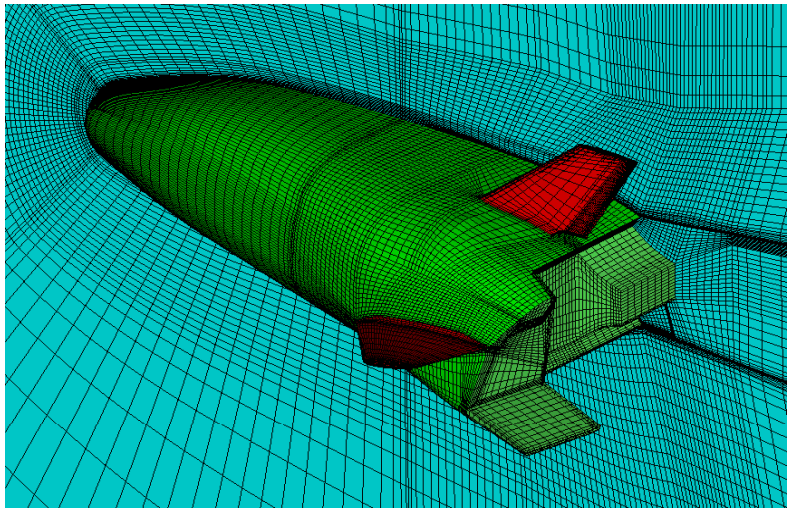


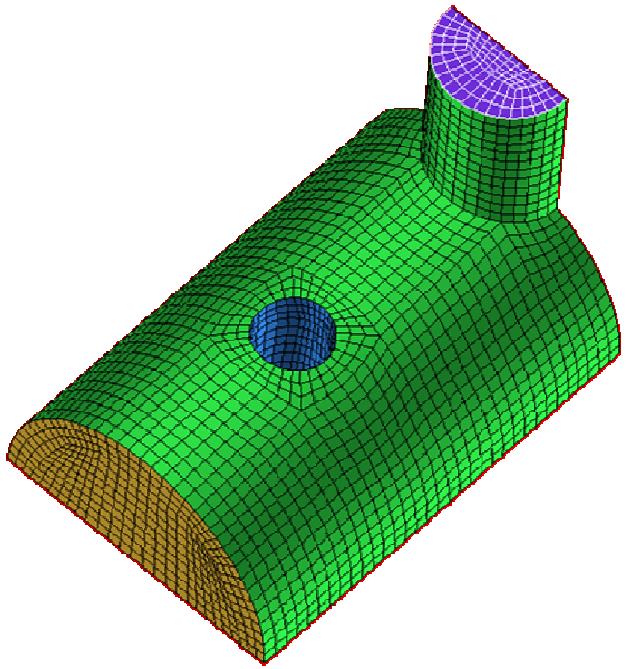
Re=200

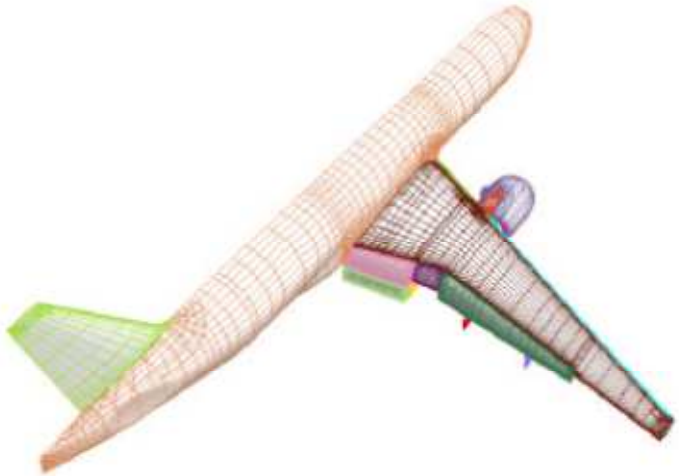


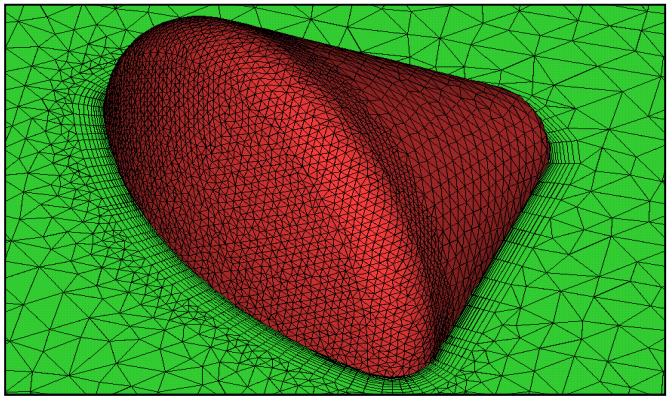
Particle number = 10240

4. 网格图

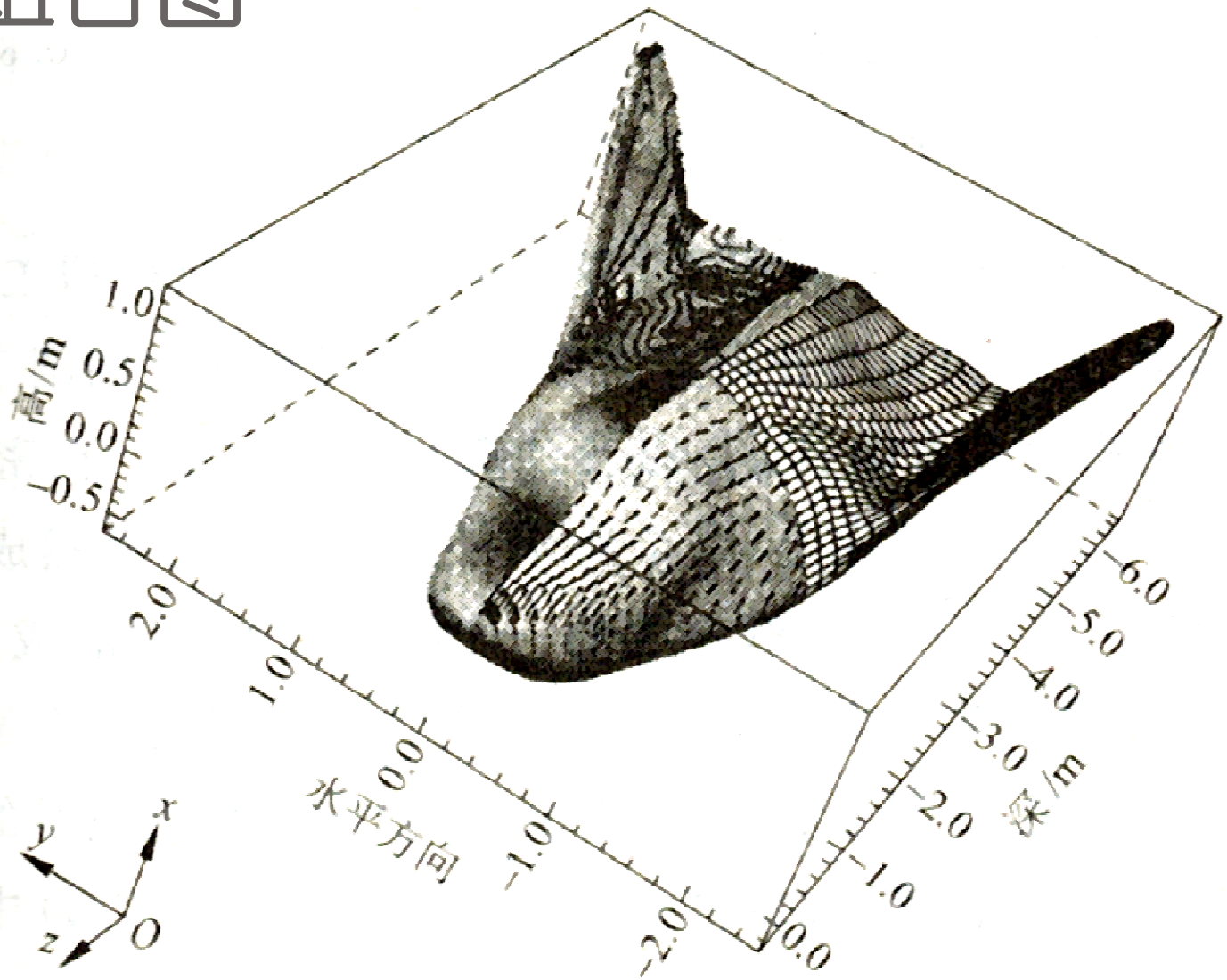








5. 组合图



输出格式

对一个可视化软件，必须输出其对应的格式，例如Tecplot：

```
FILE  * fp;

fp=fopen("result.dat","w");

fputs("VARIABLES=X,Y,RHO,U,V\n",fp);
fprintf(fp,  "ZONE I=%6d,  J=%6d,   F=POINT\n",nx,ny);


        for(y=0;y<ny;y++)
        for(x=0;x<nx;x++)
        {

          fprintf(fp,"%20.7e %20.7e %20.7e %20.7e %20.7e\n",
              (float)x/(float)(nx-1)-0.5,(float)y/(float)(ny-1)-0.5,rho[y][x],u[y][x]/0.1,v[y][x]/0.1);
        }


fclose(fp);
```

```
VARIABLES=X,Y,RHO,U,V
ZONE I=   200,  J=   200,   F=POINT
     -5.0000000e-001      -5.0000000e-001      1.0000000e+000      0.0000000e+000      0.0000000e+000
     -4.9497487e-001      -5.0000000e-001      1.0000000e+000      0.0000000e+000      0.0000000e+000
     -4.8994975e-001      -5.0000000e-001      1.0000000e+000      0.0000000e+000      0.0000000e+000
     -4.8492462e-001      -5.0000000e-001      1.0000000e+000      0.0000000e+000      0.0000000e+000
     -4.7989950e-001      -5.0000000e-001      1.0000000e+000      0.0000000e+000      0.0000000e+000
     -4.7487437e-001      -5.0000000e-001      1.0000000e+000      0.0000000e+000      0.0000000e+000
     -4.6984925e-001      -5.0000000e-001      1.0000000e+000      0.0000000e+000      0.0000000e+000
     -4.6482412e-001      -5.0000000e-001      1.0000000e+000      0.0000000e+000      0.0000000e+000
     -4.5979899e-001      -5.0000000e-001      1.0000000e+000      0.0000000e+000      0.0000000e+000
```

总结

计算机图形技术是一门正在蓬勃发展的学科；计算机图形的显示并不只是计算结果的定量显示，它也是一个艺术品。