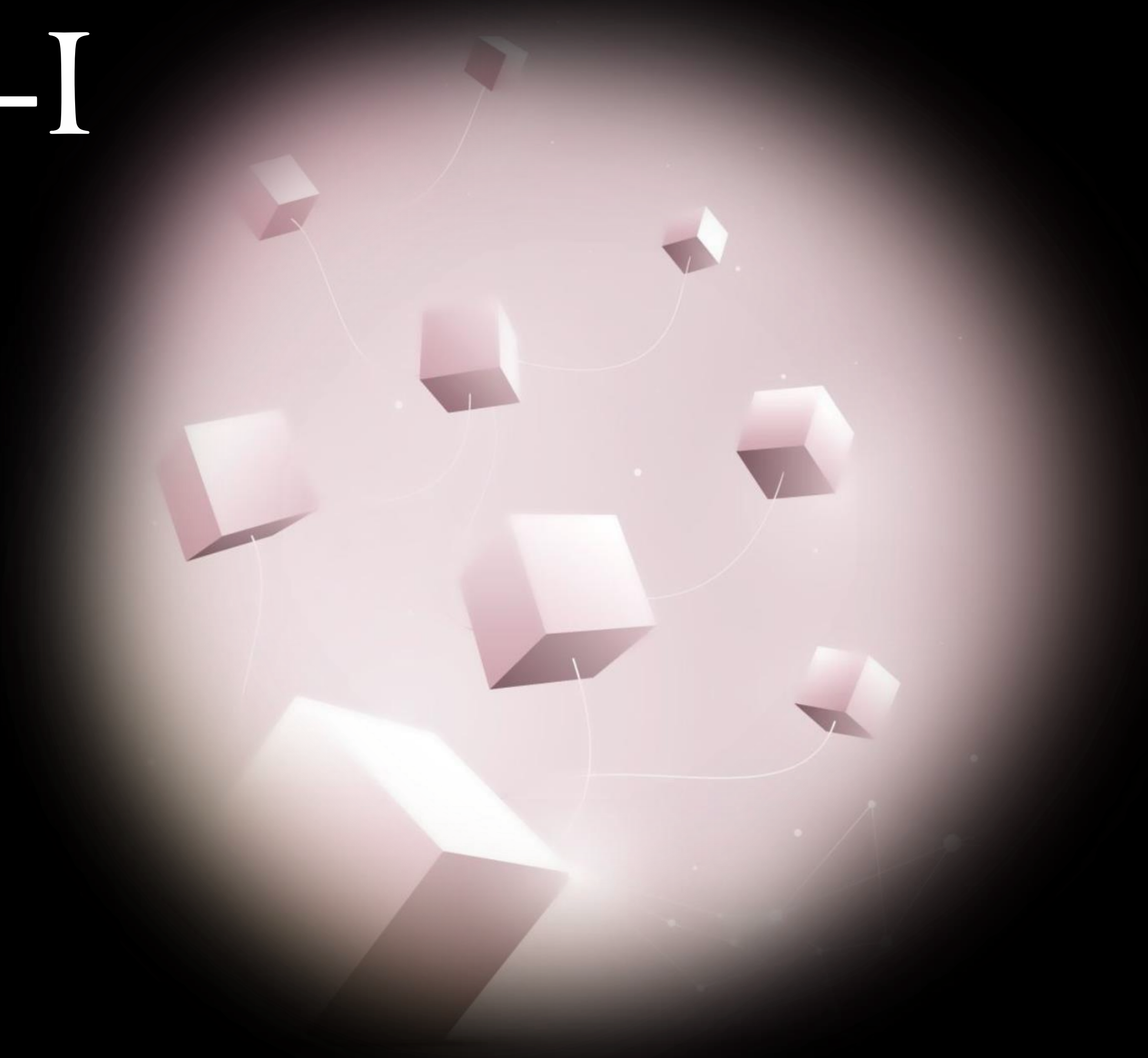
Presentation-I



LITERATURE REVIEW AND PROPOSED IDEA ON COLLISION VALIDATION

Papers Covered For Topics

- **Numerical simulation of head-on collision of two coaxial vortex rings** –Cheng,Lou and Lim
  - General Idea of co-axial vortex collision for identical and different vortices and azimuthal instability.
- **Head-on collision of two vortex rings** - Oshima(1978)
  - Experimental Study of $NH_4\mathrm{Cl}$ based smoke vortex ring collisions.
- **Head-on collision of viscous vortex rings** – Stanway, Shariff, Hussain
  - Research on temporal changes in KE and ensthrophy and the iterative solution to the problem.
- **A brief introduction to vortex dynamics and turbulence** - Mofftat
- **Head-on collision of two co-axial vortex rings** - Chu, Wang, Chang, Chang and Chang

Review

- Vortex Rings are vortices produced by turbulence from an external source.
- As a single entity, the body shows similar behaviour in ideal(inviscid) and viscous flow.
- However, interactions with other vortex rings and other solid bodies show deviations.
- The vortex rings in general can be described by the governing equation

$$\mathrm{div}(\mathbf{u})=0$$

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = -\frac{1}{\rho}\nabla p + \nu \nabla^2 \mathbf{u}$$

- The vorticity Ω and the velocity u, decrease and increase according to the gaussian function which is dependent on core radius and circulation.
- As two (opposite circulation) vortex rings approach each other, they cause mutual induction as a result of which axial velocity decreases but radial velocity increases.
- In case of identical vortex rings,the velocity rediction and the radial expansion are similar to both.

Review(Contd.)

- In case of CR > 1 or CR < 1, the core radii will be different leading to different rates of velocity reduction and expansion rates.
- In this case, in close proximity, the induced velocity of thicker ring will be more than that of the thinner ring and will cause easy slip-over of thicker ring on thinner ring.
- With increase in CR, there is a decrease in KE and vorticity dissipation but increases ensthrophy.
- Increase in Re causes increase in vorticity intensity and ensthrophy.
- If the ring release velocity is very high and the Re is also along the higher line, the ring develops a wavy nature.
- When 2 vortex rings of this type interact there is a formation of vortex ringlet and loops.
- Depending on the value of CR, the ringlets form have different angles from the plane of collision.
- The temporal trends in KE, Ensthrophy are same as before.

Proposition

- Determining the effect of vorticity and azimuthal wave number on ringlet size and angle of deviation

Implementation Methodology

- Changing exit velocity through orifice to change wave number and evaluate changes in ringlet dimension.
- We know, higher CR means a higher angle of deviation from the plane of collision.We can fix CR and modulate the circulation values to bring changes.

Presentation - II

Vortex Ring Formations

Papers Covered

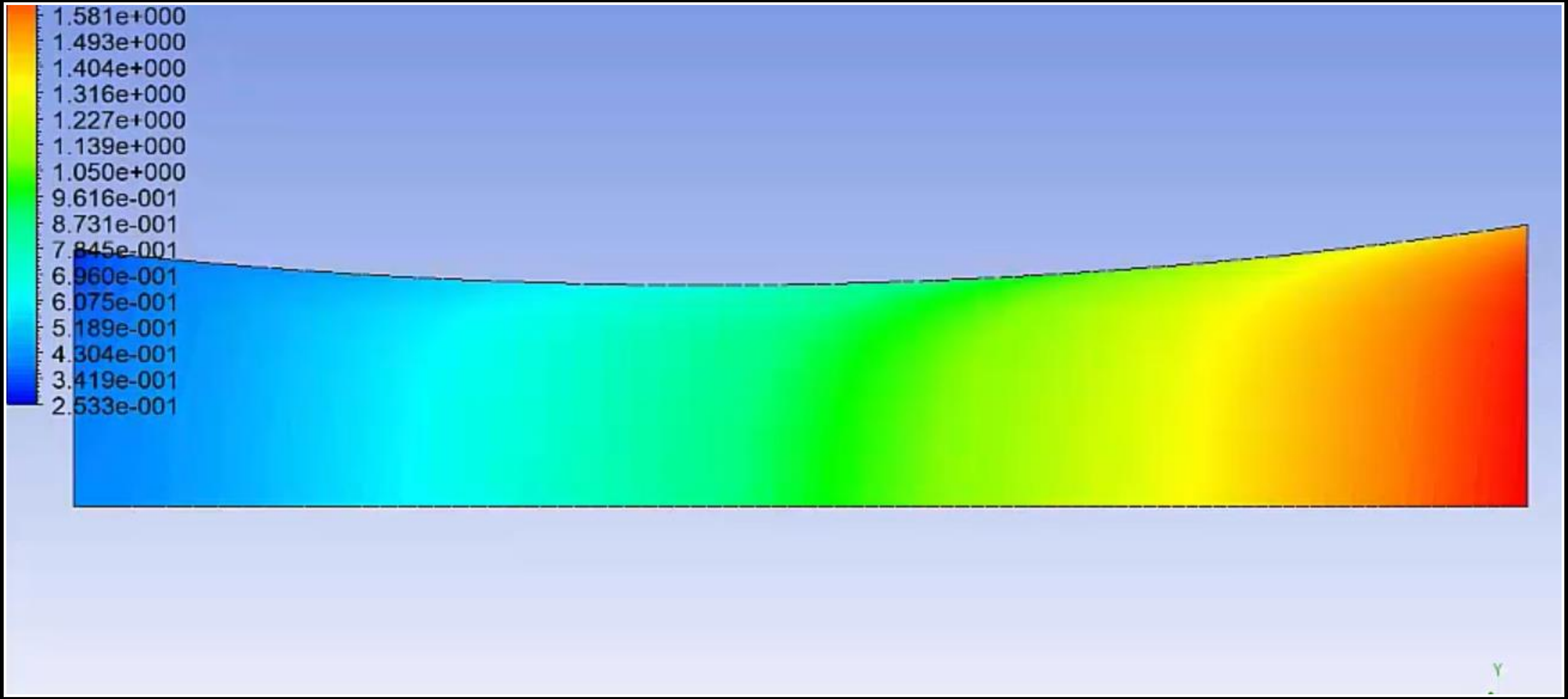
- **VORTEX RINGS - EXPERIMENTS AND NUMERICAL SIMULATIONS -Damian , Talasce, Simonesque Mihailescue**
  - **Analysing a single vortex ring after formation.**

- **Circulation Generation- Rosenfield**
  - **Process of creating vortex rings from circular nozzles**

- **Vortex Ring Time Scale – Karim, Rambod and Shariff**

Ansys Simulations Update

- Have tried analysing transient fluid flow through a nozzle alone.
- Yet to setup the container system for the nozzle in 3D to make the formation of vortex.
- Learning UDF for making variable input parameters for changing vortex size and circulation.



Single Nozzle Flow(Trial)

Presentation-III

Formation of vortex rings and starting collisions

Papers Reviews (Vortex Formation)

- **The Ring Vortex: Concepts for a Novel Complex Flow Phantom for Medical Imaging –** Ferrari, Ambrogio, Walker and more
  a) *Governing Equations on Vortex Ring*
  b) *Method For creating Vortex Rings in ANSYS*
  c) *Velocity UDF set up*
- **Numerical Simulations of 3D Compressible Vortex Ring–** Dora and more
  a) *General Dimensions of apparatus*
  b) *Difference between density dependent and independent vortex rings*
- **Circulation Generation and Vortex Ring Formation by Conic Nozzles** – Rosenfield, Katija, and Dabiri
  a) *ANSYS Setup for Vortex ring formation*
  b) *Dependence of nozzle length and exit diameter on ring characteristics.*

Papers Reviews (Vortex Formation)

- **Direct numerical simulation of a laminar vortex ring** – James, Madnia
  a) *Numerical Techniques on the formation of vortex rings*
  b) *Whether to choose nozzle or orifice.*
- **Simulations of the formation of an axisymmetric vortex ring**– Heeg and Riley
  a) *General Dimensions of apparatus*
  b) *Difference between density dependent and independent vortex rings*
- **Vortex Dynamics** – PG Saffman
  a) *General Equations of Vortices*
  b) *Relation between modulating terms and ring characteristics*

Review

- Formation of vortex rings is directly possible through orifices and nozzles.
- Vortex rings are analytically classified into 3 types – Hill, Thick and Thin
- In case of nozzles the following points must be kept in mind :
- Two sections:

  1.A straight tube of length Ls= 40 cm and a constant diameter of Dp=2.5 cm

  2.A conic nozzle of length Ln=5.1 cm dimensions are chosen to match the experimental setup and exit diameter De of De /Dp=0.2, 0.4, 0.6, 0.8, or 1. The computational domain downstream of the nozzle exit has a length of L/Dp=32, and the outer boundary is at a radial distance of H/Dp=4.

  3.An orifice is a limiting case of a nozzle when De /Dp=1 and L=0

- The circulation of a vortex ring is directly dependent on the De/Dp

  ratio.
- On the similar lines, for a given circulation and impulse, the kinetic energy is inversely dependent on the diameter ratio as mentioned above.
- Decreasing the length increases the 2-dimensional component of the ring, thus increasing circulation.

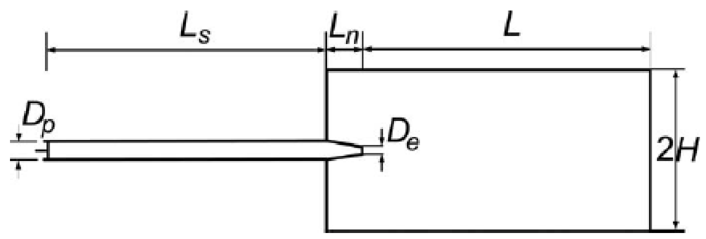


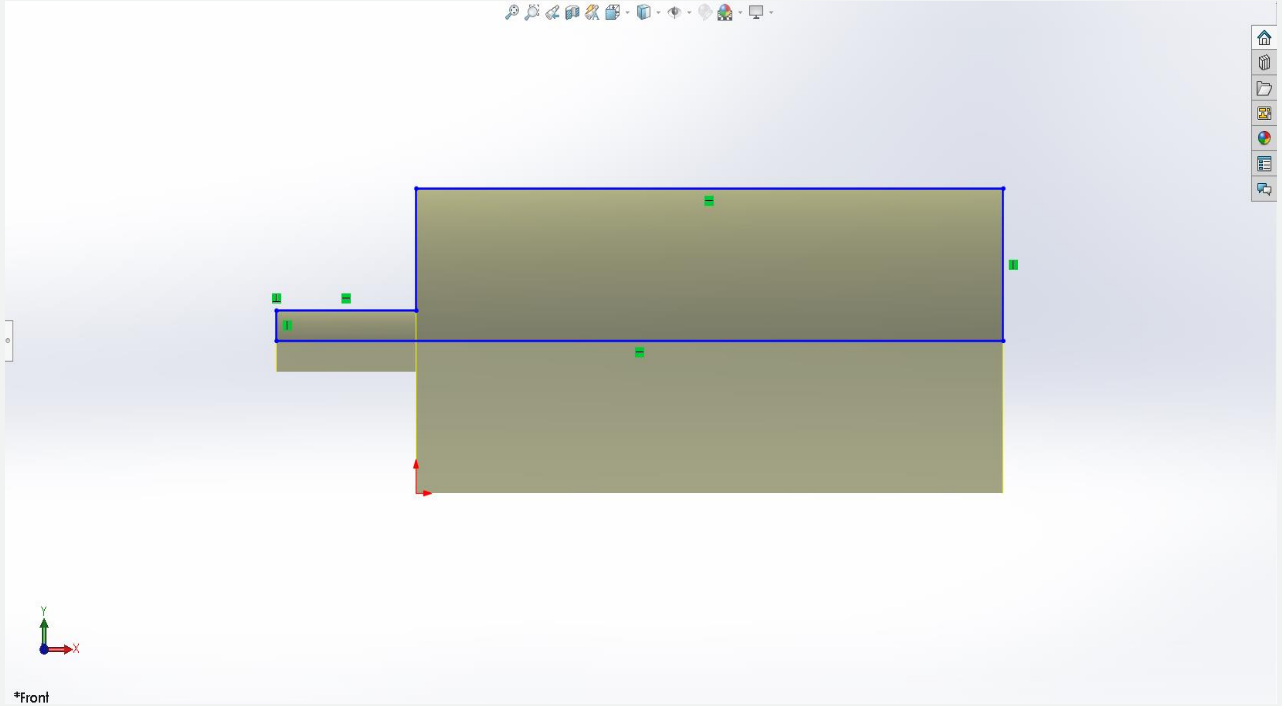
Fig. 1 Sketch of the domain of computation

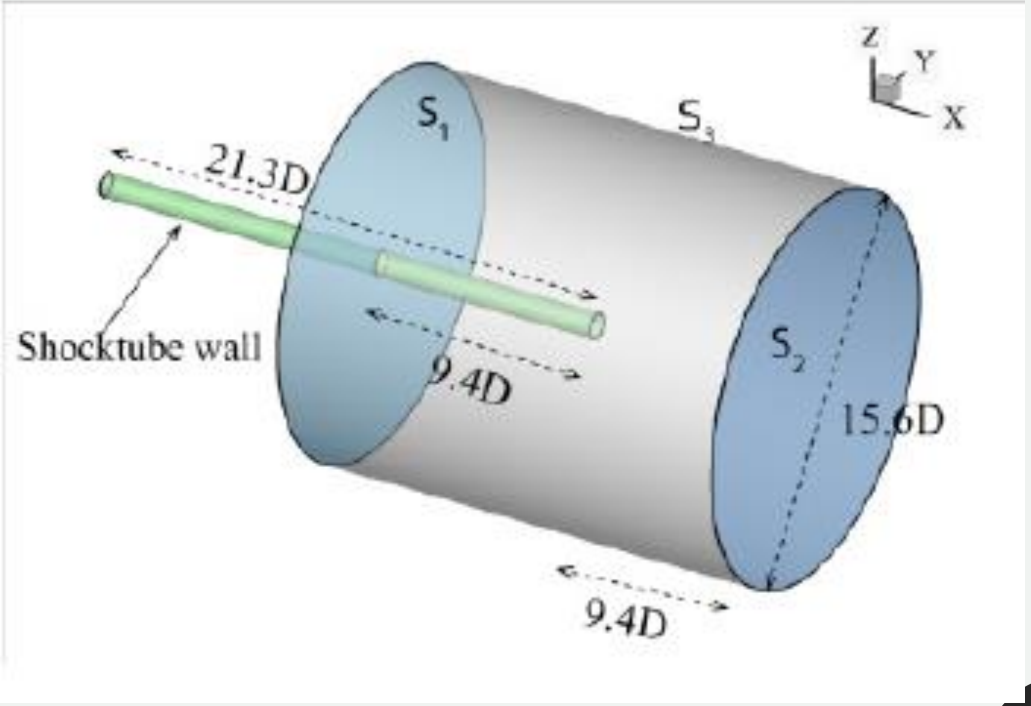
$$\Gamma^{**} = \frac{t^{**}}{2} + \frac{1}{\tilde{U} D_e} \int_0^t \int_0^{D_e/2} u \frac{\partial v}{\partial x} dr d\tau$$

Comparison

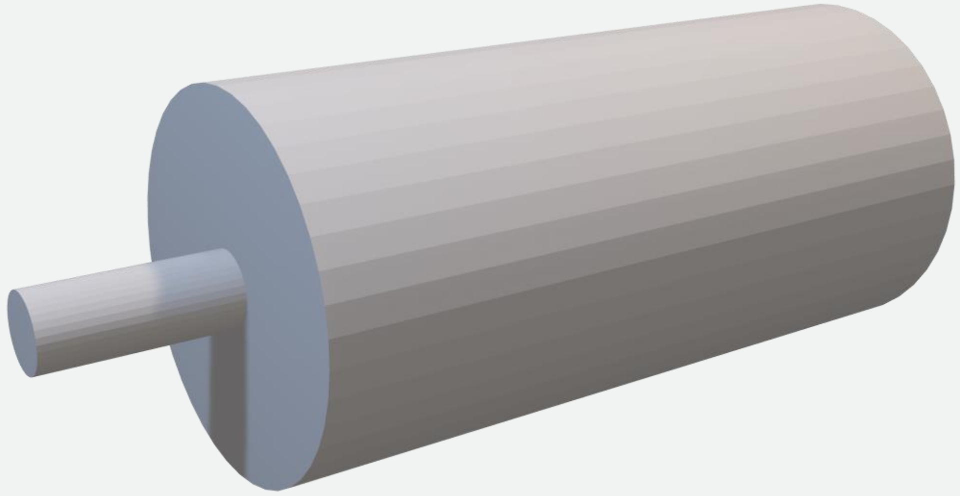
	$\Gamma^*_{e,V}$	F^*	e
Straight tube	3.99	4.2	0.18
Conic nozzle	2.79	3.8	0.22
Orifice	3.83	3.7	0.24

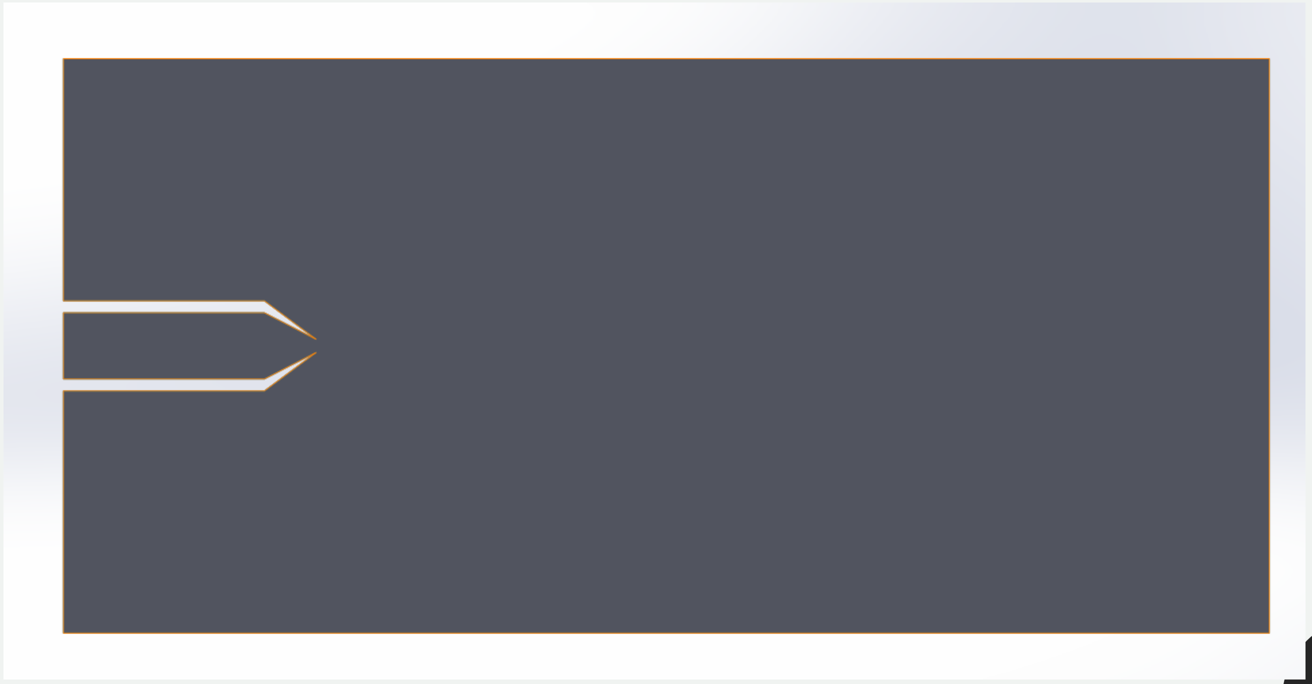
Design Used





Model





UDF Used

$$U = U_0 \cos(wt) \quad \text{for} \quad t \le T^*/4$$

$$U = 0(\text{zero velocity}) \quad \text{for} \quad t > T^*/4$$

```
#include "udf.h"

#define PI 3.1415

DEFINE_PROFILE (velocity_pulse, thread, position)
{
    face_t f;
    real velocity;
    real tme_current;
    real ang_frq=6.283;



    begin_f_loop(f,thread)
    {
        tme_current=RP_Get_Real ("flow-time");;
        if((tme_current>=0) && (tme_current<0.25)){
                velocity=10.*cos(ang_frq*tme_current);
        }else if((tme_current>=0.25)){
                velocity=0;
        }
       F_PROFILE(f,thread,position)=velocity;
    }

end_f_loop(f,thread)
}
```

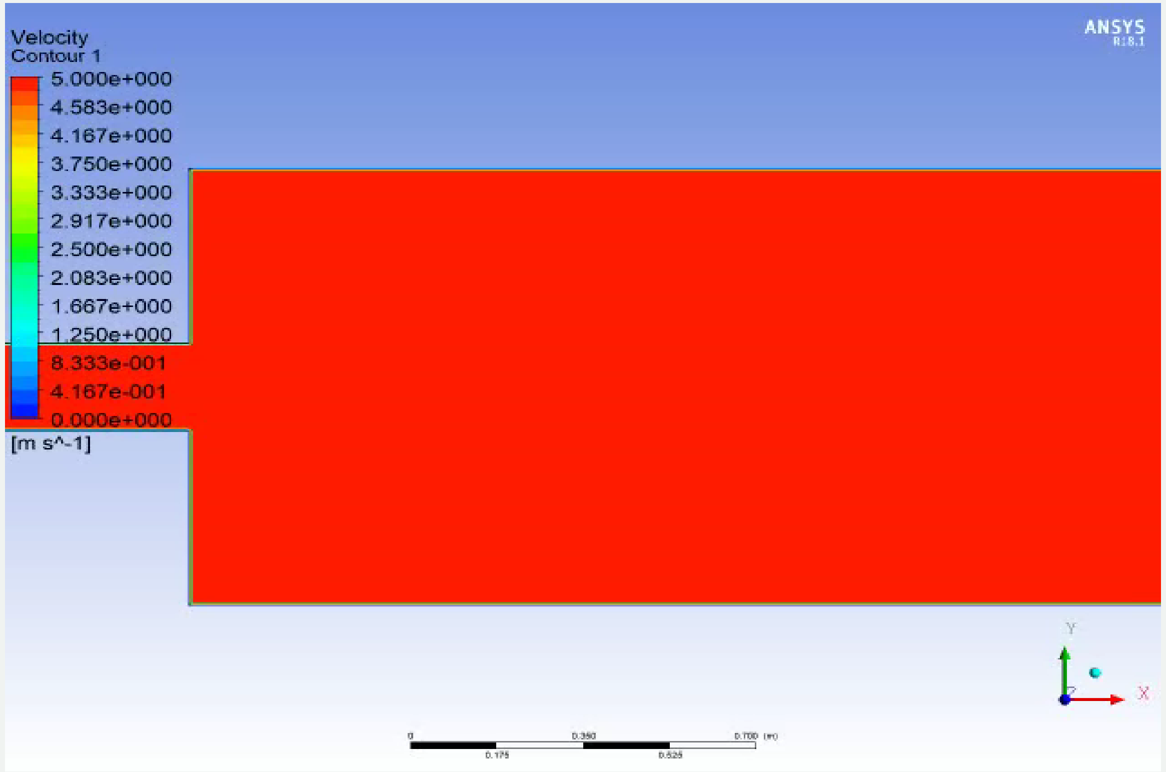
Ln 1, Col 1 100% Unix (LF) UTF-8

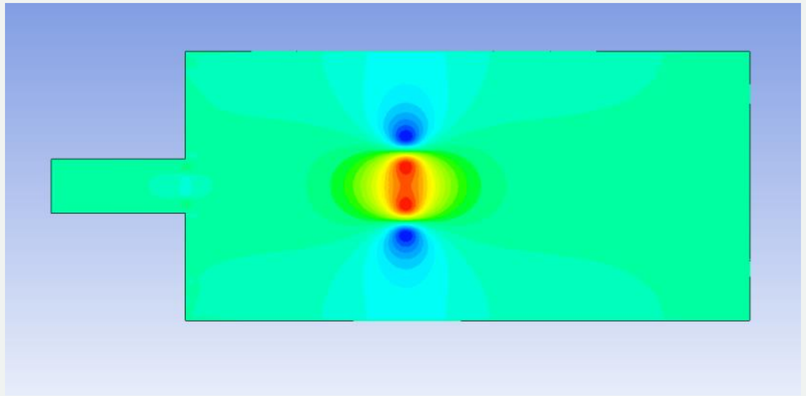
Modified UDF for Explicit Slug Formation

```
begin_f_loop(f,thread)
{
    F_CENTROID(x, f, thread);
    NV_VV(x,=,x,-,orig);
    r = NV_MAG(x);
    tme_current=RP_Get_Real ("flow-time");
    if((tme_current>=0) && (tme_current<0.02)){
            velocity=0.5*(1-exp((-5)*(1-r)))*cos(tme_current*157.079);
    }else{
            velocity=0;
    }
   F_PROFILE(f,thread,position)=velocity;
}
```

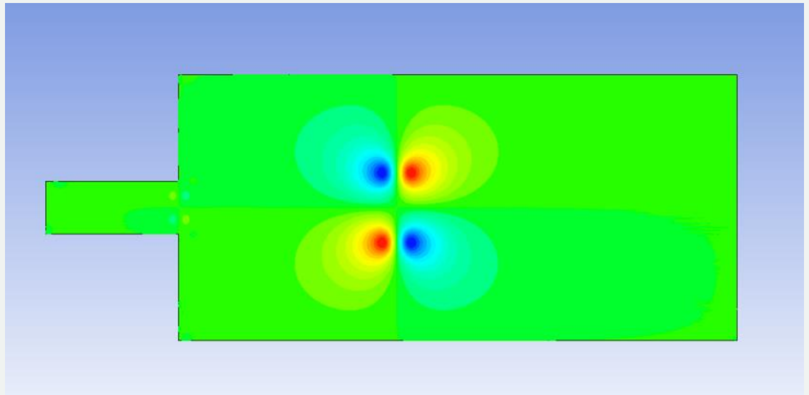
This UDF considers an exponential decrease in the initial velocity amplitude at the starting point.

Current Simulations



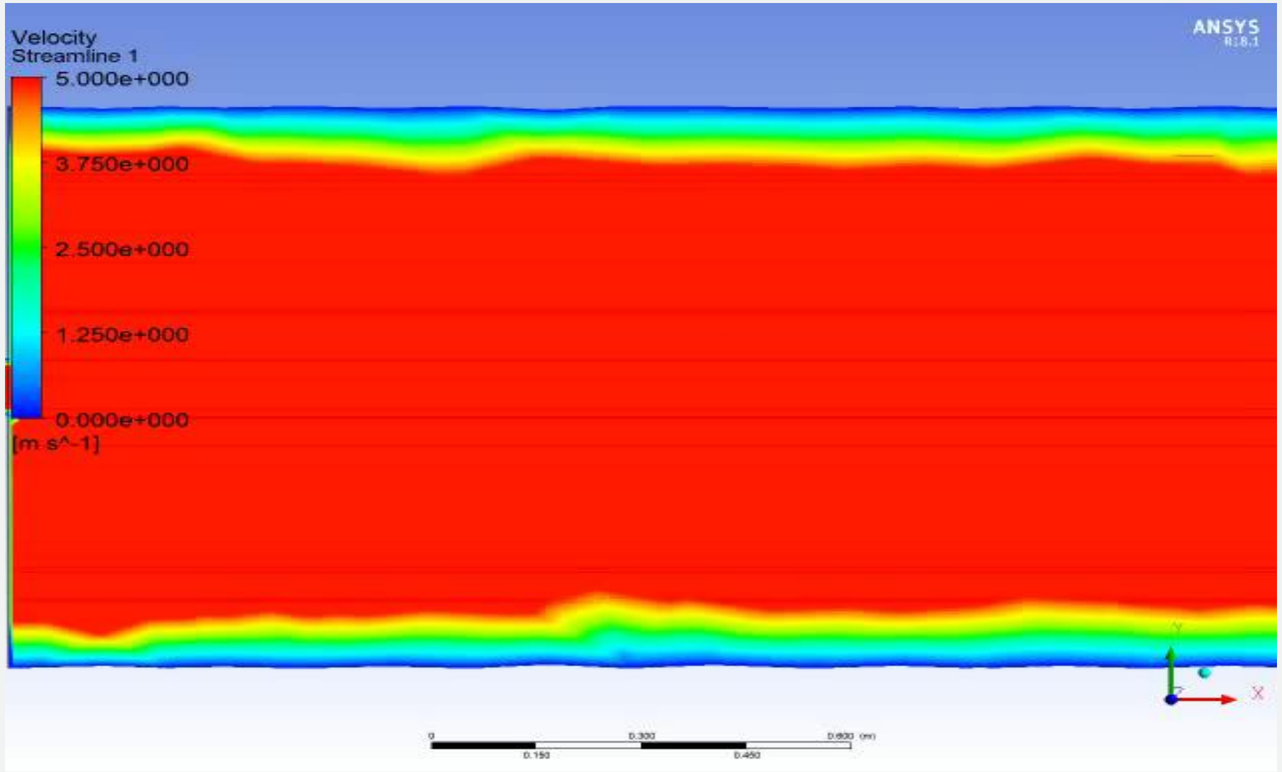


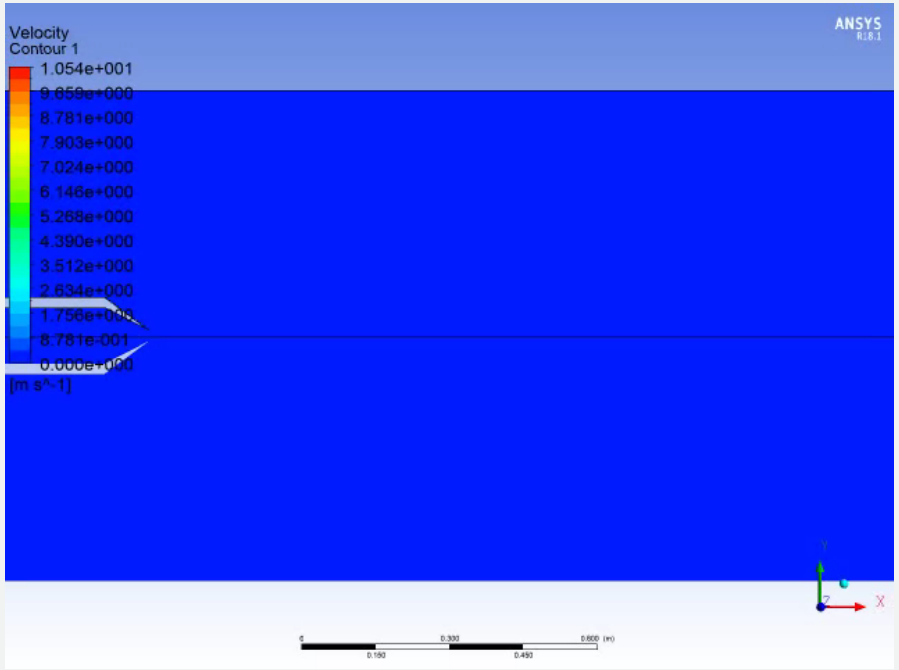
X - Velocity

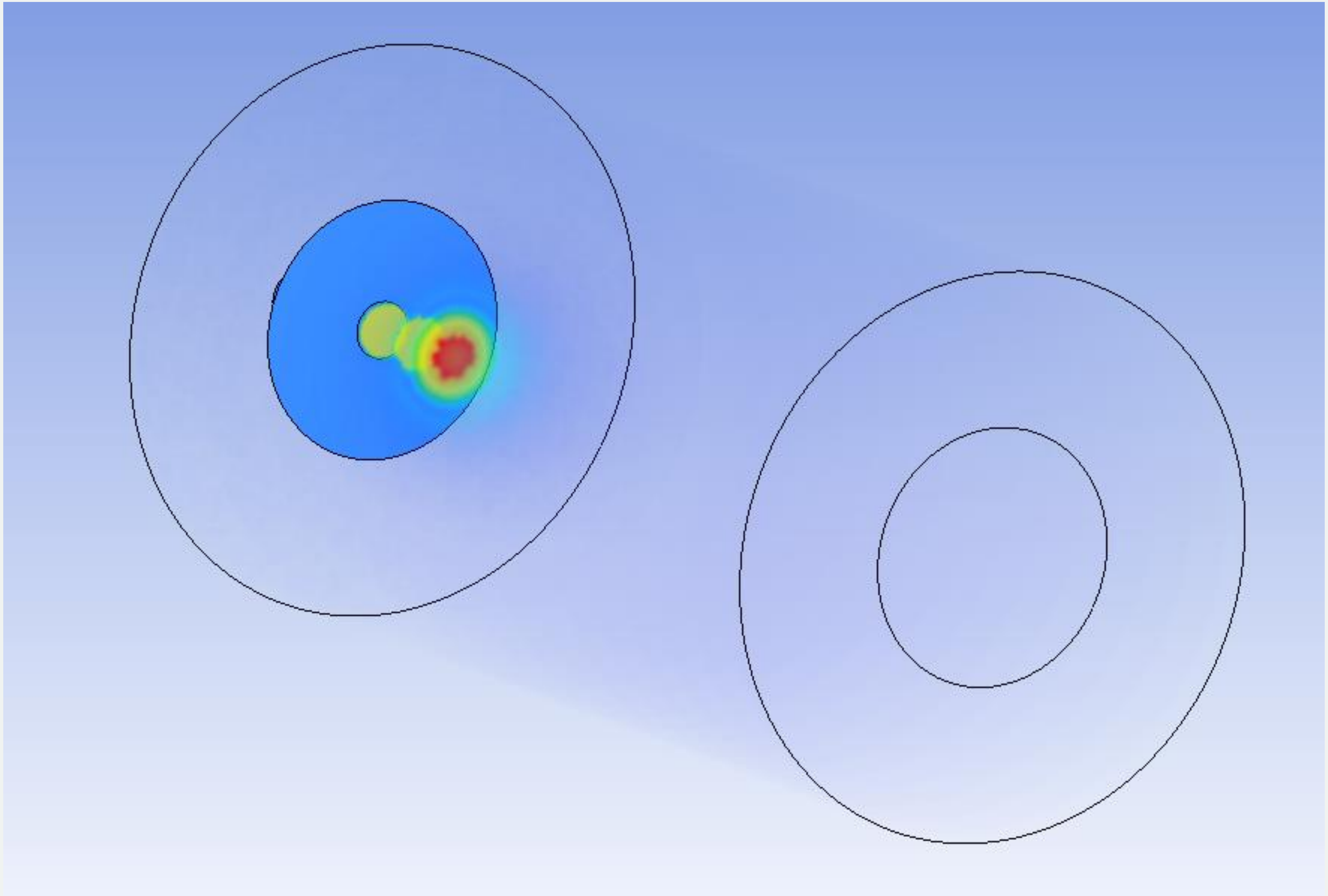


Y - Velocity

Current Simulations

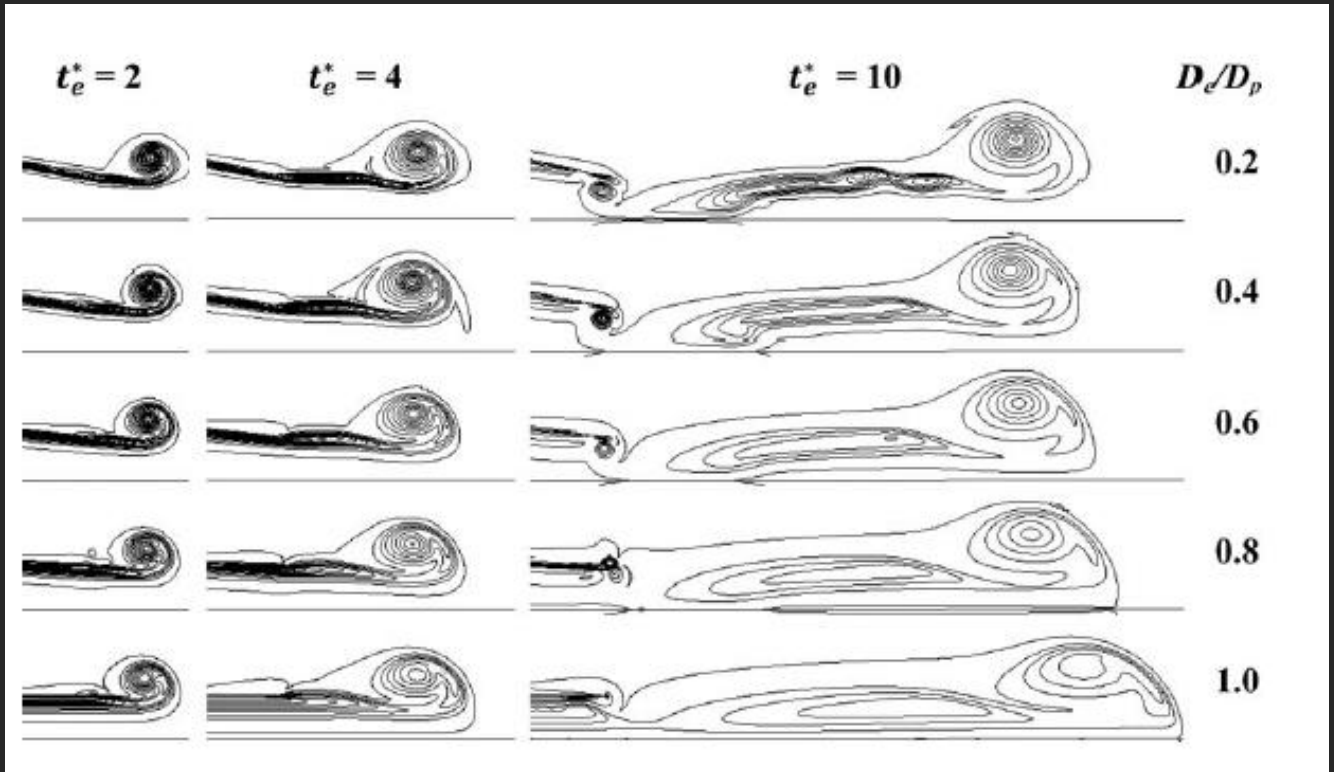






Collission Papers Covered

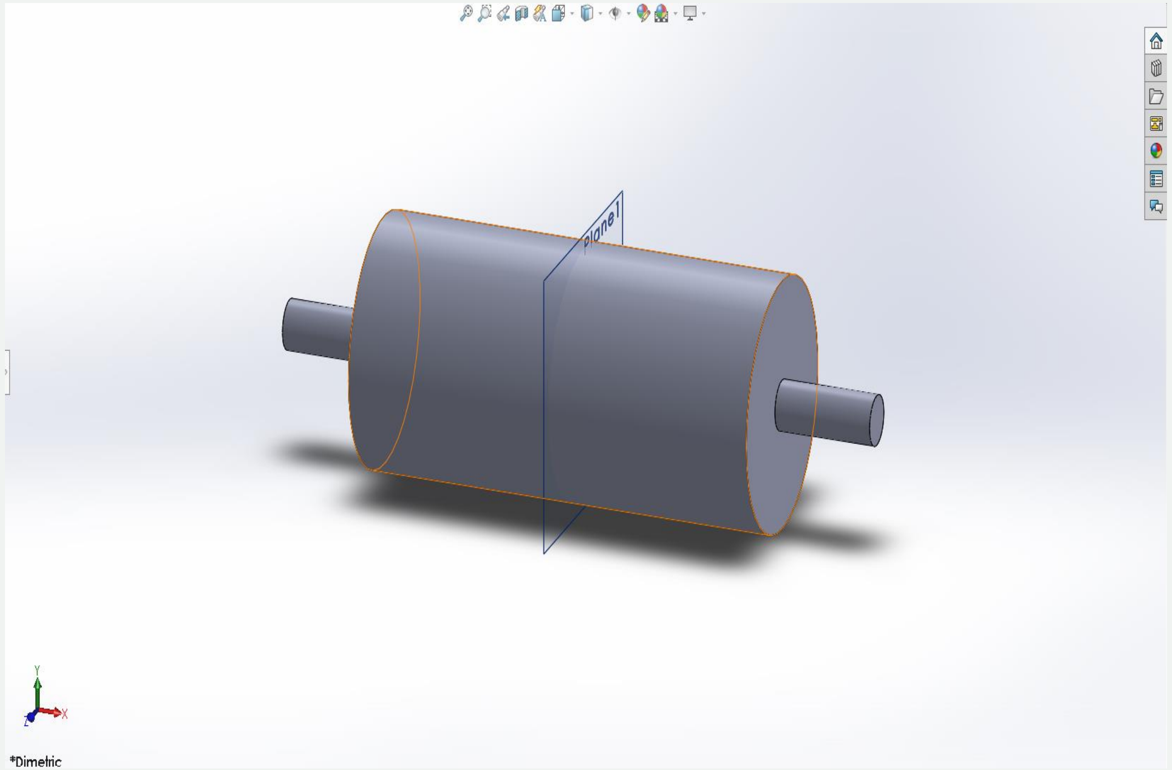
- Numerical simulation of head-on collision of two coaxial vortex rings – Cheng, Lou
- Head-on Collision of laminar vortex rings – Stanway Shariff



External Points Seen

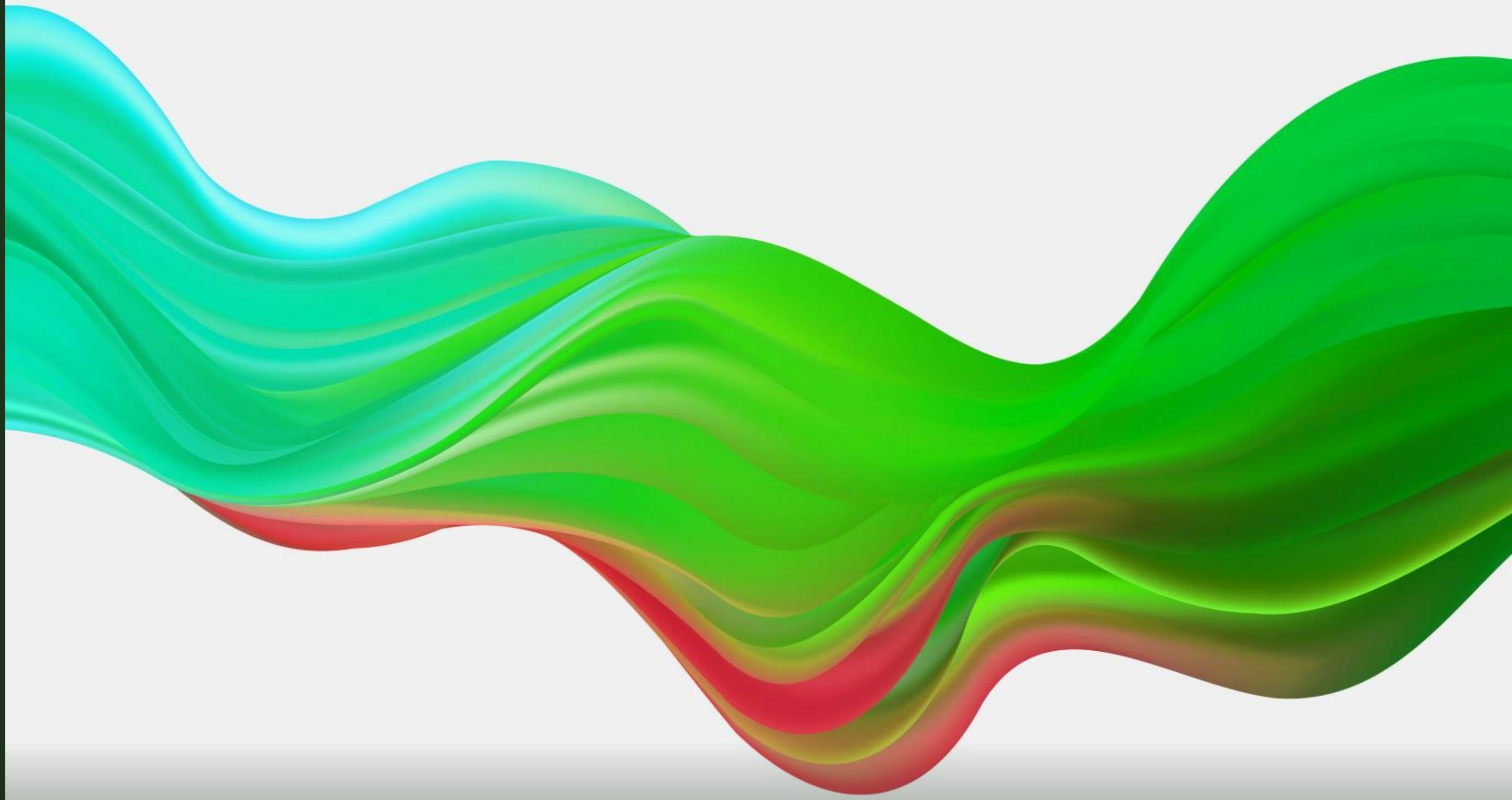
- Optimum density fluids have to used for easier visualization of the collision and for maintaining the strength of the ring.
- Collision should take place at points further away from the exit, especially in case of an orifice.
- Identical coaxial rings will be formed by same exit diameter and length.
- Coaxial rings with different core radii can be formed by changing between orifice and nozzle. However, length should be kept constant to account for the same 2-dimensional component.

Collision Update

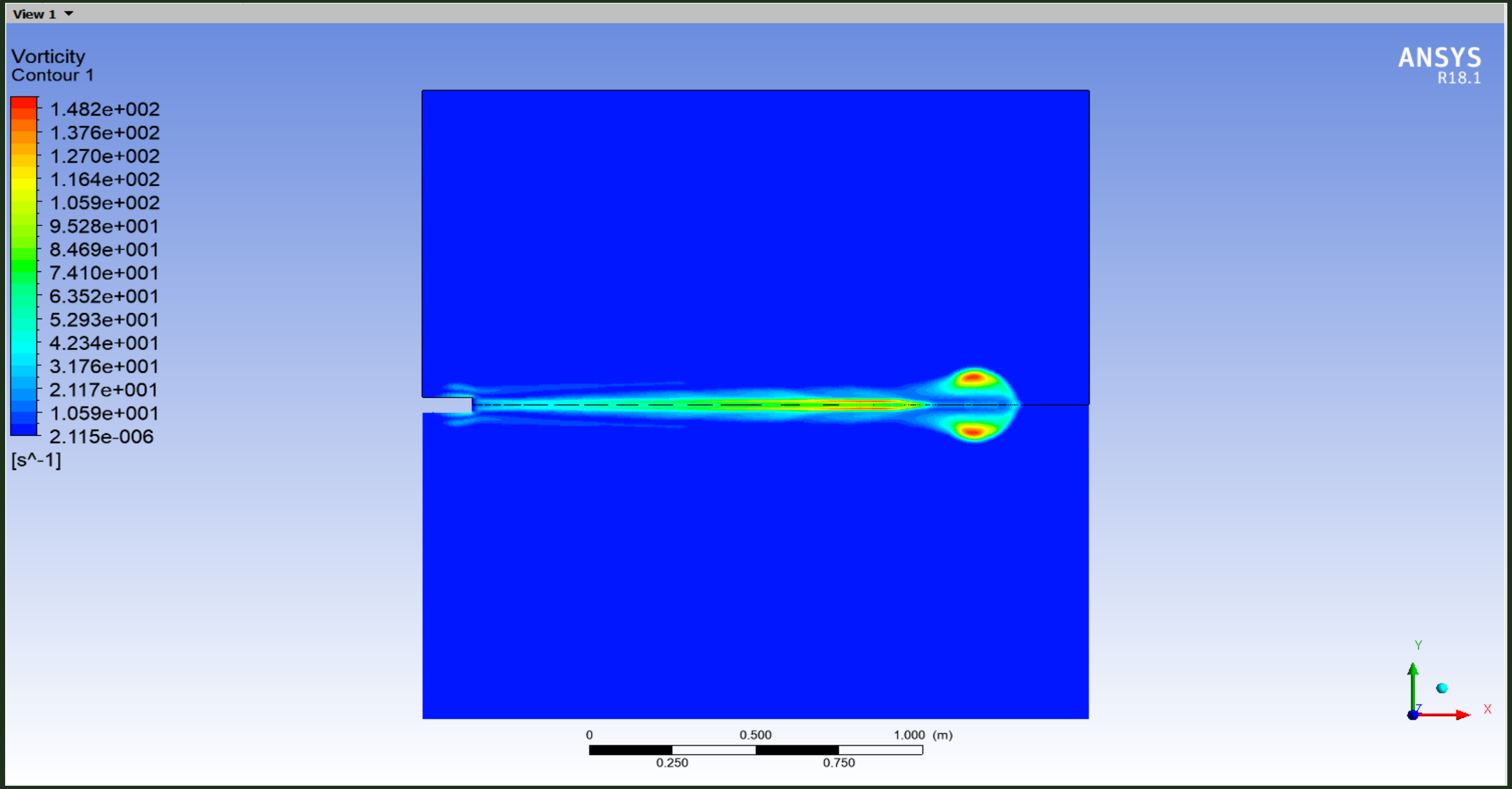


Presentation-IV

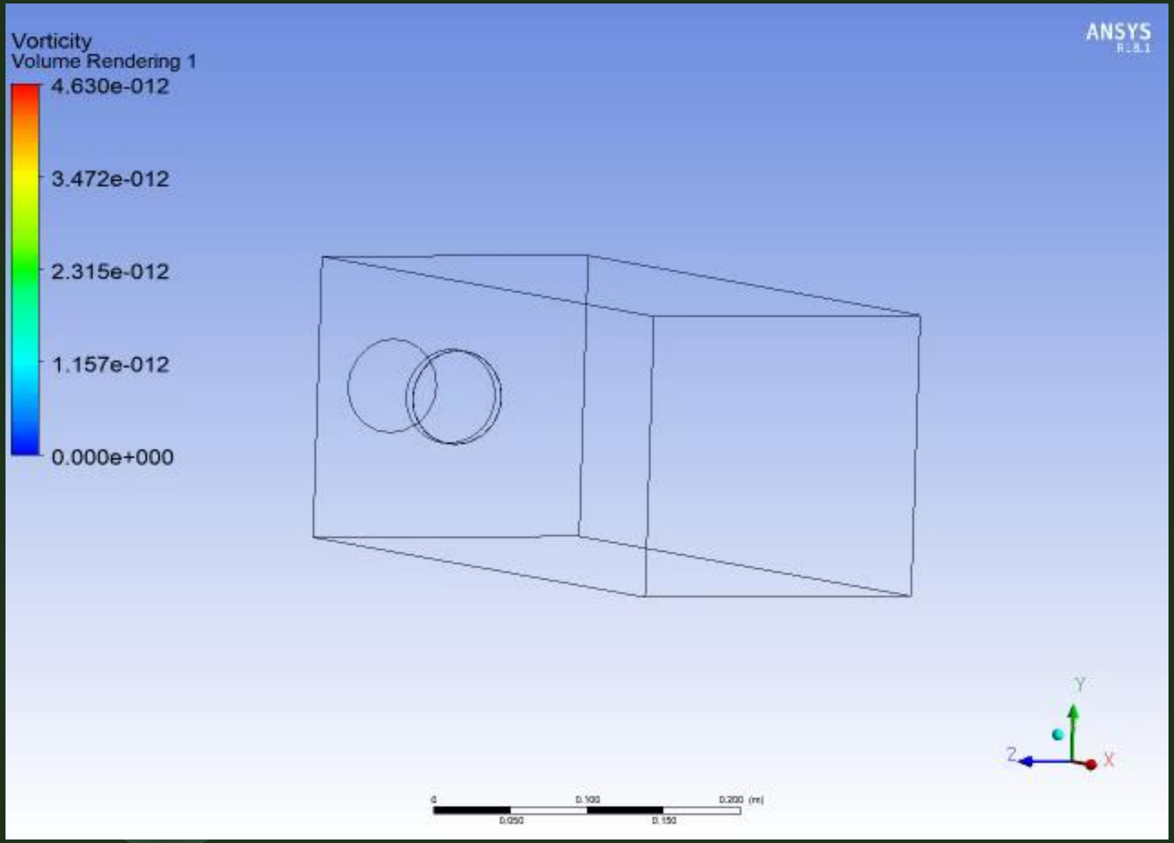
Vortex ring collision validation

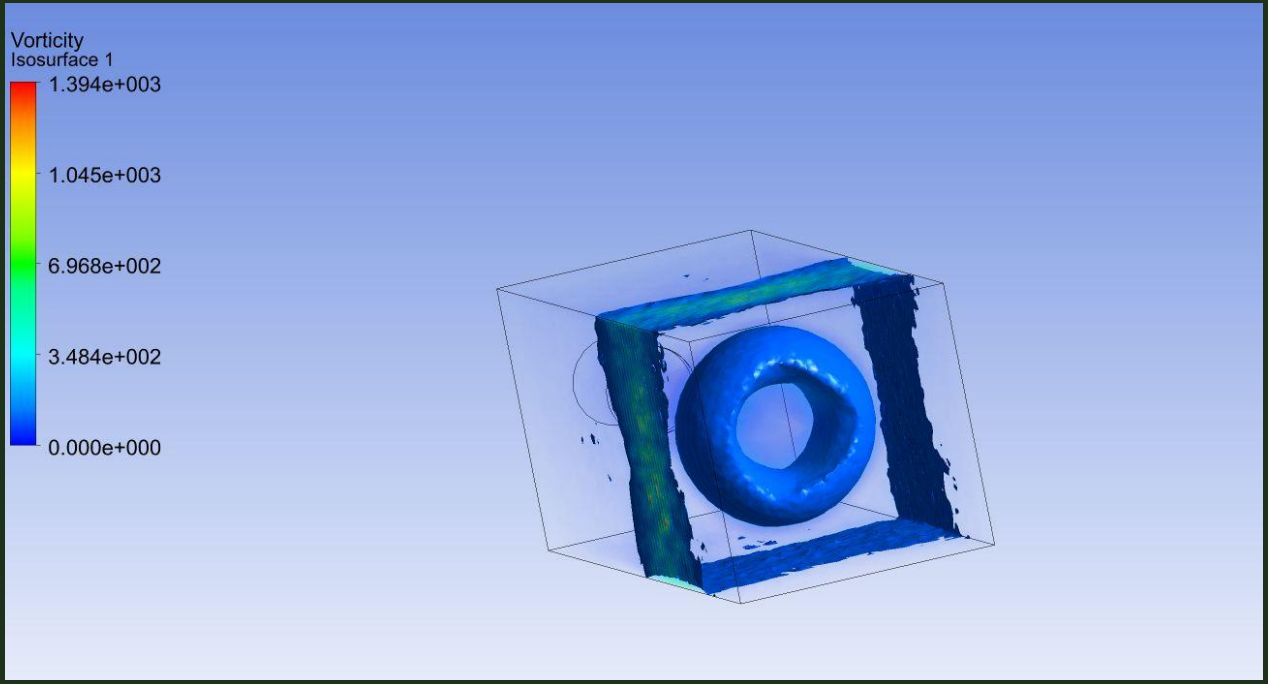


Clarity of Ring

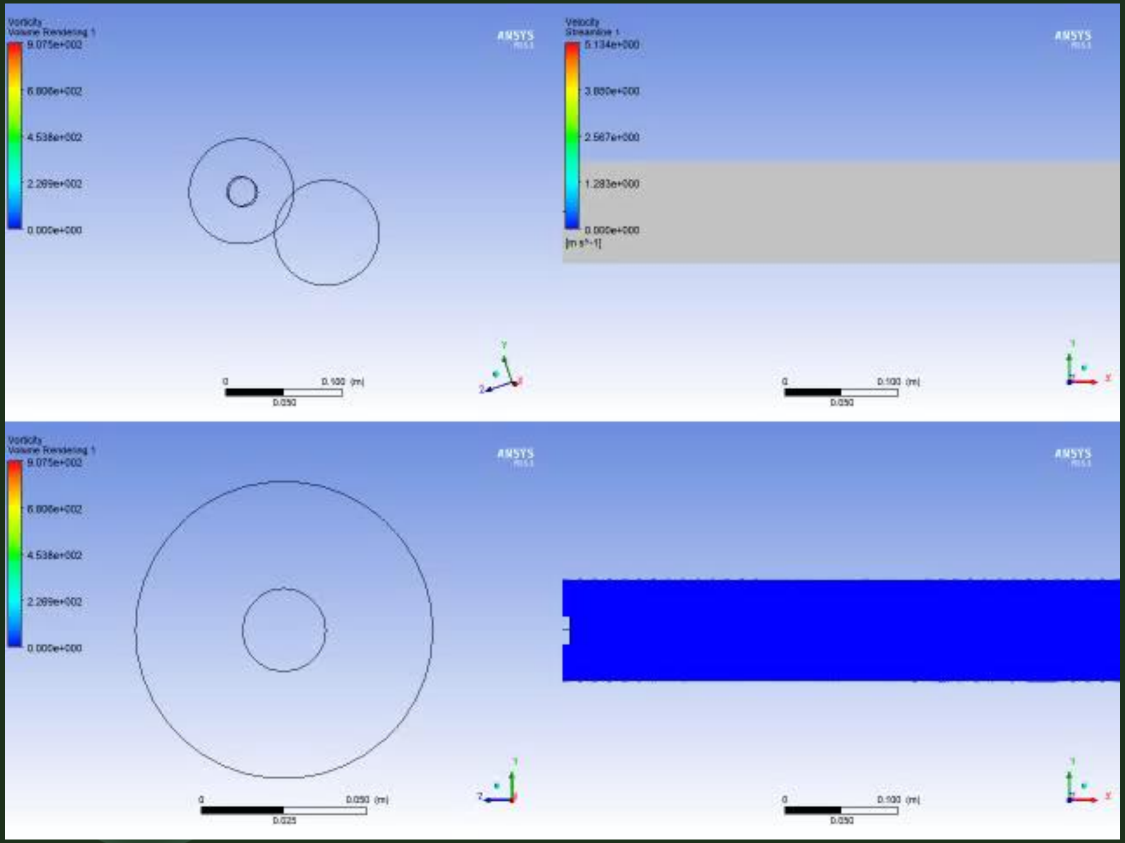


Clarity and Stability



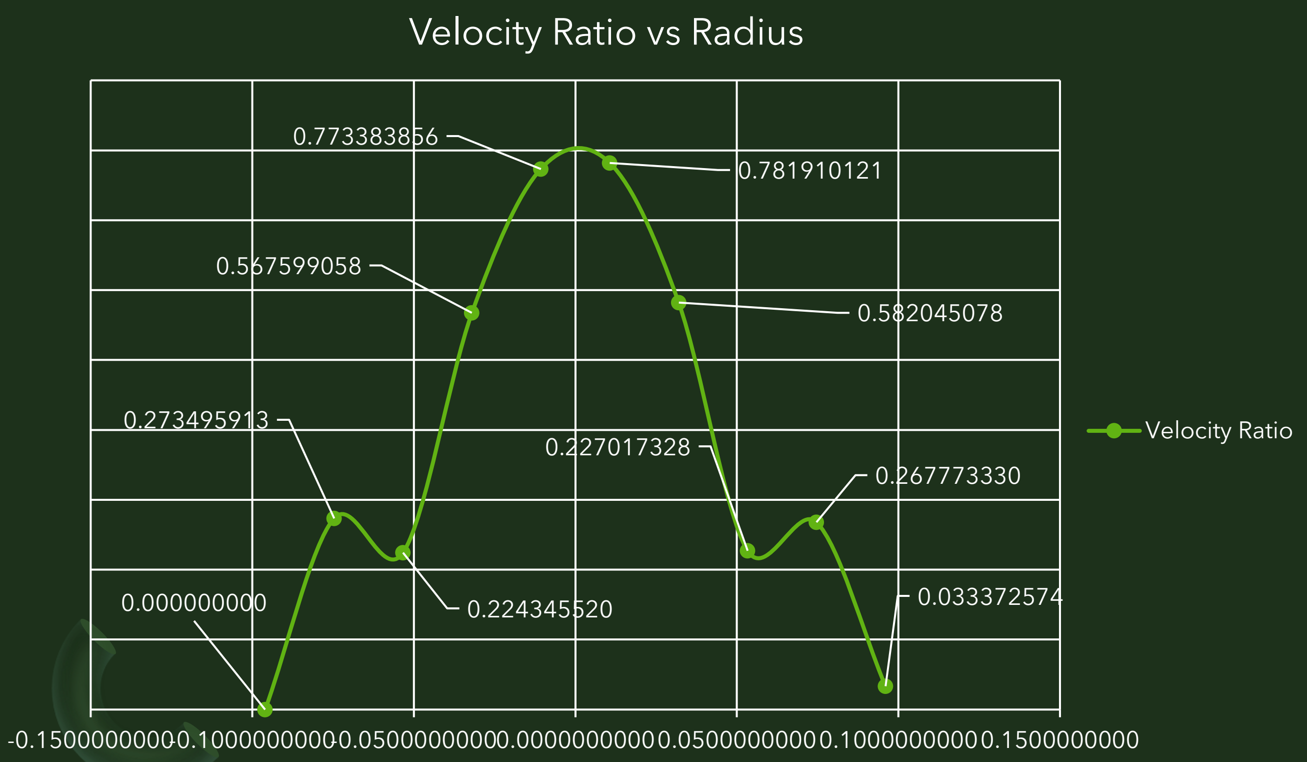


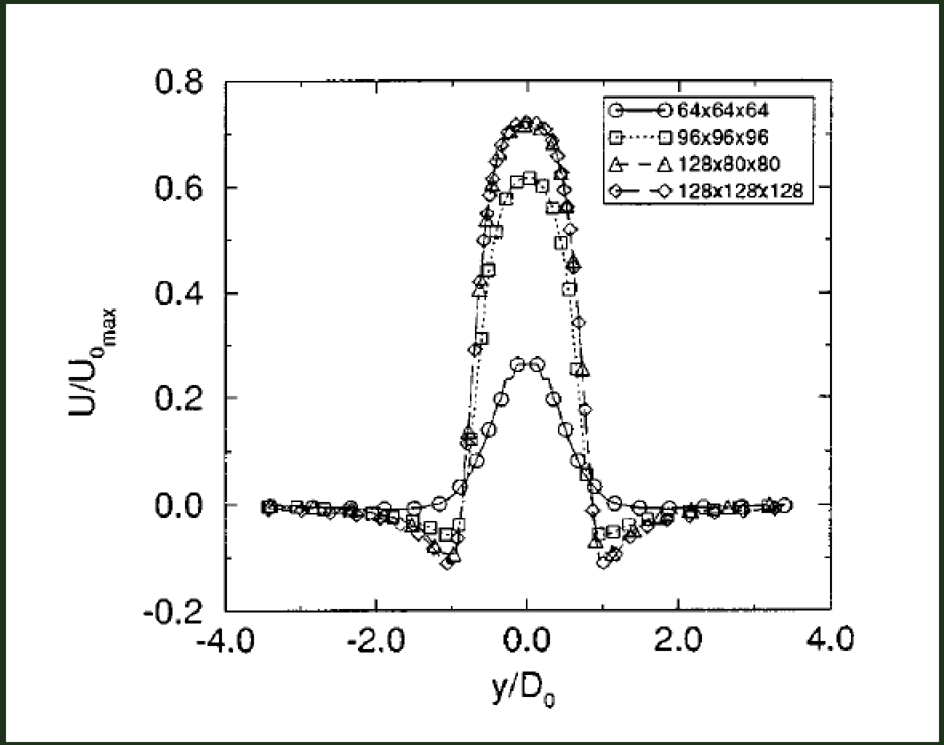
Oshima Trials



```
begin_f_loop(f,thread)
{
    F_CENTROID(x, f, thread);
    NV_VV(x,=,x,-,orig);
    r = NV_MAG(x);
    tme_current=RP_Get_Real ("flow-time");
    if((tme_current>=0) && (tme_current<0.08)){
            velocity=5.0334*(1-exp((-5)*(1-r)))*sin(tme_current*39.2699);
    }else if((tme_current>=0.08)){
            velocity=0;
    }
   F_PROFILE(f,thread,position)=velocity;
}

end_f_loop(f,thread)
```

Validation (Net Velocity Distribution with radius)





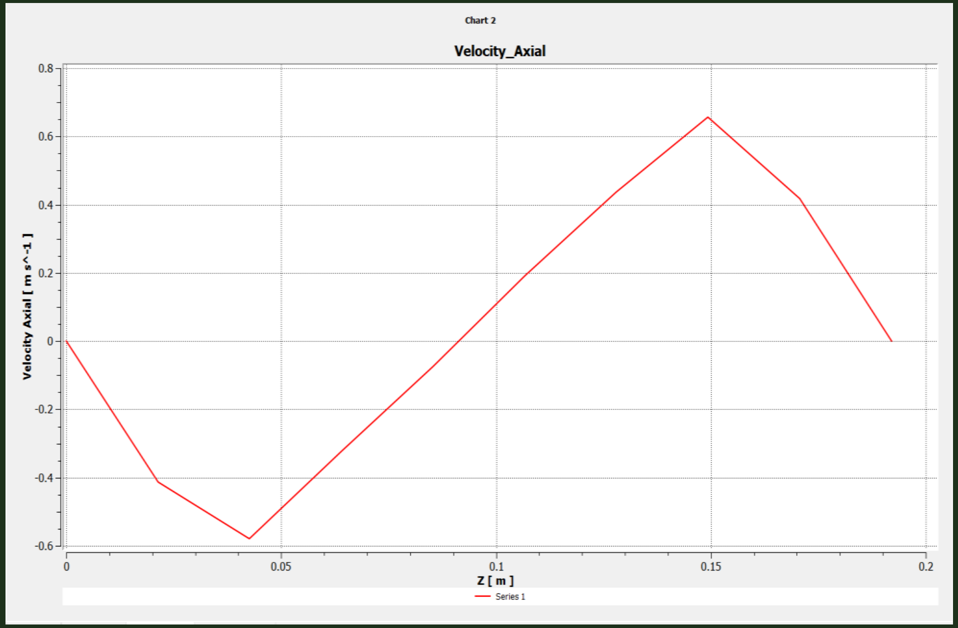
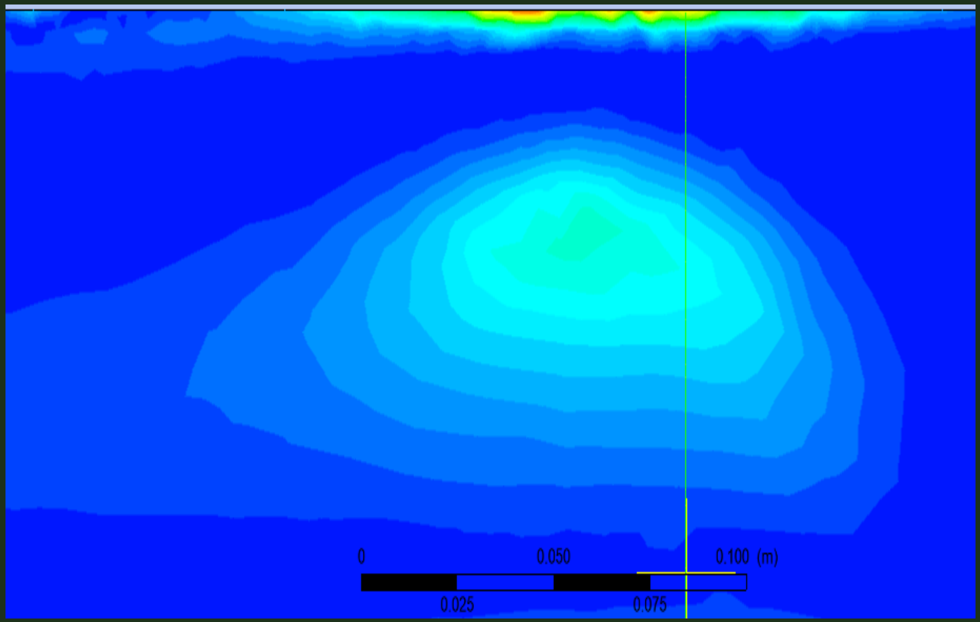
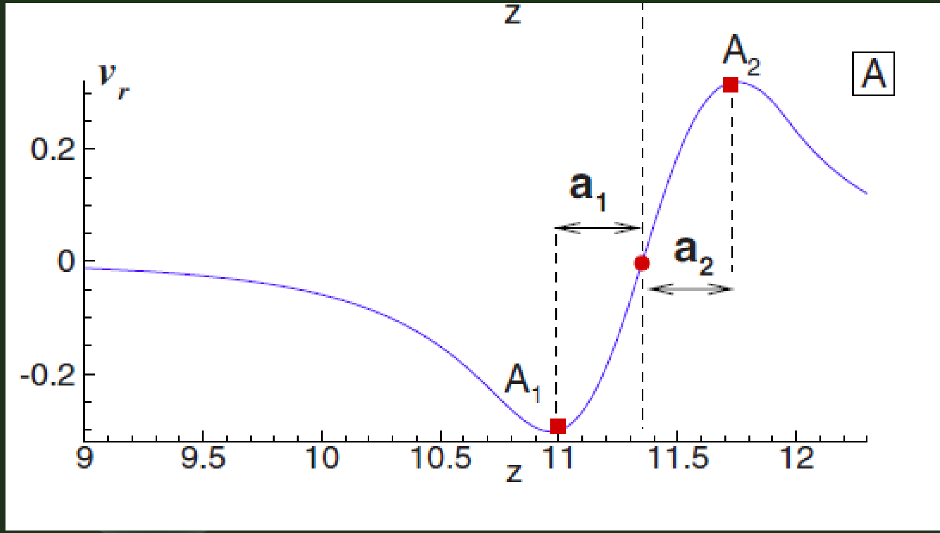


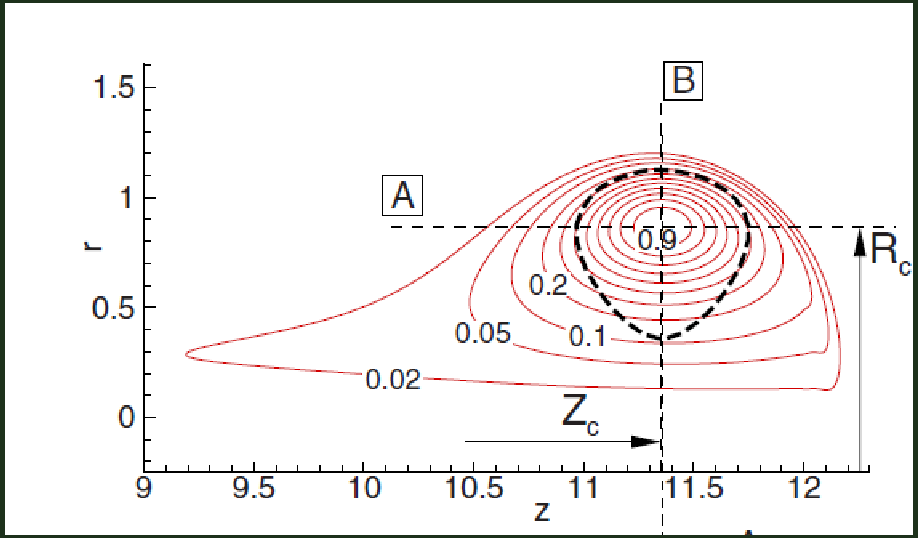
Chart 2
Velocity_Axial
Velocity Axial [m s^-1]
Z [m]
Series 1



0
0.050
0.100 (m)
0.025
0.075



v_r
A
A_1
A_2
a_1
a_2
z



B
A
r
z
R_c
Z_c
0.9
0.2
0.1
0.05
0.02

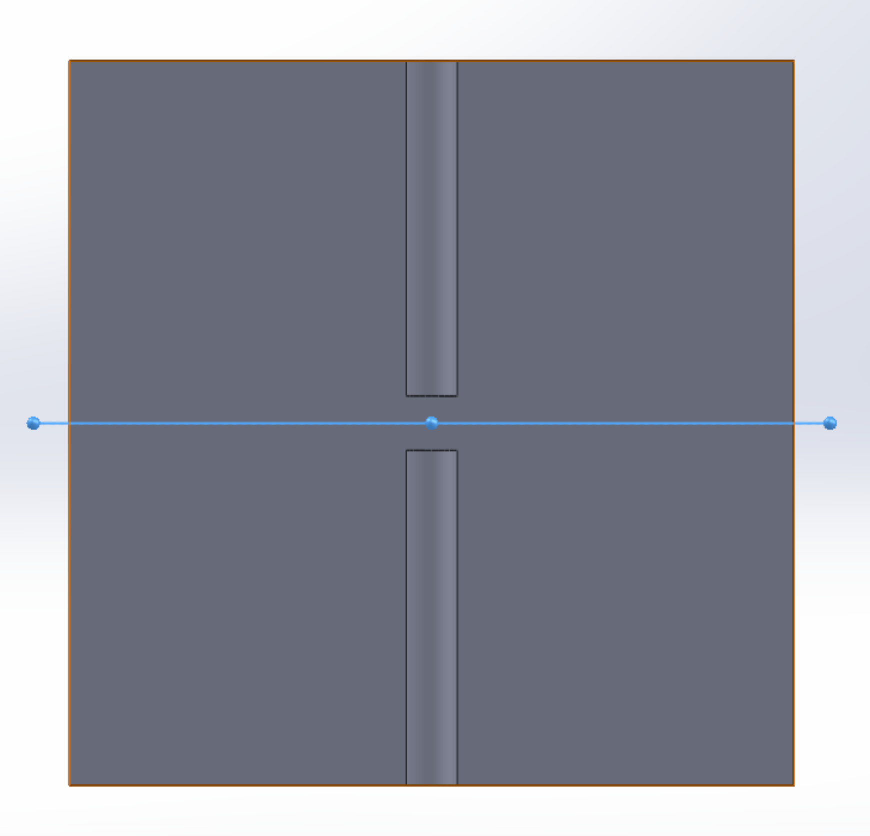
Collission
(Papers Covered)

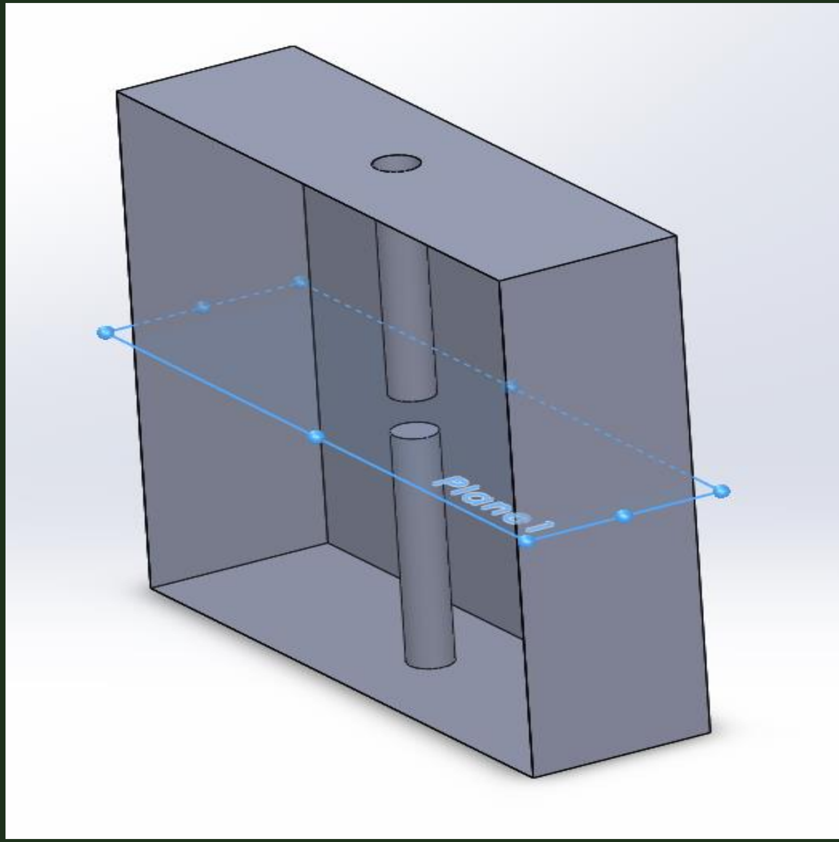
- Interaction of Two Vortex Rings moving Along common axis of symmetry – Oshima, Kambe, Asaka
  - Numerical Approach to collision
  - Provided slug model for the collision process

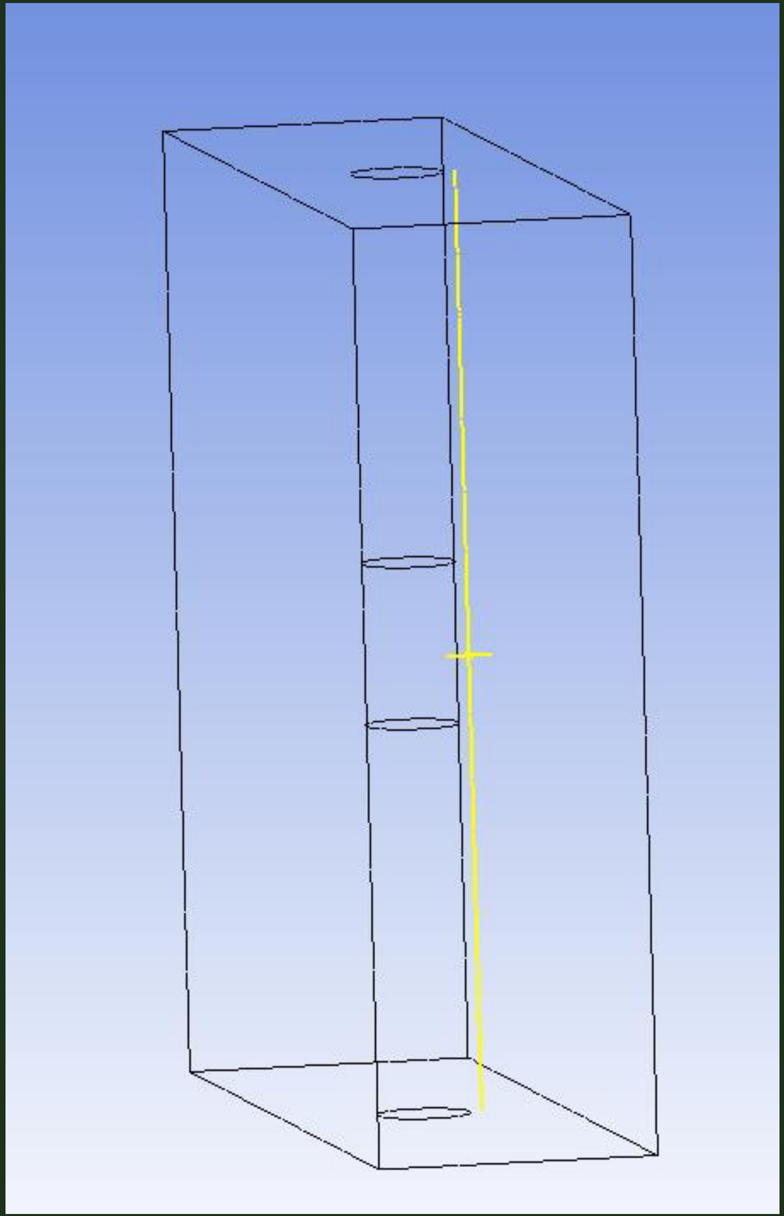
$$U_i(r) = U_{im} \frac{1 - e^{-\gamma(1-r)}}{1 - e^{-\gamma}} \sin \frac{t}{T} \pi \ ,$$

  - In this experiment, 1 D collision was created between 2 rings moving in same direction.
- Numerical Simulations of Two Coaxial Vortex Rings Head-on Collision – Guan , Wei and more

System Used

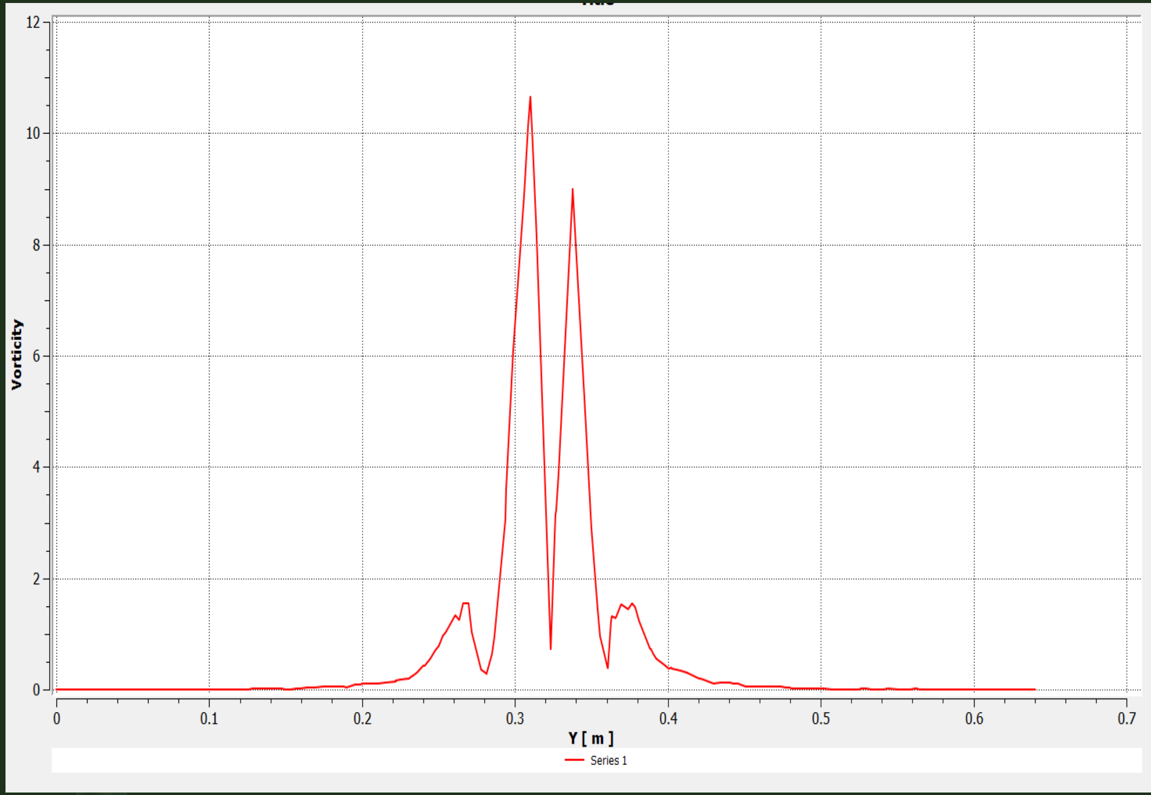


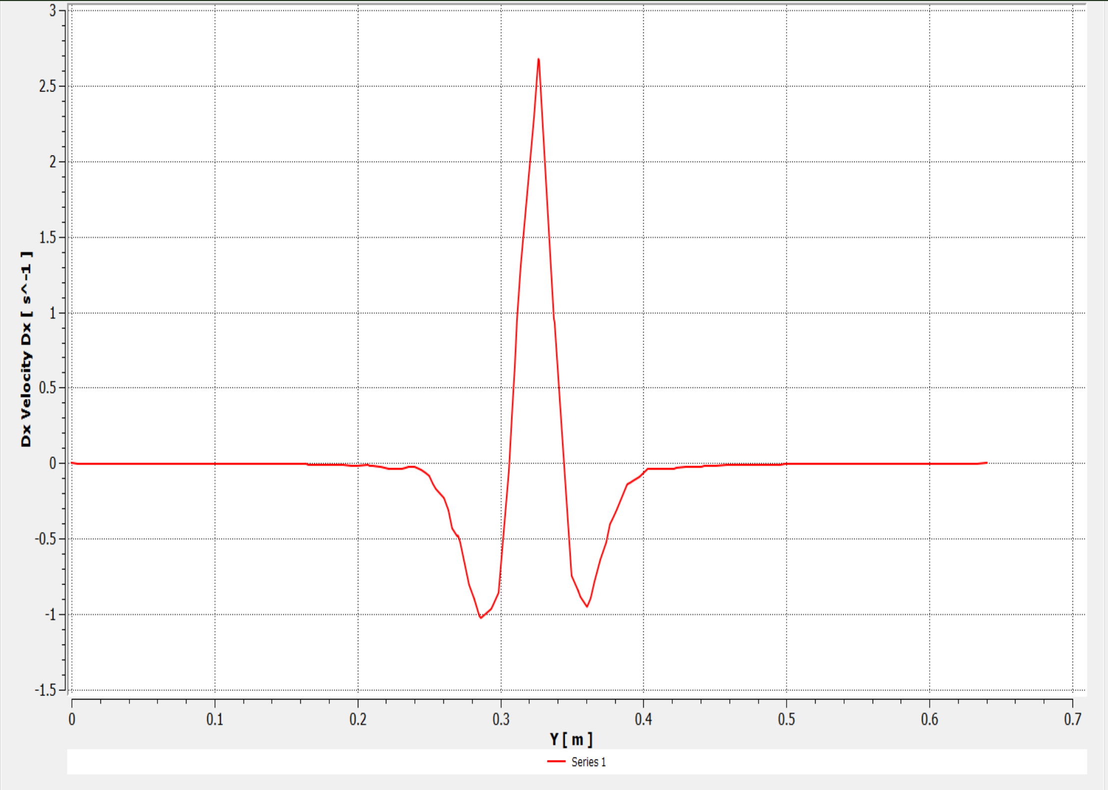


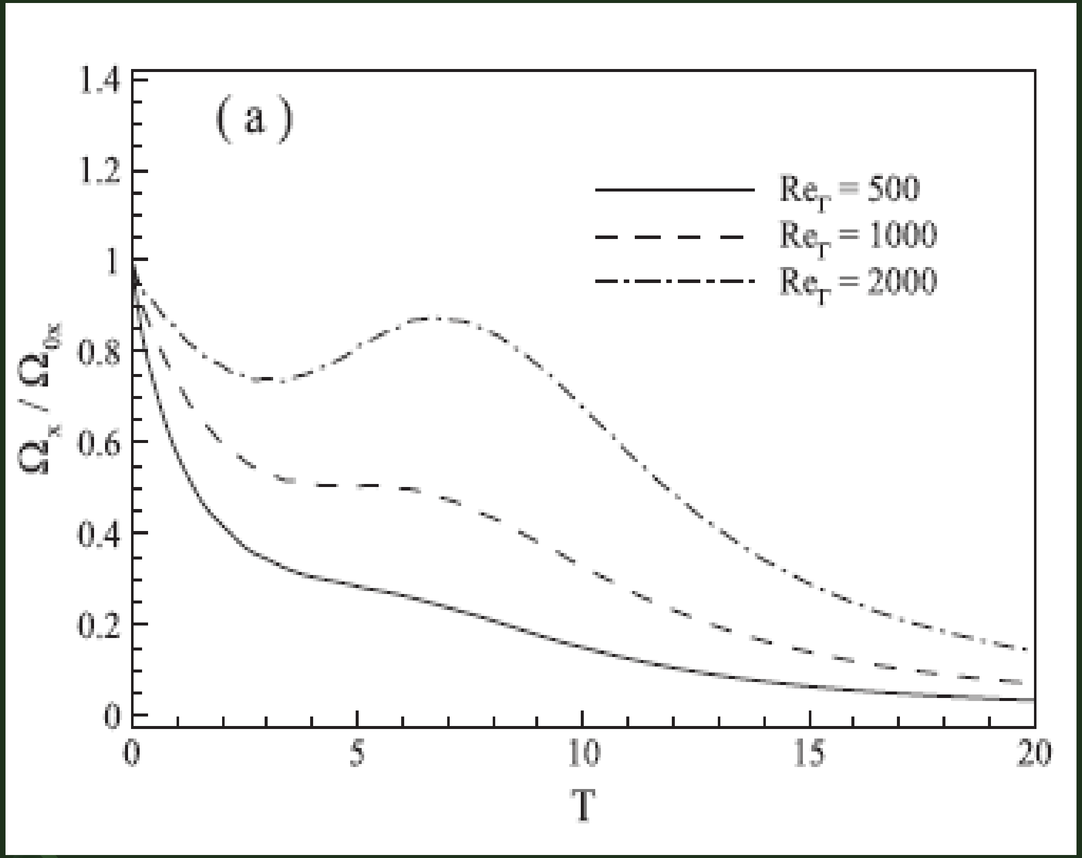


Measurement Points

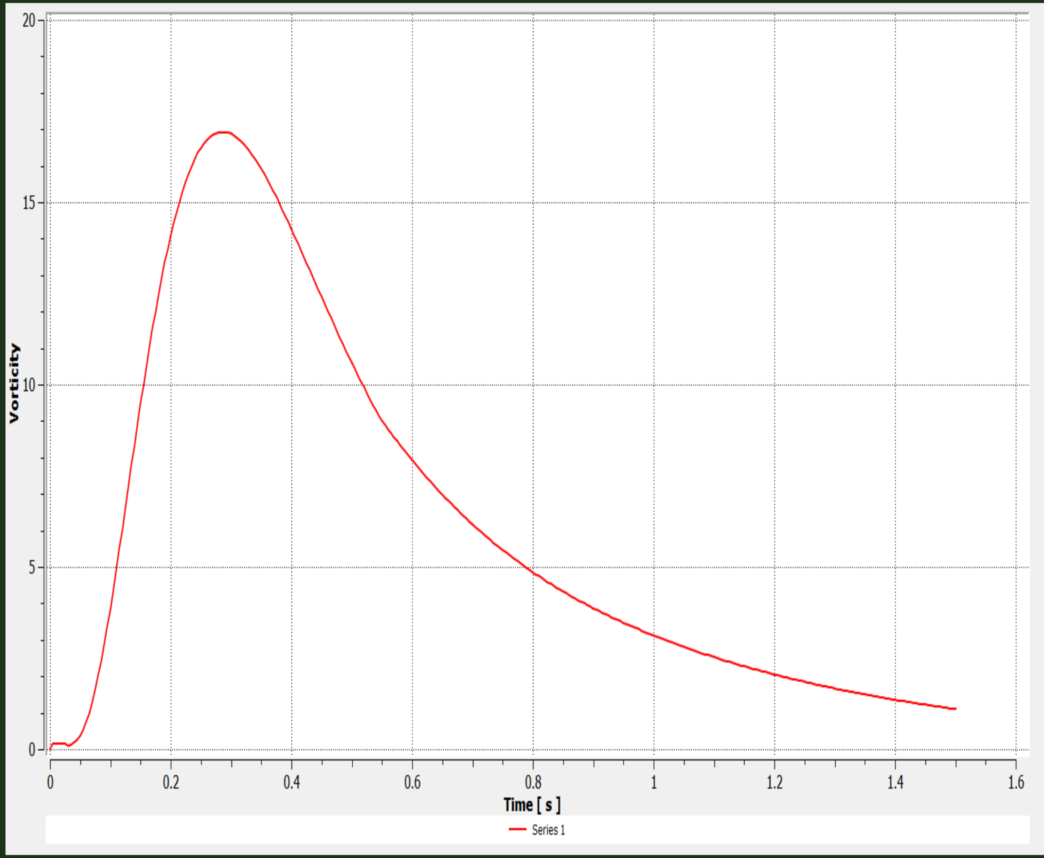
Vorticity Plots





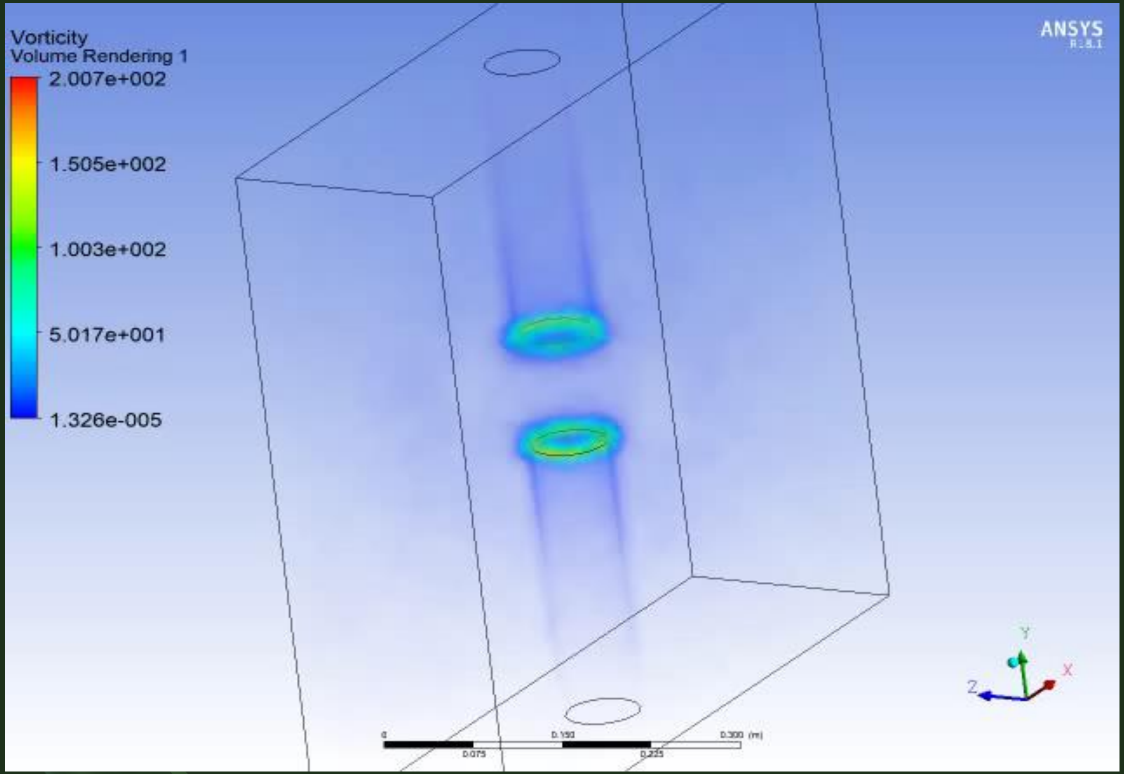


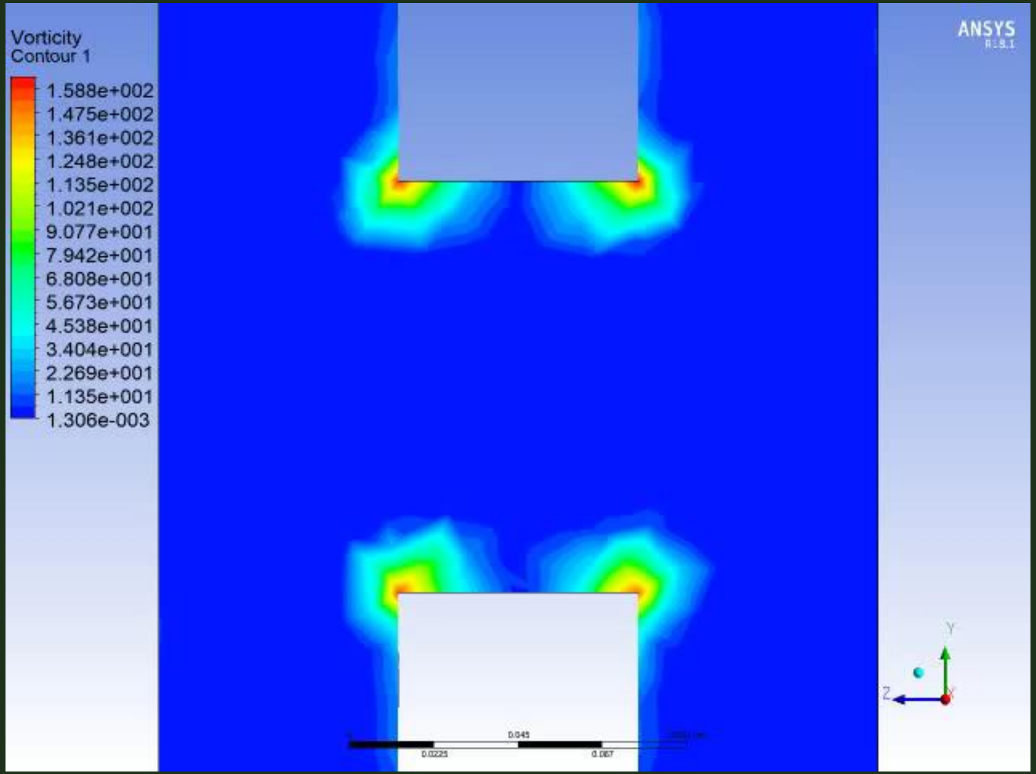
(a)
$Re_T = 500$
$Re_T = 1000$
$Re_T = 2000$
Ω_x / Ω_{0x}
T

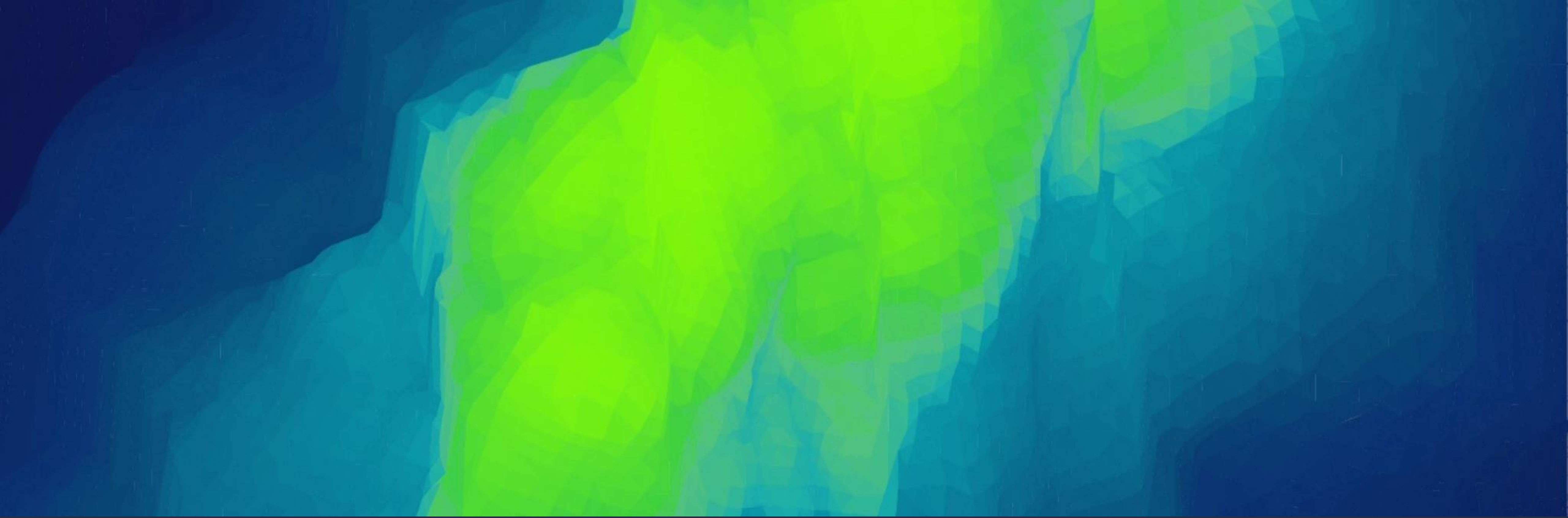


Vorticity
Time [s]
Series 1

Simulations Based on Cheng Papers

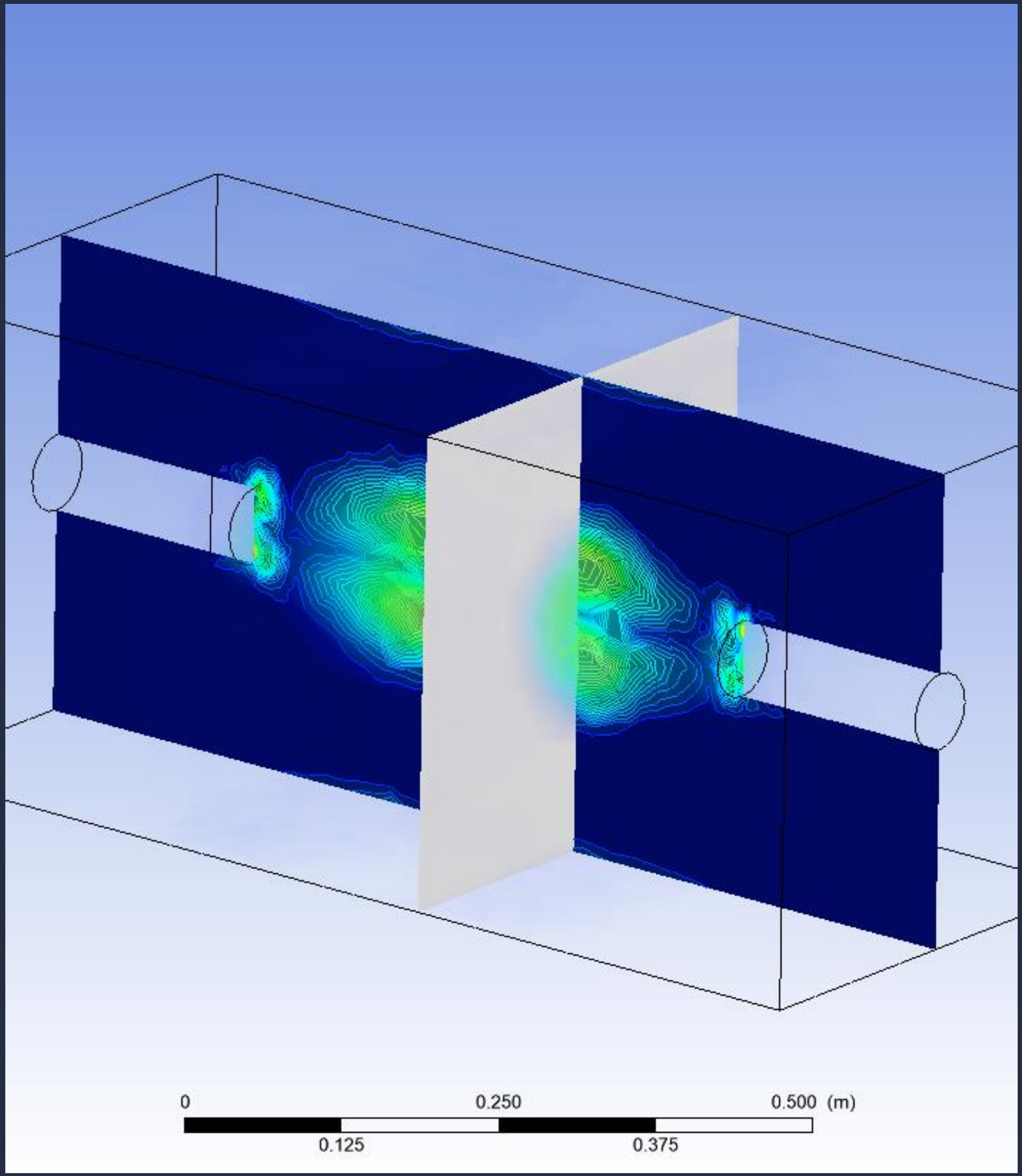






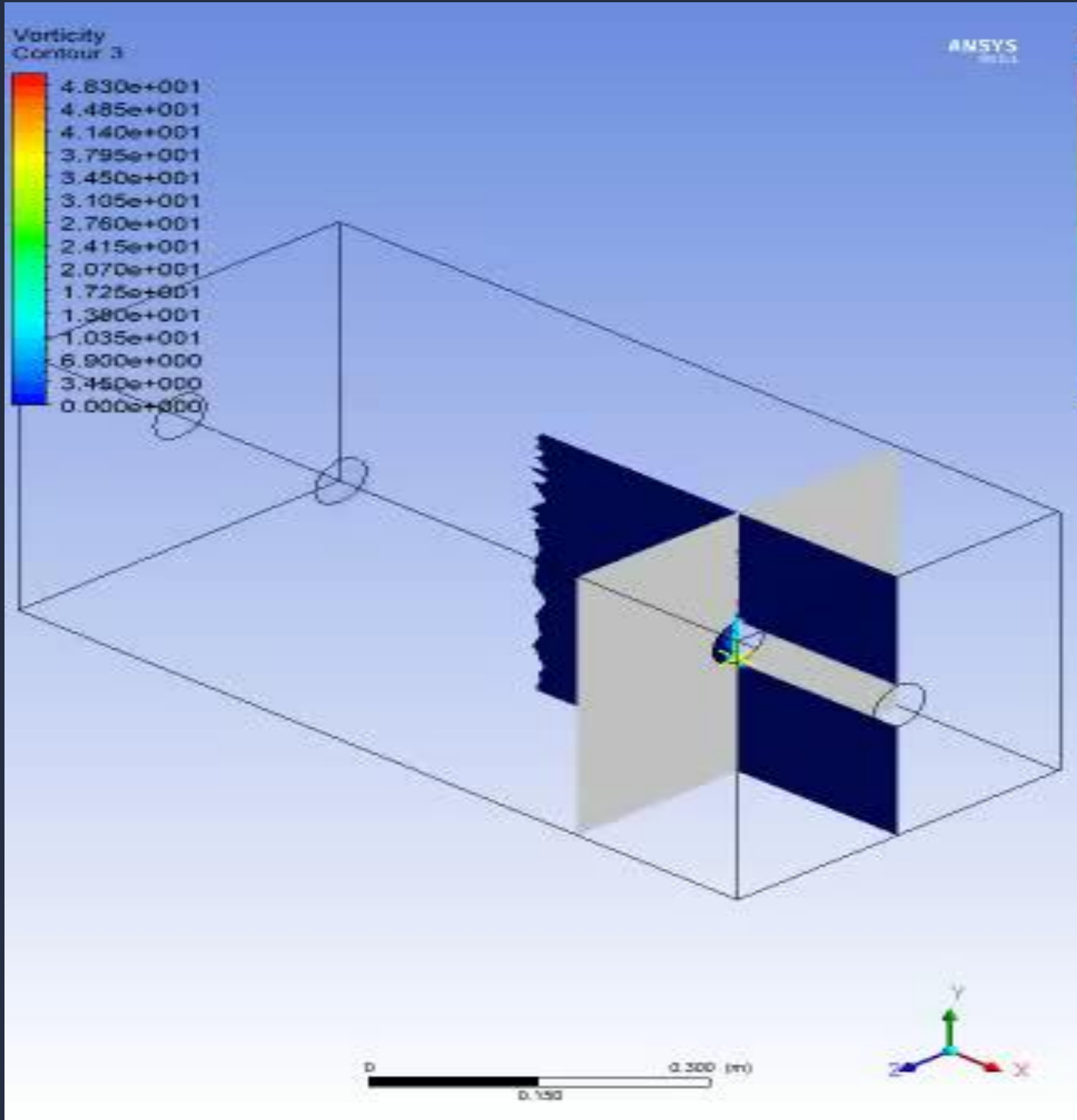
PRESENTATION V

Moving Planes and MATLAB

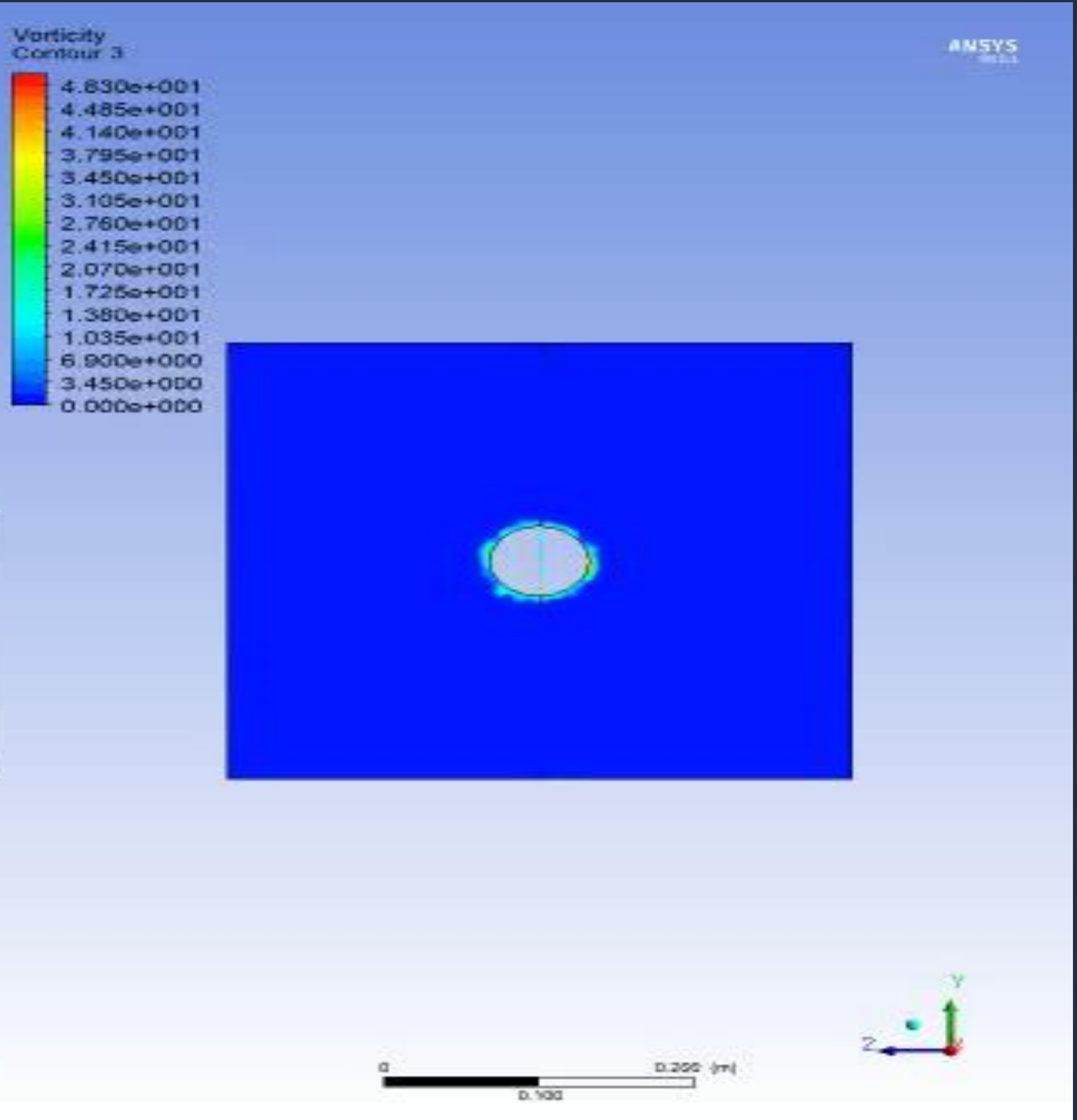


DYNAMIC CONTOURS

- Set up an expression to move the plane to the position of the maximum vorticity.
- True value of radius can be measured by this.
- Set up a point at Maximum Vorticity, Probed coordinates at that point to set up the plane and then moved the plane along the X direction.



Vorticity
Contour 3
4.830e+001
4.485e+001
4.140e+001
3.795e+001
3.450e+001
3.105e+001
2.760e+001
2.415e+001
2.070e+001
1.725e+001
1.380e+001
1.035e+001
6.900e+000
3.450e+000
0.000e+000
ANSYS
0
0.300 (m)
0.150
Y
Z
X

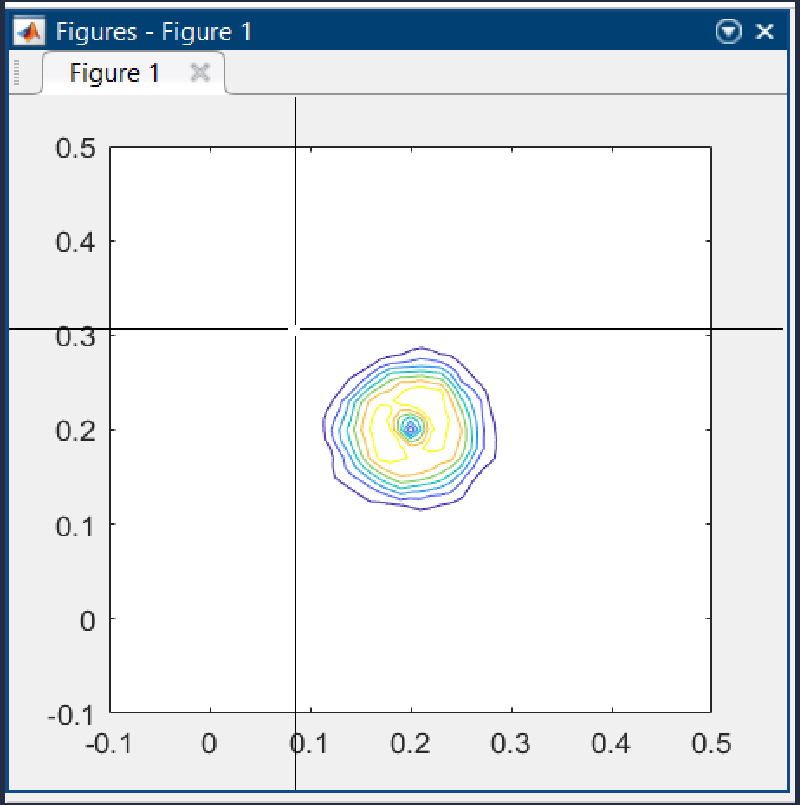


Vorticity
Contour 3
4.830e+001
4.485e+001
4.140e+001
3.795e+001
3.450e+001
3.105e+001
2.760e+001
2.415e+001
2.070e+001
1.725e+001
1.380e+001
1.035e+001
6.900e+000
3.450e+000
0.000e+000
ANSYS
0
0.200 (m)
0.100
Y
Z

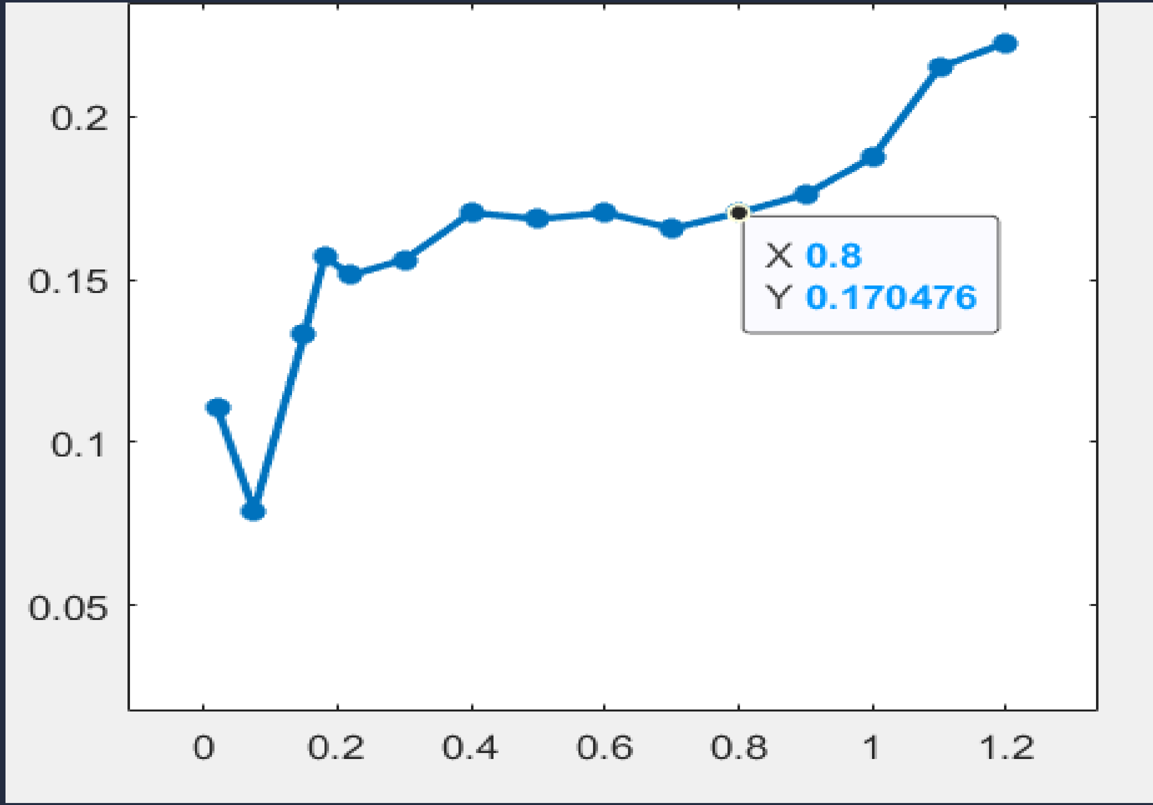
PLOTTING RADIUS

- Files at 15 timesteps were taken and exported to MATLAB.

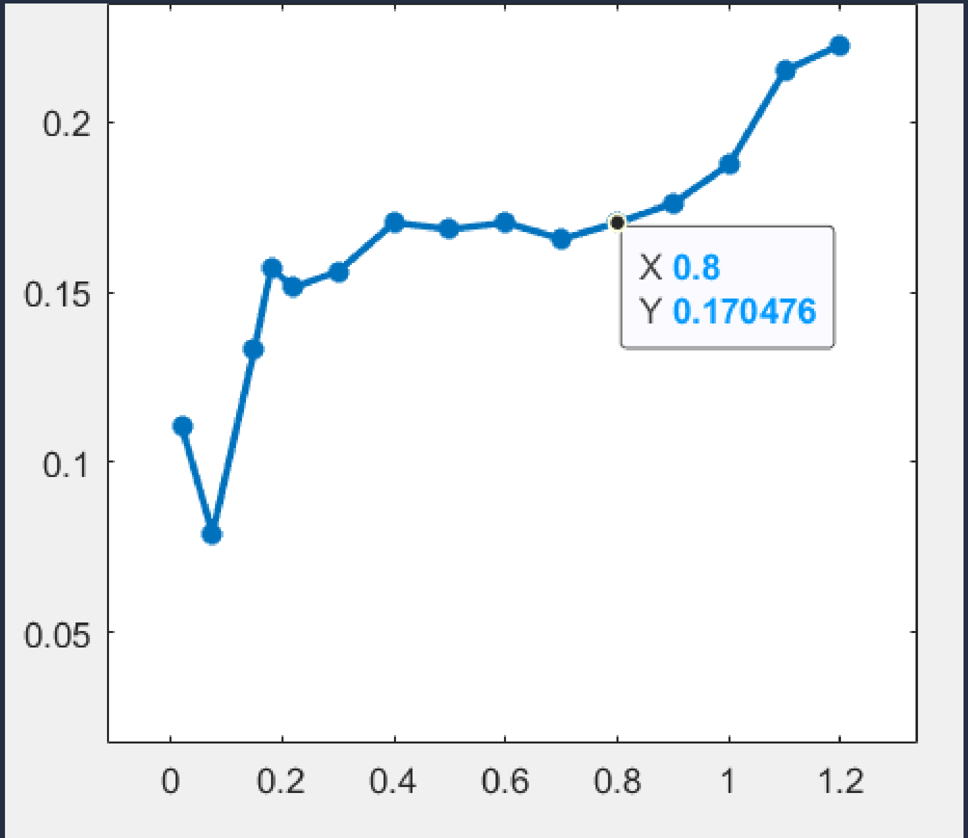
```
[Num,Txt,Raw]=xlsread("D:\savar\Documents\Intern_Material\IITK_Vortex_Colissions\Si
x=Num(:,3);
y=Num(:,4);
z=Num(:,5);
F = TriScatteredInterp(x,y,z)
[qx qy] = meshgrid(min(x)-0.1:0.01:max(x)+0.1,min(y)-0.1:0.01:max(y)+0.1)
qz = F(qx,qy);
contour(qx,qy,qz)

ma=0;
mi=max(y);
for i=1:size(x)
    if (y(i)>ma) && (z(i)>=0.25*std(z)+mean(z))
        ma=y(i);
    else if (y(i)<mi) && (z(i)>=0.25*std(z)+mean(z))
            mi=y(i);
        end
    end
end

ma
mi
ma-mi
[p,q]=ginput(2);
r=q(2)-q(1);
r
```

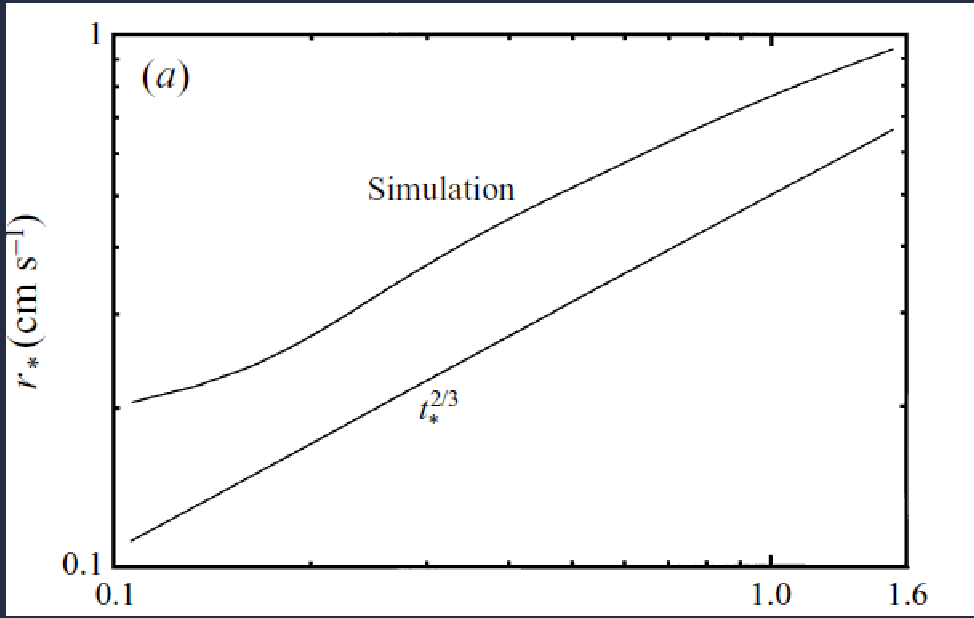


Figures - Figure 1
Figure 1
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.1
0
0.1
0.2
0.3
0.4
0.5



0.2
0.15
0.1
0.05
0
0.2
0.4
0.6
0.8
1
1.2
X 0.8
Y 0.170476


0.2
0.15
0.1
0.05
0
0.2
0.4
0.6
0.8
1
1.2
X 0.8
Y 0.170476

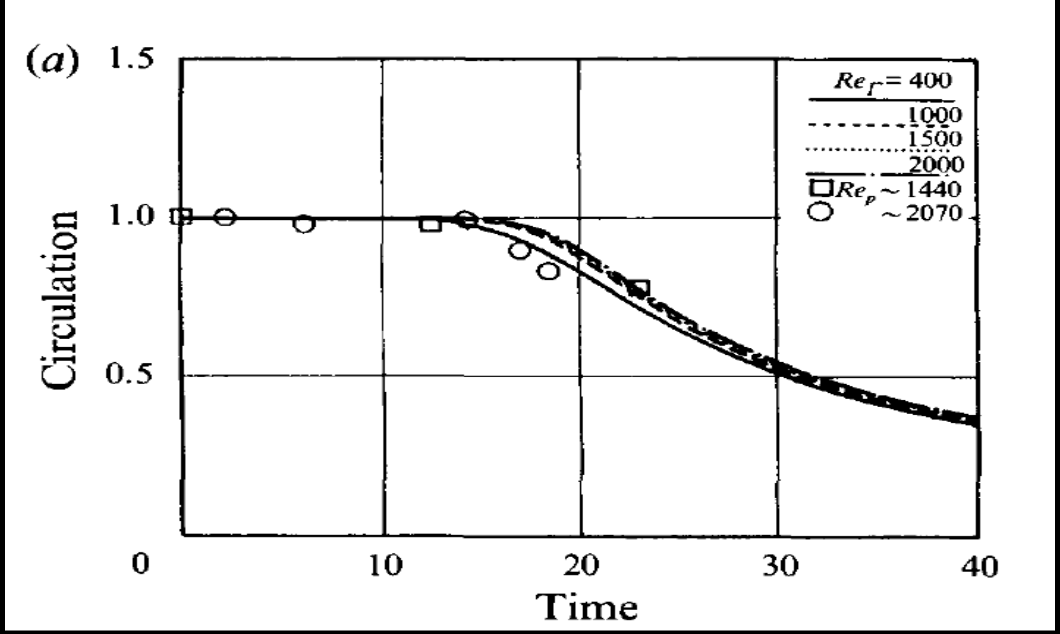

(a)
Simulation
$t_*^{2/3}$
r_* (cm s^{-1})
1
0.1
0.1
1.0
1.6

CIRCULATION RATIOS

Polyline was created at average points of the ring.

Line integral of tangential velocity was taken along the polyline.

Plot was made directly in CFD-Post as polyline couldn't be exported to MATLAB.



(a)
Circulation
Time
Re_Γ = 400
1000
1500
2000
Re_p ~ 1440
~ 2070

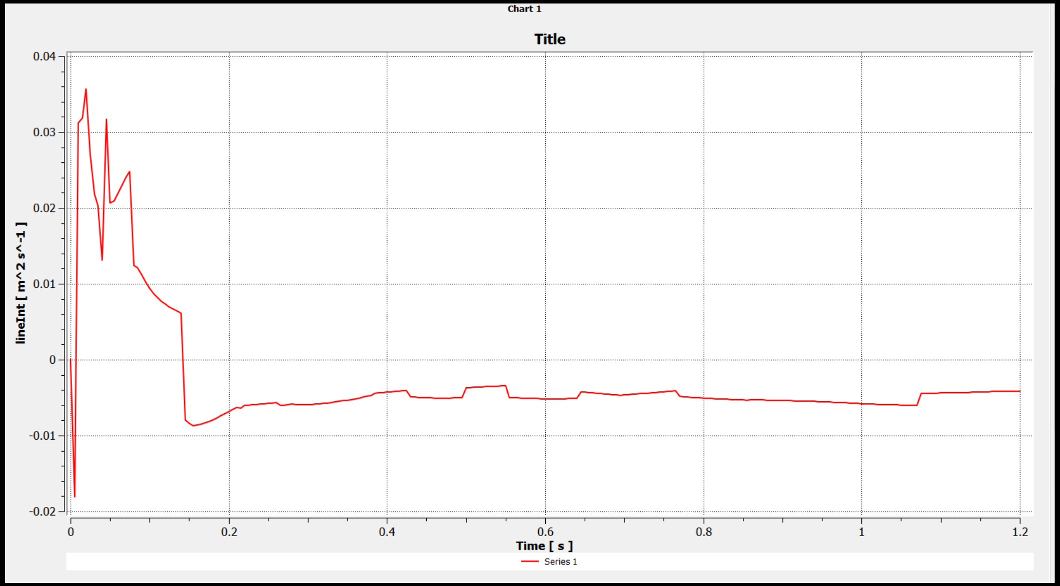
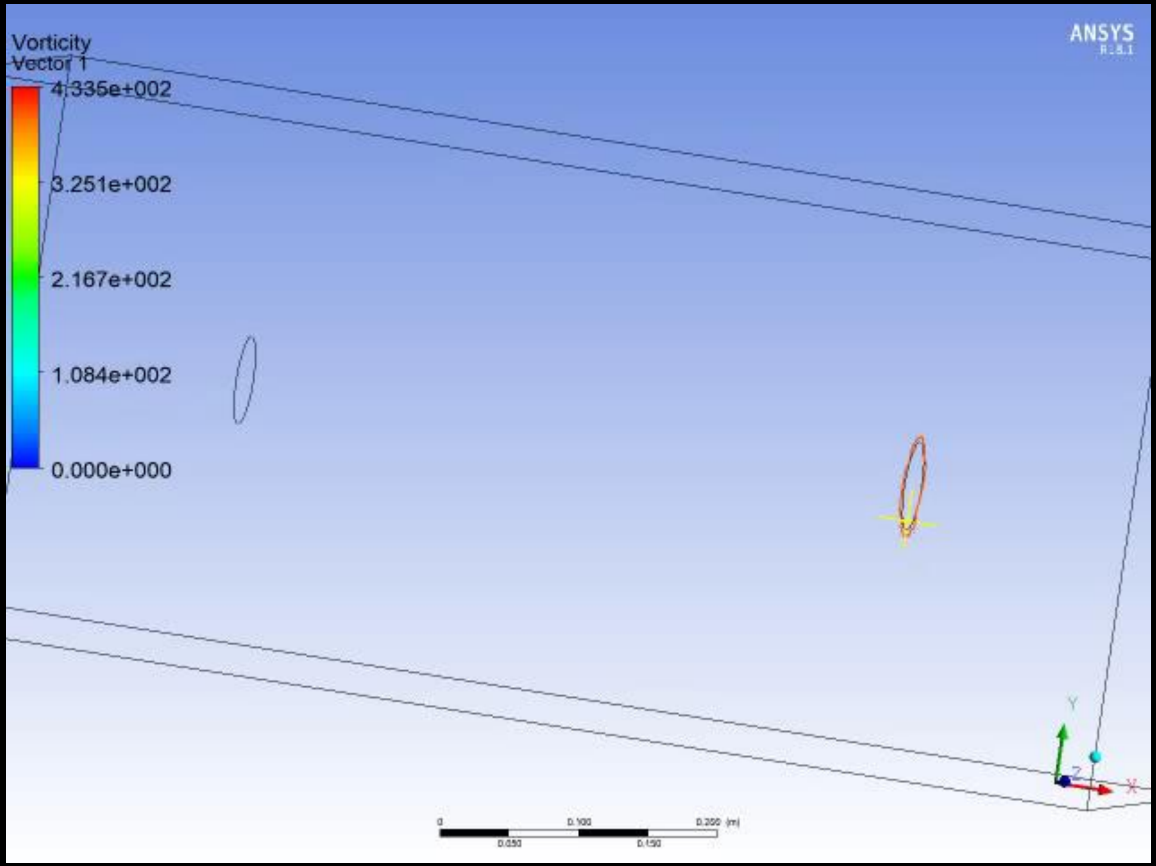
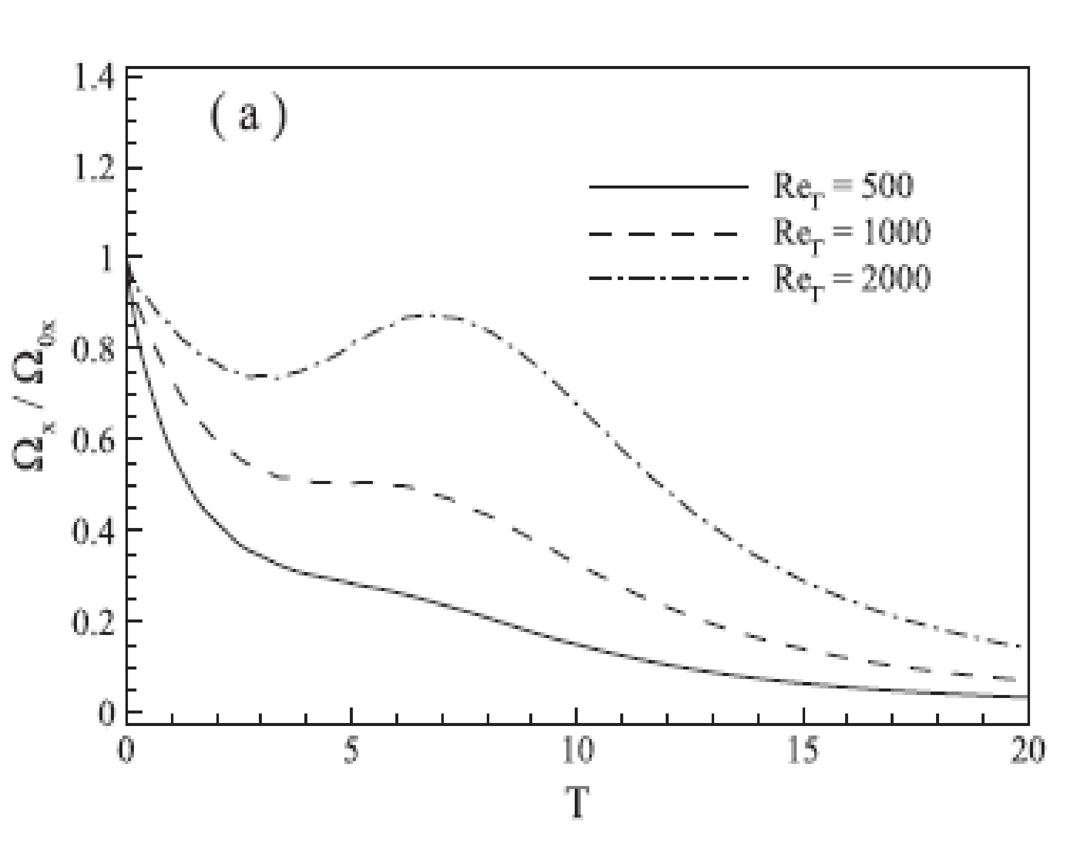
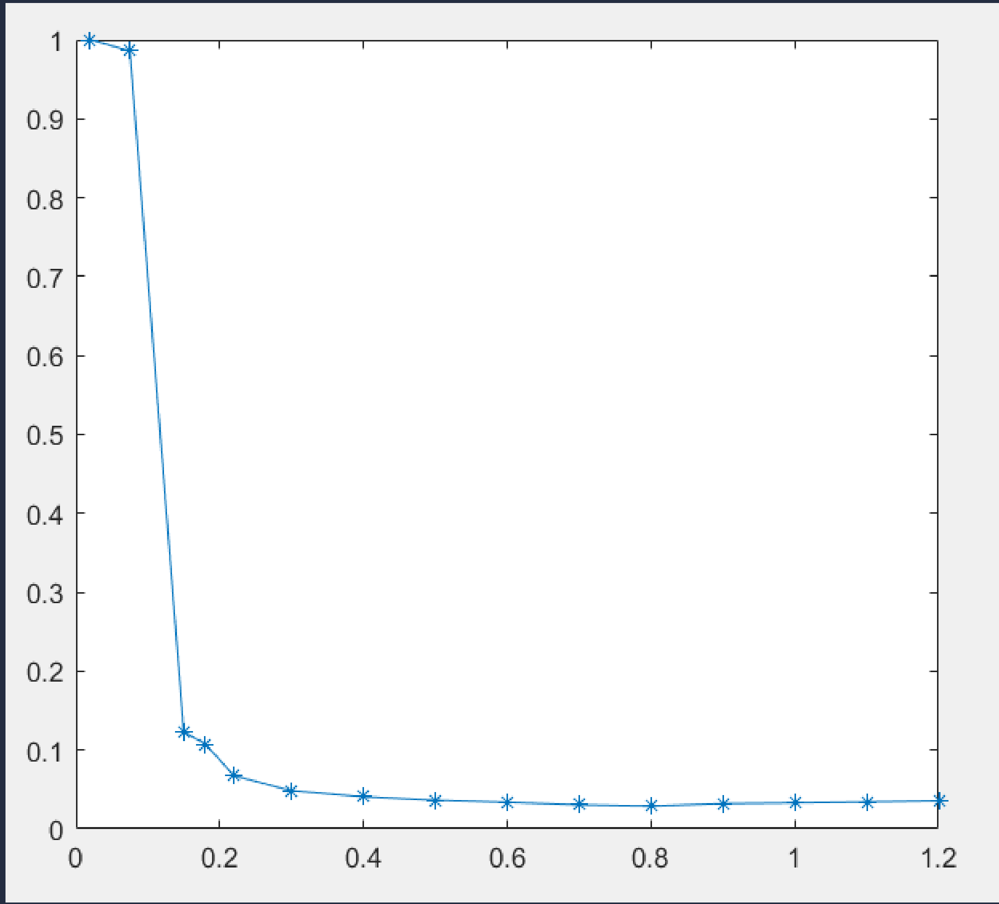


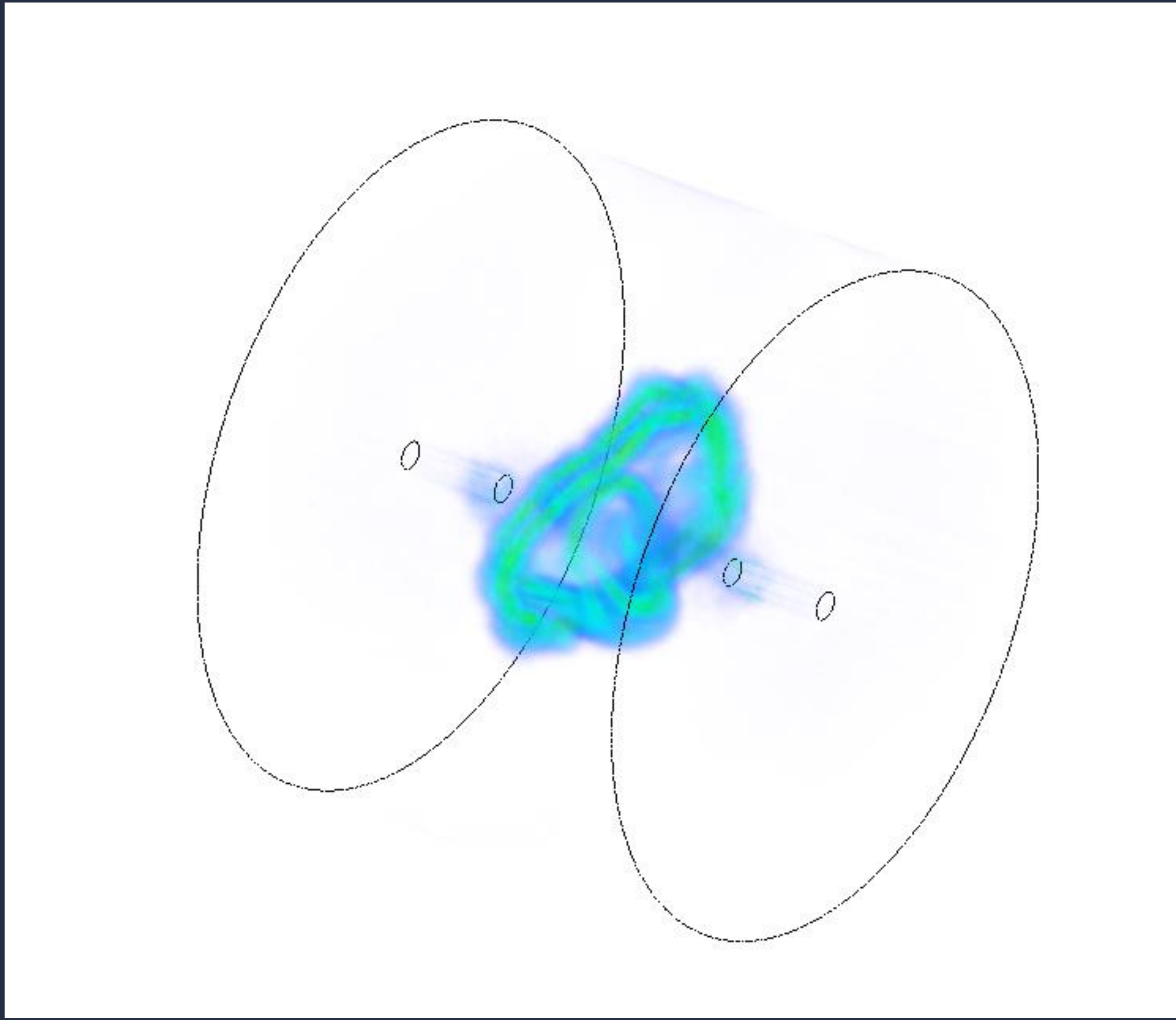
Chart 1
Title
lineInt [m^2 s^-1]
Time [s]
Series 1



Vorticity
Vector 1
4.335e+002
3.251e+002
2.167e+002
1.084e+002
0.000e+000
ANSYS


(a)
Re_T = 500
Re_T = 1000
Re_T = 2000
Ω_x / Ω_{0x}
T
0
5
10
15
20
0
0.2
0.4
0.6
0.8
1
1.2
1.4


0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1
1.2

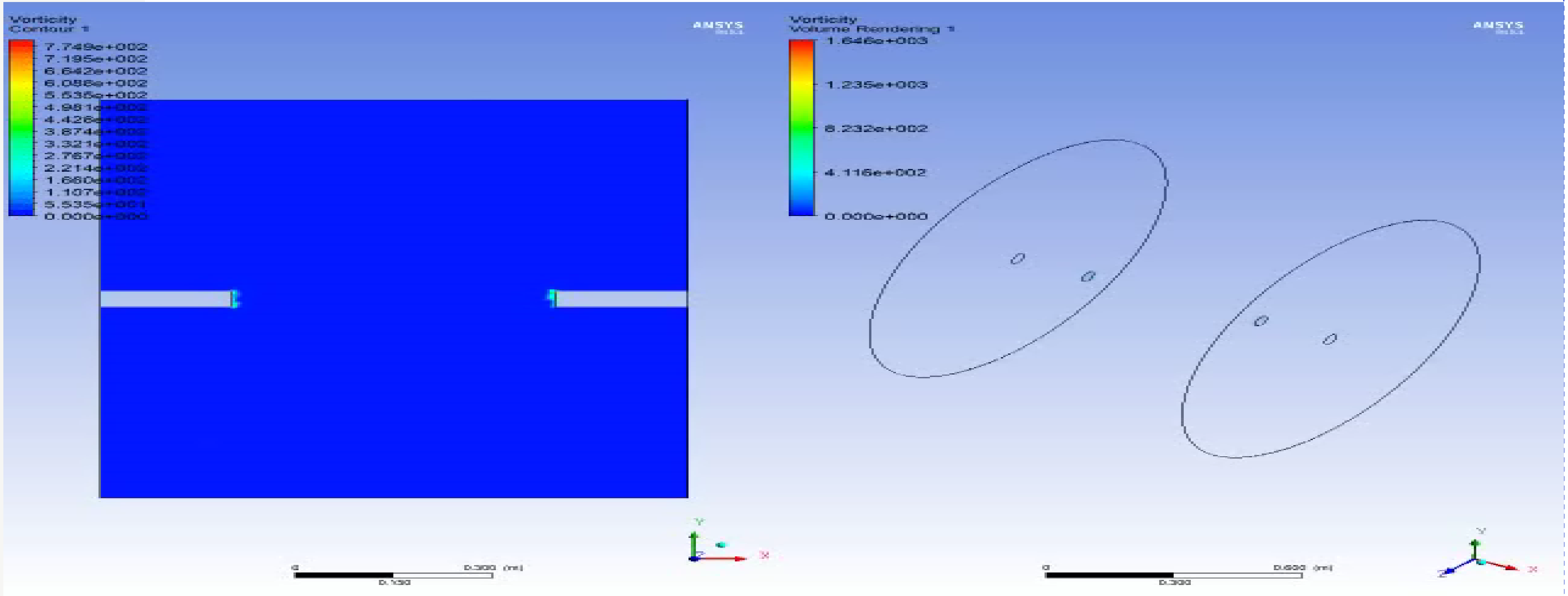


LIM NICKELS MODEL

Presentation - VI

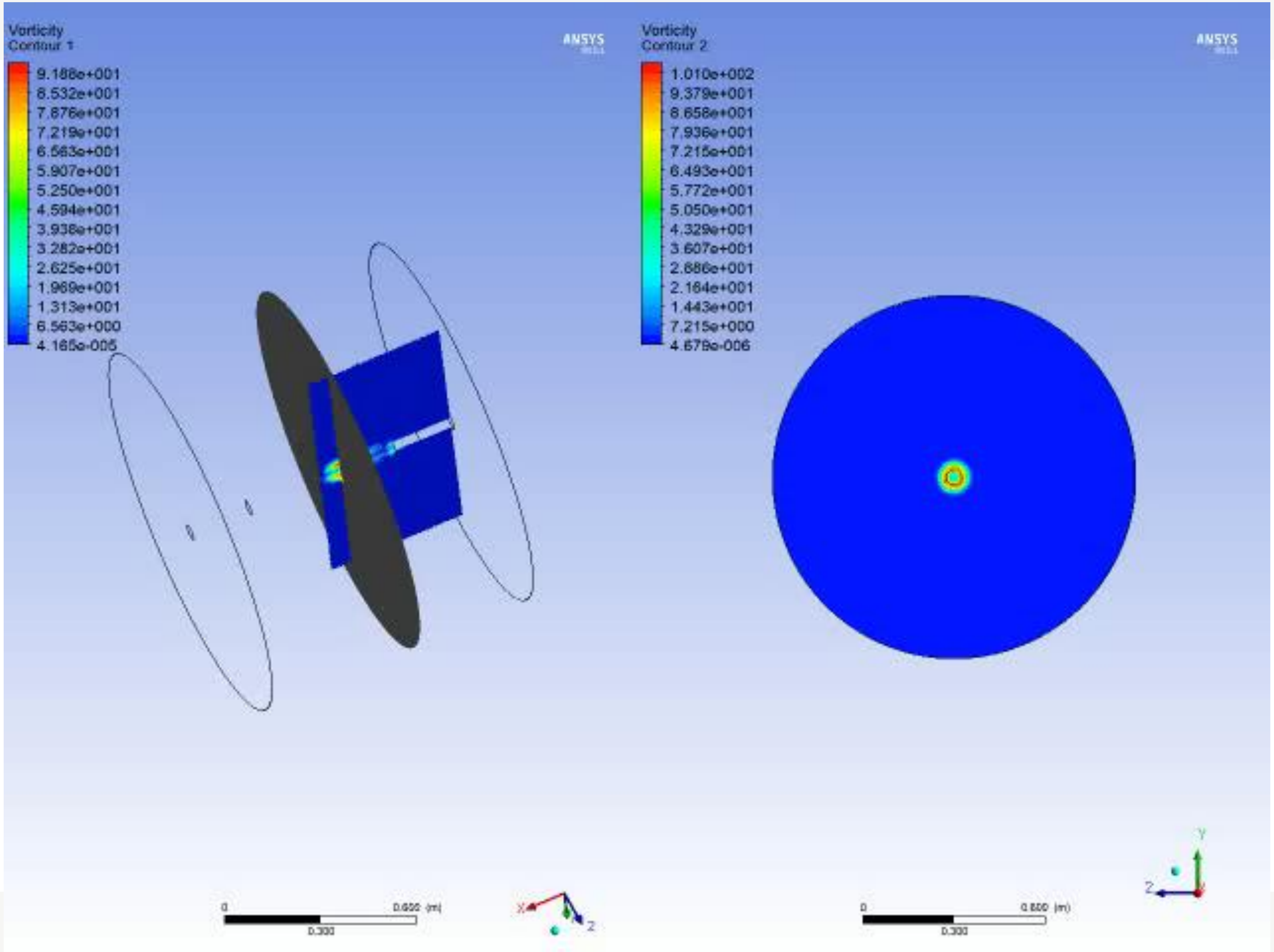
Instability Model, Looping and Slow Trials

Instability Trials

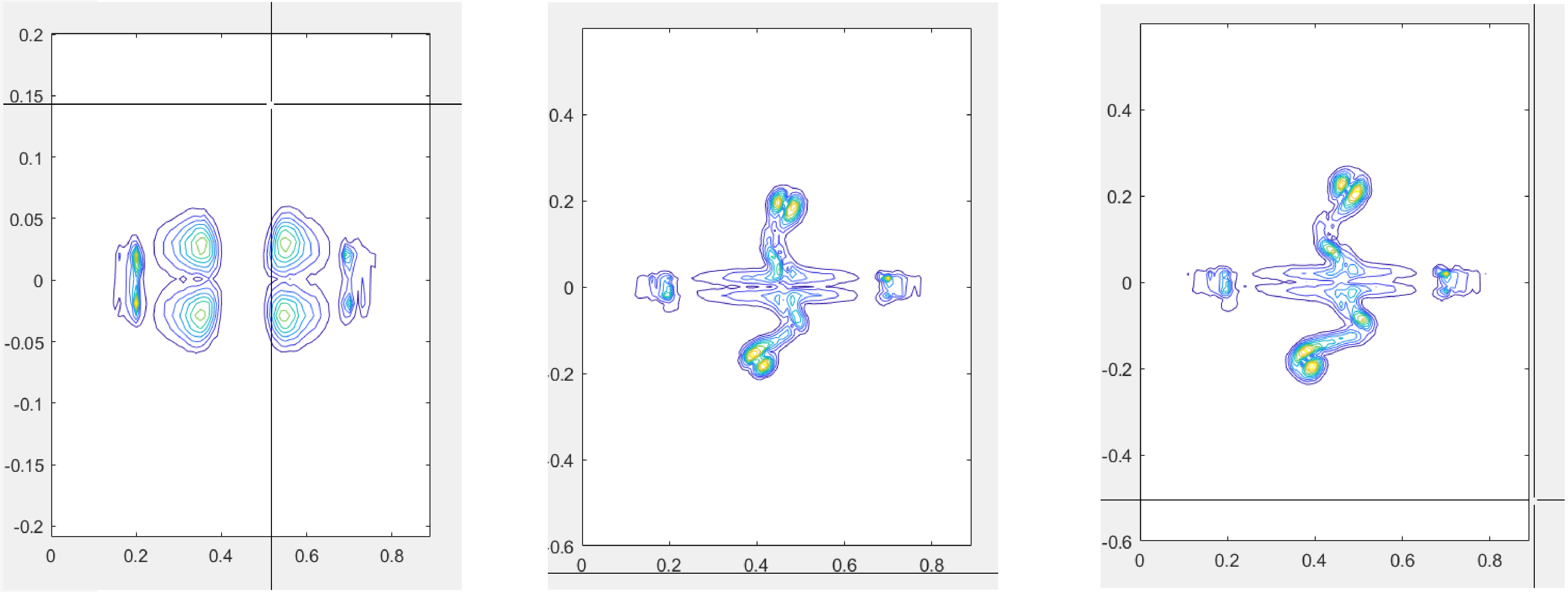


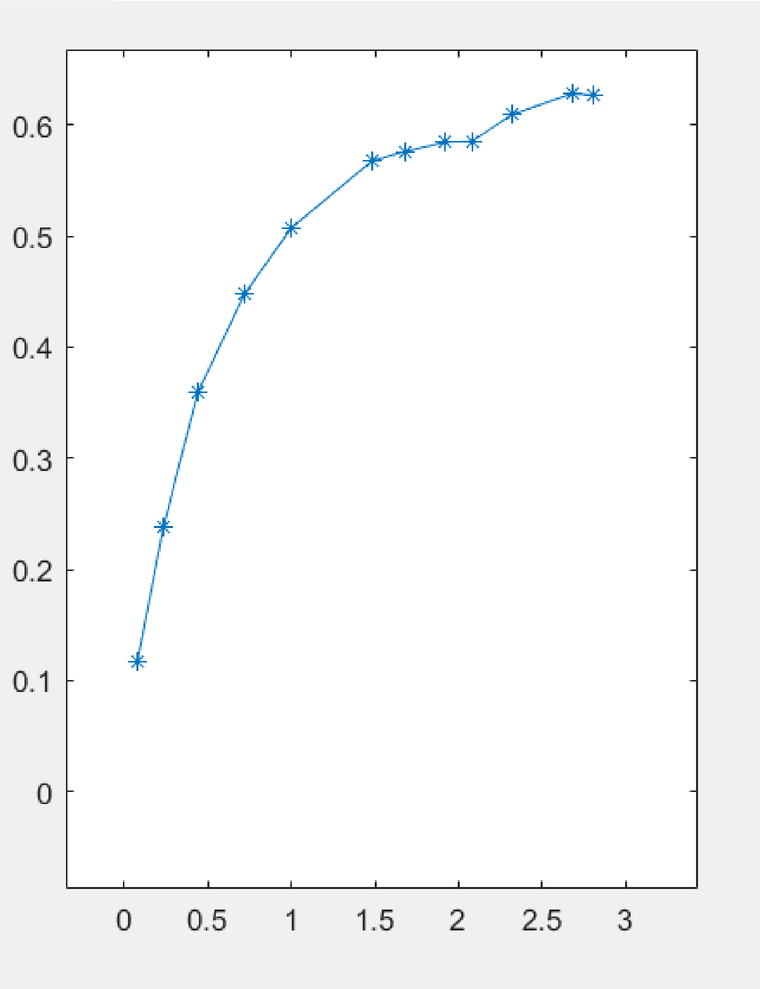
Azimuthal Instability

- Happens at higher Reynolds number
- Current analysis performed at 2000 Reynolds number.
- Apparatus same as earlier.
- The only exception is that the speed was increased tremendously to 15 m/s to provide N = 15.

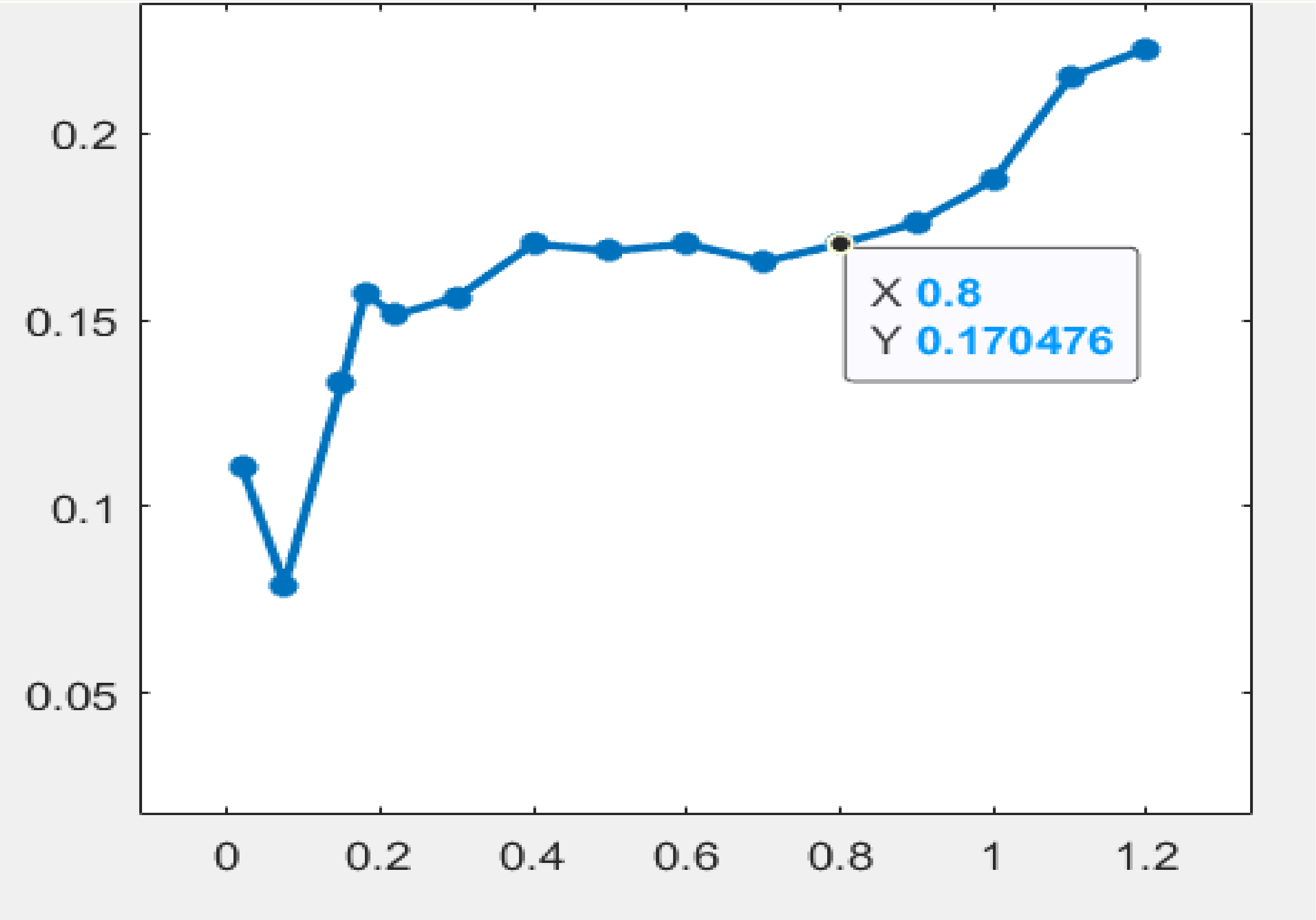

Vorticity
Contour 1
9.188e+001
8.532e+001
7.876e+001
7.219e+001
6.563e+001
5.907e+001
5.250e+001
4.594e+001
3.938e+001
3.282e+001
2.625e+001
1.969e+001
1.313e+001
6.563e+000
4.165e-005
ANSYS
0
0.600 (m)
0.300
Vorticity
Contour 2
1.010e+002
9.379e+001
8.658e+001
7.936e+001
7.215e+001
6.493e+001
5.772e+001
5.050e+001
4.329e+001
3.607e+001
2.886e+001
2.164e+001
1.443e+001
7.215e+000
4.679e-006
ANSYS
0
0.600 (m)
0.300

Radius Growth in Instability Case





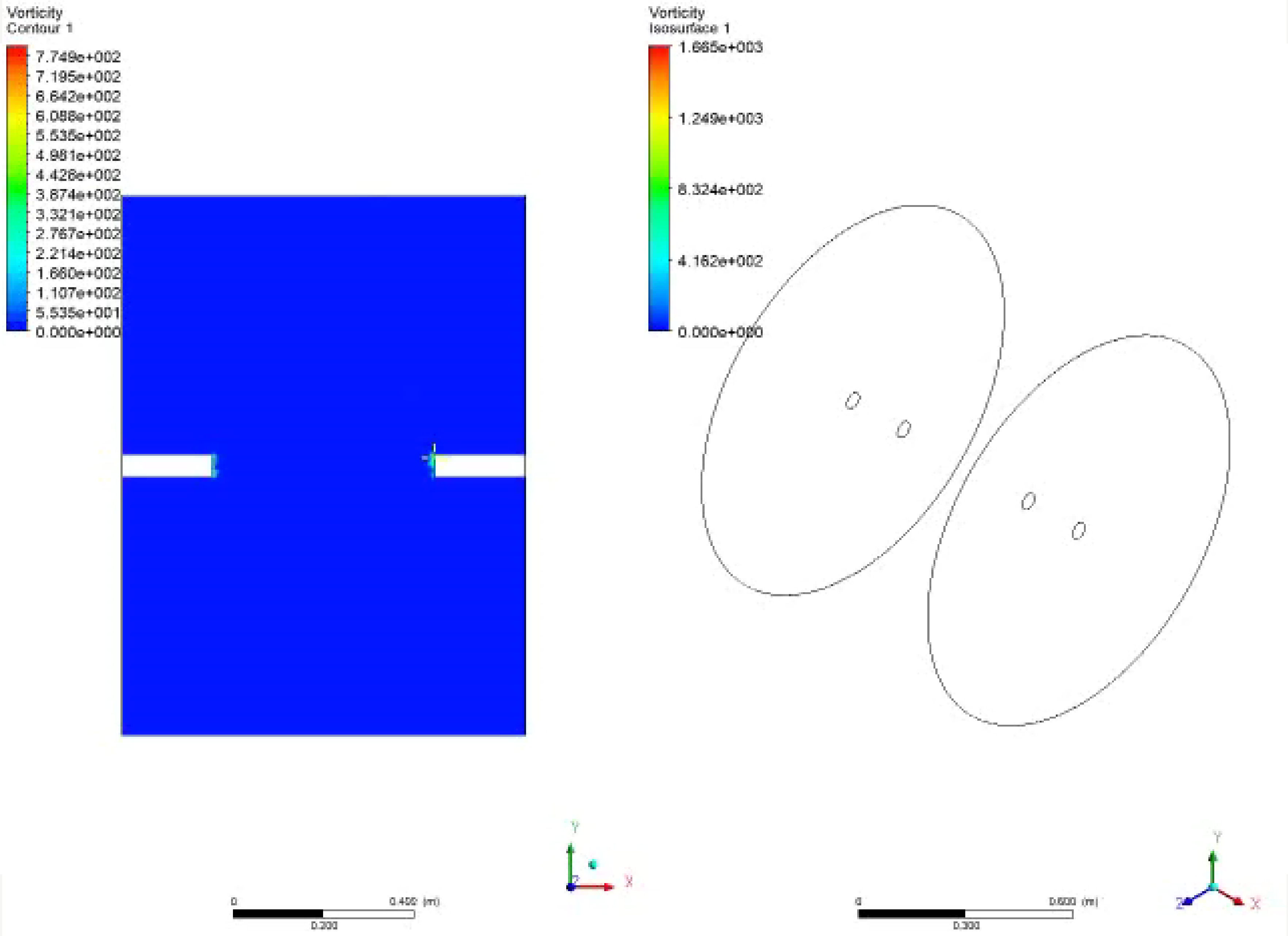
Diameter vs Time
(High Velocity)



Diameter vs Time
(Low Velocity)

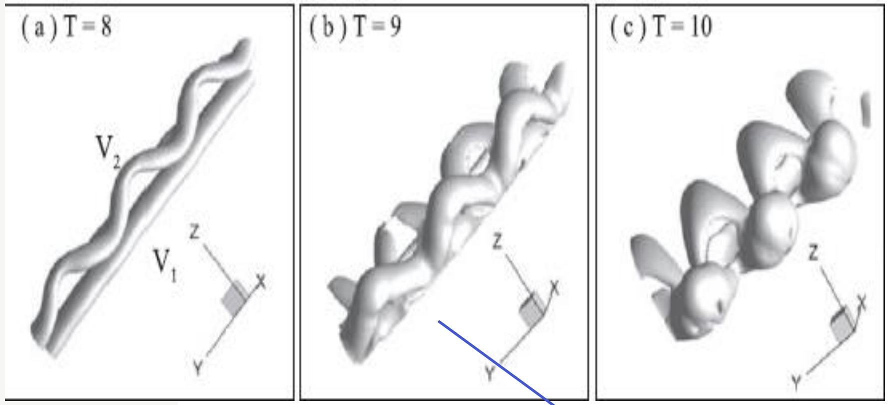
Visualisation

- Isosurfaces were made **Average + 20% Std. Deviation** in order to maintain visibility.
- As soon as collision started, the sine wave perturbation was seen and the looping mentioned was observed.



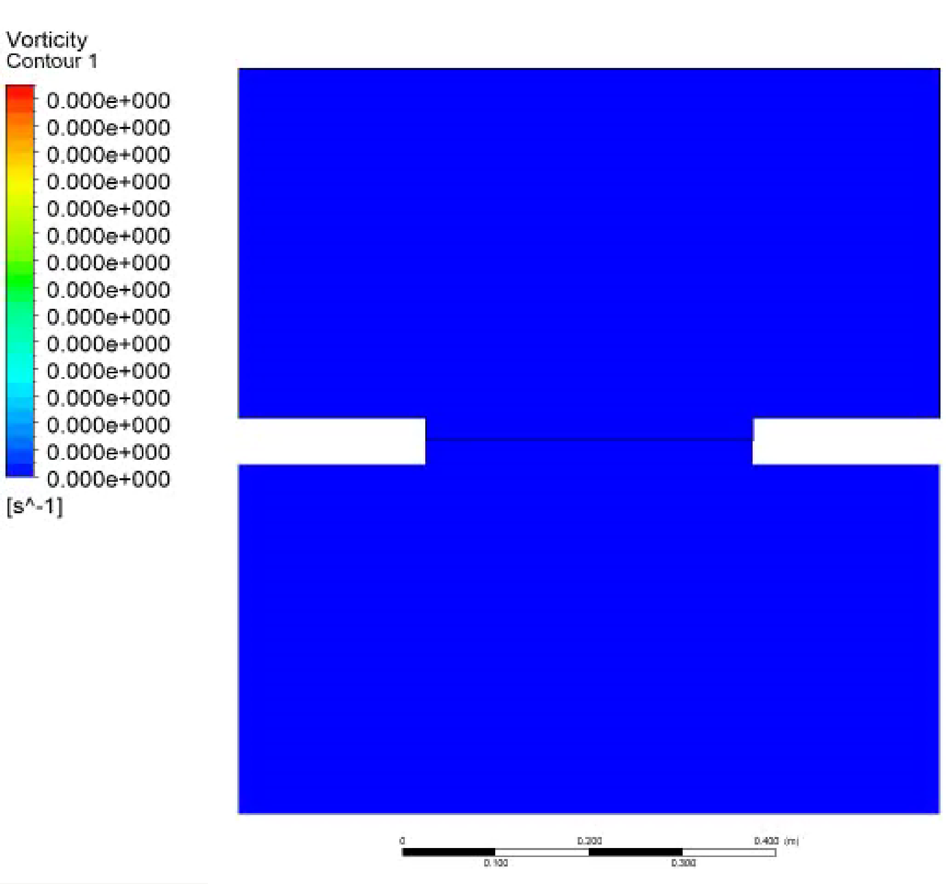
Vorticity
Contour 1
7.749e+002
7.195e+002
6.642e+002
6.088e+002
5.535e+002
4.981e+002
4.428e+002
3.874e+002
3.321e+002
2.767e+002
2.214e+002
1.660e+002
1.107e+002
5.535e+001
0.000e+000
Vorticity
Isosurface 1
1.665e+003
1.249e+003
8.324e+002
4.162e+002
0.000e+000
0
0.400 (m)
0.200
0
0.600 (m)
0.300
Y
X
Z

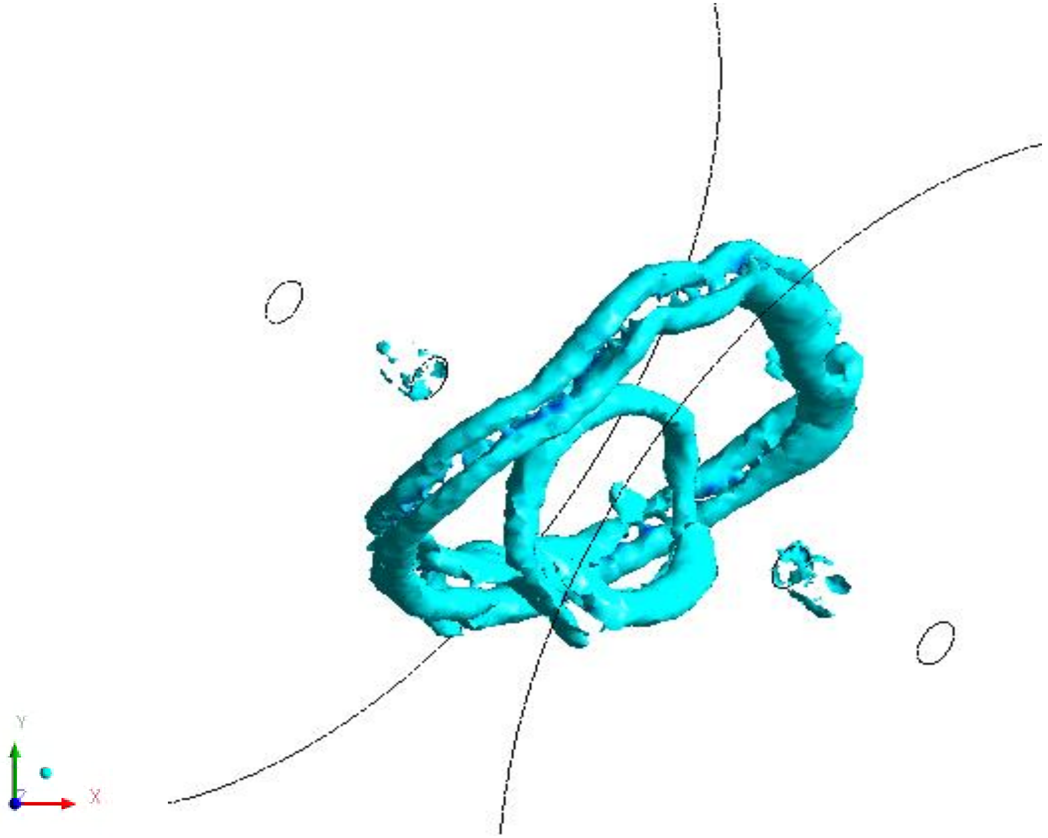
Perturbation based linking



Local
Looping for
shorter ring
formation

Secondary Collissions





- There is a secondary collision which occurs slightly concentric regions of high vorticity to the major collision.