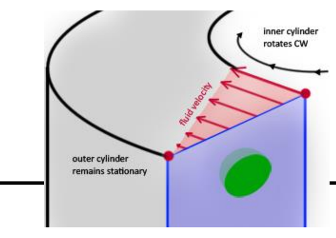
Fluid Motion Between Rotating Concentric Cylinders Using COMSOL Multiphysics®

COMSOL CONFERENCE 2015 BOSTON



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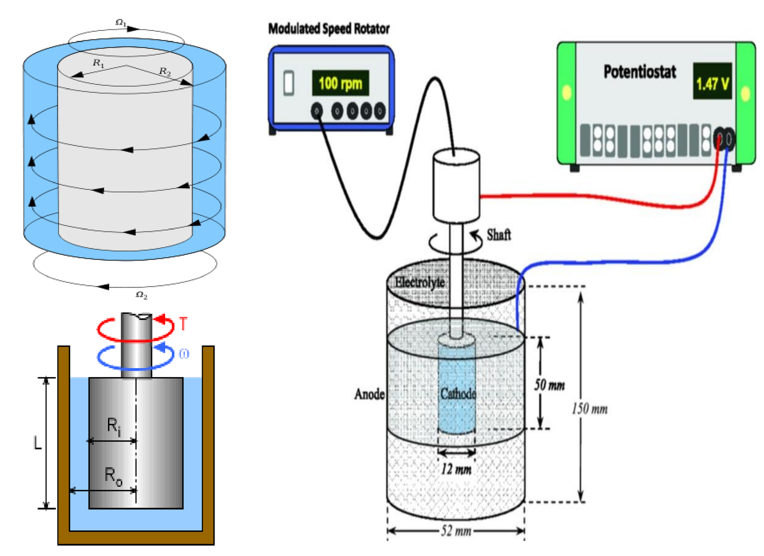
Introduction

Flow in annular regions occur in many practical applications, such as:

- Production of oil and gases
- Centrifugal separation process
- Fluid viscometers
- Electrochemical cells
- Tribology



Understanding the flow behavior in annular regions whose outer wall is stationary while inner wall rotates is important for interpretation of data & system modeling.

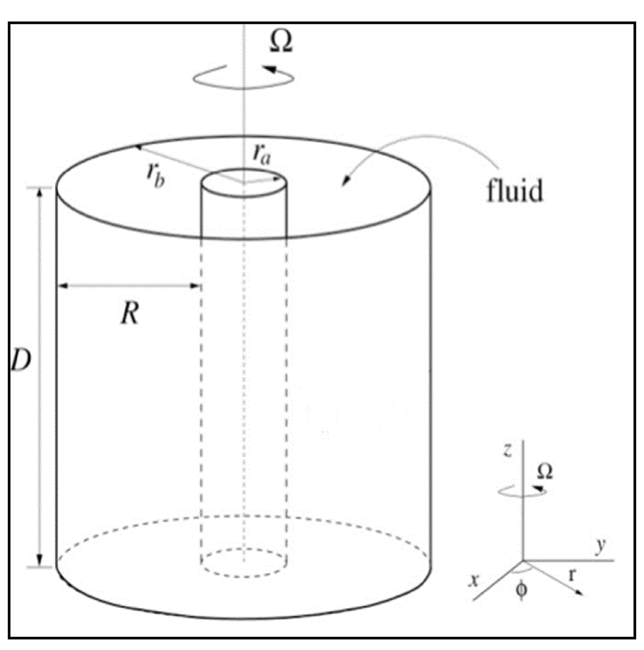


Figure 1. Rotating Concentric Cylinder.

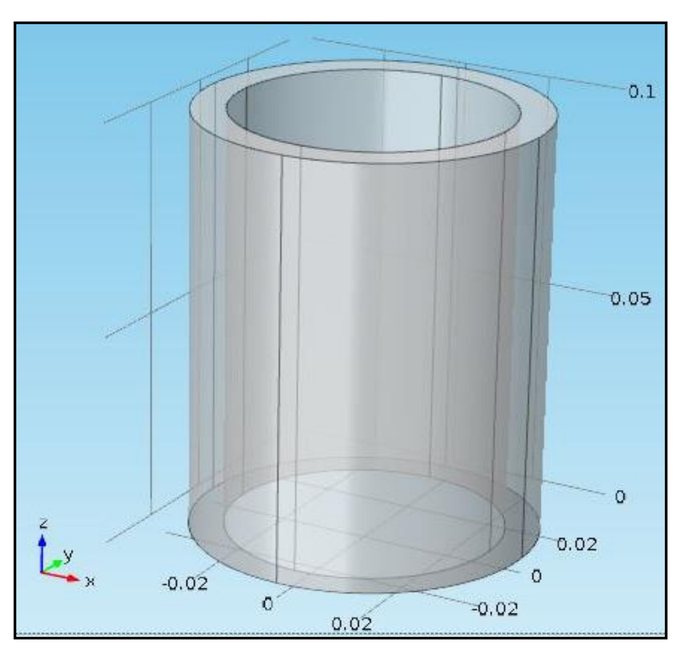


Figure 2. Transparent Geometry of Concentric Rotating Cylinder.

Objectives

Develop solutions to the fluid momentum transport equations for annular laminar flows of a Newtonian fluid in a 3-D control volume where the outer wall is stationary and the inner wall is rotating with an angular velocity Ω.

Model Equations

1-D Equations

$$\frac{\partial(v_\theta)}{\partial\theta} = 0$$

$$-\rho\frac{v_\theta^2}{r} = -\frac{\partial p}{\partial r}$$

$$\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial(rv_\theta)}{\partial r}\right)\right] = 0$$

$$-\frac{\partial p}{\partial z} - \rho g_z = 0$$

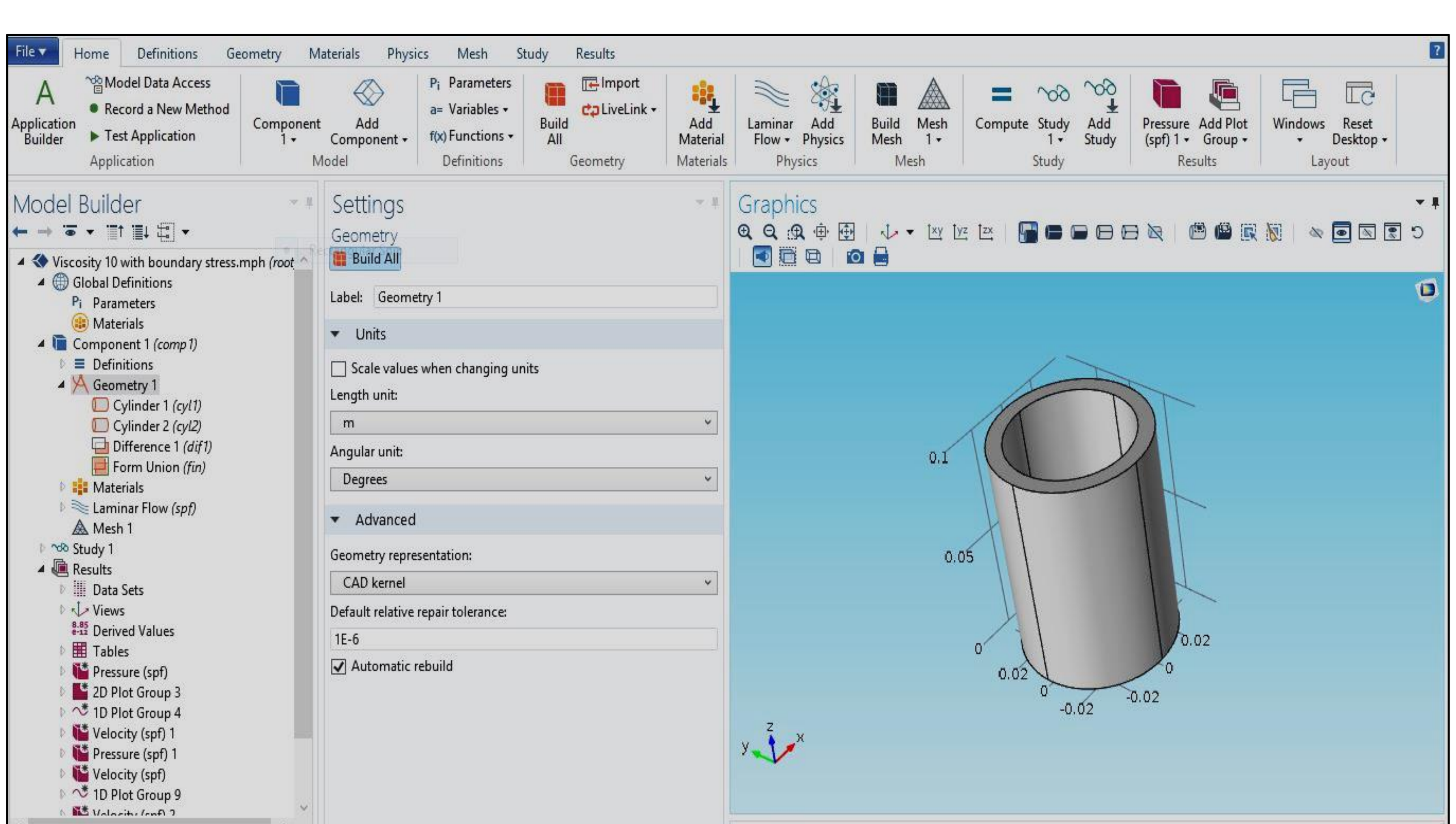
3-D Equations

$$\rho\frac{\partial v}{\partial t} + \rho(v.\nabla)v = \nabla[-p + \mu(\nabla v + (\nabla v)^T)] + F$$

$$\rho.\nabla(u) = 0$$

Here $v_\theta = v_\theta(r)$ for 1-D and $v_\theta = [v_\theta, v_r, v_z]$ for 3-D. the parameters varied include Ω, μ, and R_i.

COMSOL CFD Module



Results

Meshed Geometry

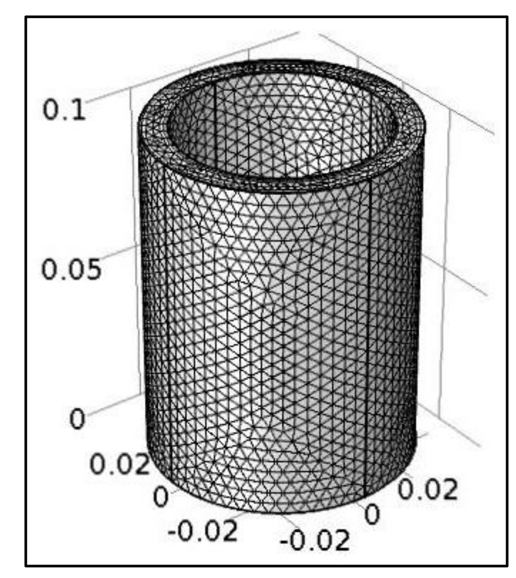


Figure 3. Meshed Geometry

Fluid Pressure Profiles

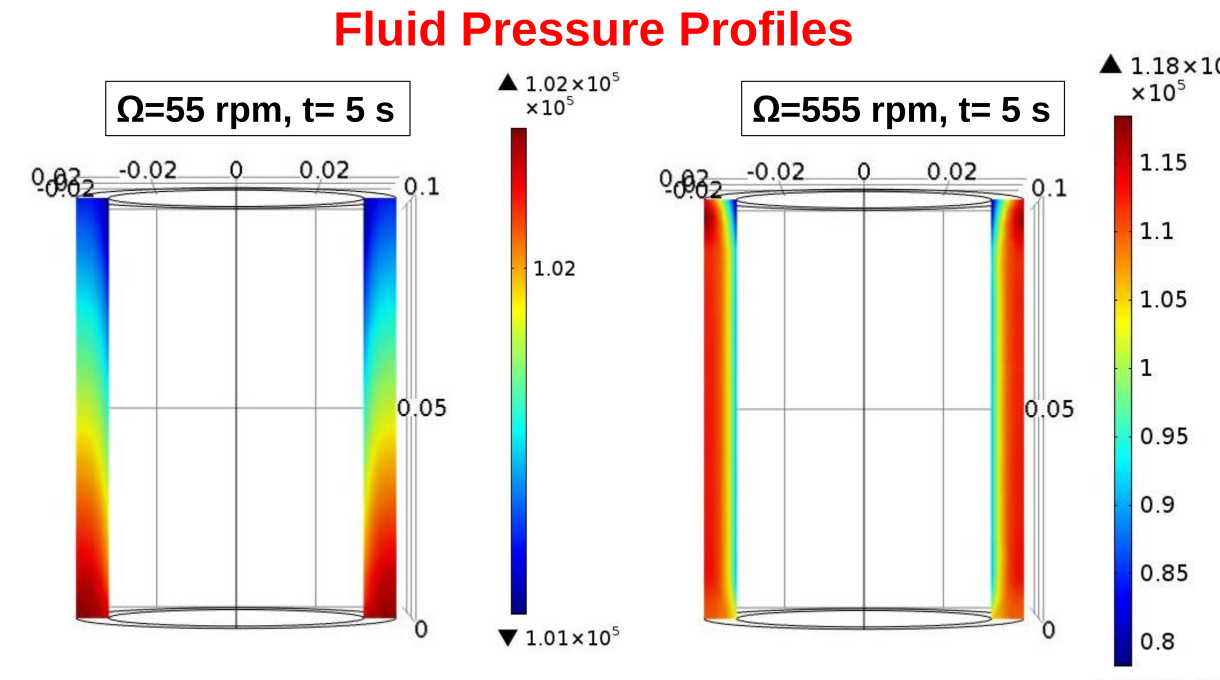


Figure 4. Pressure Profiles

Velocity Profiles and Reynolds Number

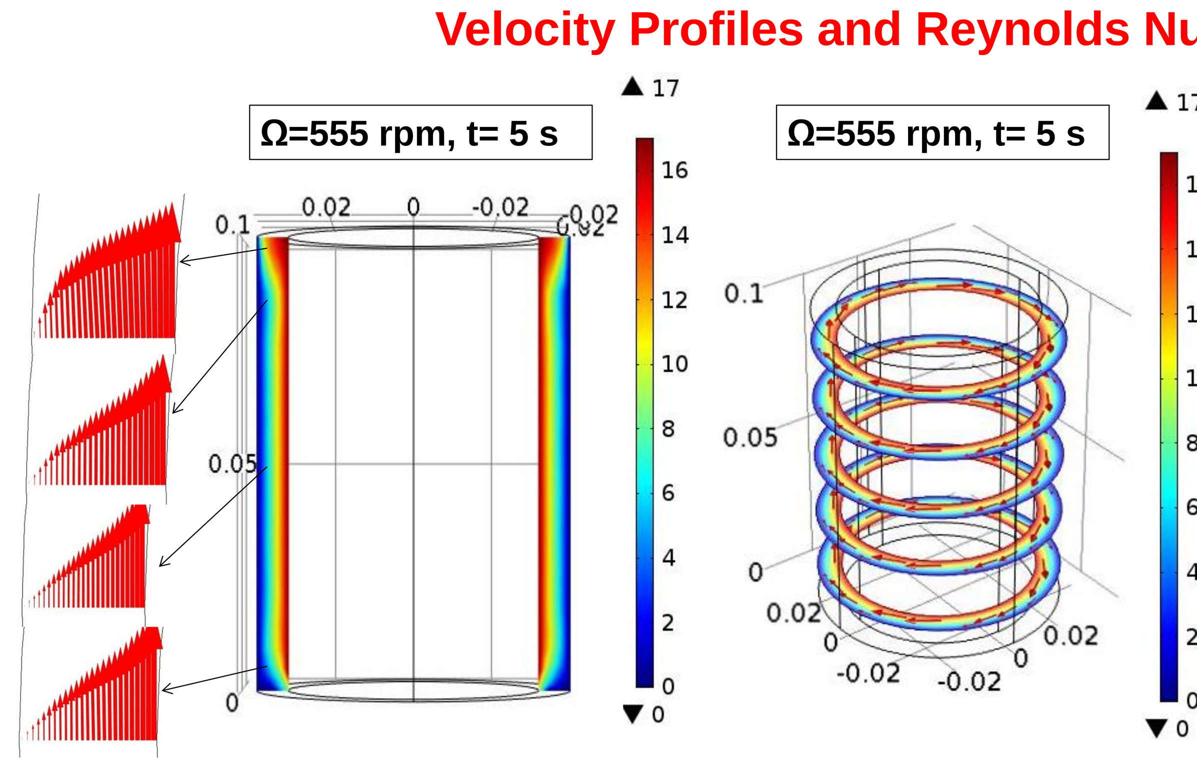


Figure 5: Velocity Profiles

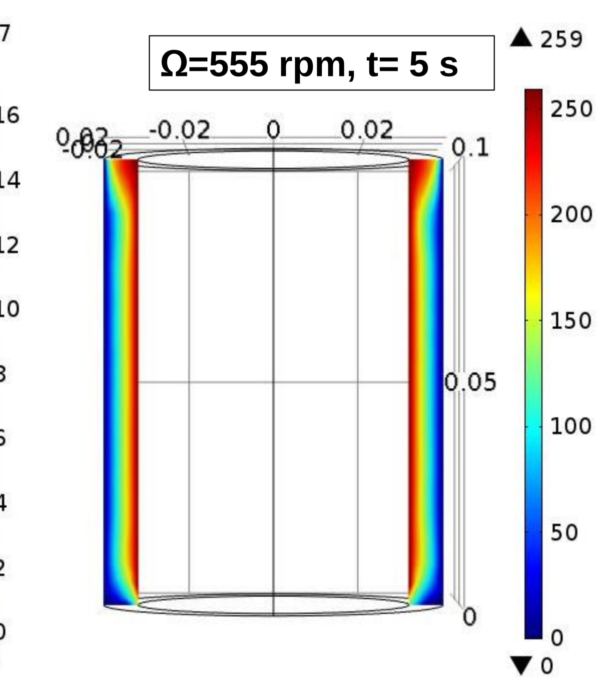
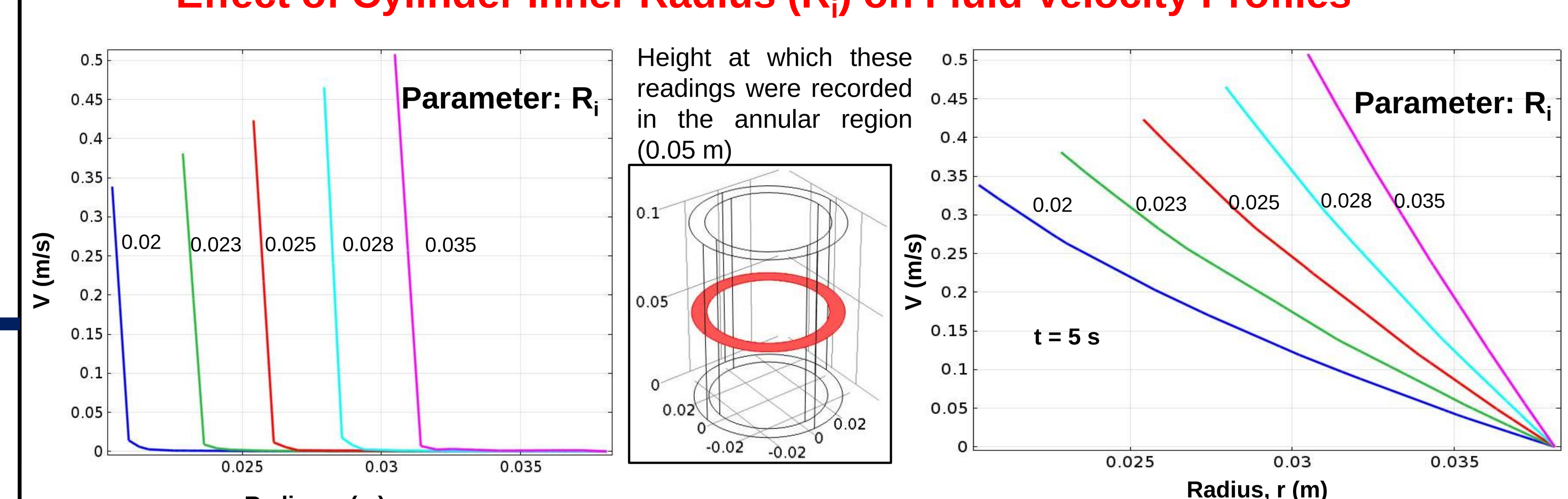
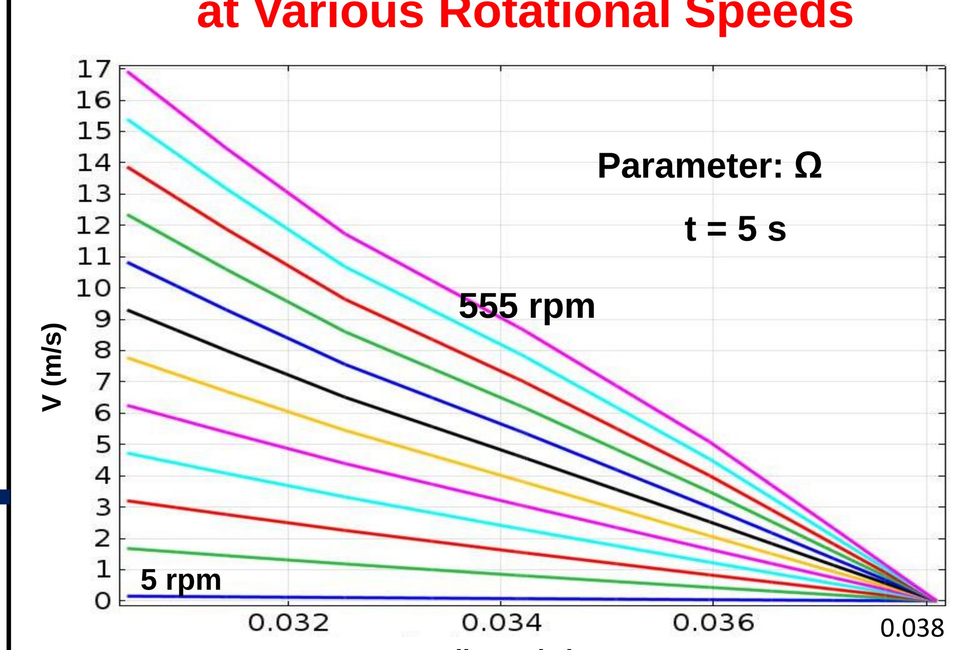


Figure 6: Reynolds Number

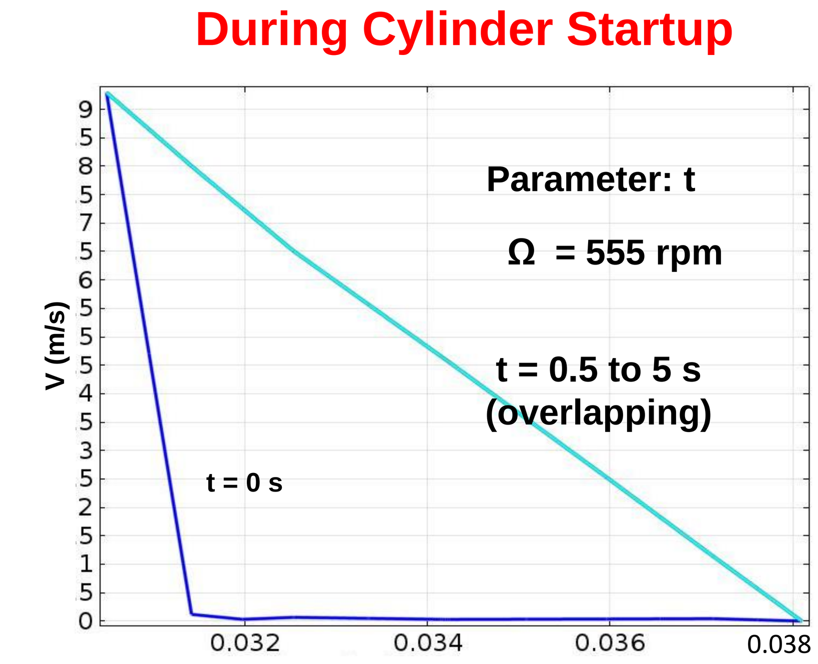
Effect of Cylinder Inner Radius (R_i) on Fluid Velocity Profiles



Velocity Profiles in the Annulus at Various Rotational Speeds



Developing Velocity Profiles During Cylinder Startup



Conclusions

- The 3-D model captures the variation of velocity in the entry and exit regions, which is not the case for the 1-D model.
- The pressure gradient increases with increasing Ω.
- A foundation has been established for extension to non-Newtonian fluids, *e.g*. drilling muds and other fluids.

References

1. R. B. Bird and C. F. Curtiss. Tangential Newtonian flow in annuli-I. *Chem. Eng. Sci.* (1959)**11**, pp.108-113.
2. R. B. Bird *et al.*, Transport Phenomena, 2nd Edn., Wiley, New York (2006)