

# Validity of Navier-Stokes Equation in Single-Textured Thrust Bearing Considering Reynolds Number and Cell Aspect Ratio

M Muchammad<sup>1,\*</sup> M Tauviqirrahman<sup>1</sup> H Nurahman<sup>1</sup> J Jamari<sup>1</sup>

<sup>1</sup>Laboratory for Engineering Design and Tribology, Mechanical Engineering Department, Diponegoro University, Indonesia.

\*Corresponding author. Email: [m\\_mad5373@yahoo.com](mailto:m_mad5373@yahoo.com)

## ABSTRACT

Research about hydrodynamic thrust bearing has been developed, the most concern is case about texture with several configuration. Numerical approaches using Reynolds equations and CFD simulation based on Navier-Stokes equations are a common method that used to analyze bearing performance. It is necessary to analyze the effect of thrust bearing geometry by using Reynolds and Navier-Stokes equation. Single-textured thrust bearing with several geometry by certain Reynolds number and cell aspect ratio was analyzed by CFD, and compared with the Reynolds equation. So that the thrust bearing with cell aspect ratio and Reynolds number configuration could be analyzed by both methods, we must configure velocity and geometry correctly.

**Keywords:** Navier-Stokes Equation, Reynolds Number, Cell Aspect Ratio.

## 1. INTRODUCTION

Hydrodynamic thrust bearing is one of the most researched, to find out effect of texture on bearing performance. The research was analyzed by using theoretical modeling based Reynolds equation and CFD simulation based on Navier-Stokes equation. The analysis is carried out by comparing the pressure distribution and load carrying capacity. Based on analysis with both methods, the inertia effect is an important subject with variations on the Reynolds number and cell aspect ratio [1].

Research about validity of Reynolds equation and inertia effect was carried out on a textured slider with infinite length in 2D geometric model. Analysis was done by comparing pressure with numerical approach using Reynolds equation and CFD simulation which applying Navier-Stokes equation. Cell aspect ratio ( $\lambda$ ) and Reynolds number (Re) were varied by ignoring cavitation condition. In addition, accuracy of the Reynolds equation can be significantly improved by using inertia effect, but the use of inertia has negative impact to reduce load carrying capacity, especially on partial textures. [2]

Validity of Navier-Stokes equation and Reynolds equation also applied to lubrication modeling with roughness scale on the surface and explain the singularity

in momentum equation can generate higher pressure on CFD simulation than using Reynolds equation by assume the fluid is Newtonian, because discusses about singularity, then inertia effect is negligible. The analysis was done through commercial CFD software simulation and numerical calculations using Reynolds equation on single-textured bearings with 2D geometry model. [3]

In this study, validity of Navier-Stokes equation is analyzed on a simple single-textured thrust bearing with variations of Reynolds number and cell aspect ratio by comparing the results of pressure distribution based on Reynolds equation and Navier-Stokes equation, so we can find out parameter and boundary in thrust bearing analyzing with both methods.

## 2. METHOD

### 2.1. Theory

For the incompressible fluid analysis, continuity and Navier-Stokes equations, governing equations in CFD analysis, were used in this study and are expressed as follow [4].

$$\nabla \cdot \vec{v} = 0 \quad (1)$$

$$\rho \frac{D\vec{v}}{Dt} = -\nabla p + \mu \nabla^2 \cdot \vec{v} + S_M \tag{2}$$

where  $\vec{v}$  is the speed in Cartesian coordinates,  $S_M$  is the body force that affects the fluid flow,  $\mu$  is fluid viscosity,  $\rho$  is fluid density, and  $p$  is fluid pressure.

In this study, Reynolds number ( $Re$ ) and cell aspect ratio ( $\lambda$ ) is used, Reynolds number equation can be seen as follow [5].

$$Re = \frac{\rho v_{ave} l}{\mu} \tag{3}$$

where  $\rho$  is fluid density ( $kg/m^3$ ),  $\mu$  is fluid viscosity (Pa.s),  $v_{ave}$  is velocity flow average (m/s),  $l$  is length characteristic in flow (m). Based on Dobrica [2], cell aspect ratio ( $\lambda$ ) is important to be concerned, cell aspect ratio equation can be seen as follow, where  $h_d$  is height of the texture, and  $h_o$  is height of initial thrust bearing at the inlet suction.

$$\lambda = \frac{h_d}{h_o} \tag{4}$$

For numerical approach based on Reynolds equation, dimensionless equation were used in this study and are expressed as follow.

$$p^* = p h_o^2 / (U \mu B_o) \tag{5}$$

Where  $p^*$  is pressure non-dimensionles,  $p$  is pressure ( $kg/ms^2$ ),  $h_o$  is minimum film bearing thickness (m),  $\mu$  is fluid viscosity (Pa.s),  $U$  is bearing velocity (m/s), and  $B_o$  is length of bearing (m).

## 2.2. CFD Model

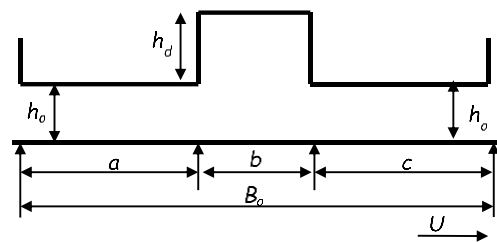
**Table 1.** Thrust bearing specifications for each region.

Parameter	Symbol	Value	Unit
Region 1 ( $\lambda = 1$ $Re = 1$ )			
Length of bearing	$B_o$	0.8	mm
Length of inlet	$a$	0.2	mm
Length of texture	$b$	0.4	mm
Length of outlet	$c$	0.2	mm
Minimum film thickness	$h_o$	0.4	mm
Depth of texture	$h_d$	0.4	mm
Inlet pressure	$P_a$	0	Pa
Sliding velocity	$U$	0.0109	m/s
Region 2 ( $\lambda = 1$ $Re = 8$ )			
Length of bearing	$B_o$	0.8	mm
Length of inlet	$a$	0.2	mm
Length of texture	$b$	0.4	mm
Length of outlet	$c$	0.2	mm
Minimum film thickness	$h_o$	0.4	mm
Depth of texture	$h_d$	0.4	mm

To find out validity of Navier-Stokes equation to Reynolds equation [2], thrust bearing single texture was analyzed without considering cavitation use 3 geometry which determined based on  $Re$  and  $\lambda$ . By divide 3 region we can identify thrust bearing characteristic as follows [2].

- Region I, where Reynolds number and cell aspect ratio used are low, on this region there is an assumption variation in film thickness with to bearing length is too few and followed by low inertia effects.
- Region II, where cell aspect ratio is low but has a huge range of Reynolds number so inertia is an important aspect that must be concerned.
- Region III, where can use high cell aspect ratio and Reynolds number so configuration can be more variable, in this region inertia effect is low, with wide variations in film thickness to bearing length.

Thrust bearing geometry in this study was analyzed by varying Reynolds number and cell aspect ratio, so there was differences in fluid velocity and texture height. Geometry of thrust bearing can be seen in Figure 1, for thrust bearing specifications in each region are shown in Table 1 and for fluid properties can be found in Table 2.



**Figure 1** Thrust bearing geometry.

Parameter	Symbol	Value	Unit
Inlet pressure	$P_a$	0	Pa
Sliding velocity	$U$	0.6977	m/s
Region 3 ( $\lambda = 16$ Re = 4)			
Length of bearing	$B_o$	0.8	mm
Length of inlet	$a$	0.2	mm
Length of texture	$b$	0.4	mm
Length of outlet	$c$	0.2	mm
Minimum film thickness	$h_o$	0.4	mm
Depth of texture	$h_d$	0.25	mm
Inlet pressure	$P_a$	0	Pa
Sliding velocity	$U$	5.5814	m/s

Table 2. Fluid properties.

Parameter	Symbol	Oil	Unit
Density	$\rho$	860	kg/m <sup>3</sup>
Viscosity	$\mu$	0.03	Pa.s

The use of computational grid was built using CFD analysis with quadrilateral type and uniform mesh structure. The number of grids in thrust bearing geometry for  $\lambda = 1$  with longitudinal ( $N_x$ ) and transverse ( $N_z$ ) directions is 200x80 and number of grids in thrust bearing geometry for  $\lambda = 16$  with longitudinal ( $N_x$ ) and transverse ( $N_z$ ) directions is 200x20, grid illustration can be seen in Figure 2.

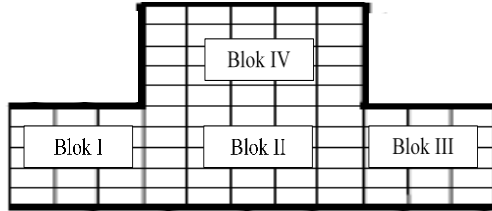


Figure 2 An illustration of the computational grid of thrust bearing.

### 3. RESULT AND DISCUSSION

Analysis was done by validate simulation model towards previously research [2] and [6]. The results of analysis on region 1 and region 2 showed the pressure distribution between both method does not match, so the geometry of thrust bearing in regions 1 and 2 only can be analyzed using Navier-Stokes equation, too low cell aspect ratio lead to few variations between bearing length and texture height that can be used, this can make configuration on velocity and thrust bearing geometry being not compatible. For region 3 showed pressure distribution on Navier-Stokes equation and Reynolds equation is suitable, so thrust bearing geometry in region 3 can be analyzed using both methods, pressure distribution Figure for each region can be seen in Figure 3.

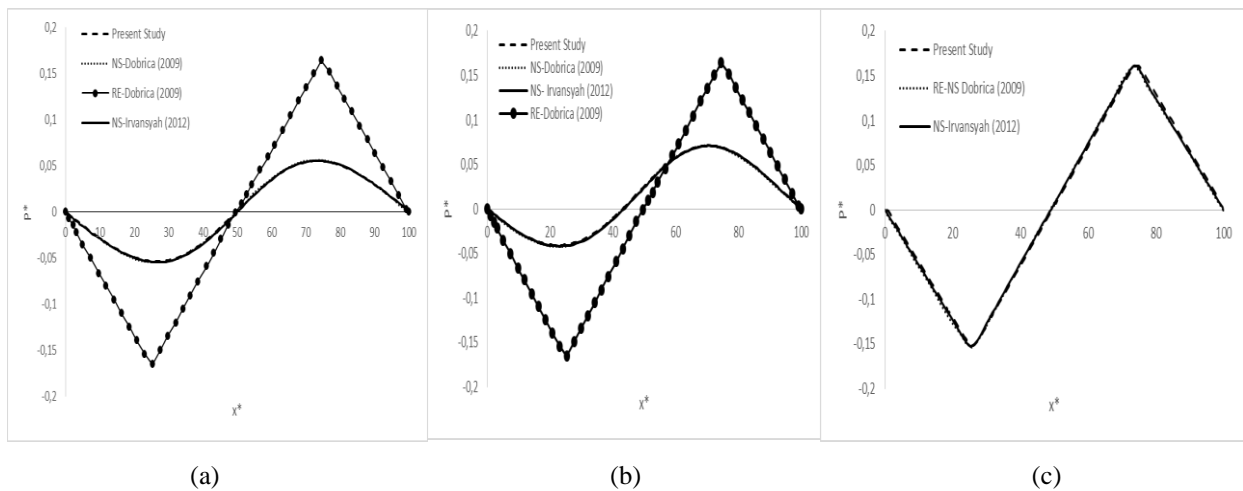


Figure 3 Pressure distribution on (a) Region 1 (b) Region 2 and (c) Region 3.

#### 4. CONCLUSION

Based on the analysis of validity Navier-Stokes, thrust bearing geometry on region 1 and region 2 can be only analyzed by using Navier-Stokes equation, while thrust bearing geometry on region 3 can be analyzed using both methods. Reynolds equation is not recommended to analyze thrust bearing with low cell aspect ratio which is a characteristic geometry on region 1 and region 2, because pressure distribution among Navier-Stokes equation and Reynolds equation have different curves. In the end, cell aspect ratio which is related to bearing geometry and Reynolds number which is related to velocity must be configured properly.

#### REFERENCES

- [1] Feldman Y, Kligerman Y, Etsion, I, Haber S, 2006 The validity of the reynolds equation in modelling hydrostatic effects in gas lubricated textured parallel surfaces. *ASME J. Tribol* **128** 345–350.
- [2] Dobrica M B, Fillon M, 2009 About the validity of Reynolds equation and inertia effects in textured sliders of infinite width *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology* **223(1)** 69–78
- [3] Almqvist A, Wall P, 2016 Modelling Cavitation in (Elasto) Hydrodynamic Lubrication. *Advances in Tribology*
- [4] Versteeg H K, Malalasekera W 1995 *An Introduction to Computational Fluid Dynamics The Finite Volume Method*, 1st ed. Essex: Longman Scientific & Technical
- [5] Çengel Y A, Cimbala J M, 2006 *Fluid mechanics: Fundamentals and applications*. Boston: McGraw-Hill Higher Education.
- [6] Irvansyah M, 2012 Effect of Wettability and roughness surface on hydrodynamic flow with slip boundary condition, Thesis Mechanical Engineering Universitas Diponegoro.