2D Flow Past a Confined Circular Cylinder with Sinusoidal Ridges

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INTRODUCTION: Using the CFD Module of COMSOL Multiphysics 5.4, we studied the flow past a circular cylinder with sinusoidal ridges (shown below), at Reynolds numbers of 20, 50, 200, and 500.

We define the cylinder in polar coordinates by

$$r(\theta) = \frac{L}{2} + a \cdot \cos(\omega\theta)\,, \quad 0 \le \theta \le 2\pi$$

Where L = 0.15m is the base cylinder diameter, a is the ridge amplitude, and ω is the number of ridges.

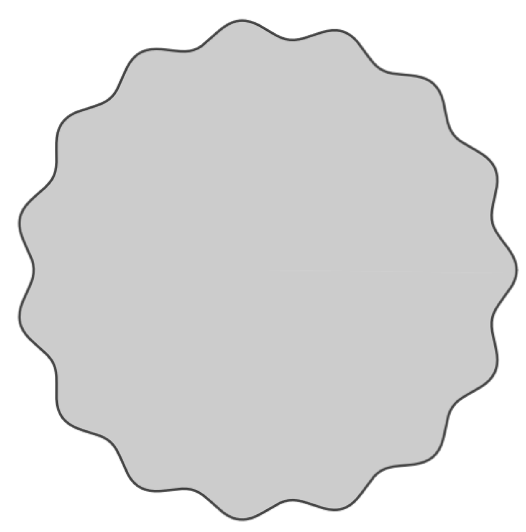
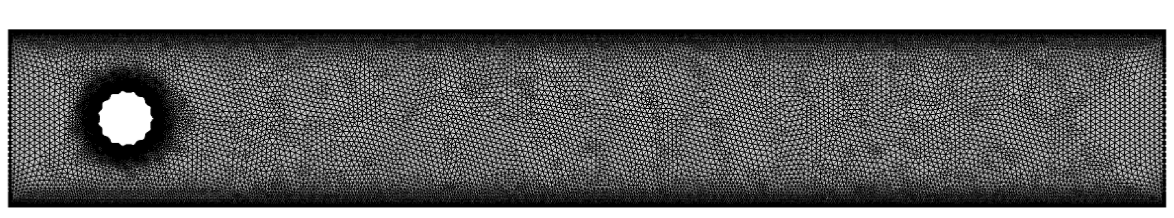


Figure 1. Sinusoidally ridged cylinder, a = L/25, ω = 15.

COMPUTATIONAL METHODS: The computational domain is a two- dimensional plane channel with length *20L* and width *3L*. The center of the cylinder is positioned in the center of the channel, a distance *2L* from the inlet. An inlet velocity with a parabolic profile is chosen at the leftmost wall, and a zero-pressure outlet boundary condition is chosen at the rightmost wall.

Inlet



Outlet

Figure 2. Computational domain with mesh

We use the following dimensionless quantities:

$$Re = \frac{\rho U_c L}{\mu} \qquad St = \frac{fL}{U_c},\; C_D = \frac{2F_D}{\rho U_c L},\; C_L = \frac{2F_L}{\rho U_c L}$$

Where U_c is the centerline velocity, f is the frequency of vortex shedding, and F_D, F_L are the total drag and lift forces, respectively.

Additionally, we perturb the flow with a brief vertical oscillation of the cylinder in order to trigger vortex shedding at Re = 200 and 500.

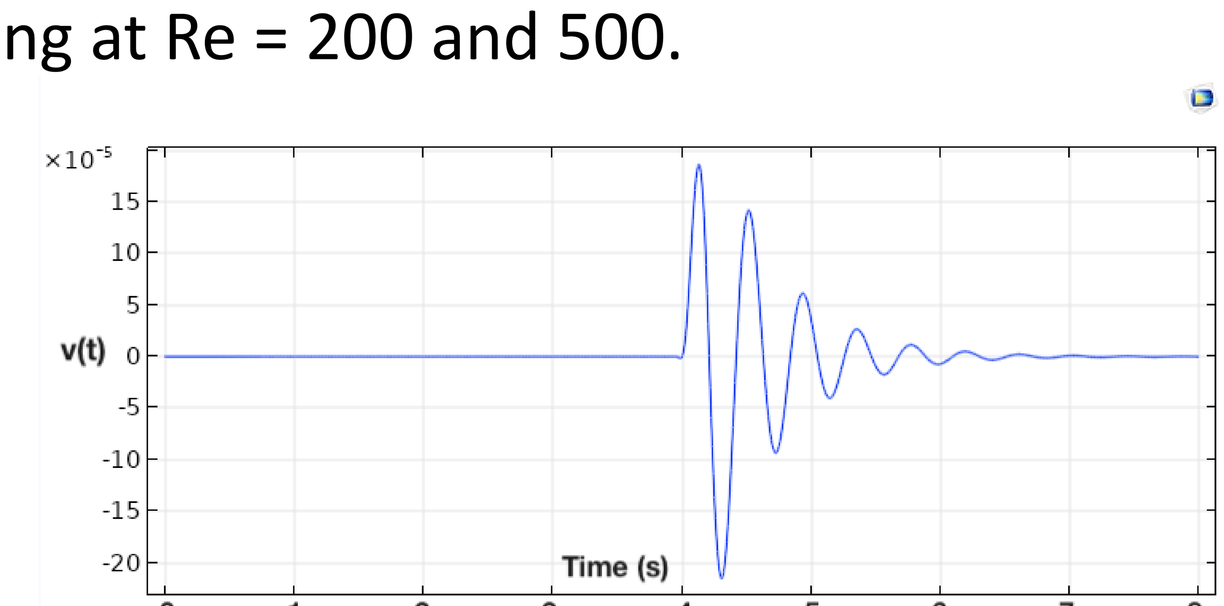


Figure 2. Perturbation velocity vs. time

VERIFICATION: We check our results for a smooth cylinder against Shäfer et al (1996)[1] and Singha (2010)[2]. The results match with excellent agreement.

RESULTS: In the laminar flow regime, we found:

- The recirculation zone length is independent from the number of ridges
- The following relationships between the number of ridges and C_D, and for ω = 4, between the counterclockwise angle of attack α and C_D:

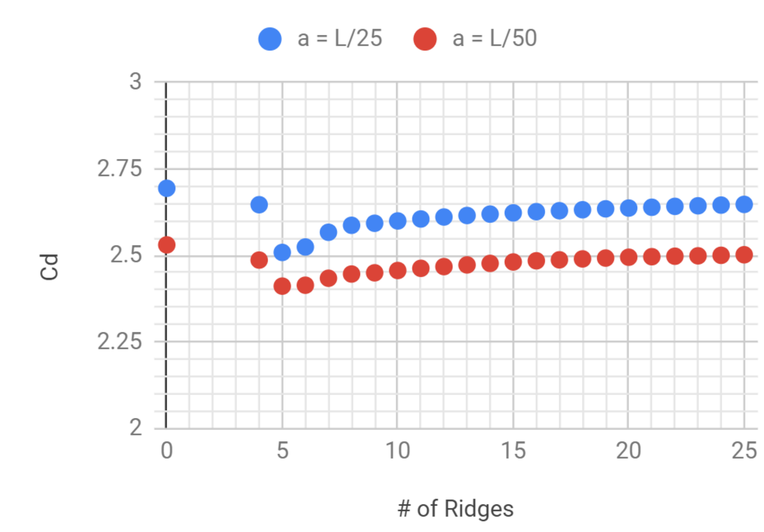


Figure 3. C_D vs. ω (Re = 50)

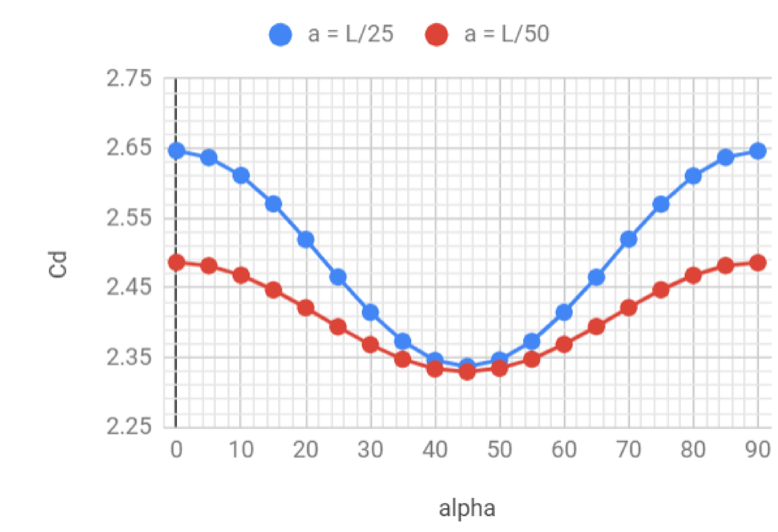


Figure 4. C_D vs. α (Re = 50, ω = 4)

- Similar relationships were found for Re = 20.

In the periodic shedding regime, we found the following relationships:

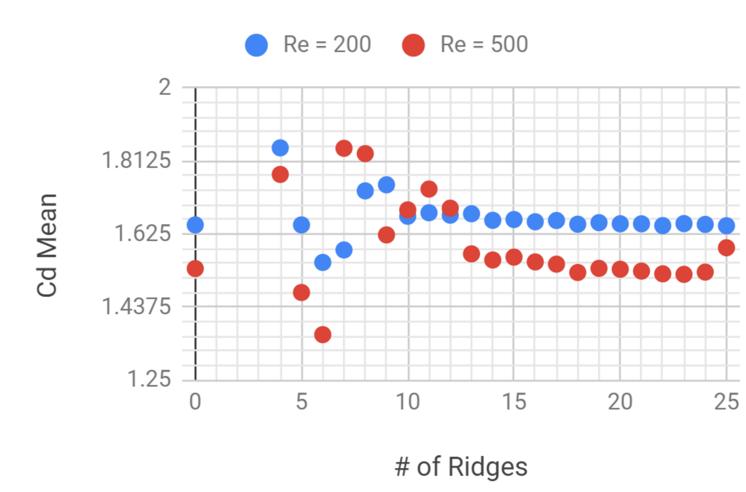


Figure 5. $C_{D,\,mean}$ vs. ω, Re = 200 and 500 (a = L/25)

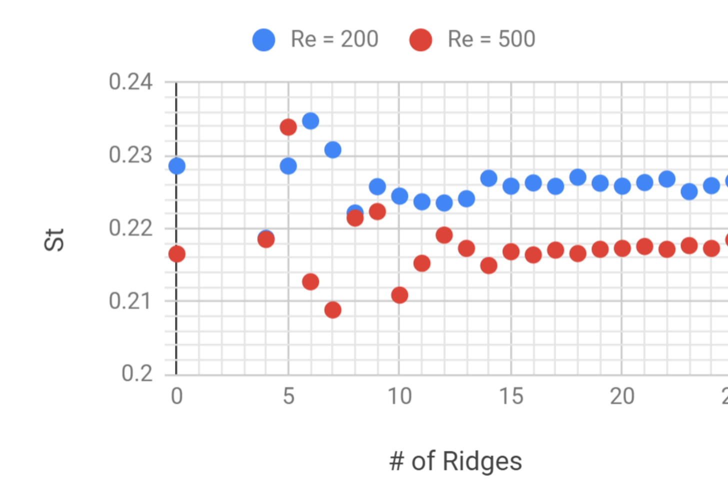


Figure 6. St vs. ω, Re = 200 and 500 (a = L/25)

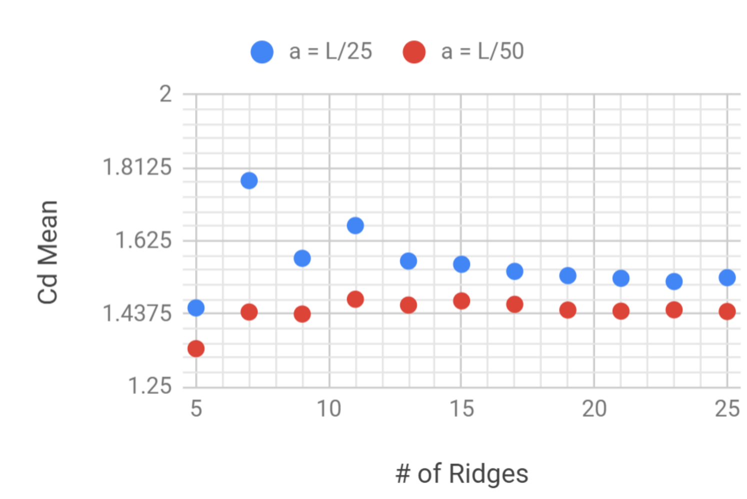


Figure 7. $C_{D,\,mean}$ vs. ω, a = L/25 and a = L/50 (Re = 500)

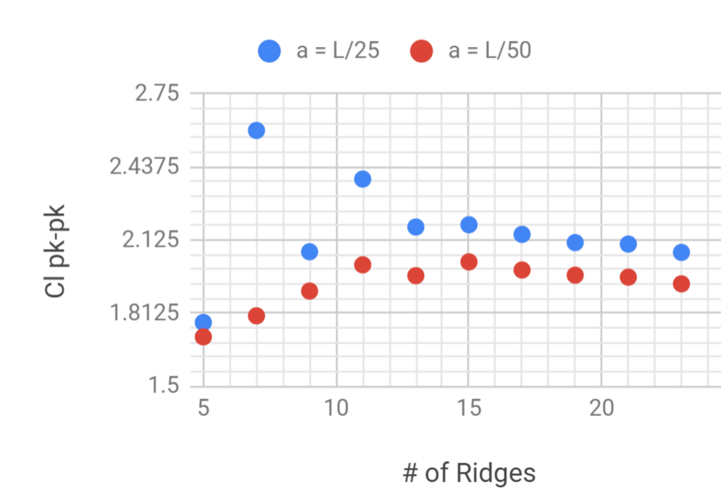


Figure 8. $C_{L,\,pkpk}$ vs. ω, a = L/25 and a = L/50 (Re = 500)

- Values for the Strouhal number, St, were also computed.

CONCLUSIONS & FURTHER RESEARCH:

- As ω increases, the C_D, C_L, and St values tend to approach that of a smooth cylinder (ω =0).
- When ω > ~13 in the periodic shedding regime, values for St, $C_{D,\,mean}$, and $C_{L,\,pkpk}$ become approximately steady. When ω < ~13, results are erratic and no clear trend can be deduced.
- More research needs to be done to investigate the unique geometry of cylinders with $1 \le \omega \le 4$.

REFERENCES:

1. Schäfer, M. et al., Benchmark computations of laminar flow around a cylinder, *Flow simulation with high-performance computers II*, pp. 547-566. Springer Vieweg Verlag, Germany (1996)
2. Singha, S. and Sinhamahapatra, K. P., Flow past a circular cylinder between parallel walls at low Reynolds numbers, *Ocean Engineering*, **37**, No. 8-9, pp. 757-769 (2010)

Acknowledgements

SUNY New Paltz Summer Undergraduate Research Experience (SURE) Program for 2018