# MECH 570C-FSI: Coding Project 1
# Fluid-structure interaction of a rigid circular cylinder

Winter Term 2, Year 2021-2022

The assignment will help build fundamentals for the fluid-structure interaction problem for a canonical problem of vortex-induced vibration by flow across a smooth circular cylinder. The fluid is modeled by the incompressible two-dimensional Navier-Stokes equations written in the arbitrary Lagrangian-Eulerian (ALE) framework. The rigid body structure with two degrees-of-freedom translation is solved in the Lagrangian description. The velocity continuity and the traction equilibrium is satisfied at the fluid-structure interface. The given code in MATLAB consists of the following functions:

1. navierStokes.m: Solves the Navier-Stokes equations in the ALE framework with generalized-$\alpha$ time integration written in predictor-corrector format. The different terms in the variational form of the Navier-Stokes equations are in turn specified in the following functions:
   - GalerkinTerms.m
   - PetrovGalerkinTerms1.m
   - PetrovGalerkinTerms2.m
   - PetrovGalerkinTerms3.m
2. rigidBody.m: Solves the rigid body equation by the generalized- $\alpha$ time integration.
3. IntegratedOutput.m: Calculate the integrated traction values at the fluid-structure interface which is then transferred to the structural equation.
4. aleMesh.m: Solves the ALE mesh Laplace equation to move the fluid mesh nodes.

The problem definition and the sequence of solution is written in main.m. The assignment consists of the following parts:

1. Read through the implementation and understand the data structures and the sequence of data transfer.
2. The function IntegratedOutput.m is incomplete with respect to the evaluation of the traction forces along the fluid-structure interface. Complete the function and validate the solver (without any ALE mesh movement) for flow over stationary cylinder at Reynolds number of $Re = \left(\rho^{\mathrm{f}} U_\infty D/\mu^{\mathrm{f}}\right) = 100$, where $\rho^{\mathrm{f}}$ and $\mu^{\mathrm{f}}$ are the density and dynamic viscosity of the fluid, $U_\infty$ is the freestream velocity and $D$ is the diameter of the cylinder. Plot the temporal variation of the lift and drag coefficients for the time steps of around 2000 with $\Delta t = 0.1$ and find out the mean drag and root mean square and maximum lift coefficients. The validation values are the following: $\bar{C}_D = 1.375, C_l^{\max} = 0.3352$ and $\bar{C}_l^{\mathrm{rms}} = 0.2368$ (about mean).
3. After validating the stationary circular cylinder problem, write the function aleMesh.m which will solve the ALE mesh Laplace equation to compute the ALE displacements and velocity for the fluid nodes. The variable for ALE displacement and velocity are Sol.aleDisp and Sol.aleVel respectively. Note that Sol.aleVel = (Sol.aleDisp Sol.aleDispPrev)/solver.dt. You can get some help in writing the function by the HINT file provided for solving a 2D Poisson equation for a scalar (Poisson2D.m).
4. Once the ALE mesh equation is implemented correctly, run a case of two degrees-of-freedom VIV of the cylinder with no damping coefficient at $Re = 200$ with mass ratio, $m^* = 4m/\left(\rho^{\mathrm{f}}\pi D^2\right) = 10$, reduced velocity $U_r = U_\infty/\left(f_n D\right) = 5$, where $m$ is the mass of the cylinder and $f_n = (1/2\pi)\sqrt{k/m}$ is the natural frequency of the elastically mounted cylinder with $k = k_x = k_y$ being the stiffness of the spring. The results can be

compared to the computations carried out in Table 1 of the following paper:
"On the vortex-induced oscillations of a freely vibrating cylinder in the vicinity of a stationary plane wall," L. Zhong, W. Yao, K. Yag, R. Jaiman, B. C. Khoo, Journal of Fluids and Structures, 65, Pg. 495-526 (2016).

Grading breakdown of this coding Project 1:

- Coding and debugging (60%): As described earlier, you need to program and debug your new codes systematically.
- Verification and validation (20%): You need to perform a systematic mesh convergence and comparison of your numerical solutions with the reference data.
- Project report (20%): In the report, you need to provide the description of FSI methodology, numerical implementation details, FSI coupling strategy.You need to critically summarize what has been done and what you learned.