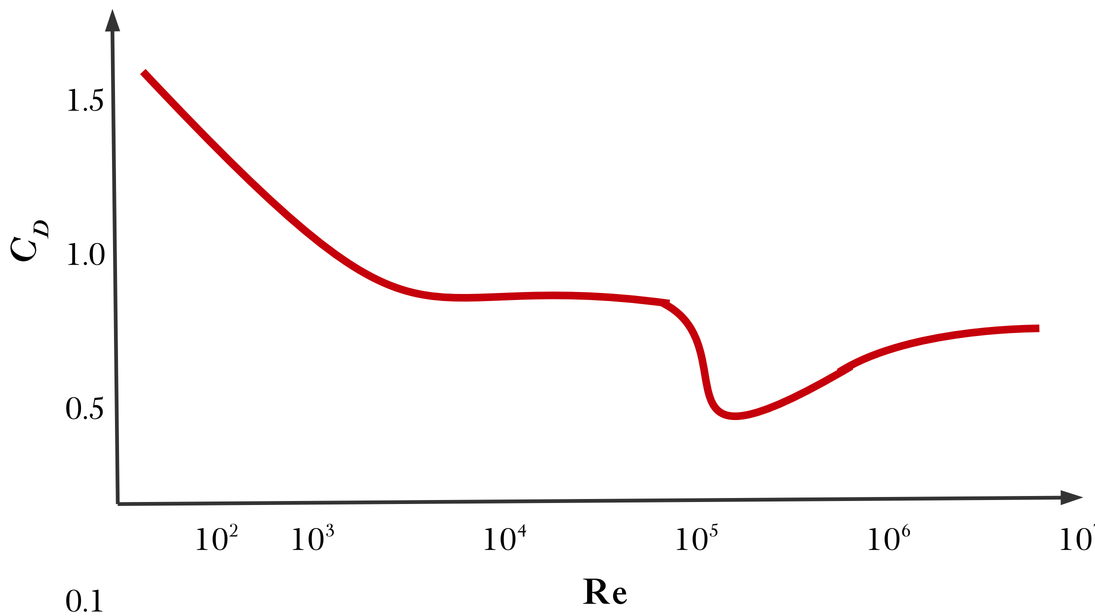
Parametric Study of Drag on a Sphere (30 points)

Drag represents the resistance to fluid flow by an interface. Commonly, the force due to drag F_D is calculated according to the *drag formula*

$$F_D = ½\, \rho\, v^2\, C_D\, A$$

where C_D is the drag coefficient; A is cross-sectional area presented to the flow; v is flow mean velocity; and ρ **is the fluid density**. Different contributions to the overall drag are important at different Reynolds numbers of stream flow, such as lift-induced drag, skin friction, wave drag, etc. NASA derived this curve to describe the relationship across a range of Re:



At very low Re, the flow remains attached (not pictured). As Re increases, Stokes flow dominates with steady separated flow (2). Vortex streets are produced around point 3, with separated unsteady flow downstream and a laminar boundary layer; as the flow speed increases, the street transitions to a fully chaotic turbulent wake (4). Finally, past point 5 we observe post-critical separated flow with a fully turbulent boundary layer[NASA]. Flow past a smooth sphere becomes turbulent around Re ~ 2300; you will need a turbulence model past this point. Should flow be considered compressible at higher Re ($M > 0.3$)? Should you use 2D or 3D?

In this exercise, you will simulate two-dimensional flow past a sphere for a range of Re values, from 10^2–10^7. You will calculate the drag coefficient C_D for at least 11 points between 10^2–10^7. In order to render this simulation more tractable, you may compose a script to automatically solve the model and calculate C_D; details are left to your discretion.

Your report should resemble the parameters given in earlier homework assignments. In particular, include details of turbulence as well as a plot similar to the NASA one of C_D v. Re for the values you calculate. Plot contours of vorticity magnitude, velocity, turbulent kinetic energy (where appropriate), etc. Finally, calculate responsibly! Validate your mesh (via convergence), confirm your turbulence model's appropriateness, etc.