**MEEN 673** **Spring Semester 2023**

# Nonlinear Finite Element Analysis

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## ASSIGNMENT No. 6

## 2-D Penalty Finite Element Model of the Navier–Stokes Equations

**Date: 3 April 2023** **Due: 6pm on 13th April 2023**

Develop a 2-D nonlinear finite element computer program based on the penalty finite element formulation and (a) direct iteration and (b) Newton's iteration to analyze steady-state flow problems in two dimensions (see Chapter 10 of the textbook). Validate your program by analyzing

(1) **Problem 1**: the linear problem of *fluid squeezed between parallel plates* (Section 10.8.2 for the data) and

(2) **Problem 2:** the nonlinear problem of the *lid-driven cavity* (see Example 10.8.4 for the data).

Duplicate the linear results presented in Figures 10.8.2 & 10.8.3 and Table 10.8.1 for Problem 1, and Figures 10.8.10 & 10.8.11 and Table 10.8.4 for Problem 2 of the text book. Use $10 \times 6$L4 and $5 \times 3$Q9 nonuniform meshes (see Fig. 10.8.1) for Problem 1. Pick $\rho = 1$ and $\mu = 1$ for the fluid squeezed between plates. Take $\mu = 1$ and vary $\rho$ to obtain the desired Reynolds number, $Re = \rho V L/\mu$ for the lid-driven cavity problem. Here $L$ is the characteristic length and $V$ is the characteristic velocity. For the lid-driven cavity problem, we take $L = 1$ and $V = 1$. You may wish to investigate the influence of the penalty parameter ($\gamma$) on the solution accuracy prior to solving the problems assigned (because you must solve them with a $\gamma$ value you consider is good enough for accuracy). The results reported in the text book are with $\gamma = 10^8$.

You must submit your computer program and results in the same form as those listed in the text book.