# ME-822: Computational Fluid Dynamics I

FINAL PROJECT

Due on Jun 27, 2011

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + (\frac{Pr}{Ra})(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2})$$

Consider a 2-D lid-driven cavity flow governed by the following nondimensional incompressible Navier-Stokes equations in a rectangular domain $0 \leq x \leq X_L$ and $0 \leq y \leq Y_L$:

$$\frac{\partial u_i}{\partial t} + \frac{\partial}{\partial x_j}\big(u_j u_i\big) = -\frac{\partial p}{\partial x_i} + \frac{1}{\text{Re}}\frac{\partial u_i}{\partial x_j x_j} \qquad \text{for } i = 1, 2$$

with the following boundary conditions on $u_i = (u, v)$:

$$u(0, y) = 0 \text{ and } v(0, y) = 0$$
$$u(X_L, y) = 0 \text{ and } v(X_L, y) = 0$$
$$u(x, 0) = 0 \text{ and } v(x, 0) = 0$$
$$u(x, Y_L) = U_\infty \text{ and } v(x, Y_L) = 0$$

where Re $= \frac{X_L U_\infty}{\nu}$, $X_L = 1$, $Y_L = 1$, and $U_\infty = 1$.

1. Develop a CFD code for the above equation using artificial compressibility method and FTCS scheme as discussed in the class with $\beta^2 = 0.6$ (factor in the coninuity equation):

$$\frac{\partial p}{\partial \tau} + \frac{1}{\beta^2}\frac{\partial u_j}{\partial x_j} = 0$$

2. Validate your results on a $81 \times 81$ uniform grid at Re $= 1000$ by comparing the u-velocity distribution along vertical centerline and v-velocity distribution along horizontal centerline with the results obtained in other numerical studies. NOTE: Numerical results for Re $= 1000$ can easily be found using internet. Use appropriate tolerance criteria.

3. Verify your results by performing grid independent studies for the parameters used in the previous step.

4. Plot the horizontal and vertical velocity component contours, spanwise vorticity contours, and velocity vector plots.

5. Plot and comment on the behavior of convergence with time. Is it monotone?

6. Study convergence on various grid sizes. Plot and comment on the CPU time vs grid sizes.

7. Study different tolerance criteria for convergence. Plot and comment on the CPU time vs tolerance. Use semilog plot.

8. Vary Re $= 100 - 1000$ with an increment of 100 and comment on the qualitative change in the flow structure; especially on the location of primary and secondary vortices. Make a table with three columns: (1) Re $= 100, 200, ..., 1000$ (2) minimum horizontal velocity ($u_{min}$) within primary vortex and (3) corresponding coordinates.

9. BONUS: Perform (3) on a $61 \times 61$ non-uniform grid such that minimum $\Delta x = 1/80$.

## PROJECT STATEMENT

You are on the design team of a new subsonic bomber aircraft. Since you have studied CFD-I, you have been tasked to analyze the flow in the weapons bay of the aircraft. As an engineer, you approximate the problem with a 2-D lid-driven cavity flow. After succesfully performing YOUR analysis, you plan to submit your findings in 2012 IEEE Aerospace Conference to be held in Montana, USA. Write a preliminary research paper strictly following IEEE template (MS word or Latex) [10 points] with the following sections:

1. Title, Author, Affiliation, and Abstract [5]
2. Introduction [10]
3. Numerical Methodology [20]
4. Results [20]
5. Discussion [20]
6. Conclusion [5]
7. Acknowledgment (if any)
8. Bibliography (at least 10 references) [5]
9. Appendix (print your code) [5]

**IMPORTANT NOTES**:

1. Page limit for the research paper is minimum 4 pages and maximum 8 pages excluding Bibliography and Appendix.
2. You are also required to give a 15 minute powerpoint presentation [25] on your work followed by Question/Answer Session. Date, time, and place will be announced later.
3. The paper will be reviewed with following possible decisions:
   (a) Accepted (85% or above)
   (b) Accepted with Minor Revisions (70% or above)
   (c) Accepted with Major Revisions (50% or above)
   (d) Rejected (below 50%)
4. Use of any unfair means, including copying or helping others in copying, will result in REJECTION of the paper.