UNIVERSITY of WASHINGTON

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Benchmark Comparison of Natural Convection in a Tall Cavity

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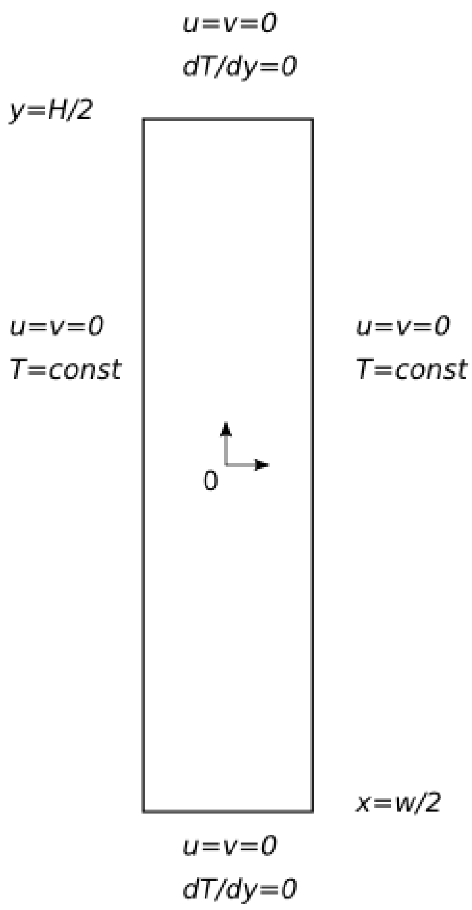
Overview

- Problem Introduction
- Literature Review
- Modeling Discussion
- Modeling Results
  - Numerical Diffusion Effects
  - Low Aspect Ratio
  - High Aspect Ratios
- Conclusions

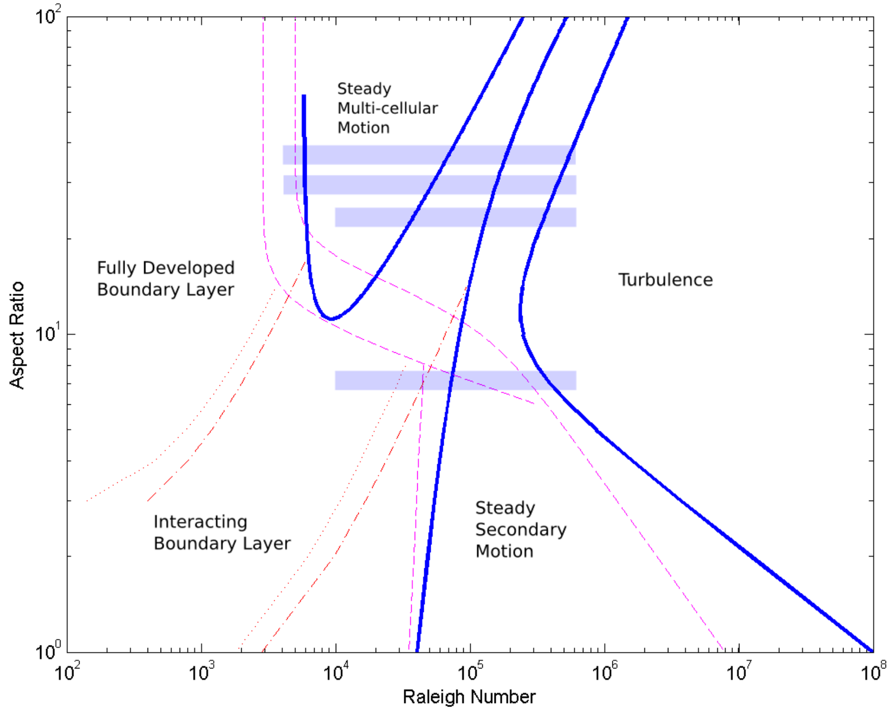
Problem Introduction

- Tall rectangular air cavity
- Isothermal vertical walls
- Temperature gradient drives natural convection
- Non-Boussinesq fluid assumption



Literature Review

- Small number of studies for non-square geometries
- Even smaller number of experimental studies, primarily only one experimental data point (Vest and Arpaci) for A=33.
- Computational map by Chenoweth shows stability lines predicted in other modeling work.



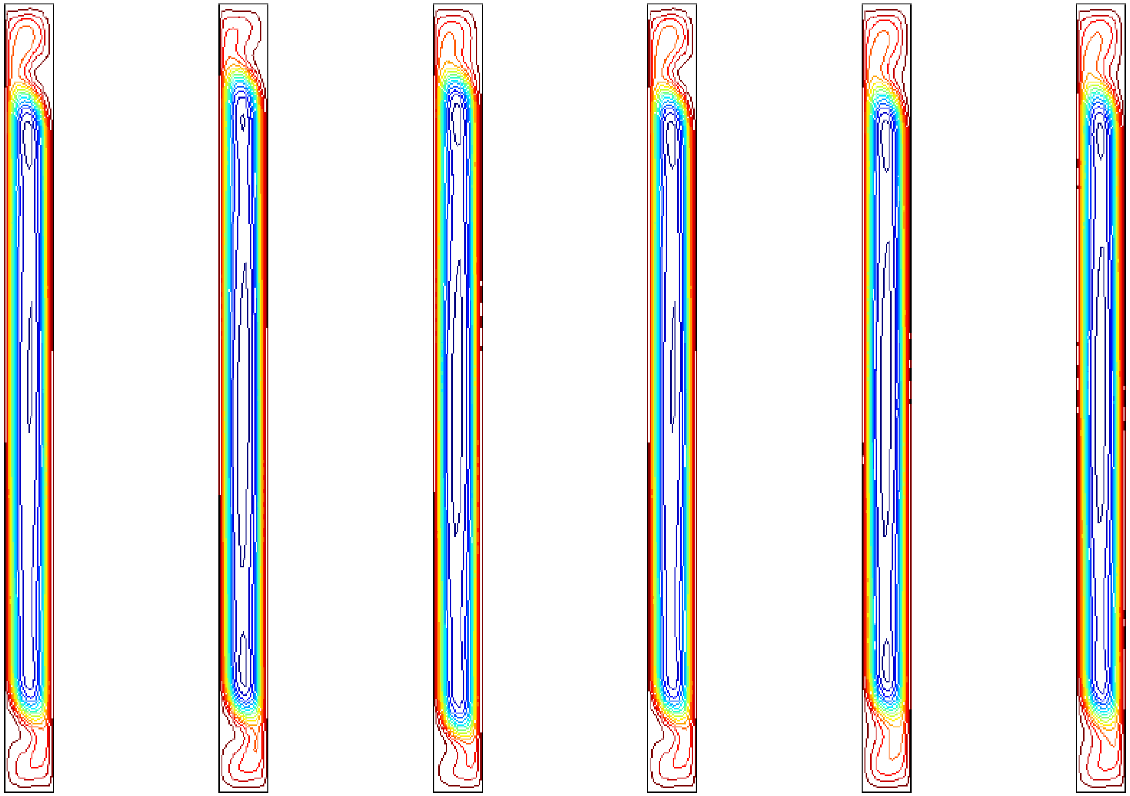
Modeling Discussion

- Weakly compressible Navier-Stokes and coupled heat transfer module
- Air properties ideal gas calculated by COMSOL and polynomial fit over appropriate range
- Started at a low Rayleigh number and increased the wall temperature in one degree increments
- 5513 degrees of freedom
- Computational time ~20 minutes per Rayleigh number
- Required extensive exploration of numerical diffusion settings in COMSOL

Modeling – Numerical Diffusion

- Several methods in COMSOL to adjust numerical diffusion
  - Isotropic diffusion. Dampens oscillations in problem of this type.
  - Anisotropic diffusion. Somewhat helpful, found a reduction from default values required.
  - Galerkin least-squares (GLS). Required for problem to converge.
  - Streamline Upwind Petrov-Galerkin (SUGP). No advantage over GLS for this problem.
  - Crosswind Diffusion. Order of magnitude reduction in tuning parameter (ck=0.01) required to match experimental results.

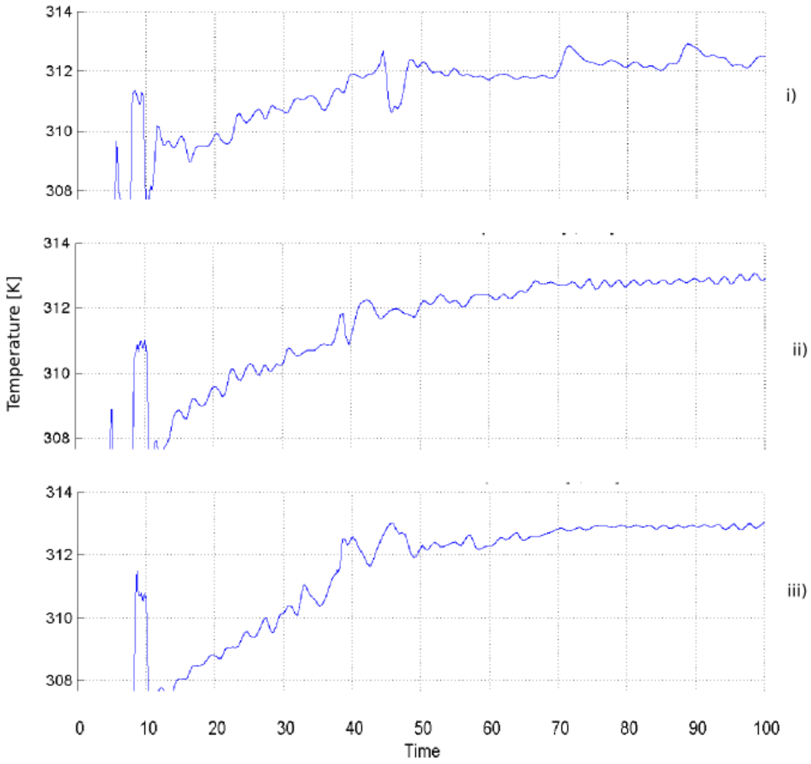
Modeling – Numerical Diffusion



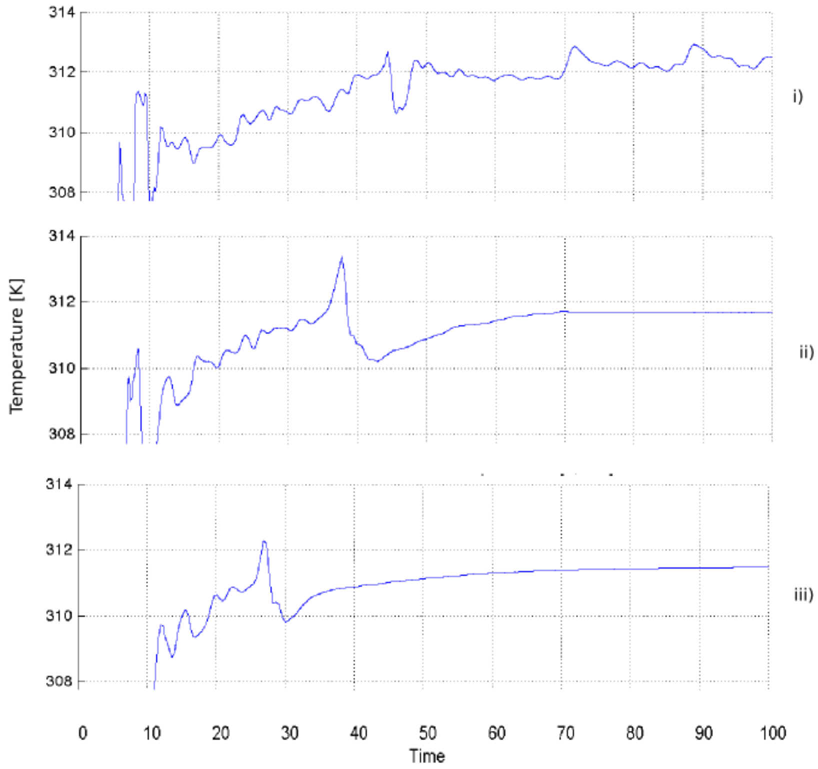
(a) $\delta_{sd} = 0.05$ (b) $\delta_{sd} = 0.15$ (c) $\delta_{sd} = 0.25$ (d) $c_k = 0.01$ (e) $c_k = 0.05$ (f) $c_k = 0.1$

Modeling – Numerical Diffusion

Anisotropic Diffusion



Crosswind Diffusion



Effect of variation of diffusion for Ra = 2:5e5, A = 15 on the air temperature located at 2/3 of the full cavity height (upper half). a) Diffusion where ck = 0:01. i) δsd = 0:05 ii) δsd = 0:15 iii) δsd = 0:25. b) Diffusion where δsd = 0:15. i) ck = 0:01 ii) ck = 0:05 iii) ck = 0:1.

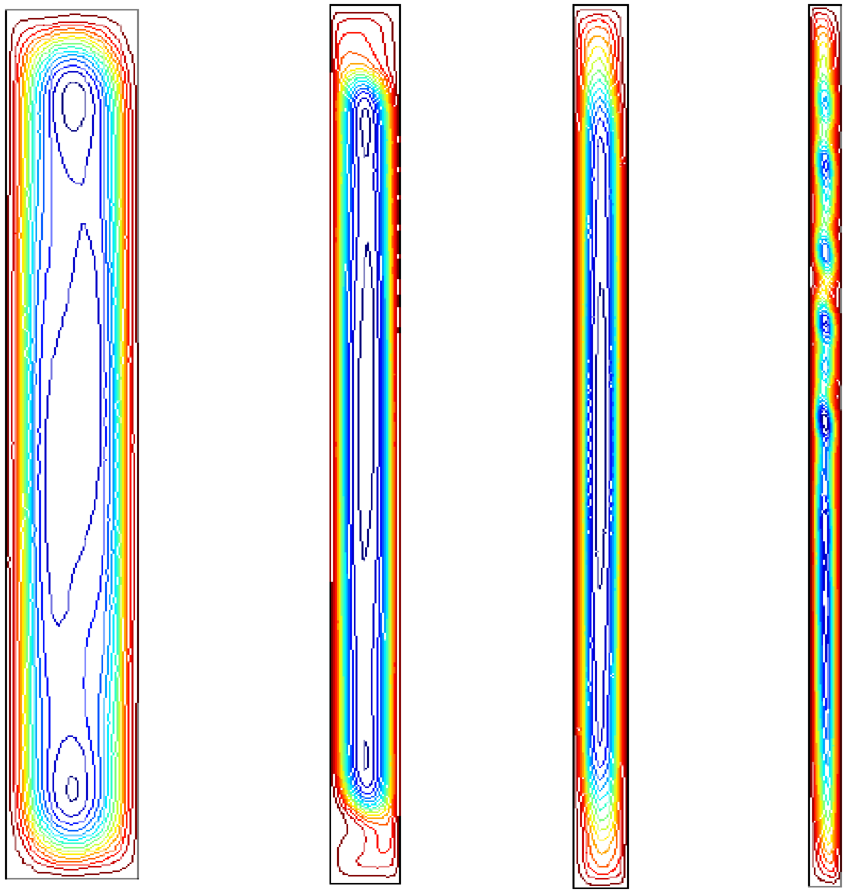
Modeling Results

- Fair comparison of critical Rayleigh number and wavenumber for experimental data point, A=33.
- Good comparison with other computational results for A=15.
- Fair comparison with other computational results for A=20 (one stability change found)
- Poor comparison with low aspect ratio computational work A=8. This may be due to non-Boussinesq assumption or numerical diffusion tuning.

Modeling Results

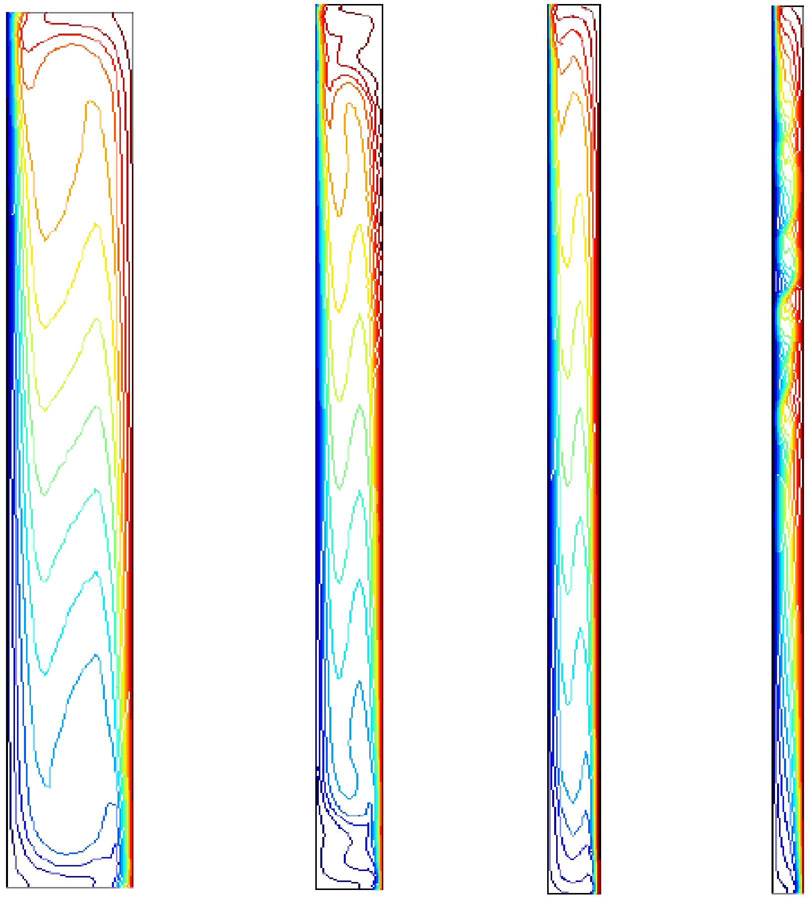
Author	Racritical	Wave Number
A = 8		
Xin and Le Quere [18]	3.1e5	1.7
Present work	-	-
A = 15		
Liakopoulos et al. [12]	1.4e5	
Present work	1.4e5	2.62
A = 20		
Lee and Korpela [11]	1.1e4	2.82
Liakopoulos et al. [12]	7.1e3	-
Vest and Arpaci [17]	3.7e5	3.5
Present work	3.2e4	-
A = 33		
Reeve [15]	6.7e3	2.77
Vest and Arpaci [17]	6.2e3	2.74
Present work	5.8e3	2.49

Modeling Results - Streamfunctions



(a) A=8 (b) A=15 (c) A=20 (d) A=33

Modeling Results – Temperature Contours



(a) A=8 (b) A=15 (c) A=20 (d) A=33

Conclusions

- Dramatic tuning of numerical diffusion parameters required in COMSOL to match experimental results.
- Lack of experimental work for this area makes it difficult to determine the accuracy of other computation models.
- COMSOL appears to compare fairly well with most other computational work in this area once numerical diffusion parameters are adjusted.