TEST CASE DOCUMENTATION
AND TESTING RESULTS

TEST CASE ID ICFD-BENCH-4.1

Convection problem

Tested with LS-DYNA® v980 Revision Beta

Wednesday 8th August, 2012

LSTC Livermore Software Technology Corp.

Document Information	
Confidentiality	**external use**
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Contents

1 Introduction

1.1 Purpose of this Document

This document specifies the test case ICFD-BENCH-4.1. It provides general test case information like name and ID as well as information to the confidentiality, status, and classification of the test case.

A detailed description of the test case is given, the purpose of the test case is defined, and the tested features are named. Results and observations are stated and discussed. Testing results are provided in section 4.1 for the therein mentioned LS-DYNA® version and platforms.

2 Test Case Information

Test Case Summary	
Confidentiality	external use
Test Case Name	Convection problem: 2D Natural Convection in a Square Cavity
Test Case ID	ICFD-BENCH-4.1
Test Case Status	Under consideration
Test Case Classification	Benchmarking
Metadata	THERMAL PROBLEM

Table 1: Test Case Summary

3 Test Case Specification

3.1 Test Case Purpose

The purpose of this test case is to illustrate the capability of the ICFD solver to solve problems characterized by free convective recirculating flow fields. It makes use of the conjugate heat transfer solver implemented within the ICFD solver.

3.2 Test Case Description

The problem considered here is that of a two dimensional flow of a Boussinesq fluid. In fluid dynamics, the Boussinesq approximation is used in the field of buoyancy-driven flows (also known as natural convection flows). It states that the fluid's density variations with temperature can be neglected except where they appear in terms multiplied by the acceleration of gravity. In that case, instead of setting up a problem with the density function of temperature, a buoyancy term is added in the momentum equation :

$$\rho \mathbf{u} \nabla \mathbf{u} = -\nabla p + \rho \mathbf{g} \beta T + \mu \nabla^2 \mathbf{u} \tag{1}$$

where $\mathbf{u}$ is the velocity, ρ, the density, p the pressure, μ the viscosity, T the operative temperature and β the volume expansion coefficient.

This model known as the Boussinesq Model is known to be accurate for many flows but should not be used if the temperature differences in the domain are large. The strength of the buoyancy-induced flow is measured by the Raleigh number :

$$R_a = \frac{g \beta T L^3 \rho}{\mu \alpha} \tag{2}$$

And the ration of momentum diffusivity to thermal diffusivity is given by the Prandtl number :

$$P_r = \frac{\mu}{\rho \alpha} \tag{3}$$

where α is the diffusivity and L the characteristic length of the problem.

The geometry of the problem consists of a simple square cavity of dimensionless length $L = 1$. The horizontal walls are insulated and the vertical walls are at constant different temperature. Fluid near the temperature sidewall will become hotter due to conduction. This fluid will become less dense than the bulk fluid and a buoyancy force acting vertically upwards will develop resulting from the density difference. The less dense fluid near the higher temperature will rise. The opposite is true for the fluid near the colder wall. This fluid will be more dense than the surrounding fluid and will fall The result is a circulation pattern developing in a counter clockwise manner if the right side temperature is larger than the left ([1]).

3.3 Model Description

The model studied here will reproduce the model described in [1] where dimensionless parameters are used allowing us to describe the fluid's physical parameters as in Table (3). The Prandtl number will remain constant and four choices of Rayleigh number will be studied.

Figure (1) offers a view of the geometry and mesh while Table (2) gives some additional information on the mesh.

Model information	
Surface Element size	0.025
Volume Nodes	3324
Volume Elements	6446
Anisotropic Elements added to the Boundary Layer	2

Table 2: Test Case Mesh Information

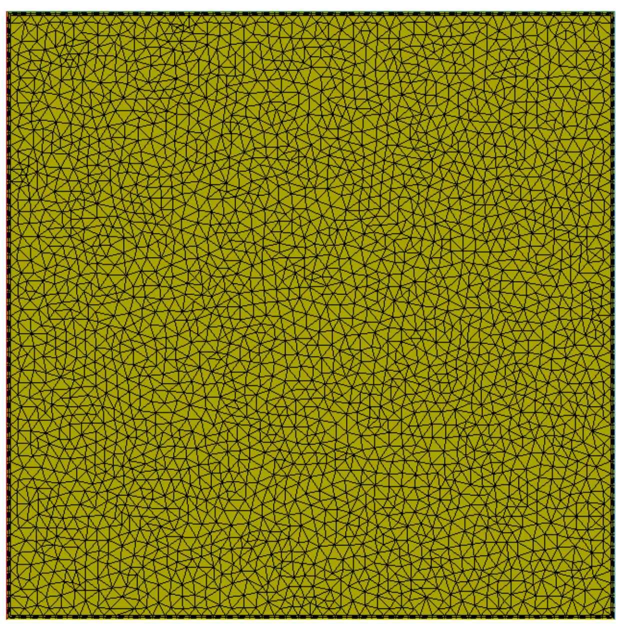

Figure 1: Test Case Mesh

Model physical parameters	
Fluid Density	$\sqrt{\frac{R_a}{P_r}}$
Thermal diffusivity	$\frac{\mu}{\rho P_r}$
Prandlt Number	0.71
Rayleigh number	10^3, 10^4, 10^5 and 10^6
Viscosity	1
Gravity	1
Volume expansion coefficient	1

Table 3: Test Case Parameters

4 Test Case Results

4.1 Test Case observations

Figure (2) shows the dimensionless Velocity Vector Field for the different Rayleigh numbers, Figure (3) shows the dimensionless temperature fringes and Figure (4) shows the horizontal and vertical velocities along $x = 0.5$ and $y = 0.5$ respectively. The results are in good agreement with the reference results of [1]. Table (4) compares the results regarding the maximum horizontal and vertical velocities with more references and further confirms the good behavior of the analysis.

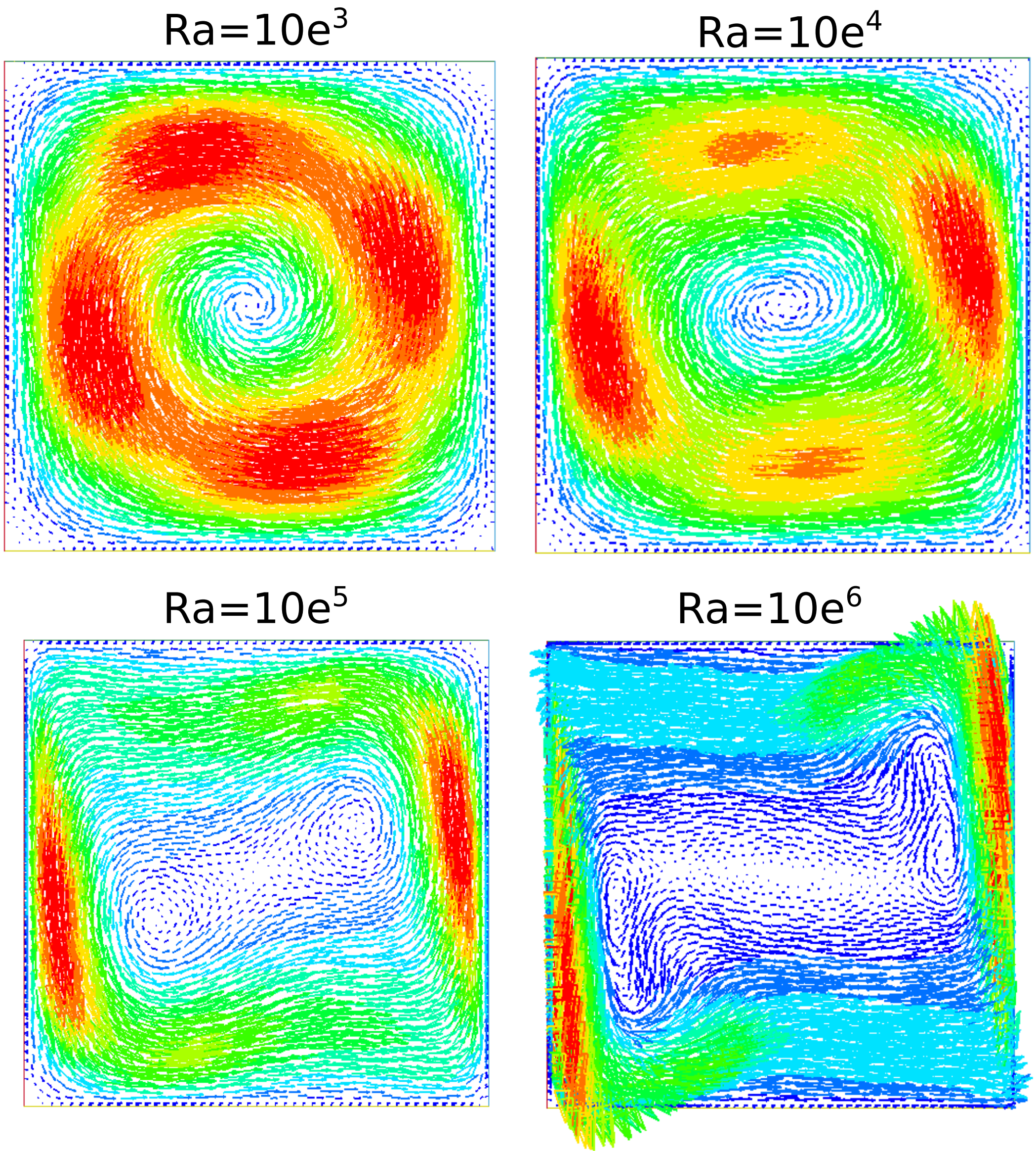

Figure 2: Dimensionless Velocity Vector Field

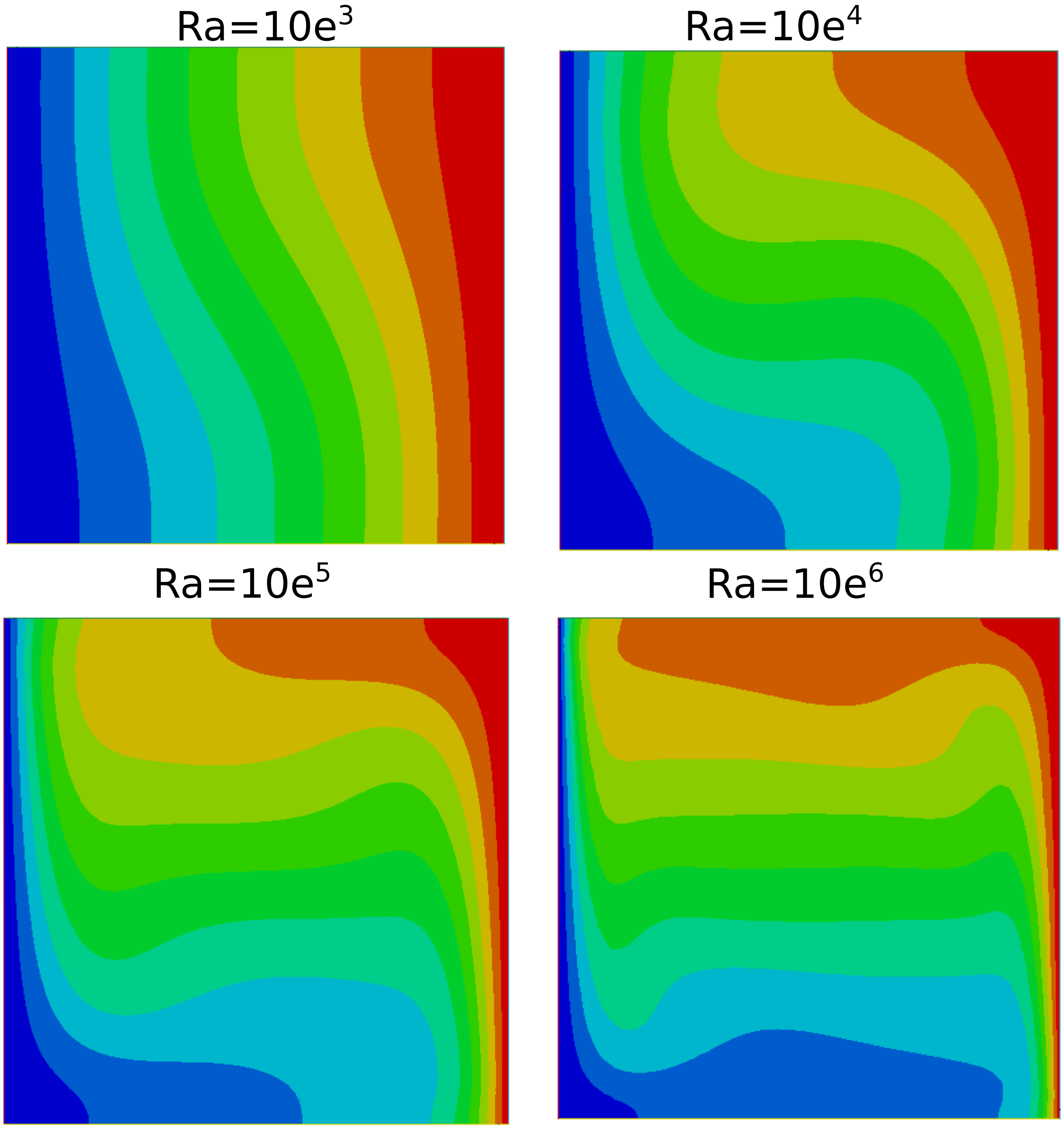

Figure 3: Dimensionless Temperature fringes

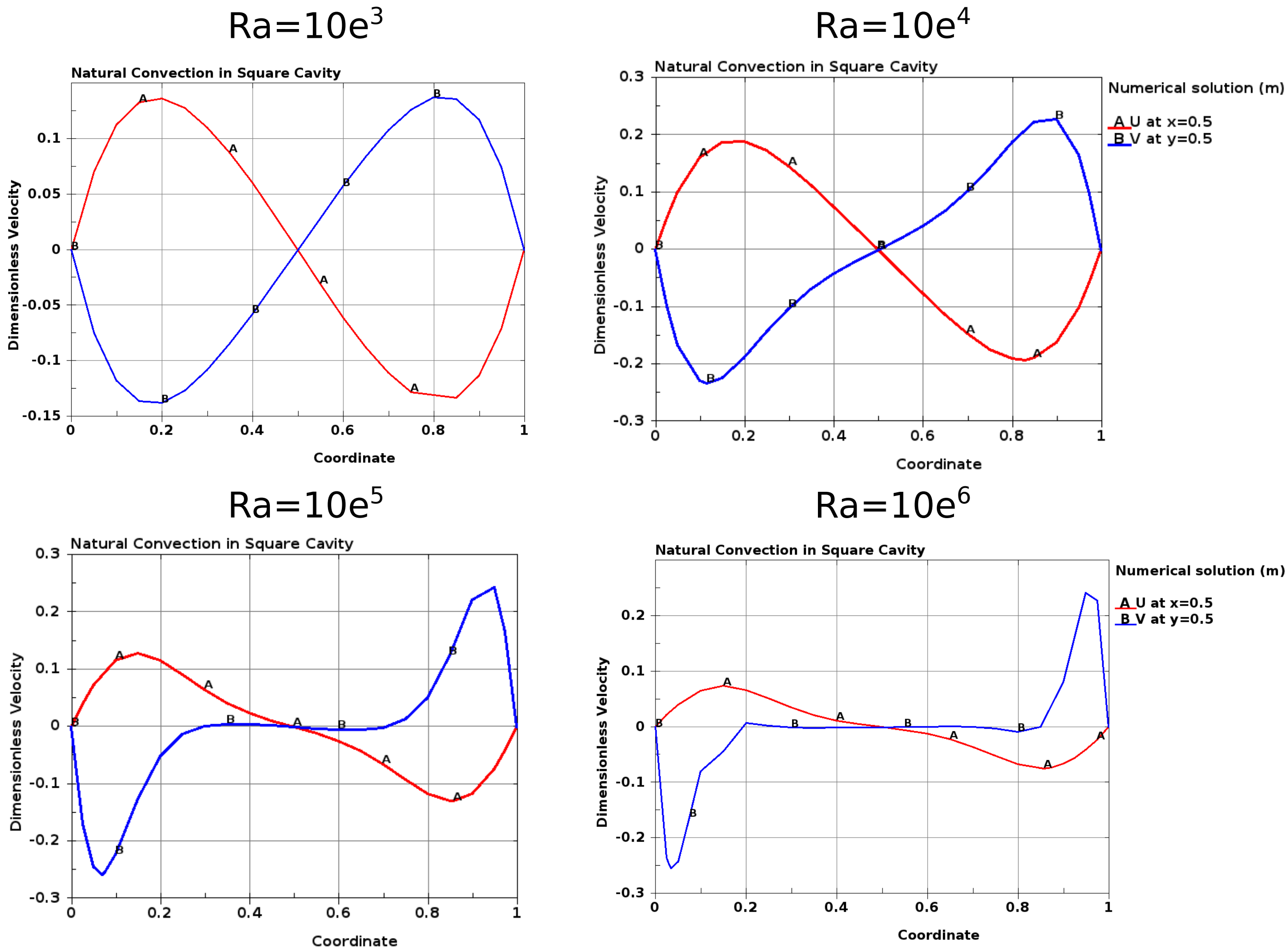

Figure 4: Horizontal Dimensionless Velocity at $x = 0.5$ in Red and Vertical Dimensionless Velocity at $y = 0.5$ in Blue.

	Present analysis	De Vahl Davis [2]	Fusegi et al [3]
$R_a = 10^3$			
U_{max} at $x = 0.5$	1.37 at y=0.810	0.136 at y=0.813	0.132 at y=0.833
V_{max} at $y = 0.5$	0.389 at x=0.177	0.138 at x=0.178	0.131 at x=0.2
$R_a = 10^4$			
U_{max} at $x = 0.5$	0.192 at y=0.830	0.192 at y=0.823	0.201 at y=0.817
V_{max} at $y = 0.5$	0.233 at x=0.116	0.234 at x=0.119	0.225 at x=0.117
$R_a = 10^5$			
U_{max} at $x = 0.5$	0.129 at y=0.859	0.153 at y=0.855	0.147 at y=0.855
V_{max} at $y = 0.5$	0.258 at x=0.069	0.261 at x=0.066	0.247 at x=0.065
$R_a = 10^6$			
U_{max} at $x = 0.5$	0.075 at y=0.858	0.079 at y=0.850	0.0847 at y=0.856
V_{max} at $y = 0.5$	0.254 at x=0.034	0.262 at x=0.038	0.259 at x=0.033

Table 4: Maximum Velocity Fields Comparison

References

[1] *FIDAP 7.0 Examples Manual*, Fluid Dynamics International, 1993.

[2] G. D. V. Davis, *Natural convection of air in a square cavity, a bench-mark numerical solution*, INTERNATIONAL JOURNAL FOR NUMERICAL METHODS IN FLUIDS, 3 (1983), pp. 249–264.

[3] D. A. Olson and L. R. Glocksman, *Transient natural convection in enclosures at high rayleigh number*, Journal Heat Transfer, 113 (1991), pp. 635–642.