UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

ESEIAAT - UPC

Study for the computational resolution of conservation equations of mass, momentum and energy. Possible application to different aeronautical and industrial engineering problems: Case 1B

Attachment A - Results

Author: Laura Pla Olea
Director: Carlos David Perez Segarra
Co-Director: Asensio Oliva Llena
Degree: Grau en Enginyeria en Tecnologies Aeroespacials
Delivery date: 10-06-2017

Contents

List of Tables ii

List of Figures iii

1 Smith-Hutton problem 1
- 1.1 $\rho/\Gamma = 10$ . . . 1
- 1.2 $\rho/\Gamma = 10^3$ . . . 3
- 1.3 $\rho/\Gamma = 10^6$ . . . 6

2 Driven cavity problem 8

3 Square cylinder 19

4 Bibliography 22

List of Tables

2.1 Error of the horizontal velocities in the vertical central plane 12
2.2 Error of the vertical velocities in the horizontal central plane 12

List of Figures

1.1 Representation of the whole domain for $\rho/\Gamma = 10$ (CDS) 1
1.2 Representation of the whole domain for $\rho/\Gamma = 10$ (UDS) 2
1.3 Representation of the whole domain for $\rho/\Gamma = 10$ (HDS) 2
1.4 Representation of the whole domain for $\rho/\Gamma = 10$ (EDS) 3
1.5 Representation of the whole domain for $\rho/\Gamma = 10$ (PLDS) 3
1.6 Representation of the whole domain for $\rho/\Gamma = 10^3$ (UDS) 4
1.7 Representation of the whole domain for $\rho/\Gamma = 10^3$ (HDS) 4
1.8 Representation of the whole domain for $\rho/\Gamma = 10^3$ (EDS) 5
1.9 Representation of the whole domain for $\rho/\Gamma = 10^3$ (PLDS) 5
1.10 Representation of the whole domain for $\rho/\Gamma = 10^6$ (UDS) 6
1.11 Representation of the whole domain for $\rho/\Gamma = 10^6$ (HDS) 6
1.12 Representation of the whole domain for $\rho/\Gamma = 10^6$ (EDS) 7
1.13 Representation of the whole domain for $\rho/\Gamma = 10^6$ (PLDS) 7

2.1 Comparison between the reference solution and the calculated one of the horizontal velocity along the vertical line in the geometric center of the cavity 9
2.2 Comparison between the reference solution and the calculated one of the vertical velocity along the horizontal line in the geometric center of the cavity 11
2.3 Horizontal velocity inside the cavity 14
2.4 Vertical velocity inside the cavity 16
2.5 Streamlines of the flow inside the cavity 18

3.1 Horizontal velocity in the channel 20
3.2 Vertical velocity in the channel 21

1 | Smith-Hutton problem

In the following sections there are represented the results of the Smith-Hutton problem for all the resolution schemes that have been coded.

1.1 $\rho/\Gamma = 10$

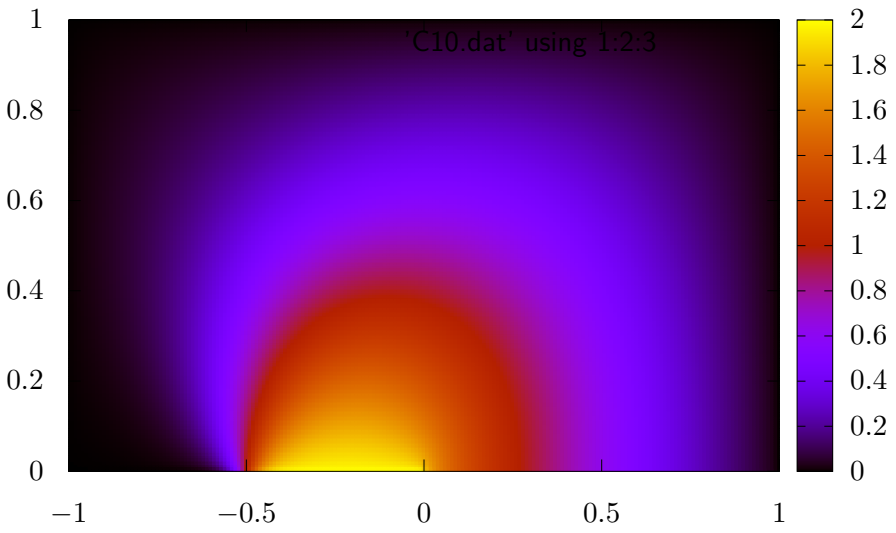


Figure 1.1: Representation of the whole domain for $\rho/\Gamma = 10$ (CDS)

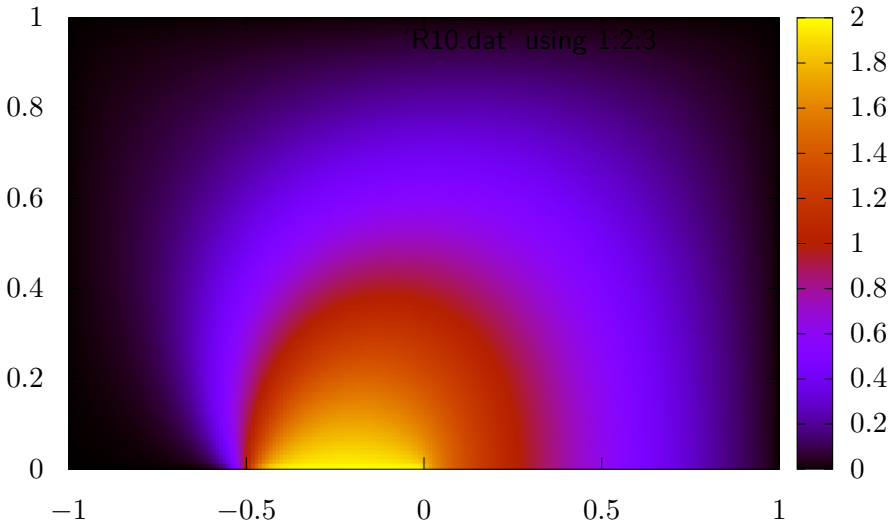


Figure 1.2: Representation of the whole domain for $\rho/\Gamma = 10$ (UDS)

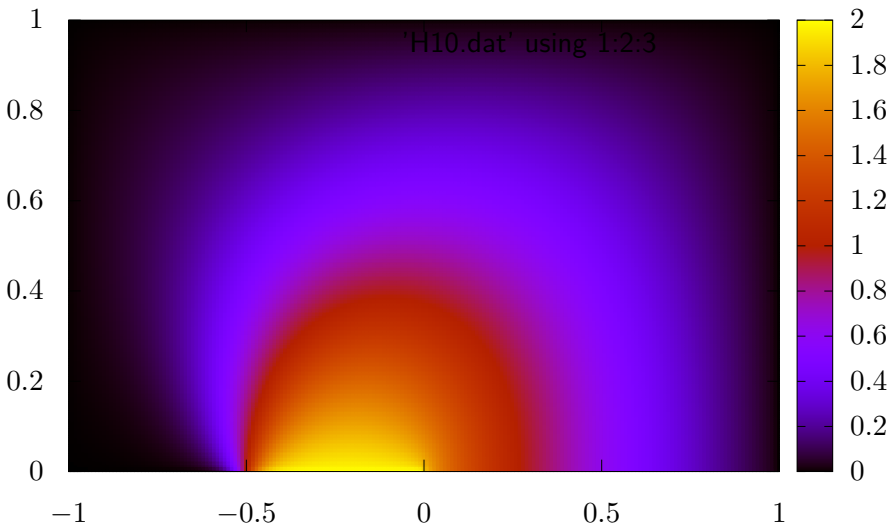


Figure 1.3: Representation of the whole domain for $\rho/\Gamma = 10$ (HDS)

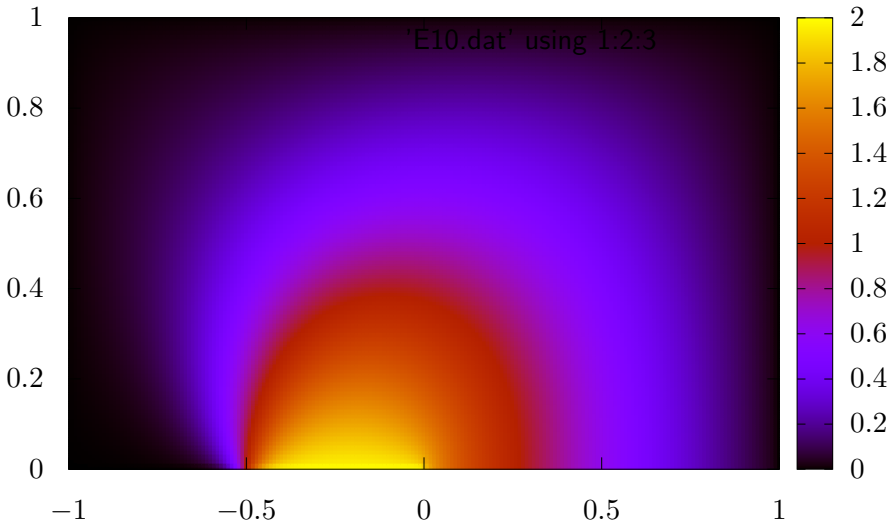


Figure 1.4: Representation of the whole domain for $\rho/\Gamma = 10$ (EDS)

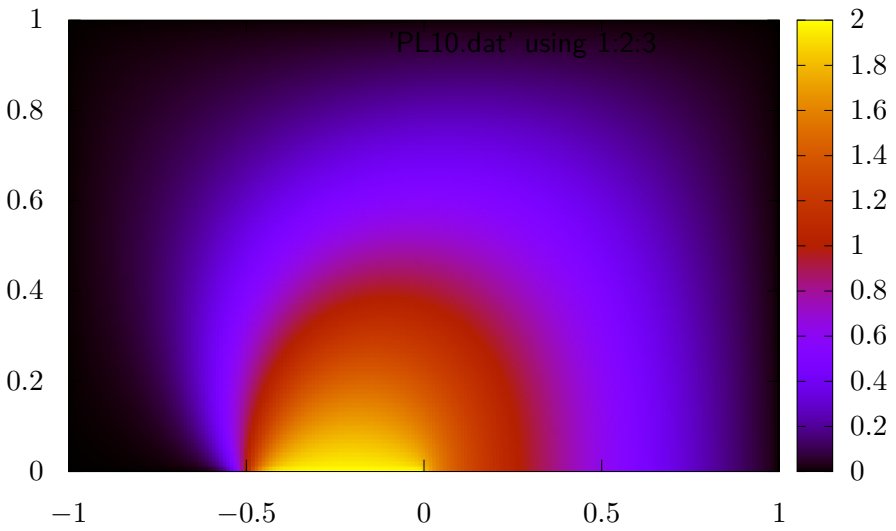


Figure 1.5: Representation of the whole domain for $\rho/\Gamma = 10$ (PLDS)

1.2 $\rho/\Gamma = 10^3$

In this section there is not a solution for the central differencing scheme because it diverges.

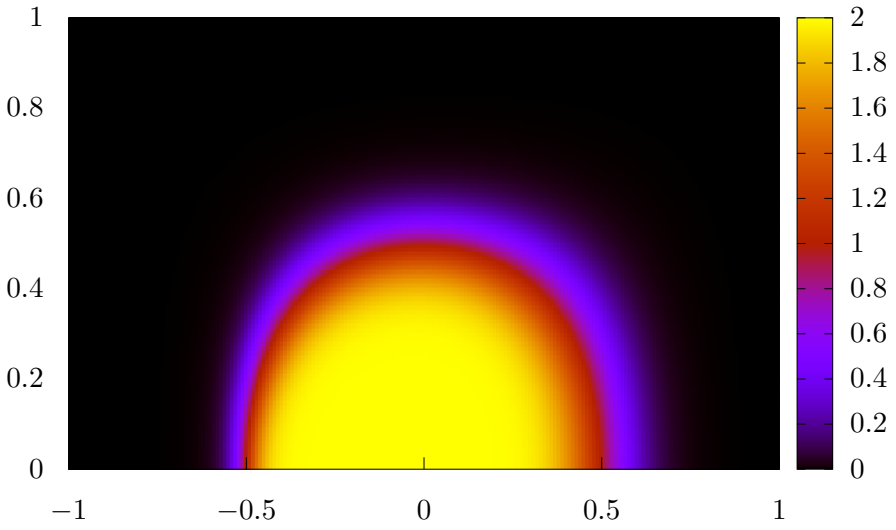


Figure 1.6: Representation of the whole domain for $\rho/\Gamma = 10^3$ (UDS)

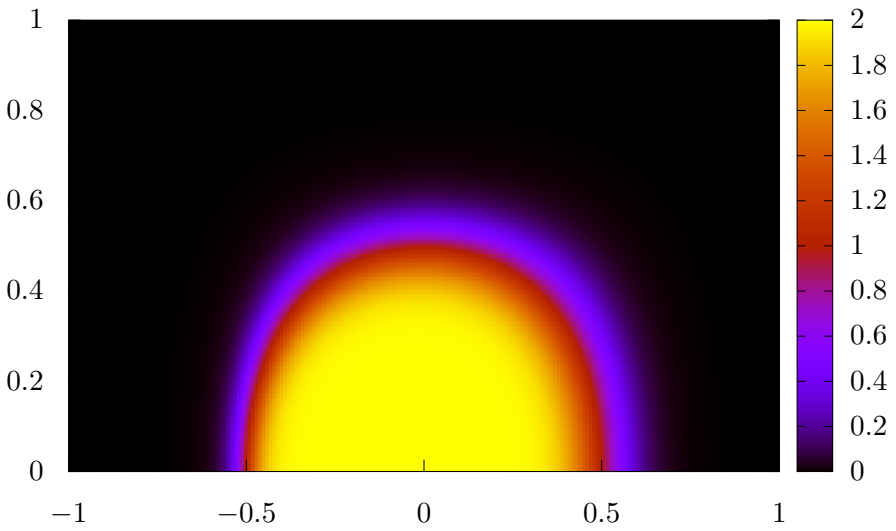


Figure 1.7: Representation of the whole domain for $\rho/\Gamma = 10^3$ (HDS)

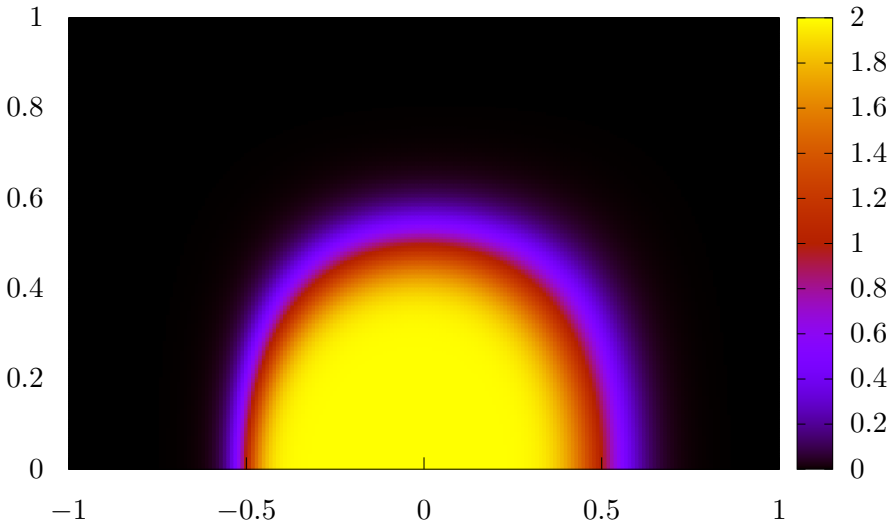


Figure 1.8: Representation of the whole domain for $\rho/\Gamma = 10^3$ (EDS)

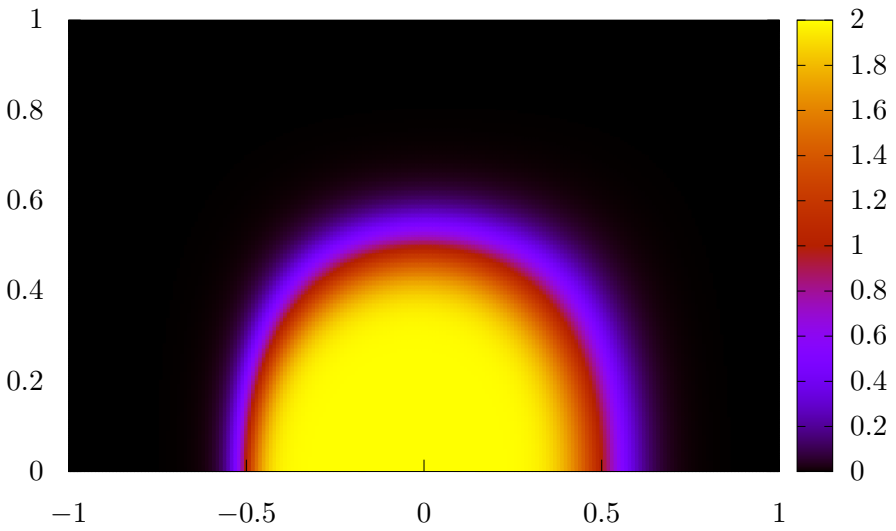


Figure 1.9: Representation of the whole domain for $\rho/\Gamma = 10^3$ (PLDS)

1.3 $\rho/\Gamma = 10^6$

Like in the previous section, in this case there is no results for the central differencing scheme because of its divergence.

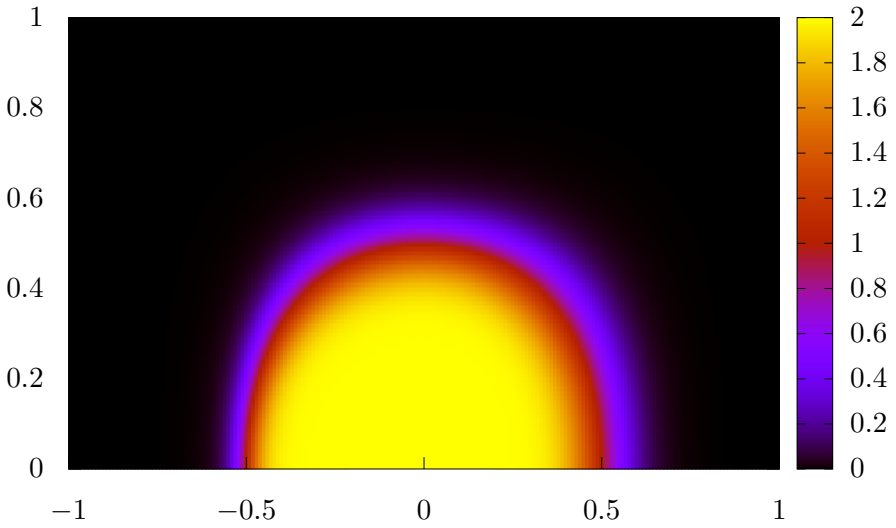


Figure 1.10: Representation of the whole domain for $\rho/\Gamma = 10^6$ (UDS)

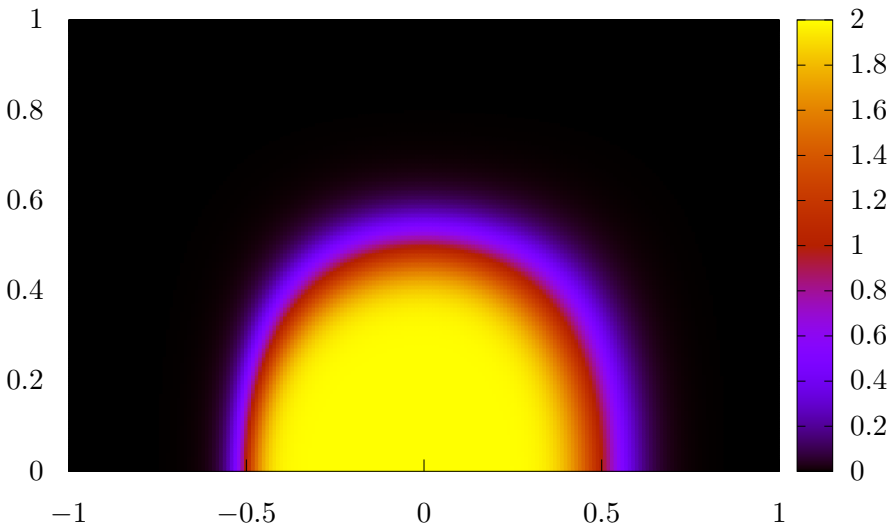


Figure 1.11: Representation of the whole domain for $\rho/\Gamma = 10^6$ (HDS)

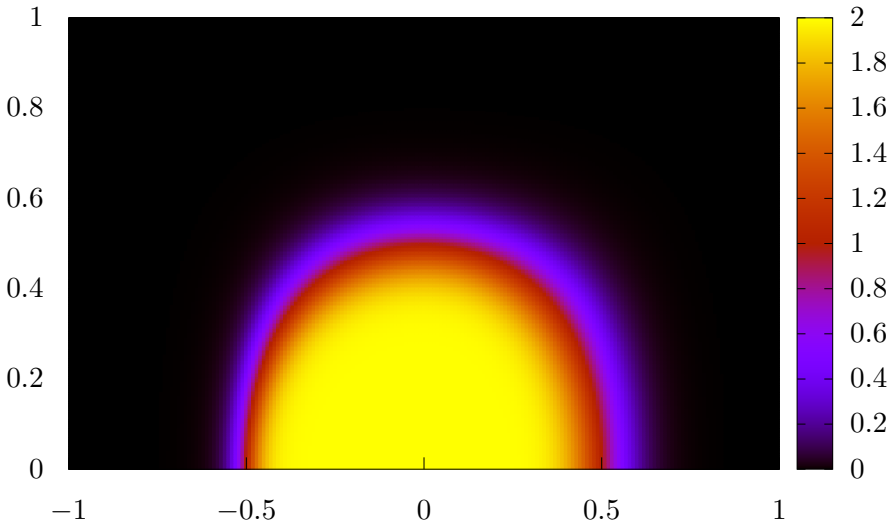


Figure 1.12: Representation of the whole domain for $\rho/\Gamma = 10^6$ (EDS)

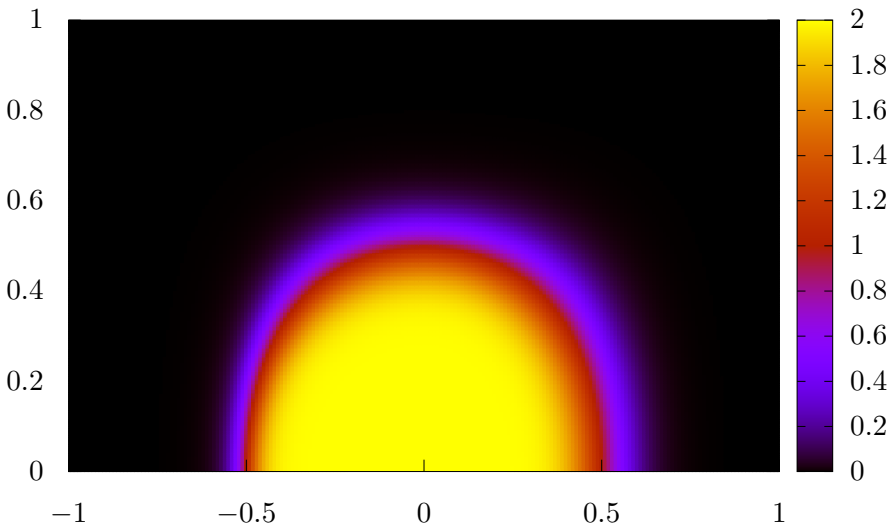
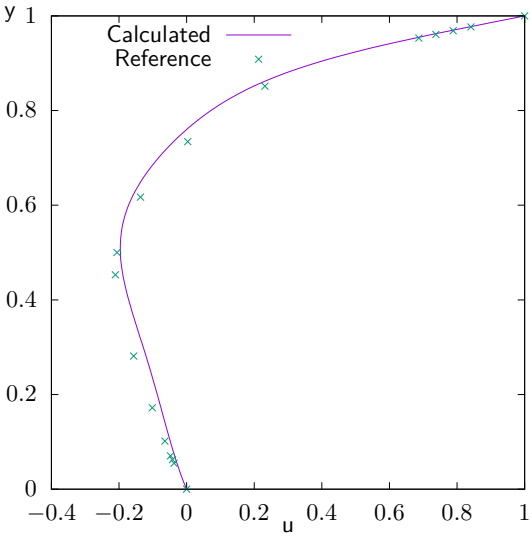
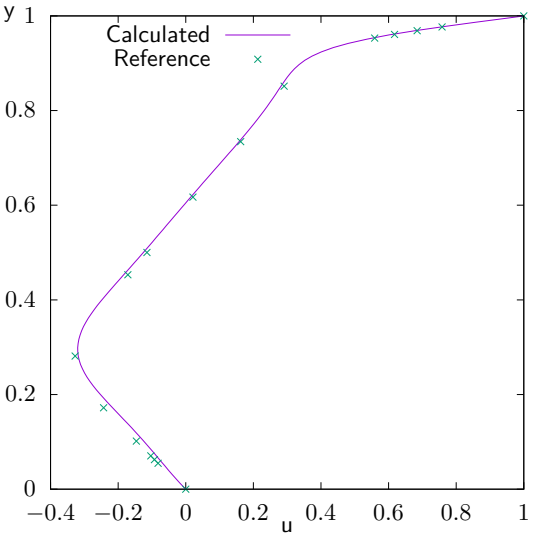


Figure 1.13: Representation of the whole domain for $\rho/\Gamma = 10^6$ (PLDS)

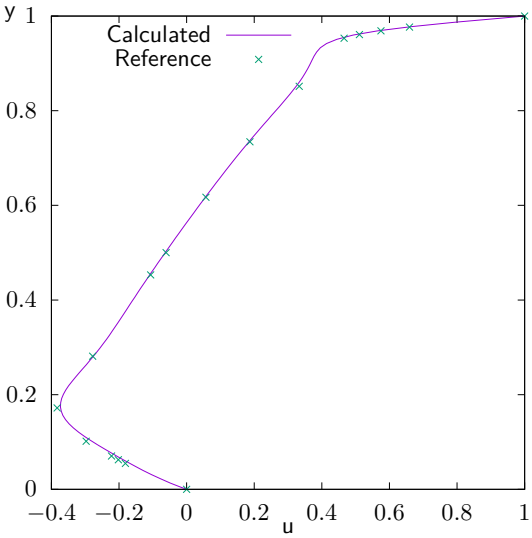
2 Driven cavity problem



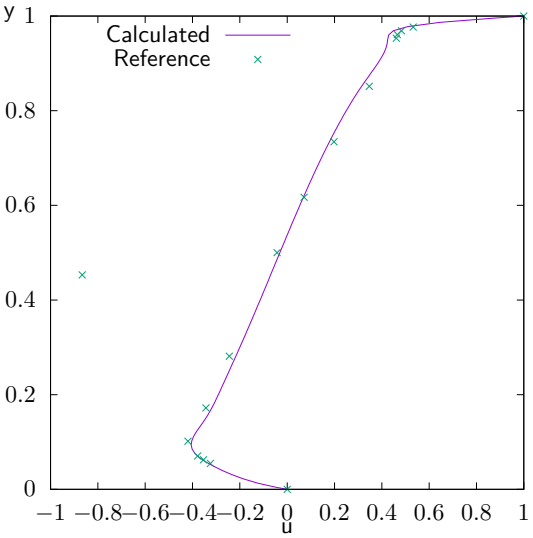
(a) $Re = 100$



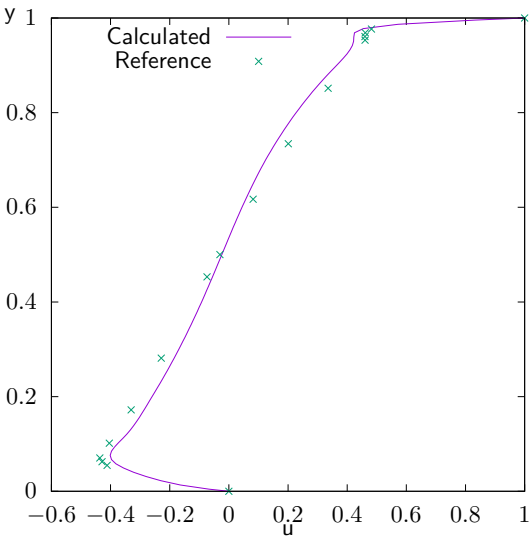
(b) $Re = 400$



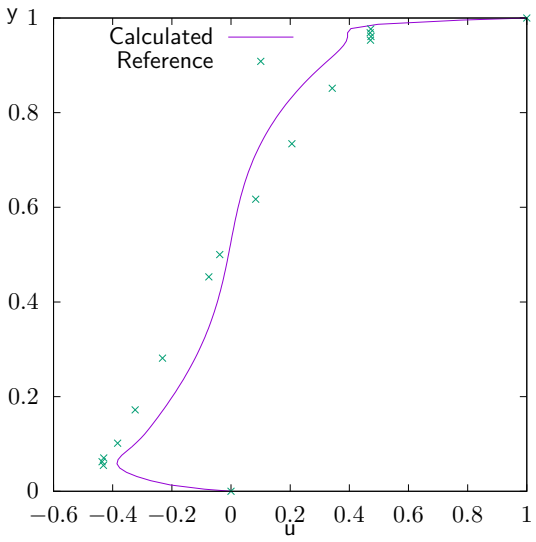
(c) $Re = 1000$



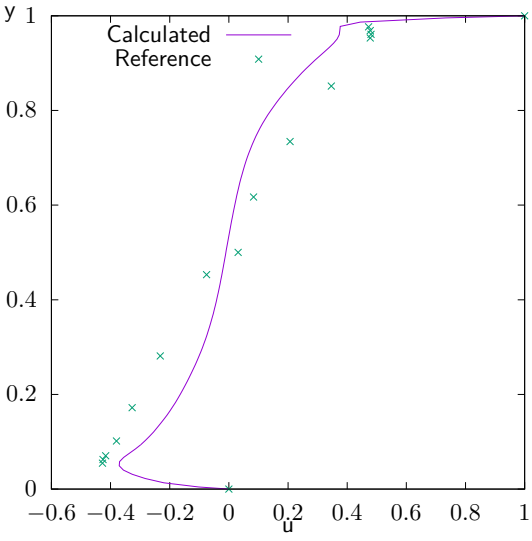
(d) $Re = 3200$



(e) $Re = 5000$

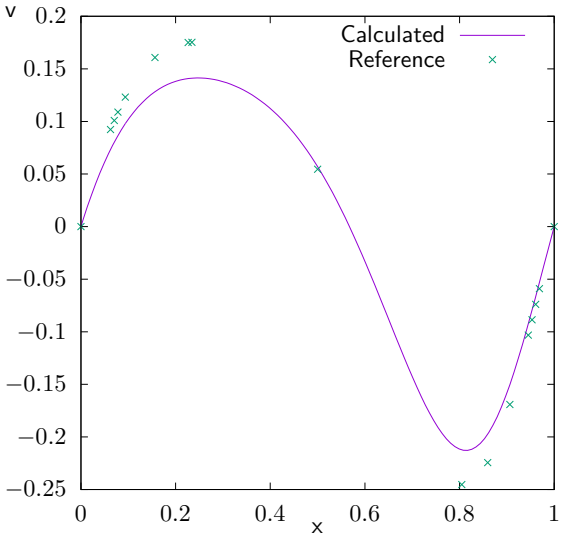


(f) $Re = 7500$

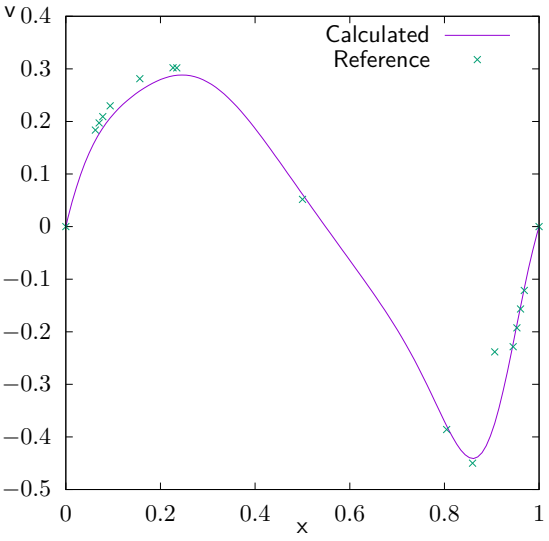


(g) $Re = 10000$

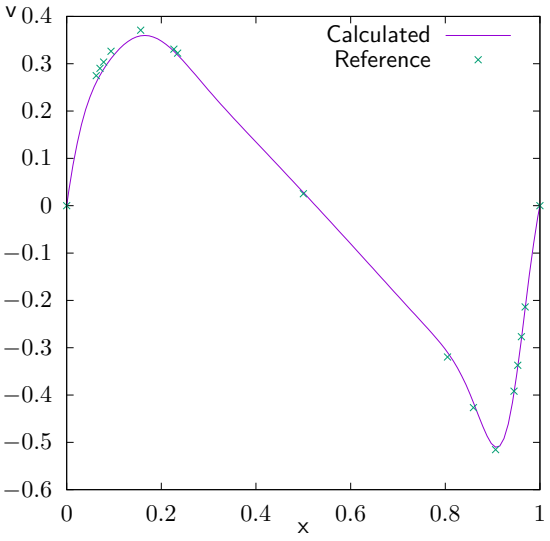
Figure 2.1: Comparison between the reference solution and the calculated one of the horizontal velocity along the vertical line in the geometric centre of the cavity [1]



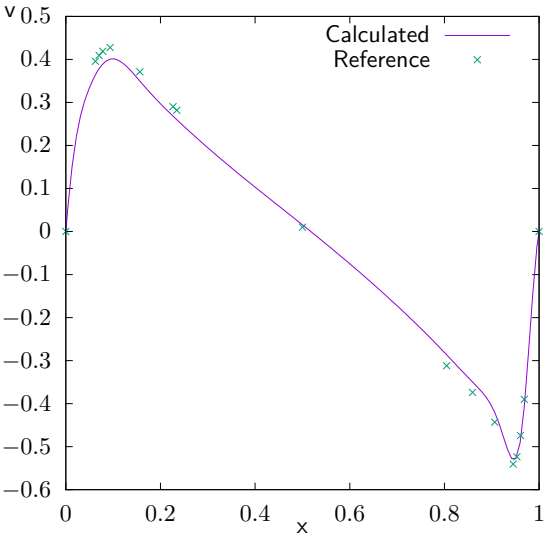
(a) $Re = 100$



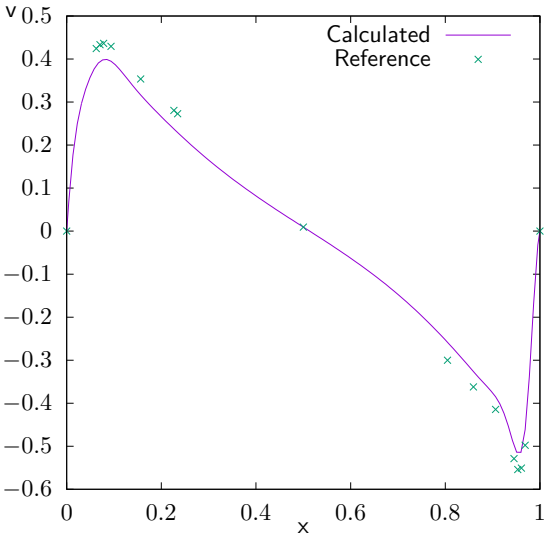
(b) $Re = 400$



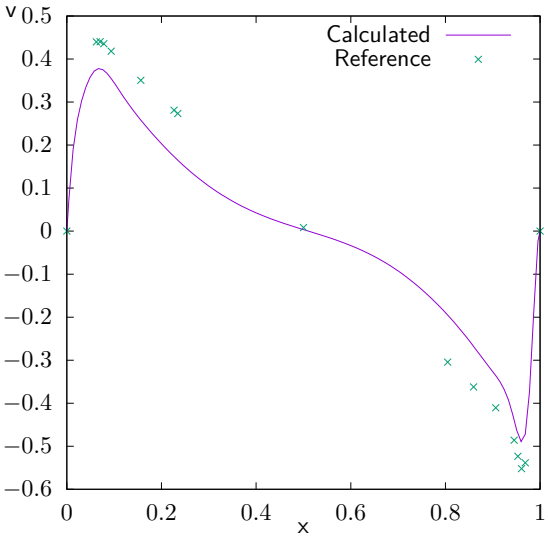
(c) $Re = 1000$



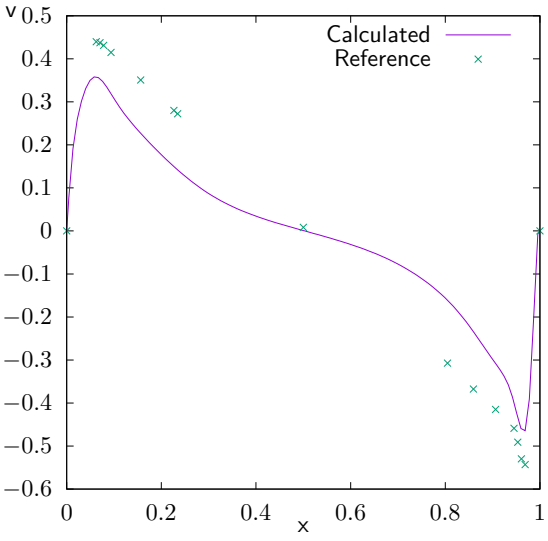
(d) $Re = 3200$



(e) $Re = 5000$



(f) $Re = 7500$



(g) $Re = 10000$

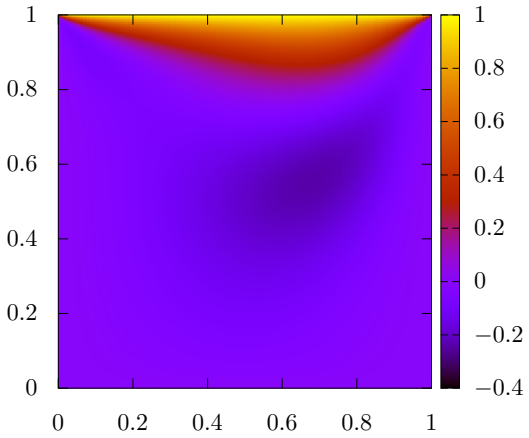
Figure 2.2: Comparison between the reference solution and the calculated one of the vertical velocity along the horizontal line in the geometric centre of the cavity [1]

x	Re=100	Re=400	Re=1000	Re=3200	Re=5000	Re=7500	Re=10000
1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0.9766	0.53%	0.41%	1.07%	5.91%	7.13%	15.08%	28.11%
0.9688	0.72%	0.49%	1.14%	6.57%	8.95%	17.61%	32.03%
0.9609	1.04%	0.77%	1.69%	7.74%	10.25%	18.46%	33.60%
0.9531	1.32%	1.06%	2.40%	8.22%	10.50%	18.68%	34.58%
0.8516	11.04%	2.76%	3.10%	8.88%	15.28%	32.24%	52.58%
0.7344	1020.07%	2.66%	2.01%	10.68%	24.81%	50.19%	73.70%
0.6172	-15.41%	25.44%	3.47%	10.85%	31.55%	61.89%	73.63%
0.5	3.19%	-7.42%	-4.01%	18.68%	30.72%	74.06%	34.89%
0.4531	7.98%	-5.56%	-1.91%	91.66%	30.59%	64.80%	112.56%
0.2813	19.18%	2.53%	1.24%	12.55%	21.26%	46.49%	55.93%
0.1719	21.37%	9.01%	3.10%	8.44%	14.73%	29.52%	49.33%
0.1016	20.90%	12.06%	5.98%	5.22%	8.95%	17.16%	36.85%
0.0703	22.33%	13.08%	7.10%	1.78%	10.75%	14.22%	25.13%
0.0625	20.17%	13.27%	7.29%	0.43%	11.22%	14.20%	22.76%
0.0547	19.93%	13.41%	7.39%	-1.15%	11.26%	13.84%	20.37%
0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

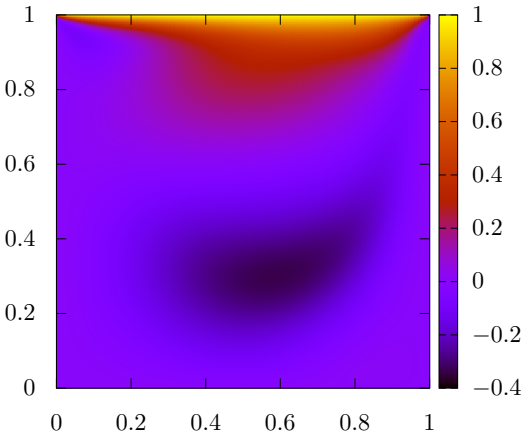
Table 2.1: Error of the horizontal velocities in the vertical central plane

y	Re=100	Re=400	Re=1000	Re=3200	Re=5000	Re=7500	Re=10000
1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0.9688	7.43%	2.41%	-1.00%	-1.16%	11.69%	17.15%	20.24%
0.9609	7.29%	2.02%	-0.95%	0.95%	10.81%	14.42%	17.89%
0.9531	7.43%	1.98%	-0.68%	2.17%	9.08%	11.53%	16.78%
0.9453	7.52%	1.87%	-0.57%	3.11%	7.55%	10.48%	18.96%
0.9063	8.21%	-57.88%	1.57%	5.68%	8.89%	18.94%	37.44%
0.8594	9.09%	1.84%	2.81%	7.39%	12.11%	26.30%	47.77%
0.8047	10.32%	1.77%	3.34%	9.04%	16.06%	35.75%	53.28%
0.5	-6.69%	-14.99%	-10.95%	-40.59%	3.41%	61.67%	331.52%
0.2344	15.90%	3.89%	1.56%	8.54%	18.07%	39.01%	46.30%
0.2266	16.04%	4.24%	1.74%	8.44%	17.50%	37.78%	45.79%
0.1563	16.84%	6.79%	3.61%	6.87%	12.28%	26.49%	44.39%
0.0938	17.15%	8.22%	4.96%	7.54%	9.99%	16.36%	32.74%
0.0781	17.29%	8.58%	5.25%	8.26%	10.81%	15.88%	29.86%
0.0703	17.31%	8.73%	5.40%	8.62%	11.32%	16.21%	29.30%
0.0625	17.29%	8.82%	5.51%	8.93%	11.70%	16.66%	29.23%
0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

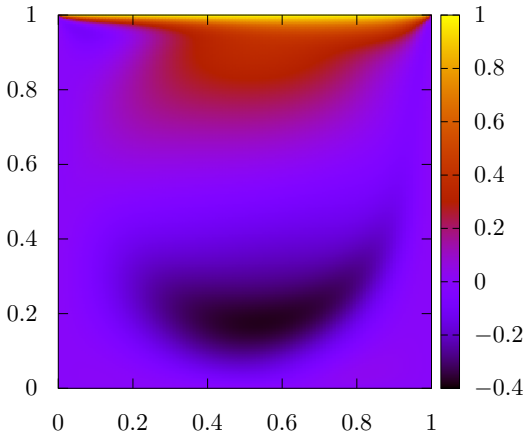
Table 2.2: Error of the vertical velocities in the horizontal central plane



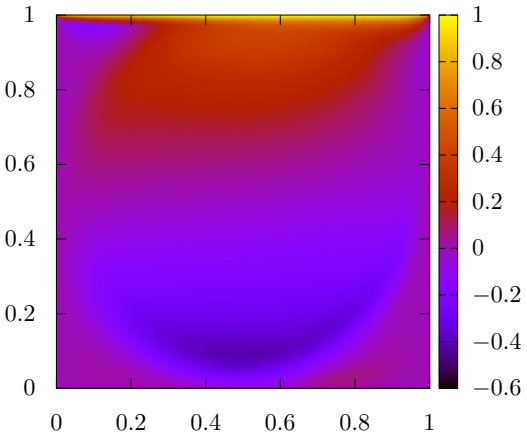
(a) $Re = 100$



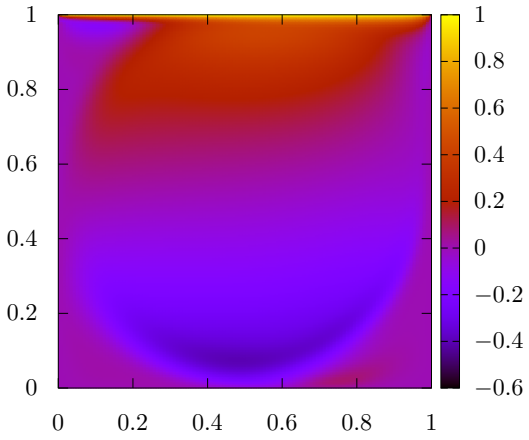
(b) $Re = 400$



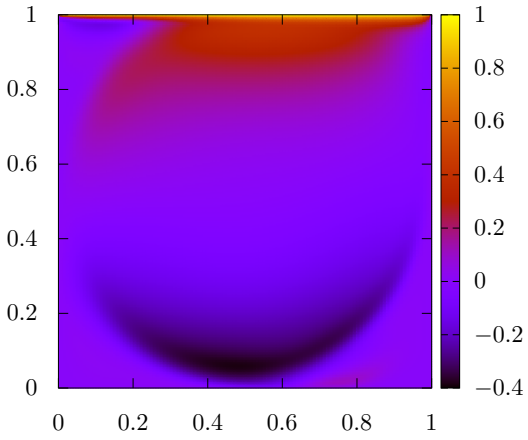
(c) $Re = 1000$



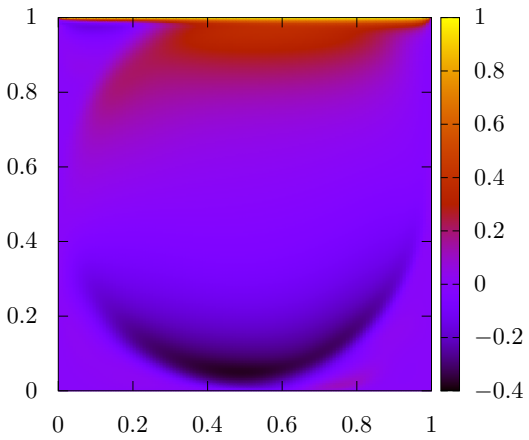
(d) $Re = 3200$



(e) $Re = 5000$

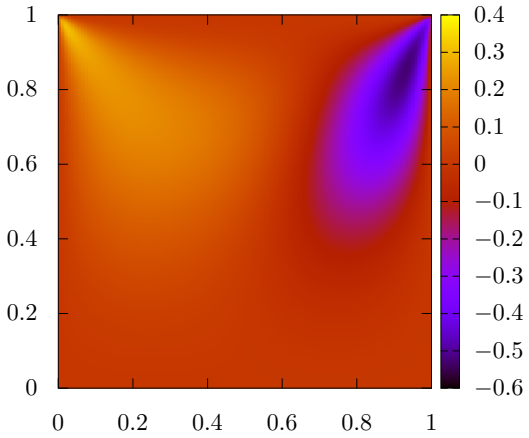


(f) $Re = 7500$

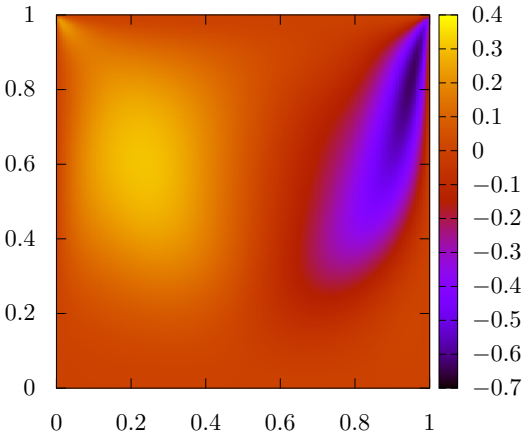


(g) $Re = 10000$

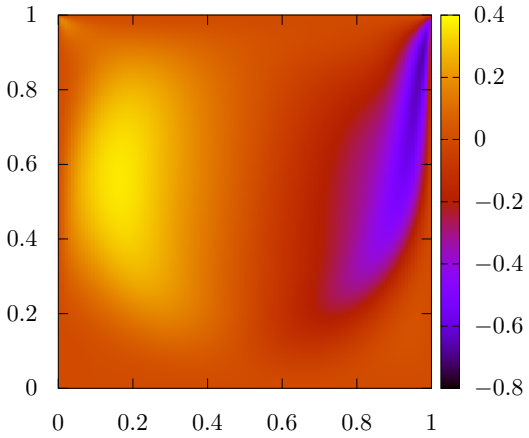
Figure 2.3: Horizontal velocity inside the cavity



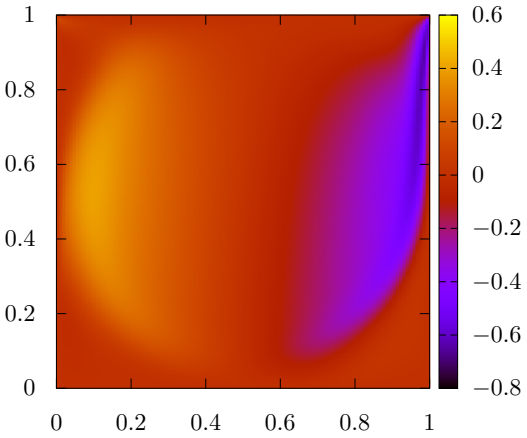
(a) $Re = 100$



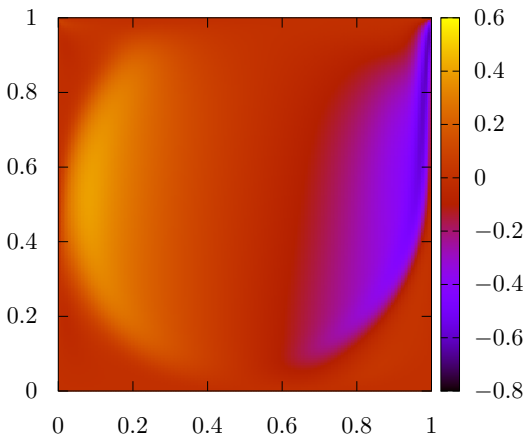
(b) $Re = 400$



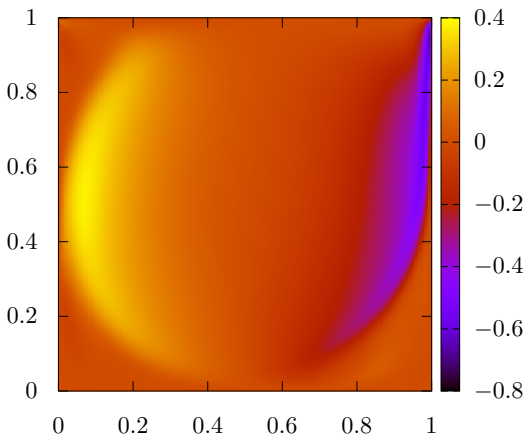
(c) $Re = 1000$



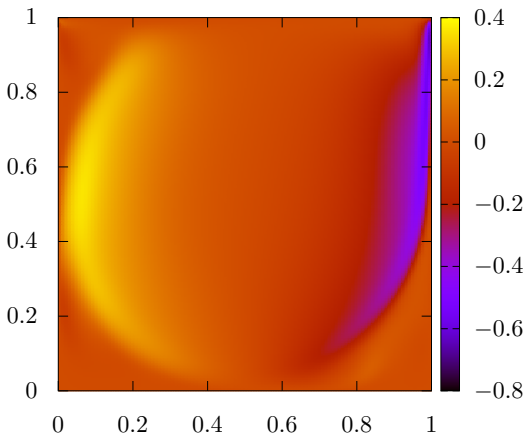
(d) $Re = 3200$



(e) $Re = 5000$

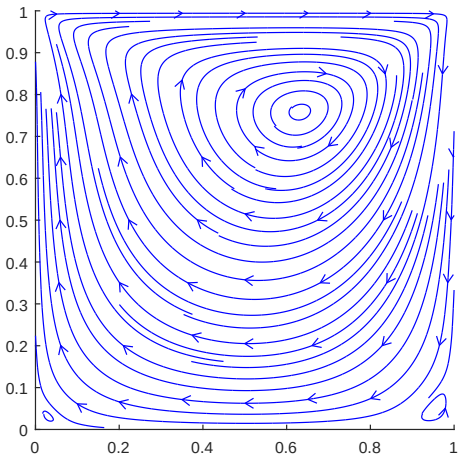


(f) $Re = 7500$

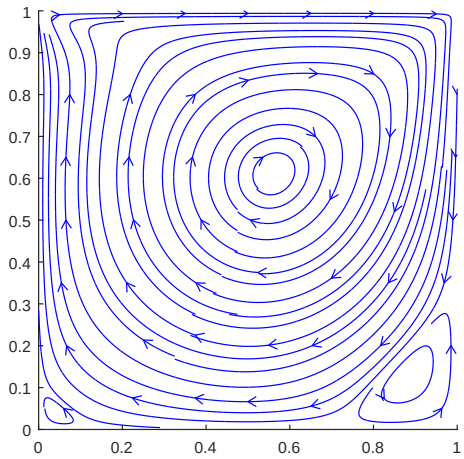


(g) $Re = 10000$

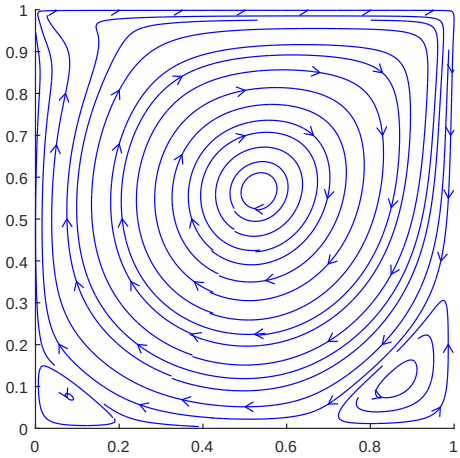
Figure 2.4: Vertical velocity inside the cavity



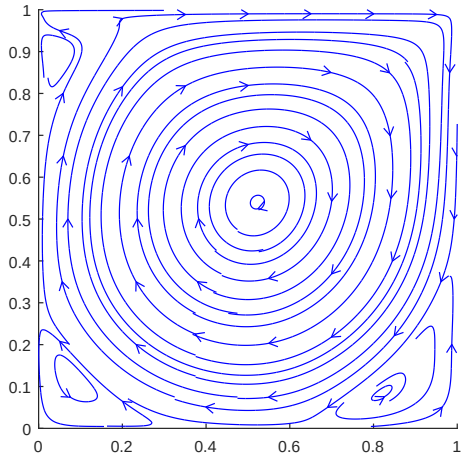
(a) $Re = 100$



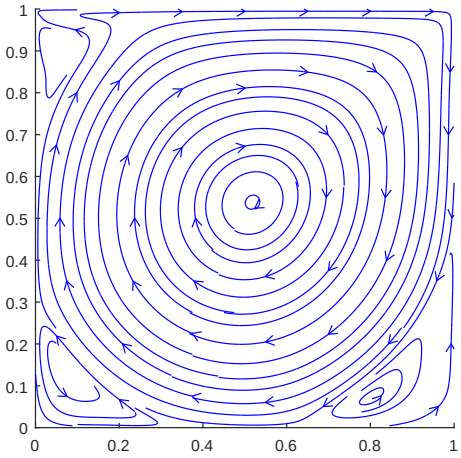
(b) $Re = 400$



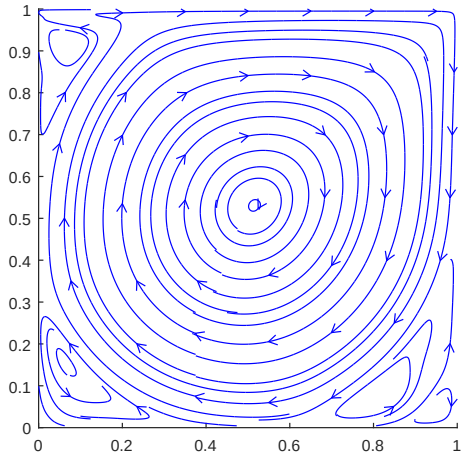
(c) $Re = 1000$



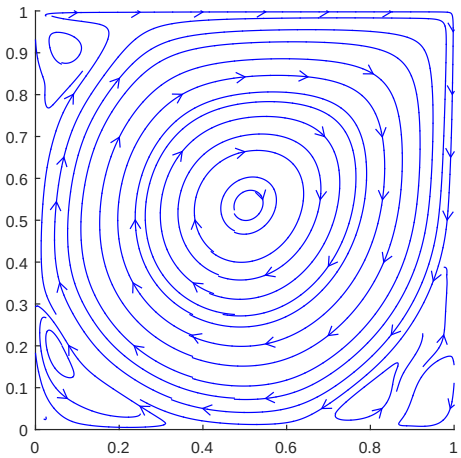
(d) $Re = 3200$



(e) $Re = 5000$



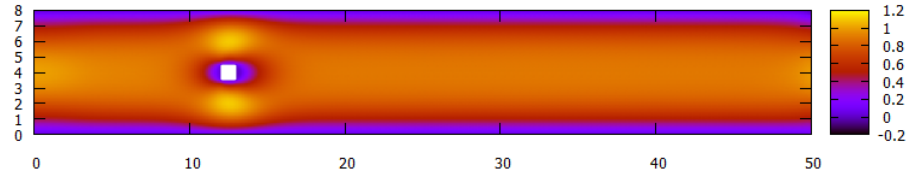
(f) $Re = 7500$



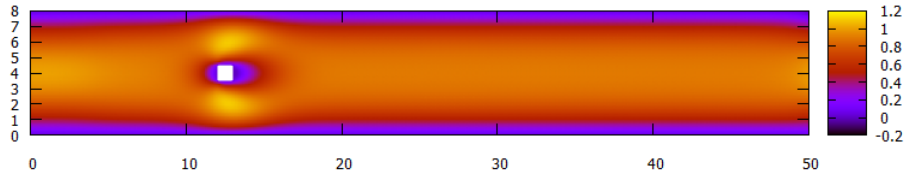
(g) $Re = 10000$

Figure 2.5: Streamlines of the flow inside the cavity

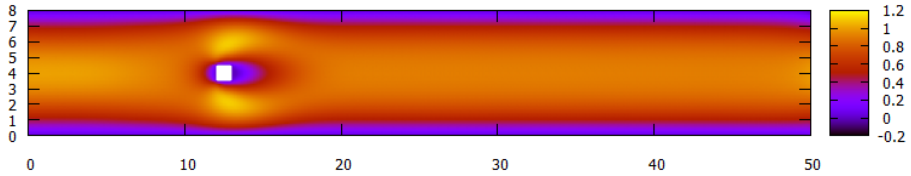
3 | Square cylinder



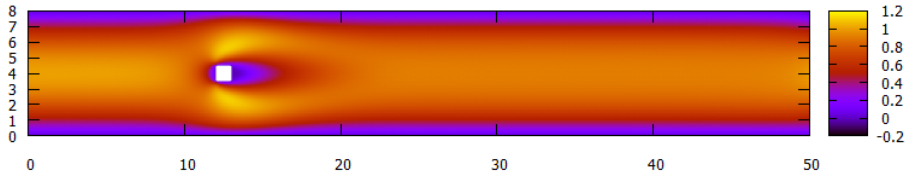
(a) $Re = 1$



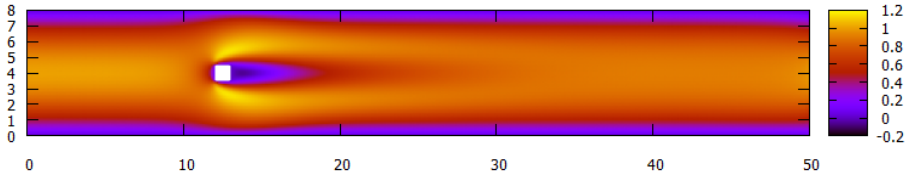
(b) $Re = 3$



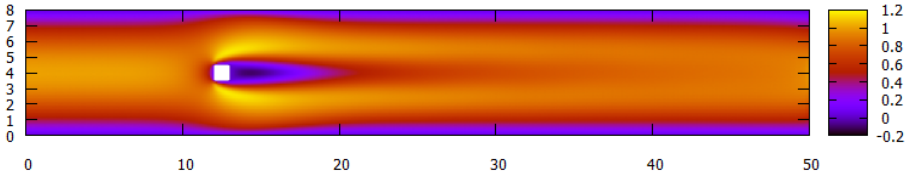
(c) $Re = 5$



(d) $Re = 10$

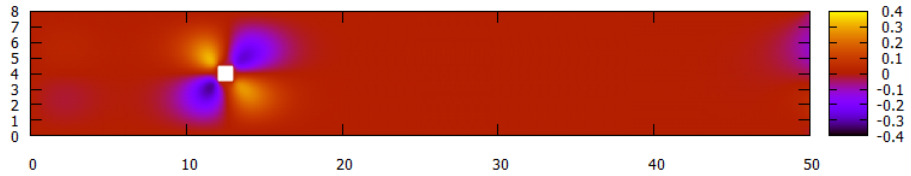


(e) $Re = 30$

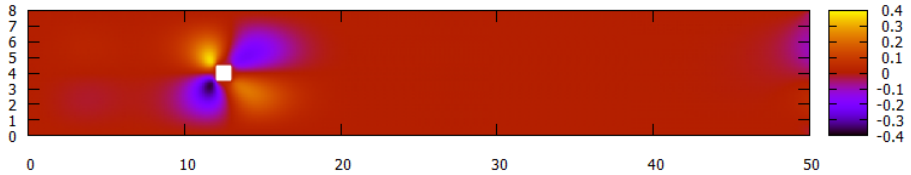


(f) $Re = 50$

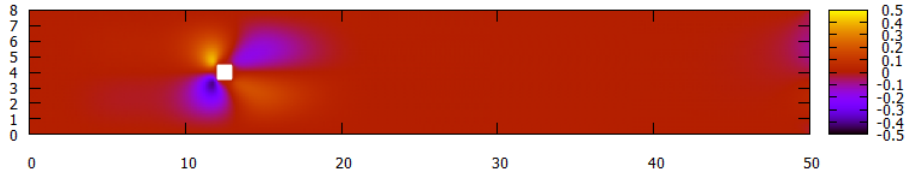
Figure 3.1: Horizontal velocity in the channel



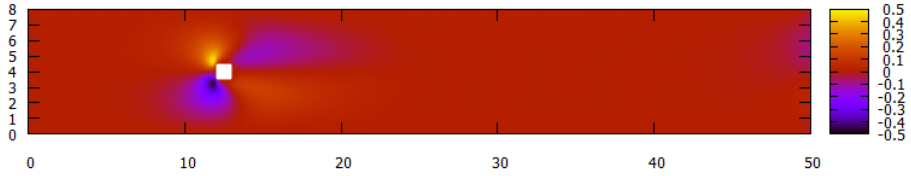
(a) $Re = 1$



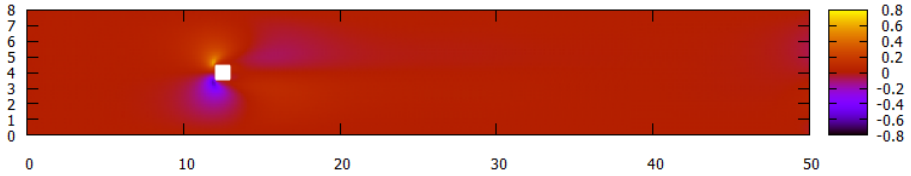
(b) $Re = 3$



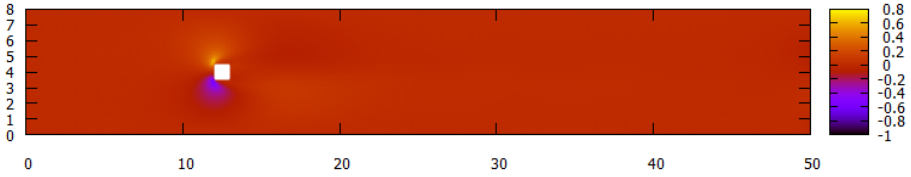
(c) $Re = 5$



(d) $Re = 10$



(e) $Re = 30$



(f) $Re = 50$

Figure 3.2: Vertical velocity in the channel

4 | Bibliography

[1] U. Ghia, K. N. Ghia, and C. T. Shin. High-Re solutions for incompressible flow using the Navier-Stokes equations and a multigrid method. *Journal of Computational Physics*, 48:387–411, 1982.