OpenFoam Assignment | The Lid-Driven Cavity

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Abstract. –SAMPLE ABSTRACT–

Keywords: computational fluid dynamics, CFD, incompressible, Paraview, R, Python, coe347, spring 2022

1. Some Text

2. Motivation

why cavity is important

3. Implementation

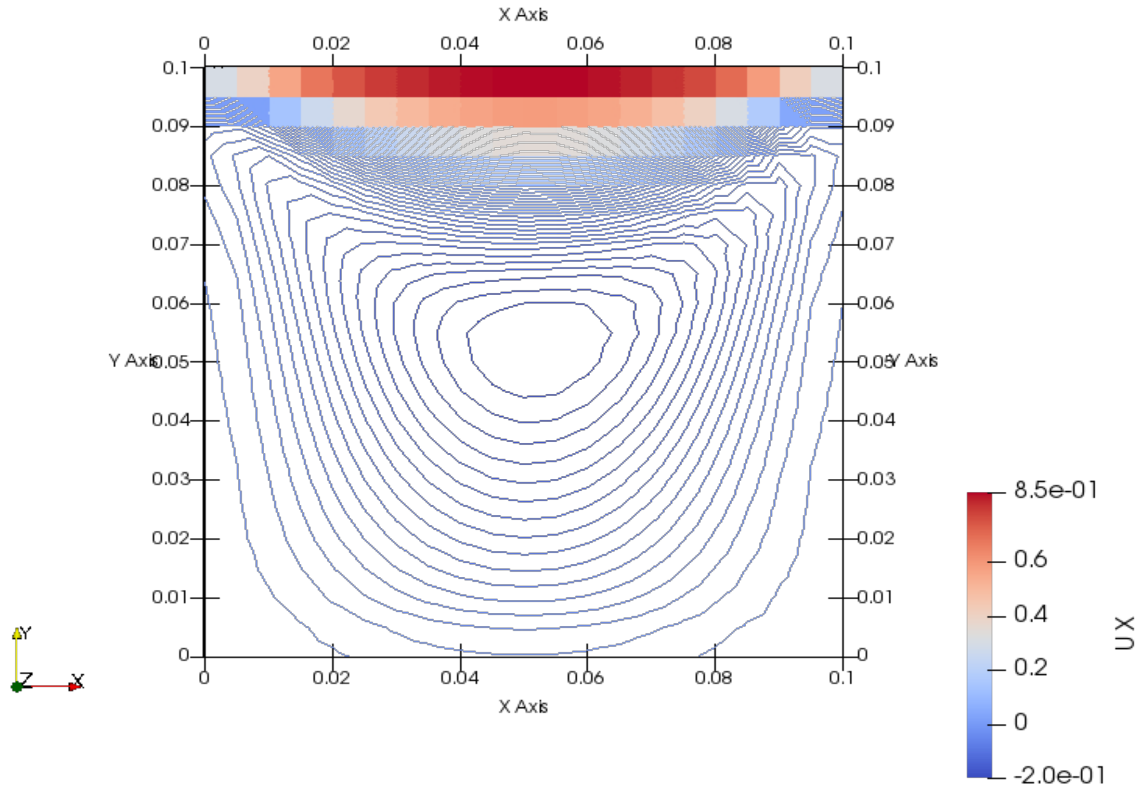
We implement all simulation with OpenFoam, analysis with Paraview and Python3 , and documentation code in R (Xie; 2021a; Urbanek; 2021; Xie; 2021b; Bengtsson; 2021; Allaire et al.; 2021; Xie; 2013, 2015, Xie (2014),Xie et al. (2018),Xie et al. (2020)).

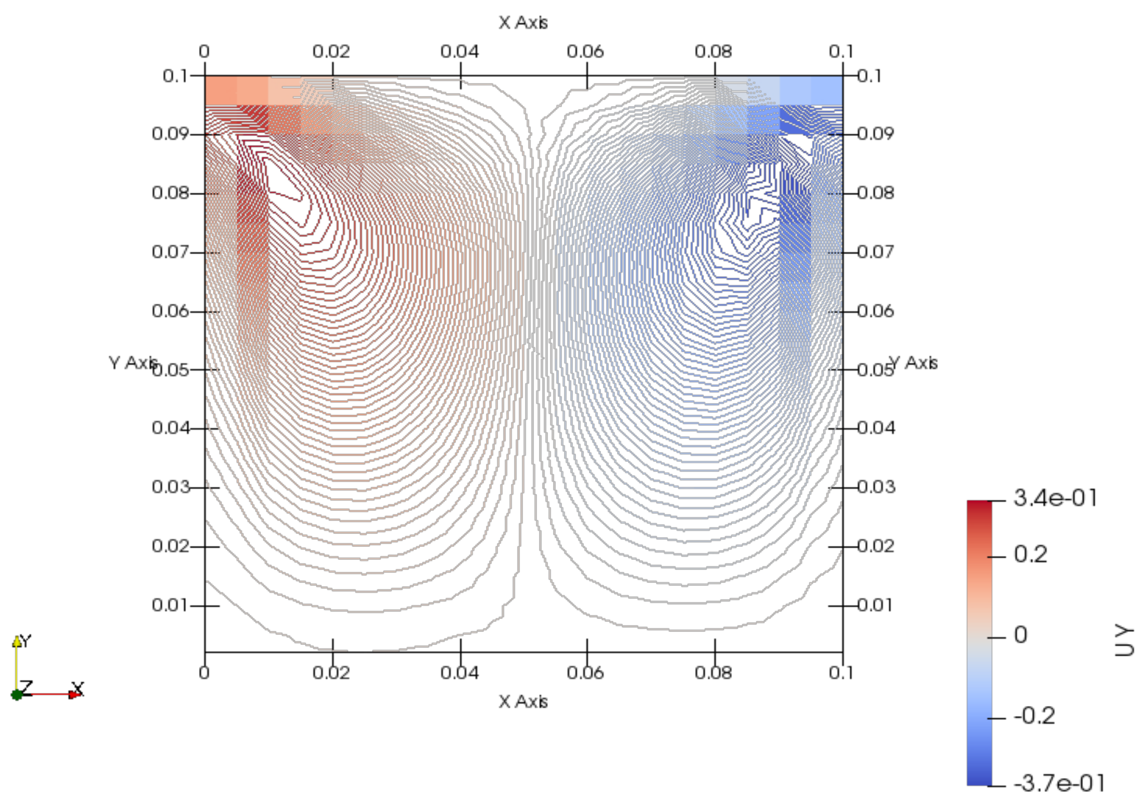
– some text —

4. Description of the flow for Re = 10

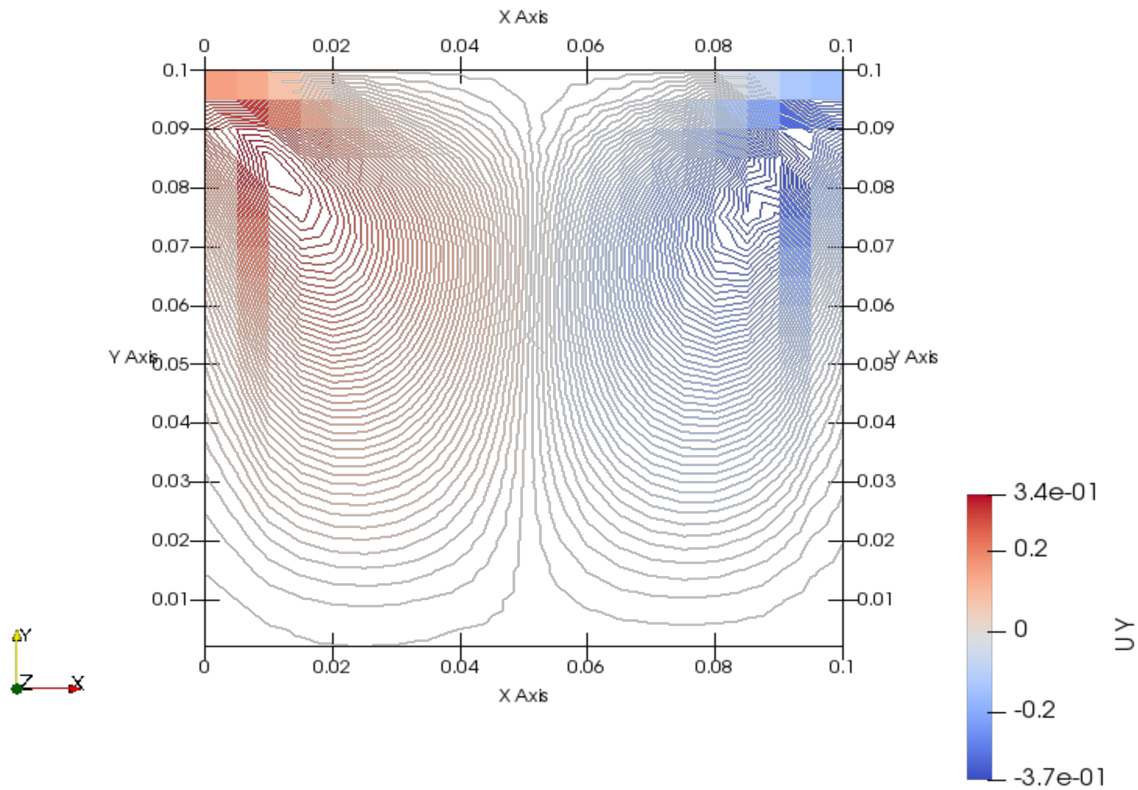
Following is the solution to the lid-driven cavity with lid velocity $U_0 = 1\frac{m}{s}$ to the right, a characteristic length $L = 0.1m$, and kinematic viscosity $\nu = \frac{\mu}{\rho} = 0.01\frac{m^2}{s}$, yielding a Reynolds number of $Re = \frac{UL}{\nu} = 10$. Note the upper plane ($y = 0.1m$) represents the moving lid.
Please note that all output variables have been nondimensionalized to allow for easier comparision. So we report $\pi = \frac{P}{\rho}$ pressure, and $\tilde{u} = \frac{U}{U_0}$, $\tilde{v} = \frac{V}{U_0}$.
20 grid points in each axis were used.

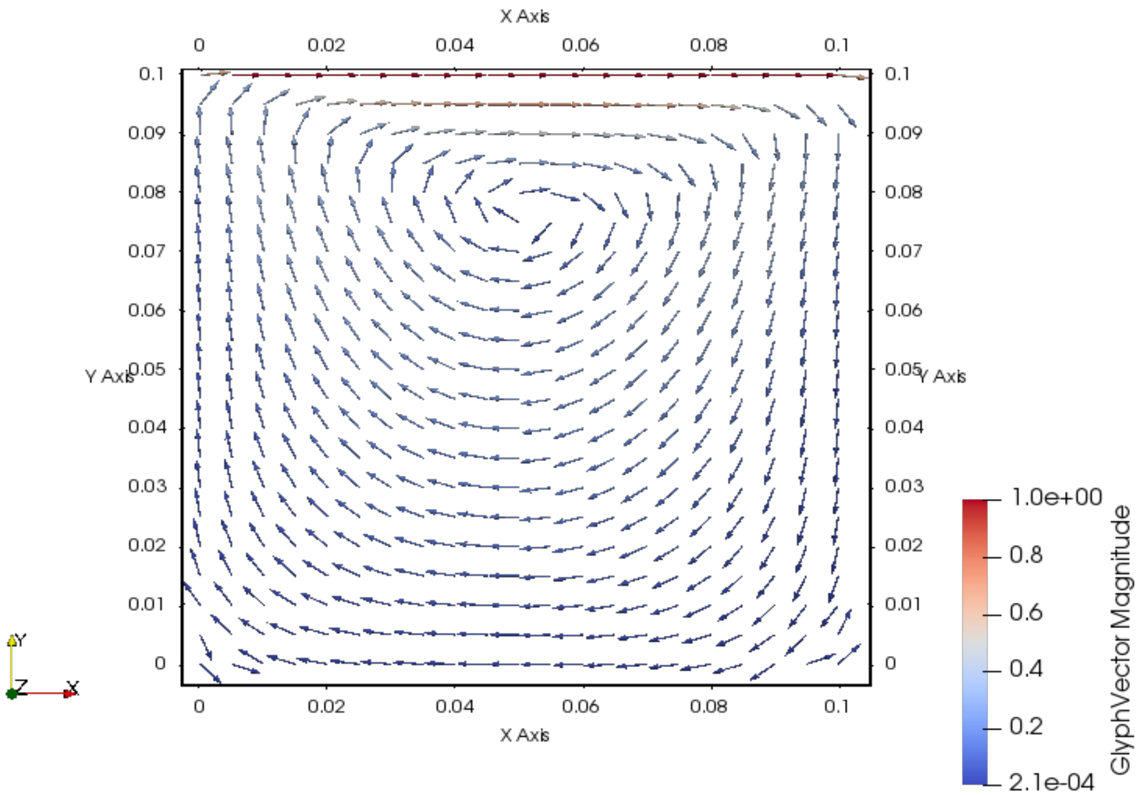
Contour plots for the X and Y components of fluid velocity, respectively:


X Axis
Y Axis
U X
8.5e-01
0.6
0.4
0.2
0
-2.0e-01

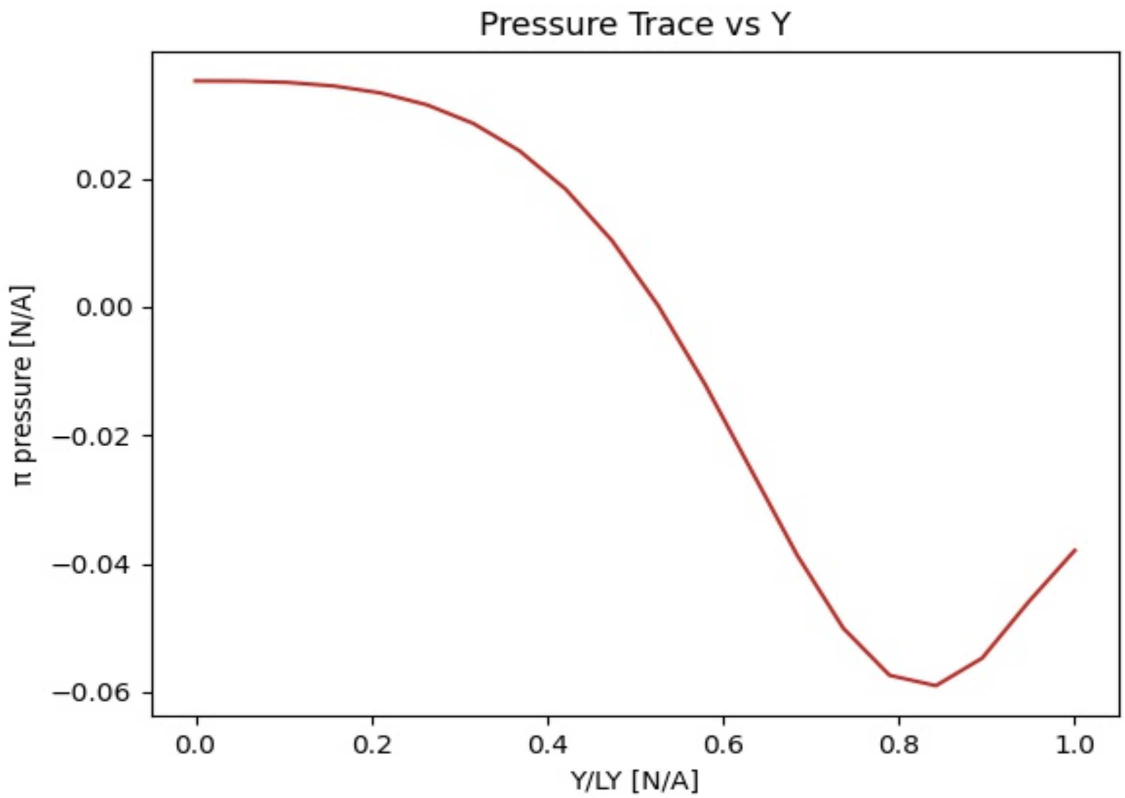

X Axis
Y Axis
U Y
3.4e-01
0.2
0
-0.2
-3.7e-01

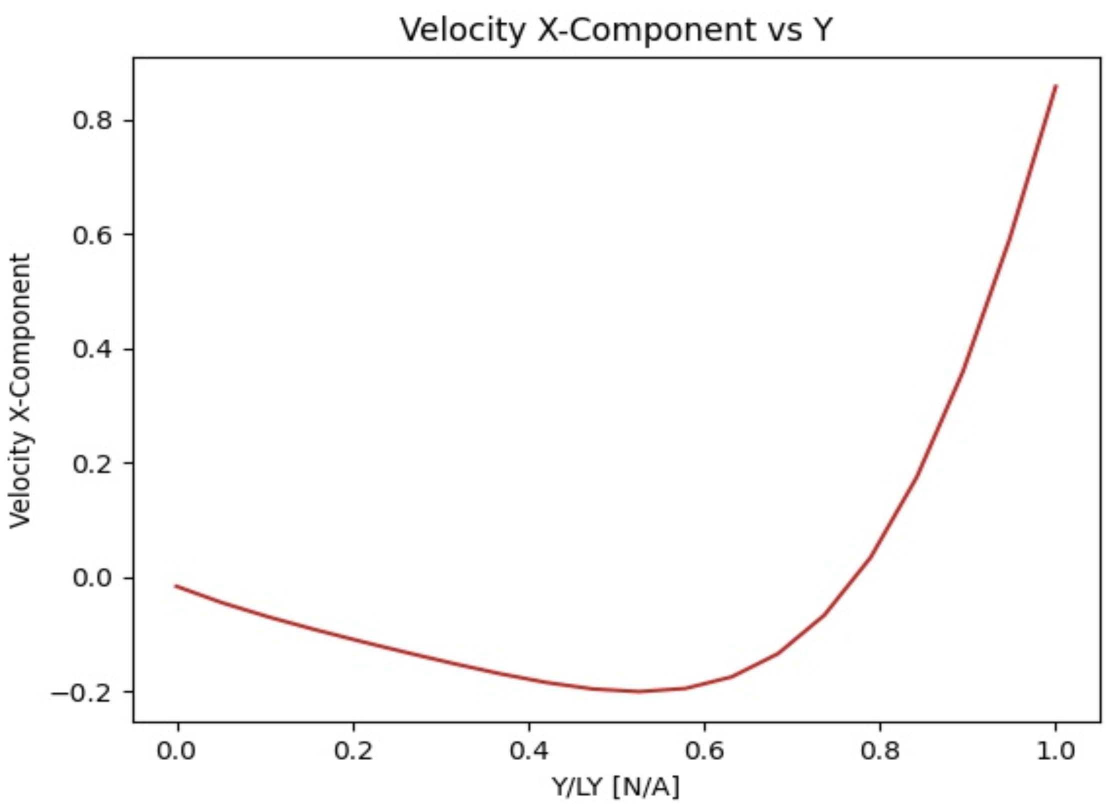
A streamline plot, and a glyph-based plot to show velocity direction:

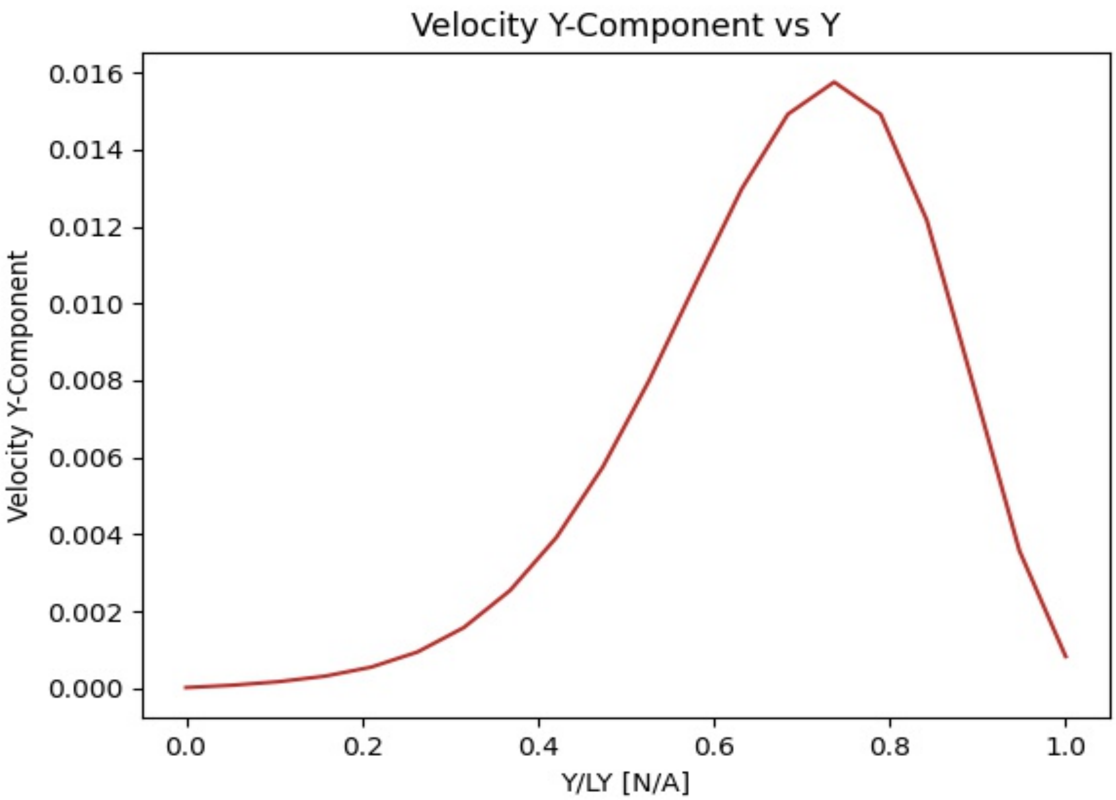




A pressure and velocity profile sampled along the midline: $\tilde{x} = 0.5$, in component form. Respectively, $\pi(\tilde{x} = 0.5, \tilde{y})$, $\tilde{u}(\tilde{x} = 0.5, \tilde{y})$, $\tilde{v}(\tilde{x} = 0.5, \tilde{y})$.

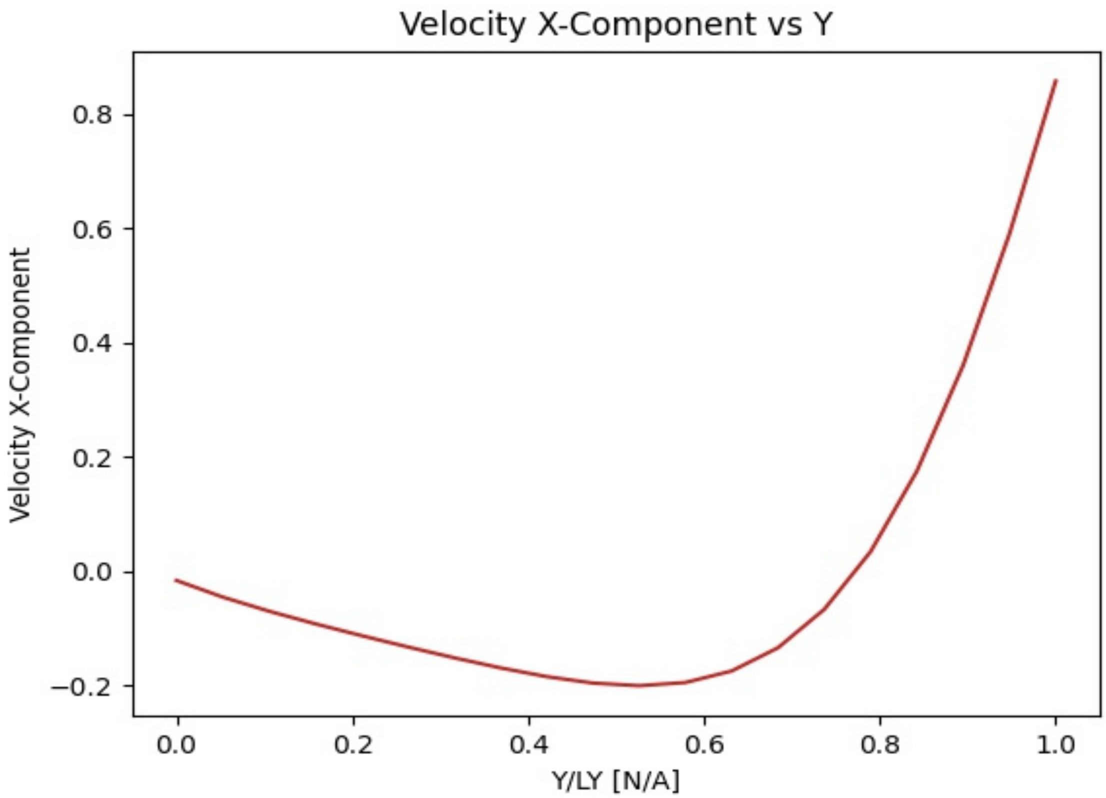

Pressure Trace vs Y
π pressure [N/A]
0.02
0.00
−0.02
−0.04
−0.06
0.0
0.2
0.4
0.6
0.8
1.0
Y/LY [N/A]

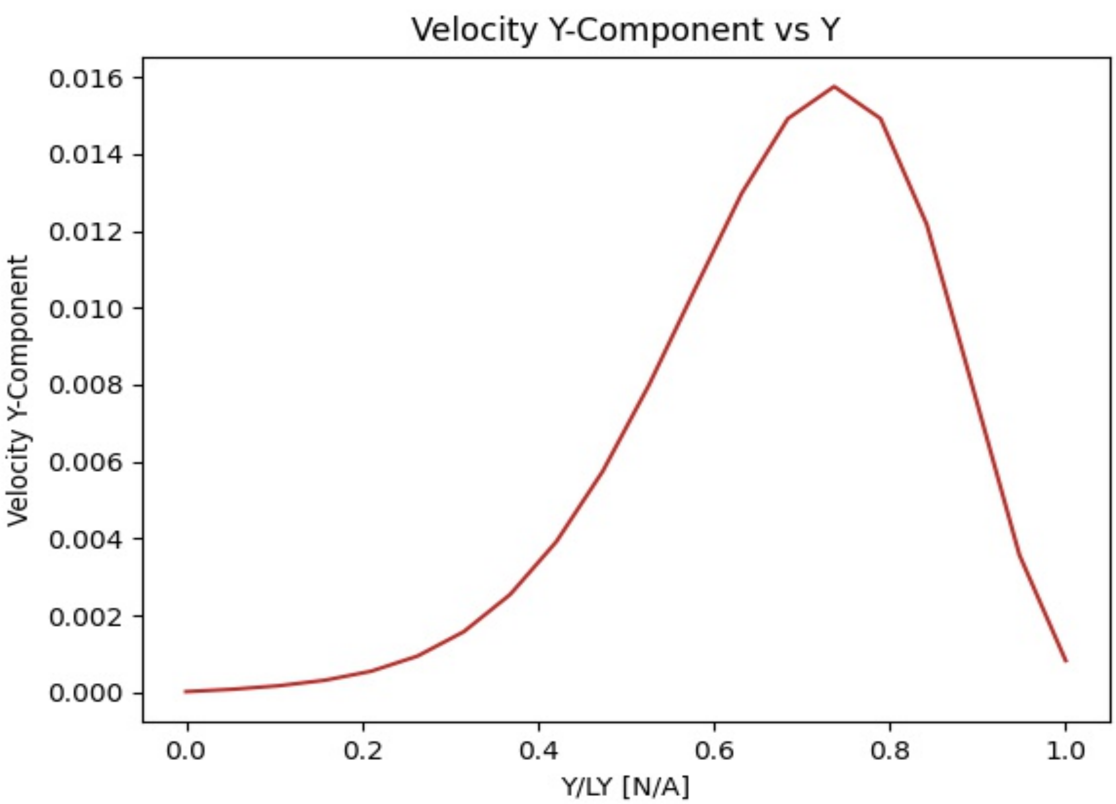

Velocity X-Component vs Y
Velocity X-Component
0.8
0.6
0.4
0.2
0.0
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
Y/LY [N/A]

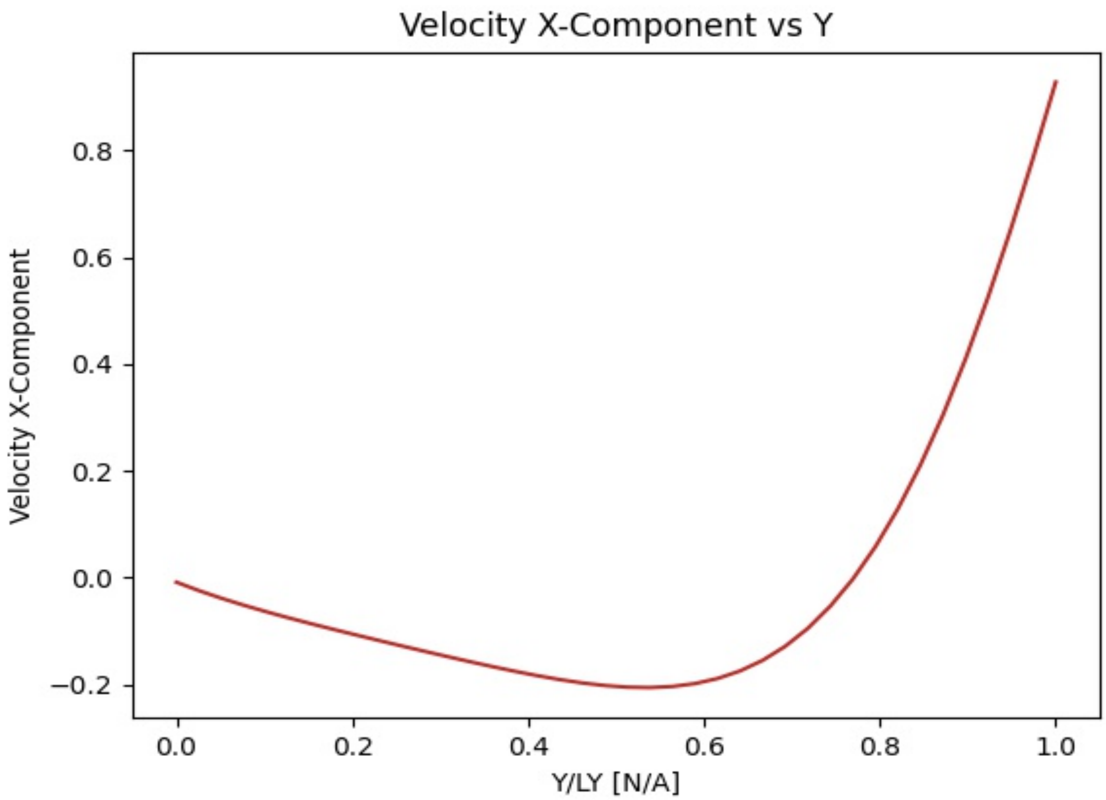


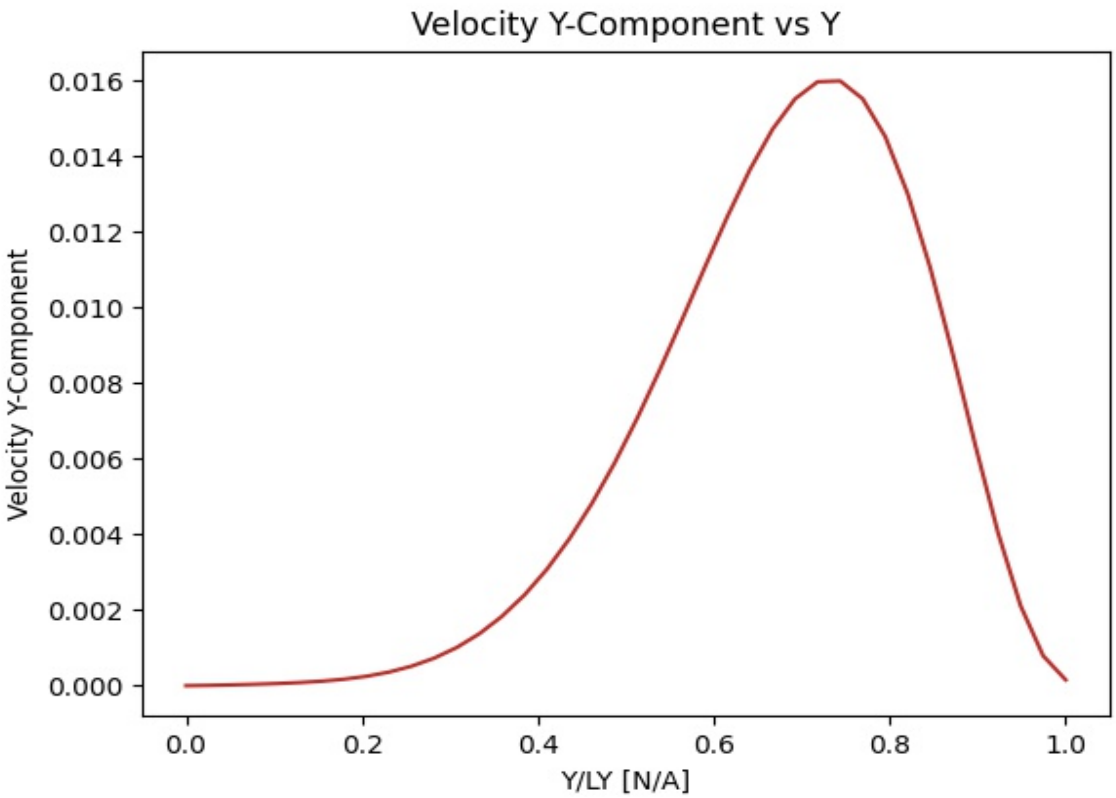
5. Refining the solution

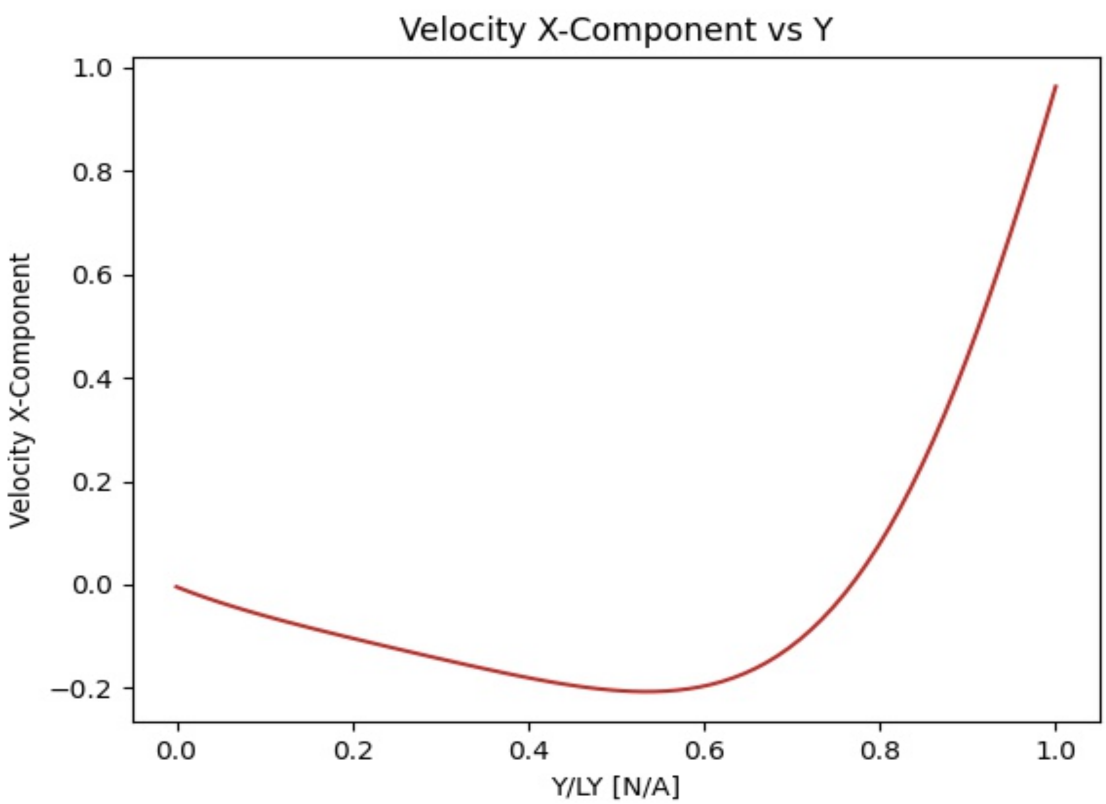
We will demonstrate the increase in image fidelity due to finer discretization. The earlier midline velocity profiles: $\tilde{u}(\tilde{x} = 0.5, \tilde{y})$, $\tilde{v}(\tilde{x} = 0.5, \tilde{y})$ are successively halved in binwidth (grid size) in all directions: x, y, and t, for comparision.

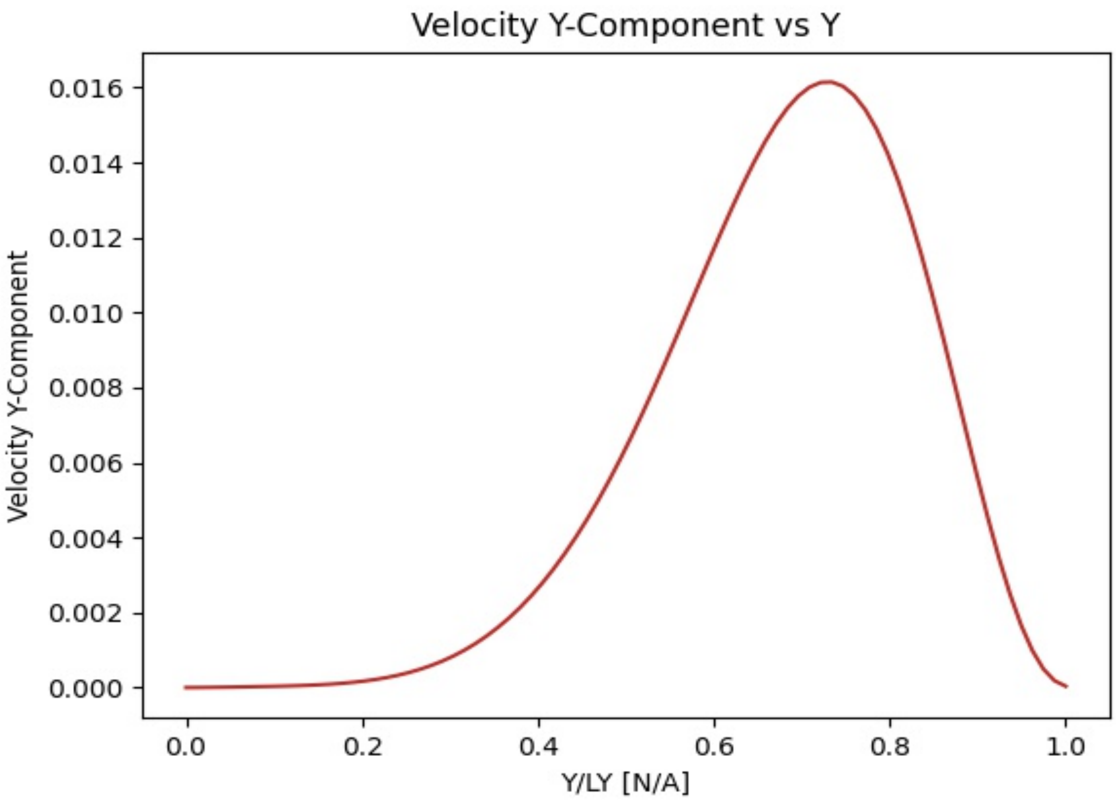

Velocity X-Component vs Y
Velocity X-Component
0.8
0.6
0.4
0.2
0.0
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
Y/LY [N/A]

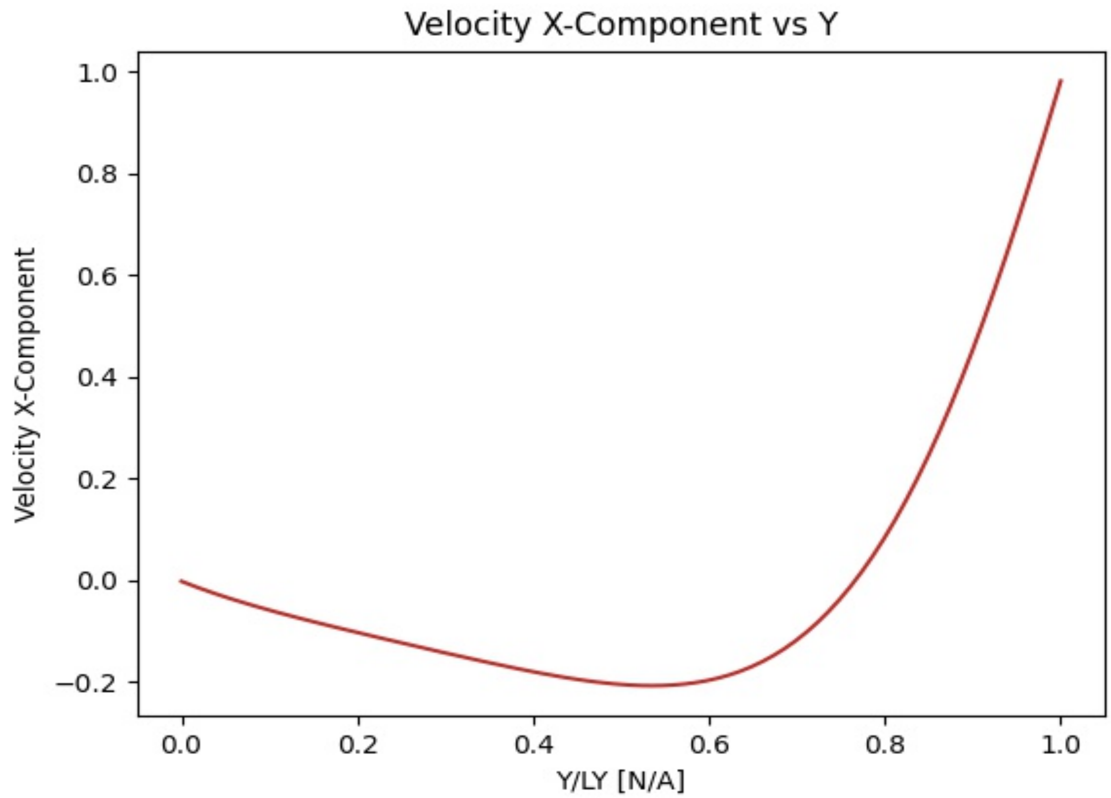

Velocity Y-Component vs Y
Velocity Y-Component
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0.0
0.2
0.4
0.6
0.8
1.0
Y/LY [N/A]

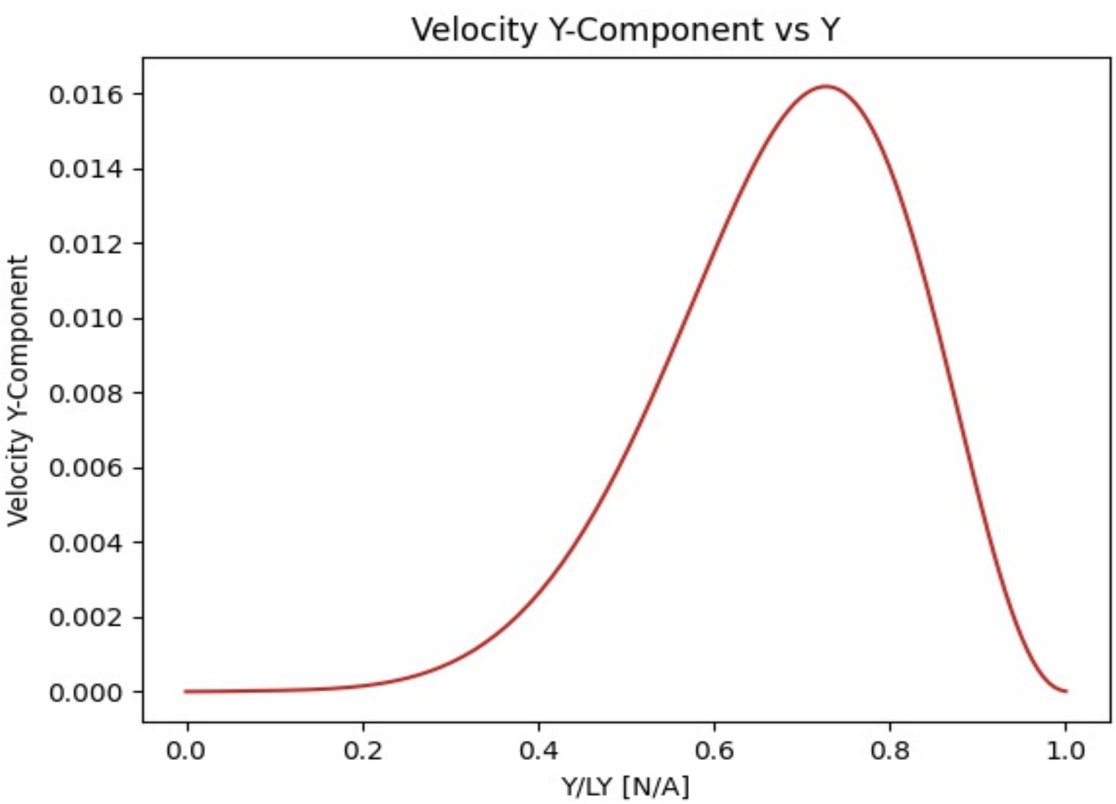

Velocity X-Component vs Y
Velocity X-Component
Y/LY [N/A]
0.8
0.6
0.4
0.2
0.0
−0.2
0.0
0.2
0.4
0.6
0.8
1.0


Velocity Y-Component vs Y
Velocity Y-Component
Y/LY [N/A]
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0.0
0.2
0.4
0.6
0.8
1.0

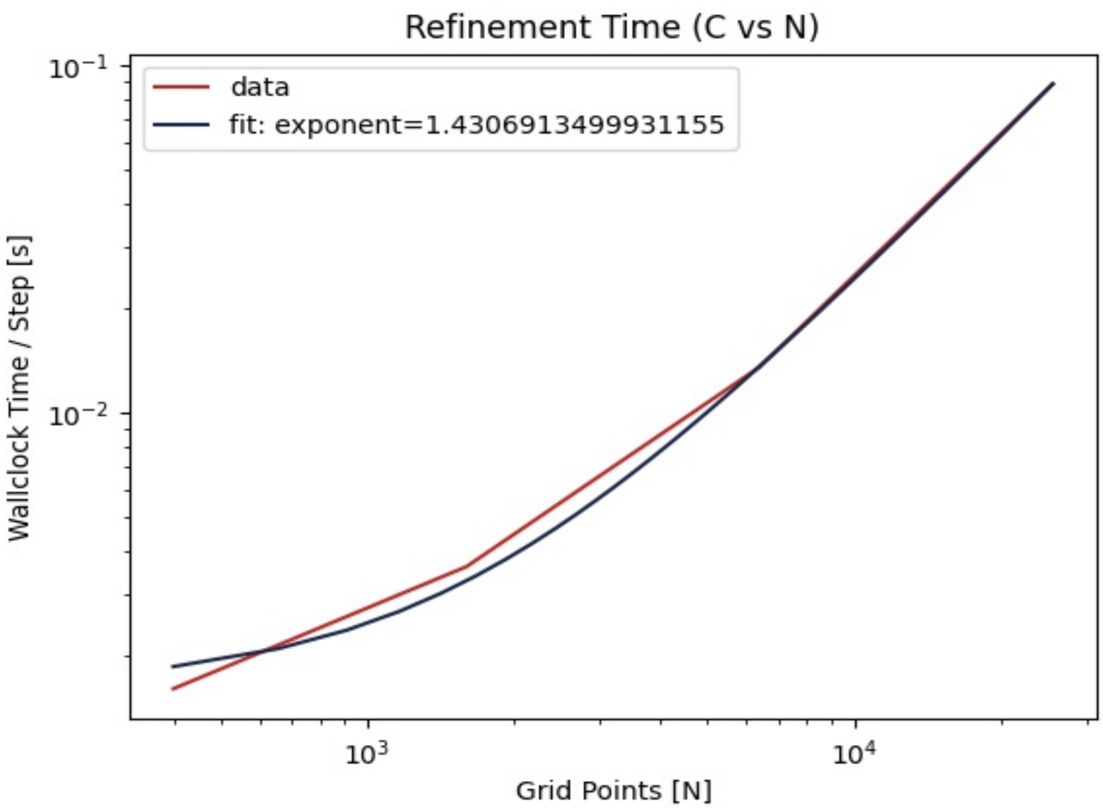

Velocity X-Component vs Y
Velocity X-Component
Y/LY [N/A]
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0.0
0.2
0.4
0.6
0.8
1.0


Velocity Y-Component vs Y
Velocity Y-Component
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0.0
0.2
0.4
0.6
0.8
1.0
Y/LY [N/A]


Velocity X-Component vs Y
Velocity X-Component
Y/LY [N/A]
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0.0
0.2
0.4
0.6
0.8
1.0


Velocity Y-Component vs Y
Velocity Y-Component
Y/LY [N/A]
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0.0
0.2
0.4
0.6
0.8
1.0

As a final comparision, we plot C, the wallclock time per second versus N, the number of grid points used. As this is a 2D simulation, we expect a form similar to $C = \gamma + \beta * N^{\alpha}$, where $\alpha = 2$, due to the number of dimensions. A fit to this curve is also shown.



Interestingly, we do not get $\alpha = 2$. The decreased alpha implies a large processing overhead necessary to start the simulation, especially as the fit is less accurate with fewer grid points. We can see that the fit has a large curvature, which would be produced by a constant overhead: the γ variable, so there is some evidence for the is explanation. A similar test with a higher overall number of grid points ought to produce an alpha closer to 2. An alternative explanation would be accuracy saturation, where the solver reaches the required accuracy in fewer steps than expected, due to the fineness of the grid, causing increased performance, but this explanation is highly improbable.

Finally, we note that there are nearly imperceptible differences between the velocity profiles for grids 3 and 4, so a grid size of 80 points per axis satisfies the necessary accuracy.

6. Conclusion

–conclusion here–

References

Appendix

Thank you so much for reading this work!

References

Allaire, J., Xie, Y., McPherson, J., Luraschi, J., Ushey, K., Atkins, A., Wickham, H., Cheng, J., Chang, W. and Iannone, R. (2021). *rmarkdown: Dynamic Documents for R*. R package version 2.11.
URL: *https://CRAN.R-project.org/package=rmarkdown*

Bengtsson, H. (2021). *R.utils: Various Programming Utilities*. R package version 2.11.0.
URL: *https://github.com/HenrikBengtsson/R.utils*

Urbanek, S. (2021). *jpeg: Read and write JPEG images*. R package version 0.1-9.
URL: *http://www.rforge.net/jpeg/*

Xie, Y. (2013). animation: An R package for creating animations and demonstrating statistical methods, *Journal of Statistical Software* **53**(1): 1–27.
URL: *https://doi.org/10.18637/jss.v053.i01*

Xie, Y. (2014). knitr: A comprehensive tool for reproducible research in R, *in* V. Stodden, F. Leisch and R. D. Peng (eds), *Implementing Reproducible Computational Research*, Chapman and Hall/CRC. ISBN 978-1466561595.
URL: *http://www.crcpress.com/product/isbn/9781466561595*

Xie, Y. (2015). *Dynamic Documents with R and knitr*, 2nd edn, Chapman and Hall/CRC, Boca Raton, Florida. ISBN 978-1498716963.
URL: *https://yihui.org/knitr/*

Xie, Y. (2021a). *animation: A Gallery of Animations in Statistics and Utilities to Create Animations*. R package version 2.7.
URL: *https://yihui.org/animation/*

Xie, Y. (2021b). *knitr: A General-Purpose Package for Dynamic Report Generation in R*. R package version 1.36.
URL: *https://yihui.org/knitr/*

Xie, Y., Allaire, J. and Grolemund, G. (2018). *R Markdown: The Definitive Guide*, Chapman and Hall/CRC, Boca Raton, Florida. ISBN 9781138359338.
URL: *https://bookdown.org/yihui/rmarkdown*

Xie, Y., Dervieux, C. and Riederer, E. (2020). *R Markdown Cookbook*, Chapman and Hall/CRC, Boca Raton, Florida. ISBN 9780367563837.
URL: *https://bookdown.org/yihui/rmarkdown-cookbook*