

Particle tracking velocimetry: Deliverables

ME 240: Fundamentals of Instrumentation & Measurement • D. H. Kelley and I. Moham-
mad • 131 points

Name:

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Student ID:

Lab partners: team laboratory project

Please write the following sentence in the box below in your own handwriting and SIGN:
*"I affirm that I have not given or received any unauthorized help on this as-
signment, and that this work will be my own."*

I affirm that I have not given or received
any unauthorized help on this
assignment, and that this work will be
my own.

Mixing the solution

1. (2 points) What mass of water is required for your solution?

157.95g

2. (2 points) What mass of copper sulfate is required for your solution?

17.5g

3. (2 points) What volume of glycerol is required for your solution?

39.5ml

Determining the fluid density

4. (2 points) What is the density of your solution?

1.124 g/mL

5. (2 points) What volume of fluid did you use to determine that density?

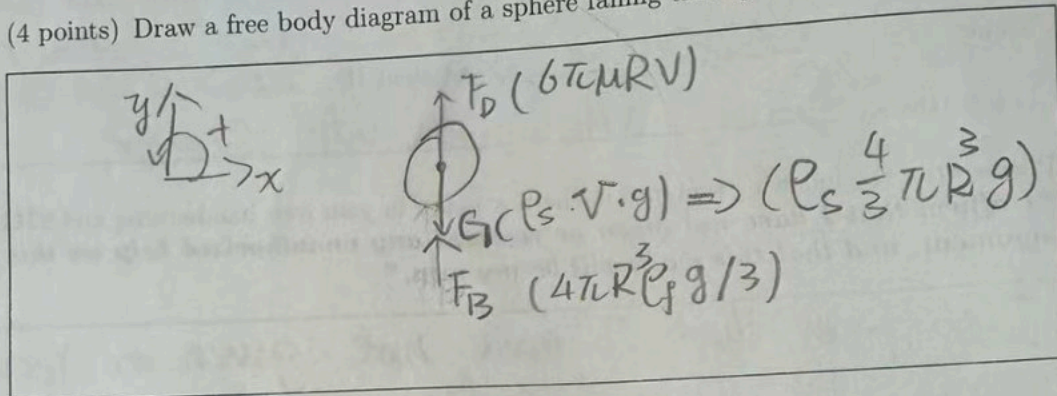
197.45 mL

6. (2 points) What was its mass?

221.97g

Determining the viscosity

7. (4 points) Draw a free body diagram of a sphere falling through a fluid.



8. (4 points) Determine a formula for μ .

$$\begin{aligned}\Sigma F &= F_D + F_B - G \\ &= 6\pi\mu R V + 4\pi R^3 \rho_f g - \rho_s V \cdot g = 0 \\ 6\pi\mu R V &= \rho_s \frac{4}{3}\pi R^3 g - 4\pi R^3 \rho_f g \\ \mu &= \frac{\rho_s \frac{4}{3}\pi R^3 g - 4\pi R^3 \rho_f g}{6\pi R V} = \frac{2\rho_s R^2 g - 2\rho_f R^2 g}{9V} = \frac{2R^2 g}{9V} (\rho_s - \rho_f)\end{aligned}$$

9. (3 points) As a sphere falls, measure its position at three different times.

time 1: 23.44s position 1: 0 cm
 time 2: 25.08s position 2: 3.6 cm
 time 3: 27.06s position 3: 8.1 cm

10. (2 points) Calculate the terminal velocity V for the interval from time 1 to time 2.

2.18 cm/s

11. (2 points) Calculate the terminal velocity V for the interval from time 2 to time 3.

2.273 cm/s

12. (2 points) Calculate the viscosity μ . 0.00345 $\frac{\text{kg}}{\text{s}\cdot\text{m}}$

$$\frac{\text{L}^2 \cdot \text{L} / \text{T}^2}{\text{L} / \text{T}} = \text{L} / \text{T}$$

$$\frac{\text{L}}{\text{T}^2} \cdot \left(\frac{\text{M}}{\text{L}^3} \right) = \frac{\text{M}}{\text{T}^2 \cdot \text{L}}$$

13. (3 points) How did you check that the sphere had reached terminal velocity?

We selected several points, making sure the velocities of them are close, so the ball is not accelerating.

14. (4 points) Discuss at least two potential sources of error in the viscosity measurement procedure.

First the reading through camera is not accurate. What's more we can't really get the terminal velocity with the cylinder in the lab because the length is too small.

Imaging the flows

15. (2 points) What is the magnet stripe width $L/2$? 1.3 cm
16. (2 points) At what critical current I_c and voltage V_c do shear bands give way to vortices?
0.091 A 18.3 V
17. (3 points) What is the size, in mm, of one pixel? 0.0629 mm
18. (2 points) What is the frame rate? 30 FPS
19. (2 points) List the filenames of the movies you recorded and the current applied for each in Table 1.

20. Attach the background image calculated



22. Attach the illustration of your slowest movie.

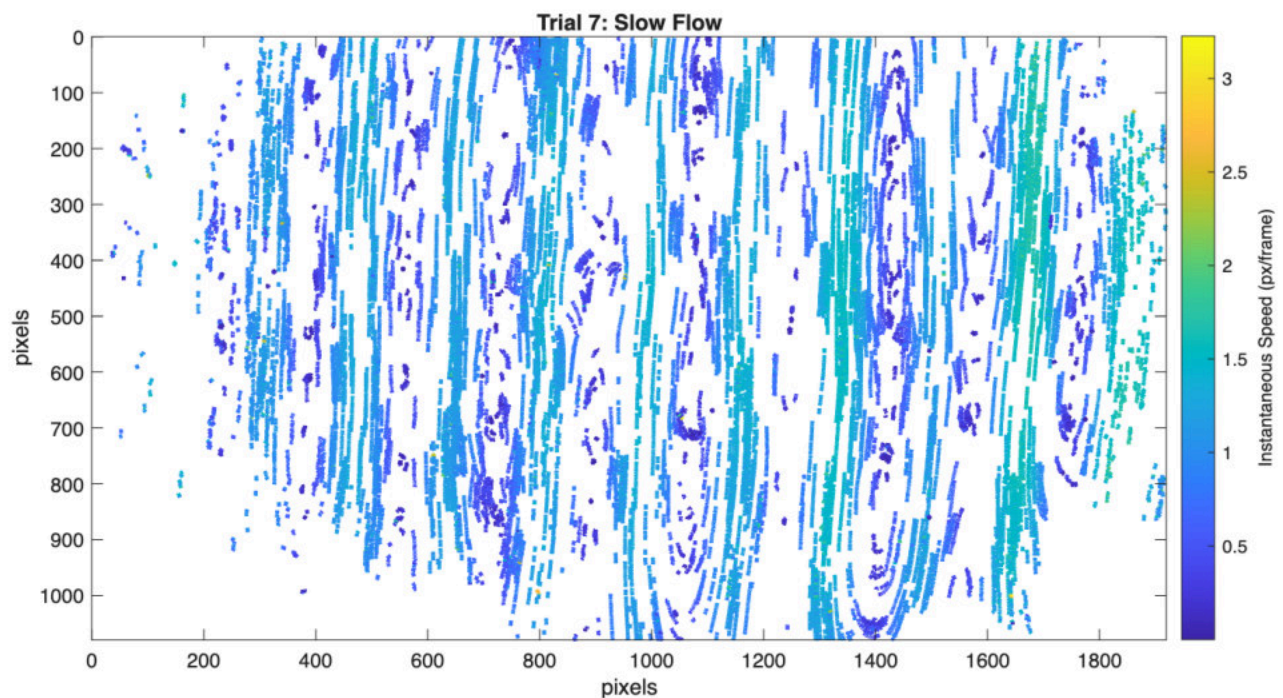


Figure 1. Track Plot of Slowest movie. The plot demonstrated the tracks of particles from the first 100 frames. The colors of the lines represent the instantaneous speed of particles. In this plot, the tracks of slow flow tend to be shear bands.

23. Attach the illustration of your fastest movie

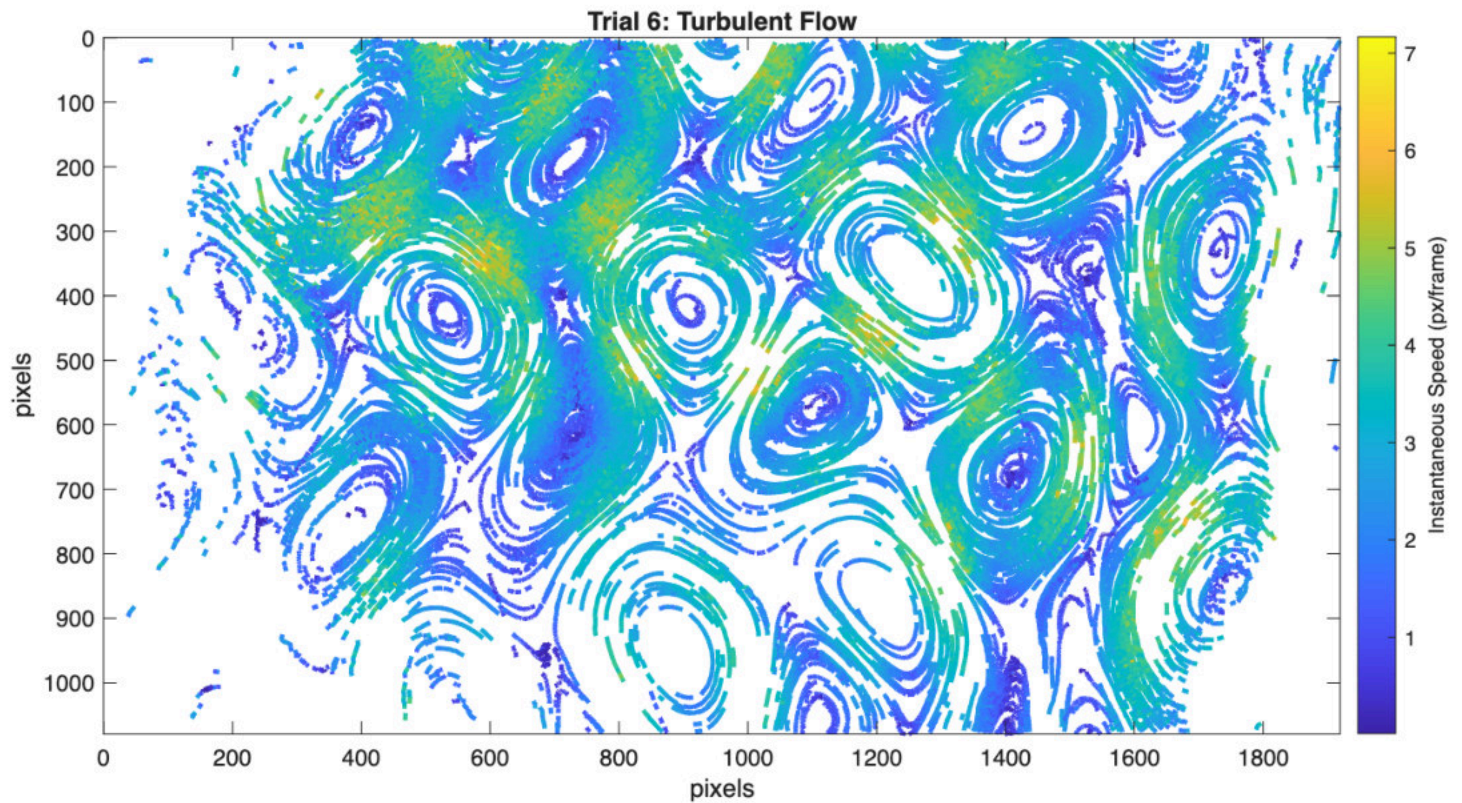


Figure 2. Track Plot of Fastest movie. The plot demonstrated the tracks of particles from the first 100 frames. The colors of the lines represent the instantaneous speed of particles. In this plot, the tracks of fast flow tend to be turbulent.

24. Attach the plot of variation of Re with applied current.

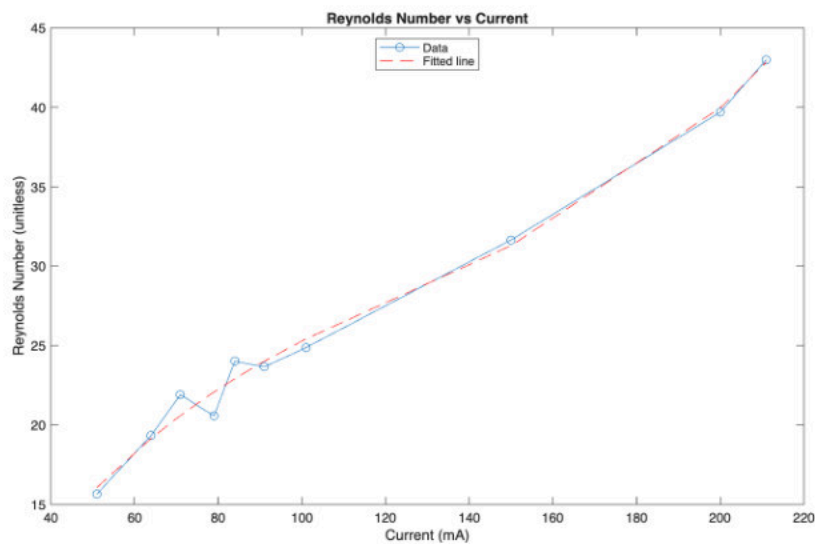


Figure 3. Reynolds number variate with applied current. The fitted line used third degree polynomial fit, which shows that the Reynolds number is positively proportional to applied current.

25. Attach the plot of root-mean-square of horizontal velocity variate with Re.

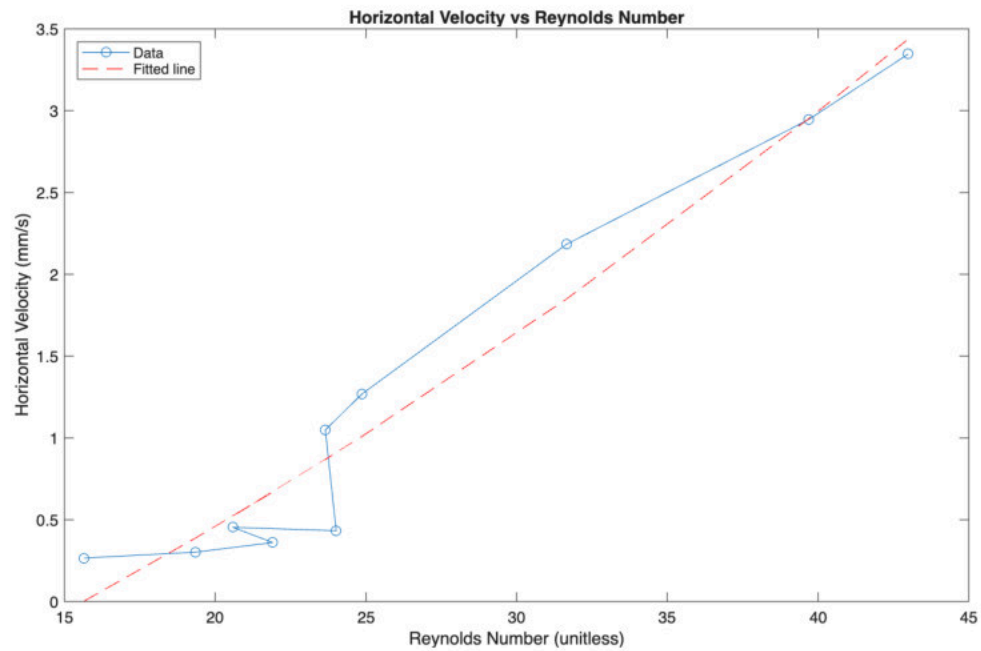


Figure 4. Root-mean-square of horizontal velocity vs Re. The fitted line used second degree polynomial fit shows that horizontal velocity tends to be positively proportional to Reynolds number. At $Re = 24.0154$, the root-mean-square of horizontal velocity has a jump, which means it's the critical Re.

26. The critical Reynolds number $Re_c = 24.0154$

I (mA)	Filename	obj.Thr (0-255)	obj.Max_disp (pixels)	$\langle u^2 \rangle^{1/2}$ (mm/s)	Re
84	trail 1 .mp4	(0-75)	4	0.4378	24.0154
91	trail 2 .mp4	(0-75)	4	1.0492	23.6541
101	trail 3 .mp4	(0-75)	3.5	1.2699	24.8774
150	trail 4 .mp4	(0-70)	3.5	2.1831	31.6515
200	trail 5 .mp4	(0-73)	3.75	2.9459	39.6909
211	trail 6 .mp4	(0-65)	4	3.346	47.99
51	trail 7 .mp4	(0-75)	4	0.266	15.653
64	trail 8 .mp4	(0-75)	4	0.3023	19.3578
71	trail 9 .mp4	(0-75)	4.5	0.3609	21.9096
79	trail 10 .mp4	(0-70)	4.5	0.4540	20.5824

Table 1. Movies and tracking results.

27. Abstract

Optical techniques are powerful and common for fluid motion. In particle tracking velocimetry (PTV), flow visualization and automated tracking of moving particles enables us to study fluid motion. This lab focuses on fluid motions manipulated by a combination of magnetic fields and electric currents result in various fluid flows, from simple shear bands to complex vortices, depending on the flow velocity and its viscosity. The ultimate goal is to predict the stability of flow motions. According to our data, we demonstrate the flow stability is associated with Reynolds number. This shows the importance of the Reynolds number in estimating the flow system's predictive stability. More generally, it shows the applicability of the basic principles of fluid mechanics to estimating complex flow behavior and system stability in various situations.

28. Methodology

The experiment determined the critical Reynolds number which the flow motion changed from simple parallel shear bands to complex vortices. In order to obtain the Reynolds number, the dynamic viscosity μ and flow velocity field are needed, by Equation (1).

$$Re = UL\rho/\mu \quad \text{Equation (1)}$$

U is determined by the MATLAB codes generated by Professor Kelly's team. μ is driven by Equation (2).

$$\mu = \frac{2R^2g}{9V}(\rho_s - \rho_f) \quad \text{Equation (2)}$$

To start the experiment, we need to produce a 175g of 10% copper sulfate in water of total mass mixed with 20% glycerol by total volume. Then measure the mass using the scale and volume using the graduated cylinder. Then drop a sphere to the fluid and record the terminal velocity using a stopwatch and ruler. $\rho_s = 1180 \text{ kg/m}^3$, $R = 794 \text{ }\mu\text{m}$. Thus, μ is determined by the parameters given using Equation (2).

Use ruler to measure the magnet strip's width and then pour the fluid into a plate until the electrodes are connected. Then scope small amount of fluorescent tracer particles using wooden coffee stir to the fluid and scatter the particles throughout the fluid. After that, drop a tiny amount of dish soap to the fluid in order to increase the visibility of the fluid under the camera. Sweep the bubbles of the fluid to minimize the error of particle detection. Connect the multimeter and fluid apparatus to the power supply in series so that we can accurately read the current and voltage. Apply a small current I to make sure the fluid is moving in parallel shear bands and then gradually increase the current to see if the fluid will be accelerated. After that, use the webcam and the Windows Camera App to capture a photo of the plate. Tune the focus of the webcam to take a clear photo. Then put a wooden ruler near the fluid layer and take a photo so that we can convert pixel sizes into mm. Then remove the ruler and connect the blue light bin to power supply and put it on the fluid plate. Then apply small current and take a video of the fluid for 5-10 seconds. Record the current, frame rate and movie file name. Then gradually increase the current and record videos for the same time range and record all the information mentioned. Iterate the process for eight more times. Then dispose the fluid. Then use the MATLAB code provided by Professor Kelly's team to analyze the fluid. Clearly choose the threshold from range 0 to 255, and maximum displacement of the

particles for each video and record the parameters used. Calculate the horizontal velocity using root-mean-square method and get the Reynolds number using Equation (1) with the velocity calculated by root-mean-square method. All the horizontal velocity must be converted into mm. Record all horizontal velocity and Reynolds numbers of each trail. Plot the velocity field of the fastest and slowest flow at 100th frame. To analyze the data, we need to collect all the Reynolds numbers calculated for each trail and the current of each trail. Then plot the Reynolds number vs the current change. In Figure 3, we can conclude that Reynolds number is positively proportional to the current. According to Figure 1 and Figure 2, the slow flows will exhibit the parallel shear bands, and the fast flows will have irregular vortices. Based on Figure 4, there is an obvious jump at Reynolds number of 24.0154, which represents that the horizontal velocity is changing largely. When we have large velocity, the flow will present complex vortices, which means the jump point is the critical Reynolds number.

29.

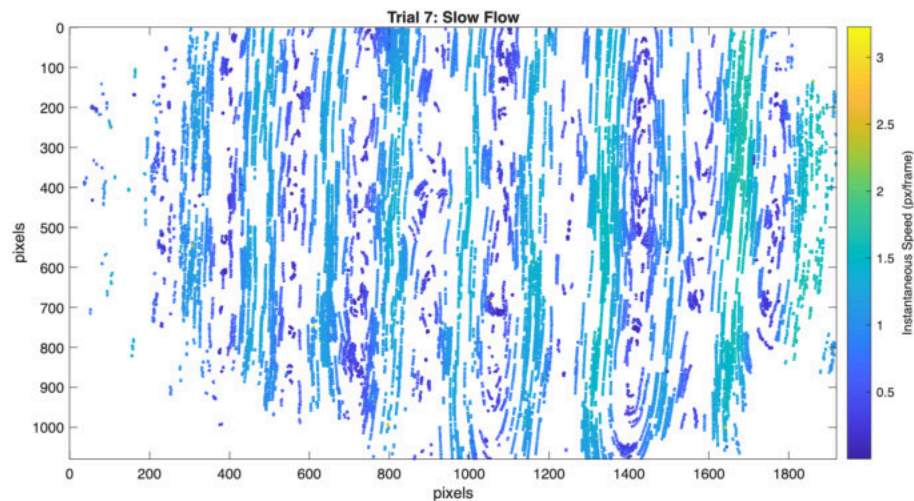


Figure 1. Track Plot of Slowest movie.

In Figure 1, the plot shows the velocity field of the slow flow at the 100th frame. It demonstrates the shape of the slow flow is simple parallel shear bands, so that the horizontal velocity of the flow is relatively small because it tends to move vertically.

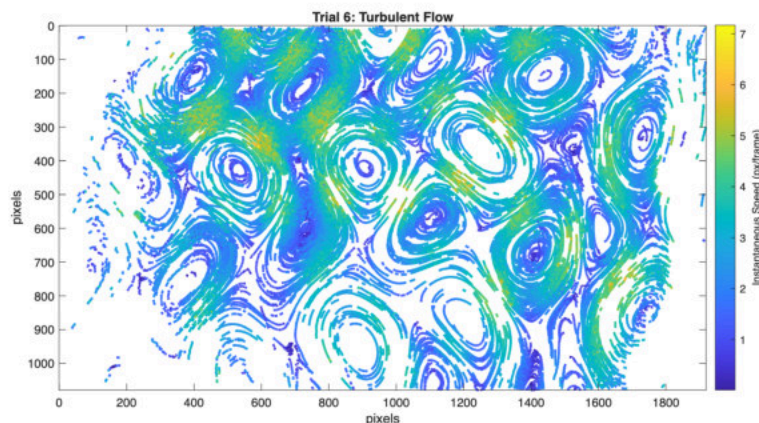


Figure 2. Track Plot of Fastest movie.

In Figure 2, the plot shows the velocity field of the fast flow at the 100 th frame. It demonstrates the shape of the fast flow is irregular vortices. In this motion, the flow will have larger horizontal velocity. Therefore, to differentiate the fast flow and slow flow, the horizontal flow would be a reference.

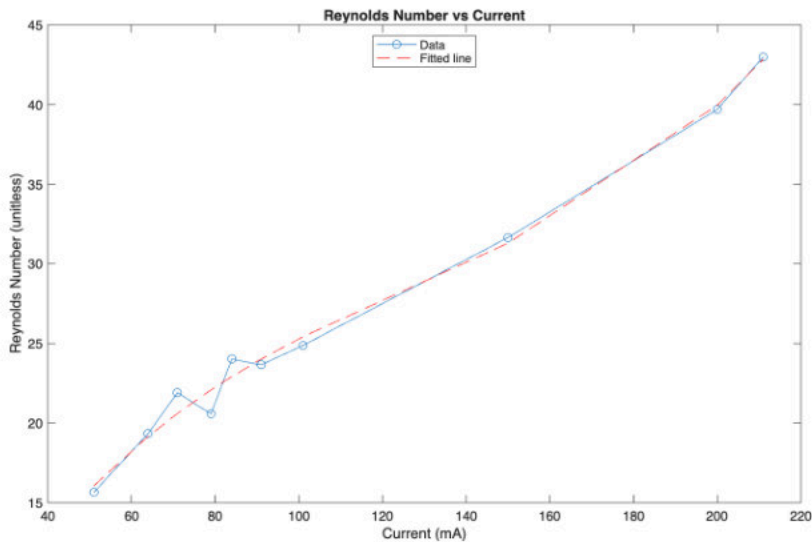


Figure 3. Reynolds number variate with applied current.

In figure 3, the plot of Reynolds number vs current shows that the Reynolds number are positively proportional to current, which means that Reynolds number can represent the flow with different currents. In the other hand, the Reynolds numbers are like the ID of the flows with different currents connected. Thus, we can plot the horizontal velocities vs Reynolds number.

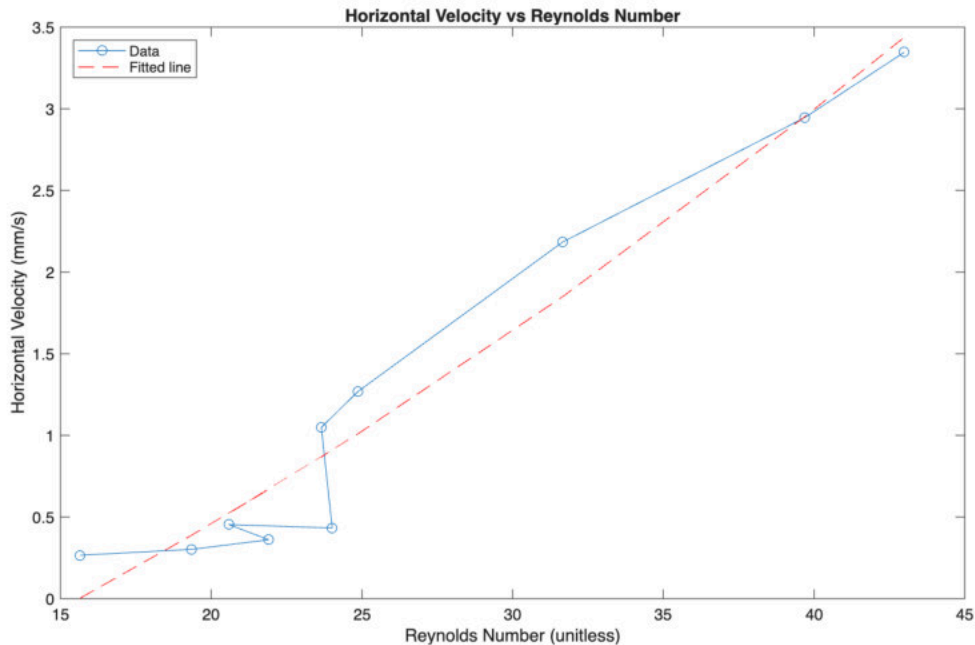


Figure 4. Root-mean-square of horizontal velocity vs Re.

In figure 4, the flows having large horizontal velocities are the ones having complex vortices. There is a jump at Re equals to 24.0154, which means the horizontal velocity changes from small velocity to higher velocity. This transition of horizontal velocities also represents the transition from slow flow to fast flow.

As a result, the threshold Reynolds number, critical Reynolds number, is determined, which is 24.0154 for the fluid used in this experiment. Since the horizontal velocity is also positively proportional to Reynolds number, we can conclude that Reynolds number can be used to predict the stability of the flow motion. Faster flows are less stable having complex vortices, and slow flows are more stable having parallel shear bands. We can also determine the critical Reynolds number by analyzing the horizontal velocity associated, where the stability of the flow changes.