Tessa Stevens

Math and Physics

Analysis of Nanowire Micro-Fluidic Tweezers

Longhua Zhao

Department of Mathematics, Applied Mathematics and Statistics

Project Goals and Objectives:

It has been shown that particles can be transported through fluids using vortices. One way to create these vertices is by rotating small particles, known as nanowire tweezers.[1] This is significant because it provides a method to transport drugs through a person's bloodstream and deliver them to a specific location without damaging the drug or the person.[2] The main goal of the proposed research is to farther analyze this method of moving particles and answer some remaining questions. Specifically, we intend to determine the ideal speed and location of the nanowire to trap the particle, determine the effects of the speed of the background flow of the fluid, and further explore the effects of other forces such as gravity on the system.

Project Description:

Various methods to transport particles through fluids have been explored.[3] One of the most promising of these methods is through using fluid tweezers to manipulate the fluid near the particle and thus transport the particle indirectly.[4] The fluid tweezer moves the particle in fluid by creating vortices from rotating the nanowire with an external force, such as a magnetic field. The particle will then become trapped in the vortex and can be transported by moving the nanowire.

We have already found that there is a relationship between the location of the nanowire, speed of the background flow of the fluid, shape of the nanowire and the probability of the particle being trapped. These results are demonstrated in the graphs below which show the position of 6 chosen initial particles (located at (x,y)=(0,0); (0,0.2); (0,0.4); (0,0.6); (0,0.8); (0,1)) over a set time interval.

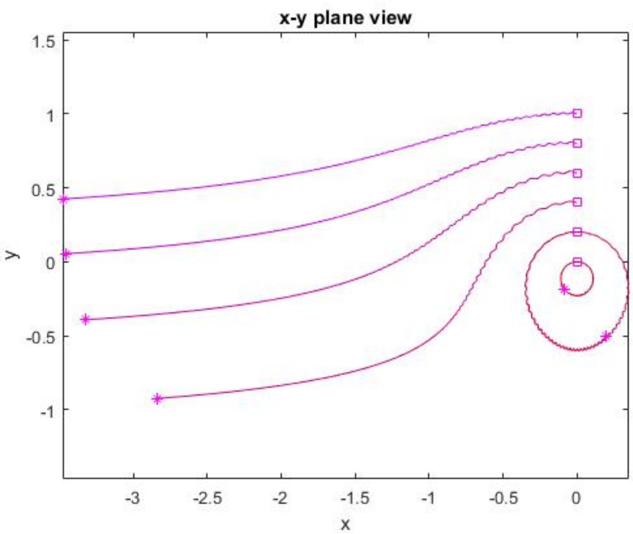

Figure 1: height of spheroid=0.167, flow speed=0.08

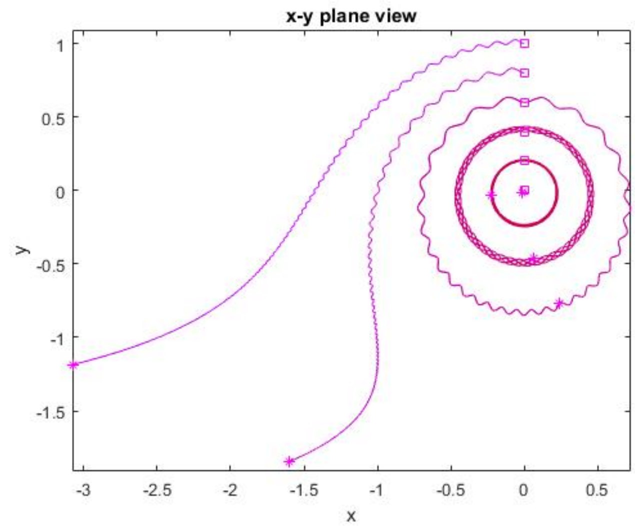

Figure 3: height of spheroid=0.0067, flow speed=0.08

In the first image, it can be seen that only two particles have periodic motion, and thus the spheroid can trap particles to a range of 0.2 units. However, in the second image, in which the shape of the nanowire was changed to more closely resemble a sphere, the distance at which the spheroid can trap particles has doubled, and four particles have periodic motion. In the last image, the speed of the background flow of the fluid was increased and as a result, the range of distances at which the spheroid can trap particles decreased.

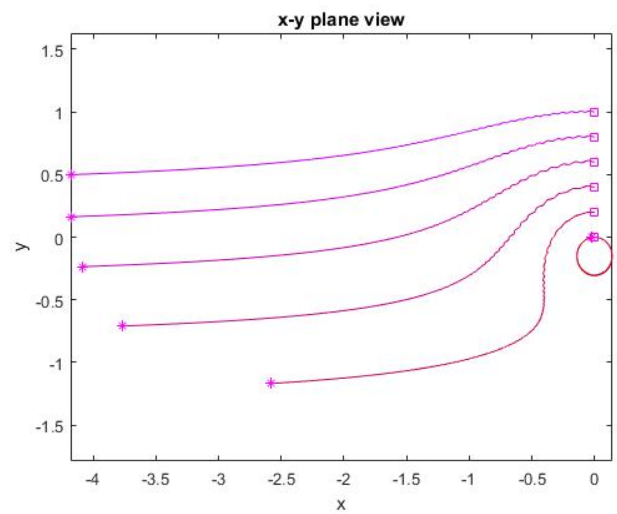

Figure 2: height of spheroid=0.0067, flow speed=0.1

However, despite knowing there is a relationship, we have not yet found an equation to represent the relationship between the location and rotation speed of the nanowire, speed of the flow of the fluid, shape of the nanowire and the probability of the particle being trapped and transported by the motion of the nanowire. This relationship will be further explored over the summer in the hopes of developing an equation that can be used to determine the initial conditions necessary to trap the particle.

Additionally, we will explore how other external forces, such as gravity, will have an effect on the probability of the particle being trapped by the nanowire. These forces have been neglected prior to this point in order to simplify the problem. However, in order for the research to have a practical application anywhere besides outer space it is necessary to consider all of the external forces that might be acting on the system.

Methodology:

The flow of fluid has been well studied and can be represented using Stokes' equations. We will use these equations to model the flow of the fluid around a spinning nanowire to determine where the fluid's motion is periodic, and thus capable of trapping a particle. We will use the Stokes equations in combination with equations representing the effect of outside forces on the motion of the fluid. These calculations and plots will be performed using Matlab or python in order to quickly calculate the path of certain initial particles of fluid. In addition, the results from these calculations will be tested by going to a laser lab at Cleveland State University and observing how the predictions of the conditions necessary to trap the particle compare to experimental data.

Time Commitment:

I plan to work on this project full time during the summer starting in late May and continuing through mid-August. I will be working on the project by both running code on my computer and by going to a laser lab to compare the experimental results to my predicted analytical results. I have already initiated work on the project during the semester, and so the project is well on its way and I will be able to devote my time this summer to researching as opposed to trying to understand the problem.

Relation to Educational Goals and Plans:

I have always been interested in trying to determine the reason behind observed phenomena, which is why I decided to attend Case Western Reserve University and declare a Math and Physics major. I currently intend to work in a government research lab and explore mathematical or physical concepts after graduating. Thus, gaining experience through working on an applied math research problem will be very helpful to me in these goals as it will give me experience working as a researcher, which will help me decide if research is truly what I want to do as a career. Additionally, working on a research problem will help me gain future research opportunities since I will be able to show that I have experience in research.

Budget Justification:

I am requesting a total of $3500 in funding. $3000 is to cover the cost of living expenses in Cleveland, with a breakdown of $2000 for housing, $800 for food, and $200 for transportation to and from the lab at Cleveland State University. $500 is to cover the cost of presenting the findings at an appropriate Conference, such as the Conference on Research in Undergraduate Mathematics Education hosted by the Mathematical Association of America

References:

[1] T. Petit, L. Zhang, K. E. Peyer, B. E. Kratochvil, and B. J. Nelson, "Selective Trapping and Manipulation of Microscale Objects Using Mobile Microvortices", Nano Letters 12, 156–160 (2012), http://dx.doi.org/10.1021/nl2032487

[2] 7A. L. Balk, L. O. Mair, P. P. Mathai, P. N. Patrone, W. Wang, S. Ahmed, T. E. Mallouk, J. A. Liddle, and S. M. Stavis, "Kilohertz Rotation of Nanorods Propelled by Ultrasound, Traced by Microvortex Advection of Nanoparticles", ACS nano 8, 8300–8309 (2014).

[3] 2Z. Liu, Y. Chen, L. Zhao, Y. Zhang, Y. Wei, H. Li, Y. Liu, Y. Zhang, E. Zhao, X. Yang, J. Zhang, and L. Yuan, Opt. Lett. 41, 2966–2969 (2016), URL http://ol.osa.org/abstract.cfm?URI=ol-41-13-2966.

[4] A. E. Cohen, and W. E. Moerner, Proc. Natl. Acad. Sci. U.S.A. 103, 4362–5 (2006).