Statement of Purpose

My introduction to Fluid Mechanics and Computational Fluid Dynamics (CFD) happened during my sophomore year when I enrolled in the Fluid Mechanics course. I vividly recall a defining moment when the professor showcased a brief video highlighting his recent research. The video featured a mesmerizing visualization of flow patterns around a circular cylinder. Witnessing the intricate flow dynamics surrounding what appeared to be a simple geometric shape left a profound impression on me. It was this moment that ignited my interest to delve deeper into the world of CFD. I consider myself fortunate to have studied at one of India's premier institutions, with an acceptance rate of less than 2%. This esteemed academic environment provided me with unparalleled opportunities to collaborate with highly knowledgeable and experienced professors. I wholeheartedly embraced these opportunities to expand my horizons and deepen my understanding of fluid dynamics and computational simulations.

In the subsequent summer vacation, I worked as an intern at DHIO Research and Engineering, India, where I was introduced to the different aspects of the CFD simulation: geometry creation, meshing, setting up the solver, applying boundary conditions, and interpreting the results. I learned about meshing and the importance of using a good mesh. Furthermore, I learned how to perform mesh independence study and validation study, an essential precursor to any research work. Most notably, I learned how to understand and interpret the flow data generated from the simulations. The final project of the internship was to simulate a cyclonic separator and predict its separation efficiency using ANSYS Fluent. The project was undoubtedly a gateway for me into the field of CFD, and despite having such a steep learning curve, I learned many things during the project.

As I found my sophomore year internship on numerical simulations interesting, I took a Numerical Techniques course in my junior year, instructed by Dr. Pritanshu Ranjan. Here I learned about the inner workings of CFD solvers. The course taught me how numerical simulations are done, starting from the governing equations, converting them to linear systems of equations, applying boundary conditions, and solving them using iterative methods such as Gauss-Seidel, TDMA, and the use of under-relaxing and over-relaxing factors along with other concepts. The first half of the course focused more on Finite Difference Method (FDM) and its limitations while the next half focused on the numerical solution of the Navier-Stokes equation using Finite Volume Method (FVM) and its implementation using staggered grids and iterative algorithms such as SIMPLE, PISO, and PIMPLE. As a part of the curriculum, I implemented some of these techniques in MATLAB codes to model well-known problems, such as Lid Driven Cavity and Poiseuille Flow.

Having developed a better understanding of fluid mechanics, I wished to explore its use in real-world problems. Prof. Kiran Ramesh at the University of Glasgow guided me in my junior year summer internship project to study the flow physics of an airfoil-based turbine to extract energy from tides. In this project, I used a Discrete Vortex Method (DVM) based in-house solver written in Julia to simulate the performance of the turbine. The project was very insightful as I learned about the state-of-the-art research in tidal energy extraction. I also learned about DVM, a method where individual vortex elements are used for simulation in contrast to a full-fledged simulation carried out in CFD. The project also introduced me to aeroelastic modeling and fluid-structure interaction (FSI) and subsequently, many of my research projects explored this area.

In my junior year, I took a design-oriented project course offered by our university, under the guidance of Dr. Vaibhav Joshi. Dr. Joshi had experience in FSI modeling, and I worked under him to understand FSI modeling using Finite Element Method (FEM). I used FEM to solve the Navier-Stokes equation, the structural equation, and the mesh movement equation. The governing equations were solved in the moving mesh Arbitrary Lagrangian Eulerian (ALE) framework. I developed the MATLAB code for 2D two-way coupled problems and used it to study an aeroelastic airfoil. I also worked under the guidance of Prof. Pritanshu Ranjan, to study passive flow control techniques for drag reduction using OpenFOAM. I was inspired to study this topic after learning about the use of dimples in golf balls. Through this project, I discovered that through optimal placing of dimples on the exterior of geometry, flow separations can be prevented, which significantly reduces the drag. In the subsequent semester, I also had the opportunity to work under the supervision of Prof. Sridhar Ravi, at the University of New South Wales, Australia to explore the use of Dynamic Mode Decomposition (DMD), which is a dimensionality reduction technique. I developed code in Julia to perform DMD on the flow data extracted from the in-house CFD solver.

My collaboration with Dr. Joshi also served as my introduction to the realm of biomimetics. One aspect that particularly piqued my interest and kindled my desire for further exploration was the study of fluid mechanics in collective motion among various species, including the coordinated flight of bird flocks and the synchronized swimming of fish schools. What intrigued me about these phenomena was their evolutionary development over millions of years, resulting in highly efficient and specialized modes of movement. Hence in my undergraduate thesis at Chalmers University of Technology, Sweden, I explored the fluid dynamics of triple synchronous flapping foils under the guidance of Dr. Yao. This was a challenging topic for me because I soon realized that the mesh movements I had used earlier were not feasible due to excessive mesh deformation. To remedy this problem, I used the Overset (Chimera) mesh technique, where the mesh attached to the structure moves independently of the background mesh, and the flow variables are interpolated between different meshes. Using Overset meshes and OpenFOAM I studied the problem, varying the spacing between the airfoils. I identified the primary thrust generation mechanism, which was due to the formation of a Leading Edge Vortex (LEV) which generated favorable pressure gradients. For multi-foil systems, I also studied the vortex interactions between the upstream and downstream foils and classified them according to the efficiency and thrust they generated.

At Columbia University, I always wanted to combine my knowledge of fluid mechanics with robotics, particularly with its applications in underwater robotics. Therefore, as a first step, I developed a bipedal walking robot, completely from scratch, starting with a concept sketch, initial and detailed CAD design, electronics, and even programming. I uploaded the journey video to YouTube as well (link). Due to the highly interdisciplinary nature of robotics, I also had the opportunity to learn more about Machine Learning, Reinforcement Learning, and GPU computing, which I continued to explore in the future.

My interest in GPU computing and its applications to CFD led me to pursue summer research under the guidance of Dr. Shaina Kelly at Columbia University where I developed JLBM.jl, a high-performance, GPU-accelerated software to model flows written in the Julia programming language. The software utilizes the Lattice Boltzmann Method (LBM), which is a method of Computational Fluid Dynamics where the Boltzmann equation is solved instead of Navier Stokes equation. The software harnessed the massive parallelization capabilities of the GPU through the

CUDA library and achieved 90% memory utilization. I am also currently working on publishing my work with Dr. Kelly. In the final semester of my Master's program, I will continue to work on JLBM.jl and apply it to model porous media flows.

My passion for teaching and research has driven me to actively pursue roles as a Course Assistant (CA). During my second semester at Columbia University, I had the privilege of serving as the CA for the Robotic Studio course, under the instruction of Professor Hod Lipson. This course, known for its inclusivity in accommodating students with diverse backgrounds, presented me with the valuable opportunity to assist students across various aspects of their robots, ranging from CAD design to electronics and programming. An important skill I cultivated during this experience was the ability to distill complex concepts into concise explanations.

In the current semester, I am honored to hold the position of Course Assistant (CA) for the Advanced Fluid Mechanics course instructed by Prof. Gerard Ateshian. As a CA, I take an active role in creating challenging and engaging homework assignments to help students in their pursuit of advanced knowledge in fluid mechanics. Serving as a CA continues to provide me with a profound appreciation for the rich diversity of individuals I interact with daily, each bringing their unique academic backgrounds and life experiences to the educational landscape.

As a prospective doctoral candidate at Columbia University, I aspire to nurture my profound passion for research and continue to build up on my graduate research work using the Lattice Boltzmann Method to study the complex problem of Carbon Storage in porous rocks. Columbia University's unwavering commitment to research and its strong ties to industry provide me with an unparalleled opportunity to channel my research efforts toward making a meaningful impact on the world. Having said that, I am also interested in the work of Dr. Pierre Gentine in the area of climate modeling using different computational techniques. Particularly, I am interested in using the Lattice Boltzmann Method to the large scale dynamics of the atmosphere and the effect of climate change.

My ultimate career ambition is to become a professor, where I can apply my acquired knowledge and honed skills to tackle real-world problems. Consequently, I approach the prospect of embarking on a rigorous Ph.D. program at Columbia University with unwavering optimism and confidence. I firmly believe that through this academic journey, I will not only fulfill my personal and professional aspirations but also contribute significantly to the advancement of the field.