STATEMENT OF PURPOSE

by

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Birds and flying insects have always been a symbol of freedom to me. Throughout my undergraduate years, as I built ground vehicles, quad-rotors, fixed-wing and transitional aircrafts, and gained research experience on the unsteady aerodynamics involved with flapping wings at the Bio-Inspired-Aero-and-Hydrodynamics Laboratory of Dr. Sunil Dash, my interest piqued in building bio-inspired robots. In addition to helping me find my primary research interest, my large and varied research background helped me realise that building robots is a highly interdisciplinary affair and requires a strong understanding of the associated physics, fabrication, control and artificial-intelligence. Furthermore, I have held Teaching Assistant positions in my fifth year, and have experience designing assessments, creating tutorials and course materials. I envisage my self-studying and creating robots capable of motion in air and water as a University Professor and Researcher. Earning a Ph.D. in Aerospace Engineering at Indian Institute of Technology Kharagpur and the University of Manchester would allow me to pursue my research interests and give me new opportunities to contribute to the field.

My tryst with aerodynamics and control theory started in my third year of undergraduate study, where I was tasked with studying the working of low-speed wind tunnels using experimental and numerical methods under the guidance of Dr. Saha. In the absence of requisite facilities (virtual education from home during COVID-19 lockdown), getting past the basic structure of the wind tunnel, we faced the challenge of fabricating the settling chamber and a stable strut incorporated with load cells. I simulated the airflow through the wind tunnel using ANSYS Fluent with a structured mesh and RANS solver to determine the turbulent kinetic energy at Re = 95,000 (Test Section Speed = 13.6 m/s). With TKE as reference, I was able to determine the sizing for the square and honey-comb mesh pores for the settling chamber. I conducted several tests to determine the pressure-correction coefficient, balance interactions, tare interference, weight and moment transfer corrections and blockage correction. The lift and drag coefficients obtained finally had an average error of 11% and 8% respectively. This term project made me realize the importance of organization and coherence of various steps in the fabrication of a machine.

My first internship gave me an opportunity to put my control theory and mechanical design concepts to work. With the help of MATLAB, I coded an iterative method using random disturbances in the lateral and longitudinal directions within a defined range, to determine the gain coefficients for a PID controller which reduced the vertical height loss in flight mode transition by over 6 meters in the longitudinal plane of the UAV. Further, I redesigned the internal structure of the UAV in SolidWorks to incorporate the updated avionics hub, and performed the detailed mechanical design of the retractable landing gear. The UAV is being currently tested as an aid to the first responder teams in fire hazards in Canada. Knowing the fact that I was able to make a contribution to a project which aims to save lives has been a humbling experience.

In a course taught by Dr. Dash, I was introduced to the research performed on flapping wing aerodynamics at his lab, and was amazed at the wide applicability of FWMAVs. Naturally, I felt inclined to undertake my bachelor thesis study under his supervision. During exploratory reading, the existing research gap on the variation of rotational and circulatory forces with respect to the parameters used in defining the kinematic profiles. I performed numerical validation studies on the effect of pivot point location and maximum pitching acceleration in lift generation. After several iterations in the pursuit of reproducing the results from the reference published paper, we found that using a structured (with 4 symmetrical blocks around the wing) dynamic mesh overset with two background meshes – a refined one for capturing the trailing wake and another for the overall domain – and a time step of 1E-05 s provided the best results within reasonable computational time. PISO (Pressure-Velocity coupling) algorithm was used owing to the transient nature of the simulation. Highly similar results were obtained on comparing the Viscous Laminar and Turbulent (k-epsilon, SA-model) solvers which proved that for a reduced frequency of 0.32 and Re = 5000 (close to dragonfly flight) showed that the flow can be considered laminar for this flight regime. We observed a major difference – a sharp peak was being captured on the onset of pitch motion from rest position – which was a clear combined manifestation of the Wagner Effect and non-circulatory forces.

Further literature review spurred my interest in developing optimized kinematics for dragonfly related flight as the parametric values for different flight modes have contrasting effects on efficiency and lift generation. I experimented with sinusoidal and trapezoidal kinematic profiles using numerical analyses and their effect on power requirements and stability of FWMAVs. In my second internship and Master Thesis Study, I worked under the joint supervision of Dr. Armanini and Dr. Dash to undertake an interdisciplinary study in aerodynamics and dynamic modelling of FWMAVs. We developed a modified form of the Eldredge function to incorporate phase syncing with stroking and heaving motions with an aim to optimize lift and thrust generation in tandem flapping wings. We simulated the newly developed kinematic profile and obtained enhanced lift (78% increase) and thrust (34% increase). We further found that the 2D model empirically derived in the work of *van Veen et al.2022* was in noticeable agreement with our findings. The major variation from the model was observed at start of stroke and stroke reversal which can be attributed to the combination of Wagner Effect and Added Mass forces, and the minor variations observed during translationally dominant phases of the flapping cycle can be attributed to vortex strength shedding. Our work was orally presented at the 75th Annual Meeting of the American Physical Society (Division of Fluid Mechanics), Indianapolis.

Parallelly, we developed the mechanical design for a FWMAV force test bed with coupled stroke-heave and independent pitch motion with the aim to test the validity of the empirical aerodynamic model derived for the novel kinematic profile. Currently, we are developing the dynamic model of the FWMAV test bed using Lagrangian formulation with an aim to study the FWMAV's response to the developed aerodynamic model and determine the unstable modes which will need mitigation by revising the mechanical design.

Obtaining a Ph.D. degree under the Joint Doctoral program at the Indian Institute of Technology Kharagpur and the University of Manchester will allow me to pursue my interest in flapping wing MAVs at the highest level and will help me gain the best of not one, but two great research institutions. My research background is foundationally focused on fluid mechanics, control and manufacturing, and I am eager to explore the depths of advanced control techniques for developing smart wing structures for flapping wing MAVs. I feel inspired by the contributions of Dr. Sunil Dash and Dr. Alistair Revell in the field of bio-inspired flapping mechanisms and computational fluid dynamics, and believe that their joint supervision would provide me with a significant edge in advancing my research career in the field of bio-inspired flapping wing MAVs. I believe that access to the state-of-the-art facilities for high end prototyping and experimentation, and my profound interest in flapping wing MAVs will help me in contributing towards the development of advanced and stable MAVs.