PROLOGUE

The real world is a messy place — not exactly in the untidy sense, but moreso in its interwoven tangled-ness. Higher order problems may be its most defining feature, salient across all disciplines, and steadfast through the ages — a complex, intricate, mixed-up system spanning extraordinary scales. The qualitative descriptors humankind has assigned the messiness nearly always precede our ability to quantify its measurables. One may casually ask, "how's the weather today?"...to be met with "a bit windy with a dry heat.", or something of the sort. Local weather patterns have always driven our day-to-day decision-making and this may never change; in present times we may assign a magnitude and direction to that 'windiness', a temperature to its 'heat', and a relative humidity to its 'dryness', but the principle question remains the same: is the weather close enough to matter and if so, how long must it be dealt with?

In more ways than one is this not unique to our human experience. Any and every 'decision-maker' gravity-bound to the terrestrial surface (or very nearly so) must contend with the frictional complexities confined to its relatively small surface layer. Geostrophic forces in the macroclimatic systems well-aloft and well-beyond our control set into motion processes in the planetary boundary layer that are characteristically complex and reside over many length and time scales. Chiefly because the diversity of life, with rare exception, spends most of its existence within this narrow band as a means to survive should we provide it overdue attention, lest, to borrow some from Sutton (1953), "the complete omission of viscosity [be] fatal".

Indeed there continues to exist a need to rigorously develop relevant simulated environments to better understand and help inform the 'decision-maker' operating near the surface. At resolutions of interest, virtual representations of these environments oftentimes discard or wash-out the temporally-dynamic and spatially-varying frictional complexities. The fan array technologies developed herein represent a toolset that can simulate, in the confines of a laboratory setting, elements of the real world that more accurately model the complex realities of environments of interest. Observations made in the real world are mapped to the virtual one as a means to set forth initial conditions. These prescriptions initiate flowfields in the physical domain that are reproducible in a manner conducive to observation. Iterative comparison of the real world observation to the lab-generated one provides the modeling framework for a given environment.

This dissertation, written from the perspective of the small autonomous flyer not fortuned enough to soar above the friction, sets down a path of study of the micrometeorological and microclimatic processes (i.e. weather) that govern the atmospheric boundary layer, with primary focus ultimately relegated to the nature of the winds and their subsequent effects adjacent to the surface. Roughness elements like buildings and trees dot the topography, as do carve-outs and canyons, in domains of interest.

Aligning our view with a prevailing wind in Chapter I allows for some progress to be made in describing the characteristic fluid features that emerge on account of the wind-wind and wind-surface-element interactions. Descriptions of the upper reaches of the atmospheric boundary layer are briefly mentioned followed by a descension into the so-called canopy layer, the primary layer of interest in this study. The prototypical flowfields likely to be encountered by the flyer near the surface in the presence of a reasonably strong wind are considered candidates for experimental simulation. The core features of the spectral overlap of the flyer dynamics and windy disturbance environment ensure that the turbulence of consideration is nearly always of the mechanical-type and is initiated from a turbulence mechanism that departs from the zoomed-out view of the canonical turbulent boundary. Instead, the dominant flow mechanism in regions of interest near canopied surfaces is augmented by the presence of coherent structures from the prevalence of locally initiated mixing layers and wakes. The task, then, becomes one of simulation of suitable forcing spectra in the physical domain for the regions of interest during anticipated times-of-flight.

In Chapter II, a conceptual framework for multi-source wind tunnels is given. The unsteady equation governing the motion along a streamline is derived and then extended to the case of a uniformly oscillating flowfield, where it is shown that fan arrays behave as low-pass filters. Visualizations of prototypical flow modalities are presented, with much of the discussion specific to fan array wind tunnels left to appendix A. The funneling influence of the module geometry and perturbation techniques driven solely by software augmentations are also left to appendices (appendix B and appendix C, respectively).

In Chapter III, the prototypical turbulent free shear flow that serves as the basic building block of turbulence generation of multi-source wind tunnels through shearing velocities initiated at the fan array outlet plane is introduced. The planar dual-stream mixing layer is further explored as a candidate flowfield to simulate a discrete gust forcing input to the flyer passing through. This well-studied class of flows provides a basis to see how well shear layers generated by fan array wind tunnels comport to the classical cases. Baseline dual-stream mixing layers are compared to the so-called triple-stream mixing layer to better understand the merging behaviors in the downstream development.

Chapter IV represents a first attempt at simulating the continuously turbulent flowfields of the atmospheric boundary layer far from local topographical effects as well as the quasi-coherent flowfields within canopied environments. It is shown, through pseudo-random modulation techniques and static reconfiguration of the multitude of fan units, that a random-phase (R-P) and quasi-grid (Q-G) configuration generates an energetic turbulence cascade well-described by a theoretical $-5/3$ region of the u-spectra in the inertial subrange. In general, increasing turbulence intensities through shearing velocity distributions at the fan array exit plane proves an effective means of increasing Re_{λ_T}.

A framework of comparison between the uniform, quasi-grid, and mixing layer flow modalities is formally presented in Chapter V based on the premise that every experimental flowfield presented meets the mixing criteria of a high Reynolds number turbulent flowfield. Conclusions are drawn and potential research directions are discussed, with strategies regarding perturbation techniques for future work preliminarily considered in appendix D.