ABSTRACT

Any and every 'decision-maker' gravity-bound to the planetary surface (or very nearly so) must contend with the frictional complexities confined to its relatively small surface layer. From the perspective of the near-surface-bound small autonomous flyer, it is the microclimatic local set of atmospheric conditions (i.e. the weather), characterized by moisture, temperature, and the parameters describing wind, that determines the baseline flowfields within which these flyers must navigate and negotiate. Unlike their human-on-board counterparts, mission parameters relegate small (nearly) massless autonomous flyers to the lower regions of the atmospheric boundary layer, where they may not be fortuned enough to soar above the effects of friction or wait for clearer skies. Relatively little focus has been placed on the experimental strategies of how these machines might *learn* to function in challenging scenarios *well-before* encountering them in the real-world. To address such shortcomings, this work focuses on the experimental simulation of flight-relevant environments through the development of multi-source wind-generating apparatuses (i.e. fan arrays) that can initialize velocity distributions discretely-individually or in-concert to produce appropriate mean and fluctuating velocities through an ample open-air test envelope that enables full-scale conventional statically-mounted aerodynamic-characterizations up through free-flight autonomous vehicle testing. Though outside the scope of current experimental work, as full of an environmental description (i.e. moisture, temperature, and wind) is given as possible, prior to ultimately reducing the scope to a neutrally stable atmosphere devoid of any major weather events other than a reasonably strong prevailing wind. Nearly always set amongst the backdrop of a high Reynolds number turbulent flowfield, two primary prototypical flowfields (continuous-gust and discrete-gust) are identified as meriting consideration for mainstay experimental simulation. The core features within the spectral overlap of these windy disturbance environments with the response characteristics of flyers of interest ensure that the turbulence of consideration is nearly always of the mechanical-type. Unlike air motions far above local effects in the inertial sublayer (ISL), the dominant flow mechanism within regions of interest near canopied surfaces is augmented by the presence of coherent structures due to the prevalence of locally initiated mixing layers and wakes such that the task becomes one of simulation of suitable forcing spectra in the physical domain for the regions of interest during anticipated times-of-flight.

Likely to prove challenging to the small autonomous flyer are encounters of a change in wind state that occur upon piercing the dividing streamline of air masses of two different velocities. From the view of the flyer navigating the built-up environment, intermittent free shear layers due to wind-interactions with surface roughness elements are unavoidable and are experienced discretely when the flyer and shear layer dynamics are decoupled. Fan array techniques for the generation of mixing layers, the basic building block of any such free shear layer, is explored as a candidate flowfield for the experimental simulation of a discrete gust forcing input for the flyer near the surface. Both initialized dual-stream and triple-stream mixing layers at flight-relevant freestream velocity differences are explored and found to principally behave like the mixing layers developed in a more conventional splitterplate experiment. The Reynolds number Re_{δ_ω} based on the velocity difference ΔU and vorticity thickness δ_ω (both outer scale parameters) is shown to linearly increase with downstream development as the vorticity thickness increases commensurately. The spectral analysis along the centerline confirms local isotropy for every tested case.

The continuous-gust flowfield (simply referred to as 'turbulence') is prevalent throughout the atmospheric boundary layer as are quasi-coherent flowfields of superimposed wakes within canopied environments. Because velocity fluctuations manifest as (predominantly) random deviations at any given instant, these flowfields are good candidates for statistical analysis. Generation techniques to produce such turbulent flowfields are introduced and compared against the uniform flow modality (i.e. all fan units set to produce nominally the same initial velocity condition to develop a well-mixed turbulent flowfield beyond $x/L \sim 0.5$ with $Re_{\lambda_T} = 135$). The random-phase (R-P) perturbation technique proves useful in increasing Re_{λ_T} upwards of nearly sevenfold with only a slight further-loss-of-uniformity (to within 3.7% of the mean). The uniform flow modality with the (R-P) perturbation activated is shown, through the presence of a -5/3 slope power law region, to be locally isotropic at relevant freestream velocities. Significant increases in Re_{λ_T} are made through a static-reconfiguring of the discrete source fan-units into a so called quasi-grid (Q-G) configuration. The highest recorded Taylor microscale Reynolds number was found to be $Re_{\lambda_T} = 2700$, likely accompanied by a non-negligible loss of uniformity at the fixed measurement location, though traverses were not undertaken during this campaign so no direct statement of homogeneity is put forth.

For all the flow modalities presented (i.e uniform, pseudo-random, quasi-coherent, and mixing layer), the high-Re number criteria ($Re_{\delta_\omega} \approx 10^4$, $Re_{\lambda_T} \approx 10^2$) has been met. This serves, then, as a necessary minimum benchmark in the development of multi-source wind tunnels with intended use as environmental simulators for flyers near the surface and also provides the basis for a spectral framework of comparison to enable systematic development of flowfields in future work. Characteristics of the evolving flowfields can further be tuned through the introduction of perturbation techniques applied as initial conditions to both increase the standard deviation of the fluctuating velocities about a desired mean as well as to initiate, evolve, and combine flowfields in representative ways. A preliminary example of one such combination of flow modalities (pseudo-random and mixing layer) indicates significant alteration of flow development compared to a nominal mixing layer case.