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Micro Planes Used as Flying Anemometers

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Abstract

Fixed and rotary wing micro planes fitted with multi-hole pressure probes are used to measure three-dimensional turbulent velocity fluctuation in the atmospheric boundary layer and in an industrial wind tunnel. The probes, aircraft and techniques are briefly described and typical data are given. Additionally a method of using the upstream wind characteristic to enhance the stability of a fixed wing MAV is detailed and it was found that the method enhanced the steadiness of the craft in gusts compared with a standard inertial system. Recommendations on the operation of micro planes as wind sensors are discussed.

1 Introduction

Micro Planes (commonly referred to as Micro Air Vehicles [MAVs] or drones), of fixed or rotary wing configuration are having a ubiquitous influence in many aspects of life. They have a role in surveillance and may, in the future, deliver a range of goods and services thus will be flying in close proximity to buildings and through "urban canyons" where turbulence levels from the wind, and its interaction with buildings, are high. Some possible challenging flight scenarios are shown in Figure 1 and a CFD simulation of the flow around a nominally cuboid (real) building in a suburban terrain is shown on the right hand side. Results from the CFD simulation, model-scale tunnel tests and outdoor measurements are being compared (Watkins et. al., 2015) and recent experiments include autonomous soaring in updrafts around the nominally 40 m cuboid building (Fisher et. al., 2016).

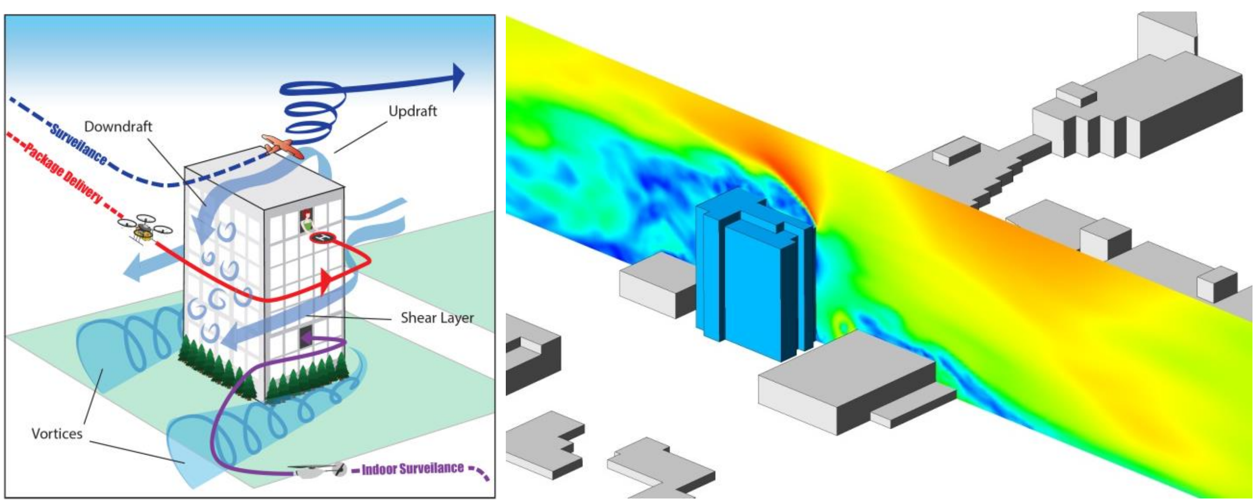


Figure 1 Possible flight path scenarios around a building (LHS) and a CFD simulation of wind around a nominally cuboid building in an urban environment (RHS), from Mohamed et. al. (2015).

Our recent work has involved documenting gusts as perceived by these small, low mass craft and investigating novel control strategies to minimize the resultant perturbations (Mohamed et. al., 2016, Panta et. al., 2018). In this paper we summarise the on-going experimental methods used to document the gusts, including using micro planes as flying anemometers. We also briefly describe a relatively new patented method of upstream flow sensing from a flying fixed wing craft which is used to provide additional control inputs (in addition to inertial sensing) resulting in better stabilization in high levels of turbulence.

2 Cobra Probes – Background, Mass Production and Use

The sensing heads of the velocity measuring system used for prior outdoor ground-based measurements and on-going measurements on flying craft are based on dynamically calibrated four-hole pressure probes known as Cobra probes, due to the initial shape of the head, (see Watkins et. al., 2006). These are being increasingly used as a relatively robust method of documenting the three-dimensional velocity components and the static pressure variations in turbulence at frequencies up to 2,000Hz. The calibration involves 3 stages; static calibration of the four pressure transducers, rotating and yawing the probe to generate calibration surfaces and a dynamic system calibration. The background can be found in Watkins et. al., (2002) and on the website https://www.turbulentflow.com.au/. The calibration surfaces relating to yaw, pitch and flow velocity magnitudes needed to be performed individually due to the hand-manufacture traditionally used in probe production. To alleviate this time-consuming calibration process we investigated rapid-prototyping the heads whereby a production batch could have a single calibration due to the similarity between probes. This was found to be successful, within a certain tolerance depending on the manufacturing details. It permitted practical use on aircraft as a damaged head could be quickly replaced with a new one at low cost. Several micro planes have now been fitted with various configurations of probe systems, see Figure 2.

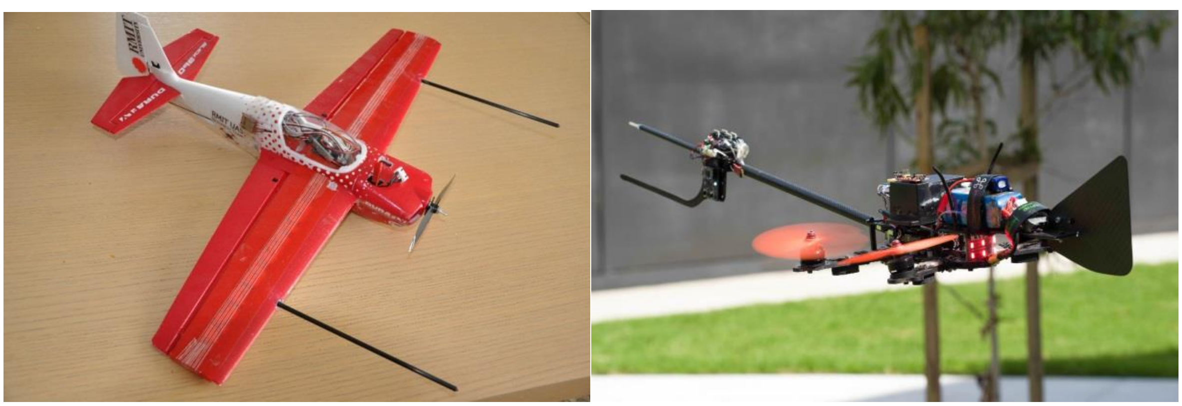


Figure 2 Slick 360 Aerobatic Model and Bespoke Quadrotor Craft Fitted with Pressure Probes.

The influence of the aircraft and rotor flowfield on the probe measurements were investigated in a series of wind-tunnel tests. With suitable placing of the probe head relative to the aircraft it was found that the influence could be negligible (Prudden et. al., 2016).

3 Augmented Fixed Wing Aircraft Stability Utilising Upstream Flow Measurements

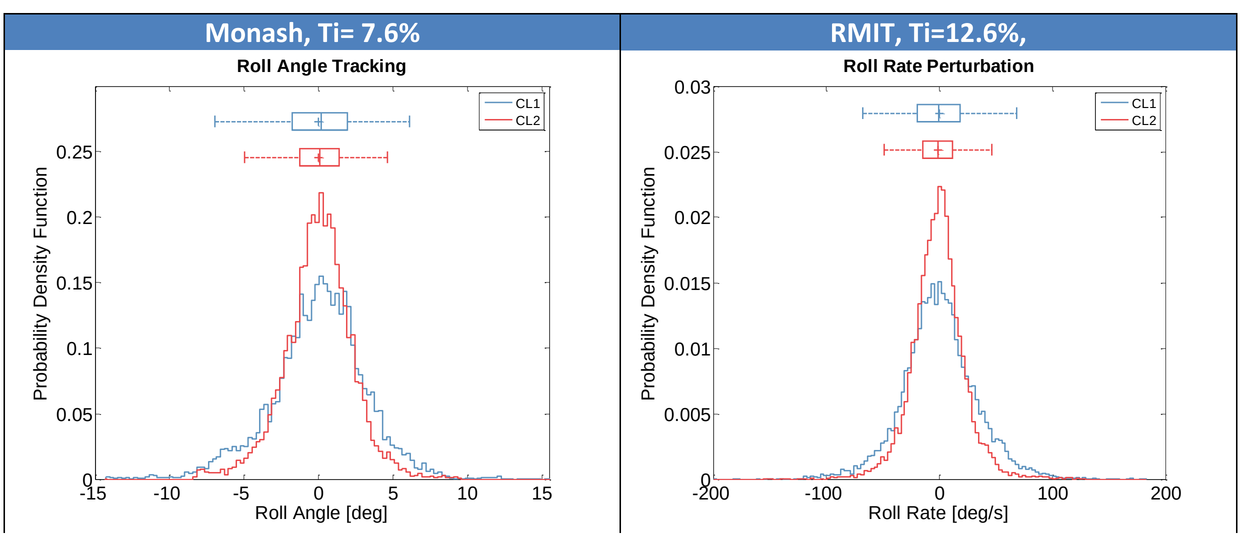
Due to the small size, low mass and MOI of such craft they are highly susceptible to perturbations by wind gusts. These can be either in the form of turbulence inherent in the atmospheric boundary layer

(ABL) or a perceived gust when traversing a flow gradient around a building (for instance when flying across the roof or around the side of the buildings shown in Figure 1).

It is now commonplace for commercially available micro planes to have inertially based stabilizing systems to mitigate these perturbations. However under significant turbulence, and even when using a military grade inertial stabilizing systems coupled with the most responsive servos, significant flight path deviations were evident, particularly on the smaller fixed wing craft.

The control challenge lies in trying to provide suitably responsive forces and moments to counteract the perturbations that would otherwise result from turbulence or gusts. For small fixed wing craft roll inputs were found to be the most problematic (for details of the nature of these inputs see Thompson et. al., 2011). The largest time delay in the control systems was found to be the actuation of the control surface, e.g. an opposing aileron control applied to eliminate the undesirable roll that arises from the variation in angle of attack across a wing span. Thus we attempted to use methods and data that gave early detection of the imminent effects including sensing the strain in main wing spars and surface pressure information across the leading edges of the wings (see Marino et. al., 2014). The most successful method involved measuring the pitch angle difference in front of the craft and using this difference to augment the inertial sensing, thus providing some feed-forward time information. The resulting hybrid control system, with suitable tuning, enabled steadier flight in turbulence and permitted relatively steady flight in small turbulent wind tunnels as well as outdoors. A full description of the system can be found in Mohamed (2016).

The Slick 360 model (Figure 2) was flown in two industrial (wind engineering) tunnels; the RMIT Tunnel fitted with a turbulence-generating grid which generated a longitudinal intensity of 12.6% and integral length scale of approximately 0.31 m and the Monash University Tunnel with a longitudinal intensity of 7.6% and integral length scale of approximately 1.0 m. The results of the roll angle probability density functions are shown in Figure 3. An experienced pilot attempted to keep the model flying at one point in space on the centerlines of the tunnels with the high frequency roll commands generated from two different control schemes; CL1 was representative of a reactive, inertial-based sensing controller and CL2 was the same as CL1 with the addition of a feed-forward component utilising the measurements from the pressure probes.



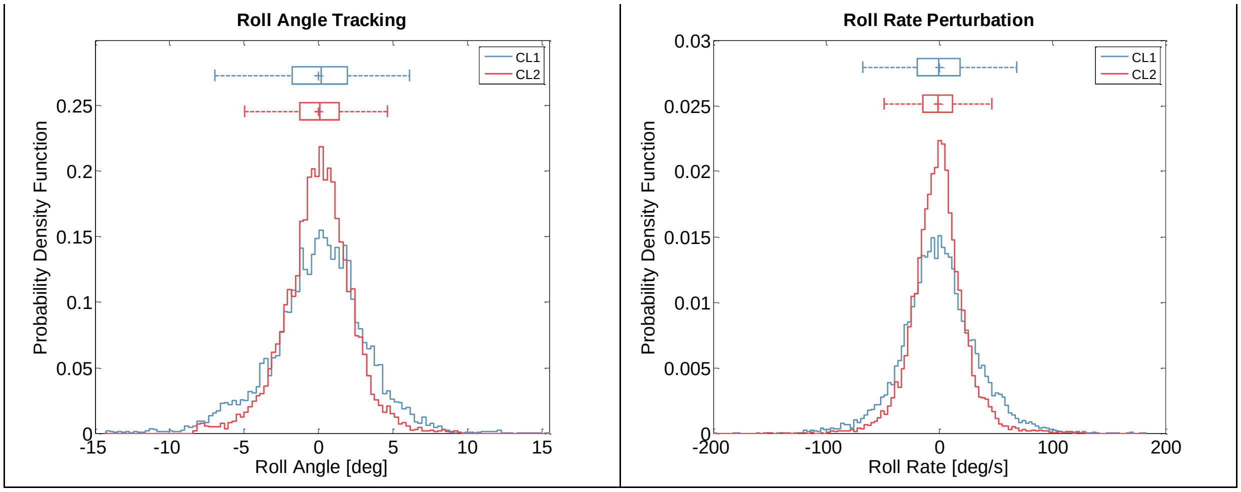


Figure 3 PDFs of Roll Angle and Rate With Different Stabilising Roll Control Systems

It can be seen from the PDFs and box plots (Figure 3) that CL2 has significantly reduced the roll perturbations. Comparisons between fixed wing and rotary craft both using standard inertially based control systems showed that the rotor craft were perturbed far less than corresponding sized fixed wing aircraft (Watkins et. al. 2010). To date we have not investigated using a similar technique on rotary craft.

4 Measurements in Turbulent Wind Tunnel Flow and in the ABL

The two craft shown in Figure 2 were then used to measure turbulence in flight. Figure 4 depicts a typical longitudinal velocity spectrum in the RMIT Tunnel (LHS) and averaged spectra from one of the pressure probes mounted forward of the fixed-wing Slick aircraft (utilising control scheme CL2), with the standard von Karman spectra indicated. The flying craft was held in a nominally stationary position in the centre of the tunnel. There is generally good agreement but the typical data from the aircraft-mounted probe can be seen to be slightly attenuated at the higher frequencies. This thought to be due to the tubing used to connect the probe heads to transducers attenuated the higher frequencies and the system did not include a correction from a dynamic calibration. (NB the energies of grid-generated turbulence in the tunnel were at significantly higher frequencies than encountered in the atmosphere.) The outdoor flight tests took place at an altitude of ~10m above uniform ground removed from local wakes (e.g. buildings). Again full descriptions of the fixed-wing craft systems, flight tests and data are given in Mohamed (2016).

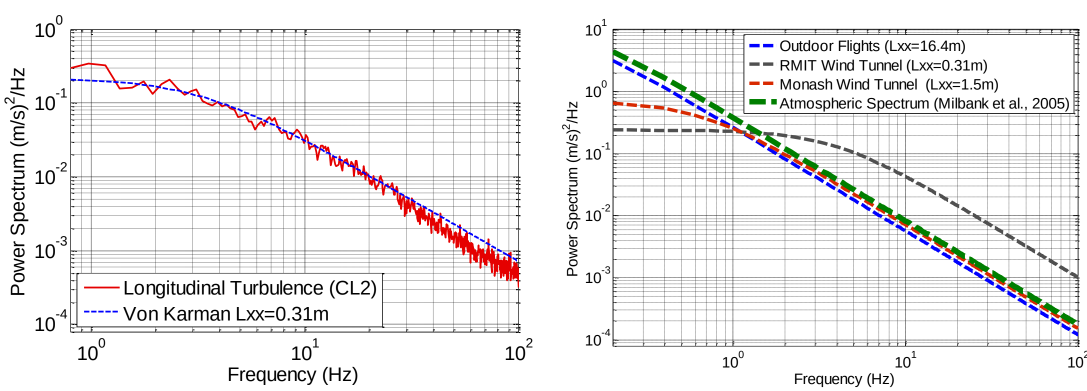


Figure 4 A Representative Spectrum in the RMIT Wind Tunnel LHS and Averaged Spectra RHS

The quadrotor craft shown in Figure 2 was used to document wind at various elevations thus providing data on the average velocity profile of the ABL. Details of the development of the craft and system can be found in Prudden et. al., (2018). To date only one short trial flight has been conducted and the results can be seen in Figure 5. The altitude (above the local ground level) time history is shown on the LHS and the corresponding wind velocity profile is shown on the RHS. There were issues identified with holding a steady position relative to the Earth but the trial demonstrated the potential and challenges of using a quadrotor- mounted system.

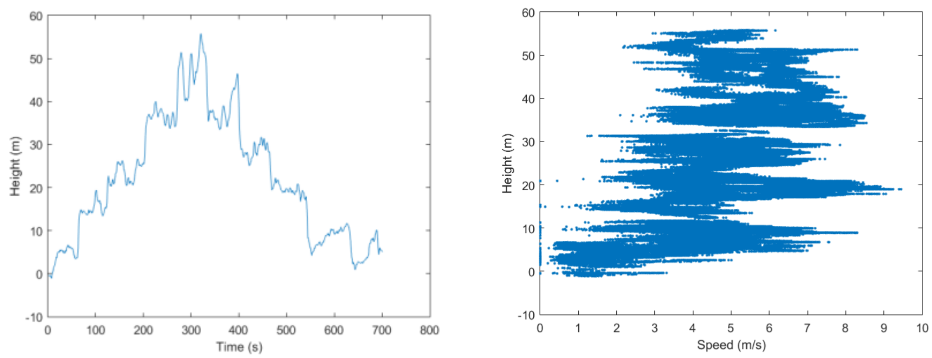


Figure 5 Altitude vs Time (LHS) and Velocity Profile (RHS) from Initial Flight of Quadrotor

5 Conclusion and Recommendations

Small unmanned craft of fixed wing or rotary configurations can be used to document turbulent flows when fitted with multi-head pressure probes, utilizing a correction for the influence of the craft and flow field, or when the probes are suitable removed to have negligible influence from the flow field. A method of mass producing the pressure probes via SLS can be used to generate similar batches of probes such that the (time-consuming) calibration process needs only to be applied to one from the batch. This means that cheap and robust probes can be fitted to flying craft relatively efficiently and the resulting systems can be used to document turbulent three-dimensional flows either in wind tunnels or outdoors (e.g. to measure the characteristics of the ABL).

Fixed wing craft can be further stabilized (over existing commonly available inertial stabilizing methods) by utilising measurements from the measured upstream flows in a “hybrid” control system that assists with minimizing the deviation of these lightly loaded craft.

Initial trials of a quadrotor to measure the wind profile of the atmosphere showed promise but the lack of endurance necessitated short sampling times at each elevation and the lack of holding repeatable elevations was problematic. However with such craft becoming more affordable, swarms could be used to overcome the short endurance, perhaps replacing the existing method of erecting masts. The portability of such systems could be beneficial in some instances and as both configurations of craft can fly at relatively high speed (~30 m/s) they could be used to measure long wind runs and be relatively unperturbed when rapidly documenting the flows around buildings. As MAVs will be attempting to hover (perhaps for deliveries) in highly turbulent areas the control systems will be challenged. We hope that measurement from these new breed of flying anemometers will be useful in documenting the wind environment in the urban canyons of the future.

Acknowledgements

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