Adapting to Limitations of a Wind Tunnel Test Facility in the Aerodynamic Testing of a new UAV

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Abstract
The 7'X5' Low Speed Wind Tunnel at The Department of Aeronautical Engineering at The University of Sydney was originally commissioned in the early 1940's. The "Seven by Five" was originally fitted with a mechanical three-component balance (lift, drag, and pitching moment) in the test section for aerodynamic tests of aircraft models and aerodynamic devices. Improvements over the years have included a new drive motor and improvements to the balance in the 1980's, and more recently an attempt on a dynamic balance capability test section. However, non-compliance of the contractors, the original of which went out of business, resulted in an incomplete test section and associated equipment being "dumped" at the doorstep of the Wind Tunnel Lab. Due to a charade of unfortunate circumstances, the department was not able to claim for any damages. Disappointing as it was, having expended much resources to setting up this potentially valuable facility, effort had to be made to salvage what was "delivered" to establish a new aerodynamic testing facility, albeit with much reduced capability. This paper reports on initial progress in setting up this new facility, using an off-the-shelf commercial six-component load cell. It reports on the status of the facility based on a series of tests on a wind tunnel model of a new design for an Unmanned Aerial Vehicle (UAV), and discusses the characterisation of its static aerodynamic and control parameters.

Keywords: Wind Tunnel; Unmanned Aerial Vehicle (UAV)

Introduction

Background

The 7'X5' Low Speed Wind Tunnel at The Department of Aeronautical Engineering (now School of Aerospace, Mechanical and Mechatronic Engineering) at The University of Sydney was originally commissioned in the early 1940's. The "Seven by Five" (dimensions of the working section, in feet) was originally fitted with a mechanical three-component balance (lift, drag, and pitching moment) in the test section for aerodynamic tests of aircraft models and aerodynamic devices. Improvements over the years have included a new drive motor and improvements to the balance in the 1980's, and more recently an attempt on a dynamic balance capability test section. However, non-compliance of the contractors, the original of which went out of business, resulted in an incomplete test section and associated equipment being "dumped" at the doorstep of the Wind Tunnel Lab. Due to a charade of unfortunate circumstances, the university was not able to claim for any damages. Disappointing as it was, having expended much resources to setting up this potentially valuable facility, effort had to be made to salvage what was "delivered" to establish a new aerodynamic testing facility, albeit possibly with reduced capability. The recommissioning of the new working section mechanical components went into a maintenance pace without any immediate project to drive it, until last year (2000). A

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need arose to characterise the static aerodynamic and control parameters of a newly developed Unmanned Aerial Vehicle (UAV) design, the *Brumby Mk II* UAV.

The *Brumby Mk II* was to be the production version of a rapid prototype *Brumby Mk I* UAV, which itself was notable in achieving first remotely piloted flight within six weeks of initial sketches of the idea.

Wind Tunnel Test Equipment

The Wind Tunnel

Figure 1 shows the general layout of the wind tunnel, while Table 1 lists its main operating characteristics.

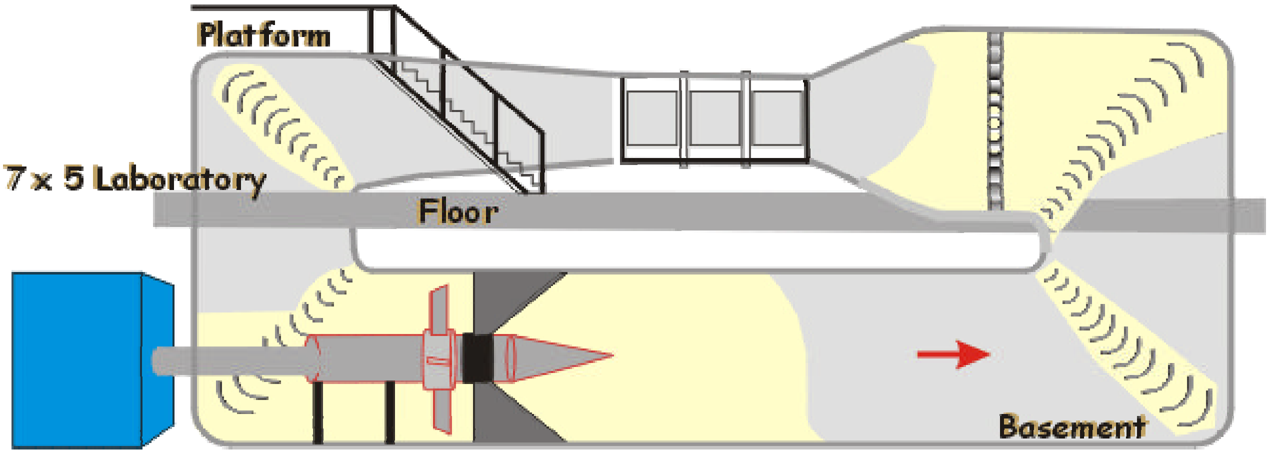

Figure 1 The 7x5 Low Speed Wing Tunnel

Type	Subsonic 7x5 Wind Tunnel
Max Speed (m/s)	42
Min Speed (m/s)	2
Mach Number range	0 – 0.12

Table 1 – Summary of 7x5 Wind Tunnel Test Section Characteristics

It is notable that the maximum speed of the 7x5 wind tunnel is determined not by the power of the 590kW motor, but by the stall of the fan blades.

The Six Component Load Cell

The new mechanism of the test section was designed to make use of an internal balance located inside models to be tested. The conventional way of attaching a model to the wind tunnel is with struts. Two or three struts are attached to the model, usually two to the wings and generally an additional third one attached to the fuselage. With this strut-type support, the forces and moments on the model are measured with an external balance. However, using a six-component load cell, a different approach could be taken. In case of an internal strain gauge balance, which is typical for a sting-type model support, the sensor that measures the forces and moments usually forms the interface between the support sting and the model. It is also desirable to place the sensor near or at the centre of gravity of the model to reduce the magnitude of cross coupling between the axes of measurement, thereby reducing the probability of overloading of the moment sensors. Figure 2 shows the load cell used and the orientation sensitivity axes of the load cell, showing how it had to be mounted in the model, the x-axis lining up with the body axis of the model. It is noteworthy that the sensor used is an off-the-shelf industrial load cell, not specifically optimised for wind tunnel work – hence its configuration is not particularly suited to mounting inside typically slim fuselages. However, the cost savings over a typical internal balance optimised for wind tunnel work far outweighs the potential complexity in adapting it for wind tunnel use.

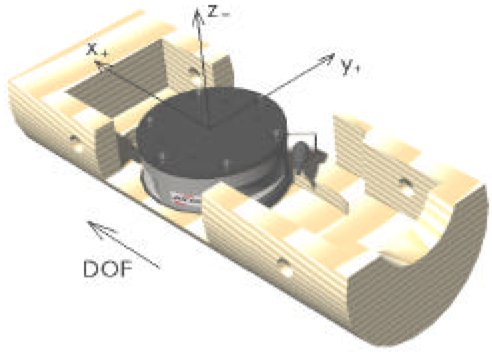

Figure 2 The 9105-ISA-Delta 6-component load cell, fitted onto the fuselage insert

The load-transducer is restricted in its sensitivity range and there is a finite resolution of the measurands (Table 2).

	Sensing range			Resolution		
	F_x, F_y	F_z	T_x, T_y, T_z	F_x, F_y	F_z	T_x, T_y, T_z
	N	N	Nm	N	N	Nm
Transducer model 9105-ISA-Delta/SI-660-60	±660	±1320	±60	0.25	0.5	0.015

Table 2 - Sensing range and resolution of the transducer

The Support Sting

Due to the design configuration of the entire set-up of the wind tunnel, and the desire to keep the model near the centre of the test section of the wind tunnel to keep the model in the same location as the support rotates to give the model various flow-incidence angles, the support sting has to be restricted to a certain length. The requirements for the sting are conflicting. The sting should be as stiff as possible and should therefore have a large diameter, to avoid flutter on the model in the airflow. On the other hand, the confined space inside the fuselage of the model requires a small diameter sting. The wind tunnel model support mechanism consists of several components. A system of levers can rotate the support, and thus the sting, but still keep it approximately in the same place. This is achieved by using a hinging parallelogram construction, which has its base, which is fixed below the model. Figure 3 highlights the turntable and pitch mechanisms relative to the model. Although the fairing for the support block is not shown, it can be noted that this arrangement resulted in the back of the fuselage being exceeding close to the mechanisms.

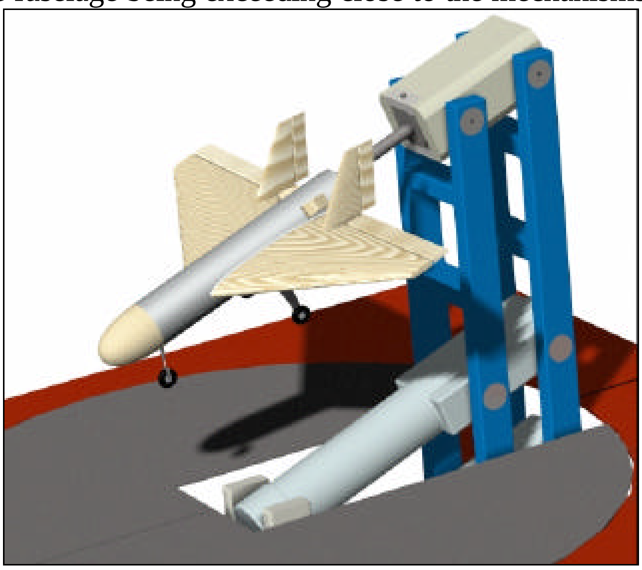

Figure 3 CAD picture showing the *Brumby* model in the Wind Tunnel

Figure 3 also highlights another problem for the configuration. When the model pitches down, the pitch drive lever intrudes into the airflow of the test section, while leaving a significant gap when the model is pitched up. A flexible membrane was fitted to the turntable to seal the gap during testing while allowing for the pitch mechanism to operate.

Another limitation of the experimental setup is that the PC-based servo motor controllers to change incidence angles were never delivered in an operational status. The hardware was obsolete and no longer supported by the time the department received it from the defunct contractors. A bootstrap approach was taken to manually control the model-support mechanism, which required a complex and tedious calibration process, followed by manual measurements of each model incidence angle to be measured. It also required significant skill to 'drive' the mechanisms without damaging either the test section or the model.

The *Brumby* UAV

The *Brumby* is one of the latest projects originating from the Aeronautical Engineering Department at the University of Sydney. This UAV is the natural follow-on of the UAV *Ariel*, which was built and flown over several years in the mid-1990's. Like its namesake being the Australian wild horse, the UAV *Brumby* is designed to be a rugged 'workhorse'. After operational experience with the *Ariel*, the *Brumby* was specifically developed to be a rapid prototype low cost research UAV, to provide a simple flight research platform in support of various research activities. The basic configuration of the *Brumby* is a delta wing configuration, with a standard dual fin and a pusher propeller. The aircraft has a conventional tricycle undercarriage, with which it operates from runways. This airframe makes effective use of simple fibreglass/nomex/foam composite construction, that allows simple and cost effective manufacture together with high maintainability and damage tolerance. The Mk I is the first version of the *Brumby* and, as an indication of the success of what the department's rapid-prototyping capabilities, it was built in less than six weeks (including the fabrication of tooling and composite moulds), from the start of initial idea through pencil sketches. The *Brumby* Mk I was first flown on 21 November 1997. It has been demonstrated to be a stable flight platform well suited to research requiring the carriage of sensors. The maximum take off weight of the *Brumby* Mk I was of 30kg, its maximum endurance was of approximately 30 minutes, and has achieved a maximum speed in excess of 100 knots (51.44 m/s). Two *Brumby* Mk I airframes have been built. The University of Ohio, USA, is currently operating the second as a flight research platform. A wind tunnel model (33.3% scale) was subsequently built and tested in the department's 4x3 Low Speed wind tunnel.

After all the success of the *Brumby* Mk I, it was decided to build an upgraded version of the *Brumby*. The new version is called *Brumby* Mk II and has the same basic configuration of the Mk I. Despite the many apparent similarities between the two versions, the *Brumby* Mk II incorporated several significant changes. The wing planform area was increased, with slight increases in span (almost half a metre) and reduction in sweep. The aerofoil section was changed from the original NACA 0010 section to that of a modified S1012 section. The section was chosen for its rearward location of maximum thickness to potentially provide room to accommodate additional equipment or fuel. The section profile was also modified towards the rear to provide a flatter shape to better fit the fins. The wing was moved forward by 0.1 meters along the fuselage, in anticipation of a heavy payload that was planned for fitting into the nose section. These changes were significant enough to necessitate a model of the *Brumby* Mk II to be built for wind tunnel testing to investigate its aerodynamic and control characteristics.

Initially, a one third scale model was chosen (so it would fit in both the 4x3 and 7x5 wind tunnels). During the design process, the scale was changed into the 40% of the full size airframe. The consequence of the change is that the model can only be tested in the 7x5 wind tunnel. This decision was made because of the availability of a six-component loadcell through the university's Australian Centre for Field Robotics (ACFR). To use the new mechanisms of the test section, the model has to be mounted at the end of an support sting arm, with the sensor interfacing between it and the model. Details of the design and construction of the model can be found in references [1] and [2]. Figure 3 shows the arrangement of the model as supported on the wind tunnel pitch-yaw mechanism. The desire to keep the centre of rotation of the aircraft configuration close to the centre of the tunnel test section forced the location of the model to be exceeding close to the large support block immediately behind the model.

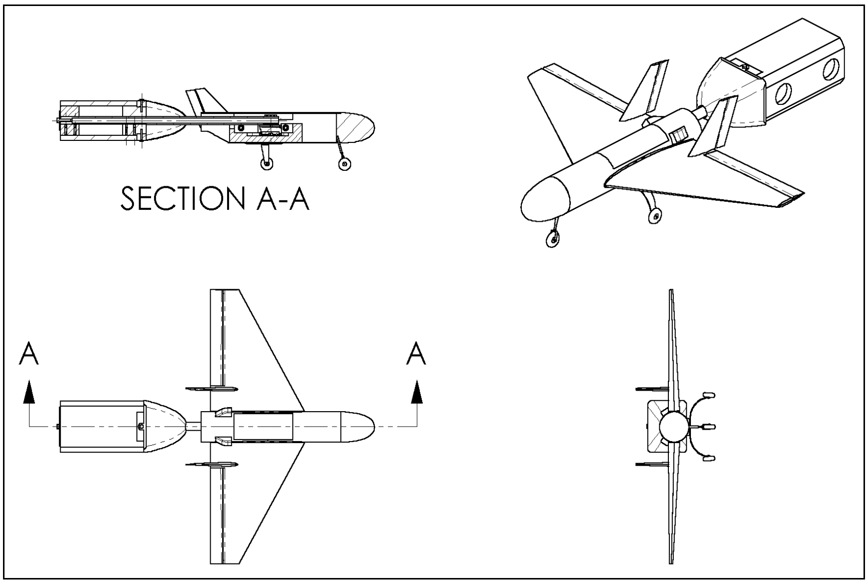

Figure 4 Model of *Brumby* Mk II as fitted onto the pitch-yaw mechanism

Results

Figure 5 shows a set of results from one of a series of tests on the *Brumby* Mk II model. These are processed data, having been transformed from the loadcell axes to the wind axes, and having been corrected for blockage effects [2]. From the test data, the *Brumby* Mk II is found to be statically stable both longitudinally and laterally. They also show positive controllability in all axes, the derivatives showing the expected signs. It is noticeable, however, that the magnitudes of the moments were particularly in a low range. This could be due to the interference of the structure behind the model. CD_0 is lower than expected and CL_0 shows a positive value at zero degrees flow incidence. Wind tunnel results were also checked with DATCOM analyses to verify trends, and were found to be satisfactory.

Due to the desire to keep the model in the centre of the working section, the spacing between the support block and the model was less than the ideal. A Styrofoam fairing was installed to reduce the interference effects, but this remains a major concern in the interpretation of acquired data. More definite investigations need to be made to correct for any interference. Otherwise, a possible future project should investigate collecting data using a longer support sting, thus moving the model further from the support block. This would however means that the model will move to different distances from the tunnel walls at different model orientations, thus in turn requiring further corrections. Future investigations should be made to quantify the merits and limitations of either approach.

Conclusions

Despite the configurational and operational limitations of the wind tunnel equipment, results from the initial series of tests were found to be satisfactory. The forces and moments measured with various control surface deflections and at various flow-incidence angles showed expected trends. While the results would eventually verified using flight test data, data from the wind tunnel tests are being incorporated into flight simulations, in support of industry sponsored research projects which requires a better understanding of flight behaviour of the airframe undergoing proposed missions. The testing of a model of the *Brumby* Mk II is the first project to use this particular wind tunnel support and the Delta six-component loadcell. As for the wind tunnel facilities, improvements are underway in installing a new servo motor controller, with position encoders to facilitate the eventual automation in collecting experimental data. The test section itself is also undergoing improvements with lights being fitted, and tunnel walls being finished to a higher surface quality.

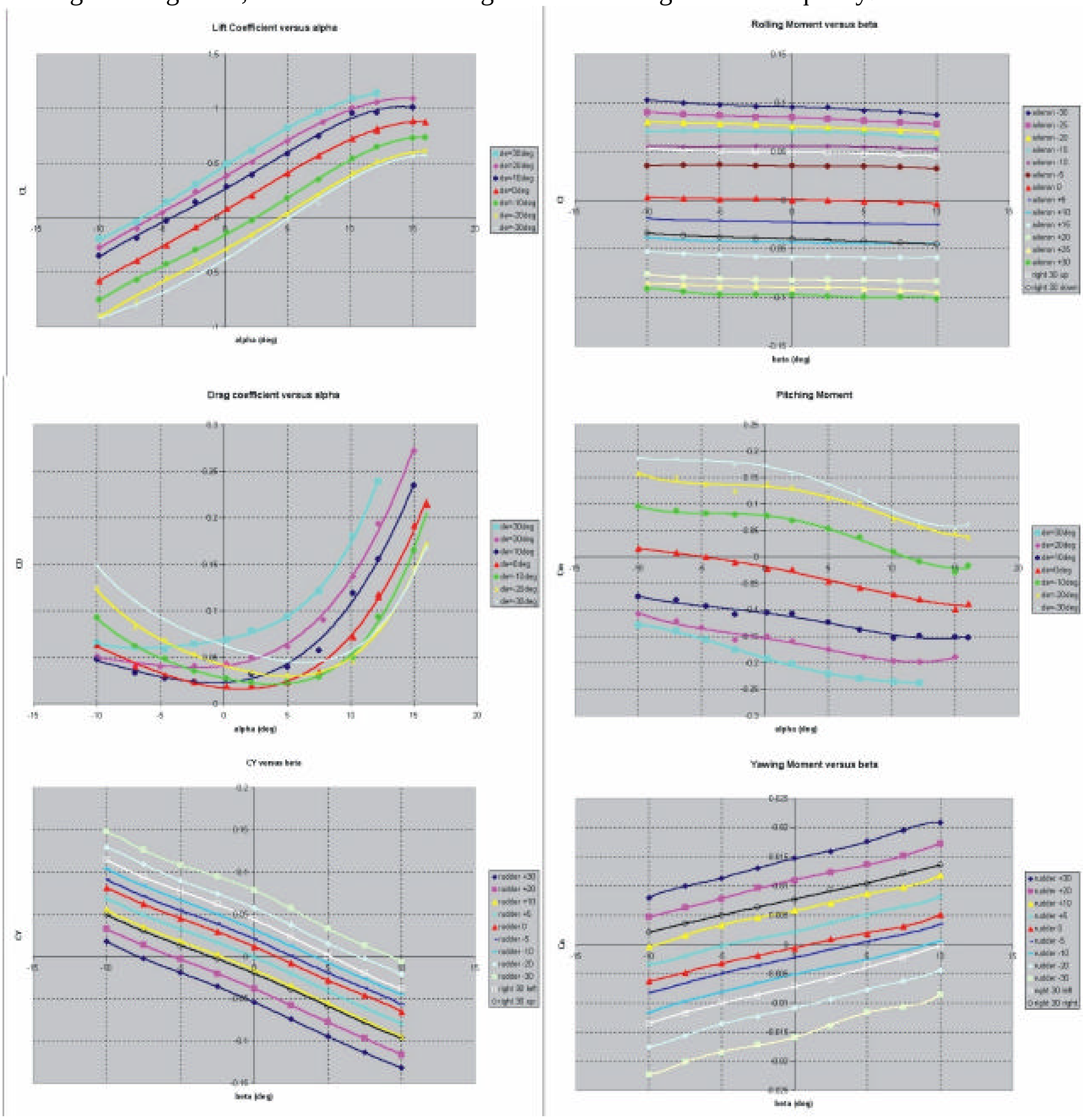

Figure 5 A Set of Results from testing the *Brumby Mk II* model

References

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