UAV Design Activities in a University Environment

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Abstract
Unmanned Aerial Vehicle (UAV) activities have been a sporadic part of the Department of Aeronautical Engineering at The University of Sydney since the department's inception in 1939. Although not much has been documented, archival photographs show various remotely piloted aircraft being developed and operated over its 62 year history. More recently, a UAV Research Group which originated in 1988, has made good progress in incorporating UAV flight platform design, development, control, and operation to the department's core teaching and research activities. This paper describes and presents an update to the range of programmes undertaken by the group: past, present and future proposed. This include the instrumentation of off-the-shelf Remote-Controlled flight platforms, the design development and operation of flight research platforms, the design and development of innovative airframe concepts, the design and development of Micro Air Vehicles (MAVs), and exploring commercial applications for UAVs. It also briefly describes a unique flight test facility in Marulan, NSW. The intention is to share this group's experience and facilitate collaborative efforts in the research and education community.

Key Words: Unmanned Aerial Vehicles (UAVs); design.

Introduction

The Unmanned Aerial Vehicle (UAV) programme at Sydney University was initiated in 1988 due to the requirement for a dynamic flight test facility to develop various aerodynamic devices on laminar flow wings. The non-availability of spin-testing facilities prompted the proposal to conduct free-flight experiments, using an appropriately instrumented flight platform. The small available departmental (Aeronautical Engineering) budget and impending certification difficulties with the airworthiness authorities ruled out the use of full-size aircraft. This led to the decision to develop an instrumented UAV for conducting flight research. The concept was further enhanced to incorporate parts of the development into the aeronautical engineering department's teaching programme, in particular in several final year thesis projects. While the airframe design and development of a modular multi-tasking research UAV was being worked on, an appropriately scaled model of a typical general aviation aerobatic aircraft was built and remotely flown to demonstrate the low-budget approach through the integration and utilisation of available technologies [1]. This initiative has consequently led to the formation of a UAV Research Group with members working on a wide variety of UAV related research projects. This paper outlines the airframe design activities of this group over the past 12 years.

Recent UAV Projects at Sydney University

KCEXP-series UAVs

The practicality of integrating available low-cost equipment into a research UAV system was investigated using the *KCEXP*-series flight platforms. Off-the-shelf equipment, including airframes, was to be used as much as possible to reduce the developmental time span. However, equipment which were not then commercially available within budget constraints had to be designed and developed. The objective was to evaluate the overall system feasibility through assembling a set of reasonable goals within each component of the system, rather than a mature blending of aerodynamics, structures, electronics, instrumentation, and control systems. The flight platform (Figure 1) was derived from a modified ¼ Scale model of the Bellanca Citabria, of which the full-size aircraft characteristics were known to be well suited to spin testing. The definitive version used in these series of tests was constructed from a combination of conventional wood and metal components, and fibreglass composite structures. Much of the instrumentation, including the air data probe and rate sensors were developed in-house, along with telemetry, data display and storage systems [1].

Figure 1 *KCEXP-3* UAV Test Platform

***Ariel* UAV**

As the development of the KCEXP-series UAVs progressed, it became apparent that a larger, modular and more capable UAV would have application not only to immediate research aims, but also to other applications. Hence a small airframe was designed and developed to be capable of supporting an instrumentation payload and providing a real-time telemetry downlink with associated data processing and display facilities. The aircraft was to be of modular construction to allow for various combinations of modules as requirements demand. Its primary function would be aerodynamic and flight dynamic research, but would be capable of simply and inexpensively carrying any small instrumentation payload which might be required to be flown in the lower levels of the atmosphere. The *Ariel* UAV [1] (Figure 2) has a wingspan of 3.02m, a maximum take-off mass of 36kg, and a maximum level speed of 100 KCAS, with a 10kg instrumentation payload capability when flown remotely. The structure of the airframe is predominantly of composite construction, designed with FAR-23 as a general guide, to load factors of +6 and –3. Dozens of students, undergraduate and postgraduate, worked with the staff on various aspects of the design, wind tunnel testing, flight simulation development, tooling design and construction, and finally the building of the flight prototype. The prototype *Ariel* first flew after approximately six years of developmental work. Flight operations were mainly conducted at Camden Airport, with a CASA issued Permit-to-fly, and full cooperation from the relevant airport authority and airport flight controllers. This project provided the UAV Research Group with much valued experience in UAV airframe and system design and development, and UAV operations in controlled airspace. It also provided the subject for numerous research papers, undergraduate and postgraduate (Masters and PhD) thesis, inter-varsity collaborative projects, and research contracts.

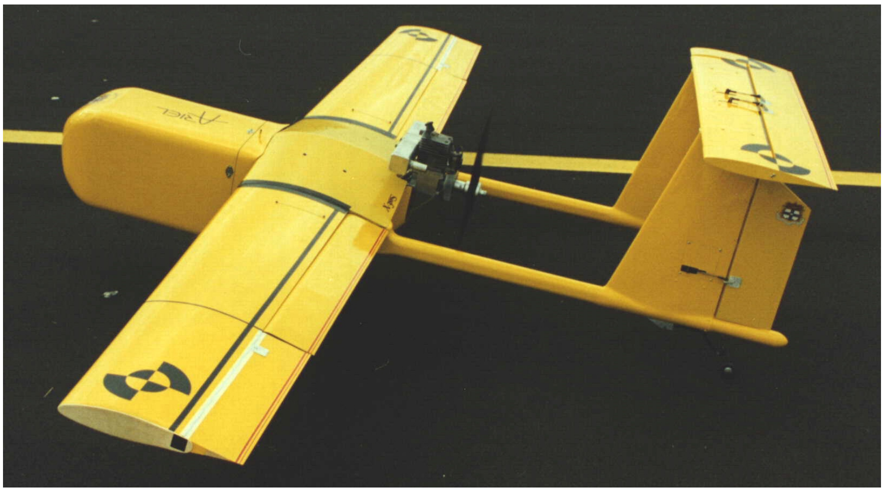

Figure 2 UAV *Ariel* ready for flight

Brumby **UAV**

The *Brumby* UAV is the natural follow-on of the UAV *Ariel* which was built and flown over several years. Like its namesake, which is 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 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. It takes off and lands in a conventional manner. This airframe makes effective use of simple fibreglass/nomex/foam composite construction, which allows simple and cost effective manufacture together with high maintainability and damage tolerance.

The *Brumby* Mk I (Figure 3-left) is the first version of the *Brumby* and, as an indication of the success of rapid prototyping, it was built in less than six weeks (including the fabrication of tooling and composite moulds). First flight was on 21 November 1997. It was demonstrated to be a stable flight platform well suited to research requiring the carriage of sensors on a flight platform. The maximum take off weight of the *Brumby* Mk I was of 30kg, its maximum endurance was of approximately 30 minutes, and 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 (Figure 3-right) 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 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 typically heavy payloads that was anticipated 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 [2]. This is currently being further developed into *Brumby* Mk III in close collaboration with BAE SYSYTEMS (Australia) for an ongoing research project in which they would be the platforms used to carry out flight missions in demonstrating innovative operational and navigational technologies [3].

Figure 3 (left) USyd AeroEng *Brumby* Mk I prototype; (right) *Brumby* Mk II prototype used in BAE SYSTEMS/USyd ACFR research project

***T-Wing* UAV**

The launch and recovery of a UAV remain critical phases of flight operations. Dr Hugh Stone started his investigations into a novel Tail-sitter VTOL UAV design in 1995. Tail-sitter UAVs promise greater operational flexibility than conventional UAVs while avoiding the performance penalties experienced by helicopter-like vehicles. This is done by allowing the vehicle to adopt a vertical attitude during takeoff and landing during which its weight is supported entirely by propeller thrust. This obviates the need for a runway. During the vertical flight phases, the aircraft is controlled by prop wash over wing and fin mounted control surfaces. Once the vehicle reaches a certain altitude it pitches over and performs a "stall-tumble" transition manoeuvre during which it trades altitude for forward speed. As the speed increases, the wings provide the lift for the vehicle. After performing a mission (for instance coast-watch, military surveillance, geomagnetic surveying etc.,) the vehicle regains vertical flight via a controlled pull-up and descent. The *T-Wing* UAV (Figure 4) project is currently supported by the ARC and Sonacom Pty Ltd to develop a flight-worthy technology demonstrator to investigate the feasibility and controllability of the launch and recovery phases [4].

Figure 4 *T-Wing* Technology Demonstrator Vehicle undergoing preliminary hover flight tests

***Bidule* UAV**

In keeping with the general theme for rapid-prototyping low-cost concept demonstrators, an electric-motor powered mAV (mini Air Vehicle) demonstrator of 410 mm in wingspan was built and flown in 1998. This aircraft, now called "*Bidule*" (Figure 5) is what would be considered a miniature Air Vehicle (mAV) by common definition. As a demonstrator, its purpose was to initially validate the basic design through remote-controlled indoor free-flight tests before considering a possible reduction to a real "micro" size. The current configuration is a flying wing powered by two electric mtors. Ninety percent of the wingspan is immersed in the prop-wash, giving the "*Bidule*" excellent low speed flight capabilities. Longitudinal and lateral control are achieved utilising a pair of elevons, and twin rudders allow the directional control. As the flight tests were successful, the development of the concept presently involves the following steps:

Figure 5 "*Bidule*" mAV Prototype

- Concept analysis and size reduction effect investigation;
- wind tunnel testing of a full-size model of the "*Bidule*" to quantify the general aerodynamics – special attentions being paid to the influence of the Reynolds number and the prop-wash effect [4].

Other Miscellaneous UAV Projects

Over the past twelve years, there has been numerous other UAV designs being investigated by staff and students at The Department of Aeronautical Engineering at Sydney University. These have included the following:

- Solar powered High Altitude Long Endurance (HALE) meteorological UAV – several final year thesis projects, including conceptual design, wind tunnel testing, and flight tests of an unpowered half-scale prototype;
- "*Vertigo*" Tilt-Duct Vertical Take-Off and Landing (VTOL) UAV concept – final year thesis project;
- Several mini/micro Air Vehicles as part of "Digital Canary" project of the ENG1001 Interdisciplinary Advanced Engineering course, developed as technology prototypes, which eventually led to the *Bidule* mAV design, developed to carry a small camera and a carbon monoxide sensor;
- "*Flying Bucket*" VTOL UAVs, multi-rotor VTOL UAV, and multi-duct VTOL mAV – final year thesis projects;
- Coastal Surveillance UAVs as part of final year thesis project, and as final year Aircraft Design project;
- UAV for Special Forces application – final year thesis project; and
- "*Willy*" Stall Resistant technology demonstrator UAV – final year thesis project, the flight platform of which is being used for numerous subsequent applications including investigations into parachute recovery of UAVs, and as a test platform for UAV instrumentation, flight control, and communication systems.

Furthermore, there has been many UAV technology related projects ranging from hardware related topics in lightweight structural design, aerofoil design and analysis, propeller design, analysis and testing, vibration-isolation engine mount design and testing, GPS attitude determination and optical attitude sensors, flight controller and payload sensor development, to system and software related projects in flight simulation development, autonomous flight controller design and optimisation, autonomous landing, trajectory optimisation, and navigation and map building research. Many of these are subjects of numerous published papers, details of which can be obtained from the author upon request.

Flight Test Facility

Having ready access to a flight test facility is crucial to the success of UAV programmes. Sites that have been utilised by the UAV Research Group for flight trials have included various hobby model aeroplane fields and the Camden Airport. More recently, a 20,000 acre university farm was made available, and work is underway to set up a permanent UAV Flight Test Facility there. Located in Marulan, NSW (near Goulburn), the site has a 300m runway, a large shed suitable for use as workshop and storage, and accommodation for the flight test teams. CASA has issued a Permit-to-fly for flight trials of *Brumby* UAVs over a designated area at the farm, with strict operational guidelines and procedures. Working closely with CASA from the early stages of any projected flight trial of UAV projects has brought very positive outcomes with respect to flight operations.

Conclusion

UAV design and development by the UAV Research Group at Sydney University has led to numerous operational flight platforms. These platforms, in turn, have been used productively for flight related research. In 1998, the UAV Research Group collaborated with the Australian Centre for Field Robotics (ACFR, which in 2000 became a Commonwealth funded Key Centre of Teaching and Research) in obtaining a small research contract with British Aerospace PLC (UK) to initialise work on decentralised data fusion and Simultaneous Localisation and Map Building using the *Brumby* UAV as the flight platform to demonstrate the technologies. This has subsequently led to a more definitive technology demonstration research contract with BAE SYSTEMS (Australia) which is currently underway, where the basic *Brumby* airframe is being developed into the Mk III variant in close collaboration with BAE SYSTEMS (Australia) [3]. In 1999 an ARC SPIRT grant in collaboration with Sonacom Pty Ltd was awarded to demonstrate the *T-Wing* VTOL UAV operational concept [4]. The UAV Research Group is also in the process of developing collaborative relationships with several other companies, research organisations, and universities. It continues to design and develop airframes to suit a multitude of potential applications in both civilian and defence market domains.

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