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Unmanned Aerial Vehicle Research at Monash University

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MONASH UNIVERSITY

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Summary: Research related to unmanned aerial vehicles (UAVs) has become very popular within universities globally largely because of the wide range of engineering challenges they pose. Other researchers are interested in the use of UAVs in support of their own research including environmental monitoring and emergency services. In sparsely populated countries such as Australia there is considerable potential for UAV use, as many missions can avoid the vexed safety issues associated with flight over populated areas. For this potential to be realised in most cases requires aircraft which can be flown with minimal setup and associated training while remaining within the Australian CASR-101 Regulations.

Keywords: Unmanned aerial vehicles, regulations, safety, flight control, training, electric.

Introduction

The Aerobotics Group at Monash University established in 2001 has concentrated on medium endurance (2 hours) electrically powered flight in the under 7Kg category with payloads to 2.5Kg. Particular attention has been placed on flight safety including flight termination protocols. Our current aircraft may be flown as computer assisted requiring only modest flying skills or fully autonomously. Our flight control systems (FCS) use a combination of inertial and IR sensors and are intended for VFR operation. Our FCSs require minimal setup and are being benchmarked against commercially available systems. We have developed comprehensive aircraft monitoring with associated telemetry and camera systems which were used in two Monash sponsored FAI World Records for electrically powered aircraft; these records are held by a member of the Monash Group. We host the Lawrence Hargrave WWW site [1] comprising a very large collection of material relating to the history of flight including UAVs along with our own research.

Although all members of the group are FAI accredited pilots we are acutely conscious of the practical issues associated with training and operations by operators who may not be trained pilots but who wish to use UAVs for the support of research. The paper will present an overview of our operational protocols and outline a number of systems applicable to university based research.

Regulations

The Civil Aviation Safety Authority (CASA) is the controlling body for all matters relating to UAV operations. CASR-101 and associated advisories detail the arrangements relating to UAV operations. These documents, while a significant step forward, requires some effort to interpret. The path taken by CASA has been to preserve, and in some cases clarify, the regulations related to model aircraft and to in simple terms distinguish between UAVs and model aircraft by observing that there is no practicable distinction between a small UAV and a model aircraft except that of use — model aircraft are flown only for the sport of flying them. CASA makes this observation in CASR-101 regulations governing radio control models and UAVs at regulation 101-235 [2]. In essence if a model aircraft is flown for profit then it becomes a UAV. This is independent of whether the aircraft has autonomous flight capability or not. A simple model aircraft demonstrated for a fee is a UAV under the regulations and requires. Model aircraft, including blimps, equipped with cameras for low cost aerial photography e.g. real-estate advertising are UAVs and require UAV Operator Certification. As these applications are now relatively widespread there has been often heated debate over the implications of CASR-101.

University research is conducted by free choice and appears to fall within the definitions relating to not for profit model aircraft operations. If this research extends to contract research then the position becomes quite unclear but would appear to require full UAV Operators certification. CASR-101 does not distinguish between educational bodies, government research groups (CSIRO, DSTO) and commercial organizations.

The Model Aircraft Association of Australia (MAAA) prohibits any model aircraft operations involving autonomous flight specifically the use of the GPS but presumably including other techniques such as ground feature based navigation. The MAAA is the CASA delegated body for controlling model aviation in Australia. The prohibition of autonomous flight appears to be related to an attempt to contain the insurance premiums of MAAA members but it is not a CASR-101 requirement.

For now our insurance assessors have advised they are satisfied that we have taken appropriate steps to comply with the prevailing regulations and that we are permitted to conduct research which entails fully autonomous flight.

It appears clear however that the for-profit distinction between model aircraft and UAV operations in the current regulations will require further clarification within the review of CASR-101 currently underway.

Operating Restrictions

We have taken a number of steps to ensure our activities present less risk than that currently existing at model RC clubs around Australia. In doing so we acknowledge the extremely good record of safety within these clubs. Our self-imposed restrictions comply with all relevant CASA regulations, the CSA Advisory Circular recommendations and with one exception, concerning GPS navigation, meet or exceed that of the MAAA. It is entirely possible the existing model aircraft the University has obtained will suffice.

The restrictions we have adopted are summarised in Table 1. These are presented in full for the consideration of other groups undertaking or considering UAV based research.

Parameter	MAAA	MU UAVG	CASA
Pilot qualifications	MAAA Club endorsement required	MAAA Club endorsement required	Club endorsement recommended
Pilot affiliation	MAAA Club membership required	MAAA Club membership required	Club membership recommended
Insurance	Available to endorsed pilots in affiliated clubs	MAAA insurance available while flying as a club member at endorsed sites, MU cover at other sites.	Not mentioned
Aircraft weight	<7 kg no inspection 7-25 kg MAAA inspection 25 – 150 kg CASA inspection. MAAA currently not authorizing flight above 25 kg	7 kg no inspection. 7-25 kg MAAA inspection. 25 kg max limit.	<25 kg MAAA rules apply. 25 to 150 kg requires CASA inspection.
Flying areas	Up to 150 kg at endorsed club sites in metro areas.	7 kg limit at endorsed club site. 20 kg limit in 'non-populous area'	Up to 150 kg at Club sites in metro areas, or any 'non-populous area'
Propulsion	Rocket, jet, turbine, propeller allowed.	Propeller only. Rockets, jets, turbines banned.	All forms of propulsion allowed.
Altitude	Nominally 400 feet. CASA has granted higher height limits to	400 feet at endorsed club sites. 1000 feet under direct	Up to controlled airspace in non-populous areas

	many club sites.	manual control in non populous areas.	
Autonomy	Stabilisers allowed. Automatic navigation (GPS tracking) not allowed.	Full autonomy, including GPS navigation, allowed up to 400 feet in non-populous areas.	Full autonomy, including navigation, allowed up to 400 feet in non-populous areas.
Airfield management	Typically very informal but generally in accordance with AC-101(0).	Formal document based on AC-101(0) plus Gliding Federation of Australia Manual of Standard Procedures.	Recommendations set out in AC-101(0)
General Risk mitigation.	None explicitly required	Formal risk analysis. Failure Modes and Effects Analysis.	None explicitly required for flights below 400 feet in non-populous areas.
Ground risk mitigation	“Common sense” expected. Varies from club to club. Generally based on AC-101(0)	Follows AC-101-3(0) plus reduced maximum weight, failure mode analysis, restricted to flying at non-populous sites.	Guidelines laid out in AC101(0
Air risk mitigation	No limit on aircraft simultaneously airborne. Build standards arbitrary and un-enforced.	Follows AC-101-3(0) plus all aircraft stress tested to 10g	Guidelines laid out in AC-101-3(0)
Communications failure & interference risk mitigation.	Frequency board	Frequency board plus spectrum scanner before and during flight.	None explicitly required
Software validation.	None explicitly required	Peer group review. Software engineering analysis.	None explicitly required
On field safety equipment.	None explicitly required	Fire extinguishers, water, dress code enforced, first aid kit, mobile phone, emergency services contacts readily available.	None explicitly required
Failsafe system	Optional	Mandatory on all aircraft over 2 kg through use of PCM receiver or software transmission integrity check.	None explicitly required
Flight Termination System	Unheard of	Mandatory for autonomous navigation	None explicitly required for flights below 400 feet.

Table 1: Monash University Operating Restrictions.

Much of our research does not require engagement of the GPS based navigation functions of our aircraft. This permits us to conduct a significant part of our research from MAAA affiliated club fields.

UAV Research Platforms

For UAVs to see wider deployment in civil and military applications requires careful consideration of operating complexity. If the UAV requires a support team of more than one or at most two people much of the financial advantage of these systems, compared with the use of conventional manned aircraft, is lost.

Our overall goal is to develop flexible platforms for those wishing to use UAVs in support of their own research. We believe it is important that these be inexpensive and require minimal training for their operation. The use of UAVs in this manner of course is heavily qualified by the CASR-101 constraints. In developing these platforms we also satisfy our own research interests which are largely in extended electric flight and associated telecommunication and mission planning elements.

Visual Flight Rule Operation

The missions of interest to us are under Visual Flight Rules (VFR) conditions. Under VFR conditions the horizon remains visible or substantially visible at all times. In our work we take advantage of the VFR conditions to obtain absolute determination of aircraft attitude.

All commercial autopilots, in fact flight control systems (FCS), we have studied rely entirely upon GPS augmented inertial navigation systems (INS). Our experience is that extreme turbulence where the aircraft is driven through large attitude excursions can subsequently result in invalid attitude solutions from the INS which persist. Some autopilots have internal consistency checks which attempt to identify loss of reliable attitude solutions. If undetected catastrophic loss of aircraft inevitably results; to date our own failsafe provisions (below) augmenting the autopilot have prevented this.

NASA in the early days of manned spaceflight considered a number of absolute attitude determination techniques. In part this is likely to have been driven by the reliability of INS in high acceleration and/or vibration environments. One of the techniques developed was the use of the relative temperature of the Earth's surface and the sky [3]. The TIROS weather satellite series launched from 1960 onwards used infrared (IR) horizon sensing to orient the cameras and antennae as the satellite orbited the earth. More recently optical and IR based sensors have subsequently been used by a number of companies to return the model aircraft to level (non-inverted) flight regardless of the aircraft attitude when the system is engaged. The commercial system does not provide access to appropriately scaled roll and pitch angle.

Under most circumstances the IR based attitude sensing system performs extremely well [4] over the last few years of operation in our aircraft.

Inadvertent flight into cloud or the formation of water droplets on the sensors can cause incorrect attitude solutions unless qualified by other information. Flight resulting in a false horizon, for example when flying along ridgelines requires additional logic over and above a simple wing levelling functionaly. For our current implementations we have included a heading gyro to hold heading between GPS updates. As our airframes are intrinsically stable the gyro along with the airspeed and barometric altitude sensors may be used to identify inconsistencies with IR sensor data allowing a degree of data fusion within our onboard computational constraints.

Energy Considerations

Our electrically powered aircraft have a cruise propulsion system power consumption of 10-30W. For best endurance it is important that the power consumption of the FCS be a small fraction of this. Two obvious major options present themselves for computational support. The first is to use a high-performance processor in burst-mode whereby updates to FCS outputs are computed periodically with the processor reverting to a low power state between updates. The second option, which we have adopted to date, is to use one or more low power primitive processors (PICs). The second option while initially attractive presents substantialy challenges with software engineering. The tools for these primitive processors tend to be similarly primitive being geared for simple interfacing applications.

Another option is to use field programmable gate arrays (FPGAs). Most of the dedicated control functions may be programmed directly as hardware relieving the processor of these periodic tasks. The processor itself is also a programmed block on the FPGA but is only responsible for navigation and mission planning functions and other functions which are run infrequently with the processor shutting down when not required.

Using the strategies including those above the computational aspects consume fractions of a Watt. In practice the control surface servos now consume the bulk of the power within the FCS. Taking into account the mechanical holding torque of the servos updates may reduced to a low frequency when the aircraft is in relatively still air.

Payload and telecommunication power consumption has not to date been of major concern however this is likely to be the case for longer range missions.

The cruise power consumption and wing surface area of our aircraft is within range of solar power augmentation. Projects to take advantage of thermal activity and slope lift are in progress.

FCS Autotuning

The time taken to tune typical commercial autopilots for a particular payload and airframe configuration is quoted as requiring several days of trial and error tuning to obtain satisfactory performance. Our own experience with one autopilot [5] confirms this. In practice of course, careful design of airframe and payload location can result in tuning parameters close to acceptable requiring only modest re-tuning with different payloads. Nonetheless the tuning process, be it through flight testing or by simulation [6], requires considerable knowledge and experience in flying model aircraft. Using a flight simulator and subjective tuning of the simulation until the aircraft appears to behave like the real aircraft, followed by the application of model identification techniques to synthesise a controller, is attractive for larger aircraft. Modelling the behaviour of our smaller aircraft, particularly with often very low Reynolds Number regimes, is less certain.

Some of the less expensive autopilots claim minimal tuning requirements; we have not yet had the opportunity to verify the operation of these when used in conjunction with aircraft in the 7Kg category of interest to us.

We favour adoption of well understood, often empirical, design of the airframes coupled with automatic in-flight tuning of the FCS. Again sophisticated model identification systems can be used but to date we have found the older well understood techniques, in our case Ziegler-Nichols to be adequate. As our aircraft are predominantly electrically powered, difficulties related to changing mass and associated inertial response do not need to be considered. We have found control gains based on airspeed, as a replacement for explicit gain scheduling, to provide acceptable performance.

Failsafe Implementation

A pilot at all times has over-riding direct radio control of our aircraft. If valid radio control signals are lost for a period (2.5S) a braking parachute is released to contain the kinetic energy of the aircraft by limiting its airspeed to approximately $10MS^{-1}$. Release of the parachute physically cuts power to the propulsion system.

The intention is not to lower the aircraft intact to the ground but to prevent potential runaway as most of our aircraft can comfortably exceed $50MS^{-1}$ and possibly double this in a full power dive before probable aircraft breakup.

For future longer-range missions, which will be outside normal radio control range, the failsafe is triggered by loss of a low power VHF beacon signal. This failsafe subsystem is entirely independent of the FCS although the FCS can also trigger, but not override, failsafe.

If the beacon or the radio control transmitter is deliberately switched off, the flight is terminated.

Figure 1: Flight Termination
(Photo: Prof G.K. Egan)

The prospect of runaway aircraft is quite real and as a consequence we have placed considerable emphasis on implementing and testing our failsafe strategies.

Aircraft

Two of our more unusual aircraft are Duigan and the P15035. Both are constructed using now common modelling materials including carbon/kevlar and glass resins.

Figure 2: Duigan in Flight
(Photo: Dr R. Naughton)

Airframe: Foam/balsa with glass and carbon fibre skin
Wingspan: 3m
Wing Area: 90dm2
Airfoil: MH62
Mass Empty: 5.5 kg
Payload: 1 kg

Engine: Direct drive Actro 40-6
Batteries: 30x3000mAH NiMH
Airspeed: 55 KpH (Cruise) 100+ KpH (Max)
Endurance: 45 min (Cruise) 15 min (Max)

P15035 and its sister aircraft P16025 were intended as prospective aircraft for net based landing capture possibly onboard ship. These "plank" aircraft have excellent stall characteristics and can tolerate relatively rough landings with little or no damage. The use Military has adopted a similar configuration for its Dragon Eye aircraft. While it is possible to hand launch our aircraft we also use a simple catapult launch system when the aircraft are carrying a full payload and for improved safety given the dangers implicit with the high-powered electric propulsion.

Figure 3: P15035
(Photo: Dr R. Naughton)

Specifications
Span: 150 cm
Chord: 35cm
Length: 106 cm Wing Section: EMX07
Controls: Elevons
Weight: 2.9 to 4.6 Kg - depends on motor battery and payload configuration
Motor: Actro 40/6 - outrunner direct drive, 16 x 13 Aeronaut Cam Carbon Prop
Motor Battery: 28 x GP3300 NiMh or 9 series x 4 parallel eTec 1200 LiPoly cells
Control System: JR3810 Tx, JR649 Rx, 2 x Hitec wing servos
Launch system: Hand and catapult
Flight Duration: 40 to 60 minutes (@ 60kph cruise)
Speed: Stall 33Kph, Cruise 60Kph, Max 150+Kph
Auto Pilot: MicroPilot 28g
Flight termination: Parachute
Payload: Pentax Optio S 3.2 mp with 2.5Ghz video down link

Telemetry

Our current primary telemetry link is VHF with UHF video links. Aircraft continuously transmit live video from one or more onboard video cameras. We have found that relatively inexpensive 4Mpixel class cameras provide adequate video while satisfying the important weight constraints. Higher quality still imagery can be taken for later analysis after the aircraft has landed. Our intention is to selectively relay still images for some applications e.g. search and rescue.

FCS state information along with navigation and on-board decision making actions is continuously transmitted on the data telemetry links.

We have commenced trials using IEEE 802.11 links because of the ease of interfacing with various groundstation requirements and the ease of forming adhoc connections between aircraft and for relaying ground-air-ground communications. Navigation information from the aircraft is to be used to steer the necessary high-gain antennas resulting from 802.11 transmission power restrictions.

Our telemetry systems were used in support of Mr Ray Cooper's FAI World Altitude Record set on 9 November 2003. Monash University sponsored the flight.

Figure 4: Big Bird before breaking the FAI World Altitude Record
(Photo: Professor J. Bird)

Research Directions

Our research platforms have now reached the stage where they provide a rich environment for undergraduate and postgraduate thesis projects. Examples of projects completed, in progress and commencing are set out below.

Projects in progress or completed:

- IR sensor based attitude control [4]
- Ground based camera recognition of aircraft attitude [9]
- Detection of man made features from airborne video [9]
- Ground based aircraft acquisition and automatic landing guidance [9]
- GPS based instrumentation for the measurement of ice shelf or glacial flow
- Aircraft based optical automatic glide-slope acquisition
- Camera based attitude control [8]

Commencing projects:

- Thermal hunting and ridge soaring
- Extension of flight using solar power
- Feature based navigation
- VTOL aircraft
- Flight control rule capture from expert human pilots

Conclusion

UAV research provides an exciting and demanding systems engineering environment for electrical engineers and computer scientists.

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