THE DEVELOPMENT OF AN UNMANNED AIRCRAFT SYSTEMS INTEGRATION LABORATORY AND MODULAR RESEARCH UAV

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Abstract

The Aeronautical Systems group of the CSIR has been involved in the development of various aircraft prototypes over the past 30 or so years, some of these being unmanned. The facilities and capabilities provided in support of these developments have recently been expanded to include an Unmanned Aircraft Systems Integration Laboratory (UASIL) and a novel modular research UAV.

The UASIL currently consists of a high fidelity UAV flight simulation capability linked to an "Iron Bird" version of the Modular UAV but with the capability to be linked to any of the CSIR UAV airframes and autopilots for development purposes

The Modular UAV has been developed to provide the capability to demonstrate a wide range of novel technologies and / or sub-systems of typically less than 10 kg. The airframe geometry is highly configurable based on research requirements.

A number of research topics are currently being supported by these capabilities.

1 Introduction

Since 1980 the Council for Scientific and Industrial Research (CSIR) has been involved in the design and manufacture of eleven aircraft, manned and unmanned. Recently the focus has been on light unmanned research platforms to assist a number of tertiary academic institutes with research into UAS related technologies. While there is a relatively strong focus on the control and navigation aspects of unmanned platforms, few of the institutes had access to a reasonable size, aerodynamically characterized aircraft platform to demonstrate their capabilities.

In 2008 the CSIR received funds from the South African Government Department of Science and Technology for the design and development of just such a capability. Two outcomes from this funding were the development of a UASIL to provide modeling and simulation facilities required by the researchers and a number of Modular Research UAVs designed to satisfy a number of widely varying research topics being pursued at the time.

2 Unmanned Aircraft Systems Integration Laboratory

The UASIL consists of a wind tunnel test version of the Modular UAV acting as an "Iron Bird" incorporating control surface position feedback linked to a CANbus linked avionic suite developed by the Electronic Systems Laboratory of Stellenbosch University in a UAS-focused collaboration with the CSIR.

Core to the UASIL are the high fidelity fixed and rotary wing flight dynamics modeling software packages FlightSIM® and HeliSIM®. A flight instrumentation panel is simulated through the use of a touch screen controlled via VAPS® display software.

For fixed wing UAV simulations a MATLAB®/Simulink® based hardware-in-the-loop application is used to link the flight dynamics models to the main avionics systems via a hardware in the loop (HIL) system. Flight control inputs are optionally entered via the radio control transmitter. Alternatively a pilot input interface unit can communicate with the flight dynamics model directly.

The "out the window" environment is provided by the graphics capabilities of the FlightGear open-source applications [2].

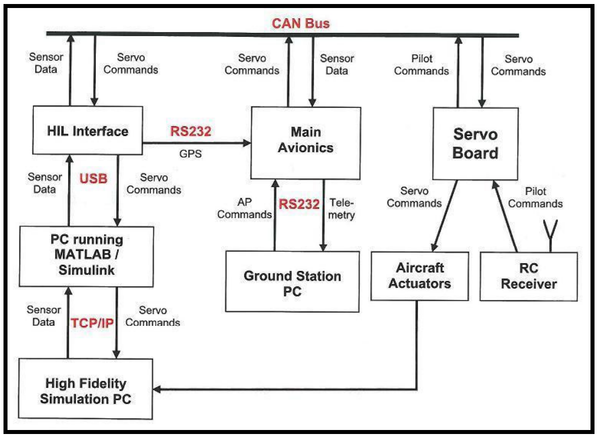

Fig. 1. CAN bus based UASIL system

A Modular UAV flight model has been developed with flight performance and stability derivative data from the full-scale airframe tests carried out in the CSIR 7m wind tunnel.

The CSIR UAV design capabilities are to be linked to the UASIL to facilitate flight behavioural modelling as part of the airframe design process. The UASIL can also used for flight control algorithm research and to provide an M&S based systems engineering capability for future UAV developments.

3 Modular UAV

3.1 Design Concept

The initial design specification for the Modular UAV was based on the requirements of a large number of UAS-related research topics being pursued by local tertiary education institutes, industry and from within the CSIR itself. While a number of the research topics required a flight simulation environment or a wind tunnel test to demonstrate their potential or feasibility, some of the research topics required an airborne test to fully validate their work or to benefit from the undeniable marketing value of a flight demonstration.

The UAV airframe was designed to satisfy those research topics requiring a flight vehicle and was purposefully not optimised for performance in its initial configuration, the layout being driven by functionality, modularity and docile handling characteristics.

The decision was made to keep the payload capability unconstrained by fuselage geometry to allow for the variability in the physical size of intended payloads. A payload pod concept was adopted, a generic payload pod being provided for the prototype airframe to facilitate the initial autopilot integration.

To maximise the potential range of payload masses and speed requirements, both the wings and stabiliser were designed with constant chords, the associated moulds thereby allowing a relatively easy adjustment of the manufactured span or lateral spacing of the fuselages.

A stability and control prediction code was developed based on the low order panel code CMARC and an in-house developed user interface and meshing tool. This capability provides rapid aerodynamic characterisation of each new configuration. Comparisons with recent flight and wind tunnel data are being made for validation purposes.

The horizontal stabiliser was designed both as a fixed stabiliser and elevator configuration and as an 'all-flying' stabilator with a servo tab for variable stability research. Both stabiliser configurations can be mounted at either the tops or roots of the fins. Provision is made for the mounting of video cameras in the fin top fairings.

The requirements of research into autopilot redundancy, online failure diagnosis and adaptation to system failures led to a twin-fuselage layout with independent electric power, control and autopilot systems in each fuselage.

The autopilot (the main board of which is shown as the green prismatic block in figure 2) can be mounted either in the payload pod as was done for the first flights or in either or both fuselages as required by the research. The brown blocks represent the Lithium polymer battery locations.

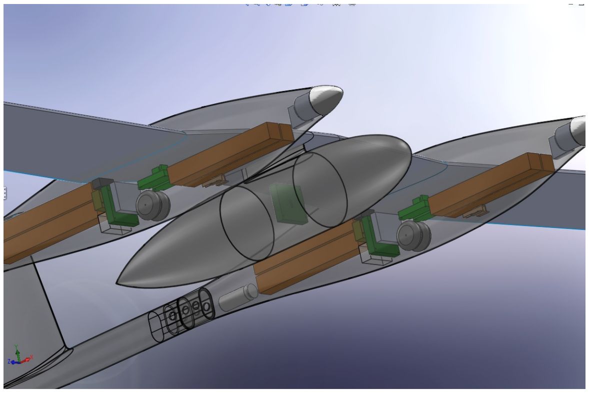

Fig. 2. Modular UAV showing alternative autopilot placement

Research into control algorithms for the prevention of stall, stall recovery and sustained flight near stall required the development of a non-linear flight model for the simulated environment to allow for development of control algorithms before committing to flight tests.

Research into piezoelectric actuators, fibre-optic sensors and optimised structures and aerofoils is currently being carried out and the results will be tested in the most applicable test facility before possibly being flight demonstrated.

Fig. 3. Baseline Modular UAV

3.2 Modular UAV Configurations

Various other research requirements are accommodated through configuration changes as illustrated conceptually in Figure 4. To date only the baseline model (Figure 3) has been flight-tested.

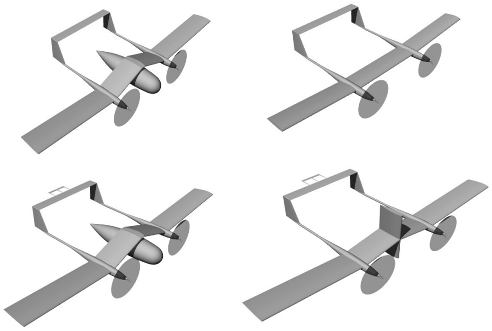

Fig. 4. Various conceptual configurations of the Modular UAV

A second identical airframe was constructed for wind tunnel testing purposes. This airframe has position feedback sensors on all control surfaces providing true control surface position feedback to the data acquisition system. The structural design of this airframe is somewhat different from that of the first due to the higher loads and factor of safety required for full-scale wind tunnel tests.

A third flight-worthy airframe has been prepared with two trailing edge control surfaces on each wing outer panel. The inboard control surface is intended to act as a combined flap and aileron or flaperon.

3.3 Characterising of the Baseline Modular UAV

The second Modular UAV airframe was tested at full scale in the CSIR 7m wind tunnel at full-scale flight speeds over most of its flight envelope. A six-component balance was mounted inside the payload pod attached to the main spar of the central wing. Control surface deflections were detected via sensors and fed back to the wind tunnel data acquisition system.

Tests up to and beyond stall angle as well as tests at large yaw angles were carried out in order to capture the non-linear data required by the autopilot development.

Fig. 5: The Modular UAV baseline configuration in the CSIR 7M wind tunnel

4 Research Topics Related to the Modular UAV

The research topics, their influence on the design of the Modular UAV and progress are discussed in more detail.

4.1 Non-linear control of airframe – flight up to and beyond stall

Research was being carried out into the control of a UAV from take-off through controlled flight behaviour and navigation to automatic landing. In the build up to this capability, research was being carried out on the control algorithms for sustained flight near the airframe's stall speed, the prevention of stall and if stalled, stall recovery. These required the development of a non-linear flight model that could be used to test the algorithms in a simulated environment.

The non-linear flight data obtained from wind tunnel tests of the airframe up to and beyond stall at various sideslip angles has been captured. The capability of the control algorithms has not yet been demonstrated.

4.2 Gain scheduling autopilots – increasing the controllable speed range

The Stellenbosch University autopilot flies the UAV within a relatively narrow speed range well within the realm of linear aerodynamic and control derivatives. In conjunction with the power effects modelling, modifications to the control law are envisaged to increase the range of airspeeds over which the UAV could be flown. This work has not yet begun.

4.3 Systems Identification – ability to determine UAV behaviour in-flight

Two postgraduate degrees are currently underway using system identification techniques for two different purposes, the one focussing on real time analysis of the UAV behaviour with the goal of identifying and isolating changes in the airframe behaviour, the other focussing on the post flight derivation of the airframe's dynamic stability and control derivatives.

A flight test has been conducted for the latter research utilising the autopilot to excite the various oscillatory modes about each axis of the UAV to extract the required data.

4.4 Reconfigurable autopilot – control of a damaged UAV

One of the requirements of a "no single point of failure" system is that if a sub-system does fail, the autopilot must be able to identify the failure, isolate the failed control and reconfigure as required in order to maintain controllability of the airframe.

All the primary flight controls of the Modular UAV (throttle, ailerons, rudders, elevators) are duplicated including the addition of inboard flaps mentioned previously for additional roll authority on the third airframe.

4.5 Single axis autopilot evaluation

A final year undergraduate project at the University of Pretoria involved the design of a single degree of freedom autopilot. This autopilot was to be designed and constructed to control the pitch of a UAV.

4.6 Solar Powered UAV Demonstrator

The University of Johannesburg were involved with a solar powered UAV development project for which the Modular UAV was offered as a potential platform.

4.7 Piezoelectric actuators demonstrator

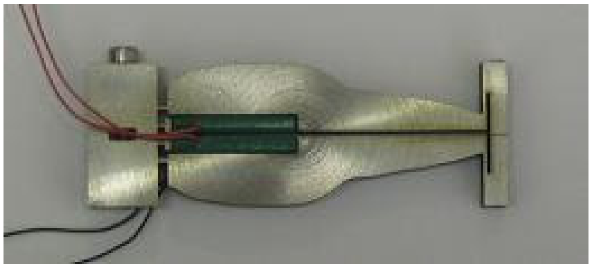

Fig. 6: Piezoelectric actuator (from [3])

Small piezoelectric actuators are being developed [3] for use in UAVs for flight control and possibly flutter suppression. Direct actuation is being proposed for aileron activation and an inchworm type for the larger deflections required by flaps. These actuators have been tested on a smaller flight surface.

4.8 Small gas turbine engine demonstrator

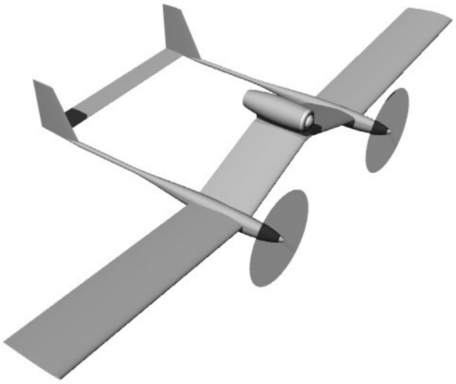

Fig. 7. Gas turbine conceptual configuration

In the longer term there is a requirement for the flight-testing of a small-scale gas turbine engine. The stabiliser of the Modular UAV would be attached at the lower end of the fins to avoid the high temperature exhaust gases.

4.9 Lightweight sensors demonstrator

A number of sensor developers expressed an interest in flight testing or demonstrating their lightweight airborne sensors on a low cost airframe.

A daylight electro-optical payload has been installed but not yet flight-tested. Funding has been provided for a low cost radiometric sensor to be flown in the following year.

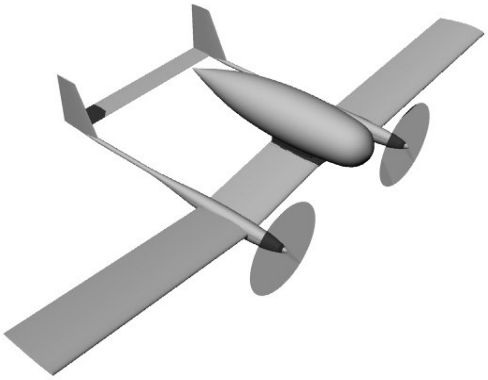

Fig. 8. Alternative sensor pod conceptual configuration

4.10 Characterisation of power effects on small airframes

With most small UAVs having significant excess power especially at low forward speeds and high power settings, modeling of the stability and control derivatives under these conditions becomes important when addressing autopilot programming. The destabilising effects of the propeller and its wake under those conditions are being predicted as part of a post-graduate research project with the University of the Witwatersrand.

Initial power effect wind tunnel tests on the Modular UAV have been made to compare against the predicted values.

4.11 UAV Flight Test Techniques training

The CSIR is also offering UAV flight-testing training using personnel who have undergone Operational Test and Evaluation (OT&E)

training at the South African Air Force's Test Flight and Development Centre (TFDC).

5 Future Developments

One area of interest is in variable pitch stability through the active control of the horizontal stabilizer. This requires a 'floating' stabilator with a servo tab controlling the stabilator deflection angles. The contribution of the stabilator forces to the overall stability of the airframe is measured through load cells mounted within the fin tip fairings. The effectiveness of the stabilator is actively controlled by the autopilot through the servo tab providing the ability to actively control the pitch stability in flight.

References

[1] Loveday PW, Long CS, Broughton B, Monk JS and Corderly G. *Development of Piezoelectric Actuators for UAV Applications*. Sixth South African Conference on Computational and Applied Mechanics, SACAM08, Cape Town, 26-28 March 2008.

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