OTIC Project Review Status for a navigation and control system for an airborne autonomous vehicle. Friday 18th December 2009

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Abstract of Project

The goal of this project is to define and develop a robust navigation and control system for airborne autonomous vehicles that will be fault tolerant. This technology will be used to support sensor development and deployment of geophysical sensors on similar and other platforms.
The development will consist of two parts. In the 1st part we will take a low cost model aircraft, an autopilot and GPS navigation system and assess, quantify and prioritize it's failure modes and integrate those with the knowledge of failure modes derived from existing systems. The failure modes are likely to include platform, electrical/electronic and software issues. Then in the 2nd part we will define strategies to tackle each failure mode. Likely strategies will include modifications to the airframe, the flight control system and the development of a seperate control system to identify and handle specific failures. The control system will be programmable and transferable between platforms. In-house hardware and software will be developed to filter and respond to sensor information using highly noise tolerant filtering such as the Kalman Filter. This kind of filter can be implemented efficiently in hardware due to the repetitive nature of the array processing involved.

Present Status:

We have made a preliminary assessement of airframe and electronic robustness of small aerial vehicles and have identified a number of single point failures that can prove terminal to the platform if they fail. The foremost of these is the engine; Antarctic aircraft always have two or more engines but the majority of UAV's only have one. The demonsttrator will have two. The vehicle will have good glide capability so that a total failure of the engines will not prove catastrophic. This means high aspect ratio wings, good slow speed control, low-angle glide slope and seperated power and control of the engines from the control surfaces. The design is still in it's infancy due to other commitments, [I've just come back from a 6-week trip to Antarctica for example], however below is a picture of the airframe before and after skinning of the wings, that has been built in the mechanical workshop to demonstrate the premises of the programme. The design has a 6 foot long, high aspect rear wing and a large front canard. This design will assist the lift during slow speed manouvers and will ensure that the aircraft can recover from slow speed stalls since the canard [which has a 3degree positive angle of attack compared top the rear wing] will always stall 1st causing the nose of the aircraft to dip while the rear wing is still providing lift. When this happens the vehicle will speed up as it slides down a glide path and lift will be restored to the front wing with no loss of lift to the rear wing.
In addition to the flight surfaces we have incorperated rotatable mounts for the engines which are mounted on the fuselage between the fore and aft engines. These can be seen in figure 1 below and will provide a further method of assisting the flight surfaces in giving lift at slow speeds. Each engine can be rotated through 120 degrees from facing fully forward horizontal to the ground plane to 30 degrees past the vertical. These enable two distinct modes of operation,
1. Fixed Wing mode where the engines face forward and the aircraft operates only as a winged aircraft, and 2. Vector mode where the rotating engines can be used to shorten take-offs and landings and assist slow speed flight. To test this method the engines and their mounts have been

mounted into a test frame which is being tested seperately from the main aircraft which will shortly be undergoing ‘trimming’ flight tests with a single rearward facing engine installed.

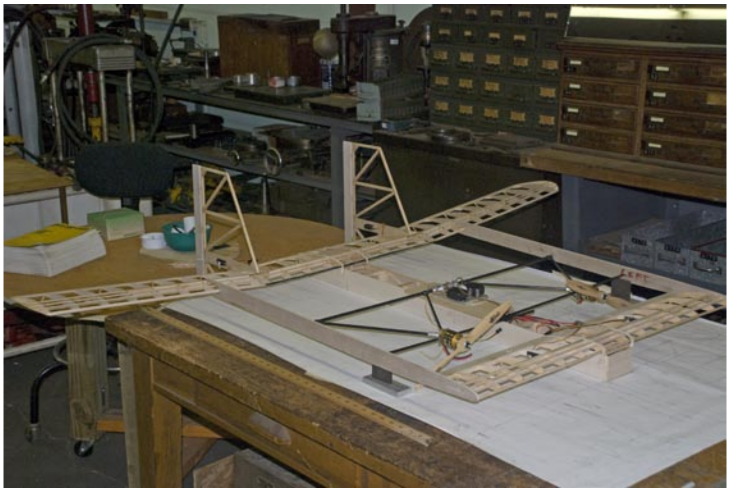

Figure 1: Complete structure before skinning of the wings 15th October 2009

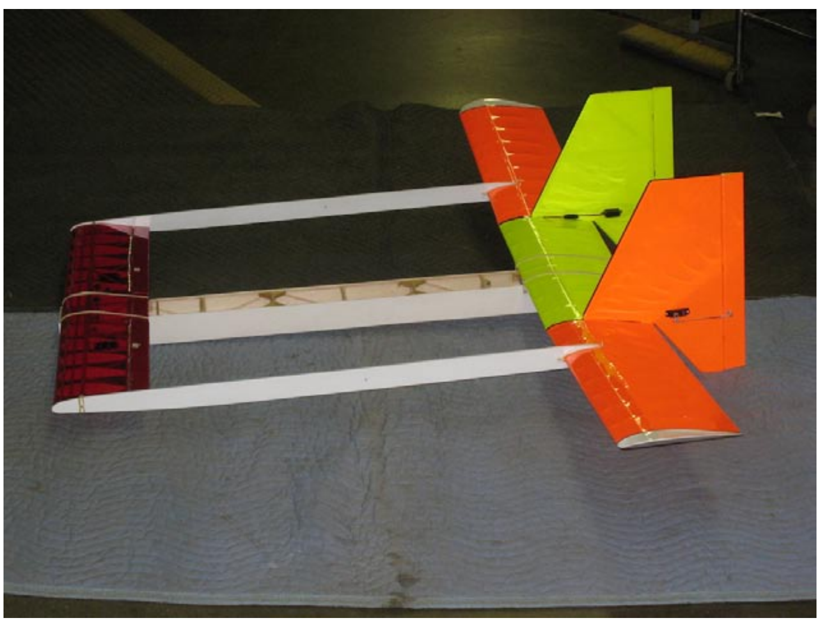

Figure 2: Airofoil surfaces plus fuselage after skinning – 19th November 2009

In addition to the slow flying, robust airframe design, I have been working on the control system and failure mode analysis [FMA] design electronics and software. Attached are the System Design block diagram and the uController detailed design document. The system consists of two independently operating dsp processors. The 1st or top one in the diagrams operates as the autopilot and provides attitude and orientation control. This takes in 3-axis gyro and accelerometer signals, filters them through a kalman filter and provides control signals to correct for pitch and roll. I have calculated that, using a small dspPIC processor, I can maintain 40Hz update rate which should be plenty to provide adequate stabilisation of the airframe. This processor will also take in GPS data that will be used to compensate for yaw rate and provide orientation for waypoint tracking. The 2nd processor will provide waypoints to the 1st processor to follow. It will also monitor it's surroundings and provide collision detection for the system. This will take the form of a simple laser range finding mechanism in all the major axis of the aircraft. On detection of an obstacle in the aircrafts path the processor will compute a new waypoint to head for that will attempt to avoid the obstacle. It will then update the Waypoint table of the 1st processor which will turn to the new heading. The 2nd processor will also control the power provided to the engines, the vector angle of the engines and will monitor the airspeed over the wings, so will be able to regulate the speed of the aircraft and monitor the lift provided by the wings and will be able to compensate for diminishing lift as the aircraft slows down with the addition of a vertical vector through the control of the vector angle of the engines. Each processor will have Watchdog electronics assigned to it. This will be able to reset either processor if it thinks that the processor has crashed. Each processor will share a common external data table [not shown on the diagrams as I haven't designed this yet but it will live in area where the two lines are connecting between the two processors!] that they will be able to pick up current data from after a crash and during normal operation. The 2nd processor will monitor current position through the GPS data and engine power versus demand. If the aircraft position varies significantly from the required position or the engine power is not producing the speed over ground in the required direction a number of faults could have occurred or a very strong cross or head wind may have been encountered. If the monitored variables go outside defined bounds the processor may elect to turn the aircraft for home or set down in a controlled manner.

I have chosen dsPIC30F4011 dsp processors for the design and on the uProcessor detailed design document it can be seen that I have allocated actual signal types to port pins on the processors so I know that the procesors can handle the variety of signals that I will be passing to them.
The design also allows the processors to pass control signals from an RF receiver onto the servo's and motor speed control units on the aircraft. In this way an operator can take control of the aircraft via a standard model aircraft transmitter. Using this philosophy we can start 'small' controlling the aircraft from the transmitter and incrementally incorporate control from the onboard processors and thoroughly test software components as they are developed.
Glide tests and airframe trimming will continue through January, as will vector control testing on the testbed airframe. Later in January I hope to have the shared memory design nailed down and a detailed schematic drawn up that I will be able to produce the 1st prototype pcb from.
The specifications for the demonstrator that I put into the proposal are as follows:-

Specification of Demonstrator

- The system will include a failure mode analysis [FMA] module and corrective action hardware/software

This is evolving into a distributed system that is a mixture of monitoring hardware and software based around a 2nd processor

- The system will include an autopilot capable of flying the platform straight and level, following a predetermined flight plan downloadable from an external source and reacting to

input from the FMA module
The 1st processor will be the autopilot and will meet the requirements above
• The system will include a dual-redundant GPS navigation system that will provide NMEA string and 1pps for internal use and data timestamping.
The demonstrator currently has a single GPS system that will provide positional data and 1pps to the system. This will be expanded to include a dual redundant unit as the project progresses.
• The system will include a robust power management system.
System power and control systems will be monitored and seperated out into two independent units that are considered to have superior fault tolerence over a single system.
• The system will provide altimetry information into the autopilot. *The 2nd processor will provide altimetry data to the shared data table that the autopilot will have access to*
• The platform will be capable of flying upto 10m/s. *The speed of the aircraft is expected to be from 0m/s to 20m/s*
• The platform will be capable of carrying 5lb of payload.
Initial engine power tests and lift calculations based on the surface area of the wings suggest that the aircraft will be able to carry in excess of 5lb in payload
• The platform will have a range greater than 5km *Calculations indicate that the aircraft should have an endurance of in excess of 10 minutes at 10m/s in forward flight which gives a range in the region of 6km.*

So far the OTIC funding has enabled me to spend some time thinking about and developing a control system for an aerial autonomous vehicle that I otherwise would not have had the funds to do. Aspects of this design have been shown to a number of groups in passing who have expressed interest in the design as it unfolds. I am confident that I will be able to make a control system that will add enhanced survival characteristics to a standard system that should help this and other platforms operate in harsh environments with some chance of success. If this works as expected it is likely to become a demonstrator that may help us to acquire extenal funds to take the process further, maybe building/controlling a larger system that will be able to carry a useful payload. For this I must thank the OTIC Committee for getting me to this point and hopefully enabling me to progress further.