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

Lead: Nick Frearson

OTIC Review Requirements

1. please provide the brief report of your progress on or by 18 december.

   Topics:
   abstract of project;
   present status;
   the benefits realized [obviously the earlier funded ones will have more to say] or anticipated;
   Plus any other info you wish to provide.

What we want to know- is OTIC doing what we set out to do??? which is: 'The Observatory Technical and Innovation Center (OTIC) is established to strengthen observation-based research at Lamont-Doherty Earth Observatory by increasing the Institutional capacity to design, develop, and utilize innovative field and laboratory instrumentation'

2. OTIC Steering Committee: We meet my office 203 oceanography at 10:30 am on monday 21 December 2009 to discuss the OTIC effectiveness towards meeting its 'Mission' goals.

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.

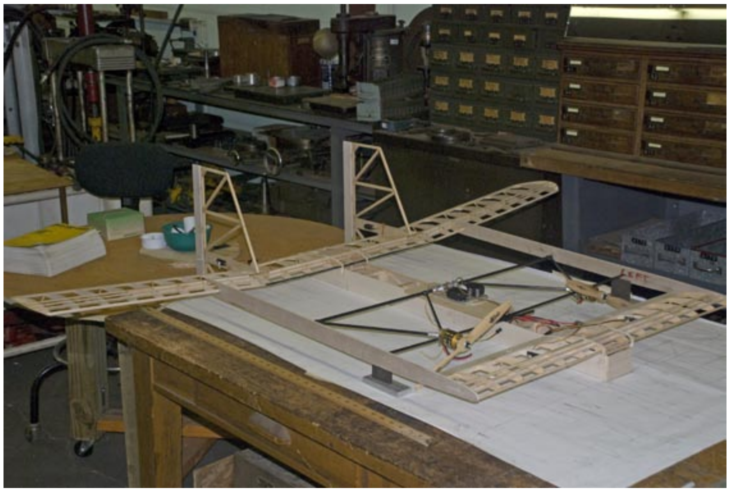


Figure 1: Complete structure before skinning of the wings 15th October 2009

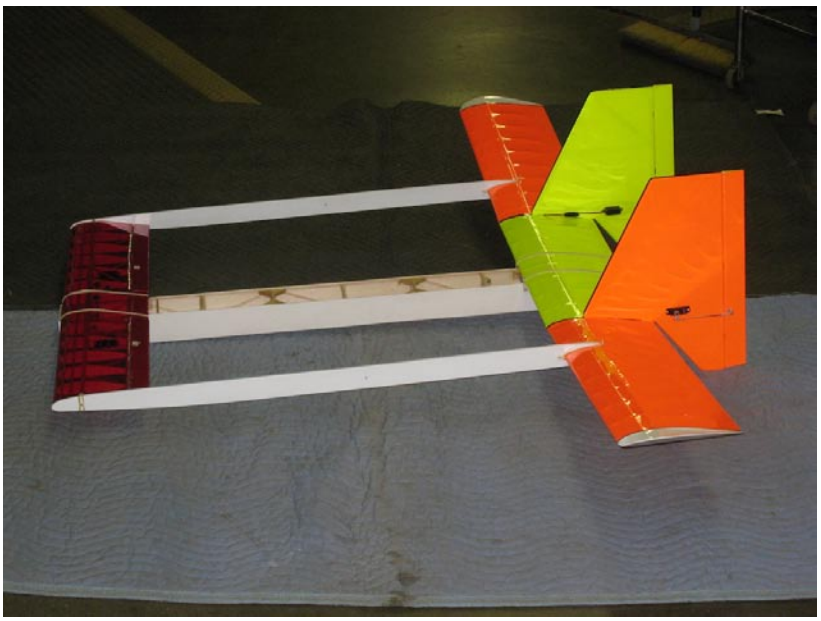


Figure 2: Airofoil surfaces plus fuselage after skinning – 19th November 2009

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

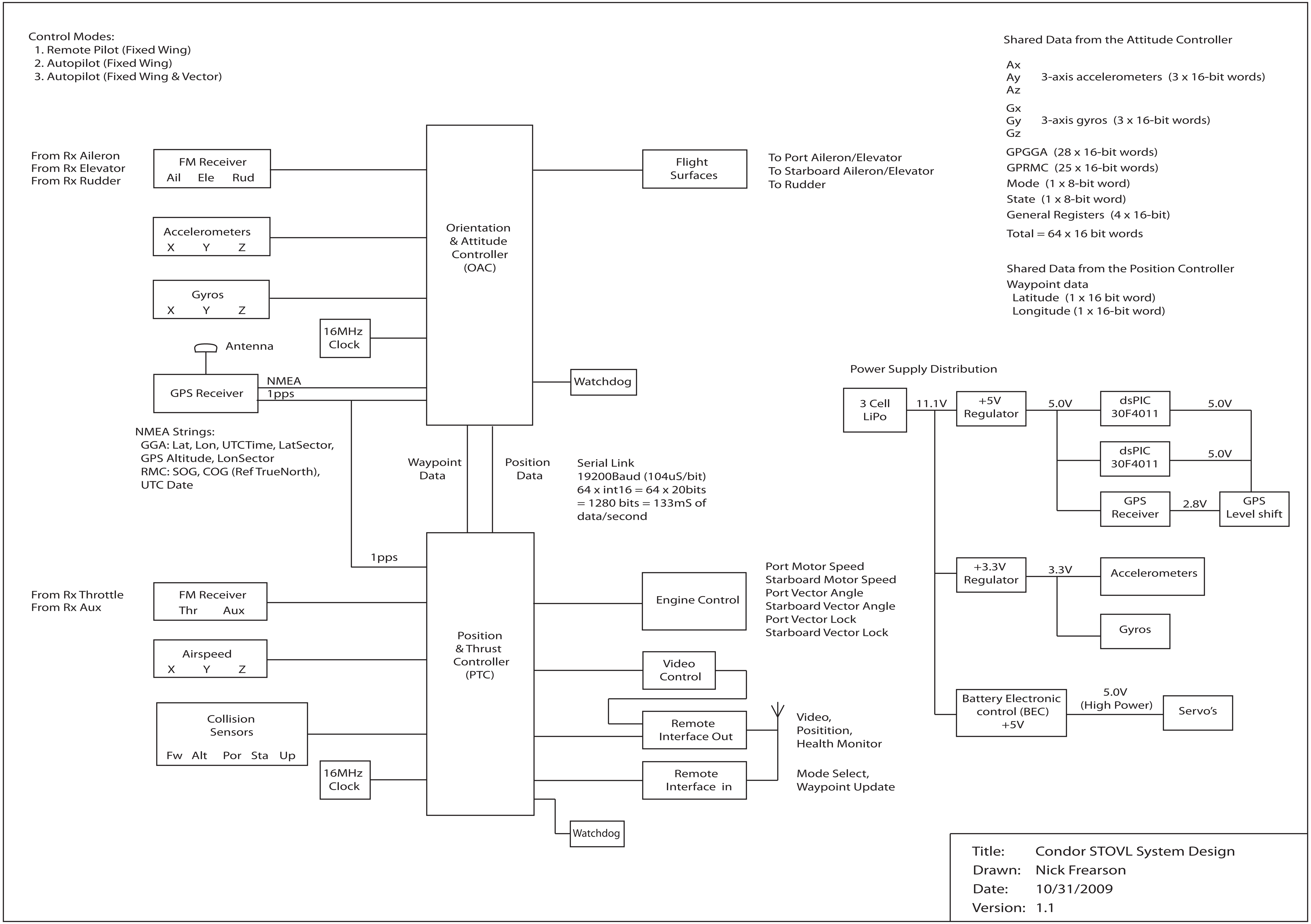
- The platform will be capable of carrying 5lb of payload.

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.


Control Modes:
1. Remote Pilot (Fixed Wing)
2. Autopilot (Fixed Wing)
3. Autopilot (Fixed Wing & Vector)
Shared Data from the Attitude Controller
Ax
Ay
Az
3-axis accelerometers (3 x 16-bit words)
Gx
Gy
Gz
3-axis gyros (3 x 16-bit words)
GPGGA (28 x 16-bit words)
GPRMC (25 x 16-bit words)
Mode (1 x 8-bit word)
State (1 x 8-bit word)
General Registers (4 x 16-bit)
Total = 64 x 16 bit words
Shared Data from the Position Controller
Waypoint data
Latitude (1 x 16 bit word)
Longitude (1 x 16-bit word)
From Rx Aileron
From Rx Elevator
From Rx Rudder
FM Receiver
Ail Ele Rud
Accelerometers
X Y Z
Gyros
X Y Z
16MHz Clock
Antenna
GPS Receiver
NMEA
1pps
Orientation & Attitude Controller (OAC)
Flight Surfaces
To Port Aileron/Elevator
To Starboard Aileron/Elevator
To Rudder
Watchdog
NMEA Strings:
GGA: Lat, Lon, UTCTime, LatSector,
GPS Altitude, LonSector
RMC: SOG, COG (Ref TrueNorth),
UTC Date
Waypoint Data
Position Data
Serial Link
19200Baud (104uS/bit)
64 x int16 = 64 x 20bits
= 1280 bits = 133mS of
data/second
1pps
From Rx Throttle
From Rx Aux
FM Receiver
Thr Aux
Airspeed
X Y Z
Collision Sensors
Fw Alt Por Sta Up
16MHz Clock
Position & Thrust Controller (PTC)
Engine Control
Port Motor Speed
Starboard Motor Speed
Port Vector Angle
Starboard Vector Angle
Port Vector Lock
Starboard Vector Lock
Video Control
Remote Interface Out
Remote Interface in
Video,
Positition,
Health Monitor
Mode Select,
Waypoint Update
Watchdog
Power Supply Distribution
3 Cell LiPo
11.1V
+5V Regulator
5.0V
dsPIC 30F4011
5.0V
dsPIC 30F4011
5.0V
GPS Receiver
2.8V
GPS Level shift
+3.3V Regulator
3.3V
Accelerometers
Gyros
Battery Electronic control (BEC) +5V
5.0V (High Power)
Servo's
Title: Condor STOVL System Design
Drawn: Nick Frearson
Date: 10/31/2009
Version: 1.1

The system consists of two independently operating dsp's that share some varaibles.
DSP#1, uses accelerometers and gyros to maintain a level platform and GPS heading to correct yaw and point it at a given waypoint. To do this it controls the left and right ailerons and the rudder. It receives waypoint information from the 2nd dsp. It also has a passthrough mode where external control signals from a remote operator can guide the plane.
DSP#2, uses airspeed to calculate how much lift is being provided by the wings. If the airspeed drops below a certain threshold the dsp will start to augment the airofoil lift with lift from the propellers by adjusting the angle of the engines to the airflow. taken to it's extreme the aircraft can come to a halt in the sky. The forward speed of the aircraft is defined by the distance to the next waypoint. A waypoint set in the distance will cause the aircraft to accelerate to cruise speed and move towards the waypoint. On approaching the waypoint the speed will drop and eventually come to zero. A waypoint close by will cause the aircraft to move slowly towards it. The 2nd dsp also includes a collision avoidance algorithm that can block out sectors of the sky and recompute routes to the next waypoint by creating intermediate waypoints that are passed to the 1st dsp.

Rx pulses are TTL +5v, 1ms - 2ms duration >25ms between pulses, interrupt on change then measure the pulse width with the capture function

The Accelerometers and Gyros have 3.3V supplies.
The dspPIC has a 5V supply.
The dspPIC reference voltage must be set to the 3.3V supply so that the ADC's and the Accelerometer and Gyro analogue outputs track together with temperature .

The ADC should be allowed to free-run and generate an interrupt when a new set of samples is ready. This will minimise softeware overhead of the ADC process.

The ADC input should be sampled at 5KHz, filtered and decimated to minimise the aliasing that is produced by the standard analogue input filters. The corner frequency of the new filter should be set to ~ 100Hz.

Use a 16MHz oscillator with 1x internal multiplier to give the required instruction throughput

The GPS Receiver accepts 5V signals in but puts out 2.8V serial NMEA and 1PPS. These must be shifted back to 5V for the dspPIC to recognise them. It also requires a backup battery to do warm/hot starts.

Switches.
1. Momentary action Reset switch
2. Passthrough/Autopilot select
 Passthrough to feed RxAileron, RxElevator and RxRudder directly to the PWM outputs
3. FixedWing/Vector select
 In FixedWing mode the engines are locked in their forward position and the platform operates only as a fixed wing aircraft.
 In Vector mode the engines are free to rotate according to the demands of the airflow monitor software
4. Spare. For future use

The dspPIC is programmed via the ICSP port

This is the reference voltage used to make the ADC inputs ratiometric and so independent of temperature and psu fluctuations. In this case the sensors operate off a 3.3V supply so the reference is tied to the regulated 3.3v supply.

The Aileron and rudder outputs will be controlled by a remote operator when the system is in Passthrough mode, or will be controlled by the Autopilot in any other mode. The left and right Ailerons will be asisted by the rudder in turns, and will operate as elevators during climb or descent.

These I/O ports are spare

The LED's will be used to indicate operational modes. The ailerons and rudder can also be used to this effect.

The GPS Receiver will provide NMEA strings:
 GPGGA [UTC time, Lat, Lat sector, Lon, Lon sector, Altitude above geoid]
 GPRMC [Speed over ground, Direction over ground (ref true north), UTC Date]
DSP#1 will parse these onto the serial bus each rising edge of 1pps together with control information:
 Autopilot mode, Aux #1 state, Fixed Wing state
Total number of bytes=128 or 1280 bits

DSP#2 will put 'Next Waypoint' data onto the serial bus referenced to 1pps but 1/2s after the rising edge of 1pps
Total number of bytes=10 or 100bits

RxThrottle will be read from the external source if the passthrough mode is selected. If one of the automatic modes is selected the throttle settings will be computed internally. In FixedWing mode the throttle settings will be calculated according to the velocity curve required to get to the next waypoint. In Vector mode the velocity curve will be modified by the demands of the vector control algorithm.

The Airflow sensors will provide analogue feedback as to the instantaneous airflow in the along-track, across-track and vertical directions

The pressure sensor will provide baro-altitude data

The collision detection unit will provide real-time obstacle locations in the reference space of the aircraft, updated once per second. Detection range will be in the order of 50m. There will be a single downward looking sensor that will double as an altimeter. There will be single port and starboard sensors. The forward sensor will scan a 256 x 256 region in front of the aircraft, nominally 50m on a side.

Switches are for future use.

The dspPIC is programmed via the ICSP port

This is the reference voltage used to make the ADC inputs ratiometric and so independent of temperature and psu fluctuations. In this case the sampled inputs operate between 1v and 5v, so the reference is tied to the 5v regulated rail.

The left and right motor vector controls define the angular positions of the left and right engine support arms. In Passthrough or Fixed Wing mode these will always be locked down in the forward position.

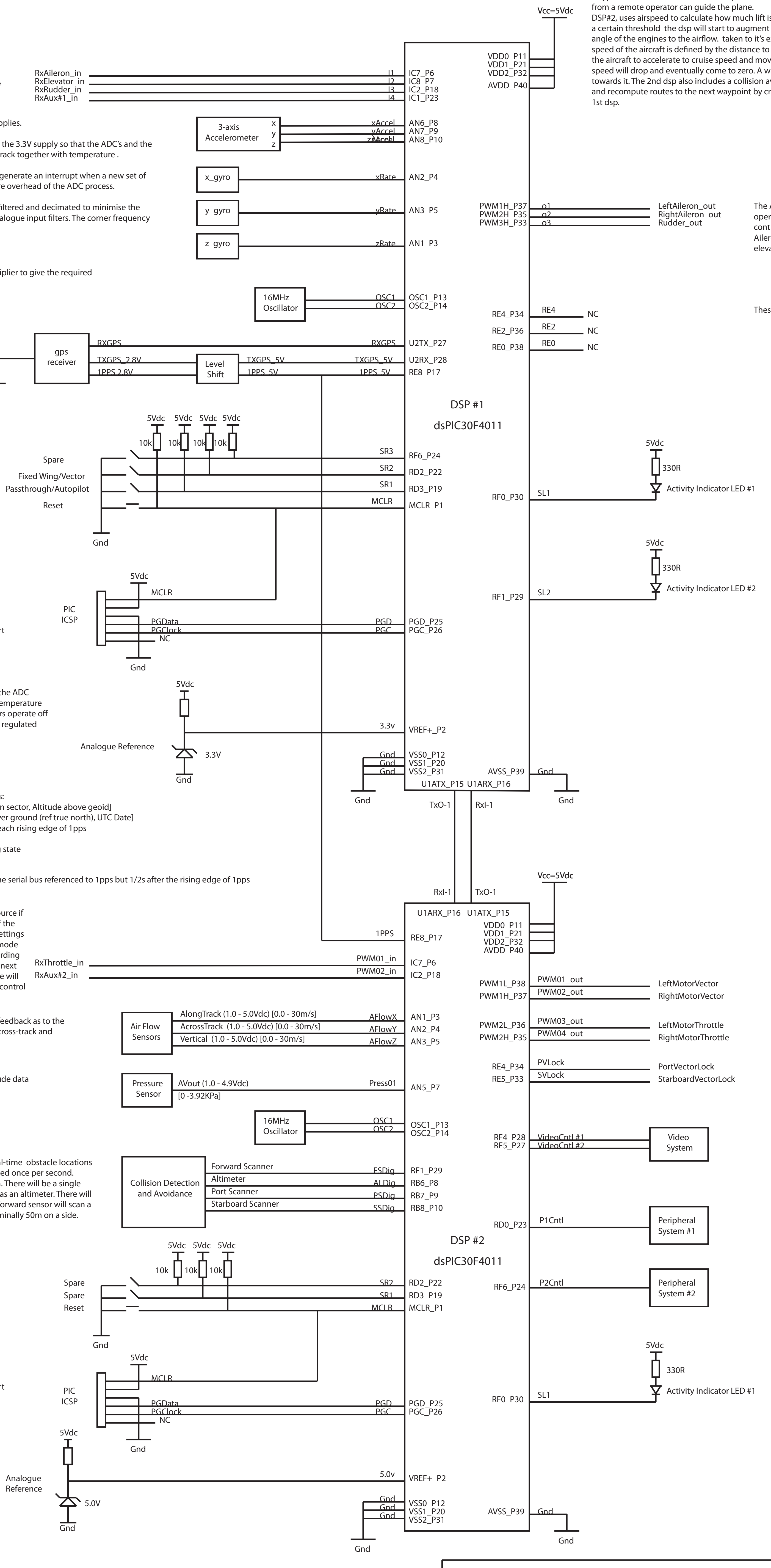
In Passthrough and Fixed Wing mode the motor throttle signals will always be equal. In Vector mode they will be defined by the demand from the forward motion subsystem and the vector angle of the engines

The Vector lock will always be asserted when the engines are in the forward position with a vector angle of zero.

The video system will operate independently from the Attitude and Position control processors apart from two control signals which may be used to turn on the recording

There are two control lines that can be used to switch on or off remote systems

The LED will be used to indicate operational modes. The ailerons and rudder can also be used to this effect.



Title:	Condor STOVL Microcontroller Interface Diagram
Drawn:	Nick Frearson
Date:	10/31/2009
Version:	1.1