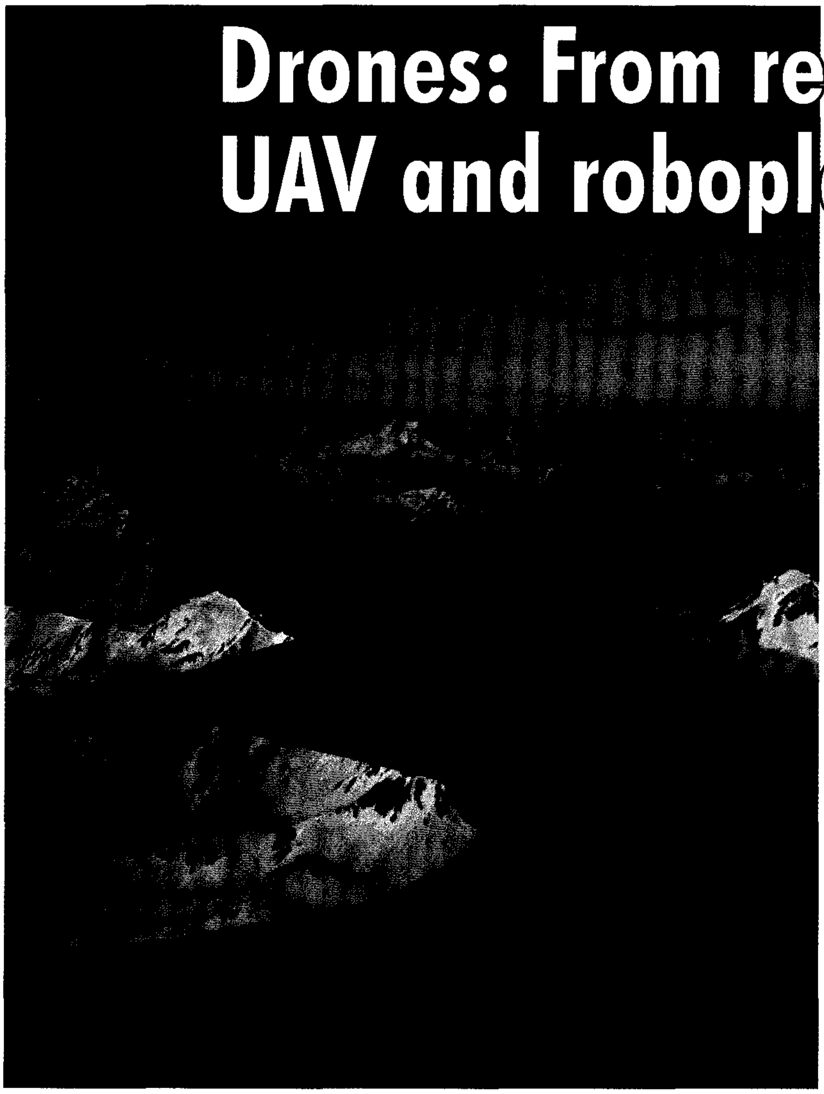
Flying Robots

Drones: From remote control to UAV and roboplane



Dassault Aviation/Alain Ernoult. Photoref.: NEURON3_15cm.JPG

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As processors become ever more powerful we are witnessing the rise of more 'intelligent' systems. We now look to sophisticated robots to assist or even replace us in difficult or hazardous environments. This is particularly true of military hardware where we have seen on our TV screens the use of unmanned aircraft and vehicles in some recent conflicts. The basic idea however is not so new; we take a look into the world of 'drones'...

The history of remotely controlled aircraft can be traced back at least to 1935 when the aircraft manufacturer De Havilland installed a radio control receiver in the passenger seat of a tiger moth biplane (christened the 'Queen Bee' [1]) for use in gunnery target practice. The bee analogy was maintained when unmanned aircraft were then given the name 'drones'. In the intervening 70 years the unrelenting drive for electronic devices to become smaller, faster and cheaper has led to the development of small artificial insects and also to 'flying robots' with control systems capable of piloting an aircraft autonomously. Falling costs and the availability of increasingly powerful processors means that enthusiastic amateurs and student groups have also been able to make contributions to the field of autonomous aircraft and helicopters.

UAV classification

Drones are categorised according to their size and purpose. Collectively they are known as *Unmanned Aerial Vehicles* (UAVs). Military versions of these aircraft basically fall into one of two categories; they can be passive; gathering intelligence, making radio intercepts and video reconnaissance or as *Unmanned Combat Aerial Vehicles* (UCAV) they can be fitted with weaponry enabling them to take part in offensive strikes.

The UAV is further classified by the method which it achieves flight; it can be classed as a fixed wing, a rotating wing or an ornithopter (flapping like a bird). Unmanned balloons and airships are lighter than air and are not classed as drones.

A further distinction is made with reference to the level of autonomy at which the UAV operates. At its simplest level the aircraft is controlled remotely via a radio link, the next level of complexity provides the aircraft with some degree of self-control (autopilot function). The most sophisticated aircraft receive GPS positional information and can follow

a flight plan using pre-programmed waypoints, sensors detect obstacles and there is sufficient on-board computing power to calculate an avoidance strategy while maintaining aircraft stability. An ongoing research topic involves the development of control algorithms enabling a group (swarm) of UAVs to collaborate on a task.
The most important classification however relates to the size of the craft:

Micro UAV

These drones can be operated by one person (**Figure 1**). In principle every average-sized model aircraft is a Micro-UAV. They are typically powered by either internal combustion or electric motors (**Figure 2**). The availability of relatively low-cost modelling components including sensors (gyroscopes and accelerometers) coupled to microprocessors enable rate-of-turn and acceleration values to be measured and an inertial guidance control system to be produced quite cheaply. On these grounds the Micro UAV is an attractive development platform for a small design team who could expect to produce a vehicle with a number of commercial applications at a reasonable cost.

Mini UAV

As you might expect this class of drone is bigger than the micro UAV and requires a larger team of operators on the ground. The 'Luna' system (**Figure 3**) produced by EMT is one example of this type of drone which has been used by the German army for a number of years, most recently seeing service in both Afghanistan and the Balkans. The Luna has a reconnaissance speed of 70 km/h with a maximum altitude of 3,500 m. It can stay aloft for around four hours carrying a payload of up to 4 kg.

MALE/HALE

MALE (*Medium Altitude Long Endurance*) is a category of UAV capable of long duration flights and operating at an altitude of 10 to 15 km. HALE (*High Altitude Long Endurance*) can operate for a similar time but at an altitude of around 20 km. Both of these are classed as large UAVs and can remain airborne for up to two days. Two of the most recognisable UAVs in this category are the Predator (MALE) and the Global Hawk (HALE) both operated by the US air force. The 1020 kg Predator (**Figure 4)** is powered by an Austrian Rotax-Motor developing around 100 hp through a pusher propeller which gives it a top speed of approximately 130 km/h at an altitude of 7600 m. It has an operational radius in the order of 640 km carrying a 200 kg load. A more recent version of the predator can be used as a UCAV. A long range variant is powered by a 130 hp German Thielert diesel [2] which is based upon the 1.7 litre engine used in the Mercedes A-class vehicles. The Global Hawk (**Figure 5**) uses a Rolls-Royce gas turbine giving it a top speed of around 600 km/h at an altitude of around 20,000 m. The craft has a 'global' range of 26,000 km with an all-up weight of 12 Tonnes. It can remain airborne for two days carrying a payload of [illegible]00 kg.

UCAV

The development of armed UCAVs for military use is currently a very active field of research and development. Preliminary performance figures of the X-45 currently under development by Boeing indicate that it has a maximum speed of Mach 0.85, service altitude of 12,000 m, an operational radius of 2000 km with a maximum payload of 200 kg. The UCAV shown on the title page is a prototype craft by the French company Dassault.

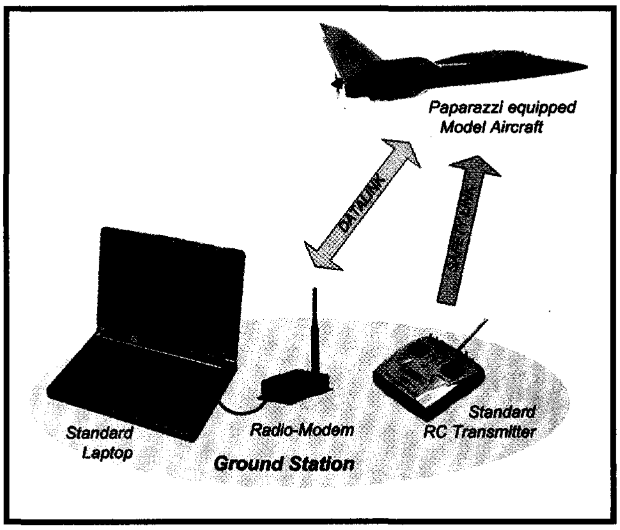


Figure 1.
The 'Open-source UAV' ground station consists of a laptop with a radio modem for communication and a standard R/C transmitter for autopilot backup.

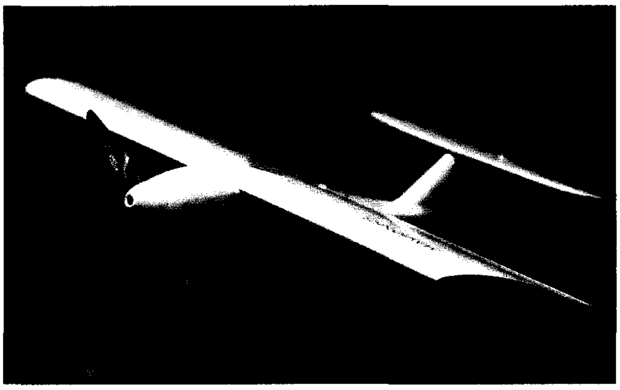


Figure 2.
The 'Carolo' is a typical example of a micro UAV using model aircraft components.

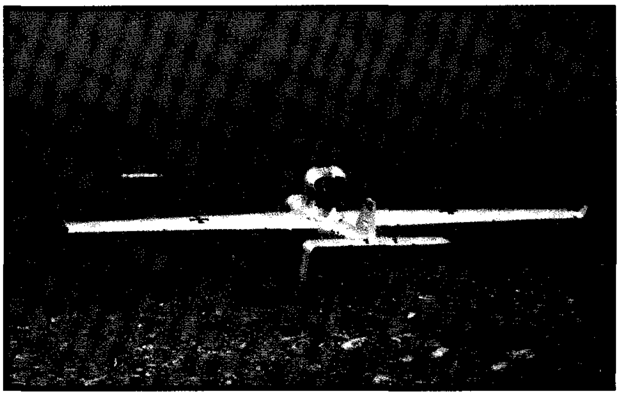


Figure 3.
The German reconnaissance vehicle LUNA has been in service with the German military since 2003.

Figure 4.
The General Atomics 'Predator' is probably the most recognisable middle category (MALE) drone.

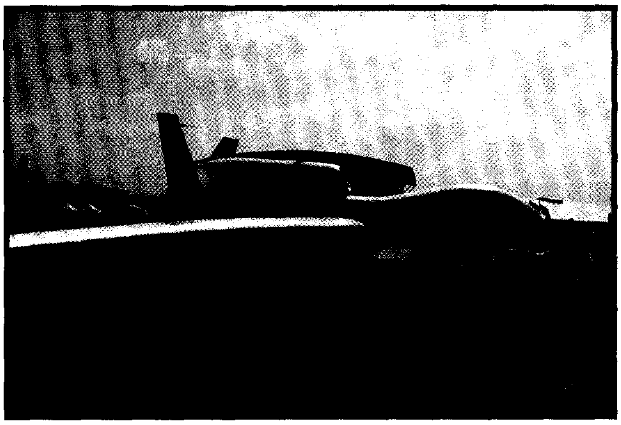


Figure 5.
The long endurance reconnaissance Global Hawk.

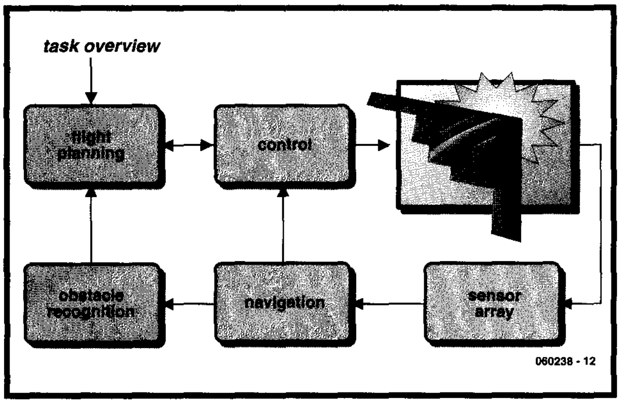


Figure 6.
The structure of a UAV-flight control system.

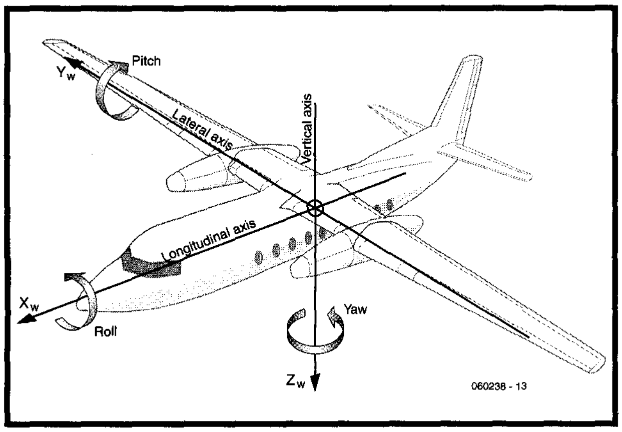


Figure 7.
Automatic aircraft control requires information from all three axes.

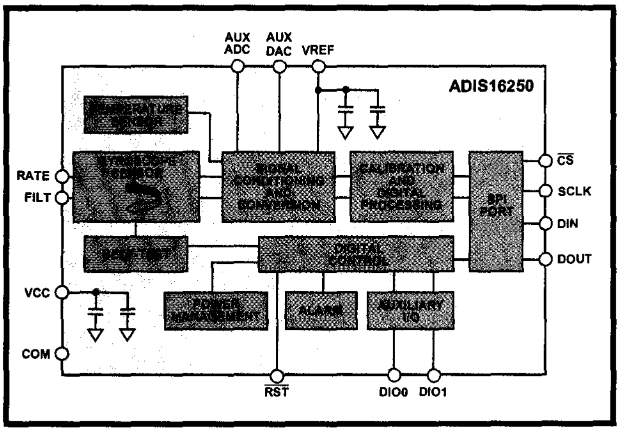


Figure 8.
This gyroscope evaluation board from Analog devices is also ideal for your own UAV project.

Flight control

The scope of this discussion will be limited to fixed-wing drones; they present fewer technical challenges and are by far the commonest type. **Figure 6** shows the structure of a typical flight control system. In a manned aircraft the pilot steers and controls the aircraft but with a UAV the pilot is replaced with a control loop, sensors and actuators to steer the UAV.

In order to maintain aircraft stability it is necessary for the control software to have information from sensors giving the craft's current situation. The following values are therefore important:

- Position (geographical coordinates and altitude)
- Speed in all three planes (forwards, sideways and altitude).
- Euler angle (Rotation around all three axes: pitch, yaw and roll **Figure 7**)

The aircraft's status can also be described using airspeed, angle of incidence and sideslip angle.

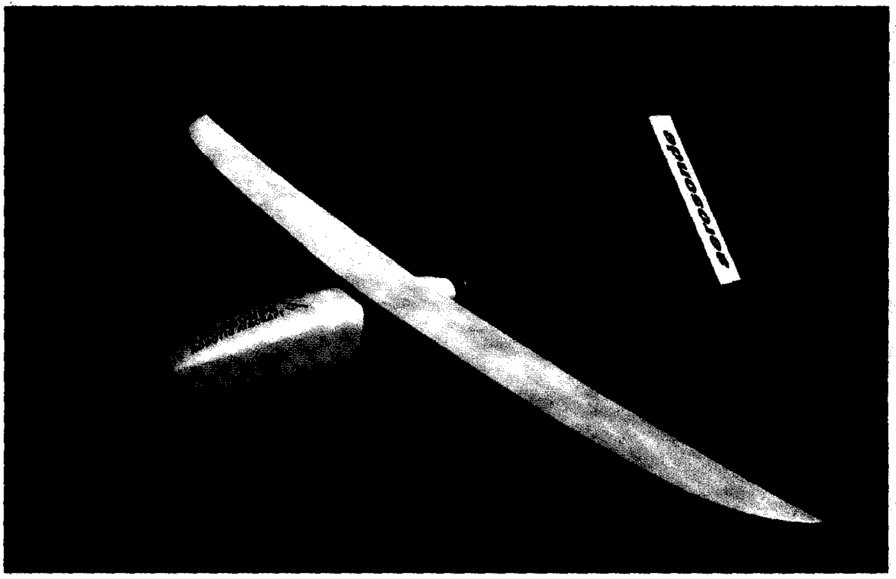
There are a number of different sensors available to measure these values. The Paparazzi UAV [3] uses a low-cost two-axis infrared thermometer for attitude determination while geographical coordinates are given by a GPS receiver. Altitude is provided by an absolute pressure sensor while rate-of-climb is measured by a dynamic air pressure sensor. The sensor readings are then scaled and converted into meaningful values in the navigation filter software.

The greater the processing power the more sensors can be used, it also allows more complicated filter algorithms to be applied to the sensor data. Additional systems can also be integrated with the motion sensors already described for example an inertial gyroscope can also provide motion information. When this additional sensor data is correctly interpreted with the existing data it will give a more complete picture of the crafts behaviour. This process known as 'sensor fusion' mimics the process occurring in the brain when you view two pictures taken by a 3D camera from slightly different positions. Both images are just two dimensional but when the left and right pictures are viewed by the corresponding eye your brain is immediately able to extract depth information from the images. In the navigation system accelerometers are used together with gyroscopes to give angular velocity information.

Figure 8 shows a gyroscope module evaluation board from Analog Devices [4]. The filter algorithm used in this device is also know as a Kalman filter. In comparison to simpler filtering techniques Kalman filtering requires the use of a powerful processor (by current day standards). The desired values are the pre-programmed waypoints defining the flight path. These waypoints can be programmed into the on-board navigation computer at the ground station before the flight begins or during flight over a radio link. Alternatively they can be generated automatically by a higher level control loop known as a trajectory planner; this represents a more sophisticated level of vehicular autonomy.

The topics of automatic trajectory planning, collision avoidance and coordination of groups (swarms) of autonomous UAVs are currently hot topics at numerous research institutes and universities.

The Record book



The first UAV to cross the north Atlantic non-stop was manufactured by the Australian company Aerosonde. The flight was made in August 1998 by the 13 kg twin-boom craft with a 2.9 m wing span carrying 7 l of fuel. It took almost 27 hours to fly the 3270 km course from Newfoundland to Scotland. The 20 cc 4-stroke Enya motor required just 5.7 litres of petrol to go the distance which works out at about 570 km per litre at an average speed of 120 km/h. This particular drone is designed to gather metrological data; its rear mounted 'pusher' prop allows the nose cone to be fitted with instruments where they are free from propeller wash.

Five years after this event in August 2003 a much smaller model aircraft named TAM 5, built by the model aircraft enthusiast Maynard Hill set an FAI record by making the 3000 km journey from Newfoundland to Ireland in 38 hr and 52 mins. Like the Aerosonde, conventional remote control was used for take-off and landing but the rest of the journey was controlled by an on-board autopilot using GPS positional data. The 5 kg balsa model has a wing span of 1.8 m and uses a modified 10 cc 4-stroke OS motor. It used all but 100 ml of its 3.3 l of fuel to make the crossing giving it a fuel economy figure of 1000 km per litre!

The altitude record set in August 2001 is held by Helios, a 75 m span electrically powered UAV which was developed by the Californian company AeroVironment in collaboration with NASA. The 580 kg craft flew to a height of 29,413 meters (about three times the height of a typical commercial flight!) driven by 14 solar-powered electric motors.

The largest unmanned aircraft at 106 tonnes was a converted Boeing 720 operated by NASA. Its final test manoeuvre carried out in December 1984 (controlled impact demonstration) was designed to test the effectiveness of a fuel additive during crash landing.

The December 2006 issue of New Scientist reported a test recently conducted on a BAC 111 airliner fitted with a UAV control interface to assess pilot workload while controlling a simulated swarm of UAVs in a battle situation. Pilots were on hand to perform the take-off and landing.

Web Links

www.aerodesign.de/peter/1999/Aerosonde/Aerosonde.html

www.aerosonde.com/drawarticle/4

www.aa.washington.edu/research/aerosonde/laima.htm

www.mfc-osnabrueck.com/TAM-5.htm

tam.plannet21.com/

www.dfrc.nasa.gov/Newsroom/X-Press/stories/050802/res_record.txt.html

www.dfrc.nasa.gov/gallery/movie/CID/index.html

www.newscientisttech.com/article/dn10675

Brain power

One or two ATmega processors usually provide sufficient processing power for a simple micro UAV but as system complexity increases for example with the use of Kalman filtering the addition of DSPs become essential. With more vehicle autonomy the necessity to process video information and data from additional sensors in real-time dictates that FPGAs and highly specialised DSPs need to be integrated into the vehicle's control system.

Payload

The on-board sensors usually take up the majority of the available payload in the UAV. The types of sensors fitted depend largely on the size of the UAV. Mikro-UAVs are most commonly fitted with cameras operating in the visible and IR part of the spectrum. Reconnaissance drones usually carry high-resolution and thermal imaging cameras for use in darkness and conditions of low visibility. Larger UAVs like the MQ-1 Predator are also fitted with conventional radar or SAR (Synthetic Aperture Radar). With the addition of anti-tank rockets this particular drone can be configured as a UCAV. The UAV payload can also consist of communications equipment to provide a radio-relay function, thereby extending the range of battlefield communications in difficult terrain. Fitted with ECM (Electronic Counter Measures) equipment the drone can also play a role in the so-called 'electronic warfare' where it can actively disrupt communication systems or identify the source of unwanted jamming signals.

The number of commercial applications for drones is also growing and they have been used for forestry surveillance and traffic monitoring. The number of internet sites devoted to this subject is evidence that the goal of producing a truly autonomous aircraft or helicopter is very appealing to many model fliers with electronics backgrounds.

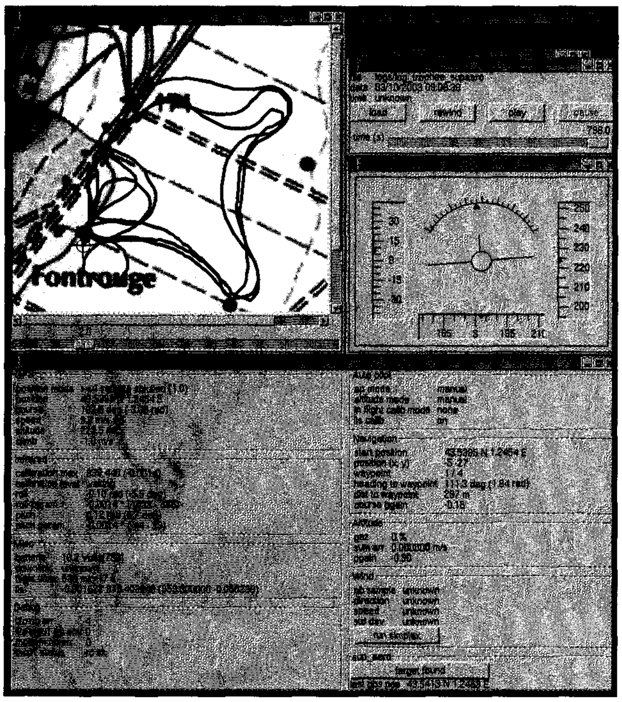


Figure 9. Screen capture of a Paparazzi flight [3] during the 2003 Supaero contest.

Projects and Competitions

A quick trawl of the Internet identifies several interesting open-source projects with a UAV theme. The most widely known is probably the 'Paparazzi' project [3], which began life at the ENAC in Toulouse and has been running for a number of years. In the process of development a small PCB fitted with ATmegas has been designed.

In Europe there are a number of competitions and conferences where researchers and design engineers meet, show off their latest designs to the public and generally exchange ideas. The European Micro Air Vehicle Conference and Competition (EMAV 2006) included a challenge with the aim to find the smallest autonomous aircraft able to most quickly fly a route using pre-programmed waypoints and finally to recognise a high-contrast symbol marked on the ground. It was impressive to see just how many of the entrants were able to complete the tasks. This year will see the third annual meeting of the 'US–European Competition and Workshop on Micro Air Vehicles' [5] held in Toulouse from the 18th to the 21st of September. There are also several small aircraft and helicopter UAV projects currently under development in some German universities for example the 'Carolo' in Braunschweig [6], the MAV series in Aachen [7] and the four rotor 'Air Quad' in Karlsruhe [8]. The University of Delft in Holland has an ornithopter project 'Delfly' [9] while 'WITAS' [10] is a helicopter UAV from the Linköping University in Sweden (based on a commercial RMAX mini helicopter from Yamaha [11]) and of course the Paparazzi project in France.

DIY UAV?

Anyone fired up sufficiently to start work on their own UAV can make a good start by browsing the pages of the open-source projects described on the internet [3] [12]. The hardware designs are available in Eagle or target file format. Software for the paparazzi project is a compiled Linux distribution containing all the necessary files. Those of you who cannot wait to get their own project off the ground could of course splash out on one of the systems offered by the US companies MicroPilot [13] or UNAV [14] these ready-made auto pilot solutions are available in a number of different versions offering varying degrees of control sophistication but expect to pay somewhere in the five-figure (dollar) region for the most complex, fully-featured system.

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Web Links

[1] www.jaapteeuwen.com/ww2aircraft/

[2] http://web.thielert.com/typo3/index.php?id=514&L=1

[3] www.nongnu.org/paparazzi/

[4] www.analog.com/UploadedFiles/Evaluation_Boards_Tools/170491614ADIS16250_PCBZ.pdf

[5] www.mav07.org

[6] www.ilr.ing.tu-bs.de/forschung/mav/

[7] http://www.dynamik.rwth-aachen.de/mav/

[8] www.presse.uni-karlsruhe.de/6400.php

[9] http://www.tudelft.nl/live/binaries/5ba8080d-6331-49cb-9d68-658e450299f9/doc/DO05-4-1microplane.pdf

[10] www.ida.liu.se/~marwz/papers/ICAPS06_System_Demo.pdf

[11] www.yamaha-motor.co.jp/global/industrial/sky/index.html

[12] www.albatross-uav.org

[13] www.micropilot.com

[14] www.u-nav.com

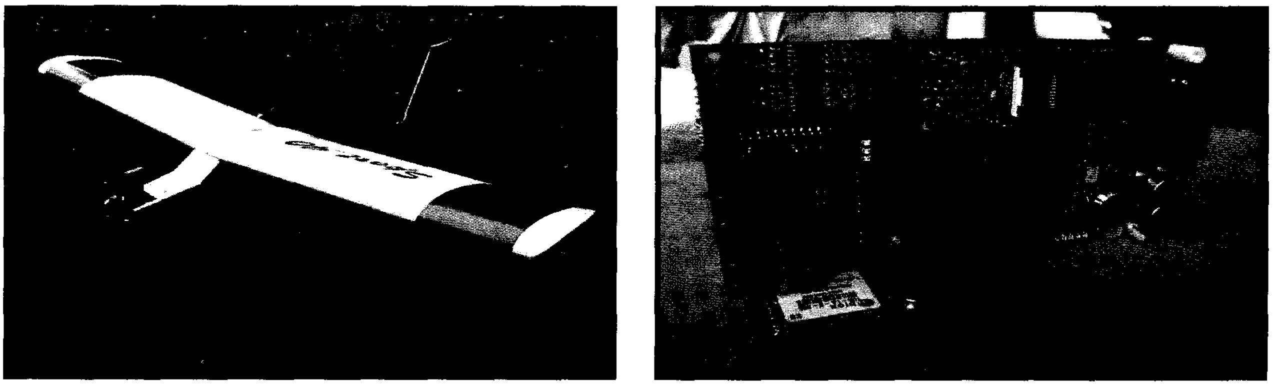

Figure 10. Two main parts of the Albatross project [12] by John Stowers and Hugo Vincent from New Zealand. Micro-UAV (left) and main board fitted with an ARM controller (right).