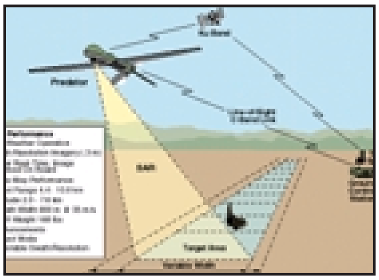
Robotic Aerial Platforms for Remote Sensing

UAVs are Now Being Developed for Use as "Satellite Substitutes"

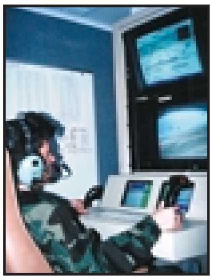
Unmanned Aerial Vehicles (UAVs) - also called drones or Remotely Piloted Vehicles (RPVs) - are a subject of ever-increasing interest over the whole area of airborne imaging and remote sensing. The reasons for this current interest are quite fascinating: indeed they may even become compelling. In particular, UAVs are now beginning to offer the possibility of continuous day-and-night operation over a particular area for a period of days - and eventually weeks or months. This capability would allow them to carry out either the long-term environmental monitoring of large areas of land and sea or the continuous surveillance of natural or man-induced disasters such as floods, tornados, earthquakes, volcanic eruptions, oil spills and forest fires, even in remote areas and over inhospitable terrain. The images of the ground or the ocean would then be transmitted from the UAVs in real time to transportable ground receiving and processing stations. As such, potentially they offer big advantages over Earth-orbiting satellites which, at best, are only able to visit a specific area for a few minutes once per day or, more usually, once every few days. Furthermore, unlike satellites, UAVs can be repaired, modified or replaced much more easily. Compared with comparable manned aircraft, UAVs are smaller, lighter and less expensive. Besides which, some of the latest UAVs offer ultra-high altitude operation, extreme long range and an endurance that is beyond the capabilities of human aircrew. Already they are being hailed as "atmospheric or stratospheric satellites" or, perhaps rather more accurately, as "satellite surrogates" or "satellite substitutes" - though there are still some tasks that only satellites and manned aircraft can undertake. The potential of the UAV is obvious - but a great deal of work has still to be done before it can be realised!

By Professor Gordon Petrie

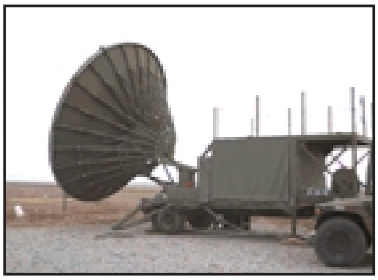


(A): The operational scheme for the Predator UAV showing the ground coverage of the TESAR imager and the radio links between the UAV and the ground control and receiving stations. (Source U.S. Army)

(B): NASA's mobile ground control and receiving station with the parabolic tracking antenna on top of the van providing the line-of-sight radio link to the UAV. (Source: General Atomics)



(C): Pilot flying the UAV from the ground station. (Source: General Atomics)



(D): The Trojan Spirit II ground station receiving the image data from the UAV via a communications satellite. (Source: U.S. Army)

UAV Classification

An almost bewildering range of UAVs is being developed at the present time. The main classes are as follows:-

(I) At the one end of the scale are small man-portable **kit planes,** usually hand launched and propeller driven by tiny battery-operated electrical motors. These small inexpensive radio-controlled aircraft have a very short range, a quite limited ceiling and a short endurance and can only carry a very light payload. Usually they are equipped with lightweight small-format photographic or video cameras. Thus they are suitable for very local use only.

(II) A second group are the **vertical take-off and landing (VTOL)** UAVs, essentially robotic helicopters, that are favoured for surveillance operations from naval vessels.

(III) Occupying the mainstream are the numerous **military tactical UAVs.** These have been designed primarily to undertake battlefield reconnaissance. In this role, they have been fielded widely and used quite extensively by American, Israeli and various European armies. Typically tactical UAVs have a reasonably long range (from 50km up to 200km), can reach a considerable flying height (up to 15,000ft. [5km]) and may have an endurance of several hours. Like the VTOL UAVs, normally these tactical UAVs are equipped with passive EO/IR (electro-optical/infra-red) imagers allowing day and night operations. Some may be fitted instead with an active SAR (synthetic aperture radar) imager for all-weather and day and night operations. However this tends to advertise their position and make them easy targets for anti-aircraft guns and missiles. The optical or SAR image data is transmitted from the UAV back to a ground station via an air-to-ground radio link or via a communication satellite to the ground receiving and processing station. From there, the image data is passed to the battlefield commanders for their assessment.

(IV) Another distinctive group are the **medium-altitude/long endurance (MALE) UAVs.** Typically these will operate at altitudes up to 25,000ft [15km] and have an endurance of 20 hours or more. Essentially this is more of a strategic type of UAV operated by air forces deep into enemy territory, rather than the tactical UAVs of the previous group operated by armies over a battlefield. They use a similar range of imagers to those used by tactical UAVs, but these are optimised to produce high-resolution images of the target area from a long range.

(V) At the far end of the scale are the **high-altitude/long endurance (HALE) UAVs.** Typically these operate at very high altitudes (up to 65,000ft [20km]), over very long ranges (up to several thousand kilometres) and have an endurance of 24 hours or more. Like the tactical and MALE UAVs, they are equipped with EO/IR and SAR imagers and transmit their image data to the ground receiving station over radio links. This article will mainly be concerned with the last two groups - which are those of most interest to the majority of civilian users as well as to military users.

Left: General Atomics Predator propeller-driven UAV with the imager turret fitted below the nose of the aircraft. Right: The gyro-stabilised turret containing the EO/IR imagers fitted to the underside of the nose of the General Atomics Predator UAV. (Source: General Atomics)

Background

Very large numbers of UAVs - notably those built by the Teledyne Ryan company - were used for military reconnaissance purposes during the later stages of the Vietnam War. Afterwards interest in the technology dropped off in Western countries. However it was kept alive by the Israeli armed forces, who used tactical UAVs extensively over Lebanon and Syria during the 1980s. This success led to a revival of interest both in the U.S.A. and in Western Europe. Derivatives of the Israeli designs - e.g. the Pioneer and Hunter used by the U.S. Army and the Crecerelle used by the French Army - as well as other designs such as the Canadair CL-289 (used by the German and French armies) and the British Phoenix UAVs have been produced in comparatively small numbers. These tactical UAVs have been used with reasonable success (but also some shortcomings), first during the Gulf War and, since then, over Bosnia and Kosovo. Currently a new generation of tactical reconnaissance UAVs is being developed for the military forces of many countries. The reasons for this development are varied. A major point is that using UAVs cuts out the potential loss of pilots flying dangerous reconnaissance or surveillance missions. Nearly 30 UAVs, mainly of the tactical type, were lost by NATO forces over Kosovo due to anti-aircraft fire or technical failures while undertaking such missions - but no pilots! Furthermore the technology has greatly

The prototype of the Helios solar-powered high-altitude flying wing UAV lands on the lake bed near Dryden Flight Research Center at Edwards Air Force Base in California. (Source: NASA)

improved. The availability of lightweight composite materials and structures; the greater reliability of digital flight control systems; and the improvements in navigation systems based on the use of inertial systems and GPS have all been important factors in this development. Still further, the development of lightweight miniaturized imagers and more robust and higher capacity data links capable of transmitting images at higher bandwidths to transportable ground receiving stations that can be operated in the field has also been a factor in this widespread acceptance of UAVs.

NASA

In the civilian area, the main agency concerned with the development of MALE and HALE-type UAVs has been NASA. The agency's studies into supersonic transport aircraft led to the need for scientific research into the potential impact of these aircraft on the upper atmosphere, including the possibility of ozone layer depletion. Besides which, the agency has been much involved with its "Mission to Planet Earth" programme and its subsequent "Earth Science Enterprise" concerned with environmental monitoring of the Earth's surface and the effects of global climatic change. In support of these various programmes, during the late 1980s, it started to operate manned aircraft as platforms for various imagers. These included a modified DC-8 jet airliner equipped with a SAR imager (AIRSAR) and two examples of the Lockheed U-2 spy plane called the ER-2. These high altitude ER-2 aircraft are equipped with Wild photogrammetric cameras and other types of imager such as the AVIRIS hyperspectral scanner, various multi-spectral scanners and a multi-spectral digital frame camera. In addition, they have been used to test out airborne versions of the various imagers (MODIS, MISR, ASTER) that have since been mounted and used in NASA's new Terra satellite. Besides using these manned aircraft, NASA decided to develop a UAV capable of high-altitude operation. This resulted first of all in the construction of the propeller driven Perseus

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UAVs built by Aurora Flight Sciences. Four examples of this experimental aircraft were constructed between 1991 and 1994. These were followed by a similar but larger UAV called Theseus that was delivered in 1996.

ERAST

In September 1994, NASA initiated its Environmental Research Aircraft and Sensor Technology (ERAST) programme. On the aircraft side, NASA's objective was to carry out further research and development into UAVs intended both for high-altitude scientific research purposes and for possible commercial remote sensing applications. On the sensor technology side, it focused its attention on the development of new miniaturized high-resolution imaging sensors and avionics systems for use both on UAVs and on its high-altitude ER-2 aircraft. With regard to its UAVs, all the initial ERAST designs were propeller driven, both to keep costs down and because slow flying speeds are preferable for accurate atmospheric measurements as well as being quite suitable for the imaging of the Earth's surface and weather features such as hurricanes and tropical cyclones from high altitudes.

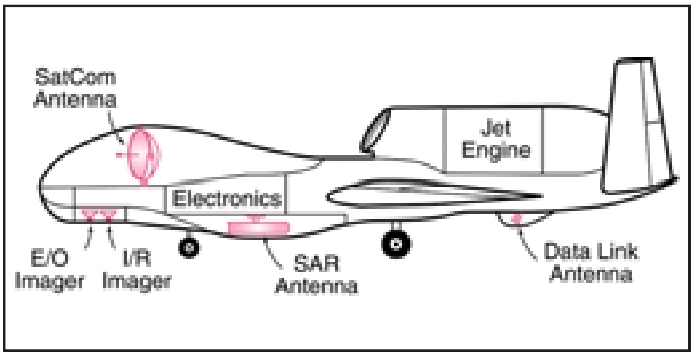
ALTUS

As one strand of its high-altitude UAV development, in the first place, NASA decided to adapt the existing General Atomics Gnat UAV for its ERAST programme. The resulting ALTUS UAV has a rather different body and a longer wingspan to that of the Gnat and features a turbo-charged engine driving a pusher propeller. An example that is now being operated by the U.S. Dept. of Energy (DOE) on scientific sampling for atmospheric research has a ceiling of 45,000ft [13.7km]. A later version called ALTUS II has been operated by NASA since July 1998. This has a two-stage turbo-charged engine and larger propellers and has an operational ceiling of 65,000ft [20km], similar to that of the manned ER-2 aircraft.

Predator

In parallel with this development, since 1992, General Atomics had also developed its Gnat design for military operations in the form of its Predator Medium Altitude/Long Endurance (MALE) UAV. This has a much lower operational ceiling - 25,000ft (7.5km) - than the ALTUS, but has a much longer endurance - 24hrs at a range of 400nm [800km]. It is equipped with a stabilised mount for its imagers, which normally comprise a colour video framing camera and a forward-looking infra-red (FLIR) imager. It can also carry a high-resolution SAR imager. A satellite data link system is also provided to

(A): Northrop Grumman Global Hawk high-altitude, long-endurance (HALE) UAV. (Source: Northrop Grumman)



(B): Diagram showing the arrangement of the EO/IR and SAR imagers and the communications antennas in the Global Hawk UAV. (Drawn by M. Shand)

transmit data to the transportable ground control and receiving station. This ground station has positions for the pilot flying the UAV and for the operator of the imagers. The station also contains workstations for the processing, display and manipulation of the imagery. More than 50 Predators have been built so far. These equip two USAF reconnaissance squadrons which have flown the UAVs extensively over Kosovo and Iraq.

Predator B

Last year (2000), NASA contracted with General Atomics for the supply of three still more advanced versions of the Predator UAV as remote sensing platforms for use in its "Earth Science Enterprise". The first of these Predator B UAVs (aircraft B 001) is equipped with a turboprop engine and has a still larger 64ft [19.5m] wingspan to give a higher speed, 242mph [390kph], and greater ceiling, 50,000ft [18.3km], as well as an endurance of 25 hours. This first aircraft in the series has just been delivered to NASA and made its initial flight on 6th February 2001. The second aircraft (B 002) will use a turbo-fan engine to increase its ceiling to 60,000ft [18.3km]. This is scheduled to be delivered to NASA and flown in the autumn of this year (2001). The third version (called ALTAIR) will have a new airframe to increase its payload, but will revert to a turboprop engine to give a maximum ceiling of 52,000ft [15.8km], but with an endurance of 32 hours. Comprehensive tests of this combination of UAVs with different configurations will be carried out by NASA over the next two or three years. The results from these tests will be of fundamental importance in deciding the direction to be taken in the future development of MALE and HALE UAVs that can be used by the scientific and mapping/GIS communities.

Imagers

As noted above, the primary imaging sensors employed on the Predator UAV are an EO/IR combination. The electro-optical (EO) imager is a colour HDTV camera equipped with a zoom lens. This produces high-resolution frame images in real time, but only during the day. The infra-red (IR) imager is a high-resolution FLIR equipped with several lenses to give different magnifications and fields of view. This can produce night-time as well as daytime images. The two imagers are mounted together in a sophisticated gyro-stabilized Skyball turret supplied by Versatron Wescam. This turret is mounted on the underside of the UAV and can be pointed in any direction by remote control. The TV camera can produce continuous video or still imagery; the FLIR usually outputs still images. With regard to the SAR imager with its all-weather, day and night operation, originally a Westinghouse Ku-Band SAR was used. This device was taken over by Northrop Grumman and is now known and supplied as the TESAR system. However General Atomics, the constructor of the Predator UAVs, has also commissioned and funded its own lightweight Lynx SAR which also operates in the Ku-Band. This has been developed on its behalf by the DOE Sandia National Labs. Besides producing conventional SAR images in the form of a continuous strip, both of these ground imaging SAR devices can also detect very small changes in a particular scene. This allows them to detect moving targets such as vehicles, to form the basis of the so-called moving target indicator (MTI). The images acquired by the Predator's SAR are then sent either over a C-Band line-of-sight radio link or relayed to the ground station via a geostationary communications satellite using a Ku-Band link.

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Solar Powered UAVs

Another entirely different approach to UAV development for remote sensing is also being supported and funded by NASA in the form of very slow flying, solar powered, long endurance UAVs. The actual development and construction of these experimental UAVs has been undertaken by the AeroVironment company which has been involved in the construction of solar powered aircraft for 20 years. Its first (piloted) aircraft, the Solar Challenger, flew from Paris to near London in 1981. This was followed by its solar powered UAV (called HALSOL), which first flew in 1983. This flying wing aircraft was made of very lightweight composite materials and featured solar panels mounted on top of the wing (together with supplementary batteries) providing power to eight small electric motors, each driving its own propeller. However, at that time, solar cell technology and the storage of the resulting electric power had not advanced enough to make this a practical aircraft. During the early 1990s, the project was revived by the U.S. Air Force, but again without too much success. Eventually NASA took over the Talon and Pathfinder prototype UAVs from these previous programmes and has supported their further development under its ERAST programme.

Pathfinder, Centurion & Helios

In 1997, the Pathfinder broke the altitude record for propeller driven aircraft reaching a height of 71,000ft [21.6km]. The aircraft was then upgraded and enhanced with an increased wingspan, more solar cells and two more electric motors and propellers. In the summer of 1998, this modified version, called Pathfinder Plus, reached an altitude of 80,000ft [24.4km]. As a result of this success, AeroVironment then built the similar but larger Centurion solar-powered UAV for NASA. A still larger version of the flying wing design with 14 electric motors called Helios has since been constructed and is now flying. This has a wing span of 247ft [80m] - larger than that of a Boeing 747 airliner! The lightweight solar cells alone cost several million dollars. Helios is expected to reach an altitude of 100,000ft. An attempt to reach this height will be made over the Hawaiian Islands in May (2001). Helios is also designed to fly for weeks, perhaps even months eventually. However initial tests will focus on attempting to fly it for four days at 50,000ft [15km] on solar power alone. Of course, on-board storage batteries will still be needed to store the energy received from the Sun during the day in order to power the UAV during the night-time periods of this extended flight. The attempt to achieve this four day flight will be made later this year (2001).

Global Hawk

Returning to military UAV developments, much attention is being focused currently on the Global Hawk HALE-type UAV built by Northrop Grumman. This jet-powered aircraft is much larger and can carry a much bigger payload than the Predator UAVs. It features a 35m wingspan and a much shorter 13.5m body. Global Hawk is designed to operate at altitudes of 65,000ft [21km] with a range of 2,200km and an endurance on-station of 24hrs. Its cruise speed is 400mph [650kph]. The aircraft has an integrated sensor suite comprising a Raytheon IR imager, a Kodak digital CCD camera and an X-Band SAR (the Raytheon HISAR) whose imagery is processed on-board the UAV before being transmitted to the ground station. Differential GPS is used to give precise position both during flight and especially during take-off and landing. The first flight of the prototype took place in 1998. So far, five Global Hawks have been delivered to the U.S. Air Force. Two more are being built and more are planned. Quite a large number of long endurance missions to Alaska and across the Atlantic from Florida to the Portuguese coast and back have been carried out successfully. An extended ferry flight across the Pacific Ocean to Australia is planned for April 2001. The Global Hawk will then undertake a series of demonstration missions over Australia's remote northwestern coastline in cooperation with Australian defence organisations. For the U.S. Air Force, the Global Hawks are seen as a supplement to its current fleet of thirty U-2 reconnaissance aircraft, but with more than three times the endurance of the manned U-2, which is limited to an eight hour mission.

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Applications

Besides the development and proving of the UAV technology and the related imaging sensors within its ERAST programme, NASA is also planning to demonstrate and validate the capability of UAVs to fly operational scientific and remote sensing missions. On the one hand, the high-altitude UAVs are being flown in the upper atmosphere for scientific purposes, e.g. for cloud research and to collect data on atmospheric chemistry. There is also talk about them being used as high-altitude platforms to host telecommunications relay stations over cities. But satisfying the many requirements of NASA's "Earth Science Enterprise" through the acquisition of suitable remotely sensed imagery is a primary objective of the ERAST programme. So is the matter of monitoring and helping to relieve or alleviate the effects of natural disasters, especially in third world countries - as proposed in the U.S. State Department's Project Peace Wing. For the Earth Science segment of the programme, coastal zone monitoring and the various applications of the imagery to precision farming are being put forward as demonstration projects. The first missions are scheduled to be flown next year (2002).

UAV Operations

Quite apart from the many hurdles to be jumped in developing the actual technology, the operational aspects of UAVs also pose problems that need to be solved. In particular, the matter of operating UAVs alongside passenger aircraft in civil-controlled airspace is one that is receiving much attention. At the high altitudes at which HALE UAVs operate, there is very little air traffic, so this is not such a serious problem. However the matter of UAVs passing through or operating at lower altitudes in areas with a lot of air traffic is much more of a problem. Automatic air collision avoidance systems (ACAS) are being developed as a possible solution. But still, at the present time, military operators of UAVs in the U.S.A. have to give 60 days' notice of a flight in civil-controlled airspace to the Federal Aviation Authority (FAA), which then imposes quite demanding requirements before giving permission for the flight. However the FAA has now had enough experience with UAVs in the western part of the U.S.A. where so much of the test flying of UAVs has taken place to have relaxed some of its more stringent requirements for UAV flights in that area.

Conclusion

As can be seen from the above account, very serious efforts (involving the expenditure of large sums of money) have been under way in the U.S.A. for some time to develop UAV technology to the point where it can be validated and transferred successfully for commercial use in airborne remote sensing. The year 2001 will see many of these efforts come to fruition. Thus the new Predator B UAVs are due to be flown and tested soon. The attempts to fly the solar-powered Helios UAV to meet its objectives of ultra-high altitude and long endurance flights will also be undertaken in the near future. And the results of the Global Hawk's forthcoming expedition to Australia will be of great interest. All of which make MALE and HALE UAVs a most interesting prospect for the future.

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