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Introduction to Unmanned Aircraft Systems (UAS)

An over-simplistic view of an unmanned aircraft is that it is an aircraft with its aircrew removed and replaced by a computer system and a radio-link. In reality it is more complex than that, and the aircraft must be properly designed, from the beginning, without aircrew and their accommodation, etc. The aircraft is merely part, albeit an important part, of a total system.

The whole system benefits from its being designed, from the start, as a complete system which, as shown in Figure 1.1, briefly comprises:

- a) a control station (CS) which houses the system operators, the interfaces between the operators and the rest of the system;
- b) the aircraft carrying the payload which may be of many types;
- c) the system of communication between the CS which transmits control inputs to the aircraft and returns payload and other data from the aircraft to the CS (this is usually achieved by radio transmission);
- d) support equipment which may include maintenance and transport items.

1.1 Some Applications of UAS

Before looking into UAS in more detail, it is appropriate to list some of the uses to which they are, or may be, put. They are very many, the most obvious being the following:

Civilian uses

Aerial photography	Film, video, still, etc.
Agriculture	Crop monitoring and spraying; herd monitoring and driving
Coastguard	Search and rescue, coastline and sea-lane monitoring
Conservation	Pollution and land monitoring
Customs and Excise	Surveillance for illegal imports
Electricity companies	Powerline inspection
Fire Services and Forestry	Fire detection, incident control
Fisheries	Fisheries protection

Gas and oil supply companies	Land survey and pipeline security
Information services	News information and pictures, feature pictures, e.g. wildlife
Lifeboat Institutions	Incident investigation, guidance and control
Local Authorities	Survey, disaster control
Meteorological services	Sampling and analysis of atmosphere for forecasting, etc.
Traffic agencies	Monitoring and control of road traffic
Oil companies	Pipeline security
Ordnance Survey	Aerial photography for mapping
Police Authorities	Search for missing persons, security and incident surveillance
Rivers Authorities	Water course and level monitoring, flood and pollution control
Survey organisations	Geographical, geological and archaeological survey
Water Boards	Reservoir and pipeline monitoring

Military roles

Navy

Shadowing enemy fleets

Decoying missiles by the emission of artificial signatures

Electronic intelligence

Relaying radio signals

Protection of ports from offshore attack

Placement and monitoring of sonar buoys and possibly other forms of anti-submarine warfare

Army

Reconnaissance

Surveillance of enemy activity

Monitoring of nuclear, biological or chemical (NBC) contamination

Electronic intelligence

Target designation and monitoring

Location and destruction of land mines

Air Force

Long-range, high-altitude surveillance

Radar system jamming and destruction

Electronic intelligence

Airfield base security

Airfield damage assessment

Elimination of unexploded bombs

1.2 What are UAS?

An unmanned aircraft system is just that – a system. It must always be considered as such. The system comprises a number of sub-systems which include the aircraft (often referred to as a UAV or unmanned air vehicle), its payloads, the control station(s) (and, often, other remote stations), aircraft launch and recovery sub-systems where applicable, support sub-systems, communication sub-systems, transport sub-systems, etc.

It must also be considered as part of a local or global air transport/aviation environment with its rules, regulations and disciplines.

UAS usually have the same elements as systems based upon manned aircraft, but with the airborne element, i.e. the aircraft being designed from its conception to be operated without an aircrew aboard. The aircrew (as a sub-system), with its interfaces with the aircraft controls and its habitation is replaced by an electronic intelligence and control subsystem.

The other elements, i.e. launch, landing, recovery, communication, support, etc. have their equivalents in both manned and unmanned systems.

Unmanned aircraft must not be confused with model aircraft or with ‘drones’, as is often done by the media. A radio-controlled model aircraft is used only for sport and must remain within sight of the operator. The operator is usually limited to instructing the aircraft to climb or descend and to turn to the left or to the right.

A drone aircraft will be required to fly out of sight of the operator, but has zero intelligence, merely being launched into a pre-programmed mission on a pre-programmed course and a return to base. It does not communicate and the results of the mission, e.g. photographs, are usually not obtained from it until it is recovered at base.

A UAV, on the other hand, will have some greater or lesser degree of ‘automatic intelligence’. It will be able to communicate with its controller and to return payload data such as electro-optic or thermal TV images, together with its primary state information – position, airspeed, heading and altitude. It will also transmit information as to its condition, which is often referred to as ‘housekeeping data’, covering aspects such as the amount of fuel it has, temperatures of components, e.g. engines or electronics.

If a fault occurs in any of the sub-systems or components, the UAV may be designed automatically to take corrective action and/or alert its operator to the event. In the event, for example, that the radio communication between the operator and the UAV is broken, then the UAV may be programmed to search for the radio beam and re-establish contact or to switch to a different radio frequency band if the radio-link is duplexed.

A more ‘intelligent’ UAV may have further programmes which enable it to respond in an ‘if that happens, do this’ manner.

For some systems, attempts are being made to implement on-board decision-making capability using artificial intelligence in order to provide it with an autonomy of operation, as distinct from automatic decision making. This is discussed further in Chapter 27, Section 27.5.

References 1.1 and 1.2 discuss, in more detail, the differences between model aircraft and the several levels of automation of UAS. The definition of UAS also excludes missiles (ballistic or homing).

The development and operation of UAS has rapidly expanded as a technology in the last 30 years and, as with many new technologies, the terminology used has changed frequently during that period.

The initials RPV (remotely piloted vehicle) were originally used for unmanned aircraft, but with the appearance of systems deploying land-based or underwater vehicles, other acronyms or initials have been adopted to clarify the reference to *airborne* vehicle systems. These have, in the past, included UMA (unmanned air vehicle), but the initials UAV (unmanned aerial vehicle) are now generally used to denote the aircraft element of the UAS. However, UAV is sometimes interpreted as ‘uninhabited air vehicle’ in

order to reflect the situation that the overall system is ‘manned’ in so far as it is not overall exclusively autonomous, but is commanded by a human somewhere in the chain. ‘Uninhabited air vehicle’ is also seen to be more politically correct!

More recently the term UAS (unmanned aircraft system) has been introduced. All of the terms: air vehicle; UAV; UAV systems and UAS will be seen in this volume, as appropriate, since these were the terms in use during its preparation.

1.2.1 Categories of Systems Based upon Air Vehicle Types

Although all UAV systems have many elements other than the air vehicle, they are usually categorised by the capability or size of the air vehicle that is required to carry out the mission. However, it is possible that one system may employ more than one type of air vehicle to cover different types of mission, and that may pose a problem in its designation. However, these definitions are constantly being changed as technology advances allow a smaller system to take on the roles of the one above. The boundaries, therefore, are often blurred so that the following definitions can only be approximate and subject to change.

The terms currently in use cover a range of systems, from the HALE with an aircraft of 35 m or greater wing span, down to the NAV which may be of only 40 mm span.

They are as follows:

HALE – High altitude long endurance. Over 15 000 m altitude and 24+ hr endurance. They carry out extremely long-range (trans-global) reconnaissance and surveillance and increasingly are being armed. They are usually operated by Air Forces from fixed bases.

MALE – Medium altitude long endurance. 5000–15 000 m altitude and 24 hr endurance. Their roles are similar to the HALE systems but generally operate at somewhat shorter ranges, but still in excess of 500 km. and from fixed bases.

TUAV – Medium Range or Tactical UAV with range of order between 100 and 300 km. These air vehicles are smaller and operated within simpler systems than are HALE or MALE and are operated also by land and naval forces.

Close-Range UAV used by mobile army battle groups, for other military/naval operations and for diverse civilian purposes. They usually operate at ranges of up to about 100 km and have probably the most prolific of uses in both fields, including roles as diverse as reconnaissance, target designation, NBC monitoring, airfield security, ship-to-shore surveillance, power-line inspection, crop-spraying and traffic monitoring, etc.

MUAV or Mini UAV – relates to UAV of below a certain mass (yet to be defined) probably below 20 kg, but not as small as the MAV, capable of being hand-launched and operating at ranges of up to about 30 km. These are, again, used by mobile battle groups and particularly for diverse civilian purposes.

Micro UAV or MAV. The MAV was originally defined as a UAV having a wing-span no greater than 150 mm. This has now been somewhat relaxed but the MAV is principally required for operations in urban environments, particularly within buildings. It is required to fly slowly, and preferably to hover and to ‘perch’ – i.e. to be able to stop and to sit on a wall or post. To meet this challenge, research is being conducted into some less conventional configurations such as flapping wing aircraft. MAV are generally expected to be launched by hand and therefore winged versions have very low wing loadings which must make

them very vulnerable to atmospheric turbulence. All types are likely to have problems in precipitation.

NAV – Nano Air Vehicles. These are proposed to be of the size of sycamore seeds and used in swarms for purposes such as radar confusion or conceivably, if camera, propulsion and control sub-systems can be made small enough, for ultra-short range surveillance.

Some of these categories – possibly up to the TUAV in size – can be fulfilled using rotary wing aircraft, and are often referred to by the term remotely piloted helicopter (RPH) – see below.

RPH, remotely piloted helicopter or VTUAV, vertical take-off UAV. If an air vehicle is capable of vertical take-off it will usually be capable also of a vertical landing, and what can be sometimes of even greater operational importance, hover flight during a mission. Rotary wing aircraft are also less susceptible to air turbulence compared with fixed-wing aircraft of low wing-loading.

UCAV and UCAR. Development is also proceeding towards specialist armed fixed-wing UAV which may launch weapons or even take part in air-to-air combat. These are given the initials UCAV for unmanned combat air vehicle. Armed rotorcraft are also in development and these are known as UCAR for Unmanned Combat Rotorcraft.

However, HALE and MALE UAV and TUAV are increasingly being adapted to carry air-to-ground weapons in order to reduce the reaction time for a strike onto a target discovered by their reconnaissance. Therefore these might also be considered as combat UAV when so equipped. Other terms which may sometimes be seen, but are less commonly used today, were related to the radius of action in operation of the various classes. They are:-

Long-range UAV – replaced by HALE and MALE

Medium-range UAV – replaced by TUAV

Close-range UAV – often referred to as MUAV or midi-UAV.

1.3 Why Unmanned Aircraft?

Unmanned aircraft will only exist if they offer advantage compared with manned aircraft.

An aircraft system is designed from the outset to perform a particular rôle or rôles. The designer must decide the type of aircraft most suited to perform the rôle(s) and, in particular, whether the rôle(s) may be better achieved with a manned or unmanned solution. In other words it is impossible to conclude that UAVs always have an advantage or disadvantage compared with manned aircraft systems. It depends vitally on what the task is. An old military adage (which also applies to civilian use) links the use of UAVs to rôles which are dull, dirty or dangerous (DDD). There is much truth in that but it does not go far enough. To DDD add covert, diplomatic, research and environmentally critical rôles. In addition, the economics of operation are often to the advantage of the UAV.

1.3.1 Dull Rôles

Military and civilian applications such as extended surveillance can be a dulling experience for aircrew, with many hours spent on watch without relief, and can lead to a loss of concentration and therefore loss of mission effectiveness. The UAV, with high resolution colour video, low light level TV, thermal

imaging cameras or radar scanning, can be more effective as well as cheaper to operate in such rôles. The ground-based operators can be readily relieved in a shift-work pattern.

1.3.2 Dirty Rôles

Again, applicable to both civilian and military applications, monitoring the environment for nuclear or chemical contamination puts aircrew unnecessarily at risk. Subsequent detoxification of the aircraft is easier in the case of the UAV.

Crop-spraying with toxic chemicals is another dirty role which now is conducted very successfully by UAV.

1.3.3 Dangerous Rôles

For military rôles, where the reconnaissance of heavily defended areas is necessary, the attrition rate of a manned aircraft is likely to exceed that of a UAV. Due to its smaller size and greater stealth, the UAV is more difficult for an enemy air defence system to detect and more difficult to strike with anti-aircraft fire or missiles.

Also, in such operations the concentration of aircrew upon the task may be compromised by the threat of attack. Loss of the asset is damaging, but equally damaging is the loss of trained aircrew and the political ramifications of capture and subsequent propaganda, as seen in the recent conflicts in the Gulf.

The UAV operators are under no personal threat and can concentrate specifically, and therefore more effectively, on the task in hand. The UAV therefore offers a greater probability of mission success without the risk of loss of aircrew resource.

Power-line inspection and forest fire control are examples of applications in the civilian field for which experience sadly has shown that manned aircraft crew can be in significant danger. UAV can carry out such tasks more readily and without risk to personnel.

Operating in extreme weather conditions is often necessary in both military and civilian fields. Operators will be reluctant to risk personnel and the operation, though necessary, may not be carried out. Such reluctance is less likely to apply with a UAV.

1.3.4 Covert Rôles

In both military and civilian policing operations there are rôles where it is imperative not to alert the 'enemy' (other armed forces or criminals) to the fact that they have been detected. Again, the lower detectable signatures of the UAV (see Chapter 7) make this type of rôle more readily achievable.

Also in this category is the covert surveillance which arguably infringes the airspace of foreign countries in an uneasy peacetime. It could be postulated that in examples such as the Gary Powers/U2 aircraft affair of 1960, loss of an aircraft over alien territory could generate less diplomatic embarrassment if no aircrew are involved.

1.3.5 Research Rôles

UAVs are being used in research and development work in the aeronautical field. For test purposes, the use of UAV as small-scale replicas of projected civil or military designs of manned aircraft enables airborne testing to be carried out, under realistic conditions, more cheaply and with less hazard. Testing subsequent modifications can also be effected more cheaply and more quickly than for a larger manned aircraft, and without any need for changes to aircrew accommodation or operation.

Novel configurations may be used to advantage for the UAV. These configurations may not be suitable for containing an aircrew.

1.3.6 Environmentally Critical Roles

This aspect relates predominantly to civilian rôles. A UAV will usually cause less environmental disturbance or pollution than a manned aircraft pursuing the same task. It will usually be smaller, of lower mass and consume less power, so producing lower levels of emission and noise. Typical of these are the regular inspection of power-lines where local inhabitants may object to the noise produced and where farm animals may suffer disturbance both from noise and from sighting the low-flying aircraft.

1.3.7 Economic Reasons

Typically, the UAV is smaller than a manned aircraft used in the same rôle, and is usually considerably cheaper in first cost. Operating costs are less since maintenance costs, fuel costs and hangarage costs are all less. The labour costs of operators are usually lower and insurance may be cheaper, though this is dependent upon individual circumstances.

An undoubted economic case to be made for the UAV is in a local surveillance role where the tasks would otherwise be carried out by a light aircraft with one or two aircrew. Here the removal of the aircrew has a great simplifying effect on the design and reduction in cost of the aircraft. Typically, for two aircrew, say a pilot and observer, the space required to accommodate them, their seats, controls and instruments, is of order 1.2 m^3 and frontal area of about 1.5 m^2 . An UAV to carry out the same task would require only 0.015 m^3 , as a generous estimate, to house an automatic flight control system (AFCS) with sensors and computer, a stabilised high-resolution colour TV camera and radio communication links. The frontal area would be merely 0.04 m^2 .

The masses required to be carried by the manned aircraft, together with the structure, windscreen, doors, frames, and glazing, would total at least 230 kg. The equivalent for the UAV would be about 10 kg.

If the control system and surveillance sensor (pilot and observer) and their support systems (seats, displays, controls and air conditioning) are regarded as the 'payload' of the light aircraft, it would carry a penalty of about 220 kg of 'payload' mass compared with the small UAV and have about 35 times the frontal area with proportionately larger body drag.

On the assumption that the disposable load fraction of a light aircraft is typically 40% and of this 10% is fuel, then its gross mass will be typically of order 750 kg. For the UAV, on the same basis, its gross mass will be of order 35 kg. This is borne out in practice.

For missions requiring the carriage of heavier payloads such as freight or armament, then the mass saving, achieved by removing the aircrew, obviously becomes less and less significant.

(a) First Costs

The UAV equipped with surveillance sensors can be typically only 3–4% of the weight, require only 2.5% of the engine power (and 3% fuel consumption) and 25% of the size (wing/rotor span) of the light aircraft.

The cost of the structures and engines within the range of manned aircraft tend to vary proportionally with their weight and power respectively. So one might think that the cost of buying the surveillance UAV would be, say, 3% of the cost of the manned aircraft.

Unfortunately this is not true for the following reasons:

Very small structures and engines have almost as many components as the larger equivalent, and although the material costs do reduce as the weight, the cost of manufacture does not reduce to the same degree.

The UAV must have a radio communications system which may not be necessary in the manned aircraft or, at least, would be simpler.

The UAV will probably have a more sophisticated electronic flight control system compared with the manned aircraft and, of course, a day/night surveillance camera system rather than an observer with a pair of binoculars, night vision goggles and digital SLR camera.

In addition, the UAV must have a more sophisticated control station (CS) for interfacing between the operator(s) and the aircraft. The CS may be ground, sea or air based.

So the overall result is not obvious but, depending upon the surveillance requirements, may be of the order of:

UAV	20–40% of manned aircraft cost
UAV control station	20–40% of manned aircraft cost
UAV + UAV control station	40–80% of manned aircraft cost

(b) Operating Costs

These figures are, to some degree, inevitably subjective. They include the following.

Approximate UAV cost as % of manned aircraft cost:

i) Interest on capital employed	40–80%	Probably about 40% or less overall
ii) Depreciation	30–60%	
iii) Hangarage [includes support vehicle and CS]	20%	
iv) Crew salaries and associated costs*	50%	
v) Fuel costs	5%	
vi) Maintenance	20%	
vii) Insurance**	30%	

* Aircrew are paid more than ground-based personnel, retire earlier and must pass regular, more rigorous professional and medical examinations.

** This will include aircrew and third party cover and may be initially higher than that suggested here for the UAV System until insurers better understand the risk.

At the other end of the scale, it could be argued that the cost saving of removing the aircrew (the cabin crew would still be required) from a large civil jet transport such as a Boeing 747 would be minimal (although it is understood that some airline circles are thinking along these lines!). The operation would have long-range navigation and control risks and probably would be psychologically unacceptable to passengers and insurers.

In addition, the cost of operating a civilian passenger airline amounts to very much more than just the 'airside' cost. Airside costs include buying, crewing, flying, hangaraging and maintaining the aircraft.

The 'ground' cost, which includes airline publicity, ticketing, check-in, baggage handling, security, policing, fire precautions, customs, air traffic control, facilities maintenance, etc. is the dominant cost which will not be reduced by UAV operation. In fact some of those costs might be increased. Therefore it is unlikely that UAV will ever operate as large passenger transports, though such observations are prone to be proven wrong!

In between these two extreme applications, economic arguments for the use of UAVs are possible, but will depend upon particular circumstances. For example, it is possible that UAV may be considered for the long-range transport of goods in limited circumstances.

1.4 The Systemic Basis of UAS

Technically, a UAV system comprises a number of elements, or sub-systems, of which the aircraft is but one. The technical functional structure of a typical system is shown in Figure 1.1.

There are, of course, other integration facets within the more global system, such as the clearance required to operate within controlled airspace, which are not shown in this figure. These issues are addressed in later chapters.

It is always most important to view each sub-system of the UAV system as an integral part of that system. No one sub-system is more important than another, though some, usually the aircraft, have a greater impact upon the design of the other subsystems in the system than do others. In the early days of UAV development, for example, some unmanned aircraft were designed, and made, with inadequate regard to how payloads would be mounted, the aircraft launched or recovered, communications effected, or the system maintained and transported in conditions under which the system was required to perform. Subsequent attempts to build an operational system around it were either doomed to failure or resulted in unacceptable compromises or unacceptable cost.

1.5 System Composition

The following section outlines the function of each of the major sub-systems. Each of these will be discussed separately in more detail in later chapters, always remembering that they do not exist in isolation, but form part of a total system. Integration of the sub-systems into a total system is addressed in Chapter 17.

1.5.1 Control Station (CS)

Usually based on the ground (GCS), or aboard ship (SCS), though possibly airborne in a 'parent' aircraft (ACS), the control station is the control centre of the operation and the man-machine interface.

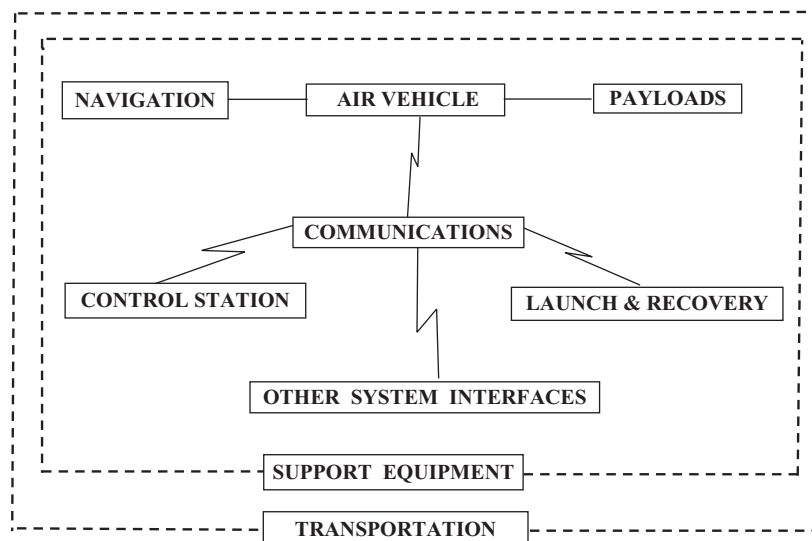


Figure 1.1 UAV system – functional structure

It is also usually, but not always, the centre in which the UAV mission is pre-planned, in which case it may be known as the mission planning and control station (MPCS). Less usually, the mission may be planned from a central command centre and the mission data is sent to the CS for its execution.

From the CS, the operators 'speak' to the aircraft via the communications system up-link in order to direct its flight profile and to operate the various types of mission 'payload' that it carries.

Similarly, via the communications down-link, the aircraft returns information and images to the operators. The information may include data from the payloads, status information on the aircraft's sub-systems (housekeeping data), and position information. The launching and recovery of the aircraft may be controlled from the main CS or from a satellite (subsidiary) CS.

The CS will usually also house the systems for communication with other external systems. These may include means of acquiring weather data, transfer of information from and to other systems in the network, tasking from higher authority and the reporting of information back to that or other authorities.

1.5.2 *The Payload*

The type and performance of the payloads is driven by the needs of the operational task. These can range from:

- (a) relatively simple sub-systems consisting of an unstabilised video camera with a fixed lens having a mass as little as 200 g, through
- (b) a video system with a greater range capability, employing a longer focal length lens with zoom facility, gyro-stabilised and with pan and tilt function with a mass of probably 3–4 kg, to
- (c) a high-power radar having a mass, with its power supplies, of possibly up to 1000 kg.

Some, more sophisticated, UAV carry a combination of different types of sensors, within a payload module or within a series of modules. The data from these several sensors may be processed and integrated to provide enhanced information, or information which could not be obtained using a single type of sensor.

For example, images from an optical (light) colour video camera, from a thermal (heat) imaging camera and possibly a radar scanner system, may be fused together. Thus the thermal image and radar image may add information hidden to the optical image. The optical colour image will add discrimination, resolution and contrast not available from the reduced contrast of the thermal image or the lower resolution of the radar image. Also, the reduction in performance of one sensor under differing light or atmospheric conditions of precipitation or pollution, may be compensated for by the complementary sensors. The images, or other data, obtained by these systems are processed into a form in which they can be transmitted via the down-link to the control station or other destination as appropriate.

A number of different types of payloads appropriate for carriage by UAV are described in Chapter 8.

1.5.3 *The Air Vehicle*

The type and performance of the air vehicle/aircraft is principally determined by the needs of the operational mission (see Chapter 2). The task of the aircraft is primarily to carry the mission payload to its point of application, but it also has to carry the subsystems necessary for it to operate. These sub-systems include the communications link, stabilisation and control equipment, power plant and fuel, electrical power supplies; and basic airframe structure and mechanisms needed for the aircraft to be launched, to carry out its mission, and to be recovered.

Other significant determinants in the design of the aircraft configuration are the operational range, air-speed and endurance demanded of it by the mission requirement. The endurance and range requirement will determine the fuel load to be carried. Achievement of a small fuel load and maximised performance will require an efficient propulsion system and optimum airframe aerodynamics.

The speed requirement will determine more fundamentally whether a lighter-than-air aircraft, or a heavier-than-air fixed-wing, rotary-wing, or convertible aircraft configuration, is used. A long endurance and long range mission for military surveillance will predominately require a high-aspect ratio fixed-wing aircraft operating at high altitude. It will be necessary for it to take off from a long paved runway to achieve the high lift-off speed demanded by the high wing-loading required for low aerodynamic drag.

UCAVs (Unmanned Combat Air Vehicles) may be required to operate at high speed. They are likely to have low aspect ratio wings and either take off from a long runway or be air-launched.

The majority of potential civilian uses of UAVs will require the air vehicle to fly at speeds lower than 50 kt (70 km/hr) for much of its mission; and many will need an ability of the aircraft to hover (e.g. for powerline inspection) or greatly benefit from a hover capability (e.g. incident control by police and fire services).

Several military roles will either need, or greatly benefit from, the ability to hover or fly very slowly, e.g. naval decoying, army NBC monitoring and laser target designation and air force base security and the detection and elimination of unexploded bombs (UXB). In addition any application, military or civilian, where operation from off-board ship or from restricted sites is required will probably benefit from a vertical take-off and landing capability in the aircraft.

Provided that the aircraft is not required to have a top speed of more than, say, 150 kt (210 km/hr), then a helicopter configuration offers the most efficient hover and low-speed performance. Also, within its speed range, because of its high rotor-blade loading it is the most insensitive of all aircraft types to air turbulence.

Compounded helicopter configurations add wings and/or a propulsive system to a basic helicopter in order to reduce the thrust required from the rotor and enable the aircraft to achieve higher speeds. The addition of a wing can give a helicopter a speed of over 200 kt. A fully compounded helicopter (with a wing and propulsive system) has reached a speed in excess of 300 kt (550 km/hr), but at considerable cost in reduction of payload and endurance.

'Convertible' aircraft configurations attempt to achieve a viable compromise between the requirement to take off and land vertically and have a long endurance. This is achieved by lifting off with the rotor(s) horizontal, but tilting them into a vertical plane to become propellers for cruise flight with the weight of the aircraft being borne upon wings. These configurations suffer a payload weight penalty compared with either a helicopter or fixed-wing aircraft.

Another rotary-wing configuration of interest is the autogyro, which attempts to dispense with the transmission system of the helicopter in the interest of reducing complexity, but it suffers in that it cannot hover. However, it is able to fly considerably more slowly than can fixed-wing aircraft. These different aircraft configurations are discussed in more detail in Chapter 3.

1.5.4 Navigation Systems

It is necessary for the operators to know, on demand, where the aircraft is at any moment in time. It may also be necessary for the *aircraft* to 'know' where it is if autonomous flight is required of it at any time during the flight. This may be either as part or all of a pre-programmed mission or as an emergency 'return to base' capability after system degradation. For fully autonomous operation, i.e. without any communication between the CS and the air vehicle, sufficient navigation equipment must be carried in the aircraft.

In the past, this meant that the aircraft had to carry a sophisticated, complex, expensive and heavy inertial navigation system (INS), or a less sophisticated INS at lower cost, etc., but which required a frequent positional update from the CS via the communications link. This was achieved by radio tracking or by the recognition of geographical features.

Nowadays, the availability of a global positioning system (GPS) which accesses positional information from a system of earth-satellites, has eased this problem. The GPSs now available are extremely light in

weight, compact and quite cheap, and give continuous positional update so that only a very simple form of INS is now normally needed. The accuracy is further improved by the use of differential GPS (DGPS, see Chapter 11).

For nonautonomous operation, i.e. where communication between aircraft and CS is virtually continuous, or where there is a risk of the GPS system being blocked, other means of navigation are possible fall-back options. These methods include:

- (a) *Radar tracking.* Here the aircraft is fitted with a transponder which responds to a radar scanner emitting from the CS, so that the aircraft position is seen on the CS radar display in bearing and range.
- (b) *Radio tracking.* Here the radio signal carrying data from the aircraft to the CS is tracked in bearing from the CS, whilst its range is determined from the time taken for a coded signal to travel between the aircraft and the CS.
- (c) *Direct reckoning.* Here, with the computer-integration of velocity vectors and time elapsed, the aircraft position may be calculated. If the mission is over land and the aircraft carries a TV camera surveying the ground, its position can be confirmed by relating visible geographical features with their known position on a map.

However, in the interests of ease of operation, it is always desirable for the system to be as automatic, if not autonomous, as possible.

1.5.5 Launch, Recovery and Retrieval Equipment

- (a) *Launch equipment.* This will be required for those air vehicles which do not have a vertical flight capability, nor have access to a runway of suitable surface and length. This usually takes the form of a ramp along which the aircraft is accelerated on a trolley, propelled by a system of rubber bungees, by compressed air or by rocket, until the aircraft has reached an airspeed at which it can sustain airborne flight.
- (b) *Recovery equipment.* This also will usually be required for aircraft without a vertical flight capability, unless they can be brought down onto terrain which will allow a wheeled or skid-borne run-on landing. It usually takes the form of a parachute, installed within the aircraft, and which is deployed at a suitable altitude over the landing zone. In addition, a means of absorbing the impact energy is needed, usually comprising airbags or replaceable frangible material. An alternative form of recovery equipment, sometimes used, is a large net or, alternatively, a carousel apparatus into which the aircraft is flown and caught. An ingenious version of the latter is described in Chapter 12.
- (c) *Retrieval equipment.* Unless the aircraft is lightweight enough to be man-portable, a means is required of transporting the aircraft back to its launcher.

1.5.6 Communications

The principal, and probably the most demanding, requirement for the communications system is to provide the data links (up and down) between the CS and the aircraft. The transmission medium is most usually at radio frequency, but possible alternatives may be by light in the form of a laser beam or via optical fibres. The tasks of the data links are usually as follows:

- (a) *Uplink* (i.e. from the CS to the aircraft):
 - i) Transmit flight path tasking which is then stored in the aircraft automatic flight control system (AFCS).

- ii) Transmit real-time flight control commands to the AFCS when man-in-the-loop flight is needed.
- iii) Transmit control commands to the aircraft-mounted payloads and ancillaries.
- iv) Transmit updated positional information to the aircraft INS/AFCS where relevant.
- (b) *Downlink* (i.e. from the aircraft to the CS):
 - i) Transmit aircraft positional data to the CS where relevant.
 - ii) Transmit payload imagery and/or data to the CS.
 - iii) Transmit aircraft housekeeping data, e.g. fuel state, engine temperature, etc. to the CS.

The level of electrical power, complexity of the processing and the antennae design and therefore the complexity, weight and cost of the radio communications will be determined by:

- i) the range of operation of the air vehicle from the transmitting station;
- ii) the sophistication demanded by transmission-down of the payload and housekeeping data;
- iii) the need for security.

1.5.7 Interfaces

All these elements, or sub-systems, work together to achieve the performance of the total system. Although some of them may be able to operate as 'stand-alone' systems in other uses, within the type of system described, as sub-systems they must be able to operate together, and so great attention must be paid to the correct functioning of their interfaces.

For example, although the communications radio sub-system itself forms an interface between the CS and the air vehicle, the elements of it installed in both the CS and air vehicle must operate to the same protocols and each interface with their respective parent sub-systems in a compatible manner.

It is likely that the UAV system may be operated by the services (both military and civilian) in different countries which may require different radio frequencies or security coding. Therefore it should be made possible for different front-end modules to be fitted into the same type of CS and air vehicle when the UAV system is acquired by various different operators. This requires the definition of the common interfaces to be made.

1.5.8 Interfacing with Other Systems

A UAV system exists in order to carry out a task. It is unlikely that the task may 'stand alone'. That is, it may require tasking from a source external to the system and report back to that or other external source.

A typical example is military surveillance where the UAV system may be operating at brigade level, but receive a task directly, or indirectly from corps level to survey a specific area for specific information and to report back to corps and/or other users through a military information network. This network may include information coming from and/or being required by other elements of the military, such as ground-, sea-, or air-based units and space-satellites, or indeed, other UAV systems. The whole then becomes what is known as a 'system of systems' and is known as network-centric operation.

A UAV system (UAS) operating alone is usually known as a 'stove-pipe system'. A representative architecture of a 'system of systems' which may include not only other UASs of similar or different types, but also include other operational elements such as naval vessels, mobile ground units or manned aircraft that provide information or mount attack missions is shown in Figure 1.2.

Similarly, in civilian operations such as fire patrol, the operators in the CS may be tasked from Fire Brigade Headquarters to move the air vehicle to new locations. It will be necessary therefore to

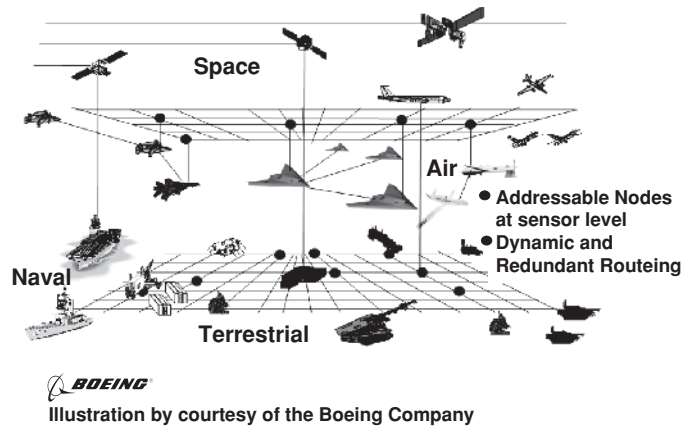


Figure 1.2 Network-centric architecture (Boeing)

provide, probably within the CS, the equipment required to communicate with the external sources and record/display data received and sent.

1.5.9 Support Equipment

Support equipment is one area which can often be underestimated when a UAV system is specified. It ranges from operating and maintenance manuals, through tools and spares to special test equipment and power supplies.

1.5.10 Transportation

A UAV system is often required to be mobile. Therefore transport means must be provided for all the sub-systems discussed above. This may vary from one vehicle required to contain and transport a UAV system using a small, lightweight vertical take-off and landing (VTOL) aircraft which needs no launch, recovery or retrieval equipment and is operated by say, two crew, to a system using a large and heavier ramp-launched aircraft which needs all the sub-systems listed, may have to be dismantled and reassembled between flights, and may require, say, ten crew and six large transport vehicles. Even UAV systems operating from fixed bases may have specific transport requirements.

1.5.11 System Environmental Capability

From the initiation of the concept of the system, it is important to recognise the impact that the environment in which it is to operate will have on the design of all elements of the system, including the provision of an acceptable working environment for the operating and support members of the crew. A system which has been designed with only low-altitude, temperate conditions in mind, will fail in more extreme conditions of altitude, temperature, solar radiation, precipitation and humidity.

It is also necessary to recognise the impact that the UAV system may have on the environment. This can be very significant, though with different accent, in both civilian and military roles. It is therefore necessary to consider all of these aspects carefully at the outset of the system design, and these factors

are discussed more fully in Chapter 2, Section 2.4.7, and expanded where relevant in subsequent chapters on design.

References

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