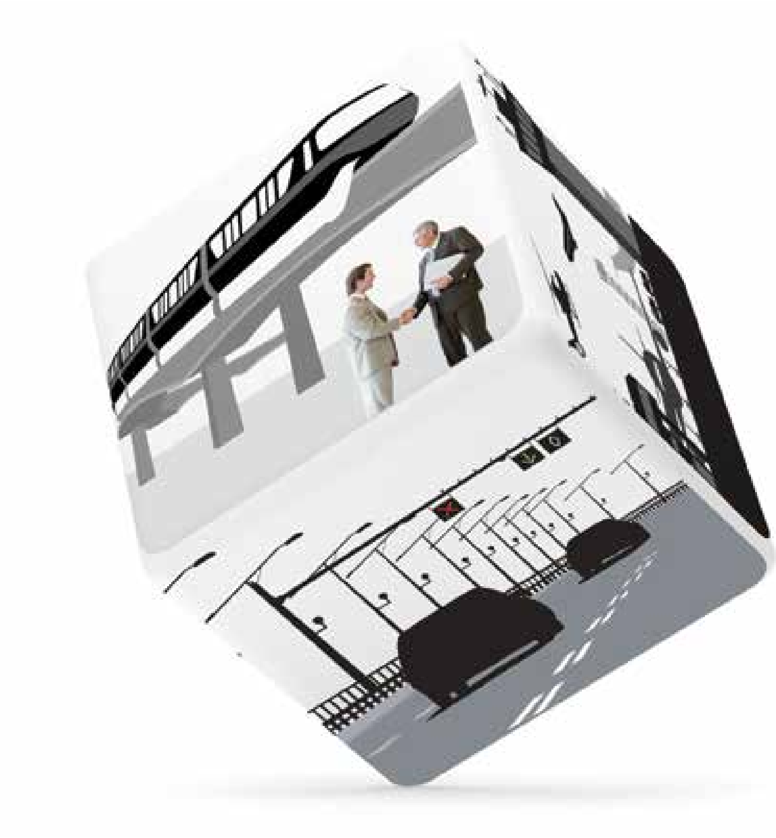
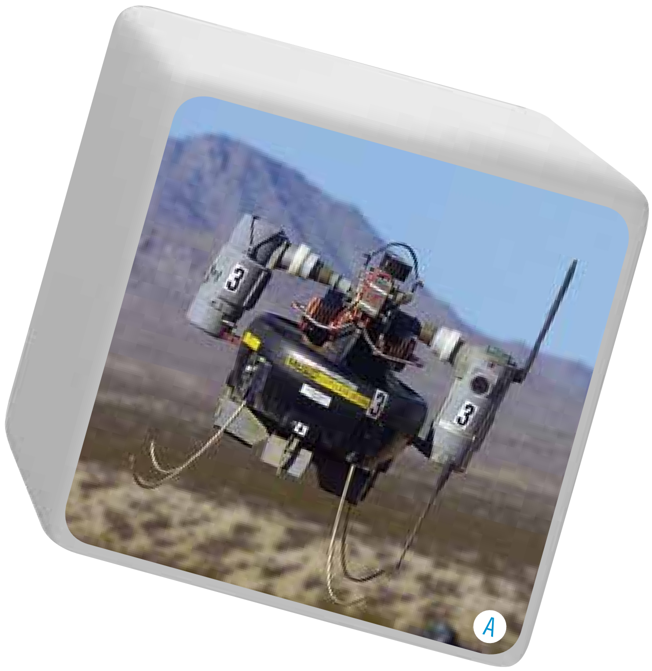
The Institution of Engineering and Technology

Unmanned Aircraft
A Future without Pilots?



Unmanned Aircraft (UA) are an increasingly common sight on our television screens and in the media. Whilst much of this coverage is focussed on military applications in, for example, Iraq, Afghanistan and more recently Syria, there is growing interest in the civilian potential of UA. High tech start-up companies, universities and traditional aerospace companies are developing UA and associated technologies along with the knowledge and experience to deploy them in a wide range of applications. The potential benefits of UA are starting to be realised but there remain considerable technical, ethical and legal issues before they are a routine site in our skies.



Transport

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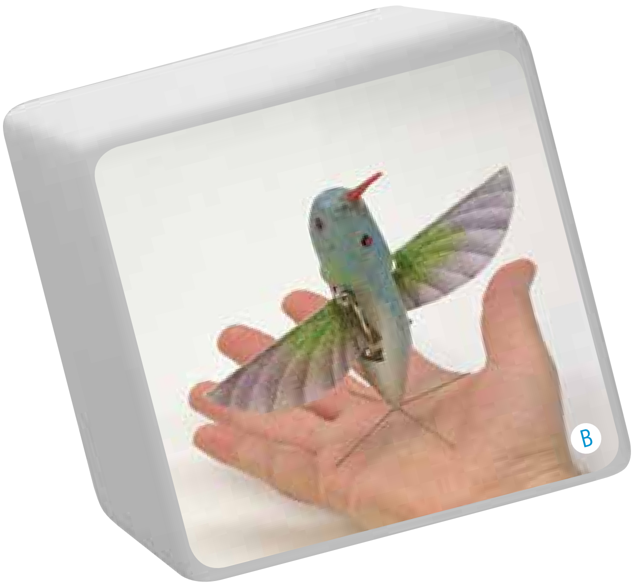
What are Unmanned Aircraft?

UA do not have a pilot on-board and vary enormously, from the Northrop Grumman Global Hawk with a wingspan exceeding 35m down to insect inspired UA, like the AeroVironment Hummingbird[See picture B], which are a few centimetres in size. UA have been around in one form or another for most of the 20th century but it is the past 10-20 years where their potential for so-called dull, dirty and dangerous missions has been recognised. The aircraft is only one part of a wider system including ground control and communications.

Classification

UA can be classified in a variety of ways including their physical size, altitude/endurance and intended use. Physical size is often used for smaller UA with terms such as nano-, micro- and miniUA although there is often little consensus on what constitutes these. Larger scale UA are typically characterised by operating altitude and endurance such as Medium Altitude, Long Endurance (MALE) and High Altitude, Long Endurance (HALE). Intended use will be explored under applications below but a common classification is between military and civilian UA. We also see a distinction between fixed wing, rotary and flapping (bird and insect like) UA.



Applications

A wide variety of applications have been proposed for UA with most falling within the dull, dirty and dangerous category. The lack of an on-board pilot frees up the UA to perform missions that are too long for human pilots, would expose them to undue danger or can be achieved at a much lower cost. Potential and existing applications of UA include:

- Infrastructure monitoring – including gas and oil pipelines, offshore oil platforms and wind farms, road and rail networks, overhead power lines,
- Police and law enforcement – aerial surveillance, accident investigation, missing person search,
- Environmental and agricultural monitoring – pollution and air quality sampling, land use including, agriculture and moorland, livestock monitoring, forest and moorland fire, Arctic/Antarctic surveying, assessing volcano plumes, archaeology,
- Disaster support and search & rescue – surveillance after natural disasters, land and sea search and rescue,
- Military – countering IEDs, convoy protection, logistics, close support for troops.

One of the key challenges is how best to utilise UA within these applications. Whilst their potential is often clear, how best to meet this potential can be challenging and requires close collaboration between UA designers, manufacturers and end users.

Examples of UA deployments include surveying the Fukushima nuclear power station site[A] and searching for survivors after Hurricane Katrina[C].

Technology

UA are revolutionising the way we think about aircraft. From micro air vehicles only a few centimetres in size to the large HALE UA, we are seeing designs that are radically different from conventional fixed wing and rotary aircraft. These designs are driven by the lack of humans on board to some extent, but more importantly it seems to be due to a freeing up of how we think about aircraft design. In the case of smaller UA, designs are often influenced by nature. We are seeing novel developments in many of the technology areas.

Aerodynamics – unconventional wing planforms, the issues of dealing with low Reynolds numbers in small UA, morphing wings instead of conventional control surfaces, the need for extreme endurances, complex flow control technologies.

Propulsion – the need for more efficient engines to meet the desired ranges and endurances (often 24hr+), miniaturised powerplants for micro air vehicles, the use of solar cells to provide unlimited endurance, improved battery performance and the use of fuel cells.

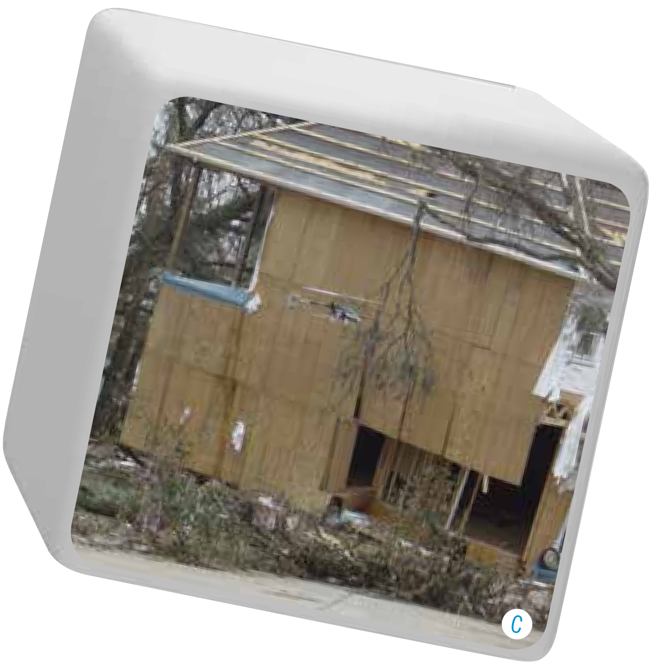
Avionics – the need for sophisticated avionics to ensure reliable, safe operation; miniaturisation of electronics has led to fully functioning autopilots only a few centimetres in size for a couple of hundred pounds.

Control – new designs require unusual control concepts leading to a rethink of how we control aircraft, at the extreme end the control of flapping wings is a substantial research challenge.

Materials and structures – the rise of UA has coincided with that of composites in aerospace, how to deal with damage such as self-healing composites, multifunctional materials that have embedded sensors and electronics.

Payloads – the potential for UA is leading to significant effort to develop sensor payloads to meet the challenges of many applications.

Universities and companies are taking up the challenge of developing novel solutions to many of these challenges. UA competitions provide the opportunity to test new ideas and compare against teams from across the globe.



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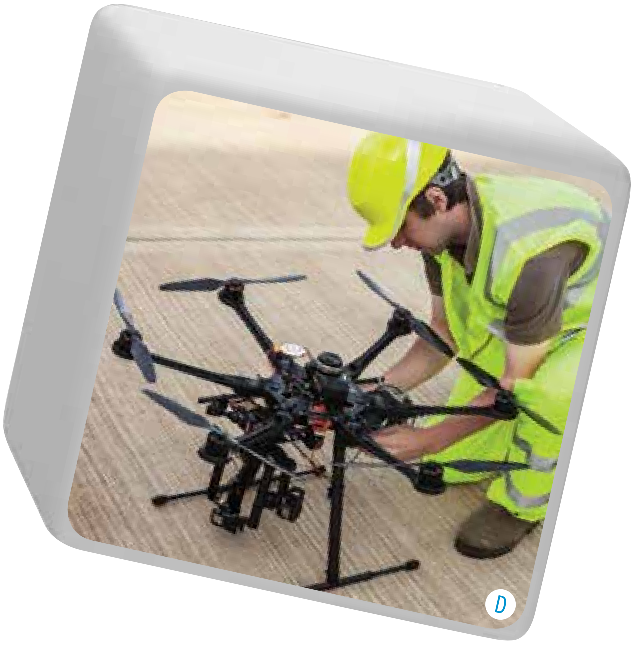


Autonomy

Many people associate UA with autonomy. Whilst this is true to some extent, it is a far more subtle issue. A number of attempts have been made to define levels of autonomy for UA. The following (adapted from Scholes, 2007) provides a taxonomy of autonomy for UA:

Level 0: Remotely operated
Level 1: Execute pre-planned mission
Level 2: Changeable mission
Level 3: Robust response to real-time faults/events
Level 4: Adapts to faults/events
Level 5: Real-time multi-vehicle co-ordination
Level 6: Real-time multi-vehicle co-operation
Level 7: Goal supervision
Level 8: Mission supervision
Level 9: Co-operative mission supervision
Level 10: Fully autonomous

This provides a full range of autonomy from effectively no autonomy at level zero through to full autonomy at level 10. These levels are clearly open to interpretation but provide a useful benchmark. Current technology is around level 2 for deployed UA with research showing results at levels 5 to 6.

A key point is to distinguish autonomy from automatic control with the former implying some level of intelligence and decision making independent of human input. At the upper end is the question of what full autonomy actually means, whether it is technically feasible and the ethical debate over whether it is even desirable. Research is certainly moving UA to the higher levels of autonomy but there remain key challenges ahead. In particular, formal verification of autonomy is a very hot topic receiving considerable research funding within the UK. This is drawing on ideas from formal software verification and agent methods to address how to verify that autonomous algorithms will behave as expected. An exciting new development is the investigation of agent methods to also address how to test that UA meet ethical considerations as well.

Regulation

One of the most significant challenges is how to certify and regulate UA. The UK is world leading in this area with the Civil Aviation Authority continuing to develop guidance and regulations related to UA. CAP722 provides detailed guidance on the safety requirements for the development and operation of UA. UA of 20kg or less are exempt from the majority of the regulations applicable to manned aircraft. UA of more than 20kg are subject to manned aircraft requirements but can be exempted. UA more than 150kg are subject to EASA regulations. Any UA operating for hire and reward - aerial work, does require a permit from the UK CAA and will need to operate within visual line of sight (VLOS) of the remote pilot. Any UA operating beyond VLOS will require segregated airspace. In the UK, West Wales Airport provides a safe test and evaluation centre for UA within restricted airspace.

Unlike piloted aircraft, a key issue for UA is the lack of formal operating procedures. The UK-funded ASTRAEA research programme is world leading in developing new technologies and operating procedures to enable UA to be operated safely in civilian airspace. They are addressing the key challenges in this area including ground control, secure communications, sense and avoid, autonomy and decision making. It is through major initiatives like this that the full potential of UA will be realised.

Co-operative and swarming

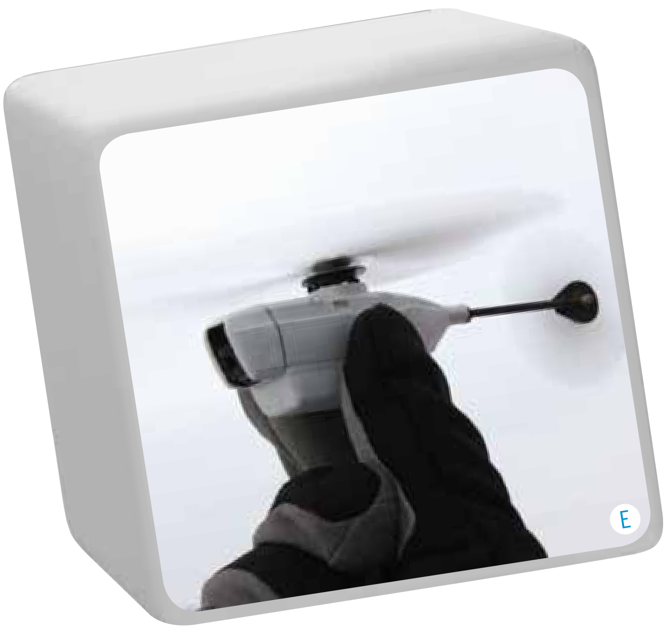
An exciting area of research is how multiple UA can work together. From groups of UA undertaking search and rescue missions over hundreds of km to swarms of small UA that can fly in formation and undertake complex tasks, the potential benefits of using many UA is a key advantage over manned aircraft. However, it is not only about UA, with co-operation between air and ground or air and sea vehicles being actively investigated. This was a feature of many of the solutions proposed for the UK MOD Grand Challenge. The need for complex control, mission planning, task allocation, optimisation and collision avoidance are all technical challenges that need to be solved to realise the potential for this exciting area.

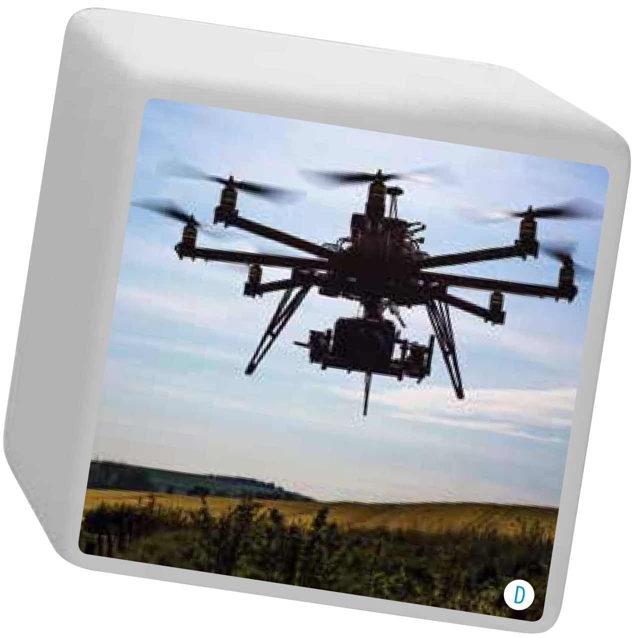
Human Factors

Whilst, by definition, UA have no on-board pilot they always have a human-in-the-loop. The human factors aspects of UA are the subject of intense research and development (McCarley & Wickens, 2005). This includes everything from hand held controllers for small UA inspired by games console controllers to sophisticated command and control ground stations working with multiple UA. For long range UA, the dislocation between the UA and the operator can lead to a loss of sensory cues and cognitive issues.

Two areas of particular research and development interest at opposite extremes of complexity are controller input devices that can be used with minimal training and complex command and control of multiple UA by a single remote operator. One of the benefits of UA is that they can often be used with minimal training and a number of potential applications would benefit from them being able to loiter near the operator. The UK Army is already equipping troops with small Black Hornet UA[E] to provide close support in identifying potential dangers. Ensuring the UA control device is intuitive and that users can trust the operation of the UA are key challenges to the widespread adoption in the civil sector.

In the future, we are likely to see multiple UA being operated and monitored by single pilots[D]. The need for intuitive operation and training standards is essential to maximise the potential use of UA and also to minimise safety issues. These issues present challenges to human factors, experts and psychologists.





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Social, Ethical and Legal Issues

Whilst the benefits of UA to society can be huge, the potential negative impact on society should not be forgotten. The use of UA to target individuals in Afghanistan, the privacy concerns about the use of UA for spying and aerial photography, safety concerns and potential misuse by terrorists and criminals are all issues that have been highlighted.

Privacy has been raised as a key concern due to the wide and easy availability of small UA and, in particular, quadrotors. Such UA can be used almost undetected to take photographs up to a few kilometres from the user. The need to regulate and legislate for such issues is paramount. However, when such UA are available as toys for a few hundred pounds the difficulty of preventing improper use is clearly very difficult.

Whilst the prevention of accidents due to human error is one of the main potential benefits of UA, the statistics reveal that the safety record of UA is worse than equivalent manned aircraft. Figures in (McGarry, 2012) highlight that the combined accident rate of the Global Hawk, Predator and Reaper in the US Air Force fleet is 9.31 per 100,000 hours of flight. This is more than three times the combined fleet (manned and unmanned) average of 3.03 per 100,000 hours of flight. As UA are increasingly deployed in civilian applications and with greater levels of autonomy, the need to ensure the safety record is at least that of equivalent manned aircraft will become more pressing. Humans tend to be more forgiving of human error and have greater expectations of technology. This requires developers, manufacturers and national regulatory bodies to exceed the standards they currently set for piloted aircraft.

Aerial terrorism is now well known in the light of 9/11, but various terrorist groups have used or planned to use UA as part of terrorist attacks (Lele and Mishra, 2009). The ability for small UA to be bought cheaply, equipped with autopilots and to fly undetected makes them a real terrorist threat. The release of even small amounts of chemicals over populated areas or crashing into critical infrastructure could lead to massive loss of life and disruption.

As with any technology, the potential for misuse is ever present and should not detract from the overwhelming potential for benefits to society. However, governments and law enforcement agencies need to be fully aware of the potential for misuse and attempt to mitigate against this through legislation and procedures. Striking the correct balance presents a significant challenge that will be closely scrutinised by the media.

> “The next major step for aviation, Unmanned Aircraft will open up a whole new branch of the industry. Their full potential will only be realised when the technologies and regulatory frameworks have been developed to allow them full integration into our airspace without restrictions yet with safety levels equivalent to manned aircraft. We must, however, ensure that this new capability is subject to rigorous legal, ethical and social review.”
>
> Lambert Dopping-Hepenstal, FREng, CEng, FIET, FRAeS, Engineering Director Systems and Strategy and ASTRAEA Programme Director, BAE Systems

Summary

UA offer massive potential to revolutionise the way we solve many problems, from more efficient ways to monitor oil pipelines to searching for survivors after earthquakes, the benefits to society and the economy can be huge. However, there remain many technological, legal and ethical challenges before we see UA routinely flying around us. This insight has provided some perspective on these challenges and the potential that UA offer.

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This IET Sector Insight, part of a series on autonomous vehicles, has been written by Dr Tony Dodd, member of the IET Transport Sector Executive and Senior Lecturer in Aerospace Systems Engineering at the University of Sheffield.

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Photographs courtesy of [A]Honeywell Aerospace, [B]AeroVironment Inc, [C]Safety Security Rescue Research Center, [D]Horizon Aerial Photography Ltd and [E]Marlborough Communications Ltd