Understanding the Drone Epidemic

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This is the first in a series of papers on drones: 1, 2, 3, 4

Series Introduction

During the twentieth century, people became used to seeing vehicles in the sky. As had been the case with horse-drawn carriages, train engines, trams and automobiles, a human in the airborne vehicle controlled its behaviour. The twenty-first century is seeing a rapid proliferation of aerial vehicles that do not have a human controller on board. In some cases, the pilot is nearby, and in others the pilot is remote, and even half-a-world away. In addition, a century of technological progress has resulted in at least some of the pilot's functions being performed automatically, particularly aircraft stability in response to turbulence. This may extend to fully autonomous operations, which may or may not be under human supervision, may or may not include automatic detection of out-of-scope conditions and auto-handover to a human pilot, and may or may not be subject to over-ride by the human pilot. With those capabilities come risks. Are those risks being adequately managed, or are measures needed to ensure that they are addressed?

This is the first in a series of papers that seek answers to those questions. This first paper establishes the basis for the remainder of the series, by providing a survey of the nature of unmanned aircraft, their characteristics, the opportunities that they create, and the risks that they give rise to. The second paper reviews prior literatures, in order to identify lessons from relevant technologies. The third and fourth papers examine the regulatory frameworks for public safety, and for behavioural privacy.

Abstract

Drones are aircraft that have no onboard, human pilot. Through the twentieth century, piloted aircraft made far greater progress than drones. During the twenty-first century, on the other hand, changes in both drone technologies and drone economics have been much more rapid. Particularly in the case of small, inexpensive devices, the question arises as to whether existing regulatory frameworks can cope. To answer that question, it is necessary to document the nature and characteristics of drones, the dimensions across which they vary, the purposes to which they are put, and the impacts that they appear likely to have. The analysis concludes that careful consideration is needed of the adequacy of controls over the impacts of drones on two important values - public safety, and behavioural privacy.

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1. Introduction

The term 'drone' is in popular usage for useful pilotless aircraft. The industry applies, and prefers, a range of more descriptive terms, which are discussed below; but this article uses the popular term throughout.

The last two decades have seen a substantial shift in the manufacturing cost of drones, with the result that they are proliferating, the increase in market-size has attracted further investment, and a leap in the functionality-to-cost ratio has occurred. This multiplies the potential for benefits and exacerbates the risks.

Many parties have an interest in talking up drones and their capabilities and applications. Many media outlets are driven by the need for revenue, and subject to limited journalistic constraints, so a great deal of the media coverage of drones comprises lightly dressed-up versions of corporate sales brochures and media releases, with limited critical thought applied by the nominal author. The implications of drones are sufficiently significant that more careful analysis is needed.

The privacy impacts of civil applications of drones have already been subjected to analysis, e.g. in Finn & Wright (2012). The scope of the research reported on here is broader than privacy, extending across the wide range of security issues that the technologies give rise to. This is the first of a series of four papers, whose combined purpose is to identify the disbenefits and risks in the use of drones, and consider the extent to which they are subject to suitable controls.

The present paper considers the definitional question of 'what is a drone?' and keeps in mind further questions, in particular 'what attributes of drones may challenge existing regulatory arrangements?'. It also identifies the potential opportunities, disbenefits and risks across a range of application areas. The second paper reviews the existing literatures on computing, data communications, robotics, cyborgisation and surveillance, in order to bring past experience to bear on the drone phenomenon. The third and fourth papers examine the extent to which current regulatory frameworks for public safety and behavioural privacy appear likely to cope, and the prospects of adapted and new measures to address the problems that drones present.

The research excludes theatres of war. Issues that are thereby out-of-scope include the ethics, politics and practices of remote-controlled delivery of armed explosives, 'war as video game', the 'post-heroic' age of warfare, the increasing acceptability of warfare with limited risk to the war-maker's personnel, the role of drones in the quiet creep of war-making by countries' executives outside the control of their parliaments, and violence committed by semi-autonomous devices on behalf of nation-states.

It is necessary, however, to keep warfare at least somewhat within the field of view. One reason is that military applications have been, and remain, a strong driver of drone developments, and the vast sums of money available for research, IR&D and production of equipment that provides military advantage heavily biases progress in particular directions. The other reason is that the early years of the 21st century have seen a dramatic increase in the application of military technologies by nation-states not only to wage war on other nations that they perceive to be enemies at the time, but also to the monitoring of activities along the country's borders, to assist in the enforcement of domestic laws, and even to the subjugation of their own people. It is unsurprising that despots would blur the line between enemies without and enemies within. On the other hand, the USA has been a leader in applying the 'war against terror' rhetoric and thereby subverting two centuries of progress in civil freedoms (Wilson 2005); and many other relatively free nations have followed the US lead. Australia, for example, has passed several score, heavily criticised `counter-terrorism' laws (APL 2013). The scope of this series of articles accordingly encompasses not only individual, corporate and governmental applications of drones, but also all forms of law enforcement and national security uses within an individual country.

The paper commences by reviewing the emergence of drones, and their attributes. On the basis of a consideration of categories of drones and not-drones, and boundary-testing examples, a working definition is proposed. The opportunities and challenges that drones present are then considered, within a wide range of current and proposed application-areas.

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2. Drones

In order to develop an appropriate working definition for a drone, this section considers in turn their precursors and origins, and the attributes of effective drones, with particular attention paid to their control and the degree of autonomy from their controller.

2.1 Emergence

Many threads of technological development have fed into the notion of a drone. Artefacts have been airborne for several millennia (in such forms as sharpened stones, spears, boomerangs and kites), and humans have been achieving flight since at least 1783, using lighter-than-air balloons or `aerostats'. Steam -powered flight was achieved by a French `dirigible' balloon in 1852. The internal combustion engine was applied by 1872, with most of the early developments taking place in France and then Germany. Nearly 150 years later, aerostats were tethered 15,000 feet above Afghanistan, transmitting live battlefield-surveillance video (Bumiller & Shanker 2011). Heavier-than-air craft were emergent through the nineteenth century in several countries. Following developments during the 1890s, the first fixed-wing aeroplane / airplane achieved sustained, manned, powered and controlled flight in the USA probably in 1901 and certainly in 1903. Rotorcraft (of which the helicopter is the most common form) had been emergent for centuries, with the first unmanned flight in 1877 in Italy, and the first manned flight in 1907, in France.

Flying artefacts have been applied to many purposes. One early use was to assist in communications, by means of lanterns, in China, at least as long ago as 2,000 years. In the area of surveillance applications, balloons were used for observation by the French in 1794, and this use was revived during the American Civil War in 1861-65. Cameras were attached to balloons in France in 1858, to kites and rockets c. 1880-1900, and to pigeons in Germany in 1907-11. Drones were being developed as means of delivering weapons as early as 1915 in the USA, and were used as targets as early as 1930 in the UK. Science fiction has played an interactive role with a number of technologies, including drones. The first major 20th-century anti-utopian novel - 25 years before Orwell's '1984' - imagined drones ('aeros') as the means by which the government observed and repressed the population (Zamyatin 1922). The surveillance and security applications of micro-drones were investigated in Stephenson (1995).

Many forms of motive power have been the subject of experimentation, and some have been harnessed. A greater challenge in the development of drones has been the means of control of the aircraft. The early focus was on control by a human pilot on board the aircraft, and, for the first century of flight, pilotless aircraft were seen as exceptions and novelties rather than the mainstream.

Yet remote control of transport devices had emerged before the first manned flight, in the form of Tesla's Teleautomaton - a radio-controlled boat, demonstrated in 1898. Automated stabilisation control of an aircraft was emergent in the USA in 1910-15. The first known pilotless rigid-frame aircraft was in testing in the USA prior to the end of the World War I.

Generally, discussions of drones refer to an individual, at distance from the drone, but in control of it. The term 'remote pilot' is commonly used, not just for historical reasons, but also because the functions performed and the visualisation capabilities and the skills required continue to be closely related to those of an onboard pilot. That may change over time, however. In addition, the prospect of fully autonomous drones requires consideration.

Even such a brief review of the origins and early years of drones makes clear that the field is beset with considerable diversity. In order to settle on a satisfactory working definition of drones, and appropriate bases for categorising them, it is necessary to identify the range of attributes that they display. The most fundamental of these are the attributes associated with the craft's survival. The following section accordingly considers the means whereby drone behaviour is controlled.

2.2 Drone Control

Close attention is warranted to the means whereby a heavier-than-air craft stays aloft, by overcoming gravity, and by sustaining its attitude within its operating envelope despite the vagaries of weather conditions. The term 'airworthiness' is commonly used to refer to an aircraft's suitability for safe flight.

An aircraft's attitude is its orientation about its center of gravity. Attitude varies in three dimensions around the centre of mass:

- roll or bank refers to rotation around the aircraft's long axis
- pitch refers to the rise and fall of the nose of the aircraft , i.e. rotation around the axis aligned with its wings
- yaw or heading refers to port-starboard / left-right swing of the nose of the aircraft, i.e. rotation around its vertical axis

Each aircraft has an operating envelope, defined in terms of its attitude, inside of which it is flyable, and outside of which it is unstable and probably unrecoverable. If the aircraft's attitude shifts outside its envelope, it suffers loss of control by the human or auto-pilot. Safe operation of a drone is therefore dependent on the aircraft's attitude being kept within its operating envelope, by conducting manoeuvres within the envelope, and by taking corrective action when the aircraft's attitude is changed by external factors, referred to as upset-conditions, such as a wind-gust or turbulence.

Key attributes that enable drone survival are:

- awareness of the drone's location within the operational space, of its attitude and of its direction and speed of movement
- sensors and/or remote data-feeds that enable maintenance of the awareness of location, attititude and movement in a sufficiently up-to-date manner
- a sufficient set of controls over the drone's attitude, and direction and speed of movement, to enable flight to be sustained under a wide variety of atmospheric conditions
- sufficiently rapid response of the drone to the controls (manoeuvrability)
- a sufficient source of power to maintain movement, to implement the controls, and to operate sensors and data-feeds, for the duration of the flight
- the ability to navigate to destination locations within the operational space
- the ability to monitor the operational space (situational awareness)
- the ability to navigate with respect to obstacles (collision avoidance)

- sufficient physical robustness to withstand threatening events such as wind-shear and turbulence

The source of drone-flight control decisions may be a human pilot or an auto-pilot. In principle, either may be on board or remote. However, a drone by definition does not carry a human pilot, and there appear to have been insufficient advantages for remote auto-pilot technologies to emerge. That may change, as the micro-drone market develops, and particularly as nano-drones emerge. In practice, however, human pilots are always remote, and auto-pilots are almost always on-board. A review of remote control and auto -pilot functions for small drones is in Chao et al. (2010). This section considers firstly autonomous control and then control exercised by the remote human pilot.

(1) Autonomous Control

In practice, drones generally exhibit at least some degree of autonomy, because such functions as stabilisation of attitude and altitude are readily delegated to electronic components. To perform these functions, an auto-pilot needs access to data, in real-time or close to it, to enable computation of attitude, location in space, and location in relation to obstacles. This data may be generated by onboard equipment such as gyros, accelerometers, magnetic sensors, electromagnetic sensors (in the visual, infra-red, microwave and radio ranges), or may be received as data-streams from remote sources including Global Positioning System (GPS) data-streams from satellites. The reliability of autonomous performance of such functions is arguably better than that of humans, at least under conditions that are within predicted ranges and relatively stable. Even under more challenging conditions, autonomous performance may be of comparable reliability.

Some higher-order functions, such as maintenance of a previously-determined flight path and take-offs, and even planning of the flight path, may also be delegated from a human pilot to an auto-pilot. It is also possible for landings to be performed entirely autonomously. This is referred to as `autoland'. This requires considerable infrastructure at the landing site, triple-redundancy of multiple components aboard the aircraft, supervision by the human pilot, and occasionally resumption of control by the human pilot. Due to the equipment costs and training levels involved, it is a very expensive option.

In the military drone environment, variously four and/or five levels of autonomy are distinguished:

- where all upper-level functions are human-controlled, the terms used include 'human-operated' (USDoD 2011, p.46) and 'human-in-the-loop' systems (EP 2013, p.6)
- where some upper-level functions remain in the hands of the pilot except during periods when the function is switched over to automatic, USDoD (2011) uses the term 'human-delegated'
- where an upper-level function is by default in automatic mode, but the pilot is able to switch control back to manual, USDoD (2011) uses the term 'human-supervised'
- EP (2013, p.6) recognises a 'mostly autonomous' mode, referred to as 'human-on-the-loop' systems. This might be inferred as meaning that control of key actions (such as those involving violence) remains in human hands. On the other hand, the text implies that the decision to launch an attack is fully delegated to the device, with the possibility of a human override (if the human exercises it in time). A similar approach might of course be adopted to surveillance and pursuit drones used by police or paparazzi, and by civilian interceptor drones
- fully autonomous drones are feasible, and are referred to in military circles as 'human-out-of-the-loop' systems (EP 2013)

An alternative set of gradations between full pilot control and full autonomy is provided by Armstrong (2010, p.14), and attributed to a BAW presentation.

At this early stage, designs of autonomous systems continue to appear seriously naive in comparison with the insights from the critical literature that are discussed in the second paper in this series. It is of serious concern that discussions of possible architectures for autonomy do not have explanation of the rationale for action or advice as a central focus of drone-with-pilot interactions.

Drone Function	Pilot Function
Full Autonomy	Interrupt

Act Unless Revoked	Revoke
Suggest Action	Authorise Action
Give Advice	Accept Advice
Give Advice if Requested	Request Advice
None	In Command

Fully autonomous drones remain experimental. On the other hand, flights have already occurred within controlled airspace. For example, "on 18 August 2005, ... the Herti-1A system (G-8-008) achieved the first CAA approved fully autonomous mission of an unmanned aircraft in UK airspace ... from Campbeltown Airfield, Scotland ... over Machrihanish Bay [600m from the end of the runway] ... [with] a fully autonomous landing back at the airfield" (UVS-Info 2005). See also Prigg (2013).

The reliability of fully autonomous operation generally decreases as the flight mission becomes more complex (e.g. target acquisition, camera control, release of munitions), and as the flight mission changes or is refined. Emergent so-called 'guided-bullet technology' will include directional flight control at ballistic speed, but it appears unlikely that it will include a recall button or an ability to prevent impact or suppress explosion (Schachtman 2008).

(2) Remote Human Control

The control of a drone ranges from fully autonomous to substantially and even fully manual, with many gradations in between. Remote human control depends on the requirements that:

- the pilot has sufficient data-feeds, of sufficient quality, in sufficient time, to enable decisions to be made
- the pilot has a sufficient instruction-set available
- communications of data and instructions are adequate
- the drone performs in accordance with the instructions provided by the pilot

Several categories of remote control need to be distinguished:

- where the pilot relies on their sight and intuition, without visual aids or instrumentation. This has long been the primary mode of operation of model aircraft
- where the pilot is aided by transmission of images or video from one or more drone-mounted cameras (referred to as first person view - FPV)
- where the pilot is aided by other forms of data-feed and associated instruments

The first category is only possible where the pilot is nearby and in line-of-sight, whereas the other two may be more distant, subject to communications capabilities and the effects of signal latency.

The dependence of drones on data-feeds and control-feeds, combined with the limited range of frequency choices for electronic communications, creates significant challenges. The airwaves are congested, especially in urban areas, but also in zones that have considerable electronic communications traffic for other reasons. Signals between drones and remote pilots, and between drones and GPS satellites, are subject to a considerable amount of interference - both accidental and intentional. This may block or modify communications, and hence may result in drone behaviour different from that intended by the remote pilot.

The following section considers other dimensions, in addition to control of the drone's flight, across which drones differ.

2.3 Other Drone Attributes

Bento (2008) identifies factors that are conventionally regarded within the industry as being key characteristics of drones, such as size, maximum altitude, endurance, range of the device's data links, and intended missions. However, in order to provide a framework for the discussion of drone attributes, it is convenient to distinguish the following drone functions:

- control - as discussed in the previous section
- navigation, in order to follow a path and/or reach a location
- operational functions, such as load-carrying and surveillance
- capabilities that are ancillary to control, navigation and operations

The operational value of drones depends on a range of characteristics, including:

- the available payload, reflecting dimensions, weight and other limiting factors such as angles ot tilt, and flammability
- operational range and flight-time, which depend on the power-source available to the drone, related to the power-demands to control, navigate and operate it
- suitability to the operational context, e.g. ground-proximity / high-altitude / indoors

Throughout the history of manned flight, pilots have been sufficiently busy performing control functions that they have needed to be complemented by other specialist aircrew who can focus on other functions. Examples of specialised roles that are relevant to drone operation include navigators, to determine and continually re-determine destinations and flight-paths, and facilities operators, in particular for cargo-handling, and for the operation of onboard equipment such as cameras.

Control, navigation and operation are dependent on the quality of onboard sensors, and remote data-feeds and control-feeds. Remote feeds in turn depend on infrastructure to support the remote pilot and operators, communications between them and the drone, and communications between any other remote data sources and the drone. In a large proportion of cases, this includes access to GPS satellites. Where communications links may be interrupted, redundant communications channels and fail-safe performance are needed. Experience to date suggests that the range of circumstances in which communications links may be broken is considerable, and that they occur sufficiently often, that such features may be fundamental requirements, even for small and inexpensive drones. In addition, where the airspace may become congested, or where attacks can be expected, collision-avoidance appears likely to quickly become a critical capability.

The communications facilities that are available to the remote pilot and operator, and that are on board the drone, may significantly influence its usability. For example, different frequencies are differently subject to interference and to congestion. Some are limited to line-of-sight operation. In some circumstances, such as where very fine and carefully-timed movements need to be executed by the drone based on human instructions, signal-latency arising from the length of the path that the signals have to travel may negatively affect control, navigation and/or operational quality.

Prior to distinguishing those drone attributes that are definitional, those that are useful bases for distinguishing sub-categories of the general class, and those that are merely descriptive, it is necessary to consider other terms and concepts that intersect with the notion `drone'.

2.4 Drone Categories and Boundary-Tests

In order to isolate the factors that determine what attributes of a drone are definitive, it is helpful to consider the varieties of artefact that are to be defined-in, but also the categories of things that are to be defined-out. The basic concept is of a single aircraft, whose pilot is elsewhere rather than on board. Alternative terms in current use are:

- Unmanned Aerial Vehicle (UAV), a term commonly used in the USA and Australia
- Unmanned Aircraft (UA)
- Remotely Piloted Aircraft (RPA), a term commonly used in Europe
- Remotely Piloted Vehicle (RPV)
- Remotely Operated Aircraft (ROA)

Another consideration is that a remotely-operated drone depends on facilities to enable the pilot to perform their functions, including:

- communication links to pass data to the pilot, from the drone and perhaps from elsewhere
- rendering of data to assist the pilot to make real-time decisions
- means for the pilot to express commands to change the drone's behaviour
- communication links to pass commands from the pilot to the drone

Terms in common use to refer to the drone together with its supporting elements, are:

- Unmanned Aerial System / Unmanned Aircraft System (UAS), primarily used in the USA
- Remotely Piloted Aircraft Systems (RPAS), adopted by ICAO and much-used in Europe

The two families of terms differ to the extent that RPA/RPAS excludes fully-autonomous drones, whereas UAV/UAS may include or exclude them.

A number of categories of not-drone are usefully identified. Generally, lighter-than-air craft are excluded, such as kites and balloons, including airships / dirigibles, blimps and zeppelins. So are artefacts that lack controls, including artillery projectiles (cannonballs, mortars, shells), and accidental projectiles (e.g. whose pilot is unconscious or dead). Largely unguided pilotless aircraft (such as the Nazi V1, buzzbomb or doodlebug, in 1944) and largely unguided rockets (such as the Nazi V2, in 1944-45) are generally excluded as well, even though they had simple auto-pilots.

A further category of flying artefacts that needs to be considered is what are commonly referred to as 'model aircraft'. Primitive forms had been evident for centuries. During the first three decades of the twentieth century, sophistication developed quickly, in parallel with manned flight. Model aircraft graduated from uncontrolled flight, to control by means of cables between the controller and the aircraft, and then to wireless control by means of radio signals that activate mechanisms to operate flight controls. Associations of enthusiasts emerged and have remained vigorous.

The distinction between model aircraft and drones is quite vague. For example under Australian Regulations, "a model aircraft is any unmanned aircraft, other than a balloon or kite, which is flown for sport or recreational purposes, weighing not more than 150 kg ..." (CASA 1998 at 101-3). If `recreational' is interpreted as being equivalent to `non-commercial', then drones used by neighbourhood and voyeuristic paparazzi are model aircraft, provided that no-one pays a fee for a service performed by the drone. And holding a competition for, say, tracking a vehicle or a person, or training for such a competition, is reasonably interpreted as `sport', even if money does change hands. It would appear that the distinction between model aircraft and drones is not functional, but essentially regulatory, and based on the purposes of use. Model aircraft are accordingly within-scope of this series of papers.

Size is significant to the analysis of the impacts of drones. The reasons include the need to carry equipment that performs a variety of engine, navigation, communications, computational, control and operational functions, but also because of marketplace realities and, significantly, historical regulatory thresholds. Consideration of the laws of various countries - which are addressed in the third paper in this series - suggests that thresholds of current legal relevance include 150kg, 20 or 25kg, possibly 7kg and 2kg, 1kg and 0.1kg. Some definitions also include reference to dimensions, however, and in at least Australia the weight and/or size threshold is contingent on the category of aircraft (airship, powered parachute, aeroplane, rotorcraft or `powered lift device' - which is undefined, but presumably means a rocket - CASA 1998 at 101-240).

A design feature that is to at least some degree associated with size is noticeability. Some drones are designed to mimic desirable attributes of flying birds or insects. Some of those, particularly some in the nano-drone range, below perhaps 0.1kg, may readily escape detection because of some combination of their size and their appearance. This may be incidental or arise from an endeavour to be `hidden in plain view' (Whitehead 2013).

A final factor to consider is the possibility that drones, rather than being used independently, may be applied in groups of two or more drones operating in an inter-dependent manner. One reason for such an arrangement is for mutual surveillance and protection, in much the same manner as static CCTV cameras are usefully positioned and oriented so as to include one another within their fields of view. Another example is the use of multiple surveillance drones in order to provide triangulated observations. Beyond small teams of drones, a considerable amount of research has been conducted into swarms of small drones (e.g. Bürkle et al. 2011). Large numbers of inexpensive drones can achieve redundancy, which is particularly useful in dangerous contexts. On the other hand, both swarms and drones that are no longer under the swarm-manager's control may create increased risk of collateral damage.

The following section concludes the review of the nature of drones by proposing a working definition.

2.5 Definition

One interpretation of a drone is "an unmanned aircraft that can fly autonomously" (Villasenor 2012). On the other hand, the first use of the term `drone' was by the US Navy in 1935. It commenced a program to produce remotely-controlled target aircraft, and, following a visit to the Royal Navy's well-established program, including demonstration of the 'Fairy Queen' and 'Queen Bee' models, it used a word related to Queen Bees for its own artefacts (Mehta 2013). Because many remotely-controlled aircraft have very limited independence, it is inappropriate to specify the ability to fly autonomously as a mandatory attribute.

An important reference-point for this analysis should be the terms and definitions used by relevant organisations around the world. For example, one document from the US regulator FAA defines a UAV as "A device used or intended to be used for flight in the air that has no onboard pilot. This devise [sic] excludes missiles, weapons, or exploding warheads, but includes all classes of airplanes, helicopters, airships, and powered-lift aircraft without an onboard pilot. UA do not include traditional balloons (refer to 14 CFR part 101), rockets, tethered aircraft and un-powered gliders" (FAA 2013, p.A-5). Agencies' definitions are of course relevant to regulatory analysis. However, regulatory agencies are constrained by constitutional limitations and their own enabling legislation, and in many cases this results in warped definitions of limited value for policy assessment. They are accordingly not heavily weighted in the analysis reported on in this paper.

Of the various industry associations, the Association for Unmanned Vehicle Systems International (AUVSI) appears not to offer definitions of relevant terms, and the UK Unmanned Aerial Vehicle Systems Association (UAVS) merely has a discursive page on meanings of relevant terms (UAVS 2013). However, Unmanned Vehicle Systems International (UVSI) provides a glossary (UVSI 2013). It deprecates `drone', `UAV' and `RPV' in favour if `RPA', and defines RPA as a subcategory of unmanned aircraft "where the flying pilot is not on board the aircraft" (and notes that this is consistent with both ICAO Circular 328 and the definition of the UK regulator CAA, in CAP722). The only other subcategories of unmanned aircraft that UVSI distinguishes are based on size, or autonomy. UVSI also deprecates `UAS' in favour of `RPAS'.

The definition used by the US Department of Defence (USDoD 2011) is that an Unmanned Aircraft (UA) or Unmanned Aerial Vehicle (UAV) is a powered, aerial vehicle that does not carry a human operator, and uses aerodynamic forces to provide vehicle lift. It expressly declares several factors not to be definitional: a UAV can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload. USDoD does not consider ballistic or semi ballistic vehicles, cruise missiles, and artillery projectiles to be UAVs.

Based on the above analysis, this paper identifies the elements of a definition of drone as being:

- the device must be heavier-than-air (i.e. balloons are excluded)
- the device must have the capability of sustained and reliable flight
- there must be no human on board the device (i.e. it is `unmanned')
- there must be a sufficient degree of control to enable performance of useful functions

Other attributes that fall short of being definitional factors include size and weight, the nature of the airframe and propulsion, the particular functions performed, the degree of remoteness of control, the nature of the operating organisation, and the degree of autonomy. The definition provided here intentionally encompasses a great many variants, in particular those subject the full range of control options - human, semi-autonomous and fully autonomous; all sizes; and irrespective of the purpose to which the device is put.

Beyond establishing a working definition, there is value in identifying categories of drones whose impact and management may be materially different. The single most important basis for recognising distinct categories of drones would appear to be some indicator of size, because this is likely to correlate sufficiently closely with other important factors such as payload, the sophistication of navigation and communications facilities, and the level of quality assurance involved in manufacture, maintenance and operation. For the purposes of the analysis conducted in this series of papers, the following four categories are adopted:

- **large drones**, commonly of the size of piloted aircraft. An indicative lower threshold, reflecting existing technologies, and aligned with thresholds used by many regulators, is 150kg for aircraft, and 100kg for rotorcraft
- **small drones**, which perform similar functions to piloted aircraft but are smaller because of the space and weight savings arising from dispensing with pilot-related apparatus. An indicative size-range, based on existing regulatory frameworks and discussions, is between 20kg (or 25kg) and 150kg/100kg. In military contexts, some sources use a lower threshold of 30kg, with a separate category of **mini-drones** in the range 5-30kg. Some other sources have suggested a maximum size of 1m in the longest dimension might also be applied
- **micro-drones**, which fall below whatever threshold is applied for small drones, down to some lower threshold, of perhaps as much as 7kg or 5kg, or 2kg or 1kg or as little as 0.1kg. Disclosures from industry consultations conducted by the Australian regulator, CASA, during 2013, suggested that a separate category in the 2-7kg range was being considered
- **nano-drones**, which are smaller than the lower threshold of micro-drones, and could perhaps be as small as 'smart particles' or 'Micro-ElectroMechanical Systems (MEMS) dust' (Berlin & Gabriel 1997), a notion that was subsequently popularised as 'smart dust'

With a reasonable degree of clarity about the scope of the drone concept, it is now feasible to identify and discuss drones' benefits, disbenefits and risks with a minimum of diversions and ambiguities.

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3. Drones as Opportunity and Challenge

This section commences by identifying the aspects of drones that give rise to benefits. It then describes key application areas, with an eye open for financial and other costs - collectively `disbenefits' - and contingent disbenefits, commonly referred to as risks.

3.1 The Scope of Drone Applications

Aeronautic technologies have delivered big payloads and high reliability. Cost-profiles have also changed very quickly, such that drones are not only attractive to the military, national security, law enforcement and big business, but are also sufficiently inexpensive that they are now available to the small business person and the hobbyist.

The absence of an airborne pilot changes several aspects of aircraft design:

- it removes the need for space and carrying-capacity:
  - for a pilot
  - for data displays and controls
  - for support facilities for the pilot, such as air-pressure controls and an oxygen supply
- it enables a much larger proportion of the space and weight-bearing capacity to be applied to:
  - fuel, hence greatly increasing flying-time and range; and/or
  - the functions to be performed
- it enables much smaller and less expensive aircraft to be built, depending on the functions to be performed, the payloads needed, and the contexts of use

In identifying the categories of opportunity, a range of limitations also need to be taken into account, including the following:

- particular features are needed for effective operation at particular altitudes
- particular aircraft characteristics are important for particular applications, such as the ability to hover, to quickly re-orient the aircraft or a device that it carries, to sustain a very steady flight along a pre-determined bearing, to remain airborne for long periods, and flexibility in take-off and landing locations and conditions
- weather frequently plays havoc with the aerodynamics of all forms of airborne devices
- weather sometimes plays havoc with both line-of-sight visibility and electronic communications
- fire, smoke and heat create serious challenges
- in a variety of circumstances, a remote pilot is unlikely to have all of the desirable situational information available, and hence may make decisions that are less good than the decision an on-board pilot would have made. In other circumstances, however, a remote pilot may have better access to relevant data, and may be better placed to make good decisions

Fixed-wing drones have advantages in relation to speed, range, endurance and robustness. Rotorcraft, on the other hand, require less space for take-off and landing, can hover, and are highly manouevrable. In practice, most applications require separate human pilots and facilities operators.

A drone is capable of many possible payloads, from doses of life-saving medications, to pizzas, to cameras, to munitions. A vast amount of research funding, and much of the early market, particularly for large drones, has related to military applications. Although these are not the primary focus of this paper, much can be learnt from the pioneering work performed in these areas. A US-centric history of combat drones is in Chapter 1 of Yenne (2004), and a broader international perspective is in Newcombe (2004).

The following, specifically military, applications of drones are noted because, although not themselves within-scope for this analysis, they have potential implications for civilian uses:

- as a target, since the 1930s
- as a means of annoyance and attention-diversion. Drones are reputed to have been successfully used by Israel to draw enemy fire, during the Yom Kippur War in 1973
- as an electronic warfare platform, to disrupt opponents' communications
- as a means of performing assaults:
  - on ground targets, conceived no later than 1915 in the USA, described in hobbyist magazines (PM 1940), and implemented at latest by the USA in Yemen in 2002 (Bowden 2013)
  - on airborne targets, including other drones. Examples are currently lacking due to parties that have access to such technologies not yet having entered into conflict with one another

The range of specifically civilian applications has been broad, including:

- as a load-carrying and -delivery device
- as a communications-relay device
- as a platform for surveillance devices, to enable observation, recording and transmission. This dates as far back as the end of the 18th century (using leashed balloons), and has been used increasingly intensively by various countries since the 1960s. The kinds of data that can be gathered are diverse, and include:
  - electromagnetic-spectrum data:
    - image and video in the human-visible range
    - near-human-visible image and video (in particular, in the infra-red spectrum)
    - radio transmissions
    - other electronic transmissions
  - other kinds of data:
    - sound in the human-audible spectrum
    - air-pressure waves of other frequencies
    - biological measures
    - magnetic and other geophysical data
    - meteorological data

'Smart dust' was originally conceived with "a wide variety of applications" in mind, "ranging from military reconnaissance (what's over that hill?) to precision farming (how much fertilizer does this particular square foot of farmland need?) to monitoring air quality or rush-hour traffic conditions" (Berlin & Gabriel 1997). Another circumstance suitable for drones is where the target is difficult to gain access to, such as in an area shielded from view, or in an area congested at ground level. A drone also has an advantage where the target may move at a speed, or following paths, that preclude pursuit on foot or in a terrestrial vehicle. The use of drones as a platform for observation, recording and transmission of sound, image and video is also proving attractive in the film and broadcast industries, including sport.

A useful classification scheme appears in multiple US defense sector documents: "dull, dirty, or dangerous missions", in which a human pilot is a limiting factor in performance. That principle is equally applicable outside the military context. Examples of dangerous civilian purposes include:

- searches for missing persons and vessels, particularly in severe weather or over or within difficult terrain, but also for long periods of time and over long distances
- monitoring of atmospheric conditions shortly prior to and even during 'heavy weather'
- emergency management, including surveys of fires, volcanic activity, earthquake zones, flood zones, and malfunctioning nuclear reactors
- fire-fighting

Categories of 'dull' civilian missions include:

- staying within a tightly-defined zone, e.g. in order to provide a communications link or perform a static surveillance function
- staying on tightly-defined flight-paths, e.g. search-patterns for lost bush-walkers / hikers / sea-farers / surfers, aircraft wreckage, and missing sea-vessels, and during the conduct of ground surveys
- other routine activities in which limited human intelligence is required, such as conducting surveillance of the electromagnetic spectrum and the collection of other kinds of data
- goods transportation

Despite the claimed richness of opportunities provided by drones, it is noteworthy that 25 of the 26 commercial drone operators that had been approved to April 2013 by the Australian regulator (CASA 2013a) had nominated surveillance uses (specifically aerial photography, aerial spotting, aerial survey, powerline inspection and surveillance), with just a single instance of a target drone. By the end of 2013, there were 69 operator certificate holders, of which 1 was approved as a target drone, and 1 was approved for training only, but 68 were approved for the various surveillance functions (CASA 2013c).

A wide range of current and potential civil applications exists. The following sections outline the primary application areas, with deeper discussion given to those that raise key issues in need of attention. The application areas discussed below are:

- Load-Carrying and -Delivery
- Hobby and Entertainment
- Journalism
- Voyeurnalism
- Law Enforcement
- Community Policing, Voyeurism
- 'Killer' Drones
- Drone-Attacks and Attack-Drones
- Passenger Transport

3.2 Load-Carrying and -Delivery

A wide variety of tasks have been touted for drones. Among the flights of fancy have been ammunition re-supply, the rescue of injured people, medicines, pizzas, and books. Many characteristics of drones generally, and of contemporary drone technologies act as major limiting factors on realistic uses for load-shifting. An indication of the more likely candidate applications is provided by the longstanding use of drones in Japan, where, through the 1990s, over 1,000 aerial devices weighing 50-60kg and with a payload of 20-30kg, were used for crop-spraying. The application involves constrained areas, populated by few people, few buildings, little high infrastucture such as electricity lines, and no other aircraft. These simplifications, combined with high degrees of computer-mediation embodied in the aircraft's control, has greatly reduced the skill-levels demanded of pilots (Wong 2001).

3.3 Hobby and Entertainment

The majority of personal use of model aircraft has long been by individuals acting with considerable care and responsibility, typically as members of a club that sets constraints, arranges insurance cover, and uses dedicated and somewhat isolated airfields. The costs involved in acquiring and operating aerial devices has plummeted, however, and the less expensive models have now come within the price-range of adolescents' Christmas presents. The rash of remote-controlled model cars terrorising neighbourhoods may be about to give way to a rash of remote-controlled devices that are not terrestrially-limited, that may exhibit many additional failure-modes, whose impact-velocity when falling from the sky may be significantly greater than that of out-of-control model cars, and whose operators may exhibit little responsibility and have little in the way of assets or insurance.

The international regulatory regime does not appear to distinguish uses of these kinds from other uses. In some jurisdictions, however, the regulatory framework applicable to `model aircraft' is different from that applicable to drones. In Australia, the key difference is that, to qualify as a model aircraft and not as a `UAV', a device must be "flown for sport & recreation and education" and/or "for private use", as distinct from "for air work, including commercial operations, in activities such as aerial photography, surveying and law enforcement" and/or "for commercial `hire and reward'" (CASA 2013b). CASA has approved an association, the Model Aeronautical Association of Australia (MAAA), to "govern the operation of" model aircraft, within the terms declared in CASR 101 (CASA 1998).

3.4 Journalism

Journalism is the preparation of news, current affairs and documentaries, by means of disciplined collection, analysis, cross-checking and presentation of information regarding events and issues that are 'in the public interest'. Journalism includes 'opinion', but opinion needs to be clearly distinguished as such.

Inexpensive drones have been applied to journalism at least since early in the new century (Corcoran 2012). It becomes possible to afford views from perspectives that were previously unprocurable without using expensive aircraft. This greatly increases the scope for the observation platform to hold position and monitor, rather than just to over-fly and produce snapshot imagery and video. Pursuits become less expensive, more feasible, and less dangerous - at least for the chaser, if not for the fugitive and bystanders.

Early examples of constructive uses by the media include by News Corp in the US in 2011 to film flood damage, and by Australia's 60 Minutes, which filmed while over-flying the Christmas Island immigration detention centre in May 2011 (Corcoran 2012). Use at sporting venues in Australia has attracted considerable attention (Corcoran 2013). The new capabilities give rise to a range of issues. For assessments of policy issues arising from journalistic uses of drones, see Goldberg et al. (2013) and Clarke (2013).

Over the last 50 years, while parliaments have been asleep at the wheel, the costs involved in data-collection have given rise to a balance between media intrusions and personal seclusion - a balance that is sometimes markedly against the interests of some individuals, but nonetheless some kind of balance. The emergence of inexpensive surveillance technologies, including drones, is shifting that balance considerably, in such ways as the following:

- the perspective of the observation is lifted up and away from the limited point-of-view of a human being. Drones add another dimension, literally as well as metaphorically. This may provide a sense of greater authority in the imagery than it actually warrants
- multiple sources and live feeds can be used at the same time

- a much greater degree of automated monitoring is feasible, including a notification service to a reporter or photographer when something interesting may be happening - enabling what are, in effect, automated stake-outs
- a much greater degree of surveillance extensiveness is feasible, approaching pervasiveness, e.g. by in effect being at each of the locations associated with a target at the same time
- a much greater degree of surveillance intensiveness is feasible, approaching continuous monitoring, unrestricted by time of day, length of wait and human attention-span
- the notions of 'informant' and 'research assistant' expand from a party who observes and then describes from memory, to anyone who can support their description with evidence

A number of additional implications are readily foreseeable, including potential conflict with law enforcement and emergency services, and increased attractiveness to law enforcement agencies of access to media sources.

Instances of irresponsibility have arisen in relation to the use of surveillance tools by journalists. In most such instances to date, however, the behaviour of the media personnel has lacked the justification of being 'in the public interest'. They are accordingly treated as a distinct application area, in the following section.

3.5 Voyeurnalism

A form of debased or corrupted journalism is widespread, in which information regarding events and issues is gathered and presented that is not 'in the public interest', but rather is 'what the public is interested in', or 'what the public may be able to be made to be interested in'. In some cases, the practices depart further from journalism by presenting information in a constructively misleading manner, or inventing pseudo-information or 'fantasy news'. A century ago, this category of media was referred to in the USA as 'yellow press' and 'yellow journalism', and the term 'sensationalist media' is used in the UK. The word 'voyeurnalism' is a concoction by this author, to deal with the absence of an established term (Clarke 2012).

A representative set of media abuses of privacy is catalogued in Clarke (2012), almost all of which involve voyeurnalism, not journalism. Helicopters and fixed-wing aircraft have been too expensive for any significant use by paparazzi, whereas drones are creating a 'Paparazzi Aloft' problem. Drones enable barriers in the line of sight to be overcome, and imagery to be captured. Vertical and angled shots can be achieved. Continuous monitoring can be undertaken of bottleneck locations such as the target's front door. Tracking becomes much easier. Paris Hilton was filmed, and tracked, by drones, on the French Riviera as long ago as 2010. A 2013 story arose from drone use at Tina Turner's wedding in Switzerland.

Given the dedication of paparazzi, and the money that can be made from 'scoop' pictures of celebrities and notorieties, it is readily predictable that there will be frequent abuses of the power of drone-borne cameras. In September 2012, there was considerable coverage of photos of Kate Middleton (the Duchess of Cambridge), captured from long distance by means of a telephoto lens. The increased scope afforded by drones leads to the conclusion that she, and many other people, can rest assured that their bare breasts are fair game, anywhere, anytime. More dangerously, the prospect of ill-judged pursuits is much-increased, as is the risk of encouraging ill-judged avoidance manoeuvres.

3.6 Law Enforcement

The scope for using drones as a form of highly-mobile, remotely-managed CCTV was apparent to law enforcement agencies at an early stage, e.g. Page (2007). On the other hand, the application of drones in Liverpool appears to have taken three years to achieve an arrest, and it then transpired that the law enforcement agency was itself in breach of the law (Lewis 2010).

There can be little doubt that successes will be achieved by law enforcement agencies applying drone technologies. Significantly, however, these will seldom arise from random image-capture. They will depend on professionalism, commitment and above all sufficient human resources applied to an investigation. Drone-based surveillance is confronted by much the same challenges that have seen almost all CCTV schemes prove to be abject failures (e.g. Edwards 2008, Groombridge 2008).

A particular concern is the extent to which law enforcement drones will be more like those designed for military or for civilian purposes. Since 2001, police forces in hitherto relatively free nations have adopted more aggressive approaches, and have begun to resemble the militarised police forces common in un-free nations. There is a serious risk that law enforcement drones and supporting systems will have characteristics in common with military facilities - including designs intended for unconstrained surveillance of an enemy, and lightly-constrained violence against an enemy, which generate vast quantities of data that require integration and interpretation and hence produce information overload which may materially affect the quality of operators' judgements (Drew 2010). The much higher cost of products for the military compared with those for civilian uses is a counter-balance against this risk. On the other hand, funding for law enforcement drones will almost inevitably be provided during a period in which law and order issues dominate common sense, and hence occasional large sums of money may be made available, enabling (de-militarised?) versions of military products to be acquired.

A sci-fi author provided some detailed scenarios for security drones: "[micro-drones] programmed to hang in space ... watching and listening, so that nothing got through [undetected]" (Stephenson 1995, pp. 56-57). Those (imaginary) surveillance drones were complemented by 'tagger' nano-drones, which attached themselves to a person immediately after they committed a criminal act. Together, the recorded video and the identification of the suspect delivered conclusive evidence to the courts (pp. 97-98, 127, 139).

That is `visionary' or `speculative'. However, whether or not such specialised security micro-drones and nano-drones actually eventuate, the prospect exists of a 'Panoptic Aloft'. The social, cultural and political risk is that many more people will cease to perform lawful behaviours, whereas there will be only limited deterrence of criminal behaviour, particularly crimes of violence. Another sci-fi author projected current surveillance capabilities a much shorter distance into the future, and included a key role for micro-drones (Bear 2010). He concluded that, in the emergent world of coordinated little brothers, "Vengeance is everywhere. Nobody gets away with anything. We're terrified of our neighbors [and] forgiveness and forgetfulness become conveniences of the past". In the bleak view of the cyberpunk genre, "In an era when everything can be surveilled, all we have left is politeness" (Stephenson 1995, p. 192).

3.7 Community Policing, Voyeurism

In addition to formal policing, drones have potential application by communities themselves, by individual, `responsible citizens', by vigilantes, and by individuals and groups seeking to impose their own morality on others. A positive aspect of this is early recognition of trouble-spots, enabling early arrival of calming infuences. The scope also exists for communities to monitor suspected polluters. There have been reports of use by groups seeking to protect wild animals (T&D 2012) and to expose abusive chicken-farming practices (Murphy 2013). A surf life saving association and various beachside local government agencies have considered and experimented with drones for shark-spotting at (SLSA 2012, RCC 2013).

A less positive prospect is 'nagging aunty' drones, identifying what an algorithm, or an inference from an example-base or from a neural-net determines to be misbehaviour, using recorded or synthesised voice to reprimand the computed perpetrator, and perhaps using intense sound or light to encourage the undesirables to leave the area (Stephenson 1995). Another possibility is a permanent drone-enabled 'neighbourhood watch' of people regarded as strangers or aliens, such as 'gypsies', newly-settled refugees, and sex offenders.

Another potential is for individuals and groups to use the guise of community protection to indulge in voyeurism - i.e. sexual gratification through observation. CCTV operators are well-known to indulge in opportunistic observation of people within their cameras' fields of view (Smith 2004), and instances abound of cameras installed in locations where titillating scenes may be able to be observed. Drones provide considerably greater empowerment to the voyeur than installed cameras, because of the flexibility of location and angle.

3.8 'Killer Drones'

The notion of `killer drones' may have begun in military contexts, but it also has relevance in civilian contexts. A great deal of experience has been garnered, in particular from US applications of drones in Yemen, Iraq, Afghanistan and Pakistan, in many cases with the pilots on the US mainland, remote from the region, the battle-zone, the time-zone and local culture (Bowden 2013).

One concern is that a grey area exists between military and civilian uses, which might be usefully termed `para-military'. Observation and pursuit of individuals reasonably suspected of criminal behaviour is a civilian matter. In many countries, civilian police are armed, at least when they are in a context in which violent confrontations may occur. So will law enforcement drones also carry arms, controlled remotely, or perhaps even autonomously? Will law enforcement agencies purchase second-hand, or even new, military drones? At this stage, "Equipping the aircraft with weapons of any type is strongly discouraged. Given the current state of the technology, the ability to effectively deploy weapons from a small UA is doubtful. Further, public acceptance of airborne use of force is likewise doubtful and could result in unnecessary community resistance to the program" (IACP 2012). But will this strong discouragement abate, once the public has come to accept police use of drones? And is it appropriate in a free society for even border protection functions, let alone civilian policing, to involve use of such military capabilities in domestic settings?

The notion of information overload arising from drone warfare is the subject of a substantial informal literature. In most cases, the reports are about those seeking to extract information from the flood of surveillance data transmitted by drones (e.g. Drew 2010). In some cases, however, the problem is cognitive overload of pilots and facility operators. Even with the advantages of being ground-based, the standard of performance required of a drone pilot, and the degree of performance stress placed on them, can approach that of an on-board pilot. Cognitive overload can result in dangerously slow or dangerously erroneous commands. It may also reduce the ability of the drone pilot and facility operators to empathise (Coker 2013), and in some cases, even to perform their functions (Sterling 1994, pp. 78, 81). The military use of `killer drones' involves highly articulated structures and processes, rules of engagement, monitoring, and reviews. Will similar controls be applied if and when law enforcement agencies use deadly force, and will review processes be `a closed shop' or transparent, as befits democratic governance?

An important aspect of military drones is that the controls used by remote pilots bear a relationship to games technologies. A range of techniques being developed in the context of Point of View Surveillance (PoVS) technologies are potentially applicable as well, such as image intensity manipulation and colouration, augmentation of displays with infra-red imagery, vision-width greater than that of natural human vision, multiple eyes pointing in different directions, warning overlays, and 'action replays'.

The relevance to the civilian context of the virtual reality aspects of drone controls is twofold. Firstly, they offer advantages and hence are likely to migrate into the civilian realm. Secondly, the person's physical remoteness from the real world in which the drone is operating is compounded by the air of unreality arising from additional information overlays. The person's detachment from physical reality can readily lead to decisions and actions that are inconsistent with the individual's normal morality, or that indulge fantasies that are normally kept under control by social norms.

In military contexts, the de-personalisation of the behaviour of pilots and facilities operators creates the risk of acts that breach the rules of engagement, that constitute extra-judicial murder, and that place low value on collateral damage to civilians. On the other hand, those behaviours are subject to pre- and post-controls. In civilian contexts, the detachment, combined with the thrill of live entertainment, can be expected to lead to enthusiastic voyeurism, which constitutes harassment, and will on occasions cross the boundary into stalking, and in some cases will culminate in acts of violence. The likelihood is that the social and institutional controls will be loose, and in the case of micro- and nano-drones, perhaps almost entirely ineffective.

The `killer drone' notion is not only relevant to law enforcement uses. The armed forces of States use large devices with substantial payloads and sophisticated custom-built electronics to deliver expensive explosives. On the other hand, what were once called guerillas and are now tagged terrorists make do with low-grade and readily available explosives, and the much smaller payloads available with cheap, small drones may be sufficient for them to achieve their aims.

Commercial and even hobbyist drones are capable of being 'weaponised' in various ways. A small payload of explosives, delivered at an appropriate location could act as a detonator for a much larger explosive potential. Or it might exacerbate a bottleneck or cripple a control element within critical infrastructure (an electricity or water supply, an airport, a data processing facility). Or an individual drone could be deployed against an aircraft during take-off or landing, perhaps through a jet-engine air-intake. Where the perpetrators want to cover their tracks, they might avoid the use of their own drone, and instead hijack a hobbyist or commercial drone to perform the task. Beyond the prospect of an individual drone, a swarm of micro-drones floated across a flight-path could be relied upon to paralyse air transport, and probably also ground transport in the vicinity, for many hours.

Even without an explosive payload, or perhaps with an incendiary payload instead, fatalities could result. With or without fatalities, events would be likely to be dramatised by the media. For example, a report of a micro-drone crashing into the Sydney Harbour Bridge (Kontominas 2013) was dramatised in London and Milan by reference to the presence in the Harbour of international naval vessels and of the UK's Prince Harry. Media reports of this nature inevitably escalate the significance of such events in the public eye, and can be expected to give rise to knee-jerk reactions by politicians, resulting in additional 'safeguards' being put in place - many of which are likely to prove to be wasteful and ineffective, and to involve collateral damage to civil liberties.

The almost complete absence of the once-touted threat of anthrax infiltrated into city water-supplies suggests that attacks of such kinds are far less simple to effect than they are to dream about. On the other hand, the theoretical existence of the threat is sufficient to ensure nervousness on the part of national security apparatus, and a convenient excuse when justifications are sought for further repressive measures. The drone epidemic therefore adds to existing tensions within contemporary societies.

This analysis of weaponised drones has focussed on law enforcement, and on individuals whose motivation is terrorism. It is applicable, with qualifications, to some other categories of people and organisations, including ordinary criminals and thrill-seekers.

3.9 Drone-Attacks and Attack-Drones

Some individuals and organisations that are targeted by drone-based activities will retaliate. Counter-measures against drones include:

- jamming of control signals and/or data transmission
- interference with geo-location data, such as the GPS data reaching the drone (BBC 2012)
- hacking of software
- ground-based interdiction of the drone itself
- predator-drones
- defensive drone-swarms
- violence aimed at remote pilots and facilities operators

Any action that undermines a drone's operation increases the risk of malfunction, and hence of damage not only to the drone but also of anything it collides with as a result of the malfunction. Any item that is used to target a drone (a bullet, a water-jet, another drone) may have that effect, but with the added feature that the projectile itself becomes an additional threat to other objects and individuals in the vicinity.

To date, there appear to have been few acts of retaliation. However, an animal rights group in South Carolina reported that a drone that they used to video a live-pigeon shoot was shot down by hunters, in close proximity to a highway (T&D 2012). Deer Trail, Colorado was reported as playfully considering paying bounties for the shooting-down of unmanned drones (Coffman 2013).

3.10 Passenger Transport

To date, all passenger aircraft carry a human pilot. Although pilots depend on a great deal of technology, and autonomous flight, take-off, and with qualifications landing, are all in use as individual elements, no passenger aircraft to date operate fully autonomously. Ross (2011) discussed factors that need to be addressed before passenger aircraft can be controlled by remote pilots, emphasising collision avoidance technology and public acceptance. In the UK, a modified commercial aircraft has conducted a flight through shared airspace, controlled after take-off and before landing by a remote pilot (Prigg 2013).

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4. Implications for Risk Management

Many of the attributes of drones that have been discussed in this paper have the potential to create challenges for existing regulatory regimes. This section identifies several aspects that appear to be of particular significance for the assessments of regulatory arrangements in the third and fourth papers in the series.

Care is required in defining what it and is not a drone. The devices evidence considerable diversity across multiple dimensions. Not only do their capability profiles vary, but so do their risk profiles. One categorisation of particular relevance is the drone's size. Large drones have large payloads, and with that come high expectations of redundant designs and quality assurance. Small, micro- and nano-drones, on the other hand, may be subject to correspondingly lower expectations, yet they are still capable of causing considerable harm. Controls need to reflect the scale of the disbenefits and risks, rather than just the costs-of-manufacture. On the other hand, there is bound to be opposition to setting minimum thresholds for safety and liability.

Two particular themes have emerged from the analysis. One, which is the focal point of the third paper in this series, is the potential for harm to property and people. Some of the controls that are effective in the context of piloted aircraft may be less effective for drones, not least because existing institutions, from the Convention on International Civil Aviation downwards, are structured on the assumption that aircraft have an onboard pilot. The much-lowered personal risk faced by a remote pilot is bound to affect concentration and decision-quality. An additional factor is that the quality and safety levels that apply to piloted aircraft bring with them high costs that are not sustainable in many segments of the drone market. In the small-drones segment, there is the risk of compromise of safety features. In the micro-drones segment, on the other hand, there is the risk of manufacture and operation with very little regard for safety. Drone costs have fallen, particularly for micro-drones for the consumer market; and, from the outset, nano-drones have been conceived as very inexpensive, mass-produced items. It can be reasonably anticipated that drones that have the attribute of expendability will have less care taken with both the drones themselves and their negative impacts, particularly after they have ceased to fulfil a useful function for the party that is (in some sense) responsible for them.

A particular concern is the wide array of `failure modes' that afflict drones. After a large drone being used for border patrol purposes crashed in New Mexico in 2006, a large number of causal and contributory errors were identified (Carrigan et al. 2008). The earliest UK use for law enforcement purposes culminated in the drone's loss in the Mersey River off Liverpool (BBC 2011). The earliest media use identified in Australia ended with the drone crashing, fortunately for those in the detention centre that had been filmed, in the adjacent Indian Ocean (Corcoran 2012). A similar cautionary tale arises from the demonstration of what was claimed to be the first police-owned drone, in Texas - a large and expensive drone rather than a micro-drone. It crashed into a police vehicle which was, fortunately, armoured (Biddle 2012). Then, in Incheon, South Korea, a large, commercial drone crashed into its control truck, killing an engineer and injuring two pilots who were `remote', but insufficiently so (Marks 2012). In May 2013, video emerged of an accident in August 2004, when a small drone, a German Luna weighing about 40kg, crashed as a result of being caught in air turbulence from a commercial passenger aircraft on approach to Kabul airport. A major disaster would have been likely had the two collided instead of having a near miss (Spiegel 2013). There have also been crashes of micro-drones in the central business districts of Auckland (Mortimer 2012) and Sydney (Kontominas 2013). Accident investigation reports for these incidents have not been located, but media reports have suggested that the causes have mostly been interruptions to GPS or control-flow transmissions, coupled with inadequate fail-safe designs to cope with signal-loss. At least one arose because the drone was in congested airspace but did not have a collision avoidance system

(Spiegel 2013). It appears that, to date, even the largest and most expensive drones do not carry such equipment (Harvey 2013). These accidents give rise to ample cause for concern about the potential for harm to people and property, and highlight the need for an assessment of the adequacy of existing regulatory frameworks for public safety.

The other theme that has emerged is the surveillance of individuals and its impact on behavioural privacy. Significantly different issues arise in the case of journalism, voyeurnalism, law enforcement community policing and voyeurism. That is the topic of the fourth paper in this series.

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5. Conclusions

The first requirement for a calm assessment of the impacts and implications of drones is clarity about the scope of the notion, their attributes, and the opportunities and challenges that their applications embody. This paper has identified the definitional factors for a drone as comprising (a) a heavier-than-air device, (b) flight reliability, (c) the absence of an onboard pilot, and (d) sufficient control that useful functions can be performed. Attributes that are important in determining the impacts that need to be managed include above all size, but also functionality, the nature of the operating organisation, the remoteness of the pilot, and the degree of autonomy.

As discussed in the third paper in this series, large drones tend to be perceived as being within-scope of existing regulatory frameworks, have navigation and communications capabilities comparable to piloted aircraft, and are manufactured, maintained and piloted within quality assurance frameworks similar to those applying to the manufacturers, maintenance organisations and pilots of manned aircraft. Critically, however, the same does not apply even to small drones, let alone to the burgeoning population of micro-drones.

Some of the impacts and implications depend not only on drone-size, but also on the category of application to which the drone is put. In particular, surveillance applications need to be differentiated according to the purpose and the operator. Harm will also arise from intentional actions by drones and their operators, including acts of direct violence against people and property, including other drones.

This paper has delivered a comprehensive framework within which the later articles in the series are able to analyse the issues in depth, assess current regulatory frameworks, identify areas in which those frameworks are deficient, and evaluate the prospects of effective reform.

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