ARES

Emerging Unmanned Threats:

The use of commercially-available UAVs by armed non-state actors

2016

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SPECIAL REPORT No. 2

PAX

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Armament Research Services

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Published in Perth, Australia by Armament Research Services (ARES)
and in Utrecht, The Netherlands by PAX

Published in February 2016.

ISBN 978-0-9924624-7-5

Credits

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Cover image: Pro-Russian separatists launch a COTS small UAV near Donetsk Airport (photo credit: Движение Интербригады*).*

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RECORD all relevant information
MARK the area to warn others
SEEK assistance from the relevant authorities

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A graduate of Auburn University with a Bachelors of Aerospace Engineering (Magna Cum Laude), Larry Friese has served in a variety of positions in both the government and private sector. In these roles, Mr Friese has worked on aerial target programs, guided munitions programs, the F/A-18 fighter aircraft program, and surface-to-air and ballistic missile simulation projects. He served over eight years with the National Security Agency (NSA) where he was a foreign missile and aircraft signals analyst, signal collection specialist, and project engineer. Mr Friese is the founder and President of Aerial Information Systems Corporation (AISC), a consulting firm focused on unmanned aircraft and flight simulation, and continues to conduct significant original research on behalf of ARES.

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Michael Smallwood has produced substantial research concerning small arms and light weapons, munitions, and military equipment in his role with Armament Research Services. He has a particular interest in emergent technologies and improvised systems, and their employment by non-state armed groups in contemporary conflict.

Acknowledgements

The authors would like to thank several individuals who contributed to the development and production of this report, including Major Crispin Burke (US Army), Kenton Fulmer, Alexander Harper, Ivan Kochin and Graeme Rice. It is the authors' hope that this report can contribute meaningfully to a more informed international discussion examining the use of UAVs by non-state actors.

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Abbreviations and Acronyms

ARES	Armament Research Services Pty. Ltd.
ARF	Almost ready-to-fly
BDA	Battlefield damage assessment
BLOS	Beyond visual line-of-sight
CAA	Civil Aviation Authority (UK)
CASA	Civil Aviation Safety Authority (Australia)
CENTCOM	US Central Command
CN	1-chloroacetophenone (lachrymatory agent)
COTS	Commercial off-the-shelf
CS	2-chlorobenzylidene malononitrile (lachrymatory agent)
DC	Direct current
DJI	Da-Jiang Innovations Science and Technology Co. Ltd.
EDF	Electric ducted fan
ESC	Electronic speed control
FAA	Federal Aviation Administration (USA)
FARC	*Fuerzas Armadas Revolucionarias de Colombia* ('Revolutionary Armed Forces of Colombia') [Spanish]
FCS	Flight control system
FPV	First-person view
GCS	Ground control station
GTOW	Gross take-off weight
HD	High-definition (video)
HE	High explosive
IDF	Israel Defense Forces
IED	Improvised explosive device
IR	Infrared
IS	Islamic State
ISM	Industrial, scientific, and medical (radio bands)
ISTAR	Intelligence, surveillance, target acquisition, and reconnaissance

LIDAR	Light detection and ranging
OC	Oleoresin capsicum (lachrymatory agent)
PAL	Permissive action links
RF	Radio frequency
RGN	*Ruchnaya Granata Nastupatel’naya* (‘offensive hand grenade’) [Russian]
RGO	*Ruchnaya Granata Oboronitel’naya* (‘defensive hand grenade’) [Russian]
RPA	Remotely-piloted aircraft
RTF	Ready-to-fly
SAA	Sense-and-avoid
SDR	Software-defined radio
SVBIED	Suicide vehicle-borne improvised explosive device
UA	Unmanned aircraft
UAS	Unmanned aerial systems
UAV	Unmanned aerial vehicle
VLOS	Visual line-of-sight
VTOL	Vertical take-off and landing

Foreword

With the rise of new technologies on battlefields and in conflict zones, modern warfare is changing significantly. Unmanned aerial systems, more commonly known as drones, have become an important tool for armed forces, especially since 2001 when armed drones have been regularly deployed by military forces and intelligence agencies. Surveillance drones have also become incorporated into many aspects of military planning and are now commonplace on operations. As a result of increased drone use, the defence industry has stepped up its investments in developing unmanned technology, making it one of the fastest growing sectors in this industry. This trend has, more recently, been reflected in the commercial sector. In recent years, armed non-state actors have been jumping on the drone bandwagon and have incorporated commercial off-the-shelf (COTS) drone technology into their operations. From Hezbollah attempting to detonate explosive packed drones in Israel, to the Islamic State in Syria and Iraq using drones for coordinating artillery fire and scouting enemy positions, drones have played an increasingly important role. Several plots by groups to use drones for terrorist attacks in Europe have been thwarted.

PAX has expressed concerns in various reports and has spoken out publically on the rapid proliferation of both military and dual-use drone technology, noting the absence of effective regulation, which lacks any connection with the reality of the booming drone market.

PAX believes protection of civilians during armed conflict in relation to the use and proliferation of unmanned systems deserves more scrutiny, especially in arms export controls. We are only at the beginning of an era where these technologies will change the state of play for states, armed groups, and terrorists. The rapid development of drones will continue; drones will get smaller, faster, more autonomous, and able to operate in swarms with a variety of payloads, including lethal options. Yet, substantial efforts to curb the flow of these unmanned systems and related technologies to unwanted end-users have been absent in many relevant export control regimes and treaties. States, as well as industry and civil society organisations, have an important role to play in preventing unwanted end-users utilizing these technologies. Bearing in mind the vast numbers of commercial drones being produced and exported, and the complexity of achieving a complete oversight and necessary export controls on these COTS items, improvement of this process is urgently needed.

This report by ARES clearly demonstrates the need for urgent action to be undertaken by the relevant authorities and organisations. Providing detailed information on the variety of commercially-available drones, their payloads, and use by non-state armed groups, this report is an important contribution to the ongoing discussion on arms export controls for drones. Furthermore, by documenting and identifying these developments, the report provides a much needed input for policy makers, licensing officers and other relevant experts and decision makers dealing with export controls. Readily-available civilian unmanned vehicles can be easily turned into a vital instrument for supporting armed actions, a challenge that calls for a coordinated global response and solution, ensuring that the gap between reality and regulation will be bridged.

Jan Gruiters
Director PAX

Introduction

The past decade has witnessed an explosion in the popularity, availability, variety, and capability of small, remotely-piloted aerial vehicles designed and produced for the commercial market. A corresponding increase in the use or attempted use of such systems by non-state actors and armed groups has been documented, with such systems being employed to support operations in ongoing conflicts, criminal activity, and terrorist attacks. The use of these technologies can provide non-state actors with advanced capabilities which offer tactical flexibility without the requirement for a complex support network, making them ideal force enablers for asymmetric and 'hybrid' conflicts.

Non-state armed groups have employed commercial off-the-shelf (COTS) unmanned aerial vehicle (UAV) technology since the early 1990s. Sometimes known as 'drones', UAV technology has advanced rapidly in the commercial sector in recent years. There has been a notable increase in the frequency and sophistication of the employment of these technologies, especially within asymmetric conflicts. Recent hostilities in Iraq, Libya, Syria, and Ukraine have brought increased media attention to the use of UAVs by non-state actors, however assessments of the operational history of COTS small UAVs in conflicts zones remain comparatively limited.

In most cases, COTS small UAVs have been used by non-state actors to support intelligence, surveillance, target acquisition, and reconnaissance (ISTAR) missions and information operations. This is partially due to a lack of strong communications and intelligence infrastructure amongst many armed groups, with UAVs offering a comparatively accessible and cost-effective alternative to traditional military ISTAR platforms and systems[1].

With military UAVs typically unavailable to all but the largest non-state actors who enjoy the support of benefactor states, COTS small UAVs offer attractive alternative. In some respects, similar functionality can be achieved through the use of commercial systems, especially in light of the more localised nature of conflicts fought by many non-state armed groups. Cheap, highly portable systems which can offer a distinct tactical advantage are ideally suited for modern asymmetric warfare as practiced by many non-state actors.

In order for policymakers and other key stakeholders to correctly identify and address potential threats to security posed by this growing phenomenon, a basic technical literacy must first be made available. This report provides the reader with a technical overview of small UAV systems, their technologies, capabilities and applications, as well as addressing broad market trends and horizon developments within the COTS small UAV sector. This report further provides an indicative use history of UAV systems in service with non-state armed groups and an assessment of operation trends associated with this use and proliferation, followed by an examination of current and proposed regulatory controls and counter-measures.

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[1] See, for example (Argentieri, 2015).

Key Findings

Recognising the inherent limitations in examining the use of emergent technologies in conflict zones and amongst non-state actors, the report presents the following key findings:

- There has been a significant increase in the quantity, variety, and capability of COTS small UAVs employed by non-state actors;
- COTS small UAVs can offer non-state actors capabilities that may not otherwise be readily available to them;
- Man-portable, lightweight UAVs with advanced capabilities offer non-state armed groups tactical flexibility without the requirement for a complex support network, making them ideal for asymmetric conflicts;
- COTS small UAVs have been employed by non-state actors in a variety of roles, including ISTAR, information operations, and offensive capacities; and
- A range of non-state actors employ COTS small UAV technology, and are not clearly limited by either geography or ideology (see Fig. I).

Figure I – Confirmed, planned, or suspected use of COTS small UAVs by non-state actors in support of violent actions

Source: ARES, 2016

Definitions

Understandings as to precisely what constitutes an UAV can differ depending on the institution or organisation providing the definition. This report will use the US Department of Defense distinction, which defines UAVs as:

> *"Powered, aerial vehicles that do not carry a human operator, use aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload.[2]"* (Bone & Bolkcom, 2003).

There are myriad other terms used to refer to UAVs, including unmanned aircraft (UA), unmanned aircraft systems (UAS), remotely-piloted aircraft (RPA), drones, and model (or remote-controlled) aircraft. RPA, UA, UAS, and UAV are all commonly used, sometimes interchangeably, by stakeholders including government agencies, military organisations, and industry groups. In general, whilst RPA, UA, and UAV refer discretely to the airborne vehicle, the UAS term also includes other equipment involved in the piloting of these aircraft, namely control stations (ADF, 2015). UAS is sometimes considered synonymous with the term "UAV systems". The term "drone" is applied liberally when referring to UAVs, in particular by the media. The broad use of 'drone' as a catch-all for any unmanned aerial vehicle (and, on occasion, for unmanned ground or naval platforms) has resulted in little-to-no technical distinction being associated with the term. Whilst some have claimed it refers specifically to those UAVs that fly completely autonomously, without human input, this is not widely accepted in lay usage (Villasenor, 2012). The lack of technical specificity through its overuse means that the term 'drone' is actively avoided by many industry and academic parties and, accordingly, it will not be used in this publication. Model aircraft, often known as "remote-control" or "remote-controlled" aircraft, are generally considered to be UAVs flown strictly for hobby and recreational use, with no commercial, government, or research purpose[3] (CASA, n.d.; FAA, 2015).

Because the weight of UAVs can vary dramatically, a size or other categorical descriptor can often precede many of the above terms. A 'small UAV'[4] is defined within this publication as any UAV weighing less than 25 kg. This weight boundary generally agrees with many civil aviation authority regulations, particularly the US Federal Aviation Administration (FAA), which defines 'model aircraft' as those unmanned aircraft flown for hobby or recreational use that weigh no more than 55 pounds (25 kg) (FAA, 2015). The United Kingdom's Civil Aviation Authority (CAA) also uses weight categories to classify UAVs, with those in excess of 20 kg requiring registration or other special conditions (CAA, n.d.). For many countries the weight of unmanned aerial vehicles is an important threshold for categorising UAVs, and the introduction and implementation of UAV policy and regulation.

"Commercial off-the-shelf[5]" (COTS) is a phrase often used by government departments or agencies, generally referring to products, supplies, and services that are available in the commercial marketplace[6]. In the context of this publication, the term 'COTS' is applied to those UAV systems and components that are commercially available and can be purchased by members of the general public, in order to distinguish them from purpose-built or homemade items, or items restricted to use by certain qualified parties. In the common vernacular, this is sometimes considered to be synonymous with the term 'consumer-grade'; however, the price point and target market of some COTS items places them outside the realm of what would typically be considered as such.

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[2] Many US Department of Defence publications make the further distinction that "ballistic or semiballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles" (JCS, 2009).

[3] Some interpretations of the term 'model aircraft' can specifically refer to remotely-piloted aircraft that are scale models or miniaturized replicas of full sized, manned aircraft.

[4] In some publications this is denoted 'sUAV'.

[5] Sometimes referred to as 'commercially available off-the-shelf'.

[6] The COTS term can sometimes have further qualifiers, dependent on the government department or agency.

Section 1: COTS small UAV Technology

This section seeks to broadly assess the wide range of shapes, sizes, and types of COTS small UAVs which are produced for the commercial market. The majority of these can be categorised as either fixed wing or rotary wing aircraft. UAVs are further described using characteristics such as range, endurance, altitude, speed, and payload capacities (Table 1 gives a comparison of some common COTS small UAVs). Their operational roles are enabled by key technologies including autopilots, communications, ground control stations, and various propulsion technologies, allowing the carriage and employment of various payloads. Common payloads can be generally divided into sensor payloads and offensive payloads. Finally, this section will address general market trends and current developments, as well as examining those developments on the horizon.

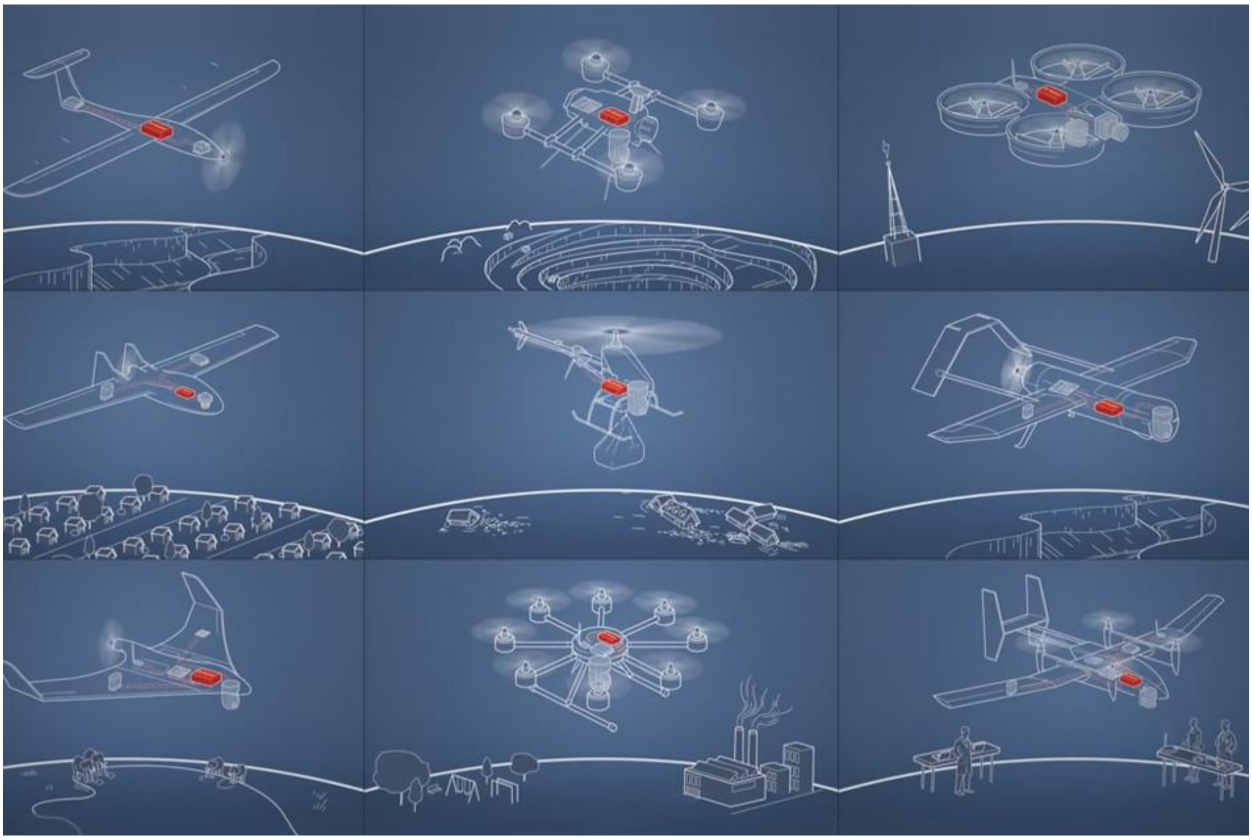

Photo credit: MIT Airware

UAV Types and Classifications

Fixed Wing

Fixed wing aircraft, commonly called aeroplanes[7], develop lift from one or more fixed aerodynamic lifting surfaces (FAA, n.d.). A basic fixed wing aircraft is typically comprised of a fuselage, tail, and a single wing[8] and one or more engines for propulsion (Shevell, 1989). In the extensive range of COTS small UAV designs it is not uncommon to see a wide variety of wing configurations. Propulsion is provided by one or more engines, with installation point dependant on the particular design. The majority of fixed wing, COTS small UAVs utilise a single engine placed in the nose or the tail, known as a tractor or pusher configuration respectively (Shevell, 1989). These engines usually take the form of electric motors or internal combustion engines which use gasoline, diesel, or kerosene as fuel.

Fixed wing, COTS small UAVs can be launched and recovered in a variety of ways (Gundlach, 2012). Those with gross take-off weights (GTOW) of 10 kg or less can generally be hand-launched, where a person throws the aircraft into the air. Heavier UAVs tend to use purpose-built catapults powered by bungee cords, or tension lines anchored to the ground on one end. Recovery is usually accomplished via parachute, deep stall landing[9], or skid landing. A deep stall landing occurs when the aircraft is flown in at low altitude and the nose is pulled up to below stall speed. It loses aerodynamic lift and falls to the ground. A skid landing is similar to a conventional landing; keeping in mind many small UAVs do not have landing gear.

Photo 1: A typical configuration for a fixed wing COTS small UAV, in this case a Finwing Penguin (photo credit: Ben Boughton)

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[7] In American English, “airplanes”.

[8] The wing is generally considered to be a single assembly with a left and right side separated by the fuselage.

[9] Sometimes known as “deepstall” landing.

Rotary Wing

Rotary wing aircraft, or "rotorcraft", achieve lift through the rotation of an aerodynamic surface known as a rotor (FAA, n.d.). Many rotary wing aircraft use a single main rotor which articulates to produce lift as well as thrust for horizontal motion, with these designs commonly known as helicopters (Johnson, 1994). The action of this main rotor produces a torque reaction which must be counteracted, generally through a tail rotor on a horizontal axis of rotation. Other approaches to counteract this torque reaction typically involve tandem rotors whose rotations counteract each other; however, COTS small UAVs utilizing this design are not common. If used, they typically take the form of a coaxial configuration[10]. Small rotary lift aircraft use either electric motors or internal combustion engines to power the rotors.

Two key strengths of rotary wing aircraft are found in the ability for vertical take-off and landing (VTOL), and the capability to hover. VTOL capability can allow operation in areas where fixed wing aircraft are physically unable, whilst hovering allows the helicopter to maintain station[11], often an advantage in surveillance applications. These advantages come with a practical trade-off, however, in that any loss of power means a loss in lift. Under certain conditions, rotary wing aircraft can autorotate[12] to attempt a safe landing. These special capabilities and limitations generally make helicopters more difficult to pilot. This challenge, with their mechanical complexity, relatively high cost, and their lower endurance and top speed generally make them less popular amongst the COTS small UAV community (Gundlach, 2012).

Photo 2: A typical configuration for a helicopter-type rotary wing COTS small UAV, in this case a E-flite Blade 400 3D (photo credit: Wikimedia Commons)

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[10] A coaxial configuration (or "coaxial rotor") is defined as having an upper and lower rotor which rotate in opposite directions, achieving torque balance (Coleman, 1997).

[11] An aerial position.

[12] Autorotation is an emergency procedure whereby the aircraft uses forward and vertical motion to store energy in the main rotor by keeping it in motion. This energy is extracted in a flare maneuver at the last moment before landing to minimize vertical and horizontal motion (Johnson, 1980).

Another type of rotary lift aircraft which constitutes a significant percentage of COTS small UAV designs, use multiple rotors[13] to generate lift, each controlled by an individual motor or engine, arranged around the periphery of the aircraft. These aircraft are commonly called “multi-rotors”. Thrust is controlled by varying the power settings of each motor orienting the UAV to produce lift in the desired direction of motion. Most multi-rotor UAVs share a common design principle where the motors are installed on the periphery of the aircraft and slightly tilted[14], helping to balance torques[15] and provide stability and control (Mansson & Stenberg, 2014). The number of motors is determined in large part by the mass of the UAV, with more motors allowing a larger GTOW. A degree of symmetry is required to keep the aircraft balanced, with the most common designs having three (tricopter), four (quadcopter), six (hexacopter), or eight (octocopter) motors. Multi-rotors are almost exclusively powered by electric motors due to their lower weight and ease of integration and operation, although there are designs employing internal combustion engines which allow for better endurance, power, and payload weight (Airstier, 2015).

Multi-rotor UAVs offer similar benefits to rotary wing designs with regards to VTOL and hovering capabilities, however there are some key differences. Importantly, they cannot autorotate, so inflight power failures can be catastrophic, especially for tricopters and quadcopters[16]. As compared to other rotary wing designs, multi-rotor endurance and speed tends to be less (Gundlach, 2012). Despite these drawbacks, powered lift UAVs have become a far more popular platform than the rotary wing aircraft in the COTS small UAV market, as evidenced by the success of large commercial manufacturers specialising in these UAV types.

Photo 3: One typical configuration for a multirotor-type rotary wing COTS small UAV, in this case a Gaui 840H hexacopter (photo credit: Drones Magazine)

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[13] Importantly, these designs use fixed propellers, as opposed to the articulating wings found in helicopter designs. These articulating wings in the main (or coaxial) rotor blades of a helicopter can move individually, or as a system, depending on the specific design.

[14] For example, in a quadcopters, there are two pair of motors that lean towards each other. This allows for the UAV to turn left and right.

[15] Roll, pitch, and yaw; often referred to as ‘moments’.

[16] With one engine ceasing to function, tricopters and quadcopters can no longer maintain balance. The redundancy and motor layout of hexacopters and octocopters can sometimes allow them to tolerate the loss of one or more engines, depending on the design.

Photo 4: A powered-lift type UAV displayed by Amazon Prime Air (photo credit: Amazon)

These classifications capture the vast majority of UAV types, but are not exhaustive. In some cases UAVs can or could employ different designs. A contemporary example is seen in promotional material for the proposed Amazon Prime Air service, which shows a UAV of a powered lift design[17] (see Photo 4).

Technical Characteristics

Range

The term 'range' can refer to two distinct measures of UAV performance: aircraft range[18] and datalink range. Aircraft range refers to the maximum distance the aircraft can fly in a given configuration and at a prescribed flight condition (Gundlach, 2012). For example, a given UAV with a particular payload will be capable of flying a specified maximum distance at a given speed and altitude. Many variables can affect aircraft range, including altitude, aerodynamic efficiency, battery or fuel capacity, propulsion efficiency, speed, weight, and wind. The aircraft range for the vast majority of COTS small UAVs can be anywhere between 1 kilometre[19] and tens of kilometres (Gundlach, 2012).

Datalink range is the maximum distance at which the aircraft can successfully maintain communication with the ground control station (GCS). This depends on a multitude of factors including environment, frequency, and power levels. For UAV operations datalink range is often the primary constraint. Transmission power is often limited by the manufacturer's design, industry standards, or regulation. Civilian UAV users have fewer radio frequency options, and must often use higher frequencies which have greater path losses as well as being more susceptible to

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[17] Powered lift aircraft, as defined by the FAA, depend principally on engine-driven lift devices or engine thrust for lift during these flight regimes and on nonrotating airfoils for lift during horizontal flight.

[18] When expressed simply as 'range', this report refers to aircraft range.

[19] It should be noted that especially small UAVs – such as those that fit entirely in the palm of one's hand – can have aircraft ranges significantly less than 1 km.

environmental factors such as moisture[20]. There is some flexibility with regards to the type of antenna used, but compromises must be made to extend range. For example, one way to extend range is to use a directional antenna that points towards the UAV. If the UAV moves out of the view of the antenna, however, the datalink performance may be significantly degraded. With these limitations, UAV datalink ranges are typically be between 1 and 10 kilometres for COTS designs[21].

Endurance

Endurance is generally considered the primary performance parameter for COTS UAVs, and is a measure of how long the UAV can stay in the air. It may be measured as total flight time or the amount of time the aircraft can stay on station (on-station time)[22] (Gundlach, 2012).

As with measures of range, endurance varies significantly from one UAV design to another. High endurance UAVs typically have long narrow wings and streamlined fuselages to minimize drag. High endurance small UAVs also tend to use propellers because of their superior efficiency. For example, the military-use ScanEagle UAV has an endurance in excess of 24 hours with its internal combustion engine (Boeing, n.d.). Meanwhile another military UAV, the electric powered Puma AE, has endurance in excess of 3.5 hours (AeroVironment, 2013). Electric-powered COTS fixed-wing small UAVs can be expected to have an endurance on the order of 60 to 90 minutes (Gundlach, 2012). It should not be inferred that military UAVs have substantially more endurance than their civilian counterparts, however. UAVs that are comparable in aerodynamic design, size, and technology generally achieve comparable performance.

Unlike aeroplanes, multi-rotors have much less endurance due to their powered lift rather than aerodynamic lift designs. Most COTS configurations have an endurance on the order of only 20 to 30 minutes. Endurance can be increased through modifications, such as exchanging payload weight with extra batteries, but this can have obvious drawbacks depending on the application. Endurance limitations are generally accepted by most users, but it is worth noting its significance as a factor affecting sustained flight operations, and thus the viability for use in conflict applications.

Altitude

The maximum operational altitude of UAVs is typically constrained more by payloads and operational choices than by the performance of the aircraft. As with all aircraft, lift and thrust are negatively affected by lower density air, whether caused by elevation or temperature. This limitation, if it becomes a factor affecting the UAV, is addressed by decreasing the aircraft's GTOW, often resulting in a decrease in the weight of fuel or the payload carried. Payloads may be constrained themselves by the maximum range or field of view of a sensor, affecting the practical maximum altitude at which the carrying UAV can operate. Military users often make a compromise between payload performance and reducing the probability of being detected by the opposing force. Hobbyists and commercial operators are typically constrained by regulation to avoid other air traffic. Non-state actors may or may not need to respect regulations or other restrictions in order to achieve their goals. In the broadest sense, COTS small UAVs can be capable of flying anywhere between ground level and upwards of 300 meters above the ground[23].

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[20] For more information on path losses, see (Poole, n.d.)

[21] Author's analysis; barring very short range systems.

[22] The time an aerial platform is able to remain active within an area of operations and capable of conducting its primary mission.

[23] Author's analysis. Several COTS small UAV models are capable of maximum altitudes of a few kilometres.

Speed

Fixed wing UAV speeds are selected and adjusted primarily to deliver optimum performance for a particular phase of flight. For example, there are ideal speeds to use for maximum range and endurance; these are often considered the most important. Speeds vary significantly with weight, design, propulsion, and other factors, but they are typically between 10 and 50 meters/second for fixed-wing small UAVs (Gundlach, 2012). High speed is usually not a top priority for the vast majority of COTS small UAV users, but are possible through specifically optimised aircraft designs, especially those which utilise jet or pulsejet engines. While not a COTS item, one specially-designed model aircraft set a world speed record of 196 meters/second in 2013 (Raposo, 2014).

Rotary wing and powered lift UAVs, by comparison, are typically only capable of much lower flight speeds, and tend to vary from zero to around 15 meters/second for COTS models[24]. As with fixed wing designs, much faster speeds have been achieved with specialist designs of both helicopter and multi-rotor aircraft[25].

Payload Capacity

Payloads can be installed in a variety of locations on a small UAV (Gundlach, 2012). The vast majority are typically located towards the nose or on the centre bottom of the aircraft's fuselage, either external to, or sometimes within, the fuselage itself. This is allows camera and sensor payloads a clear field of view. Internal payloads have the benefit of reducing aerodynamic drag, and increasing endurance, range, and speed. Cameras and similar sensors can be fixed to moveable mounts known as gimbals, while fixed sensor payloads require the UAV to manoeuvre more to adjust the field of view. The gimbal solves these limitations by allowing the payload to move independent of the UAV in two or three axes. The simplest gimbal has two servos, one for pan and one for tilt, controlled by the pilot or a payload operator. More advanced gimbals also have inertial stabilization which helps to mitigate the effects of manoeuvring, vibration, and air turbulence.

Payload capacity can vary significantly depending on the UAV design, but a generalised rule of thumb suggests that maximum payload capacity usually falls between 10 to 20% of the aircraft's GTOW[26] (Raymer, 2015). This applies to all small UAVs regardless if their aeroplanes or multi-rotors. Thus, larger models within the category of COTS small UAVs could potentially have maximum payload capacities in excess of 5 kg. It should be pointed out, though, that this rule applies to circumstances where the best possible endurance, range, or some other performance factor is a goal. As in many parts of aircraft design and operation, payload weight can be traded for performance. For example, multi-rotor lifting capacity depends on propeller thrust. The thrust is governed by propeller diameter, pitch, and speed as well as air density and the number of blades making up the propeller. The typical approach to achieving large increases in thrust is to increase propeller diameter or speed. Both approaches, however, absorb more power (Lowry, 1999). This will result in less endurance if additional battery capacity or fuel is not provided. A good demonstration of this trade-off has been provided by a COTS small UAV user who experimented with various payload weights. He found the DJI *Phantom 3* could carry about 1 kg of payload, but lost an estimated 14.4 minutes of flying time from the no-payload baseline[27] (DronExpert, 2015). The motor may also be limited to the amount of power it can deliver. This problem can be overcome through significant design changes, as evidenced by Airstier's *yeair!* multi-rotor design. Instead of electric

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[24] Author's analysis.

[25] For helicopters, one design was recorded at approximately 77 m/s (Radu, 2015), and a quadcopter thought to be capable of over 35 m/s has also been seen (Engelking, 2015).

[26] It is important to note that there are a great many factors which can affect this figure.

[27] The baseline was 1.206 kg GTOW at a flight time of 24.4 minutes.

motors, the developer employs combustion engines to rotate larger 13-inch propellers at speeds up to 12,000 revolutions per minute. The resulting increase in thrust supposedly allows a payload capacity which is 30-45% of the GTOW as well as an endurance approaching one hour (Airstier, 2015).

Table 1 – Comparative technical characteristics of selected COTS small UAVs

Manufacturer	Model	Span (mm)	Weight (g)	Payload Weight (g)	Flight Time (min)	Datalink Range (m)	Maximum Speed (m/s)
Rotary Wing (multi-rotors)							
Parrot	Bebop 2	463	500		25	300	18
DJI	Phantom 3 PRO	350	1280		23	5000	16
DJI	Phantom 3 STD	350	1216		25	1000	16
DJI	Inspire 1	581	2935		18	500	22
DJI	Inspire 1 PRO	559	3400		15	5000	18
3D Robotics	Solo	367	1500	500	25	800	15
3D Robotics	X8+	618	2560	800	15	300	
Yunteec	Q500 Typhoon	510	1700		25	500	
Fixed Wing							
3D Robotics	Aero-M	1880	3000	500	40	1000	15
X-UAV	Talon	1718	3500				
Skywalker Tech	X-8	2120	3500	1000			25
SenseFly	Ebee	960	690		50	3000	25

Source: manufacturers' specifications.

Key Technologies

Autopilots

An autopilot is the part of the UAV control system[28] located on-board the aircraft. For small UAVs, it is usually a single assembly comprised of the hardware and software necessary for:

- Stabilisation of the aircraft;
- Controlling the aircraft's orientation, position, speed and course; and
- Controlling sub-systems on-board the aircraft including the payload and communications[29].

The degree of autonomy – a system's ability to execute a task without human intervention – a UAV autopilot system is capable of is often a source of confusion, as many manufacturers advertise their

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[28] More complex autopilot flight systems may be referred to as 'flight control systems' or FCS.

[29] Sub-systems such as payloads may be controlled completely separately from aircraft controls. However, for small UAVs, where weight, space, and power are at a premium, designers will often try to integrate several functions into one on-board unit.

UAVs or autopilots as ‘completely autonomous’. To better understand this point, one must consider the mode of operation used by the autopilot: semi-autonomous or fully autonomous (Huang, 2004). Semi-autonomous autopilots automatically control some functions at all times during operation, and others at the operator’s discretion, upon command from the operator. When a UAV is fitted with a fully autonomous autopilot, operator influence decreases even further. The operator provides parameters, such as reaching a certain destination at a certain time, or finding and tracking targets or a certain type, and the autopilot controls the UAV in order to complete the set task. When this definition is applied, very few operational autopilots are genuinely *fully* autonomous (Huang, 2004).

Most autopilot systems control flight stabilisation and functions that reduce pilot workload. These functions can include holding altitude, course, and speed, as well as following given or known paths[30]. As a result, when an autopilot manufacturer speaks of a “fully autonomous flight”, they often mean that mission data is pre-programmed for the autopilot to execute on a time or event basis. Several autopilots also have a manual control mode where the pilot can bypass the autopilot and directly control the aircraft with joysticks or another input device.

An autopilot is not a necessity, as evidenced by the decades of model aircraft use before autopilot technologies were commonplace. Manual control flight, especially with first-person view (FPV) technology, can be a very effective means for small UAV piloting (see General Market Trends section, below). Flight stabilization systems are a kind of single-purpose autopilot[31], and can also be used in conjunction with a remote control to make piloting easier.

Autopilots rely on a variety of hardware components which are readily available today as a result of advances in consumer electronics and automobiles. They require one or more microprocessors and the capability to measure flight parameters such as acceleration, angular velocity, orientation, and position, as well as aircraft health parameters such as battery voltages or fuel reserves. Simple autopilots do not require powerful processors and sensors. Several military UAVs still operate with technology that is over 10 years old because of strict qualification requirements[32]. Civil users, especially those not bound by civil aviation authority regulations, are more likely to move to new technology as it becomes available because of increased capabilities, ease of development and support, and the desire to use the latest components available. The speed of adoption, however, can be driven by the autopilot’s design. Highly integrated autopilots, where the processor(s) and sensors are on a single electronics board, will slow migration to newer technology due to the need to redesign the boards. Meanwhile, plug-and-play[33] autopilots separate the processor(s), sensors and other components. This approach allows the designer to upgrade individual components over time.

Communications

The communications pathway between the aircraft and the ground is known as a ‘datalink’. Datalinks come in many forms to meet design requirements, as well as the capabilities of the manufacturer and user. Table 1 lists the general types of datalinks used with COTS small UAVs. Note that with an autopilot, a datalink is not necessarily a required piece of equipment.

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[30] See, for example, (UAVFlightcontrol, n.d.).

[31] See, for example, (Eagle Tree Systems, 2014).

[32] Author’s analysis; interviews with confidential sources.

[33] The notion of ‘plug-and-play’ components is derived from the computer industry, where manufacturers or users can alternately interchange a number of different components as required. Standards are employed to ensure hardware and software interfaces will function as intended when the components which meet such standards are combined.

Table 2 – Datalink Technologies

Type	Purpose	Ground Equipment	Aircraft Equipment	Example
Command Uplink	Control the aircraft and payload	Transmitter	Receiver	72 MHz Remote Control
Telemetry Downlink	Send instrumentation data to the ground	Receiver	Transmitter	900 MHz Digital Radio
Video Datalink	Send video to the ground	Receiver	Transmitter	5800 MHz Analog Video
Bi-directional Datalink	Moves command and telemetry data and may also send digital video	Transceiver	Transceiver	2400 or 5800 MHz WiFi

Sources: (Hitec Multiplex, n.d.; Digi, n.d.; RF-Links, n.d.)

It is not uncommon to see separate command, telemetry, and video datalinks on a single aircraft. This is largely due to radio frequency (RF) interference issues and the lack of completely integrated bi-directional datalinks. Manufacturers must use frequency diversity when employing this many datalinks, however, to prevent interference. For example, a command and telemetry link may exist in the 900 MHz band whilst the video datalink operates in the 2400 MHz band. Frequencies for civil use tend to be found within industrial, scientific and medical (ISM)[34] radio bands, but they can also be found in radio bands set aside for amateur radio (FPV Hobby, n.d.).

Some COTS small UAVs have also utilised cellular and satellite communications. Both create technical hurdles for autopilot designers, but are nonetheless viable approaches. In fact, UAV development programs by Alphabet (formerly Google) and Amazon (for its Prime Air service) intend to utilise existing cellular networks as their primary communications platform (Harris, 2015).

Ground Control Stations

A ground control station (GCS) is a system of hardware and software through which the operator controls the aircraft, monitors its health, and may perform pre-flight mission planning. A GCS can be a simple hand held remote control with interfaces such as joysticks and switches. For more sophisticated UAV operations, the GCS usually consists of custom software installed on a desktop or laptop computer where the UAV is controlled via inputs from the keyboard and mouse. Typically, some type of remote control system is included for aircraft that have manual flight modes. DJI and some other new manufacturers of COTS small UAVs employ smartphones and tablets running a free application, such as DJI Go, that are mounted on their custom remote control (Apple, n.d.). They also offer a software interface for third parties to develop their own applications (DJI, n.d.). Most manufacturers allow only one aircraft per pilot, and this will most likely be a legal requirement in the future (FAA, 2015b). Some UAV control technology already in use, however, does allow for multiple aircraft to be controlled by one pilot (Ugcstv, 2014). This technology could potentially be used to an advantage by a non-state actor as it would reduce the number of trained pilots required, as well as lowering the cost of GCS equipment.

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[34] ISM radio bands are unregulated radio frequencies designated for industrial, scientific, and medical applications by the member states of the ITU (ITU, n.d.).

Photo 5: an example of a small UAV ground control station, or GCS (photo credit: Gary McCray)

Propulsion

Designs of COTS small UAV propulsion systems are dominated by propellers driven by internal combustion or electric motors. All multi-rotors and many of the small fixed-wing UAVs utilise direct current (DC) brushless motors built for model aircraft. They are available in a number of power ratings from a variety of global manufacturers, and require an electronic speed control (ESC) which is connected to the UAV's control system. Some UAVs employ conventional jet engines, whilst others use units known as electric ducted fans (EDFs). As the name implies, EDFs are small fans driven by an electric motor. In the model aircraft world, they are used to mimic the appearance of a jet aircraft.

Internal combustion engines are commonly found on larger UAVs, especially when greater endurance or aircraft range is a mission requirement. These engines are typically developed for aircraft use, but owe their lineage to small power tools such as chain saws and trimmers (Popular Mechanics, 2010). Gasoline engines are generally more common, but diesel and kerosene engines are also available (RCV, n.d.). Controls are more complex and typically require a mechanical control (i.e. a servo) to actuate levers for power setting and possibly for fuel mixture control.

Another propulsion option is the pulse jet, used with fixed wing aircraft. Today's pulse jets are similar in operating principle to those used by the German V-1 missile of WWII. Small pulse jet kits as well as plans are readily available for purchase worldwide, but they generally are used only by experimental hobbyists due to their more eccentric operational characteristics which included difficulty in starting as well as significant heat and noise[35] (Simpson, n.d.). They do however offer a very affordable alternative to jet engines for high speed flight. This could prove a future concern if non-state actors sought to employ COTS small UAVs for attacks where high flight speed provides a significant tactical advantage.

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[35] See, for example (Simpson, 2009).

Payloads

Sensor Payloads

Sensors, in particular cameras, constitute the overwhelming majority of payloads carried by COTS small UAVs. Even if it has a primary mission not related to obtaining imagery, most UAVs will still have a camera on-board for piloting purposes or secondary objectives. Such items are commonly used to effect intelligence, surveillance, target acquisition, and reconnaissance (ISTAR) missions.

Camera and other sensor payloads on COTS small UAVs vary significantly, primarily dependant on the specific application, UAV size, and the user's budget. The simplest and lowest-cost FPV and aerial video systems use COTS analogue cameras[36]. The video is typically transmitted to a monitor on the ground via a wireless link operating in one of a number of amateur or ISM radio bands. These systems are usually sourced from the security and monitoring industry (Supercircuits, n.d.).

Many high definition (HD) cameras used in COTS small UAVs are essentially consumer video cameras. Installations can vary significantly, and depend on the type and model of UAV, size and weight of the camera, requirements of the operator, and other factors. Some COTS video cameras can be modified to work with existing remote control radios, either through mechanical manipulation of the camera controls, or through an electrical interface provided by the manufacturer for remote control applications (Sony, n.d.). Some major manufacturers produce 'stripped-down' models of their high-end, COTS camera hardware, intended for industrial use (Sony, n.d.). This type of camera hardware is often used with UAVs for commercial and military applications, integrated through a standard electrical interface provided by the camera manufacturer. whilst this hardware is available to hobbyist and other non-commercial or non-military operators, there are generally cheaper and less complex options available that suit the majority of this market's needs.

The introduction of lightweight 'action cameras' with a small form-factor, such as popular brands Garmin and GoPro, has provided a significant step-up in imaging capabilities, compared against the integration difficulties of their heavier, bulkier predecessors. These cameras are widely available, with a range of capabilities regarding resolution, framerate, camera modes, and other features. Perhaps the most significant advance, however, was the development of models which allowed the user to connect to the camera via an ad hoc[37] Wi-Fi network, using a smartphone, tablet, or similarly enabled device. This approach presents two significant challenges. One is the inherently short range of Wi-Fi, and the other is radio frequency interference with UAV controls.

Full HD video links are available to military users and, to lesser extent, some commercial users. Typically, if civil users want to view video from an attached HD camera, they either need to transmit the video in standard definition or add a second standard definition camera. For a long time, the military faced similar problems, but they have had the resources as well as the flexibility in radio spectrum [38]to develop custom solutions to this problem. The market available to general consumers, by comparison, is still young and faces numerous technical and legal hurdles to attaining a high enough speed connection for real-time HD transmission, but progress is being made by some developers. One of the best examples is DJI's Lightbridge, which is oriented towards commercial

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[36] Analogue refers to the manner in with the video signal is encoded. Common standards for this type of video are known as NTSC, PAL, and SECAM.

[37] An 'ad hoc' WiFi network is a special-purpose local area network where devices communicate directly with each other without the need for a base station to coordinate messages. It is also known as a peer-to-peer network.

[38] Nations allocate parts of the radio spectrum for specific uses. Military UAVs generally have access to a larger total portion of the radio spectrum than commercial UAVs. See (FCC, n.d) for more information on allocation.

UAV operations (DJI, n.d.). Like standard WiFi, it operates in the 2.4 GHz ISM band which limits its range and makes it susceptible to radio frequency interference.

Infrared (IR), or thermal cameras, can be increasingly found on COTS small UAVs as a secondary payload, and have a range of industrial applications such as use in the agricultural and security sectors. Use controls, cost, and form factors have long been traditional barriers to private entities using high grade IR cameras. Some companies have now released versions of their cameras specifically for use on COTS small UAV systems at relatively affordable prices, and with fewer export restrictions (FLIR, 2015). In some states, like the United States, higher resolution and frame rate models of IR cameras remain subject to export controls[39]. In some instances, IR camera kits are for sale on the internet, though their effectiveness for use on COTS small UAVs remains in question. The increasing availability and accessibility of more advanced technologies, such as IR cameras, is a trend that is likely to continue. There are other, more specialised, payloads available to COTS small UAV operators. These payloads (see Table 3) are less commonly deployed ue to their cost, immature markets, and relatively narrow applications. Some payloads, particularly those associated with agriculture, energy, mining, and security, will become more prominent as those markets mature.

Table 3 – Other UAV Payloads

Payload	Description	Applications	Applications by a Non-State Actor
Hyperspectral Camera	A camera that simultaneously collects images at a high resolution over a wide part of the light spectrum.	Survey[40] Security	Counter-concealment
SAR **(Synthetic aperture radar)**	A type of imaging radar which can provide imaging through clouds, fog, foliage, rain, and smoke.	Navigation[41] Survey	Counter-concealment Survey Surveillance
LIDAR **(Light detection and ranging)**	Analogous to SAR, but uses lasers instead of radio which limits penetration capabilities.	Navigation Survey	Counter-concealment Survey Navigation
Stereoscopic Camera	A camera which captures 3-dimensional (3D) imagery.	Film Navigation Survey	Counter-concealment Survey
Magnetometer	A sensor to measure the Earth's magnetic field over small areas at high resolutions.	Survey	Counter-concealment
Radio Frequency (RF) Devices	A radio that receives signals over a defined range of the radio spectrum.	RF Survey	Signals Intelligence

Sources: Bayspec, n.d.; Matthews, 2008; AutonomousStuff, 2014.

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[39] See, for example, (FLIR, n.d.).

[40] Survey could include markets such as agriculture, energy, environmental, mapping, mining, and transportation.

[41] Used as an additional sensor for control of the UAV.

Offensive Payloads

Apart from sensor payloads, COTS small UAVs have been equipped with both lethal and non-lethal offensive payloads, either using the UAV as a weapons platform, or as a guided weapon itself. Weaponised UAVs in service with militaries contain models that fit into both categories. A good example of the latter is the AeroVironment Switchblade. The Switchblade is a military-use, dual-role UAV employed to perform ISTAR functions, whilst also containing an integrated warhead capable of engaging targets in much the same way as a small air-launched precision munition. If no target is found, it can return to the operator for reuse (AeroVironment, 2012). It is considered a 'loitering munition' by some observers. Whilst the vast majority of UAVs that serve as weapons platforms in military use are beyond the 'small' definition that is the focus of this report, the ongoing miniaturisation of precision guided munitions suggests that their incorporation into small UAV systems in the future is a distinct possibility. Modern example of these small precision guided munitions include the Raytheon Pike laser-guided missile, with a range of over 2 km and a weight of less than 1 kg (see Photo 6), as well as the Lockheed-Martin Shadow Hawk (Photo 7) and the US Naval Air Systems Command Spike munition programme (Gibbons-Neff, 2015; Lockheed Martin, 2012; McDuffee, 2014). The trend towards the miniaturisation of PGMs means there are likely to be a number of munitions in the 1 – 5 kg class which could theoretically be carried by COTS small UAVs. However, the integration of such munitions is likely to prove difficult, with reliability and safety posing significant concerns. The launch and recovery methods of small UAVs may not be widely compatible with externally-mounted munitions, for example.

Photo 6: Raytheon Pike precision guided munition (photo credit: Brendan McGarry / Military.com).

Photo 7: Lockheed Martin Shadow Hawk precision guided munition (photo credit: Gizmag).

In the law enforcement sector, a handful of manufacturers are employing less-lethal weapon payloads on small UAVs, and in some cases this includes COTS models. The South African company Desert Wolf, for example, have marketed the *Skunk* octocopter UAV as a “riot control copter” (see Photo 8). The Skunk is equipped to fire paintballs, OC (‘pepper spray’) projectiles, and solid plastic projectiles (Kelion, 2014). Another manufacturer offers a riot control UAV equipped with a 38 mm less-lethal launcher, for use with riot control agents and other projectile types[42] (Vinveli, n.d.). Some early adoption of small UAVs equipped with less-lethal payloads has already occurred, including the purchase of five small UAVs intended for riot control use by law enforcement in Lucknow, India (Sarkar, 2015). In a similar vein, the US state of North Dakota recently passed a law that gives police the option to employ small UAVs equipped with rubber bullets, OC, CS (‘tear gas’), sonic weapons, and conducted electrical weapons (such as the prevalent Taser brand) (Glawe, 2015) There is a growing interest in the development and acquisition of UAVs to deliver less-lethal payloads, and the increased adoption of such systems could result in their acquisition by non-state actors (Crowley, 2015).

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[42] Rounds include 2-chlorobenzylidene malononitrile (CS), chloroacetophenone (CN), oleoresin capsicum (OC), marking dye, and flares.

Photo 8: Desert Wolf Skunk ‘riot control copter’ UAV (photo credit: Desert Wolf).

Of greater concern to many stakeholders is the weaponisation of COTS small UAVs by non-state actors, criminal groups, or individuals seeking to commit violent acts. The range of weapons and weapon types that could be integrated with COTS small UAVs by these groups is potentially vast, and includes small arms, such as handguns or submachine guns; conventional munitions, such as mortar projectiles or grenades; improvised explosive devices (IEDs); and chemical or biological weapons. The method of weapon payload integration, and the effectiveness of such payloads, will also vary significantly, determined by a range of factors including desired application; UAV type, size, and GTOW; payload type, size, and method of function; and more.

One common threat scenario is the employment of a COTS small UAV to deploy explosive devices, whether an IED or repurposed conventional ordnance like hand grenades or mortar projectiles. This could potentially be used against a populated area for a mass casualty strike, or a more precision strike where a UAV may offer advantages in the entering of a secure area. Depending on the size and capability of the UAV, and the method of integration of the payload, more than one explosive device could be carried, potentially allowing for a significant increase in tactical capability. Any deployable payload would also require the inclusion of a remotely operated release mechanism and addressing the payload’s specific arming and initiation requirements.

Another common threat scenario is the employment of a COTS small UAV as an airborne IED, with explosives integrated into the UAV itself, which acts as a delivery mechanism. An integrated explosive device would require an initiation system, most likely a time-delay fuze, an impact fuze on the fore-end of the UAV, a command-activated detonator, or any combination of these. Depending on the explosive compound employed, even a relatively small weight of high explosive (HE) could prove destructive against unarmoured targets including people, automobiles, buildings, or critical infrastructure.

A less common option for weapons payload is the integration of small arms, likely a pistol or other lightweight, small calibre firearm, with a COTS small UAV capable of holding a fixed position. Only a handful of examples of this have been seen; the best known was a project from a Connecticut college student, with a quadcopter-mounted pistol capable of firing multiple rounds (Martinez, 2015). The efficacy of this application is questionable at best, with even the relatively small amount of recoil associated with a small calibre firearm dramatically affecting the stability of the UAV, and thus the accuracy of the weapon. A UAV with a larger GTOW would likely aid in the reduction of this recoil effect.

Chemical or biological payloads dispersed from COTS small UAVs could prove devastating against vulnerable open-air targets, such as large crowds or water reservoirs. The potency of such an attack would depend almost entirely on the specific payload, but even an ineffectual payload could have a substantial symbolic or psychological impact. Attempts to distribute chemical weapon payloads have a historical precedent in the unrealised efforts by Japanese doomsday cult *Aum Shinrikyo* to employ a radio-controlled helicopter to distribute sarin gas in 1994 (Ballard et al., 2001). Some civilian and law enforcement technologies already under consideration or development, such as less-lethal payloads and 'crop duster drones' (see Photo 9), could potentially be adapted for the distribution of biological or chemical agents.

Photo 9: A UAV conducting crop-dusting operations (photo credit: Juniper Research).

While not conventionally considered a weapon, certain RF devices, such as some of those outlined in Table 2, could be used for offensive purposes. Payloads designed to penetrate wireless networks for surveillance and cyberattack purposes have already been built (Greenberg, 2011). Software-defined radios (SDR)[43] such as the Hack RF One, as well as traditional radios, could be used to jam signals for aircraft navigation, law enforcement and first responders, or a number of wireless networks in use today (GSG, n.d.).

Finally, non-state armed groups may not even require a lethal payload to successfully employ a COTS small UAV in an offensive capacity. One of the key threats posed by COTS small UAVs being assessed by security analysts is the possibility of a 'bird strike' type attack, wherein a UAV is intentionally flown into the jet engine of a passenger aircraft (Bunker, 2015). Civilian UAV use has already resulted in a number of close calls; the UK Air Proximity Board noted in January 2016 that consumer-grade UAVs had been involved in four serious Category A close misses in recent months (BBC, 2016).Inert payloads may also prove a threat. For open air events with large crowds, dropping inert powder, liquids, or devices from a COTS small UAV – giving the impression of chemical, biological, or explosive attack – may be enough to cause mass panic. This could, in turn cause injuries outright, or function as a distraction or decoy as part of coordinated, complex attacks.

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[43] A software defined radio is a radio where some of the physical components have been replaced through software functions. See (Wireless Innovation Forum, n.d.) for additional background information.

General Market Trends & Current Developments

Wider Appeal

Remotely controlled model aircraft, which have been around since the 1930s, have been historically dominated by airplanes and helicopters powered by internal combustion engines, usually flown at established model aircraft airfields or other large, open areas (AMA, n.d.). More recently, a variety of new technologies and materials have enabled the rise of electric COTS small UAVs. These aircraft are comparatively simple for the user to operate, can be operated in more areas, and can be less expensive than their combustion engine predecessors, making them very popular with those not traditionally a part of the model aircraft community. In 2015, a market research firm forecast that global sales of civilian unmanned craft will approach $5 billion USD in 2021 (Economist, 2015). As of 2015, Chinese company DJI (大疆创新科技有限公司; 'Da-Jiang Innovations Science and Technology Co. Ltd.') is estimated to comprise about 70% of the consumer UAV market.

Smaller and More Portable

One of the most significant market trends regarding COTS UAV technology is the prevailing progress towards smaller and more portable models. China's DJI firm specialises in COTS small UAVs, and in 2014 alone sold around 400,000 units of various small, multi-rotor UAVs ranging between 1 and 11 kg (Mac et al., 2015). Many other manufacturers are seeking to gain commercial access to this exploding market, with some pursuing very small designs. Microdrone 3.0, weighing a mere 71 grams, is just one of many examples of crowd-funded efforts to develop a UAV which will fit in the palm of your hand (Kerswell, 2015). The continued development of advanced materials, hardware and software technologies, and manufacturing processes will likely allow even smaller UAV designs in the near future.

Advances in Materials & Manufacturing Methods

There has been a dramatic change in materials used for small, unmanned aircraft over the last few decades. Complex, multi-piece kits comprised predominantly of metal, plastic, and wood, with associated long build times, constituted the bulk of model aircraft materials in the past, which created a barrier to entry for new hobbyists or enthusiasts. This barrier was lowered significantly with the introduction of foam models. These models generally come in two forms: ready-to-fly (RTF) and almost ready-to-fly (ARF). As the name implies, RTF models can be flown right out of the box. ARF models are sold in kit form, but they have a relatively low parts count and large components, such as the fuselage and wing, are provided as whole pieces. With fewer parts, assembly is markedly easier and quicker. Repairs to foam models are also easier because of the natural energy-absorbing nature of the material, and the multitude of easy and affordable repair techniques. Finally, foam has made manufacturing significantly more efficient and affordable which has led to lower prices and increased choice in model designs, from many more vendors. Models can be manufactured via moulds and hot wire cutting. Companies such as China's HOOAH Aviation Technology Co., Ltd (owners of the popular 'X-UAV' brand name) make several models of ARF kits, including the 'Talon' UAV model documented in use with Islamic State forces in Iraq, discussed in Section 2, below (Friese, 2015).

While polymers are not new in the model aircraft industry, advances in plastic manufacturing processes have played a significant role in the explosive growth of consumer grade multi-rotor UAVs. As with many other consumer products, plastic moulding techniques[44] allow for low-cost mass production. DJI's Phantom series (see Photo 10) demonstrates this concept in its extensive use of

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[44] See (D&M Plastics, n.d.) for more information on different manufacturing processes.

plastics for almost every part of the aircraft. The extensive use of polymer components may impact the long-term durability of certain COTS UAVs, however, reducing the aircraft's resistance to collisions, hard landings, and general wear and tear. Manufacturers may offer a variety of replacement parts as well as ensuring by design that it is possible for users to repair their aircraft (Fisher, 2015). Commercial users may eventually find these issues too costly and transition to aircraft utilizing more composite materials[45] or advanced polymers. Composites such as carbon fibre-reinforced polymers are a popular choice for professional grade and military UAVs due to their low weight and high strength despite their more complicated manufacturing processes and higher cost (Gundlach, 2012).

Photo 10: A DJI Phantom 3 Standard rotary wing UAV, which makes extensive use of polymer components (photo credit: DJI).

Integration with Consumer Electronics

COTS small UAVs and common consumer electronics are becoming more integrated by the day, with the most obvious example seen in the widespread use of consumer camera technology. In the past, the practical integration of heavy still cameras with model aircraft, most often model helicopters, required a great deal of effort, expense, and technical skill. This integration has become easier over time, with the advent of smaller, lighter, less expensive, and more capable camera technology. This ranges from basic hand-held video cameras through to today's high definition (HD), lightweight action cameras such as the ubiquitous GoPro series.

Each jump in camera technology has corresponded with a jump in COTS small UAV capability. In the past imagery was recorded on-board and viewed after the aircraft completed its flight. Many cameras now offer WiFi connectivity, providing short range, two-way communications, allowing pilots to not just record an image, but to frame it and make other adjustments in real-time to improve the quality of the captured image. As lightweight and affordable wireless technology has become more readily available and integrated, video feeds have enabled FPV piloting. FPV pilots use an onboard, forward-facing camera transmitting to a video display on the ground, flying from the perspective of being on-board the aircraft. On-screen display devices can also be added that overlay data from on-board sensors, providing useful information to the pilot. Some dedicated, COTS FPV

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[45] See (CompositesUK, n.d.) for a more in depth discussion of composite materials.

piloting devices have been developed, further reducing the barrier to entry for this use of UAVs (Spektrum, n.d.).

Advances in widely used consumer electronics have had a significant impact regarding the control systems used with COTS small UAVs. Model aircraft have traditionally used a handheld controller consisting of joysticks and a variety of switches and dials. It is connected via a wireless link to a receiver on the aircraft which is then connected directly to servos to move the controls. Early UAV control systems built on this concept by combining joystick controllers and a computer with an on-board autopilot communicating over one or more wireless links. Increasingly, COTS small UAV systems utilise modern phones, tablets, and other ‘smart’ devices, running purpose-built software. These devices may serve as the primary pilot input, or can act as a secondary input that complements a traditional joystick controller. In both cases, the device can also act as a display for sensor data from the aircraft, including the display of video feeds and real-time mapping which marks the position of the UAV on a map like that of smartphones and automobile navigation devices.

Open Source Development & Information Sharing

While proprietary software is generally supplied with COTS small UAV models, open source development methods have become more popular in COTS small UAV software design and operation, which has lowered the barriers to entry for some new developers. With open source design philosophies popular in other parts of the software industry, developers have the opportunity to collaboratively develop, and distribute their software designs[46]. Some elements of the small UAV community have also embraced open source methods to produce small UAV hardware, including mechanical and electronics designs.

The best example of open source methods in the small UAV market is with UAV autopilots like OpenPilot (OpenPilot, n.d.). Developers and the public alike can download the bill of materials, circuit diagrams, and software to build their own autopilots. Build-on-demand companies can then fabricate the required hardware in individual or bulk quantities. Open source projects sometimes sell hardware or accessories to cover expenses.

Online platforms can also provide a good resource for enthusiasts and other parties to share advice and information regarding small UAV use, maintenance, and modification. These are generally in community-oriented online forums, but at least one documented example, discussed under Operational Trends below, shows how information sharing through online platforms can be utilised explicitly by non-state armed groups and affiliates.

Crowd-Funding

Crowd-funding has become a very popular approach to funding new COTS small UAV projects. Organisations and individuals are using platforms like Kickstarter and IndieGoGo to obtain much needed funding to cover professional design, manufacturing, and distribution requirements. This has proven to be a successful technique when used to develop entire aircraft, as well as individual components. Because a business case is generally less integral, it is possible for crowd-funding to allow the development and production of products that may not have found funding through more conventional means. For the same reason, crowd-funded projects are generally more susceptible to supply disruptions, and in some instances can culminate in a complete failure to deliver the promised outcomes. A recent, widely reported example of this was the failure of the *Zano* UAV project, funded through Kickstarter (Cellan-Jones, 2015).

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[46] See, for example, software projects on popular open source development websites like GitHub. Specific open source development references withheld on security grounds.

Additive Manufacturing

Additive manufacturing, commonly known as 3D printing, is also making its mark on COTS UAV development and manufacture. Both complete aircraft and individual components have already been manufactured using 3D printers (Clare, 2015). For individuals or groups with design skills, it opens the door to fabricating a variety of complex components from advanced polymers and, increasingly, metals. When combined with open source communities, 3D printable parts can be designed by individuals and quickly and easily distributed for production.

For companies, additive manufacturing can offer a low-cost method of production for low volume parts or prototyping new components – something which can often prove invaluable for smaller COTS small UAV manufacturers. When supported by 3D scanning technologies, additive manufacturing also allows for easy reproduction of existing parts, and it will become increasingly simple to purchase an existing aircraft and copy many parts of it with relatively little experience or expense.

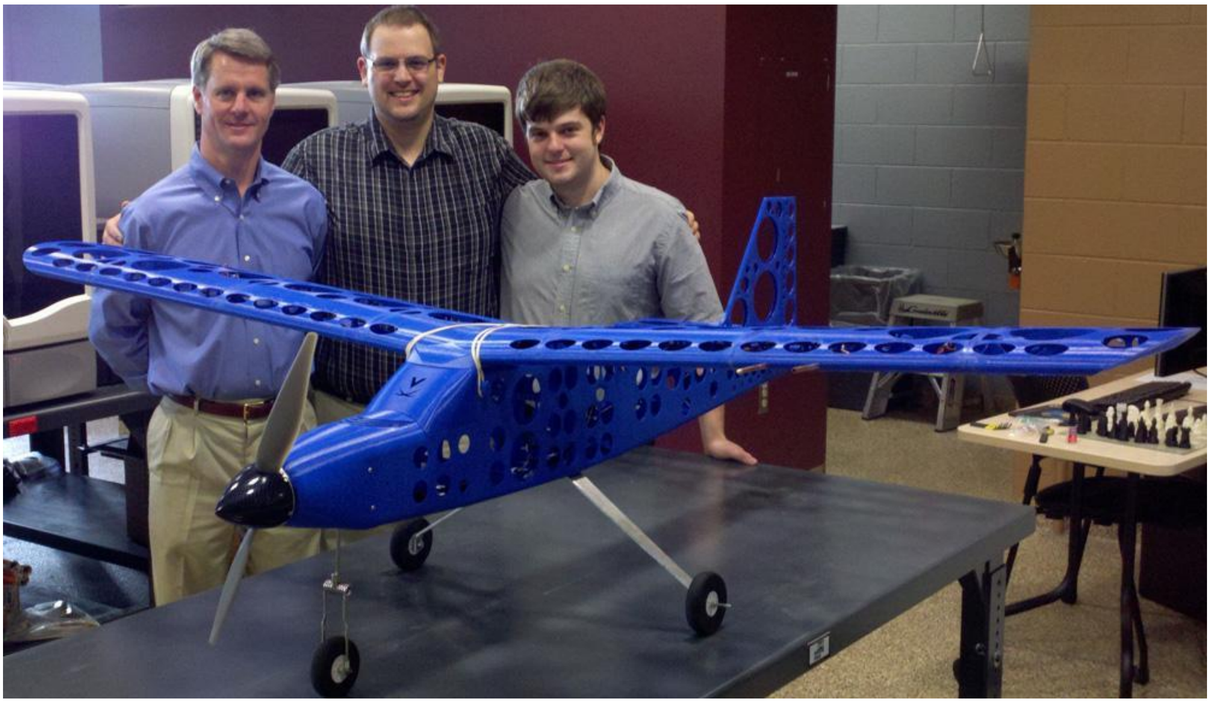

Photo 11: 3D printed exoframe, a copy of a SIG Kadet Senior design, of a fixed-wing UAV (photo credit: University of Virginia).

Horizon Developments

Airspace Integration

Seamless airspace integration between manned and unmanned aircraft is likely to be one of the most significant developments to be realised in the near-term. Most COTS small UAVs are restricted by regulation to visual line-of-sight (VLOS) operation, but some may be technically capable of operating beyond this. This capability is known as beyond visual line-of-sight (BLOS[47]) operation. There are some commercial operations, both proposed or already in development, that will require this capability. The best example of this is UAV package delivery, as proposed by online retailer Amazon amongst others (Rundle, 2015). A primary issue with commercial applications that require BLOS operation, especially those applications requiring fully autonomous UAVs, is the necessity for a

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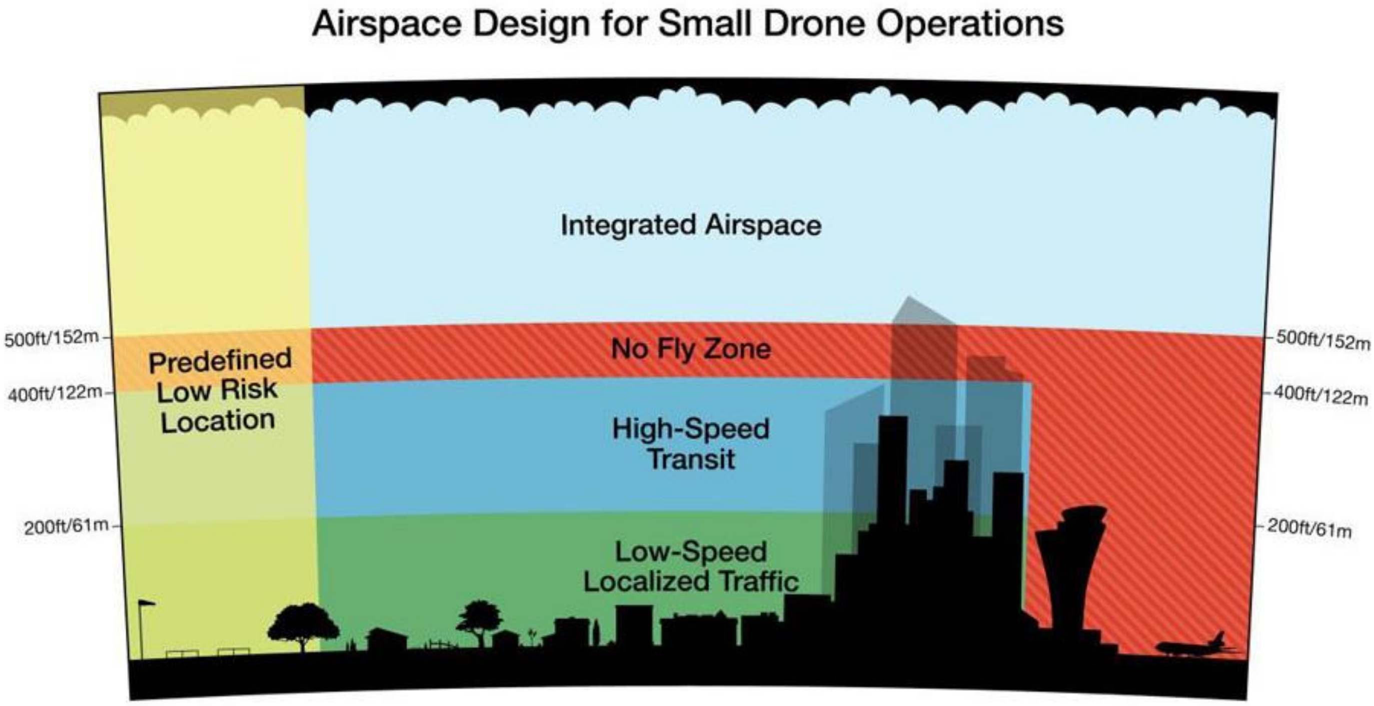
[47] Sometimes 'BVLOS'.

UAV to detect and avoid other aircraft or obstacles, known as sense-and-avoid (SAA) capability. Whilst human operators have historically served as the primary (and in the vast majority of cases, only) detection and avoidance controls, the increasingly widespread realisation of BLOS operations will require the reliable automation of these processes. Some of the proposed technologies to address this SAA requirement include the use of transponders, which will broadcast the UAV's position to air traffic controllers and other aircraft, and specialised SAA radar that will alert small UAVs to nearby aircraft (Allen, 2013). The most significant challenge with incorporating these new technologies is often in miniaturising the technology to fit inside current UAV form factors (Berry, et al., 2009).

In two recently published white papers, Amazon Prime Air discusses the need for developing clear airspace regulation for BLOS small UAVs (Amazon Prime Air, 2015a). Specifically, Amazon calls for the segregation of airspace below 500 feet - the current limit set by the FAA for small UAVs, and above which the majority of civil and military aviation occurs (Atherton, 2015). This segregation would see a 'high-speed transit' space for those UAVs which meet a predetermined minimum capability to sense-and-avoid, and otherwise operate safely and autonomously (Amazon Prime Air, 2015b) (see Figure II). The formation of a sector of airspace specifically for highly autonomous, BLOS-capable small UAVs could create huge potential for various commercial applications, and could result in substantial further changes to COTS small UAV regulations, use, and technologies in the future.

Figure II – One example of suggested air space design for small UAVs, as proposed by Amazon Prime



Source: Amazon Prime

Swarming

Swarming refers to a number of autonomous aircraft, networked together, and working towards a common goal. Currently, there are no strict definitions regarding specific behaviours or how many UAVs are required to constitute a 'swarm' (Bunker, 2015). In military applications, a swarm would likely be tasked with overwhelming a target or targets through weight of numbers and avenues of attack (Gettinger, 2014). Each UAV would have a role and a relationship with other UAVs in the swarm (see Photo 12). They would communicate and coordinate in order to accomplish a common mission. The United States Navy is currently studying the use of swarms of thirty ship-launched, low-cost, small UAVs. The swarm is designed to launch, assume a formation around a 'parent' UAV, and conduct operations with little to no human interaction (Warwick, 2015).

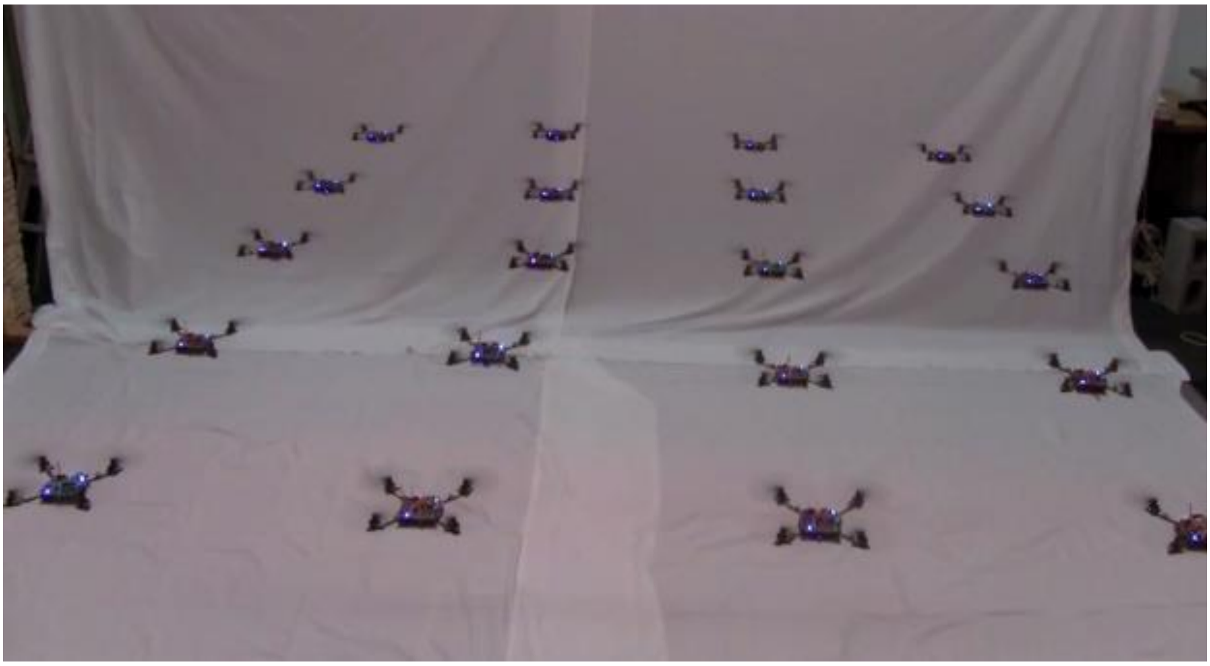


Photo 12: COTS small UAVs demonstrating basic swarming behaviour (photo credit: MIT).

Swarming technology also has the potential to aid in civilian applications, such as various agricultural tasks, or search and rescue operations. Swarming could allow small, automated UAVs with different individual payloads to conduct operations in a collaborative manner[48]. While swarming requires very advanced control and communications architectures, it could potentially allow for the use of smaller, single-purpose UAVs[49], reduce the number of pilots required, and reduce the instances of long-range communications required to operate multiple UAVs effectively.

While the continued development of swarming technologies is being undertaken by the military and some commercial actors, it remains a possibility that such a capability could eventually become available within automated, COTS small UAVs. As such, swarm capability is being carefully examined as a potential threat posed by non-state actors in the future (Bunker, 2015).

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[48] For instance, one UAV observes the signature of a person in a damaged building using a thermal sensor. This UAV could designate the location and request a second UAV with a camera to image the location and verify the finding.

[49] This means that one UAV would perform one specific role. For example, one UAV could carry an IR camera whilst another carries a standard camera.

Section 2: Operational Use History of COTS Small UAVs

Selected Use History

Early Use by Non-State Groups

The first group known to have experimented with COTS small UAVs, in the early 1990s, was the Japanese apocalyptic cult *Aum Shinrikyo*. Preceding their widely-known attack on the Tokyo Subway system in 1994, the organisation unsuccessfully tested remote-controlled helicopters with aerial spray systems designed to release the nerve agent Sarin (Ballard, et al., 2001).

Other attempts at modifying COTS small UAVs for use in terror attacks include several alleged attempts by al-Qaeda and affiliated individuals. These included a planned attack using UAVs armed with IEDs, targeting then-US President George W. Bush and other world leaders at the 2001 G8 conference in Genoa, Italy. Two further al-Qaeda plots were discovered in 2002, one apparently seeking to employ a biological agent (anthrax) against the English House Commons, and another in which a civilian airliner was the intended targets (Bunker, 2015). None of these operations were attempted, and the available evidence indicates that they were unlikely to have moved past the conceptual stage.

Further terror attacks by al-Qaeda and affiliates have been successfully countered in the United States. In 2008, Christopher Paul, and American citizen who had undergone training with al-Qaeda in Afghanistan, plead guilty to planning terrorist attacks in the US and Europe (US DOJ, 2008). Paul reportedly investigated the use of a five-foot long model helicopter as well as a model boat as potential delivery platforms for an IED. In 2011 another US citizen, Rezwan Ferdaus, was convicted of planning a terror operation in which he intended to fly remote-controlled model aircraft carrying IEDs into US government buildings (Cruickshank & Lister, 2011).

Israel, Gaza, and the West Bank[50]

Unconfirmed reports from December 2002 suggest that the Palestinian militant group *Fatah al-Islam* was allegedly testing COTS small UAVs, with the intent of using them to deliver IEDs against Jewish targets in Jerusalem. Hundreds of these UAVs were apparently ordered by Jerusalem-based toy importers with subsidies from humanitarian organisations (DefenseTech, 2003). According to reports, Israeli security forces countered this threat in at least one instance before it was put into operation (Bennet, 2013). Hamas also appears to operate models of UAV which do not fall within the scope of this report, some purported to be armed[51].

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[50] Lebanon is considered under both this sub-heading and under *Syria, Iraq, and Eastern Lebanon*, below.

[51] In July 2014 reports indicated that Hamas UAVs had been intercepted by Israeli Patriot missile systems. Some reports claimed that these drones were developed and produced within Gaza (McCluskey, 2014; Winer, 2015; Okbi & Hashavua, 2015). A video was later released by Hamas showing a large UAV supposedly similar to the earlier downed vehicle; the aircraft in question appears to draw heavily on Iranian military technology, and is neither a COTS model, nor 'small' under the definition of this report.

In November 2004, a UAV[52] operated by Hezbollah infiltrated Israeli airspace for approximately five minutes before crashing into the sea off the Lebanese coast (Harel, 2004; CNN International, 2004). Hezbollah is also known to operate military UAV models, believed to be variants of Iranian-produced designs, which fall outside the scope of this report[53].

Ukraine

The ongoing conflict in eastern Ukraine has seen the extensive use of UAVs by both Ukrainian armed forces and pro-government non-state groups and by separatist forces. The available evidence suggests that the Ukrainian government and pro-government forces have employed a wider range of COTS small UAVs in larger numbers than their opposition. Several videos posted to social media and video sharing websites have indicated that parties on both sides of the conflict have employed COTS small UAVs in the ISTAR role and, in particular, to act as aerial observers for adjusting artillery fire (Ferguson & Jenzen-Jones, 2014). Separatist forces have also employed COTS small UAVs as weaponised platforms, as well as significant numbers of military UAVs of Russian origin (Rawnsley, 2015). Notably, Separatist forces have also employed Soviet and Russian-produced jamming systems which have severely impacted government and independent observer UAV activities (Rawnsley, 2015; Ferguson & Jenzen-Jones, 2014).

Photo 13: DJI Phantom 2 series drones sent by US support groups received by Ukrainian National Guard fighters (photo credit: Chicago Automaidan).

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[52] The specific model of the UAV in question remains unclear, though one source describes it as having a 2.9 m overall length and 3.0 m wingspan (Harel, 2004). This would fit the general profile of some Iranian UAVs, such as the Mohajer 4, which is not a COTS model.

[53] One report suggests that Iran supplied Hezbollah with eight such UAVs, and trained some 30 personnel in their operation (Miasnikov, 2004). Attack operations conducted by three of these aircraft during the 2006 Lebanon War were unsuccessful, however one UAV was able to successfully engage an Israeli naval vessel with an Iranian guided missile (Plushnick-Masti, 2006). Several later operations have also been attempted; see (Hoenig, 2014) for a fuller accounting.

Photo 14: A multi-rotor (hexacopter) COTS small UAV operated by the Ukrainian military's *Aerorozvidka* unit (photo credit: Aerorozvidka).

Ukrainian government forces, facing the challenge of limited and aging equipment combined with a pressing need for tactical ISTAR capabilities, have been utilising commercial UAVs. Recognising the importance of this technology, private initiatives have attempted to assist Ukrainian security forces, using crowd-funding campaigns to fund the design and procurement of COTS small UAVs (Jozuka, 2015). These start-ups and developers produced or retrofitted numerous UAVs which they have delivered to units on the ground[54]. The Ukrainian military has even formed an aerial UAV reconnaissance unit, *Aerorozvidka*, which initially relied entirely on commercially available models (Tucker, 2015).

Pro-Russian separatists have also been observed employing COTS small UAVs, with a separatist news website showing a group of fighters in Donetsk using a COTS rotary wing UAV (see Photo 15) in a target acquisition and surveillance role (Ferguson & Jenzen-Jones, 2014). It is also believed that separatist forces have employed weaponised UAVs, outfitting quadcopters to drop hand grenades as improvised air-delivered munitions. In at least one incident, Ukrainian soldiers described how a grenade was dropped on their position by a UAV piloted by separatist fighters; for an unknown reason, it failed to function correctly ('Stas Teren', 2014). Another photograph uploaded to a social media platform shows an improvised assembly configured to drop an RGO or RGN type hand grenade, potentially with additional fragmentation material, from a small UAV (see Photo 16) (Сводки от ополчения Новороссии, 2014).

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[54] Independent organisations in the US have also sent commercial drones such as DJI Phantom series quadcopters to Ukrainian forces (see Photo 13) (Pawlyk, 2015).

Photo 15: Pro-Russian separatists launch a COTS small UAV near Donetsk Airport (ohoto credit: Движение Интербригады).

Photo 16: An improvised assembly developed by pro-Russian separatists, designed to drop a hand grenade from a small UAV (photo credit: Сводки от ополчения Новороссии).

Syria, Iraq, and Eastern Lebanon

The most significant numbers of COTS small UAVs have been deployed by non-state actors in Syria, Iraq, and the eastern border of Lebanon, largely since mid-2014. The Islamic State (IS) accounts for a significant portion of these aircraft, operating numerous UAVs in both Iraq and Syria. COTS small UAVs have become a fixture of the ongoing conflict in this region, and have been documented in the hands of various other militant groups.

Islamic State

Since mid-2014, IS has made widespread use of COTS small UAVs on the battlefields of Syria and Iraq. This is particularly evident in a number of IS propaganda videos, and supported by examples of IS UAVs recovered by various opposing forces. These systems appear to be primarily used for ISTAR and information operations purposes. Kurdish forces have alleged that, in at least one instance, IS has attempted to weaponise a COTS small UAV, fitting it with an IED (see Photo 18) (Hambling, 2015).

An early example of IS use of COTS small UAVs is included in the May 2014 propaganda video "The Clanging of the Swords Part 4", released after the capture of Falluja, Iraq (Zelin, 2014). Subsequently sustained evidence of IS use of such systems has been documented, with numerous propaganda videos featuring both rotary and fixed wing UAVs. Table 4 provides selected examples of IS use of COTS small UAVs, including details on date, location, type, model, and primary mission, where such information is known. The available evidence of IS UAV use is broadly limited to material released by the Islamic State or the various forces fighting against them. It is plausible that their use of COTS small UAVs is significantly higher than is widely recorded.

Photo 17: A Kurdish fighter shows DJI Phantom series UAVs operated by IS forces and shot down over Kobane (photo credit: ANHA).

Photo 18: A Skywalker X8 FPV recovered by Kurdish forces. Kurdish forces have claimed this UAV contained an IED (photo credit: ANHA).

An IS propaganda video released in December 2014 contained UAV footage interspersed with footage of a series of suicide attacks on Kurdish positions during the Battle for Kobane (see Photo 19) (Moodley, 2014). Kurdish forces defending the town captured or shot down a number of IS-operated COTS small UAVs, identified as DJI Phantom series quadcopters (Shiloach, 2015). In August 2014, another video published by IS showed the use of multiple UAVs over the Tabqa airbase near Raqqah, shortly before its capture by IS forces. The visible imagery appeared of insufficient detail to provide comprehensive tactical intelligence, but provided IS forces with a generalised, operationally-useful view of the facility's layout, geography, and defensive positions (Cenciotti, 2014). Shortly before the December 2014 assault by IS forces on a Syrian Arab Army facility near Deir el-Zour, Syrian sources reported multiple COTS small UAVs in the area (SOHR, 2014).

Further examples of the Islamic State's use of COTS small UAVs are evidenced in videos showing attacks on the Baiji oil refinery in Iraq, as well as the storming of the Kweres airbase in Syria. The Baiji video is particularly high quality propaganda by IS standards; aerial footage is interlaced with images of artillery fire and shots of a command and control centre acting as the GCS for UAVs in the area (see Photo 20). IS forces appeared to employ multiple UAVs, make unknown, for target acquisition and correcting artillery fire delivered from mortars and artillery guns (Vocativ, 2015). IS also appeared to employ UAVs to support artillery fires from 155 mm M198 howitzers during the siege of the SAA-controlled Kweres airbase in Syria (Oryx Blog, 2015).

Photo 19: Still from an Islamic State propaganda video interspersed with clips of SVBIED employment in Kobane, 2014 (photo credit: IS).

Photo 20: An Islamic state operations centre receiving ISTAR information from COTS small UAVs (photo credit: IS).

At least four IS UAVs have been destroyed on the ground by US airstrikes in both Iraq and Syria, as reported by US Central Command (CENTCOM) (US CENTCOM, 2015a; b; c; d). Both UAVs and UAV operators have been targeted by US and coalition forces (Bier, 2015). Whilst not explicitly clear from available CENTCOM reports, it is likely that at least some of these strikes have been carried out by coalition UAVs active over Syria and Iraq, including MQ-1 Predator and MQ-9 Reaper models.

It is worth noting that IS has also threatened to attack Israel with UAVs (Halevi, 2014). It is probable that organisations such as IS attach a high symbolic value to the use of UAVs in warfare, particularly in regions where such technology has historically been employed by their more powerful adversaries, such as Israel and the United States. ARES interviews with Syrian sources have indicated that there is a certain ‘prestige factor’ associated with operating UAVs – even small COTS models – in support of combat operations[55].

UAV footage included in IS propaganda videos, with documented evidence of IS aircraft captured or successfully downed by forces opposing IS, suggests that the Islamic State employ a good mix of both rotary wing (especially multi-rotor) and fixed wing UAV designs. In particular, the ubiquitous DJI Phantom series quadcopters, of Chinese origin, have proven popular, with several models observed in use with IS (see Table 4). Several fixed wing X-UAV *Talon* and Skywalker *X8 FPV* model UAVs – both also manufactured in China – have been observed (Kurdistantv/ official, 2015; Green Lemon, 2015). The high frequency with which Chinese COTS small UAVs are documented is not particularly surprising, given the enormous market share of the global COTS small UAV industry held by Chinese companies.

Table 4 – Islamic State use of COTS small UAVs (selected examples)

Date	Location[56]	Aircraft Type	Model	Primary Mission[57]	Source
August 2014	Raqqah, Syria	Rotary wing	Unknown (suspected quadcopter)	ISTAR	Abu Aminah (س), 2014
September-December 2014[58]	Kobane, Syria	Rotary wing	Unknown (suspected quadcopter)	ISTAR & Information operations	Moodley, 2014
October 2014	Kobane, Syria	Rotary wing	DJI Phantom 1	Unknown	Shiloach, 2015
December 2014	Kobane, Syria	Rotary wing	DJI Phantom 2	Unknown	‘عبد الله’ , 2015; A Dunon, 2014)
May-August 2014[59]	Fallujah, Iraq	Rotary wing	Unknown (suspected quadcopter)	Information operations	Zelin, 2014
August 2014	Tabqa Airbase, Syria	Rotary wing	DJI Phantom FC40	ISR	Cenciotti, 2014
December 2014	Deir el Zour, Syria	Unknown	Unknown	ISR	SOHR, 2014
April 2015	Baiji Oil Refinery, Iraq	Rotary Wing	Unknown (suspected quadcopter)	ISR	Vocativ, 2015
17-18 March 2015	Fallujah, Iraq	Unknown	Unknown	Unknown	US CENTCOM, 2015a
26-27 June	Raqqah, Syria	Unknown	Unknown	Unknown	US CENTCOM, 2015b

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[55] ARES interviews with confidential sources, January 2016.

[56] Given as the nearest town/city or, in some cases, prominent feature such as a military base or refinery.

[57] Note that drones used primarily for ISTAR missions often contribute secondarily to information operations.

[58] Estimated

[59] Estimated.

2015					
2 August 2015	Ramadi, Iraq	Unknown	Unknown	Unknown	US CENTCOM, 2015c
December 11	Manbij, Syria	Unknown	Unknown	Unknown	US CENTCOM, 2015d
January-May 2015	Kweres Airbase, Syria	Unknown	Unknown	Unknown	Oryx Blog, 2015
May 2015	Iraq	Fixed wing	X-UAV Talon	Unknown	Kurdistantv/ official, 2015
August 2015	Mosul Dam, Iraq	Fixed wing	Skywalker X8 FPV	Unknown	Green Lemon, 2015
24 December 2015	Syria	Rotary wing	Unknown (suspected quadcopter)	Information operations & ISTAR (BDA)	Heba, 2015
28 December 2015	Bashiqa, Iraq	Fixed wing	Unknown	Information operations & ISTAR (BDA)	Zaid Benjamin, 2015
June 2015	Iraq	Fixed wing	Unknown	Unknown	(‘سرايا انصار العقيدة ‘, 2015)
October 2015	Ramadi, Iraq	Fixed wing	X-UAV Talon	ISR	Friese, 2015
December 2015	Kobane, Syria	Fixed wing	Skywalker X8 FPV	Strike (IED)	Hambling, 2015

Photo 20: Kurdish forces show a fixed-wing UAV which was likely operated by Islamic State forces over Mosul (photo credit: YPG).

Other Non-State Actors in Syria & Iraq

Other non-state armed groups operating within Syria and Iraq have also employed COTS small UAVs in support of their combat and information operations. Videos released by *Jabhat al-Nusra* indicate that they have used COTS small UAVs to further their goals within Syria. In October 2014, Nusra released a propaganda video highlighting the role of UAVs in breaking the siege of al-Maliha (see Photo 22) (Poplin, 2014). In November 2015, two videos were released covering Nusra operations in Idlib province and around Aleppo, with the footage seemingly shot from UAV platforms. The first included high quality, top-down footage of ongoing battles in the countryside south of Aleppo, including imagery of Nusra ground manoeuvres (reUp, 2015). The second video documented a suicide vehicle-borne IED (SVBIED) attack and subsequent assault on Shi'a enclave towns in Idlib governorate under siege by Nusra and other anti-regime forces (Syria Pulse, 2015).

Photo 22: A still taken from footage taken over al-Maliha, Syria released by Jabhat al-Nusra (photo credit: Al-Nusra).

Photo 23: Saraya al-Khorasani militant operating a DJI Phantom series COTS small UAV (photo credit: Saraya al-Khorasani).

As noted earlier, Hezbollah has been operating comparatively sophisticated, larger UAVs for some time. A recent video, however, shows that Hezbollah is also employing COTS small UAV models. At least one example was used to coordinate and target artillery fire during fighting with Jabhat al-Nusra militants in the Qalamoun mountain range, near the Lebanese-Syrian border (Blanford, 2015). It is interesting to note that Hezbollah has chosen to augment its access to Iranian military UAVs with COTS examples.

As early as November 2013, media reports indicated that Free Syrian Army (FSA) units in Homs had captured[60] what appears to be a DJI Phantom series quadcopter which had filmed extensive footage of the city. This was alleged to belong either to Syrian Arab Army forces, or to allied pro-government militias (Arnott, 2013). In 2015 *Suquor al-Sham*, a militant group aligned with the Syrian regime, released a video showing their use of a COTS small UAV transmitting real-time video (see Photo 23) (Truitte, 2015). In August 2015, the Iranian-backed Iraqi Shi'a militia, *Saraya al-Khorasani*, released a video showing their use of a DJI Phantom series quadcopter operating alongside their forces combatting IS in Iraq. The footage showed various arms, munitions, and vehicles of Iranian origin (الخراساني سرايا الاعلام, 2015).

Kurdish Peshmerga and irregular forces have also been supported by COTS small UAVs in Iraq and Syria. With the support of a former US Airforce intelligence officer, Kurdish Peshmerga forces made use of reconnaissance photos of Sinjar, Iraq collected by a Lehmann Aviation LA300 fixed wing UAV fitted with a GoPro series camera (see Photo 24). A Kurdish intelligence officer noted that whilst Peshmerga forces are supplied with reconnaissance imagery collected by US UAVs such as the General Atomics MQ-1 Predator, such intelligence is often provided too late to be of use (Argentieri, 2015). The immediate nature of intelligence collected by such unmanned systems has significant operational benefits; Peshmerga officers, for example, have partially attributed battlefield successes to support from UAVs.

Photo 24: An extract from footage taken during a UAV overflight of Sinjar in support of Kurdish forces (photo credit: Third Block Group).

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[60] Interestingly, the FSA representatives claimed that the quadcopter was brought down through the use of "frequency interference".

It is also worth noting that some non-state organisations not affiliated with armed actors in the conflict have planned to use COTS UAV technology in support of humanitarian goals. The Syrian Airlift Project, a crowd-funded American organisation, aims to use custom-made UAVs to deliver humanitarian supplies to Aleppo by air. At the time of writing, it was not clear if or when the project will commence, but the organisation already appears to have garnered significant financial and technical support for the programme (Mooberry, 2015). Should the project proceed, there would be a risk that humanitarian UAVs could fall into the hands of armed actors on the ground.

Mexico

As UAV technology becomes cheaper, widely available, and more sophisticated, criminal organisations are increasingly using such systems in support of their operations. Numerous instances of COTS small UAVs being used to illicitly transport narcotics between Mexico and the US have been reported (Davis, 2015). US Drug Enforcement Agency officials have estimated that in excess of 150 cross-border smuggling flights were conducted by UAVs in 2014 (Berger, 2015). UAV systems offering the ability to pre-set GPS coordinates have been preferred, allowing them to avoid any kind of radio countermeasures that might ordinarily be employed to prevent their operation.

The payload restrictions many commercial UAVs are currently subject to limits their utility in transporting significant quantities of narcotics. Advances in COTS UAV technology are likely to make such systems more attractive to smugglers in future, however. COTS small UAVs are also believed to be an attractive option for Mexican cartels seeking to surveil security forces, in support of smuggling operations (Gray, 2015).

Photo 25: A COTS small UAV which crashed in Tijuana, Mexico, near the US border, in January 2015 whilst carrying 3 kg of methamphetamine (photo credit: AP).

Other Areas: Libya, Pakistan, Colombia

In August 2002, the Columbian Army seized a number of remote controlled planes from a FARC jungle camp. While the intended use of these UAVs was not clear, Colombian military sources have suggested that they were to be used to deliver IEDs against state targets (Gormley, 2003). Similarly, in 2005 the Pakistani military discovered Chinese-made remote-controlled planes in the course of raids on al-Qaeda camps in Northern Waziristan. These were believed to be employed primarily in the ISTAR role, but it was also assumed that they were intended to deliver IEDs (Bunker, 2015).

A small, COTS quadcopter-type UAV employed for surveillance purposes was documented in Libya in 2011. Rebel forces fighting against Qaddafi acquired a commercially available 'dual-use'[61] Scout model quadcopter from the Canadian company Aeryon Labs Inc. (valued at some $120,000 USD) and used it in an ISTAR role to support their ground operations (see Photo 26) (Hill, 2011). According to ARES sources within Libya, COTS small UAVs have remained popular since the Civil War, both with private citizens and with certain *katibas* (militia brigades)[62].

Photo 26: Thermal camera footage from an Aeryon Scout quadcopter operated by Libyan rebels in 2011 (photo credit: Aeryon Labs).

COTS small UAVs have also been used by criminal elements to smuggle narcotics, pornography, and other contraband into restricted areas within prisons. This has proven a relatively widespread phenomenon throughout the developed world, with incidents reported in Australia, the United Kingdom, the United States, and elsewhere (Boyle, 2015; RT, 2015). Also noteworthy is the use of COTS small UAVs by groups or individuals as part of public protest. In April, 2015, for example, a small UAV carried a package of radioactive[63] sand onto the roof of the Japanese Prime Minister's office, protesting the Japanese government's nuclear energy policy (Bolton, 2015). In September 2013, a small quadcopter was flown within metres of German Chancellor Angela Merkel and other German officials in order to protest German surveillance policies (see Photo 27) (Gallagher, 2013). Both incidents were widely scrutinized in the media, and have precipitated further discussion regarding responses to the potential threat posed by small UAVs.

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[61] The EU defines dual-use items as those "goods, software and technology that can be used for both civilian and military applications and/or can contribute to the proliferation of Weapons of Mass Destruction" (EC, 2015).

[62] ARES interviews with confidential sources.

[63] Reports indicated that the radiation levels of the package were too low to be harmful to human health.

Photo 27: A Parrot AR rotary wing COTS small UAV approaches German Chancellor Angela Merkel and others in September 2013 (photo credit: EPA).

Operational Trends

Acquisition & Lifecycle Support

In assessing the employment of COTS small UAVs by non-state actors, an overarching theme is that these groups will make use of whichever UAV technology is available, modifying systems as required and as resources allow. The increase in the popularity of COTS small UAVs amongst non-state corresponds with the increasing affordability and availability of the technology, and is likely to be the major driver in the acquisition of these systems by such groups. Other, interrelated, factors may include: the extensive use of UAVs by the opponents of such groups, especially NATO militaries such as the United States; the increasing public and media profile of such technology; the radicalisation of western or westernised youth; regional developments in UAV technology; and the proliferation of UAV technology to the armed forces of developing nations.

COTS UAVs are available to non-state actors, in most cases, via direct purchases from manufacturers or retailers. Many of these companies now have an online presence and offer versatile, worldwide delivery options. In some cases, these systems are provided free of charge by individuals or organisations supporting the group, or assembled from components. There are numerous documented instances of individuals affiliated with non-state armed groups being interdicted whilst attempting to smuggle UAVs into conflict zones. Various arrests have taken place along the Lebanese-Syrian border, with the Lebanese government now seeking to monitor and regulate drone sales (The Daily Star, 2015). Similar incidents have taken place in Turkey, with suspected IS fighters being arrested attempting to smuggle weapons and a fixed wing drone into Syria (Doğan News Agency, 2015).

In most cases, COTS small UAVs can be employed by non-state actors without requiring the extensive support networks common to many military systems. Additionally, most COTS small UAVs are comparatively simple to operate, and can be used in conjunction with common consumer-grade electronics such as smart phones, tablets, and digital cameras. Maintenance and minor repairs are also correspondingly simpler.

In some cases, non-state actors have sought to improve or adjust the performance characteristics of the UAVs they operate. There have been documented cases of non-state actors heavily modifying[64] multi-rotor UAVs in order to increase aircraft range and endurance[65]. Whilst some groups have employed fixed wing UAVs with more substantial range and endurance characteristics, the prevalence of multi-rotor UAVs in certain conflict zones is such that modifications may prove practical and expedient.

With the widespread distribution of knowledge facilitated through the internet, it has become relatively easy to find instructions enabling the operator to increase the range and performance of commercially-acquired platforms with readily available technology. Supporting this is the presence of at least one instructional guide to modifying the DJI Phantom 2 quadcopter, posted by an Islamic state sympathiser and directly addressed to “the IS fighters that are piloting Islamic state planes of the type Phantom 2 in the battle of Kobani…” (‘عبد الله’, 2015).

Missions & Roles

Intelligence, surveillance, target acquisition & reconnaissance (ISTAR)

ISTAR is, and is likely to remain, the most critical mission fulfilled by COTS small UAVs in service with non-state armed groups, particularly those groups involved in military conflicts. UAVs fulfil the roles of generating battlefield intelligence, conducting reconnaissance and surveillance missions, supporting targeting of artillery and other assets, and gathering information for battle damage assessments (BDA).

Broadly speaking, ISTAR platforms and payloads enable the collection of information and intelligence. The British Army defines ISTAR as “The co-ordinated acquisition, processing and dissemination of timely, accurate, relevant and assured information and intelligence which supports the planning, and conduct of operations, targeting and the integration of effects and enables commanders to achieve their goals …” COTS small UAVs have been used by non-state armed groups to conduct reconnaissance and in the provision of tactical intelligence, including the active vectoring of friendly forces towards targets (Vocativ, 2015; Cenciotti, 2014).

The British Army defines target acquisition is defined as “the detection, identification and location of a target in sufficient detail to permit the effective employment of weapons”. UAVs can assist in the positive identification (PID) of targets, and aid in observing the characteristics of the target, including the consideration of physical, functional, and environmental factors which may affect how or if a target is engaged. Depending on the rules of engagement of the armed group operating the UAV, correct PID can be instrumental in avoiding catastrophic collateral damage or a loss of military advantage. Unmanned aerial platforms have also been employed to support artillery fires. In Eastern Ukraine, separatist fighters aligned with the Donetsk People’s Republic have employed COTS small UAVs to aid in target acquisition and to serve as an aerial artillery observer (or ‘spotter’), providing information to artillery gun and mortar crews allowing them to adjust fires based on real-time or near-real-time information (Ferguson & Jenzen-Jones, 2014).

UAVs may also be used to support the conduct of a battle damage assessment (BDA), which the British Army defines as “the timely and precise assessment of the effects of the application of lethal or non-lethal force against a pre-determined objective.” The Islamic state, for example, has used

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[64] Particularly in the areas of power and communications.

[65] ARES interviews with confidential sources in Syria.

COTS small UAVs to effect BDA operations, filming a convoy of oil tankers and transport trucks targeted by Russian airstrikes in December 2015 (Heba, 2015).

Information operations

For some non-state armed groups, COTS small UAVs have also played an important part in the conduct of information operations. The extent to which commercial UAVs are being utilised in propaganda videos demonstrates the symbolic value inherent in their use. The ability of non-state armed groups to employ technology that was formerly the strict purview of advanced militaries allows them to project an image of greater technological parity; a construct in which they are not just the victims of the predations of Western UAVs, but are able to harness the potential of a weapon of war which has been used against them for years. Thus, beyond their tactical and operational utility, COTS small UAVs occupy an important position in the information operations battle that is taking place in current asymmetric conflicts. This has acquired a significant international dimension given the media attention focused on these conflicts, the numbers of foreign fighters present, and the ability of terrorist organisations to perpetrate attacks abroad.

Simply the ability to operate UAVs in contested territory can prove a valuable information operation. For Hezbollah, each UAV flight into Israel represents a significant propaganda victory. One report noted that Hezbollah UAV activity in Israel is “primarily intended to cause panic” (Hoenig, 2014). Referring to the 2004 drone flight conducted by Hamas within Israeli airspace, the IDF issued a statement indicating their belief that the flight was primarily intended to achieve a propaganda mission (Harel, 2004). Matthew Levitt of the Washington Institute noted “They love being able to say, ‘Israel is infiltrating our airspace, so we’ll infiltrate theirs, drone for drone.’”(Dreazen, 2014).

Offensive capabilities

There have been several documented instances of non-state groups employing, or seeking to employ, weaponised UAV technology. These range from the early tests conducted by Aum Shinrikyo in the 1990s, to allegations of the use of UAVs to deliver IEDs levelled against groups or individuals in the US, Gaza, Colombia, Iraq, and Syria. An alleged December 2015 attempt by the Islamic State to employ a weaponised UAV as a makeshift precision guided munition (essentially a ‘flying bomb’) garnered only limited media attention, however the phenomenon remains in its nascent stages. Whilst the delivery of offensive payloads has thus far been limited, its future significance cannot be discounted. Certain terrorist organisations, and individuals claiming to be affiliated with these organisations, have demonstrated a willingness to employ UAVs as delivery vectors for improvised explosive devices, as well as chemical and biological weapons. Western security officials have warned that advances in the availability and sophistication of commercially available drones increases the likelihood of such events occurring in the future (Gutteridge, 2015).

Regulatory controls and countermeasures

National & International Regulatory Controls

Existing export controls on arms and other military materiel, in general, do not capture COTS small UAVs. For example, they are not subject to the Wassenaar Agreement’s Dual-Use List (9.A.12) covering UAVs, though they may be controlled to some degree through the eight criteria of the European Union’s Common Position on arms exports (Zwijnenburg & van Hoorn, 2015). Another option is through the application of economic or other sanctions on parties known to supply non-state actors of concern with UAV technology. In November 2015, the US penalised two Chinese companies and one Lebanese company accused of supplying UAV technology to Hezbollah (Hoskinson, 2015).

Controls at the national level could include the prohibition of sales to designated persons, entities, or nations, as seen in the United States Export Administration Regulations Section 746 (Sanctioned Destinations) and List of Parties of Concern (BIS, 2015; BIS, n.d.). This approach could assist with slowing the flow of UAV technology into conflict zones, and to non-state actors attempting to import UAVs. A more direct national approach to controlling COTS small UAVs has been seen in Lebanon. With documented cases of individuals attempting to smuggle drones to militants on the Syrian-Lebanese border, the Lebanese government and commercial retailers have begun to monitor COTS UAV sales, and now reportedly require buyers to obtain a permit issued by the military before they may acquire restricted UAV items (The Daily Star, 2015; Kullab, 2015).

While various options have been discussed, debated, and accepted around the world, there are challenges to fully implementing many of these measures. As the barriers to UAV manufacturing lower over time, and the number of manufacturers and associated businesses grow, governments of many nations with underdeveloped economies will likely encounter pressure to open their doors to these companies or lose them to competing nations. Even developed nations are struggling with the rapidly changing UAV environment, with some companies suggesting they are prepared to move business elsewhere if UAV operation and export regulations do not favour them or move quickly enough (Trotman, 2014). Perhaps a greater challenge still is the need for a harmonised, global approach to export controls in order for such measures to affect non-state armed groups in a meaningful way. With Chinese UAVs constituting a significant portion of the items seen within non-state actors' arsenals, efforts to control exports from Western nations alone may have little effect.

The control of individual COTS UAV technologies is in question as well, with dual-use items, particularly electronics, presenting a significant challenge. As with other dual-use products, nations must strike a balance between freely allowing the transit and use of the products for civil purposes, and preventing their use for nefarious or undesired purposes. Many Wassenaar member nations have already placed controls on entire assemblies and software related to UAV systems, but find it difficult to tightly control the very capable autopilots found on existing COTS models – as well as the microprocessors and sensors in commercial autopilot systems – because these are largely the same as electronics found in common consumer products such as smartphones. Further still, in some documented instances, the commonality of specific components and ready access to a global marketplace has meant that export controls as enacted by one state can be avoided simply by purchasing the controlled component in another (Argentieri, 2015).

Then there is the issue of compliance. Some manufacturers and retailers in nations subject to arms control agreements and national regulations are aware that certain items such as autopilots, IR cameras, and navigation systems are controlled, but many are not. Export education programs are run by some nations, but it can be difficult to reach many small businesses in model aircraft and hobby electronics niches. Some businesses will continue to operate out of ignorance while others may seek ways around regulations because of the compliance costs[66].

Use of COTS small UAVs has also created significant problems for civil aviation authorities around the world. Some nations have been proactive with regards to the introduction of UAV technology, while others have not. All, however, probably underestimated the rapid growth of the civilian UAV market. Civil aviation authorities are accustomed to working with manufacturers and fliers trained and experienced in the ways of the aviation community. The advent of widely available, affordable UAVs has brought both new manufacturers and new users who are challenging the community in

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[66] From the author's experience in the United States: UAV technology developers who are small business concerns must be very careful about the context of their product development. Military funding or the use of controlled components could place their product or service under ITAR regulations rather than dual-use regulations. If they are recognized by the government as a defense product or service provider, they must register with the government at a large cost, regardless of whether they export the product or service.

many ways, significantly with regards airspace regulations. Legacy model aircraft have traditionally operated from fixed locations which usually coexisted with nearby airports through a mechanism of minimal regulation and cooperation. The portable nature of new consumer UAVs has somewhat erased this model, and has led to these aircraft being flown in places that can pose a hazard to other aircraft, as well as persons and facilities on the ground. Nations such as the United States have stepped up education efforts through websites like *Know Before You Fly* (KBYF, 2015). This education lays out the basic rules of the air, but has problems addressing the growing number of regulations regarding UAV use from other government agencies and levels of government. The private sector has also engaged users, providing some UAV users with real-time information on no-fly zones via the internet[67].

The most substantial regulatory measure affecting COTS small UAV users in the United States is the recent introduction of rules requiring all pilots of UAVs with a GTOW of more than 250 grams to be registered with the FAA. Any UAV flown outdoors that exceeds this classification would also be required to carry a serial number, helping to identify its owner to authorities after any incident (FAA, 2015c). While these measures are for now limited to aviation authorities in the United States, it appears likely that other developed countries will adopt similar approaches. It remains to be seen how effective these education and registration efforts will be in controlling rogue pilots or other actors.

Technical-use Controls

Technical-use controls are one method by which authorities, manufactures, or other parties may control where COTS UAVs can operate. Such controls would typically be integrated into the autopilot or GCS software, and could deliver various effects. Most commonly, these controls are incorporated by manufacturers and seek to prevent flight within a designated area. DJI, for example, controls into some models which prevent flights within designated no-fly zones, such as near airports. This technology was recently adjusted, allowing the pilot to operate within these restricted areas provided they 'self-certified'[68] as having permission to do so (Williams, M., 2015). Some secure locations, including prisons and nuclear facilities, remain off-limits, without the self-certification options. Technical-use controls are likely to see more widespread adoption amongst manufacturers, and may become the norm within the COTS UAV market. Typical no-fly zones are likely to include airports, military bases, critical infrastructure, and other secure areas – particularly those in which airspace controls are already in effect.

Other technical-use controls could be adopted from those existing or proposed for nuclear weapons and guided light weapons. These could include timer-based enabling or disabling, remote disabling ('kill switches'), coded enabling, or what are known as 'permissive action links' (PAL). A PAL is a two-way communications system which requires the operator to input a "request code" and a higher authority to remotely authorise the function of the UAV through a "response code" (Jenzen-Jones, 2015). This could allow for the control of UAV technology distributed to non-state armed groups, but would be unlikely to be incorporated into COTS UAVs.

There are obstacles to the global adoption of technical-use controls, however, particularly in developing regions. The primary issue is that accurate no-fly zone boundary data may not be readily available for every nation. Manufacturers may instead choose – or be required – to 'region lock' their models, setting a larger no-fly boundary which may encompass portions of one or more countries. Updating technical use controls on existing models of UAV is likely to require a connection

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[67] See, for example, (Airmap, n.d.).

[68] This certification includes the submission of limited identifying information to DJI, such as credit card or mobile phone information. DJI has indicated that in the event of a security incident they would cooperate with all relevant authorities.

to the internet, which could pose an issue in developing or remote areas with weak data coverage. Finally, technical use controls may be vulnerable to circumvention by knowledgeable or determined persons. As with export controls, interested parties are likely to be able to purchase autopilot or CGS technology lacking technical-use controls from alternative manufacturers or open source communities.

Counter-UAV Systems

Numerous systems have been developed to counter the threat posed by the operation of the dangerous, threatening, or illegal use of UAV systems. Numerous militaries have already introduced technologies which are suitable for tracking, identifying, and engaging unmanned systems. These have primarily been developed from systems intended to counter other aerial threats, including manned aircraft, guided missiles, and smaller munitions including direct and indirect fire projectiles. In most cases, these use a kinetic interceptor, such as a projectile or missile. Some more recent developments, including various systems tested by Boeing, Rheinmetall Defence and MBDA, employ directed energy weapons such as lasers (Sweetman, 2015).

There have been several recent developments in RF detection and jamming equipment and offensive cyber systems (Bunker, 2015; CACI, n.d.). Because small UAVs can be difficult to detect with conventional radar systems, many counter-UAV systems also include specialised radar. Existing radar may also receive software modifications in order to better acquire and track small UAV targets. For example, Saab offers an update to its Giraffe series radar with an 'enhanced low, slow and small' function for tracking UAVs (Saab, 2015). Other systems allow for the engagement of threat UAVs as well. Systems such as Selex ES' Falcon Shield, Blighter Surveillance Systems' AUDS, and Lockheed Martin's ICARUS allow the operator to identify, track, and engage threat UAVs with electronic and cyber warfare capabilities (see Photo 28). According to Lockheed Martin, their system can "disable the UAV's onboard cameras, knock the system out of the sky, or confiscate control of the vehicle and land it in a safe zone" (Jean, 2015). A man-portable device seeking to deliver similar effects was demonstrated by the US Army Cyber Institute at West Point in October 2015[69] as was the portable DroneDefender system developed by Battelle (see Photo 29) (Limer, 2015; Matyszczyk, 2015).

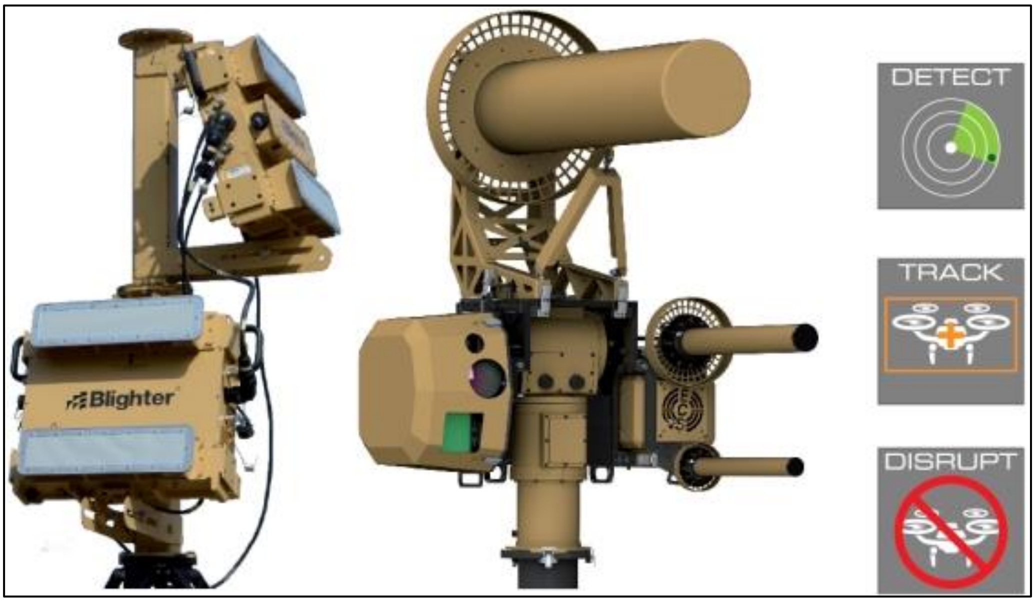

Photo 28: *The Blighter Anti-UAV Defence System or AUDS (photo credit: Blighter Surveillance Systems).*

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[69] It should be noted that the capabilities of this developmental demonstrator rifle are not entirely clear, however it appears these may be limited to one model of UAV.

Photo 29: *The Battelle DroneDefender counter-UAV system (photo credit: Battelle).*

On the battlefield, or in defence of civilian populations and infrastructure, COTS small UAVs constitute an aerial threat which poses unique technical challenges, but they will require a proportional response. Israel's Iron Dome system would be capable of engaging UAVs, for example, however the cost of Tamir interceptor missiles is estimated to be in the region of $100,000 USD (Opall-Rome, 2014). This mammoth cost disparity between the target and counter-target capability enabler calls into question the long term sustainability of such systems, particularly when the payload or intent of a COTS small UAV can be difficult to determine. High-value targets such as government buildings, military facilities, critical infrastructure, and large open-air events may require adjustments to weapons and tactics which are focused on the prevention or reduction of collateral damage, and allow for the operation of counter-UAV systems by law enforcement or private authorities. It is not just kinetic counter-UAV systems which may face operational hurdles in civilian areas. The use of electronic warfare techniques targeting satellite navigation signals or UAV datalinks will likely prove difficult to safely employ in the vicinity of facilities such as airports or military airbases. The employment of even non-kinetic systems may raise liability concerns for operators.

Conventional militaries are already beginning to target UAV capabilities exhibited by non-state armed groups. Aside from successfully engaging UAVs which have been launched into Israeli airspace, the IDF has also conducted airstrikes targeting UAV production and storage facilities in Gaza (Benari, 2012; Ronen & Yonah, 2014). Israel continues to conduct a series of counter-UAV training operations, training personnel to respond to threats posed by UAVs with a range of capabilities (Ronen & Yonah, 2014). US and coalition airstrikes in Syria and Iraq have targeted COTS small UAV systems and their operators in 2015 (see Table 4). A pentagon spokesperson, discussing one such strike, said: "We observed it flying for approximately 20 minutes. We observed it land. We observed the enemy place it in the trunk of a car and we struck the car … It was a commercially available, remotely piloted aircraft, really something anyone can get" (Tilghman, 2015; US CENTCOM, 2015a).

Law enforcement organisations have also recognised the potential threat posed by COTS small UAV systems. The Tokyo Metropolitan Police Department, for example, has introduced a small fleet of "interceptor" UAVs, fitted with a 2 x 3 m net, used to entangle and control suspicious UAVs. Similar systems have been demonstrated in France (see Photo 30) and the US (Williams, R., 2015). The Dutch National police have explored a more novel option – emplotying trained birds of prey to take small UAVs out of the sky (see Photo 31) (Thielman, 2016). There have been suggestions that other law enforcement customer, including the UK's Metropolitan Police Service, are also interested in examining this low-tech solution (Rawlinson, 2016).

Photo 30: *A French 'drone catcher' demonstration in La Queue-en-Brie, east of Paris, in February 2015 (photo credit: Fracois Mori/AP).*

Photo 31: An eagle strikes a COTS small UAV before bringing it to the ground (photo credit: Guard From Above).

Conclusion

Many key stakeholders now consider the proliferation of COTS small UAV technology amongst non-state armed groups to constitute a significant concern. Historically, the use of UAVs by non-state actors has been sporadic and rudimentary. Recent conflicts in the Middle East and Ukraine have coincided with global jumps in the capabilities and availability of COTS small UAVs, however. It is clear that combatants in many of these conflict zones see the utility of these aircraft and appreciate the new capabilities they can deliver. Other groups, including criminal enterprises, see similar benefits.

Improvements in design, materials, and payloads have made modern systems smaller and even more portable than legacy model aircraft. Their integration with consumer electronics such as smartphones is enabling rapid capability advancements, as well as making them easier to pilot. Many traditional barriers to manufacturing have been lowered as new production methods such as additive manufacturing become available, and access to knowledge and funding continue to cross borders as a result of open source and crowd-funding movements.

A variety of different payloads are available for small UAVs. Platforms primarily used for ISTAR purposes, and video cameras in particular, will remain the dominate type of payload for commercial, consumer, and military small UAVs. Video technology will continue to advance in parallel with consumer electronics. IR cameras are, and will probably remain, a strong secondary payload option due to their commercial applications and military utility. Non-lethal and lethal offensive payloads are already a reality for law enforcement and military small UAVs, as advances in miniaturisation of PGMs and integration of munitions for small platforms advance apace. The modification of COTS small UAVs by non-state actors is likely to emulate this trend, and the ‘flying bomb’ IED delivery device may become increasingly commonplace. Offensive payloads which are potentially available to non-state actors include the use of re-purposed conventional munitions, small arms, various types of IEDs, chemical or biological agents, and RF devices for electronic warfare and cyberattacks.

Significant developments for COTS small UAVs lie on the horizon. Government and military developers and users are seeking to improve batteries and sensors as well as establish the technology to better share airspace and radio spectrum. Swarming using massed small UAVs offers advantages include fewer pilots, the possibility of lower-cost aircraft, and reduced requirements for long range communications. The military is currently the primary driver of this technology, however there are potential civilian applications. Seamless airspace integration is necessary for BLOS operations to begin being conducted on a regular basis. UAVs must be able to detect the presence of other aircraft, sense if they are a threat, and then manoeuvre to avoid a collision in a manner that is at least equivalent to the effectiveness of manned aircraft. This will require advances in miniaturisation of key components and in software controls. The concerns and priorities of government and military users are not necessarily reflected in the commercial space, however.

It is likely that we will see a short-to-medium-term increase in the quantities, varieties, and capabilities of COTS small UAV platforms employed by non-state actors. Whether these groups are able to maintain longer-term use, particularly of the more advanced systems on the horizon, may well hinge on the success of counter-proliferation efforts.

Any counter-proliferation efforts are likely to face significant challenges, primarily those related to the dual-use nature of many of the technologies which comprise COTS small UAV systems, including exclusions for model aircraft from existing arms controls agreements, and the choice by some nations and user communities to freely share or market UAV technology. National regulatory approaches may prove useful in applying specific sanctions or embargoes targeting non-state actors, their affiliates, and states which support them. Securing the cooperation of manufacturers and retailers, and engaging the commercial and hobbyist user communities, is likely to prove critical to the success of any counter-proliferation measures.

Technical controls are another option available to those seeking to control consumer UAV use. Informal technical controls are already incorporated by some manufacturer, creating *de facto* no-fly zones. This approach has limitations, however. Non-state actors, in particular, may seek to remove or circumvent controls which artificially limit how and where they can operate COTS small UAVs.

Counter-UAV weapons, doctrine, and training operations are likely to see increased funding and support from the military, law enforcement, and private sectors. Developing cost-effective measures to counter COTS small UAVs is likely to prove a key focus for these industries. The engagement of UAV threats within civilian areas will require novel approaches which minimise the potential for collateral damage. As the UAV sector continues to evolve and expand, commensurate growth and development is expected for counter-UAV solutions.

Non-state actors will continue to use COTS small UAV platforms to support a range of mission types. These are likely to remain primarily in the ISTAR domain, providing intelligence gathering and surveillance capabilities which would otherwise be difficult or impossible for such groups to realise. Target acquisition, aerial artillery observation, and battle damage assessment will also remain important missions for these platforms. It is also critical to appreciate the importance of COTS small UAVs as components of non-state actors' information operations. The operation of UAV platforms of any type often constitutes a propaganda victory for these groups.

As non-state groups gain more experience operating UAV platforms, further novel and technically-advanced uses can be expected. The ability for these groups to weaponise COTS small UAVs will depend on commensurate developments of munitions for equivalent military and law enforcement platforms, and the proliferation of these weapons, as well as a process of experimentation and operational testing of improvised offensive payloads by non-state actors.

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