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First "Robotic Skies" Workshop: The Role of the Private Sector and Public Policy in Shaping the Drones Industry

A workshop organized by Oxford University's
Centre for Technology and Global Affairs and Measure UAS, Inc

EXECUTIVE SUMMARY

On June 21 and 22, 2018, Oxford University's Centre for Technology and Global Affairs hosted the First "Robotic Skies" Workshop: The Role of the Private Sector and Public Policy in Shaping the Drones Industry in Rhodes House, Oxford. This workshop, organized in partnership with Measure and other drone companies and organizations, brought together practitioners, policymakers, and experts from industry, government, and academia to explore the future governance landscape of civil airspace and the global industry for Unmanned Aerial Vehicles (UAVs) and Autonomous Aerial Vehicles (AAVs).

Divided into five thematic sessions, discussions at the workshop examined existing governance and regulatory challenges associated with the burgeoning commercial drone industries. The objectives of the workshop were to:

- identify governance and regulatory barriers to further commercialization of UAVs and AAVs;
- brainstorm potential solutions to overcoming existing technical and regulatory obstacles;
- survey cutting-edge research and technologies essential to promoting beneficial civil applications of UAVs and AAVs; and
- examine the security and defence implications brought by the expanding use of UAV and AAV technologies.

Dynamic presentations and discussions at the workshop resulted in the identification of several major challenges faced by the drone industry and by governments that need to monitor and regulate this sector. Based on the workshop's proceedings, this report proposes the following concrete measures to tackle each of the key factors that directly affect the use of the technologies and the growth of the industry.

Regulations: Policy formation currently lags behind technological advances in the sector. The introduction of a harmonized international regulatory framework engaging industry, government, and academia is essential to increasing the speed of commercialization and expanding civil applications of UAV and AAV technologies.

Public Perception and Safety: Negative public perception and a lack of public awareness of relevant rules and guidelines limit further commercialization of consumer UAVs. Industry-led initiatives such as knowledge quizzes and geofencing[1] constitute valuable steps in preventing misuses of the technology.

Security and Privacy: Uncertainty regarding security and privacy significantly limits industry growth. More explicit guidelines and shared understanding of best practices regarding data security and privacy are essential to move the industry forward.

Technology: Competence to operate Beyond-Visual-Line-of-Sight (BVLOS) are essential for full integration of commercial UAVs and AAVs into civil airspace in the future. Relevant governance regimes, including spectrum allocation and telecommunications standards, need to be brought into the debates. Multiple aspects pertinent to enabling BVLOS operations should not be discussed in silos.

1 A virtual geographical boundary created using GPS and/or radio-frequency identification (RFID) technologies.

WORKSHOP PROCEEDINGS

Session 1—Innovation and Commercialization: Promoting Early Adoption of UAV Technologies

The opening session examined how innovation and commercialization can jointly promote consumer UAVs in benefiting society. The composition of the panel provided an eclectic mix of perspectives, demonstrating a variety of priorities and concerns from diverse actors in the drone industry, including views from an end-user, a manufacturer, a data analyst, and a provider of drones-as-a-service.

Aerial Capabilities: The New Frontier

The aerial capabilities provided by commercial UAVs have taken this technology to a new frontier, and the work of the companies and institutions represented in this panel demonstrate clearly that the applications of UAVs stretch far beyond military applications.

Not only can commercial UAVs be used for leisure—for aerial photography, for example—but they can also be used for more specialized operations. Use of commercial UAVs can, for example, produce significant savings in inspecting wind turbines and other critical infrastructure. They can also play a significant role in global reforestation by planting seed pods on an industrial scale. In emergencies, they have also been employed as first responders to provide essential aerial assessment in dangerous situations.

First response operations in emergencies, along with human inspections of critical infrastructure, often entail considerable risks. By utilizing the aerial capabilities provided by commercial UAVs, the risks posed to law enforcement officers and human inspectors can be greatly reduced.

Nevertheless, to further promote early adoption of UAV technologies, the industry would need to tackle two main barriers: first, inadequate and insufficient regulations; and second, the negative perception of drones among the general public.

Regulations: Overcoming Regulatory Constraints

Experiences shared by the panellists suggest that civil applications of commercial UAVs often need to overcome significant regulatory barriers. In one instance, a participant noted that it had taken two years and over 500 test flights before a certificate from the U.S. Federal Aviation Administration (FAA) could be secured for one specific parcel-delivery UAV. Similarly restrictive regulations are also faced by those who need to transport UAVs for sustainability projects: commercial UAVs that were imported for the purpose of reforestation were regularly held up at airports, requiring time-consuming efforts to secure their clearance.

The current norm of prohibiting operations beyond-visual-line-of-sight (BVLOS) significantly limits the business uses of UAVs. In the United States, for example, the aerial inspection of one wind turbine currently requires the presence of two inspectors - one drone operator and one spotter. This poses considerable limitations for companies that wish to scale up their commercial UAV operations. The business use of commercial UAVs can only become truly viable in the longer term when BVLOS operations are allowed, and when functions such as licensing and flight authorization can be automated and become more efficient.

Because the use of commercial drones in the United States is currently under the jurisdiction of the FAA, the regulatory landscape imposes the same set of rules for all drone users, regardless of their familiarity with and experiences in piloting commercial UAVs. One panellist argued that trained and experienced operators should be granted permission to perform more sophisticated tasks, and that such differentiation could contribute to faster commercialization of UAVs.

Moreover, as the FAA is the relevant entity in regulating drone use nationwide, the UAV industry finds itself facing much greater challenges than companies in other sector, such as Uber, which only need to convince relevant local authorities to provide a favourable regulatory environment. While local regulations enjoy a certain level of flexibility and can be more responsive to immediate industry needs, nationwide regulations often lag behind technological developments and are slower to adapt to change.

Public Perception: Safety Innovation and Gaining Public Acceptance

The second barrier to increased drone usage is the public perception of commercial UAVs. One panellist referenced a December 2017 poll[2] conducted by the National Endowment for Science, Technology, and the Arts in the United Kingdom, pointing out that 33 percent of respondents said that they do not have a good understanding of drones nor of their potential uses; more than half (54 percent) indicated that they do not have a good understanding of the rules and regulations governing the use of drones. The poll also showed that the public generally perceives drone flights operating below 20 metres as a disturbance to social activities.

To address such concerns, one commercial drone manufacturer has introduced a number of features to

2 https://www.nesta.org.uk/news/drones-in-our-cities-by-2020-predict-a-quarter-of-people-rising-to-half-by-2024/

enhance operational safety of commercial UAVs. These innovative measures include pre-programmed knowledge quizzes for users, advanced obstacle-avoidance technology, and safety-enhancing technology such as geofencing. The latest version of geofencing integrates data from Global Navigation Satellite Systems (GNSS), along with a pre-programmed list of restricted areas (e.g., airports) and other security-sensitive locations (e.g., prisons, nuclear power plants). This geofencing feature also incorporates updates on airport restrictions every 28 days and provides live updates of other temporary restrictions due to major emergencies and incidents, including events such as the 2018 Royal Wedding at Windsor Castle and major stadium events.

Data Management and Privacy

After having surveyed main regulatory challenges and industry-initiated measures to ensure public safety, the panel moved on to discuss data management and privacy issues. Today, the UAV industry witnesses increasing competence in data ingestion, aggregation, and organization. Commercial UAVs are becoming increasingly capable of generating and collecting data. Yet, the lack of a coherent national and international regulatory framework means that there is substantial uncertainty regarding data privacy for this information. In particular, the industry is uncertain of the policy position that regulatory bodies such as the FAA and the European Commission (EC) hold in relation to data privacy for commercial drones.

This workshop session closed with a series of questions that warrant further discussions between the academia, industry and government. What are the guidelines for handling telemetry and other data collected and generated by commercial UAVs? Are there any best practices that small and medium sized enterprises (SME) and start-ups may refer to in storing and processing drone-generated data? How can major drone manufacturers reassure consumers that the data collected will not infringe individuals' rights and privacy?

Jessie Mooberry from Airbus

Session 2—Regulations as Enablers of Innovation: A Global Perspective

The second session gathered key regulatory actors from local, regional, and national entities. Speakers at this session included an experienced drone entrepreneur working in the aerospace sector, former senior regulatory figures on drones and aviation from the United States, as well as representatives from transport authorities at the local and European regional level. Discussions at the session allowed for transatlantic and multilevel comparisons in approaching the integration of commercial UAVs and AAVs into daily life, reflecting a truly global perspective in examining the future of civil airspace.

Regulations as (Counter-)Enablers of Innovation?

Drawing from their extensive experience working with different regulatory environments across the world, panellists at this session observed that regulations can either make or break an enterprise. In Singapore, the governing environment allows technology start-ups to have direct interactions with regulators. Across the globe, however, an attempt to deliver humanitarian aid to Syria failed to take off due to an inadequate regulatory environment and a lack of governmental support. The absence of a government-industry forum to discuss associated challenges can very often stifle innovation. Instead of enabling innovation, regulations at times appear to serve the opposite purpose, leading one of the panellists to lament that regulations are "dis-," "anti-," and "counter-enablers" that inhibit innovation.

Regulators prioritize public safety because they are accountable to the public. They tend to take a more prudent approach when making policy decisions. Policymaking, especially at the national and international levels, is designed to be risk-averse and reiterative. As such, many professionals in the technology sector are bitterly aware of the fact that regulations often lag behind technological advances. The majority of today's air traffic management (ATM), for example, continues to rely on legacy technologies such as radar and radio communication for air traffic control (ATC). Satellite-based air-ground communication systems, such as the IRIS system developed by the European Space Agency, have only emerged in recent years. It is envisioned that these types of systems will support ATM in the near future.

Toward a Harmonized International Governance Framework for Airspace Mobility

Unlike many ground-based modes of transport (e.g., buses, underground rail networks), which are regulated by local authorities, drone operations currently fall under national jurisdiction in both the United States and the United Kingdom. In the United Kingdom, London airspace—

the busiest airspace in the world—is currently regulated by the Civil Aviation Authority (CAA) and managed by the National Air Traffic Services (NATS). Ground-based transport in the city, however, falls within the responsibility of the Transport for London (TfL). In a highly-populated city such as London, the incorporation of civil uses of commercial UAVs could contribute greatly to improving urban mobility. One potential use is the transportation of organs for transplants by commercial UAVs between hospitals, which could potentially eliminate up to 90 percent of the current delivery time. Before rapid drone delivery for transplantable organs can become reality, however, a robust regulatory framework that allows for airspace prioritization would need to be implemented.

A harmonized approach to airspace management, both at the national and international levels, could move governance of civil airspace forward. In Europe, the European Commission has suggested the concept of U-Space in recognition of the need to establish interoperability across different countries in the region. U-Space seeks to achieve a harmonized and integrated approach to managing drone traffic. Registration, identification, and geofencing would become core aspects in realizing this vision.

Across the Atlantic, industry and regulators in the United States are also examining possible models of unmanned traffic management (UTM) to regulate and control drone traffic. In Silicon Valley, a simulation project is currently being developed to evaluate policy options and viable operational models to manage all future airborne traffic in civil airspace.

In spite of ongoing industry efforts to develop UTM, questions remain regarding how future traffic control and management systems for drones could be funded and implemented. How much additional cost would such a system incur? In the United States, the current ATC system is public and funded largely by the FAA. In the United Kingdom, however, a public-private partnership with NATS in 2001 resulted in NATS acquiring the government's ATM assets.[3] NATS now holds a monopoly on air traffic control in the United Kingdom.[4] Would UTM follow either of these two main operational models? And would its costs be similar in scale to that of ATC?

Lastly, expanding on discussions in relations to governance, concerns were raised over the future governance of spectrum. It is known that the bandwidth consumed by a single Global Hawk drone (a high-precision UAV) far exceeds the entirety of bandwidth that was used during the Gulf War.[5] How would the current spectrum regime handle additional pressure on frequency if drones are to become widely accessible consumer products?

The commercialization of the drone industry touches upon regulatory areas in aviation, spectrum, privacy, and cyber security. These interrelated topics are currently discussed in silos, and many are governed separately by different international entities (e.g., the International Civil Aviation Organization for aviation-related issues, the International Telecommunication Union for spectrum allocation). Such complexity poses considerable barriers to innovation. A multi-disciplinary and multi-sectoral forum of discussions needs to be established in order to address all these domain-specific regulatory challenges concurrently.

Session 3—Emerging Technologies and the UAV Industry: New Trends and Visions

The third workshop session surveyed and explored cutting-edge research currently being conducted at Oxford, as well as developments of new start-ups at the forefront of UAVs and AAVs. These new research and industry efforts contribute to optimizing performance of autonomous systems, managing drone traffic, providing heavy-lift logistic solutions, improving urban air mobility, and enabling BVLOS operations.

The Next Generation of UAVs and AAVs: Vehicles Capable of Flights BVLOS

BVLOS operations were a recurring theme throughout discussions at the workshop. Many delegates at the workshop have argued that the commercial case for drones can only be viable when BVLOS operations become possible. The industry's vision is to acquire competence to operate BVLOS with highly automated drones in controlled and highly congested airspace. Regulatory limitations aside, a number of technical challenges pertaining to operating BVLOS still remain. Research and technology presented in this session provided valuable insights into how BVLOS operations could become a reality.

Looking to Nature for Answers

BVLOS operations by drones have the potential to significantly improve logistics in defence. The defence sector currently relies heavily on helicopters (e.g., Chinooks) to deliver essential goods with low commercial value, such as food and water, to frontline troops in contested areas. If UAVs could deliver heavy payloads to theatre, not only could they reduce transportation costs, but they could also reduce the risks associated with piloted resupply missions. BVLOS will, however, be essential for such types of unmanned delivery.

3 https://news.delta.com/sites/default/files/The%20Costs%20of%20Privatizing%20Air%20Traffic%20Control_0.pdf

4 https://www.nao.org.uk/wp-content/uploads/2002/07/01021096es.pdf

5 Ian Annett and Roddy Dennis, "Increasing Resilience in Space-Based Capabilities for the UK through Improved Space Situational Awareness and Regulatory Control," *RUSI Journal*, April/May 2018, p. 17.

In addition to developing the ability to operate BVLOS, the current designs of UAVs need to overcome two technical challenges: first, they need to be able to sustain heavier payloads; and second, they need to operate stably under turbulence or strong wind conditions. The majority of commercial drone companies today turn to quadcopter technology for solutions. While quadcopters can be efficient for carrying cameras for aerial photography, their designs are not effective for delivering heavy payloads, nor can they withstand turbulent weather conditions. If one looks to nature for inspiration, one can see that the flying patterns of eagles and storks often resemble soaring, without needing to regularly flap their wings. In other words, the way they fly is more akin to paragliding, rather than relying solely on the constant rotation of rotors as seen in Vertical Take-Off and Landing (VTOL) vehicles and helicopters. An alternative UAV design—for example, one with a pre-deployed parachute and a propeller—could be safer and carry heavier payloads.

Quadcopters also have another shortcoming: if one rotor fails, then the whole vehicle fails and needs to rely on a parachute for safe landing. In this scenario, nature could also give us inspiration for a different and safer design approach. A dragonfly, for example, can continue to fly even when one of its wings is damaged. A design modelled on a dragonfly's flapping movements can thus be more resilient to technical failures, turbulence, and adverse weather.

Robotics Optimization

Along with exploring alternative designs for aerial robotics, research continues to optimize functions based on existing models of UAVs. One way to advance UAV technologies for BVLOS operations is to improve UAVs' real-time assessment capabilities by introducing more accurate primary and secondary sensing, enhanced data coverage, and onboard computing abilities. The goal is to develop aerial robotics that can navigate through non-planar, dynamically unstable, changing or unknown environments. Multimotion Visual Odometry (MVO) could potentially improve autonomy for the next generation of UAVs. Equipped with a stereo camera, MVO could estimate vehicle motion in an environment without access to Global Navigation Satellite System (GNSS).

Ubiquitous Connectivity Enabled by Satellites and Strengthening the Satellite Infrastructure with UAVs

While robotics researchers are exploring ways to ensure safe operations even in the absence of support from GNSS, continuous improvement in satellite infrastructure and space data analytics could bring society closer to ubiquitous connectivity, thus helping to enable BVLOS operations in the future.

Satellite activities are currently essential to, and responsible for, earth observation (monitoring, including weather forecasts), communications (mobile and internet connections), and navigating (geospatial location). These are all critical features if UAVs are to be fully integrated into civil airspace in the future. At the same time, technical advances in the drone industry could also enhance current capabilities of satellite infrastructure. Consider the example of the Sentinel Climate Change Mission. The mission provides full global coverage every six days. Data collected would need to be processed, however, before being passed to end users (e.g., farmers, economists). Drones could support this mission by, for example, checking areas that have been flagged as blind spots or that require additional information.

Looking into the future, ongoing R&D on high altitude pseudo-satellites (HAPS)—an innovation described as a cross between drones and satellites—could provide stable and reliable earth observation and communications platforms at a working altitude of 20 kilometres. Once commercialized, this innovation could complement current functions of GNSS, contribute to establishing ubiquitous connectivity, and strengthen the satellite infrastructure.

Toward a Future of Urban Air Mobility

As UAVs, AAVs, and their complementary technologies (i.e., UTM, BVLOS capability, satellite-enabled connectivity) mature, we can envision a future of urban air mobility—where aerial capabilities take traffic off the road and into the air. A number of start-ups are already developing and testing projects that could transport individuals for short-haul flights in on-demand, shared VTOL vehicles.

In spite of numerous successful test flights with passengers on board, VTOL developers find the greatest challenges to be public acceptance and government regulations. In order to gain greater social acceptance, multiple VTOL projects currently incorporate pilots (i.e., Volocopter, Uber Air) into their plans, although the models currently being developed could be piloted remotely or even autonomously.

The panel in general recognized that battery life continues to constitute a shared technical barrier for UAVs and AAVs (commercial UAVs have an average battery life of around 30 minutes; VTOL vehicles typically cannot fly longer than 40–60 minutes). Nevertheless, the majority of the panel did not consider technology to be a major barrier. Many in the industry believe that the comprehensiveness of the ecosystem is more important, emphasizing the need for end users and vendors contributing jointly to building a strong business case for drones. The panel also recognized that gaining social acceptance is critical, and this cannot be achieved without an effective enforcement mechanism, which can assure that bad actors and misuses of the technology are duly sanctioned.

Keith Dear from the University of Oxford and RAF

Session 4—The Future of Robotic Skies: Security and Defence Implications

Commercialization of UAVs can be a double-edged sword for the defence and law enforcement sector. On the one hand, it could support law enforcement or military operations by reducing risks posed to officers and armed forces. On the other hand, however, drones' increasing affordability means that ill-intentioned individuals could easily gain access to such technology and use it for malicious purposes. This workshop session gathered professionals with security and law enforcement backgrounds, as well as a political scientist and an ethicist, to examine the implications associated with a future when commercial UAVs and AAVs are integrated into the airspace.

Applications of UAV Technologies in Humanitarian Situations and in Law Enforcement

Public perception constitutes one of the largest barriers to further integration of UAVs for the law enforcement and defence sectors. Due to drones' initial use in military operations (i.e., Predators and Reapers), traditional powers such as the United States suffer from a highly militarized image of drones among the public. There is growing activism from civil society in calling for a comprehensive ban on the weaponization of emerging technologies. This disproportionate focus on the military applications of the technology, whether factual or perceived, makes it difficult for the same technology to be adopted for peaceful, civilian or humanitarian purposes.

Echoing technical discussions in Session 3, panellists concluded that UAVs can be a particularly useful technology in contested areas, not only in providing logistical support to troops, but also in delivering humanitarian aid to regions where access is cut off or is extremely dangerous. Recent conflicts show that cities are increasingly being targeted; siege is used strategically in conflicts and hunger is also used as a weapon. In such emergencies, unmanned cargo drones could be the only viable means through which humanitarian aid can reach the population in need.

New developments in unmanned cargo drones (i.e., pouncers) are being designed to provide scalable responses. The amount of aid and individuals to be fed can be scaled up by deploying more drones. Similarly, aid delivery could be scaled up or scaled down depending on the level of risk that aircraft face in different airspaces: cheaper UAVs can be deployed for airspace under high air threat; more expensive aerial vehicles can be used in areas facing lower levels of air threat.

Alongside defence and humanitarian actors, law enforcement entities have also increasingly turned to UAVs for support. The use of commercial UAVs in the police force can increase situational awareness, aid decision-making, and provide valuable aerial assets at a reduced cost. They can be utilized for reactive support in the aftermath of an incident (e.g., providing aerial information for search and rescue missions, as well as supporting responses to road traffic collision, fire, and crime scenes); they can also be used proactively in planning for events such as football matches and concerts, or for intelligence-gathering. In the United Kingdom, the use of UAVs for law enforcement purposes is currently governed by the CAA and the 2016 Air Navigation Order. Exemptions to certain articles could be granted, however, depending on the use cases and specific scenarios. Given this flexibility, a higher degree of consistency and transparency is advised for future guidelines in granting exemptions.

Preventing Misuses and Malicious Uses of Drones: An Intersectoral Effort

Law enforcement units face enormous challenges in responding to incidents that take place in airspace. First, police are not currently equipped with sufficient resources and equipments to investigate or halt suspected misuses of commercial UAVs. Second, it is difficult to verify in real-time, in the absence of dedicated equipment and personnel, whether commercial UAVs are operating in compliance with the law.

Thus far, the majority of workshop delegates have acknowledged the need to establish a robust regulatory framework regarding UAV operations. Yet, regulations can only be meaningful if they can be effectively enforced. Enforcement of drone regulations thus constitutes a topic that warrants further discussion.

Cost Innovation and its Global Security Implications

From enhancing law enforcement capacity to entrepreneurship in the counter-drone business, all stakeholders strive to improve and enable the safer use of commercial UAVs. Nevertheless, at the international level, there are persistent concerns regarding data security associated with commercial drone operations. In spite of the fact that traditional powers (e.g., the United States)

were among the first to employ high-precision drones for military purposes, today's largest commercial drone manufacturer actually originates from China. Increasingly, Western powers have found themselves lagging behind China's rapid cost innovation, where the conception of an idea can be quickly taken to prototyping, testing, manufacturing, and marketing stages, all made possible thanks to a comprehensive and concentrated ecosystem. For the commercial UAV industry to expand further, major manufacturers in China must address widespread concerns over privacy and data security.

For traditional powers, such as the United States and the United Kingdom, the focus will be on how to keep their military capabilities relevant in an era where cost and/or frugal innovation can produce products that perform similarly to the expensive high-precision equipment that they possess. There is little surprise that China is today's largest commercial drone manufacturer. Traditional powers with high-precision drones (e.g., Predators, Reapers) previously had little to no interest in investing in cheap UAVs that can be easily detected, offer low situational awareness, and have an extremely short battery life. Coupled with the lack of a comprehensive ecosystem that encourages cost innovation, traditional powers today find themselves alarmed in face of the possible development of asymmetric warfare, in which swarms of cheaper products (i.e., commercial UAVs) could be deployed by non-traditional powers to overpower conventional military capabilities.

A Balanced Dialogue on Emerging Technologies

A balanced awareness needs to be established between the benefits that technologies can bring to society and the threats associated with the increasing militarization and weaponization of emerging technologies. Regulators need to promptly put forward rules establishing which uses of UAVs are acceptable and which are not. At the international level, it is in both China's and Western powers' interests to come to a shared understanding on privacy, data security, and commitment to the non-weaponization of commercial UAVs, especially in low-altitude airspace. On the one hand, manufacturers can benefit from a higher level of public confidence in their products and move to expand their markets. On the other hand, the international community can rely on norms, practices, and global governance for assurance that new technologies will not be routinely weaponized. Civil society has become increasingly engaged in monitoring the development and use of new technologies, and is particularly sensitive to misuses and potential weaponization. There are already calls for restraining the development of autonomy, by maintaining meaningful human control in increasingly autonomous systems. If governments and industry do not take the lead in reassuring the public with safeguard initiatives, they will face mounting pressure from civil society and campaigns calling for limitations, if not comprehensive bans, on development and specific uses of emerging technologies. Dialogue between the security and defence sectors and civil society is critical to avoid polarized views on the use of emerging technologies.

Session 5—The Future of the UAV Industry: Policy Implications

After examining various strategic approaches that regulators could take in response to issues in the burgeoning UAV industry, this workshop session explored some concrete and technical matters within existing regulatory frameworks that directly affect research and business operations in the sector. Speakers from both academic and technical backgrounds highlighted the direct impact that current regulations have on their work.

Constraints in Advancing the United Kingdom's Defence R&D

The previous workshop session explored the dilemma that traditional powers face in terms of creating a conducive environment for innovation. Traditional powers, mostly developed economies, are not competitive in the areas of production costs or frugal innovation. In terms of R&D in the defence sector, industry in the United Kingdom invests in high-precision designs that seek to improve the quality of performance. There is heavy emphasis on redundancy in order to ensure safety. This stands in sharp contrast to disruptive innovation, in which products or services that were originally of lower quality, once established, hold the potential to challenge the positions of dominant market leaders. Chinese drone manufacturing is a classic example of disruptive innovation.

Developed economies are less tolerant of risks, and this is reflected in more stringent national regulations. The UK aerospace and defence industry, for example, has only limited airspace operation entitlements. Aircrafts are required to fly in segregated airspace. While there are certain exemptions in place for testing and research, the constraints remain considerable. For example, tests that involve low speed stalling are not possible; testing of aircraft that fly faster than 250 knots below Flight Level 100 is also not normally permitted. As a result, not only do traditional powers lack the ecosystem to test, prototype, and manufacture cost-innovative products, but they also face constraints in improving their high-end, high-performance defence R&D.

At the Boundary of Regulations

While advanced research on unmanned aerial capabilities

faces constraints in moving forward, developments in extreme drone-racing and in the increasing use of micro- and nano-drones appear to be at the boundary of existing regulations.

In the United Kingdom, the current drone code, which limits drones operations within visual-line-of-sight and below 400 feet, does not appear to take into account most hobbyists' use of small UAVs, including professional drone-racing. International drone-racing competitions generally enlist pilots to manoeuvre quadcopters through obstacle courses at high speeds of up to 90 miles per hour. Pilots wear First-PersonView (FPV) headsets to operate the quadcopters. In such scenarios, are the pilots wearing the headsets operating within visual-line-of-sight? Would a spotter be needed?

Furthermore, it is extremely difficult to enforce the drone code for micro- and nano-drones (also known as toy drones, due to their low cost and smaller kinetic impact). Should owners of such devices be allowed to operate their small UAVs in their own private backyards? Should pilot registration be required for manoeuvring micro- and nano-drones for personal leisure within the owner's private property? What if the device accidentally flies into a neighbour's garden?

At present, the cost of training and obtaining a drone operating licence for commercial activities (i.e., PfCO, Permissions for Commercial Operations) in the United Kingdom far exceeds the cost of purchasing a micro-drone. If, however, a micro-drone owner uploaded footage taken by the micro-drone to his/her YouTube channel, which in turn generated profits, would a permission be required? If licensing became mandatory for micro- and nano-drone operations, this would effectively end the business case for micro- and nano-drone developers in the United Kingdom, and possibly beyond.

Additionally, current models of micro-drones have a battery life of approximately eight minutes, which suggests that enthusiasts need to have multiple batteries on hand. Current international norms and regulations in shipping, export, and import limit shipments to one battery per parcel, posing further barriers for SMEs developing micro-drones to scale up or expand their businesses.

Spectrum Allocation

At this workshop session, spectrum also returned as a topic because many delegates felt that it required further discussion. Certain models of micro-drones rely on 5.8 gigahertz (GHz) for analog video transmission. Currently, there is no dedicated spectrum allocated for UAVs' analog transmission. This suggests that the 5.8 GHz frequency is being shared with other users and may be subjected to interference.

Improved governance, standards, and technologies surrounding spectrum are essential for advancing aerial inspection works with UAVs. Multi-bearer communication capability would need to be developed, along with hardware standards to establish interoperability. Real-time to near-real-time assessment of weather and other telemetric data would require reliable communication links, especially when the industry is currently pursuing capacity to operate BVLOS. While the current use of ADS-B (Automatic dependent surveillance—broadcast) could be expanded to facilitate communications and command-and-control, there is the understanding that ADS-B technology is not yet advanced enough to secure ubiquitous connectivity.

CONCLUSION AND RECOMMENDATIONS

The discussions at the "Robotic Skies" workshop sessions highlight the complexity of the challenges associated with the commercial drone industry. The wide array of stakeholders, from micro-drone developers to enterprises using fixed-wing drones, from UTM providers to high-precision UAV developers in the defence sector, all have different priorities and face different regulatory constraints in advancing their products and services. While public perception constitutes a barrier, one panellist argued that the legacy mindset shared by many regulators actually poses the greatest challenge in moving the industry forward. With the emergence of commercial UAVs and AAVs challenging the very definition of "aircrafts" and the conventional segregation of airspace, many of the existing regulatory efforts continue to mirror traditional approaches in regulating commercial airliners. For example, earlier discussions of UTM at the workshop appear to assume a centralized approach in managing drone operations, similar to the centralized, nationwide approach of many current ATC systems found in European countries and the United States. The possibility of decentralizing regulations—by devolving regulations and enforcement competence to local authorities—appears to be missing from current debates.

Political scientists have long noted that there exist only two main policy instruments: to prohibit or to regulate. From an implementation perspective, prohibition could be easier to enforce. Prohibition allows for a clear understanding of actions that are not permitted. Nevertheless, given the pace of technological advances in the commercial drone sector, and the potential benefits that this technology can bring to society, prohibition is not the most appropriate governing approach.

Effective regulation of commercial UAVs, however, hinges upon the congruence of multiple factors, including

efficient spectrum governance, maturity of sense-and-avoid technology, further improvement in platforms, and reliable and ubiquitous connectivity for continuous tracking and real-time communications, among many others. Before all of these developments materialize, industry-initiated norms, practices, and standards (e.g., codes of conduct) could play a critical role in ensuring progressive commercialization of UAV and AAV technologies.

Synthesizing input from the workshop, the five main challenges that the industry currently faces are summarized below. Each challenge is followed by recommendations for concrete actions that relevant stakeholders could take to proactively address these barriers:

1) Policy formation lags behind technological advances and developments in the industry.

The reiterative nature of policymaking and the legacy mindset limit policy options available for regulating the operations of commercial UAVs. Current practices in regulating commercial UAVs in the United States, the United Kingdom, and continental Europe often mirror a centralized approach in regulating operations of commercial airliners within and across national airspaces. In contrast to commercial airliners that often operate across cities and countries, however, most current operations of commercial UAVs are short-distance journeys in specified local areas. Furthermore, regulations of UAVs touch upon multiple governance areas, including data security, spectrum allocation, air and urban traffic control, as well as telecommunications standards. Exploration of a multilevel and intersectoral governance framework that engages both industry and local authorities could help to effectively manage the widening use of UAVs and AAVs in future civil airspace.

Recommendations:

- introduce a sustainable forum of dialogue to discuss multiple relevant aspects of drone policy congruently;
- engage representatives from industry and academia, as well as local, national, and international authorities, to explore policy options;
- look to a multilevel governance approach to support and implement agreed policy frameworks.

2) Negative public perception and a lack of public awareness pose major barriers to commercialization.

The adoption and commercialization of UAV technologies are greatly hindered by a disproportionate focus on the weaponized use of drones. This is further compounded by a lack of public understanding of the pertinent rules and regulations governing the civil applications of UAVs. Industry-led initiatives, such as the introduction of knowledge quizzes, constitute valuable steps to ensure that end users are aware of national guidelines. Nevertheless, further government-industry partnerships are required to strengthen awareness. In addition, academia, as guardian of knowledge, can function not only as an essential collaborator in advancing research, but also as an experienced partner in educating the public. Partnerships with academia in launching public engagement events could contribute to addressing negative overhype and misconceptions associated with UAVs. Academics could also introduce the public to the technologies' many civil applications.

Recommendations:

- consolidate existing public engagement efforts in partnership with government and academia;
- consider multilateral government and industry-led discussions to assure the public of commitments to safety and security, especially in low-altitude civil airspace.

3) Uncertainty regarding security and privacy limits industry growth.

There is currently a lack of explicit rules or guidelines on how best to store and process data generated and collected by commercial UAVs. Handling of the telemetric, geospatial, and imagery data collected has substantial privacy implications. These concerns, if unaddressed, would limit further commercialization of UAV technologies. This is of particular importance to major drone manufacturers. Furthermore, there are also questions regarding the security of communications links and the command-and-control channels of commercial UAVs. Recognizing that many avionic communications are currently unencrypted, further measures to strengthen the security of UTM and communications links would need to be explored if future management of UAVs is based on current ATC systems.

Recommendations:

- encourage intersectoral dialogue and engagement with the public on the security and privacy implications brought by the commercialization of drone technologies;
- establish voluntary industry-wide pledges and best practices as first steps to address privacy and security concerns prior to lengthy development of national and international legislations.

4) Preventing misuses and malicious uses of commercial UAVs will require intersectoral efforts.

While a robust regulatory framework is essential for the future of the UAV industry, regulations must be duly enforced in order to be effective. Enforcement at the moment face enormous challenges.

Many law enforcement units are not currently equipped with the training, resources, and experience to monitor and sanction misuses and malicious uses of commercial UAVs. Even when suspected non-compliance is identified, technologies and equipment to defeat rogue UAVs are still in the early stages of development. Governmental entities need to innovate in conjunction with the private sector to develop effective measures (e.g., counter-drone technology) to deter misuses of UAVs. In addition to educating the public about the boundaries of the law, training provided to law enforcement personnel could also support them in executing relevant regulations.

Recommendations:

- engage law enforcement units in discussions of UAV regulations;
- provide guidelines and training to law enforcement personnel to help them identify and sanction non-compliance.

5) BVLOS operations are critical to future developments in the drone industry.

In order for society to benefit widely from the applications of UAVs and AAVs, competence in operating BVLOS is essential. Attaining this capacity will involve the maturity of various complementary technologies, many of which will in turn rely on an increased level of automation. Essential enabling technologies include automatic sense-and-avoid ability, ubiquitous connectivity, automatic licensing, and trajectory-planning. Improved situational awareness would also require more reliable communications links, as well as efficient spectrum sharing or allocation.

Recommendations:

- commence intersectoral discussions on efficient spectrum governance in anticipation of expanding uses of commercial UAVs and AAVs;
- consolidate industry-academia linkages to advance technologies and research critical in bringing about competence in operating BVLOS.

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The Centre is based in the Department of Politics and International Relations at Oxford University. It is supported by core funding from Kluz Ventures.

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