Department for
Business, Energy
& Industrial Strategy

Government
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THE UK VALUE STREAM FOR REMOTELY PILOTED CIVIL AIRCRAFT SYSTEMS (RPAS)

Literature Review

February 2017

Executive summary

Ipsos MORI was commissioned by the Department for Business Innovation and Skills and Government Office for Science to undertake a review of the evidence base on the UK value stream for Remotely Piloted Aircraft Systems (RPAS). The objective of this research was to understand the current and potential structure of the UK RPAS value stream and its potential economic benefits to the UK.

Remotely Piloted Aircraft Systems

RPAS are aircraft piloted from a remote station and can operate under varying levels of autonomy. A few decades ago the technology was almost exclusively confined to a hobbyist market, but it is now finding commercial applications across many areas of economic and social activity.

Research Objectives

The overarching objective of the study is to provide Government with a better understanding of the scale and composition of the current and potential civil commercial UK RPAS value stream in terms of activity, the interconnections between different elements, areas of competitive advantage, barriers to growth and the gaps which exist within the civil RPAS sector.

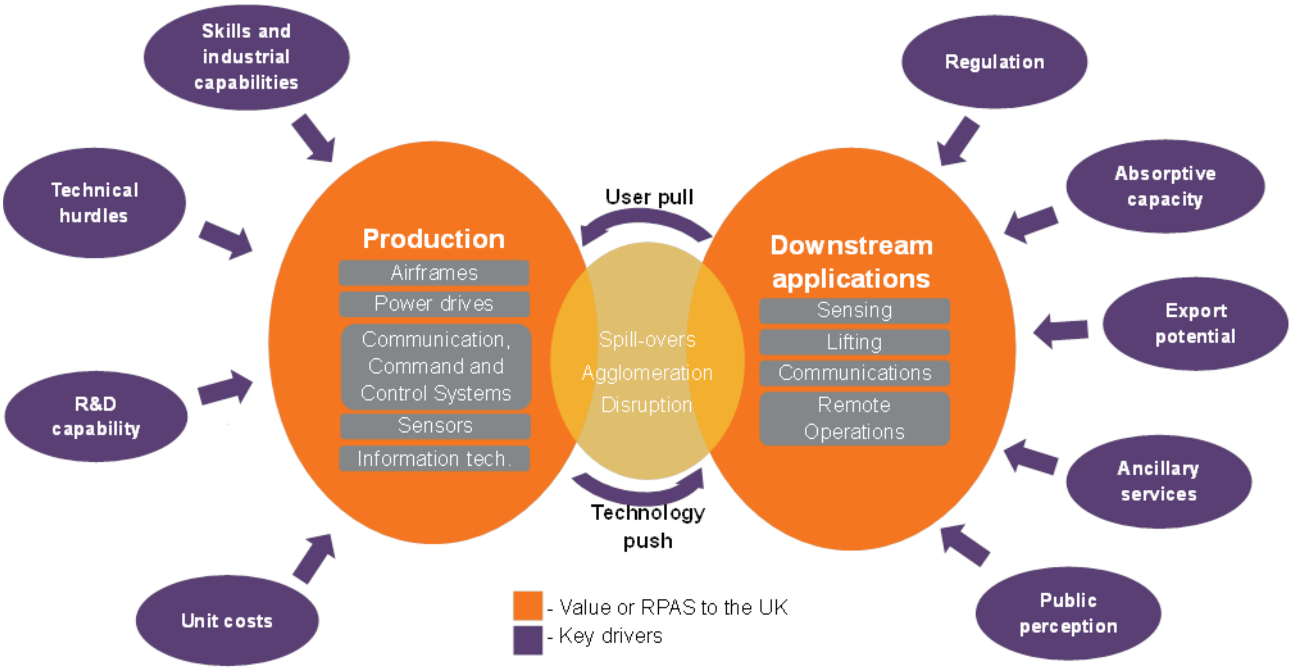
This review has sought to explore how, unlocked by rapid technological development and the advantages offered to users, RPAS technology is finding numerous commercial applications in the UK with its use set to be a potential driver of productivity over the coming decade. The research also considers the technological hurdles that need to be overcome before the full economic potential of the RPAS value stream can be realised, as well as the significance of regulatory and other barriers to the use of RPAS. This has involved:

- The development of an analytical framework to underpin the research.
- Identification and review of relevant literature and documentation covering: academic publications, publically funded projects, regulatory documents, market projections, commentary outputs and RPAS company websites.
- A small scale programme of consultations with key stakeholders with an interest in RPAS production, R&D and downstream applications to supplement the existing evidence.

An Analytical Framework for the UK RPAS Value Stream

In the context of this study, the concept of 'value stream' is defined so as to encompass all sources of economic value originating from the development and diffusion of RPAS. This captures the value added at each stage of the RPAS manufacturing process through the production and assembly of components and sub-systems (similar to the concept of traditional manufacturing supply chains). However, the scope of this study also extends to other sources of value associated with RPAS, including R&D, downstream applications, and supporting services. This analytical framework is illustrated in Figure 1 below.

Figure 1: An Analytical Framework for the Value OF RPAS to the UK



RPAS Markets, Production and R&D Activity

Global RPAS markets and production

Research conducted by Frost and Sullivan[1] offers a quantitative assessment of the current global market sizes for the sale of consumer and commercial RPAS units, at £349m and £919m respectively. This market is typically segmented by weight (small, light, and large RPAS). The vast majority of models fall into the smaller categories, and many RPAS are available at prices that make them accessible to households. However, the performance characteristics of these models are typically limited, offering low endurance and range as well as difficulties in flying in adverse weather conditions. Overcoming these performance limitations is typically costly, with those devices with the highest technical specifications commanding prices of up to £100,000. Although large RPAS are available for military use, a market for civil applications for devices at this scale is yet to emerge, likely due to the significant costs involved.

The available literature offers very little quantitative insight into the characteristics of the RPAS supply chains. Stakeholder evidence suggests that there might be a distinction between RPAS destined for consumer markets and higher value RPAS. The former tend to focus on the integration of 'disposable' componentry with little value added. The higher value that can be obtained by RPAS with superior technical characteristics has, however, enabled some firms to develop higher value added componentry.

The main hubs of international production are located in Asia, and one Shenzen-based firm (DJI) has emerged as a dominant market leader in producing small RPAS (claiming 72 percent of the market). The success of firms based in this region has partly been attributed to their expertise in the manufacture of electronic devices (with small RPAS manufacturing having

[1] Frost & Sullivan (2015) research offers a quantitative assessment of current market sizes for consumer and commercial RPAS, at £349m and £919m respectively.

more in common with this sector than with aerospace). However, there are also prominent manufacturers based both in Europe and North America, where firms have been able to create some competitive advantage through competing on quality.

UK RPAS Production Activity

Although it has not been possible to obtain systematic figures, the evidence suggests that a strong RPAS manufacturing cluster has not emerged in the UK. Thirteen manufacturers of complete RPAS were identified through this review, some of which were primarily or solely involved in producing large or small models for military markets (which are outside the scope of this study). Additionally, 55 manufacturers of RPAS components and sub-systems were identified. It has been challenging to identify clear evidence describing the challenges that the UK has faced in developing manufacturing expertise in civil applications, though the predominance of small devices has meant that it has not been possible to exploit adjacencies with the aerospace industry in which the UK has a competitive advantage.

Research and Development

Global R&D spending on RPAS R&D appears to be in a range between £2.5 and £3.5bn, covering both military and non-military sectors; it is challenging to disentangle military and non-military estimates in this area. While a large number of active UK RPAS R&D activities were identified, the quantitative evidence suggests that the UK R&D spending is possibly a relatively small share of this total.

RPAS Applications

While the use of RPAS is not new, both the recent scale of their use by consumers and the range of commercial applications, represent a marked break with the past. The falling price of RPAS with higher performance specifications has in recent years made it more cost-effective to adopt these devices in a range of commercial processes.

At the time of writing there were more than 1,400 commercial operators approved by the Civil Aviation Authority in the UK (a nine percent increase on the position two months earlier at the start of the study). This strength suggests that the UK is adopting the technology rapidly and accounts for a significant share of the number of licenced operators globally. However, it is important to note that the study team have not been able to assess the size of these operators, or the scale of the revenues that they are generating from offering RPAS services.

The evidence base identifies four types of application for RPAS including: collecting and transmitting sensory data (sensing), carrying and delivering goods (lifting), supporting telecommunications (communications), and interacting with the built or natural environment to carry out specific tasks (remote operations). As illustrated in Table 1 below, the review suggests that, to date, commercialisation in the UK has largely been focused on the first of these general applications, with particularly rapid adoption by the media industry and to some degree in the inspection of large scale industrial structures.

Table 1: Extent of Use of RPAS by Industry and by Application

Sector / Application	Leisure / consumer	Film and media	Agriculture	Logistics	Oil and gas	Other infrastructure	Law Enforcement
Sensing							
Photography and filming							
Inspection and Monitoring:							
Mapping and Surveying							
Other sensors (including chemical)							
Lifting							
Parcel Delivery							
Large Cargo Delivery							
Passenger Transport							
Other							
Communications							
Remote Operations							

Note: Darker shading indicates the prevalence of the activity identified in the UK through the research presented in Section 4. Unshaded boxes indicate where there is little or no current RPAS applications.

Source: Ipsos MORI analysis

The literature review provided substantial evidence that RPAS have the potential to raise productivity through delivering cost, performance, and safety benefits. Productivity gains also have the potential to be realised across a large number of industries, including agriculture, oil and gas extraction, energy production, media, and law enforcement. However, while there is a range of evidence on the quantitative magnitude of productivity improvements in specific situations (such as monitoring the health of a particular crop), there has been no systematic research examining which industries stand to realise the most significant gains in productivity through the adoption of RPAS.

While it is clear that the emergence of RPAS has supported the development of new service models in the UK, there is very little detailed evidence available on the economics of the industry. It is unclear how far RPAS are being adopted directly by firms as an input into industrial and commercial processes, or whether the technology is primarily supporting the growth of new service industries. Additionally, no evidence is available on the commercial performance of firms entering the market in terms of their revenues, growth, employment, output and productivity. Finally, there is also no evidence that would support an assessment of how far the UK has been able to translate rapid growth in the number of commercial RPAS operators into export sales.

Although there is very little in the way of evidence describing the economic value of the ancillary services provided or required by RPAS operators, the evidence that is available suggests that the development of supporting services has kept pace with the overall growth in RPAS operators (though previously there may have been issues originating in the insurance market). One possible constraint identified, however, was the availability of training for RPAS pilots at the more advanced levels that might be required for more complex flights (such as within highly constrained external or internal environments).

Developments

Anticipated Future Value Stream

Few studies have sought to quantify the potential future value stream associated with RPAS. One estimate suggests that the benefit of integrating RPAS into the US National Aerospace System could amount to some £57.4bn over a ten year period. Other studies have demonstrated the significance of potential savings that could arise from RPAS use in the oil and gas sector, in utilities inspection, in precision agriculture and in small item delivery.

Key Technological Trends

The evidence base documents six primary technological trends in occurring in recent years:

- R&D supporting the increasing use of polymer composites in airframes
- The development of detect and avoid capabilities
- The use of 3D printing in production processes along with component miniaturisation
- The development of increasingly sophisticated software for imaging and modelling
- Experimentation with alternative power drives
- Improvements in the quality and variety of the available sensor payloads.

Technological Challenges and Potential Developments

Looking across the five core RPAS components that determine the overall level of performance characteristics of the device the following technological challenges have been identified:

- **Airframes** – The development of frames for small and micro RPAS with increased use of composite materials,
- **Power drives** – Continued dominance of conventional combustion engines and electric motors but experimentation with alternative power drives,
- **Communications, Command, and Control systems** – An increase in detect and avoid capability for all classes of RPAS,
- **Sensors** – Increased demand for small RPAS applications has led to increases in the quality and variety of the available sensor payloads,
- **IT/data processing** – The increased development of software and its transition to open source for small RPAS along with software development to support the demand for imaging and modelling capability.

Regulation as a Barrier to RPAS Adoption

Regulatory issues represent a particularly important potential barrier to the realisation of the benefits from the expansion of RPAS applications. While the UK regulatory environment is generally seen as more supportive in international terms, its evolution to support more autonomous flight and applications that are Beyond the Visual Line of Sight (BVLOS) of operators was identified as an important agenda. Other regulatory aspects around data protection, privacy, and spectrum allocation have also been identified as potential issues. However, it is not entirely clear the extent to which these will represent major problems.

Public Perceptions as a Barrier to RPAS Adoption

A number of factors have been identified as driving a negative perception of RPAS, including privacy issues, associations with military applications and concerns about misuse. This dissatisfaction was identified through the research as a barrier with the potential to hold back RPAS use in the UK.

RPAS as a Disruptive Technology

Many new RPAS applications can be associated directly with new economic opportunities where they are creating value in ways that are not possible in the absence of this technology – for example undertaking filming where the use of a manned helicopter would not be feasible. In contrast a number of examples have been identified through the research where the application of RPAS will displace existing economic activity. However, the benefits from RPAS use in terms of increased productivity and cost/price reductions will tend to produce countervailing effects through expanding demand for many of the services involved – for example, if inspection becomes more cost effective, it may be undertaken more regularly.

Growth Forecasts

Numerous forecasts have sought to predict the growth of the RPAS industry, and ten relevant market forecasts undertaken in the last two years were explored through this research. While these vary in terms of their methods, their scope, and the amount of detail available, they all predict that the non-military RPAS sector and all of its sub-segments will expand substantially over the next five to ten years. The forecasts for the total global RPAS market range between £7.8bn and £30bn in 2025.

Gaps in the Evidence Base

A very large volume of material has been generated exploring the potential of RPAS. However, the evidence base that has emerged focuses heavily on examples of current and near term RPAS applications, technological developments and regulatory aspects. Relatively little evidence appears to be available on several important areas of the value stream:

- **Quantification of the UK value stream**: Overall the quality of information available on the RPAS sector is less strong than that available for many traditional industries, and it is highly challenging to identify reliable economic data regarding the scale of RPAS production or applications in either the EU or the UK.
- **Ancillary and supporting services**: Only a very limited volume of information is available about this broader set of activities.

- **Manufacture of components and sub-systems**: While it is possible to identify leading RPAS manufacturers, it has not been possible to map their supply chain.
- **The basis for economic forecasts**: While a number of forecasts have been developed, very little detail is available on how these have been developed or their underlying assumptions.
- **Financial and economic issues**: The evidence base has focused heavily on technical or regulatory aspects of RPAS use, with limited coverage of economic aspects.
- **Business models**: The notion of 'Drones as a service' is frequently identified in the evidence base as the key future market, but there is relatively little analysis of what this might look like in practical terms.

Opportunities for Further Research

The study team have identified four areas where further research would help to plug these evidence gaps:

- Further analysis of Innovate UK application data
- Further secondary data analysis building on the lists of companies collected through this research exploiting ONS datasets, as well as international patent and academic publications data
- Further qualitative research to explore aspects of RPAS applications in greater depth.

Contents

1.0 Introduction

Ipsos MORI was commissioned by the Department for Business Innovation and Skills and Government Office for Science to undertake a review of the evidence base on the UK value stream for Remotely Piloted Aircraft Systems (RPAS). The objective of this research was to understand the current and potential structure of the UK RPAS value stream and its potential economic benefits to the UK. The study was required to inform the work of a cross government working group on RPAS and small drones, as well as to identify any gaps in information and develop recommendations for filling these gaps.

1.1 Remotely Piloted Aircraft Systems

RPAS are aircraft piloted from a remote station which can involve varying levels of autonomy in their operation. A few decades ago the technology was almost exclusively confined to a hobbyist market, but it is now finding commercial applications rapidly and is forecast to grow substantially over the next decade. RPAS have been identified by the Government as a technology with potential applications across many areas of economic and social activity. A cross-government working group has been created to support pathfinder projects to test and understand a range of potential applications, including parcel delivery, agriculture, geo-mapping, and infrastructure inspection.

This review has been undertaken to explore how, unlocked by rapid technological development and the advantages offered to users, RPAS technology is finding numerous commercial applications in the UK with its use set to be a potential driver of productivity over the coming decade. The research also considers the technological hurdles that need to be overcome before the full economic potential of the RPAS value stream can be realised, and the significance of regulatory and other barriers to the use of RPAS.

1.2 Research Objectives

The overarching objective of the study is to provide Government with a better understanding of the scale and composition of the current and potential civil commercial UK RPAS value stream in terms of activity, the interconnections between different elements, areas of competitive advantage, barriers to growth and the gaps which exist within the civil RPAS sector.

The research was required to develop an appreciation of the RPAS value stream including the following aspects:

- Companies, organisations and academic centres involved in RPAS research,
- Technology and development,
- The developers of the systems themselves as well as producers of the elements that make up the aircraft platforms,
- The structures, control and communication systems,
- Propulsion and power systems,
- The sensors used both in their operation and to gather data and other components,

- Users and operators,
- Providers of repair, upgrade or maintenance services, facilities for the operation and testing of RPAS,
- Companies and organisations involved in training, safety and regulation, and
- Developers of software used by manufacturers and/or operators - or for the analysis of the data which are produced by sensors.

The research was required to consider these aspects in order to understand:

- The structure of the value stream, current participants in each element and their positioning,
- The possible evolution of the value stream, assuming sufficient regulatory, technological and commercial progress takes place,
- The segments with the highest potential economic benefits to the UK, considering both the potential commercial and public sector end users, with an assessment of the extent of these economic benefits,
- The level of interconnection between the value stream segments and potential connections with adjacent markets.

1.3 Research activities

This report draws on the delivery of the following research tasks:

- **Development of a research framework** – the study team developed an analytical framework describing the production of RPAS, their downstream applications and the factors influencing these. This was initially prepared in draft form and refined following discussions with a steering group drawn from across government at a project inception meeting.
- **Initial identification of relevant literature** – An initial bibliography for the literature review was developed by interrogating a range of on-line databases using an array of RPAS relevant search terms (detailed in the Appendix Table A.1), Consideration was also given to publications produced by a set of relevant organisations. Members of the project steering group helped to identify additional evidence, and a number of other sources were also identified over the course of the review:
  - **Academic publications**: A large volume of academic research has been published on RPAS. This literature primarily documents novel applications and technological developments (with little in the way of economic research into the technology area).
  - **Gateway to Research**: The Gateway to Research portal provides details of all Innovate UK and Research Council funded research projects (including records of the organisations involved and abstracts describing the focus of the project). A search for research funding mentioning key RPAS terms yielded 75 relevant projects, providing intelligence on technological approaches and applications currently being developed in the UK. Access to the applications prepared by applicants to relevant Innovate UK competitions was sought through the study, though it did not prove possible to secure this information within the timescale of the project.

  - **Regulatory and policy roadmaps**: Significant policy attention has been given to the regulatory issues associated with the emergence of RPAS at an international level. Policy papers and other outputs from these debates provided context on the key debates and the potential direction of travel of regulatory arrangements.
  - **Market projections**: A wide range of projections or forecasts have been prepared by public and private sector organisations that describe the anticipated trajectory of demand for RPAS and the potential revenues that may be generated by their downstream applications.
  - **Trade bodies**: Publications from these groups have provided additional detail on RPAS issues from the perspective of the sector.
  - **Wider analysis and commentary**: A number of additional sources were identified by the project steering group, by stakeholders and from internet searches on particular RPAS topics.
  - **Company websites**: Analysis of company websites was used to develop evidence on a sample of UK RPAS businesses. This included businesses identified using RPAS search terms, recipients of Innovate UK grants to develop RPAS, and companies listed as providing RPAS based services on the ARPAS-UK web-directory. In addition, 20 leading global RPAS manufacturers were identified and researched.

- **Consultations with key stakeholders** - The desk review was supplemented by a small scale programme of consultations with nine key stakeholders with an interest in RPAS production, research and development, and their downstream applications and regulation (the key individuals of interest were identified by the Project Steering Group). A topic guide was developed for these interviews based on the research framework. Interview notes were then imported into NVIVO alongside the literature evidence. In addition observations were taken at an industry event hosted jointly by the law firm Bird & Bird, the trade body techUK and the Royal Aeronautical Society. This offered the opportunity to discuss key issues emerging in the research with a broader range of stakeholders in a 'Chatham House Rules' setting.
- **Review of literature** – An assessment of was made of the information provided in each of these sources against the research framework. A summary of the sources reviewed is included in Appendix Table A.2.
- **Synthesis and gap analysis** – The NVIVO software package was used to synthesise this evidence against the analytical framework to contribute to an interim paper and this final report.

1.4 Report Structure

This report aims to inform this process by mapping the existing available information on the value stream associated with RPAS. It is structured as follows:

- This section has set out the **objectives for this report** and outlined the **research methods** deployed.
- Section two develops the **analytical framework** for understanding the RPAS value stream that was developed and applied in this study.
- Section three presents an overview of **RPAS R&D, production and markets**, considering both global evidence and intelligence about this activity in the UK.
- Section four focuses on the **uses of RPAS technology**, identifying existing and anticipated applications in the UK and globally.
- Section five explores the potential for **developments in the RPAS value chain** by critically assessing the potential significance of technological, regulatory or reputation related barriers to RPAS use in the future.
- Section six discusses the available set of **RPAS market forecasts**.
- Section seven concludes by identifying the **gaps in the** existing **evidence base** and suggesting approaches that could be deployed to provide this information, as well as discussing some of the policy implications of the evidence identified.

2.0 RPAS Value Stream

This section sets out an analytical framework that describes key components of the value stream for Remotely Piloted Aircraft Systems in the civil sector, as well as the range of wider factors that will be influential in determining the scale of the future value stream for the UK. This analytical framework has been used as an organising framework in structuring the analysis of the literature, consultations, and wider data collected as part of this study.

2.1 RPAS Value Stream

In the context of this study, the concept of 'value stream' is defined so as to encompass all sources of economic value originating from the development and diffusion of RPAS. This captures the value added at each stage of the RPAS manufacturing process through the production and assembly of components and sub-systems (similar to the concept of traditional manufacturing supply chains). However, the scope of this study also extends to other sources of value associated with RPAS, including:

- **Research and development** into RPAS will be a source of economic value in itself (i.e. both the wages paid to relevant R&D personnel and any profits derived from either licensing agreements or research contracts will be monetised as Gross Value Added in national accounting measures). Additionally (as described in Section 2.3), R&D activities clearly have the potential to lead to feedback effects that result in greater value added either in RPAS production or their downstream applications. R&D activities may also, of course, produce spillover benefits to other sectors.
- **Downstream applications**: RPAS can be described as a platform technology with the potential to enable a range of commercial applications across an array of industrial sectors. RPAS could result in greater value added through raising the productivity of primary, production and service sectors to the extent that they are adopted as an input by relevant firms (either directly or through outsourcing). This can occur either by supporting the emergence of new activities, or where the use or RPAS offers the opportunity to reduce costs (e.g. the significant potential to achieve cost savings through RPAS use for inspection compared to existing procedures).
- **Supporting services**: Finally, the emergence of civil applications for RPAS has the potential to generate demand for enabling support services, with the potential in a number of applications for moderate to significant cost savings over conventional applications together with corresponding productivity gains.

These different elements of the value chain are described in more detail in the following sub-sections.

2.2 Production of RPAS

The economic value associated with the production of RPAS can be broadly understood to originate in the production and assembly of five core inputs[2]. The configuration of these inputs will determine the performance characteristics of the RPAS in terms of its navigation capabilities, endurance, payload capacity, durability, and safety, as follows:

- **Airframe**: The airframe integrated into a RPAS will reflect a range of design considerations that will influence its performance. Materials choices will often involve a trade-off of desirable features (for example, strength and durability) against aspects that adversely affect performance such as weight. Aerodynamic considerations influence fuel efficiency, speed and agility, and the range of exterior conditions in which the RPAS can be reliably expected to operate. Safety considerations are also important: heavier and more rigid designs will carry a greater level of kinetic energy that will need to be dissipated in the event of a collision (and therefore involve greater potential hazards). The intended operational environment may influence the desirable dimensions of the device. Design considerations also need to factor in the need for the manufacturer to produce the airframe at an acceptable unit cost.
- **Power drive**: The performance characteristics of RPAS will also be significantly influenced by the choice of power drive – with higher power densities enabling smaller or lighter devices and lower fuel consumption, enabling longer ranges. However, one of the advantages of the RPAS over manned flight systems is that it enables issues associated with pilot fatigue to be avoided, and power systems that enable continuous operation are potentially desirable.
- **Communications, Command, and Control systems**: The operation of an RPAS will potentially involve up to four telecommunications links. These include an uplink between the user and the device facilitating its control and a downlink allowing the device to communicate information on system health and data collected from sensors. In addition, RPAS may potentially benefit from links to the Global Positioning System to facilitate navigation, as well as links to Air Traffic Control, with the reliability and security of these links central in determining the safety of RPAS when operating in their intended environments. Sensor technology may also enable varying degrees of autonomy in flight, potentially resulting in safety and performance improvements (such as detection and evasion of other air users or ground objects).
- **Sensors**: A wide variety of sensors can potentially be integrated into RPAS to support a range of eventual applications. These include sensors to capture images (i.e. cameras, infra-red sensors), radar, LIDAR, multispectral and hyperspectral sensors used for detecting chemicals compounds, acoustic sensors, magnetometers, and meteorological sensors.
- **Information technology**: Finally, RPAS have the potential to collect large amounts of data and appropriate on-board or ground based computing and data processing technologies are needed to facilitate many of their intended applications.

The total economic value associated with RPAS production will be equivalent to the value of global sales of the devices. This will in turn be linked to the willingness of users or operators to

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[2] Unmanned Aircraft System (UAS) Service Demand 2015 to 2035: Literature Review and Projections of Future Usage, John A. Volpe National Transportation Systems Centre, September 2013. Available at http://ntl.bts.gov/lib/48000/48200/48226/UAS_Service_Demand.pdf (accessed February 2016).

pay for RPAS, which will be linked to both the extent to the value their use creates in their intended operational environment (and it can be anticipated that higher quality systems with superior performance characteristics will generally be able to command higher prices and margins). This value will be distributed to varying degrees across prime manufacturers (those engaged in the assembly or integration of the components described above), manufacturers of components and sub-systems (Tier 1 suppliers), and manufacturers of inputs further down the supply chain.

The current and future potential value of RPAS production to the UK will depend on how far firms are able to claim a significant share of the market, which will in turn depend on:

- **Skills and industrial capabilities**: The production of RPAS will demand a range of specialised engineering skills as well as capital equipment, and the economic value of production will be linked to how far these industrial capabilities are present in the UK or can be realistically developed in the future.
- **Research and development**: The attainment of higher values will likely require meeting a range of technical challenges involved in either optimising RPAS performance (facilitating higher prices) or improving industrial processes (reducing costs). This will likely require research and development drawing on a wide range of scientific, engineering, and computing disciplines. The ability of the UK to address these technical challenges will be partly linked to how far the required skills align with the expertise originating in its academic institutions and industrial organisations, as well as the broader infrastructure that facilitates the capitalisation and commercialisation of early stage research R&D projects.
- **Unit costs**: The ability of the UK to compete in export markets will also be linked to its ability to supply either complete RPAS or componentry and sub-systems at acceptable unit costs. While this will in part be linked to the efficiencies that can be realised through the application of industrial and scientific expertise, other factors – including pressures on the costs of key factor inputs (wages, land, etc.) and exchange rates - will also be influential in determining the competitiveness of UK based producers.

2.3 Demand: Civil Applications of RPAS

The commercial value of RPAS originates in their ability to fly to a specified location, perform a task, and potentially return to their origin or an alternative destination – while delivering an outcome that is more cost effective or efficient than existing methods. To date, RPAS can typically perform one or more of four functions: the collection and transmission of sensory data (the nature of which will depend on the characteristics of the sensors on board), the lifting and delivery of a payload to its desired location (e.g. acting as telecommunications carriers or broadcast services), and interacting with its environment to perform remote operations.

RPAS have the potential to deliver productivity improvements to a range of processes through enabling them to be completed more cost-effectively, more effectively, or more safely than the available alternatives (typically manned flights or through manual labour). RPAS tend to be smaller and less expensive to manufacture, operate and maintain than manned aircraft. This supports their use in situations where the costs of manned flights would be prohibitive, or in environments that would otherwise be inaccessible. Equally, RPAS can more safely complete tasks in hazardous situations that would otherwise only be possible through manual inputs (such as inspections of tall structures) and, depending on the quality of on board sensor and data processing technology, complete these tasks more effectively. As such, RPAS have the potential to find a wide array of applications across a range of industries.

The potential economic value of RPAS to the UK will largely depend on the following:

- **Industrial strengths**: The scale of productivity gains supported by RPAS adoption will likely vary substantially across industries. As such, the value of the technology to the UK will be partly linked to how far those industries that stand to benefit to the greatest degree have a significant presence in the country.
- **Absorptive capacity**: The ability of the UK to maximise the economic value will also be dependent on the ability of key industries to absorb the technology. While relevant factors might include the supply of suitable skills to operate RPAS effectively in their intended environments, the extent to which adopting industries are able to process the data collected by RPAS will be critical in determining the size of the productivity gains which can be realised.
- **Ancillary services**: The adoption of RPAS both domestically and overseas may also result in spin-off demand for supporting services of both a traditional nature (e.g. financial and insurance services) and non-traditional services (e.g. RPAS pilot training). The ability of the UK to generate additional value from these services will again depend on the strength and competitiveness of the relevant industries, and their ability to adapt their service offerings to the user needs emerging from their use of the technology.
- **Scope to develop new business models**: The economic value of RPAS may not necessarily be delivered through their adoption as an input by production industries; new business models have the potential to emerge in the service sector allowing production industries to derive the benefits of the technology through outsourcing.
- **Export potential**: Where there is scope to develop service models organised around the use of RPAS, there may also be scope to export those services (increasing their value to the UK).

2.4 Factors Influencing the Value Chain

Alongside the broad framework identified above, other factors may influence the scale of the UK value chain for RPAS:

- **Agglomeration effects**: The future value of RPAS will be determined by interactions between users and producers of the technology. One the one hand, user needs will help frame the research agenda pursued by manufacturers and academic institutions (user pull). On the other, the research process may lead to technical innovations for which users ultimately find a commercial application (technology push). If there is scope for clustering effects to emerge (whereby users and producers of the technology are proximate in space), then this could support positive feedback effects through more rapid exchange of knowledge thus leading onto more rapid development of the technology. Such processes can lead to the emergence of hubs of expertise that attract further inward investment, creating an on-going process of agglomeration and regional specialisation.
- **Technological spill-overs**: The development of RPAS may also result in technological spill-overs that generate productivity gains in adjacent industries. For example, new or data processing technology developed in response to the emergence of RPAS could potentially find uses elsewhere (satellite applications for example). Technological spill

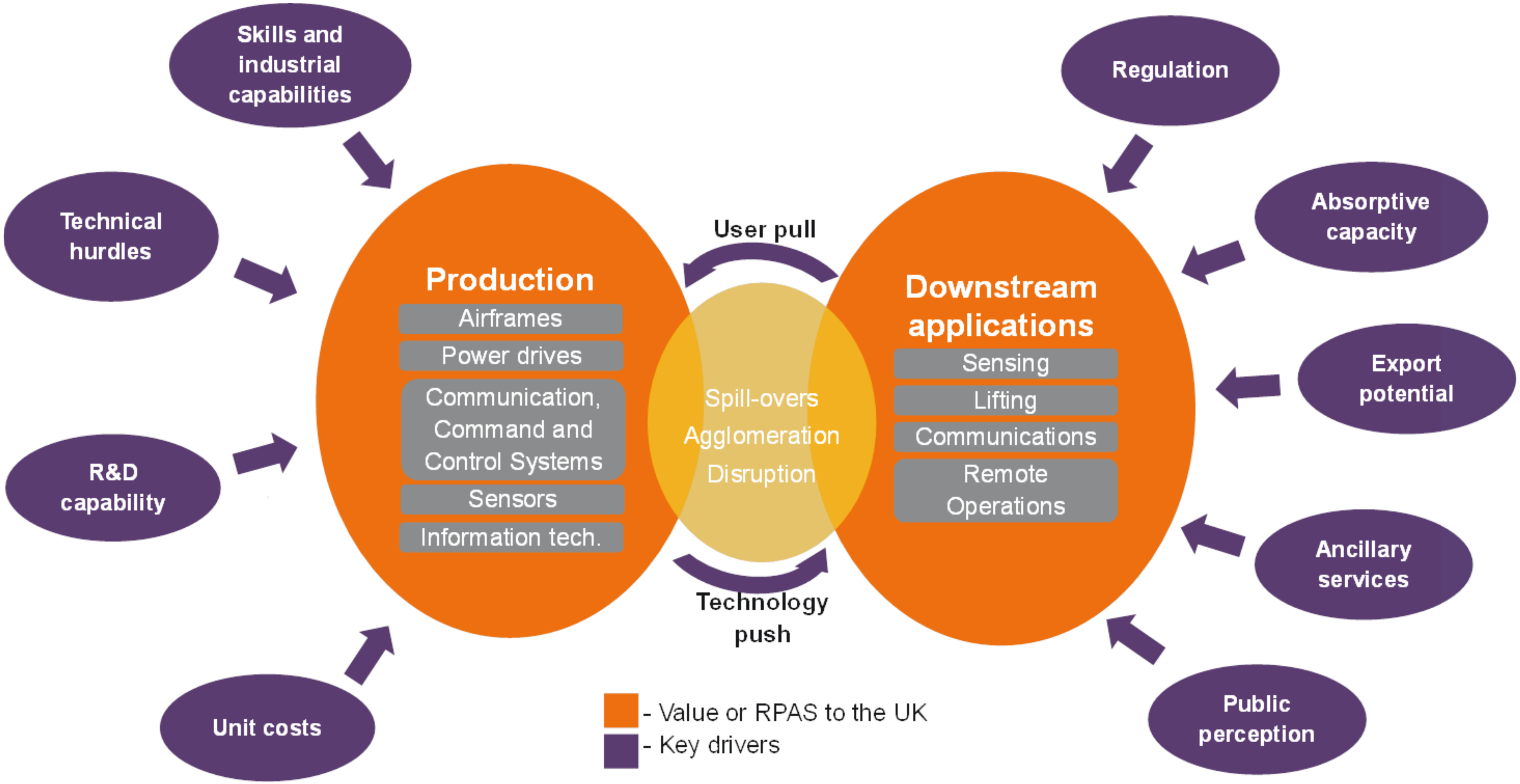
overs may arise as a result of interactions between military and civil RPAS manufacturing activities. Historically, much of the impetus and funding for the development of RPAS has been driven by demand from the military sector. While the focus of this study is on civil applications of the technology, it may not necessarily be straightforward to treat the two as strictly separate. In particular, as there are manufacturers of military RPAS based in the UK, there is scope for technological spill-overs that create value in civil markets and vice versa.

- **Regulation**: The economic value of RPAS in the UK will be influenced by the nature of the regulatory regimes at a domestic and European level, as well as those adopted in other overseas territories. While more permissive regimes are likely to promote technological development and adoption, the potentially hazardous nature of collisions with other air users as well as ground based objects will mean that regulators will have cause for caution until it can be demonstrated that the technology has evolved to a point where those risks are acceptable (which may constrain growth). If there are significant differences in regulatory regimes across international territories, then this could act as a barrier to the export of both manufactured RPAS and services oriented around the technology.
- **Disruption**: RPAS are potentially disruptive and could lead to the redundancy of industrial processes completed manually or using manned flight. As such the emergence of RPAS could have offsetting effects through reducing the economic value of other value streams, and the UK may be more or less exposed to these types of threat depending on their nature.
- **Competitive threats**: Equally, development of hubs of expertise in overseas territories could represent a threat to the value chain in the UK in both production markets and tradable service markets, either inhibiting the emergence of an industry in the UK or placing competitive pressure on margins.
- **Public perceptions**: Finally, public perceptions of the risks associated with RPAS operation (which are being explored in a parallel study commissioned by the cross-government working group) may also set limits on the regulatory pathway that is deemed acceptable, as well as influencing purchasing decisions.

2.5 Overview of the Analytical Framework

A summary of the analytical framework is illustrated in the figure overleaf.

Figure 2.1: An Analytical Framework for the Value of RPAS to the UK



3.0 RPAS Markets, R&D and Production Activity

This section sets out an analysis of key aspects of the current civil RPAS value chain, exploring recent trends in R&D spending and production activities (applications and ancillary services are considered in the following section). The section first considers these issues on a global scale before examining recent trends in the UK.

3.1 Global Context

3.1.1 Market Segmentation

A great number and variety of RPAS are available on the market. In 2014, there were 1,708 different RPAS models available worldwide[3]. While aircraft designed for manned flight are comparatively conservative in design owing to the limitations associated with housing human pilots, crew, and passengers, RPAS do not suffer from these constraints and, as a result, the range of configurations is relatively broader. The RPAS market is segmented predominantly on the basis of weight, as detailed in Table 3.1 below.

Table 3.1: RPAS Market Segmentation by Size

Size	Approximate weight	Current and potential applications	Price and quantity
Small (<20kg)	Micro/ Nano/ miniature/ 'toy' RPAS (few hundred grams)	• Leisure use • Commercial use (surveillance and inspection of hard to reach areas) • Limited flight capability due to poor battery life	• Available to buy on the high street and online • ~£100 for leisure use • ~£10,000 for specialised use • Estimated to be tens of thousands of toy-like RPAS in the UK
	Small RPAS (< 2kg)	• Leisure use • Commercial use (photography)	• £100–£900 • Estimated to be thousands in the UK
	Small RPAS (2–7kg)	• Mainly commercial use (photography, aerial surveying and inspection) • Large recreational models also available	• £500–£4,000 • ~360 units used commercially
	Small RPAS (7–20kg)	• Mainly commercial use (photography, aerial surveying and inspection) • Some specialist recreational models produced	• £4,000–£20,000 • ~150 units used commercially

[3] Teal Group (2014). Teal Group Predicts Worldwide UAV Market Will Total $91 Billion in Its 2014 UAV Market Profile and Forecast. Teal Group Corporation. www.tealgroup.com/index.php/about-teal-group-corporation/press-releases/118-2014-uav-press-release. Date accessed: 27/01/2016.

Size	Approximate weight	Current and potential applications	Price and quantity
Light (20-150kg)	Light RPAS (20–50kg)	• Potential to inspect pipelines/power cables, spray crops, search and rescue	• £40,000–£100,000 depending on endurance and technology • 2 units used commercially
	Light RPAS (50–150kg)	• Potential for border surveillance; forest fire Monitoring	• Few for commercial use • < £300,000 depending on airworthiness certification requirements
Large (>150kg)	Large RPAS (> 150kg)	• Potential for cargo transport • Potential to remain airborne for days, if not months, and travel thousands of miles	• > £500,000 • None used commercially at present, though some may be in testing

Source: House of Lords (2015)

Material was identified describing the technical characteristics of small mass produced RPAS models that are typically marketed for hobby applications, personal photography or as toys. Analysis of RPAS listed on the product comparison site SpecOut.com, which includes a broad range of such devices, suggested these models have an average flight time of 18 minutes, a range of 1,400m and a median price of approximately £420[4,5]. Table 3.2 below presents a summary of the key features of a selection of commercially available RPAS, which highlights some of their present technical limitations. Flight times are typically short, while many models are limited in the range of weather conditions in which they can operate. As illustrated in the table, overcoming these limitations can be costly. For example, models that are able to operate in windy conditions or light rain are at least 7 times more expensive than those able to operate in dry conditions alone.

While this source includes some larger drones that are likely to have professional applications, consistent and comparable data of this nature has not been identified for RPAS intended specifically for professional applications. The core technological features of different size RPAS models are discussed in Section 5.1 and 5.2.

[4] The Remote Control Project (2016). Hostile Drones: The Hostile Use of Drones by Non-State Actors Against British Targets. Open Briefing.
[5] All currencies are given in GBP at the following exchange rates: USD 1.4312; EURO 1.2864. XE.com. Date Accessed: 18/02/16, 10.49 UTC.

Table 3.2: Features of Selected Commercially Available Small RPAS

Model	Weight	Payload	Flight Time	Range	Max Speed	Camera	Operating Conditions	Price
Parrot BeeBop	0.4kg	0kg	12mins	250m (extendable)	29mph	Yes (14MP)	Dry Conditions Only	£700-£900 (RTF)
Blade 350 QX2	1kg	0.2kg	10mins	1000m	32mph	Yes	Dry Conditions Only	£200-£300 (RTF)
3DR IRIS+	0.9kg	0.2kg	16mins	800-1000m	40mph	Yes	Dry Conditions Only	£500-£600 (RTF)
DJI Phantom 2 Vision +	1.2kg	0.2kg	25mins`	600m	33mph	Yes (14MP)	Dry Conditions Only	£800-£1,200
DJI Phantom 3 Professional	1.2kg	0.3kg	28mins	1900m	35mph	Yes (12MP)	Dry Conditions Only	£1,000-£1,200
Walkeera Scout X4	1.7kg	0.5-1kg	25mins	1200m	40-50mph	Yes	Dry Conditions Only	£700-£900
Yuneec Q500 Typhoon	1.1kg	0.5kg	25mins	600m	54mph	Yes (12MP)	Dry Conditions Only	£900-£1,100 (RTF)
SkyJib-X4 Ti-QR	15kg	7.5kg	15mins	3000-25000m	24mph	Yes	Wind	£7,500-£8,000
Altura Zenith ATX8	3.1kg	2.9kg	45mins	1000m	44mph	Yes	Light Rain/Snow	£15,000-£20,000
Microdrones MD4-1000	*2.65kg*	*1.2kg*	*88ms*	*5000m*	*26mph*	*Yes*	*Light Rain/Snow*	*£20,000-£30,000*

Source: Remote Control (2016)

The segmentation set out above aligns with regulatory requirements in the UK and abroad that differentiate between RPAS based on their weight because of the risks posed by various devices (see Section 4 for additional detail here). Presented in Table 3.3 below Frost and Sullivan have developed a more detailed market segmentation focusing on small RPAS by sub-sector, also identifying illustrative models to describe each sub-segment. Table 3.3 also shows a similar relationship between the cost of RPAS and their performance characteristics.

Table 3.3: Frost & Sullivan Market Segments (Small RPAS only)

Sub-sector	Price	Example product	Weight	Endurance	Description
Consumer	<$1,500	DJI Phantom	1280 g	Approximately 23 minutes	Small quadcopter RPAS fitted with a mounted camera. Available in 4 models, 4k, Standard, Advanced and Professional.
Prosumer	$1,500 - $5,000	DJI Inspire	2,935 g	Approximately 18 minutes	Quadcopter RAS manufactured by the same company as the Phantom and of a similar size. Available in two versions with the Raw/Pro versions designed for professional filmmaking.
Professional	$5,000 - $50,000	Freefly Systems Cinestar 8	3,050g	30 minutes	A larger more expensive octocopter design. Applications include photography, mapping and surveying.
Commercial 1	$50,000 - $100,000	Microdrones MD4-1000	2,650g	Average of 45 minutes but a maximum of 90 with endurance configuration	German made quadcopter design manufactured from carbon fibre. Able to fly by GPS as well as remote control and in a variety of weather conditions.
Commercial 2	> $100,000	Aeryon Labs Skyranger	2,400g	Up to 50 minutes	Small Quadcopter design built to military and government specifications.
Fixed wing	$5,000 - $50,000	Parrot/ senseFl yeBee	690g	Up to 50 minutes	Fixed wing professional mapping RPAS.

Source: Frost & Sullivan (2015)

3.1.2 Global Demand for RPAS

Overall demand for RPAS can be broken down into military, commercial and consumer sources. This study focuses on the latter two categories, though it is important to note that the global market for RPAS has historically been driven by military demand. The US military has played a significant role over the past decade[6] and has accumulated a fleet of RPAS fleet comprising 6,000 vehicles[7] with an annual budget of £1.5bn in 2015[8]. Data available for the UK that indicates it has spent more than £2bn on military unmanned aircraft between 2007 and 2012[9].

Research conducted by Frost & Sullivan[10] offers a quantitative assessment of the current sizes of the markets for consumer and commercial RPAS, at £349m and £919m respectively. The only other study indicating current RPAS market size is provided by Teal Group (2015) which includes the military sector in addition to consumer and commercial RPAS. This estimates the current market at £2.8bn. This suggests that the military market for RPAS may currently be larger than the commercial and consumer markets. However, the study team have not had full access to the methodology and calculations underpinning these estimates so cannot confirm the extent to which the larger figure identified by the Teal group includes military RPAS and/or involves other differences in coverage.

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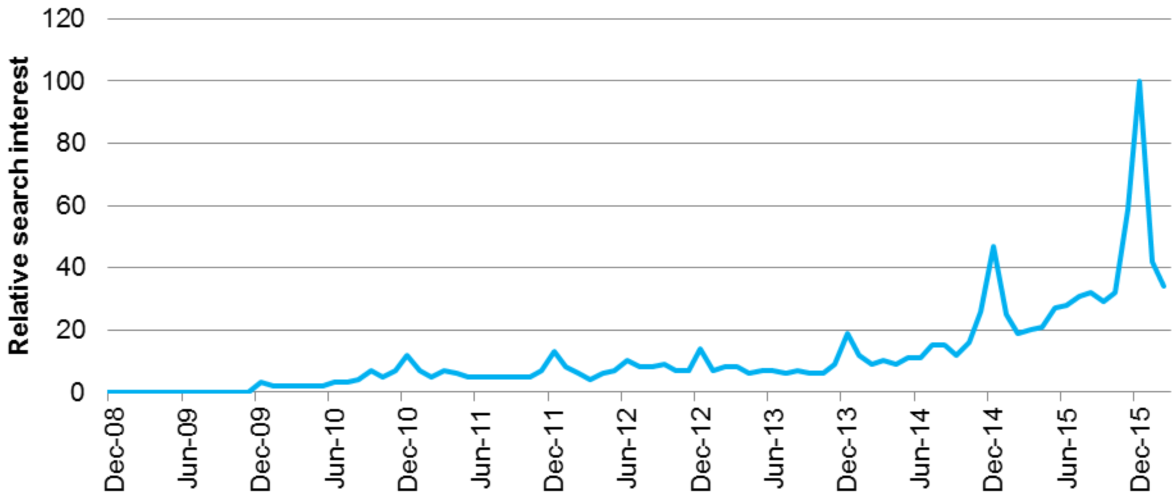
[6] Qi3 (2014). Qi3 Insight: Unmanned Aerial Vehicles – Growing Markets in a Changing World.
[7] Royal Aeronautical Society (2013). Unmanned Aerial Vehicles: A New Industrial System? Discussion Paper.
[8] Office of the Under Secretary of Defence (2015). Program Acquisition Cost by Weapons System. US DoD Fiscal Year 2016 Budget Request.
[9] Guardian (2012). Britain's military drones spending tops £2bn. www.theguardian.com/world/2012/sep/26/drone-spending-britain-tops-2bn. Date Accessed: 28/01/16
[10] Frost and Sullivan (2015). Prospects for the Burgeoning Global Commercial UAS Market.

Analysis of Google search data confirms the growing significance of consumer RPAS markets. The jumps in the data seen in December in Figure 3.1 below imply that gift purchases are likely to be a significant current market driver.

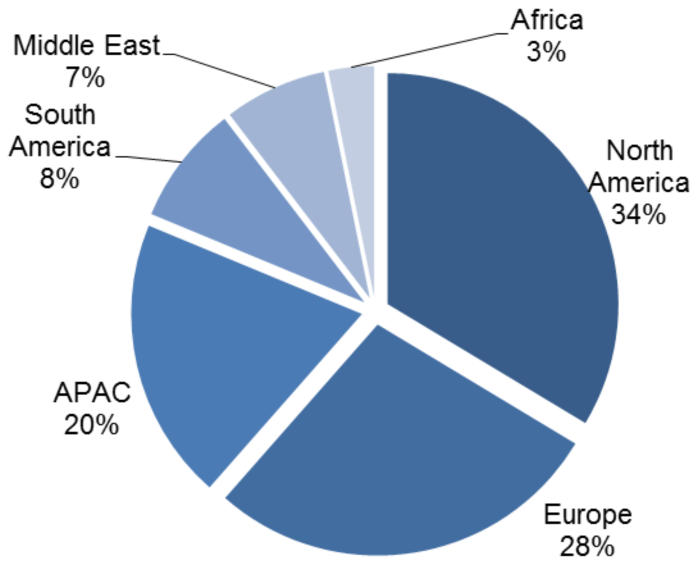
Figure 3.1: Relative Search Interest for RPAS



Source: Google Trends, using the search term "drone review". Completed: 15/01/16

Only one quantitative estimate was available from the evidence base of the global distribution of demand for RPAS. Figure 3.2 below identifies North America, Europe and the Asia Pacific area (APAC) as the current key areas of RPAS demand, by revenue.

Figure 3.2: Total Commercial RPAS Market: Revenue Forecast by Region 2015



Source: Frost & Sullivan (2015)

3.1.3 Global Production of RPAS

Total civil RPAS production in 2015 was just over one million units, 71 percent of which were destined for consumer markets (hobby) and 29 percent for commercial markets[11]. The study team identified 20 leading RPAS manufacturers (on the basis of a number of lists provided in the literature), and used web searches to provide a headline analysis of this group. One Chinese based company, DJI, is significantly larger than other RPAS manufacturers, and has achieved explosive growth since 2011, capturing as much as 70 percent of the consumer RPAS market[12]. The Shenzen-based firm was also identified by stakeholders and journalists as a clear market leader, dominating several of the largest RPAS sectors. It appears that the breakthrough success of DJI has been associated with a single model, the Phantom, which has managed to meet consumers' needs more closely than competing products through a combination of appealing design, the inclusion of specific advanced technologies (such as new gimbal technologies) and advanced flight controllers.

Analysis of this group of 20 leading RPAS manufactures identifies a mix of APAC, American and European manufacturers. As noted above, the study team have not been able to identify consistent data to compare turnover by region. However, the scale of DJI positions China as the most significant location for RPAS manufacture. The majority of leading producers are, to a large degree, solely producers of RPAS (rather than firms with significant scope in other products).

Table 3.3: Headquarters of Leading RPAS Manufacturers

APAC	Europe	HQ Country	Manufacturer
• DJI (China) • Walkera (China) • Yuneec (China) • Yamaha (Japan)	• Parrot (France) • AirRobot (Germany) • Ascending Technologies (Germany) • MicroDrones (Germany) • UAV Factory (Latvia) • Aerialtronics (Netherlands)	• Aervon Labs (Canada) • Draganfly (Canada) • 3DR (US) • AeroVironment (US) • Blade Helis (US) • INSITU (US) • Trimble (US)	• Aeronavics (New Zealand) • Steadi Drone (South Africa)

Source: Ipsos MORI analysis (2016)

Literature reviewed by the study team also identifies the US and Israel as leaders of RPAS manufacturing.[13] Their success in leveraging their military experience was identified as a key factor behind this position.[14] In Israel, the integrated civil-military air navigation system was identified as a factor that has supported the development of civil RPAS production.[15] Reflecting the table above, Europe was identified as a key location in one study which looked at 1,708 different RPAS models, identifying 566 as assembled in Europe.[16] In addition, a broader range

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[11] Frost and Sullivan (2015). Prospects for the Burgeoning Global Commercial UAS Market.
[12] Forbes (2015). Bow To Your Billionaire Drone Overlord: Frank Wang's Quest To Put DJI Robots Into The Sky. www.forbes.com/sites/ryanmac/2015/05/06/dji-drones-frank-wang-china-billionaire/#1add49eb210c. Date Accessed: 17/02/16.
[13] European Commission (2014). A new era for aviation - Opening the aviation market to the civil use of remotely piloted aircraft systems in a safe and sustainable manner (COM/2014/0207).
[14] Royal Aeronautical Society (2013). Unmanned Aerial Vehicles: A New Industrial System? Discussion Paper.
[15] Foster, J. (2015). Report on safe use of remotely piloted aircraft systems (RPAS), commonly known as unmanned aerial vehicles (UAVs), in the field of civil aviation (2014~2243(INI)). European Parliament Committee on Transport and Tourism.
[16] Teal Group (2014). Teal Group Predicts Worldwide UAV Market Will Total $91 Billion in Its 2014 UAV Market Profile and Forecast. Teal Group Corporation. www.tealgroup.com/index.php/about-teal-group-corporation/press-releases/118-2014-uav-press-release. Date accessed: 27/01/2016.

of secondary production locations are also identified, including Brazil, India and Russia.[17] Australia and South Africa have also been identified among 50 other countries currently developing RPAS.[18]

3.1.4 Global Production of RPAS Components and Sub-Systems

The analytical framework presented in Section 2 above identifies a set of components and subsystems that the study team understand are key features of RPAS. However, the evidence base assembled for the study provides limited coverage of how supply chains for these components and sub-systems operate. For example, it has not been possible to confirm the typical extent of vertical integration within the supply chain (i.e. the extent to which RPAS OEM produce these components themselves or source them from suppliers). Stakeholders offered conflicting evidence here. One indicated that RPAS production is dominated by globally made components that are assembled with only modest added value, suggesting that innovation and competitive advantage for OEMs comes from working with suppliers and understanding user needs. Another indicated that the highest quality RPAS are sourced from Germany and Switzerland and that these manufacturers strive to keep much of the sub-system manufacture in house in order to keep quality high.

Stakeholders indicated that margins for mass-produced components are very small, but that some European manufactures are creating high quality and value componentry that might be associated with larger margins. These strengths of German and Swiss manufacturers are also confirmed in Foster's work.[19]

3.1.5 Global R&D Activity

It has been challenging to obtain evidence or estimates relating to the scale of global R&D activity focusing on civil applications for RPAS. However, global R&D and procurement activity including military applications was estimated to be £3.6bn in 2014 by the European Commission[20] and £2.8bn in 2015 by the Teal Group.[21] It is difficult to disentangle the military RPAS R&D from these estimates, though military spending is likely to be a significant component, with one source indicating that military RPAS R&D budgets would be £1.5bn in 2016 (with the US accounting for two thirds of this total). To put these figures into context, this represents less than one percent of global R&D spending, though it is comparable in scale to aerospace R&D spending in the UK (which totalled £1.7bn in 2014).[22]

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[17] European Data Protection Supervisor (2015). Opinion of the European Data Protection Supervisor on the Communication from the Commission to the European Parliament. European Data Protection Supervisor.
[18] Foster, J. (2015). Report on safe use of remotely piloted aircraft systems (RPAS), commonly known as unmanned aerial vehicles (UAVs), in the field of civil aviation (2014~2243(INI)). European Parliament Committee on Transport and Tourism.
[19] Ibid.
[20] European Commission (2014). A new era for aviation - Opening the aviation market to the civil use of remotely piloted aircraft systems in a safe and sustainable manner (COM/2014/0207).
[21] Teal Group (2014). Teal Group Predicts Worldwide UAV Market Will Total $91 Billion in Its 2014 UAV Market Profile and Forecast. Teal Group Corporation. www.tealgroup.com/index.php/about-teal-group-corporation/press-releases/118-2014-uav-press-release. Date accessed: 27/01/2016.
[22] ONS (2014). Business Expenditure on Research and Development 2014, Office for National Statistics, November 2015 available at www.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcm%3A77-386019 (accessed February 2016).

3.2 The UK Context

3.2.1 Production of RPAS and Components in the UK

Although the UK is home to an international competitive aerospace industry[23], a cluster of UK based manufacturers of finished civil RPAS has not so far emerged. As illustrated in Table 3.4 above, the UK is not the headquarters of any of the global market leaders in the manufacture of complete RPAS, and this broad perspective was confirmed by the range of stakeholders consulted.

Obtaining accurate information on the production of RPAS in the UK is challenging as it is not classified as a sector in the Standard Industrial Sector. However, it has been possible to compile a list of relevant firms through from lists of members of the two main trade associations as well as lists of firms which have been successful in their applications for Innovate UK grants. From 466 companies identified through this process, only 13 were determined to be manufacturers (on the basis of a review of their website) and 55 were determined to be manufacturers of components.

Table 3.5 below lists and seeks to detail the companies that have been identified as producers of complete systems. A number of these have a strong emphasis on military RPAS, and it appears that one may still be at a pre-production stage of development. However, there was insufficient information available on these firms to enable any analysis relating to their commercial performance (sales, employment or profitability). For large firms, RPAS revenues were not reported separately from other product lines, while smaller firms did make their accounts available through their websites.

Table 3.5: Manufacturers of RPAS in the UK

Manufacturer	Description
AESIR Ltd	AESIR have developed a family of Vertical Take Off and Landing (VTOL) Unmanned Airborne Vehicles. These are designed to operate in both urban and rural environments providing a platform suitable for a variety of uses including, but not limited to, surveillance and cargo lift.
Athene Works Limited	Recipient of an Innovate UK grant to support R&D in this area; however, the study team have been unable to confirm whether this firm is an active RPAS manufacturer.
BAE Systems	BAE Systems is a large multinational defence, aerospace and security firm with 80,000 staff. Its involvement in RPAS represents a small part of the overall business. However, it has made significant developments through the Taranis, Mantis and Herti designs, all of which are large RPAS (>150kg). Taranis and Mantis are being developed for use in combat exclusively whereas the Herti project has secondary applications in the civil sector for surveillance and border patrol tasks. One particular achievement for BAE Systems was the completion of the first RPAS flight approved by the CAA.

[23] KPMG (2013). The Future of Civil Aerospace. A study on the Outlook for the UK Civil Aerospace Manufacturing Sector. KPMG LLP.

Manufacturer	Description
Barnard Microsystems Limited	Manufacturers of the InView iRPAS. Developed for use in scientific, commercial and state applications utilising its 700 km range. Activities focus on unmanned aircraft systems designed for use in oil, gas and mineral exploration, pipeline and installation monitoring and in the detection of threats to military personnel. The InView has a ‘dry weight’ of less than 20kg and a wingspan of 5m.
BlueBear	Blue Bear Systems offer 3 fixed wing UAVs – Redkite, iSTART and Blackstart. Their craft have three main applications: defence, commercial and emergency service use. The inspection of critical infrastructure and the monitoring of emergency situations are two key roles for their craft.
Enhanced Protection Systems UK Limited	A UK firm that produces vehicle, amour and unmanned aircraft systems for use by the military and the security industry, with the former dominating. In terms of RPAS, it produces 7 models, 2 of which are quadcopter designs whilst the other 5 are fixed wing designs. Products are all less than 20kg in mass and therefore qualify as small RPAS
QuestUAV Ltd	Northumberland based QuestUAV offer various versions of their Q-200 design as well as a more compact, but similar, Datahawk model. Their products are aimed at and adapted for the surveying and research markets in particular and they utilise Sony, Tetracam, Flir and Panasonic as sensor suppliers. All models are fixed wing.
Snelflight Ltd	Produces two RPAS firmly in the small range in terms of mass and primarily aimed at the hobbyist market with prices less than £800. The company itself was created to manufacture indoor helicopters for the toy market and has since joined forces with Autonomous Technologies Ltd to design and develop the UAS on offer.
SuperMarine Unmanned Ltd	Supermarine offers four RPAS on their website. Two of these are fixed wing, one is a tri-copter (3 arms) design and one a quadcopter. Prices start from £15,999 and they are designed for cargo, law enforcement and aerial photography/video work. Limited technical information is available on the site on the majority of their RPAS. The maximum payload of their X-6 Trooper model is 2000g and it comfortably falls into the sUAS category.
Tekever	Develops innovative technologies for the Enterprise, Aerospace, Defence and Security Markets. It is a global operation with activities divided into either the Information Technology division or the Aerospace, Defence and Security Divisions. It produces 6 models of RPAS with 5 fixed wing variants and 1 quadcopter design. Applications of the products span a wide variety of sectors, including security missions, environmental surveillance, antiterrorist surveillance, maritime surveillance and infrastructure monitoring.(Prices unavailable but considering the uses, designs and customers (police force) for the UAS as fairly substantial potentially £20k+).
Thales Group	Thales is a large multinational company with expertise in aerospace, space, defence, security and transportation. For example, they are a world leader in air traffic management. Their RPAS operations involve contributions towards the ASTRAEA programme and various contributions in sensors and payload systems whilst their Watchkeeper UAS demonstrates a complete RPAS for intelligence surveillance and reconnaissance. Watchkeeper is currently the largest single UAV programme in Europe and the UAS has seen use in Afghanistan. Its Current market is the military sector for information, surveillance, target acquisition, and reconnaissance (ISTAR) missions with the potential to cross into the civil market with governments in the future.
VTOL Technologies	VTOL technologies have designed a unique RPAS – VTOL Flying Wing. The craft is a wing shaped frame with undercarriage and a motor at each corner of the wing. It is capable of vertical take-off from a stationary position or from moving craft such as a ship, and is designed for use in the fields of energy distribution, transportation, logistics and agriculture.

Source: IUK data, Duedil directory 2016 and company websites (2016)

Stakeholders confirmed the limited level of non-military RPAS manufacture in the UK. While several were able to identify examples of UK firms developing RPAS with military applications which have an interest in entering the civil market, a consistent perspective emerged about the current position. Stakeholders stressed that the development of small RPAS has so far had little in common with the aerospace sector (in which the UK has significant strengths), and has been more closely related to the manufacture of electrical devices. As such, other locations - and Asia in particular – have been able to leverage strengths in electronics to take an early mover advantage in this market. It was also suggested that countries such as Germany and Switzerland were able to leverage their reputation for exceptionally high quality manufacturing to capture some of this market (by competing on quality rather than price).

Analysis of UK registered companies also suggests that the UK is also currently not a hub for the production of RPAS components and sub-systems. As highlighted above, it was possible able to identify 34 UK companies focused on the production of RPAS components and sub-systems, with coverage of all key components aside from airframes (and a discussion is set out Table 3.6 overleaf). It is important to note that without direct research with firms, this may understate the number of potentially relevant firms (many RPAS components may be generic to aviation and other industries - e.g. electric motors may have multiple applications[24]). This analysis may therefore understate the extent of RPAS component and sub-system manufacture in the UK. Table 3.6 below reflects the specialisms of these firms against the RPAS components and sub-systems within the analytical framework (Section 2).

Stakeholders interviewed also supported the view that the UK is not a leader in the manufacture of RPAS components or subsystems. Several niche developers were however identified by stakeholders, including a battery company (Oxis Energy) identified as a world leader in Lithium Sulphur battery chemistry with particular RPAS applications. Examples of automation hardware strengths within spin-outs from academic institutions were also identified.

[24] An attempt was made to examine the origin of the componentry in popular RPAS models to overcome this issue, though the material made available through company websites did not support such analysis.

Table 3.6: Analysis of UK RPAS Components and Sub-System manufacturers

Component Subcategory	Description
Airframes	From the analysis of the companies operating in the UK gathered from the Duedil directory, ARPAS membership list and Innovate UK data we found no evidence of manufacturers that could be classified in this sector. AmSafe Bridport do, however, create textile solutions designed to withstand high loads which can be used on RPAS – the company is registered with the Unmanned Aerial Vehicle Systems Association (UAVSA).C & B Composites, based in Poole, also manufacture carbon fibre components that can be applied to RPAS airframes.
Power Drives	We have identified 4 small UK firms that have some involvement with the power drives of RPAS. Oxis Energy is concerned with the development of battery technology such as lithium sulphur cells. They aim to find a use for this power source to enhance batteries on UAS. UAV Engines Ltd manufactures whole engines for use specifically in RPAS of both small and medium size across 25 countries, either water or air cooled designs. Sigma Lithium Ltd are currently involved in a project funded by Innovate UK looking to improve battery design of Lithium-ion batteries, enabling RPAS to fly longer with more capacity. They intend to achieve this in a short timescale through the use of technology that can be quickly deployed. Lastly, Adelan Limited develops solid oxide fuel cells to be used as an energy source in RPAS which are lighter and require less maintenance than batteries. One major name involved with the production and testing of engines is Cosworth who are making engines for US military RPAS. Their strength lies in the production of large, whole engine systems that are not suitable for small civil RPAS.
Communication, Com. & control	Cobham Mission Systems Ltd has been identified as having developed a satellite communications system for UAVs in the military, commercial and public sector/science markets – The AVIATOR UAV 200. This is designed to be both faster and lighter than similar products enhancing the capabilities of RPAS communication. The company itself is a large defence firm based in the UK with a particular emphasis on the aerospace industry. Skycircuits have produced a selection of autopilot avionics that find use in many industries such as forestry, agriculture, archaeology, surveying, infrastructure and research. They are a small firm based in Salisbury. Tata Communications limited are registered with the UAVSA and they have considerable expertise in communication technology on a large scale.
Sensors	The study team identified a number of UK companies producing sensor equipment for use with RPAS, the products of which range from the more 'basic' imaging equipment such as video cameras through to thermal imaging cameras and advanced surveying and mapping technology. For example Mapping Solutions Limited specialise in producing equipment instrumental for Optical & Thermal Hyperspectral, LiDAR data acquisition, processing and spectral analysis. Photonics and Analytics specialise in Spectral Imaging & Optical Solutions and can apply this knowledge to remote sensing using RPAS. OptoSignal Limited is currently conducting research into an acoustic camera that would allow RPAS to fly at night to add to their current product range which includes imaging software. Sensor equipment is vital in allowing an RPAS to carry out a specific mission/requirement and the variation in sensing equipment illustrates the variety of tasks the craft can be applied to. Roke Manor Research has produced a miniature altimeter that has been effectively added to a low flying UAV that can automatically detect its altitude when being used to imitate the threat of an incoming missile. They have also developed a system of sensory equipment that allows a UAV to land autonomously.
Information Technology	The study team identified in particular three UK companies supplying information technology components or systems for RPAS. Flock provide flight management software aimed at minimising the disruption of RPAS flights. They achieve this through the utilisation of people's location data. OptoSignal also produce software which stitches photographs together to create a large image. Altitude Angel provide programming interfaces and other software for use in and with RPAS as well as making available a range of data and open source RPAS software.

Source: IUK data, Duedil directory 2016 and company websites

3.2.2 R&D activity in the UK

As with information on the economic value of RPAS production in the UK, there is very little evidence on the level of private R&D spending by firms in developing the technology. However, it was possible to identify 79 R&D projects funded by Innovate UK and the Research Councils (RCs). The total public contributions to these projects was £22.7m, of which £14.7m was in the form of grants given through Innovate UK competitions (which are more likely to be oriented towards the commercialisation of research rather than the basic research typically funded by Research Councils). It is important to note that a large share of this research funding (72 percent) has been allocated to the flagship ASTRAEA programme. The strength of the UK's R&D infrastructure is considered in more detail in Section 5, though this quantitative evidence suggests that UK R&D spending is possibly a relatively small share of estimated global spending of between £2.5-3.5bn.

3.3 Summary

- **Global Markets**: Research conducted by Frost and Sullivan[25] offers a quantitative assessment of current market sizes for consumer and commercial RPAS, at £349m and £919m respectively.

- **Market segmentation**: The market for RPAS is typically segmented by weight (small, light, and large RPAS). While there are a large number of RPAS models available for civil use, the vast majority of these fall into the smaller categories. Many RPAS are available at prices which make them accessible to households (at £1,000 or less), and market reports suggest that the leisure or hobby market accounts for a large share of demand in terms of units sold. However, the performance characteristics of these models are typically limited, offering low endurance and range as well as difficulties in flying in adverse weather conditions. Overcoming these performance limitations is typically costly, with those devices with the highest technical specifications commanding prices of up to £100,000. Although large RPAS are available for military use, a market for civil applications for devices at this scale is yet to emerge, likely due to the significant costs involved.

- **Structure of the value chain**: The available literature offers very little quantitative insight into the characteristics of the RPAS value chain. However, stakeholder evidence suggested that there is typically little in the way of value added generated in the production of RPAS destined for leisure markets (which typically integrate 'disposable' components). The higher value that can be obtained by RPAS with superior technical characteristics has, however, enabled some firms to develop higher value added componentry.

- **International leaders**: The main hubs of international production are located in Asia, and one Shenzen-based firm (DJI) has emerged as a dominant market leader in producing small RPAS (claiming 72 percent of the market). The success of firms based in this region has partly been attributed to their expertise in the manufacture of electronic devices (with small RPAS manufacturing having more in common with this sector than with aerospace). However, there are also prominent manufacturers based both in Europe

[25] Frost & Sullivan (2015) research offers a quantitative assessment of current market sizes for consumer and commercial RPAS, at £349m and £919m respectively.

and North America, where firms have been able to create some competitive advantage through competing on quality.

- **RPAS production in the UK**: Although it has not been possible to obtain systematic figures, the evidence suggests that a strong RPAS manufacturing cluster has not emerged in the UK. 13 manufacturers of complete RPAS were identified through this review, some of which were primarily or solely involved in producing large or small models for military markets (which are outside the scope of this study). Additionally, 55 manufacturers of RPAS components and sub-systems were identified. It has been challenging to identify clear evidence describing the challenges that the UK has faced in developing manufacturing expertise in civil applications, though the predominance of small devices has meant that it has not been possible to exploit adjacencies with the aerospace industry in which the UK has a competitive advantage.

- **Research and Development**: Global R&D spending on RPAS R&D appears to be in a range between £2.5 and £3.5bn, covering both military and non-military sectors; it is challenging to disentangle military and non-military estimates in this area. While a large number of active UK RPAS R&D activities were identified, the quantitative evidence suggests that the UK R&D spending is possibly a relatively small share of this total.

- **Quality of information**: RPAS manufacturing has not reached a stage of development where it is yet recognised in industrial classification systems employed by public statistics authorities. As a result, it has been highly challenging to identify reliable economic data regarding the size of the RPAS production sector either within the UK or the EU. Key items of interest, such as the number of jobs supported, output, profitability and productivity, and growth can only feasibly quantified with further primary research.

4.0 RPAS Applications

This section focuses on the economic value associated with RPAS technologies. It presents evidence on the application of RPAS technologies to deliver sensing, lifting, communications and remote activities. The analysis details examples of UK operations, as well as examples from the rest of the world, and explores of the range of economic benefits arising from each area of application in turn. This section also examines the role of RPAS in creating demand for supporting ancillary services.

4.1 Emergence of RPAS applications

The use of RPAS is not new. In 1898, the civil inventor Nikola Tesla was granted a patent for what was likely the first remote control and unmanned vehicle. RPAS applications in the civil sector, common to many other innovative technologies perfected during the 20th century, largely emerged from research and development with military applications in mind. Hobby uses of RPAS also have a long history. Early examples included 19th Century hydrogen filled model airships, post-world-war models including the use of devices controlled for the ground remotely with metal wires and more recently by radio control.[26]

The commercial use of RPAS is more recent. Stakeholders consulted as part of this review suggested that this did not start until mid-2000s while some applications did not experience their 'firsts' until 2010. For example, the first inspection of a wind turbine by a RPAS took place in 2010, and the first live flare inspection in the oil and gas industry only in 2012.[27]

The evidence base identifies the emergence of RPAS applications with a predominant focus on forms of remote sensing. This encompasses the capture of still images, and video as well as more sophisticated systems that detect particular features (e.g. a deformation) or track change (in the case of maintenance). The balance of available evidence stresses this as the primary current use of RPAS. Three additional types of application have been identified for non-military RPAS, but the evidence base included no examples of their active use. These were 'lifting' (delivery of parcels, cargo or even passengers), 'communications' (such as the use of pseudo-satellites), and 'remote operations' through the integration of robotic features into RPAS to allow them to interact with their environment.

[26] History of Model Flying. British Model Flying Association. undated, https://bmfa.org/Info/History-of-Model-Flying. Date accessed: 19/02/2016
[27] CYBERHAWK (2016). CYBERHAWK World Firsts. CYBERHAWK Innovations Ltd www.thecyberhawk.com/about/cyberhawk-world-firsts/. Date accessed: 15/02/2016

4.2 Current UK and Global RPAS Applications

4.2.1 Global Market for RPAS applications

This literature review found very little evidence on the current scale of the global market that has emerged around the use of the RPAS, either in terms of firms or other institutions that have adopted them as a production input or the related service sector that has emerged. However, the shift towards mandatory registration for commercial RPAS operations provides some comparative data on the scale and distribution of the global market. As of the 20th January 2016 the US Federal Aviation Authority had granted 3,129 Section 333 petitions for commercial operations[28], while research in 2015 identified 2,500 operators in Europe and 2,342 operators in the rest of the world[29], suggesting that while the EU may lag other regions in the production of small RPAS, the technology is being rapidly adopted by commercial firms (though systematic data on the nature of these firms, and their performance is unavailable).

4.2.2 Commercial Operators of RPAS in the UK

There is limited information available on the number and type of firms using RPAS as an input into the production process in the UK. The Civil Aviation Authority provides a public list of firms that have registered as commercial operators of small RPAS[30], which suggests that 1,416 licenses have been granted to operate RPAS of up to 7 kilograms in weight, while 316 had been approved for commercial flights of RPAS of between 7 and 20 kilograms.

Although time series data is unavailable, it is apparent that the number of operators is growing rapidly (and indeed grew by 9 percent between the end of December 2015 and February 2016 alone, equivalent to an annualised growth rate of 67 percent). These figures also suggest that the UK claims a significant share of the global market, accounting for more than half of the registered operators in the EU and approximately 25 percent of those globally. The database, however, provides limited information on how the devices are employed by commercial users or their commercial performance. One stakeholder suggested that a large proportion of companies registered to provide RPAS services may not be generating large revenues from offering these services, and that many may be micro-scale operations supporting only one or two members of staff. This stakeholder suggested that there might be only three firms in the UK employing more than 20 staff: Callen Lenz, Sky Futures and Cyberhawk.

The ARPAS-UK trade association provides details of its 266 members that have developed a service model oriented around their use (with details on the types of services offered and location for 214 of these). As illustrated in Figure 4.1, around 75 percent of those members offer aerial photography or video services. Surveying and mapping, aerial cinematography, industrial inspection and agricultural inspection services are also offered by a substantial share of the members for which details were available. The majority of firms included within the database offer a variety of services – for example only seven of the 66 firms offering industrial inspection provided this as their only service.

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[28] Federal Aviation Authority (2016) Authorizations Granted Via Section 333 Exemptions, available from www.faa.gov/uas/legislative_programs/section_333/333_authorizations/. Date accessed 22/02/2016

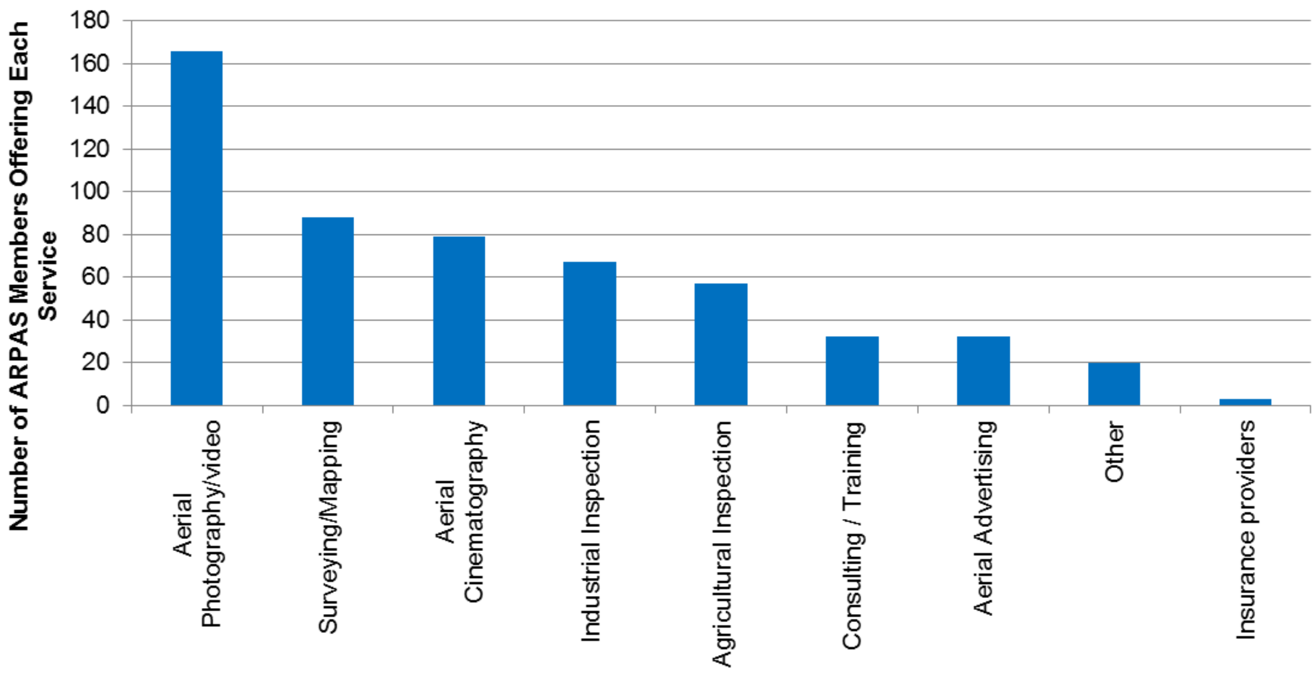
[29] Foster, J. (2015) Report on safe use of remotely piloted aircraft systems (RPAS), commonly known as unmanned aerial vehicles (UAVs), in the field of civil aviation (2014~2243(INI)), European Parliament Committee on Transport and Tourism.

[30] Civil Aviation Authority Approved Commercial Small Unmanned Aircraft Operators. Civil Aviation Authority. February 2016. Available from: http://publicapps.caa.co.uk/modalapplication.aspx?appid=11&mode=detail&id=7078. Date accessed: 02/2016

Clearly, this dataset is not comprehensive, though it does suggest that that the main service models that have developed to date have been focused on the ability of RPAS to collect and transmit information, with little evidence that firms have developed business model exploiting their potential to carry cargo, support telecommunications, or undertake remote operations. A review of the CAA list of approved commercial RPAS operators suggests that this view of the applications market is broadly accurate and that it can potentially be characterised by high levels of competition. A number of police forces are approved operators (suggesting that RPAS have found security applications), as well as major media organisations (such as the BBC and ITV).

Analysis of ARPAS-UK members also suggests that the industry is largely clustered in the Greater South East of England (London, the South East and the East of England), though it is present to varying degrees throughout Great Britain. Given the emphasis of current applications on imaging, photography and cinematography, this may reflect clustering in proximity to the broader media industry that has a strong presence in these regions (though this is speculative).

Figure 4.1: UK Firms Offering RPAS Services by Type



Source: Analysis of ARPAS-UK members from www.arpas.uk

4.2.3 Specific UK RPAS Applications

Several distinct types of RPAS application were identified through the course of the research, and are discussed in detail in this section with a focus on four classes of application identified: sensing, lifting, communications, and remote operations. Some, such as sensing, are very much current applications and are used by countless hobbyists. Others are being explored or tested (such as parcel delivery) but have not been commercialised to date. For each class of application, this section presents existing examples of UK applications, international examples, and identifies ongoing activity to explore potential future applications. It also identifies the benefits being realised by those making use of RPAS. However, it has not been possible to compare the pattern of activity with that internationally.

Table 4.1 Extent of Use of RPAS by Industry and by Application

Sector / Application	Leisure / consumer	Film and media	Agriculture	Logistics	Oil and gas	Other infrastructure	Law Enforcement
Sensing							
Photography and filming							
Inspection and Monitoring:							
Mapping and Surveying							
Other sensors (including chemical)							
Lifting							
Parcel Delivery							
Large Cargo Delivery							
Passenger Transport							
Other							
Communications							
Remote Operations							

Note: Darker shading indicates the relative prevalence of the activity identified through the research presented in Section 4. Dark shading indicates this is an actively used application. Lighter shading indicates that this is an area either being explored, or pursued by a small group of early adopters. Unshaded boxes indicate where there is little or no current RPAS applications.

Source: Ipsos MORI analysis

4.2.4 Sensing

The following sensing applications of RPAS were identified through the course of the review as of particular importance within the UK.

- **Leisure Use**: The decreasing costs associated with RPAS use was identified by many sources as supporting a surge in leisure and hobby uses of RPAS (see for example House of Lords 2015), making it currently by far the dominant form of application for RPAS[31]. Applications here included the flying of toys as a hobby as well as the use of RPAS as personal cameras, offering 'holiday snaps'. An example of this type of device is the recent Lily Camera. New novel leisure applications are also developing such as the sport of 'drone racing'[32].
- **Photography, Film and Broadcasting**: Capturing film and TV images is one of the most widely recognised applications of RPAS, and its use in the UK is widely documented (e.g. House of Lords 2015). TV channels employ internal teams using UAVs - the BBC introduced a team that uses a hexacopter to film aerial shots in 2014. A related area of application is real estate imagery – the use of RPAS to capture attractive pictures of houses was identified as an increasing trend in the UK by stakeholders. In many instances the use of RPAS for aerial filming and photography is cheaper than a full-scale helicopter, less intrusive, more convenient, faster to set-up, portable and safer. For example, GPS technology has built in safety features such that the RPAS will return to a pre-defined 'home station' if the radio signal is lost. While companies specialising in delivery of these services, such as Bee Aerial's, put safety as a primary concern, there have been several highly publicised incidents of RPAS crashing[33].
- **Inspection and Monitoring**: This area was identified by stakeholders as an increasingly significant area of RPAS application in the UK, with a particularly dramatic increase in uptake in the past two to three years. Examples were identified by stakeholders of firms using RPAS to inspect a broad range of structures and roofs in particular. Infrastructure inspection appears to be of particular importance, with examples being actively pursued in the UK including:
  - Environment Agency use of RPAS to survey rivers to map flood risk[34] and to monitor waste sites[35].
  - Network Rail has established a framework agreement for RPAS inspection work. A particular advantage here is the potential to conduct inspection work from a position of relative safety[36].

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[31] House of Lords (2015). Civilian use of Drones in the EU~7th Report of the Session 2014-15. House of Lords. www.publications.parliament.uk/pa/ld201415/ldselect/ldeucom/122/122.pdf. date accessed: 27/01/2016

[32] Bloomberg Business (2015). New Drone Racing League Wants to Be the Next Nascar. Bloomberg Business. www.bloomberg.com/news/features/2016-01-26/new-drone-racing-league-wants-to-be-the-next-nascar. Date accessed: 27/01/2016

[33] Bee Aerial (2016). Benefits of Drones ~ Aerial Filming Drone Hire for TV and Film London UK. Beeaerial. www.beeaerial.co.uk/benefits-using-drones-aerial-filming-uk/. date accessed: 19/02/2016

[34] Water and Waste Water Treatment (2015). Project Focus~ Drone imagery helps map flood risk. WWT. wwtonline.co.uk/features/project-focus-drone-imagery-helps-map-flood-risk#.Vssa_H2LTcs . date accessed: 19/02/2016

[35] UK Construction Online (2015). Environment Agency use AIR drone to monitor waste sites. UK Construction Online. www.ukconstructionmedia.co.uk/news/environment-agency-use-air-drone-to-monitor-waste-sites/. date accessed:19/02/2016

[36] House of Lords (2015). Civilian Use of Drones in the EU~ 7th Report of the Session 2014-15. House of Lords. www.publications.parliament.uk/pa/ld201415/ldselect/ldeucom/122/122.pdf. date accessed: 27/01/2016

- Aircraft Inspection, scanning large aircraft to detect defects caused by hail and lightning strike damage[37]
- Nuclear facilities inspection in environments where it would be hazardous to send an individual.
- English Heritage are using RPAS to monitor over 400 historic sites and monuments in England[38]
- Oil and gas facilities (identified through stakeholder consultations)

In addition, stakeholders indicated that the potential use of RPAS to monitor wind farms is being actively explored by several UK operators. International examples of infrastructure inspection include the use with rail tracks, dams, dykes and power grids in Europe[39], and to survey quarries, and rivers in Canada[40]. A related range of potential future RPAS applications related to inspection have been identified in the area of underwriting and loss adjustment. These include the idea of using RPAS to provide high resolution images of the exterior of properties, using thermal images to detect leaks, to capture images following catastrophes to aid claims professionals, or for surveillance to detect fraud and validate claims[41].

There are clear benefits from using of RPAS for industrial inspections. A leading provider of these services described these as:

- Reduced costs – by minimising downtime of equipment subject to inspection
- De-risk planned shutdowns – operators have necessary information to fully plan and budget turnarounds
- No plant outage – site stays online and operational during inspection
- A safer working environment – removing the need for people to work at height
- Higher quality information – flights in proximity to physical assets allows providers to locate and diagnose problems quickly.

Specific examples identified through stakeholder consultations indicated that there have been instances when inspection that previously took six men 14 weeks was completed by one RPAS operator in two days. RPAS were also associated with software developments that aid comparison of changes through time. Two independent sources indicated that inspections in oil

[37] Aviation Week (2015). More Airlines Use UAVs For Aircraft Inspection. MRO. MRO Enterprise Software content from Aviation Week. http://aviationweek.com/mro-enterprise-software/more-airlines-turn-uavs-aircraft-inspection. Date accessed: 15/02/2016

[38] House of Lords (2015). Civilian use of Drones in the EU~7th Report of the Session 2014-15. House of Lords. www.publications.parliament.uk/pa/ld201415/ldselect/ldeucom/122/122.pdf. date accessed: 27/01/2016

[39] European Commission (2014). Communication from the commission to the European Parliament and the Council~ A new era for aviation. European Commission. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52014DC0207. Date accessed: 28/01/2016

[40] Whitehead, K. et al (2014). Remote sensing of the environment with small (UASs), Journal of Unmanned Vehicle Systems, 2014, 2(3): 69-85

[41] Munich RE (2015). Focus on: Drones and the Commercial Sector. Munich Reinsurance America, Inc. www.munichre.com/site/mram-mobile/get/documents_E-564385086/mram/assetpool.mr_america/PDFs/3_Publications/Research_Spotlight/focuson_drones_commercial.pdf . Date accessed: 25/01/2016

and gas settings can result in client savings of tens of millions of US dollars – on one occasion $35m in a specific case of a flare inspection[42].

- **Precision Agriculture**: Some stakeholders engaged in this review also indicated that RPAS are actively being used by a number of farmers in the UK to survey their land and to target their crop management strategies. Defra has been providing grants to support the diffusion of the technology through the Countryside Productivity Scheme administered by the Rural Payments Agency. However, it appears that application of RPAS to precision agriculture is more developed in other advanced economies such as Japan.[43] In Japanese rice production, RPAS have been used since late 1980s when the government procured some of the early RPAS produced by Yamaha. In May 2015 Yamaha became the first company to secure permission to fly a crop-spraying drone in the US that resembles a helicopter and is called RMax – the plan is to use it to spray vineyards in the Napa Valley.[44]

  Other international examples identified in the evidence base include:

  - Sensing different water statuses across a commercial Spanish orchard to develop a new watering strategy[45]
  - Crop monitoring to detect variations in fertilisation[46]
  - Remote sensing to identify areas needing additional water, chemicals, pesticides and herbicides[47]

  The benefits from using RPAS within agriculture are well documented. Farm trials have shown a yield benefit of £20/ha based on the use of zone management practices[48]. A more recent example by farms.com provided an example of a 100 acre field in Ontario which saw an increase in annual revenues of as much as $70/ac[49]. In these cases RPAS use is seen as an alternative to satellite imagery with RPAS viewed as a less expensive and more readily accessible substitute[50]. A recent survey by one of the companies providing services for farmers using RPAS indicates a high demand for use of RPAS in

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[42] ADS Advance (2016). Bristow enters UAV services market through Sky-Futures. ADS Advance. www.adsadvance.co.uk/bristow-enters-uav-services-market-through-sky-futures.html. Date accessed: 19/02/2016

[43] Everaerts, J. (2008). The use of unmanned aerial vehicles (UAVs) for remote sensing and mapping. www.isprs.org/proceedings/XXXVII/congress/1_pdf/203.pdf. Date accessed: 14/01/2016

[44] FT (2015). Yamaha aims to unlock US and EU markets with agricultural drone. Financial Times. www.ft.com/cms/s/0/626684e2-2181-11e5-aa5a-398b2169cf79.html#axzz40Roc4gZy. Date accessed: 15/02/2016

[45] Gonzalez-Dugo et al (2013). Using high resolution UAV thermal imagery to assess the variability in the water status of five fruit tree species within a commercial orchard. Precision Agriculture December 2013, Volume 14, Issue 6, pp 660-678

[46] Hunt, E. et al. 2010. "Acquisition of NIR-Green-Blue Digital Photographs from Unmanned Aircraft for Crop Monitoring." Remote Sens. 2, no. 1: 290-305.

[47] Whitehead, K. et al (2014). Remote sensing of the environment with small (UASs), Journal of Unmanned Vehicle Systems, 2014, 2(3): 69-85

[48] See: 1. Godwin et al (2003) An Economic Analysis of the Potential for Precision Farming in UK Cereal Production, Available online at https://dspace.lib.cranfield.ac.uk/bitstream/1826/746/4/Economic_analysis-UK_cereal_farming-2003.pdf Accessed online 19th February 2016 or Seelan, S. K., Laguette, S., Casady, G. M. and Seielstad, G. A. (2003), 'Remote sensing applications for precision agriculture: A learning community approach', Remote Sensing of Environment, vol. 88(1), pp 157 – 169.

[49] Farms.com (2016). Precision Agriculture Economics ~ Precision Agriculture. Farms.com. www.farms.com/precision-agriculture/economics/. Date accessed: 19/02/2016

[50] Zhang, C., & Kovacs, J. M. (2012). The application of small unmanned aerial systems for precision agriculture. Precision Agric (2012) 13:6. pp.693-712

the UK, where the farming community understands the benefits to be, in order of importance[51] :

- Increased margins
- Reduced input costs (agricultural inputs)
- Improved understanding of field performance and variation
- Targeted inputs and management,
- Better decision-making yield forecasting,
- More consistent crops and yields, and
- Reduced environmental losses (pollution).

- **Mapping and Surveying**: A limited number of mapping and survey uses of RPAS were identified within the UK, particularly focused on rural areas - especially in relation to atmosphere monitoring, wildlife, biodiversity and geology surveys[52]. A broad range of international examples have been identified – ranging from observing patterns of deforestation[53] to surveying of salmon locations in British Columbia[54]. Further research would be required to confirm the extent to which such activities are also pursued in the UK, but a broad body of evidence has emerged reflecting the benefits of RPAS use for these applications and is summarised below:

  - Reduced time – large areas surveyed up to 50 times faster than ground-based land surveying with multiple teams allowing rapid deployment
  - Improved safety – survey hazardous areas with minimal ground access and less time on site due to rapid data collection
  - Better information – vertical and oblique photography combined with accurate topographic data, digital terrain modelling and volumetric analysis
  - Improved decision making – more detailed and up-to-date than off-the-shelf data

  In comparison to conventional fixed-wing aircraft or helicopters RPAS offer:

  - Reduced costs – conventional aircraft can cost hundreds of dollars per survey hour once the costs of transporting the devices to a survey site, and mobilising them there are considered. RPAS can survey more than 100 Ha (1km2) in a day
  - Reduced infrastructure requirements – most RPAS can operate more flexibly than conventional craft; rotary RPAS have a minimal space footprint and many fixed-wing RPAS are launched by being thrown by an operator or assistant
  - More flexible operation – in particular avoiding low cloud

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[51] British Farmer and Grower (2016). Drones become more common but beware the eye in the sky. Ursula Agriculture. www.ursula-agriculture.com/wp-content/uploads/british_farmergrower_January_2016.jpg
[52] House of Lords (2015). Civilian use of Drones in the EU~7th Report of the Session 2014-15. House of Lords. www.publications.parliament.uk/pa/ld201415/ldselect/ldeucom/122/122.pdf. date accessed: 27/01/2016
[53] Koh, L. P., & Wich, S. A. (2012). Dawn of drone ecology-low-cost autonomous aerial vehicles for conservation. Tropical Conservation Science (2012) 5:2
[54] Whitehead, K. et al (2014). Remote sensing of the environment with small (UASs), Journal of Unmanned Vehicle Systems, 2014, 2(3): 69-85

- Improved accuracy – improved geospatial accuracy, particularly important for repeated observations can be achieved using RPAS because the implementation of autopilot systems is available at a much lower costs than for conventional aircraft
- Improved safety – the low speeds and altitudes required for many surveys introduce inherent dangers for conventional craft with crashes by small aircraft a leading cause of work-related mortality among wildlife researchers (Watts et al 2010).

For mapping and image classification RPAS have also been confirmed to provide a low-cost, more rapid, and more flexible alternative to airborne LiDAR for geomorphological mapping with consistency of flightpath identified as a strength[55]. This has been empirically confirmed by Hugenholtz et al, 2012[56]. The main benefits over the common approach utilising helicopters are:

- Higher efficiency for data collection using unmanned aircraft systems (UAS) which can be equipped with many different cameras or sensors.
- Reduced price in comparison to using helicopters,
- Ability to perform more regular measurements at the same cost.
- Speed of collecting information (possibility of regular intervals).

For other wildlife monitoring applications the low capital and per flight costs, the ease in flight planning, quick responses and the potential to gain high quality images are the key benefits identified[57]. Automation has been identified as a key feature for conservation activities and mapping large areas[58]. There is a not-for-profit international organisation ConservationDrones.org which seeks to share knowledge of building and using low-cost unmanned aerial vehicles for conservation-related applications with conservation workers and researchers worldwide, especially those in developing countries. Sumatra Orangutan Conservation Programme for example uses UAVs for habitat monitoring and research[59].

- **Law enforcement**: A number of UK police forces have attempted to make use of RPAS, with mixed results. A high profile incident occurred when a police RPAS crashed into the River Mersey in 2011[60]. The Merseyside police force identified a number of issues with their application, including technical challenges, the availability of trained staff, training costs and inoperability in poor weather. A survey of UK police forces in 2014 identified that many forces have experimented with RPAS use, but faced significant technical issues that have deterred many from further pursuing the technology[61]. Further

[55] Watts, A. C.,et al (2010). Small Unmanned Aircraft Systems for Low-Altitude Aerial Surveys. Journal of Wildlife Management. (2010). 74(7):1614-1619.
[56] Hugenholtz, C. et al (2012). Small unmanned aircraft systems for remote sensing and earth science research. Earth and Space Science News. (2012). Volume 93, Issue 2519. p236
[57] Hardin, P. J. (2010). Small-Scale Remotely Piloted Vehicles in Environmental Research. Geography Compass. (2010). Volume 4, Issue 9, pages 1297–1311
[58] Koh, L. P., & Wich, S. A. (2012). Dawn of drone ecology-low-cost autonomous aerial vehicles for conservation. Tropical Conservation Science (2012) 5:2
[59] Sumatran Orangutan Conservation Programme (undated) Drone Technologies. www.sumatranorangutan.org/drone-technology. Date accessed: 19/02/2016
[60] BBC (2011). Police drone crashes into River Mersey. BBC News. www.bbc.co.uk/news/uk-england-merseyside-15520279. Date accessed: 27/01/2016
[61] Jones(2014). Back from the Battlefield: domestic-drones-in-the-uk-final.pdf. https://dronewarsuk.files.wordpress.com/2014/05/domestic-drones-in-the-uk-final.pdf. Date accessed: 15/02/2016

international examples of the current and anticipated application of this technology to law enforcement are included in FAA 2013[62] Harrison 2013[63] and Taylor Vinters 2014[64].

Mulero-Pazmany et al 2014 assessed the use of remotely piloted aircraft systems for anti-poaching activities to protect the decreasing rhino population in South Africa[65]. The proposed approach could serve as a tool for surveillance of sensitive areas, for supporting field anti-poaching operations, as a deterrent tool for poachers and as a complementary method for rhinoceros ecology research. The research identifies the cost of employing anti-poacher companies and detailed costings of using RPAS. However, the research authors admitted that the benefit of integrating RPAS in anti-poaching work is difficult to evaluate in economic terms, as its calculation would involve putting a price on the life of a rhinoceros and evaluating how many could be saved by using RPAS.

4.2.5 Lifting

An application identified in a number of literature sources and by stakeholders as being actively explored, but not yet a commercial reality is the use of RPAS to move objects, and potentially even passengers. Two distinct types of lifting application were identified in the review. The first is the use of small RPAS to lift small objects. The potential to use RPAS to deliver parcels is being explored by Amazon[66] and pizza delivery is being explored by Dominos[67]. Flirtey is exploring a similar use in New Zealand[68] and stakeholders identified interest in using RPAS to deliver other small items such as medical supplies (also identified in France-Presse 2015)[69].

The second class of application identified by stakeholders was the use of large RPAS to move freight, or to lift very large objects (such as a wind turbine), though this would likely necessitate the development of civil RPAS at 500kg or more. Although specific testing activities have been identified, both of these types of application were viewed as currently some way from market both because of required technical developments and regulatory considerations (as explored in Section 5).

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[62] FAA (2013) Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap. Federal Aviation Authority.

[63] Harrison, G. (2013) Unmanned Aircraft Systems (UAS)~ Manufacturing Trends, Congressional Research Services. www.fas.org/sgp/crs/natsec/R42938.pdf. Date accessed: 27/01/2016

[64] Taylor Vinters (2014) Qi3 Insight~ Unmanned Aerial Vehicles. Qi3 Insight. www.qi3.co.uk/wp-content/uploads/2014/02/Qi3-Insights-White-Paper-UAVs-Growing-Markets-in-a-Changing-World-2014021903.pdf. Date accessed: 25/01/2016

[65] Mulero-Pázmány, M., Stolper, R. et al (2014). Remotely piloted aircraft systems as a rhinoceros anti-poaching tool in Africa. PLoS ONE 9(1)

[66] Popper (2015). Drones could make Amazon's dream of free delivery profitable. The Verge. www.theverge.com/2015/6/3/8719659/amazon-prime-air-drone-delivery-profit-free-shipping-small-items. Date accessed: 19/02/2016

[67] Gye (2013). Domino's builds DRONE to deliver pizzas by air and beat the traffic. Daily Mail Online. www.dailymail.co.uk/news/article-2336324/Dominos-builds-DRONE-deliver-pizzas-air-beat-traffic.html. Date accessed: 19/02/2016

[68] House of Lords (2015). Civilian use of Drones in the EU~7th Report of the Session 2014-15. House of Lords. www.publications.parliament.uk/pa/ld201415/ldselect/ldeucom/122/122.pdf. date accessed: 27/01/2016

[69] France-Presse (2015) Rwanda chosen for world's first 'drone-port' to deliver medical supplies ~ Technology. The Guardian. www.theguardian.com/technology/2015/sep/30/rwanda-chosen-for-worlds-first-drone-port-to-deliver-medical-supplies. Date accessed: 19/02/2016

4.2.6 Communications

Google and Facebook have both publically stated their interest in making use of RPAS to provide internet access in remote areas[70]. Stakeholders indicated that these services could potentially be delivered by RPAS that operate at high altitudes and run on solar power, climbing higher during the day to store energy and descending at night. One stakeholder also identified that a UK firm is exploring the potential to use RPAS to provide communications coverage to 'blackspot' areas when particular needs arise, such as to cover major police operations. Again, such applications have not been proven commercially at this stage.

4.2.7 Remote Operations

A potential future area of activity identified in the evidence base would be using RPAS, not only to inspect and detect issues, but also to remedy issues remotely though some form of remote operations such as stopping gas or chemical leaks[71]. This integration of RPAS and other remote operating systems would be of immediate appeal on efficiency and health and safety grounds, but is not an area that has received commercial attention (as far as it was possible to determine within the bounds of this literature review).

4.3 Ancillary Services

The material together for this study provides limited evidence about the provision of related services to RPAS operators and users, and the evidence that was available predominantly suggests that the ancillary service market is developing in line with the growth of the industry more broadly. The provision of insurance services has been identified as a growing opportunity for underwriters[72]. One stakeholder suggested that insurance for RPAS had in the past been difficult to access, but was now readily available. RPAS insurance is now widely marketed by companies such as Insurance4drones (www.insurance4drones.com)[73]. It is important to note however that stakeholders indicated that many RPAS operators were not aware of the need for, or the availability of, such insurance provision. In addition, stakeholders indicated that the use of RPAS was being raised as a potential liability for investigation by insurers currently offering cover for infrastructure. This indicates that the structure of underwriting and liabilities in these areas has not been fully established.

Through the course of the research the study team identified a number of firms marketing legal services to drone users and operators.

The evidence review did not suggest that access to finance has proven a particular issue for RPAS operators[74]. Nevertheless, further research would be required with RPAS operators in

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[70] House of Lords (2015). Civilian use of Drones in the EU~7th Report of the Session 2014-15. House of Lords. www.publications.parliament.uk/pa/ld201415/ldselect/ldeucom/122/122.pdf. date accessed: 27/01/2016

[71] European Commission (2014). Communication from the commission to the European Parliament and the Council~ A new era for aviation. European Commission. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52014DC0207. Date accessed: 28/01/2016

[72] Munich RE (2015). Focus on: Drones and the Commercial Sector. Munich Reinsurance America, Inc. www.munichre.com/site/mram-mobile/get/documents_E-564385086/mram/assetpool.mr_america/PDFs/3_Publications/Research_Spotlight/focuson_drones_commercial.pdf. Date accessed: 25/01/2016

[73] Insurance4drone. 2016. www.insurance4drones.com. Date accessed: 22/02/2016

[74] Note that while access to funding was identified during stakeholder interviews it was suggested to the study team that this was an issue common to any UK sector experiencing rapid development, rather than an RPAS specific issue.

order to determine the presence of missing markets or barriers to accessing needed ancillary services (as well as estimate the economic value associated with the provision of those services).

Stakeholders did however identify some concerns about the provision of one area of ancillary services. Some stakeholders expressed concern about the quality and standard of training offered. It was noted that a strong and growing market had evolved of companies offering RPAS training. This is confirmed by analysis of RPAS membership presented in section 3. However, it was suggested that much of this training is at a relatively basic standard. It was suggested that many training providers are not specialist trainers but companies that offer RPAS services looking to supplement their income. It was suggested that, while a strong market had emerged offering RPAS training to meet the gateway requirements to demonstrate competence, provision of more advanced training (for example to operate larger RPAS or in more challenging environments) is not widely available. One stakeholder noted that the majority of the training available does not meet the standards that they would impose on a new recruit.

4.4 Summary

- **History of RPAS**: The use of RPAS in industrial and commercial processes (as well as leisure) is not new, though prior to the 2000s applications were dominated by leisure or hobby and military applications. However, the falling price of RPAS with higher performance specifications has in recent years made it more cost-effective to adopt these devices in a range of commercial processes.
- **Commercial operators of RPAS in the UK**: At the time of writing, there were over 1,400 commercial operators approved by the Civil Aviation Authority in the UK (largely concentrated in the South East of England), a number that has been growing rapidly (with 9 percent growth observed over the 2 month duration of this study). The evidence collected as part of the review suggests that the UK has adopted the technology rapidly, accounting for a significant share of the number of licensed operators globally, and approximately half of those registered in the EU.
- **Commercial applications**: As highlighted in section 2, four key applications of RPAS have been identified in the literature, including collecting and transmitting sensory data (sensing), carrying and delivering goods (lifting), supporting telecommunications (communications), and interacting with the built or natural environment to carry out specific tasks (remote operations). This review suggests that, to date, commercialisation has largely been focused on the first of these general applications, with particularly rapid adoption by the media industry and to some degree in the inspection of large scale industrial structures.
- **Productivity benefits**: The literature review provided substantial evidence that RPAS have the potential to raise productivity through delivering cost, performance, and safety benefits. Productivity gains also have the potential to be realised across a large number of industries, including agriculture, oil and gas extraction, energy production, media, and law enforcement. However, while there is a range of evidence on the quantitative magnitude of productivity improvements in specific situations (such as monitoring the health of a particular crop), there has been no systematic research examining which industries stand to realise the most significant gains in productivity through the adoption of RPAS.
- **Commercial performance**: While it is clear that the emergence of RPAS has supported the development of new service models in the UK, there is very little detail available on the economics of the industry. It is unclear how far RPAS are being adopted directly by firms as an input into industrial and commercial processes, or whether the technology is primarily supporting the growth of new service industries. Additionally, no evidence is available on the commercial performance of firms entering the market in terms of their revenues, growth, employment, output and productivity. Finally, there is also no evidence that would support an assessment of how far the UK has been able to translate rapid growth in the number of commercial RPAS operators into export sales.
- **Ancillary services**: Although there is very little in the way of evidence describing the economic value of the ancillary services provided or required by RPAS operators, the evidence that is available suggests that the development of supporting services has kept pace with the overall growth in RPAS operators (though previously there may have been issues originating in the insurance market). One possible constraint identified, however, was the availability of training for RPAS pilots at the more advanced levels that might be required for more complex flights (such as within highly constrained external or internal environments).

5.0 Developments

This section looks to anticipate developments in the RPAS sector. It focuses first on the potential value stream emerging from the application of RPAS, presenting both aggregate estimates and examples in relation to specific applications. Secondly, the section considers the primary technical challenges facing the development of RPAS, identifying the potential role of research and development in meeting these challenges. Thirdly, it assesses the non-technological challenges that may impede new RPAS applications. Finally, the section considers the potential for RPAS to disrupt existing economic activities.

5.1 Quantifying Future Benefits from the Development of RPAS

5.1.1 Anticipated Future Value Stream

There have been very few studies that have examined or estimated the potential future value stream associated with RPAS. However, the Association for Unmanned Vehicle Systems International attempted to document the economic benefits to the United States once RPAS are integrated into the National Airspace System (NAS)[75]. The analysis was based on an assessment that precision agriculture and public safety are the most promising commercial and civil markets and would comprise approximately 90 percent of the known potential markets for RPAS. The study estimated that the economic impact of the integration of RPAS into the NAS would total more than £9.5 billion in the first three years of integration and would grow sustainably for the foreseeable future, cumulating to more than £57.4 billion between 2015 and 2025. The methodology for calculating the economic impact and the level of implied impact on productivity of these changes is not clear from reviewing the report. It appears that the calculation is based on strong assumptions such as that the RPAS can be projected by analysing current airspace activity and infrastructure in individual states of the US. It is also important to note that there may be limits to the extent to which this finding can be applied to the UK given the differences between agricultural operations in the US and UK.

5.1.2 Estimating the Future Potential Value of Specific Applications

Examples of estimates of value from specific applications are summarised below. These draw from, and look to quantify, the types of benefit identified in Section 3.2.4 above:

- **Sensing (Oil and gas)**: Inspection of industrial plants and their sub-structures in the oil and gas industry using traditional rope and scaffolding methods is a time and labour intensive process. Stakeholder consultations and desk research indicate that some of these inspections may require shut downs for extended periods of time, even when large teams are performing the inspection. The obvious cost saving in terms of labour is in staff time, estimated at about £280 per day excluding VAT[76]. In one example of inspecting a gas flare, a team of six inspectors on ropes working for 14 weeks would be required, equating to about £165,000 in labour costs. More important, the UAV completed the work in two days and prevented a prolonged shut down period, potentially resulting in the loss of millions of pounds of output. In another case of a flare inspection a company claims to have saved their client £24.45 million. The speed and ability to perform live inspections is

[75] AUVSI (2013). The Economic Impact of Unmanned Aircraft Systems in the United States.
[76] People4Business.com (2016). www.people4business.com/seller-324095.htm. Date accessed: 15/02/16.

especially valuable in emergency cases which typically involve an event requiring a decision on whether a plant needs to be shut down temporarily.

- **Sensing (Utilities)**: Inspection of wind turbines using RPAS was found by a recent study[77] to form a potential large future growth market delivering economic benefits through more cost-effective service delivery. It indicated that at the beginning of 2015 there were nearly 270,000 individual wind turbines operating globally with more than 800,000 spinning blades. An industry journal[78] outlined a comparison of a scenario for inspecting 45 wind turbines in which the standard time for inspection by rope is two per day in comparison to four inspections per hour using a UAV. The authors' conclusion is that, if performed at scale, the cost of inspection can be reduced to £10.48 per wind turbine. Current inspections by rope are contract-based and costs range between £175 and £699 per turbine[79] depending upon the individual company's quote and the nature of the inspection.

- **Sensing (Precision Agriculture)**: The benefits from using RPAS within agriculture are well documented. Farm trials have shown a yield benefit of £13.97/ha based on the use of zone management practices.[80,81,82] A more recent example by farms.com provided an example of a 100 acre field in Ontario which saw an increase in annual revenues of as much as £48.9/ac[83].

- **Lifting (Small item delivery)**: A recent analysis by an investment firm Ark identifies big potential economic savings if the largest internet retailer rolled out delivery of sub-5lbs packages by drones. It concluded that a conservative estimate of price per delivery would be under £0.7 per item delivered, compared to USPS Priority at £3.67 per item[84].

These estimates all illustrate the potential value created by various RPAS applications, and all represent potential productivity benefits for firms making use of RPAS. It would be possible to undertake further research to develop further estimates in this vein for other RPAS applications such as aircraft[85], shipping or power line inspection. It would also be possible to scale these up to likely economy wide productivity effects - for example, by considering the number of oil and gas facilities to be surveyed, and a potential adoption rate an aggregate figure could be developed for that industry. The evidence base currently contains little evidence on the potential balance of productivity effects between the application of RPAS within different sectors.

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[77] Navigant Research (2015). Drones for Wind Turbine Inspection. www.navigantresearch.com/research/drones-for-wind-turbine-inspection. Date accessed: 15/02/16.

[78] Benoit, M. (2014). Inspecting Gadgets May Make Wind Energy Industry Safer, More Efficient. http://projourno.org/2014/08/inspecting-gadgets-may-make-wind-energy-industry-safer-more-efficient/. Date accessed: 15/02/16. Projourno.

[79] Ibid.

[80] Godwin, R. J., Richards, T. E., Wood, G. A., Welsh, J. P., & Knight, S. M. (2003). An economic analysis of the potential for precision farming in UK cereal production. Biosystems Engineering, 84, 533–545.

[81] Seelan, S. K., S. Laguette, G. M. Casady and G. A. Seielstad (2003). Remote sensing applications for precision agriculture: A learning community approach. Remote Sensing of Environment 88: 157-169.

[82] Nex, F., & Remondino, F. (2014). UAV for 3D mapping applications: a review. Applied Geomatics, 6(1), 1-15.

[83] Farms.com. Precision Agriculture Economics www.farms.com/precision-agriculture/economics/. Date accessed: 15/02/16.

[84] The Verge (2015). Drones could make Amazon's dream of free delivery profitable. www.theverge.com/2015/6/3/8719659/amazon-prime-air-drone-delivery-profit-free-shipping-small-items. Date accessed: 15/02/16.

[85] Specifically in regard to the inspection of aircraft following lightening strikes stakeholders suggested that RPAS were being developed that could use advanced sensors to undertake a full inspection of a passenger airplane in 40 minutes, that might typically take eight hours using a 'cherry picker'.

5.2 Technological Challenges and Potential Developments

As identified in Section 2, RPAS manufacturing can be described as being organised around the integration of five core components that determine the overall performance characteristics of the device.

- **Airframes** – The development of frames for small and micro RPAS with increased use of composite materials,
- **Power drives** – Continued dominance of conventional combustion engines and electric motors but experimentation with alternative power drives,
- **Communications, Command, and Control systems** – An increase in detect and avoid capability for all classes of RPAS,
- **Sensors** – Increased demand for small RPAS applications has led to increases in the quality and variety of the available sensor payloads,
- **IT/data processing** – The increased development of software and its transition to open source for small RPAS along with software development to support the demand for imaging and modelling capability.

5.2.1 Airframes

Previous research efforts have considered the means through which low-cost manufacturing processes can be adopted, especially in light of increased demand for small, low cost RPAS[86]. Increased research and development into the use of polymer composites in the manufacture of airframes has facilitated this agenda (Box 5.1).

Box 5.1 – Composite manufacturing processes (Volpe, 2013)

- **Automated fibre placement** – This involves the placement of pre-impregnated composite fibres onto a tool at a high speed which supports faster rates of production, reduced weight and greater component complexity and flexibility.
- **Resin Transfer moulding** – This is used mainly to mould components with larger surface areas and complex shapes. The resin is thermally activated, supporting a longer fill time and lower injection pressure.
- **Through thickness reinforcement** – involving structural pins that stitch a material together through a combination of friction and adhesion, providing superior damage tolerance.
- **Electron beam curing** - providing high-endurance coatings to structures with cost savings from power and technical efficiency gains.

Stakeholders indicated that the development of cheaper manufacturing processes has facilitated the uptake of small RPAS for civil applications, especially now that airframe structures can be purchased on a global market through the internet. While the use of other

[86] Volpe, J. (2013). Unmanned Aircraft System (UAS) Service Demand 2015 to 2035: Literature Review and Projections of Future Usage. National Transportation Systems Centre.

materials such as glass fibre has been tested for structural RPAS elements, the continually increasing demand for payload capacity and performance has led to a vast increase in composite airframe production which is expected to grow globally by over 300 percent by the year 2020[87]. For large RPAS, where design and component access are not constrained by size to the same extent, material choice is less limited and stiffer composites are utilised[88].

No particular technical challenges holding back the development of RPAS airframes in the UK were identified. Stakeholders indicated that the main constraint on the production of small RPAS in the UK manufactures is economic; firms with extensive manufacturing experience using advanced composites exist but there is no incentive for them to enter the RPAS market because of the cost leadership enjoyed by overseas suppliers, such as the Chinese firm DJI.

5.2.2 Power drives

The range of civil applications supported by RPAS is directly constrained by the length of time RPAS can conduct activities; stakeholder cite that some activities, such as extended infrastructure inspection, are not yet feasible as a result. The continued use of conventional internal combustion engines is well documented as the most established means of propulsion of RPAS[89]. While electric motors and batteries are also used as power drives, especially in small RPAS, their endurance is limited. Research into alternative sources of power that have lower mass and size requirements is a key trend. For example, research into the use of fuel cells has explored their application in small RPAS for use in energy infrastructure inspection and was able to boost flight length by one third[90]. Other research into battery performance has focused upon lithium sulphur rechargeable batteries[91].

Moving forward, efforts should focus on overcoming overall performance issues arising from the need to carry expendable fuel sources and the efficiency and reliability of alternative sources. As such, the development of novel power drives look to optimise the size, weight and efficiency of such systems, inducing positive impacts on the airflow, range, efficiency, and speed of vehicles as a whole. Specific, novel developments in relation to power drives include:

- **Hydrogen (Fuel Cells)** – The use of hydrogen is held back by technological limitations and the high cost of storage and fuel cells[92]. Research that looks to optimise this storage and integrate it within the RPAS could support increased payload and range compared with lithium batteries[93].

[87] Volpe, J. (2013). Unmanned Aircraft System (UAS) Service Demand 2015 to 2035: Literature Review and Projections of Future Usage. National Transportation Systems Centre.
[88] Austin, R. (2010). Unmanned aircraft systems. http://airspot.ru/book/file/1152/Reg_Austin_-_Unmanned_Air_Systems_UAV_Design__Development_and_Deployment_-_2010.pdf. Date accessed: 12/01/2016
[89] Volpe, J. (2013). Unmanned Aircraft System (UAS) Service Demand 2015 to 2035: Literature Review and Projections of Future Usage. National Transportation Systems Centre.
[90] Kim, T., & Kwon, S. (2012). Design and development of a fuel cell-powered small unmanned aircraft.Available online at: www.sciencedirect.com/science/article/pii/S1876610214030884
[91] Austin, R. (2010). Unmanned aircraft systems. http://airspot.ru/book/file/1152/Reg_Austin_-_Unmanned_Air_Systems_UAV_Design__Development_and_Deployment_-_2010.pdf. Date accessed: 12/01/2016
[92] Volpe, J. (2013). Unmanned Aircraft System (UAS) Service Demand 2015 to 2035: Literature Review and Projections of Future Usage. National Transportation Systems Centre.
[93] Kim, T., & Kwon, S. (2012). Design and development of a fuel cell-powered small unmanned aircraft.available online at: www.sciencedirect.com/science/article/pii/S1876610214030884

- **Electric** – Various attempts have been made to optimise the power management and optimisation of electric power systems with the explicit aim of improving overall endurance[94].
- **Lithium Anode Battery Technology** – Development of a new electrode which will aims to double the energy density of Lithium ion batteries; technology here is based on the power drive utilised in 2010, by Zephyr[95], the light RPAS made by QinetiQ[96].
- **Other experimental** – A number of other power drive systems are being developed for RPAS use including solar turbine[97], solar electric[98], steam[99], HydroICE[100], magnetic resonance[101], laser[102], nuclear[103] and magneto hydrodynamics[104].

5.2.3 Command, Control and Communications systems

In the case of command, control and communications, interference with any of the following requires consideration:

- Uplink control data (RPAS payload control),
- Downlink information and RPAS health status,
- Navigation data,
- Availability and reliability of command and control for air traffic control.[105]

One of the more significant developments in control of RPAS of all classes has been the experimentation with detect-and-avoid and sense-and-avoid technologies (DSA) to provide the ability to avoid collisions. 'Be seen' technologies such as flashing lights or infrared or radar images could facilitate detection. However, a high proportion of RPAS are unlikely to be

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[94] Volpe, J. (2013). Unmanned Aircraft System (UAS) Service Demand 2015 to 2035: Literature Review and Projections of Future Usage. National Transportation Systems Centre.
[95] Note we understand that this device has not been approved for civil use in the UK
[96] Gateway to Research analysis
[97] SUAS News (2012). AirScape UAV Solar Turbine to Deliver 30 to 90 Days of Flying Time! www.suasnews.com/2012/11/19684/airscape-uav-solar-turbine-to-deliver-30-to-90-days-of-flying-time/. Date accessed: 15/02/16.
[98] Silent FalconTM UAS Technologies. www.silentfalconuas.com/Silent_Falcon_spec_sheet.pdf. Date accessed: 15/02/16.
[99] Washington Post (2012). Making Steam Without Boiling Water, Thanks to Nanoparticles. http://articles.washingtonpost.com/2012-11-19/national/35505658_1_steam-nanoparticles-water. Date accessed: 12/02/16.
[100] Gizmag (2012). HydroICE Project Developing a Solar-Powered Combustion Engine. Gizmag. www.gizmag.com/hydroice-solar-powered-engine/25139/. Date accessed: 15/02/16.
[101] New Scientist (2012). UAVs Fly Wireless Power to Remote Locations.
[102] NBC News (2012). Laser Beam Keeps Robo-plane Buzzing for Two Days Straight. http://cosmiclog.nbcnews.com/_news/2012/07/12/12690006-laser-beam-keeps-robo-plane-buzzing-for-two-days-straight. Date accessed: 15/02/16.
[103] Sweetman, B. (2012). Benefits of Nuclear UAVs. Defense Technology International. www.aviationweek.com/awmobile/Article.aspx?id=/article-xml/DT_05_01_2012_p14-450521.xml&p=1. Date accessed: 15/02/16.
[104] Justin Mullins (2008). Invention: Plasma-powered Flying Saucer. New Scientist. www.newscientist.com/article/dn13840-invention-plasmapowered-flying-saucer.html. Date accessed: 15/02/2016.
[105] Volpe, J. (2013). Unmanned Aircraft System (UAS) Service Demand 2015 to 2035: Literature Review and Projections of Future Usage. National Transportation Systems Centre

equipped with such visual aids[106]. DSA technology systems traverse this issue by utilising sensors to automatically detect a possible oncoming collision. Two methods exist in practice where a sensor either detects possible collision from the RPAS itself or from a ground position. The latter requires more bandwidth and on board RPAS sensors for collision detection are predicted to be preferred in the long term because of their ability to utilise on-board processing and memory storage capabilities[107].

DSA technology has manifested itself through vision-based systems which utilise various sensors to facilitate both the imaging of incoming 'targets' and the assessment of possible outcomes. One study looked to achieve vertical take-off and landing using a vision-system through measuring the translational optical flow (the relative change in motion between an observer and a surface) on a spherical camera along with data commonly collected on aircraft for navigation purposes[108]. Another study examined the potential to autonomously land an unmanned aerial system using a real-time vision-based system that utilises an algorithm and strictly geometric landing pad[109]. Neither of these attempts was made in an end user operational setting.

A key development which would potentially enable the largest increase in civil RPAS applications is the ability to operate beyond line of sight (BVLOS). The greatest challenge holding back applications of this nature is the still nascent maturity of autonomous flight capabilities. Applications of this nature were cited as extremely desirable by stakeholders because of the increased flexibility they would provide in terms of applications, the improved safety outcomes provided to staff and the economic benefits generated from the removal of requirements to have RPAs applications completely monitored visually. Autonomous RPAS operation is currently held back by three main technological challenges: the experimental and unverified nature of transponders and DSA technology, dynamic flight planning and connectivity and security issues.

The development of DSA techniques would support BVLOS applications through installing confidence in the ability of the RPAS to avoid airborne collisions. While there has been success through vision based and algorithmic approaches[110] (Frew et al. (2004)[111], stakeholders agreed that continued hardware and software engineering support is necessitated to improve:

- Algorithm efficiency to enable close to real-time decision making,
- The reliability of systems in an operational environment through verification of novel systems,
- Safety measures either within the system or through mitigation measures such as ballistics testing.

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[106] Austin, R. (2010). Unmanned aircraft systems. http://airspot.ru/book/file/1152/Reg_Austin_-_Unmanned_Air_Systems_UAV_Design__Development_and_Deployment_-_2010.pdf. Date accessed: 12/01/2016

[107] Volpe, J. (2013). Unmanned Aircraft System (UAS) Service Demand 2015 to 2035: Literature Review and Projections of Future Usage. National Transportation Systems Centre.

[108] Herisse, B. et al (2008). Hovering flight and vertical landing control of a VTOL unmanned aerial vehicle using optical flow. IEEE Transactions on Robotics. 28(99):1 - 13.

[109] Saripalli, S., Montgomery, J. F., & Sukhatme, G. S. (2003). Visually guided landing of an unmanned aerial vehicle. IEEE Transactions on Robotics. 19 (3) pp371-381

[110] Allaire et al (2009). FPGA implementation of genetic algorithm for UAV real-time path planning. Wyeth, Gordon & Upcroft, Ben (Eds.) Proceedings of the 2010 Australasian Conference on Robotics & Automation.

[111] Frew, E. (2004). Vision-based road-following using a small autonomous aircraft.

The extent to which DSA technology is needed was questioned by one key stakeholder who argued for the alternative solution of fitting transponders to RPAS. This device is able to produce a response when it receives a radio frequency which allows the RPAS to be located using apparatus such as RADAR. However, another stakeholder suggested that, while in theory a transponder is able to provide geographical information, it cannot be consistently possible for an RPAS to provide a location if its own location is unknown. Further research into the benefits of both technologies will no doubt uncover the most appropriate solution for each class of RPAS.

The introduction of real-time flight planning, with or without a set flight path capability, would enable RPAS to respond directly to their surrounding environment when making navigation decisions[112]. Autonomous flight planning in real time would require less operational involvement and would permit flight paths to actively respond to their environment, facilitating BVLOS operation and in particular activities that require active RPAS responses, such as tracking or search and rescue. An analysis by Chao et al. (2010) identified a range of existing autopilot hardware units which were available on the market at the time[113]. A number of the readily available systems were judged to be of a high enough standard from a hardware perspective. However, the introduction of flight planning capabilities is still at an early stage with challenges remaining, for example:

- The hardware requirements of such systems create the need for more efficient computation of algorithms[114],
- A large majority of applications are in need of verification for reliable, safe civilian application in light of safety, legal and ethical considerations[115],
- Further software development is needed to improve performance in turbulent weather conditions, sensory-based systems for navigation decisions and coordination between multiple autonomous RPAS vehicles[116].

The application of BVLOS is also constrained by connectivity and security issues. The inherently remote nature of BVLOS operations makes it paramount that all functionality, including communication with various entities such as the ground control station and foreseeably air traffic control and other RPAS, to be conducted via telecommunications networks is in full operation. Obstructions in line of sight will have an effect on connectivity performance. For small RPAS, the use of satellite or cellular connectivity links is not entirely suitable because of the slow data link and relative costs of cellular tower and booster expansion respectively. Further still, the actual networking requirements for small RPAS are much higher in relative terms compared to their manned counterparts in terms of limited bandwidth capacity, data delivery and service discovery[117]. This presents a challenge to the industry, especially in the context of lower quality connectivity than expected for smaller RPAS

[112] Jung, Ratti, Tsiotras (2009). Real-time implementation, validation of new hierarchical path planning scheme of UAVs. Journal of Intelligent and Robotic Systems. Vol 4. Nos 1-3. pp163-181
[113] Chao, H., Cao, Y., & Chen, Y. (2010). Autopilots for small unmanned aerial vehicles, a survey. International Journal of Control, Automation and Systems. (2010). 8:(1). pp 36-44
[114] Jung, Ratti, Tsiotras (2009). Real-time implementation, validation of new hierarchical path planning scheme of UAVs. Journal of Intelligent and Robotic Systems. Vol 4. Nos 1-3. pp163-181
[115] ibid
[116] Frew, E. (2004). Vision-based road-following using a small autonomous aircraft.
[117] Frew, E. (2004). Vision-based road-following using a small autonomous aircraft.

applications, no matter which networking system is adopted[118]. A number of solutions that support connectivity improvements are given in Box 5.2.

Box 5.2 – Possible connectivity solutions in the BVLOS context (Frew et al. 2004; Gupta, 2015)

- Meshed networks - a network design in which signal relays feature on RPAS units themselves enabling connectivity between RPAS and the ground control station. A flight of multiple RPAS would permit a high field of operation through the extensive relay network created. Two types of meshed networks are described below:
  - Mobile ad-hoc networking (MANET) – a self-configuring network of mobile routers which are can randomly move within a locality. The MANET organisation changes rapidly due to the motion and the nodes in the network rapidly self-organize in response.
  - Delay Torrent Networking (DTN) - this facilitates connectivity when real-time connection is challenging due to motion and thinly spread relays. It supports the transmission of data between RPAS in quick bursts as and when opportunities arise.

  Meshed structures such as this suit RPAS applications because of their ability to reform and organise; the network becomes resilient to failure due to environmental constraints. Such applications have only really previously been observed in a military context; their application for civil purposes is something to be explored.

While networking unmanned aerial systems fundamentally supports their operation it is also the very same factor that makes them susceptible to cyber-attack[119]. This in itself acts as a deterrent to commercial application because of the heightened risk in terms of staff safety and loss of commercially sensitive information. An informed security assessment of cyber threats to RPAS uncovered some of the more prominent cyber-security risks for RPAS of all classes including[120]:

- **Denial of services (DoS):** DoS or DDoS (Distributed DoS) attacks are mainly based on network congestion in the RPAS network card such that the system will appear unavailable
- **Spoofing**: A situation in which one person or program successfully pretends to be something else through the falsification of data.
- **Eavesdropping**: Activities involving the unauthorised real-time interception of private communications, which could transpire in content being recorded or replicated without knowledge of the operator or RPAS ground control team.
- **Signal interruption**: This could manifest itself in altering command signals or jamming them entirely.

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[118] Frew, E. W., & Brown, T. X. (2009). Networking issues for small unmanned aircraft systems. Journal of Intelligent and Robotic Systems March 2009. Volume 54. Issue 1. pp 21-37
[119] Hartmann & Steup (2013) The Vulnerability of UAVs to Cyber Attacks - An Approach to the Risk Assessment, available from https://ccdcoe.org/cycon/2013/proceedings/d3r2s2_hartmann.pdf accessed 09/03/2016
[120] Javaid, A. Y., Sun, W., Devabhaktuni, V. K., and Alam, M. (2012). “Cyber security threat analysis and modeling of an unmanned aerial vehicle system,” in 2012 IEEE Conference on Technologies for Homeland Security (HST), 585–590. doi:10.1109/THS.2012.6459914

The development of encrypted secure software through research at Imperial College London aims to address security issues both early in the design cycle and during its operation through maintenance and system adaptation. The development of the open source application Ponder2 has supported the management and security of RPAS networks and is used extensively throughout industry and academia[121].

5.2.4 Sensors

The commercial use of RPAS has seen the development of a wealth of novel sensory payloads, including: high fidelity cameras, infrared sensors, multi/hyperspectral sensors, radar, LIDAR (Light Detection and Ranging), acoustic sensors, magnetometers and meteorological sensors[122].

Interest from various sectors is a function of the extent to which RPAS can support relevant activities such as data collection or processing. The development of an array of commercially ready sensor offerings in this space in light of physical, technical and financial constraints is a significant opportunity for the UK value stream. This is especially so given the potential efficiency and safety benefits in firms requiring the use of inspection services. The development of sensory capability for communications and control is also a valuable opportunity. This requires research focussing on vision-based methods that look to increase the field of vision of RPAS, their sensory capability or the level of integration in the application of such solutions in operational settings[123].

This is an area where the evidence base includes extensive additional material that could be considered for inclusion within a final draft, if appropriate.

5.2.5 IT/Data processing

The growth in computing power, miniaturisation of hardware components and improved algorithms for managing and interpreting data are key trends in IT and data processing.

Computing power is being supported through the use of cloud computing. Quantum computing provides the ability to utilise the power of atoms and molecules to undertake processing tasks at a miniaturisation level with a low energy requirement which is ideal for use in RPAS[124].

Nanotechnology facilitates large storage/processing ability for RPAS; Qinetiq has concentrated on miniaturising and raising the efficiency of systems along with general savings of weight in the airframe. The record flight of more 82 hr made at heights of over 18 000 m, indicates the success of this formula. Qinetiq believes that Zephyr is very close to an operational system

[121] Willetts (2014). Developing our capability in cyber security - Academic Centres of Excellence in Cyber Security Research. HM Government.
[122] Zhang, C., & Kovacs, J. M. (2012). The application of small unmanned aerial systems for precision agriculture. Precision Agriculture. 12/2012; 13(6) pp 9274-5
[123] Campoy, P. et al (2009). Computer vision onboard UAVs for civilian tasks. Unmanned Aircraft Systems 2009. pp 105-135
[124] Volpe, J. (2013). Unmanned Aircraft System (UAS) Service Demand 2015 to 2035: Literature Review and Projections of Future Usage. National Transportation Systems Centre.

with one more step of improvements required to design a robust and reliable system that will remain airborne for months[125].

RPAS provide a platform to facilitate a number of downstream applications that tend to orient around the collection and processing of information to support decision making. Stakeholders agreed that many potential procurers will require data management and processing services facilitated by RPAS, such as 3D-modelling, photo mosaicking and topography services, not just operational capabilities.

CyberHawk, a UK UAV industrial inspection company has capitalised upon this opportunity to provide supplementary software to support client data interpretation. Techniques that generate order from chaotic unstructured data to facilitate more effective decision making will lead to minimal human involvement in the form of quality assurance. Creating an end-to-end service that utilises drones in this manner represents a significant opportunity for the UK to realise value.

5.2.6 Industrial Processes

3D printing is a process that has been increasingly used in the production of RPAS. It permits extremely quick production of computer-based designs. This is highly desirable in the development of RPAS because it enables prototype components to be fine-tuned in an iterative manner in response to testing and application type. As such, there is a clear economic case for the use of this process: a turbofan engine that previously took five years manufacture and cost around £175, 0000 to produce now takes only four months and costs only £1,400 to produce using 3D printing[126].

Component miniaturisation is also a key trend. The size and mass of components and payloads have a direct effect on RPAS performance and the ability to boost endurance and maximise payloads are key factors in supporting RPAS applications. Smaller components can also be utilised in an increasing number of models with different altitude and endurance capabilities)[127].

Miniaturisation of airframes, hardware, batteries and sensors in light of limited space will boost RPAS endurance and is a key area for development. Overall mass poses a challenge to battery life and heavy payloads will have negative effects on flight time and performance[128].

One industry stakeholder cited that the cost of manufacture, application and end processing, despite their downward trajectory, are a major constraint on commercial uses. As an example, applications that require extensive UK coverage in dangerous environments have sometimes proved less cost effective than alternatives in current applications. This is said to be a result of the costs associated with developing suitable commercial accreditation and a track record of safety and vigilance. An opportunity for supportive ancillary services to manage the commercial compliance and accreditation requirements of RPAS applications will generate value.

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[125] Austin, R. (2010). Unmanned aircraft systems. http://airspot.ru/book/file/1152/Reg_Austin_-_Unmanned_Air_Systems_UAV_Design__Development_and_Deployment_-_2010.pdf. Date accessed: 12/01/2016

[126] Volpe, J. (2013). Unmanned Aircraft System (UAS) Service Demand 2015 to 2035: Literature Review and Projections of Future Usage. National Transportation Systems Centre.

[127] Houses of Parliament (2014). Civilian Drones. PostNote Number 479. October 2014.

[128] ibid

Cost issues are rife for larger RPAS vehicles too. A key stakeholder cites that a movement away from a hobbyist style of manufacturing is required, especially in the context of design to improve reliability and costs of production. A number of UK-centric research interests have emerged in recent years that pay attention to innovation in design and manufacturing processes.

5.3 UK R&D Activity

This subsection examines the make-up of the UK R&D landscape and how far there is significant alignment with the technical challenges described above. It provides a descriptive account of RPAS R&D activity and considers all relevant academic institution research strengths, the infrastructure available and the geographical distribution of institutions. A thorough analysis of RPAS-related grant-funded projects through Innovate UK and The Research Councils is included and provides an in-depth insight into the total and average amounts of funding channelled into RPAS R&D, the spread of research interests and the composition of lead applicants. Finally, a discussion of possible solutions to support commercialisation of research efforts is provided, drawing greatly on key stakeholder consultations.

5.3.1 Academic Infrastructure

There has been a considerable amount of UK-based academic and industrial interest in RPAS. Twelve UK academic departments have specific RPAS research functions[129]. However, through an examination of university websites and Gateway to Research data, this report finds 30 academic institutions engaged to some degree in the development of RPAS (which are relatively evenly distributed across the UK, though with clusters in the North West and Scotland). A summary of these strengths in provided in Table 5.1. This was developed from the list of lead participants in projects identified on the Gateway to research portal and through web searches of UK RPAS (and associated search terms) activity. Boxes are shaded reflecting the specialisms identified on academic department or project-specific webpages. Full sources for this analysis are included within the annex.

It is important to note that no bibliometric analysis was identified through the literature review, so it has not been feasible to benchmark the UK's research strengths against international competitors in terms of the volume of research output or its impact. However, it is important to review this section in the context of global R&D activity in this technology area (in which in somewhere between £2.5bn and £3.5bn is invested annually).

There are three leading institutions, however, in terms of overall RPAS capabilities: Cranfield University, Imperial College London and the University of Southampton, all of which have dedicated research facilities to support RPAS development:

- **Cranfield University** has a wealth of experience in applied aerospace systems and technologies, with a history of collaboration with industry primes and SMEs. The University has a dedicated centre for aerospace integration and research (AIRC). Recent examples of its work include the development of a fuel-cell powered RPAS powered with hydrogen pellets and the development of systems that autonomously monitor aircraft health,

[129] Houses of Parliament (2014). Civilian Drones. PostNote Number 479. October 2014.

- Over 10 years of experience resides within **Imperial College London**'s Aerial Robotics Lab which achieved best aeronautics department in the 2014 Research Excellence Framework. The University has particular specialties in the development of RPAS capable of aquatic activity – i.e. RPAS with the capability to operate both in the air and to dive into water[130],
- **Southampton University** has developed a number of unique platforms including the world's first 3D printed aircraft and the UK's first CAA approved RPAS over 20kg.

All of these universities offered focused undergraduate and postgraduate study in RPAS, including the application of autonomous systems and RPAS design, as well as an array of aerospace programmes.

Overall there is strong activity in the areas of C3, sensors and downstream applications. In the case of C3 there is a particular interest in automation of RPAS functionality and the coordination of swarms of multiple small RPAS. For example, the University of Bristol explored the use the multiple deployment of up six RPAS at any one time in a trial for the MoD[131] and the University of Manchester is exploring the development of automated navigation via vision based systems. Harper Adams University and the National Institute for Agricultural Biology are seeking to develop precision agricultural practices through the use of sensors to support crop yield optimisation and pest control[132]. In the case of novel applications, the University of Lancashire is exploring adapting RPAS for civil uses such as search and rescue as well as inspections.

The findings do highlight a lack of UK HEI activity in relation to research into industrial processes and power drives though it is important to note that this review considers only technological development applied directly to the context of RPAS. While an analysis such as this is informative, it does not account for those universities conducting foundational research or research that is relevant but applied in an entirely different context. For example, many institutions may be conducting foundational research into power drives in some capacity but only a proportion of them may have applied their findings in the RPAS context. An assessment of the extent to which the existing foundational UK research base could be applied in the RPAS setting and the barriers preventing that transition is something that could be explored in later research.

[130] Siddall et al. (2014). Launching the AquaMAV - bioinspired design for aerial-aquatic robotic platforms. Bioinspiration & Biomimetics, Volume 9, Number 3

[131] UK Government (2015) Dstl Bristow trial develops future protection against hostile UAS - Press releases - GOV.UK. www.gov.uk/government/news/dstl-bristow-trial-develops-future-protection-against-hostile-uas. Date accessed: 18/02/2016

[132] Gateway to Research data 2016

Table 5.1 Summary of UK RPAS research strengths by HEI

HEI	Airframes	Communications, Command, Control	Industrial processes	IT/Data processing	Power drive	Sensors	Downstream applications
Cranfield University	X	X	X	X	X	X	X
Harper Adams University				X			
Imperial College London	X	X	X	X	X	X	X
King's College London						X	X
Lancaster University							X
Liverpool John Moores University		X		X		X	X
Loughborough University						X	X
National Institute of Agricultural Botany				X		X	
National Oceanography Centre						X	X
Queen's University		X				X	X
Scottish Association of Marine Science							X
University of Bath		X					X
University of Birmingham		X			X	X	X
University of Bristol	X	X				X	X
University of Edinburgh					X		X
University of Exeter						X	X
University of Glasgow	X	X		X		X	
University of Hull				X			
University of Lancashire						X	X
University of Leicester		X					X
University of Liverpool		X		X			X
University of Manchester	X	X				X	
University of Nottingham					X		
University of Oxford		X					
University of Sheffield	X	X	X				
University of Southampton	X	X	X	X		X	X
University of St Andrews						X	X
University of the West of Scotland			X			X	X
University of Worcester						X	X
Kingston University		X		X	X		
Total	**7**	**15**	**5**	**9**	**6**	**17**	**21**

Source: GtR application data (2016)

5.3.2 Public R&D Funding

An analysis of publicly funded research and development was completed by interrogating Gateway to Research (which captures details of all Innovate UK and Research Council grants). A total of 79 projects with a clear focus on RPAS development were identified through this process. Of these, 60 were funding by Innovate UK with 19 supported by the following Research Councils (BBSRC, EPSRC, NERC and STFC). This involved a commitment of a total of £22.7m of public funding, though this does not capture the private contributions that will have been made by firms to Innovate UK funded projects.

Table 5.2 Public funding for RPAS R&D projects by funder

Funder	Project count	Total (£m)
IUK	60	14.7
EPSRC	11	6.7
NERC	6	0.9
STFC	1	0.1
BBSRC	1	0.4
Total	**79**	**22.7**

Source: GtR application data (2016).

The evidence reviewed suggested that there was some concentration of publicly funded R&D activity in the following areas:

- **(Autonomous Systems Technology Related Airborne Evaluation & Assessment) ASTRAEA**: The co-ordinated ASTRAEA research programme accounts for 56 percent of total publicly funding RPAS R&D. It looks to conduct a number of practical R&D exercises to support the regular use of RPAS in all classes of airspace without the need for restrictive or specialised conditions of operation. Key research themes include automation and BVLOS applications. The research effort itself also utilises industry investment, making a total of £62 million; the programme is led by a consortium of seven companies: Airbus Defence & Space, AOS, BAE Systems, Cobham, QinetiQ, Rolls-Royce and Thales.

- **Barnard Microsystems Ltd**: Banard Microsystems Limited (BML), a London based firm, designs, develops and manufactures RPAS for use in civilian and security applications and has been awarded a total of £810k for 14 separate project activities. BML has developed its own RPAS, InView, to support oil and mineral exploration[133]. Its research interests mainly involve the incorporation of sensors and IT to support collision detection and the generation of 3D imaging.

5.3.3 Focus of Publicly Funded R&D

The following discussion looks to break down grant funding by research interest. This is based upon an examination of the composition of overall research themes, an in-depth examination of popular research themes and a brief discussion of areas where funding is sparse. Table 5.3

[133] BML (2016). InView UAV Overview. www.barnardmicrosystems.com~inview~overview.html. Date accessed: 18/02/01

shows grant-funded projects by research interest and suggests the most significant research area by funding and project count to be in the area of communications, command and control systems (largely reflecting the investments made in ASTRAEA as described above). Downstream application is the second largest area of interest in terms of projects, accounting for a further £3.2m of publicly funded R&D spending, while sensor and power drive development have been other areas of moderate focus.

The evidence suggests that the main areas of R&D focus in the UK relate less strongly to optimising the manufacturing process and design of the key components that determine their flight performance (the power drive and the airframe), and focus more on the development of on-board technologies.

Table 5.3 Publicly funding R&D Projects by Area of Focus

Research Area	Number of Projects	Total (£m)
Communications, Command and Control Systems	23	15.8
Downstream RPAS application	22	3.2
Sensors	14	1.1
Power drive	5	2.1
IT/Data processing	4	0.2
Industrial processes	4	0.2
RPAS prototype	3	0.1
Ancillary services	3	0.0
Airframes	1	0.1
Total	**79**	**22.65**

Source: GtR application data (2016).

Table 5.4 below provides a more detailed overview of the nature of R&D activity being completed in each of these areas.

Table 5.4 Overview of R&D Activity by Research Area

Research Area	Overview
Communication, Command and Control Systems	C3, or command, control and communications, activities look to improve RPAS navigation, human RPAS interaction, autonomous RPAS activities and data connectivity and transfer capabilities, to name but a few (Volpe, 2013). Of total public funding for research in this area, 78 percent has been allocated to six projects associated with autonomous control in airspace. These attempt to utilise vision-based system and other sensors such as acoustic and thermal imaging sensors to inform navigation and airborne detection. As an example, the University of Manchester leads on an EPSRC funded project that aims to improve the tracking and vision of an RPAS vehicle to support activities where algorithms cannot respond quickly enough. Specifically the project looks to integrate sensory vision and control systems to reduce processing power requirements, supporting the RPAS to be capable in real-time estimation and mapping for navigation purposes. Verification of the safety and reliability of autonomous systems is the next most frequent research area. This process in general looks to test the C3 components of RPAS to ensure high standards of safety, ethics, reliability and legality are maintained. This is especially important for the use of RPAS in civil airspace. The next largest spend area within C3 is the coordination of multiple RPAS in one flight session. One example of this is a study conducted by Cranfield University to support increased coverage, autonomy and mission success through developing and validating a framework that assesses the guaranteed dynamic and kinetic performance of multiple RPAS. This is required because single RPAS dynamics are substantially different in terms of vehicle to vehicle and vehicle to environment interactions. The co-ordination of multiple RPAS units is the next biggest research interest in terms of funding, with £0.5m allocated, followed by the enhancement of control systems at £300k. The smallest areas of interest in C3 in terms of funding looks into vertical take-off and landing and methods to promote efficient RPAS positioning and stabilisation.
Downstream RPAS applications	This category refers to projects where the direct application in a research, proof of concept or a commercial setting was deemed to be the main emphasis by the study team, as opposed to the technology used. Surveying and inspection, precision agriculture, and climate studies account for the majority of spending under this heading (£2.7m of the £3.2m). In the context of surveying and inspection, the majority of projects were exploring the feasibility of using RPAS to inspect and maintain energy infrastructure assets such as wind turbines or other electricity and gas assets. The remaining projects looked to use RPAS to carry out inspections of landfill sites to search for valuable commodities.
Sensors	Sensor research represents just under 18 percent of total projects and just under 5 percent of total funding. The most common applications of sensors are for the purposes of 3D imaging and collision detection, with three projects each, accounting for 17 percent and 14 percent of total sensor funding respectively. However, the largest sensor research effort by funding is a precision agriculture project, led by the UK agronomist services firm, Agrii. The work is testing canopy sensors based on chlorophyll fluorescence (a common indicator for photosynthetic energy conversion) and hyperspectral imaging systems, which collect information across the electromagnetic spectrum to support early detection of biotic and abiotic stress.
Power Drives	This field represents just of 6 percent of projects and the second highest amount of total funding at 10 percent and involves the second highest average cost per project. The main areas of interest here are the application of fuel cell and hydrogen power sources for use in small RPAS. Research is being conducted into the use of lithium anode batteries and as a power source for large RPAS. The project lead, Sigma Lithium, cites that the development hopes to double the energy density of Li-ion batteries with the aim of prolonging flights of HALE RPAS such as The Zephyr. Efforts were also made that explored optimisation of chip design and power management and distribution to support power drive efficiency.

Research Area	Overview
Information Technology	75 percent of projects in this field are led by Bernard Microsystem limited and are awarded just under £200k in total funding with average project funding of £50k. These are concerned with the means and methods of developing 3D imaging and modelling service in real time, utilising software based on multiplayer computer gaming graphics technology and Internet connectivity. The applications also hope to incorporate the ubiquitous 3D CAD software to support an easier transition to market. The final project again looks at processing real-time 3D images through the use of a Stereo Vision Processor (vision-based system) that generates the translation and rotation vectors from two pairs of overlapping stereo image pairs on the RPAS.
Industrial Processes	Research into novel manufacturing considers the development of structural components using 3D textiles technology, electronic and photonic components for use in C3 applications, novel antenna development to improve frequency range and sensor miniaturisation for the use in surveying. The total and average funding for this research theme is similar to that of IT/data processing.
Ancillary Services	Three projects looked to develop complementary RPAS services, including providing online marketplaces for operators and developing a long term intellectual property strategy for RPAS with long endurance. This area was provided with the lowest amount of funding at just £5,000 per project.
RPAS prototypes	Three projects were awarded a just under £80k to develop novel whole RPAS units of varying size, mass and purpose. What is clear here is the noticeable influence the end application has on initial design phases and the substantial variety in intended uses. For example, two projects were given £5k to fund the development of RPAS with the specific intention to support costal rescue services and act as a telepresence device for patients with motor disabilities respectively. The other project looked to provide a handheld RPAS for the use of extending individual vision of the operator and in essence act as aerial binoculars.
Airframes	With less than 1 percent of grant funding and the fourth average grant, one project specifically looked at the development of airframes. Specifically the project sought to utilise technological Airframes and commercial benefits of advanced composites as structural elements of unmanned vehicles and was led by the University of Manchester.

Source: GtR application data (2016).

5.3.4 Barriers to commercialising UK R&D

As the use of RPAS becomes more abundant so too does the rising disparity between technological capabilities and applications in commercial environments[134]. While it is generally thought that the technological capability in the UK is sufficiently sound to support applied research for commercial ends, a number of barriers potentially prevent the translation of academic R&D into a commercial offering.

One of the key factors that are inhibiting this transition is the issue of co-ordination. The majority of overall RPAS technology developments would benefit the majority of commercial applications. However, the inability to coordinate interest and activities is considered by stakeholders to have stifled investment. Broad technological development would benefit application in all sectors, perhaps apart from the development of niche sector specific sensors. However, the fragmented nature of such sectors creates a difficulty in assessing the interest and intent to invest in broad technology areas so that raising capital to fund such activities is inhibited. Securing a sufficient return on investment is difficult to achieve in any one sector alone[135]. Additionally, two industry experts, citing the expected prevalence of small RPAS (less

[134] ibid
[135] ibid

than 25kg), highlighted the need for coordinated efforts to support research efforts looking to verify the integrity and safety of RPAS, especially when introducing new autonomous BVLOS functionality. The research cost in this area is high because of the need to complete multiple sets of code, have them verified by experts and test them operationally. Efforts to further coordinate stakeholders in a number of different contexts will result in better investment prospects. Stakeholder consultations suggested that there could be a coordination role for government to play, especially to ensure consensus around safety and compliance. This could potentially involve an enhanced cross-cutting RPAS publicly funded investment vehicle and coordinating network[136].

5.4 Production Barriers and Threats in the UK

The study team sought to explore with stakeholders the barriers to the future development of further RPAS production activities in the UK. A typical response was that the biggest barrier to future development was the limited scale of current RPAS production and associated componentry manufacture activities in the UK (discussed in Section 3 above). The suggestion was that the key limitation on our ability to capture future value in this area is that now 'others are ahead on their development'. The following more specific issues were identified in addition:

- **Adapting to new business models**: RPAS represent a fundamentally different model of operation to existing aviation markets. Traditional approaches to pricing aircraft do not translate; development cycles are likely to be much shorter; and interoperability with other peripherals (such as computers) is increasingly important.[137]
- **Military export licences**: Stakeholders identified a challenge that the requirement to obtain licences to export or import military technology created issues for their operations, delaying or preventing the use of some military RPAS components and sub-systems in their non-military projects. In particular, this was seen as a barrier holding back access to US technologies for UK companies, though other countries may experience similar challenges in accessing these technologies.
- **Geography of production**: One stakeholder did flag a risk for the UK relating to the current geography of key production nodes. They saw production focusing strongly on Asia where both OEMs and their suppliers are frequently co-located. This was described as a different model to that seen in major manufacturing industries in the past – for example European and US automotive R&D firms have been benefited from co-location with automotive OEMs, helping them to compete with lower cost locations. The fact that in this industry, several OEMs are based in these low-cost locations implies that UK R&D firms may not have this spatial advantage.
- **UK public procurement**: While the research has identified numerous instances of the UK public sector commissioning RPAS services, stakeholders suggested that some other countries, and in particular a number of Gulf States, were more advanced in their activity here. It was suggested by stakeholders that UK RPAS production was held back because the UK government is not a vanguard for RPAS use and does not prioritise the use of UK produced RPAS in its procurement processes. It was suggested that this has two negative effects: it directly supresses demand, but also can make it difficult to sell RPAS

[136] ibid
[137] Royal Aeronautical Society (2013). UNMANNED AERIAL VEHICLES:A NEW INDUSTRIAL SYSTEM?. http://aerosociety.com/Assets/Docs/Publications/DiscussionPapers/UASDiscussionPaper.pdf. Date accessed: 15/02/2016

or sub-systems abroad because potential international government customers are concerned that the manufacturer has failed to secure domestic sales.

5.5 The Availability of RPAS Testing Facilities as a Barrier to R&D

The availability of testing facilities for RPAS was a specific potential barrier to the development of RPAS production activities identified by the steering group and explored through the research. While this was not an issue covered in the literature reviewed, stakeholders offered a number of opinions here.

- **Small scale indoor and outdoor testing sites**: Academic stakeholders in particular identified a broad range of indoor and outdoor facilities available within their institutions and other universities with which they partner. Provision of this nature was described in positive terms.
- **Large scale outdoor testing sites**: Stakeholders stressed the importance of larger facilities where it is possible to test more advanced RPAS functions, and in particular their ability to operate in a more autonomous manner and to test BVLOS capabilities (all within the confines of the site). Two types of sites were identified – military ranges operated by QineiQ and one airfield in Wales. Stakeholder perspectives on these facilities were mixed. One stakeholder indicated the volume of activity they are currently undertaking on these sites, and identified no issues in gaining access to or working with such facilities. In contrast, one stakeholder stressed that the high costs involved with accessing military ranges was an issue. In particular they identified an inflexible approach to the management of these facilities and their services as a barrier to their development of programmes. One stakeholder identified that they were aware that some companies had identified issues in this area, and that this was something that they were also researching within the industry with a view to feeding this information back to government.

5.6 Other Potential Challenges and Barriers

5.6.1 Regulation as a Barrier to RPAS Application

A key concern reported in several sources and by multiple stakeholders is a fear that regulatory issues will limit RPAS use and hold back demand[138]. Relaxed regulatory positions have been identified as promoting the development of RPAS applications and associated industrial strengths. The extensive use of RPAS in agriculture in Japan was aided significantly by their classification as agricultural tools and specific relaxed regulations not available to other forms of aviation[139]. The 'ambiguous legal environment in the United States' up to 2007 has been identified as an enabler of growth in the US up to that date[140].

[138] Clothier, Williams & Fulton(2015). Structuring the safety case for unmanned aircraft system operations in non-segregated airspace. Safety Science, vol. 79, pp. 213-228.
[139] European Commission (2014). A new era for aviation - Opening the aviation market to the civil use of remotely piloted aircraft systems in a safe and sustainable manner (COM/2014/0207)
[140] Watts, A. C.,et al (2010). Small Unmanned Aircraft Systems for Low-Altitude Aerial Surveys. Journal of Wildlife Management, 74(7):1614-1619

The following features of regulations are identified as particular challenges both in the UK and abroad:

- **BVLOS**: Limits on uses of RPAS that are out of visual contact with operators on the ground were identified as significantly restricting RPAS applications. For example, it was suggested by stakeholders that this regulation places limitations on the area that an RPAS can survey in a given amount of time because of the need to land the vehicle and relocate the operator. Stakeholders noted however that when using batteries as a propulsion technology this is a more minor issue because of limited endurance and flight times,
- **Automation**: A related concern stressed by several stakeholders was that regulations have prevented the development of applications where additional elements of autonomy could be introduced to reduce the workload or skill requirements of pilots. It was also suggested that regulations prohibiting the use of autonomous systems have held back their development because investors cannot be confident of gaining a return on their investment,
- **Use in controlled environments**: Several stakeholders suggested that typical regulatory regimes were often too blunt to account for the fact that in some specific instances an RPAS operator could implement measures to much better control the risks associated with RPAS use. It was suggested, for example, that lesser restrictions on RPAS use on an unmanned offshore platform, or in an area where the operator can restrict access and ensure there are no persons might be appropriate.
- **Arms regulations**: Some RPAS technologies are classified as weapons and require an export licence[141]. Stakeholders suggested that obtaining such licences can make the use of some specific technologies infeasible in a civil setting,
- **International variations**: Significant variations in regulations between countries have been identified as creating an additional burden for RPAS based businesses[142].

Looking across the global regulatory landscape one recent study concluded that “if no action is taken promptly, there is a risk that the economic potential and positive effects of RPAS will not be fully realised”[143]. The remainder of this section explores this concern in more depth in relation to the UK context.

The UK Regulatory Context

The UK appears to have a more permissive regulatory environment than many of our international competitors, including the US[144]. There are examples of international companies expressing frustration with the regulatory system in the USA and scaling back their RPAS

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[141] Harrison, G. (2013). Unmanned Aircraft Systems (UAS)~ Manufacturing Trends, Congressional Research Services. www.fas.org/sgp/crs/natsec/R42938.pdf. Date accessed: 27/01/2016

[142] Foster, J. (2015). Report on safe use of remotely piloted aircraft systems (RPAS), commonly known as unmanned aerial vehicles (UAVs), in the field of civil aviation (2014~2243(INI)). European Parliament Committee on Transport and Tourism.

[143] ibid

[144] Houses of Parliament (2014). Civilian Drones. PostNote Number 479. October 2014.

activities there but continuing to work in the UK environment. The current UK regulatory landscape is summarised in the box below[145].

Box 5.3– Summary of UK CAA Rules

Articles 166 and 167 of the Air Navigation Order 2009 (ANO) outline the rules with which RPAS pilots in the UK are required to comply. These rules apply to all small unmanned aircraft (SUA) - i.e. under 20kg in mass - and pilots are expected to adhere to these when operating RPAS. In brief, RPAS pilots are required to:

- Ensure the operation does not endanger anyone or anything,
- Ensure the aircraft remains within visual line of sight,
- Ensure Permission is sought from the CAA if the aircraft is to be used for surveillance, and
- Ensure Permission and approval is acquired if the flight is to be conducted for “aerial work”, i.e. receiving payment for services.

RPAS pilots are prohibited from:

- Flying within 50m of people or property not under their control,
- Straying within 150m of large crowds (1000+ people),
- Flying within 150m of congested areas unless the craft has a maximum take-off weight of under 7kg,
- Rising to a height of more than 400ft from ground level or further from the pilot than 500m,
- Flying within controlled airspace, e.g. airports or military airspace or,
- Operating outside of daylight hours.

The table below outlines the CAA requirements for RPAS and their pilots based on the mass of the aircraft.

Table 5.5: Summary of CAA Regulations

Aircraft Mass	Airworthiness Approval	Registration	Operating Permission	Pilot Qualification
20 kg and less	No	No	Yes*	Yes* / **
More than 20 kg, up to and including 150 kg	Yes (Note 3)	Yes (Note 3)	Yes	Yes **
More than 150 kg	EASA approval; or, CAA approval in certain cases	Yes	Yes	Yes**

* Applicable for aircraft used for Aerial Work purposes or if flown within a congested area or close to people or property.

** Equivalent pilot experience will be considered on a case-by-case basis during application for an operating permission.

Note: It may be possible to obtain certain exemptions from the airworthiness and registration requirements

Source: CAA (2015) CAP 722: Unmanned Aircraft System Operations in UK Airspace – Guidance

[145] Guardian (2014) Amazon threatens to take drone testing abroad as US delays approval ~ World news ~ The Guardian. www.theguardian.com/world/2014/dec/09/amazon-threatens-drone-testing-abroad-us-delays-approval. Date accessed: 27/01/2016

Several examples were nevertheless identified through the course of the research where UK regulations were seen as holding back novel RPAS applications. The limitations on BVLOS use in particular was flagged as a challenge and it was suggested that this might not be necessary in certain specific low risk environments where operators can reasonably expect to control the environment. However, this view was not unanimous amongst stakeholders interviewed. Some suggested that the technologies required to operate beyond visual line of sight had not yet developed to operational standards, identifying the issues of sense and avoid and transponder locations discussed above in Section 4. This would imply that regulatory issues are not currently a primary barrier to RPAS applications. However, it was suggested by stakeholders that regulatory barriers on the use of these technologies might be holding back investment in their development.

On balance it is therefore difficult to confirm the overall extent to which UK RPAS regulations are holding back applications. It is clear however that regulation will need to evolve to keep pace with technological developments, and confidence in this programme of reform will be important to encourage investment in R&D. The significance of this issue is likely to be more acute for regulations governing the development of large RPAS as their regulations are more onerous. This reform agenda is the subject of the next section.

In relation to the enforcement of UK regulation, several stakeholders noted that CAA resources for dealing with RPAS related enquiries and processing applications are severely limited. It was suggested that this is causing delays for companies manufacturing RPAS and offering RPAS services. The long timeline required to secure product registration (as well as its cost) and for registering complete RPAS were also identified as having a range of other undesirable effects for companies delivering RPAS services.

Examples were identified of service firms needing to take products that they had purchased (typically imported) through the CAA registration process themselves in order to achieve the certification that their corporate clients required. Purchasers of RPAS services for infrastructure investment also suggested to the study team that the challenges involved with this process are reducing their potential number of suppliers.

Anticipated Evolution of RPAS Use Regulations in the UK

The importance of developing an increasingly enabling regulatory regime for RPAS as the technology evolves and becomes more robust was stressed by several stakeholders. There is a long term ambition for the integration of RPAS use into civilian aircraft management systems. Detailed in Table 5.6 below, the Roadmap for the Integration of civil RPAS into the European Aviation System, published in June 2013 by the European RPAS Steering Group outlines a staged approach of how this might be achieved in practice.

Table 5.6 Roadmap for the Integration of Civil Drones into European Airspace

Date	Intended Position
2013	Some limited, light civil drone flights under strong regulations without harmonisation.
2014-2018	Increased harmonisation and daily operations within visual and extended visual LOS, including urban areas; possibly low-altitude operations beyond visual LOS in isolated areas; some operations at higher altitudes in less congested airspace.
2019-2023	Licenced pilots operate in most airspace categories; full integration at low altitudes, regardless of LOS, expanding to more populated areas; public EU flights complying with different sets of national regulations.
2024-2028	Operations in most airspace alongside manned aircraft; common rules envisaged for public EU flights; cross border EU flights without special authorisation or excessive administrative burden.

Source: As summarised in Boucher 2014[146]

The roadmap details a set of proposals for a unifying framework of RPAS regulation across the EU based on a two core components:

- A risk-based approach differentiating between:
  - Low / open - covering craft of a maximum of 25kg (Includes a ‘harmless’ sub-category only subject to market regulations),
  - Medium / specific - requiring remote operator certification,
  - High / certified – each to be certified to a significantly higher standard, broadly in line with existing aviation guidelines.
- The establishment of restricted and no-fly zones by member states, supported by functionality that supports the automatic identification of these built into market standards.

Stakeholders identified significant support for this agenda in both the UK and internationally. However, concerns about the length of time that it will take to achieve international regulatory reform were raised. Several technical hurdles were identified that will need to be resolved before an integrated air traffic system could be achieved. In particular the technical issue of how RPAS can establish their location reliably in order to communicate it was identified.

A fear was also expressed about the achievability of the European timetable. Rather than identifying fundamental political roadblocks, stakeholders pointed to the number of interests and organisations involved in the reform process as a factor that is likely to result in very slow decision making. Stakeholders stressed that, because of uncertainty at the European and global level, it is important for the UK to progress a domestic reform agenda until European regulations can be implemented. In this sense the progress of international reform should be viewed as a risk factor for the future adoption of RPAS technologies.

[146] Philip Boucher (2014) Civil Drones in Society~ Societal and Ethics Aspects of Remotely Piloted Aircraft Systems, JRC Science and Policy Reports.

Data Protection and Privacy Regulation

RPAS have the potential to collect large volumes of personal data, and therefore many uses must comply with data protection requirements[147]. In the UK this is governed by the 1998 Data Protection Act, but will be superseded by the new EU General Data Protection Regulation in 2018. Through their operation RPAS were identified by stakeholders as having the potential to collect data through which it is possible to identify individuals in three ways:

- Directly identifying individuals through imaging (e.g. survey images at sufficient resolution to recognise individuals)
- Indirect identification of individuals (e.g. by capturing and recording car licence plates)
- Capture of platform data that includes personal data (e.g. some systems have developed to make use of Wi-Fi signals to track their location and may inadvertently be capturing personal data)

Currently, under the Data Protection Act, where RPAS are collecting or processing personal data, they require a fair and lawful basis for this. While some applications, such as law enforcement, are exempt from this requirement, there will typically be a need to obtain consent from those whose personal data is being processed. In some instances signage can be used to gain this, but that may be challenging for open-area applications. The EU General Data Protection Regulation will additionally require any processing to be 'transparent' and involve a process that is clear to those with an interest in the data. Again, this will be challenging to achieve for many applications. In addition, specific regulations have been developed for CCTV cameras, such as the requirement to notify individuals of recordings and offer access to their data, and these will apply equally to many RPAS systems[148]. Finally, where this activity could be classified as a form of covert surveillance additional regulations relating to the Regulation of Investigatory Powers Act also apply, requiring the use of a warrant.

Nevertheless, stakeholders did not identify this issue as a key barrier holding back the commercial application of RPAS in the UK. Instead a number of management strategies (including the careful designation of data controllers, data processors and their contractual relationships) and product design approaches that consider data protection (such as the use of built in software to identify and blur recognisable features, in a similar way to that used in Google Street View) have been advocated as responses to this challenge. Confirming this view, a recent review of the data protection landscape concluded that current frameworks are appropriate but with challenges in relation to educating the RPAS industry about its obligations[149].

Spectrum Regulation

As discussed in Section 4, command and control systems for RPAS require secure and stable links in order to be reliable. Live data feeds providing information from RPAS sensors will increase the load on these links. In addition to representing a technical challenge, this is also a regulatory issue as the available spectrum for this communication is highly regulated. Frequency bands are allocated for specific uses by national regulators operating within

[147] European Data Protection Supervisor (2015). Opinion of the European Data Protection Supervisor on the Communication from the Commission to the European Parliament.

[148] Finn, R. L., & Wright, D. (2012). Unmanned aircraft systems-Surveillance, ethics and privacy in civil applications. Computer Law & Security Review. April 2012. Volume 28. Issue 2. pp 184–194

[149] Finn, R. et al. (2014) Study on privacy, data protection and ethical risks in civil Remotely Piloted Aircraft Systems operations, European Commission.

international arrangements. A European review has identified that the 34MHz band is required for ground based control of RPAS and that the 49MHz band is required for control from a satellite system[150]. The study team has been unable to confirm from the existing evidence base whether this bandwidth is likely to be protected and therefore the extent to which this represents a barrier to further RPAS applications.

5.6.2 Public Perceptions as a Barrier to Use

A number of factors have been identified as driving social dissatisfaction with RPAS, including privacy issues, associations with military applications and concerns about misuse. This dissatisfaction was identified through the research as the other core barrier with the potential to hold back RPAS use in the UK.

Privacy Concerns

As noted above, RPAS have the potential to capture a large volume of personal data and, separate from data protection arrangements, many commentators have identified public concerns about the privacy impact of RPAS. Research has linked these image and privacy issues to resistance to RPAS use[151]. A particular concern appears to be that, unlike traditional, fixed-in-place surveillance systems, RPS can compromise privacy in ways that an individual may find it difficult to appreciate and avoid[152]. This research included a survey of the Risk Insurance and Management Association, the members of which identified privacy concerns as posing the greatest issue in relation to the adoption of RPAS for commercial uses.

Public Association with Military Uses

The association of RPAS with military applications also gives rise to a broad range of concerns[153]. The risk that this negative perception (or a risk of a negative reaction to an incident) is holding back the use of RPAS in the UK was suggested to the study team by stakeholders. However, it appears that more recently police forces have been increasingly open to the use of RPAS, with reports in the media that the National Police Chief's Council lead on drones has suggested that the public should expect to see more police-controlled drones flying around the country[154].

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[150] EUROCONTROL (2010) UAS C3 Channel Saturation Study Final Report. https://www.eurocontrol.int/sites/default/files/content/documents/single-sky/uas/library/spectrum_d5_final_report_v_1_doc.pdf. Date accessed: 25/01/2016

[151] Taylor Vinters (2014) Qi3 Insight~ Unmanned Aerial Vehicles. Qi3 Insight. www.qi3.co.uk/wp-content/uploads/2014/02/Qi3-Insights-White-Paper-UAVs-Growing-Markets-in-a-Changing-World-2014021903.pdf. Date accessed: 25/01/2016

[152] Munich RE (2015). Focus on: Drones and the Commercial Sector. Munich Reinsurance America, Inc. www.munichre.com/site/mram-mobile/get/documents_E-564385086/mram/assetpool.mr_america/PDFs/3_Publications/Research_Spotlight/focuson_drones_commercial.pdf. Date accessed: 25/01/2016

[153] Philip Boucher (2014). Civil Drones in Society~ Societal and Ethics Aspects of Remotely Piloted Aircraft Systems, JRC Science and Policy Reports.

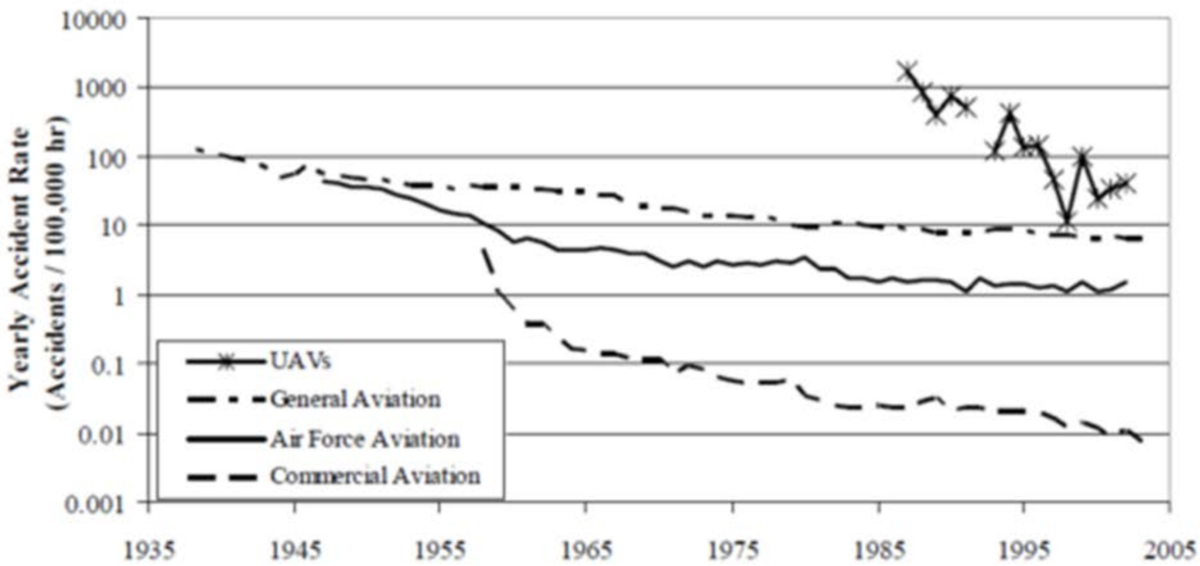
[154] Shaed (2016). Police could soon use drones. Business Insider. http://uk.businessinsider.com/police-could-soon-use-drones-2016-1. Date accessed: 22/02/2016

Concern about Dangerous or Socially Undesirable RPAS Uses

A number of different sources indicated concerns that RPAS use may be dangerous or risky, potentially deterring users:

- Compared to conventional aviation RPAS are associated with a higher failure rate and incidence of crashes. Stakeholders suggested that currently the commercial RPAS market is performing with a safety record equivalent to that of manned aviation in the 1960s. A number of high profile stories[155], or a high profile incident of a commercial RPAS coming close to colliding with a skier[156] may have raised awareness of the risk here.
- A number of RPAS have been reported as operating close to passenger aircraft, raising concerns about a potential collision[157].
- Criminal uses of RPAS have been reported, such as the smuggling of drugs and other items into prisons[158]. The potential for the terrorist use of RPAS has also been identified[159].

Figure 5.3: Comparisons on accident rate trends (per hour of operation) between different classes of aircraft



Source: Jarus Working Group 6 (2015)

Stakeholders suggest that these different public concerns are holding back a number of RPAS applications with some companies concerned about the potential reputational damage associated with their use of RPAS. In addition to this direct effect, public concerns in this area

[155] Lowbridge (2015). Are drones dangerous or harmless fun. BBC News. www.bbc.co.uk/news/uk-england-34269585. Date accessed: 22/02/2016
[156] Grez (2015). Drone almost hits skier. CNN.com. http://edition.cnn.com/2015/12/23/sport/marcel-hirscher-drone-crash/. Date accessed: 22/02/2016
[157] UK Airprox Board (2016). www.airproxboard.org.uk/home/. Date accessed: 22/02/2016
[158] BBC (2015). Drone carrying drugs found in prison grounds at HMP Manchester. BBC News. www.bbc.co.uk/news/uk-england-manchester-34764417. Date accessed: 22/02/2016
[159] Bolton (2015) Terrorists could use drones to attack planes and spread propaganda, government security adviser warns, Available from: www.independent.co.uk/life-style/gadgets-and-tech/news/drone-terrorist-attack-isis-propaganda-colin-smith-a6762411.html accessed 09/03/2016

may slow the pace of regulatory reform and, along with privacy issues, have been identified as causing a delay to the US integration procedure[160].

Overall, there is a clear and significant potential for public perceptions to hold back the use of RPAS in the UK. Several stakeholders did however stress that the increased commercial use of RPAS across a variety of applications, will inevitably result in a more balanced perspective. This includes some uses where perceptions are likely to be positive – for example: search & rescue; delivery of food and medicines in natural or other disasters; improved safety and reduced exposure to risk for people working in hazardous environments. Some of these could help to generate a set of 'good news' stories. The issue of public attitudes is an aspect that is currently being explored in greater depth, through the existing government sponsored Drones Public Dialogue (http://dronespublicdialogue.co.uk/).

5.7 The Potential Disruption from Increased RPAS Use

As outlined in the analytical framework in Section 2, the economic benefits associated with RPAS may be mitigated if the use of RPAS activity acts to disrupt existing industries. This would be the case if, for example, the use of RPAS directly replaces other economic activities. However, the extent to which these applications are displacing other economic activities receives little explicit coverage in the literature. It is possible however to draw a set of inferences from the nature of the applications identified above and from messages from stakeholders in this area.

There are a large set of RPAS applications which are novel and creating value in ways that would not be possible in the absence of this technology – for example, undertaking filming where use of a manned helicopter would not be feasible, or where its downdraft might disrupt activity on the ground, such as a sailing race.

In contrast, a number of examples have been identified through the research where the application of RPAS will displace existing economic activity. For example, using RPAS to deliver an inspection of an oil facility might be an alternative to using roped climbers. In other cases efficiencies gained through RPAS use - such as in inspection and monitoring – will likely reduce the requirements for existing workers. As such, they may not drive increased economic activity directly and may well tend to reduce the turnover of some service providers. However, even in these cases, the reduction in prices from the productivity impacts will produce countervailing effects through the expansion of demand.

Stakeholders also stressed that in the contexts explored, the need for skilled engineers or technicians will remain to use RPAS as a tool, and in particular to review the data collected by sensors and to take appropriate action. Similarly in film the skills required to secure the right shot will still be needed. The need for re-skilling was identified in order to enable technicians to make the most of RPAS technology, e.g. a switch from inspection to analysis. It is also important to stress that some of the activities displaced by RPAS are inherently dangerous (any roles taken by civil RPAS will be either "dirty, dull and/or dangerous" - Royal Aeronautical

[160] Philip Boucher (2014) Civil Drones in Society~ Societal and Ethics Aspects of Remotely Piloted Aircraft Systems, JRC Science and Policy Reports.

Society 2013)[161]. The key likely implication is that one impact of the expanded use of RPAS will be to drive a change in the skill structure of the workforce.

5.8 Summary

- **Potential economic value of RPAS**: One estimate suggests that the benefits of integrating RPAS into the US National Aerospace System could amount to some $82bn over a 10 year period. Other studies have demonstrated major potential efficiency benefits from potential sensing applications in agriculture and the oil and gas and utilities sectors, as well as from the use of drones for the delivery of small parcels.
- **Key technological trends in recent years include**: R&D supporting the increasing use of polymer composites in airframes; the development of detect and avoid capabilities; the use of 3D printing in production processes along with component miniaturisation; the development of increasingly sophisticated software for imaging and modelling; experimentation with alternative power drives; and, improvements in the quality and variety of the available sensor payloads.
- **Key technological challenges** remain in relation to securing improvements in navigation performance, verification, connectivity and security issues, in particular to facilitate the acceptability of BVLOS operation. Further progress is also needed in the areas of IT/data processing, power drives and sensors.
- **UK production limitations**: The limitations of the UK production base for RPAS and associated componentry seem to derive largely from the cost advantages enjoyed in particular by Chinese competitors. However, the absence of a mechanism for co-ordinating the diffuse potential demands for applications in different sectors has been identified as inhibiting the commercialisation of UK R&D.
- **Regulation**: Regulatory issues represent a particularly important potential barrier to the realisation of the benefits from the expansion of RPAS applications. The UK regulatory environment is generally seen as one of the more supportive in international terms, although it is important that both the UK and the EU regulatory regimes are able to adapt to technological developments and the growth in RPAS use. Data protection and privacy aspects and the protection of spectrum frequencies for communication with RPAS have also been identified as potential issues, although it is not entirely clear that these represent major problems.
- **Public perceptions**: Public concerns associated with privacy, the association with military uses and safety aspects also have the potential to hold back the development of RPAS applications through both their influence on the regulatory environment and through the concerns which they create about reputational damage amongst potential adopters of the technology within the corporate sector.
- **Impact on UK manufacturing growth**: It seems unlikely that any of these latter factors account for the relatively slow pace of development of RPAS related production activity within the UK as reported in Section 2.

[161] Royal Aeronautical Society (2013). UNMANNED AERIAL VEHICLES:A NEW INDUSTRIAL SYSTEM?. http://aerosociety.com/Assets/Docs/Publications/DiscussionPapers/UASDiscussionPaper.pdf. Date accessed: 15/02/2016

- **Applications**: Many new RPAS applications will help to create new economic opportunities. In other cases existing activities will tend to be displaced, although the associated benefits in terms of increased productivity and cost/price reductions will tend to produce countervailing effects through expanding demand for many of the services involved. Changing patterns of service delivery and economic activity will clearly require adaptations in the skill composition of the workforce within the sectors which are affected.

6.0 Forecasts of Future Market Growth

This section presents findings from review of available RPAS market growth forecasts. It outlines the headline estimates for the total RPAS market as well as its specific segments based on user type, geography, application and business model type.

6.1 RPAS production forecast

Numerous forecasters have sought to predict the global growth of the RPAS industry, and ten relevant market forecasts undertaken over the last two years were identified as part of this literature review. While there are significant variations in their estimates, all reflect a confidence that the area of activity has the potential to expand substantially over the next five to ten years.

The studies identified all vary in terms of their methodologies, the assumptions or factors that are taken into account and the scope of their focus. The differences between the methodologies used, the assumptions included, and the variety in scope and validity of individual forecasts are reviewed in Annex Table C.1. Key differences include variations in methodological complexity and in the sources of evidence which were taken into account. The simplest of the methodologies focused on only the three largest manufacturers and their predictions for growth while the most complex approaches were based on historic trends in the growth of comparable sectors, triangulating such evidence in some cases with more than 30 sector expert interviews. All of the forecasts have a global scope but, while some are restricted to consumer and or commercial segments, one also includes military RPAS.

Only three of the ten forecasts presented direct estimates for the total market size (covering sales of both consumer and commercial RPAS). The lowest prediction was £5.5bn by 2020[162]; a short term prediction for the next three years was £5.9bn[163] and the most optimistic prediction was also the longest term at £18.2bn by 2025[164]. These forecasts are presented in Figure 6.1 below[165]. In this figure the study team have undertaken analysis to make the forecasts as comparable as possible, and to extrapolate forwards the shorter term projections. This has allowed the team to develop an indicative average of the forecast that predicts a 2025 global RPAS market of £20bn. To place the scale of this market into context it is worth noting

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162 Frost & Sullivan (2015). Prospects for Global Commercial UAS_ATI_ 8thOct2015. Frost & Sullivan

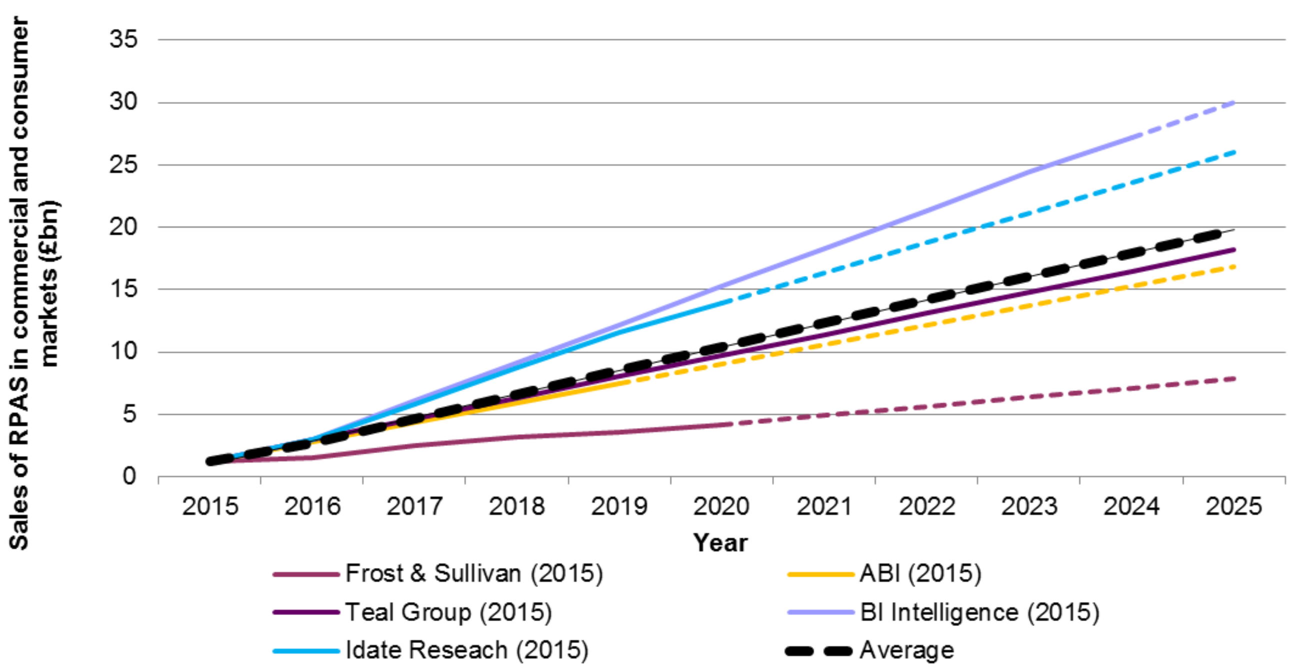
163 ABI Research (2015). Small Unmanned Aerial Systems Market Exceeds US$8.4 Billion by 2019, Dominated by the Commercial Sector and Driven by Commercial Applications. ABI Research. www.abiresearch.com/press/small-unmanned-arial-systems-market-exceeds-us84-b/. Date accessed: 15/02/2016

164 Teal Group (2015). Teal Group Predicts Worldwide UAV Market Will Total $91 Billion in Its 2014 UAV Market Profile and Forecast - Teal Group Corporation~ Aerospace and Defense Market Intelligence ~ Analysis and Forecasts. www.tealgroup.com/index.php/about-teal-group-corporation/press-releases/118-2014-uav-press-release. Date accessed: 27/01/2016

165 Note on analysis presented in Figure 6.1: While the market forecast from BI Intelligence only provided an indication on number of units sold we have applied estimated unit price over the period developed by Frost & Sullivan (2015) and include this estimate in the figure along with the three forecasts and an average estimated growth. Similarly, the market forecast by Idate Research only indicates a cumulative spending up to 2020 and therefore the growth rate is only a linear estimation of growth from 2015 estimates reported by Frost & Sullivan. Both of these forecasts indicate high growth of RPAS markets and if extrapolated to 2025, point towards a potential of market size of £30bn. The average developed is based on the extrapolation of forecasts using a simple linear trend. A linear trend rather than a constant growth rate was applied in this instance because (as illustrated in these figures) the forecasts which offer multiple data points predict a slowing in the growth rate as the scale of activity increases.

that all but one of these forecasts predicts that in ten years the global RPAS market will still be smaller than the current UK aerospace industry turnover (estimated at £27.8bn in 2015)[166].

Figure 6.1: Summary of forecasts of Global RPAS growth as a whole (comprising commercial and consumer markets)



Source: Ipsos MORI Analysis, 2016

6.2 Market Segment Forecasts

6.2.1 Forecasts of the Balance between Military, Civil and Hobby Markets

The forecasts suggest that there is substantial uncertainty both as to whether civil applications will eventually overtake the military market, and if so when. Among the forecasts reviewed as part of this study, only one provided specific figures for the growth of global military RPAS as a segment, predicting that this would grow to £46.8bn per annum by 2025[167]. Another study indicating a much smaller overall size of the market - £5.9bn in 2018 - compared the commercial and military markets only in relative terms and concluded that the commercial RPAS market would be two times larger than the military segment by 2018 and five times larger than the consumer segment[168]. However, these findings appear to conflict with research from the Royal Aeronautical Society stating that the US currently has an RPAS fleet

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[166] ADS (2015) Aerospace Industry Outlook

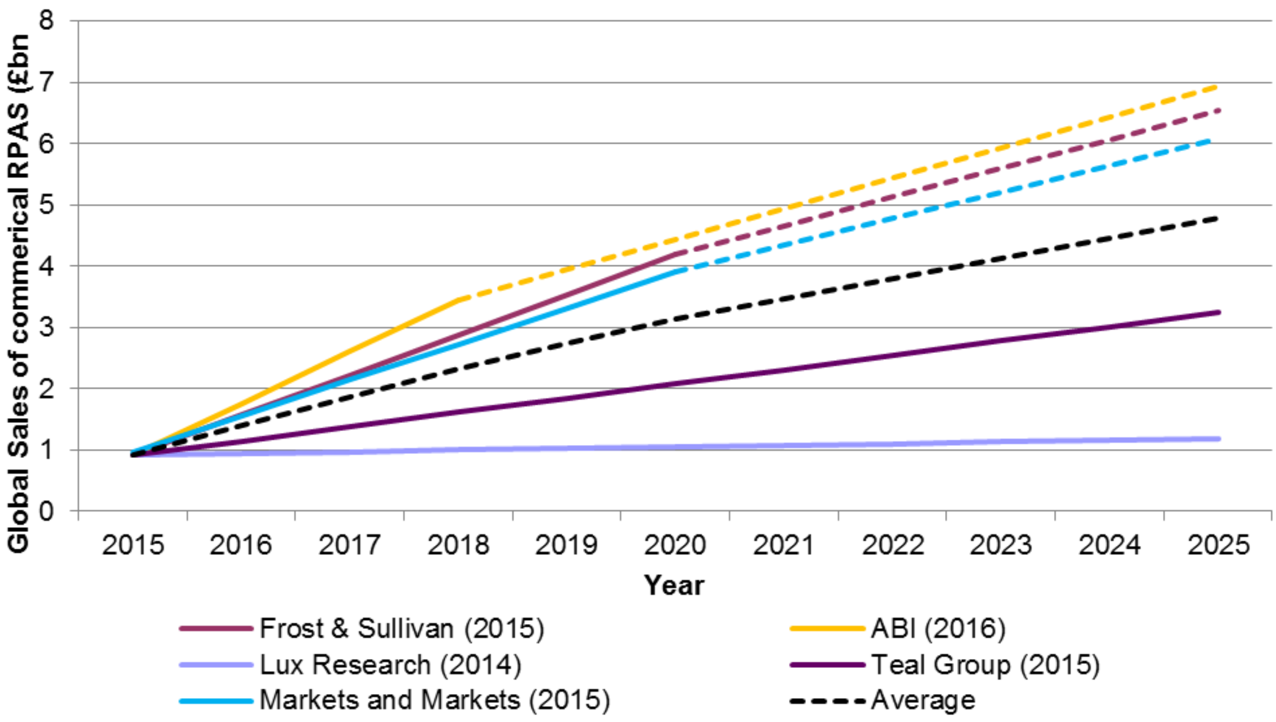
[167] Teal Group (2015). Teal Group Predicts Worldwide UAV Market Will Total $91 Billion in Its 2014 UAV Market Profile and Forecast - Teal Group Corporation~ Aerospace and Defense Market Intelligence ~ Analysis and Forecasts. www.tealgroup.com/index.php/about-teal-group-corporation/press-releases/118-2014-uav-press-release. Date accessed: 27/01/2016

[168] ABI Research (2015). Small Unmanned Aerial Systems Market Exceeds US$8.4 Billion by 2019, Dominated by the Commercial Sector and Driven by Commercial Applications. ABI Research. www.abiresearch.com/press/small-unmanned-arial-systems-market-exceeds-us84-b/. Date accessed: 15/02/2016

comprising 6,000 vehicles with an associated total budget of $17.9bn (equivalent to £12.3bn) in total over the coming decade[169].

Forecasts for commercial global RPAS markets (i.e. excluding devices targeted at the consumer) vary between £1.2bn and £6.6bn by 2025 (if they are extrapolated on a linear basis). The most conservative forecast is based mainly on the assumption of precision agriculture driving growth (up to 2025) and the most optimistic ones are said to be driven by the photo and video sub-segments[170] and data, operator and modelling services[171]. Based on an analysis of limited amount of evidence in the previous chart, this suggests that the size of the markets for those devices with higher technical specifications that can command higher values are likely to be comparatively small (though these forecasts do not allow for any development of a market for large RPAS). Results of these forecasts are presented and referenced in Figure 6.2 below.

Figure 6.2 - Summary of Forecasts of Growth in Global Commercial RPAS



Source: Ipsos MORI Analysis, 2016

There is an especially large variation in the forecasts of the consumer/hobby market segments. Frost & Sullivan (2015) estimate this global market to be worth only £1.3bn in 2020 with sales of 3.2m units (though this may be conservative, as the largest manufacturer is forecasting sales of £1bn in 2016)[172]; other forecasts quoted 60m units in the hobby market alone (ABI, 2016) and a market value of up to £15bn, in 2025. Idate Research is based on number of

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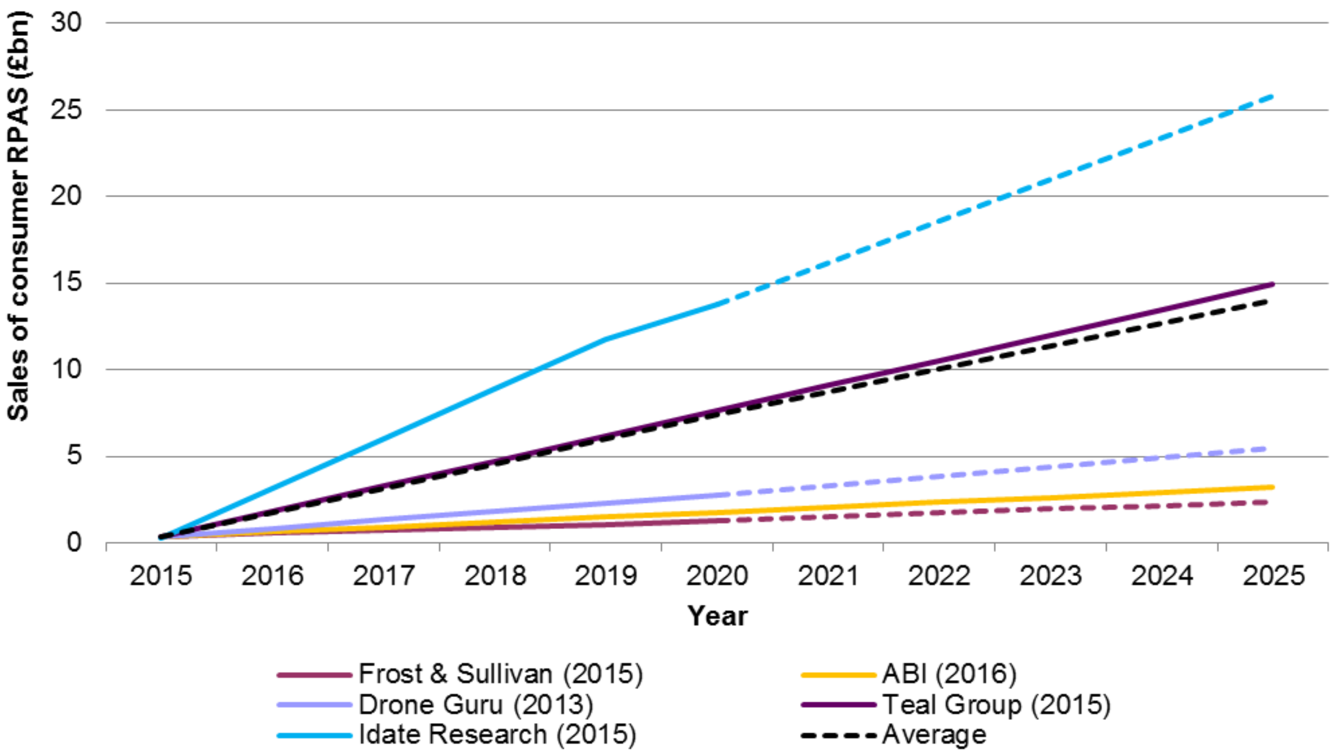
169 Royal Aeronautical Society (2013). UNMANNED AERIAL VEHICLES:A NEW INDUSTRIAL SYSTEM?. http://aerosociety.com/Assets/Docs/Publications/DiscussionPapers/UASDiscussionPaper.pdf. Date accessed: 15/02/2016
170 Frost & Sullivan (2015). Prospects for Global Commercial UAS_ATI_ 8thOct2015. Frost & Sullivan
171 ABI Research (2015). Small Unmanned Aerial Systems Market Exceeds US$8.4 Billion by 2019, Dominated by the Commercial Sector and Driven by Commercial Applications. ABI Research. www.abiresearch.com/press/small-unmanned-arial-systems-market-exceeds-us84-b/. Date accessed: 15/02/2016
172 Frost & Sullivan (2015). Prospects for Global Commercial UAS_ATI_ 8thOct2015. Frost & Sullivan

RPAS at an average price and indicates possible most optimistic market growth[173]. Results of these forecasts are presented and referenced in the chart below.

Figure 6.3: Summary of Forecasts of Growth in Global Consumer (Hobby) RPAS



Source: Ipsos MORI Analysis, 2016

Frost & Sullivan (2015)[174] identify the possibility of an overlap and the challenge of differentiating between consumer and professional services with a ‘prosumer’ segment emerging between these two market segments. This vertical market segment setup is demonstrated in the reconstructed figure overleaf which forecasts growth in all segments.

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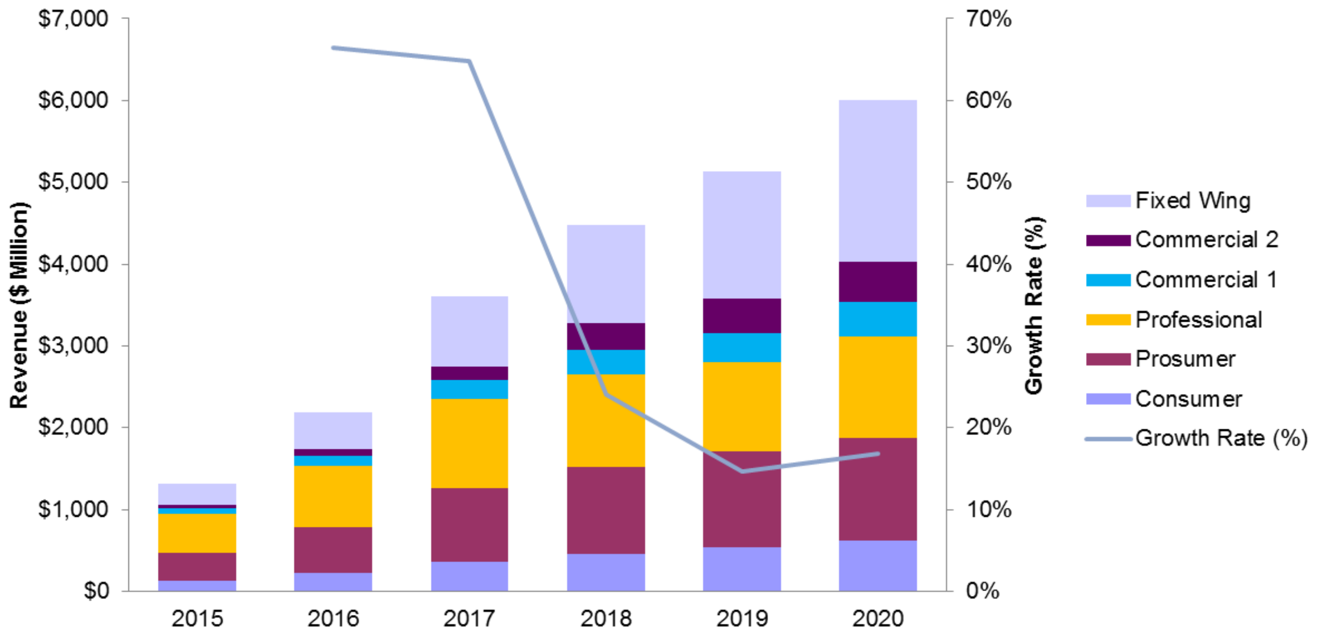
[173] Idate Research (2015). Commercial and consumer drones. Idate Research. Market report - 04/05/2015. www.idate.org/en/Research-store/Commercial-and-consumer-drones_1005.html

[174] Frost & Sullivan (2015). Prospects for Global Commercial UAS_ATI_ 8thOct2015. Frost & Sullivan

Figure 6.4: Total Commercial Global RPAS Market: Revenue Forecast by Vertical Market Segment, Global, 2015-2020



Source: Frost & Sullivan 2015

As noted above, individuals consulted as part of this research tended to suggest that the demand within the consumer market has been almost exclusively for micro and small devices to date (i.e. less than 20kg). Forecasts for consumer markets almost exclusively focus on small devices as an existing market. Stakeholders identified one programme for the development of large RPAS in the UK, the Thales Watchkeeper referred to above. However, it was stressed that this programme has not secured approval for use in civil applications. The review has been unable to identify evidence predicting the growth of markets for large RPAS but one consultee pointed out that modern design and manufacturing techniques have a potential to make scaling up of small RPAS a straightforward exercise.

Stakeholders suggested to the study team that the demand for greater endurance and more complex systems may drive a shift towards larger RPAS in the future (either within the small class of RPAS or up to the light class above 20kg), or a shift towards the more efficient fixed wing RPAS, as indicated in Figure 6.4. Others suggested that using larger RPAS would allow operation in a broader range of conditions. However, it has been suggested that current low levels of demand for large RPAS reflects the 'unaffordability' of large scale RPAS for all but a few institutions[175] (as indicated in Section 3, this research identified the cost of a light RPAS at £40,000 - £300,000). Safety concerns and the ease of deployment by relatively unskilled operators were also identified as key drivers of the relative growth in demand for small RPAS[176].

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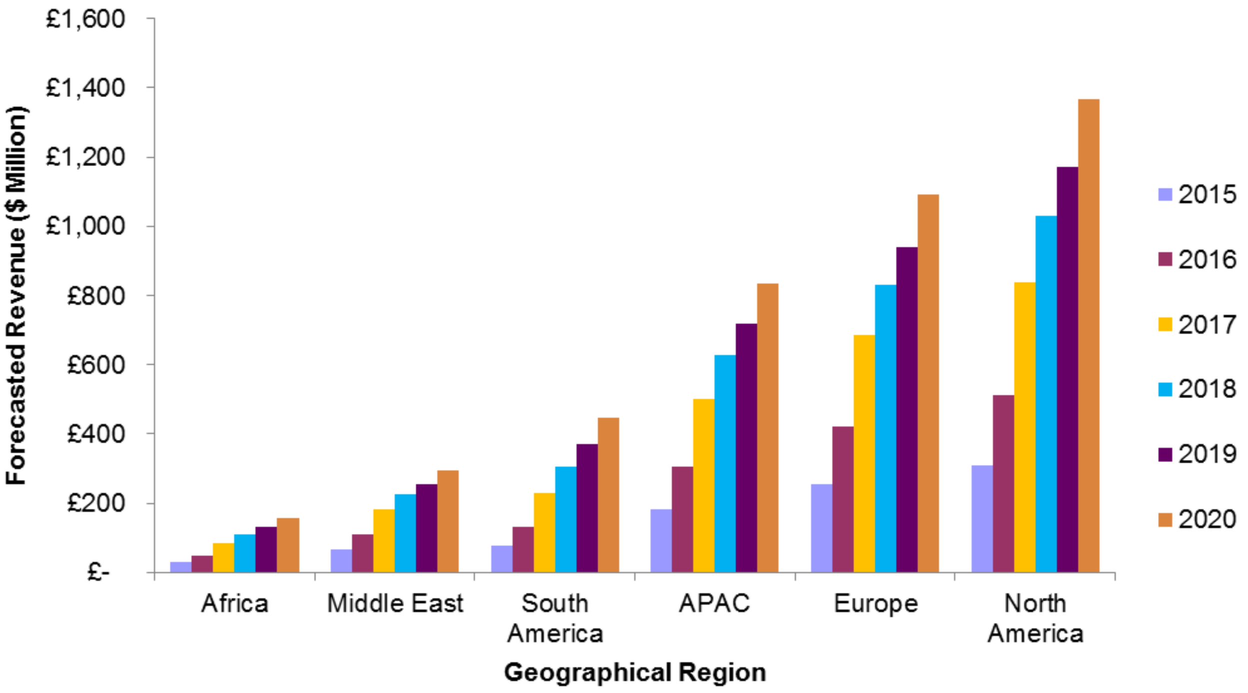
[175] Houses of Parliament (2014). Civilian Drones. PostNote Number 479. October 2014.
[176] Royal Aeronautical Society (2013). UNMANNED AERIAL VEHICLES:A NEW INDUSTRIAL SYSTEM?. http://aerosociety.com/Assets/Docs/Publications/DiscussionPapers/UASDiscussionPaper.pdf. Date accessed: 15/02/2016

6.2.2 Forecasts of the Geography of RPAS Markets

Only two studies have analysed which regions will drive the growth of RPAS. Frost & Sullivan was the only source identified through the research which developed current estimates and forecasts of the demand for RPAS use by global region between 2015 and 2020. Illustrated in Figure 6.5 below, this study forecasts a compound annual growth rate of at least 33% for all regions, with Africa and South America expected to see the highest proportionate rate of market growth, albeit from relatively low bases.

Figure 6.5: Commercial RPAS Market (Revenue) by Region 2015-2020



Source: Frost & Sullivan 2015

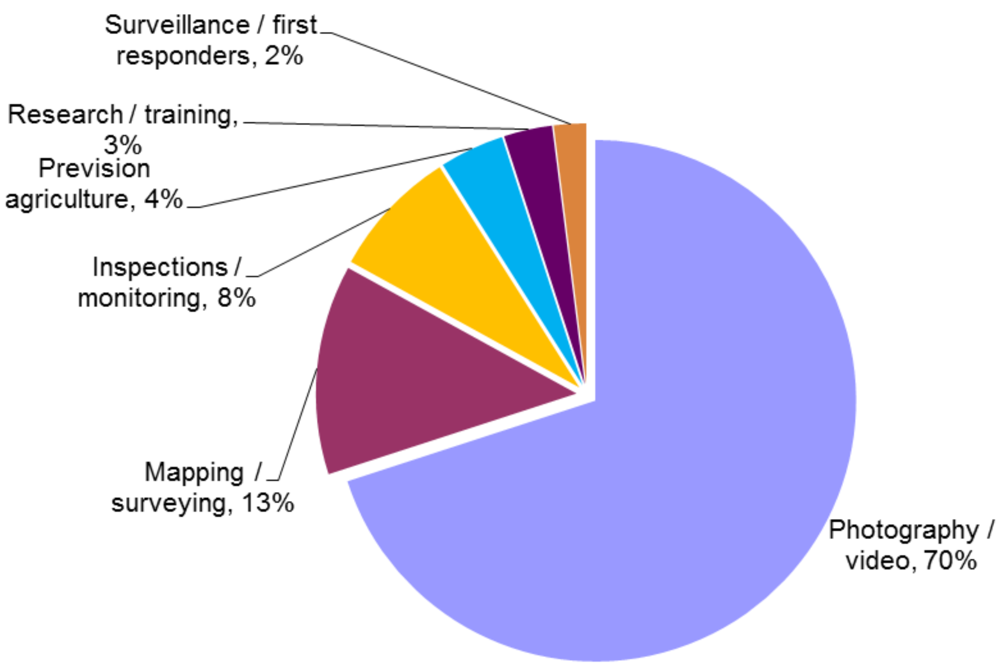
330,000 units in 2025, while Europe and South America follow, each with around 200,000 units. Our consultations with experts however suggested that RPAS could be one of the examples of 'technological leapfrogging' - for example, in parts of Africa RPAS use could develop in advance of conventional ground transportation - if the business model of food delivery to remote places in Africa can be arranged cost effectively it may take place before such services are offered in Europe.

6.3 Forecasts of RPAS Applications

Two of the RPAS market forecasts indicate the balance of applications which will be the dominant driver of growth and further two forecasts list top applications without offering an indication on their relative balance. As illustrated below however, there is very little consistency between these forecasts. The most detailed of these is produced by Frost & Sullivan and breaks the commercial RPAS market into six different applications, all of which represent some form of sensing, underlining the dominance of this type of application. While this is not explicitly stated in the report with reference to this data, it has been assumed that this chart relates to the 2015-2020 forecast period of the paper. As illustrated in Figure 6.6 this research identifies that the most important application, accounting for more than two thirds of global demand, will be photography and video. Mapping, surveying, inspections and monitoring are identified as other significant uses.

Precision agriculture, research and training and surveillance / first response applications are expected to experience lesser demand.

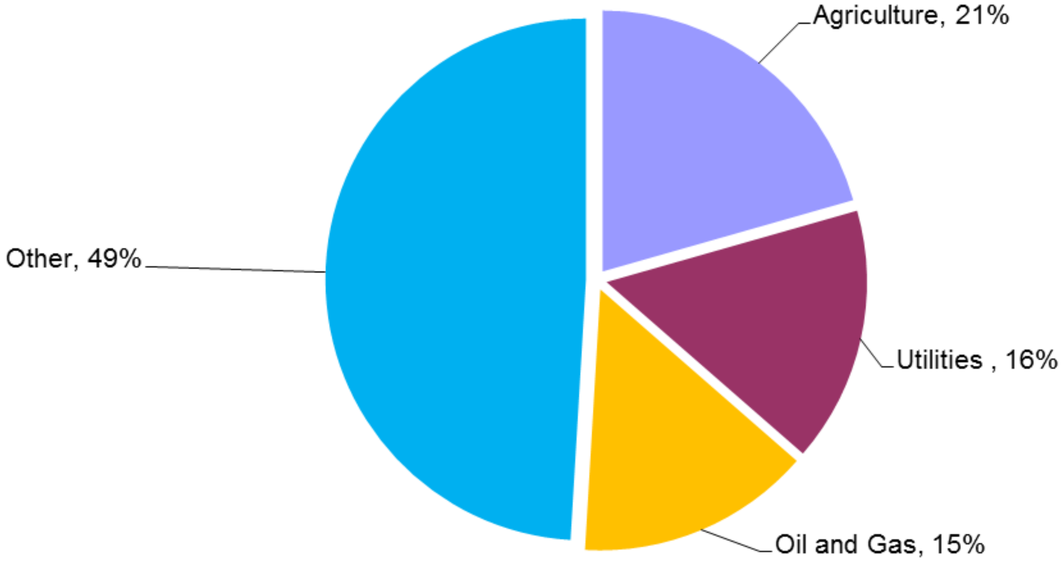
Figure 6.6: Forecast 1 RPAS Applications by Market Segment, Global



Source: Frost & Sullivan 2015

The second market forecast indicating balance between applications driving growth was produced by Lux Research and specifies that agriculture will be the most significant application, followed by utilities and oil and gas. These findings are presented in Figure 6.7 below.

Figure 6.7: Forecast 2: RPAS Applications Forecast by Market Segment for 2025, Global



Source: Lux Research 2015

As pointed out above and discussed in detail in Annex C, it is important to stress the limitations of these forecasts. This is particularly apparent when looking at statistics on different RPAS applications where significant discrepancies arise:

- **Precision agriculture**, alongside **public safety**, was identified by the Association for Unmanned Vehicle Systems International as the two key RPAS markets, likely to account for 90% of demand, with precision agriculture being the larger of these two markets[177]. Lux Research (2014)[178] and BI Intelligence (2015)[179] both specified agriculture as the top application but other commentators have expressed concern about the capacity of the sector to exploit this technology[180]. BI Intelligence also identifies energy, utilities, mining, construction, real estate, news media, and film production as the main areas of growth.
- **Parcel delivery** is identified as a key application of RPAS technology by a number of sources (e.g. Guardian 2014)[181]. In contrast it has also been indicated to be one of the

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[177] AUVSI (2013). THE ECONOMIC IMPACT OF UNMANNED AIRCRAFT SYSTEMS INTEGRATION IN THE UNITED STATES. Association for Unmanned Vehicle Systems International. https://higherlogicdownload.s3.amazonaws.com/AUVSI/958c920a-7f9b-4ad2-9807-f9a4e95d1ef1/UploadedImages/New_Economic%20Report%202013%20Full.pdf. Date accessed: 22/02/2016

[178] Lux Research (2015). Led by Agriculture, Market for Commercial Drones Will Reach $1.7 Billion in 2025. Lux Research. www.luxresearchinc.com/news-and-events/press-releases/read/led-agriculture-market-commercial-drones-will-reach-17-billion. Date accessed:15/02/2016

[179] BI Intelligence (2015). THE DRONES REPORT: Market forecasts, regulatory barriers, top vendors, and leading commercial applications. Business Insider UK. http://uk.businessinsider.com/drones-report-market-forecast-2015-3?r=US&IR=T. Date accessed: 22/02/2016

[180] Droneanalyst.com (2014). Film or Farm: Which is the Bigger Drone Market? – Part 2. Drone Analyst Skylogic Research LLC. http://droneanalyst.com/2014/06/11/film-or-farm-which-is-the-bigger-drone-market-part-2/. Date accessed: 22/02/2016

[181] Guardian (2014). Amazon threatens to take drone testing abroad as US delays approval ~ World news. The Guardian. www.theguardian.com/world/2014/dec/09/amazon-threatens-drone-testing-abroad-us-delays-approval. Date accessed: 27/01/2016

applications which is the furthest from market[182], and as a beyond 2020 market segment[183].

- **The Hobby / toy sector** is forecast by Frost & Sullivan to be five times the size of the commercial civil market over the next decade. The ABI research predicts the exact opposite. However, it is important to note that there may be some overlap between these market segments.

In practice, the emergence of these different uses will depend on a complex interaction between the technical developments discussed in Section 4 (technology push), and the benefits arising from their use (user pull). Stakeholders stressed that it will be down to individual entrepreneurs to bring together potential RPAS users and the emerging technology to create new applications. This innovation process is fundamentally difficult to predict, implying that while there is great confidence in the increased application of RPAS in general terms, considerable uncertainty remains about its nature.

6.4 Predicted Features of the RPAS Global Market

6.4.1 Emerging RPAS Business Models

Stakeholders described RPAS as either an information technology or a platform technology upon which a set of services will be offered. This presentation of RPAS as a tool rather than an aviation device was suggested by stakeholders to be in sharp contrast to many other manufacturing sectors, and aviation in particular. The Royal Aeronautical Society suggested that the likely model for the RPAS market might better reflect the space sector than the conventional aerospace market: "As in the Space sector, increasing platform availability and capability will generate a new wave of 'downstream' applications where the platform hardware comprises a relatively small element in the total value chain."[184] (For context, the latest 'Case for Space' report published by the UK Space Agency estimates that manufacturing represents only 8% of the total sector turnover, operations 12% with applications and ancillary services accounting for 80% of turnover[185].

Frost & Sullivan described the idea of Drones as a Service (DaaS) as 'The Real Market'[186]. This reflects a belief shared by stakeholders that the core commercial market for RPAS will be a business-to-business service offer. Rather than for example, farmers looking to purchase individual RPAS and handle their operation, maintenance and insurance themselves, the tendency and trend is thought to be towards the emergence of specialist companies providing a package of RPAS services embedding them into a portfolio of tools used by service providers.

This approach will confer immediate advantages, such as the potential to share fixed costs of RPAS use across multiple clients. It also allows for the emergence of highly specialist service

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[182] House of Lords (2015). Civilian use of Drones in the EU~7th Report of the Session 2014-15. House of Lords. www.publications.parliament.uk/pa/ld201415/ldselect/ldeucom/122/122.pdf. date accessed: 27/01/2016
[183] Frost & Sullivan (2015). Prospects for Global Commercial UAS_ATI_ 8thOct2015. Frost & Sullivan
[184] Royal Aeronautical Society (2013). UNMANNED AERIAL VEHICLES:A NEW INDUSTRIAL SYSTEM?. http://aerosociety.com/Assets/Docs/Publications/DiscussionPapers/UASDiscussionPaper.pdf. Date accessed: 15/02/2016
[185] London Economics (2015) The case for Space 2015: The impact of space on the UK economy, available from www.ukspace.org/wp-content/uploads/2015/07/LE-Case-for-Space-2015-Full-Report.pdf accessed 07/03/2016
[186] Frost & Sullivan (2015). Prospects for Global Commercial UAS_ATI_ 8thOct2015. Frost & Sullivan

providers that develop to serve the needs of a common set of customers. For example, one stakeholder identified the development and integration of image processing software alongside their RPAS inspection services that facilitate intertemporal comparisons of inspections (such as the tip of a specific wind turbine blade the last three times it was inspected) as an additional service that they can offer as a package that is not available as a separate ancillary service.

Stakeholders reported that there are no issues with the development of ancillary services (such as insurance) to support either direct use of RPAS, or DaaS. They did however identify several challenges that complicate the pursuit of the DaaS business models and may impede their development:

- **Standards**: How to demonstrate and differentiate sophisticated service providers from 'hobbyists' was identified as an issue by stakeholders. An aspect identified by several stakeholders was the ease with which operators can obtain CAA certification through a short training course. It was suggested that, while this might be appropriate in some instances, it is seen by individuals in the industry as a basic qualification that does not confirm skill and expertise in using RPAS for more complex operations. Two alternative recommendations were advocated by stakeholders in response to this challenge:
  - One stakeholder suggested that additional regulation may be required to distinguish credible commercial operators from 'hobbyists'.
  - Others suggested that a second and higher professional standard could emerge from within the sector, and advocated a professional membership model of regulation.
- **Contracting and liability**: There is a high level of complexity in the relationship between an organisation interested in making use of RPAS and an operator, with stakeholders identifying a challenge in knowing what an appropriate RPAS contract might look like. In particular they had identified concerns amongst companies that were considering working with RPAS service suppliers that they did not know how issues of liability or data protection are typically handled. It was suggested that some form of guidance or the development of template contracts would support the uptake of RPAS applications.
- **Poor current profitability**: Stakeholders suggested to the study team that they believe that very few businesses are currently deriving a profit from offering RPAS services. It was suggested that businesses are currently experimenting with business models and trying to build markets by simultaneously pushing technology boundaries (technology push) and attracting in potential customers (demand pull). This was seen as a costly activity characterised by high failure rates. It was suggested that future entrants to the market might be able to benefit from this experimentation and will avoid poor investments. Stakeholders suggested however that a typical model for market entry here would be acquisition or investment in companies that have demonstrated initial viability offering a potential return for initial investors. An example of this might be the investment by the Bristow Group in UAV inspection service provider Sky-Futures[187]. Stakeholders reiterated the leading positions of Chinese producers in the hobby RPAS market, Japanese producers in agricultural RPAS for spraying and German and Swiss RPAS for inspection and mapping.

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[187] Bristow Group (2016) Bristow Group Enters Unmanned Aerial Vehicle (UAV) Services Business: Invests in Sky-Futures, the leading provider of drone inspection data services, available from http://bristowgroup.com/bristow-news/latest-news/2016/bristow-group-enters-unmanned-aerial-vehicle-uav-s/ accessed 10/03/2016

In the downstream applications market the barriers to entry were seen to be minimal, especially with progress in user friendly applications for sensing and image capture. The principal issues were identified as lack of experience and a track record of successful projects, the number of trained staff with qualifications, certification by national aviation authorities to operate commercial RPAS and, most of all, software to analyse the data once gathered.

6.4.2 The Export Potential of RPAS Services

Stakeholders consulted as part of the research suggested that the majority of RPAS services companies focus on offering provision in their local area – for example providing surveys and roof inspections in a particular city – rather than serving national or international markets. While the study team did conduct interviews with businesses which were actively exporting their services (such as oil and gas infrastructure inspections), it was suggested that export orientation may be comparatively unusual in the sector. Stakeholders suggested that exporting may only be appropriate for particularly high value applications where the RPAS supplier has a specialist expertise to offer to justify the increased costs of working with an overseas supplier.

The study team have not been able to identify broader evidence on the current export outlook for the RPAS sector; however, it appears likely that this is currently a niche activity. Equally, no projections of future trade growth have been identified. However, it is important to stress that the development of other sectors has shown a complex relationship between current local strengths and future export activities, with one often leading to the other[188]. In this way, the UK's advanced position as an adopter of RPAS technologies may in the future drive export activities as other countries look to catch up.

6.5 UK RPAS Forecasts

None of the forecasts discussed throughout this section offer specific coverage of the likely growth of RPAS related manufacturing activities or markets in the UK. The anticipated significant growth of the market for RPAS clearly offers an opportunity for UK firms to create more value through the manufacture of whole RPAS, or components and sub-systems. However, stakeholders were broadly dismissive of this potential, suggesting that UK firms manufacturing firms are not well placed to connect to the anticipated global growth of small RPAS, and, as noted in Section 3, the development of many components for small RPAS is associated with small margins.

A suggestion did emerge from research with stakeholders that it would be particularly advantageous to the UK if a market for large RPAS did emerge. The UK has a strength in conventional aerospace markets – the government-backed Aerospace Growth Partnership identified the UK as having the strongest aerospace sector in Europe, and second only to the USA globally.[189] Several stakeholders confirmed that the sector for large RPAS would share more commonalities with the broader aviation sector than small. For example, UK strengths in avionics (UK operating firms such as Cobham, BAE Systems, HR Smith, and GE Aviation[190])

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[188] Porter (1998). Clusters and the New Economics of Competition. Harvard Business Review. https://hbr.org/1998/11/clusters-and-the-new-economics-of-competition. Date accessed: 22/02/2016

[189] Aerospace Growth Partnership (2013). Lifting Off – Implementing the Strategic Vision for UK Aerospace. Aerospace Growth Partnership. www.theagp.aero/wp-content/uploads/sites/9/2014/01/lifting-off.pdf. Date accessed:15/02/2016

[190] KPMG (2013). The Future of Civil Aerospace.KPMG. https://assets.kpmg.com/content/dam/kpmg/pdf/2013/06/the-future-of-civil-aerospace.pdf. Date accessed: 19/02/2016

are felt to be not currently translating into the RPAS market because it is not possible to make the technical leaps required to miniaturise a system from that required for a passenger aircraft to a small RPAS. The market for large RPAS (500kg+) was identified as a test-bed which could provide an interim platform on which these systems could be developed and further miniaturised, potentially eventually reaching a scale that could be used with small RPAS.

6.6 Summary

- **Projections of future demand for RPAS**: While the recent forecasts for RPAS market vary in their method and scope, they all predict that that the non-military RPAS market and, all of its sub-segments have potential to expand substantially over the next five to ten years. The forecasts for the total Global RPAS market range between £7.8bn and £30n in 2025.
- **Drivers of growth**: It is important to note that the drivers of this growth vary between the forecasts, with some specifying the highest growth area to be the consumer (hobby) segment and others commercial segments (mainly identifying precision agriculture, the photo and video sub-segments and data, operator and modelling services). Parcel delivery which has received a high level of media interest has been identified as one of the areas of application that is the furthest from the market and is likely to only represent a significant market sub-segment after 2020.
- **Market segments**: Both desk research and stakeholder interviews suggest that the consumer market will continue to focus almost exclusively on micro and small devices. There is also a high level of confidence that there will be growing demand from commercial users for small RPAS (under 20kg). However, the review has been unable to identify evidence predicting the growth of markets for large RPAS, other than confirming that larger devices may be required to respond to the need for greater endurance and payload that some applications will require.
- **Geography**: Forecasts which focus on geographical segmentation of RPAS markets indicate that the United States, Europe and South America will offer the largest sales volumes, while Africa and South America are expected to see the highest proportionate rate of market growth, albeit from relatively low bases.
- **Applications**: RPAS was described as emerging as a platform technology upon which a set of services will be most commonly be offered, reflecting the space sector in which increasing platform availability and capability generates a new wave of ‘downstream’ applications. These new applications may require the emergence of new business models, especially in business-to-business relationships. These developments are conditioned by a number of challenges relating to the imposing of new standards, contracting procedures, standardisation of profit margins and overcoming barriers to entry. The notion of providing RPAS as a service in most cases means that the service is delivered locally to users, with the exception of high value applications where the RPAS supplier has a specialist expertise to offer to justify the increased costs of working with an overseas supplier.

7.0 Conclusions

7.1 Key Messages

This research has reviewed the evidence base on the UK value stream for non-military RPAS. Drawing on published literature as well as consultations with key stakeholders, the study team have explored the full range of sources of economic value, including through: the manufacture of complete RPAS, through the development of their components and sub-systems, through related R&D activity, through their use and the generation of benefits for commercial users, as well as through the delivery of associated services such as insurance and training.

The market for non-military RPAS has changed dramatically in recent years. A technology that was until recently predominantly serving a niche market of hobbyists has developed to create a mass consumer market and an expanding variety of commercial applications. A global market worth approximately £1.3bn has already developed, with 70 per cent of this coming from consumer RPAS. This market is currently segmented predominantly by weight, and to date the development of this market has focused strongly on small RPAS weighing less than 20kg.

It has been possible to identify only limited evidence detailing the global production of RPAS components and sub-systems. The available literature offers very little quantitative insight into the characteristics of the RPAS value chain. Stakeholder evidence suggests that there is typically little value added generated in the production of RPAS for consumer markets (at least in the UK) but higher value added may be obtained by RPAS with superior technical features and reliability that serve commercial markets.

The main hubs of international production appear to be located in Asia, with one Shenzhen-based firm (DJI) accounting for a claimed 72 per cent of the market for small RPAS. The success of firms in this region has partly been attributed to their expertise in the manufacture of electronic devices. However, a broader set of prominent manufactures have emerged in Europe and North America.

Although the UK is home to an internationally competitive aerospace industry, a cluster of UK based manufactures of finished RPAS has so far not emerged, and the UK is not the headquarters of any of the global market leaders in the manufacture of complete RPAS. At least 13 UK manufacturers of complete RPAS and 34 manufacturers of RPAS components and sub-systems, were identified through the research. However, a number of these have a strong emphasis on military RPAS, and there was insufficient information available on these companies to enable any analysis relating to their commercial performance in relation to RPAS (sales, employment or profitability).

Focusing on the use of RPAS, the study team has identified a variety of applications that have already been found for RPAS technologies – as well as evidence that UK is home to an internationally significant and rapidly growing pool of commercial RPAS operators (with the number of approved operators growing at an annualised growth rate of 67 percent over the course of this study). Current uses focus strongly on sensing applications, including photography and video for consumers, for media professionals, and for inspection and monitoring uses. However, the use of RPAS for delivery and to support communications is being actively explored. These uses have been associated with significant benefits to users that are likely to make up a significant part of the value stream.

These include:

- Cost savings compared to the use of piloted aircraft or satellite systems, due to their reduced scale, complexity and lesser infrastructure requirements.
- Greater flexibility, predominantly due to their reduced scale which allows an increased range of uses.
- More precise control of devices due to the greater availability and affordability of autopilot systems.

Three distinct areas were identified by the study team as significant potential barriers to the ongoing development of these applications:

- **Technical challenges**: Key technological challenges remain in relation to securing improvements in navigation performance, verification, connectivity and security issues, in particular to facilitate the acceptability of BVLOS operation. Further progress is also needed in the areas of IT/data processing, power drives and sensors. The evidence base identifies a number of UK strengths in each of these areas; however, the limitations of the UK production base for RPAS and associated componentry seems to derive largely from the cost advantages enjoyed in particular by Chinese competitors.
- **Regulatory hurdles**: The existing global regulatory environment for RPAS was identified in the evidence base as directly holding back several areas of RPAS application, in particular the use of RPAS in operations beyond the visual line of sight. International variations in regulations and constraints caused by the regulation of some RPAS as military technology were identified as further issues (particularly in the development of tradable service models). While the UK appears to offer a supportive regulatory environment by international standards, the evidence review has confirmed the importance of sustaining ongoing regulatory reform.
- **Public perception**: Concerns about the privacy implications of RPAS use, their association with military use, and concerns about dangerous uses of RPAS have been associated with public dissatisfaction with RPAS technologies. This has significant potential to hold back the commercial use of RPAS in the UK and slow the pace of regulatory reform.

While the recent forecasts for RPAS market have varied in their method and scope, they all conclude that the market and its segments have the potential to expand substantially over the next five to ten years. These forecasts predict that the global, non-military RPAS market will grow from £1.3bn in 2015 to between £7.8bn and £30bn in 2025, with an average of £20bn. However, there are no comparable forecasts for the market for RPAS applications and ancillary services (which are considered by some to be likely to be the most significant component of the RPAS value chain in the future).

7.2 Policy Implications

Several of these key findings have significant policy implications:

- **Manufacture of small RPAS**: This evidence review has identified a large volume of material detailing the current and potential UK value stream from RPAS. The balance of the evidence suggests that the UK has not developed a significant market share in manufacturing activities associated with the manufacture of RPAS or the components and sub-systems of small RPAS. Despite the UK's considerable identifiable strengths in R&D, the evidence base offers little reason to suggest that this performance in relation to the manufacture of small RPAS will change.
- **Manufacture of large RPAS**: In contrast, the manufacture of large RPAS might offer a better opportunity for the UK to build on its existing strengths in manned aviation and military RPAS. Unlike small RPAS where the market has already emerged, the future of demand for large, non-military RPAS is highly uncertain. A number of potential applications have been identified but major technological and regulatory hurdles need to be overcome before this market can start to emerge.
- **RPAS applications**: There is unambiguous evidence about the potential of the value stream arising from the use of RPAS in the UK. In contrast to manufacturing, the UK appears to perform well and was identified to be a leading location for the application of RPAS technologies. However, the study team identified a suggestion that many businesses are currently finding it difficult to develop profitable business models in this area.
- **Regulatory reform**: The UK was identified through the research as offering a more progressive regulatory environment for RPAS use than many other locations. Nevertheless, the need to sustain regulatory reform to keep pace with, and to help unlock investment in, RPAS technologies (particularly those that allow RPAS to fly beyond the visual line of sight of their operators) was demonstrated in the evidence base.
- **Regulator capacity**: Stakeholders were consistently positive about the 'pragmatic' attitude of the CAA. However, several stakeholders noted significant capacity constraints at the organisation. It was suggested that this is creating some challenges for UK RPAS operators and may be an aspect that warrants further exploration.
- **Pilot training**: Some concerns were raised regarding the depth of training required for accreditation under the current regulatory regime, and the lack of availability of advanced training (though there is evidence that industry bodies are acting to develop these forms of training programme). There may be merit in monitoring the situation as it development.

7.3 Gaps in the Evidence Base

A very large volume of material has been generated exploring the potential of RPAS. However, the evidence base that has emerged focuses heavily on examples of current and near term RPAS applications, technological developments and regulatory aspects. Relatively little evidence appears to be available on several important areas of the value stream:

- **Quantification of the UK value stream**: Overall the quality of information available on the RPAS sector is less strong than that available for many traditional industries. RPAS manufacturing and the delivery of RPAS services have not reached the stage of development where the sector is yet recognised in the industrial classification systems employed by public statistics authorities. As a result it is highly challenging to identify reliable economic data regarding the size of the RPAS production or its applications within either the UK or the EU. Key items of interest such as the number of jobs supported, output, profitability, productivity, and growth can only be feasibly quantified through further primary research.
- **Ancillary and supporting services evidence**: A review of the evidence base has identified a limited volume of material detailing the development of services that support the sector such as insurance, finance, or training. Without this information it has not been possible to confirm that RPAS users are able to access such services.
- **Manufacture of components and sub-systems**: The study team have been able to develop a map of the home locations of 20 leading RPAS manufacturers to indicate the global pattern of production. However, it has not been possible to identify the structure of this activity with confidence. For example, only limited evidence was developed on the balance between operations that focus on assembly vs. in-house production of components and sub-systems.
- **The basis for economic forecasts**: Limited detail is available about how the economic forecasts for the growth of the RPAS market have been developed, their underlying assumptions, or in some cases the specifics of their scope. For some studies only headlines are freely available as the forecasts have been prepared by consultancies for sale or commercial purposes. This makes it difficult to assess their credibility and likely robustness.
- **Financial and economic issues**: Aside from the forecasts, only a modest number of studies focus on the economic, rather than technical or regulatory, aspects of RPAS use. The literature appears to focus primarily on potential applications, rather than analysing completed case studies and presently viable uses. This was a point identified in Whitehead (2014)[191].
- **Business models**: The notion of 'Drones as a service' is frequently identified in the evidence base as the key future market. Stakeholders stressed that the provision of RPAS services is emerging as the key commercial model for RPAS. But there is relatively little analysis of what this might look like in practical terms.

[191] Whitehead, K. et al (2014). Remote sensing of the environment with small (UASs), Journal of Unmanned Vehicle Systems, 2014, 2(3): 69-85

7.4 Opportunities for Further Research

Through undertaking this research the study team have identified three areas where further research would help to plug these evidence gaps:

- **Analysis of Innovate UK applications data**: The study team identified 75 Innovate UK grants to companies to pursue RPAS R&D. The application forms for these grants, as well as any other unsuccessful applications in this area, may provide evidence on how companies in this sector expect to see markets and technologies develop.
- **Further secondary data analysis**: In undertaking this review the study team have developed a database of more than 300 UK companies involved with either the manufacture or use of RPAS. The CAA publically lists the 1,400 companies who have registered with it as commercial RPAS service providers. It would be possible to exploit these lists as the basis for a data linking exercise to exploit various firm level micro data including:
  - **VML**: The ONS Virtual Microdata Laboratory provides access to the Business Structure Database, the Annual Business Survey, and the Business Expenditure on Research and Development. Together, these datasets could provide longitudinal evidence on (1) employment and turnover associated with industry participants, (2) their overall GVA and productivity, (3) annual R&D spending, and (4) low fidelity information on export behaviour.
  - **PATSTAT**: Evidence on the patenting activity of UK firms in technology areas relevant to RPAS. As PATSTAT covers international patent applications and registrations, the dataset could also be used to identify areas of relative technological advantage.
  - **Bibliometric analysis**: A bespoke analysis of bibliometric data focusing on benchmarking the UK's academic institutions against international competitors could produce clearer insights into the relative strengths and weaknesses of the UK's R&D infrastructure.
- **Further qualitative research**: Stakeholders proved to be a very rich source of intelligence for the research. In particular they were able to offer more up-to-date assessments than the literature. They also proved to be a rich source of detail and depth on many of the economic issues, in many instances going beyond the coverage of published literature. There may therefore be value in further extending this consultation to contact additional individuals to support the further refinement of this research. This could include:
  - **Interviews** with individuals that the study team were not able to cover within the research window and resources which were available. A wider group of potential stakeholders and interviewees were identified by the project steering group from which the consultees for this research were selected who could be interviewed as part of a wider study.
  - **Focus groups** oriented around particular RPAS applications (such as their use in inspection and monitoring) could be used to test and further refine the messages contained within this report. Given the enthusiasm shown for the research to date we believe that these are events that could be arranged in partnership with trade associations.

- **A survey of the UK RPAS sector**: Primary research could be used to feed a broader range of perspectives into the research and to develop the quantitative evidence base. It could be used in particular to assess the current scale of the RPAS value chain, to test forecasts for its development, and to more precisely map the needs of the sector. This research could be delivered as either a web or telephone based survey, and would be particularly valuable if combined with data-linking, as firm level micro-data are unlikely to be of practical use where the production or application of RPAS are not firms' sole line of business.

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