Unmanned Aircraft Systems: A Case of Dual Use Technology and Product Innovation

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**ABSTRACT:** While Unmanned Aircraft Systems (UAS) have their genesis in military operations, this paper applied an innovative dual use technology lens to conceptualize UAS as a valuable and emerging airborne sensory system or ‘eyes in the skies’ with widespread commercial and civilian applications. The case evaluation also matched commercial and civilian applications of UAS technology to platform types, subsequently exposing sensor and communication payload, endurance and range attribute sensitivities. Commercial applications still have legal and regulatory safety of flight impediments that must be overcome, if civilian variants are to occupy 11-14% of the global UAS market. Future developmental trajectories suggest that low cost packaged sensors, lean airframe manufacture, and multi-UAS swarm applications offer growth opportunities in this US$1.6 billion global industry.

**Keywords:** Emerging Technologies, Product Development, Technology, Technology Innovation.

**COMMERCIAL EYES IN THE SKIES**

Spillovers of new innovations and dual use technology from military to civilian uses have been an important spur to economic development, especially in the United States. Mowery’s (1992) seminal work on the US national innovation system notes the importance of publicly funded military research on the development of its semiconductor industry. Similar trends have been observed in other technology-based industries, including aerospace (Niosi & Zhegu, 2005), mobile telecommunications (Eliasson, 2011) and composite materials (Pett & Wolff, 2011), with technological transfers being tangential (as was the case in Wichita where aircraft technologies spurred the development of a medical technology cluster), or potentially more direct in nature (as was the case for Boeing, which transferred engine technologies between its military and civilian aircraft designs). In the academic context, it has been observed that universities and institutions of higher learning can also facilitate these processes of direct and indirect knowledge transfer (Etzkowitz & Leydesdorff, 2000).

Interestingly, the concept of unmanned air vehicles has a long history dating back to the 1800s when Venice was bombed using unmanned balloons (Boyne, 2003), with similar unmanned balloon bombardment witnessed during the American civil war (Bowen, 1977; Haydon, 2000). In
terms of information gathering and surveillance, some of the first airborne reconnaissance activities were undertaken during the Spanish-American War of 1898 where cameras with remote triggers were mounted on large kites (Brunn, Cutter & Harrington, 2004; Hannavy, 2008). Hence, more recent developments in UAS technology, also known variously as Drones, Unmanned Aerial Vehicles (UAV) and Remotely Piloted Aircraft (RPA), has emerged from a long history of technical innovations (Watts, Ambrosia & Hinkley, 2012), largely characterized by military deployments in various global trouble spots, including the Middle East and Africa. Notwithstanding some of the public controversy surrounding their use, military UAS have been used to target hostile forces and deliver precision guided munitions in tasks for which they are technically well suited (US DOD, 2005).

However, if we divert from these military applications, the concept of Commercial UAS (CUAS) actually dates back to the mid-1700s. Specific to this time period, Benjamin Franklin famously flew his ‘electrical kite and key’ in order to prove his hypothesis that lightning was comprised of electricity (Jernegan, 1928). Since then, the civilian uses of UAS have employed the capabilities developed for military applications in a myriad of innovative ways (e.g. agriculture, survey, photogrammetry). In this paper, we look beyond military functionalities and conceptualize the commercial use of UAS technology as airborne sensory systems or ‘eyes in the skies’. In this respect we look to explore the broader commercial and civilian use of UAS in the information gathering and processing context, with commensurate non-agriculture related growth in the non-military UAS industry segment (see Table 1) (Teal Group Corporation, 2014).

Table 1 UAS Global Market and Forecasts here

In this paper, we examine the conceptual transition of Unmanned Aircraft Systems (UAS) from military to civilian applications using an innovative dual use technology lens (Mowery, 2009, 2010) and an adaption of the dual use technology transfer framework developed by Boeing (Blanding, 1997) (see Figure 1). From the theoretical perspective, our adapted framework asserts that the transfer of dual use technologies (either military to commercial, or commercial to military) can enable innovative product driven processes; a systematic understanding of the product economics and costs; a focus on customer value; integration of sound business practices into innovative product designs;
and, greater differentiation between technical and business (commercial) decisions (Blanding, 1997). Consistent with this framework, the advent of commercial UAS has raised several technical and business issues, such as low cost manufacturing (Harrison, 2013), commercial and economic viability (Jenkins & Vasigh, 2013), and safe business operating practices (Mulac, 2011), which will be discussed through answering the research questions set out below. Hence, UAS provide an important theoretical and practical example of dual use technology evolution that can be explored in accordance with the emergence of several commercial and civilian applications of this core technology.

Figure 1 Dual Use Technology Transfer Framework here

Accordingly, this conceptual paper will address two major questions: (i) What commercial and civilian applications are supported through the future development of non-military UAS? The deployment of UAS as a non-military system suggests that the applications must draw on systemic strengths, dependent on platform altitude, endurance and range (Watts et al., 2012). Accordingly, commercial and civilian applications will need to be tailored to the various forms of UAS, subject to technical and economic considerations (Harrison, 2013); and, (ii) What are the critical impediments to non-military UAS industry growth? The growth of the non-military UAS industry sector will be dependent on resolving some key business and technical issues including the legal and ethical use of such systems (Finn & Wright, 2012; Stilgoe, Owen & Macnaghten, 2013), and safe commercial flight operations in regulated airspace (Sharma & Ghose, 2009; Mulac, 2011). In sum, the capacity to answer both questions will add to our knowledge of UAS concepts and how this evolving dual use technology might be used as an innovative and economically viable commercial system.

The paper proceeds as follows. The first section will discuss the development of UAS in the military and non-military context, giving emphasis to dual use technology and industry development considerations. Next, we will identify the impediments to growing the non-military UAS industry sector, while also identifying other areas for industry and technology development. The paper closes with some concluding remarks and future directions for dual use UAS industry research.

**DUAL USE TECHNOLOGY AND INDUSTRY DEVELOPMENT**

The military focus on UAV
Arguably, the military pedigree of UAV has its most relevant contemporary foundations in the 1950-1970s period when the United States Air Force (USAF) and Navy (USN) used ‘drones’ for target practice (Sullivan, 2006). While there was early debate as to whether UAV might be considered a mature or evolving technology (Erwin, 2003), in 2005 the US Department of Defense (US DOD) deemed these air vehicles essential for operations with re-designation as UAS (incorporating all surface elements and aircraft components) (Pappalardo, 2005; Sullivan, 2006), and establishment of a UAS deployment roadmap through to 2030 (US DOD, 2005).

The US DOD UAS roadmap acknowledged that since 2004, US military forces had flown over 100,000 hours of critical UAS missions in support of Operations Enduring Freedom and Iraqi Freedom as part of the Global War on Terrorism (GWOT) (US DOD, 2005). This level of operational intensity suggested that UAS funding and acquisition needed better decision-making in areas such as network-centric situational awareness, systems controls, payloads and sensor configurations, and weapons delivery (US DOD, 2005). Subsequently, while strategic targeting, munitions delivery, and force multiplication have been offered as key use cases for UAS, the area most likely to benefit from further evolutions of the system will be military Intelligence, Surveillance and Reconnaissance (Sullivan, 2006; Samad, Bay & Godbole, 2007). This assertion is consistent with other published studies that points to UAS becoming an advanced airborne platform for non-military applications (Jenkins & Vasigh, 2013; Teal Group Corporation, 2014).

Creating dual use UAS knowledge and technologies

Since the early 1990s, studies of dual use technologies and innovation in military Research and Development (R&D) have identified the importance of vertical product integration and globalization of technologies (Watkins, 1990); exploring commercial uses for military aligned technologies (i.e. conceptual dual use) (Alic, 1994; Cowan & Foray, 1995; Kulve & Smit, 2003); the comparative expansion and growth of commercial product markets (Molas-Gallart, 1997; Kulve & Smit, 2003); and, the use of military R&D as a knowledge trigger for innovative and dual use products (Molas-Gallart, 1997; Ruttan, 2006; James, 2009).
Further, concomitant models of dual use technology innovation depict military and civilian influences and operating contexts providing composite shaping of generic technologies (Kulve & Smit, 2003) and the creation of generic scientific knowledge (Martin, 2001; James, 2009). In applying these concepts to the CUAS platform, the influential forces can enable the development and evolution of aerospace, aviation and sensor electronics, communications systems, and computing technologies that might be shared in dual use formats (Molas-Gallart, 1997; Martin, 2001; Mowery, 2009, 2010, 2012). In addition, UAS developments sponsor the concomitant creation of generic tranches of knowledge in areas such as aerodynamics and unmanned flight, remote sensing methods, communications schemas and protocols, and data processing and computational methods (Martin, 2001; Ruttan, 2006; Mowery, 2010). The technology-science exchange process allows scientific knowledge to be leveraged in the development of dual use technologies (Mowery, 2009, 2012). The populated model in Figure 2 theoretically depicts how the dual use technology models of innovation can shape UAS development into commercial and civilian streams with multiple associated applications.

The end result are highly developed UAS products that, in addition to their military capabilities and applications, can serve several commercial and civilian roles (Mowery, 2009, 2010, 2012; Austin, 2010). Importantly, we acknowledge that some segments of the industry have already demonstrated how military grade UAS, such as the General Atomics Aeronautical Systems Inc. MQ-9 Predator B, can be modified with different payloads and sensors to take on commercial and civilian dual use tasks (e.g., NASA Ikhana UAS for research and commercial missions) (Ambrosia, Wegener, Zajkowski, Sullivan, Buechel, Enomoto, Lobitz, Johan, Brass & Hinkley, 2011) (see Figure 3). Hence, it can be argued that the technology and scientific knowledge (Guillou, Lazaric, Longhi & Rochhia, 2009) associated with UAS developments has wider emerging applications beyond military institutions, and offers an opportunity to conceptualize UAS as a more generic airborne platform with a broad range of capabilities and functions that can serve different market segments (Teal Group Corporation, 2014).
Setting to one side the area of military operations, several studies have examined the use of UAS platforms for various commercial and civilian activities (e.g. farming and agriculture, land management and survey, environmental monitoring and scientific research, geographic information capture and mapping, mining and geological survey, archaeological exploration, pollution control, search and rescue, law enforcement and emergency management) (Sarris, 2001; Nonami, 2007). In order to integrate the key platform attributes (operating altitude, endurance, and range), we have used the UAS platform classifications outlined in Watts et al. (2012) (see Table 2). This table depicts the breadth of operating performance capabilities available to non-military users, including CUAS missions in public emergency and safety support roles, (see examples 1 and 2, Table 2), dependent on the air vehicle size and sensor-communications payload selected.

Table 2 UAS platform attributes

Studies have already confirmed that UAS provide an excellent platform for photogrammetric workloads that support agriculture and primary production (Hammer, Johnson, Strawa, Dunagan, Higgins, Brass, Slye, Sullivan, Smith, Lobitz & Peterson, 2001; Herwitz, Johnson, Dunagand, Higgins, Sullivan, Zheng, Lobitz, Leung, Gallmeyer, Aoyagi, Slye & Brass, 2004). In addition, other investigations show that UAS have found favor with land managers and park rangers that require high quality images in order to cover vast areas and establish ‘ground truth’ (including very rough terrain) prior to recommending agricultural treatments and making decisions (Hardin & Jackson, 2005; Rango, Laliberte, Steele, Herrick, Bestelmeyer, Schmugge, Roanhorse & Jenkins, 2006; Laliberte, Winters & Rango, 2011). Hence, the agricultural and land management sectors have presented higher volume commercial pathways for UAS deployment (e.g. it is projected that approximately 82% of UAS sales in the United States will be dedicated to agriculture applications by 2025) (Jenkins & Vasigh, 2013).
The literature also exposes the use of UAS for the command and control functions required for natural disaster and emergency management (Sarris, 2001; Nonami, 2007; Muttin, 2011). The researchers were able to deploy advanced thermal infrared (IR) and night vision scanners, and high resolution photographic and video cameras in order to monitor wild fire and land slide events in real-time, while also deploying the UAS to conduct post disaster surveys (Casbeera, Kingstona, Bearda & McLain, 2006; Hinkley & Zajkowski, 2011; Pastor, Barrado, Royo, Santamaria, Lopez & Salami, 2011; Niethammer, James, Rothmund, Travelletti & Joswig, 2012). Importantly, the platforms also displayed their capacity to conduct search and rescue operations and ballistic damage inspections in difficult and potentially hazardous situations (Goodrich, Morse, Gerhardt, Cooper, Quigley, Adams & Humphrey, 2008; Murphy, Steimle, Griffin, Cullins, Hall & Pratt, 2008; Bernard, Kondak, Maza & Ollero, 2011). The versatility of the UAS, particularly in the system sensor, durability and endurance contexts, makes it an ideal platform for disaster, emergency and urgent search and rescue missions.

Unsurprisingly, it is probably in the areas of remote sensing; geographic imaging and mapping; surveying, prospecting and mining; and specialist geological and earth science activities that UAS have found their most innovative non-military uses (Brunn et al., 2004; Everaerts, 2008; Hannavy, 2008; Watts et al., 2012). As examples, winged and multi-rotor UAS platforms have conducted cartographic and photographic work, geological and seismic surveys, and botanic and fauna observation and monitoring (Hammer et al., 2001; Cress, Sloan & Hutt, 2011; Watts et al., 2012). In these contexts, the UAS can enter inhospitable environments and gather soil/earth, water and air samples that may not necessarily be accessible by land vehicles or humans on foot (e.g. volcanic craters and slopes, mine gas release shafts) (Bartolmai & Neumann, 2010; Watts et al., 2012).

However, the UAS platform may also be used as a specialist data and information gathering tool (Eisenbeiss & Sauerbier, 2011). Exemplar studies show us that archaeologists, historians and paleontologists have deployed the UAS to collect vital photogrammetric information on excavations and land areas of interest (Chiabrando, Nex, Piatti & Rinaudo, 2011; Hendrickx, Gheyle, Bonne, Bourgeois, De Wulf & Goossens, 2011). Hence, remote sensing applications are well-suited to the
deployment of UAS for high quality data gathering and information processing, noting that sensor and communications payloads strongly influence the selection of the UAS size and platform capabilities (e.g. MUAS quad-rotor fitted with a digital camera for aerial photography versus a MALE fixed wing UAS fitted with magnetometer, electro-optical IR and laser sensors for mining surveys) (Mining Technology, 2009; Insitu, 2015; Hendrickx et al., 2011).

In sum, these aforementioned studies demonstrate the adaptability of the airborne platforms for dual use commercial tasks and missions that deliver command and control and information gathering functions (Ambrosia et al., 2011; Fladeland, Sumich, Lobitz, Kolyer, Herlth, Berthold, McKinnon, Monforton, Brass & Bland, 2011). Accordingly, as a summary, we constructed a table that combines commercial and civilian applications with platform attributes, thereby providing an instructive set of CUAS use cases (see Table 3 – the top half covers private sector use cases with an underlying profit motive, while the bottom half addresses not-for-profit public agency functions and services).

Table 3 Commercial and Civilian Applications for UAS Platforms here

Managerial challenges associated with commercial and civilian UAS tasks

While CUAS might render a range of new and exciting business opportunities, we would assert that the management of tactical day-to-day operations will continue to challenge most commercial operators. Probably at the forefront of management concerns will be the statutory requirement to maintain safe flight operations under the respective regulatory regime (FAA, 2015, 2016). Critically, a failure to comply with air safety regulations and procedures could see a CUAS operator’s license suspended or potentially revoked (FAA, 2016). In addition, as the competitive commercial sector develops, it is conceivable that CUAS operations managers will likely face further pressures to make more frequent lawful, ethical and sound business decisions within shortened time frames (e.g. time critical law enforcement activities, urgent public safety actions, sensitive media coverage) (Finn & Wright, 2012; Stilgoe et al., 2013). From the technical perspective, CUAS operators will also need to routinely maintain and repair air vehicles and sensor payloads in order to remain commercially competitive and economically viable (Harrison, 2013; Jenkins & Vasigh, 2013).
This, in turn, will place further operational and economic demands on management as modern CUAS designs can include avionics and highly advanced sensors that require regular systems testing, calibration, precision maintenance and software upgrades (Austin, 2010). On this basis, we posit that the projected doubling of the civil UAS market by 2023 (Teal Group Corporation, 2014) will challenge most CUAS operators in the industry to continually improve the business and technical dimensions of their enterprise.

CRITICAL IMPEDIMENTS TO UAS INDUSTRY GROWTH

While deploying a CUAS may have great commercial potential, serious legal and regulatory issues stand as barriers to their future growth (Harrison, 2013). Some contemporary studies call into question whether UAS represent a threat to society in physical and/or virtual terms (e.g. privacy, collisions, accidents, economic/costs). As an example, McBride (2009) warns of impacts on personal privacy, data and information security, and civil liberties should UAS be deployed in widespread civilian applications. Other studies advance these concerns and raise the prospect of unethical use of the UAS platform (Stilgoe et al., 2013), potential subjugation and persecution of disadvantaged and minority groups, and unreasonable (possibly unlawful) actions by law enforcement and national security agencies (Finn & Wright, 2012). In the larger legal sense, some researchers have argued that there are insufficient legal protections and remedies for injured parties for UAS deployments in commercial and civilian scenarios (Wright, Friedewald, Gutwirth, Langheinrich, Mordini, Bellanova, De Hert, Wadhwa & Bigo, 2010; Finn & Wright, 2012).

In raising different problems and significant technical issues, other studies have exposed extreme difficulties associated with system certification and safety of flight, including the ability to avoid other aircraft operating in the same airspace; conduct autonomous and semi-autonomous missions; and return to earth safely under routine and system emergency conditions (i.e. system failure, software corruption) (Dalamagkidis, Valavanis & Piegl, 2008; Sharma & Ghose, 2009; Mulac, 2011; FAA, 2016). As an example, the potential future use of miniaturized electro-optics, radar, acoustic and Light Detection and Ranging (LiDaR) sensors to avoid mid-air collisions illustrates the criticality of flight safety in commercial operations and airspace transit (Geyer, Singh & Chamberlain,
2008). As noted in recent years, safety of flight and future changes in commercial operating regulations will be an ongoing issue as UAS platforms evolve into other non-military formats (e.g. changes in operating weights, pilot training, time of day operations, and entry and access to geolocations and controlled airspace) (FAA, 2015).

Importantly, CUAS operations must also remain financially viable and affordable for commercial customers and clients (Cowan & Foray, 1995; Bellais & Guichard, 2006). Studies show that while UAS may be cost effective when compared to larger piloted aircraft systems, the advent of lower cost sensors and imaging technologies should allow manufacturers and operators to resist high and unreasonable capital and ongoing support costs for CUAS (Cowan & Foray, 1995; Fladeland et al., 2011; Carrivick, Smith, Quincey & Carver, 2013). This is of critical importance to the ongoing viability of this dual use technology (Cowan & Foray, 1995). As an example of the importance of the identified economic (and airspace safety) issues, we have compiled a trend analysis using data from Jenkins & Vasigh (2013) (see Figure 4). The example shows that, without full CUAS integration into the US airspace, American industry could forego up to 22,000 aircraft sales per year, and direct spending growth (i.e. local labor hire, goods and services purchases, and capital works contracts) approaching over US$700 million per annum, including highly accelerated market growth over 2015-2018. Hence, economic viability and growth in the industry sector are concomitant and highly synergized in this area of dual-use technology (Cowan & Foray, 1995). Note, using Lucintel estimates that 70% of global UAS growth is based in the United States segment of the market, suggests that this could translate to approximately US$1.01 billion in annual direct global spending increases (Lucintel, 2011). This modelling underscores the importance of resolving the legal, regulatory and safety of flight issues for CUAS platforms.

Figure 4 Estimated Non-agriculture UAS Sales (Fully integrated into US Airspace) – 2015-2025 here

In sum, the application of UAS as an advanced tool for collecting, processing and storing high quality information is not without serious legal and safety problems. While much of the literature argues that UAS is a perfect candidate for ‘3D’ type work activities (dull, dirty and dangerous) (Finn & Wright, 2012), there are still legal, technical and economic hurdles that must be monitored and
ultimately resolved in the medium to longer term for this dual use technology (Jenkins & Vasigh, 2013).

**Further UAS development trajectories**

Given our articulation of the CUAS platform, the technical development trajectory for non-military UAS opens up three key areas of interest for operators and industry. First, the dependency of the CUAS on its key sensors and communications suggests that a ‘plug and play’ modular packaging of these payload components is a critical area for product development going forward. The capacity to ‘clip on’ a new payload package, rather than integrate a group of disparate sensors and communications systems would appear to have some merit in building greater systemic flexibility and capability (Austin, 2010).

Second, given the ongoing need for collision avoidance behaviours, further product development efforts and innovations might be directed at UAS squadrons or teams, operating in complex commercial operations, including swarm patterns (Sharma & Ghose, 2009). Importantly, the ability to saturate an area of commercial operations with sensors provides enhanced information gathering functionality built on multiple and largely magnified data sources (more than one sensor on each target). We would argue that team operations represent significant developmental and innovative value to CUAS, and a larger source of ongoing revenues in capital and maintenance terms.

Third, although the civilian non-military UAS market is small, the ability to deploy low cost air vehicles is a critical aspect of future UAS product development (Mowery, 2010). As a complementary step to packaged sensor development, the ongoing design and promotion of low cost air vehicles (including lean aero-structures manufacturing) will assist in further penetration of this form of UAS into commercial and civilian markets. Applying further economies of scale in CUAS manufacturing would assist market expansion opportunities in all commercial areas including large scale agriculture applications (Harrison, 2013).

**CONCLUDING REMARKS**

The case of CUAS is an unambiguous example of dual use technologies and innovation where military R&D has provided a critical lever (Ruttan, 2006; James, 2009; Mowery, 2010) for
examining how a military weapon system and allied technologies (i.e. conceptual dual use) (Alic, 1994; Cowan & Foray, 1995; Kulve & Smit, 2003) might be expanded into other commercial product and civilian markets (Molas-Gallart, 1997; Kulve & Smit, 2003; Mowery, 2010). Importantly, the overall process of technical duality also sponsors and augments the creation and use of generic technologies and scientific knowledge kernels in military and non-military product developments (e.g. General Atomics Aeronautical Systems Inc. MQ-9 UAS) (Mowery, 2010). Hence, dual use UAS product designs can be considered as highly synergistic in nature, representing strong combinations of business practices and product designs (Blanding, 1997); deliberate public policies (Mowery, 1998; Guillou et al., 2009); and close cooperative strategies for system developments (Kulve & Smit, 2003; Bellais & Guichard, 2006; James, 2009; Mowery, 2010).

Looking forward from the issues and concepts raised in this paper, we suspect that the most significant problem facing the broad based use of UAS in commercial and civilian applications is the issue of safe operations in commercial airspace environments (Mulac, 2011; Harrison, 2013; FAA, 2016). In particular, the matter of collision avoidance and safe regulated UAS operations presents a barrier to those seeking to expand the use of this airborne platform (Dalamagkidis et al., 2008; Sharma & Ghose, 2009). We note with guarded optimism that some developments, including the RESQU (QUT-Boeing) project in Australia, offer great promise that these issues will find solutions in the short to medium term (Silva, 2014). Notwithstanding some of these regulatory and legal difficulties, the use of UAS as an airborne information collection and processing platform represents an innovative and commercially viable step forward for the technology.

The case of UAS also highlights the importance of innovation systems at a macro level that integrate policy, universities and the market. In this particular case, the way that their activity is regulated will fundamentally affect the profits and economic growth (particularly contributions to national accounts) that will emerge from the civilian uptake of this technology. Importantly, the projected growth of CUAS technology deployments is also not without ongoing managerial challenges, and strong concomitant economic arguments for advancement of the sector. Industry projections out to 2023 show annual civilian UAS purchases valued at up to US$1.6 billion, and while
the majority of sales would serve precision agriculture applications, UAS platforms delivering information collection and processing functions and capabilities would potentially generate around 18% of sales by volume or US$288 million (with opportunities for double digit growth beyond 2023) (Teal Group Corporation, 2014). This typifies the need for good managerial decision making and cost management (Blanding, 1997), and the significant financial impetus to move forward with evolving this dual use technology into more customer-driven commercial and civilian functions.

In closing, we suspect that precision agriculture and ‘eyes in the sky’ will be some of many viable commercial and civilian applications for UAS. Future research might examine the different applications that emerge over time, and how they are shaped by changes in sensor and collision avoidance technologies, changed manufacturing processes and economies, and changes in regulatory and legal settings. Indeed, if current sales and revenue projections prove to be correct, the next ten years promises to be a fascinating economic and technological journey for the CUAS sector (Jenkins & Vasigh, 2013; Teal Group Corporation, 2014).

REFERENCES


Jernegan, M, (1928) Benjamin Franklin's "Electrical Kite" and Lightning Rod. The New England Quarterly 1(2), 180-196


Figure 1 Dual Use Technology Transfer Framework, adapted from Blanding (1997)
Figure 2 Model of Dual Use Technology Innovation for UAS, adapted from Martin (2001)
Figure 3 USAF Predator weapon system (2001) or NASA Ikhana (2006)? – A dual-use technology conversion

Figure 4 Estimated Non-agriculture UAS Sales (Fully integrated into US Airspace) – 2015-2025
### Table 1 UAS Global Market and Forecasts (Dual use Military and Civil use cases)

<table>
<thead>
<tr>
<th>Year</th>
<th>Market Segment</th>
<th>Share/Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014 Total Market (US$6.4 Billion)</td>
<td>Military</td>
<td>89% of Total Market Value = US$5.7 Billion</td>
</tr>
<tr>
<td></td>
<td>Civil (non-military)</td>
<td>11% of Total Market Value = US$0.7 Billion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agriculture: US$0.574 Billion Other: US$0.126 Billion</td>
</tr>
<tr>
<td>2023 Forecasts (US$11.5 Billion)</td>
<td>Military</td>
<td>86% of Total Market Value = US$9.9 Billion</td>
</tr>
<tr>
<td></td>
<td>Civil (non-military)</td>
<td>14% of Total Market Value = US$1.6 Billion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agriculture: US$1.312 Billion Other: US$0.288 Billion</td>
</tr>
</tbody>
</table>

### Table 2 UAS Platform performance attributes, taken from Watts et al. (2012)

<table>
<thead>
<tr>
<th>UAS Platform</th>
<th>Altitude (m)</th>
<th>Endurance (hrs)</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Miniature UAS (MUAS)</td>
<td>Up to 330</td>
<td>0.1 – 0.5</td>
<td>Up to 500</td>
</tr>
<tr>
<td>2 Low Altitude, Short Endurance (LASE – no runway required)</td>
<td>Up to 1,500</td>
<td>0.5 – 1.0</td>
<td>Up to 2,000</td>
</tr>
<tr>
<td>3 Low Altitude, Short Endurance (LASE-Close) – runway required</td>
<td>Up to 1,500</td>
<td>1.0 – 10.0</td>
<td>Up to 5,000</td>
</tr>
<tr>
<td>4 Low Altitude, Long Endurance (LALE)</td>
<td>Up to 3,000</td>
<td>10.0 – 24.0</td>
<td>Up to 500,000</td>
</tr>
<tr>
<td>5 Medium Altitude, Long Endurance (MALE)</td>
<td>Up to 10,000</td>
<td>10.0 – 24.0</td>
<td>Up to 7,500,000</td>
</tr>
<tr>
<td>6 High Altitude, Long Endurance (HALE)</td>
<td>Up to 20,000</td>
<td>More than 30</td>
<td>Over 13,000,000</td>
</tr>
</tbody>
</table>

CUAS Example 1 (LALE): NASA and US Forest Service (USFS) deployed an Ikhana UAS for strategic fire imaging missions in the western US (Ambrosia et al., 2011).

CUAS Example 2 (LASE-Close): USFS UAS demonstration flights used the smaller Arcturus T-16 Aerial Vehicle to conduct tactical fire imaging reconnaissance and intelligence gathering (controlled burn conditions) trials (Hinkley & Zajkowski 2011).
Table 3 Dual-use Commercial and Civilian Applications for UAS Platforms, adapted from Watts et al. (2012).

<table>
<thead>
<tr>
<th>Commercial/Civilian Application</th>
<th>UAS Platform</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerial Photography</td>
<td>LASE/LASE-C</td>
<td>FW/VTOL. Video and digital cameras mounted on quad-rotors. Mainly video and stills footage. No time criticality, real-time processing or security priorities.</td>
</tr>
<tr>
<td>Agriculture – farm management</td>
<td>LASE-C/LALE</td>
<td>FW/VTOL. Video and digital cameras mounted on quad-rotors. Mainly video camera footage. No time criticality, real-time processing or security priorities.</td>
</tr>
<tr>
<td>Electricity – network inspection services</td>
<td>LASE-C/LALE</td>
<td>FW. Longer distance transmission system inspections using IR sensors and Hi-Res color digital cameras.</td>
</tr>
<tr>
<td>Mining and Exploration</td>
<td>LALE/MALE</td>
<td>FW. Fitted with magnetometers and broad range IR sensors and digital color cameras.</td>
</tr>
<tr>
<td>Oil and Gas – pipeline inspection services</td>
<td>LASE-C/LALE</td>
<td>FW. Long distance pipe inspections using Hi-Res video and digital cameras and IR sensors.</td>
</tr>
<tr>
<td>Water – reservoir inspection services</td>
<td>LASE-C/LALE</td>
<td>FW. Resource inspections using Hi-Res video cameras and IR sensors.</td>
</tr>
<tr>
<td>Atmospheric and Meteorological services</td>
<td>MALE/HALE</td>
<td>FW. Mainly for higher altitude and upper atmosphere applications. EO, SAR, IR sensors and streaming video systems. Some on-board data processing. High level atmospheric testing requires high performance UAS.</td>
</tr>
<tr>
<td>Customs and Border Protection</td>
<td>LASE-C/LALE</td>
<td>FW. Need for accurate and complete data in a secure operating environment. Economical collection is of lesser importance. Real-time video systems are typically installed.</td>
</tr>
<tr>
<td>Emergency and Fire Services</td>
<td>LASE – LALE</td>
<td>FW/VTOL. Need for accurate and complete data in a secure operating environment. Timeliness is an important factor - Real-time video systems are typically installed. Economical collection is of lesser importance.</td>
</tr>
<tr>
<td>Environmental Monitoring – rivers/lakes</td>
<td>LASE-C/LALE</td>
<td>FW. Fitted with Hi-Res video and digital cameras. Timeliness may be important in some scenarios, such as pollution control. Real-time video streaming systems are typically installed.</td>
</tr>
<tr>
<td>Law Enforcement and Policing</td>
<td>LASE – LALE</td>
<td>FW/VTOL. Need for accurate and complete data in a secure operating environment. Timeliness can be an important factor in tactical response situations. Economical collection is of lesser importance. Real-time video streaming systems are typically installed.</td>
</tr>
<tr>
<td>Rangeland and Vegetation Management</td>
<td>LASE-C/LALE</td>
<td>FW. Fitted with Hi-Res video and digital cameras. Primarily ground station processing of data to improve accuracy.</td>
</tr>
<tr>
<td>Search and Rescue</td>
<td>LASE – MALE</td>
<td>FW/VTOL. Need for accurate and complete data in a secure operating environment. Time is often critical. Economical collection is of lesser importance. Real-time streaming video is important in this application.</td>
</tr>
<tr>
<td>Traffic Management and Control</td>
<td>LASE-C/LALE</td>
<td>FW. Need for accurate and complete data. Decision-making information is critical. Real-time streaming video systems are preferable and important in this application.</td>
</tr>
</tbody>
</table>

Note: FW = Fixed Wing; VTOL = Vertical Take Off and Landing (Rotary wing)