The Changing Face of the Interface:

An Overview of UAS Control Issues & Controller Certification

For UATAR Working Group 27

20 February 2008

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Many issues confront the successful integration of unmanned aircraft into an airspace system that has evolved around the principles of manned flight. The movement of the pilot from airframe to ground location at first glance appears relatively simple. However, while the aircraft corresponds to familiar aerodynamics, the dynamics of control within the unmanned system are unfamiliar and unbounded in variety.

While the traditional conception of the pilot's role is as master of the machine, developments over the first century of manned flight have altered the relationship between pilot and aircraft. Early avionics systems were developed to augment human capability, but had the effect of dissolving the pilot's status as the "confident master of throttle, stick, and rudder"[1] into the "organic component of a larger system."[2] Removing the pilot from the cockpit altogether is simply the latest extension of the trend towards greater integration of, and reliance on, automation.

The UAS controller's role depends largely on the interface with which they interact. The interface is the boundary between human and machine and will exhibit varying degrees of human dependency. The inherent characteristics of UAS control, however, mean that the relationships that form at this boundary are distant to traditional conceptions of pilot and aircraft. This has complicated the task of the regulator.

Like any aircraft component, the human component requires certification to ensure that the system operates safely as a whole. This will require an investigation into the control structures within the unmanned system, as well as the external interaction between the aircraft and the airspace. Further, ensuring the safe operation of the system requires a certain level of controller proficiency. Civil regulators must determine the appropriate standard and define the mixture of skills, knowledge, and experience that constitute it. This is problematic due to the diverse array of abilities that different interfaces require from their controllers. Setting the standard too high or low could have devastating consequences for the industry.

This paper will provide an overview of the problems inherent in UAS control, using the US military experience to provide examples. I will examine a small selection of UAS and suggest the skills required from their controllers. The focus in this regard will be on the ways that remote or autonomous operation affects controller requirements. The impacts of UAS performance, type, and size are not considered. Highlighting the differences between UAS control and traditional piloting will also guide consideration of the implications on the controller's legal responsibility. It is not the objective of this paper to conduct a detailed analysis, rather to illustrate the issues at hand.

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[1] Schultz, Timothy Paul, *Redefining Flight: How the Predecessors of the Modern United States Air Force Transformed the Relationship Between Airmen and Aircraft* (PhD Thesis, Duke University, 2007), "iv"

[2] Above, note 1, 11

1 The Evolution of Pilot Expatriation

The desire to augment human capability drives the advance of automation across all sectors. In practice, automation involves appropriation by the machine of traditionally human tasks. In early forms of flight, all the elements of the aircraft were subject to the control of the pilot. Early aviation was indeed a “seat-of-the-pants” exercise whereby “the eyes, brain, and finesse of the pilot controlled the aircraft and pushed it to its maximum capabilities.”[3] However, as war-time imperatives for ever-greater performance influenced design, the machine began to push back and human physiological limitations couldn’t match increasing machine capabilities. The human therefore became the limiting factor in aircraft design and increased cockpit automation has become the norm for civil and military aircraft alike.

The unmanned aircraft system (UAS) embodies the logical extension of cockpit automation. However, in current examples the pilot has only been relocated, rather than removed from the system completely. Removing the pilot from the cockpit removes the limitations imposed by human physiology. This allows the air vehicle component (UAV) to fly in environments that are hostile to humans, such as high altitude and speed, as well as providing gains in manoeuvrability and endurance. Further tactical, economic, and aerodynamic advantages are inherent in the unmanned configuration.

Despite this, the relocation of the pilot brings with it a unique set of problems for manufacturers and operators. In fact, a study conducted by the US Office of the Secretary for Defense noted that “adaptation of the cockpit environment to the ground control station is more difficult than anticipated.”[4] Interestingly, just as cockpits differ from aircraft to aircraft, ground control stations (GCS) also differ markedly amongst current systems in terms of both configuration and operation.[5] The experience of piloting unmanned systems differs accordingly.

2 UAS Control

Control of unmanned aircraft may take place by a number of means but can be classified into three groups according to the amount of input required from the UAS controller. UAS may be classified as –

(i) Ground-controlled;
(ii) Semi-autonomous; or
(iii) Autonomous.[6]

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[3] Above, note 1, 13

[4] DeGarmo, M, *Issues Concerning Integration of Unmanned Aerial Vehicles in Civil Airspace* (Virginia : MITRE Corporation, 2004), “2-15” - available online < http://www.mitre.org/work/tech_papers/tech_papers_04/04_1232/04_1232.pdf > (20 February 2008)

[5] There are a number of efforts underway to produce a common ground station, for instance the AAI One System, and Raytheon’s Universal Control System: see below, paragraph 2.2.5

[6] Lazarski, A, ‘Legal Implications of the Unmanned Combat Aerial Vehicle’ (2002) 16:2 *Aerospace Power Journal* 79

The reality is, however, that modern UAS exhibit characteristics of several control types and rely on some degree of autonomy. In unmanned systems, autonomy can be defined as "flight independent of real time UAV-pilot control input".[7] The type of control employed within a particular UAS, therefore, exists as part of a spectrum that ranges from completely dependent on human input, to complete independent. While control of remotely-operated UAS typically resembles traditional flight, autonomous control requires supervision rather than "hands-on" piloting. The use of autonomy is best illustrated by a brief analysis of several unmanned systems in the US military's inventory.

2.1 Illustrative Examples of Control

2.1.1 General Atomics RQ-1/MQ-1 Predator

Description of the air vehicle

The Predator is a Medium-Altitude Long-Endurance UAV measuring 14.84m across the wings, capable of 40 hour endurance and altitudes of approximately 7920m.[8] The US Air Force employs the Predator for reconnaissance, surveillance, and attack missions.

Control of the system

The Predator system is controlled by two elements known as the Ground Control Station (GCS) and the Mission Control Station (CS).[9] The GCS contains two identical pilot stations, a line-of-sight datalink, and a satellite relay. The GCS is forward-deployed to facilitate control of the Predator during take-off and landing. Once airborne, control of the Predator is handed to the CS, which remains in the United States and is responsible for on-station control, mission planning and execution, and sensor data dissemination.[10] The CS is housed in a 40-foot container containing pilot workstations, a 6m antenna for receiving sensor video, and a differential GPS.

Despite the array of control equipment, Predator doesn't feature advanced automation and in fact requires "a pilot and sensor operator to actively fly the entire mission, including take-off and landing."[11] The pilot interface includes familiar features such as "a conventional control stick, throttle and rudder pedals."[12] The pilot therefore essentially operates in a ground cockpit –

> *Two stacked television screens show the view from the boresighted day television camera mounted in the nose and the infrared/day*

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[7] Great Britain. Ministry of Defence, *Defence Sandard 00-970 Part 9: Design and Airworthiness Requirements for Service Aircraft – UAV Systems* (Online, 2006), paragraph 1.3 - available online < http://www.dstan.mod.uk/data/00/970/09000400.pdf > (20 February 2008)

[8] Drew, J et al, *Unmanned Aerial Vehicle End-to-End Support Considerations* (Santa Monica : RAND Corporation, 2005), 102

[9] Above, note 8, 78

[10] Above, note 8, 79

[11] Colucci, F, 'Air Force Refines Training Programs for UAV Operators' *National Defense* (United States) May 2004, 36

[12] Above, note 11

> *television sensor in the gimballed payload turret. Above the camera displays, a digital map with an aircraft symbol pinpoints the position of the UAV. Besides the pilot's-eye view on the video displays, two command and status screens present graphic flight data including airspeed, attitude, angle of attack, and an artificial horizon.*[13]

Control conditions for the Predator therefore attempt to emulate a cockpit environment.[14]

2.1.2 Northrop Grumman RQ-4 Global Hawk

Description of the air vehicle

The USAF Global Hawk is a High-Altitude Long-Endurance system that can fly missions of over 32 hours duration, at up to 20000m. Global Hawk is one of the largest UAS in operation, featuring a wingspan of 40 metres.[15]

Control of the system

Global Hawk is a highly capable and complex system, but it operates with minimal human input. Yenne notes that -

> *Global Hawks can take off autonomously, fly halfway around the world, and land without an operator on the ground doing anything more than monitoring its systems remotely.*[16]

Control of the Global Hawk takes place via the combination of equipment housed in two metal containers: the Mission Control Element (1536m^3) and the Launch and Recovery Element (640m^3).[17] The MCE, which plans and executes the mission on-station,[18] houses four computer workstations, satellite and radio communications equipment, and image exploitation equipment.[19] The LRE contains similar equipment but includes a differential GPS for precise navigation for take-off and landing.[20] Missions are generally pre-programmed using GPS and executed through a "point-and-click" waypoint interface.[21]

2.1.3 IAI RQ-5/MQ-5 Hunter

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[13] Above, note 11. Note that Predator now incorporates a Heads-Up Display.

[14] Note, however, that 90% of UAS spending is invested on the aircraft component, while only 10% goes to the ground station. Poor GCS design has been implicated in up to 67% of Predator accidents: Jean, G, 'Investments in Unmanned Aircraft Focus on Ground Operators' *National Defense* (United States) Jan 2007, 34

[15] Above, note 8, 104

[16] Yenne, B, *Attack of the Drones: A History of Unmanned Aerial Combat* (St Paul : Zenith Press, 2004), 74. The Global Hawk proved these capabilities during its trip across the Pacific in 2001.

[17] Croft, J, 'Send in the Global Hawk' *Air & Space Smithsonian* (United States) Dec 2004 – Jan 2005, 22

[18] Above, note 8, 64

[19] Above, note 17

[20] Above, note 17

[21] Above, note 8, 67

Description of the air vehicle

The Hunter is a tactical UAV with a wingspan of 8.84m, capable of approximately 15 hours endurance, and altitudes up to 6100m.[22] The Hunter replaced the RQ-2 Pioneer in service with US Marine Corps in 1996.

Control of the system

The Hunter is operated by the combination of an internal and external pilot. The external pilot controls the aircraft during take-off and landing from a location outside the GCS where visual contact with the UAV is possible. Controls similar to RC hobby aircraft are employed during these portions of the flight.[23] Once the UAV is safely airborne, the external pilot hands control over to the GCS, which consists of three control bays mounted in a utility vehicle. The internal pilot, however, does not exert significant control over the UAV, but rather monitors the execution of the flight as controlled by the autopilot.[24] While the internal pilot can control the UAS through conventional flight sticks, typical operation is through an interface that allows the pilot to "select flight parameters using knobs on the GCS console".[25] The system therefore exhibits aspects of both remote and autonomous operation, though the operation is different in both respects than that described for Predator and Global Hawk systems.

2.1.4 DARPA Micro Air Vehicle (MAV)

Description of the air vehicle

The MAV is a 6.3kg ducted fan VTOL UAV designed for reconnaissance in urban operations in Iraq.[26] Despite being only 53cm wide, the unit offers a maximum endurance of 40 minutes and is capable of altitudes up to 3200m.[27]

Control of the system

Ground control equipment for the MAV is minimal. Control of the air vehicle is via a small tablet PC carried by the solider operator.[28] The MAV utilises inertial navigation and GPS and flights are completely pre-programmed by waypoint.[29] Input of the flight plan is by way of a touchpad incorporated into

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[22] Above, 8, 102

[23] Weeks, J, *Unmanned Aerial Vehicle Operator Qualifications* (Mesa : United States Air Force Research Laboratory, 2000), 6

[24] Barnes, J et al, *Crew Systems Analysis of Unmanned Aerial Vehicle (UAV) Future Job and Tasking* (Maryland : Army Research Laboratory, 2000), 4 and above, note 23, 6

[25] McCarley, J & Wickens, C, *Human Factors Implications in the National Airspace* (Online : University of Illinois, 2005), 14 – available online < http://www.humanfactors.uiuc.edu/Reports&PapersPDFs/TechReport/05-05.pdf >, 14 (20 February 2008)

[26] Robinson, C, 'Mighty Minis Find Foes' *Signal* (United States) Jun 2006, 47

[27] Above, note 26, 48

[28] Above, note 26, 51

[29] Above, note 26, 51

the screen, which also displays real-time video fed from the MAV's sensors.[30] While the MAV can be re-tasked during flight, its operation is largely autonomous and the senior scientist involved with its development claims that "a soldier enters the go command, and the vehicle autonomously launches on a mission."[31]

2.2 Controller Requirements

Even a cursory examination of the systems presented above shows the diversity in capabilities and configurations that derive from unmanned systems. This has led to confusion as to UAS controller requirements. This confusion is most evident within the various positions adopted by the US military. As the most prolific user of unmanned aircraft, the US Department of Defense will spend an estimated US$16.6 billion on more than 10000 systems between 2006 and 2015.[32] However, even the DoD has not formulated a conclusion as to what is required from the UAS controller.

The Air Force staffs its UAS ranks with only experienced Air Force pilots or navigators that posses commercial instrument ratings.[33] These officers are "pulled directly from fighters, bombers, and transport aircraft".[34] Of this group, 80 percent are drawn from fighter and bomber assignments and 20 percent from airlift squadrons.[35] Predator pilots are required to have completed one tour on a manned aircraft and are generally transitioned to the UAS as part of a 3-year "career broadening tour".[36] The requirements are different in the other services, however. The US Navy and the Marine Corps operate UAS with enlisted personnel that posses private pilot licenses.[37] The US Army, on the other hand, imposes no aviation rating requirements on its UAS pilots.[38]

A 2005 study of the role of human factors in UAS mishaps, however, indicated some interesting results. Firstly, the study found that human error was involved in 60.2% of UAS accidents amongst the US armed forces.[39] The study also found that although piloting requirements were the strictest in the Air Force, 79.1% of UAS accidents involved general human causal factors as compared to 62.2% in the Navy/Marines, and 39.2% in the Army.[40] Furthermore, Air Force UAS accidents involved the highest frequency of skill-

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[30] Above, note 26, 51

[31] Above, note 26, 51

[32] Doyle, J, 'World UAV Market Predicted to Reach $8.3 billion by 2015' *Aerospace Daily & Defense Report* (United States) 7 March 2007, 3

[33] Hoffman, J Maj, 'At the Crossroads: Future "Manning" for Unmanned Aerial Vehicle' (2005) 19:1 *Air & Space Power Journal* 31, 34

[34] Wilson, J, 'UAVs and the Human Factor' *Aerospace America* July 2002, 54, 55

[35] Above, note 11, 37

[36] United States. United States Air Force, *The US Air Force Remotely Piloted Aircraft and Unmanned Aerial vehicle Strategic Vision* (Online : United States Air Force, 2005), 19 – available online < http://www.af.mil/shared/media/document/AFD-060322-009.pdf > (20 February 2008)

[37] Above, note 4, "2-15"

[38] Above, note 4, "2-15"

[39] Tvaryanas, A, Thompson, W & Constable, S, 'Human Factors in Remotely Piloted Aircraft Operations: HFACS Analysis of 221 Mishaps Over 10 Years' (2006) 77:7 *Aviation, Space, and Environmental Medicine* 724, 727

[40] Above, note 39, 727

based errors, occurring in 47.2% of mishaps, while this was apparent in 33.3% of Navy/Marines and only 23.1% of Army incidents.[41]

The differences in this data, as well as the differences in controller qualifications, are partially due to the unique systems used by each service. For instance, the USAF operates the larger and more complex systems such as Global Hawk and Predator, the USN and USMC having operated the mid-sized Pioneer,[42] and the Army using the hand-launched Desert Hawk. The inconsistencies are emphasised, however, by the fact that several unmanned systems are common to more than one service. The Sky Warrior ERMP, for instance, is a variant of the General Atomics Predator due to enter service with the Army in 2009.[43] Demonstration versions of this aircraft are already operating in Iraq.[44] The RQ-2 Pioneer was used by the USN, USMC, and US Army before retiring this year after a 20 year career.[45] Further, the AAI Corp Shadow is in service with both the Army and the USMC.

The US military experience provides insight into the difficulties in establishing controller criteria and prefaces the debate regarding the value of prior flight experience. It is difficult to directly determine this value, and it is noted that –

> *While opinions are varied and easy to come by, there is very little empirical research to guide the leadership in determining the best policy for selection and training.*[46]

Flight licensing is the process by which a person is given legal permission to undertake certain aerial activities. Different licenses therefore bring different levels and kinds of experience to the table. But how does such experience compare with the qualities required by the UAS? A quick glance at the term "experience" reveals that it encapsulates a variety of concepts, such as:

(i) *Active participation in events or activities, leading to the accumulation of knowledge or skill;* or
(ii) *The knowledge or skill so derived*.[47]

In the context of the debate pertaining to UAS controller requirements, "experience" therefore refers to –

(i) The sum of prior operation of manned flight ("piloting background");

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[41] Above, note 39, 728

[42] The Pioneer is generally similar in capability and configuration to the Hunter which replaced it in service with the USMC. The USN Pioneers, now retired, were ship-borne assets, however.

[43] Roosevelt, A, 'Warrior Alpha UAS Successful In Theatre, Officials Say' *Defense Daily* (United States) 15 December 2006, 1

[44] Above, note 43

[45] Stegherr, L Ens, 'UAV Det Launches Final Pioneer Flight' *US Federal News Service, Including US State News* 8 November 2007, 1

[46] Schreiber, B et al, *Impact of Prior Flight Experience on Learning Predator UAV Operator Skills* (Mesa : Air Force Research Laboratory, 2002), 1

[47] *The American Heritage Dictionary of the English Language, Fourth Edition* (Boston : Houghton Mifflin Company, 2004)

(ii) The body of knowledge derived from that operation or involvement; and
(iii) The set of skills possessed as a result of the operation or involvement.

Finally, aspects of the illusive concept of "airmanship" pervade the discussion of prior flight experience valuation. I would like to outline that discussion using some of the example systems described above to illustrate the differences between manned and unmanned flight. It is further important to note that unmanned flight itself can take different forms. Thus I will address the fit between a piloting background and controller requirements for remotely-operated and autonomous UAS. Caution must be exercised, however, as much of the evidence is anecdotal, and even the empirical evidence is contradictory.

2.2.1 Human Factors and Piloting Background

There are essential differences between the experience of conventional and remote flight. UAS controllers experience the flight indirectly, via the electronic equipment that enables unmanned technology. This results in "sensory isolation" that can include the loss of sensory cues such as –

(i) ambient visual information;
(ii) physical and balance-related sensations; and
(iii) auditory sensations.[48]

The result of sensory isolation is a degraded "situational awareness"; that is, an impaired perception of the aircraft's current and projected status relative to its flight environment.[49] Clearly, the experience of controlling an aircraft under these conditions differs from that encountered in the cockpit. By way of illustration, McCarley and Wickens note that –

> *...to the pilot of a manned aircraft, turbulence is signalled by visual, auditory, and kinaesthetic/haptic information. To the pilot of a UAV with a conventional display, in contrast, turbulence is indicated solely by perturbations of the camera image provided by the UAV sensors.*[50]

Such would be the case for a remotely-operated system like Predator. However, degraded situational awareness can also occur where aircraft control is automated as this has the effect of leaving the controller "out of the loop".[51] Where a piloting background is based on cockpit conditions dissimilar

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[48] McCarley, J & Wickens, C, *Human Factors Concerns in UAV Flight* (Illinois : University of Illinois, 2004), 1

[49] The leading definition of "situational awareness" is "…a perception of the elements in the environment within a volume of space and time, the comprehension of their meaning, and the projection of status in the near future": Endsley, M, 'Situation Awareness Global Assessment Technique (SAGAT)' *Proceedings of the National Aerospace and Electronics Conference* (Ohio, 1988)

[50] Above, note 48, 2

[51] Above, note 25, 4

to those just described, reliance on that background would not only be inappropriate, but may even impede performance.

In 2002, the Air Force Research Laboratory examined the relevance of piloting background as it pertained to Predator operations ("the Predator study"). The study analysed the performance of several groups ranging from experienced Predator pilots to participants with no aviation background whatsoever across a number of tasks. The non-pilots performed surprisingly well in a simulated landing task[52] – considered to be one of the most difficult aspects of flight – and the study suggested that –

> *Experienced pilots may need to "unlearn" some aspects of piloting (e.g., use of vestibular and peripheral cues), whereas nonpilots who train only on the Predator would not.*[53]

In general, however, the Predator study indicated that the experienced pilots consistently performed better than the other groups. The non-pilots consistently performed worse.[54] Interestingly, T-38 pilot and civilian instrument pilot performance was comparable to that of recently selected Predator pilots.[55] The authors suggested this may indicate some advantages to a pilot background in a manned aircraft with similar handling characteristics to the Predator.[56]

While intriguing, the findings of this study apply only to Predator operations. Research by the US Army Research Laboratory in 2000 ("the ARL study") into Army controller requirements concluded that piloting background was not required for external pilots that control UAVs through visual contact:

> *…the somatic and visual cues that pilots use during aircraft landings would not be useful (and perhaps even counter-productive) for the different skill sets and perceptual viewpoint necessary for controlling radio-controlled landings.*[57]

The assumption that experienced pilots make better UAS operators, therefore, is of doubtful accuracy. Rather, the value of a piloting background will likely depend on the similarity between the aircraft and the UAS in question.

In examining skill requirements, I do not wish to overly define "skill". I take the term to refer to "abilities" generally involving a degree of practical application.

2.2.2 Skill Requirements for Remotely-Operated UAS

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[52] The non-pilots were able to reach criterion levels in Basic Manoeuvring and Landing Tasks in approximately 161 attempts. T-1, T-38 and civilian instrument program pilots normally perform over 200 landings before graduation: see note 46, 37

[53] Above, note 46, 37

[54] Above, note 46, "v"

[55] Above, note 46, "v"

[56] Above, note 46, "v"

[57] Above, note 24, 12

Despite its limitations, the Predator study may be helpful in suggesting skill requirements for control of remotely-operated UAS in general. After extensive consultation with experienced Predator pilots, the study proposed three simulated tasks to test various aspects of pilot skill and formulate pass/fail criteria. One may distil a set of controller skill requirements from these tests.

The requirements of the Basic Manoeuvring and Landing Tasks show that the Predator operator must be able to –

(i) Interact with a unique interface that includes stick-and-rudder as well as an unusual Heads-Up Display;
(ii) Fly the Predator using instruments only;
(iii) Control the airspeed, altitude, and heading of the aircraft and effect changes in all three axes simultaneously during all phases of flight; and
(iv) Accommodate unique UAS characteristics such as transmission delay and stability augmentation while controlling the aircraft.

The Reconnaissance Task, on the other hand, was designed to test more advanced cognitive skills. The task required the operator to position the aircraft such that the onboard camera was fixed on a target for as long as possible during breaks in cloud cover.[58] This required the ability to –

(i) Plan the mission;
(ii) Manoeuvre in the target area; and
(iii) Maintain orientation.

According to the consulting Predator pilots, this task "would require substantial aviation-related spatial reasoning skills".[59] Furthermore, success in this task was said to require "good planning, good understanding of the three-dimensional problem space, and proper execution".[60] The study concluded that some piloting background was required. Hoffman commented that this was justified due to controllers requiring skills –

> *…making critical system inputs… having to deal with simultaneous emergencies, evaluating last-minute threats, and sustaining situational awareness.*[61]

The list of skills presented above is obviously not exhaustive. It was suggested that communication, decision making,[62] and airspace management skills are all important,[63] and may "fall under the rubric of 'airmanship'".[64] Experienced pilots are generally assumed to possess these skills, however,

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[58] Above, note 46, 8
[59] Above, note 46, 8
[60] Above, note 46, 9
[61] Above, note 33, 33
[62] Above, note 46, 1
[63] Above, note 46, 3
[64] Above, note 46, 1

some evidence suggests they make as many judgement, decision-making, and perception errors as the inexperienced.[65]

2.2.3 Skill Requirements for External Controllers

Remote manual control may also take place through visual contact with the UAS. The Hunter, for instance, requires external pilots to conduct take-offs and landings, as noted above. Many UAS slated for civil applications are also controlled in this way. There appears, however, to have been little study of the skills required. External pilots typically operate controls resembling those used with model aircraft,[66] manipulating the joysticks on the handheld unit to control the flight surfaces of the UAS.[67]

External pilots are simply assumed to require similar skills to that of the model aircraft enthusiast. Indeed, external pilots of the Hunter are screened according to “performance assessment with a radio-controlled model airplane”.[68] However, external controls can create orientation issues. For instance, when the controller and the aircraft are facing the same direction, a rightward joystick input correlates to rightward motion relative to the controller. However, when the controller and aircraft face in opposite directions, this input correlates to a leftward motion.[69] External piloting, then, may require some of the spatial reasoning skills noted in the Predator study to maintain orientation. External pilot selection criteria for the US Marine’s Pioneer indeed required that pilots “display superior adaptation to three-dimensional spatial relationships”.[70] Results of the ARL study also recorded the value of visualisation and anticipation skills, which one external pilot referred to as “getting ahead of the air vehicle”.[71]

2.2.4 Skill Requirements for Autonomous UAS

There is a general trend in aviation towards a conception of the pilot as “the manager of switches, dials, and buttons.”[72] Highly autonomous interfaces, such as Global Hawk’s, epitomise this trend and can impact pilot skill requirements in several ways. Rather than the pilot’s eye-view presented to Predator pilots, Global Hawk pilots use graphical displays for situational awareness.[73] One Global Hawk pilot succinctly describes how this translates to unique skill requirements –

> *…We’re looking at two-dimensional math plot. The pilot has to visualise the three-dimensional model. That’s where the piloting skills come in.*[74]

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[65] Above, note 39, 731

[66] Above, note 25, 7

[67] Williams, K, *Human Factors Implications of Unmanned Aircraft Accidents: Flight-Control Problems* (Oklahoma : Federal Aviation Administration, 2006), 2

[68] Above, note 23, 6

[69] Above, note 25, 7

[70] Above, note 23,

[71] Above, note 24, 12

[72] Above, note 1, 9

[73] Above, note 11, 39

[74] Above, note 11, 39

Another Global Hawk pilot also defends the value of piloting skills –

> *There's still a certain amount of air sense you have to have to be able to manipulate the aircraft…*[75]

The contention is, then, that prior experience with manned aircraft instils the pilot with certain conceptual abilities. Instrumented flight was developed to allow the pilots to operate in environmental conditions in which visual orientation was not possible.[76] Highly autonomous UAS also necessitate operation absent of visual cues. In the Global Hawk programme, the IFR requirement ensures that pilots have this proficiency. However, the shift towards the role of pilot as a managerial asset begs the question as to whether a qualified pilot is required. Specifically, the lack of conventional aircraft controls have led some to contend that –

> *…an engineer with some pilot background (knowledge of basic flight dynamics, weather, instrument flight rules, Federal Aviation Administration Rules etc), experience with home-computer flight-simulator games, extensive familiarity with flight systems and mission planning, and 250 to 500 hours of simulator time would be a model candidate as a remote pilot for the Global Hawk.*[77]

For highly-autonomous systems, skill requirements pivot largely on mission and airspace management rather than aircraft handling techniques.[78] Pilots often speak of the value of anticipation; that is, pre-empting rather than reacting to problems.[79] Indeed, timely and effective intervention is one of the most important managerial tasks for pilots of autonomous UAS –

> *Autonomy is currently doing a lot of the 'pilot's' job, but not all of it… As this proportion changes we need to consider effectively de-skilling the human – at least insofar as direct control of the air vehicle is concerned. This presents us with the problem of how to keep [operator] interest alive and immediately responsive to potential events that may happen only once in a blue moon.*[80]

Communications link management, on which safe operation of the UAS depends, is another aspect of autonomous operation that conventional pilots may not be familiar with.[81]

The precise fit of a piloting background with the requirements of increasingly autonomous systems remains unclear. The ARL study provides some

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[75] Above, note 17, 26

[76] Above, note 1, 9

[77] Above, note 33, 31

[78] Mahon, T, 'Operators Standing By: Companies Face Training Challenges as UAVs Take Off' *Training & Simulation Journal Online* (United States) 24 December 2007 available online < http://www.tsjonline.com/story.php?F=3059201 > (20 February 2008)

[79] Above, note 24, 11

[80] Above, note 78

[81] Above, note 11, 39

guidance. Hunter Air Vehicle Operators – who monitor the autonomous flight after take-off and before landing – must be able to interpret flight instruments, plan the mission, and handle emergencies.[82] However –

> *…outside of communication skills, raters did not consider flight-related skills of great importance to UAV operations*.[83]

The authors therefore concluded that the practice of selecting rated aviators to pilot the Army's unmanned aircraft was "of little value".[84]

2.2.5 New Interfaces and New Skills

The limitations of current generation UAS interfaces arguably require some piloting background, however, new technologies are set to change revolutionise the pilot/machine relationship. Work being undertaken at the AFRL is proceeding in three phases:

- (i) Improving remotely-operated interfaces;
- (ii) Continuing to develop the capability of autonomous systems; and
- (iii) Developing swarming technology, whereby a single operator can control multiple unmanned aircraft.[85]

This work is indicative of global research in the area having branched into two paths: focusing on the human and improving situational awareness by improving the interface, and focusing on the computer to raise its level of autonomy.

The interfaces of remotely-operated UAS continue to evolve far beyond the simple television guidance systems employed by controllers of the Ryan BGM-34 Firebees in the 1970's.[86] In Italy, A2Tech has developed the RealityVision system for use with smaller UAS, such as its RV-02 demonstrator. The system's Ground Control Station –

> *…replicates the forms and functions found in typical manned aircraft such as the stick and pedals, as well as a panoramic display, video goggles with integrated head-up data, and synthetic vision toolsets.*[87]

Even the stalwart Predator interface is getting a facelift. Raytheon's Universal Control Station (UCS) features three wide-screen monitors that extend the pilot's field of view up to 120 degrees.[88] This is achieved by merging the

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[82] Above, note 24, 4

[83] Above, note 25, 13

[84] Above, note 25, 13

[85] Above, note 34, 56

[86] Munson, K, *World Unmanned Aircraft* (London : Jane's Publishing Company Limited, 1988), 196. For an interesting and detailed description of the Ryan Firebee family's development and operations, see Peebles, C, *Dark Eagles: A History of Top Secret US Aircraft* (New York : ibooks, inc, 2003)

[87] La Franchi, P, 'Remote Control' *Flight International* (United Kingdom) 13-19 November 2007, 49

[88] Jean, G, 'Investments in Unmanned Aircraft Focus on Ground Operators' *National Defense* (United States) Jan 2007, 34, 36

Predator's narrow camera imagery with wide-angle synthetic imagery based on terrain databases.[89] Raytheon turned to the computer gaming industry to increase pilot situational awareness, producing a system that –

> *…boils [flight] information down into an intuitive gaming symbol… Operators can click on the aircraft they want to control and navigate quickly through Windows-based menus for diagnostics data.*[90]

While these systems may improve situational awareness by designing the system around the human pilot, even here there is evidence of increasing autonomy. For instance, Raytheon's UCS offers the ability to control up to 8 dissimilar UAVs simultaneously.[91] This necessitates that the aircraft operate independently for long periods. Even with reliable automation, the task of monitoring multiple aircraft is a difficult one.[92] An extension of multiple-control is the idea of swarming, which is predicated on system autonomy and close coordination between the UAVs themselves.[93] The operator is left largely out of the loop, providing only "high level" input. However, several systems have demonstrated the potential of swarming configurations.

In mid-2007, Boeing demonstrated the simultaneous control of three cooperating UAVs by one controller.[94] The controller monitored but did not manipulate the aircraft as they searched, located, identified, and intercepted moving targets.[95] Similarly, Proxy Aviation's SkyForce system allows the operation of up to 12 UAVs controlled by onboard "virtual pilots"[96] to –

> *…work together as a co-operative unit. They will fly in the same piece of operational airspace, will swap out on specific tasks, will manoeuvre in a co-ordinated fashion around each other and return to land. Everything they do together… will be the product of pre-programmed, autonomous, rule-based task assignments.*[97]

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[89] Warwick, G, 'Raytheon 'Cockpit' to Tackle UAV Mishaps' *Flight* International (United Kingdom) 7-13 November 2006, 24

[90] Above, note 88, 36. Note too that the UCS actually features two Xbox-type game controllers at each workstation: Harvey, D, 'Predator's Perceptual Shift' *Unmanned Vehicles* (United Kingdom) May 2007, 12

[91] Above, note 88, 34 & Richfield, P, 'New 'Cockpit' for Predator?' *C4ISR Journal* (United States) 31 October 2006 available online < http://c4isrjournal.com/story.php?F=2323780 > (20 February 2008)

[92] Above, note 25, 12

[93] I use "swarming" in a general sense, but note that "teaming" is another form of UAV group control. Clough defines "swarming" as "A collection of autonomous individuals relying on local sensing and reactive behaviors interacting such that a global behavior emerges from the interactions." For an excellent discussion of "swarming" and "teaming" see Clough, B, *UAV Swarming? So What are Those Swarms, What are the Implications, and How do we Handle Them?* (Ohio : Air Force Research Laboratory, 2002)

[94] Fulghum, D, 'UAVs Cooperate to Find Targets Without Human Intervention' *Aviation Week & Space Technology* (United States) 6 August 2007, 48

[95] Above, note 94

[96] Hughes, D, 'Not Ready for ATC: Civil Airspace Likely Won't See UAV Swarms' *Aviation Week & Space Technology* (United States) 17 September 2007, 82

[97] Harvey, D, 'Thinking Big, Co-Operatively' *Unmanned Vehicles* (United Kingdom) Dec 2006 – Jan 2007, 28

The system's capabilities were proven in August 2007 when two UAVs cooperated with two simulated UAVs to successfully locate Improved Electronic Devices.[98] The UK's QinetiQ has also demonstrated the ability of a pilot flying a modified Tornado to control a droned BAC 1-11 and 3 other simulated UAVs simultaneously.[99]

In swarming systems, the controller gives only high-level commands to the collaborative system and does not control individual UAVs. Thus –

> *…instead of manipulating sensors and manoeuvring aircraft, the operator tells the automated system, 'I need pictures taken in these spaces… You figure out how to do it; and if you find something interesting, cue me so I can look at it. Meanwhile I'm going to be doing something else*.[100]

In fact, with speech recognition software now in development at the Massachusetts Institute of Technology, the operator will *literally tell* UAS what to do through verbal commands.[101] One engineer at the AFRL likened the resulting relationship to that of pilot and co-pilot, or pilot and wingman.[102]

The functions of the swarm controller do not accord with the traditional conception of the pilot in any way. In fact, swarm controllers no longer even command an aircraft as such and the skill implications are therefore unclear. That something very different is required is quite clear, however, and "may indeed be more akin to an air traffic controller's responsibility than that of a traditional pilot".[103] Experts have stated their belief that piloting skills will be helpful, but not necessary required.[104]

2.2.6 Knowledge Requirements

In a recent article investigating the USMC's training arrangements for the introduction of AAI Corp's RQ-7 Shadow 200, company officials stated that a Shadow pilot –

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[98] Hughes, D, 'Two Proxy Aviation UAVs Cooperate During USAF Flight Demo' *Aerospace Daily & Defense Report* (United States) 13 August 2007, 3. Augusta Systems has demonstrated a similar capability using their SensorBridge and SensorPort technologies mounted on two Aerosonde Mk III's: 'Augusta Systems Technologies Support Unmanned Vehicle 'Swarming'' *Wireless News* (United States) 2 September 2007, 1.

[99] Butterworth-Hayes, P, 'Remote-Controlled Flight Technology Matures' *Aerospace America* September 2007, 4

[100] Above, note 94, 49

[101] 'One Pilot Flying Two Planes' *InTech* (United States) Feb 2005, 20

[102] Morris, J, 'Air Force Research Lab Exploring Methods of 'Managing' Multiple UAVs' *Aerospace Daily* (United States) 3 July 2001, 4

[103] Above, note 4, "2-53"

[104] Above, note 102

> *…never actually takes on a flight control. You're not changing any of the flight processes…Nobody's moving an aileron, nobody's moving any rudders. That's all automated by computer.*[105]

The author of the article therefore concluded that piloting skills were not required.[106] Interestingly, though, prospective Shadow pilots spend four weeks learning the FAA commercial pilot ground certification course.[107] The ground course, defined by FAR 61.125 headed "Aeronautical Knowledge", requires instruction in the following areas:

> (1) Applicable Federal Aviation Regulations of this chapter that relate to commercial pilot privileges, limitations, and flight operations;
>
> (2) Accident reporting requirements of the National Transportation Safety Board;
>
> (3) Basic aerodynamics and the principles of flight;
>
> (4) Meteorology to include recognition of critical weather situations, windshear recognition and avoidance, and the use of aeronautical weather reports and forecasts;
>
> (5) Safe and efficient operation of aircraft;
>
> (6) Weight and balance computations;
>
> (7) Use of performance charts;
>
> (8) Significance and effects of exceeding aircraft performance limitations;
>
> (9) Use of aeronautical charts and a magnetic compass for pilotage and dead reckoning;
>
> (10) Use of air navigation facilities;
>
> (11) Aeronautical decision making and judgment;
>
> (12) Principles and functions of aircraft systems;
>
> (13) Manoeuvres, procedures, and emergency operations appropriate to the aircraft;
>
> (14) Night and high-altitude operations;

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[105] Weible, J, 'Casting a Larger Shadow: US Marines Join Army in Training on Popular Unmanned System' *Training & Simulation Journal Online* (United States) 24 December 2007 available online < http://www.tsjonline.com/story.php?F=3146338 > (20 February 2008)

[106] Above, note 105

[107] Above, note 105

(15) Procedures for operating within the National Airspace System; and

(16) Procedures for flight and ground training for lighter-than-air ratings.

Clearly, what is being imparted here is knowledge rather than skill. Piloting skills may not be required for controlling Shadow; however, piloting knowledge remains important. Basic aeronautical knowledge is required for safe operation regardless of the characteristics of the UAS. All pilots are well versed in this area; however, the unique characteristics of the UAS in question cannot be ignored. SC-203 recommends instruction specific to the UAS in question in the areas of:

- *Mission Planning*
- *Pre-flight Procedures*
- *Take-off and transit to Operations Area*
- *Flight Operations*
- *Recovery and Landing*
- *Post-flight Procedures*
- *Emergency Procedures and Contingency Operations*
- *Maintenance Procedures.*[108]

In sum, the requirement is for adequate knowledge of both the airspace and the aircraft. Knowledge obtained as part of a piloting background will not satisfy the latter.

2.2.7 Summary of Pilot Requirements

Autonomous systems will continue to alter the way that pilots interact with machines. Over time, these interactions will require less “hands-on” control in favour of supervisory control over the aircraft, or multiple aircraft. This movement does not necessarily dictate that less skill is required, but rather that different skills are required. The content of any particular skill set depends on the type, size, operating environment, and control characteristics of the UAS in question. Therefore, there may not be a “one size fits all” solution to the question of controller requirements. However, safety dictates two primary requirements for UAS pilots: they must be proficient in controlling the aircraft and interacting with other assets in the airspace.[109] Further, an examination of the preceding paragraphs shows the recurrence of several themes that fit within the primary requirements.

Effective Control with Limited Information

All UAS controllers rely on technology to feed them the information that would otherwise be unobtainable outside the cockpit. The technology in current

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[108] SC-203, *Best Practices for Small Unmanned Aircraft System Operations (Revision B)* (Washington : RTCA, Inc, 2006), 5 - available online < http://uatar.com/RTCA%20SC-203%20Document%20Control%20Form.pdf > (20 February 2008)

[109] Above, note 4, “2-52”

generation ground stations fail to capture and/or effectively present all the information normally available to pilots of manned aircraft. UAS pilots therefore rely on imperfect or inadequate information to perform their tasks. Visual contact with the aircraft may partially negate the effects of this, however, the ability to effectively interpret and utilise flight instruments may be necessary for the larger, more complex, and more automated UAS. Simply put, the requirement of any UAS controller is to be able control the aircraft with limited flight information.

Mission Management

Aspects of mission management have pervaded the pilot's world since cockpits began to automate lower-level functions. Modern conventional pilots have become adept at these skills. Unmanned systems, though, have taken the use of automation to new heights. Nowadays, highly autonomous systems require little human input but much human monitoring. This has concurrently increased the focus on the management skill set for UAS controllers, and skills relating to effective monitoring, communication, and timely intervention in emergencies are amongst the most important elements of the UAS controller's arsenal.

Spatial Awareness

Much of the anecdotal evidence relating to skill requirements refers to the need for a so called "air sense". This is apparently an aspect of the broader art of "airmanship" and seemingly refers to a controller's ability to visualise the aircraft within its immediate and future flight environment. While the elusive character and questionable value of such a skill will obviously create problems for regulators, the ARL study did show that experienced and inexperienced external pilots relied on different mental functions during difficult situations. Appropriate testing could lead to a skill requirement in this regard.

This list is not exhaustive but merely suggests that there is some common ground even amongst diverse unmanned systems. The common elements are most evident in the need for a controller to anticipate, detect, and safely intervene to avoid mishap. Such action requires a mixture of abilities that will largely dictate controller criteria. However, formulation of specific criteria must be balanced against the industrial impact and the risks associated with the system in question. De Garmo summates that –

> *It's fair to assume that a large UAV operating out of a major airport would likely require a pilot with extensive certification criteria similar to a commercially licensed, instrument rated pilot of a manned aircraft. However, a pilot wishing to operate a slow, electric-drive, 6lbs UAV to photograph wildlife, may require minimal or no licensing.*[110]

Further study is necessary to determine where to place the fulcrum in this balancing act.

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[110] Above, note 4, 2-52

3 Pilot-in-Command or Pilot-in-Chains?

The inherently different roles and skills involved in flying UAS has led to the debate regarding whether those at the controls should be called “pilots”, or “simply operators or controllers”.[111] The debate is of more than just academic interest. If UAS flyers are not considered pilots, the question is whether they have the same or perhaps diminished responsibilities.

Aviation law has grown up around the ideal of the pilot that conquers the sky through mastery of the machine. The rules of the *Chicago Convention* of 1944 tasked the pilot in command with ensuring safe operation of the aircraft. This was no easy task at the time, and indeed required a detailed understanding of the mechanics and aerodynamics of a machine that was only just beginning to demonstrate its enormous potential. The principles set forth at this early stage remain in force today. In the meantime, however, the role of the pilot has been radically altered by new technology. Modern pilots must ensure flight safety in conditions that allow far less direct involvement. Mastery of the machine now requires intimate knowledge of increasingly complex and increasingly sovereign computer systems.

The delegation of traditionally human tasks to machines means that many aspects of flight are not under the direct control of the pilot at any given time. The ideas of control and responsibility are closely linked. The traditional conception is that responsibility presupposes the ability to control an outcome. The delegation of control to machines restricts this ability and creates the concern that –

> *…human beings might no longer be controlling [the aircraft] and thus might no longer be able to assume responsibility for it.*[112]

In unmanned systems, the pilot is not even onboard the aircraft and is therefore unable to exert physical control over the machine. Furthermore, unmanned swarming technology involves the delegation of control to multiple non-deterministic machines.[113] Clough explains that a swarm’s operation –

> *…is best described by a probability distribution, and one can never say that you know what a swarm will do, just that you know what it does most of the time.*[114]

Holding the pilot responsible for damage caused by the actions of unpredictable autonomous elements seems mightily unjust. The legal concept of responsibility, however, is far wider than the traditional conception. In

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[111] De Meo, L Jr, ‘UAV Operators are not Pilots’ *Aviation Week & Space Technology* (Correspondence) (United States) 15 May 2006, 6

[112] Schmid, R, ‘Pilot in Command or Computer in Command?’ (2000) 25:6 *Air & Space Law* 281, 285

[113] Clough, B, *UAV Swarming? So What are Those Swarms, What are the Implications, and How do we Handle Them?* (Ohio : Air Force Research Laboratory, 2002), 11

[114] Above, note 113

Australia, CAR 224 *imposes* responsibilities on the pilot in command with relation to –

> *(a) the start, continuation, diversion and end of a flight by the aircraft; and*
> *(b) the operation and safety of the aircraft during flight time…*[115]

While the controller is considered the pilot in command,[116] the regulations say nothing about whom or what is in actual control of the aircraft. The burden of ultimate responsibility is borne by the pilot in command, meaning that advances in autonomous technology have resulted in no change to the pilot's legal position.[117] Diederiks-Verschoor explains that this is because –

> *…the captain's personal assessment and handling of the situation, and his timely intervention remain paramount for a proper discharging of his duties and, consequently, the deciding element when it comes to determining his responsibility.*[118]

Therefore, so long as an ability to intervene remains, UAS controllers will continue to make decisions that imbue them with responsibilities. In any event, safety considerations require that somebody undertakes responsibility for flight operations.

4 CASA's Interpretation

The problems presented above are central to the regulator's task of defining controller criteria. It is therefore beneficial to examine the conclusions that CASA has reached.

A person is eligible for certification as UAV controller under CASR 101.295(2) if he or she –

> (a) qualifies for the issue of a radio operator's certificate of proficiency; and
> (b) has been awarded a pass in an aviation licence theory examination (other than a flight radio operator's examination); and
> (c) has been awarded a pass in an instrument rating theory examination; and
> (d) has completed a training course in the operation of the type of UAV that he or she proposes to operate of the type of UAV that

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[115] *Civil Aviation Regulations 1988* (Cth) reg 224(2). See also duties under *Civilian Aviation Regulations 1988* (Cth) reg 233

[116] See above, note 36, 20: "In all cases the RPA or UAV operator is considered the pilot in command (whether rated or unrated, officer, enlisted, or civilian) and is responsible for the aircraft."

[117] Diederiks-Verschoor, I, *An Introduction to Air Law 8th Revised Edition* (The Hague : Kluwer Law International, 2006), 197

[118] Above, note 117

he or she proposes to operate, conducted by the UAV's manufacturer; and

(e) has at least 5 hours experience in operating UAVs outside controlled airspace.[119]

Several aspects of these requirements are worthy of attention. CASA has determined the value of the piloting background to be relatively low. Flight crew qualifications are not required, and CASA have stated that –

> *It is conceivable that other qualifications may be entirely appropriate provided that the operator is able to physically control the UAV, particularly where controlled airspace or other traffic is not a factor. What is required is an understanding of airspace and airspace requirements and experience in compliance with those criteria.*[120]

CASA's approach emphasises the value of knowledge rather than the skills possessed as a result of a piloting background. General aeronautical and instrument knowledge requirements echo the importance attached to these elements by the military. A piloting background is "desirable" but "not required",[121] and it is stated that a flight crew license with command rating (and the military equivalent) will satisfy several requirements. These qualifications, however, will not satisfy the need for training and experience on the UAS the controller seeks to use, emphasising the uniqueness of individual systems. The US military experience is therefore evident within the CASA requirements. It is important to note, however, that these are minimum certification requirements, and CASA may impose restrictive conditions under CASR 101.300 based on the details provided with the application.[122]

5 Summary

Unmanned aircraft are not pilotless aircraft. Rather, the pilot's role in the system has been redefined. The process of redefinition has been underway for some time. Since the dawn of aviation, the latter part of the human-machine interface has increasingly influenced the way the former experiences flight. Early advances in flight instrumentation enabled flight in ever-harsher conditions, but forced the pilot to rely on machines for information. As these machines evolved from mechanical to digital they acquired greater capability and, in turn, were given greater responsibilities in the conduct of aircraft operations. Taking the pilot out of the cockpit and wirelessly connecting the onboard computer to the ground is simply another iteration of the trend towards separating the pilot from the traditional experiences of flight. Some UAS have even done away with the stick.

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[119] *Civil Aviation Safety Regulations 1998* (Cth) reg 101.295(2)

[120] Walker, M, *The Evolution of Specific Legislation Governing Australian Unmanned Aerial Vehicles (UAVs)* (Unpublished : Civil Aviation Safety Authority, 1999), 9

[121] Above, note 120

[122] *Civil Aviation Safety Regulations 1998* (Cth) reg 101.300. Under CASR 101.290, an applicant must provide full details of any aviation licenses held, aeronautical experience, examinations undertaken, experience with UAVs, and UAV training courses undertaken.

For both airborne and grounded pilots, however, all these changes have not altered the pilot’s legal responsibility to ensure flight safety. Regardless of the degree of autonomy, the controller’s ability to intervene in control of the aircraft premises the imposition of these responsibilities. However, simply intervening when necessary is not enough: ensuring safety requires effective intervention. This requirement, above all, illustrates the importance of UAS controller proficiency.

The skill requirements of any particular system are unique to that system. However, a certain blend of knowledge, mental abilities and motor skills are necessary for any UAS controller to effectively intervene and avoid mishap. These elements are evident in the mission management, spatial awareness, and effective control skill sets, which analysis of US military experiences suggested were common to the operation of all UAS.

Setting the threshold for of controller requirements is a balancing act that requires the regulator to balance the ideals of ensuring safety and encouraging industry. Finding the fulcrum entails a valuation of prior flight experience, and aspects of the debate on this topic are evident in CASA’s controller certification regime. The appropriateness of CASA’s standards will best be judged by how many UAVs are seen in Australian skies. The definition of the UAS controller’s role, however, will continue to evolve with the technology on which it depends.

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