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Considerations of a Legal Framework for the Safe and Resilient Operation of Autonomous Aerial Robots

by

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Abstract

Aviation industry analysts project the market for Unmanned Aircraft Systems ("UAS"), commonly referred to as drones, may reach almost $15 billion in annual worldwide sales within the current decade, and foresee exponential growth after that. They are destined to perform an unprecedented variety of tasks once the aircraft are integrated into our airspace in 2015, as set out in the Federal Aviation Administration ("FAA") Modernization and Reform Act of 2012. These systems will perform search and rescue, survey rugged terrain, deliver pizza, photograph the world in a wide range of media, battle forest fires and perform other tasks that stretch the limits of the imagination. The extent of innovation for UAS is seemingly limitless. Yet, within this futuristic vision emerges an essential issue that cannot be ignored: safety.

It is a paramount concern that all UAS must have significant safety systems to ensure inherent resilience in the event of system failure or an external mishap. However, one potential subset of this new fledgling industry that presents unique safety challenges is autonomous UAS. Currently, many aerial systems operate under mostly human control; however, some segments of their operation can and will soon undoubtedly be done autonomously. For example, in the event of lost communications with the human operator, otherwise known as a lost link, or in a near collision that can trigger an automatic response in some systems, the UAS could be thrust into a total autonomous mode to alleviate the potential emergency.

Still other UAS on the market now and next are designed to operate under complete autonomy from takeoff to touchdown. In short, the spectrum for aerial robots operating autonomously is broad and increases by the day. The rapidly advancing technology raises numerous potential safety issues for all aircraft operating in the National Airspace System ("NAS"), as well as everyone occupying the ground below.

For now, the FAA has indicated that even when UAS are integrated into the NAS, its legal framework will not permit the use of autonomous technology. Foreclosing the use of such technology may stifle or end investment into some of the most promising and beneficial UAS platforms. Although challenging, the FAA should work to develop a legal framework that allows for the use of autonomous UAS technology. Legal rules for this UAS subset must account for many factors such as the underlying software, algorithms and mathematics that drive the robotic systems, the interface between the robotic systems and potential human operators, if any, the interface between the robotic system and the collision avoidance system, as well as all inherent onboard authority systems.

With this paper, the authors hope to begin the important discussion on developing a unified set of legal principles that may serve as the foundation to someday permit the operation of autonomous UAS. A legal framework will ensure that designers and manufacturers have the freedom of invention and innovation while having a defined set of rules with which to develop their aerial robotic systems to ensure safe, resilient autonomous and semi-autonomous operations in the national airspace. It will ensure that operators understand the bounds with which their vehicles must operate safely in the NAS. As importantly, such a framework assists legal practitioners and the judicial system in defining areas of product liability, operator liability, as well as areas of negligence and potential criminal culpability.

Our discussion is informed by the "UAS Autonomy Spectrum," a visual system developed by the authors. While initially prepared for application to autonomous UAS, our ideas may be adaptable to other related new technology, including unmanned underwater robots, self-driving land vehicles, and any type of robotic vehicle that has varying degrees of autonomous capabilities. It touches upon the regulatory framework for aircraft under the Federal Aviation Regulations; with a particular emphasis on the new consensus-driven standards that are envisioned will reshape the design and certification of small general aviation aircraft. While our discussion is by no means complete, nor intended to serve as a final set of legal rules that can govern autonomous aerial technology, we hope that it will serve as a guide for stakeholders and help to ensure that unmanned aerial robots become the safe and resilient transformative innovations that they are destined to be.

Introduction

Brief introduction on UAS

You may not know this, but Unmanned Aircraft Systems ("UAS"), or drones, are not new technology. In fact, unmanned aerial technology has existed since the Wright Brothers.[1] However, its access to airspace across the globe has been severely limited or proscribed altogether. In the United States, the Federal Aviation Administration currently prohibits the commercial use of UAS, while requiring public agencies, universities and researchers to obtain specific authorization to use the technology.[2] That will soon change. A law passed in 2012 paves the way for public and commercial use of UAS in the U.S. by 2015.

[1] Russell Freedman, The Wright Brothers: How they Invented the Airplane 31 (1991).

[2] In February 2007, the FAA published a "policy statement" that exists to this day and prohibits UAS operations without specific authority from the agency. *See* Unmanned Aircraft Operations in the National Airspace System, Docket No. FAA-2006-25714; Notice No. 07-01, 72 Fed. Reg. 29 at 6689 (Feb. 13, 2007). A recent decision by an NTSB administrative law judge finds that this "policy statement" is not controlling law. The FAA has appealed that decision. Decisional Order, Administrator v. Raphael Pirker, NTSB Docket No. CP-217 (March 6, 2014).

The wide-scale use of this technology is likely the most significant change to the aviation industry since the introduction of the jet aircraft, now many decades ago. Today, the NAS consists of more than 100,000 manned aircraft flights each day, and more than 18,000 commercial aircraft and 230,000 general aviation aircraft.[3] Integration of UAS technology thus presents countless challenges for federal regulators and to the NAS, already the world's most busy and complex.

The Modernization and Reform act of 2012

Signed into law by President Obama in February 2012, the FAA Modernization and Reform Act of 2012 (the "2012 Act") requires the Department of Transportation ("DOT") to integrate UAS into the NAS by September 2015.[4] Specifically, it requires the DOT to "develop a comprehensive plan to safely accelerate the integration of civil unmanned aircraft systems into the national airspace system."[5] The plan must include the necessary rulemaking to be conducted, thus mandating that the FAA promulgate specific regulations concerning the unique issues and challenges that the operation of UAS presents to the NAS.[6] The Act also requires that the plan consist of standards for certification, registration and operation of civil UAS, standards for operators and pilots, and ensure that all civilian-operated UAS have an acceptable "sense-and-avoid" capability to avoid mid-air collisions.[7]

By the 2012 Act, the FAA was required to select six test ranges for UAS. Although late in doing so, in December 2013, the FAA fulfilled that obligation through the selection of six sites to address research, development and operational questions that will aid in the development of regulations and standards for UAS operations.[8] Test sites in Nevada, Texas, Virginia, Alaska, New York and North Dakota, each have unique goals that should eventually provide regulators with valuable information.[9] The New York site, for example, will work on research surrounding the sense-and-avoid questions, including developing test procedures and assisting with a plan to manage UAS operating in the congested skies over the Northeast corridor of the U.S.[10]

As also required by the 2012 Act, in November 2013, the FAA unveiled its UAS Comprehensive Plan that outlines the necessary steps to safely integrate UAS into the National Airspace System (the "Plan"). At the time, the FAA also released its Civil Unmanned Aircraft Systems (UAS) in the National

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[3] U.S. Gen. Accountability Office, Unmanned Aircraft Systems, Measuring Progress and Addressing Potential Privacy Concerns Would Facilitate Integration into the National Airspace System (2012), at 4-5.
[4] FAA Modernization and Reform Act of 2012, Pub. L. 112-95, § 332(a).
[5] *Id.*
[6] *Id.* The 2012 Act required the Department of Transportation to present its comprehensive plan, including the necessary rulemaking, within one year of enactment. To date, however, the DOT has not delivered the plan, nor have any rulemaking steps been taken by the government. It is also worth pointing out that, as of the date of this paper, the authors are aware that a recent decision by an National Transportation Safety Board ("NTSB") Administrative Law Judge raises significant doubt on the existence of any enforceable federal regulations specifically concerning the operation of UAS, whether the operation is for commercial or private purposes. Decisional Order, Administrator v. Raphael Pirker, NTSB Docket No. CP-217 (March 6, 2014).
[7] 2012 Act at 332(a)(1)-(2).
[8] FAA, *FAA Selects Six Sites for Unmanned Aircraft Research*, Press Release, December 30, 2013, *available at* http://www.faa.gov/news/updates/?newsId=75399.
[9] *Id.*
[10] *Id.*

Airspace System (NAS) Roadmap (the "Roadmap").[11] For many stakeholders, these document indicate that the FAA plans to integrate UAS slowly over a lengthy period of time, which will include protracted research, testing and federal rulemaking. For potential commercial operators of medium-to-large size UAS, final authorization to operate these aircraft may take a decade or longer.

As explained by the FAA, one goal of the Roadmap is to "guide aviation stakeholders in understanding operational goals and aviation safety and air traffic challenges when considering future investments."[12] Scattered amongst the broad goals that the FAA hopes will shape investment of UAS, are a number of requirements and assumptions that will likely govern future operations, including that UAS comply with existing operating rules or procedures, the need for an airworthiness certificate, a requirement to operate under an Instrument Flight Rules ("IFR") flight plan (like certain manned aircraft operations), the use of a transponder, and air traffic separation capabilities, just to name a few.[13]

The FAA also makes crystal-clear that it will not permit autonomous UAS operations; instead, each UAS must have a "flight crew" that includes a pilot-in-command who "has full control, or override authority to assume control at all times during normal UAS operations."[14] The Roadmap suggests that UAS weighing less than 55 pounds ("sUAS") may avoid some of these rules, provided that they operate *exclusively* within visual line-of-sight of the flight crew.[15]

Brief Introduction on UAS Technology

It is important to understand UAS and associated technology to appreciate the legal challenges that they pose on the current regulatory landscape. Most UAS are one of four different types of airframes, or a variation on the four: (1) fixed-wing airplane design; (2) rotary-wing design; (3) tilt-rotor airframe; and (4) a lighter-than-air model type. Each design offers different capabilities and benefits in terms of speed, range and maneuverability. Generally, these are the main factors that go into choosing the technology best suited for use in a given operation.

The advantages that UAS offer over their manned counterparts are significant. As an engineer for the US Navy working on that organization's UAS program commented: "There's … persistence and endurance. So where a manned pilot can only go for a certain number of hours before human fatigue sets in, [UAS] can keep going and keep going and keep going until it runs out of fuel. Once we demonstrate aerial fueling, we're talking about mission endurance that goes well beyond 20, 40 hours before it has to come back for maintenance." In fact, one manufacturer rumored to be in talks for acquisition by

[11] The FAA also released a third document accompanying the Plan and Roadmap, titled "Notice of Final Privacy Requirements for UAS Test Sites. All three of the documents are available on the FAA website: http://www.faa.gov/about/initiatives/uas/.
[12] Roadmap at 6.
[13] Roadmap at 33-35.
[14] Roadmap at 34. Importantly, the Roadmap also states that "At the core of these policies is the concept that each aircraft is flown by a pilot in accordance with required procedures and practices." Roadmap at 9 (emphasis added). The document also identifies one goal to establish certification requirements for pilots of UAS weighing less than 55 pounds ("sUAS"), including medical requirements and training standards. *Id.* at 52. In sum, these statements suggest that the FAA will at least initially attempt to regulate UAS operations very similar to their manned counterparts, requiring ground-based pilots who have undergone specific training, possible pass an FAA-mandated pilot exam, and who are medically qualified by an FAA-qualified medical examiner.
[15] Roadmap at 34.

Facebook, Titan Aerospace, has developed a UAS that can carry up to 250 pounds in payload and remain airborne for as long as 5 years.[16]

Aside from the more obvious range and endurance benefits, UAS can operate in spaces that manned aircraft cannot, or it is unsafe for them to do so. UAS are also less expensive to design and manufacture, and have the potential for less in operational expenses, though the FAA's Plan to require certified flight crews may lessen that upside.

Generally speaking, each UAS platform is developed for a specific operation and/or application. Often that includes some form of data collection, e.g., audio, video, photography, and remote sensing. Put simply, such systems operate much like a personal computer with data processing capabilities that are controlled remotely via radio devices or, as this article addresses, autonomously and/or through preprogrammed flight.

Exact payload and data handling capabilities that UAS can carry depends on the design and operational needs. In many instances, the user may want streaming data and onboard data backup should something interrupt that stream. That requires advanced data collection and storage, which itself may allow for the live streaming of data in the form of videos, photographs and other information gathered from onboard equipment. Given the modern storage devices on the market, large onboard data retention is possible at relatively small payload weight.

UAS may be custom configured to perform specific in-flight functions as required by each operator. Payloads can be adjusted to fit on various UAS airframes, and each flight may have a different configuration and/or data communication method. In data streaming applications, UAS can transmit real-time video or data to a ground unit and on to points across the globe. In advanced configurations, UAS often have Internet connectivity through an Inmarsat satellite and may therefore transmit data directly over the Internet.

Much of this UAS technology is available today. It can be outfitted on UAS that weigh as little as several ounces and which can operate at very low altitudes.[17] Most typical civilian applications consist of a small, inexpensive UAS often controlled by a smartphone or table PC. The mobile device contains a custom application developed by the aircraft manufacturer or the operator that is downloaded onto the mobile device for use. In many cases, the UAS and the application together can cost as little as $300. There are numerous potential uses of this small and lightweight UAS technology, including photography and video, research and data collection, flight and aviation training, search-and-rescue, agricultural and meteorological analysis, mapping and geographic surveying, infrastructure inspection and repair, amongst others.

Many of the more cutting-edge new UAS designs, most notably of the rotor design, call for the use of autonomous technology for navigation and other in-flight purposes. This technology promises still more benefits for end-users. In certain operations, for instance, autonomous UAS are better suited to

[16] Alan Mark De Luzuriaga, *Facebook Drones: Mark Zuckerberg and Facebook Buy Titan Aerospace for $60 M to Blanket Areas with Wi-Fi; Trounce's Google's Balloons and Amazon's Drones*, The Bitbag, March 12, 2014, *available at* http://www.thebitbag.com/facebook-drones-mark-zuckerberg-facebook-buys-titan-aerospace-60-m-blanket-areas-wi-fi-trounces-googles-balloons-amazons-drones/71247; Sarah Perez & Josh Constine, *Facebook Looking into Buying Drone Maker Titan Aerospace*, TC News, March 3, 2014, *available at* http://techcrunch.com/2014/03/03/facebook-in-talks-to-acquire-drone-maker-titan-aerospace/.

[17] Megan Treacy, *Insects Inspire World's Smallest Autonomous Flapping Drone*, The Treehugger, February 26, 2014, *available at* http://www.treehugger.com/gadgets/insects-inspire-worlds-smallest-autonomous-flapping-drone.html.

identify and maneuver around airborne or ground-based obstacles, as opposed to UAS controlled by an individual from a remote location.

Most of these uses fall outside of the line-of-sight and prohibition on autonomous operations requirements that the FAA insists will eventually become law. As a result, the FAA's proposed regulatory framework may actually stifle or end investment into the smallest and most beneficial UAS platforms. Other UAS developers may move their operations overseas. To prevent such results, the FAA should develop a legal framework that accounts for the unique opportunities and benefits presented by autonomous UAS.

Much of the Current Regulatory Structure and Liability Framework are Ill-Suited for UAS and Autonomous UAS Technology

Thus far, the FAA has offered only mixed messages to the UAS and aviation industries on how it will eventually regulate the technology. On one hand, the FAA has stated that it will attempt to develop rules, regulation and guidance that allow for and support evolving and efficient UAS technology and operations.[18] The agency also understands that it is difficult to apply existing FAA regulations and guidance to the UAS industry.[19] However, the Roadmap states that a baseline requirement will be for UAS to operate under existing flight and operating rules, and they will be required to have a ground-based flight crew and pilot-in-command.[20] Adding to the confusion, in 2011, the FAA in fact initiated legal action against an operator of a sUAS claiming that he violated regulations that apply to pilots of traditional manned aircraft.[21]

The existing Federal Aviation Regulations ("FARs") were never intended to apply to unmanned aircraft. For instance, Part 91 of the regulations, which set forth the general operating and flight rules[22], apply "to each person on board an aircraft being operated under this part, unless otherwise specified." 14 C.F.R. § 91.1. Not surprising then is the fact that many of the regulations contained within Part 91 make no sense when applied to UAS. Courts interpreting the regulations have similarly understood that they apply to manned aircraft. In *Elassaad v. Independence Air, Inc.*, 613 F.3d 119 (3d Cir. 2010, the Third Circuit Court of Appeals scrutinized the meaning of 14 C.F.R. § 91.13(a), prohibiting the reckless or careless operation of an aircraft:

> [T]he statutory and regulatory definitions of "operate" state that a plane is only being operated, within the meaning of § 91.13(a), when it is being "use[d]" for "navigation," and the Aviation Act's definitions of "navigate aircraft" and "air navigation facility" demonstrate that the term "navigation" principally applies to the takeoff and landing of an aircraft, and the "piloting" that occurs during the flight. These definitions contemplate a flight crew's interaction with an aircraft and with passengers who are on the aircraft.

[18] Roadmap at 5.
[19] *Id.* at 6.
[20] For example, the Roadmap states that "UAS will also need to be flown by a certified pilot in accordance with existing, revised, or new regulations and required standards, policies and procedures." Roadmap at 10. For more, see Roadmap at 33.
[21] Administrator v. Raphael Pirker, NTSB Docket No. CP-217 (July 18, 2013).
[22] For flight and operating rules that govern air carrier and other similar operations, see 14 C.F.R. Parts 121 and 135.

Elassadd, 613 F.3d at 130. *See also Abdullah v. American Airlines, Inc.*, 181 F.3d 363, 368 (3d Cir. 1999) ("Congress's purpose in enacting the FAA was to promote safety in aviation and thereby protect the lives of persons who travel on board aircraft.") (citation and internal quotation marks omitted).

The framework for liability that arises from aviation mishaps is grounded on similar assumptions that fault lies with pilot error, technical failure, an external condition such as terrorism, or a combination thereof—all involving human interaction and/or error. Civil liability arising from aviation accidents or incidents most often sound in tort and include theories of liability that range from negligence, strict liability and products liability. Briefly, to successfully bring a negligence lawsuit, the claimant must prove that another party failed to take reasonable care in preventing the risk that led to the injury. Strict liability, on the other hand, can be established without proving fault by simply showing that the individual or entity was engaged in the activity. An injured party may also bring a product liability lawsuit alleging a manufacturing defect, a design defect, a breach of warranty, and/or a failure to warn.

For aircraft operations, regulations and liability principles have historically rested on the pilot-in-command principle, which the Roadmap states will remain in effect for UAS operations.[23] Pursuant to the FARs, the pilot-in-command of an aircraft is directly responsible for, and acts as the final authority as to, the operation of the aircraft.[24] The FARs generally define pilot-in-command as the person who (1) has the final authority and responsibility for the safe operation of the flight; (2) has been designated as the pilot-in-command before or during the flight; and (3) holds the appropriate certification and ratings for the conduct of the flight.[25]

Similarly, federal regulations mandate that it is the pilot's responsibility to see and avoid other aircraft.[26] Courts have echoed this requirement that pilots use all available means to avoid other aircraft, while on the ground and in the air.[27] These rules and principles are also important for purposes of liability because in many jurisdictions a violation of the FARs is evidence of negligence.[28]

The FAA also regulates the design and manufacture of aircraft through the FARS, again grounded on the basis that all aircraft will consist of at least one pilot operator. Most small airplanes and commuter airplanes with a maximum takeoff weight of less than 19,000 pounds are certified under Part 23 of the FARs.[29] Aircraft certified under Part 23 include, for example, the basic four-seat Cessna 172, nineteen seat Beechcraft 1900D turboprop airliner, and small business jets.[30] It is possible that regulators attempt to fold UAS airworthiness, certification and design rules into Part 23, or they may attempt to create an entirely new set of rules specific to UAS design and certification. Although the Roadmap

[23] As the D.C. Circuit has stated, the "ultimate decision is the pilot's since he knows the condition of his aircraft, its capabilities and must deal with the unusual and unexpected during flight." *Neff v. United States*, 420 F.2d 115, 120 (D.C. Cir. 1969).
[24] 14 C.F.R. § 91.3(a).
[25] 14 C.F.R. § 1.1.
[26] 14 C.F.R. § 91.113(b).
[27] *PanAm v. Port Authority*, 787 F. Supp. 312, 318 (E.D.N.Y. 1992); *Spaulding v. United States*, 455 F.2d 222 (9th Cir. 1972) (flight crew members have a continuing duty to be aware of dangers which they can perceive with their own eyes); *In re Aircraft Disaster at John F. Kennedy Int'l Airport on June 24, 1975*, 635 F.2d 67, 74 (2d Cir. 1980) (pilots cannot fail to use their own eyes and ears to be aware of danger; *United States v. Schultetus*, 277 F.2d 322 (5th Cir. 1960)("[A] clearance issued by a tower … either by radio or visual signal is permissive in nature and does not relieve the pilot from exercising a reasonable degree of caution in executing the provisions of the clearance); *Thinguldstad v. U.S.*, 343 F. Supp. 551, 557 (S.D. Ohio 1972) (flight crew members have a continuing duty to be aware of the dangers which they can perceive with their own eyes").
[28] *See, e.g., Texasgulf Inc. v. Colt Electronics Co.*, 615 F. Supp. 648, 660 (S.D.N.Y. 1984).
[29] 14 C.F.R. §§ 23.1, 3.
[30] Larger transport category airplanes, like the Boeing 737 and Airbus A380, are certified under Part 25. 14 C.F.R. § 25.1.

suggests that the FAA may use both some new and existing certification regulations, it also suggests that the proposed regulatory framework may be much more burdensome than UAS developers had hoped for.

Currently, Part 23 consists of highly specific areas of test, verification and inspection, many of which are relevant only to manned aircraft.[31] In fact, it includes over 360 different areas that manufacturers and designs must satisfy before a new aircraft is certified as airworthy. As is discussed in more detail, *infra*, that has become a barrier to manufacturing small aircraft with modern equipment. One estimate pegs the cost to develop a small airplane in the range of $100 million from start to finish.[32]

This broadly summarizes the legal and regulatory framework that exists for much of the aviation industry today. It also helps to explain why the FAA is not ready to upend the legal and regulatory framework that has been constructed around the concept of manned aircraft. The introduction of the UAS—and the autonomous UAS, in particular—complicates these long-standing principles. Without an individual operator in the air or on the ground, for example, the list of potential parties at fault for an accident or incident may change. Such a list might include: the operator or owner of the platform, the UAS manufacturer, the automator, and the programmer, just to name a few. In short, there are countless regulatory and liability issues that demand early attention so that they will not prevent the many benefits promised by the use of autonomous UAS.

The UAS Autonomy Spectrum

Simply put, the mandate of all UAS operators is to fly the aircraft in a safe manner. This of course applies to manned aircraft as well. To do so effectively requires strict adherence to aerodynamic principles. These principles apply to pilot control as well as autonomous control and all varying degrees in between. Thus, there is a spectrum of autonomy that lies between total pilot control and total autonomous control.

In this paper, the spectrum shall be called the "UAS Autonomy Spectrum". Figure 1 depicts the Autonomy Spectrum with full pilot control represented on the right and full system control represented on the left with varying degrees depicted in the central portion converging on a central point which represents equal aircraft control by both entities. This point shall be called the "control ball".

Figure 1 The UAS Autonomy Spectrum

[31] For example, Part 23 includes topics on oxygen and pressurization systems and seat construction. 14 C.F.R. § 23.
[32] *Washington Report: FAR Part 23 Rewrite*, Air Facts, Nov. 13, 2012, *available at* http://airfactsjournal.com/2012/11/washington-report-far-part-23-rewrite/.

Pilot control, system control, or a blending of both on the Autonomy Spectrum provides the foundation for the safe flight of the aircraft. The operation of a UAS requires that the aircraft maintain aerodynamic lift while retaining stability and control in a safe and reliable manner. Stability is the aerodynamic behavior of an aircraft to remain in its current state in time at rest or in motion regardless of the disturbances such as wind, turbulence, or friction that act upon it. A UAS must be stable if it is to maintain safe flight. Stability indicates that the aerodynamic forces of lift, drag, thrust and weight are all in relative balance and if disturbed will be quickly restored to the original state of stable equilibrium.

Control, on the other hand, is maintaining the balance of the aircraft on its respective axes while in flight. The axes are pitch, roll, and yaw. The aircraft must be in a state of control as aligned through its control surfaces which vary depending on the particular UAS design, but in terms of general fixed wing aircraft they are elevator, aileron, and rudder control.

The stability and control as well as the overall operation of the UAS will be a blend of pilot control and system control, or one of the two extremes on the Autonomy Spectrum. The location of the control ball on the spectrum diagram represents the degree of control present in the current scenario.

Pilot Control

Pilot control reflects full pilot operator control of the aircraft and is represented on the UAS Autonomy Spectrum in Figure 2. It means that the operator is in full control of all three axes of the aircraft: the roll axis, the pitch axis and the yaw axis.

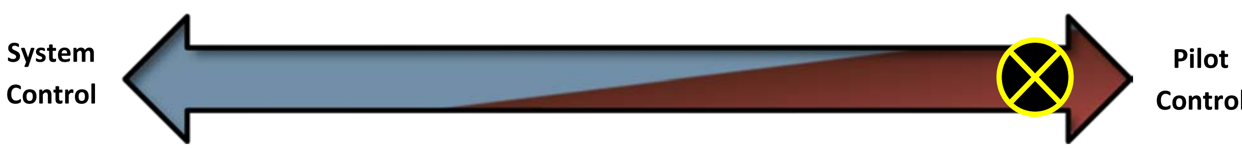

Figure 2 Full Pilot Control

Pilot control also means that the pilot is fully controlling the means of stabilizing the aircraft, such as controlling thrust by maintaining control of the propulsion system, maintaining lift, and maintaining the equilibrium of the airframe as it operates against opposing forces. It also means that the pilot is controlling various systems in the aircraft such as navigation systems, communication systems, payload systems, sensor systems, and so forth.

The term "pilot" is actually a general term with unmanned systems, as there can be many individuals involved with the control of the aircraft, especially complex UAS systems with advanced payloads:

- **Pilots**: human operators that control or partially control the aircraft from a distance;

- **Payload Specialists**: personnel that control and operate the payloads of the aircraft to ensure optimal performance;

• **Safety Personnel**: personnel that monitor operations to ensure safety in all areas of UAS operations including spotting and collision avoidance;

• **Launch and Recovery Personnel**: provide support for safe launch and recovery operations;

• **Operations Supervisors**: provide overall supervision to the UAS evolution;

• **Navigation and Communication Specialists**: direct and control communications and navigation operations.

At any one time, several of these individuals may be in control of the aircraft or directing control of the aircraft. Thus legal liability may rest on a number of individuals in the event of a mishap or incident. However, for general discussion purposes and simplicity, the term pilot will be used on the Autonomy Spectrum and will encompass all of the operators that are in control of the aircraft.

<u>Autonomous Control</u>

Autonomous control reflects that the control of the aircraft is maintained through the aircraft hardware and software systems. In a UAS this control is maintained by the onboard computer system which is fed information by onboard sensors, actuators, controllers, GPS and navigational signals, as well as complex software algorithms which all together maintain the operations, stability and control of the UAS in all aspects of its flight. In a fully autonomous flight, all of these systems are working in tandem to ensure a safe, reliable flight to perform the mission of the UAS. Fully autonomous flight is depicted in Figure 3.

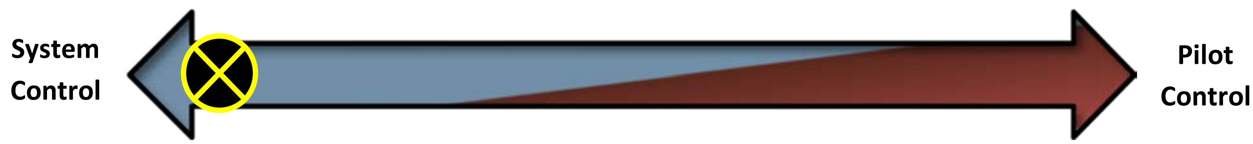

Figure 3 Full Autonomous System Control

Autonomous control means that the UAS as a complex system is in full control of the roll, pitch, and yaw axes of the aircraft. It also means that the UAS internal computer system is fully controlling the means of stabilizing the aircraft: propulsion control, lift maintenance, equilibrium maintenance, as well as internal systems operations control of the payload, navigation system, sensors, and so forth. With full autonomous control, the internal computer, guided by external stimuli and navigation inputs, is controlling the aircraft.

The degree of control can be relatively fixed in the computer algorithms, where the source and destination locations are programmed into the system by the operators and general sensor inputs control the altitude, attitude and airspeed of the aircraft. The degree of control can also be more flexible with more artificially intelligent algorithms programmed into the computer allowing the UAS to make decisions during its operation in addition to its general autonomous control capabilities. The degree of complexity of these artificial intelligence capabilities varies considerably depending on the scope and mission of the UAS.

Migrating from Pilot to Autonomous Control

The operation of a UAS will cause the control ball in the Autonomy Spectrum to continually shift from right to left in varying degrees throughout flight operations. The degree to which the pilot depends on the UAS system to control the flight will greatly depend on the sophistication and complexity of the aircraft.

In general, automatic flight control systems within a UAS have several degrees of autonomous system control:

- **Throttle Control**: to maintain control of the propulsion system to control the UAS airspeed;
- **Altitude Control**: to maintain lift to fly at a designated altitude;
- **One Axis Control**: Controls the roll axis, usually through ailerons on fixed wing aircraft;
- **Two Axis Control**: Controls the roll axis and the pitch axis, through the ailerons and elevators on fixed wing aircraft;
- **Three Axis Control**: Controls the roll, pitch and yaw axes, through the ailerons, elevators and rudders on fixed wing aircraft.

The pilot has the capability to vary the control of the aircraft between full pilot control, one, two and three axis control. The pilot can also determine the degree of throttle control and altitude control. Handing over three axis control combined with full throttle control and altitude control to the UAS would be giving the aircraft full autonomous control of its flight operations. The pilot has the flexibility to vary the autonomy throughout the flight with perhaps no autonomy during takeoff and landing operations and full autonomy during midflight. With the pilot in full control, the degree of autonomy, if any, is at the discretion of the pilot in command.

Voluntary Autonomy

The scenario where the pilot has full control of the autonomy of the aircraft is deemed voluntary autonomy. In this scenario, the pilot is free to take full control of the aircraft or shift control to the UAS system in varying degrees, depending on the specific needs and requirements of the pilot in the current situation. The degree of autonomy is fully controlled by the pilot, and autonomy can be revoked at any point in time for any reason by the pilot.

In some scenarios, the UAS can be set into fully autonomous mode from launch to recovery, but this is considered voluntary, even if the system strays off of its intended path, since the operator has set the system as autonomous from mission initiation. This voluntary mode requires careful considerations of the limitations of the internal navigation and computational systems of the aircraft to ensure that the aircraft does indeed complete its flight according to the predetermined waypoints.

Involuntary Autonomy

Involuntary autonomy arises when the pilot loses control of the aircraft through means external to pilot control. This instance can come about instantaneously or gradually over time through a cascading effect of systems failures.

One way to invoke involuntary autonomy is through a lost link. This is when the communications of the ground station are lost with the UAS, and the aircraft is forced to fly in fully autonomously. Lost link can be caused by weather, terrain, communications systems failures, electrical systems anomalies, and many other factors. The internal algorithms and systems of the UAS will determine how the aircraft responds to this situation.

In response to a lost link, the aircraft can hover or circle and attempt to reconnect the communications link. It can attempt an auto-land. It can maintain its current heading and attempt a communications reconnect. The varieties of lost link algorithmic recoveries are vast, depending on the complexity and sophistication of the computational system within the aircraft. In some lower end systems, a lost link will mean a certain crash of the aircraft.

A second method of involuntary autonomy is the result of a system failure. In this event, the pilot loses one, two or three axis control or throttle control or altitude control. The pilot may have partial control of the aircraft or none at all depending on the extend of the damage of the aircraft. Some advanced UAS systems have an auto-land feature which can help mitigate this situation, if it is indeed functional after the systems failure. Other systems have no methodology and the aircraft will thus become fully or partially autonomous with or without full aerodynamic stability and control of the airframe. With this type of involuntary autonomy, the loss of control can have catastrophic consequences if measures are not built into the system by the manufacturer or if specified operations are not put in place by the operator to handle the situation expeditiously and judiciously.

A final issue to mention is the loss of pilot control through malicious means, such as GPS spoofing or viruses and malware. With GPS spoofing a UAS could be hijacked and crashed or set into autonomous mode by spoofing its live GPS signal. Viruses and malware can cause the internal computer system to execute unscripted commands, relinquishing pilot control and forcing the system into autonomous control. Malicious means can also give a third party access to the controls of the UAS, resulting in loss of pilot control and internal autonomous control.

Malicious third party intervention in UAS operations has a dangerous and chilling effect in the safe operations of unmanned aircraft in the national airspace. As such, both manufacturers and operators must ensure that safeguards are in place to avoid these scenarios, since malicious control or malicious involuntary autonomy can lead to catastrophic consequences both in the air and on the ground.

UAS Autonomy Spectrum as a Guide for a Legal Framework

The UAS Autonomy Spectrum is visual guide for a legal framework to assist lawmakers in visualizing the degree of pilot and system control in an unmanned aircraft. Through this visualization, regulations can be developed to ensure the safe and reliable operation of the UAS in the NAS. It is important to remember that the point of control is continually changing in flight operations, and thus it may be difficult to determine the actual degree of autonomy in the system at any given time. Therefore, the UAS Autonomy Spectrum should only be used as a point of reference and not as a definitive measure of autonomous control in terms of actual system operations.

It is vital for lawmakers and legal professionals to understand the autonomous systems in an unmanned aircraft, and their impacts on the aircraft through stability and control to effectively craft effective legislation to regulate UAS. A lack of understanding of this technology can lead to misguided laws resulting in confusion both in manufacturing and in the operational side of unmanned systems which can have a negative cascading effect on the safe operations of unmanned systems. As such, the UAS Autonomy Spectrum is a critical tool to help orientate and educate legal professionals on the autonomous capabilities and systems of UAS and the varying degrees of autonomy that can be present in a UAS at any one time during flight operations.

Broad Considerations that Should be Taken Into Account in Any Legal Structure for Autonomous UAS

The mere fact that UAS will be flying in the NAS means that some of the aircraft will be flying in an autonomous mode at any given point in time regardless of the current regulations. This does not mean that operators are trying to bypass the law. As demonstrated in the Autonomy Spectrum discussion, an unmanned system may be thrust unexpectedly into fully autonomous mode. This will place the operator and the manufacturer into a nebulous liability situation if laws and regulations are not in place to handle the situation, and force the courts to make the legal decisions on this highly technological matter.

Operators and corporations, too, will be pushing the envelope on autonomous unmanned aircraft for the delivery of their product, for the hosting of their aerial wireless WI-FI clouds, and for uses only the future can dream up. The reality is that if UAS are permitted into the national airspace in large numbers, operators will continually push the “control ball” left in the UAS Autonomy Spectrum slowly and under the proverbial legal radar until fully autonomous systems are operating in the norm, with the regulatory system left in the dust. This is what historically happens in the technological world where the law lags behind by many years or decades. Unfortunately, with unmanned aircraft flying in the midst of manned aircraft in the NAS, UAS law cannot afford to repeat this historic trend.

Therefore, the UAS Autonomy Spectrum must be considered when crafting laws and regulations regarding UAS autonomy and the varying degrees of UAS autonomy. In conjunction with the UAS Autonomy Spectrum, the following broad considerations should be considered as guide points for analyzing the structure and purpose of UAS laws to ensure the safe, reliable operation of unmanned systems and to ensure that all entities involved in their manufacture and operation understand their roles and responsibilities in maintaining a safe national airspace. These considerations are purposely broad to ensure that they cover salient points while not being too overbearing with details as to distract from the purpose of the paper which to give a broad overview of the myriad issues that permeate the field of unmanned aircraft integration into the national airspace.

Human-Systems Interdependence

Will self-sufficient and autonomous UAS mean less liability for their human operators? This is one of the most logical considerations for operators of all autonomous machines, not just UAS. Self-sufficient UAS may lead to human operators with decreased capability to observe and understand the autonomous operations and it will become a taxing legal concern. This becomes a problem of interaction between in human-machine interaction. Moreover, it is conceivable that full autonomous UAS may not communicate effectively so as to allow for human interdependence.

An operator that is unable to understand what the autonomous UAS is doing, why it is doing it, or when it will finish, will be much less likely to take on risk of liability for the autonomous activity. This is both a design and legal concern. In fact, one outcome may be that increased knowledge requirements and skill demands are imposed on operators through regulation and/or standards of liability. Too, a regulatory framework might require autonomous UAS to have the capability to communicate effectively and work interdependently with human operators.[33]

As the "control ball" moves left towards systems control the human operator becomes more of an observer or monitor of the system than an operator as seen in Figure 4. UAS operation thus becomes a human factors situation which has many training and skill implications that are quite different from basic piloting skills. It also has a different set of responsibilities which must be reflected in laws and regulations.

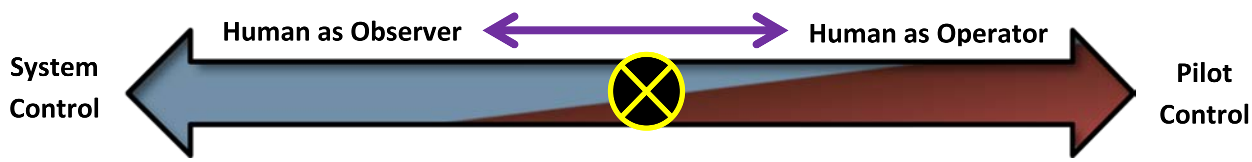

Figure 4 Human-System Interdependence Considerations

In larger UAS operations, two or more personnel perform these functions, one as the pilot, and one as the observer. However, in many situations, the tasks will be performed by a single human. Given the complexities of flight, this dual nature of operator and observer can inject risks into the unmanned

[33] For more on this concept, see M. Johnson, et al., *Autonomy and Interdependence in Human-Agent-Robot Teams,* IEEE Intelligent Systems, Vol. 27, No. 2 (2011), at 43-51.

aircraft operations. Thus considering the UAS as a human-in-the-loop system is important for a regulatory framework. The fields of Human Factors Engineering and Human Computer Interaction (HCI) as well as their related fields therefore must be considered when crafting UAS regulations. These fields are constantly changing and improving, so specialists in these respective fields should be consulted by lawmakers on a regular basis to ensure that the latest research and analysis is reflected in UAS law and regulations.

Un-commanded/Involuntary Autonomy

What about automation surprises – new features, options and modes that create new demands, types of errors, and paths toward failure? Un-commanded, involuntary full autonomy must be a situation that is carefully considered in a regulatory framework as it is an inevitable scenario that will be played out continually in the national airspace as more and more UAS permeate the sky.

To illustrate this situation, the one of the authors performed a comprehensive study[34] of the largest power user of UAS in the United States, the US Air Force, which operates over 66 percent of the unmanned military aircraft in the United States arsenal[35]. In this comprehensive study of ten years of unmanned aircraft Class A mishaps within the Air Force, between fiscal years 2004 and 2013, there were 75 Class A mishaps.

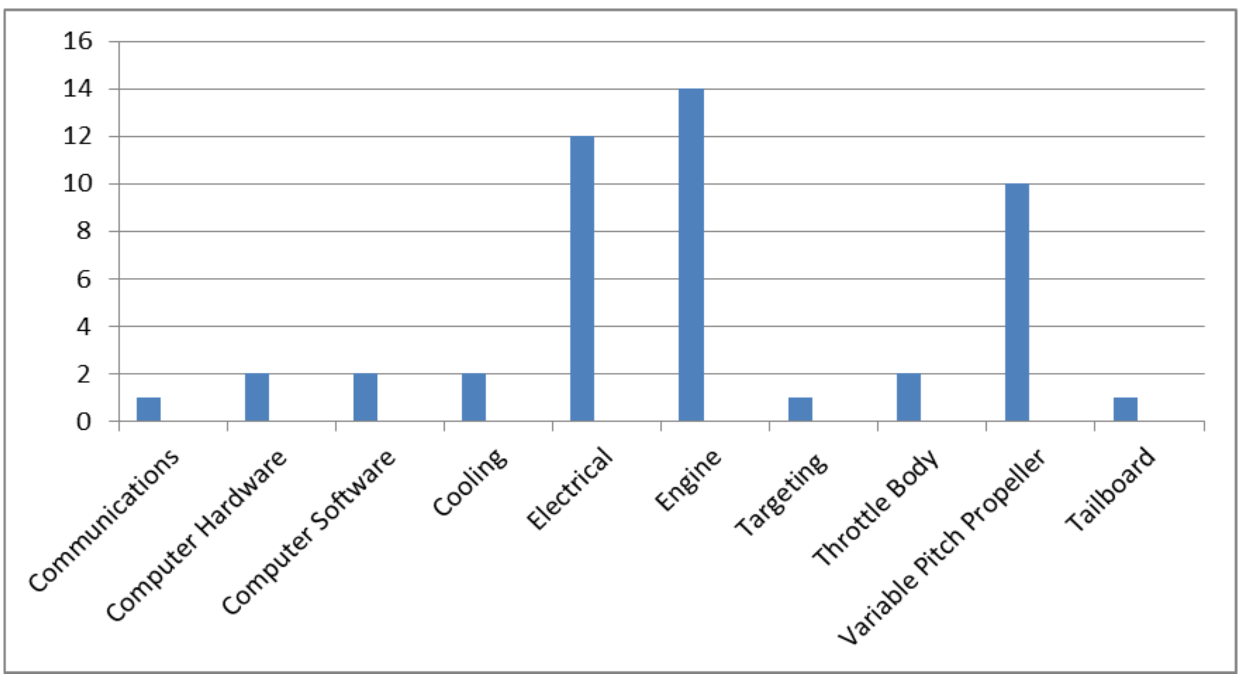

Figure 5 Air Force Class A Unmanned Aircraft Hardware and Software Systems Mishap Causes

[34] For the full results of the study, see Beyer, D., Dulo, D. Townsley, G. & Wu, S. (April 5, 2014). Risk, Product Liability Trends, Triggers, and Insurance in Commercial Aerial Robots. WE ROBOT Conference on Legal & Policy Issues Relating to Robotics. April 4-5, 2014, University of Miami School of Law.

[35] Bowie, C. & Isherwood, M. (Sept. 2010). The Unmanned Tipping Point. Air Force Magazine. http://www.airforcemag.com/MagazineArchive/Pages/2010/September%202010/0910rpa.aspx

The Air Force defines a mishap as an unplanned event or series of events resulting in death, injury, occupational illness, or damage to or loss of equipment or property, or damage to the environment. It defines a Class A mishap as a noncombat accident that results in a death, a permanent total disability, or damage of at least $1 million[36]. Figure 5 demonstrates the various systems that failed during the ten year study resulting in loss of the control of the aircraft while in operation.

Systems failures such as the ones in Figure 5 cause the "control ball" in the UAS Autonomy Spectrum to suddenly and unexpectedly shift hard to the left, making the pilot an instant unwitting observer, and in many cases extracting all operator control from the pilot instantaneously as depicted in Figure 6. This sudden shift of the control ball can have catastrophic consequences, especially if the pilot is unable to regain partial control of the aircraft to enable a controlled crash or to initiate an auto-land of the system.

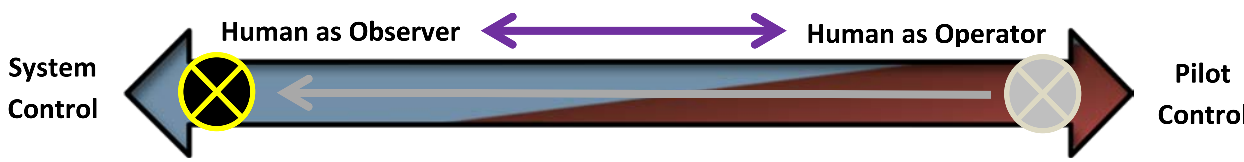

Figure 6 Un-commanded/Involuntary Autonomy Considerations

UAS have demonstrated a high accident rate in the Air Force as compared to the manned aircraft fleet. The Bloomberg BGOV Barometer statistics indicate that Northrop's Global Hawk and General Atomic's Predator and Reaper have a combined 9.31 accidents for every 100,000 hours of flying time which is the highest rate of any aircraft of any category and more than triple the Air Force fleet wide average of 3.03 accidents for every 100,000 hours[37].

This high accident rate is indicative of the need to focus civilian regulations on the safe manufacture of unmanned aircraft to prevent un-commanded and involuntary autonomy. The systems failures in Figure 5 give a clear initial indication of which areas of the UAS systems to focus upon in these regulations, although more detailed studies over time across a wide variety of unmanned aircraft models would be most beneficial to lawmakers. However, the point being that studies like the one mentioned above coupled with informed and accurate statistics of UAS failure rates, manufacturer specifications of UAS model performance and designs, as well as the results of crash tests and risk mitigation studies on the various aircraft are vital to the legislative and regulatory decision making process in the area of unmanned systems.

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[36] Air Force Safety Agency (July, 2000). Air Force System Safety Handbook. HQ AFSC/SEPP Kirtland AFB, NM.
[37] McGarry, B. (June 17, 2012). Drones Most Accident-Prone U.S. Air Force Craft: BGOV Barometer. http://www.bloomberg.com/news/2012-06-18/drones-most-accident-prone-u-s-air-force-craft-bgov-barometer.html

Sense and Avoid Considerations

Sense-and-avoid – is operator/owner liable for the sense and avoid actions of the UAS? The FAA has specific national goals for sense and avoid capabilities. In the Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap First Edition-2013[38], the FAA targets an Airborne Sense and Avoid (ABSAA) certification for the national airspace in 4 stated goals:

- **Goal 1**: Initial FAA certification of ABSAA that facilitates UAS operations without the requirement for a visual observer by 2016–2020.

- **Goal 2**: Installation and certification of ABSAA developed to meet industry standards for use by the DoD and other public and civil entities that provide the SAA functions required in the NAS for Classes A, E, and G airspace, and operations approved without the requirement for a visual observer or a COA.

- **Goal 3**: DoD or other public entity certification of initial ABSAA systems that enable the DoD and other public entities to safely operate ABSAA-equipped UAS in all NAS airspace classes without the need for a COA.

- **Goal 4**: Installation and certification of ABSAA systems for use by the DoD and other public and civil entities that provide the SAA functions that facilitate integrated operation of manned and unmanned aircraft in all NAS airspace classes.

The goals are broad and ambitious but lack specificity as to the desired actions of the aircraft during the sense and avoid operations. This is deliberate as the Roadmap is of a high level. However, in the details of the laws that are developed from this roadmap, the conditions of autonomy that may be initiated must be a part of the regulatory scheme for several reasons.

During a sense and avoid operation, one of both of the aircraft will be diverted to an alternate path that most likely will be independent of pilot control. As such, the pilot will be in the position of an observer rather than an operator, which will shift the control ball on the UAS Autonomy Spectrum to the left. This may be an unexpected event, and if the pilot is caught unaware, the pilot may counteract the sense and avoid commands of the aircraft causing even more disruption to the already diverted flight path.

The degree of sense and avoid may in fact correspond to the degree of autonomy in the system, as depicted in Figure 7, which is another way to ensure safety, but is another way to facilitate fully autonomous systems in the national airspace. Sense and avoid algorithms may be programmed into the UAS to correspond to the current level of automation in the UAS at the time, thus if the pilot is in full control, the sense and avoid systems will send a warning to the pilot to divert. If the system is in autonomous mode or in a higher degree of autonomy than pilot control, the sense and avoid system architecture will trigger fully autonomous collision avoidance.

[38] FAA. (2013). Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap First Edition-2013. http://www.faa.gov/about/initiatives/uas/media/uas_roadmap_2013.pdf

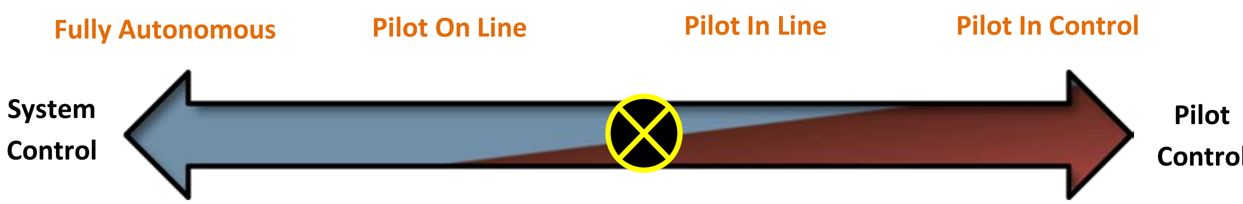

Figure 7 Sense and Avoid Considerations

The matching of the degrees of sense and avoid and the Autonomy Spectrum are depicted in Figure 7. The degrees of automation in relation to sense and avoid are as follows:

> **Pilot in Control**: The pilot directly commands the stability and control of the aircraft on all axes including throttle and altitude control;
>
> **Pilot in Line**: The unmanned aircraft follows a pre-programmed flight but the pilot can take full control of the aircraft at any time in a sense and avoid situation;
>
> **Pilot on Line**: The unmanned aircraft follows a pre- programmed flight but the pilot can only take over the navigation control (set inputs as headings or waypoints only). The pilot cannot take over the aviation function of the aircraft even in a sense and avoid situation, the aircraft systems are relied upon fully during sense and avoid scenarios;
>
> **Fully Autonomous**: The unmanned aircraft controls all stability and control functions including throttle and altitude control during a sense and avoid situation.

The degree of autonomy, thus the position of the control ball on the UAS Autonomy Spectrum, will play a major part in the rulemaking. Aircraft systems that are highly automated will need more safe and reliable sense and avoid subsystems than those unmanned systems which rely primarily on pilot control. Lawmakers must be cognizant of this fact and create a stratified sense and avoid regulatory scheme, not a one size fits all set of laws.

The actions of the unmanned aircraft in the sense and avoid system will be dependent on the algorithmic programs developed by the manufacturer, which will be dependent on the regulations that are based upon the FAR §91.113. An aviation rulemaking committee of the FAA is currently evaluating FAR §91.113, which prescribes aircraft right of way rules to accommodate UAS sense and avoid systems so that they can avoid aircraft collisions.[39]

The FAA has stated that it expects sense and avoid standards to be published by 2016.[40] Hopefully, these standards will reflect the real, not theoretical needs of the UAS industry and will

[39] See Clarey, B. (July 22, 2013). FAA Plans Unmanned 'Sense and Avoid' Rule in 2016. AIN Air Transport Perspective. http://ainonline.com/aviation-news/ain-air-transport-perspective/2013-07-22/faa-plans-unmanned-sense-and-avoid-rule-2016
[40] Id.

consider the current and future autonomy requirements to ensure that as UAS inch closer to fully autonomous control, the sense and avoid standards and regulations will accommodate them without the need for disruptive and time wasting revision.

Malicious Control Considerations

Malicious Takeover – what is the extent of liability if a third party takes over the aircraft, through autonomous means or direct control; what measures should have been in place to prevent liability? Malicious control is a major threat to the UAS industry as a whole. The field of Information Assurance is expansive in the computer and information fields, and this logically extends to unmanned systems as the control and operations of unmanned systems are extremely data and communications intensive. However, information assurance and information security seem to be on the backburner to safety yet they are the possible direct first line causes of malicious takeovers or loss of control that can cause safety issues in the first place.

An unmanned aircraft is not merely an aircraft that flies by itself but in systems engineering terms, it is a "system of systems" consisting of the aircraft, the ground station, the GPS satellite constellation, the communication infrastructure (L-Band and C-Band or radio-controlled, for example), the launch & recovery infrastructure, the personnel, etc. All aspects of these systems must be secured and maintain information assurance, as data is constantly transmitted in the form of information and commands.

UAS operations have computational and communicational complexity giving rise to increasing risk to information assurance threats. Attacks can occur in: embedded UAS systems, software, hardware or any combination of them, as depicted in Figure 8.

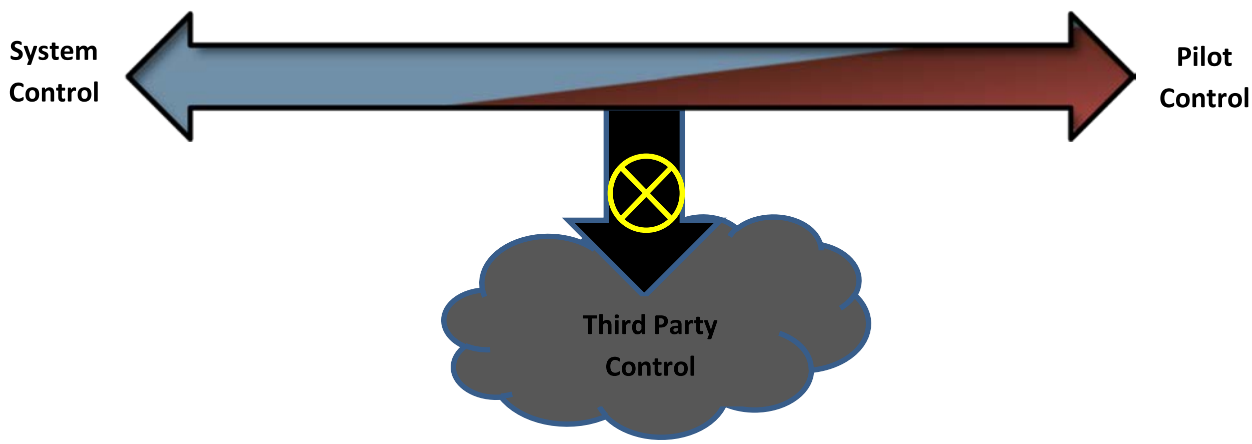

Figure 8 Malicious Control Considerations

Embedded systems security is a major concern for UAS as well as manned aircraft and satellite systems. Embedded systems tend to have generic hardware & software, which in many cases do not have a development process with mandatory security protocols. This can result in built in vulnerabilities in the chips (integrated circuit hardware) and the software that drives the chips. The interconnectivity of the system of systems makes these vulnerabilities pervasive throughout the entire system. Example: A virus in a UAS chip can spread to the ground station or a networked UAS.

Malicious software in embedded systems such as Integrated Circuits (IC) or Programmable Logic Controllers (PLC) can inflict physical as well as informational damage in a UAS. Controllers are real time computer chips that have the potential to manipulate electrical outputs based on the programming conditions within the controller or integrated circuit. The chips or controllers are connected to electrical devices such as pumps, motors, sensors, or other electromotive devices which have a specific electrical purpose controlled by the chip or circuit. Through what is called ladder logic, the laws of physics, as well as the laws of information technology, enable the fusion and functionality of the controller, the computational logic, the software, and the UAS electronics to operate in a viable manner.

An embedded cyber-attack acts impede the physical processing of the controllers; this is what makes it dangerous and deadly. Malicious manipulations of the controllers can lead to logic issues resulting in software corruption or in the worst case scenario physical damage to the hardware of the system due to erroneous electrical impulses in the physical manifestations of the logic carried out in the electronics attached to the controllers. The result is damage to the UAS and possibly catastrophic failure or malicious control of the UAS from rearranged logic signals. The overall result is an unexpected shift into non-pilot control through either failure (fully autonomous mode) or through a malicious third party (third party control).

Viruses, worms and other forms of software based malware are critical threats for UAS systems; both aircraft and ground stations. These forms of malicious software are particularly dangerous even though they are often dismissed as issues in unmanned systems. To demonstrate the possible catastrophic effects of malware in an aircraft system consider the fate of a civilian airliner. On August 20, 2008, Spanair Flight 5022, an MD-82 crashed on takeoff from Barajas Airport in Madrid killing 154 and critically injuring 18 others. The cause of the crash was an improperly functioning takeoff warning system, whose failure was caused by a malware infection in the central computer system of the aircraft. The official accident report speculated that the malware entered the system through a USB port or a VPN connection[41].

A final malicious issue to mention is GPS spoofing. GPS civilian signals are an open standard, with free accessibility signals. This
transparency and predictability has created a major weakness – the ability to be spoofed which means it can be replicated easily. This means that the GPS signal can literally be faked to an unmanned system causing it to follow fake GPS coordinates, which means that the malicious third party "spoofer" can gain control of the aircraft. There are various technological ways to conduct GPS spoofing, and the equipment is not very expensive, thus this vulnerability remains a considerable threat to unmanned systems in the national airspace.

Lawmakers and legal professionals must take information security and information assurance as seriously as they do safety as there is a direct correlation between security and safety, as mentioned

[41] Comision De Investigacion De Accidentes E Incedentes De Aviacion Civil. "Accident Involving Aircraft MD DC-9-82 (MD-82) Registration EC-HFP, Operated by Spanair at Madrid Barajas Airport on 20 August 2008". Interim Report A-032/2008, August 4, 2009.

above. A maliciously hijacked unmanned aircraft is a danger to everyone in the national airspace and on the ground, and an infected autonomous aircraft fares no better.

Regulations and laws governing UAS must place mandates on the minimum levels of information assurance and security that are built into unmanned systems as well as policies and procedures that are followed in unmanned systems operations. Failure to do so places the entire national airspace at risk, and we do not want to wait until a maliciously controlled UAS flies into the engine of a passenger filled jetliner to get the idea of creating informations security regulations. Security must be at the forefront of a UAS regulations and laws, right up there with safety.

Regulatory Considerations

The development of a regulatory framework that is easily adaptable to technological change and innovation is key. One of the most significant problems for aircraft manufacturers and designers has been the large regulatory burden that prevents the introduction of innovative technology. The small airplane design and certification requirements of Part 23 were drafted under a long-held assumption that small airplanes are simple, slow and generally less complex than large transport airplanes.[42]

For several decades, Part 23 offered a basic and efficient process to design, certify and produce small airplane. But that is no longer true. Technological advances in manned aircraft and the aviation industry, more generally, have skyrocketed over the last several decades. And, some of the most innovative technological advances are being implemented in UAS products.

Despite the rapidly evolving airplane design advancements, few significant changes have been made to the certification process for small aircraft. The FAA has instead implemented countless piecemeal rule changes to Part 23. The practice effect of those changes has resulted in crushing oversight and complex certification specifications for many small aircraft manufacturers. The costs to comply with the myriad requirements have become a barrier to producing small airplanes with modern safety equipment, and they are one of many reasons that the U.S. has is at a 50-year low for certified private pilots.

The FAA is in the process of re-working Part 23 and the agency should use what it has learned there to develop certification requirements for UAS, particularly the autonomous UAS. Rigid and quickly outdated rules should be discarded for certification requirements set by consensus-driven industry panels comprised of consumers, manufacturers, and other key stakeholders.

Regulators plan to reorganize Part 23 on these principles and a similar process is already now in use for aircraft certified under the light sport aircraft category. For that new sector of the aviation industry, the consensus-driven certification model has resulted in significant benefits.[43] The bottom line is that the FAA must not let technological advances outpace the regulatory framework. Nor should it foreclose some of the newest autonomous UAS technology from seeing the light of day because it is not prepared to handle their operation.

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[42] Federal Aviation Administration, Part 23 – Small Airplane Certification Process Study 6, 16, 20 (2009), *available at* www.faa.gov/about/office_org/...offices/.../CPS_Part_23.pdf.
[43] Robert Goyer, *Certification Rules that Make Sense*, Flying Magazine, July 2013, at 12.

Conclusion

Pilot versus autonomous control is a vital issue that must be considered when crafting legislation for unmanned systems in the national airspace. While the FAA has indicated that it will prohibit autonomous control of UAS in the national airspace, it is inevitable that fully autonomous aircraft will emerge whether the aircraft are in that state on a voluntary or involuntary basis. The issue is not if but when and therefore a system of regulations to delineate liability must be developed to assist manufacturers, operators, and legal professionals in understanding the limits of civil liability when unmanned systems are involved in civil actions. The proposed framework, based on the presented UAS Autonomy Spectrum is an initial proposal to start the discussion in this critical area of jurisprudence. With the emerging pervasiveness of unmanned systems in the national airspace, a proactive stance in this area is mandatory to ensure that all participants in the operation and development of unmanned systems understand their roles and responsibilities in keeping the national airspace safe for everyone.

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