INTRODUCTION TO UNMANNED AIRCRAFT SYSTEMS

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1 History

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1.1 THE BEGINNING

The history of unmanned aircraft is actually the history of all aircraft. From centuries past when Chinese kites graced the skies to the first hot air balloon, unmanned flying craft came first before the risk of someone climbing on board occurred. One early user of unmanned aircraft was by the Chinese General Zhuge Liang (180–234 AD) who used paper balloons fitted with oil-burning lamps to heat the air; he then flew these over the enemy at night to make them think there was a divine force at work. In modern times, unmanned aircraft have come to mean an autonomous or remotely piloted air vehicle that flies about mimicking the maneuvers of a manned or human-piloted craft. Even the name assigned to unoccupied aircraft has changed over the years as viewed by aircraft manufacturers, civil aviation authorities, and the military. Aerial torpedoes, radio controlled, remotely piloted, remote control,
autonomous control, pilotless vehicle, unmanned aerial vehicles (UAVs), and drone are but some of the names used to describe a flying machine absent of humans.

In the early years of aviation, the idea of flying an aircraft with no one inside had the obvious advantage of removing the risk to life and limb of these highly experimental contraptions. The German aviation pioneer Otto Lilienthal, circa 1890s, employed unmanned gliders as experimental test beds for main lifting wing designs and the development of lightweight aero structures. As a result, several mishaps are recorded where advances were made without injury to an onboard pilot. Although such approaches to remove people from the equation were used, the lack of a satisfactory method to affect control limited the use of these early unmanned aircraft. Early aviation developmental efforts quickly turned to the use of the first “test pilots” to fly these groundbreaking craft. Further advances beyond unmanned gliders proved painful as even pioneer Lilienthal was killed flying an experimental glider in 1896.

As seen in the modern use of unmanned aircraft, historically unmanned aircraft often followed a consistent operational pattern, described today as the three D’s, which stand for dangerous, dirty, and dull. Dangerous being that someone is either trying to bring down the aircraft or where the life of the pilot may be at undue risk operationally. Dirty is where the environment may be contaminated by chemical, biological, or radiological hazards precluding human exposure. Finally, dull is where the task requires long hours in the air making manned flight fatiguing, stressful, and therefore not desirable.

1.2 THE NEED FOR EFFECTIVE CONTROL

The Wright Brothers’ success in flying the first airplane is more of a technical success story in solving the ability to control a piloted, heavier-than-air craft. Doctor Langley, the heavily government-financed early airplane designer competing with those two bicycle mechanics from Ohio, also wrestled with the problem of how to control an airplane in flight. Doctor Langley’s attempts with a far more sophisticated and better powered airplane ended up headfirst in New York’s harbor, not once, but twice over the issue of flight control. After the Wright Brothers taught the fledgling aviation world the secrets of controlled flight, namely, their wing-warpin approach to roll control, development experienced a burst of technical advancement, furthered by the tragedy of World War I. The demands of the 1914–1918 war on early aviation drove an incredible cycle of innovations in all aspects of aircraft design ranging from power plants, fuselage structures, lifting wing configurations, to control surface arrangements. It was in the crucible of the war to end all wars that aviation came of age and, along with this wave of technological advancement came the critical but little recognized necessity of achieving effective flight control.

1.3 THE RADIO AND THE AUTOPILOT

As is often the case with many game-changing technological advances, inventions of seemingly unrelated items combined in new arrangements to serve as the catalyst for new concepts. Such is the case with unmanned aircraft. Even before the first Wright Brothers’ flight in 1903, the famous electrical inventor Nicola Tesla promoted
the idea of a remotely piloted aircraft in the late 1890s as a flying guided bomb. His concept appears to have been an outgrowth of his work building the world’s first guided underwater torpedoes called the “telautomatization” in 1898. Tesla preceded the invention of the radio in 1893 by demonstrating one of the first practical applications of a device known as a full spectrum spark-gap transmitter. Tesla went on to help develop frequency separation and is attributed by many as the real inventor of the modern radio.

While the electrical genius Tesla was busy designing the first electric architecture of the City of New York, another inventor, Elmer Sperry, the founder of the famed flight control firm that today bears his name, was developing the first practical gyrocontrol system. Sperry’s work, like Tesla’s, focused initially on underwater torpedoes for the Navy. He developed a three-axis mechanical gyroscope system that took inputs from the gyros and converted them to simple magnetic signals, which in turn were used to affect actuators. The slow speed of water travel and weight not being as critical an issue for seacraft, allowed Sperry to perfect his design of the world’s first practical mechanical autopilot. Next, Sperry turned his attention to the growing new aircraft industry as a possible market for his maritime invention, not for the purpose of operating an aircraft unmanned, but as a safety device to help tame early unstable manned aircraft, and to assist the pilot in maintaining their bearings in bad weather. Sperry began adopting his system of control on early aircraft with the help of airframe designer Glenn Curtis. Together they made a perfect team of flyer–designer and automation inventor. Following excellent prewar progress on the idea, the demand during World War I to find new weapons to combat Germany’s battleships combined the inventions of the radio, airplane, and mechanical autopilot to field the world’s first practical unmanned aircraft, an aerial torpedo.

1.4 AERIAL TORPEDO: THE FIRST MODERN UNMANNED AIRCRAFT (MARCH 6, 1918)

In late 1916, with war raging in Europe, the U.S. Navy, a military arm of a still neutral country, funded Sperry to begin developing an unmanned aerial torpedo. Elmer Sperry put together a team to tackle the most daunting aerospace endeavor of the time. The Navy contract directed Sperry to build a small, lightweight airplane that could be self-launched without a pilot, fly unmanned out to 1000 yards guided to a target and detonate its warhead at a point close enough to be effective against a warship. (See Figure 1.1.) Considering that the airplane had just been invented 13 years earlier, the ability to even build an airframe capable of carrying a large warhead, against an armored ship, a sizable radio with batteries, heavy electrical actuators, and a large mechanical three-axis gyrostabilization unit was by itself incredible, but then integrating these primitive technologies into an effective flight profile—spectacular.

Sperry tapped his son Lawrence to lead the flight testing conducted on Long Island, New York. As the United States entered the World War I in mid-1917, these various technologies were brought together to begin testing. It is a credit to the
substantial funding provided by the U.S. Navy that the project was able to weather a long series of setbacks, crashes and outright failures of the various pieces that were to make up the Curtis N-9 Aerial Torpedo. Everything that could go wrong did. Catapults failed; engines died; airframe after airframe crashed in stalls, rollovers, and crosswind shifts. The Sperry team persevered and finally on March 6, 1918, the Curtis prototype successfully launched unmanned, flew its 1000-yard course in stable flight and dived on its target at the intended time and place, recovered, and landed, and thus the world’s first true “drone.” Thus, the unmanned aircraft system was born.

Not to be outdone by the Navy, the Army invested in an aerial bomb concept similar to the aerial torpedo. This effort continued to leverage Sperry’s mechanical gyrostabilization technology and ran nearly concurrent with the Navy program. Charles Kettering designed a lightweight biplane that incorporated aerostability features not emphasized on manned aircraft such as exaggerated main wing dihedral, which increases an airplane’s roll stability, at the price of complexity and some loss in maneuverability. The Ford Motor Company was tapped to design a new lightweight V-4 engine that developed 41 horsepower weighing 151 pounds. The landing gear had a very wide stance to reduce ground roll over on landings. To further reduce cost and to highlight the disposable nature of the craft, the frame incorporated pasteboard and paper skin alongside traditional cloth. The craft employed a catapult system with a nonadjustable full throttle setting.

The Kettering aerial bomb, dubbed the Bug, demonstrated impressive distance and altitude performance, having flown some tests at 100 miles distance and 10,000-ft altitudes. To prove the validity of the airframe components, a model was built with a manned cockpit so that a test pilot could fly the aircraft. Unlike the Navy aerial torpedo, which was never put in service production, the aerial bomb was the first mass-produced unmanned aircraft. While too late to see combat in World War I, the aircraft served in testing roles for some 12 to 18 months after the war. The aerial bomb had a supporter in the form of then Colonel Henry “Hap” Arnold, who later became a five-star general in charge of the entire U.S. Army Air Forces.
cultural opposition by manned aircraft pilots and their leadership. A large segment of a nation’s defense budget is dedicated to the procurement of military aircraft and the training and employment of large numbers of pilots, navigators and other crew members. Most air forces choose their senior leaders after years of having proved themselves in the cockpit flying tactical aircraft. The very idea of cheaper, unmanned aircraft replacing manned platforms ran against what President Eisenhower warned as the self-fulfilling “military–industrial complex.”

1.16 OVERCOMING THE MANNED PILOT BIAS

From the 1990s to the terrorist attacks of 9/11, unmanned aircraft made slow progress, leveraging the increases in small, compact, low-cost computers and the miniaturization of a more accurate GPS signal. However, the barrier to widespread acceptance lay with manned aircraft platforms and the pilots who saw UAS technology as replacing their livelihoods. When 9/11 struck, the U.S. Army had only 30 unmanned aircraft. In 2010, that number was over 2000. The argument against unmanned aircraft had finally given way to the low cost, the reduced risk, and the practicality of a drone, as the press still calls them today, performing the long, boring missions of countless hours of surveillance in both Iraq and Afghanistan. With a person still in the loop of any lethal missile leaving the rails of an Air Force Predator UAS, the “responsibility” argument has for the time being been addressed.

1.17 WILL UNMANNED AIRCRAFT SYSTEMS REPLACE MANNED AIRCRAFT?

The band of unmanned aircraft control runs from a completely autonomous flight control system independent of any outside signals to one that employs a constant data link enabling a pilot to remotely fly the aircraft and, of course, variations in between. A fully autonomous aircraft could in theory fly without the effects of enemy signal jamming and carry out a variety of complex missions. The disadvantage is that a fully autonomous flight control system can be simulated in a computer, enabling the enemy to develop counters to the system much in the same way as video gamers do with autonomous opponents. Once the program flaws are identified, it becomes a simple task to defeat the autonomous system. Additionally, fully autonomous systems will most likely not be allowed to employ lethal force since the chain of responsibility is nonexistent. At the other end of the spectrum, an aircraft that depends on an outside signal, no matter how well it is encrypted, has the potential to be jammed or worse: directed by the enemy through a false coded message. Even if true artificial intelligence is developed enabling an unmanned aircraft to act autonomously with the intuitiveness of a human being, the responsibility factor will prevent UAS from fully replacing manned aircraft. This is even truer with civil applications of passenger travel where at least one “conductor” on board will be required to be held accountable for the actions of the aircraft and to exercise authority over the passengers.
DISCUSSION QUESTIONS

1.1 List and discuss the three D’s of UAS employment.
1.2 What is considered to be the first modern unmanned aircraft and in what year did it make its first successful flight?
1.3 Discuss the groundbreaking advances with the WWII U.S. Navy assault drone.
1.4 What was the most significant unmanned aircraft of WWII?
1.5 Discuss the various uses of unmanned aircraft from 1918 to today.
2 Unmanned Aircraft System Elements

Joshua Brungardt

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2.1 INTRODUCTION

2.1.1 WHAT MAKES UP AN UNMANNED AIRCRAFT SYSTEM (UAS)

In this chapter we will briefly discuss the elements that combine to create a UAS. Most civilian unmanned systems consist of an unmanned or remotely piloted aircraft, the human element, payload, control elements, and data link communication architecture. A military UAS may also include elements such as a weapons system platform and the supported soldiers. Figure 2.1 illustrates a common UAS and how the various elements are combined to create the system.
2.2 REMOTELY PILOTED AIRCRAFT

Unmanned aircraft are fixed-wing, rotor-wing, or lighter-than-air vehicles that fly without a human on board. In more recent years there has been a push to change the term unmanned aircraft (UA) to remotely piloted aircraft (RPA) or remotely piloted vehicle (RPV). Unmanned aircraft is really a misnomer considering how much human involvement is crucial to the operation of the system.

RPAs are categorized into five groups by the U.S. Department of Defense as seen in the following table.

<table>
<thead>
<tr>
<th>UAS Category</th>
<th>Max Gross Takeoff Weight</th>
<th>Normal Operating Altitude (ft)</th>
<th>Airspeed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>&lt;20 pounds</td>
<td>&lt;1200 above ground level (AGL)</td>
<td>&lt;100 knots</td>
</tr>
<tr>
<td>Group 2</td>
<td>21–55 pounds</td>
<td>&lt;3500 AGL</td>
<td>&lt;250 knots</td>
</tr>
<tr>
<td>Group 3</td>
<td>&lt;1320 pounds</td>
<td>&lt;18,000 mean sea level (MSL)</td>
<td></td>
</tr>
<tr>
<td>Group 4</td>
<td>&gt;1320 pounds</td>
<td></td>
<td>Any airspeed</td>
</tr>
<tr>
<td>Group 5</td>
<td></td>
<td>&gt;18,000 MSL</td>
<td></td>
</tr>
</tbody>
</table>

*Note:* If a UAS has even one characteristic of the next higher level, it is classified in that level.

2.2.1 FIXED-WING

A fixed-wing UAS has many missions including intelligence gathering, surveillance, and reconnaissance, or ISR. Some military fixed-wing UAS have adapted a joint mission combining ISR and weapons delivery, such as the General Atomics Predator series of aircraft. The Predator™ was originally designed for an ISR mission with an aircraft designation of RQ-1. In the military aircraft classification system the *R*
stands for reconnaissance and the \( Q \) classifies it as an unmanned aerial system. In recent years however the Predator’s designation has been changed to MQ-1, the \( M \) standing for multirole, having recently been used to deliver hellfire missiles.

Fixed-wing UAS platforms have the advantage of offering operators long flight duration for either maximizing time on station or maximizing range. Northrop Grumman’s RQ-4 Global Hawk™ has completed flights of more than 30 hours covering more than 8200 nautical miles. Fixed-wing platforms also offer the ability to conduct flights at much higher altitudes where the vehicle is not visible with the naked eye.

The disadvantages of fixed-wing UAS platforms are that the logistics required for launch and recovery (L&R) can be very substantial (known as a large logistical “footprint”). Some may require runways to land and takeoff, whereas others may require catapults to reach flying speed for takeoff and then recover with a net or capture cable. Some small fixed-wing platforms such as AeroVironment’s Raven™ are hand launched and recovered by stalling the aircraft over the intended land spot or by deploying a parachute.

### 2.2.2 Vertical Takeoff and Landing

A vertical takeoff and landing (VTOL) UAS platform has numerous applications. A VTOL platform can be in the form of a helicopter, a fixed-wing aircraft that can hover, or even a tilt-rotor. Some examples of a VTOL UAS would be the Northrop Grumman MQ-8 Fire Scout™ or the Bell Eagle Eye™ tilt-rotor (Figure 2.2). These UAS platforms have the advantage of small L&R footprints. This means that most do not need runways or roads to takeoff or land. Most also do not require any type of equipment such as catapults or nets for the L&R. Unlike fixed-wing platforms, the helicopter UAS can monitor from a fixed position requiring only a small space to operate.

Smaller electric helicopters, radio-control size, have advantages of very rapid deployment times making them ideal for search and rescue, disaster relief, or crime

**FIGURE 2.2** Piccolo™ SL autopilot unit. (Copyright Cloud Cap Technology, a Goodrich Company.)
fighting. Simple helicopter systems can be stored in a first responder’s vehicle and launched within minutes. These small helicopters also offer the advantage of being somewhat covert when in operation at low altitudes. With no gasoline engine, the electric motor is quiet enough to allow it to operate at altitudes where it cannot be detected audibly. The disadvantages of small electric helicopters are that battery technology to date has not enabled long endurance to be achieved beyond 30 to 60 minutes.

2.3 COMMAND AND CONTROL ELEMENT

2.3.1 AUTOPILOT

The concept of autonomy is the ability for an unmanned system to execute its mission following a set of preprogrammed instructions without operator intervention. A fully autonomous UAS is able to fly without operator intervention from takeoff to touchdown. The amount of autonomy in a UAS varies widely from none to full autonomy. On one end of the spectrum the aircraft is operated completely by remote control with constant operator involvement (an external pilot). The aircraft’s flight characteristics are stabilized by its autopilot system; however if the pilot were to be removed from the controls the aircraft would eventually crash.

On the other end of the spectrum the vehicle’s onboard autopilot controls everything from takeoff to landing, requiring no pilot intervention. The pilot-in-command can intervene in case of emergencies, overriding the autopilot if necessary to change the flight path or to avoid a hazard. The autopilots for these vehicles are used to guide the vehicle along a designated path via predetermined waypoints.

Many commercial autopilot systems have become available in recent years for small UASs (sUASs). These small autopilot systems can be integrated to existing radio-controlled (hobby) aircraft or onto custom-built sUAS platforms. Commercial autopilot systems (often referred to as COTS for commercial-off-the-shelf systems; COTS is a widely used acronym for many different technologies) for sUAS have become smaller and lighter in recent years. They offer many of the same operational advantages that large RPA autopilots offer and are far less expensive. For example, the Cloud Cap Technology’s Piccolo series of autopilots offers multivehicle control, fully autonomous takeoff and landing, VTOL and fixed-wing support, and waypoint navigation.

Autopilot systems for UASs are programmed with redundant technology. As a safety feature of most UAS autopilots, the system can perform a “lost-link” procedure if communication becomes severed between the ground control station and the air vehicle. There are many different ways that these systems execute this procedure. Most of these procedures involve creating a lost-link profile where the mission flight profiles (altitudes, flight path, and speeds) are loaded into the memory of the system prior to aircraft launch. Once the aircraft is launched, the autopilot will fly the mission profile as long as it remains in radio contact with the ground control station. The mission or lost-link profile can be modified when necessary if connectivity remains during flight. If contact with the ground station is lost in flight, the autopilot will execute its preprogrammed lost-link profile.
Other examples of lost link procedures include having the vehicle:

- Proceed to a waypoint where signal strength is certain in order to reacquire connectivity.
- Return to first waypoint and loiter or hover for a predetermined time in an attempt to reacquire the signal and then returning to landing waypoint to land if this is unsuccessful.
- Remain on current heading for a predetermined amount of time. During this time, any secondary means of communication can be attempted with the aircraft.
- Climb to reacquire link.
- Orbit where link was lost; at this point the external pilot then takes over using remote control technology, which uses VHF line-of-sight radio technology.

### 2.3.2 Ground Control Station

A ground control station or GCS is a land- or sea-based control center that provides the facilities for human control of unmanned vehicles in the air or in space (Figure 2.3). GCSs vary in physical size and can be as small as a handheld transmitter (Figure 2.4) or as large as a self-contained facility with multiple workstations. Larger military UASs require a GCS with multiple personnel to operating separate aircraft systems. One of the foremost goals for future UAS operation will be the capability for one crew to operate multiple aircraft from one GCS.

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**FIGURE 2.3** MQ-1 Predator GCS.
A GSC usually consists of at least a pilot station and a sensor station. The pilot station is for just that: the pilot-in-command who operates the aircraft and its systems. The sensor station is for the operation of the sensor payload and radio communications. There can be many more operations, depending on the complexity of the UAS, which each require more workstations. For smaller less complex UASs these workstations may be combined requiring only one operator.
2.4 COMMUNICATION DATA LINK

Data link is the term used to describe how the UAS command and control information is sent and received both to and from the GCS and autopilot. UAS operations can be divided into two categories: radio frequency line-of-sight (LOS) and beyond line-of-sight (BLOS).

2.4.1 LINE-OF-SIGHT

Line-of-sight (LOS) operations refer to operating the RPA via direct radio waves. In the United States civilian LOS operations are usually conducted on the 915 MHz, 2.45 GHz, or the 5.8 GHz radio frequencies. These frequencies are unlicensed industrial, scientific, and medical (ISM) frequencies that are governed by Part 18 of the Federal Communications Commission (FCC) regulations. Other frequencies such as 310–390 MHz, 405–425 MHz, and 1350–1390 MHz are discrete LOS frequencies requiring a license on which to operate. Depending on the strength of the transmitter and receiver, and the obstacles in between, these communications can travel several miles. Signal strength can also be improved utilizing a directional tracking antenna. The directional antenna uses the location of the RPA to continuously adjust the direction in which it is pointed in order to always direct its signal at the RPA. Some larger systems have directional receiving antennas onboard the aircraft thereby improving signal strength even further.

ISM frequency bands are widely used making them susceptible to frequency congestion, which can cause the UAS to lose communication with the ground station due to signal interference. Rapid frequency hopping has emerged as a technology that minimizes this problem. Frequency hopping is a basic signal modulation technique used to spread the signal across the frequency spectrum. It is this repeated switching of frequencies during radio transmission that minimizes the effectiveness of unauthorized interception or jamming. With this technology, the transmitter operates in synchronization with a receiver, which remains tuned to the same frequency as the transmitter. During frequency hopping a short burst of data is transmitted on a narrowband, then the transmitter tunes to another frequency and transmits again, a process that repeats. The hopping pattern can be from several times per second to several thousand times per second. The FCC has allowed frequency hopping on the 2.45 GHz unlicensed band.

2.4.2 BEYOND LINE-OF-SIGHT

Beyond line-of-sight (BLOS) operations refer to operating the RPA via satellite communications or using a relay vehicle, usually another aircraft. Civilian operators have access to BLOS via the Iridium satellite system, which is owned and operated by Iridium LLC. Most sUASs do not have the need or ability to operate BLOS since their missions are conducted within line of sight range. Military BLOS operations are conducted via satellite on an encrypted Ku band in the 12 to 18 GHz range. One UAS in the market operates almost continuously through Ku band. Its launch phase is usually conducted using LOS and then transferred
to BLOS data link. It is then transferred back to LOS for its recovery. One drawback of BLOS operations is that there can be several seconds of delay time once a command is sent to the aircraft, for it to respond to that command. This delay is caused by the many relays and systems it must travel through. With technological improvements over the past several years it is possible to conduct launch and recovery of the aircraft through BLOS data link.

2.5 PAYLOAD

Outside of research and development, most UASs are aloft to accomplish a mission and the mission usually requires an onboard payload. The payload can be related to surveillance, weapons delivery, communications, aerial sensing, or cargo. UASs are often designed around the intended payload they will employ. As we have discussed, some UASs have multiple payloads. The size and weight of payloads is one of the largest considerations when designing a UAS. Most commercial application sUAS platforms require a payload less than 5 lbs. Manufactures of some sUAS have elected to accommodate interchangeable payloads that can be quickly removed and replaced.

In reference to the missions of surveillance and aerial sensing, sensor payloads come in many different forms for different missions. Examples of sensors can include electro-optical (EO) cameras, infrared (IR) cameras, synthetic aperture radars (SAR), or laser range finder/designators. Optical sensor packages (cameras) can be either installed by permanently mounting them to the UAS aircraft giving the sensor operator a fixed view only, or they can employ a mounted system called a gimbal or turret (Figure 2.5). A gimbal or turret mounting system gives the sensor a predetermined range of motion usually in two axes (vertical and horizontal). The gimbal or turret receives input either through the autopilot system or through a separate receiver. Some gimbals are also equipped with vibration isolation, which reduces the amount of aircraft vibration that is transmitted to the camera thus requiring less electronic image stabilization to produce a clear image or video. Vibration isolation can be performed by either an elastic/rubber mounting or using an electronic gyrostabilization system.

2.5.1 ELECTRO-OPTICAL

Electro-optical cameras are so named because they use electronics to pivot, zoom, and focus the image. These cameras operate in the visible light spectrum. The imagery they yield can be in the form of full motion video, still pictures, or even blended still and video images. Most sUAS payload EO cameras use narrow to mid field of view (FOV) lenses. Larger UAS camera payloads can also be equipped with wide or ultrawide FOV (WFOV) sensors. An EO sensor can be used for many missions and combined with different types of sensors to create blended images. They are most frequently operated during daylight hours for optimal video quality.

2.5.2 INFRARED

Infrared cameras operate in the infrared range of the electromagnetic spectrum (approximately 1–400 THz). IR, or sometimes called FLIR for forward-looking
to enable the UAS to reach flying speed (Figure 2.8). A catapult system is also available for the Aerosonde. For the landing phase it can “belly land” on grass or hard surfaces, or it can recover into a moving net.

2.7 HUMAN ELEMENT

The most important element of the UAS is the human element. At this point the human element is required for the operation of the UAS. This element consists of a pilot, a sensor, and supporting ground crew. As previously mentioned, some of these positions can be combined into one depending on the complexity of the system. In the future, the human element will likely get smaller as technological capability increases. As with commercial airliners of the past, automation will require less human interaction. The UAS pilot in command is responsible for the safe operation of the aircraft. This element is described in greater detail in Chapter 11.
3 U.S. Aviation Regulatory System

Douglas M. Marshall

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3.1 U.S. AVIATION REGULATORY SYSTEM

3.1.1 INTRODUCTION

Aviation regulations in the United States have existed nearly as long as the technology that is being regulated. All levels of government in civilized countries impose various regulations on their citizens and their activities.

Regulations in any technical environment such as aviation are typically driven by original equipment manufacturers (OEMs) and operators. As users experience incidents, problems, or anomalies, those events are properly reported to the Federal Aviation Administration (FAA). Should the number of events reach a certain critical mass or the outcome is sufficiently severe (fatalities, injuries, or property damage), the data generated may provoke a review of the relevant regulation, if any.

The introduction of a new technology or procedure into the National Airspace System (NAS) requires a comprehensive safety analysis before the FAA can allow