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Investigation into Unmanned Aircraft System Incidents in the National Airspace System

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The Federal Aviation Administration (FAA) forecasts the sale of commercial and hobbyist Unmanned Aircraft System (UAS) to rise from 2.5 million to 7 million USD in the timeframe of 2016 – 2020 (Federal Aviation Administration, 2016). A status report in March from the FAA revealed that more than 4,000 exemptions were issued to insurers, individuals, or commercial organizations in order to operate commercially registered UASs' in the National Airspace System (NAS) under Section 333 authority of the FAA Modernization and Reform Act of 2012. Additionally, over 408,000 UASs' have been registered (Federal Aviation Administration, 2016). The UAS market will continue to be the most dynamic growth sector within aviation (Federal Aviation Administration, 2016).

For Unmanned Aircraft Systems (UAS) to effectively operate in the NAS, it is important for these vehicles to abide by certain regulations and standards which ensure that the safety of manned operations, both in the air and on the ground, are not compromised. Compliance with the operational regulations can be designed into a UAS's control architecture (e.g. avionics) limiting a UA from flying higher than 400 feet above the ground.

Descriptive statistical analysis techniques were used to determine the frequency of reports containing accounts of airspace violations and Near Mid-Air Collisions (NMAC) by UASs' in the NAS. Additional incident frequency statistics are also presented as they relate to location, sponsor category, phase of flight, altitude and airspace type. The data used for this analysis was obtained from reports archived in the FAA Aviation Safety Information Analysis and Sharing (ASIAS) system, specifically the FAA Accident and Incident Data Systems (AIDS), National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS), FAA Near Mid-Air Collision System (NMACS), and the FAA Preliminary UAS Accident and Incidents reports, as well as FAA-released UAS Sightings Reports. The second portion of this paper will discuss mitigation techniques and various systems being developed to manage air traffic and minimize incidents involving UASs more effectively'. Techniques such as geofencing will be discussed along with systems being developed such as AirMap, NASA's UAS Traffic Management (UTM) system, and Volpe's Ground-Based Sense and Avoid (GBSAA) automation system. Advantages and disadvantages associated with each system will be explored in addition to regulatory challenges it may pose.

Regulations in Place

14 CFR Part 107 and Part 101

Federal Aviation Regulations (FAR) are governing rules that apply to all aspects of aviation in the United States of America (Aviation Safety Bureau, 2010).

FAR's dictate a plethora of requirements for each and every entity in aviation, with new ones being formulated as more entities are introduced into the aviation system. Abiding by all FARs leads to safe aviation system as far as procedures and programs are concerned (Aviation Safety Bureau, 2010). While FARs serve to protect aviation personnel and the general public, they are also mandated to protect the national security of the United States (Aviation Safety Bureau, 2010). An added benefit of FARs is that it adds standardization to the industry which inherently boosts its safety record and efficiency of operations. The two FARs that relate to the operation of UASs' are Title 14 Chapter 1 Subchapter F - Part 101 Subpart E and Part 107, both of which will be discussed. Most incidents archived in Aviation Safety Information and Analysis Sharing system reports involve UASs' not properly complying with these FARs.

Part 101 Subpart E – Special Rule for Model Aircraft

The Part 101 Subpart E FAR applies to all Unmanned Aircraft (UA) operation that strictly operates under the following conditions (e-CFR, 2016):

- Hobby or recreational use only
- "In accordance with community-based set of safety guidelines and within the programming of a nationwide community-based organization" (e-CFR, 2016)
- Total weight does not exceed 55 pounds. If the total weight does exceed this quantity, then it must be certified through a "design, construction, inspection, flight test, and operational safety program administered by a community-based organization" (e-CFR, 2016)
- The operation does not pose a safety hazard to manned aircraft. A UAS pilot must always give way to any manned aircraft and cannot threaten the safety of the NAS.
- If flown within 5 miles of any airport, the UAS pilot must establish contact with the airport operator and an air traffic control (ATC) tower (if present) to receive approval before flight.

Part 107 – Small Unmanned Aircraft Systems

The Part 107 FAR does not apply to any Small Unmanned Aircraft System (sUAS) operating under the governance of FAR Part 101. When there exists a condition which no longer qualifies a sUAS to operate under the Part 101 regulation, a sUAS pilot must ensure that aircraft operation complies with Part 107.

The remote Pilot-In-Command (PIC) of a sUAS must obtain a remote pilot certificate with a sUAS rating (Federal Aviation Administration, 2016). This certificate is issued by the FAA and must be completed prior to the operation of a sUAS (Federal Aviation Administration, 2016). If the person manipulating the flight controls of a sUAS does not hold this certificate, then the operation of the sUAS must be supervised by a certified remote PIC, who has final authority (Federal Aviation Administration, 2016).

The operation of a sUAS in Class B, C, or D airspaces in addition to within the lateral boundaries of the Class E airspace designated for an airport is not permitted unless the remote PIC has prior authorization by the ATC or airport operator. In addition to communication, it is vital for a remote PIC to be aware of the airspace layout and overall classification definitions.

A sUAS cannot be flown higher than 400 feet above ground level (AGL) unless flown within 400 feet of the structure, in which case the sUAS cannot operate higher than 400 feet above the structure's highest point (Federal Aviation Administration, 2016). If operation above the aforementioned altitude restrictions is conducted then the remote PIC must abide by the rules regarding airspace limitations, i.e. prior authorization is required via ATC or the airport operator.

A sUAS is permitted to fly at or near an airport with no notification or specific authorization unless it is conducted within controlled airspace (Federal Aviation Administration, 2016). Apart from being aware of traffic patterns and approach corridors, a remote PIC must not cause the controlled sUAS to interfere with airport or any manned aircraft operations (Federal Aviation Administration, 2016).

Definitions

Definition of a Near Mid-Air Collision

A Near Mid-Air Collision (NMAC) is an incident wherein the operation of an aircraft can result in the possibility of a collision occurring, specifically when the proximity is less than 500 feet to another aircraft (Federal Aviation Administration, 2016c). Some reported NMAC events also detail incidents wherein a pilot or flight crew observed a collision hazard between two or more aircraft (Federal Aviation Administration, 2016c). Often when an NMAC is imminent, the flight crew or pilot receives an indication, with a varied degree of reliability, from onboard flight systems that a potential for a collision hazard exists which may require the pilot to execute evasive actions.

Definition of National Airspace System Violation

For this study, a National Airspace System (NAS) violation is considered to occur when a UAS is flown in either one of the following conditions:

- At or within 5 miles of an airport without prior authorization from an ATC or airport operator – 14CFR Part 107 and Part 101 Subpart E
- Above 400 feet AGL, or higher than 400 feet above the tallest part of a structure if flown within 400 feet of the structure, without prior authorization from the closest ATC or airport operator – 14CFR Part 107
- Operation within Airspace Classes B, C, D, or within the lateral boundaries of Class E for an airport without prior approval from ATC or airport operator – 14CFR Part 107
- The incursion into controlled airspace without prior approval from ATC or airport operator.

Report Information

The following discusses the characteristics of archived reports in FAA ASIAS system as well as the FAA-released UAS Sightings reports. The data captured in these reports form the basis for the descriptive statistical analysis highlighted in this paper.

FAA Accident and Incident Data Systems

The FAA Accident and Incident Data System (AIDS) database details incident data records for all facets of civil aviation (Federal Aviation Administration, 2016d). The events captured in this database do not meet the aircraft damage and personal injury thresholds required for the incident to be deemed as an accident according to the National Transportation Safety Board (NTSB; Federal Aviation Administration, 2016d). An example of such an incident is a bird strike, which may not have resulted in significant damage to both aircraft and personnel, but the occurrence of which is important to know for both analytical and preventive purposes (Federal Aviation Administration, 2016d). The database covers incidents that have occurred between 1978 and the present and can be textually searched across various data fields typically associated with reported incidents, such as location, time, and phase of flight (Federal Aviation Administration, 2016d).

Aviation Safety Reporting System. Established under the FAA Advisory Circular No. 00-46D, the Aviation Safety Reporting System (ASRS) is a voluntary, confidential and non-disciplinary reporting system which is funded and administered by the FAA and NASA respectively (Federal Aviation Administration 2016e). Incidents can be reported by all members of the aviation community including flight crew, air traffic controllers, maintenance technicians, ground personnel, etc. as long as they have either observed or were involved in the incident (Federal Aviation Administration, 2016e). The incentive to report incidents to this database is that the FAA grants immunity from regulatory-based discipline along with identity protection for personnel involved contingent upon the fact that the report is filed within ten days of the incident (Federal Aviation Administration, 2016e). Typically data collected in the ASRS is used in human factors research and to develop recommendations for future operational procedures (Federal Aviation Administration, 2016e). The ASIAS and NASA portal both contain reports between 1988 and the present (Federal Aviation Administration, 2016e; Carmona, 2016).

FAA Near Mid-Air Collision System. The FAA's Near Mid-Air Collision System (NMACS) report presents reported incidents wherein the reporter believed he or she was involved in or witnessed an NMAC (Federal Aviation Administration, 2016c). With that being said, the accuracy of the nature of the incident can be somewhat skewed depending on the reporter's perception of the event (Federal Aviation Administration, 2016c). Likewise, pilot experience (e.g., unaccustomed to flying routinely in relatively proximity with aircraft can alter one's definition of an NMAC), fear of receiving a penalty, or simply the lack of awareness of the NMAC reporting system can all greatly affect the data captured in the database (Federal Aviation Administration, 2016c).

As stated by the FAA "It is the responsibility of pilots and flight crew members to determine whether an NMAC did occur and, if so, to initiate an NMAC report" (Federal Aviation Administration, 2016c). It is important to note that there is no legal requirement or regulation which mandates pilots or flight crews to report NMAC incidents (Federal Aviation Administration, 2016c). For this reason, data captured in NMAC reports are subjective to a certain degree which dictates that evaluation of data contained in each report must be handled with discretion. Furthermore, the data captured does not account for all possible NMAC events.

FAA Preliminary UAS Accident and Incidents Reports

The FAA Preliminary UAS Accident and Incident reports detail accidents and incidents involving UASs' (Federal Aviation Administration, n.d.). The period of coverage is from 2010 to 2014 (Federal Aviation Administration, n.d.). Each event is categorized as incident or accident, where an accident describes UAS operation that has resulted in total loss of control and hence loss of the aircraft, and an incident involves UAS operation that has resulted in non-compliance with FAR's. Various data fields are included with each event including sponsor category, event date, location as well as aircraft type.

FAA-released UAS Sightings Reports

On August 21, 2015, the FAA released a report encompassing events involving UASs' reported by pilots, air traffic controllers, and citizens (Federal

Aviation Administration, 2015). This report covers incidents that occurred from November 13, 2014, through August 20, 2015 (Federal Aviation Administration, 2015). An additional report was released on March 25, 2016, which spans events taking place from August 22, 2015, through January 31, 2016 (Federal Aviation Administration, 2016f). Each incident is detailed using event date and time, location, and a narrative provided by the reporter (Federal Aviation Administration, 2015).

Literature Review

Fern (2012) discusses the challenges associated with UAS integration into the NAS specifically human factor challenges focused on the dynamics of the NAS when interactions between manned aircraft and unmanned aircraft systems are present. The author asserted that the most significant challenge would be to integrate UASs' with the conventionally employed air traffic management system in a non-disruptive manner. From a UAS pilot standpoint, it is imperative to supply UAS pilots with information which can improve situation awareness. This information sharing can be achieved by providing pilots with intuitive and easily interpretable traffic information, information about the airspace environment such as airspace class definitions, and sense-and-avoid capabilities comparable to manned aircraft such that a UAS pilot can safely maneuver the aircraft to maintain separation and collision avoidance. The author also details a simulation experiment conducted to evaluate baseline compliance of UAS operations in the NAS. A Cockpit Situation Display (CSD) was integrated into a UAS Ground Control Station (GCS) and was assessed based on UAS pilot performance, workload, and situation awareness in a controlled airspace sector. The results of such an experiment indicated that the UAS pilots were able to comply with ATC instructions and that the new system improved situation awareness and reduced workload associated with UAS and ATC communications.

Gimenes et al. (2013) examined the necessary regulations required for the safest integration of UASs' in the NAS. The author proposes guidelines intended to support UAS regulations for future integration of UASs' into the Global Air Traffic Management System (GATM). The guidelines discussed are based on three viewpoints: (a) aircraft, (b) piloting autonomous system (PAS), and (c) integration of a UAS into an airspace not specifically segregated for its operation. The conclusion from this paper is that the integration of UASs' into the GATM paradigm should be derived from genuine aeronautical rules and principles, eliminating conceptual adaptations.

Dalamagkidis, Valavanis, and Piegl (2008) discussed aviation regulations and analyzes issues and factors which may affect future regulations as they both pertain to UAS integration into the NAS. As UAS development continues by both universities, research labs, and commercial entities it is vital to keep in mind the limitations imposed by the regulations in place regarding the aircraft's operation in controlled and uncontrolled airspace. The primary goal of UAS regulations is to ensure the safety of the public including pilots of manned aircraft in the NAS. Functionally, this can be achieved through the development of technologically advanced and robust sense-and-avoid systems. Operationally, UAS pilots will fly by the same rules as pilots of manned aircraft which entails that UASs' must be capable of communicating with Air Traffic Controllers and responding to commands as directed. The author stresses the importance of developing and testing technologies associated with UAS integration, specifically fault-tolerant control, fail-safe systems, accurate sense-and-avoid capabilities, and reliable long-range communication systems among others. Such is conducted through a risk assessment factoring in various failure modes and outcomes.

Lincoln Laboratory (2015) discusses the operation and development of the Airborne Collision Avoidance System X (ACAS X). As Lincoln Laboratory (2015) explains, the difference between the currently used Traffic Alert and Collision Avoidance System II (TCAS II) and ACAS X is the basic method of operations. The ACAS X system utilizes probabilistic models to represent areas of uncertainty (e.g., pilot miscommunication and surveillance errors) and optimization routines to determine safe and operational objectives. The system uses sensor measurements from onboard surveillance systems in conjunction with advanced tracking algorithms to determine approximate position and speed of an aircraft. ACAS X compensates for the possibility of communication latencies and imperfect sensor operation by taking dynamic uncertainty into account and representing the position and speed as probabilistic state distributions. An additional benefit to the incorporation of ACAS X is its simple integration into the Automatic Dependent Surveillance-Broadcast (ADS-B) which allows both pilots and ATC to view an aircraft's position, speed, and altitude with higher precision. There are four variants of the ACAS X each one intended to detect different aircraft classes. The ACAS Xu is specifically optimized for UASs'. Lincoln Laboratory (2015) concludes by stating the benefits of the ACAS X including the fact that studies have shown a reduction in mid-air collision risks by 59% and unnecessary, disruptive alerts by 25%.

Brooker (2013) focuses on the safety aspect associated with Air Traffic Control (ATC) Systems as it pertains to the integration of UASs' in the NAS. The author highlights the safety statistics associated with ATC systems and categorizes it as a High-Reliability Organization (HRO). This status stems from the fact that this system has constantly been refined and improved through various technological advancements stemming from feedback from accidents/incidents as well as an underpinning safety culture. The author feels that the major risk of UAS integration into the NAS is its threat to the safety of operations associated with ATC systems. This can be achieved by demonstrating that UAS operation meets current safety requirements. The author states that a there is a fundamental need for UASs' to have Airborne Collision Avoidance Systems (ACAS) Xu equipment which can be linked to Flight Management Systems (FMS) and generate automatic responses to collision hazards and traffic alerts. The author concludes by stressing the importance to conduct a thorough analysis and testing to systems associated with strengthening the safety of operations in the NAS, as it relates to UASs'.

Research by Clothier, Williams, and Fulton (2015) primarily focuses on a risk assessment scheme known as the Barrier Bow Tie (BBT) model. This model documents how a UAS operator intends to manage and appropriately deal with risks associated with in-flight operations such as mid-air collisions. This model was constructed using derivatives of lessons learned from other models describing mid-air-collision incidents and provides a structured approach to understanding the safety dynamics as they relate to unmanned system operation in non-segregated airspace. The advantage of using the BBT model is that it allows for more effective management of risk controls and can provide an assessment of which controls most efficiently reduce risks of mid-air collisions. Additionally, the model can be used as a systematic means of classifying risk controls. The main use case for this model is to aid in the development of regulations intended to satisfy safety targets for UAS operations in non-segregated airspaces.

Joslin (2015) conducted a study to improve upon the utility of the Aviation Safety Information and Analysis Sharing system databases with the intention of improving safety associated with civil and public UAS usage by identifying various types of anomalous events. Identification of these various types will provide meaningful insight into future areas of UAS development specifically targeting safety improvements. From this study, it was determined that the leading cause of anomalous events was due to command and control equipment failures followed by non-equipment related causes involving pilot error. The most frequent non-equipment error was Near Mid-Air Collision (NMAC) closely followed by airspace violations, and altitude and procedural deviations. More unique to UAS operations, the study revealed that anomalous events were often the result of control station facility degradation and a reliance on backup telephonic communication systems to communicate with ATC.

Sathyamoorthy (2015) provides an overview of the security threats posed by UASs' in addition to categories of intrusion. More importantly, mitigation steps for UAS incidents are also discussed including geo-fencing, detection systems, and electronic and kinetic defense systems. Global Navigation Satellite Systems

(GNSS) enforced geofencing can prevent UASs' from flying into airspace where UAS operation is prohibited. The author brings up a noteworthy point – radar detection of UASs' is rather difficult due to similar radar signatures between such vehicles and birds, usage of ineffective radar-reflective material for UAS construction, and UAS operation below 100 feet. For this reason, the Blighter system can be used in conjunction with operators who are trained to distinguish between a UAS and a bird. Acoustic sensing systems operate by detecting the unique noise generated by typical UAS systems such as electric motors; however, such detection offers only reliable short-range capabilities. Radio Frequency (RF) emission sensing can be used to detect data link transmissions which occur during UAS control. Such a system can be used to identify the location of both the UAS and the operator. The author concludes by discussing more electronic defense strategies such as communication link jamming in addition to a kinetic defense option which involves physical damage to the UAS.

The Federal Aviation Administration (FAA; 2013) identifies the regulatory structure necessary for the incorporation of UASs' in the NAS. This includes developing minimum standards for Sense and Avoid (SAA) capabilities, Command, Control and Communication (C3) protocols, and separation management to ensure that regulation conformance is met. It is vital to understand the privacy, security, and environmental implications that UAS regulations may create. Additionally, the FAA (2013) states that developing design standards, as they relate to UAS size, weight, performance, and mode of control, will be crucial to strengthening the safety of UAS operations in the NAS. Challenges in adapting current regulations to suit UAS operation are also addressed denoting that new rulemaking and guidance will be required for regulation creation. Technological challenges are also addressed stating that over dependencies could have an impact on the safety of operations. Additionally, the need to improve control interfaces so as to improve sensory and environmental cues to the UAS pilot would also increase safety. Furthermore, the FAA (2013) discusses the challenges associated with UAS operation in a controlled airspace wherein communication with ATC is required. For safe incorporation into the NAS with minimal impact on efficiency or complexity of ATC operations, UAS pilots must properly remain in contact and comply with ATC instructions, understand airport approach patterns, and review environmental requirements.

UAS Vision (2015) discusses the interim Minimum Operational Performance Standards (MOPS) released by the RTCA Special Committee (SC) 228. SC-228 highlights the MOPS required for Detect-And-Avoid (DAA) systems and Command and Control (C2) data links. It is important to note that DAA MOPS does not apply to UASs' below 55 pounds in weight, operating below 500 feet but instead will support operations within Class D, E, and G airspaces excluding surface operations, flight in visual flight rule traffic patterns, or in Class B or C airspaces around airports. The sensors specified by the DAA MOPS are Mode S surveillance, Automatic Dependent Surveillance – Broadcast (ADS-B), Traffic Alert and Collision Avoidance System (TCAS) II collision-avoidance systems, and radar to detect other aircraft that the ADS-B system does not receive. All these sensors help the UAS pilot in detecting other aircraft. The C2 MOPS is composed of airborne and ground-based radios and antennas operating at 960 – 1164 MHz (L-band) or 5030 – 5090 MHz (C-band). These systems are selected so as to ensure proper communication with systems onboard the UAS along with ATC.

The RTCA (2016) discusses the Minimum Operational Performance Standards (MOPS) for the Traffic Alert and Collision Avoidance System (TCAS). This system is the Aircraft Collision and Avoidance System (ACAS) X_A system with “A” denoting active surveillance. Surveillance is conducted using a Mode S transponder in addition to the utilization of Automatic Dependent Surveillance – Broadcast (ADS-B) systems. This reduces the spectrum congestion on the 1090 MHz frequency.

Selinger (2016) discusses the FAA Pathfinder program which intends to test UAS detecting systems at airports. The goal of doing so is to address the concern about UAS operation near airports and NMAC incidents involving major commercial aircraft on final approaches to busy airports. Airfence is a portable system which is already deployed at major airports in Europe. Airfence units detect UASs’ and their pilots by triangulating positions of radio communications even if they are encrypted. The Consolidated Analysis Centers, Inc. (CACI) developed SkyTracker is a tripod-mounted structure which uses typically employed UAS communication frequencies to track and locate UAS positions both in the air and on the ground and integrates easily into existing airport operation systems. The advantage of this particular system is that it can quickly detect UASs’ traveling at high speeds and issue prompts to the appropriate personnel. Skylight, a system built by Gryphon Sensors utilizes radar for detection, radio-frequency to identify the target type, and slew-to-cue video to track targets. By using advanced techniques in waveforms and signal processing, this system is capable of distinguishing between targets of similar sizes, such as birds and UASs’.

Academy of Model Aeronautics (AMA; 2016) details an analysis of drone sightings from the data released by the FAA spanning the period of August 21, 2015, through January 31, 2016. The data utilized contains 582 new events released by the FAA on March 25, 2016, in addition to the trends observed from the previously released report, which spanned a period of November 13, 2014, through August 20, 2015. The analysis indicates that there has been an improvement in the terminology used for each reported event allowing AMA (2016) to better decipher how to classify each event – NMAC, NAS violation, or a combination of both. Additionally, the number of reported “near miss” events account for only a small number of sightings. A more recent analysis of the 582 new events reveals that “near-miss” events only account for 3.3% of the overall data set, implying that a majority of reports are purely UAS sightings. Out of these sightings, 38 reports detail incidents wherein UAS operation was conducted at or below 400 feet above ground level, compliant with the FARs. Similarly, an analysis of the events reported between November 13, 2014, and August 20, 2015, shows that NMAC incidents account for 3.5% of the overall data set. An analysis of the data released in the previous report shows that evasive action was only taken in 1.3% of the reports, contrasted with 2.4% from the reports released on March 25, 2016. AMA (2016) also states that the difference between reports could be because there is no published definition associated with the term “near miss” or “close call,” as a lot of reports employs such terminology. Due to this, subjectivity is introduced into each report and evaluation of captured data becomes more difficult. Although UAS sales have increased rapidly in 2015, the number of UAS sightings has decreased on a monthly basis from August 2015 through December 2015. This may be the result of improved regulation awareness, utilization of education programs such as AMA’s “Know Before You Fly,” or simply a lack of reporting and omission of sensitive data such as UAS military usage.

Method

For this study, the analysis method chosen was a descriptive, statistical approach to analyzing data in archived reports. Different from inferential statistics, descriptive statistics is used to describe the trends that a dataset may reveal (Trochim, 2006). Inferential statistics are typically used to arrive at conclusions that may extend beyond the confines of the data (e.g. using sample statistics to infer the nature of the entire population; Trochim, 2016). Differential statistics are typically used to summarize data and can be combined with graphical analysis techniques to depict easily comprehendible information (Trochim, 2016). This method of statistical analysis is often used when the nature of large amounts of data must be determined (Trochim, 2016).

The first step in a descriptive statistical analysis is the collection of the data which must be analyzed. In this case, the data comes from archived reports in the Aviation Safety Information and Analysis Sharing (ASIAS) system and FAA-released UAS Sightings Reports. Within the ASIAS system, there are several reports which contain data regarding UAS operation in the NAS. These are as follows:

- FAA AIDS

- NASA ASRS
- FAA NMACS
- FAA Preliminary UAS Accident and Incidents reports

While the FAA-released UAS Sighting Reports detail all events including sightings in the NAS as well as NMACs, it is vital to go through the narratives provided with each event to determine if it pertains to this study. For this reason, a few reported events were removed, e.g. incidents involving birds, balloons or simply non-hazardous and regulation compliant UAS operation sightings. To obtain relevant data from the reports in the ASIAS system the following search terms were used – “UAS OR drone OR UAV OR unmanned OR RC,” ensuring that it was not case-sensitive. However, even with specific search terms, some derived events may not pertain to this study; for example, an event in the NASA ASRS database detailed an incident wherein a manned aircraft collided with an “unmanned” fuel truck. All derived events in each report were reviewed for their relevance to this study.

The second step involved conducting the actual statistical analysis portion which entailed determining the total number of incidents that occurred each year for every year recorded in the database. While some reports only encompass events taken place in the 21st century, there exist a few events which date back to the late 1970s. By reading the description or narrative provided with each event, a determination was made as to what is the nature of the event – NMAC, NAS violation, or both. Using this data, a trend was computed regarding the progression of these types of events within the period of the database. Moreover, since unique additional data is presented in the reports such as geographical (i.e. State) location of incidents, airspace class, the phase of flight, and altitude where the incidents occurred, summaries with regards to these variables were made and are presented in this paper. The presentation of data is achieved using tables, figures, and histogram plots which depict the frequency of a variable (e.g., the number of events) as it relates to its associated timeframe (e.g., year).

Results

The results presented in this paper are separated by the data source, i.e. the different databases. Each source is presented in its own light as events captured by each report are unique in its own nature and bounded by different time periods, reporting requirements, and other confounding variables.

FAA Accident and Incident Data System

Table 1 and Figure 1 depict data about any incident involving a UAS from January 13, 1978, through April 26, 2016; this may not be specifically limited to an NMAC or NAS violation and could potentially include collision events. These data indicate that 2004 experienced the highest number of reported incidents, with a decrease in subsequent years. Figure 2 contains incident frequency data overlaid on a map of the United States of America. The majority of reported events took place in California (Figure 2). Figure 3 illustrates a conventional traffic pattern for an aircraft along with other phases of flight. This graphic contains incident frequency data categorized according to the flight phase in which it occurred. The highest number of reported events occurred during the ground operations and approaches to landing phases of flight (Figure 3).

FAA Aviation Safety Reporting System

Table 3 shows UAS-related event data from the FAA ASRS database spanning a period of February 1, 1993, through June 1, 2016. This data is graphically represented in Figure 4 in the form of a histogram. The trend exhibits a gradual increase in the number of events from 2011, with the highest number of reported events in 2015. The majority of reported events took place in California (Figure 5). Figure 6 is a histogram plot depicting the frequency of reported events involving UASs' categorized by the operational type of the manned aircraft involved. This showed that the majority of reported events involved conflicts with commercial manned aircraft transporting passengers (Figure 6).

NASA Aviation Safety Reporting System

Table 6 and Figure 7 portray data associated with any event involving a UAS reported to the NASA ASRS and covering the period from April 1994 through June 2016. Similar to the trend observed in the FAA ASRS database, the highest number of reported events took place in 2015 stemming from a gradual increase dating starting from 2011. The highest number of reported events involving UASs' occurred in California (Figure 8) and occurred during the cruise and final approach portions of the flight envelope (Figure 9). Additionally, a majority of reported events transpired in Class B Airspace as seen in Figure 10 – a graphical representation of airspace architecture overlaid with UAS incident frequency data.

FAA Near Mid-Air Collision System Reports

Table 9 and Figure 11 depict the number of events reported in the FAA NMACS involving UASs' categorized by year. The period of this data spans from January 14, 2001, through July 31, 2016. The highest number of NMAC events involving UASs' occurred in 2016, with a decrease in subsequent years. The majority of these events took place in Texas and New York (Figure 12) and during the cruise and descent portions of the flight envelope (Figure 13). Figure 14 is a histogram plot of reported NMAC events categorized according to the altitude corridor wherein the event was reported to have transpired. These data also indicates that the highest number of reported events occurred between 1000 feet to 2000 feet above ground level (Figure 14).

FAA UAS Accident and Incident Preliminary Reports

Table 12 reveals the number of events taken place between 2010 and 2014 involving UASs' as detailed in the FAA UAS Accident and Incident Preliminary Reports. The highest number of reported events took place in 2011 closely followed by the number of events in 2013 (Figure 15). From an operational standpoint, academic institution sponsored UASs' account for the highest number of reported events, followed by NASA-sponsored UAS activity (Figure 16)

FAA-released UAS Sightings Reports

Table 14 and Figure 17 depict data from the FAA-released UAS Sightings Reports for the period of November 2014 through August 2015. The various colors present in the histogram plot illustrate the nature of the reported event – NMAC and NAS violations. These data reveal that the highest number of reported events took place in 2015. Out of these events, the majority are only NAS violations. The highest number of reported events occurred in the state of California (Figure 18). Table 16 and Figure 19 illustrate the data from the same type of report but spanning the period from August 2015 through January 2016. Akin to the previously released report, these data indicate that 2015 experienced the highest number of reported events with most events being a NAS violation. Likewise, California was the state wherein the highest number of reported events took place (Figure 20).

Analysis

A majority of analyzed databases indicate that the highest number of UAS-related events transpired in 2015 or 2016. Additionally, the expansion of the UAS market and the development of more commercial applications can also be a factor for the rise in the number of reported events (Meola, 2016). The increase in military funding toward UAS development and testing in conjunction with market growth in recreational and commercial sectors could be another reason as to why a higher number of reported events are taking place in recent years (Meola, 2016).

The FAA AIDS database shows that 2004 experienced the highest number of reported events. This could be the result of an increase in UAS deployment and testing in 2004, both for U.S. Customs and Border Protection (CBP) and preparation for UAS military missions abroad (Michel, 2015; Serle, 2015).

The FAA UAS Accident and Incidents Preliminary Reports reveal that the highest number of UAS-related events took place in 2011. Statistical analysis of data in Table 12 shows that the mean of the dataset is 20.8 and the standard deviation is 3.63. The fact that the standard deviation is only 17.5% of the mean illustrates that data reported for 2010 through 2014 tends to hover close to the mean value. This could be the result of a fluctuation of UAS-related events which occurred from 2010 through 2014 or simply reporting frequency inconsistencies, as reporting an event is voluntary.

Most databases indicated that the highest number of reported events took place in California followed by New York. This may be attributed to the fact that the airspace in California, specifically Southern California, is one of the busiest in the nation (Weikel, 2015). Likewise, the airspace in the New York City metro area and surrounding regions are the most congested and complex airspace systems in the NAS (National Business Aviation Association, 2011).

NASA's ASRS database indicated that most UAS-related events occur in Class B airspace. The structure of a Class B airspace is similar to that of an upside-down wedding cake, where the altitude floor heights decrease closer to the airport, i.e. within 3 miles of the airport Class B airspace may start from the surface and extend to 4000 feet AGL while 5 miles away from the airport the airspace may be defined from 1200 feet AGL to 4000 feet AGL (Aircraft Owners and Pilots Association, 2009). Class B airspaces can span several miles and often cover a much larger volume of airspace than other controlled airspaces such as Class C or Class D airspaces (Aircraft Owners and Pilots Association, 2009. For this reason, UAS-related airspace incursions in Class B airspaces are far more common.

Furthermore, Class B airspace is typically associated with large, busy airports and experiences a high volume of passenger-carrying commercial aircraft traffic operating at low altitudes during the approach and landing phases of flight (Rossier, 1998). During these phases, an aircraft is typically between 1000 and 2000 feet AGL and close to the airport (within Class B Airspace). This altitude corridor accounts for the largest number of reported incidents involving UASs'.

Managing Aircraft in the National Airspace System

With a constantly increasing number of possible applications for UASs' from package delivery, search and surveillance missions, to agricultural monitoring and management, it is becoming increasingly vital to develop an infrastructure which supports safe operation of UASs' while managing UAS air traffic typically associated with low-altitude airspace (National Aeronautics and Space Administration 2015). This infrastructure should be capable of supporting both commercial applications as well as recreational flight ensuring that the regulations are closely followed. This section will discuss several systems being developed to manage UAS operations better and mitigate the number of incidents involving UASs'.

DJI Geo-Fencing. Pioneered by DJI, geofencing is a control-based method which prevents operation of a UAS in restricted airspace such as temporary flight restrictions imposed by forest fires, sports stadiums, VIP travel, etc. in addition to areas where UAS operation raises non-aviation security concerns such as power plants, prisons, and other security-sensitive regions (DJI, 2015). Additionally, this system prevents a UAS from taking off from a location which presents aviation safety or security concerns, such as operation near a busy airport (DJI, 2015). The system combines current information about airspace restrictions and structure, a warning and flight-restriction system, and a mechanism for permitting flight into locations wherein the operation is permitted under certain conditions along with a minimally-invasive accountability system for flight operation (DJI, 2015).

It is important to note that as far as regulations are concerned; the geofencing system is advisory only, meaning that it is the responsibility of the operator to check current laws and regulations concerning the operation of UASs' (DJI, 2015). Geo-fencing operates by leveraging Geospatial Environment Online (GEO) data which features up-to-date information regarding airspace restrictions or any possible airspace modifications (DJI, 2015). These data are obtained from a California-based company called AirMap (DJI, 2015).

AirMap. A California-based company, AirMap is focused on increasing safe and regulatory compliant UAS operation awareness while strengthening the safety of the NAS (Moynihan, 2016). AirMap achieves this by creating an architecture for a system utilizing real-time airspace data, such as temporary flight restrictions and the overall structure of various airspace classes while providing communication protocols between UAS pilots and manned aircraft pilots (Moynihan, 2016). Using AirMap a UAS pilot also can plan their flight using airspace information (Moynihan, 2016). This is advantageous because this information can be relayed to airport operators and ATC which can be used for air traffic management, alerting manned aircraft of potential UAS operation and aids in mitigating the possibility of incidents taking place (Moynihan, 2016). Furthermore, the addition of the Digital Notice and Awareness System (D-NAS) provides airport controllers with real-time data regarding the location of a UAS (AirMap, 2016). This data is transmitted via an encrypted digital flight notice to a secure dashboard stationed at an airport's operations control center (AirMap, 2016).

Through this channel of communication, an airport operator can send messages to a UAS pilot informing them of unsafe operations or providing specific instructions so as to ensure the safety of the aviation system is not compromised within the vicinity of the airport (Moynihan, 2016). Additionally, the usage of the D-NAS helps UAS pilots comply with the FARs by providing airports with notice of flight before approval when the flight is conducted within 5 miles of the airport (AirMap, 2016). By allowing AirMap to easily integrate into typical existing control platforms where UASs' are controlled or monitored from a phone or tablet, it promotes the usage of such a system with little to no burden associated with its implementation from a UAS operator standpoint.

NASA Unmanned Aircraft System Traffic Management. NASA is currently researching and developing a system optimized to provide safe, reliable and efficient low-altitude operation of UASs' called UAS Traffic Management (UTM) system (National Aeronautics and Space Administration 2015). The UTM system provides UAS pilot with information regarding airspace design, flight path corridors, weather, and wind data in addition to services such as air traffic information via Automatic Dependent Surveillance and Broadcast (ADS-B) data, dynamic geofencing, terrain avoidance, route planning, separation management and contingency management (National Aeronautics and Space Administration, 2015). The UTM system is designed to reduce human factors associated errors by increasing automation levels for certain functions and operations (National Aeronautics and Space Administration, 2015). The UTM system could also be used to restrict operations to registered UASs, or those which have received prior approval, in the NAS and even provide preventive measures to ensure that UAS pilots do not operate the aircraft in unsafe conditions, such as unfavorable weather (National Aeronautics and Space Administration, 2015). NASA envisions two deployable forms of the UTM system (National Aeronautics and Space Administration, 2015). The first one is a movable platform which can be stationed in specific areas to support precise agricultural and disaster relief operations and the second would provide continuous coverage for a much large geographical area (National Aeronautics and Space Administration, 2015). The success of both systems will depend on receiving constant Communication, Navigation, and Surveillance (CNS) coverage to provide the most up-to-date information (National Aeronautics and Space Administration, 2015).

Ground-Based Sense and Avoid Automation System. According to a 2014 report published by the Volpe National Transportation Systems Center, the number of UASs' operation in the NAS will surpass 250,000 by 2025 (Volpe, 2016). This increases the need for a system which can maintain the critical safety standards for the aviation system, specifically manned operations (Volpe, 2016). To mitigate NMAC events, it is important for a UAS to feature sense-and-avoid capabilities which would prevent flight into or near other entities in the NAS. Jointly working with the United States Air Force, Volpe has developed a low-cost sense-and-avoid system which would enable UAS pilots to avoid NMAC events and ensure that safety standards are met even with an increasing number of UASs' in the NAS (Volpe, 2016). The Ground-Based Sense and Avoid (GBSAA) system employs air traffic data from various sources to provide UAS pilots with real-time data of other aircraft, manned and unmanned, in the surrounding airspace (Volpe, 2016). This is achieved by utilizing NAS radar equipment and infrastructure to track and locate aircraft within the airspace, even ones that do not electronically broadcast their position or speed (Volpe, 2016). Additionally, the system can notify a UAS pilot of potential imminent conflicts and issue suggested evasive action to mitigate conflicts (Volpe, 2016). The architecture of this system is composed of a modified FAA terminal automation system which is the primary display unit for alerting UAS pilots to surrounding aircraft (Volpe, 2016).

Most military UAS activity is cordoned off to special use airspace so as to ensure the protection of the civilian airspace if mishaps occur. With an increasing amount of UAS being deployed and tested this airspace can become a limitation as the flight is somewhat limited. The intended function of the GBSAA is to allow the United States Air Force to routinely fly UAS missions in airspaces not specifically segregated for military operation (Volpe, 2016). This in turn can lead to a possible expansion of the civil airspace by reducing the size of military operation areas (Volpe, 2016). By doing so civil aircraft can potentially fly more direct routes, minimizing distances flown and hence fuel consumption, all while meeting aviation safety standards (Volpe, 2016).

B4UFLY Smartphone Application. Developed by the FAA, B4UFLY is a smartphone application aimed at helping inform UAS pilots of possible airspace restrictions or unique operational requirements in effect at the intended location of flight (Federal Aviation Administration, 2016g). Available on both operating system platforms, Apple's iOS and Google's Android, the application provides pilots with a status indicator depicting the current state of flight as it relates to regulation compliance (Federal Aviation Administration, 2016g). Additionally, B4UFLY can be utilized as a flight planning tool helping the FAA mitigate the risks associated with unsafe operations of UASs' in the vicinity of airports, over populated locations, or nearby of manned aircraft (Federal Aviation Administration, 2016g).

The application is primarily intended for the hobbyist or recreational UAS pilot as the parameters are in accordance with the Special Rule for Model Aircraft in the FAA Modernization and Reform Act of 2012, which states that a UAS pilot is required to notify the airport operator or ATC prior to operation of the vehicle if

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conducted within 5 miles of the airport (Federal Aviation Administration, 2016g). This is different than the guidelines established for commercial UAS operations, specified in Section 333 of Public Law 112-95, which require both a certified UAS pilot and a registered UAS (Federal Aviation Administration, 2016g). The B4UFLY application complements the Know Before You Fly education campaign intended to educate UAS pilots on safe and responsible UAS operation (Federal Aviation Administration, 2016g).

Conclusion

The majority of ASIAS databases indicated that there is an upward trend in the frequency of NMAC and NAS violation related events involving UASs' occurring each year. In order to permit the growth of the industry and to improve the public opinion of UAS operations, it is necessary to address safety issues (Vallese, 2016). The systems being developed specifically to improve the safety of UAS operations in the NAS were discussed and analyzed as far as system architecture and functionality is concerned. The most comprehensive system which seems to leverage the largest amount of data, and hence keep UAS pilots most informed regarding the nature of their operation, is NASA's UTM system. Not only does this system provide UAS pilots with information regarding other aircraft, both manned and unmanned, it also supplies users with data regarding terrain, weather, wind, airspace design, flight corridors, and approach patterns (National Aeronautics and Space Administration, 2015). Combining the UTM system's capabilities with the advantages of the GBSAA system, along with FAA Pathfinder projects such as the SkyTracker and Skylight systems, can help increase the size of the civil airspace, reduce the number of NMAC and NAS violation related events reported to various databases, and strengthen the safety of UAS operations in the NAS.

Recommendations

The need for a system which effectively manages and integrates UAS operations, while keeping manned aircraft informed, and confines UAS operation within the scope of regulations is a mitigation technique which can result in the reduction of NMAC and NAS violation events reported in the discussed databases. It is vital to establish such a system as mandatory for all UAS pilots – commercial, recreational, and military.

An overall reduction in the number of incidents and an optimized UAS air traffic methodology may be brought about through the usage of the UTM system. The UTM system would allow UAS operators to view flight path corridors and airspace information (National Aeronautics and Space Administration, 2015). One benefit of using the UTM system is that its dynamic geofencing capability can prevent UAS flight into restricted airspace or airspace classes without prior authorization (National Aeronautics and Space Administration, 2015). The UTM system also provides UAS pilots other information vital to an operation such as weather and air traffic data via the ADS-B system (National Aeronautics and Space Administration, 2015).

The GBSAA system poses an advantage in its ability to capture traffic not covered by the bandwidth of the ADS-B system. UA and manned aircraft not equipped with an ADS-B system can still pose a danger to the NAS, and the GBSAA system's detection methods can be used to alert personnel in the NAS of such an aircraft's presence. Additionally, the usage of FAA Pathfinder projects such as the SkyTracker and Skylight can be utilized to strengthen detection capabilities to cover small UASs' and recreational UAS operation. To prevent incidents involving UAS operation directly over airports, the SkyTracker system can be deployed along with kinetic-based countermeasures so as to prevent malicious UAS operation or one that presents a safety concern.

UAS regulation and operation education efforts, such as the B4UFLY smartphone application, specifically administered to UAS operators in states with the highest frequency of reported incidents could result in a reduction in airspace incursions and NMAC reports. Regulation awareness and compliance in those states can lead to an overall decrease in manned air traffic disruption caused by UASs'.

A mitigation technique to reduce the number of incidents reported to take place in Class B airspaces may involve the employment of several strategies. From a UAS pilot standpoint, this includes the usage of AirMap and proper radio communication. The information sent through D-NAS can be used by ATCs to manage air traffic within the airspace and prevent incidents involving manned aircraft (AirMap, 2016). If an imminent danger is present ATC can send messages via AirMap or radio communication to the UAS pilots concerning evasive actions to be taken. AirMap also provides UAS pilots with real-time traffic alerts (AirMap, 2016). The benefit of using AirMap is that it integrates easily into typically utilized UAS control stations, i.e. smartphones or tablets with a cellular data signal (AirMap, 2016).

The statistical study described in this paper utilizes data regarding UAS-related events obtained from several databases all of which are based on a voluntary reporting system. As a result, there is a certain degree of subjectivity associated with each reported event. Likewise, each event is a personal account of the incident introducing the possibility of misperceptions. The findings of this study could be strengthened if the databases utilized a mandatory reporting system wherein UAS pilots, manned aircraft crew, or aviation personnel are required to report any incident involving a UAS.

Each event examined was obtained using specific search terms – “UAS OR drone OR UAV OR unmanned OR RC.” It is possible that some reports involving UAS activity do not use these terms in their descriptions. For this reason, an improvement in search terms employed and search methodology can be explored to capture all UAS-related events from a database.

An analysis of reported events focusing on the UAS manufacturer type can be used to indicate whether a specific manufacturer should consider making technological modifications or advancements to improve the safety of operations of their UASs’. A similar analysis focusing on the operational sector (i.e. commercial, recreational, public use, or military) could reveal what the majority of operations will encompass. Knowing who the primary user is aided in the development of systems intended to mitigate UAS-related events.

References

Aircraft Owners and Pilots Association (2009) Airspace for everyone. *Safety Advisor.* 38002 06/09. Edition 5.

AirMap (2016) Airspace intelligence. *Airmap.* Retrieved from https://www.airmap.com/

AirMap (2016) AirMap and the American Association of Airport Executives (AAAE) launch UAS notice system. *PR Newswire.* Retrieved from http://www.prnewswire.com/news-releases/airmap--the-american-association-of-airport-executives-aaae-launch-uas-notice-system-300242406.html

Academy of Model Aeronautics (2016) An analysis of the FAA's March 2016 UAS sightings. *Academy of Model Aeronautics.* Retrieved from http://amablog.modelaircraft.org/amagov/files/2016/06/AMA-Analysis-FINAL-6-1-16.pdf

Aviation Safety Bureau (2010) Federal Aviation Regulations. *Aviation Safety Bureau.* Retrieved from http://www.aviation-safety-bureau.com/federal-aviation-regulations.html

Brooker, P. (2013) Introducing Unmanned Aircraft Systems into a high reliability ATC system. *Journal of Navigation. 66*(5). 719-735. doi: https://doi.org/10.1017/S0373463313000337

Carmona, M. (2016) ASRS Database Online. *Aviation Safety Reporting System.* Retrieved from http://asrs.arc.nasa.gov/search/database.html

Cho, Y. (2014). Lost in Debate: The Safety of Domestic Unmanned Aircraft Systems. *Journal of Strategic Security, 7*(4), 38–56. doi:10.5038/1944-0472.7.4.4

Clothier, R. A., Williams, B. P., & Fulton, N. L. (2015). Structuring the safety case for unmanned aircraft system operations in non-segregated airspace. *Safety Science, 79,* 213–228. doi:10.1016/j.ssci.2015.06.007

Dalamagkidis, K., Valavanis, K. P., & Piegl, L. A. (2008). On unmanned aircraft systems issues, challenges and operational restrictions preventing integration into the National Airspace System. *Progress in Aerospace Sciences, 44*(7-8), 503–519. doi:10.1016/j.paerosci.2008.08.001

DJI (2015) DJI Introduces new geofencing system for its drones. *DJI.* Retrieved from https://www.dji.com/newsroom/news/dji-fly-safe-system

Geister, D., & Geister, R. (2013). Integrating unmanned aircraft efficiently into hub airport approach procedures. *Navigation*, *60*(3), 235-247. doi:10.1002/navi.40

e-CFR (2016) Electronic Code of Federal Regulations Title 14 Chapter I Subpart F Part 101. *U.S. Government Publishing Office.* Retrieved from http://www.ecfr.gov/cgi-bin/text-idx?rgn=div5&node=14:2.0.1.3.15

Federal Aviation Administration (2016) *FAA aerospace forecast fiscal years 2016-2036, TC16-0002*. Washington, DC: U.S. Department of Transportation.

Federal Aviation Administration (2016) Small Unmanned Aircraft Systems (sUAS). *Advisory Circular No. 107-2*. Washington, DC: U.S. Department of Transportation.

Federal Aviation Administration (2016c) FAA Near Mid-Air Collision System (NMACS). *FAA Aviation Safety Information Analysis and Sharing (ASIAS).* Retrieved from http://www.asias.faa.gov/pls/apex/f?p=100:35:0::NO::P35_REGION_VAR:1

Federal Aviation Administration (2016d) Aviation accident and incident database. *FAA Aviation Safety Information Analysis and Sharing (ASIAS).* Retrieved from http://www.asias.faa.gov/pls/apex/f?p=100:15:0::NO::P15_REGION_VAR:1

Federal Aviation Administration (2016e) Aviation Safety Reporting System (ASRS). *FAA Aviation Safety Information Analysis and Sharing (ASIAS).* Retrieved from http://www.asias.faa.gov/pls/apex/f?p=100:43:0::NO::P43_REGION_VAR:1

Federal Aviation Administration, (n.d.) FAA UAS accident and incident preliminary reports. *FAA Aviation Safety Information Analysis and Sharing (ASIAS).* Retrieved from http://www.asias.faa.gov/pls/apex/f?p=100:446:0::NO:446::

Federal Aviation Administration (2015) FAA releases pilot UAS reports. *Federal Aviation Administration.* Retrieved from https://www.faa.gov/news/updates/?newsId=83544

Federal Aviation Administration (2016f) FAA released updated UAS sighting reports. *Federal Aviation Administration.* Retrieved from https://www.faa.gov/news/updates/?newsId=85229

Federal Aviation Administration (2013). *Integration of civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) roadmap*: *2013-AJG-502.* Washington, DC: U.S. Department of Transportation.

Federal Aviation Administration (2016g) B4UFLY smartphone app. *Federal Aviation Administration.* Retrieved from https://www.faa.gov/uas/where_to_fly/b4ufly/

Fern, L. (2012) UAS Integration into the NAS: An examination of baseline compliance in the current airspace system. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 56*(1) 41-45.

Gimenes, R. A. V., Vismari, L. F., Avelino, V. F., Camargo, J. B., de Almeida, J. R., & Cugnasca, P. S. (2013). Guidelines for the integration of autonomous UAS into the global ATM. *Journal of Intelligent & Robotic Systems. 74* (1-2), 465–478. doi:10.1007/s10846-013-9945-0

Insurance Journal (2016) The future of commercial drone use. *Insurance Journal.* Retrieved from http://www.insurancejournal.com/news/national/2016/03/29/403149.htm

Joslin, R. (2015). Synthesis of Unmanned Aircraft Systems safety reports. *Journal of Aviation Technology and Engineering*, *5*(1), 2. doi:10.7771/2159-6670.1117

Kapnik, B. (2012). Unmanned but accelerating: navigating the regulatory and privacy challenges of introducing unmanned aircraft into the National Airspace System. *Journal of Air Law & Commerce*, *77*, 439.

Lincoln Laboratory (2015) Tech Notes Airborne Collision Avoidance System X. *Lincoln Laboratory Massachusetts Institute of Technology.* Retrieved from https://www.ll.mit.edu/publications/technotes/TechNote_ACASX.pdf

Luchian, A., Prisăcariu, V., & Cîrciu, I. (2014). Unmanned Aircraft Vehicle (UAV) in the Romanian airspace. An overview. *Journal of Defense Resources Management (JoDRM), 5*(1), 123-128.

Meola, A. (2016) Drone usage expected to triple by 2020. *Business Insider.* Retrieved from http://www.businessinsider.com/faa-says-drone-usage-will-triple-by-2020-2016-3

Michel, A. (2015) Customs and border protection drones. *Center for the Study of the Drone at Bard College.* Retrieved from http://dronecenter.bard.edu/customs-and-border-protection-drones/

Moynihan, T. (2016) Airmap for ios lets drone pilots easily avoid incidents. *WIRED.* Retrieved from http://www.wired.com/2016/05/airmap-app-drone-flight-reporting/

National Aeronautics and Space Administration (2015). Unmanned Aircraft System (UAS) Traffic Management (UTM). *National Aeronautics and Space Administration.* Retrieved from https://utm.arc.nasa.gov/

National Business Aviation Association (2011) New York metro airspace overview. *National Business Aviation Association.* Retrieved from https://www.nbaa.org/ops/airspace/issues/new-york-airspace/

Rossier, R. (1998) Class B Basics: The ABCs of Class B airspace. *AVweb.* Retrieved from http://www.avweb.com/news/avtraining/183284-1.html

RTCA (2016) Terms of Reference Special Committee (SC) 147 aircraft collision avoidance systems revision 14. *RTCA.* Paper No. 079-16/PMC-1478.

Sathyamoorthy, D. (2015) A review of security threats of Unmanned Aerial Vehicles and mitigation steps. *The Journal of Defense and Security. 6*(1). 81.

Selinger, M. (2016) To address a growing threat, the FAA is evaluating systems that detect and track UAS at airports. *Association for Unmanned Vehicles Systems International.* Retrieved from https://issuu.com/auvsi/docs/pages_from_08_unmannedsystems_web

Serle, J. (2015) Monthly drone report, May 2015: US strikes kill at least 48 in three countries. *The Bureau of Investigative Journalism.* Retrieved from https://www.thebureauinvestigates.com/2015/06/02/monthly-drone-report-may-2015-us-strikes-kill-at-least-48-in-three-countries/

Simpson, A. (2015) Insurers AIG, USAA Receive OK to test use of drones. *Insurance Journal.* Retrieved from http://www.insurancejournal.com/news/national/2015/04/08/363647.htm

Trejos, N. (2013) New York airspace seeks a decongestant. *USA Today*. Retrieved from http://www.usatoday.com/story/travel/flights/2013/01/28/new-york-congested-air-traffic/1871901/

Trochim, W. (2006) Descriptive statistics. *Research Methods Knowledge Base.* Retrieved from http://www.socialresearchmethods.net/kb/statdesc.php

UAS Vision (2015) First interim standards for unmanned aircraft detect-and-avoid Released. *UAS Vision.* Retrieved from http://www.uasvision.com/2015/10/08/first-interim-standards-for-unmanned-aircraft-detect-and-avoid-released/

Vallese, F. (2016) New rules fuel the growth of the commercial drone industry. *Tech Crunch.* Retrieved from https://techcrunch.com/2016/08/05/new-rules-fuel-the-growth-of-the-commercial-drone-industry/

Volpe (2016) System enables drone operators to “sense and avoid” other aircraft. *Volpe The National Transportation Systems Center.* Retrieved from https://www.volpe.dot.gov/air-traffic-systems-operations/air-traffic-management-systems/ground-based-sense-and-avoid

Weikel, D. (2015) FAA proposes state-of-art traffic control system for L.A.’s crowded skies. *Los Angeles Times.* Retrieved from http://www.latimes.com/local/california/la-me-air-traffic-control-20150616-story.html

Williams, K. (2004) *A summary of unmanned aircraft accident/incident data: Human factors implications*, *DOT/FAA/AM-04/24.* Washington, DC: U.S. Department of Transportation Federal Aviation Administration.

Young, D. (2013, April). Unmanned Aircraft Systems (UAS) integration in the National Airspace System (NAS) project: Security risk assessment process for UAS in the NAS CNPC architecture. In *2013 Integrated Communications, Navigation and Surveillance Conference (ICNS)*. doi:10.1109/icnsurv.2013.6548624

Appendix A

Tables

Table 1

FAA Accident And Incident Data System – Number of Events (1978-April 26, 2016)

Year	Number of Events
1978	1
1979	2
1997	3
1999	3
2001	3
2003	2
2004	6
2006	3
2007	3
2011	1
2012	1
2014	2
2016	1

Note: Only years when UAS-related reported events took place are represented. Adapted from "Aviation Accident and Incident Database" by Federal Aviation Administration, 2016d, *FAA Aviation Safety Information Analysis and Sharing (ASIAS),* Adapted with permission.

Table 2

FAA Accident and Incident Data System – Number of UAS-related Events per State

States	Number of Events
Arizona	1
California	6
Idaho	1
Illinois	2
Kansas	1
Louisiana	1
Maryland	1
Maine	1
Missouri	1
North Carolina	2
Nebraska	1
New Jersey	2
Oregon	2
Pennsylvania	2
Washington	3
West Virginia	1

Note: Only states where UAS-related reported events took place are represented. Adapted from "Aviation Accident and Incident Database" by Federal Aviation Administration, 2016d, *FAA Aviation Safety Information Analysis and Sharing (ASIAS),* Adapted with permission.

Table 3

FAA Aviation Safety Reporting System – Number of UAS-related Events (1993-June 1, 2016)

Year	Number of Events	Year (Contd.)	Number of Events
1993	5	2010	10
1994	4	2011	9
1995	7	2012	24
1996	3	2013	32
1997	5	2014	87
1998	10	2015	190
1999	3	2016	88
2000	10		
2001	5		
2002	1		
2003	3		
2004	2		
2005	1		
2006	6		
2007	8		
2008	7		
2009	4		

Note: Only years when UAS-related reported events took place are represented. Adapted from "Aviation Safety Reporting System (ASRS)" by Federal Aviation Administration, 2016e, *FAA Aviation Safety Information Analysis and Sharing (ASIAS),* Adapted with permission.

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Table 4

FAA Aviation Safety Reporting System – Number of UAS-related Events per State

States	Number of Events	States	Number of Events
Alabama	4	North Dakota	2
Arizona	31	Nebraska	3
California	65	New Hampshire	5
Colorado	5	New Jersey	20
Florida	45	New Mexico	10
Georgia	11	Nevada	3
Idaho	2	New York	32
Illinois	14	Ohio	7
Indiana	16	Pennsylvania	6
Kansas	2	Rhode Island	1
Kentucky	4	South Carolina	1
Louisiana	3	Tennessee	4
Massachusetts	3	Texas	39
Maryland	4	Utah	60
Michigan	8	Virginia	7
Minnesota	21	Vermont	23
Missouri	2	Washington	1
Mississippi	2	Wisconsin	1
Montana	3	West Virginia	3
North Carolina	10	Wyoming	1

Note: States where UAS-related reported events took place are represented. Adapted from “Aviation Safety Reporting System (ASRS)” by Federal Aviation Administration 2016e, *FAA Aviation Safety Information Analysis and Sharing (ASIAS),* Adapted with permission.

Table 5

FAA Aviation Safety Reporting System – Number of UAS-related Events per Operation Type

Operation Type	**Number of Events**
Ambulance	3
Passenger	133
Personal	67
Cargo / Freight	7
Training	44
Photo Shoot	4
Tactical	18
Utility	2
Ferry	7
Aerobatics	1
Test Flight	5
Traffic Watch	1

Note: Only operation types which encountered UAS-related reported events are represented. Adapted from "Aviation Safety Reporting System (ASRS)" by Federal Aviation Administration, 2016e, *FAA Aviation Safety Information Analysis and Sharing (ASIAS),* Adapted with permission.

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Table 6

NASA Aviation Safety Reporting System – Number of UAS-related Events (1994-June 2016)

Year	**Total Number of**	**National**	**Near Mid-air**
1994	1	0	1
1998	1	1	0
2000	2	0	2
2001	1	1	0
2003	1	0	1
2006	1	1	0
2007	1	0	1
2009	2	2	0
2011	2	0	2
2012	6	4	2
2013	11	7	4
2014	37	17	20
2015	78	31	47
2016	34	7	27

Note: Only years when UAS-related events took place are represented. Adapted from "ASRS Database Online by Carmona, M. (2016), *Aviation Safety Reporting System* Adapted with permission.

Table 7

NASA Aviation Safety Reporting System – Number of UAS-related Events per State

State	# of Events	State	# of Events
Arizona	11	Mississippi	1
California	27	North Carolina	5
Colorado	2	New Hampshire	2
Florida	16	New Jersey	5
Georgia	4	New Mexico	3
Idaho	1	Nevada	1
Illinois	5	New York	18
Indiana	3	Ohio	2
Kentucky	2	Pennsylvania	3
Louisiana	1	Rhode Island	1
Massachusetts	2	Tennessee	1
Maryland	2	Texas	11
Michigan	3	Utah	3
Minnesota	10	Virginia	10
Missouri	1	West Virginia	1

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Table 8

NASA Aviation Safety Reporting System – Number of UAS-related Events per Airspace Class

Airspace Class	Total Number of Events
E	50
A	17
D	23
G	6
Special Use	1
C	12
B	61

Note: Only years when UAS-related events took place are represented. Adapted from "ASRS Database Online by Carmona, M. (2016), *Aviation Safety Reporting System* Adapted with permission.

Table 9

FAA Near Mid-Air Collision System – Number of Events (2001-July 31, 2016)

Year	Number of Events
2001	2
2012	1
2014	9
2015	52
2016	87

Note: Only years when UAS-related events took place are represented. Adapted from "FAA Near Mid-air Collision System (NMACS)" by Federal Aviation Administration, 2016c, *FAA Aviation Safety Information Analysis and Sharing (ASIAS),* Adapted with permission.

Table 10

FAA Near Mid-Air Collision System – Number of UAS-related Events per State

States	# of Events	States	# of Events (Contd.)
Alabama	1	New Hampshire	2
Arizona	2	New Jersey	6
California	9	New York	19
Connecticut	5	Ohio	8
Delaware	1	Oklahoma	2
Florida	11	Oregon	2
Georgia	5	Pennsylvania	9
Illinois	4	Rhode Island	3
Indiana	2	South Carolina	2
Louisiana	1	Tennessee	1
Massachusetts	9	Texas	21
Maryland	5	Utah	1
Michigan	2	Virginia	5
Minnesota	2	Washington	4
North Carolina	1	Wisconsin	2
North Dakota	1	West Virginia	3

Note: Only states where UAS-related events took place are represented. Adapted from "FAA Near Mid-air Collision System (NMACS)" by Federal Aviation Administration, 2016c, *FAA Aviation Safety Information Analysis and Sharing (ASIAS)*, Adapted with permission.

Table 11

FAA Near Mid-Air Collision System – Number of UAS-related Events per Altitude Range

Altitude Range (Feet)		**Number of Events**	**Altitude Range (Feet)**		**Number of Events**
Floor	Ceiling		Floor	Ceiling	
0	1000	17	12000	13000	1
1000	2000	39	13000	14000	1
2000	3000	30	14000	15000	1
3000	4000	16	15000	16000	1
4000	5000	17	16000	17000	0
5000	6000	15	17000	18000	0
6000	7000	4	18000	19000	0
7000	8000	5	19000	20000	1
8000	9000	3	20000	21000	2
9000	10000	4	21000	22000	1
10000	11000	3	22000	23000	0
11000	12000	2			

Note: Only years when UAS-related events took place are represented. Adapted from “FAA Near Mid-air Collision System (NMACS)” by Federal Aviation Administration, 2016c, *FAA Aviation Safety Information Analysis and Sharing (ASIAS),* Adapted with permission.

Table 12

FAA UAS Accident and Incident Preliminary Reports – Number of Events (2010-2014)

Year	Number of Events
2010	20
2011	26
2012	16
2013	22
2014	20

Note: Only years when UAS-related events took place are represented. Adapted from "FAA UAS Accident and Incident Preliminary Report" by Federal Aviation Administration, n.d., *FAA Aviation Safety Information Analysis and Sharing (ASIAS),* Adapted with permission.

Table 13

FAA UAS Accident and Incident Preliminary Reports – Number of Events per Sponsor Category

Sponsor Category	Number of
NASA	41
Academia	44
DOI	2
Law Enforcement	9
DOC	5
DOE	1
Special Airworthiness Certificate - Experimental Category	2

Note: Years when UAS-related events took place are represented. Adapted from "FAA UAS Accident and Incident Preliminary Report" by Federal Aviation Administration, n.d., *FAA Aviation Safety Information Analysis and Sharing (ASIAS),* Adapted with permission.

Table 14

FAA-released UAS Sightings Reports– Number of Events Categorized by Year and Event Type

Year	# Total Incidents	National Airspace System Violations	Near Mid-air Collision & National Airspace Violations
2014	33	33	17
2015	650	650	292

Note: The report spans the time period from November 2014 to August 2015. Adapted from "FAA Releases Pilot UAS Reports" by Federal Aviation Administration, 2015, Adapted with permission.

Table 15

FAA-released UAS Sightings Reports– Number of Events per State

State	# of Events	State	# of Events	State	# of Events
Alabama	5	Montana	1	Maine	4
Arkansas	2	North Carolina	12	Michigan	6
Arizona	20	North Dakota	2	Minnesota	6
California	150	New	2	Missouri	3
Colorado	17	New Jersey	23	Mississippi	2
Connecticut	9	New Mexico	1	Utah	4
Florida	79	Nevada	5	Virginia	9
Georgia	18	New York	74	Washington	30
Idaho	2	Ohio	8	Wisconsin	5
Illinois	24	Oklahoma	3	West Virginia	1
Indiana	2	Oregon	9	Maryland	5
Kansas	1	Pennsylvania	20	Texas	39
Kentucky	5	Rhode Island	4	Massachusetts	27
Louisiana	4	South Carolina	4	Tennessee	4

Note: The report spans the time period from November 2014 to August 2015. Adapted from "FAA Releases Pilot UAS Reports" by Federal Aviation Administration, 2015, Adapted with permission.

Table 16

FAA-released UAS Sightings Reports– Number of Events Categorized by Year and Event Type

Year	No. of Total Incidents	National Airspace System Violation	Near Mid-air Collision & National Airspace Violation
2015	422	359	201
2016	75	66	38

Note: The report spans the time period from August 2015 through January 2016. Adapted from “FAA Releases Pilot UAS Reports” by Federal Aviation Administration, 2016f, Adapted with permission.

Table 17

FAA-released UAS Sightings Reports– Number of Events per State

State	# of Events	State	# of Events	State	# of Events
Alabama	6	Louisiana	2	Ohio	7
Alaska	2	Maine	1	Oklahoma	6
Arizona	16	Maryland	6	Oregon	8
Arkansas	2	Massachusetts	12	Pennsylvania	17
California	111	Michigan	10	Puerto Rico	4
Colorado	6	Minnesota	4	South Carolina	3
Connecticut	4	Mississippi	2	Tennessee	5
DC	4	Missouri	4	Texas	39
Florida	59	Montana	2	Utah	5
Georgia	15	Nevada	3	Virginia	12
Hawaii	1	New Hampshire	1	Washington	8
Illinois	7	New Jersey	25	West Virginia	1
Indiana	6	New Mexico	1	Wisconsin	3
Kansas	3	New York	51		
Kentucky	6	North Carolina	7		

Note: The report spans the time period from August 2015 to January 2016. Adapted from “FAA Releases Pilot UAS Reports” by Federal Aviation Administration, 2016f, Adapted with permission.

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Appendix B

Figures

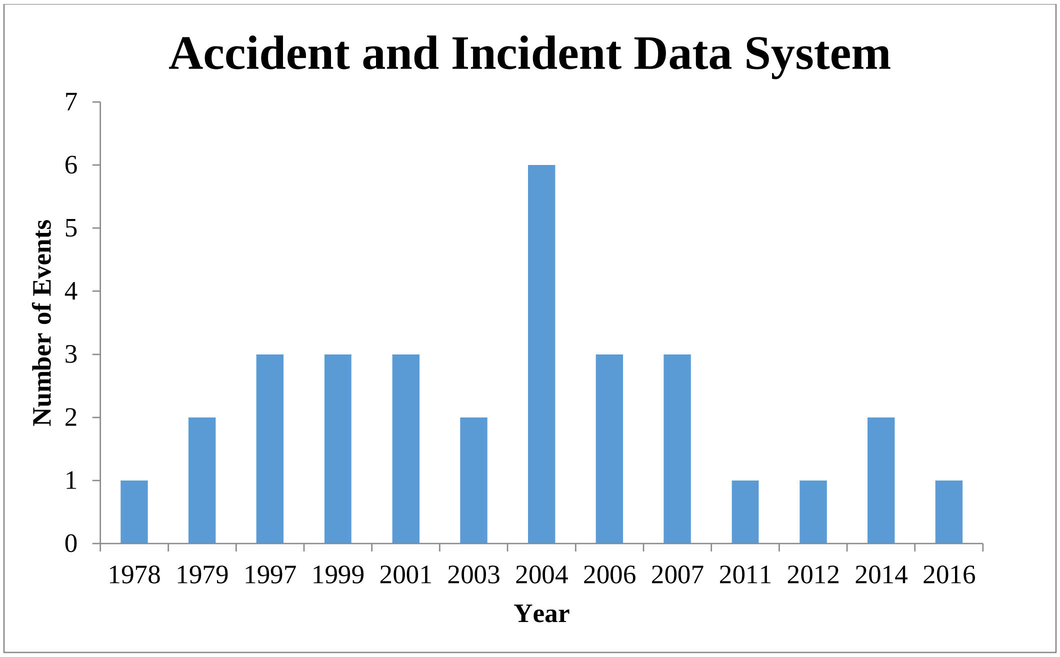

Figure 1. UAS-related events between 1978 and April 26, 2016 as reported in the FAA Accident and Incident Data System (AIDS).

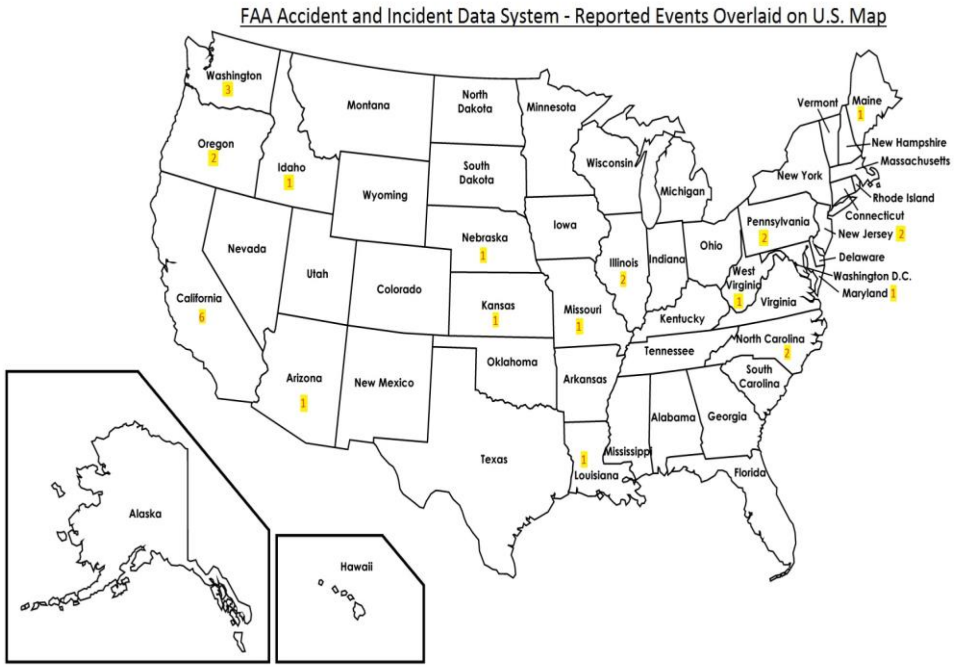

Figure 2. Number of UAS-related Reported Events per State (1978- April 26, 2016) as recorded in the Accident and Incident Data System (AIDS).

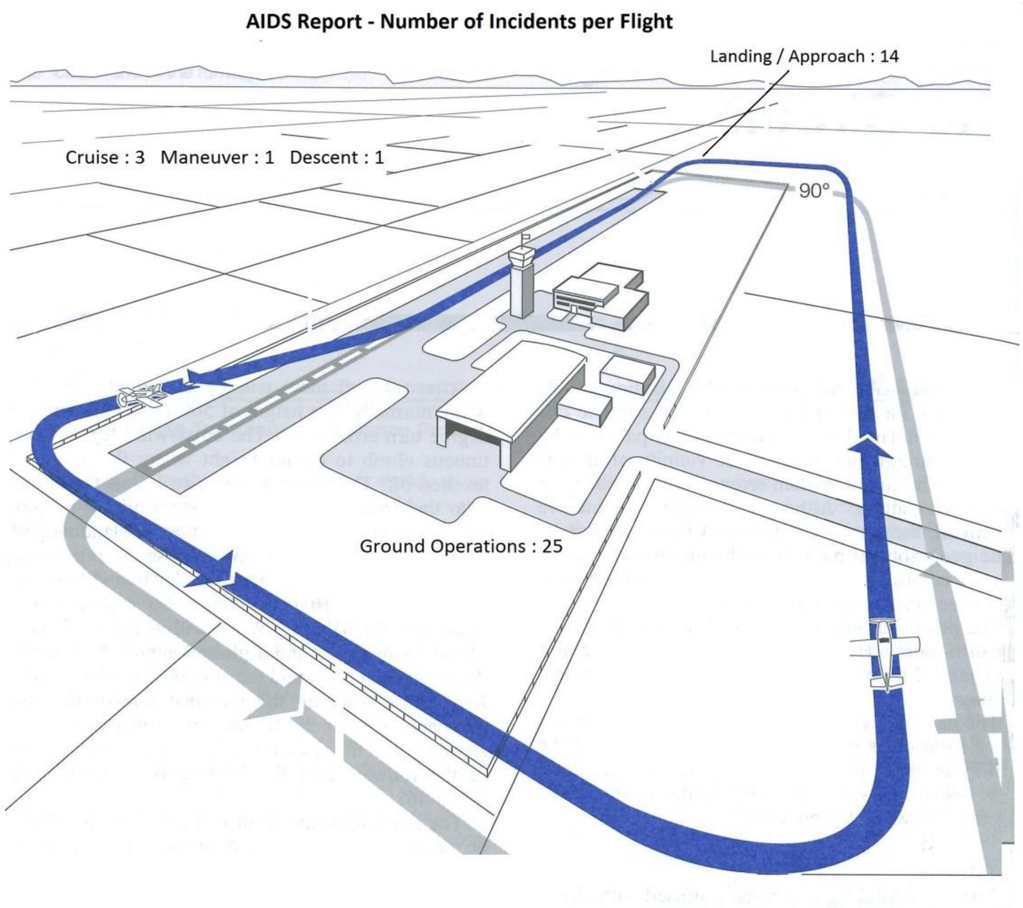

Figure 3. Number of UAS-related Reported Events per Flight Phase (1978-April 26, 2016) as recorded in the Accident and Incident Data System (AIDS), Adapted from “Canadian Aviation Regulations Part 1” by Langley Flying School Inc., 2016, *Langley Flying School*.

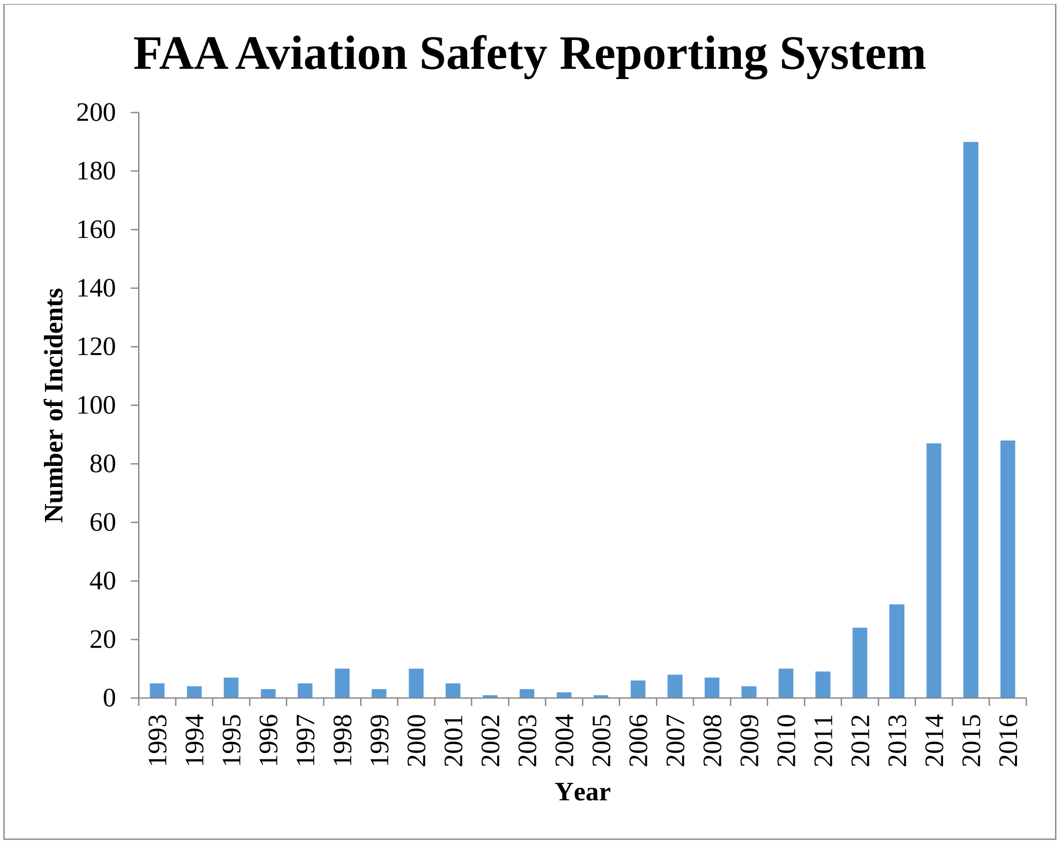

Figure 4. UAS-related events between 1993 and June 1, 2016 as reported in the FAA Aviation Safety Reporting System (ASRS).

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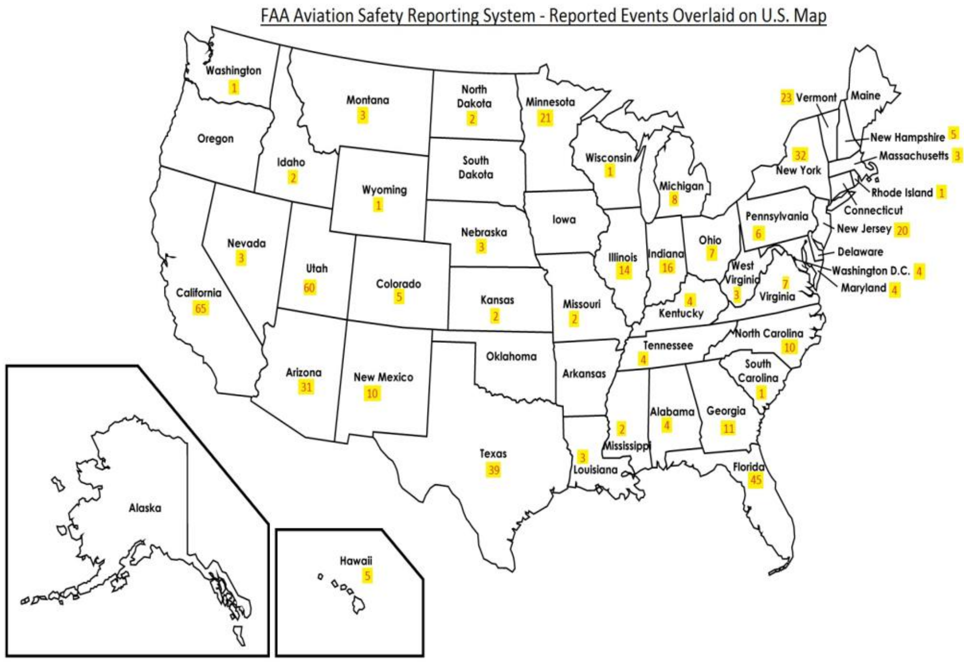

Figure 5. Number of UAS-related Reported Events per State (1993-June 1, 2016) as recorded in the FAA Aviation Safety Reporting System (ASRS)

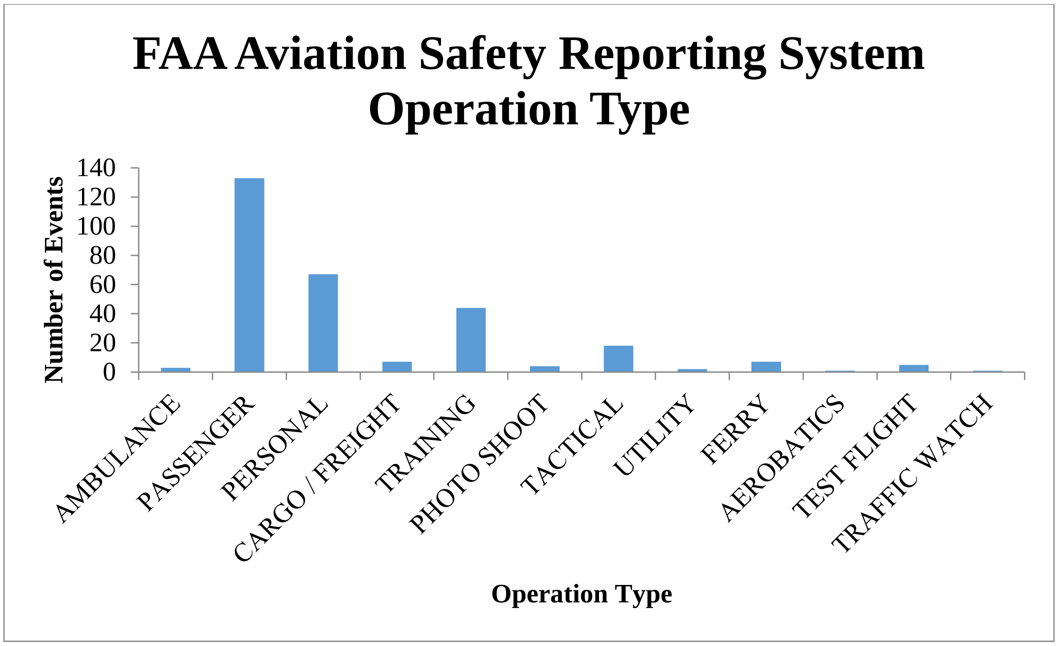

Figure 6. UAS-related Reported Events per Manned Aircraft Operational Type (1993-June 1, 2016) as recorded in the FAA Aviation Safety Reporting System (ASRS).

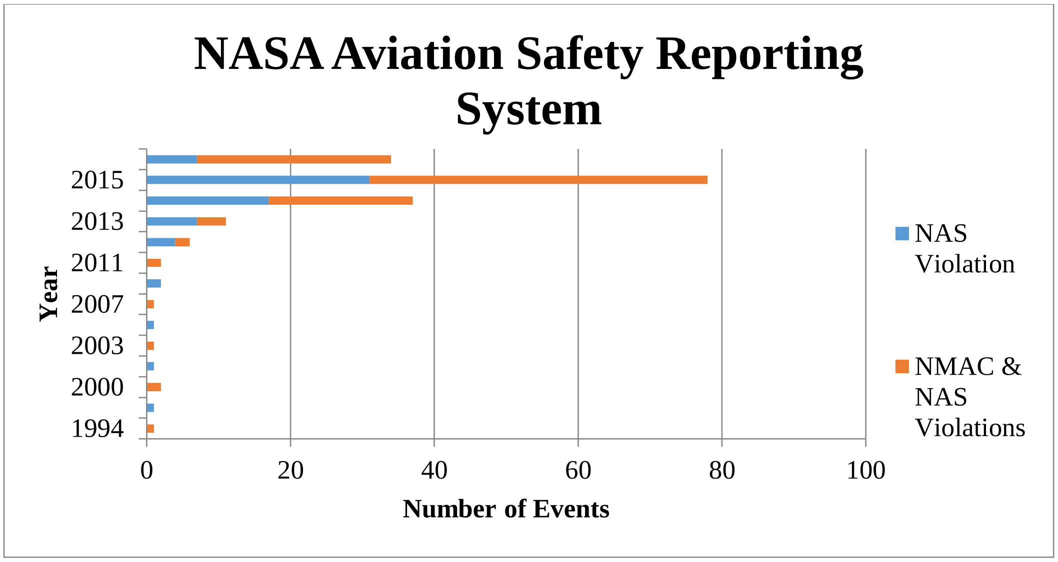

Figure 7. UAS-related events between 1994 and June 2016 as reported in NASA's Aviation Safety Reporting System (ASRS).

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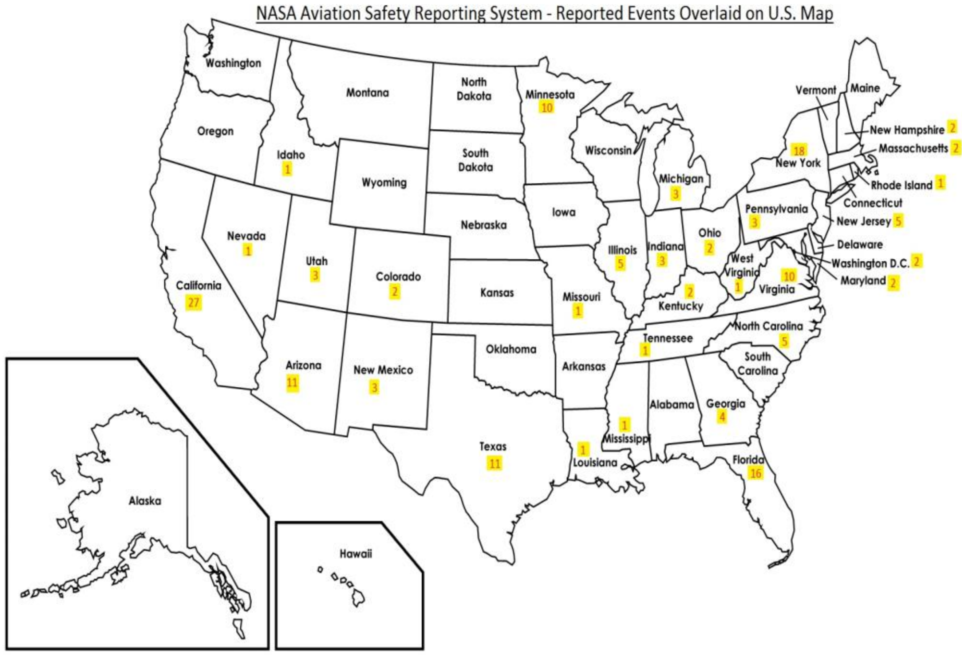

Figure 8. Number of UAS-related Reported Events per State (1994-June 2016) as recorded in the NASA Aviation Safety Reporting System (ASRS)

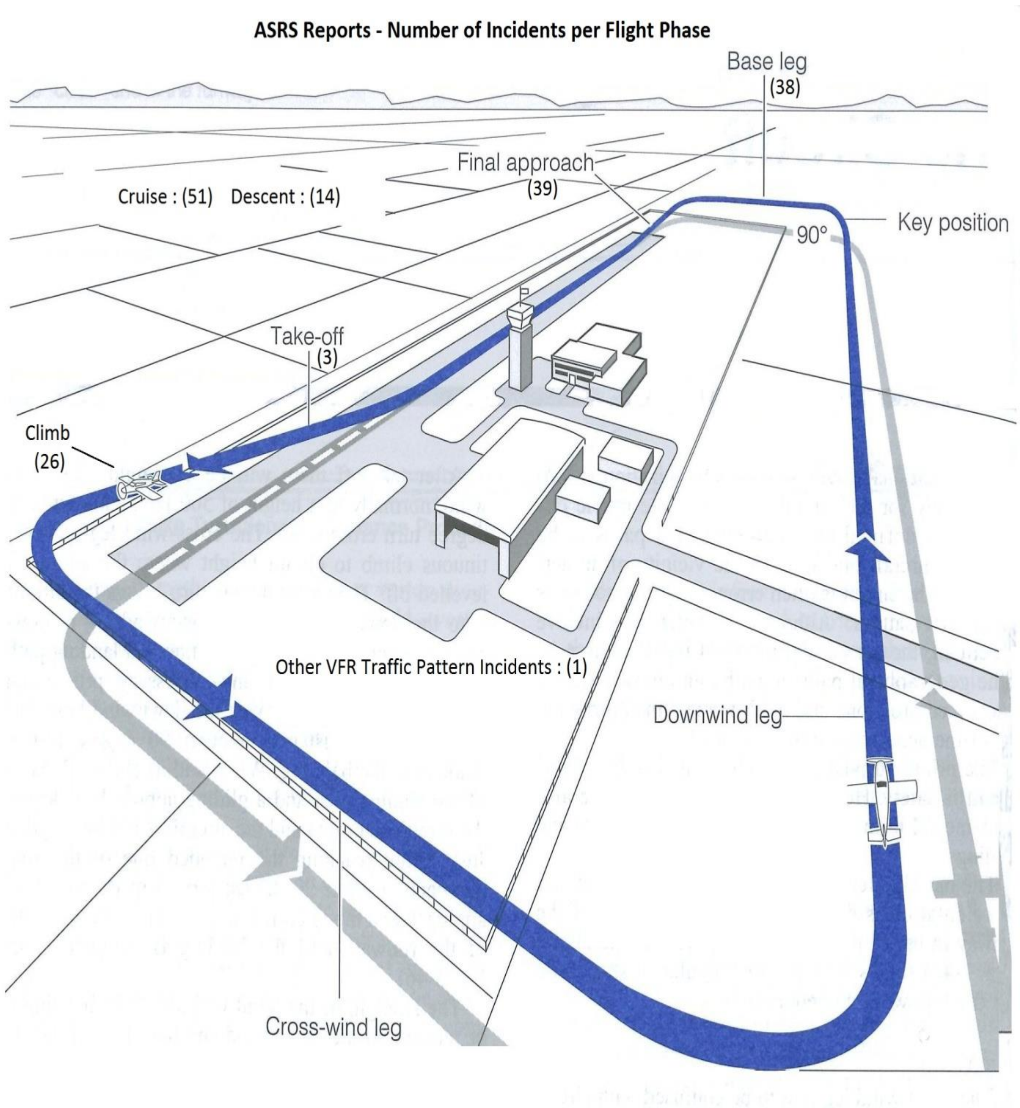

Figure 9. Number of UAS-related Reported Events per Flight Phase (1994-June 2016) as recorded in the NASA Aviation Safety Reporting System (ASRS). Adapted from "Canadian Aviation Regulations Part 1" by Langley Flying School Inc., 2016, *Langley Flying School.*

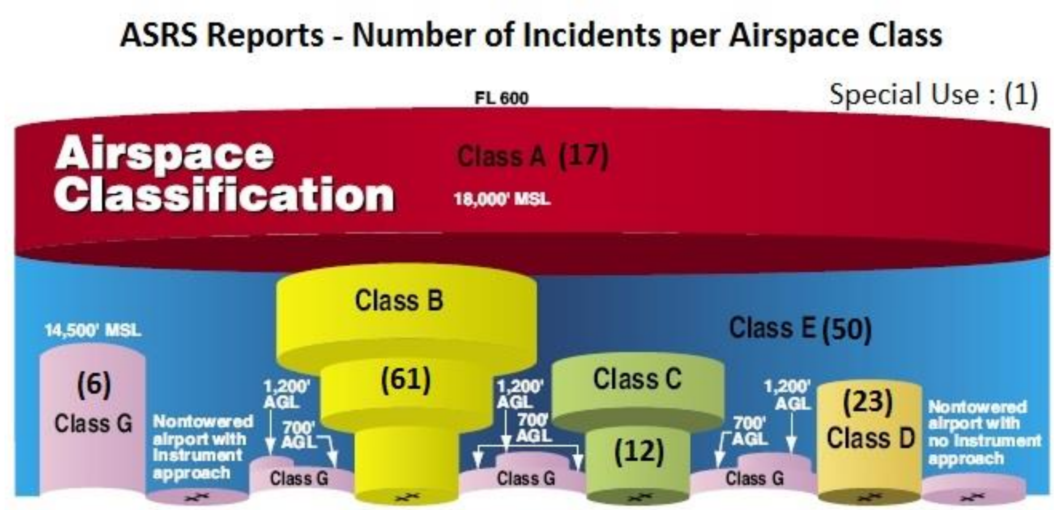

Figure 10. Number of UAS-related Reported Events per Airspace Class (1994-June 2016) as recorded in the NASA Aviation Safety Reporting System (ASRS). Adapted from "Classes of Airspace" by Federal Aviation Administration, 2016, *Federal Aviation Administration.*

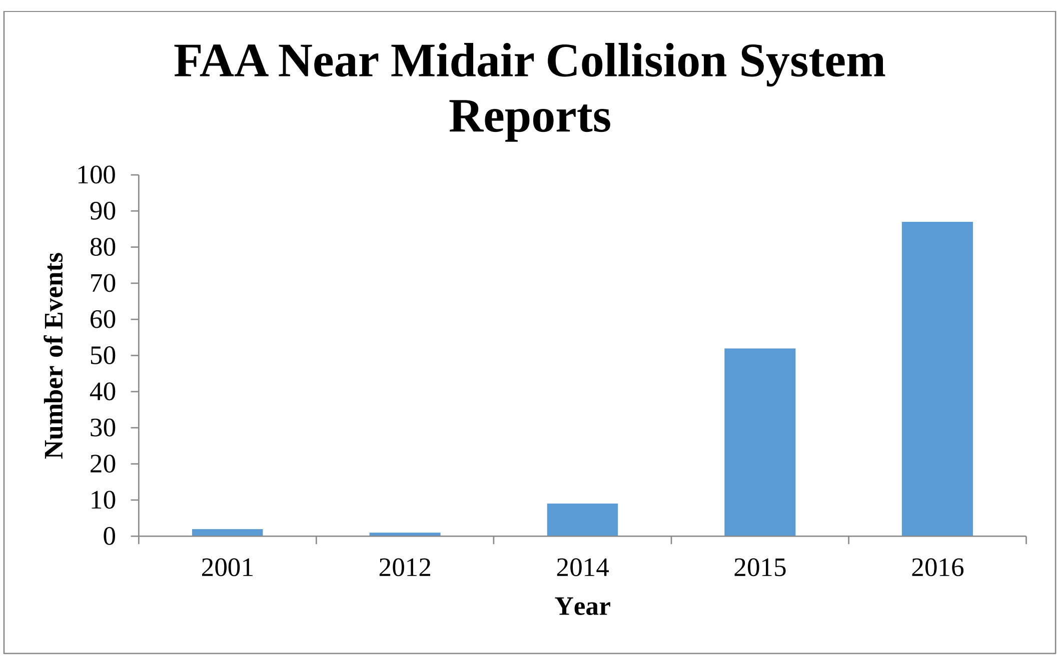

Figure 11. UAS-related events between 2001 and July 31, 2016 as reported in the FAA Near Mid-Air Collision System (NMACS).

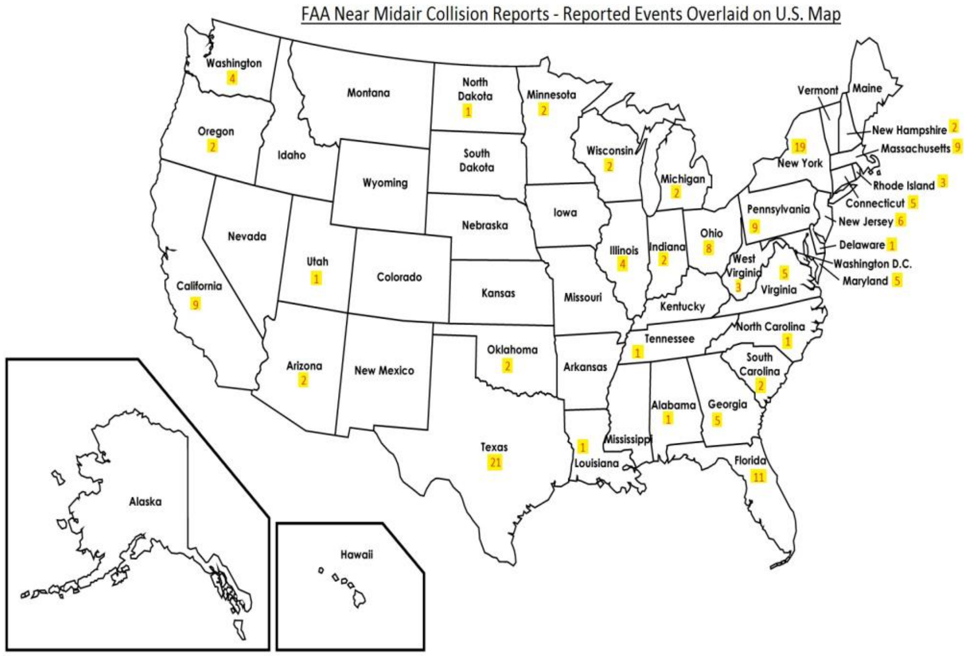

Figure 12. Number of UAS-related Reported Events per State (2001-July 31, 2016) as recorded in the FAA Near Mid-Air Collision System (NMACS).

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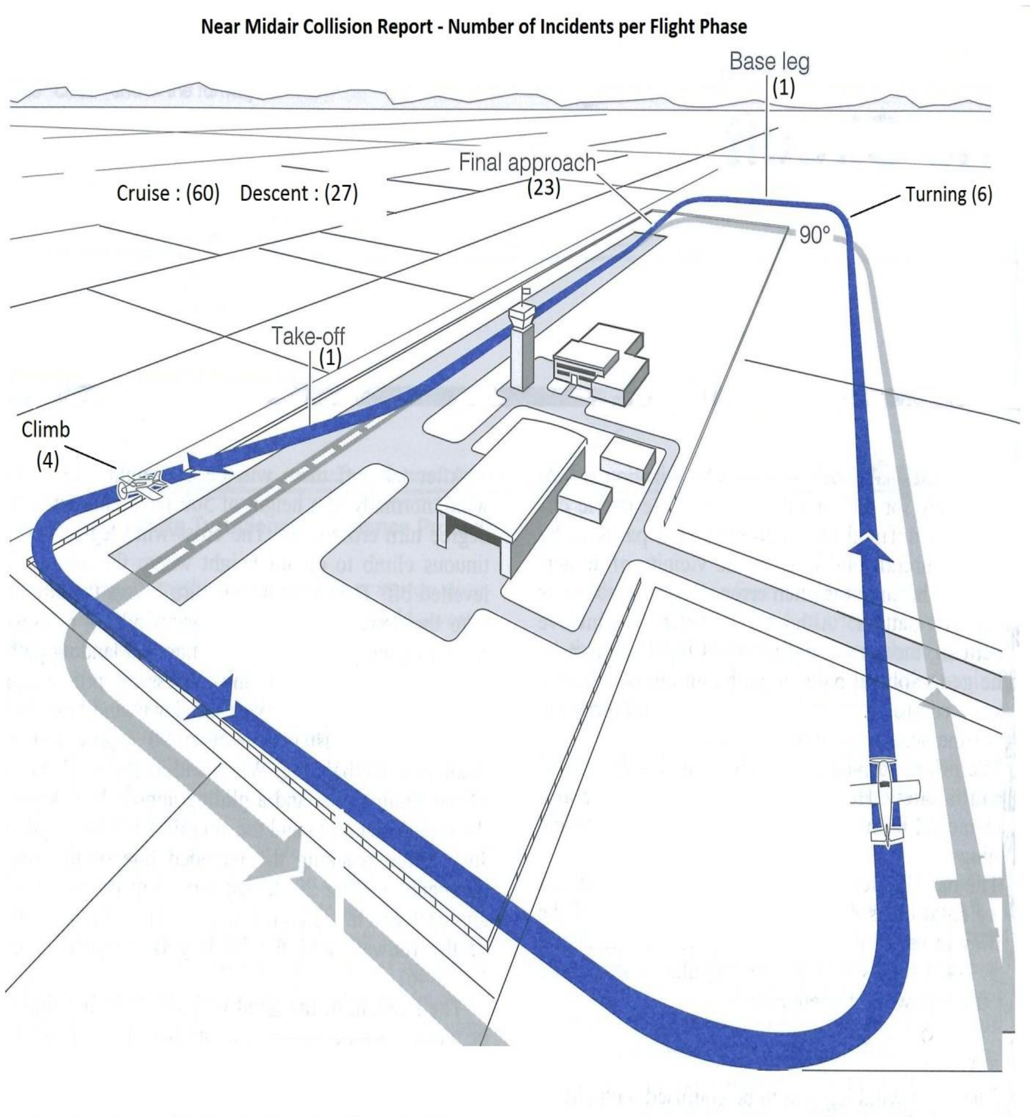

Figure 13. Number of UAS-related Reported Events per Flight Phase (2001-July 31, 2016) as recorded in the FAA Near Mid-Air Collision System (NMACS). Adapted from "Canadian Aviation Regulations Part 1" by Langley Flying School Inc., 2016, *Langley Flying School.*

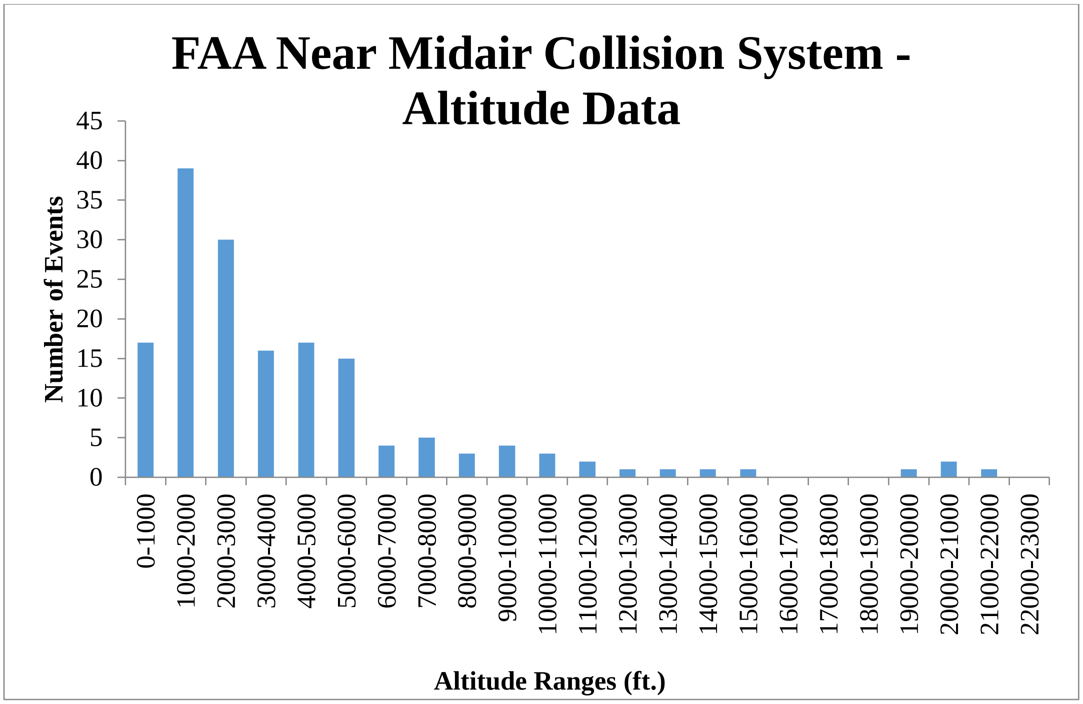

Figure 14. UAS-related events categorized by altitude ranges between 2001 and July 31, 2016 as reported in the FAA Near Mid-Air Collision System (NMACS).

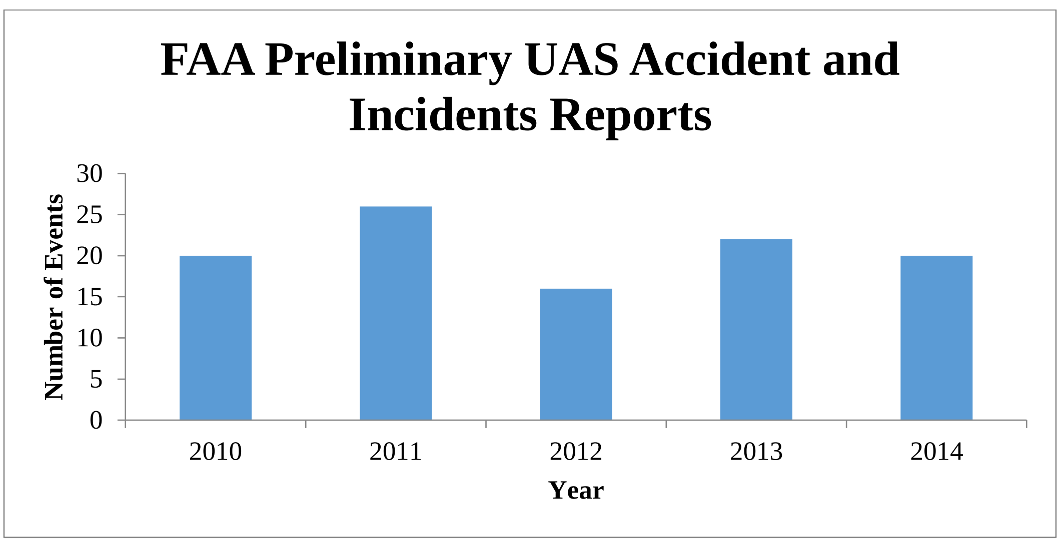

Figure 15. UAS-related events between 2010 and 2014 as reported in the FAA Preliminary UAS Accident and Incidents Reports.

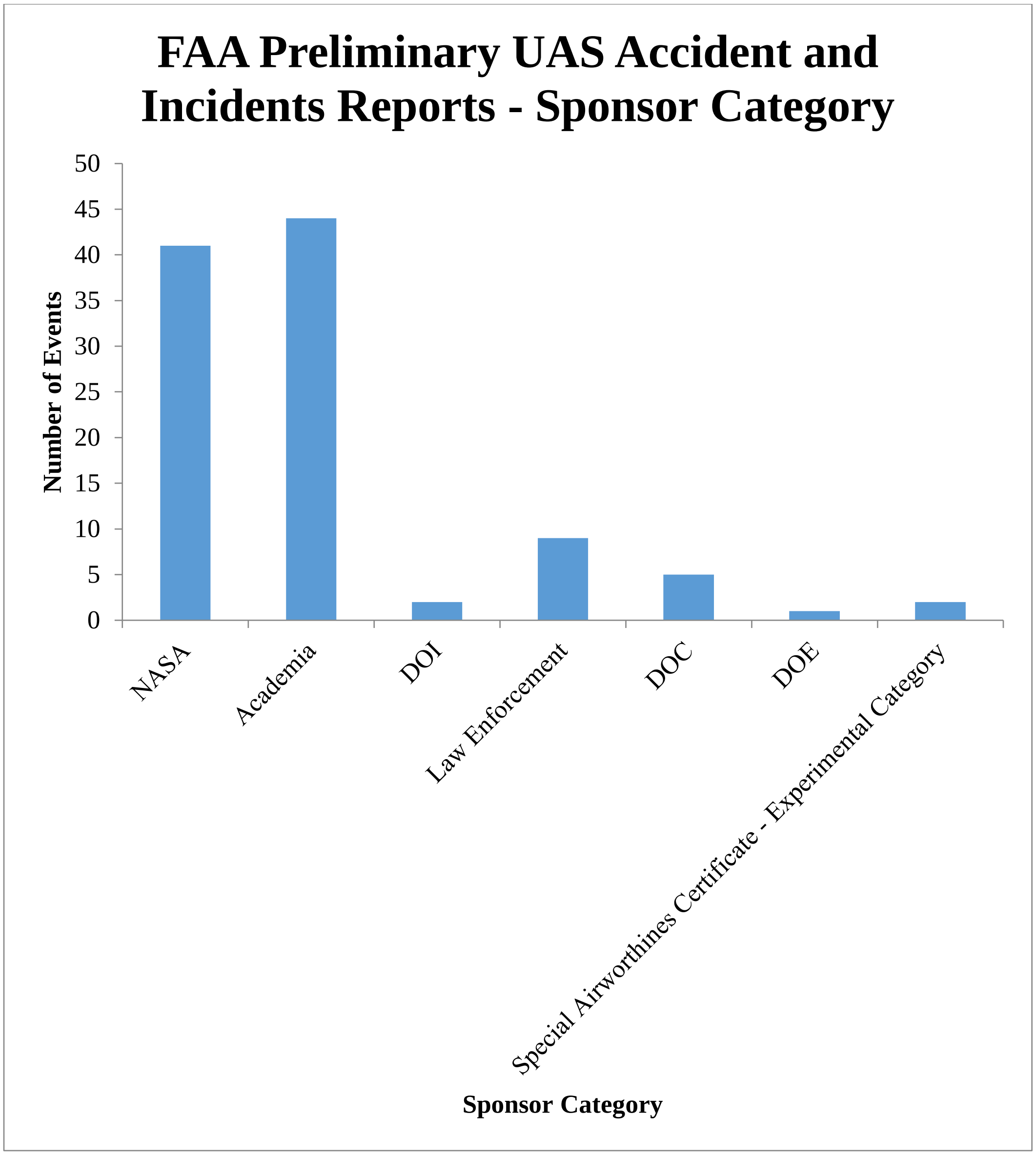

Figure 16. UAS-related events per sponsor category between 2010 and 2014 as reported in the FAA Preliminary UAS Accident and Incidents Reports.

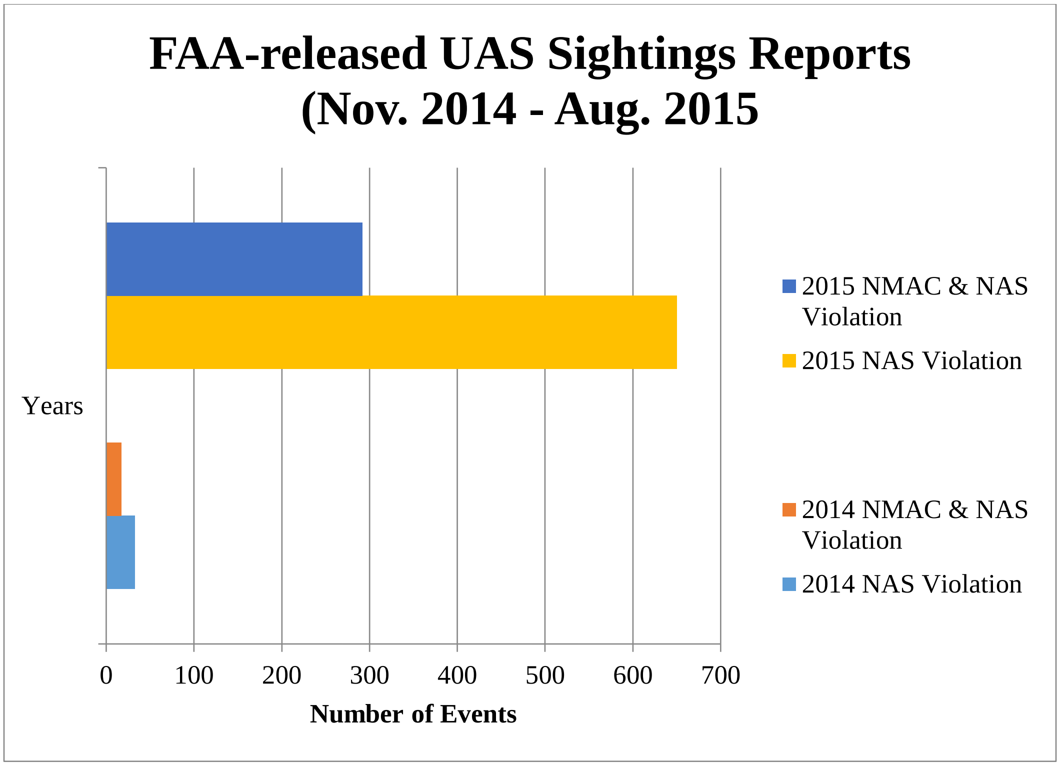

Figure 17. UAS-related events between November 2014 and August 2015 as reported in the FAA-released UAS Sightings Reports.

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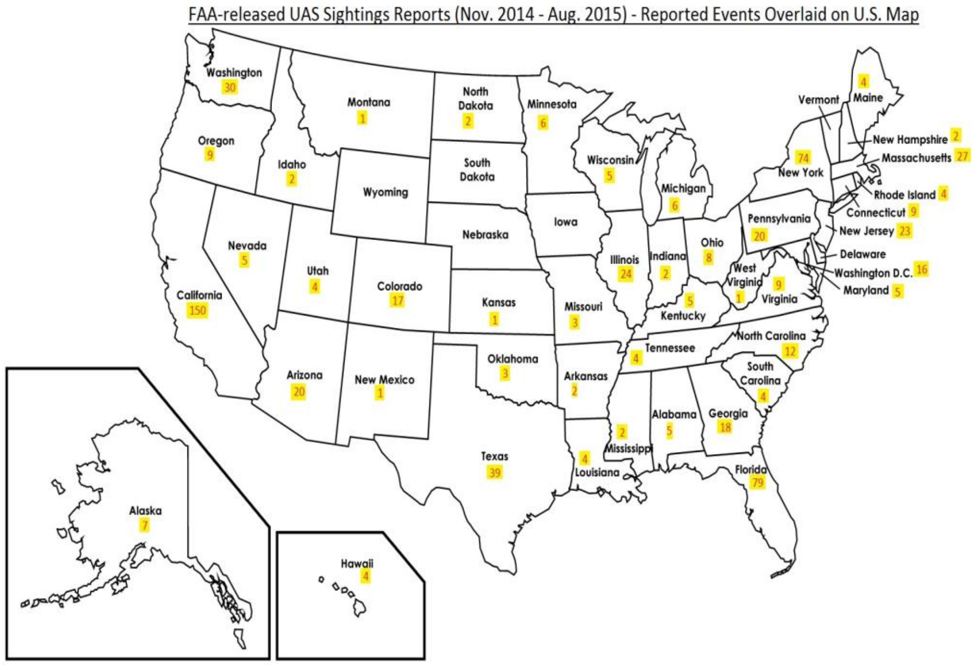

Figure 18. Number of UAS-related Reported Events per State as recorded in FAA-released UAS Sightings Reports (November 2014 through August 2015).

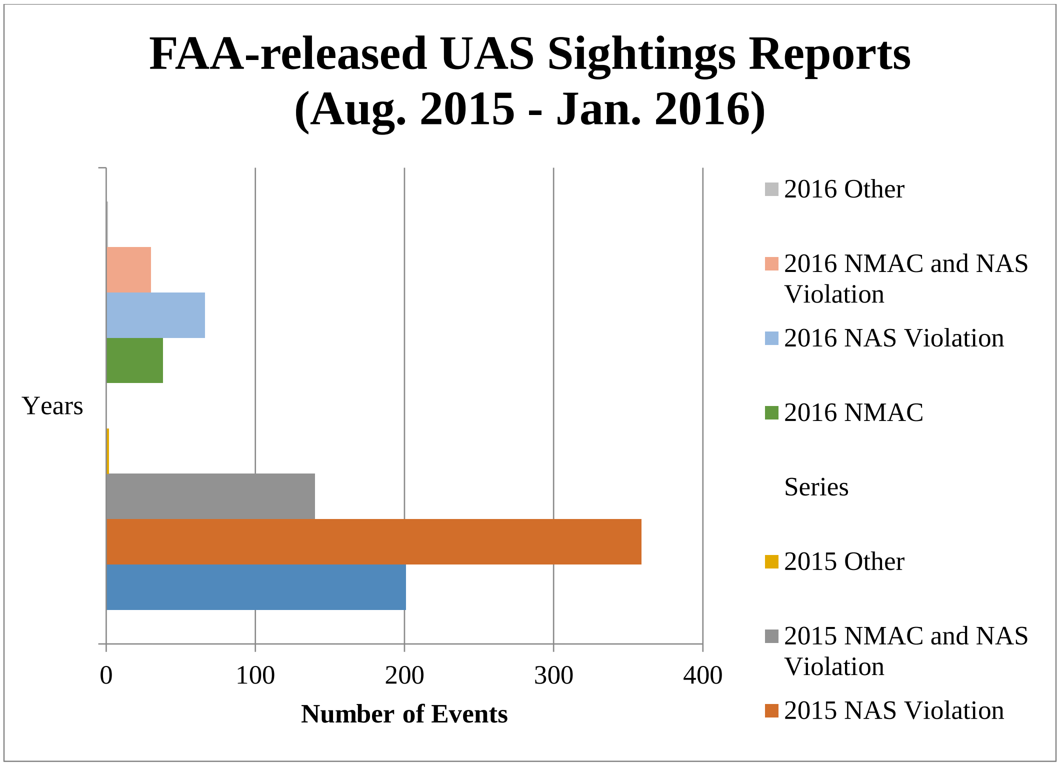

Figure 19. UAS-related events between August 2015 and January 2016 as reported in the FAA-released UAS Sightings Reports.

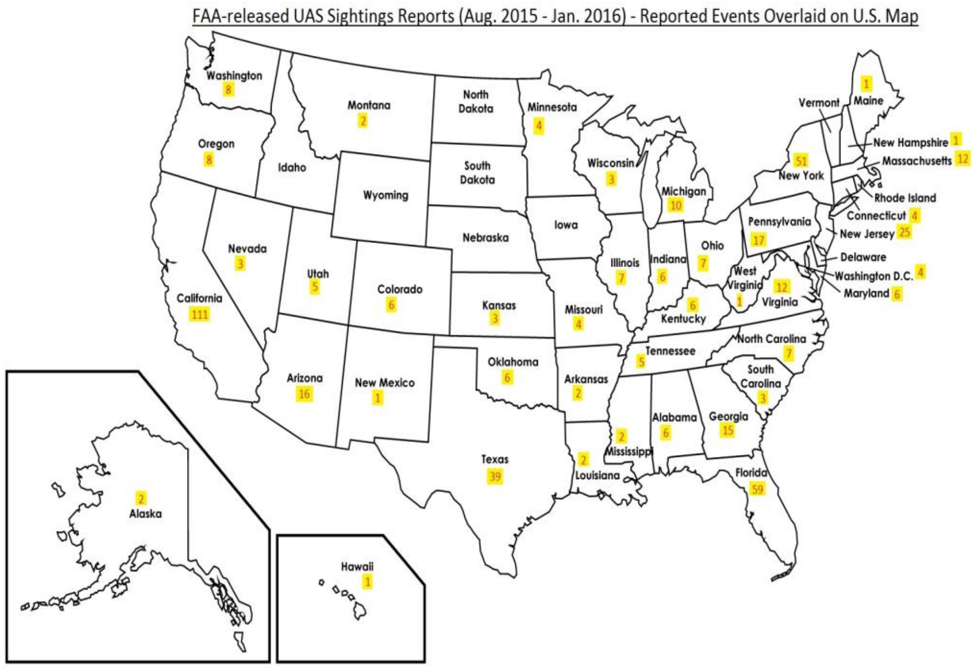

Figure 20. Number of UAS-related Reported Events per State as recorded in FAA-released UAS Sightings Reports (August 2015 through January 2016).