

Human Factors Considerations for the Integration of Unmanned Aerial Vehicles in the National Airspace System: An Analysis of Reports Submitted to the Aviation Safety Reporting System (ASRS)

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13. ABSTRACT (Maximum 200 words) Successful integration of Unmanned Aerial Vehicle (UAV) operations into the National Airspace System requires the identification and mitigation of operational risks. This report reviews human factors issues that have been identified in operational assessments, experimental research, incidents, and accidents, and discusses the findings of an analysis of reports submitted by pilots, controllers, and UAV operators to the Aviation Safety Reporting System. The analysis of UAV-related reports from the ASRS database yielded 220 relevant events, from controllers (17% of all reports), UAV pilots (15%), and pilots of manned aircraft (68%). Controllers describe operational limitations of UAV that affect controller tasks, communication issues with UAV pilots, and problems with UAV pilot understanding of the ATC clearance. UAV pilot reports highlight the need for clear guidance on operational restrictions and the unpredictability of current operations. Reports from manned aircraft pilots describe the need to be protected from UAV operations and the difficulty of seeing UAVs within the time needed to initiate an avoidance maneuver. Both pilots and controllers describe incidents of distraction caused by UAV activity. Recommendations are provided to mitigate risks associated with the human factors issues identified.				
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
mL	milliliters	0.034	fluid ounces	fl oz
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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Acronyms and Abbreviations

AGL	Above Ground Level
ACN	Accession Number
AFB	Air Force Base
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATSAP	Air Traffic Safety Action Program
ASAP	As soon as possible
ADS-B	Automatic Dependent Surveillance-Broadcast
ASIAS	Aviation Safety Information Analysis and Sharing
ASRS	Aviation Safety Reporting System
BOS	Logan International Airport
CFI	Certified Flight Instructor
CBP	Customs and Border Patrol
COA	Certification of Authorization
DEN	Denver International Airport
DUATS	Direct User Access Terminal Service
ERAM	En Route Automation Modernization
EASA	European Aviation Safety Agency
EFC	Expect Further Clearance
EZF	Shannon Airport
FBL	Faribault Municipal Airport
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FCF	Functional Check Flight
FT or ft	Feet
FO	First Officer
FL	Flight Level
FLM	Front Line Manager
FTY	Fulton County Airport-Brown Field
GA	General Aviation
GPS	Global Positioning System
IAH	George Bush Intercontinental Airport
IAS	Indicated Airspeed
IA	Inspection Authority
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
JFK	John F. Kennedy International Airport

KTAS	knots true airspeed
LOA	Letter of Agreement
LVK	Livermore Municipal Airport
MOR	Mandatory Occurrence Report
MSL	Mean Sea Level
MIA	Miami International Airport
MOA	Military Operations Area
MOS	Military Operations Specialist
MSP	Minneapolis–Saint Paul International Airport
NAS	National Airspace System
NTSB	National Transportation Safety Board
NM	Nautical Miles
NMAC	Near Mid-Air Collision
NORDO	No Radio
NFP	Non-flying Pilot
NOTAM	Notice to Airmen
PF	Pilot Flying
PIC	Pilot in Command
RA	Resolution Advisory
RC	Radio Control
RCAG	Remote Center Air/Ground
RNAV	Area Navigation
SUA	Special Use Airspace
TRACON	Terminal Radar Approach Control
TAS	Traffic Advisory Systems
TA	Traffic Alert
TCAS	Traffic Alert and Collision Avoidance System
TMU	Traffic Management Unit
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
VFR	Visual Flight Rules
VLOS	Visual Line of Sight
VMC	Visual Meteorological Conditions

Preface

This report was prepared by the Aviation Human Factors Division of the Safety Management and Human Factors Technical Center at the John A. Volpe National Transportation Systems Center. It was completed with funding from the Federal Aviation Administration (FAA) Emerging Technologies Office (AJV-0). We are thankful for our support from our sponsor Bill Davis (AJV-0).

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Executive Summary

Unmanned Aerial Vehicle (UAV) operations are characterized by human factors issues that must be resolved for their successful integration into the National Airspace System (NAS). An understanding of these issues can help to enable safe and efficient operations in the NAS. Here, we review human factors issues identified in operational assessments, experimental research, and findings from incidents and accidents. Next, we discuss the findings of an analysis of reports submitted by pilots, controllers, and UAV operators to the Aviation Safety Reporting System (ASRS). We conclude with recommendations for wider implementation of all types of (large and small) UAV operations.

The results of the review of the literature and analysis of ASRS reports point to several operational issues. Training for both controllers and UAV pilots needs to be improved. Controllers also need access to a standard briefing package that includes information on each UAV mission, flight plan, pilot contact information, lost link procedures, and contingency plans. Currently, communications between Air Traffic Control (ATC) and UAV pilots are neither standard nor predictable, causing confusion and increasing controller workload. Ideally, the feasibility of including automation to handle UAV operations should be explored (i.e., changes in UAV flight planning, a UAV-squawk code, and an inclusion of UAV performance characteristics in conflict prediction algorithms).

The analysis of UAV-related reports from the ASRS database yielded 220 relevant events, from controllers (17% of all reports), UAV pilots (15%), and pilots of manned aircraft (68%). A subset of reports mention a conflict or a potential conflict with a UAV, many of which were in busy airspace. Several human factors issues were identified from the report narratives. The general theme of the controller reports is that UAV operations need to be more proceduralized, including compliance with current procedures and the development of new procedures to increase the predictability of UAV operations. Controllers indicate that deficiencies in UAV pilot training, including understanding of their clearance limit, compliance with simple clearances, and understanding standard phraseology. UAV pilot reports most frequently describe an altitude deviation related to a lost link, mechanical malfunction, weather, or pilot error (e.g., lack of awareness of applicable restrictions or ATC clearances) – highlighting the unpredictability of current operations. Reports from manned aircraft pilots include “possible sightings” of UAVs, to near-collisions, with and without avoidance maneuvers. Almost half of the potential conflicts occurred in proximity to an airport. Pilots report on the distraction caused by these events and the increased risk to operations. Pilots also indicate that it is very difficult to identify a UAV, there is little or no time to respond to the presence of a UAV, and that they are unable predict the UAV performance resulting in an inability to confidently maneuver.

Recommendations are provided for future operational assessments (i.e., with a focus on controllers’ experienced in UAV operations), experimental research (i.e., to identify tools/mitigation strategies), data collection from incidents/accidents, continued review of data from Mandatory Occurrence Reports for performance monitoring and of the ASRS and Air Traffic Safety Action Program databases for insights into the current issues. Recommendations are included for the Federal Aviation Administration to convene a multi-disciplinary group to identify and implement risk mitigation strategies. Short-term recommendations, based on this review of the literature and data analysis are also provided.

I. Literature Review

I.1 Introduction

Unmanned Aerial Vehicle (UAV) operations have been plagued by human factors issues that will need to be resolved for successful integration of increased UAV operations into the National Airspace System (NAS). Neville and Williams (2017) note that when UAV operations were first introduced in the military, human factors was considered an unaffordable luxury and was sacrificed to quick implementation. Specifically, they quote Col. John Dougherty at a 2012 Conference of the Association for Unmanned Vehicle Systems International, “Human factors was not integrated into the original design of the Predator. They were never given the time” (p. 200).

As UAV operations increase in the NAS, so will the need for seamless integration. Currently, small UAV operating in visual line of sight (including both hobbyist and Part 107 operations) are enabled in the NAS and their popularity continues to rise. Future integration seeks to enable operations over people and in extended or beyond visual line of sight (Federal Aviation Administration [FAA], 2012; 2013; 2016). The current work aims to identify air traffic control human factors issues that need to be resolved for successful integration of UAV. An understanding of these issues, including current research gaps, can help to enable safe and efficient UAV operations in the NAS. This paper starts with a review of human factors issues identified in operational assessments, experimental research, and findings from incidents and accidents. The second part of this paper discusses the findings of an analysis of reports submitted by pilots, controllers, and UAV operators to the Aviation Safety Reporting System (ASRS).

I.2 Operational Assessments

One approach to understanding the impact of UAV operations in the NAS is to gather feedback from Air Traffic Control (ATC) personnel. Abrahamsen and Fulmer (2013) sought feedback from over 100 ATC representatives at four Air Route Traffic Control Centers (ARTCCs). Representatives included ATC specialists, supervisors, traffic and military coordinators and airspace/procedures personnel. Using open-ended questions and questionnaires, the team identified several common operational issues across the ARTCCs. A similar, recent assessment by Thompson, Sollenberger, and Pastakia (2016) sought feedback from 78 controllers (30 of whom said they dealt with UAV operations more than once a year and 20 of whom said they never dealt with a UAV) and five individuals with “UAV experience” (only one of whom was current). Input was solicited on the effects of contingency operations (i.e., lost link, lost communication, loss of the ability to detect and avoid aircraft, and engine failure) on ATC workload and performance. Since the findings of these two studies were similar, they will be discussed together.

Training. In both operational assessments, the need for improved and additional training was a primary concern. Most training that controllers had was computer-based and currently, there is not a national training curriculum for UAV. Initial and re-current training is needed – ideally face-to-face (Abrahamsen

& Fulmer, 2013, Thompson et al., 2016). Training should also include information on contingency operations (Pastakia et al., 2015).

Information on UAV flights. Controllers need access to information on UAV operations, and in particular, to the information that pilots included in the Certification of Authorization (COA). Furthermore, this information needs to be standardized so that the information that is operationally required by the controller (e.g., pilot contact information) is always included and available to the controller. Currently, the location and accessibility of this information is not standard across facilities (Abrahamsen & Fulmer, 2013; Thompson et al., 2016). Without national guidelines, facilities determine how to accommodate UAV missions, sometimes on a case-by-case basis (Abrahamsen & Fulmer, 2013).

The format of this information is also important: it should be succinct and only include information that is relevant to the controller (Thompson et al., 2016). The “briefing package” should include: UAV mission, flight plan, contact information, including back-up contact information, lost link procedures and contingency plans (Abrahamsen & Fulmer, 2013; Thompson et al., 2016).

The briefing package provided to controllers should include UAS mission, flight plan, contact information, including back-up contact information, lost link procedures and contingency plans.

Controller feedback indicated that UAV vary in terms of how their design defines criteria for “lost link”; this can vary by aircraft, the airspace, or the amount of “lost link” time elapsed. Additionally, this information is not always considered an emergency, and therefore, not consistently communicated to ATC. There need to be standard parameters for when a lost link is declared (Thompson et al., 2016).

Thompson et al (2016) indicated that controllers, in general, are not familiar with UAV contingency procedures—and may not necessarily know when a UAV contingency procedure is in place. Controllers stated that there is standard information about UAV contingency procedures that should consistently be provided (Thompson et al., 2016) – such as aircraft intentions and the timeline for when the aircraft will maneuver. Information is also needed about the lost link loiter point (that is, where the aircraft is programmed to fly to, in the case the control/communication is lost with the operator). Ideally, UAV operators should squawk their lost link status (cf. Pastakia et al., 2015). Given various airspace and traffic constraints, controllers should have input on lost link loiter points (e.g., appropriate location and altitude)—ideally a database of lost link loiter points should be created (Thompson et al., 2013). Standards and predictable lost link procedures would enable controllers to safely and efficiently issue clearances to nearby aircraft (cf. Kaliardos & Lyall, 2015).

There needs to be some standardization of lost link procedures, such as when a lost link is reported to ATC.

Communications. Communications between pilots and air traffic control is a vital link to safe and efficient operations. While communications between ATC and UAV pilots need to be standard and

predictable, they are often associated with a variable delay (Wickens & McCarley, 2005). While some

Standard and predictable lost link procedures would enable controllers to safely and efficiently issue clearances to nearby aircraft (cf. Kaliardos & Lyall, 2015).

ATC representatives did not feel that delayed communication with pilots was an issue in low-traffic or segregated airspace (Abrahamsen & Fulmer; 2013), it became increasingly problematic in areas of high traffic or during a lost link situation. Controllers also lamented on the ability to reach the UAV pilot via landline when needed (Abrahamsen & Fulmer, 2013) and stressed the need for back-up communication plans (Thompson et al., 2013). In addition, controllers perceive communication with UAV operators to be of poor quality – UAV operators may also not be familiar with standard phraseology (Thompson et al., 2013). This can cause confusion and increase controller workload.

Automation Support. Feedback from controllers also indicated difficulties in understanding UAV flight plans, and the need for more automation support in the handling of UAV operations (Abrahamsen & Fulmer; 2013). Specifically, many UAV flight plans, specified in latitude and longitudes, are too long for the En Route Automation Modernization (ERAM) system. If so, a UAV would need to file two flight plans for a single mission, and controllers need to cancel and activate each of these flight plans when needed. Thompson et al. (2013) suggested that the UAV flight plans could use Global Positioning System (GPS) fixes (specified as radial/distance fixes e.g., MSP180020). Since not all UAS flights have an aircraft identifier, and not all that do may be entered into the ERAM database, not all UAS flights in controlled airspace are identified to the controller as a UAS. ERAM also does not incorporate UAV performance characteristics, which allow the system to predict aircraft performance. These factors contribute to the unpredictability of operations, the lack of information provided to controllers to handle operations, and the need for standardization.

Ideally, UAV operators would squawk their lost link status.

Controllers should have input on the location and altitudes of lost link loiter.

UAV Performance. Another identified issue was the lack of coordination in building UAV flight plans. Kaliardos & Lyall (2015) point out that these flight plans are built sometimes weeks in advance and often cannot be changed in real-time, thus impacting the ability of UAV operators to accept

ATC instructions. Controllers also noted the inability of some UAV operators to accept simple ATC instructions, due to heading and/or altitude constraints in their flight plan, or an inability to perform the maneuver (e.g., holding instructions). Such inconsistencies increase the complexity of the controller's task, and hence, controller workload.

Performance variability of UAV also impacts that predictability of operations. Compared to manned aircraft, UAV have variable performance characteristics suited to their missions (e.g., search and rescue, maintenance, inspection, commercial operations, environmental monitoring, etc.; cf. FAA, 2012). As such, the flight profiles and altitudes of the aircraft greatly differ – this can lead to increased workload for controllers (Kaliardos & Lyall, 2015). Additionally, the location and climb rate of UAV is more easily

affected by winds than manned aircraft, increasing the variability of performance.

1.3 Experimental Research

Another approach to understanding human factors issues impacting the integration of UAV operations in the NAS is through human-in-the-loop studies, which examine pilot and controller performance (e.g., workload, communications, timeliness of responses, etc.) in experimental scenarios. A series of studies were carried out by the FAA's William J. Hughes Technical Center.

Impact of UAV Operations. An early study by Buondonno, Gilson, Pastakia, and Sepulvado (2012) examined controller performance with multiple UAV in

Class D airspace. UAV traffic density was incrementally increased in a series of experimental scenarios. Controllers also handled off-nominal situations (e.g., engine failure, lost link). Descriptive data indicated that operations as implemented in this study were not feasible, due to negative impacts on safety (e.g., compliance with ATC instructions), efficiency (e.g., increased traffic delays), communication (e.g., use of non-standard phraseology), and workload. It must be noted, however, that this study included only two participants.

Contingency Operations. Pastakia et al. (2015) also focused on the impact of contingency operations on controller performance, but with 24 controllers who were familiar with the simulated TRACON airspace that included both arrivals and departures. Contingency operations included lost link (e.g., UAV flies to loiter point), lost communication, UAV fly-away (e.g., UAV has lost link, but does not fly to loiter point), flight termination, emergency divert, multiple UAV loss, and engine failure. A baseline UAV scenario (without a contingency event) was included for comparison. As in the operational literature, the unpredictability of contingency operations had a negative impact on controller performance. Findings from Pastakia et al. (2015) generally indicate that UAV operations were associated with increased controller workload (for example, increased mental demand, effort, and frustration), and increased the frequency of communication between pilots and controllers. Flight delays (i.e., measured in time and distance flown) were also observed.

"See and Avoid". Truitt, Zingale, and Konkel (2016) investigated how the inability of UAV to "see and avoid" impacts controllers' performance—in terms of both workload and efficiency. Twelve controllers handled arrival traffic in scenarios with multiple low approaches, a missed approach, and into an arrival stream, both with and without UAV. In the majority of scenarios, aircraft flew a greater distance when UAV were present, and spent longer time in a sector. Controllers reported that the UAV operations had a negative impact on their workload. Similar to Pastakia et al. (2015), the presence of UAV led to more frequent and shorter pilot-controller communications; more clearances were issued to aircraft too (e.g., speed, heading), suggesting an impact on both airspace efficiency and controller workload. Taken together, this series of studies reinforces many issues identified in operational assessment.

Controllers need to be able to reach the UAV pilot via landline when needed and have a back-up communication plan.

UAV lack the ability to see and avoid other aircraft, and therefore cannot accept visual clearances (cf. Kaliardos & Lyall, 2015). Recent research examined the impact of a traffic display for UAV. Specifically, Fern, Kenny, Shively, and Johnson (2012) compared UAV pilot and ATC performance with and without a “cockpit” traffic display, in high- and low-density traffic. Interestingly, the implementation of the traffic display did not impact controller performance, however, workload was perceived to be higher with increased traffic (both manned and unmanned; Fern et al., 2012). Thus, while the display may allow UAV pilots to make more appropriate and timely requests to controllers, this did not translate into a reduction in workload (or aircraft predictability) for controllers.

1.4 Analysis of Accidents and Incidents

Analysis of accident and incident reports is a rich source of human factors issues that result in errors in UAV operations. While the accident/incident data for civil UAV operations is limited, and much of the information from military operations is not accessible, there are a few studies that discuss UAV pilot errors.

Williams (2004) examined available data from the Army, Navy, and Air Force, with a focus on the role of human factors in the accident/incident. In general, he observed a higher accident rate for UAV compared to manned aircraft, however, relevant human factors varied with the UAV system (e.g., Hunter, Shadow, Predator, etc.). Errors were more prevalent when the UAV required an external pilot for take-off and landing, such stages of flight were associated with difficulties in controlling the aircraft, and adequately transferring control between pilots. Multiple issues were also observed concerning pilots’ understanding of the aircraft displays (e.g., autopilot, alerts/alarms), which can in turn translate into difficulties communicating timely and accurate information to ATC.

Wild, Murray, and Baxter (2016) analyzed accident/incident data from various aviation agencies (i.e., International Air Transport Association [IATA], International Civil Aviation Organization [ICAO], European Aviation Safety Agency [EASA], FAA, Boeing, Airbus) across many sources (e.g., ASRS, National Transportation Safety Board [NTSB], Aviation Safety Information Analysis and Sharing [ASIAS]). Reports were categorized with respect to occurrence type (e.g., loss of control, runway safety, etc.), phase of flight, and safety issues (e.g., human factors, equipment problems, etc.). Data on commercial air transport incidents was obtained from EASA for comparison. Compared to commercial air transportation, Wild et al. (2016) observed that loss of control events are more common in UAV primarily due to equipment problems. Similar to Williams (2004), more events occurred during take-off and landing for UAV than commercial aircraft.

A similar analysis by Tvaryanas, Thompson, and Constable (2006) on military operations found an interaction between equipment (i.e., mechanical) failures and human factors. In particular, mechanical failures were often associated with a human factors failure, for example, an engine failure accompanied by a delayed response from the flightcrew. Similarly, the pattern of errors varied by aircraft type—highlighting the current variability between systems and the need to incorporate human factors guidance into the design and standardization of systems.

1.5 Directions for Future Research

The development of UAVs preceded, and has out-paced, the human factors research on UAV systems, their operations, and integration into today and tomorrow's ATC environment. One reason for this was that the industry was originally driven by military missions, the criticality of which out-weighed the desire to ensure that the systems were designed to minimize human error or be easily incorporated into the air traffic control system. Another reason is that the timelines associated with acquiring research funding, conducting the research, and applying the research findings are painfully insufficient, when compared to the speed at which the industry is evolving. For these reasons, the need for research into various topics must be weighed against the likelihood that the results of such research would be applied and benefits realized.

In order for the benefits of UAV research to be realized, the research must be responsive to today and tomorrow's operational needs. Furthermore, the methods used must ensure that the results are directly applicable to the operations and yield feasible recommendations. One productive strategy would be to mine the experience of UAV pilots and controllers who regularly encounter UAV flights. Soliciting feedback on operational issues and solutions to known problems is a quick and efficient means of solving operational problems. Another line of research that should be conducted on a continuing basis is the analysis of accidents, incidents, and reports of issues from pilots and controllers. These reports are in the form of Mandatory Occurrence Reports (MOR) of adverse events and voluntary reports, such as those submitted to the ASRS.

2. ASRS Analysis

2.1 Introduction

To gain insight into UAV operations in the NAS, we searched the ASRS for any narratives containing "UAS", "UAV" or any variant of "drone". The search yielded 260 unique reports, submitted between 2003 and September 19, 2016, of which only 220 (85%) were relevant; the others used one of the key terms in a different context, e.g., "the drone of the engines" or reports in which "UAS" referred to an undesired aircraft state. (This is an example of the pitfalls of automated analysis; had we included these reports in our findings, the results would have been flawed).

While ASRS reports are rich in insights into errors and causal factors, the frequency of reported errors should not be interpreted as the frequency of such events in the NAS, as not all events are reported. Other sources would need to be used to determine the incidence of such events. Furthermore, the information included in the reports is subjective and often from a single user's point of view; other data would need to be used to determine the degree to which the findings from ASRS analysis is representative of operations.

2.2 Characteristics of Reported Events

2.2.1 Frequency of Reports by Year

As shown in Figure 1, the earliest relevant report was filed in 2003 and there was a sharp increase in reports filed by year which reflects the increase in operations. (Note, Figure 1 includes frequency data *through* December 2016; the remainder of the analysis includes ASRS reports submitted before September 19, 2016).

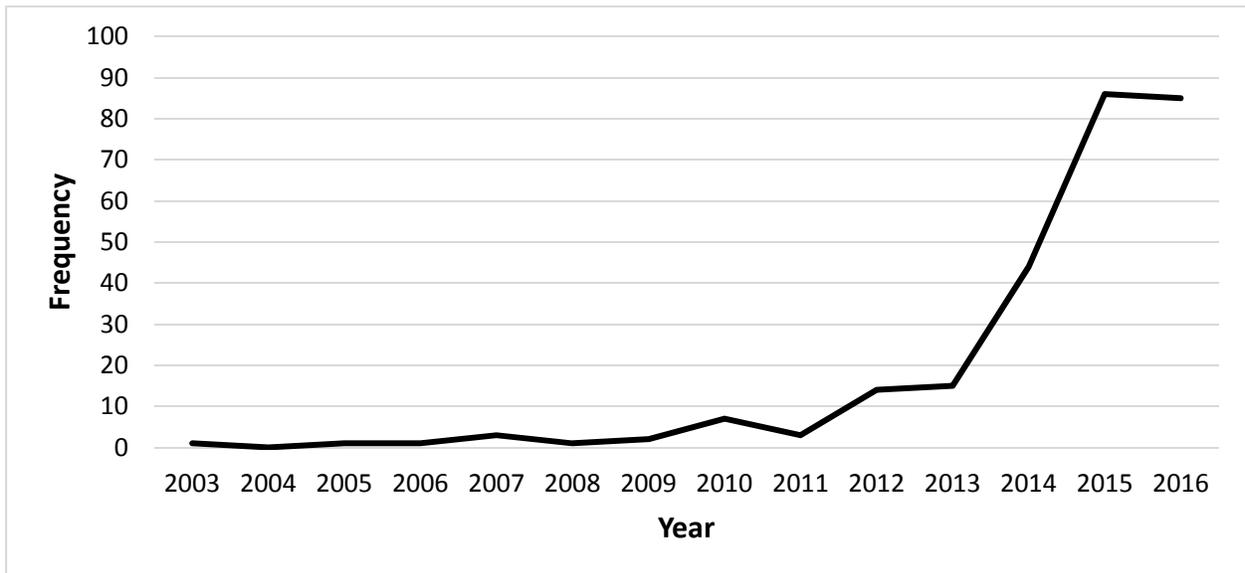


Figure 1. Frequency of relevant ASRS reports by year.

2.2.2 Altitude of Event

As shown in Figure 2, about 94% of the reports included the pilot's estimate of the altitude of the event. The majority of these events (58%) were reported as occurring between 1,001 and 10,000 feet, while about 10% of the events were reported as below 400 feet.

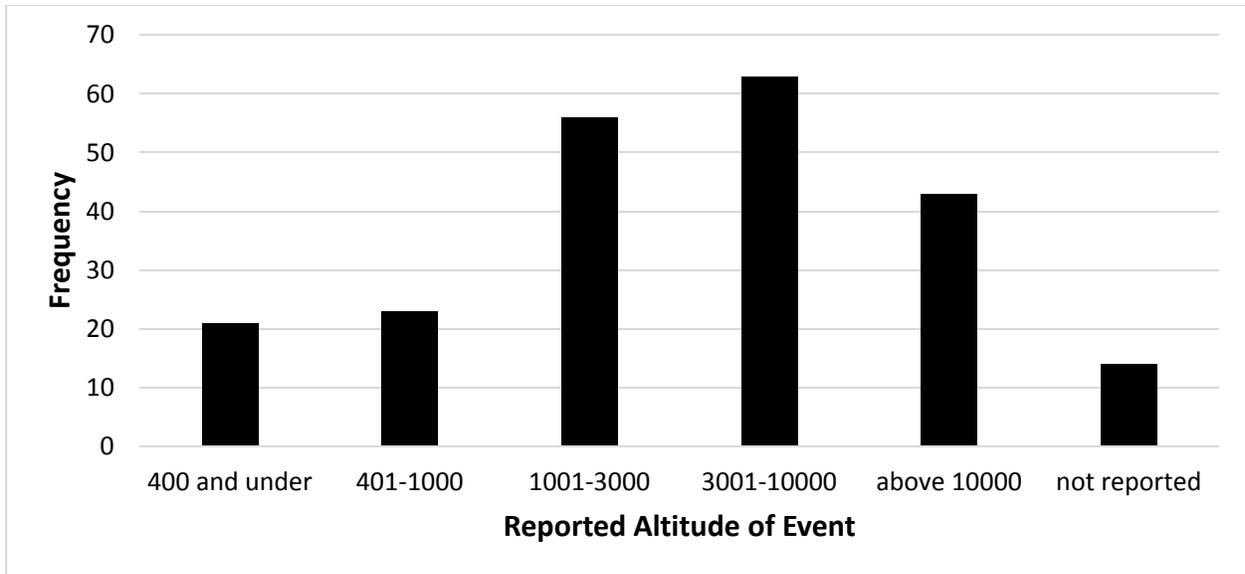


Figure 2. Frequency of reported altitude of event.

2.2.3 Reporter and Aircraft Type

Most of the reports were submitted by aircraft pilots (68%). Reports were also submitted by controllers (17%) and UAV operators (15%).

The reported events involved Federal Aviation Regulations (FAR) Part 91 (General Aviation; GA), Part 135, Part 129, and Part 121 operations. As shown in Figure 3, the majority of the events involved GA aircraft (56%). One reporter mentioned Part 107 operations (not shown in Figure 3). In about 6% of the events, the type of operation was unknown or not reported.

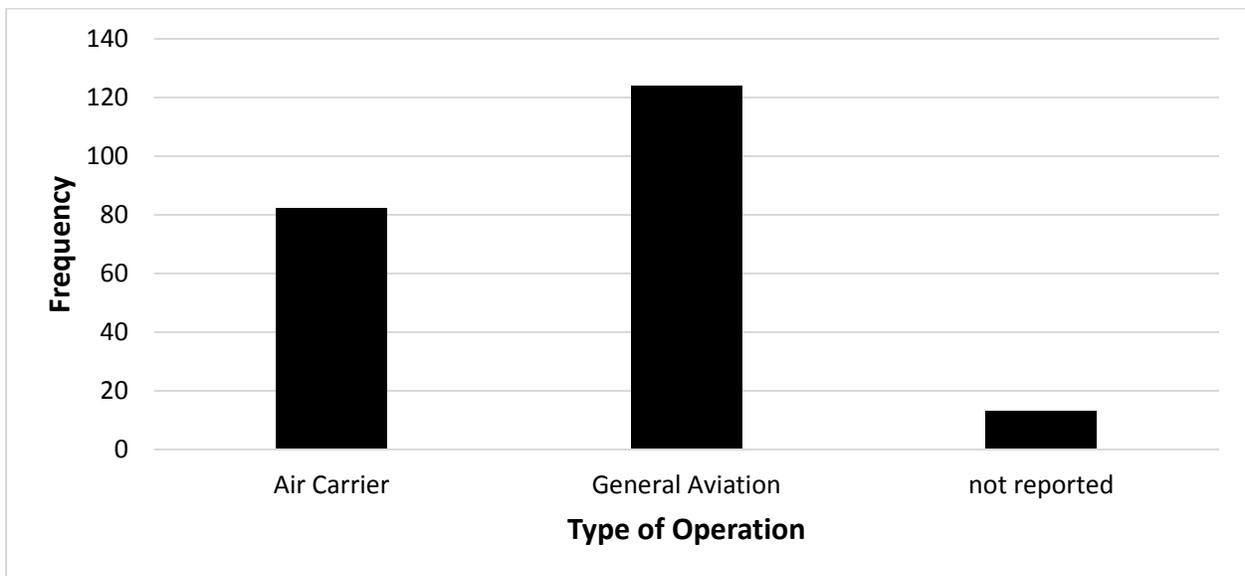


Figure 3. Frequency of reports by type of operation.

2.2.4 Time of Day

The majority of the reported events occurred mid-day, after 12pm and before 6pm (46%; see Figure 4). Reports could be more frequent mid-day for a number of reasons—this may be when the majority of operations occur, and/or UAV operations may be visible during the day. Note, that the reports do not provide sufficient information to determine the day of the week (i.e., weekday versus weekend).

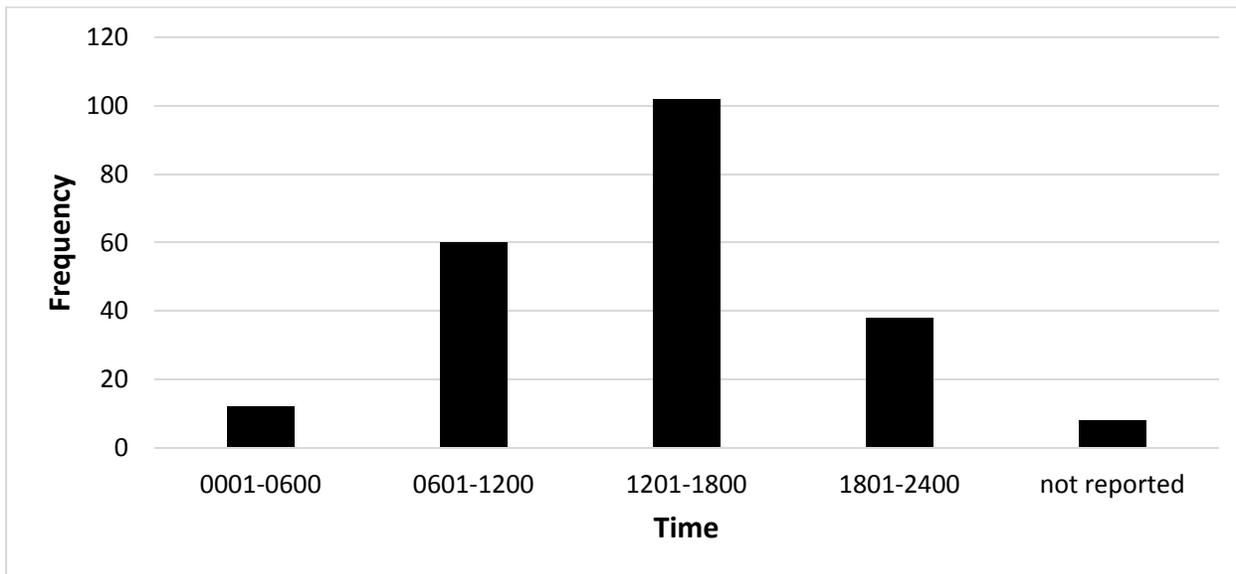


Figure 4. Frequency of reports by time of day.

2.2.5 Conflicts

Many of the reports submitted by pilots, UAV operators and controllers describe unanticipated behavior of a UAV or unexpected sightings of UAV by pilots. About 44% of the reports describe an event in which the reporter (pilot, n=89 or controller, n=7) perceived a potential conflict with the UAV. The ASRS database classifies an event as a conflict if the reporter described the situation as a “conflict” or “potential loss of separation”, or if action was needed to avoid a potential conflict with another aircraft or with airspace. This was the definition of conflict used to identify the seven conflicts in controller reports. The 89 pilot reports of conflicts have more specific information on estimated closest proximity, so more stringent criteria were used. An event reported by a pilot was classified as a “conflict” if it met any one of the following criteria:

- The pilot described the event as a Near Mid-Air Collision (NMAC) or “near-miss”,
- The UAV was described as flying within 500 feet of, or “very closely to”, the manned aircraft,
- The pilot stated that they took evasive action to avoid a collision.

An analysis of the conflicts by airspace observed that many of the reported potential conflicts occurred in controlled airspace (see Figure 5), and in particular, in Class B airspace surrounding the nation’s busiest airports. Indeed, 48 events were reported in Class B airspace, of which 25 (52%) included a potential conflict. Reported conflicts were also prevalent in Class E airspace (25 out of 45 reported events). Eighty-three of the reports did not include information on the airspace involved, indicating that

the type of airspace was not discernable from the details in the report.

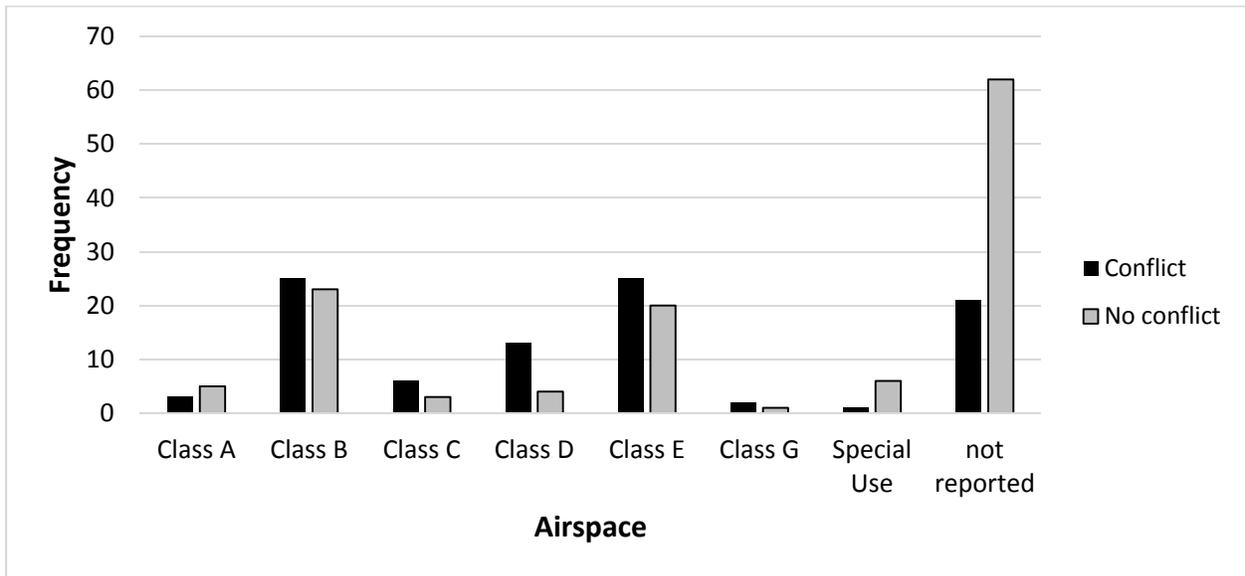


Figure 5. Frequency of reports by airspace.

As shown in Figure 6, a greater number of conflicts were reported during cruise compared to all other phases of flight; this is likely due to the longer duration of this phase of flight. While more events were reported in cruise, a higher proportion of conflicts were reported on approach: 50% of reports from aircraft on initial approach described a conflict, as did 61% of reports from aircraft on final approach (in contrast, 34% of reports from aircraft during cruise reported a conflict). It is unknown whether such conflicts are more likely to occur in the lower altitudes or pilots are more likely to detect such conflicts when they near an airport because their attention is more 'heads up' and out the window when taking off and landing than when flying en route.

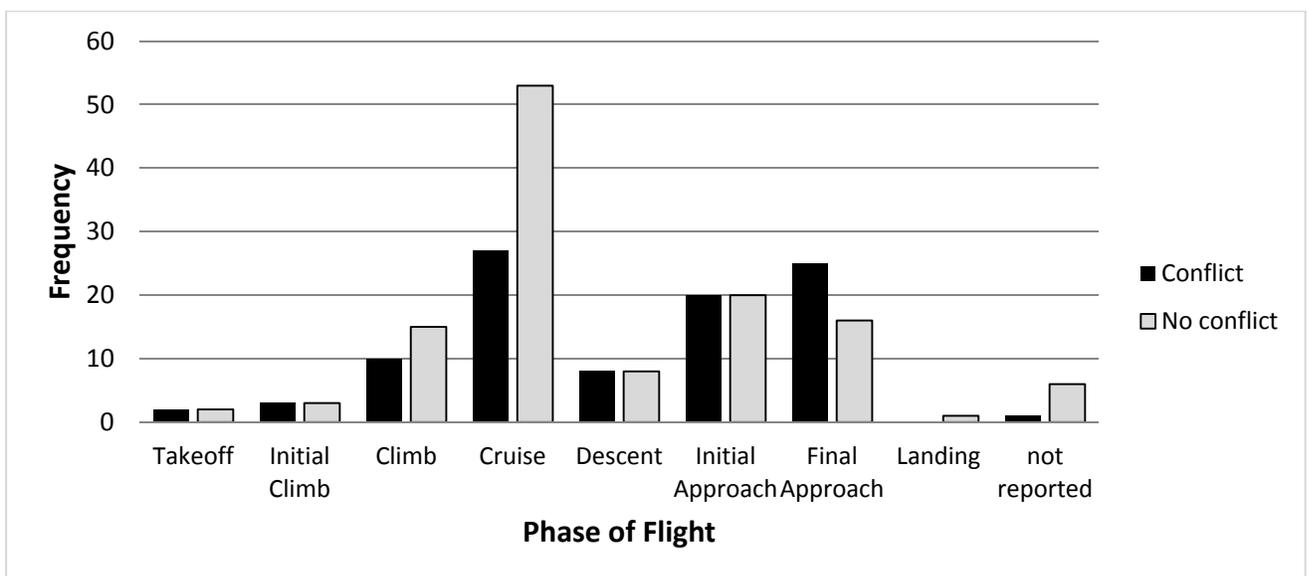


Figure 6. Frequency of reports by phase of flight.

Further analysis of the frequency of conflict by aircraft type as reported by manned aircraft pilots, shown in Figure 7, observed that while the relative number of conflicts is similar for Air Carrier (Part 121, Part 135 and Part 129) and GA operations (i.e., 42 and 47, respectively), the relative proportion of reported conflicts is greater for GA operations compared to Air Carrier (i.e., 66% and 55%, respectively).

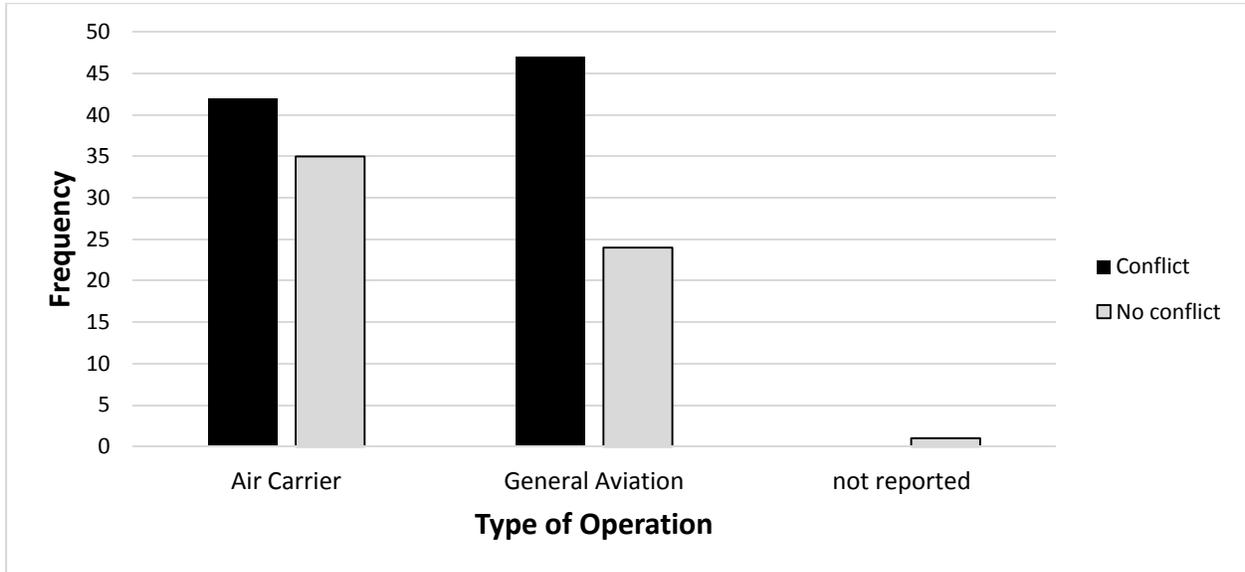


Figure 7. Frequency of potential conflicts by type of operation, as reported by aircraft pilots.

As shown in Figure 8, a subset (61%) of the conflicts reported by pilots included approximate information about both the altitude and proximity at which the conflict occurred (note, two outliers are not shown: one with an altitude of 24,000 feet and a proximity of 250 feet, and another with an altitude of 3,300 feet and a proximity of 5,280 feet). Stated proximities are based on the pilot's judgment and then averaged, if necessary. For example, if the pilot stated that the UAV came within 100-200 feet, the proximity was identified as 150 feet. Also, the proximities are bounded by the definition of conflict.

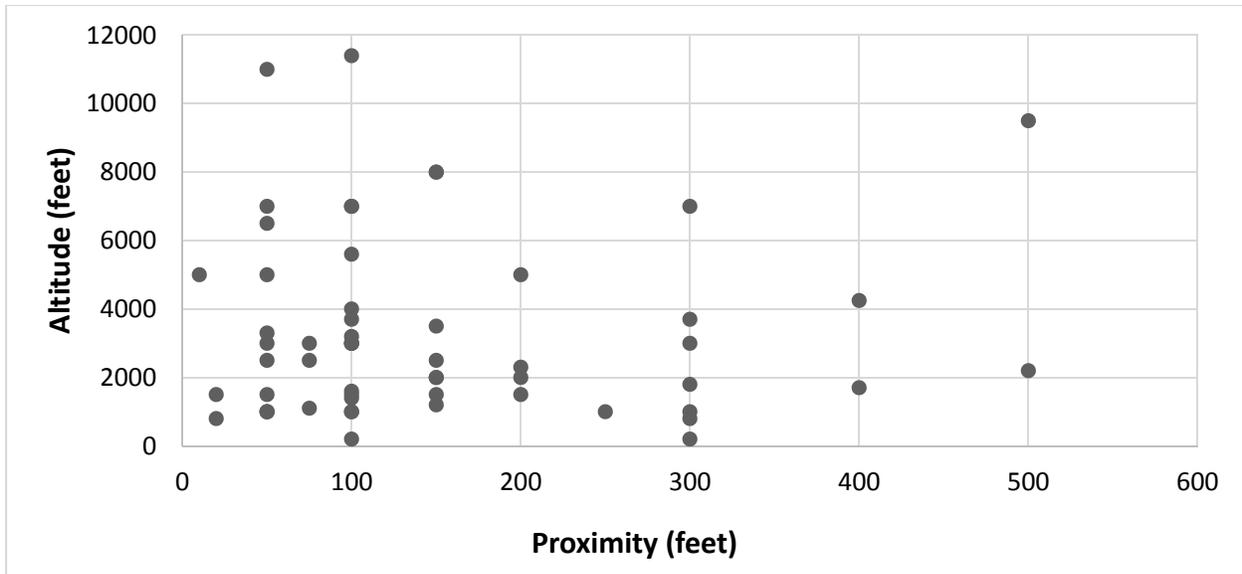


Figure 8. Proximity by altitude of potential conflicts.

2.3 Human Factors Issues

The narratives provided in the ASRS reports shed light on some of the relevant human factors concerns. Event, causal characteristics and recommendations from controllers, UAV pilots, and manned aircraft pilots are described below. When reviewing the specific reports, it is helpful to consider when the reports were written. Each excerpt identifies the year the report was submitted and the accession (ACN; i.e., report) number.

2.3.1 Reports submitted by Controllers

There were only 38 reports in the database submitted by controllers. These reports were submitted between July 2003 and April 2016. Eighteen percent describe a specific conflict with another aircraft. The vast majority mention procedures – either in the context of current procedures that were not being adhered to, the need for clarification of current procedures, or changes in procedures.

“... We need to be better briefed on how to handle NORDO with a remotely piloted aircraft.” (ACN 1163221)

2.3.1.1 Procedures

In general, the theme of the reports from controllers is that UAV operations need to be more proceduralized. The following excerpts from two reports of adverse events eloquently express this:

“...Many of us as controllers are uncomfortable with the lack of procedures for remotely piloted aircraft. At least in this instance we figured out a way to communicate with the pilot, but it still

was an unsafe situation. We need to be better briefed on how to handle NORDO [No Radio] with a remotely piloted aircraft.” (ACN 1163221, 2014)

“...In this situation, having a predetermined non-radar route to transition from approach control into the restricted areas would have solved the problem. In the bigger picture, there is a big push from the highest levels of government to get these drones integrated into the airspace system. Yet, very little thought seems to [be] given by these individuals as to what it really involves, how complex it is and most importantly, how to do it safely. All that seems to matter is it needs to be done so that people can make money. This is a very dangerous path to follow and can only lead to serious problems down the road. Safety should be the first order of business, not money. Procedures need to be developed to insure safe operation for all involved. These procedures need to be clear and not buried in legal terms.” (ACN 1264229, 2015)

“...In this situation, having a predetermined non-radar route to transition from approach control into the restricted areas would have solved the problem.” (ACN 1264229)

Several of the reports describe situations involving deviations from current procedures. The following report describes a conflict between an aircraft at 5500 feet and a UAV that is supposed to fly at or below 800 feet:

“Aircraft X, a VFR [Visual Flight Rules] aircraft inbound from the South, was informed of the local UAV field that is located 3 miles south of the Twin Falls airport. The UAV field was operational at or below 800 AGL. Aircraft X was level at 5500 when he reported a remote controlled aircraft that he estimated to be 200 feet above his altitude and about 3/4 to 1 mile north to his location. The pilot of the UAV was contacted and told of the error. In addition this is the second time, within a week that the UAV operators have been too high. Twin Falls is a location with lots of land and open spaces, I recommend that the UAV Field be relocated to a different area that is not within [Twin Falls] class delta airspace. In my opinion, it is only a matter of time before we have an accident due to operation of remote control aircraft within controlled airspace. I have spoken to UAV operators and they don't have accurate equipment that displays altitude information in real time. To my understanding they can attach equipment that will tell them what altitude they flew at, however, that is only after they have landed. The UAV within Class Delta airspace introduces unnecessary risk into the NAS. Please look into this issue.” (ACN 1347469, 2016)

The following excerpt describes a conflict in Class D airspace due to a UAV being at 2500 feet after the controller approved operations up to 2000 feet. The situation resulted in conflict alert for the controller and a pilot reported responding to a Traffic Alert and Collision Avoidance System (TCAS) Resolution Advisory (RA). The controller also notes the

“Procedures need to be developed to insure safe operation for all involved. These procedures need to be clear and not buried in legal terms.” (ACN 1264229)

limitations of 'seeing and avoiding' UAV.

"...The pilot of Aircraft X reported to the east radar controller that he was responding to a TCAS RA and climbing. Aircraft X climbed to 3400 ft and then resumed descent for PNS [Pensacola airport] when the conflict was cleared. I called NFJ [Choctaw Nolf] tower and told them the UAV was supposed to be below 2000 ft. They rogered, then descended the UAV to 1500 ft. Then they climbed the UAV back to 2500 ft. Shortly after, I observed the UAV entering Eglin AFB [Air Force Base] restricted area R2915a. The pioneer UAV is about the size of a small go-kart with wings. They are painted gray. The likelihood of a pilot acquiring these UAV's visually in enough time to take evasive maneuvers is small to nil." (ACN 707636, 2006)

Other reports describe the UAV operations deviating from current procedures.

"I discovered that the route the [UAV] aircraft flew was also not an approved route....the potential for mishap is great if the needed information is not given to the controllers working the positions. The proponents/users need to ensure coordination with the affected facilities prior to UAV flights. Controllers need to have ready access to lost-link and lost-comm procedures and phone numbers of the remote pilots. ERAM needs to be adapted ideally to show the correct aircraft type but at a minimum ERAM needs to indicate whether an aircraft is a UAV or not." (ACN 1118355, 2013)

"Controllers need to have ready access to lost-link and lost-comm procedures and phone numbers of the remote pilots. ERAM needs to be adapted ideally to show the correct aircraft type but at a minimum ERAM needs to indicate whether an aircraft is a UAV or not."
(ACN 1118355)

"I discovered that the checklist provided by the UAV mission was incomplete, but had been provided to controllers working the flight anyway. The flight had already gone through our airspace for the day and was expected back daily for five days, during daylight hours at FL [Flight Level] 270/280. The information provided by the UAV Mission Office and given to controllers working the flight did not include pilot contact information or lost link procedures, instead the following was listed: 1. Pilot Contact Info listed: Pilot contact information also put in Remarks section of filed flight plan. 2. Lost Link Procedures Info listed in a reference document. The two most important pieces of information here were left out and I feel that it is very inadequate coordination. Unfortunately, due to training and inconsistent scheduling at the Mission Coordinator Desk (who is responsible for getting the correct information to the controllers on the floor), it seems to have slipped through the cracks. To further complicate the issue: I could not find the original email to see if any attachments were included that might provide more information. I suspect it may have been archived on another user's login and inaccessible from mine (another problem with OPSPROXY - see previous report regarding our facilities MOS and OPSPROXY). More importantly, when I tried to locate the COA on our facilities computer, it was

password protected. This means, neither the controllers working the flight, nor the MOS [Military Operations Specialist] had access to the COAs associated with the flights: a. Pen and Ink Change and b. FAA Form 7711-1 COS along US Borders. I recommend ALL COAs pertaining to any UAV flight in ARTCC airspace must be made available to controllers and MOS at all times, without a password needed because controllers need quick easy access to information for these crucial missions. Mission Coordinators at ARTCC facilities should ensure all pilot contact information and lost link procedures are provided before a mission enters a facility's airspace and ensure it is easily accessible for controllers." (ACN 1142006, 2014)

"Mission Coordinators at ARTCC facilities should ensure all pilot contact information and lost link procedures are provided before a mission enters a facility's airspace and ensure it is easily accessible for controllers." (ACN 1142006)

One report identified an ambiguity in a current procedure:

"The UAV flight should not have been allowed to operate in an altitude not previously coordinated. In addition it is unclear if operating at 510B600 gives a UAV permission to operate above FL600". (ACN 1136290, 2013)

The following reports exemplify that changes in procedures are needed in order to increase the predictability (and hence, decrease the complexity) of the operations:

"Every single time that we have Raptor go active they do something different or wrong. It really has to be clarified. Maybe it falls on our Military liaison. As a Controller we just want to know what airspace is active or not. This is very confusing when no one knows, and when our higher ups and the military are having emergency meetings all day, especially when F22's/UAV's are working in the same area that we're clearing (passenger carrying) civilian aircraft through." (ACN 893357, 2010).

"These UAV missions are planned and handled erratically. Sometimes they involve Special Use Airspace, which is called up in advance - or not called up in advance. The flight plan usually shows a TAS of 130, however observed ground speeds correspond to approximately 190 KTAS [knots true airspeed] while enroute. The 'missions' often involve non-RADAR operations in Class 'D' airspace, but frequently these facilities have no information on the flight. The fact that the operator has real-time knowledge of the position of the aircraft is of limited value if we have to use a commercial line to reach them, have responsibility to relay such information, and the line is busy. We have never had the 'lost link' procedure available at the sector. If these flights are to be handled as 'normal' operations, then off-airways routing in areas without RADAR or RCAG [Remote Center Air/Ground] coverage are not acceptable where it harms our ability to move IFR [Instrument Flight Rules] traffic in and out of airports. TAS [Traffic Advisory Systems] errors on the order of 50% are not acceptable. If they're not 'normal,' then the operator or missions desk needs to ensure that coordination with adjacent facilities is complete and timely. Sectors need

concise, accurate information, including the lost link procedure. These operations have been allowed to deteriorate, with half-baked verbal briefings becoming the norm. This agency and others have historically conducted offshore law enforcement operations, with manned aircraft, under due regard - is that an option?" (ACN 1003828, 2012)

A follow up to an earlier ASRS report identified that progress had been made through better coordination between the FAA and the military.

"Callback conversation with reporter revealed the following info: reporter advised that the military and FAA have since established policies and practices in which the unmanned aerial vehicle will operate. Reporter advised that interagency coordination is being finalized to prevent a similar occurrence and to insure timely coordination of such special events." (ACN 587775, 2003)

Such progress is highly localized; best practices should be identified to determine if the same procedures would be effective in mitigating risk in other airspace.

Another problem that increases complexity for the controller is when an aircraft does not comply with its altitude clearance.

"The aircraft descended out of FL350 to FL300 without a clearance. When questioned by the controller, the remote pilot stated that he could not maintain FL350 so he descended." (ACN 1031905)

"While working an adjacent sector I witnessed a UAV deviate from his assigned altitude. This UAV was cleared to maintain FL350. The aircraft descended out of FL350 to FL300 without a clearance. When questioned by the controller, the remote pilot stated that he could not maintain FL350 so he descended. I feel this event happened due to the training of the remote pilots of the unmanned aircraft. I had no role in the event other than witness. I was informed by the controller and the FLM [Front Line Manager] that they were not going to file any paperwork on the event. The accountability and standards for unmanned aircraft remotes should be equal to the standards of the commercial

pilots. Also unmanned aircraft must be held to the same restrictions as manned aircraft. For example, in the Global Hawk System, if the aircraft loses data link it will fly its programmed flight plan. It will not maintain its last assigned altitude. In this example positive separation cannot be maintained." (ACN 1031905, 2012)

2.3.1.2 Use of Airspace

Equally important, is the ability of the UAV to accurately navigate through the airspace, as described in the following report, along with the suggestion that UAVs, like other aircraft, should be instructed by ATC as to when to begin a climb.

"CBP [Customs and Border Patrol] has said with certainty that this aircraft can navigate these areas without violating the Beaver MOA [Military Operations Area]. The Predator came within 1 mile of the BEAVER MOA while active with TWO-F16's. This procedure is not safe due to the

UNMANNED aircraft not having the ability to safely navigate clear of Active MOA's, there is simply not enough space for the Predator to get through.” (ACN 1060965, 2013)

“I think the UAV complicated the situation by having a point where he is to start his climb automatically to a very common altitude. Three thousand is used very often and no aircraft should climb automatically. The UAV should be instructed by ATC when he may begin his climb. I think this was just a small contributing factor but nonetheless did add to the loss of separation between the BE20 and the T34”. (ACN 1065133, 2013)

One mitigation, suggested by more than one controller, is to confine UAV activity to MOAs and other restricted airspace:

“My opinion is UAV activity should only be done inside of restricted areas and MOAs, outside of NAS airspace. ... I have turned this aircraft for a 'Traffic Alert' previously, only to have them request to be able to return to their intended route ASAP [as soon as possible]. I highly doubt this activity would be acceptable anywhere else in the nation, but somehow because these are Contract Towers it's allowed here?” (ACN 1037209, 2012)

“... While [military UAV operations] often use restricted airspace for testing, some of the recent flight plans are expansive and are completely outside Special Use Airspace (SUA). This will bring an increasing workload on the controllers and the NAS. Confining them to SUA airspace and only allowing transit to and from is something the FAA will need to consider as flights per day increase. The other option is to create ultra ultra high sectors to deal with UAV aircraft. The military doesn't understand how the rules and regulations apply to UAV aircraft. Quite simply, they think they don't need to 'play' by the same rules since they are the only ones 'up there.' Next generation aircraft, private sector UAV, and military programs will all be vying for this newly accessible airspace. This report pertains to the massive amount of data to file flight plans for these UAV aircraft, and the lack of proper flight planning and deconfliction by the military for these flights which create several concerns on every flight.” (ACN 915857, 2010)

As the number of UAV operations increases, the feasibility of limiting the operations to certain airspace decreases. Procedures will need to be developed to safely integrate UAV operations into the NAS. This will involve identifying the differences between UAV operations and manned aircraft operations, the risks inherent in these differences and developing effective error mitigation strategies.

The following excerpt highlights the increase in risk attributable to the fact that in a conflict between two manned aircraft, each aircraft has the capability to ‘see and avoid’. The ability of a pilot of a manned aircraft to see a UAV in time to avoid it is doubtful.

“...This was a very unsafe situation, because it involved a Drone aircraft with no TCAS whom we do not know to be reliable for stopping or turning to avoid other aircraft.” ACN 1071669 (2013)

2.3.1.3 Education and Training

Several of the reports, similar to the following, point to knowledge (and hence, training) deficiencies in

UAV pilots:

"... I don't believe that UAV aircraft are safe enough to put in the mix of regular air traffic. I don't think the pilots of these aircraft understand well enough how they affect our operations. I've had a couple UAV's deviate from their clearances with no communication at all, and showing a lack of knowledge about the NAS and how control instructions and communication work. I think there needs to be more training for everyone involved with the UAV flights. I have been told that they want to hire UAV pilots that do not have regular pilot's licenses, and I think that will cause even more problems than what we have now." (ACN 1162909, 2014)

"I advised [the UAV pilot] the Letter of Agreement (LOA) doesn't supersede ATC clearances and he cannot descend without a clearance from ATC. If we are expected to work more and more UAVs then the pilots of the UAVs need to be trained pilots in the NAS. They should hold current pilots licenses with proper ratings. They need to understand they must obey all ATC clearances and that an ATC clearance supersedes any other LOA or flight plan or anything. Also UAVs are notoriously hard to get a hold of sometimes and they often go NORDDO for long periods of time. Their radios are poor and transmissions are hard to understand much of the time. If this UAV hadn't finally responded to me he could have been over VYLLA at FL200 at the same time as the BE20. Of course I would have tried to move the BE20 but when dealing with Foreign ATC sometimes they get lost in the transfer and they don't ship aircraft until they are over VYLLA. This could have been worse than a loss of separation. I feel that we need to relook at UAVs in the NAS. Are they safe? Are the pilots properly trained and do they understand how things operate in the NAS?" (ACN 1223768, 2014).

"I advised [the UAV pilot] the LOA doesn't supersede ATC clearances and he cannot descend without a clearance from ATC". (ACN 1223768)

In a 2016 report, the controller laments the fact that the UAV was not able to comply with a routine ATC instruction (holding) and that the UAV pilot made a request that was undecipherable to the controller:

"When I tried to issue him (UAV) holding instructions he informed me that he is unable to accept 'FAA Holding instructions' and was just requesting a 'delay.' I have no idea what issuing a 'delay' does and how I can possibly ensure separation or ensure I know what the aircraft is doing if I simply tell him to delay as requested. I was then handed paperwork on an area of airspace and instructed to ask the

"When I tried to issue him (UAV) holding instructions he informed me that he is unable to accept 'FAA Holding instructions' and was just requesting a 'delay.' I have no idea what issuing a 'delay' does." (ACN 1347459)

Aircraft X pilot if he was familiar with 'the ops area northeast of LAS.' The aircraft was not familiar. The whole thing was a cluster and I was busy with other airplanes and normal complexity of an already busy sector. I felt like my entire area had no idea how to handle the situation, including the MOS who had been called down to help me or try to provide answers. Aircraft X ended

up just flying in circles in my sector with no real 'holding' instructions established because he couldn't accept them. There was no incident but it was a safety issue because the level of distraction that this one operation caused me put my sector in an unsafe situation. These drone operations need to be more clearly defined and the pilots need to be made aware of the requirements. They can't just expect to get to hold and not be able to accept holding instructions ... I want to make ATSAP aware of the distraction this caused myself while working a busy sector, and the distraction it caused my entire area." (ACN 1347459, 2016).

"UAVs do have limitations, but accepting an ATC clearance [at the UAV operator's own discretion] should not, and cannot, be one of them." (ACN 1173570)

The pre-programmed nature of some UAV flights can also increase the complexity for the controller as it limits the typical options for the controller (to move any of the aircraft involved in a potential conflict).

"The UAV was delaying in M4S, M5S, M6S areas with an EFC [Expect Further Clearance] of XA00z. When [these type of flights] delay in these 'Mike Boxes' controllers separate aircraft, not airspace like a MOA or ATCAA. When a traffic situation arises I normally leave the UAV type of flight alone

and move the other aircraft. Today I tried turning the UAV. I issued a 180 heading to the UAV. The UAV response was that they were on a preprogrammed flight. I questioned the pilot, 'UAV verify that you are not accepting an ATC clearance?' The UAV did not respond. This left me with only the option of moving another aircraft. UAV do have limitations, but accepting an ATC clearance [at the UAV operator's own discretion] should not, and [cannot] be one of them. I think that the level of service that our facility and controllers give to UAV flights has allowed the UAV operators to become complacent. I think that they believe that they have a sense of entitlement, knowing that legislation has been passed that the FAA shall integrate UAV into the NAS. This mind set must change." (ACN 1173570, 2014)

"The [UAV] aircraft have difficulty holding altitudes and headings. The radios are not efficient enough with the lag time to communicate with the pilots when we need to. They are not safe to be flying in the NAS with other aircraft". (ACN 1205232, 2014)

"I think that they [the UAV operators] believe that they have a sense of entitlement, knowing that legislation has been passed that the FAA shall integrate UAV into the NAS. This mind set must change." (ACN 1173570)

2.3.1.4 Information Requirements

While it should not be assumed that the problems identified in these reports still exist today, the successful integration of UAV operations in the NAS require that all of these identified issues be resolved to mitigate the risks. The most clearly identified need for UAV operations is predictability. Controllers need the same type of information regarding UAV operations as for other aircraft. The following report clearly identifies the controller's information requirements for a briefing package:

“The briefing package at the sector was vague and had no detailed information on the UAV aircraft or the mission. It was just a black and white map. Not even sure if lined up exactly with the warning Area W168. Procedures and the Military desk should prepare and distribute a comprehensive detailed package to brief ongoing missions and particularly these missions. The briefing package should include times, altitudes, call signs, aircraft types, routes, maps, frequencies, etc and should be available for controller reference and briefing prior to assuming the position. When this type of aircraft is involved it should include lost com procedures and operator/pilot phone numbers. Lost link procedures and possible 'Loiter Points' and loiter altitudes as well as frequencies and radio capabilities”. (ACN 1206672, 2014)

Controllers are also distracted and concerned by manned aircraft pilot reports of uncoordinated UAV activity in their airspace. The following recent report from Class-B airspace is particularly concerning:

“I was working all East side sectors combined and the IAH [George Bush Intercontinental Airport] Finals. This was Mid-Shift operation. An air carrier was inbound to IAH from the northeast. I issued an approach clearance and a few minutes later the pilot reported a near miss with an unmanned aerial vehicle. The pilot reported a 3-5 ft tubular aircraft at 8,500 ft passed 'very close' to their aircraft. The pilot called in on the phone later to confirm details and said the UAV was large enough to have taken down their aircraft had they hit it. It was unlit and grey in color. All three people in the cockpit saw it. The co-pilot described it as looking like a fixed wing long aircraft. They continued with the approach and there were no subsequent sightings. I turned off all filtering on my scope and still could not see any returns in the area that could be identified. This occurred within the Class-B airspace.” ACN 1346224, 2016)

The following report exemplifies the fact that uncertainty in any form can be a distraction that increases risk in the operations:

“The supervisors, TMU [Traffic Management Unit] and military coordinators had been trying to figure out for hours what we were going to do with the UAV because we do not normally work them and have no procedures in place for working them currently. I was distracted by that activity, as well as my regular traffic, including issuing reroutes to two other aircraft, and did not notice that an A380 [Airbus 380] was head-on with the B757 [Boeing 757].” (ACN 1162618, 2014)

“I was distracted by that [UAV] activity, as well as my regular traffic, including issuing reroutes to two other aircraft, and did not notice that an A380 was head-on with the B757”. (ACN 1162618)

Controllers have identified UAV operations as distracting in the following circumstances:

- The appearance of the UAV in the airspace is unanticipated;
- The controller has difficulty contacting the UAV pilot;
- The UAV does not comply with pre-coordinated route;
- UAV cannot accept (comply) with an instruction the controller issues;

- The UAV does not comply with an accepted instruction or clearance;
- The behavior of the UAV is unexpected; and
- The required actions for the controller are unknown or unclear.

2.3.1.5 Mitigation Strategies

Many of the reports offer remedies for the problems described. To summarize, controllers identified the need for the following:

- A real-time, reliable indication of the UAV altitude for the UAV operator;
- An indicator in ERAM to identify the UAV as a UAV (as differentiated from a manned aircraft) to the controller;
- Clearly stated lost link procedures. Controllers voiced the need for more clarity in the lost link procedures for any given operation. However, from a human factors standpoint, as the number of UAV operations increases, so will the need for standardization of lost link procedures to increase the predictability, and decrease the complexity, of the UAV operations in the NAS;
- Immediate notification when the UAV cannot comply—or is not complying—with an ATC clearance;
- A complete briefing package for identifying the time and location of the operation. The briefing package should include: aircraft type, call sign, time of flight, route map, radio capabilities, frequencies, operator/pilot phone numbers, lost communication procedures, lost link procedures, possible loiter points and loiter altitudes.

2.3.2 Reports submitted by UAV Pilots

ASRS reports provide a unique resource for UAV pilots to contribute to aviation safety. By filing a report they can identify situations that led to human errors or otherwise present challenges to safe integration of UAV operations into the NAS.

There were 33 reports submitted by UAV pilots (military, commercial, and hobbyists) between August 2005 and June 2016. One of these reports lacked sufficient detail to identify the nature of the report, leaving 32 reports for analysis. The reports identify both the results of these errors and the reasons for the situations that can lead to a conflict with a manned aircraft.

2.3.2.1 Resulting Events

The most common resulting adverse event, described in 10 (31%) of these reports was an altitude deviation incurred by UAV pilots in communication with ATC. Four (12.5%) of the reports described airspace violations. The six reports involving small UAV operations describe types of events that are likely to increase as operations increase. Four reports described operating within 5 miles of an airport. The two other reports included a small UAV hitting a building and a toy going into an ‘uncontrolled vertical climb’ out of sight and never found.

Two reports were of anomalous events that are unlikely to increase in reporting with an increase in operations. In one case, a UAV observer aircraft complained that the GA aircraft that was issued a traffic advisory for the UAV came within 1 mi of the UAV. In the other, the reporter stated he operated without notification and without a transponder under an FAR 91.215 exemption – the purpose of the report was unclear.

Similar to the controller reports, several of the reports from UAV pilots describe events which increase controller workload. The following event, while unique in its nature, illustrates the need for ATC and the UAV operator to have a common understanding of the operational rules:

“ATC cleared our UAV via a vector change to our route of flight due to active military airspace. The new route took the UAV over the populated area of a nearby large city. We are not allowed to fly the UAV over populated areas, so asked for vectors around the city. ATC then assigned a heading of 095 which would have put the UAV over the populated area of an adjacent smaller city so we again asked for another heading to avoid populated areas. They then assigned a heading of 085 to avoid overflight of the smaller city. Center continued to provide vectors around all the populated areas. Once clear, Center handed us off to Approach and recovery was made without further incident.” (ACN 1029448, 2012)

2.3.2.2 Causal Factors

2.3.2.2.1 Lost Link

While twelve of the reports describe an altitude deviation, only three (25%) of these were attributed to a “lost link”; one of which involved a loss of communication in addition to an altitude and track deviation due to an “unplanned system reset”. In fact, of the 32 reports that described a problem, only six (19%) cited a “lost link” as the causal factor of the problem. This points to the fact that, while “lost link” is commonly thought of as the root of most UAV deviations, the current data point to human factors as a more common causal factor. In terms of the results, in one case, the lost link resulted in the small UAV hitting a building destroying the UAV and breaking a window 25 stories up. The other five cases involved larger UAVs, three resulted in altitude track deviations - one also deviating from its assigned route and another in addition to the loss of communication with ATC due to an 'unscheduled system reset'.

2.3.2.2.2 Mechanical malfunctions

In addition to the six lost link incidents, there were four reported mechanical malfunctions. In one case, a “toy” malfunctioned, went into an “uncontrolled vertical climb” and;

“...continued to climb until we lost visual contact. The device had approximately 80% battery life remaining, and can fly up to 5-10 minutes at full charge. I do not know how high the UAV climbed out of control before it began a descent. The UAV has not been found. There were no other aircraft in the immediate vicinity. A brief search on[line] indicates other users having similar problems with these Toy/Consumer UAV devices.” (2014) ACN 1228374.

Another small UAV was programmed to fly a grid pattern nearby within Visual Line of Sight (VLOS) and not to exceed 400 feet, but had a NMAC with a helicopter at 550 feet. (ACN 1330573, 2016)

In a mechanical failure on a larger UAV, the landing gear failed on landing and “departed the aircraft” (ACN 1286283, 2015). Two other incidents, one resulting in an altitude deviation and the other resulting in a route deviation, were attributed to autopilot malfunctions. In one case, the military UAV autopilot unexpectedly switched to waypoint tracking which caused a track deviation outside of SUA.

2.3.2.2.3 Weather

The performance of many UAVs is widely known to be affected by strong winds. However, in this analysis, even the two adverse events attributed to weather could be said to be rooted in errors in pilot judgement. In one case, the pilot overestimated his ability to maintain control despite known strong winds aloft resulting in an airspace violation. In the other case, the pilot relied on a camera to identify weather that would affect performance:

“Before entering into a climb I asked the Second Officer to perform a full sweep with the camera to look for cloud location and adverse weather. None was noted. Climbing through FL210 conditions were encountered that affected the performance of the aircraft and resulted in a loss of altitude from FL210 to 16,500 MSL.” (ACN 1019368)

“I requested a climb from FL190 to FL250 to climb above weather. Before entering into a climb I asked the Second Officer to perform a full sweep with the camera to look for cloud location and adverse weather. None was noted. Climbing through FL210 conditions were

encountered that affected the performance of the aircraft and resulted in a loss of altitude from FL210 to 16,500 MSL. Due to my efforts to fully regain positive control of the aircraft I was unable to declare an emergency as the main concern was to regain positive control of the airplane and prevent further descent. As soon as I regained positive control I initiated an immediate climb to the cleared altitude of FL250. ATC advised of the deviation in altitude. I advised ATC that the descent was due to weather and the aircraft currently in a climb to FL250. The flight level request was amended to FL290 in order to fly above weather.” (ACN 1019368, 2012)

2.3.2.2.4 Pilot Error

By far, the largest percentage of reports described events due to pilot error. Two reports submitted in 2016 from commercial operators described uncertainty about the (general) rules under which they were authorized to operate.

Five reports describe pilots being unsure of legal requirements to fly within a vicinity of an airport. Reports describe:

- A pilot who was unaware that he was not permitted to operate within two miles of an airport;
- A pilot being “made aware that my flight with a small multi-rotor model aircraft... may have been in violation of entry with an 'aircraft' into Class B airspace near [one mile south of] the MSP [Minneapolis–Saint Paul International] airport”;
- A pilot who was unaware that he was within five miles of an airport;
- A commercial operator who flew with permission within 3.5 miles of a towered airport and then wondered if the permission was actually required;
- A pilot who contacted the tower and received permission to fly within two miles of the airport but then was unsure if he violated any rules when he received a call and was questioned by ATC.

While these reports precede the recent changes in rules for commercial operations for small UAV (Part 107), they highlight the need for operators to know the rules and their location in relation to airports.

Many of the reports describe pilot errors that are similar to those of manned aircraft. These errors would be expected to increase with an increased number of operations if risk mitigation strategies are not in place to keep them in check. These include:

- UAV programmed to the wrong altitude;
- Pilot descended without a clearance after intending to, but forgetting to, cancel the IFR clearance;
- Pilots entering airspace without proper authorization;
- Altitude deviation due to a miss-set altimeter;
- Misinterpretation of the clearance limit.

The following incidents point to critical areas of education for UAV pilots:

- Transfer of Control: A UAV crashed upon landing due to the internal pilot transferring control to the external pilot prior to his ability to control it.
- Operational Rules: A commercial operator 'did not understand 500 ft rule' and came within 20' of people.
- Airspace Restrictions and ATC Authorization: Two reports of pilots failing to obtain the required coordination from ATC.

The most serious errors identified were ones in which UAV pilots demonstrated a lack of understanding of the meaning of simple clearances, that is, they did not understand the clearance limit. There were two instances of UAV pilots not understanding the nature of ATC clearances, the equivalent of flying the flight plan, not the clearance. The difference is that in these cases, the UAV pilots thought that the authorization allowed this. In one case, a Predator pilot climbed though the ATC cleared altitude because the certificate of authorization allowed the climb. The pilot did not

“Cleared for takeoff, cleared for unrestricted climb on runway heading to 15,000 feet... I thought I was to maintain runway heading until reaching 15,000 feet and then proceed on the flight plan route” (ACN 1008476)

realize that a real time altitude clearance (or restriction) issued by an air traffic controller needs to be complied with, despite an altitude stated in an authorization. In another case (ACN 1008476, 2012), a military UAV pilot who was told, “Cleared for takeoff, cleared for unrestricted climb on runway heading to 15,000 feet.” said that he “thought I was to maintain runway heading until reaching 15,000 feet and then proceed on the flight plan route”. The same report interestingly identifies an additional misinterpretation of ATC operations. The pilot acknowledges that he climbed through 15,000 feet to “almost 16,000 feet” but stated, “Given the tremendous climb rate I actually only considered this a minor deviation.” What followed, was also very telling on the presumed responsibilities of pilot and controller:

[I climbed through 15,000 feet to ‘almost 16,000 feet’]... “Given the tremendous climb rate I actually only considered this a minor deviation.” (ACN 1008476)

“In this instance there were no other aircraft in the vicinity, but there could have been. For that reason we need to ensure that ATC fully understands what the unrestricted climb is and that they do not clear us for the climb if there are any potential traffic conflicts.” The pilot acknowledges that this could have resulted in a conflict with another aircraft but associates this with a need for ATC to fully understand UAV operations. It

would be interesting to know if he is also identifying a need for a clearance for an ‘unrestricted climb’ to a specific altitude to imply a clearance to a higher altitude if needed.”

2.3.2.2.5 Other Concerns

In a very thoughtful and detailed report, a military UAV pilot noted their reliance on ATC for detection of potential conflicts with other aircraft due to the practical limitations of ‘See and Avoid’. “One of my major concerns is that neither the QF-16 nor the QF-4 [UAV and chase aircraft] have radar, TCAS, or data link systems of any kind installed.” He then noted the

“One of my major concerns is that neither the QF-16 nor the QF-4 [UAV and chase aircraft] have radar, TCAS, or data link systems of any kind installed.” (ACN 1008476)

limitations of the pilot in the chase aircraft to identify potential conflicts between the UAV other aircraft due to other duties, “During the FCF [Functional Check Flight], the pilot must spend considerable time looking both inside the cockpit at various instruments as well as outside looking at various flight control surfaces. This means very little time and attention is available for clearing the flight path; therefore, ATC provides an invaluable service to our program. In fact in my opinion, this program could not be safely accomplished without ATC services. (ACN 1008476, 2012)

“... The pilot must spend considerable time looking both inside the cockpit at various instruments as well as outside looking at various flight control surfaces. This means very little time and attention is available for clearing the flight path.” (ACN 1008476)

2.3.3 Reports submitted by Manned Aircraft Pilots

The largest category of reports were those submitted by pilots of manned aircraft. This is not surprising as these pilots are more accustomed to filing ASRS reports than are controllers or UAV pilots. There were 149 reports from pilots of manned aircraft of incidents in US airspace involving UAV; the dates on these reports ranged from March 2007 to June 2016.

One of these reports was anomalous, but points to a safety issue for air carriers that may become increasingly common with the popularity of recreational drones:

“During passenger boarding, a passenger brought a large case on board. When the Flight Attendant (FA) told him that the case could not fit in the overhead bin, the passenger told her that the case could not go on the cart because it contained lithium batteries. During their conversation, the FA learned that the case contained a drone with a lithium battery installed along with six spare batteries (4 batteries @ 81 wH and 2 smaller batteries of unknown capacity). We could find no information in the FOM [Flight Operations Manual] about the carriage of lithium batteries other than in Flight Crew Information File 2016-0043 which only addressed pilot battery packs. Dispatch and Ops didn't have any pertinent information. FA manual states station agents are responsible for ensuring battery does not exceed limits, is labeled and properly documented, removed from the device and packaged accordingly. This did not get done as the agents were not even aware of the batteries. I am also concerned by my perception as to the lack of clear guidance on this at the station level. FA manual also states that FA SHALL ensure battery is stored in overhead bin above the customer. (This was impossible due to the relative size of his case to our overhead bins). What is unclear from the FA manual is if there is a maximum number of batteries or a cumulative total of wH allowed. (7 batteries total with a combined wH rating of over 400 wH). We called the Duty Officer for insight, but he had none, and by this time, Operations had already decided to pull the passenger and his batteries. Still, this question needs resolution. Kudos to both FAs for their tenacity to ensure that the issue was addressed and for their expertise in finding the pertinent guidance to resolve the issue. To the credit of the passenger, he did not attempt to put the case on the cart. Had he done so, no one but he would have known that the batteries were in the aft hold: a disturbing consequence on several levels. While the delay and the resulting chaos on display resulting from the lack of information was embarrassing, several passengers thanked us for our vigilance and attitude towards safety.” (2016) ACN 1349837

2.3.3.1 Resulting Events

All of the reports provide details how the encounter with UAV operations affected the manned aircraft's operation. The reports describe events that range from “possible sightings” of UAVs that were surprising and sometimes distracting, to near-collisions, with and without avoidance actions taken. There was one report of a presumed collision with a UAV:

“Departing LVK [Livermore Municipal Airport] during climbout at approximately 4800 feet we felt a bump in the airframe, and heard a thud. No other anomalies were noted, and after discussion and evaluation of the aircraft instruments and visual areas of the airframe, we continued on to destination. After landing I examined the aircraft and found a 3 inch long damaged area on the lower nose cowl, and scratch marks on the back of 2 of the 3 propeller blades near the propeller root and at a position consistent with the nose damage. No other damage was noted. The aircraft was subsequently inspected by an Inspection Authority (IA) [mechanic] and confirmed to be airworthy. I believe we struck a small UAV being operated in the vicinity of the Del Valle reservoir, in violation of the applicable FARs. If the device had been 1 foot higher, it likely would have impacted the windshield with devastating results.” (ACN 1258130, 2015)

2.3.3.2 Conflicts

Including this collision, there were 89 incidents that were classified as “conflicts”. Again, an event was classified as a “conflict” if it met any one of the following criteria:

- The pilot described the event as a NMAC or “near-miss”,
- The UAV was described as flying within 500 feet of, or “very closely to”, the manned aircraft,
- The pilot stated that they took evasive action to avoid a collision.

The following is an example of a report that was classified as a conflict:

“On an assigned heading of 220 in a climb to an assigned altitude of 6,500 FT (flight following) while transitioning through Miami Class-B airspace I noticed a small flying object coming directly at me. We made a small deviation to the right and the object passed at the same altitude in opposing direction, heading northbound towards Miami. The object has no lights and was not under control by Miami Arrivals and appeared to be a small unmanned vehicle. It looked like miniature ultralight with a camera mounted to it. It would have certainly caused significant damage to the engine/airplane.” (ACN 1156418, 2014)

2.3.3.2.1 Conflicts involving Airport Operations

Of the 89 conflicts, almost half (48%) were reported by aircraft near an airport, either in the pattern to land or shortly after takeoff. It is important to recall that ASRS reports are not suited to assessing how often something happens. Also, it is unclear if pilots are more likely to detect such conflicts when they near an airport than en route because their attention is more ‘heads up’ and out the window when taking off and landing. However, it is the case that conflicts with UAVs during the critical phases of flight of takeoff and landing present risk to operations in the NAS, particularly when they occur at busy, large airports:

“On a 3 mile final - We were landing at DEN [Denver International Airport] with the FO [First Officer] hand flying in VMC [Visual Meteorological Conditions]. At 1000 AGL [Above Ground Level] approximately 3 miles out a large yellow drone (approximately 4 feet across) flew right underneath our aircraft. It was about 50 feet below us. We did not have time to maneuver the

aircraft at all in an avoidance maneuver...” (ACN 1302962, 2015)

“On approach to 31R into JFK [John F. Kennedy International Airport] we had a near miss with a silver or white colored drone. It passed approximately 100 FT or less off the left wing at our altitude on approach. It appeared to be approximately 3 feet square in size...” (ACN 1283651, 2015)

“On final approach to Runway 31R around 1,000 feet MSL [Mean Sea Level], I saw two white drones on the left side of our aircraft appeared to be hovering. I notified the JFK Tower immediately. The authorities will have to do something about this 'drone' problem. It is

becoming out of control.” (ACN 1309452, 2015)

“The authorities will have to do something about this 'drone' problem. It is becoming out of control.” (ACN 1309452)

As one pilot reports, low-level operations may be particularly susceptible to drone encounters:

“...I was flying on the shoreline east of [a Class B] airport and I almost had a mid-air collision with a drone flying at the same altitude. I didn't see it until it was few feet from my aircraft. This was really scary and I reacted abruptly. This definitely could [have] been a disaster with dead people involved not only on the aircraft but also on the ground. I researched it and found many companies offering drone aerial services openly. Is there anyone doing anything against these companies? According to the FAA regulations commercial drone activity is prohibited. This represents a huge risk to flying aircraft, specially tour helicopters and banner operators that usually fly low level. Please do something to stop these people flying around risking the lives of many people.” (ACN 1179489, 2014)

Perhaps the most thoughtful report came from a commercial pilot who is also a UAV pilot:

“While turning base to final for Runway 21 at Scottsdale, AZ, (SDL) I passed within approximately 100-200 FT horizontally, and no more than 50 FT vertically of a DJI

Phantom Drone (I own one, hence the familiarity with it). The horizontal distance may have been closer as it was difficult to completely ascertain. I was moving at approximately 120-130 KTS IAS [indicated airspeed], the airport elevation is 1,510 FT MSL, but the approach is over gradually rising terrain, and over what appears to be a residential golf course development. I took immediate evasive action, and reported the incident to the Tower. The Tower Controller asked if it was a 'little radio controlled plane' to which I responded that it was a drone, and could have just been in a high orbit above the final approach flight path. While I cannot recall exactly, the Controller indicated he was a hobbyist and flew RC [Radio Control] models. I spotted the

“This represents a huge risk to flying aircraft, [especially] tour helicopters and banner operators that usually fly low level. Please do something to stop these people flying around risking the lives of many people.” (ACN 1179489)

object approximately 5 seconds before passing it and initially thought it was a bird. However, as it appeared closer, I could definitely see the distinct 4 quadcopter pillars and pick out the red tape on top of the unit. Keep in mind this unit has a cross section of about 12 inches, so I may have been much closer than I realize. These drones contain a 5200mAh, 11v, lithium polymer battery. While my engines have had to withstand bird ingestion testing, I seriously doubt they were tested ingesting such potentially explosive materials. This could have caused an explosion or other potentially fatal situation, (imagine it igniting a fuel tank if it struck the wing and caused a spark). I personally enjoy using my Phantom drone, and it provides unique perspectives that I enjoy, especially with my pilot background. I hate to take any action which could potentially result in the limitation of my ability to use it. However, as a pilot, and when carrying passengers, the assumption of the responsibility to safely start, continue, and end a flight requires that something be done. These units can be purchased for under \$1,000, launched from a balcony directly in busy airspace (or non-busy airspace, until it is), and have the potential to completely cripple a small jet, or other aircraft.” (ACN 1186633, 2014)

Pilots also describe how encounters that do not involve a conflict affect the safety of their flight. For both controllers and pilots, unpredictable events increase workload and can prove distracting. UAV operations can distract pilots in two ways. The most disturbing is when the pilots are surprised by drone activity and then contact ATC to learn that they, too, are unaware of activity. When the pilot is informed by ATC of possible drone activity, then the pilot’s attention is directed to looking for the traffic and can distract from other duties. The following excerpts describe: 1) a helicopter pilot forgetting to file the requisite risk assessment and wait for approval, and 2) two pilots who forgot to contact the tower while landing:

“...Although no maneuvering was necessary, the sighting and relaying of the drone's location clearly distracted from my other duties during one of the most critical phases of flight...(ACN 1288638)

“... I built the risk assessment on the iPad and didn't push send because I was waiting for our com center to send the flight to ZZZ. I went and talked with the flight crew to make sure that they would be comfortable with the thunderstorms out west and go over the risk assessment

with them.... As I was walking through the com center I was told that there was a drone operating in one of the parking lots next to helipad and that the com center was going to call to have them stop operations. This was the biggest distraction for me. I knew nothing about any scheduled drone activity. When I lifted off I called the control tower and asked if they had been informed that there was a drone operating in their airspace. They also were unaware of the drone. The control tower said they would call the state police. Once I was clear of the hospital and no longer worried about the drone I realized I forgot to push send on the iPad for my risk assessment and wait for approval ...I got distracted and forgot to push send and wait for the approval from [Control].” (ACN 1361710, 2016)

“...While being told to switch to 118.45, FTY [Fulton County Airport-Brown Field] Tower frequency, a drone was noticed passing below us and to the left. We made mention of it and

now were a bit nervous and on extra high alert keeping an eye out for another that might be in the area. During this time we were also having to execute an accelerated approach (adding flaps and gear in a much more compressed time frame due to being closer than normal to the airport). When on short final (around 1 mile) and approximately 300 ft I looked at the radio and noticed tower frequency, 118.45 had been typed in but we had not switched over to it from Atlanta Approach... the compressed timeframe and the spotting of a drone close to the airport led to being distracted and forgetting to switch until short final.” (ACN 1313436, 2015)

“I did not call the tower before landing. I was distracted by approach telling us to be on the lookout for a [UAV] on final, and seeing three big birds above us on final just miss us.” (ACN 1300748, 2015)

A final report describes distraction on visual approach:

“At 800 feet over Boston Harbor while on a visual approach to Runway 04R at BOS [Logan International Airport], what at first glance seemed to be a large white bird caught my attention at our 3-3:30 position, some 200 feet-400 feet below our altitude, and an estimated 100-200 yards to our right. I'm sure I wouldn't have noticed the 'bird' over land, but it stood out against the deep blue-green of the harbor. And its wings weren't flapping. Oops. I then quickly recognized the familiar shape of a toy, it was a DJI Phantom drone. Because it was well beneath us, no avoidance maneuvering was necessary, but I called out its position to the Captain Pilot Flying (PF) and then to BOS Tower, who quickly relayed the alert to traffic following us on the approach, and who, after we landed, asked me to phone the Tower Supervisor with details, which I did. Although no maneuvering was necessary, the sighting and relaying of the drone's location clearly distracted from my other duties during one of the most critical phases of flight... It may be one of the most harmless drone/aircraft encounters on record, yet it was still, if for no other reason than the distraction, a hazard to air navigation.” (ACN 1288638, 2015)

2.3.3.3 See and Avoid

Several reports describe both the difficulty in seeing UAVs and, if spotted, the little or no time available to respond.

“... As we were accelerating, we hit a patch of rough air. I elected to select 250 knots for a temporary climb speed to climb a little quicker into smoother air. Just as I pulled the speed selector to command the flight guidance to maintain 250 knots, something caught my eye. Orlando approach requested we switch to Jacksonville Center frequency at the same time. As the First Officer began to read back the instructions, the same thing caught his eye, also. He stopped mid-sentence. What we saw was a small remote controlled red aircraft with white and blue markings. I was fortunate to have pulled for open climb at 250 knots, because if I had let the aircraft accelerate, we may have been on an intersecting flight path. As it was, we only had 2-3 seconds to respond, but did not have to respond aggressively. We passed above the remote aircraft by 100-200 feet. All of this happened 17-18 northwest of MCO at approximately 10,200-10,500 feet MSL.” (ACN 201410, 2014)

Even when pointed out by the co-pilot, detection of a UAV can be difficult:

“I was flying the RNAV [Area Navigation] GPS approach to [runway] 9 at MIA [Miami International Airport]. While stable on the glidepath at about 7 or 8 hundred feet above the ground I saw the co-pilot begin pointing at something out of the corner of my eye. At first he didn't say anything, I think because he wasn't sure what he was seeing. After a few seconds I looked to see if I could see what he was pointing at but I didn't see anything. A few seconds later he pointed again and this time I could see what he was pointing at. When I saw it, it was to our left (north of us), it appeared to be at the same altitude which was about 500 feet and it appeared to me to be moving away from us. I only saw it briefly but the object appeared to me to be a drone. It appeared to be very close to us when I saw it, perhaps 1/4 mile. The co-pilot told me later that when he first saw the drone it was to our right or South of our flight path and it then moved across our path. Had we arrived a few seconds sooner or had the drone gone by a few seconds later I think that there is a real possibility that we would have struck it. Obviously I think that there needs to be some restrictions on the areas and altitudes where these craft can fly”. (ACN 1327730, 2016)

In several reports involving conflicts, the pilots noted that they did not see the UAV in time to command an avoidance maneuver. Some reports detailed why the UAVs were difficult to see:

“Approximately 3 NM [Nautical Miles] northwest of 06FA, I encountered a drone that came close enough to hear the propeller noise from the drone inside my cabin. Neither TCAS nor ATC advised of the drone, which was approximately the size of a bird and traveling at a high rate of speed. The small size of the drone made it impossible to see in early morning haze and low light conditions. The drone did not have any operating lights. All navigation and anti-collision lights were on for my aircraft. I advised ATC of the presence of the drone, shortly before being handed off to the next ATC facility. The small size of the drone made it impossible to see until it was too late to take any evasive action, and but for luck, the drone would have impacted the aircraft.” (ACN 1184194, 2014)

“...The drone was very small and painted white, blending into the background of the mid-morning sky. Where the drone was in my line of sight presented an extremely small to almost non-existent cross section with which to visibly locate and identify it. The lack of a transponder gave no advance warning that there was traffic in my vicinity.... The drone was painted white and blended in with the background of the morning sky. A potentially more 'unnatural' paint color or scheme would serve to help visually identify it if there is no transponder on board.” (ACN 1044401, 2012)

Clearly, color and contrast cannot guarantee sufficient visibility to make “see and avoid” a viable risk mitigation. This is what one pilot had to say about a UAV he saw from 1100 feet, two miles east of the approach end of Runway 24 at EZF [Shannon Airport]:

“...The UAV appeared to be Red, White, and Black in color to resemble a model airplane with a wingspan of roughly 3-4 feet... There was no warning by means of radio transmission, NOTAM [Notice to Airmen], ADS-B [Automatic Dependent Surveillance-Broadcast] signature, etc. of the operation of this UAV, and I would deem it nearly impossible to spot visually until within roughly 200 FT of the airborne UAV.” (ACN 1218902, 2014)

“... The small size of the drone made it impossible to see until it was too late to take any evasive action, and but for luck, the drone would have impacted the aircraft”. (ACN 1184194)

As with conflicts between manned aircraft, the geometry of the conflict and location of aircraft “blind spots” also affects the pilot’s ability to detect the traffic:

“... The drone was below our field of vision until it was basically passing us, so collision avoidance had it been on track to hit us, would have been difficult at best. The object also passed us at a high rate of speed..., spotting this small of an object until it is in close proximity is difficult.” (2016) ACN 1326310

“I was completing a pleasure flight on a beautiful summer afternoon in my Stearman, approaching FBL [Faribault Municipal Airport], from the northeast, at about 1,800 MSL (about 800 AGL). Something caught my eye to my right at my altitude, and I thought it was probably a hawk, a common sighting in Minnesota. I turned my head and looked, and was surprised to see the 'hawk' had what appeared to be attachments (gear? antenna? camera?)! It passed about 300 FT off my right wingtip. Very glad I didn't hit it, as a Stearman is very blind straight ahead, and if it had been about 300 FT further to the left I never would have seen it until I hit it! So much for the 400 FT max altitude for drones I guess!” (ACN 1193759, 2014)

2.3.3.4 Pilot Suggestions

2.3.3.4.1 Increased FAA oversight

The overwhelming sentiment among pilots is that there needs to be more FAA regulation of drone operations within controlled airspace. While some of the specific suggestions offered in the reports are more useful than others, most involved restricting UAV operations and ensuring that the restrictions are adhered to.

“...Due to our airmanship we avoided an RA; however a TCAS TA [Traffic Alert] did occur. Drones are to be flown below 400 FT. This was at 4,000 FT. It demonstrates careless and reckless operation (FAR 91.13) of the drone pilot. If it was a military aircraft and it needs to be maneuvering like that, it needs to be done in a Military Operations Area. MOA's are designed to separate or segregate certain non-hazardous military activities from IFR traffic-not on final approach of a commercial airport.” (ACN 1072844, 2013)

“...As with lasers, drones need to be regulated strictly, swiftly and quickly. Unfortunately, it will take a fatal accident to change the view of how deadly

“As with lasers, drones need to be regulated strictly, swiftly and quickly”. (ACN 1350507)

drones can be to any aircraft, especially passenger carrying aircraft. It is clear to me that current regulations in place are not strong enough to prevent people from flying drones. Something needs to change before there is a loss of life.” (ACN 1350507, 2016)

One pilot proposed a proscriptive technological solution:

“...Legislation requiring firmware in these commercially manufactured drones that prevents operation outside of the FAA limits would improve safety.” (ACN 1284007, 2015)

2.3.3.4.2 Education of UAV Pilots

Several reports identified a need for increased education on the part of UAV pilots as to airspace regulations.

“...The distribution of information to drone purchasers regarding local flight restrictions, airport locations, etc. may also help prevent this incident from occurring.” (ACN 1284007, 2015)

Some reports offered details as to how a collision with a UAV would damage an aircraft and wanted to ensure that operators of UAVs are aware of these hazards. One pilot even put the website in his report, in an effort to help educate operators:

“... I've spoken with several other pilots who know friends and neighbors with drones, or who have purchased one for themselves or their children. I would hope they all realize that the very dense and heavy nature of the batteries on these machines are going to cause far greater damage than a bird of equivalent weight, when one finally, and it seems inevitably, impacts a windscreen, jet engine, or flap assembly. It's going to be ugly, and we really need to spread the word. So I would urge anyone reading this who operate drones, to ask them to visit <http://knowbeforeyoufly.org> and make sure they fully understand where and when drones are appropriate...”(ACN 1288638, 2015)

A pilot who encountered “a small remote controlled red aircraft with white and blue markings” at 10,200-10,500 feet MSL just north of the Orlando VOR, had several recommendations, including a requirement for a written test:

“... The remote controlled vehicle should be subject to the same rules as any other aircraft. If it flies into A B, C [airspace] or above 10000 feet in E airspace, it must have a transponder. There should also be a maximum distance and altitude a remote controlled vehicle can fly from its operator. Two miles high is too far for an operator to safely maneuver his craft safely. And finally, a written exam should be given to any operator of a class of remote controlled aircraft that can fly high enough, or fast enough to come into conflict with a traditional aircraft. If the test is not taken, or if it failed, the operator should be prohibited from flying his craft until the test is taken and passed.” (ACN 1214366, 2014)

“Bird activity also creates hazards...and I have had several near collisions with birds... flying over many years. However, birds usually dive out of the way while the drone did not. This drone also likely weighed significantly more than a bird.” (ACN 1284007)

2.3.3.4.3 Increase pilot awareness

Pilots want to be aware of operations in the area. One report detailed frustrations in trying to decipher a NOTAM on the Direct User Access Terminal Service (DUATS) on UAV activity. The report below is an older report (2013) that points to the need for information on UAV activity (and how it affects usable airspace) to be unambiguous and readily available:

“So what does this mean, can I fly there or not? ... The military erects two barrier fences to 'capture' the UAVs, if necessary, on the 2,500 FT grass strip during the entire operation. The runway is definitely UNUSABLE. I have two issues with the above. One, all the information should be in DUATS. That is the hallmark of DUATS. Two, the runway and indeed the airspace was unusable to the aviation public. Why is this not emphatically conveyed in the NOTAM? As a footnote I wish to point out that the local airport users and the military have worked together to provide a valuable activity for our national interests. The operation is very valuable, and was a success. I think the fact that two of the local pilots took it upon themselves to call the surrounding small airports and advise them of the runway status has prevented any incidents.” (ACN 1115974, 2013)

The most common recommendation was to require UAVs to be equipped with transponders so they are visible on the pilot's TCAS display.

“... upon breaking out of a small cloud layer at approximately 7,800 FT the UAV passed very closely by the left wing. It was immediately necessary to increase my rate of turn to

“UAVs and their operators should at least be held to the same standards for certification and required equipment as all other aircraft and pilots when operating at such altitudes.” (ACN 1198718)

the right to increase the distance between my plane and the UAV. Given the occasional IMC [Instrument Meteorological Conditions] while flying in and out of cloud layers, it was impossible to see and avoid the UAV at any point prior. ...The UAV was not of a style with wings or a tail, but rather a drum-shaped version grey in color. This is clearly a case that highlights a severe deficiency in the safe operation of the NAS. There was no way for ATC or the equipment in the aircraft to sense the presence of the UAV; and there was most certainly no way to see and avoid it while in IMC. Since this encounter happened at an altitude that was less than 10,000 FT above Class C airspace, an operating transponder was a mandatory piece of equipment. UAV's and their operators should at least be held to the same standards for certification and required equipment as all other aircraft and pilots when operating at such altitudes. (ACN 1198718, 2014)

...The object did not show up on my TCAS system as a threat. These vehicles need to show up in the cockpit as a threat or stay within the MOAs." (ACN 1010005, 2012)

One of the reports suggests that the transponders could be traceable for enforcement actions:

"... I'm not sure there is anything we as pilots or the tower controller could have done to prevent this uncomfortably close encounter between a drone and a large passenger airplane unless these objects are made to be detectable on radar and/or TCAS and traceable to their extraordinarily irresponsible owners/operators." (ACN 1242105, 2015)

Another pilot wondered if ADS-B could be able to be used to convey the position of UAVs to pilots, if TCAS was not an option:

"... When I saw the object, I thought I was crazy for thinking I saw one of these above 5,000 feet. I actually did some research online after this, and I've read about people seeing these as high as 7,000 feet. A system that works with our TCAS would be amazing to have in the future. I'm not sure if the technology is quite there yet. Maybe with the upcoming ADS-B rules, this could be on the table?" (ACN 1326310, 2016)

There was also a suggestion that ATC be notified immediately of any "lost link" in uncontrolled airspace so that ATC could then notify pilots in the area:

"My concerns are these: 1) I'm sure that [company X] has permission to test fly their drone aircraft in certain unpopulated areas. I'm sure that it does not include a mile or two from an airport. 2) I don't know when they communicated to ATC that they had lost control of one of their drones, but this information was never communicated to me by departure control who told me that there was no traffic in the vicinity of ZZZ. 3) The [drone] staff tried to conceal their identity on 122.8 only creating confusion for myself. I thought that some private drone owner was on the 122.8 frequency and flying their personal drone around the airport. (There has been instances of privately owned drones flying illegally in our area of recent past.) I would think that ATC should be notified immediately and updated as to the location of the drone. ATC, in turn, needs to communicate this to pilots operating in the area." (In this case, the drone operator apparently had GPS data as to where the drone was.)" (ACN 1281994, 2015)

“...A system that works with our TCAS [to display UAVs] would be amazing to have in the future. I'm not sure if the technology is quite there yet. Maybe with the upcoming ADS-B rules, this could be on the table?” (ACN 1326310)

A Certified Flight Instructor (CFI) suggested that changes in a pilot's scan may be help spot drone activity:

“Such a small vehicle is difficult to spot until very close in. I usually focus on traffic scanning at distances that are further away. I had recently attended a meeting at PAO [Palo Alto] for CFIs where reports of nearby

drone activity was mentioned and I think this helped me recognize it as a drone more quickly. Some pilot awareness of local drone activity may help facilitate close-in visual scanning and faster recognition of these small vehicles...” (ACN 1284007, 2015)

A pilot who seemed accustomed to encountering drones during flight suggested that controllers need to use binoculars more in the tower to monitor for UAVs. He also stated that it was recommended to him that pilots use the IDENT function on the transponder after a near-miss with a UAV to help controllers identify the location of the conflict:

“...While on short final for runway 31L at 1500 feet, a drone/UAV was headed straight for our aircraft at a bearing of 135 at a high rate of closure and barely missed us.... This drone incident was a great concern to me compared to the other encounters reported by aircraft this year for a variety of reasons. First, was the deliberate nature of the drone's operator in heading right for our aircraft down the center line of a major US airport runway in a difficult political climate. Next, was the type of drone used. This drone was not your typical four-rotor toy as in previous encounters. The four to five foot fixed-wing, diamond-shape, stealthy police/military style fuselage, with short, blended, delta wings and down sloping winglets, had a belly mounted camera globe. This was closely related to an upgraded 'Killer Bee (or Bat)' drone I once spotted during my time as an aviator in the military. Finally, I was concerned that ATC had no ability to track this larger UAV and find those responsible. We need more visual binocular scanning from tower, rather than relying on Airport Radar which doesn't seem to pick up drones of the size and type I encountered. [Authorities] recommended to me that a pilot should hit the ident button on the transponder when you see a drone coming in close proximity to your aircraft. He said it helps ATC better pinpoint the location of these small vehicles.” (ACN 1312110, 2015)

The descriptions of the controllers' responses after they were informed of a conflict with a UAV were varied. Several reports describe an appropriate level of controller concern and immediately took action to warn other pilots:

“... The drone passed so fast that no action could be taken. We notified ATC and they did a good job of making call outs to other traffic in the area....” (ACN 1261985, 2015)

“... I called out its position to the Captain PF and then to BOS Tower, who quickly relayed the alert to traffic following us on the approach, and who, after we landed, asked me to phone the Tower Supervisor with details, which I did.” (ACN 1288638, 2015)

In a few cases, however - presumably due to high workload - there was no obvious controller response to the pilot's report:

"Initially, I was looking inside the cockpit performing NFP [Non-flying Pilot] pre-landing duties. PIC [Pilot in Command] startled me as he brought my attention outside. I looked up in time enough to see the drone, shining and stable passing less than 300 feet off the starboard side. It might have been about 5 feet in length. It passed less than 300 feet below us. My gut is that it may have been as close as 150 below and 200 starboard. I immediately called TRACON [Terminal Radar Approach Control], but she was occupied and delayed in responding to me. When I got her attention I reported us having passed a drone; the controller did not seem concerned and did not ask any questions. I even asked that she copied my report - she acknowledged and went on about her duties..." (ACN 1364983, 2016)

"A C303 in the VFR traffic pattern, on a right base to runway 34 at approximately 3,000 feet, reported sighting a 'UAV' approximately 500-1,000 feet below him. This was reported to the control tower on tower frequency. The tower controller reported this to the OCIC [supervisor]. The OCIC failed to log the incident or file an MOR. No record of contacting anyone else, including law enforcement. [Controllers need] Training on 'drone' procedures/reporting requirements." (ACN 1253974, 2015)

2.3.3.4.4 Pilot and Controller Reporting Protocol

Protocols should be developed for pilots to easily report an encounter with a UAV. This information could be used in real time to warn other pilots in the area. A protocol would also prescribe the tower, TRACON, or center controller's response including what information would need to be included in a Mandatory Occurrence Report (MOR). Detailed data collection is essential to monitor NAS performance.

"From what I have researched today, the FAA receives 2 reports a day involving drone/aircraft sightings. This is unacceptable and is only a matter of time before there is an accident." (ACN 1284244)

"... A cursory search does not avail a drone reporting system, and I would suggest that either one be created or that this ASRS system provide accounting for drones. I would like to know what if anything can be confirmed about this incident, and express my serious concern for a drone at 6800 MSL, unreported, without TCAS, and passing so close to manned aircraft." (ACN 1364983, 2016)

While controllers typically file a MOR when a pilot informs ATC that they responded to a TCAS RA, it is unclear as to whether they include the involvement of a UAV. The following is a report from a pilot who responded to a 'DESCEND NOW' RA from a conflict with a UAV:

"... Departure Control was very busy, bordering on saturated. TCAS cleared the conflict, we saw the traffic -- a UAV working in the area, I reconfirmed climb clearance as well as notified Departure that we had a full TCAS RA commanded descent. 'Roger' was the reply. They were still

very busy. We completed the climb clearance, were given a frequency change, I acknowledged it and again advised we had a TCAS RA just to be clear on the tapes due to the congestion.” (ACN 826737, 2009)

2.3.3.4.5 Enforcement Action

Pilots of several reports noted current restrictions on UAV operations, and stress that such restrictions need to be enforced:

“...It is obvious that catastrophic damage could have occurred to the aircraft if we would have struck the drone. It is my understanding that drones are not to be operated above 400 ft AGL and at least 5 SM outside the area of an airport. If this is the law it should be enforced.” (ACN 1318529, 2015)

The following report, from 2014, sums up the difficulty of ‘see and avoid’, the potential hazard to manned aircraft. It is prophetic in its discussion of the popularity of UAVs and the need for enforcement action.

“The threat to commercial operations from recreational drones must continue to be addressed by the Federal Aviation Administration, not only with changes in regulatory requirements but in vigorous enforcement action against violators.” (ACN 1215270)

“...Based on my observations, the drone would have been flying at a minimum of 3500 feet MSL and possibly over 4000 feet MSL, well in excess of what I believe is the authorized altitudes . A mid-air collision with a drone could cause substantial damage or an engine failure to a commercial

aircraft. The small size of these drones makes them particularly hazardous. In my opinion, they could be comparable to the threat from a large bird strike, only potentially much, much serious. Not only are they not equipped with transponders but by the time a pilot acquires them visually it is likely too late to take evasive action. And I imagine the impact from one would be much worse than that with a bird based on the materials used in their construction. The threat to commercial operations from recreational drones must continue to be addressed by the Federal Aviation Administration, not only with changes in regulatory requirements but in vigorous enforcement action against violators. Historically, the community of hobbyists who operated Radio-Controlled airplanes acted responsibly in staying clear of unauthorized airspace. In recent years, as drones have become much more popular, inexpensive, and easy to operate, it appears that more people who are either unaware of the rules or irresponsible to the privileges of operating RC aircraft have taken up the hobby. When I searched online, I found some for under \$100! And their performance capabilities have improved in recent years so as to make them more of a threat to the operating environment of FAA-regulated airspace. 'Recreational use of airspace by model aircraft is covered by FAA Advisory Circular 91-57, which generally limits operations to below 400 feet above ground level and away from airports and air traffic.'

(http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=14153). Yet, I don't believe there are any training, registration, or certification requirements for someone to purchase and operate these model aircraft. Currently, operators of larger drones for commercial or governmental purposes may register with the FAA to operate in excess of 400 feet, but my concern is that the general public will continue to do so without detection or enforcement action unless the FAA takes a much more firm approach.” (ACN 1215270, 2014)

“Currently, operators of larger drones for commercial or governmental purposes may register with the FAA to operate in excess of 400 feet, but my concern is that the general public will continue to do so without detection or enforcement action unless the FAA takes a much more firm approach.” (ACN 1215270)

3. Recommendations and Next Steps

Operational data, experimental research, and an analysis of ASRS reports indicates several human factors issues that must be addressed to enable the safe and efficient integration of UAV into the NAS. Controllers need to be able to effectively communicate with UAV pilots in their airspace. UAV pilots need to be understand airspace rules and when and where authorization is required. UAV pilots operating in controlled airspace need to understand their clearance limit, know what information is required to be transmitted to ATC and when. Operators of small UAV need to know and comply with applicable restrictions and need to ensure that they have received authorization when operating within five miles of an airport. The specific recommendations offered here seek to progress these operational requirements and facilitate the further integration of UAV operations in the NAS.

3.1 Recommendations for Operational Assessments

While the research conducted by Thompson et al (2016) asked many important and elucidating questions, the questions were not asked solely of controllers who had experience with UAV operations. Furthermore the controller responses were not segregated into controllers who regularly saw UAV operations in their airspace and those who did not. (Recall that of the 78 controllers surveyed, some never dealt with UAVs and others handled them on a daily basis.) It would be interesting, and important, to examine how their perceptions of the effects of UAV operations in their airspace relates to their level of experience with UAV operations. Future operational assessments should only include controllers, and other operators as required, who have experience with UAV operations.

A comprehensive look at UAV operations (by type of operation, performance characteristics/limitations of UAV, etc.) should be reviewed to identify the specific ways in which these operations affect air traffic operations and to identify mitigation strategies. Controller information requirements need to be explored in detail under a variety of conditions to identify what information is needed and when. For

example, some information is needed immediately (i.e., in the event of a lost link) while other information is only needed on a contingency basis.

Operational assessments, utilizing UAV and ATC expertise, are needed to explore the extent to which lost link procedures could be standardized, for example, how long should operators try to trouble-shoot lost link before informing the controller? Also, what information should be standardized and communicated to the controller regarding the aircraft intentions and the timeline of events?

An operational assessment should be conducted to examine the impact of UAV operations on flight paths of other aircraft. While it is known that UAV operations increase the number of speed and heading changes to manned aircraft, this relation has not been quantitatively assessed in actual operations. Such an assessment would help to quantify both the increased controller workload (by the number of additional clearances issued) and the cost of the UAV's inability to "see and avoid" to manned aircraft's flight efficiency.

Operational research is required to identify the realistic limitations of "see and avoid", for both small and large UAV and explore the feasibility of mechanisms for flight deck display of UAV activity.

3.2 Recommendations for Experimental Research

Now that UAV operations are occurring in the NAS, the value of experimental research to identify controller operational needs in today's environment is limited in its usefulness compared to studies that solicit feedback from controllers experienced in UAV operations. Operational issues have already been identified; experimental research is needed to help identify solutions, human-in-the-loop simulations should be conducted to examine the effectiveness of various tools and risk mitigation strategies. Also, as tools for UAV pilots are developed, research will be needed to explore how these tools affect controller tasking. Again, these simulations should be conducted using experienced operators (pilots and controllers).

3.3 Recommendations for Analysis of Accidents and Incidents

Analysis of accidents and incidents needs to be an ongoing activity to continue to identify sources of error in UAV operations and help to develop risk mitigation strategies. As previously stated, while ASRS reports are an excellent source of insights into the causal and contributing factors of human error, the reports cannot be relied upon as a performance measure or for information as to the incidence of such events in the NAS. MORs are a good mechanism for such a measure, and will need to be mined on a continuing basis. However, the information that is collected and reported should be enhanced and structured to provide more information as to the causal and contributing factors.

3.4 Recommendations for Analysis of Reports Submitted to ASRS

The ASRS database should be periodically mined for additional insights into UAV operations, from the controllers', pilots', and UAV operators' perspectives. Additionally, since controllers are more accustomed to filing reports with the Air Traffic Safety Action Program (ATSAP), than ASRS, the ATSAP database should be mined.

3.5 Recommendations for FAA

Complex challenges require multi-faceted solutions. A successful model for developing a multi-faceted approach is that of the Joint Safety Analysis and Implementation Teams implemented for Runway Safety. These teams enjoyed a wide cross-section of air carrier operators, FAA, air traffic and human factors expertise. The approach began with an in-depth data analysis to identify key issues and then discussed the development and implementation of risk mitigation strategies.

Meanwhile, these results of the literature review and the analysis of ASRS reports convene on several recommendations for present and future operations:

- FAA should facilitate structured interactions between air traffic and UAV operators to develop and ensure a common understanding of operational needs and limitations.
- Roles and responsibilities between controller and UAV operators (including those involved in UAV flight planning) need to be defined and clearly communicated to all facilities and users so that all involved have a common understanding of procedures and expectations.
- Controllers who are expected to encounter UAV operations need training on such operations including the performance characteristics of various UAVs.
- Controllers need to be supplied with the information and tools to identify and communicate with the UAV.
- A succinct, but complete briefing package should be required and provided to the relevant controllers for each UAV mission. In addition to the flight plan, contact information and back-up contact information, lost link procedures (including loiter points) and other contingency plans should be included. This information should be available in a standard location that is easily accessible to controllers.
- FAA should facilitate operators working with ATC to define the lost-link loiter points (location and altitude) in their airspace.
- A database of lost link loiter points should be created and be available to controllers.
- FAA needs to ensure that UAV pilots are proficient in ATC communications. This includes when to contact ATC and what information needs to be communicated, the meaning of ATC clearances (especially the clearance limit) and ATC terminology. The equipment with which UAV pilots communicate with ATC needs to be of sufficient quality to be operationally suitable.
- Controllers need to be able to identify UAVs as such on their situation display and have a

squawk code for UAVs with transponders. The feasibility of incorporating UAV performance characteristics into ERAM to allow controllers to predict UAV performance should be explored.

- As the popularity of recreational UAVs increases, the transport of lithium batteries by airline passengers may become a safety concern (and a restriction on the number of lithium batteries carried by passengers may be needed).
- Local problems require local solutions. One of the lessons to be learned from ASRS reports is that local problems have been solved by opening the lines of communication between the ATC facility and the (in this case, military) UAV operators.

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