Insights from the Nogales Predator Crash for the Integration of UAV's into the US National Airspace System under FAA Interim Operational Approval Guidance 08-01

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Abstract

In April 2006, an Unmanned Aerial Vehicle (UAV) crashed near Nogales, Arizona. This incident triggered one of the most sustained studies into the causes of failure involving Unmanned Aerial Systems (UAS). The National Transportation Safety Board (NTSB) together with the US Customs and Border Protection (CBP) agency under the Department of Homeland Security identified many lessons from this mishap. The following pages use the insights provided from the Nogales crash to support a critical review of the most recent FAA guidance on the integration of UAS into the U. S. National Airspace System. The existing version of FAA's Interim Operational Approval Guidance 08-01 addresses many of the problems identified in the NTSB report into this incident. However, we conclude that greater oversight is needed to support the exemptions that are permitted for the provisions within this document. In particular, our analysis questions whether a process that enables the same agency to act as regulator and operator of a UAV can be justified within the National Airspace System especially when Federal Agencies delegate operational responsibility to sub-contractors. It is also argued that the Nogales crash illustrates the need for greater coordination between UAS operational staff and Air Traffic Management in order to improve mutual situation awareness under normal operations but also to support coordination under degraded modes. Finally, it is argued that the existing requirements for the certification of maintenance technicians and of maintenance management processes under FAA 08-01 should be strengthened *beyond those for conventional aviation* to avoid the sense of complacency that undermines the safety of UAV operations within the National Airspace System.

Introduction

The term Unmanned Aerial Vehicles (UAVs) refers to the airborne component of the wider Unmanned Aircraft Systems (UAS'). Within the US military alone funding for UAS development has increased from $3 billion in the early 1990s to over $12 billion for 2004-2009 [1]. UAVs perform a wide variety of surveillance and reconnaissance operations ranging from monitoring forest fires and oil spills through to border security applications. They are, typically, deployed in operations that otherwise threaten the safety of flight crews. However, there are numerous safety concerns. UAVs have a significantly higher accident rate than manned aircraft [1, 2, 3]. Previous incidents have been caused by human factors issues including shortfalls in individuals' skill and knowledge (checklist error, task mis-prioritization, lack of training for task attempted, and inadequate system knowledge), situation awareness (channelized attention), and crew coordination [4]. Concerns have also been raised about the standards that are used in the engineering of UAS platforms, which often fall below those required in conventional aircraft.

Many countries have begun to identify ways in which unmanned aerial vehicles might be incorporated as operational air traffic outside of segregated airspace. There are numerous justifications for this, including the increasing ability of UAVs to support long duration missions that would be difficult, if not impossible, to resource using conventional aircraft. Examples include the monitoring work being undertaken by the Customs and Border Patrol on the US-Mexico border. They also include more speculative proposals to incorporate UAVs into the security systems for the 2012 London Olympics. Balanced against the potential benefits offered by integrating UAVs into controlled airspace, there are also a host of safety concerns. There is a requirement to ensure that UAV operations should not increase the risk to other airspace users; that ATM procedures should mirror those applicable to manned aircraft; and that the provision of air traffic services to UAVs should be transparent to ATC controllers. Rather than develop an abstract hazard analysis for predicted problems from the integration of UAVs outside segregated airspace, this paper uses direct operational safety experience to validate the recommendations made in [1, 2, 3]. The novel contribution of this paper is to use an incident reports to validate the recommendations made in the FAA's Interim Operational Approval Guidance 08-01: Unmanned Aircraft Systems Operations in the U. S. National Airspace System. This is one of several similar documents including EUROCONTROL's Spec-0102 on the Use of Military Unmanned Aerial Vehicles as Operational Air Traffic Outside Segregated Airspace and the UK Civil Aviation Authority's CAP 722: Unmanned Aircraft System Operations in UK Airspace – Guidance that are being published to help regulators keep place with the increasing demands to deploy UAVs in a host of new environments. While these documents address many of the hazards identified in military and civil UAV accident reports, the following pages argue that further revisions are required in order to ensure that ATM personnel can respond effectively under the emergency conditions that have arisen when UAVs begin to diverge from their intended course.

Overview of the Nogales Predator Mishap

In the early hours of 25th April, 2006, a Predator Type B UAV manufactured by General Atomics Aeronautical Systems, Inc. (GA-ASI), crashed northwest of Nogales International Airport, Arizona. Although it landed in a sparsely populated residential area, there were no injuries but there was substantial damage to the aircraft. The UAV was owned by the US Customs and Border Protection (CBP) agency but at the time of the crash was being operated under contract with GA-ASI. This commercial relationship is explained by the CBP's requirement to rapidly increase their use of unmanned surveillance aircraft to improve security along the United States' southern borders. As we shall see, it also created a context in which the CBP had to ensure that GA-ASI continued to fulfil the FAA's operating requirements for the operation of the UAS within the National Airspace System. The Predator B is a turboprop aircraft with redundant, fault-tolerant avionics. It can be flown by a remote pilot or autonomously. It was designed as a long-endurance, high-altitude platform with a wingspan of 66 feet, a maximum weight of 10,000 pounds and a maximum speed above 220 knots. The National Transportation Safety Board (NTSB) coordinated the immediate investigation of the mishap [5]. They argued that the loss of the Predator was caused by the pilot's failure to use an appropriate checklist when switching control from one pilot payload operator position (PPO-1) to another (PPO-2). In making this change, he forgot to alter the position of the controls in the new position. This resulted in the fuel valve inadvertently being shut off, which in turn starved the engine. The decision to focus on this mishap is justified by the level of detail provided by the NTSB account. It is also motivated by the manner in which regulatory and organizational factors contributed to the context in which the operator 'error' was likely to jeopardize mission success. It provides direct operational insights into the extent to which FAA Interim Operational Approval Guidance 08-01: Unmanned Aircraft Systems Operations in the U. S. National Airspace System might help operators and regulators to focus on the hazards that have undermined previous applications.

FAA Interim Operational Guidance 08-01

Existing regulatory provisions cannot easily be extended to UAS operations. For instance, Title 14 of the US Code of Federal regulations covers rights of way for aircraft. It includes terms such as 'see and avoid' that make little sense in the context of unmanned operations. In consequence, regulatory bodies, including the CAA and the FAA, as well as international advisory agencies, such as EUROCONTROL, have begun to issue detailed guidance on the integration of UAS' into controlled air space. Many of these documents are provisional. There is a recognition that they will have to be revised as the operational profile and technical infrastructure for these systems are changing rapidly. However, the regulatory documents are important because they provide a 'gold standard' against which we can contrast the operational problems that have arisen during previous and present UAS operations. FAA Interim Operational Guidance 08-01 was issued in March 2008. It is intended to help determine if UAS may operate within the U. S. National Airspace System (NAS). Members of the FAA Aviation Safety Unmanned Aircraft Program Office and Air Traffic Organization use 08-01 to evaluate applications for a Certificate of Waiver or Authorization (COA) and airworthiness certificates whenever an organization makes a request to begin or renew UAS operations.

National Security

At the time of the Nogales accident, the CBP Predator was operating under a COA that reflected their role within the Department of Homeland Security. FAA 08-01 explains the standards that should be applied to approve Certificate of Authorizations that relate to 'national security'. The Departments of Defence or Homeland Security may decide that the operation of a UAV is necessary to protect national interests. In such circumstances, 08-01 recognises that the FAA might approve an application that would not otherwise be acceptable. However, the applicant must identify and accept all risks that arise from any authorisation. Approval has to be given at the level of the Administrator. Many of the issues addressed in this section of the interim guidance were illustrated by the Nogales Predator accident[5]. The CBP asked that the NTSB did not release specific information in the COA that might provide details about the operation of the Predator. However, the investigation did identify some of the safety issues that arose from the acceptance of the COA. For instance, the investigators reported that "At the time of the accident, CBP was unable to certify to the FAA that BP-101 was airworthy. Because of national security issues and past experience with similar UASs, the FAA temporarily waived this requirement for the issuance of the Certificate of Waiver or Authorization (COA) to operate in the National Airspace System (NAS)". Section 6 of 08-01 address air worthiness requirements and stipulates that all UAS must be in a fit state to conduct operations in the NAS. In particular, there is a requirement that the components of the system be maintained and conform to "the same airworthiness standards as defined for the 14 CFR parts under which UAS are intended to be operated". One of the reasons why it was determined that requirements under section 6 might not be enforced on the CBP was that they had, in turn, been directed to start flying the Predator B programme at short notice, in response to the perceived need to address problems with cross-border immigration.

Air Worthiness Requirements

As mentioned above, the CBP COA provided exemptions from some of the requirements under FAA 08-01 for civil operators; these stated that COA applicants must apply for a special airworthiness certificate and that they must submit all the necessary data to demonstrate that the UAS is "designed, built, and maintained in a safe and airworthy condition". The Nogales accident illustrates how far the CBP strayed from these civil requirements under their exemptions for national security. An important factor in the underlying causes of the accident was that 'work arounds' were routinely accepted to enable safety-critical operations to continue [4]. Previous papers have emphasised the hazards associated with long term acceptance of 'degraded modes of operation' [6]. Maintenance procedures were often poorly documented and there was a lack of information about corrective actions. The high number of previous failures and the inadequate maintenance actions may also have reflected deeper problems in the risk assessment practices that were intended to guide the operation of the CBP UAS programme [4]. The accident was triggered by the lock-up in the ground control system. A review of a computer log showed nine previous lock-ups in the three months before the mishap. Two of these occurred before launch on the day of the accident. The maintenance logs did not record any attempts to correct another incident that had occurred six days before. The NTSB, therefore, concluded that these incidents had become 'normal' or 'routine'. They were corrected by cycling the power and by finding 'work arounds' rather than by addressing the source of the problem and fixing it. In consequence, there was no attempt to perform the types of sustained cause-consequence analysis that might have identified the potential outcome of lock-up events during CBP operations. These consequences include increased pilot workload and loss of situation awareness incurred each time the crew had to change working positions from PPO-1 to PPO-2.

It can be argued that some of these practices reflected the heavy demands that were being placed on the CBP to sustain and increase their UAV operations in the face of strategic and political concerns over the integrity of the border. These practices may also have come about as a result of the need to integrate CBP activities with support functions from a number of sub-contracting companies. However, such arguments neglect the extent to which the accident departs from the types of requirements that might 'normally' be placed on UAV operators under the requirements of FAA 08-01. The NTSB investigators could not find any explicit process for testing the UAS after any maintenance to determine whether or not it could be safely returned to service. In particular, there was no method for checking whether the workaround of rebooting the ground control system console following a lockup had any undesired side-effects prior to launch. Further examples include the manner in which the processor circuit board was switched between the two consoles following the last lockup before the flight. This did little to alleviate a potential problem as it simply transferred the fault to PPO-2. The NTSB, therefore, concluded that "neither the CBP nor its contractors had a documented maintenance program that ensured that maintenance tasks were performed correctly and that comprehensive root-cause analyses and corrective action procedures were required when failures, such as console lockups, occurred repeatedly. As a result, maintenance actions could not be relied upon to be effective or repeatable, which is a critical factor in ensuring airworthiness" [5].

It is important to place the NTSB findings in a wider context. Previous studies have remarked that the general standards of maintenance tend to be lower for unmanned as opposed to manned vehicles both in military and in civil systems [7, 8]. One reason for this is that UAS are frequently seen as experimental, they are subject to frequent modifications that can be necessary to tailor the vehicles to operational requirements and to novel environments in a manner that is not typical for manned systems. Similarly, the segregation of UAS operations from other traffic in the National Airspace System can (incorrectly) be seen to offer a degree of mitigation that implicitly supports lower standards of maintenance. The feeling of 'corporate responsibility' that often characterises teams of co-workers who maintain commercial aircraft is less apparent in some UAV operations. The FAA arguably acknowledges these differences in Section 6 of 08-01 when it states that in the future "UAS Maintenance Technician certification will parallel existing standards for manned aviation. As with airworthiness standards, Maintenance Technicians Requirements will be reviewed as part of the data collection process." The Nogales accident and similar studies of military incidents involving UAVs [7, 8] suggest that these requirements should be strengthened to ensure that there is no sense of complacency in the maintenance and management of these systems.

<u>Public Use, Regulation and Sub-Contracting</u>

Subsequent paragraphs in 08-01 require that applicants develop effective maintenance programmes to ensure the continued safe operation of UAVs. The guidance includes a recommendation that any application for a COA be supported by documentation on the operators' continuing airworthiness programme, maintenance training programme as well as "any inique skill sets or maintenance practices relating to their aircraft and/or aircraft operations that may be outside the current scope and practices of manned aviation and a process to report any applicable data relating to the operation and maintenance of the UAS". This is intended to help the FAA monitor the skills and procedures that support a range of different types of UAV as they evolve rapidly over time. However, previous sections have described the way in which the Nogales Predator was dispatched with unresolved maintenance issues that caused the Ground Control System to lock. It was also found that the CBP lacked effective procedures to ensure that such deficiencies were resolved in a controlled fashion. In spite of the exemptions for National Security reasons, these deficiencies undermined confidence in the program and its ability to maintain the airworthiness of the UAS. The investigators, therefore, did not simply focus on the workarounds involving PPO-1 and PPO-2. Instead they recommended that the CBP review their maintenance and inspection procedures to ensure that they could effectively pursue known problems until they had both identified and addressed the root causes. Any subsequent interventions should then be followed by formal verification to establish that the work had been completed and that there were no side effects that might also undermine the safety of subsequent operations.

Tracing the root causes of the Nogales accident, the subsequent investigation returned to the 'public use' provisions under which the COA was granted – the use of this term is instructive because it represents an important distinction from the 'national security' reference that is retained within FAA 08-01. The relevance of these exemptions are summarised in the observation that the CBP was acting both as the regulator and also the operator of the UAS. It is for this reason that they were charged both with implementing an effective maintenance plan but also monitoring that level of effectiveness. This overloading of responsibility is, typically, not permitted in safety-critical industries. Many previous accidents have stemmed from confusion between regulation and operation [7]. These issues might have been resolved if the CBP had chosen to adopt a more focused regulatory role, while their sub-contractor GA-ASI had taken a narrow operational responsibility. However, the investigations argued that the CBP lacked the necessary resources, especially maintenance and engineering expertise, to oversee GA-ASI and their operational responsibility for airworthiness. If the contingencies of 'public use' and 'national security' considerations are to continue to justify exemptions from FAA 08-01 requirements then it seems clear that agencies such as the CBP need to recruit sufficient expertise to discharge their regulatory role. A more difficult political question is whether such waivers ought to be allowed in the first place given the clear threats to public safety that arose from the regulation of UAVs both before the Nogales crash and with the continued provisions for exclusions embedded in FAA 08-01. Any subsequent revision of the FAA guidance should require that 'public use' and 'national security' exemptions must be supported by detailed descriptions of the regulatory processes that will be used to monitor airworthiness in lieu of the FAA. These are likely to be less onerous than the provisions for civil operators. However, there is a need to maintain public confidence in the safe operation of UAVs when they are operating in the National Airspace System. Nobody was killed in the Nogales crash; we may not be so fortunate in the future.

<u>'Lost link Profiles' and Autonomous Operation</u>

Several sections of the FAA guidance refer to the need to create and maintain lost like profiles for UAS operation. These provide a flight-plan that can automatically be triggered when the UAV detects that it is no longer in communication with a base station. For example, 08-01 requires that "In all cases, the UAS must be provided with a means of automatic recovery in the event of a lost link. There are many acceptable approaches to satisfy the requirement. The intent is to ensure airborne operations are predictable in the event of lost link". The development of autonomous capabilities following an interruption to communications is critically important because it undermines another of the requirements within the interim guidance relating to flight termination systems. There is a requirement on operators to ensure that if the UAV suffers system failures that undermine the safety of continued operations then the pilot in charge should be able to manually activate a flight termination system. However, such an application could only be triggered after communications had been restored to a UAV.

Following the Nogales accident, NTSB investigators found that there were three lost link profiles stored on the ground control system. Only one of these could be active at any one time. However, the pilot could change their selection during an operation in response to changes in the area in which the UAV was being flown. For the Predator involved in this mishap, the profiles were typically intended to ensure that the UAV would turn to a lost-link heading, climb for approximately 50 seconds on full power at 105 knots in order to gain time and help reacquire the signal. The UAV then establishes a waypoint 2.5 nautical miles from the location where the link was first lost on the heading established for the profile. When this waypoint is reached or after half an hour, the vehicle will fly the rest of the profile to predetermined locations and altitudes. If contact cannot be re-established then the Predator cannot land and it will crash when the available fuel is exhausted.

Considerable care is clearly required in creating and maintaining a lost link profile. FAA Guidance 08-01 Section 8 notes the dangers of UAV operations over populated areas. The interim document states that “It is the applicant’s responsibility to demonstrate that injury to persons or property along the flight path is extremely improbable... UA with performance characteristics that impede normal air traffic operations may be restricted in their operations”. Similarly, UAS operations should avoid routes with heavy traffic or with open assemblies of people. These can only be approved in emergency or relief situations if ‘the proposed mitigation strategies are found to be acceptable’. This requires that applicants conduct a formal risk assessment with associated safety argument to demonstrate that the residual hazards are “extremely improbable”. In contrast, the NTSB investigation argued that there “was no standardized safety-based method for determining the routes for the lost-link flightpath and that inadequate consideration was given to ensuring the flight path did not include flight over population centers, property, or other installations of value”. The lost-link profile followed by the Predator on the day of the accident was unnecessarily complicated. It was also argued that the pilots were uncertain about the actual flightpath of the UAV following the loss of communications with the vehicle. The investigation also found that the UAV would crash along the route specified in the lost link profile. This created considerable uncertainty about the potential location for any ‘landing’. In future, it was recommended that lost link profiles lead to a ‘safety zone’.

It is important not to focus too narrowly on the lessons that Nogales provided for the handling of lost link profiles in UAS operations. This mishap also provided more general insights into the potential hazards of autonomous operations within National Airspace System. FAA 08-01 recognises this connection in section 8 when it states that although all UAVs will have an element of autonomous operation; it is a requirement that there should be ‘pilot in the loop’ capability before they can be allowed within the National Airspace System outside of various categories of restricted air space. They also acknowledge that the pilot will technically be out of the loop during a lost link recovery but that this scenario is not covered by the section 8 requirements. Hence although the Nogales accident provides most direct insights into the lost link provisions in FAA 08-01 it also serves to reinforce the reservations about autonomous operations. In other words, the problems in pre-programming a ‘safe’ flight-plan for autonomous recovery in this accident provides further justification for the interim guidance that there must be some means for direct pilot intervention during other stages of flight.

Air Traffic Control (ATC) Communications

Section 8 of FAA Guidance 08-01 also establishes the communications requirements for the operation of UAS inside the US National Airspace System. Pilots must have immediate radio contact with relevant ATC facilities at all times if the UAV is being operated in class A or D airspace or under instrument flight rules. The FAA guidance also requires communication with ATC is this is required within the COA or airworthiness certificate. In addition, the CBP should have notified the FAA and ATC of any changes to their lost link profiles within a COA. These updates would have helped to coordinate any response to an emergency. However, the changes to the ‘lost link profiles’ had not been communicated to these other agencies. The NTSB, therefore, argued that there was a real potential for an in-flight collision as the UAV created a significant hazard for other users of the National Airspace System. During the incident itself, the COA under which the Nogales Predator was operating has a requirement that following the loss of communications link, the pilot in command was to immediately inform ATC of:

1. The UAS call sign.
2. UAS IFF [Identification, Friend or Foe] squawk.
3. Lost link profile.
4. Last known position.
5. Pre-programmed airspeed.
6. Usable fuel remaining (expressed in hours and minutes).
7. Heading/routing from the last known position to the lost link emergency mission loiter.

However, there was no communication between Albuquerque Air Route Traffic Control Center and the UAV pilot about the lost link profile, as required by the COA. This lack of communication was compounded by the loss of power to the UAV following the console lock-up that triggered the accident. UAV functionality was seriously compromised as it began to rely on battery power. The aircraft shut down its satellite communication system and the transponder. If the transponder had continued to work with mode C altitude data then ATC might have been able to track the course of the UAV and warn other airspace users. An important finding from the Nogales crash was the need to modify UAS design so that transponder functionality should continue even under degraded modes of operation. Arguably, this ought to be an explicit requirement within 08-01, the importance of transponder information would seem to be more critical than in other forms of aviation.

A key objective for the coordination between UAS pilots and ATC is to ensure adequate separation between aircraft within the same air space. In order to help meet this requirement, the UAV was only authorised to operate in temporarily restricted airspace. Any other aircraft wishing to operate within this area had to contact ATC before entering. For the CBP operations, the UAV's restricted operating air space extended along the southern border from 14,000 to 16,000 feet MSL. However, the loss of power prevented the UAV from maintaining its altitude. The Predator breached the lower limit of the restricted zone. The investigators, therefore, argued that the UAV was operating autonomously in unprotected airspace until it crashed. ATC contacted the Predator's pilot after they lost contact with the vehicle and the transponder had stopped working. However, the pilot did not inform them that the UAV had descended below the 14,000 feet MSL. At this point, the pilot or the ATCO should have declared an emergency and taken measures to alert traffic in the area. They should have alerted neighbouring centres to monitor the missing vehicle. The ATC could also have started efforts to increase the level of surveillance on the UAV, for instance by contacting the Western Area Defense Sector to gather information using their height finding radar.

These observations from the Nogales accident arguably show that documents such as FAA 08-01 ought to be extended and strengthened to include additional requirements on UAV operators within their COA's to increase the level of cooperation with ATC. Section 8 and the associated requirements in the existing document simply specifies a minimum level of communication and coordination that proved to be insufficient to ensure mutual situation awareness and coordination during the Nogales accident. In particular, prior to the accident ATCOs were only provided with mandatory training on the UAS operations in the form of a 30-minute briefing and a Powerpoint presentation. The NTSB investigators, therefore, argued that the CBP should conduct more exytensive and 'face to face' reviews between the UAS operations group and the ATC organisation, to include ATCOs and pilots. The intention of these meetings is to clarify their response and required actions both during standard and degraded modes of operation; "These operational reviews should include, but not be limited to, discussion on lost-link profiles and procedures, the potential for unique emergency situations and methods to mitigate them, platform-specific aircraft characteristics, and airspace management procedures".

Risk Management

FAA 08-01 requires that formal risk assessments are conducted to justify UAV operations. This can be difficult given the lack of long-term operational experience with many UAS applications. The quantitative aspect of these assessments may have to be based on expert judgement rather than the performance of complex safety-related systems in comparable operations. Similarly, the guidance for the integration of UAS extends exemptions for national security to override the risk mitigation requirements that would be expected for civil COA. However, this *does not* exempt the operators from conducting such a risk assessment in the first place. In other words, it is acceptable for national security considerations to justify an increased level of acceptable risk – providing an agreement is reached with the FAA Administrator. However, it is a requirement that such an explicit risk assessment is conducted in the first place to identify the hazards that are being accepted.

The Nogales accident demonstrated that the operators lacked any clear plan to mitigate the risks associated with the operation of the UAS under degraded modes of operation [6]. The lock-up on PPO-1 was only one example of several other deficiencies. For instance, another unresolved component problem had disabled the satellite communication control function of PPO-2. The investigators argued that one potential mitigation would have been to introduce a minimum equipment list or a deviations guide. These documents can help operators to identify spare parts that should be retained in order to help engineers promptly respond to any failures that do occur. However, there were remarkably few parts at the CBP Predator facility. This may have constrained the opportunities that maintenance technicians had both to intervene in but also to diagnose those failures that did occur. Minimum equipment list and deviations guides can also be used to establish the conditions under which operations should be suspended or describe alternate operating procedures that support potential 'work arounds' without compromising the underlying safety of operations. Without such documents it was difficult for the operators or the CBP acting in their regulatory role to determine whether or not the level of safety/reliability was sufficient to justify continuing operations. In particular, it can be hard to assess the residual risk that might arise if further components should fail during flights that are adjacent to controlled air space or to residential areas.

Conclusions and Further Work

In April 2006, an Unmanned Aerial Vehicle (UAV) crashed near Nogales, Arizona. This incident triggered one of the most sustained studies into the causes of failure involving Unmanned Aerial Systems (UAS). The National Transportation Safety Board (NTSB) together with the US Customs and Border Protection (CBP) agency under the Department of Homeland Security identified many lessons from this mishap. This paper has used insights provided from the Nogales crash to develop a critical review of the most recent FAA guidance on the integration of UAS into the U. S. National Airspace System. The existing version of FAA's Interim Operational Approval Guidance 08-01 addresses many of the problems identified in the NTSB report into this incident. However, we have argued that greater oversight is needed to support the exemptions that are permitted for the provisions within this document. In particular, our analysis has questioned whether a process that enables the same agency to act as regulator and operator of a UAV can be justified within the National Airspace System even given the contingencies of national security, especially when Federal Agencies delegate operational responsibility to sub-contractors. Previous sections have also shown that the Nogales crash illustrates the need for greater coordination between UAS operational staff and Air Traffic Management staff, not just in order to improve mutual situation awareness under normal operations but also to support coordination under degraded modes of operation.

This paper has focused on a single accident and the insights that it provides for the future regulation of UAS within the National Airspace System. Previous sections have argued that there are relatively few accounts at a similar level of detail – but that much can be learned from the accidents that have occurred involving remotely controlled model aircraft – just as UAVs continue to exploit control models from these 'toy' systems. Similarly, there is a growing number of accident reports describing mishaps involving military UAS in both Iraq and Afghanistan [8, 9]. Future work intends to build on the analysis in this paper and combine it with our previous work on UAV incidents in the US, British and Canadian armed forces where there is a growing expertise in the integration of manned and unmanned vehicles within the same air space even if the context of operations is radically different from those that apply within most areas of the National Airspace System. Finally, it is argued that the existing requirements for the certification of maintenance technicians and of maintenance management processes under FAA 08-01 be strengthened beyond those for conventional aviation to avoid the sense of complacency that can undermine the safety of UAV operations within the National Airspace System.

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