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UAS Maintenance: A Critical Component in Maintaining Airworthiness

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Over the last several decades, the notion of traditional aircraft design has significantly changed. While there are many modern aircraft that resemble earlier models, their components, systems, and overall architecture have evolved, including the introduction of unmanned aircraft systems. The introduction of such aircraft into the National Airspace System (NAS) has resulted in several challenges, from maintaining airworthiness to the oversight of safety operations. Despite the growing consumer attraction to own and operate unmanned aircraft systems, the subsequent safety impact of these aircraft is in question. A major concern is to ensure that all aircraft which fly in the NAS are deemed airworthy. For manned aircraft, this is accomplished via required scheduled maintenance procedures, such as the Federal Aviation Administration's (FAA) Maintenance Steering Group 3 (MSG-3) procedures which are based on manufacturer and other stakeholder guidelines. Preventive maintenance also supports the airworthiness of an aircraft by gathering and evaluating component reliability data to determine when certain components need to be removed or undergo maintenance. Overall, these efforts improve the safety of the NAS by ensuring that all aircraft are safe for flight. However, these same requirements have not been extended to include small unmanned aircraft systems (sUAS), which presents a gap in safety.

Statement of the Problem

As the issue of maintenance for sUAS and particularly scheduled maintenance is not well understood, the authors employed a qualitative exploratory research approach in the form of a literature review and corresponding gap analysis to gain insight into the question of the need for formalized sUAS maintenance procedures. The effort was completed through an examination of the current information available from regulators, original equipment manufacturers (OEMs) and owner/operators to gain insight into whether gaps exist in some of these efforts, namely the requirement for a scheduled maintenance program.

Literature Review

In an effort to explore potential gaps in existing sUAS maintenance procedures, a review of the relevant literature was necessary. Several key areas were explored including current legislation related to airworthiness requirements, scheduled maintenance programs, the role of component reliability data, current incident and accident data reporting methods, and operational commonalities and differences. The below sections are the results of that review.

Maintaining Airworthiness – Small Unmanned vs Manned

Before examining the similarities and differences in regulations pertaining to the safe flight of small unmanned aircraft systems, it is important to first identify the rules and regulations that pertain to both. The Federal Aviation Administration (FAA) is the national authority within the United States to regulate all aspects of civil aviation. As it pertains to sUAS operations, the FAA has identified two options for flying in the NAS. The first applies to those that fly for recreational or hobby use only. They fall under Special Rule for Model Aircraft, Section 336. Under this rule, hobbyists are required to adhere to community-based safety guidelines that are developed by organizations in their area and within the programming of a nationwide community-based organization, such as the Academy of Model Aeronautics (AMA). To assist sUAS hobbyists with the flight process, the AMA has several resources, namely the AMA Safety Code and AMA Safety Handbook. Both of these documents outline the requirements for safely operating a sUAS and can be found on the AMA website, under education, learn sUAS (http://suas.modelaircraft.org/). The other option refers to those who fly for recreational or commercial use and have obtained a Remote Pilot Certificate from the FAA (herein after referred to as "remote pilots"). They operate under

Title 14 CFR, Part 107. While it is not within the scope of this paper to extensively review the Special Rule for Model Aircraft, Section 336 or Title 14 CFR, Part 107, it is important to identify the governing documents that outline current requirements for maintaining small unmanned aircraft systems. The following sections will review current maintenance requirements for both manned and unmanned aircraft.

Airworthiness, the determination of an aircraft's suitability for safe flight, is predicated on creating and sustaining a safe flight environment. This section will review the requirements for maintaining airworthiness for both manned and unmanned aircraft. While there are some commonalities between the two, there are also distinct differences. An understanding of these inconsistencies is necessary to determine if gaps in current legislation exist.

To operate a manned aircraft in the National Airspace System (NAS), a certificate of airworthiness is required by the Federal Aviation Administration (FAA), as outlined in Title 14 of the Code of Federal Regulations. To obtain a certificate, the registered owner/operator must submit an application to the FAA, upon which a determination is made on whether or not the aircraft is eligible and in a condition for safe operation (FAA, 2016a). Once obtained, the certificate is effective as long as required maintenance, preventive maintenance, and provisions are performed in accordance with Title 14 CFR, Parts 43 and 91. The requirement to maintain airworthiness ensures the safety of all involved in the flight process, from the pilot in the cockpit to the mechanic on the ground. It is a safety measure that arose from previous aircraft incidents and accidents. Maintaining airworthiness has become a way of life for owners and operators; a necessary component in assuring a safe for flight status. Despite the increased reliability of certain components, a robust maintenance plan which accounts for scheduled and unscheduled maintenance actions is not only necessary, but required, in order to maintain airworthiness. While it is not necessary to review all sections of Title 14, for the purposes of this paper, certain sections are pertinent; those that are authorized to perform maintenance (§43.3), and the maintenance requirements for maintaining airworthiness (§43.13).

Per Title 14 of the CFR, only those personnel who hold a mechanic or repairman certificate, or those under the supervision of someone who holds such a certificate, are authorized to perform maintenance, preventive maintenance, or alterations on an aircraft, airframe, aircraft engine, propeller, appliance, or component part to which this part applies. Doing so ensures that all maintenance procedures are performed accurately and in accordance with prescribed instructions as required by the manufacturer. The requirement of a certificate also acts as a measure of legal accountability. Those with an airworthiness certificate are legally required to perform maintenance in accordance with the manufacturer's and the FAA's regulations.

The maintenance requirements for upholding airworthiness require:

> All maintenance, alteration, or preventive maintenance on an aircraft, engine, propeller, or appliance shall use the methods techniques and practices prescribed in the current manufacturer's maintenance manual or Instructions for Continued Airworthiness prepared by its manufacturer, or other methods, techniques, and practices acceptable to the FAA. (Title 14 §43.13, 2018, a)

While specific maintenance actions are not listed under Title 14, the conduct of the actions themselves are governed by a regulating authority, the FAA. This too acts as a measure of legal accountability, ensuring that maintenance is conducted and performed by those with the necessary knowledge to safely uphold airworthiness requirements.

For unmanned aircraft, the airworthiness requirements are outlined in Title 14 Part 107§15, the condition for safe operation. It states that:

> No person may operate a civil small unmanned aircraft system unless it is in a condition for safe operation. Prior to each flight, the remote pilot in command must check the small unmanned aircraft system to determine whether it is in a condition for safe operation. (Title 14 §107.15, 2018, a)

Unlike manned aircraft, small unmanned aircraft systems are not required to comply with FAA airworthiness standards or to obtain an aircraft certification. However, the operator of the unmanned aircraft is required to perform a preflight visual and operational check to ensure that all safety-pertinent systems are functioning properly (Advisory Circular 91-57A, 2016; Title 14 §107, 2018).

Importance of Scheduled Maintenance Programs

As noted in the previous section, aircraft maintenance is critical to maintaining airworthiness for manned aircraft. Additionally, while CFR Title 14 does not prescribe specific maintenance activities, the regulations require operators to develop the actual maintenance program according to Original Equipment Manufacturer (OEM) information and Maintenance Steering Group 3 (MSG-3) guidance provided in FAA AC 121-22C (FAA, 2012). OEMs of manned aircraft actively contribute to the maintenance planning document (MPD), which is the source document for the initial maintenance program.

Scheduled maintenance for manned aircraft has evolved over time. As with most processes, aircraft maintenance in the early days of aviation was a “fly-fix-fly” approach that simply identified the cause of accident, corrected the issue for the future, and these preventative actions eventually became standards or regulations (Leveson, 2003). However, simply correcting the immediate problem only addressed part of the overall aircraft system and did not incorporate design, operations, or management as potential contributors to accidents. The formalization of aircraft maintenance activities to incorporate design, materials, and operations did not occur until the 1960s with the creation of the handbook "Maintenance Evaluation and Program Development" that was impetus or first iteration of the Maintenance Steering Group (MSG) process. With the advent of MSG that was first utilized for the B-747 aircraft, the needed parties such as manufacturers, operators, the FAA and suppliers now had a seat at the table to develop more forward-thinking aircraft maintenance programs (McLoughlin & Beck, 2006).

Scheduled maintenance is only one part of an aircraft maintenance program, but undoubtedly the most important category of maintenance performed to maintain airworthiness. Scheduled maintenance is often referred to as interval, block, check, or phased maintenance (Emeneker, 2014). The word scheduled denotes a specific timeframe for completing the maintenance tasks. The established timeframes for scheduled maintenance are based on standard utilization rates and historical observations usually in the form of flight or operation hours. The interval based or scheduled maintenance requires the operators to allocate time and resources to conduct the prescribed maintenance tasks. In commercial aviation the increasing scrutiny of the inspections are denoted by the level of check, i.e. daily checks, A checks are primarily visual while D checks are intensive structural inspections of the entire airframe (Hessberg, 2000). The value of scheduled maintenance is found in these periodic opportunities to allow for identification of discrepancies and to correct them before the item or component fails.

With MSG-3 as the foundation, manned aircraft maintenance activities have continued to advance to be more predictive in nature rather than reactive and include risk-based analyses (Ahmadi, Soderholm & Kumar, 2010). As time and technology have advanced, aircraft maintenance has along with other industries moved beyond condition-based maintenance and predictive maintenance to the concept of prescriptive maintenance that is rooted in data analytics

(Bellias, 2017). The history of the use of data whether in the form of a handwritten record, a keypunch card, a computer printout, or the instantaneous data analytics available today all form the cornerstone of the concept component reliability.

Role of Component Reliability Data

Component reliability is the evidence today of the efforts that started 50 years ago to make better design decisions, material choices, improve construction and changes in procedures to improve the life span of the components and in turn the aircraft (Goglia, 2014). As noted in the previous section, data has driven manned aircraft maintenance actions from a fly-fix-fly approach to the component that operates for years between repairs or replacement. The bathtub curve in Figure 1 provides a typical representation of the results of the data collected over time for a part or component.

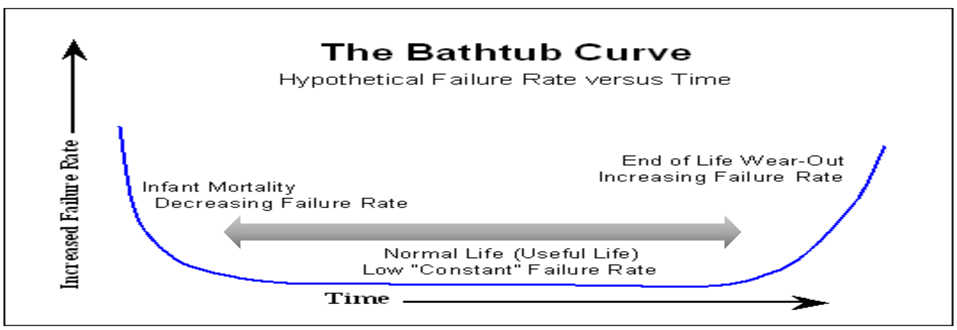

Figure 1: The Bathtub Curve. Adapted from Reliability HotWire at http://www.weibull.com/ hotwire/issue21/hottopics21.htm

The operational data collected on the part or component over time provides reliability analysts with the information needed to know when design or quality failures are evident as depicted in the infant mortality region of the curve. The flat part of the bathtub, illustrated by the gray arrow, is the derived probability that an item will perform without failure for a stated period of time. The low failure rate area or flat line is also referred to as the useful or design life (Wilkins, n.d.). As the item reaches the end of the predicted and probable life span, the wear out failures will increase as noted on the right side of the bathtub curve. Each part, component, system and subsystem that make up an aircraft has a past and that historical information from the baseline on which aircraft maintenance programs are designed, built and delivered.

The pathway to improved maintenance practices have been paved through the years by communication and cooperation between the parties involved in fostering aircraft reliability and ultimately safety (Emeneker, 2014). Aviation is not unique in the need for maintenance programs, reliability and safety. Many other industries have embraced programmatic maintenance programs and cross communication to improve operational efficiency, reliability, and safety. The question then arises as to why the unmanned aircraft system industry has not recognized this need. Or is it role of industry to do so? Just as scheduled maintenance and component reliability provide industry with operating norms, the role of incident and accident data also contribute an important part in understanding operational failures of parts or components. Incident and accident data provide the link between aspects such as manufacturing defects to the real-life operation of the component or part to complete the model of component reliability.

Current Incident and Accident Data Reporting Methods

Estimates of component reliability, and therefore schedules for preventive maintenance, depend upon predictive data as well as historical data from failure rates, including accident and incident data. OEMs of manned aircraft provide predictive data for maintenance, but OEMs of sUAS generally do not, either because failure data is not available, or because competitive pressures discourage disclosure of this information. Regarding historical data from accidents and incidents, manned aircraft operators are required to report accidents involving death, serious injury, or substantial damage to the aircraft to the National Transportation Safety Board. Incidents that do not meet accident criteria must also be reported if they affect safety of operations. Further, any occurrences that may affect safety of flight, including runway incursions, near mid-air collisions, or damage to the aircraft other than an accident must be reported to the FAA. These accident and incident reports can result in safety bulletins, recommendations, new regulations, or Airworthiness Directives (FAA, 2018).

Accident reports, while an important source of information for conducting hazard analysis and risk mitigation, are reactive in nature, and need to be combined with proactive risk management. For every incident or accident that is reported, there are many more occurrences or near-mishaps that can also be of value in assessing risk. Therefore, manned aircraft pilots are also encouraged to voluntarily report regulatory violations and other occurrences that could impact safety through NASA’s Aviation Safety Reporting System (ASRS). Since its inception in 1975, the ASRS program has generated 1.5 million reports that have helped the aviation industry identify hazards and mitigate risk (NASA, 2016).

UAS operators also have accident and incident reporting requirements. UAS operators must report any mishap that results in serious injury or death, or substantial damage to an unmanned aircraft weighing over 300 pounds to the NTSB. UAS operators must also report any serious injury, loss of consciousness, or damage to property in excess of $500 to the FAA. However, the FAA specifically exempts model aircraft from these reporting requirements. Due to the nature of sUAS accident and incident reporting requirements, total destruction of a vehicle, battery fire, lost link, and even fly-away of the vehicle do not necessarily need to be reported. As a result, little data exists on failure rates and modes in sUAS. However, if larger UAS offer any indication, the major mishap rate of USAF Q-9 type aircraft was 2.09 per 100,000 flight hours in

2016, or roughly three times that of USAF manned aircraft (USAF, 2016). Although, in a 2017 report published by the FAA which spanned from August 2015 to January 2016, 519 incidents involving unmanned aircraft were reported. Out of the 519 incidents, 36.2% could be classified as close encounters, or an instance where a pilot declared a "near midair collision", while 63.8% were sightings or incidents where an unmanned aircraft was within sight of the pilot, but did not pose an immediate threat (FAA, 2016b). The rise in demand for sUAS has only exacerbated this issue; the FAA now receives more than 100 incident reports each month related to unmanned aircraft (FAA, 2018). This data demonstrates the potential safety hazards related to unmanned aircraft that currently exist. The rising number of UAS that fly near manned aircraft further demonstrate the need for required maintenance practices for these aircraft.

Regarding voluntary reporting, UAS operators may also use the ASRS program. However, out of the 91,970 total ASRS reports filed in 2016, only 26 came from UAS pilots, and most of these were filed by remote pilots who also held manned aircraft ratings, suggesting that ASRS use is not widespread among remote pilots who do not already have a manned aviation background (Aviation Safety Reporting System, 2017). Along with possible cultural factors, reporting may be cumbersome because no specific reporting form exists that is tailored to UAS, as there are for pilots, maintainers, air traffic controllers, and cabin crew (NASA, 2016). The lack of a suitable voluntary reporting system means that key data for system reliability is not being collected (Robbins, Geraci, Bracewell, & Carson, 2016).

Another voluntary reporting system commonly used in manned aircraft is the Aviation Safety Information Analysis & Sharing (ASIAS) repository (FAA, 2017). The system leverages internal FAA data sets, airline proprietary safety data, and manufacturer's data. The information is solely for the purpose for the advancement of safety; it is a non-punitive reporting system that uses a collaborative approach toward maintaining safety in the aviation industry.

Operational Commonalities and Differences

Although there are important differences in operational realities between manned and unmanned aircraft, the fundamental fact is that sUAS share airspace with manned aircraft, and the safe operations of one affect the safe operations of the other. Even though the intent of unmanned traffic management is to segregate most sUAS and manned aircraft activities, altitude and airspace restrictions may not prevent sUAS from entering airspace reserved for manned aircraft.

In spite of this shared airspace, design and manufacturing standards, aircraft systems, and maintenance tasks all differ considerably between manned and unmanned aircraft. These differences affect UAS maintenance and airworthiness, which may in turn affect safety.

Unlike manned aircraft, at this time there are no design and manufacturing standards or requirements for small UAS (Ley, 2016). Due to both the absence of a regulatory structure surrounding sUAS design and construction, and the derivation of most sUAS from consumer electronics rather than aircraft, a variety of materials are used that have not typically been used in aircraft, and for which little history exists regarding maintenance issues and failure rates (Ley, 2016). While there are proposed maintenance requirements for sUAS that are intended to establish some baseline for continued airworthiness and maintenance (ASTM 2018; Ley 2016), none are explicitly required by the FAA.

sUAS also require systems such as data and communication links and ground control stations that have no analog in manned aircraft (Hobbs, Cardoza, & Null, 2016). The continued airworthiness of these critical systems is essential for safe operations (Ley, 2016). Propulsion systems also differ dramatically, with most consumer grade sUAS powered by lithium batteries that are very sensitive to heat and deformation. Maintenance, care, and inspection of these batteries is necessary to assure continued safe operation. Finally, most manned aircraft are not assembled and disassembled as a part of each flight, but for most sUAS, repeated assembly and disassembly are a reality that may affect the life of hardware components.

Maintenance in sUAS includes not just hardware issues, but software and firmware as well. The firmware and software are often subject to updates that affect system functionality, both for the vehicle and for the controller. These updates do not follow the same process as software updates for avionics used in manned aircraft, nor are the updates tracked in the same way as for manned aircraft. The skill set needed to manage these updates may not overlap with the skills typical in hardware maintenance.

The combination of a lack of design and manufacturing standards, the absence of continuing airworthiness requirements, and the requirements for subsystems that have not been proven in manned aviation has implications for safety. According to Hobbs, Cardoza, and Null (2016), “The higher accident rate for RPA can be partly explained by technological factors such as the use of non-certificated components and a lack of system redundancy” (p. 3). The absence of typical maintenance practices is also relevant. Robbins, Geraci, Bracewell, and Carlson (2016) wrote “Operations without pre and post flight inspections as well as regularly scheduled maintenance will lead to equipment failure and possible damage or loss of equipment and possible injury to personnel” (p. 38). While it is evident that many commonalities exist between traditional manned aircraft and newer unmanned systems, there are clear differences in terms of design and manufacturing standards as well as maintenance requirements. The requirement to maintain airworthiness must be supported with an appropriate regulatory structure that outlines preventive and required maintenance practices, which are rooted in OEM guidelines and component reliability data.

Inadequacies and Gaps in Current Requirements

In an effort understand the implications of these elements within the aviation industry and all who operate in an around the NAS, a review of current and available maintenance practices and regulations for both manned and unmanned aircraft systems was completed and a comparative analysis was conducted to determine if any gaps in research were present. The analysis indicated that current gaps in research regarding safe and efficient scheduled maintenance practices for unmanned systems could compromise those who operate in the NAS, as well as those organizations that rely on these systems for daily business operations. The lack of design and manufacturing standards, the absence of continuing airworthiness requirements, and the requirements for subsystems that have not been proven in manned aviation has implications for safety which have not been addressed in current regulations. Accident and incident data related to unmanned aircraft, combined with the growth of the unmanned industry, further support the need for an established maintenance program framework. The inclusion of component reliability data in this process utilizes established measures which have been validated by the manned aviation industry. Such a program supports operational efficiency, reliability, and safety.

Conclusions and Recommendations

After conducting the literature review and addressing current gaps in sUAS maintenance procedures, the authors propose the following: a consolidated incident/accident data repository which provides more accurate component reliability information, require OEMs to assist in the development of maintenance planning documents, and extend FAA scheduled maintenance activities for unmanned aviation. While current incident/accident data repository systems may be adequate for addressing manned aviation needs, the diverse pool of sUAS operators and remote pilots have resulted with unique challenges regarding the reporting of unmanned incidents/accidents, such as lack of oversight and cognizance of reporting systems. The limited accident data available further exaggerates this problem. However, a centralized repository, such as the Aviation Safety Information Analysis and Sharing (ASIAS), would provide an optimal opportunity to consolidate critical information such as FAA sighting reports, Section 333 exemptions, and Maintenance & Repair (M&R) information.

Another key conclusion was the role of OEMs in the development of the MPD. This has proven both beneficial and necessary for manned aviation. An industry steering committee (ISC) that is made up of operators, manufacturers and regulators, work together to follow AC-121-22C (MSG-3) and create a scheduled maintenance program, culminating in the maintenance review board report (MRBR) which is the basis of the MPD. This would assist sUAS operators and remote pilots in ensuring their aircraft remained airworthy and safe for flight.

Finally, in order for the aforementioned efforts to be fully realized, they must be supported by the FAA. Current regulations only require sUAS operators and remote pilots to maintain an appropriate state of airworthiness. That state of airworthiness is left up to the operator and as such, is completely subjective based on the knowledge of the operator. The vagueness in this requirement, combined with the growth of the unmanned industry, compromise the safety of the NAS. The number of sightings alone necessitate the need for enhanced regulations regarding the safe use and operation of sUAS.

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