ASSURE
UAS Research and Development Program

UAS Research Requirement: UAS Maintenance, Modification, Repair, Inspection, Training, and Certification Considerations

UAS Research Area: UAS Crew Training and Certification

REVIEW OF RELEVANT LITERATURE

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List of Acronyms

Air Traffic Control \hspace{1cm} ATC
Air Transport Association \hspace{1cm} ATA
Airframe and Powerplant \hspace{1cm} A&P
Advisory Circular \hspace{1cm} AC
Advisory Directive \hspace{1cm} AD
Aviation Maintenance Technician \hspace{1cm} AMT
Aviation Rulemaking Committee \hspace{1cm} ARC
Code of Federal Regulations \hspace{1cm} CFR
Commercial Off the Shelf \hspace{1cm} COTS
Composite Affordability Initiative \hspace{1cm} CAI
Certificate of Authorization \hspace{1cm} COA
Carbon Fiber-Reinforced Polymer \hspace{1cm} CFRP
Department of Defense \hspace{1cm} DOD
Department of Labor \hspace{1cm} DOL
European Aviation Safety Agency \hspace{1cm} EASA
Electronic Code of Federal Regulations \hspace{1cm} eCFR
Federal Aviation Administration \hspace{1cm} FAA
Federal Aviation Regulation \hspace{1cm} FAR
General Aviation \hspace{1cm} GA
Ground Control Station \hspace{1cm} GCS
High Altitude Long Endurance \hspace{1cm} HALE
Horizontal Take Off and Landing \hspace{1cm} HTOL
Low Earth Orbit \hspace{1cm} LEO
National Airspace System \hspace{1cm} NAS
Notice of Proposed Rulemaking \hspace{1cm} NPRM
Occupational Safety and Health Administration \hspace{1cm} OSHA
Original Equipment Manufacturer \hspace{1cm} OEM
Quality Management System \hspace{1cm} QMS
Radio Controlled \hspace{1cm} RC
Rocket Assisted Take Off \hspace{1cm} RATO
Safety Management System \hspace{1cm} SMS
Small Unmanned Aircraft Systems \hspace{1cm} sUAS
Standards and Recommended Practice \hspace{1cm} SARP
Unmanned Aircraft \hspace{1cm} UA
Unmanned Aircraft System \hspace{1cm} UAS
Vertical Take Off and Landing \hspace{1cm} VTOL
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Abstract

*Keywords: UAS, UA, maintenance*

There is a significant lack of knowledge and understanding regarding the initial and continuing airworthiness of UAS and how it differs from manned aircraft. UAS are often fabricated from materials, such as foam or unique composites that are not normally found in previously type certificated aircraft and have little to no documentation of sustainment considerations. There are components of UAS, such as ground control stations and communication links that create new concerns for ensuring continued airworthiness. Additionally, the skill set required to effectively sustain a UAS may differ substantially from traditional aircraft maintenance technician skills. All of the above issues must be resolved to safely integrate UAS into the National Airspace System with the same level of safety assurance that currently exists.
Introduction

Background

The aviation industry has seen significant growth since its pioneering stages forward to recent technologies in the field of Unmanned Aircraft (UA). These advancements have led to global awareness of the capabilities and use of these platforms along with a host of potential concerns and operational considerations that must be addressed in order to ensure safe and reliable operations in the National Airspace System (NAS). An unmanned aircraft is defined as “...an aircraft designed to operate with no human pilot on board” while an unmanned aircraft system (UAS) not only includes the UA but also all “...system elements necessary to enable the taxiing, take-off/launch, flight and recovery/landing of [the] UA, and the elements required to accomplish its mission objectives” (Blyenburgh, 2008).

The United States Department of Defense (DOD), the Federal Aviation Administration (FAA), and the European Aviation Safety Agency (EASA) currently utilize the term UAS to reference UAs, which is “...meant to signify that UAS are aircraft and as such airworthiness will need to be demonstrated and they are also systems consisting of ground control stations, communication links and launch and retrieval systems in addition to the aircraft itself” (Tzafestas, Dalamagkidis, & Valavanis, 2009).

While UAS have been used for decades, recent technological advances and breakthroughs have supported modernization. The advent of these technologies and innovation has also sparked high demand for the miniaturization of components to support smaller platform development. UAS applications are unbounded, hosting a wide variety of industries. These applications are widespread to include significant variance in type of aircraft, propulsion, utility, payload, operations, maintenance requirements, etc. These areas of operation must be addressed in order to define best practices and operational profiles for a given platform. Wide Commercial off the Shelf (COTS) availability of airframes is apparent as the industry continues to
grow. The sale of aircraft to recreational, commercial, and governmental stakeholders has indicated an exponential trend over a relatively short amount of time.

Although designs have branched into several categories based on operational considerations, existing frameworks to guide maintenance related elements have yet to be established. Division exists between groups of UAS platforms based on complexity, propulsion, and size, but a streamlined methodology to define best practices and standardized maintenance procedures has not been established. Ideally, existing manned aircraft maintenance procedures and protocols could support a viable framework of foundational guidelines to standardized UAS maintenance and repair practices.

The maintenance proceedings to compliment many of these systems has not been standardized to develop proper procedures or protocols for safe operation. Manufacturers often do not provide the necessary operational information or maintenance documentation to describe proper preventative maintenance or standardized procedures necessary to safely operate a given platform. The production of these materials may be impeded by availability constraints of information and other criteria necessary for proper development. Manufacturers may be reluctant to share information because of the possible loss of competitive advantage or lack of standardization. They may also lack a robust technical infrastructure, requiring specialized skills, content management systems or any other information technology.

Problems to be discussed through this research project includes an analysis of the maintenance procedures currently being practiced for all categories of UAS, the lack of standardization in maintenance proceedings currently being practiced, and the need of standardized maintenance procedures for UAS. The approach to conduct this research involves an analysis of conventional maintenance procedures referenced in 14 Code of Federal Regulation (CFR) in order to analyze their respective feasibility or transferability for varied UAS groups. In the case feasibility is compromised, this research will help define gaps that must be discussed in order to develop standardized procedures, protocols, and methods for safe UAS operations.
Historical Data

Resistance from the public may be apparent as UAS become more available to non-commercial operators. Privacy matters have been addressed as cause for major concern, but the integration of UAS into the NAS must be addressed as a primary issue. Information from FAA reports seem to relay that hundreds of UAS have had close calls, near misses, and near mid-air collisions (NMACs) with manned aircraft. The Academy of Model Aeronautics (AMA) looked further into this data and discovered that, of the 764 reports of close calls, only 27, or 3.5%, of these reports specifically make note of a NMAC, near collision, or near miss situation while 392 of these records, or 51%, state that there was no evasive action taken (AMA, 2015). “Only 1.3% of the records (10 of 764) explicitly note that a pilot took evasive action in response to a drone” (AMA, 2015). In addition to reports of NMACs, there have also been reports of UAs being operated following improper procedures, some of which have been found to be false. The AMA has recommended to the FAA that steps must be taken before releasing their report to ensure that the data is correct, separating military, commercial, and endorsed operations from other, unauthorized operations.

Maintenance Induced Failures

System reliability may contribute to perceived operational risks associated with UAS due to the condition they may not require the same system redundancy as manned aircraft. Additionally, less redundancy may reduce reliability, because aviation maintenance technicians (AMTs) are more susceptible to quality control issues from malfunctioning or improperly installed equipment.

An issue operators reported with small UAS (sUAS) regards transport damage commonly referred to as “ramp rash” (Hobbs et al., 2006). This is a maintenance issue that could prove quite common for UAS due to the frequency of transport and disassembly. sUAS are often designed using lightweight materials to minimize mass and weight. These systems are more susceptible to damage as a result in the reduction of robustness and lack of materials integrity such designs may render.
At this time, it is unknown how maintenance induced failures will affect UAS operations in the NAS. The FAA in cooperation with this research has allowed access to a Maintenance and Repair database (M&R) comprised of quantitative data to represent multiple UAS platforms. The analysis of this data will lead to advancement in the reliability of maintenance procedures and protocols by enhancing the understanding of maintenance standards currently set in place for varied platforms.

**Legislative Timeline**

A UAS Aviation Rulemaking Committee (ARC) was founded by the FAA in 2011 as an effort for the development and refinement of recommended policies, procedures, and standards before UAS were allowed operational access to the NAS (DOT, 2015b).

In June, FAA Deputy Administrator Michael Whitaker stated that between 40 to 50 exemptions are currently being approved per week for low risk commercial UAS operations in controlled environments through Section 333 of the 2012 FAA Modernization and Reform Act (Bellamy, 2015a). At the time of this writing, over 3,600 Section 333 exemptions have been filed (See Faa.gov ‘Section 333 Exemptions).

“...Whitaker told lawmakers Wednesday that the long awaited federal rule regulating the commercial operation of [SUAS] will be published by June 2016” (Bellamy, 2015). Registration requirements for sUAS became effective on December 21, 2015. Non-commercial/hobbyist operators who are over 13 years of age and hold U.S. citizenship or legal permanent resident status must obtain a registration number from the FAA for any aircraft that weighs over .55 lbs. (250 g) and less than 55 lbs. UAS operators who are operating for commercial purposes must register their aircraft by paper.

The UAS roadmap may be found at the following link:

http://www.faa.gov/uas/legislative_programs/uas_roadmap/
Projected Growth of UAS

At the moment, there are constraints regarding the commercial use of UAS due to the underlying complexity and number of issues regarding safe UAS operations in the NAS. To this point, initiatives to promote and facilitate the use of UAS for civilian applications have become more apparent in industry. The development of mobile applications and other software to increase public awareness has aided in developing a consistent knowledge base of general UAS guidelines.

UAS operations are expected to surpass manned aircraft operations, for both military and commercial domains, by 2035. A report accomplished by Aerospace Industries Association indicates “growth of unmanned systems for military and civil use is projected to continue through the next decade. It is estimated that UAS spending will almost double over the next decade, from $6.6 billion to $11.4 billion on an annual basis, and the segment is expected to generate $89 billion in the next 10 years.” (The Teal Group, 2012). The technologies needed to support this transformation are developing rapidly, costs are diminishing, and applications are indicating positive trends in growth. However, there are considerable challenges to UAS market growth for operations within the U.S. that must be overcome to realize the full economic and social potential UAS will provide. These challenges primarily include regulatory, policy, and procedural considerations; social issues, such as privacy and nuisance concerns; environmental issues, such as noise and emissions; and safety (DOT, 2013).

Regulation

Releasing one set of maintenance regulations pertaining to UAS poses a unique challenge. While UAS can be categorized into groups by weight and category, maintenance issues will vary both across these groups and within them. Additionally, regulations pertaining to conventional manned aviation may not easily be transposed laterally to UAS technologies. The FAA Center of Excellence for General Aviation Research (CGAR) has determined that, of the regulations currently relevant to manned aviation, only 30% of these regulations are applicable to UAS as they are (Tzafestas et al., 2009). Additionally, 54% may apply either as they are or if they are
revised while 16% do not apply at all (Tzafestas et al., 2009). Figure 1 below illustrates how current regulations relate to specific elements of UAs (cite M&R Database).

<table>
<thead>
<tr>
<th>Maintenance Element</th>
<th>Element Description</th>
<th>Related Regulation Documents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appliances</td>
<td>Any instrument, mechanism, equipment, part, apparatus, or accessory (exclusive to airframe/avionics) that is used for operational flight.</td>
<td>FAR Part 91.405 (a) - (d), FAR Part 91.409 (a) - (g), FAR Part 91.417 (a) - (d), FAR Part 91.327, FAR Part 43, FAR Part 39, FAR Part 43 Appendix D (a) - (g), NPRM Subpart E, NPRM §107.101 (a) - (g), ASTM F-38 Committee F2584-06</td>
</tr>
<tr>
<td>Airframe</td>
<td>Those systems inclusive of the hull form and wing assembly. Examples include fuselage, airfoil surfaces, and landing gear.</td>
<td>FAR Part 91.405 (a) - (d), FAR Part 91.409 (a) - (g), FAR Part 91.417 (a) - (d), FAR Part 91.327, FAR Part 43, FAR Part 39, FAR Part 43 Appendix D (f) - (h), NPRM Subpart E, NPRM §107.101 (a) - (g), ASTM F-38 Committee F2584-06</td>
</tr>
<tr>
<td>Powerplant</td>
<td>&quot;The system that provides thrust to overcome drag, thereby allowing for lift. Not inclusive of auxiliary power unit.&quot;</td>
<td>FAR Part 91.405 (a) - (d), FAR Part 91.409 (a) - (g), FAR Part 91.417 (a) - (d), FAR Part 91.327, FAR Part 43, FAR Part 39, FAR Part 43 Appendix D (a) and (h), NPRM Subpart E, NPRM §107.101 (a) - (g), ASTM F-38 Committee F2584-06</td>
</tr>
<tr>
<td>Auxiliary Power Unit</td>
<td>&quot;The system that supplements additional power requirements for other sub-systems exclusive of powerplant.&quot;</td>
<td>FAR Part 91.405 (a) - (d), FAR Part 91.409 (a) - (g), FAR Part 91.417 (a) - (d), FAR Part 91.327, FAR Part 43, FAR Part 39, FAR Part 43 Appendix D (a) and (h), NPRM Subpart E, NPRM §107.101 (a) - (g), ASTM F-38 Committee F2584-06</td>
</tr>
<tr>
<td>Payload</td>
<td>&quot;The systems that provide additional mission/platform specific capabilities outside of functional flight.&quot;</td>
<td>FAR Part 91.405 (a) - (d), FAR Part 91.409 (a) - (g), FAR Part 91.417 (a) - (d), FAR Part 91.327, FAR Part 43, FAR Part 39, FAR Part 43 Appendix D (a) and (h), NPRM Subpart E, NPRM §107.101 (a) - (g), ASTM F-38 Committee F2584-06</td>
</tr>
<tr>
<td>Avionics</td>
<td>&quot;The electrical systems that provide additional flight capabilities such as communication, navigation, and control.&quot;</td>
<td>FAR Part 91.405 (a) - (d), FAR Part 91.409 (a) - (g), FAR Part 91.417 (a) - (d), FAR Part 91.327, FAR Part 43, FAR Part 39, FAR Part 43 Appendix D (a) and (h), NPRM Subpart E, NPRM §107.101 (a) - (g), ASTM F-38 Committee F2584-06</td>
</tr>
<tr>
<td>Command and Control System (Unmanned Aircraft)</td>
<td>The system that provides communication to the Control Station (such as video and telemetry).</td>
<td>FAR Part 91.405 (a) - (d), FAR Part 91.409 (a) - (g), FAR Part 91.417 (a) - (d), FAR Part 91.327, FAR Part 43, FAR Part 39, FAR Part 43 Appendix D (a) and (h), NPRM Subpart E, NPRM §107.101 (a) - (g), ASTM F-38 Committee F2584-06</td>
</tr>
<tr>
<td>Control Station Systems</td>
<td>The systems facilitating command and control of the Unmanned Aircraft (including the human interface).</td>
<td>FAR Part 91.405 (a) - (d), FAR Part 91.409 (a) - (g), FAR Part 91.417 (a) - (d), FAR Part 91.327, FAR Part 43, FAR Part 39, FAR Part 43 Appendix D (a) and (h), NPRM Subpart E, NPRM §107.101 (a) - (g), ASTM F-38 Committee F2584-06</td>
</tr>
<tr>
<td>Command and Control System (Control Station)</td>
<td>The system that provides communication to the Unmanned Aircraft (such as control instructions and updates).</td>
<td>FAR Part 91.405 (a) - (d), FAR Part 91.409 (a) - (g), FAR Part 91.417 (a) - (d), FAR Part 91.327, FAR Part 43, FAR Part 39, FAR Part 43 Appendix D (a) and (h), NPRM Subpart E, NPRM §107.101 (a) - (g), ASTM F-38 Committee F2584-06</td>
</tr>
<tr>
<td>Takeoff Equipment</td>
<td>&quot;Those systems facilitating (or supplementing) procedural takeoff of the Unmanned Aircraft.&quot;</td>
<td>FAR Part 91.405 (a) - (d), FAR Part 91.409 (a) - (g), FAR Part 91.417 (a) - (d), FAR Part 91.327, FAR Part 43, FAR Part 39, FAR Part 43 Appendix D (a) and (h), NPRM Subpart E, NPRM §107.101 (a) - (g), ASTM F-38 Committee F2584-06</td>
</tr>
<tr>
<td>Landing Equipment</td>
<td>&quot;Those systems facilitating (or supplementing) procedural landing of the Unmanned Aircraft.&quot;</td>
<td>FAR Part 91.405 (a) - (d), FAR Part 91.409 (a) - (g), FAR Part 91.417 (a) - (d), FAR Part 91.327, FAR Part 43, FAR Part 39, FAR Part 43 Appendix D (a) and (h), NPRM Subpart E, NPRM §107.101 (a) - (g), ASTM F-38 Committee F2584-06</td>
</tr>
</tbody>
</table>

Figure 1 Relevant FARs per M&R Database (cite M&R Database).

A Certificate of Waiver or Authorization (COA) is an authorization issued by the Air Traffic Organization to a public operator for UA activity (FAA, 2016). These waivers are reviewed by the agency to ensure aircraft operators meet specific criteria, to include, airman knowledge and certification, aircraft airworthiness, maintenance requirements, incident reporting, airport or airspace usage requirements, etc. The FAA currently uses an online process for COA applications, which may be reviewed at the following link: https://ioeaaa.faa.gov/ioeaaa/.

“An “Airworthy condition for UAS subject to a COA” means that the applicant must show that the UAS are maintained in a condition that will ensure that only Airworthy UAS are operated in
the NAS, and in compliance with the applicable requirements of Title 14 of the Code of Federal Regulations (14 CFR) Part 91” (Department of Transportation, 2015a). Members of the Flight Standards Service (AFS) that “…review of COA applicants’ UAS maintenance and inspection requirements must adhere to the guidance in Order 8900.1, Volume 8, Chapter 5, Section 13, Support for Issuing an Airworthiness Certificate for Unmanned Aircraft Systems” (DOT, 2015a).

**Recent Regulatory Policies**

Many UAS operators have expressed concern that if a problem or incident is reported, they may experience some level of reprisal. This may lead to a number of incidents not being properly reported, further compounding current problems and stunting future progress for the UAS integration process. Reporting programs exist for conventional manned aviation, allowing pilots and maintenance personnel to report a problem or safety hazard without fear of repercussions. In the absence of a comparable system for UAS, incident information may be lost along with any benefit that could have been gained by operator or manufacturer self-reported input.

The International Civil Aviation Organization (ICAO) concurs that such data is valuable, especially for the development of future Standards and Recommended Practices (SARPs). In addition to their value on the regulatory front, this data will also help to broaden the knowledge and understanding of these systems (ICAO, 2011).

**Aircraft Registration**

Conventional methods for registering manned aircraft requires strict criteria regarding ownership and use. An aircraft may be registered only by and in the legal name of the owner with an Aircraft Registration Application, AC Form 8050-1. The owner or operator must prove ownership of the aircraft and U.S. citizenship must be proven for all owners. Foreign owned aircraft must show that 60 percent of flights start and stop in the United States.

Registration for larger UAS follow many of the conventions for registration of manned aircraft with size as a consideration, however; many UAS platforms do not meet the size
requirements for conventional aircraft N-number standards. This issue may be mitigated by exemption of applicable Federal Aviation Regulations (FAR) and modified to support smaller airframes.

Mandatory regulation for the use of sUAS was recently released by the FAA in December, 2015. This regulation is applicable to those UAS weighing less than 55 lbs. and over .55 lbs, or 250 grams. The on-line registration process allows users to register by name with the agency, then issues a registration number for use on all aircraft being operated by that user. The process is currently in place to support any aircraft meeting given criteria, even if that aircraft was purchased prior to the requirement to register. The operator must be at least thirteen years of age and must submit their name and street address for registration. Their mailing and email addresses are designated as optional additional information as well as a phone number and serial number of the UA. There is a nominal fee and U.S. citizenship or legal permanent resident status is required for successful aircraft registration through the online process. The following link provides detailed registration information necessary to obtain registration for a hobbyist sUAS system registered in the U.S.: http://www.faa.gov/uas/registration/.

This registry is web based allows sUAS owners and operators the ability to register through online methods. Once registered, an electronic certificate is sent and a paper copy may be requested. The certificate contains the registrant’s name, an FAA-issued registration number, and the FAA registration website to confirm registration information.

The operator must affix the registration number to the UA being operated or provide the serial number to the FAA at time of registration. Identifying information, such as a serial number or an FAA registration number, upon close visual inspection must be readily accessible without the use of tools and must be maintained in a readable condition.

It is important to note, that at the time of this publication, the FAA is currently reviewing registration requirements that may omit aircraft weighing less than 2 kg, or 4.4 lbs.
Required Inspections for Manned Aircraft

Guidance for manned aviation inspections can be found in 14 CFR Part 43 Appendix D. The two main types of inspections are 100-hour and annual. Other inspections include walk-around, preflight, progressive, special, conformity, and conditional. Annual and 100-hour inspections are in depth in respect to the scope and detail included in their procedures.

Aircraft inspections generally start with the AMT making sure the aircraft and its engine are clean, then opening access doors and removing necessary inspection plates, fairings, and cowlings, allowing the mechanic easy access to inspect all components. Per 14 CFR Part 43 Appendix D, there are eight main sections for thorough inspection, divided into the fuselage and hull group, the cockpit and cabin area, the components of the engine and nacelle group, the landing gear area, the components of the wing, the empennage area, the propeller group components, and the radio group, with an additional section at the end of the list requiring the inspection of “...each installed miscellaneous item that is not otherwise covered by this listing for improper installation and improper operation” (Department of Transportation, 2016a).

Regulatory Policy for Maintainers

“AMTs work in a number of technical occupations, which include avionics, airframe, powerplants, and non-destructive testing” (Haritos, 2005). That being said, a wide variety of training must go into this certification process. AMT certification sanctioned by the FAA includes on the job (OTJ) training, computer based training (CBT), video training, and face-to-face training. Schools certified under 14 CFR Part 147 are designated Aviation Maintenance Technician Schools, from which a maintainer could, upon graduation, earn an A&P certificate. Other options exist for maintenance certification. If the mechanic can provide:

“(a) At least 18 months of practical experience with the procedures, practices, materials, tools, machine tools, and equipment generally used in constructing, maintaining, or altering airframes, or powerplants appropriate to the rating sought; or
(b) At least 30 months of practical experience concurrently performing the duties appropriate to both the airframe and powerplant ratings” (DOT, 2016b).

The current FAR governing maintenance, preventative maintenance, rebuilding, and alteration is 14 CFR Part 43. AMT requirements are listed further in 14 CFR Part 65, 145, and 91.

**Maintainer Qualification and Certification**

Maintenance personnel are skilled in areas of concentration such as airframes, powerplants, and avionics. While multiple areas may be achieved, this practice may create less proficiency in each area over all and may create situations of not having the required technician when needed due to administrative circumstances. UAS technologies may differ from what is commonly required for manned aircraft maintenance technicians. This research will aid in defining both similarities and gaps between these types of operations.

When considering what type of maintenance manning is required for UAS, all aspects of the initial training and certification must be considered as well as the requirements to keep those certifications current. The initial certification will normally include formal school and or organizational training. This process is sanctioned by the FAA, and the student will receive a certification for the training completed after meeting the criteria as listed in 14 CFR § 65.71. Basic requirements to become an aircraft mechanic are as follows:

- You must be
  - At least 18 years old;
  - Able to read, write, speak, and understand English.
- You must get 18 months of practical experience with either power plants or airframes, or 30 months of practical experience working on both at the same time. As an alternative to this experience requirement, you can graduate from an FAA-Approved Aviation Maintenance Technician School.
- You must pass three types of tests;
  - A written examination
An oral test

A practical test

(FAA, 2016)

Part 23

The current FAR governing airworthiness certification for aircraft in the normal, utility, aerobatic, and commuter categories is 14 CFR Part 23. Many considerations are evaluated when the airworthiness of an aircraft is brought to question. Airworthiness requirements will require significant change which will be defined by a number of operational and physical characteristics to include, inherent risk, size, weight, speed, etc. In 2009, a Certification Process Study (CPS) was conducted to assess the adequacy of current airworthiness standards throughout a small airplane’s service life while anticipating future requirements (FAA, 2009). This study may be reviewed at the following link:
https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/air/directorates_field/small_airplanes/media/CPS_Part_23.pdf

Specialized Training for UAS Operators

UAS training is still an area of exploration and one of the content areas the FAA is researching to define. Size of aircraft may become a determinant for the type of airman certificate required for operations. From a maintenance perspective, this variation in aircraft complexity may require special certifications or specific knowledge, skills, and abilities for individuals working in the capacity of a field technician or maintainer.

While some companies require UAS operators to have experience in certain types of systems, others may be less discriminative, selecting radio controlled (RC) aircraft pilot as their operators. It has been argued that RC pilot operators lack both knowledge and discipline in aviation. In addition to the operational aspect, maintenance and troubleshooting backgrounds may be in sufficient with an individual who has not received this specialized training. RC operators may not have the training base or licensure required to perform maintenance on manned
aircraft, and therefore will not have been exposed to the formal, and structured maintenance and airworthiness qualities that certified Airframe and Powerplant (A&P) mechanics have experience working with. It may be necessary to define metrics for operations that do not require maintainers to hold an FAA certificate or have previous maintenance background in any type of aircraft.

**Liability/Insurance**

Based on publically available data, insurance will require proof of a specified maintenance program to be defined.

The likelihood that incidents and accidents will occur in UAS operations is high. Users must be aware that operations may cause some damage to persons or property both on the ground and in the air. An established method for determining causation and frequency must be assessed in order to define how these areas will play a role amongst UAS groups by classification, certification of airman, record keeping and reporting, etc. Premium costs and requirements may be supported by authorized maintenance plans by users.

Risk assessment may be assumed similar to that of manned aircraft operations. Categorically summarizing aircraft into groups defined by a given set of metrics will support a systematic approach to quantifying risk.

**UAS Classification**

Releasing one set of regulations applicable to UAS as a whole would prove both difficult and impractical. Small GA aircraft are not held to the same certification standards as commercial aircraft; similar systems could be implemented for UAs. Several methods for separating UAs into groups have been introduced. One of the main methods focus on level of autonomy while the other focuses on weight, operating altitude, and operational airspeed. Below, Figure 2 depicts UAS divided into five categories via the second method discussed.
It is foreseeable that maintenance procedures will follow in the framework of conventional manned aviation. For example, UAS Groups 2 and 3 may have specific maintenance procedures while Groups 4 and 5 have different procedures that are more relevant to the respective systems.

<table>
<thead>
<tr>
<th>UAS Category</th>
<th>Max Gross Takeoff Weight</th>
<th>Normal Operating Altitude (Ft)</th>
<th>Airspeed</th>
<th>Current Army UAS in Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>&lt; 20 pounds</td>
<td>&lt; 1200 above ground level (AGL)</td>
<td>&lt; 100 Knots</td>
<td>RQ-11B Raven</td>
</tr>
<tr>
<td>Group 2</td>
<td>21-55 pounds</td>
<td>&lt; 3500 AGL</td>
<td>&lt; 250 Knots</td>
<td>No current system</td>
</tr>
<tr>
<td>Group 3</td>
<td>&lt; 1320 pounds</td>
<td>&lt;18,000 mean sea level (MSL)</td>
<td>Any Airspeed</td>
<td>RQ-7B Shadow</td>
</tr>
<tr>
<td>Group 4</td>
<td>&gt; 1320 pounds</td>
<td>&gt; 18,000 MSL</td>
<td>Any Airspeed</td>
<td>MQ-5B, MQ-1C</td>
</tr>
<tr>
<td>Group 5</td>
<td></td>
<td></td>
<td></td>
<td>No current system</td>
</tr>
</tbody>
</table>

Figure 2  UAS Current Systems (United States Army, 2010)

**UAS Maintenance**

For the safe integration of UAS into the NAS, many safety considerations must be taken into account. Human in the Loop (HITL) interactions are especially important in regards to maintenance tasks involving human subjects. For the purposes of this research, the term maintenance will be defined as “...any activity performed on the ground before or after flight to ensure the successful and safe operation of an aerial vehicle” (Hobbs et al., 2005). It is important to keep in mind that maintenance for these systems include not only the UA, but also the ground control station (GCS) and any other related peripheral equipment.

Maintenance practices being utilized for a variety of UAS are derived by individual manufacturers. Some classes of UAS will likely follow existing frameworks and methodologies of manned aircraft maintenance protocols. An existing number of previously qualified aircraft mechanics and technicians exhibit the necessary knowledge to perform similar tasks on varied airframes and technologies. sUAS owners and operators may lack existing knowledge and skill sets to properly assess issues that may arise due to preventative or induced maintenance failures. Exposure of maintenance induced failures due to various causal factors may lead to further negative impact if provisions are not properly set in place to mitigate appropriate risk factors.
Human factors influence may still be apparent in the absence of traditional manned aircraft configurations. Williams (2004) performed a study on U.S. military data involving UAS accidents and found that, depending on the type of UAS, for 2 - 17% of the reported accidents involved maintenance procedures. Additionally, Williams discovered that electromechanical failure was more common in UAS accidents than operator error for the majority of the systems included in the study. Another study conducted and discussed by Manning et al. (2004) concluded that 32% of accidents investigated involved human error in some manner while 45% involved material failure either singularly or with contributing factors. These results indicate maintenance criticality towards UAS airworthiness.

Specialized Equipment and Tooling

On top of system reliability, airframe integrity will play a key role in UAS development. Due to their light weight and strength properties, composite materials are commonly used in unmanned system, comprising of up to 90% of the total area of the system (Li, Jing, Zhou, & Li, 2012). However, if these composites were to be damaged either through normal operation or unusual circumstances, a special set of skills and equipment may be necessary for an approved repair.

AMTs must maintain a plethora of aircraft systems and components. All systems must be included in the scope of maintenance work and regulations, to include but not limited to launch and recovery systems, computer hardware and software, autonomous systems, and other systems unique to a given platform.

UAS platforms include the aircraft, ground based systems, and other peripheral systems. According to Hobbs et al. (2006) “The broad scope of UAS maintenance has implications for the skill and knowledge requirements for maintenance personnel”. Every aspect of a UAS must be considered in order to attain airworthiness and safety. Unique conditions that exhibit a dichotomous relationship between manned and unmanned aircraft may exhibit more or less impact in a given maintenance induced failure or compromised equipment scenario. For instance, the loss of communication may cause more negative impact when experienced in a UAS
platform. A lost communication link scenario may not carry as much issue for manned aviation, because of the position of the pilot. Lost communication scenarios in UAS may provide different levels of severity, based on the type of communication failure in question. With heavy reliance placed on the integrity of communication, maintenance of the data link system between the GCS and the UAS becomes a critical airworthiness issue. Hobbs et al. (2006) reported that 32% of the interviewees spoke on the issue of loss of link, but no steps or maintenance were provided or offered for the insurance of uninterrupted wireless communication. In 2003, the U.S. military reported loss of signal as the incriminating factor in 11% of UAS failures (Office of Secretary of Defense, 2003).

**Airframe Certification**

The group or size of UAS will aid in the determination of certification standards for criteria specific to airframe airworthiness. In the examination of sUAS, airworthiness criteria is limited when compared to larger UAS. The operator is expected to maintain the aircraft in a safe operational condition. The aircraft items evaluated depend on information such as aircraft make, model, age, type, maintenance records, aircraft complexity, and overall condition.

**Materials**

“The implementation of innovative, low-cost manufacturing processes, along with consideration of manufacturing costs and sustainment throughout the design process, will be key to the development of UAS airframes. Processes that reduce the number of parts, simplify tooling, reduce energy requirements, and minimize waste will be preferred. Complicating the need for low-cost processes is that production quantities for some UAS will initially be small. Therefore, the primary criterion for the expanded use of polymeric composites in structural applications is the potential for low-cost manufacturing processes” (NAP, 2000).
The use of metals on manned aircraft is slowly declining as composites are developed and proven. Composite or exotic materials provide added reductions in weight, size, and cost. Added weight associated with protective layers and equipment in the airframe may be reduced, allowing more utility for other system or payload components.

**Composites vs. Traditional Materials**

Rapid growth in the aviation industry has led to a shift in the materials research and implementation. The use of these materials will forward development in platform durability, payload capacity, longer endurance, and extended airframe longevity.

“Although it might be an oversimplification, in the UAS industry, weight is a disease and composites are the cure. It is noteworthy that all of the almost 200 UAS models considered in this market outlook include some composite parts. Glass and quartz fiber composites are regularly employed in sensor radomes, nose cones and small fairings. There are a number of cases where glass fiber composites were used in earlier medium-size airframes, but the demand for payload capacity, extended performance, and spiral development of unmanned systems have helped make carbon fiber-reinforced polymer (CFRP) the primary materials used in construction of UAS airframes. And as the UAS market has grown, so has the need for advanced composites” (Red, 2009).

In 1996 the Composite Affordability Initiative (CAI) was implemented to reduce the production cost of high-performance composites for aircraft. A jointly funded project by the Air Force, Navy, and commercial manufacturers (Boeing, Lockheed Martin, and Northrop Grumman) to “develop the tools, methodologies, and technologies necessary to design and manufacture a composite airframe utilizing revolutionary design and manufacturing practices to enable breakthrough reductions in cost, schedule, and weight”.

The CAI analyzed the following methods; Fiber placement, Resin transfer molding (and vacuum-assisted resin transfer molding), Low-temperature/vacuum bag curing, Through-thickness reinforcement (e.g., stitching/3-D weaving/Z pinning), and Electron beam curing.
Although polymeric composite structures may dominate future UASs, significant advances in the processing of high-performance metallic alloys will also be required. Metallic structures will continue to be driven by traditional weight and durability considerations where cost is expected to become an even greater issue. Net-shape processing and integrated manufacturing techniques have the potential to reduce costs. Promising processes for producing metal airframe structures in small quantities at reduced cost include, but are not limited to the following: Solid free-form fabrication, Super-plastic extrusion, Spray forming electron-beam physical vapor deposition, and Advanced sheet metal processes.

Benefits may be apparent to UAS manufacturers as more common materials, processes, and design features aid in the reduction of cost and components.

**Powerplant**

Methods for propulsion are varied amongst UAS platforms. Both military and civilian requests for additional flexibility is a mechanism for large reinvestment by industry to support growth and innovation. Military requests are driving adaptation of current units to use diesel and JP 4/5/8 heavy fuels to reduce logistical requirements in remote areas and on deployed vessels. The civilian sector is developing enhanced electrical and fuel systems that may extended flight times from hours or days to weeks, months, or years. Ultra-high endurance systems may be used to replace Low Earth Orbit (LEO) communication satellites for a host of future applications.

Propulsion types:

- Fuel Cell: Still in development and not widely used, this type of propulsion derives electrical energy from a chemical reaction. Commercial grade propane may be used for this type of energy source.
• Nuclear: Proposed for High Altitude Long Endurance (HALE) vehicles. This type of unit would only be capable of being serviced and repaired by the manufacturer or certified repair stations.

• Diesel - Requires specialized certification for regular and unscheduled maintenance.

• Turbine - Including the Turbojet and Turbofan variants, these units also require specialized training for scheduled and unscheduled maintenance as well as very high quality facilities for operation and testing.

Two and Four-stroke Reciprocating Engines - These units are very widespread across the globe and vary widely in number of pistons, from one to four usually, and can be air or water cooled. Considered by most users to be very reliable and comparatively cost effective. Maintenance needs are still moderate with skilled mechanics and scheduled maintenance being required.

• Battery systems - Current use is a replaceable battery/pack that is recharged after use with minimal skill required. Endurance is limited with current technologies, which has become an area of concentrated research. Battery technologies are becoming integral components of airframe structures, which aid in weight reduction and systems integration. Solar cells are also being used to augment power utility for a number of systems.

“Power and propulsion systems of current UASs have proved to be a major source of UAS accidents; therefore, a higher reliability will be required to comply with the future-developed regulations” (Guglieri et al., 2010).

Hazardous Materials/Environmental Concerns

Personnel must be aware of the materials, chemicals, and mechanical hazards they may encounter while working with potentially hazardous materials. The Department of Labor’s (DOL)
Occupational Safety and Health Administration (OSHA) department is the regulatory authority on workplace safety and provides information, training and workplace inspections. OSHA provides employers and workers with the tools and information to conduct operations in the safest way possible utilizing training, safety equipment, known safe techniques and a reporting system to alert others of dangerous situations.

Likely sources of hazardous materials or environmental elements UAS operators may encounter are fuel sources, repair materials, spinning blades, heat and exhaust fumes, etc. Fuel sources may include batteries and their charging systems, light fuels (gas and alcohol), heavy fuels (JP 4/5/8) and engine oil.

Batteries and components may not be removable or disposable or rechargeable. Inspecting the batteries should be accomplished during pre-flight to ensure there is no damage, leaking or swelling of the units. Any of these indicate a problem and should not be used. Disposal of battery systems must be accomplished using approved methods, such as recycling centers. Charging systems may be specific to a given UAS or may charge multiple systems.

Working with fuels and oils should always be done in a well ventilated area or outside. The fumes as well as the fluids may be volatile. Contact should be avoided with bare skin or inhalation and all open sources of flame well clear of open containers or spills.

Repair materials may include solvents, glues and epoxy resins which have specific guidelines to be used safely and effectively. The original containers will have directions and manufacturers contact for questions or problems. The OSHA website also provides a full list of the products in use in the U.S. and their dangers as well as storage requirements.

Environmental hazards may vary greatly in different types of operational environments. It is imperative for the operator and all stakeholders to be familiar with environmental impact factors that may affect a given operation.

**Software and Firmware (updating requirements)**

UAS AMTs must be skilled in many practices for effective maintenance of these platforms. Through the course of his interviews, Hobbs et al. reports that a high level of interviewees
discussed the need for AMTs to be familiar with updating procedures for the autopilot and other peripheral software. Hobbs et al. (2006) conducted interviews with several industry individuals and, of the interviewees willing to discuss their maintenance practices, 35% discussed software maintenance as a human factors issue.

**Payloads**

While conventional manned aircraft are generally assembled in a factory and generally remain intact, small and medium sized UAS are often disassembled between flights. This repetitive method is convenient for transport and storage, but may lead to future maintenance complications. The electrical system causes a particular area of concern with frequent connection and disconnection. Improperly mated or frayed connections may easily impact the operation of the UAS in a negative way.

In addition to improper electrical configuration, physical mounting is an important consideration for payload installation. Improper mounting could be subject to material fatigue or fastener failure if not properly inspected and maintained.

UAS AMTs must have specific knowledge of the payloads incorporated into each system they maintain. Troubleshooting may be focused or systematic and is required to solve a given problem within the system. AMTs and technicians must be adequately trained to understand all schematic and wiring data for a given system.

**Ground Control Stations**

Ground Control Stations (GCS) are becoming as varied and versatile as the UAS in use. The FAA’s Notice of proposed rulemaking (NPRM) Operation and Certification of Small Unmanned Aircraft Systems defines a control station as “[a]ssociated elements that are necessary for the safe and efficient operation of the aircraft [to] include the interface that is used to control the
small unmanned aircraft” (DOT, 2015c). Large UAS require essentially a recreation of the cockpit and flight controls that would be in a traditional aircraft, with all associated communication, training, maintenance, and support to remain effective. The small UAS are being controlled from desktop computers, laptops, and handheld controllers. Programs are available to load into your UAS and any controller type device the operator has available with adequate processing speed and programming. This includes standard joystick type control or touch screen capability.

In addition to preventative maintenance for the electronic aspect of the ground control station, maintenance considerations must be taken into account for the physical aspects as well.

Launch and Recovery Mechanisms

The most common types of take off systems include: vertical takeoff; horizontal take off; catapult, to include bungee, hydraulic, and pneumatic systems; hand launch, rocket assisted take off (RATO); and parasail. The most common types of landing systems include: vertical landing; horizontal landing; net recovery; arresting line; skyhook; windsock; parasail; and a ballistic or parachute approach.

While there are a wide variety of launch and recovery mechanisms, most require their own particular actions to maintain their integrity and effectiveness. For example, an improperly set catapult could launch the UAS on an irregular flight path, potentially leading to a loss of aircraft situation. Even properly calibrated equipment may lead to future damage of a system; for example, the skyhook and arresting line approaches bring the UA to an abrupt halt and, due to this sudden, dramatic deceleration, there is a limit to how often these systems can be operated due to their landing mechanism.

Another factor to take under consideration is the maintenance of these systems. Some systems, like hand launch, would require none to minimal maintenance. However, more complex systems, like hydraulic catapult and ballistic landing systems, would require higher maintenance attentions. While there are no universally acknowledged regulations currently in place for launch and recovery mechanisms, “[i]t is expected that dedicated certification rules will be required for
launch and recovery system, to assure adequate reliability in the critical phases of takeoff and landing” (Guglieri et al., 2010).

Record Keeping and Standardization

Current Standards

Record keeping requirements will be varied amongst systems. The existing framework for manned aircraft may adequately support larger systems; however, wide variability in smaller airframes may indicate different methods or metrics for record keeping requirements.

Quality Control

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. The responsibility of the owner and/or operator to manage not just the maintenance but the oversight of that maintenance program is crucial and currently required for air carriers under the FAA’s 14 CFR § 91.409 Inspections.

(a) Except as provided in paragraph (c) of this section, no person may operate an aircraft unless, within the preceding 12 calendar months, it has had—

(1) An annual inspection in accordance with part 43 of this chapter and has been approved for return to service by a person authorized by §43.7 of this chapter; or

(2) An inspection for the issuance of an airworthiness certificate in accordance with part 21 of this chapter.
Currently, UAS are not required to follow this rule as crew and passengers are not present. There is still a danger to the operating personnel and others in the area of operation that have the expectation of safety due to proper use and care of UAS.

Lack of Manual Standardization

Aircraft operation and maintenance manuals are currently written by the manufacturer and follow the Air Transport Association of America standard. This has allowed the air carrier industry to standardize repair manuals allowing certified maintainers to locate information needed to work on different aircraft. This policy is not followed in the UAS industry, limiting needed maintenance to be performed only by a maintainer certified by the respective manufacturer. This severely hinders standardization and regulation. Without following a similar path as the air carrier industry, the ability to confidently train, certify, monitor and revoke qualifications and airworthiness certificates will prove almost impossible. There are two categories of documents used in aviation operations, controlled and uncontrolled. The controlled category is primarily the FAA approved operating limitations and required maintenance practices utilized for a specific aircraft. These documents are updated on a regular cycle and have a limited distribution within the operating agency. A master list is retained of all revisions, changes, rescinded pages as well as all pages that are still active. Uncontrolled documents usually contain company policies, user requested products such as an illustrated parts catalogs and equipment data.

A problem evident with many sUAS today is the lack of manufacturer provided maintenance manuals or checklists. Additionally, operators have reported that some UAS have been delivered with no technical information such as wiring diagrams, rendering troubleshooting and repair of electrical systems much more challenging. Even if documentation is provided, maintenance personnel have sometimes been unsatisfied with the quality of included procedures and documentation. Much of the documentation paperwork from UAS manufacturers do not follow the Air Transport Association (ATA) chapter numbering system many AMTs are accustomed to. Due to the lack of material or lack of satisfaction with provided
many operators have developed their own maintenance documentation and procedures. Many of the individuals Hobbs et al. (2006) interviewed recommended that careful, detailed logbooks be kept of all maintenance tasks performed on the UAS.

Inventory Control and Projection

Associated time between failures will likely allow UAS operators and users to predictively assume when a component may need to be replaced. The M&R database may provide substantial contributions that will allow users to most efficiently project specific component and hardware times.

OEM vs. User Responsibility

With conventional manned aviation, certain responsibilities and expectations for preventative maintenance fall on the owner and operator of the aircraft. Similar parallels have the potential to be drawn, especially in relation to sUAS, due to the fact that many maintenance actions will be performed on site.

A two-tiered maintenance program has emerged in the UAS industry. AMTs responsible for the upkeep of UAS have accepted the responsibility of inspections and minor repairs while many systems requiring major repairs are shipped to the manufacturer in place of maintenance personnel troubleshooting on site. However, it has not been universally decided what the manufacturer is responsible for providing; how much maintenance the operator is responsible for; and how these maintenance procedures are to be approached; and what maintenance the manufacturer is responsible for providing.

Compliance with Required Documentation

Conventional manned aviation requires compliance with several publications to include FARs, Airworthiness Directives (ADs), and Advisory Circulars (ACs). Often, ADs and ACs are
released to announce a safety complication impacting certain models of manned aircraft and a method of rectifying the problem. These documents are released for the promotion of aviation safety and, based on their importance, necessity, and safety impact, most documents require compliance on a time sensitive schedule. It can be anticipated that a similar system may arise for UAS, assuming a reliable time measuring system can be incorporated for both this purpose as well as time sensitive maintenance practices.

**Conclusion**

It is imperative to understand how UAS maintenance procedures and methods must be derived in order to ensure a safe operational environment amongst groups. UAS operators may have varied requirements based on inherent risk, aircraft complexity, and user requirements.
References


7) Department of Transportation (DOT) (2016b). Electronic code of federal regulations, chapter 14, part 43, appendix d: scope and detail of items (as applicable to the particular aircraft) to be included in annual and 100-hour inspections. Washington, DC: Federal Aviation Administration.


