# A.5 UAS Maintenance, Modification, Repair, Inspection, Training, and Certification Considerations

## Draft Technical Report of UAS Maintenance Data Preliminary Analysis

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# 1 INTRODUCTION

A significant lack of knowledge and understanding is associated with the initial and continued airworthiness of unmanned aerial systems (UAS) and how concomitant maintenance practices differ from those associated with manned aircraft. Consequently, implementation of UAS sustainment practices and the creation of requisite supporting documentation are rare. Compounding these deficiencies, components that are uniquely associated with UAS, such as ground control stations and communication links, 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 (NAS).

The key components of the A.5 research include: 1) a review of existing data available for maintaining UAS of all sizes; 2) a comparison of existing maintenance data for UAS with the type of data available for manned aircraft; 3) a determination of whether a delineation between different types/sizes of UAS should be developed to establish varying thresholds of maintenance rigor; 4) identification of best practices for maintaining various classes of UAS within the context of their operational environment; 5) compilation of the current training materials and qualifications required for various UAS platforms, and; 6) a recommendation of training and certification requirements for UAS maintenance technicians and repair stations across the spectrum of all UAS classes. These research components build upon prior research to develop justifiable recommendations to the FAA on how UAS should be maintained to support the FAA's roadmap to integration of UAS into the NAS.

In support of these considerations, this paper is focused on conducting a preliminary analysis of the existing UAS maintenance data. This includes capturing information across all UAS types, sizes, and operational environments. The primary data collected included maintenance practices and technical documentation, reporting requirements and maintenance records, and maintenance technician training.

# 2 PRELIMINARY ANALYSIS OF EXISTING MAINTENANCE PROGRAMS AND DATA

## 2.1 INTRODUCTION

The researchers conducted a review of available data for maintaining UAS of all sizes. This review included data covering maintenance, repairs, inspections, records, in-service difficulty reporting, and training. The research team identified and approached numerous manufacturers and/or operators of UAS across the type and size spectrum for the purpose of collecting details of their current maintenance and maintenance technician training programs. The collected data on maintenance and training programs were compiled into tables to facilitate an analysis of the current range of industry practices.

The primary research questions addressed by these surveys were:

1. What is the current state of UAS maintenance practices and training throughout the industry?
2. What are the requisite elements of UAS maintenance for all types/sizes of UAS?

3. In comparison to manned aircraft operations, what elements of maintenance are unique to UAS and what implications do these differences have on related training procedures and certification of unmanned systems?
4. Is there a need to differentiate between different Risk Classes of UAS when determining maintenance and training requirements?

This report outlines and discusses the findings of two key surveys completed for Task No. 1, Review of Existing Maintenance Programs and Data, and supports the continued exploration of this research to provide answers and recommendations to the questions listed above.

### 2.1.1 Problem Statement

At present, little to no civil regulatory requirements compel UAS manufacturers to design, produce, and support their aircraft to a tested and approved standard. Therefore, the availability and quality of maintenance practices, standards, and technical documentation to support these aircraft is not known, and a comparison to manned aircraft maintenance practices cannot be achieved.

### 2.1.2 Limitations/Constraints of Task 1

The greatest barrier to completion of this task was obtaining sufficient industry participation during the data collection surveys to complete a thorough review and analysis of the information across the spectrum of in-service UAS. Adequate information is available online and through the Association for Unmanned Vehicle Systems International (AUVSI) database for identifying manufacturers, aircraft models and performance; however, there is little subject matter expert (SME) contact information available from each of those manufacturers. Receipt of the Maintenance and Repair (M&R) prototype database information was delayed, but review of the content showed that the preceding survey work was consistent and supportive of M&R database content.

## 2.2 METHODS

The following activities listed in Table 2-1 were performed to support Task 1: Review of existing maintenance program and data. The following sections describe the work performed in each subtask.

*Table 2-1. Task 1 Work Breakdown*

| Task | Description |
|---|---|
| **Task 1** | **Review of Existing Maintenance Programs and Data** |
| Task 1a | Perform literature review of relevant publications, standards, and regulatory requirements for manned and unmanned aircraft maintenance. |
| Task 1b | Review of M&R prototype database for relevant data to be collected |
| Task 1c | Identification of UAS manufacturers and operators in each category/class of UAS with existing maintenance programs |
| Task 1d | Collection of maintenance program information from manufacturers |
| Task 1d(i) | Collection of documented programs |
| Task 1d(ii) | Cataloging of program information |
| Task 1d(iii) | Sanitize proprietary data |
| *Deliverable 1* | *Draft technical report of the UAS maintenance data* |
| Task 1e | Analysis of UAS maintenance data |
| *Deliverable 2* | *Draft technical report of UAS maintenance data preliminary analysis* |

### 2.2.1 Identifying UAS Manufacturers

Identifying UAS manufacturers was a task largely supported by AUVSI's database of UAS and corresponding manufacturers. After reviewing this database, fifty four different unmanned aircraft were selected for the data source pool based upon the criteria that the aircraft was currently operational and also based upon the Risk Class in which the aircraft would be categorized. The goal was to have an equal distribution of representative aircraft across all 6 defined Risk Classes (1-6). Table 2-2 is derived from the unpublished draft advisory circular (AC) designated AC 20-xx-xx, which addresses UAS type design approval under 14 CFR 21.17(b). This draft AC outlines the criteria for categorizing aircraft within specific Risk Classes based upon kinetic energy (KE) at cruise speeds and takeoff weight. These Risk Classes allow UAS to be categorized based upon their capacity to cause damage to persons and property in the event of an accident or mishap. It follows that UAS that are larger and fly faster carry with them increased operational risk that must be mitigated. The identified Risk Classes served as a starting point for identifying a sample of aircraft and their respective manufacturers across the full UAS Risk Class spectrum.

*Table 2-2. Criteria for Categorizing Aircraft within Risk Classes as Described in AC 20-xx-xx**

| Risk Class | Kinetic Energy (KE) in Ft*Lb | Examples |
|---|---|---|
| 1 | KE ≤ 529 | Up to 5.0 lb at 44 kts airspeed |
| 2 | 530 ≥ KE ≤ 24,999 | 55 lb weight at 90 kts airspeed |
| 3 | 25,000 ≥ KE ≤ 799,999 | 300 lb at 90 kts to C150 at 107 kts |
| 4 | 800,000 ≥ KE ≤ 5,999,999 | C152 at 115 kts to Beech G36 at 176 kts |
| 5 | 6,000,000 ≥ KE ≤ 49,999,999 | Beech G58 at 185 kts to Beech H90 |
| 6 | KE ≥ 50,000,000 | King Air 350 to Boeing 737-200 |

*The information contained within this chart was extracted from draft AC 20-xx-xx which is not published and is subject to change.

The aircraft that were selected and used to populate the data tables, and on which the UAS maintenance data preliminary report is based, are found in Appendix No. 1 *List of Surveyed UAS Manufactures and Aircraft***.** The only Risk Class not represented is Risk Class 5. Due to the sampling of a representative population of similar aircraft (i.e., similar in terms of design, construction, and application) within Risk Classes 4 and 6, bracketing Risk Class 5, the lack of a representative sample of Risk Class 5 aircraft was not a major concern.

### 2.2.2 Distributions within the UAS Survey Pool

Manufacturers of aircraft from a representative distribution of Risk Classes were identified and targeted for surveys. Manufacturers of twenty aircraft in the targeted pool responded to the surveys. Figure 1 represents the distribution of aircraft across Risk Classes within the targeted pool. Figure 2 represents the distribution of aircraft across Risk Classes that were actually surveyed for this study, capturing twenty aircraft in all. The responses to surveys were used to analyze and compare maintenance, record-keeping, and training programs within this report.

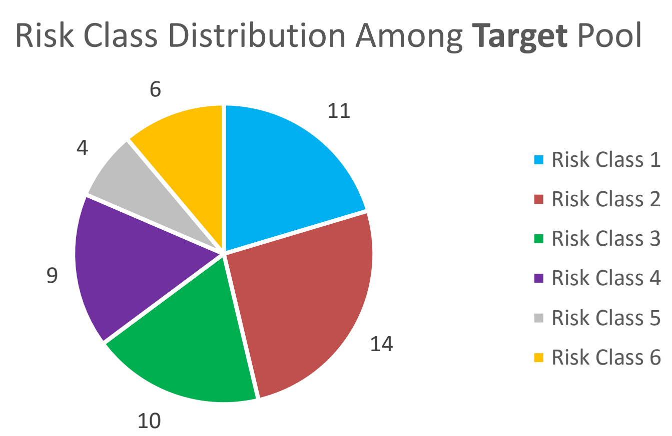


*Figure 1. Risk Class Distribution of UAVs Targeted for Surveys*

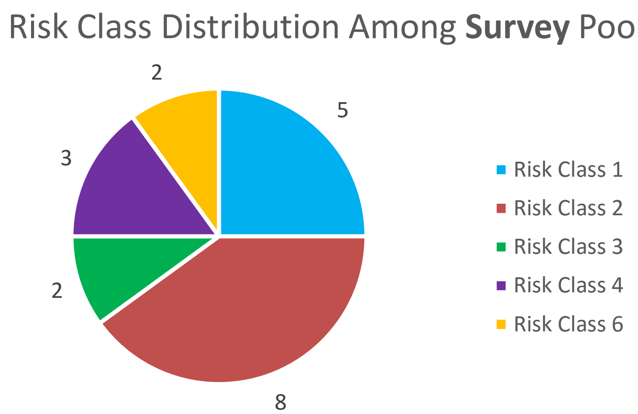


*Figure 2. Risk Class Distribution of UAVs Surveyed*

In addition to categorizing and segregating UAS aircraft by Risk Class, they were also isolated within operational class groupings. For the purposes of this report, an operational class is defined by the type of application(s) or operational environment(s) into which the user/operator will deploy the UAS. The operational classes used within the surveys includes Commercial, Defense (Military), Civil Support (non-defense, police, fire, emergency response, etc.), and Dual-use (aircraft that have both Commercial and Defense applications). It was sometimes difficult to assign an operational class to an aircraft because many of the aircraft can play different roles depending on who purchases the platform.

UAS that were identified as Defense/Military use primarily fell into Risk Classes 4 and 6 (Figure 3). Once the aircraft was categorized into Dual-use, the Risk Class distribution widened to include Risk Classes 1 through 4. From Figure 2, it can be seen that there is a slightly greater number of smaller Risk Class 1 and 2 aircraft when compared to larger aircraft in Risk Classes 3, 4, and 6. Risk Class 6 aircraft were relegated specifically to Defense applications. Aircraft within Risk Classes 1 and 2 dominated the Commercial market. This also indicates that the UAS within the current Commercial market are primarily classified within the category of small UAS (sUAS).

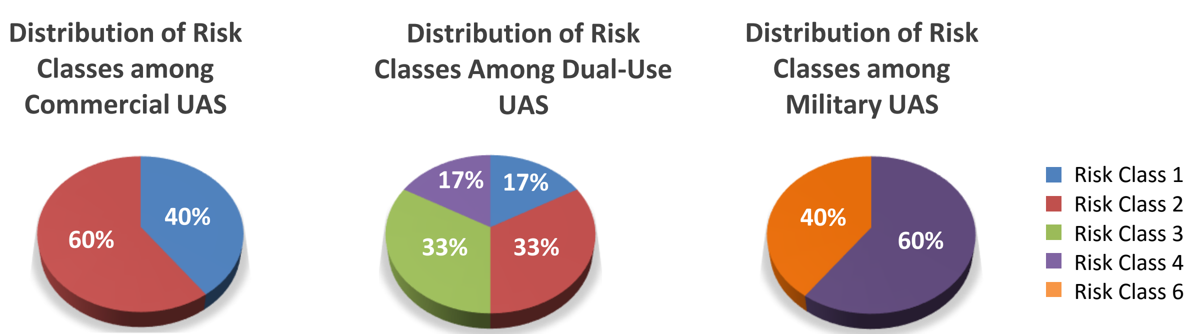


*Figure 3. Survey Distribution of Risk Classes among Different Operational Categories*

### 2.2.3 Collecting Maintenance Program Information

Surveys were conducted to collect maintenance program data from UAS Original Equipment Manufacturers (OEMs) and operators. Two independent surveys identified as Level 1 (L1) and Level 2 (L2) were performed. This data collection methodology served three purposes. It allowed the establishment of a rapport with the OEM/operator through a dialog that was not overly onerous or intrusive, provided access to multiple levels of Subject Matter Experts (SMEs) that were best aligned with the information to be captured, and assured a maximum level of useful data by reducing the risk of failure to capture more detailed maintenance program data from the OEM/Operator should they elect to forego participation in the Level 2 survey.

Appendix 2 provides a summary of the data fields and questions associated with the L1 and L2 surveys. L1 surveys were intended to gather basic information whereas L2 questions were intended as follow-up, detail questions which were developed as the result of responses to the L1 survey. The L1 and L2 surveys captured information across three broad categories and were inclusive of questions that supported other elements of the A.5 research such as identifying OEM/operator training practices. These broad categories included maintenance data & documentation, reporting and records requirements, and training programs.

L1 and L2 data table samples, provided in Appendices 4 and 5, summarize the data collected. Contact information was collected and placed into the data tables. Sources of data included public domain internet sources and SMEs within the UAS community. Surveys were also conducted during the AUVSI "Xponential" Conference held in New Orleans, LA, during the week of 2 May 2016. From these surveys, additional data was acquired for 5 additional platforms from the companies of Insitu (Boeing), SenseFly, and Aeryon Labs.

# 3 REVIEW OF DATA

## 3.1 MAINTENANCE DATA & DOCUMENTATION

The main focus of the L1 survey for the area of maintenance data and documentation was to identify the type of technical documentation published for UAS and the quality of that documentation as compared to that published for type certificated and military aircraft. The survey included a selection of the following types of technical documents:

- Illustrated Parts Catalogs
- Aircraft Maintenance Manuals
- Engine Maintenance Manuals
- Component Maintenance Manuals
- Fault Isolation Manuals
- Service Directives
- Engineering Orders
- Flight Manuals
- Owner/Operator Manuals

In comparison to manufacturers of more complex UAS and those used in military applications, companies marketing smaller, simpler UAS did not publish specific technical data in stand-alone manuals. In such cases, the technical data topic was captured within the associated technical document category (an example is provided below). This methodology is likely to skew results in a way that suggests the supporting maintenance data associated with lower level Risk Classes is of greater complexity than is warranted. This is apparent for UAS platforms within Risk Class 1 and 2. For example, Risk Class 1 and 2 aircraft of simple construction and design generally included all of their power plant, maintenance and inspection manuals, parts lists, troubleshooting guides (fault isolation manuals), and flight manuals within a single document, such as an Owner's/Operator's Manual. Therefore, the associated maintenance data and documentation is based on the availability of published topics as opposed to the existence of a specific, stand-alone manual.

Higher Risk Class UAS are generally utilized in Dual-use and Military operations in which technical documentation was found to be similar to that associated with manned aircraft documentation in terms of type and quality. Comparison of the quality of related data revealed differences in the structure and content of maintenance tasks included in the manual or instructions. Details of the method of comparison is included in the sections that follow.

### 3.1.1 Focus Area – Type of Publications Distributed to Operators

Figures 4 and 5 illustrate the link between Risk and Operational Classes and the list of technical references included with associated UAS. Each listed technical reference 'data bar' represents all OEMs surveyed, and captures a total of 20 aircraft. Some aircraft manufacturers do not publish the specified technical reference, and this circumstance is identified by the gray bar "Document Not Published."

When comparing publications distributed to operators based on UAS Risk Class (Figure 4), Owner/Operator's Manuals (O/OM) were associated only with Risk Class 1 and 2 aircraft. These aircraft were generally small in size and simple in design and construction. Owner/Operator Manuals were not used for aircraft within Risk Classes 3 and above. Only 38% of Risk Class 1 and 2 aircraft included any kind of technical documentation beyond an O/OM. Larger, more complex aircraft defined within Risk Class 4 and above all had a full set of technical references sources selectable within the survey.

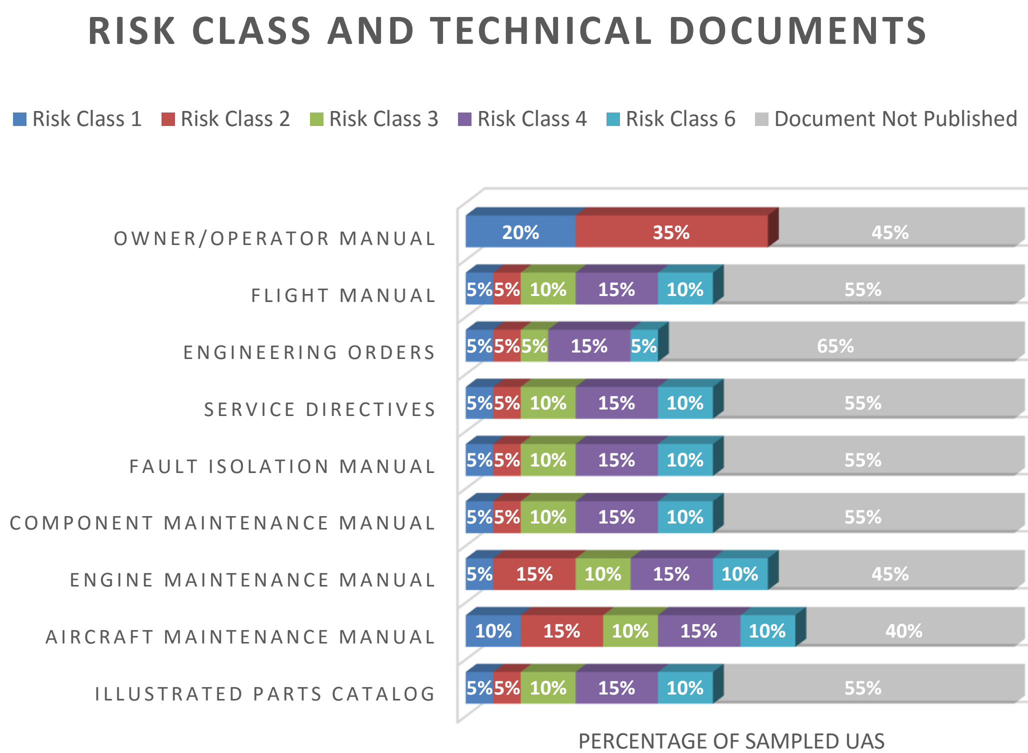


*Figure 4. Risk Class and Technical Documents Published*

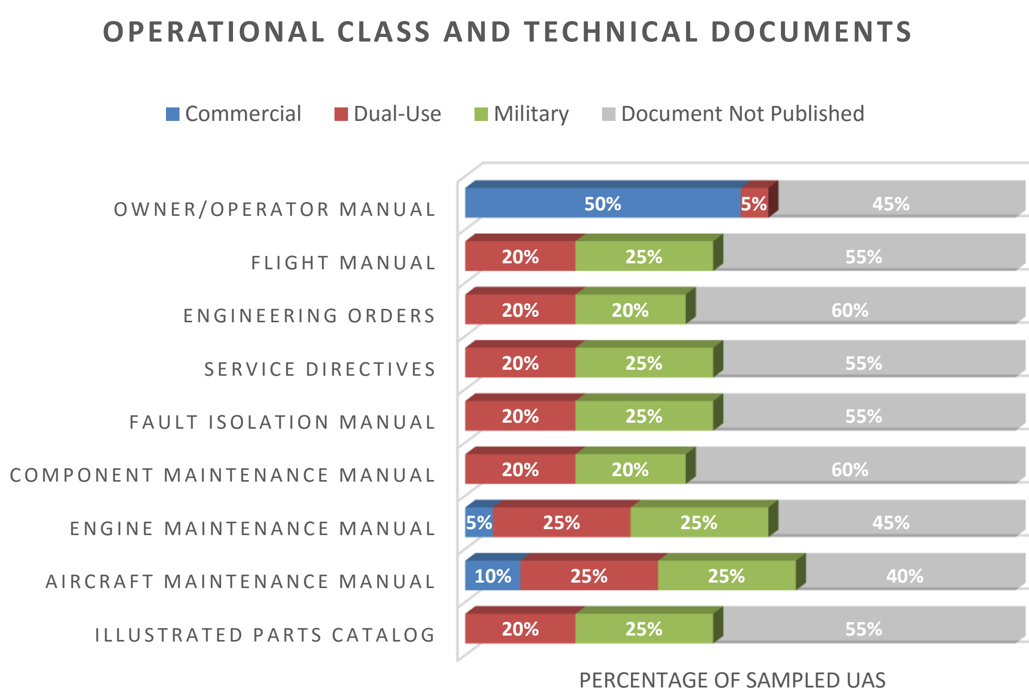


*Figure 5. Operational Class and Technical Documents*

The information that can be gleaned from Figure 5 illustrates the relationship between Operational Class and the Technical Documents used. First, no information specifically unique to the operational class Civil Support was captured. This is because the OEMs within the research pool do not design and manufacture aircraft specific to this application, but rather adapt existing platform models used within Commercial and Defense applications. The distribution of technical documentation shown within Figure 4 is similar to that of Figure 5. Another observation is the fact that, of all the surveyed UAS manufacturers, nearly half do not publish technical documentation across the full spectrum of listed technical documents (i.e. "Documents Not Published"). This can be interpreted as a lack of homogeny of maintenance task content or topical standards for UAS technical documentation across all Risk and Operational Classes.

Commercial UAS operations are currently dominated by Risk Class 1 and 2 aircraft. Therefore, these smaller UAS accounted for the majority of O/OM distribution. It was observed that all Commercial UAS had a published O/OM while only one Dual-Use aircraft and no Military aircraft had a published O/OM. It is not surprising that only 20% of Commercial UAS had any kind of technical documentation beyond an Owner's/Operator's Manual. Similar to Risk Classes 3-6, Dual-Use and Military aircraft had a greater variety of technical documentation published. All of the surveyed manufacturers with military aircraft provide an Illustrated Parts Catalog (IPC), Aircraft Maintenance Manual (AMM), Engine Maintenance Manual (EMM), Fault Isolation Manual (FIM), Service Directives (SD), and Flight Manual (FM). Eighty percent of that same class included Component Maintenance Manual (CMM) and Engineering Orders (EO) for technical reference sources. For Dual-Use aircraft, all surveyed manufacturers provide an AMM and EMM while 80% provide an IPC, CMM, FIM, SD, EO and FM. The trend observed is that more complex operational classes of aircraft also have a more comprehensive list of available technical documents to sustain the aircraft. Excluding the O/OM, the remaining nine out of ten manuals addressed within the surveys were assciated with Military and Dual-use aircraft.

### 3.1.2 Focus Area – Technical Data Quality

The quality of technical data published by OEMs was also analysed. Quality was determined based upon descriptions of the technical references provided by the surveyed SMEs, or by review of technical reference documents by the researchers. The survey identified the 'quality' of technical reference manuals and content using the following criteria:

- Consistent with type certificated aircraft
- Consistent with military standards
- Instructions published, limited scope & detail
- No instructions provided

Because manned aircraft require instructions for continued airworthiness defined within the Federal Aviation Regulations (FARs), technical data references are available that span the entire list of technical publications was selectable within this survey. The full breadth of engineering, design, logistics, sustainability, and safety systems and processes are imbedded within the documents and are made available to the aircraft operator and maintainer. Military and Dual-use platforms follow this pattern of product development and thus follow similar standards for technical publications. Aircraft within Risk Classes 3 through 6 were predominantly associated with military product development standards and had technical reference documents consistent with military standards (Figure 6). From that pool, one aircraft in seven had technical document standards consistent with type certificated aircraft. Eighty-five percent of the aircraft assigned to Risk Classes 1 and 2 were described as having "instructions published but limited in scope and detail." The remaining aircraft were subject to military standards and were considered Dual-use aircraft.

When comparing the quality of technical data within Operational Classes, Military and Dual-use aircraft subject to military design, engineering and sustainment standards were accompanied by published technical data consistent with those standards. By contrast, technical documentation available for Commercial UAS aircraft demonstrated what is considered to be a simpler approach having "instructions published but limited in scope and detail." This is likely due to two key components: 1) There is no requirement to follow a defined standard for continued airworthiness within the Risk Classes associated with Commercial operations (as it exists today), and 2) The design and construction of the aircraft is simpler, operation is within visual line of sight, and maintenance publications do not require the depth and breadth of technical content required of more complex systems.

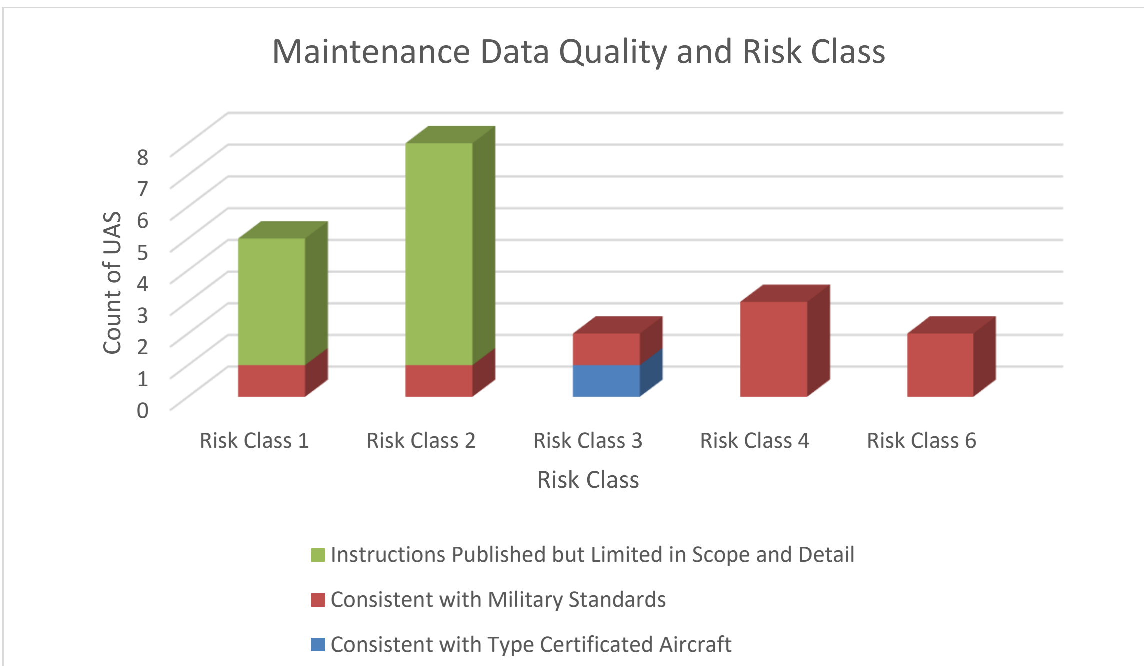


*Figure 6. Maintenance Data Quality and Risk Class*

### 3.1.3 Exploring the Maintenance Data and Documentation Data Further

An evaluation of the Level 2 (L2) survey data from aircraft operating within Risk Class 1 yielded the following maintenance practice observations:

- All aircraft have factory recommended pre- and post-flight procedures to visually inspect the aircraft for any signs of damage.
- Specific inspections are provided with pre-flight pass/fail criteria.

- Any repairs not found in the aircraft Owner/Operator Manual require the operator to return the aircraft to the OEM or distributor for repairs.
- Major repair or major alteration definitions, requirements, or procedures, are neither discussed nor provided.
- Firmware and software configuration control is managed through the ground control station.

The aircraft evaluated in the surveys within Risk Class 2 were both from the OEM Insitu. Therefore, the practices associated with maintenance and technical documentation are nearly identical. Insitu markets these aircraft to both military and commercial markets (Dual-use). As previously discussed, the availability of technical documentation is robust for these aircraft. Maintenance intervals are standardized based on airframe time, cycles, and calendar months similar to the intervals required for manned aircraft. Insitu defined field maintenance for their aircraft as any task that could be performed through aircraft maintenance manual instructions. This permits an average skilled maintenance technician to perform the task without supervision or special instructions provided by the OEM. Insitu defines a major repair or alteration as any task that requires repair to damaged composite structure. Operational maintenance includes visual and functional checks of the aircraft and the ground control station (GCS). The GCS has its own maintenance manual separate from the aircraft. Insitu also provides troubleshooting tasks for the aircraft and the C2 control link. The firmware and software for the sensors and aircraft are updated through synchronization with the GCS.

The only UAV amongst the Level 2 surveys to represent Risk Class 4 was the General Atomics Gray Eagle operated by the U.S. Army. The US Army and General Atomics indicated that they maintain this aircraft using technical documentation and maintenance practices no different than they do with manned aircraft systems. The Gray Eagle has an OEM-provided maintenance schedule based upon airframe time, cycles, landings and calendar days. Field maintenance is not as clearly defined with the Gray Eagle because what is considered field maintenance depends on the maintainer’s access to specific types of technical documentation. Major repairs and alterations are not defined by the OEM or the US Army. The term appears to be unique to requirements for continued airworthiness defined by certificated aircraft. The aircraft undergoes pre- and post-flight inspections with pass/fail criteria similar to that of the U.S. Army's manned aircraft. The Gray Eagle has separate tasks for the aircraft, GCS and command & control elements including procedures for packing and unpacking equipment due to mobility requirements. Troubleshooting guidance is provided for commonly occurring problems related to vibration, engine temperature and C2 link. System software updates for the aircraft and GCS are downloaded from the OEM after extensive functional and compatibility testing and are then recorded in both paper and electronic logbooks.

### 3.1.4 Maintenance Data & Documentation Observations

The following observations have been made after careful review of the L1 and L2 survey data.

- Smaller UAS (Risk Class 1 and 2) have few published technical documents and limited maintenance programs.
    - This would be expected as smaller UAS are of simpler design and construction compared to larger counterparts. Thus, maintenance typically entails removal and replacement of components by the operator in the field.

- Defense/Military and Dual-use aircraft have the most extensive maintenance programs and the most complete set of technical reference manuals.
  - Aircraft designed for military applications, regardless of Risk Class, must meet similar sustainment system criteria. Therefore maintenance standards and technical manual documentation is similar to that found for manned aircraft.
  - As a result of the rigor of maintenance and documentation required of all military UAS, these sustainment systems follow a standard similar to that of type certificated aircraft.
- Regardless of risk or operational class, UAS aircraft that cannot be fixed in the field are sent back to the manufacturer or a distributor for repair.
  - In the case of Risk Class 1 and 2, this is often an issue of required skill of the technician, the equipment not being designed in a manner that allows an effective field repair, or is simply a warranty issue to keep the warranty of the equipment intact.
  - For Risk Classes 3 and higher, the aircraft are more complex and the OEM prefers some repairs to be made by them. As an advantage to the operator, depot facilities are not required as the aircraft can be crated and shipped back to the OEM who has the tooling, material and expertise to affect a repair.
- The approach to the maintenance of larger and more complex aircraft marketed to the military is more standardized and organized and includes scheduled maintenance and inspection intervals similar to manned aircraft. The associated technical reference data details much of the required maintenance actions to be performed by the operator in the field.
- Field service support personnel have a presence within the US Military, usually provided under contract to support sustainability and mission readiness of the aircraft. This allows operators to keep aircraft in the field longer by including OEM trained personnel in the decision-making and repair processes necessary to ensure sustainability of the aircraft. For smaller UAS, technical support is available, but generally a phone call or mouse-click away. These manufacturers have deployable field service support that is typically offered as a service through the OEM distributor network. The cost-base for acquiring these systems is fairly high, but is supported by effective and responsive technical support by the more popular OEMs for smaller UAS.
  - For sUAS OEMs that offer this level of service, it follows they also offer a more robust set of instructions and online resources to support the sustainment of their aircraft. Essentially, they offer as much "Do it yourself" flight and maintenance instruction as is practical.
- The simpler UAS found in Risk Class 1 and 2 utilize a progressive system of social media and online resources to communicate new information and techniques with their customers. Without the structure of mandatory standards, they adapt quickly to the demands of the market and the expectation of their customers. To remain competitive, they must have an edge over their competition in a manner that is very responsive and adaptive to changes in technologies and preferences in user interfaces.
  - The lifecycle of these aircraft is relatively short-lived. Because these aircraft do not have to conform to a type design, they can create new models each year with progressively more impressive arrays of payloads, GCS, and aircraft performance. The energy and focus of these companies is innovation and not sustainability. Because their lifecycle is short,

the creation of the criteria for maintainability and repairs beyond the normal lifecycle of these UAS is generally not worth the investment of resources.

## 3.2 REPORTING & RECORD REQUIREMENTS

At present, continued airworthiness requirements for manned aircraft require a system of documenting maintenance and repairs performed on the aircraft as well as a methodology by which manufacturers communicate in-service issues with the mechanical systems or operations of the aircraft that impact safety of flight. This research included surveys that captured the methods by which OEMs and/or operators accomplish this within the UAS community. The survey determined if maintenance record entries were made within a logbook (paper or electronic) and did not include a sampling of the content of those entries.

### 3.2.1 Focus Area – Maintenance Logbooks

Smaller UAS aircraft were less likely have a logbook for maintenance records. Figure 7 shows that 40% of Risk Class 1 and 25% of Risk Class 2 aircraft OEMs and operators reported utilizing a maintenance logbook to record maintenance. On the other hand, 100% of Risk Class 3, 4, and 6 aircraft OEMs and operators were reported to utilize maintenance logbooks. When comparing the use of maintenance logbooks across Operational Classes, Figure 8 shows that only 50% of Commercial OEMs and operators reported using them. For UAS operated within Defense and Dual-use applications, 100% of those aircraft had maintenance logbook entries (Figure 8).

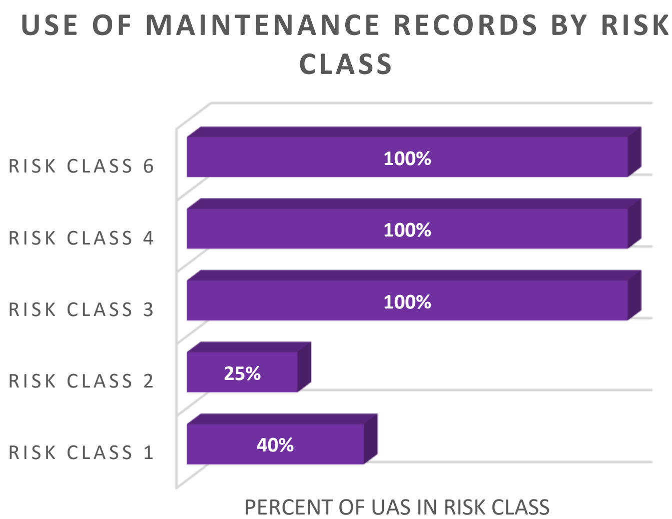


*Figure 7. Use of Maintenance Records by Risk Class*

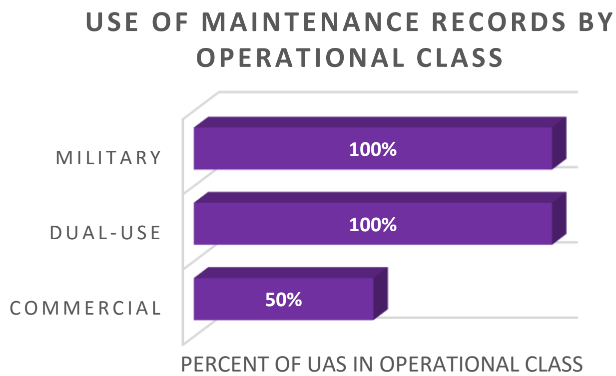


*Figure 8. Use of Maintenance Records by Operational Class*

### 3.2.2 Further Analysis of Reporting and Record-Keeping Requirements

Operators of Risk Class 1 aircraft reported the use of a paper maintenance logbook to keep track of maintenance performed on the air vehicle. These OEMs also indicated they will soon offer a digital logbook option and all utilize a form of Service Directive (traditionally identified as service letters or service bulletins within the type certificated aircraft community) to inform customers/operators of in-service issues. The Service Directives are sent out through both conventional and electronic mail, and are stored online for historical reference. The OEMs surveyed were very progressive in utilizing online applications to most effectively communicate in-service issues to their customers and available (often required) software and firmware updates for their GSC and aircraft. Customers receive notification popups via email and when logging in to the platform's application web page.

Risk Class 2 aircraft within the Dual-use Operational Class were also associated with paper logbooks. It was indicated that paper is often a requirement of both US and foreign militaries. This is primarily because of the remote locations in which these aircraft operate, with or without internet access; consequently, records must be kept on-site near the aircraft. The main difference in record-keeping requirements with Risk Class 2 aircraft compared to Risk Class 1 aircraft is that the manufacturers require compliance to published Service Directives provided to the operator by letter or by email. Compliance to the Service Directive is confirmed when a user logs into the GCS.

Reporting and record requirements for Risk Class 4 aircraft are more complex than previous classes discussed. Paper and electronic logbooks are used to record maintenance. The operator, in this case the US Army, keeps their own logs in their UAS-I computer software found within a stand-alone, ruggedized mobile PC. When Service Directives are released by the manufacturer, they are sent out through email to the operator and also kept in a technical reference library (paper and electronic) at the base of operations. The Gray Eagle, representing this class, has procedures for reporting in-service issues using two different reporting levels. Low-level difficulties are recorded by logbook while high-level difficulties are recorded into the logbook and have an additional step that requires a report to the OEM's engineering department. High-level issues are subjective and are issues that generally fall outside the normal operating and maintenance conditions of the aircraft. These are also issues that could impact the fleet and should be brought to the attention of the OEM for appropriate inquiry and analysis. In these circumstances, it is the OEM field service personnel on-site that will make the determination and communicate as required.

In summary, Risk Class 1 and 2 aircraft for Commercial operations are associated with less record-keeping resources for their aircraft—predominantly paper entries. OEMs with higher-value aircraft offer electronic logbook entry and configuration management tools using simple PC and mobile interfaces. Service difficulty reporting was direct to the user via email and archived within the provided OEM support web page. Configuration control of the aircraft was performed in a similar manner using the GCS and the latest online software and firmware updates to ensure user compliance to OEM operational recommendations. Aircraft in Risk Classes 3 and higher have reporting and record-keeping requirements consistent with those of both military and civilian manned aircraft. Although the reporting methodologies do not have the functionality and flexibility of lower Risk Class online reporting systems, they do have robust structures in place that are supported by decades of successful aircraft sustainment processes and include mobile electronic record-keeping. In this manner, the operator can see the health and status of the entire fleet, regardless of location, and can identify resources and parts necessary to sustain those systems.

### 3.3 TRAINING PROGRAMS

Effective sustainment of UAS includes the programs for training of flight crews and maintenance personnel. The research related to training programs focused on the type of training offered, the method of delivery, who is trained, and where the training is delivered. The types of training that were selectable within the survey included:

- Flight
- Servicing & ground operations/line/organizational-level/field maintenance technician
- Overhaul/heavy/depot/sustainment maintenance technician
- Inspection

Of the 20 survey respondents, 95% of OEMs offered flight training delivered by either the manufacturer or a third party (Figure 9). Fifty-five percent of that same group did not offer any form of basic servicing, field, or line-level maintenance training. Even fewer (35%) offered overhaul/heavy/depot/sustainment and inspection technician training.

The surveyed OEMs that offer overhaul/heavy/depot/sustainment technician training did so for Risk Class 3 or greater (Figure 9) aircraft. About 35% of surveyed OEMs offer inspection training. Surveyed OEMs delivered only flight training for aircraft within Risk Classes 1 and 2. Risk Class 1 and 2 aircraft were barely represented by respondents for technician training that involves servicing and ground operations/line/organizational-level/field maintenance; this type of training was offered to a higher degree for Risk Classes 3 through 6. An interesting observation from Figure 9 is the absence of maintenance training offered by all respondent OEMs and operators. Flight training is prevalent, but the lack of maintenance training offered by the survey pool represented 55-65% of all aircraft.

As shown in Figure 10, aircraft within Dual-use and Military operational classes were represented by OEMs offering the largest percentage of training within each training category listed. For OEMs surveyed that offered flight training, commercial UAS manufacturers accounted for 40% of the total while Military and Dual-use UAS manufacturers comprised 45% of the total surveyed.

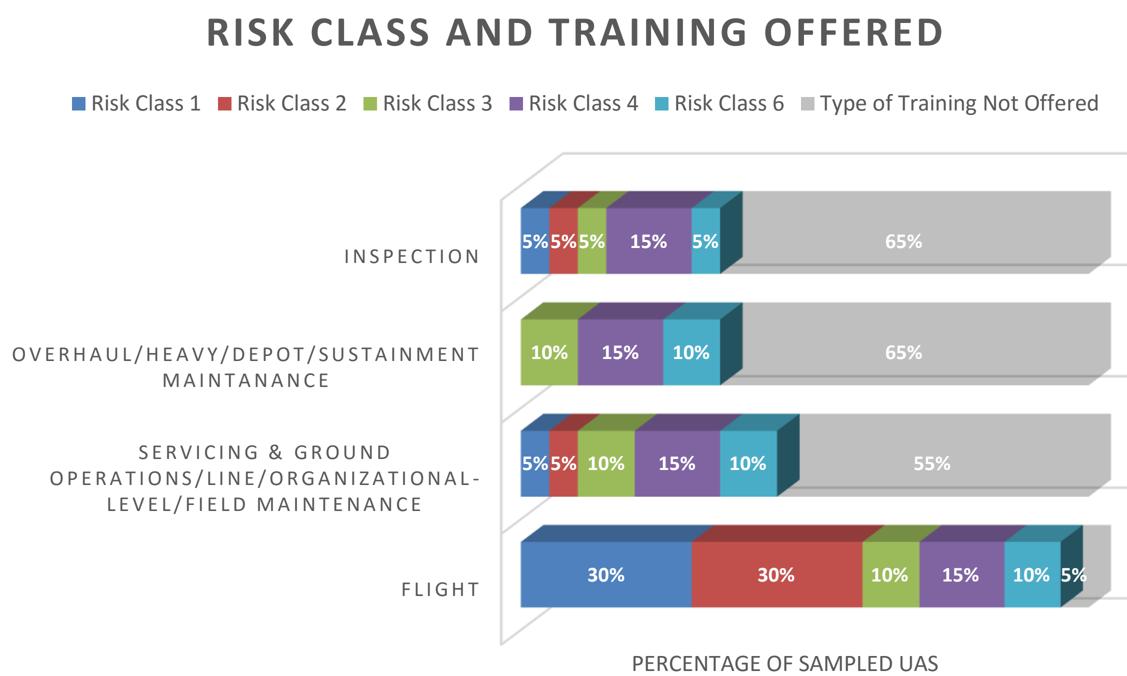


*Figure 9. Risk Class and Training Offered*

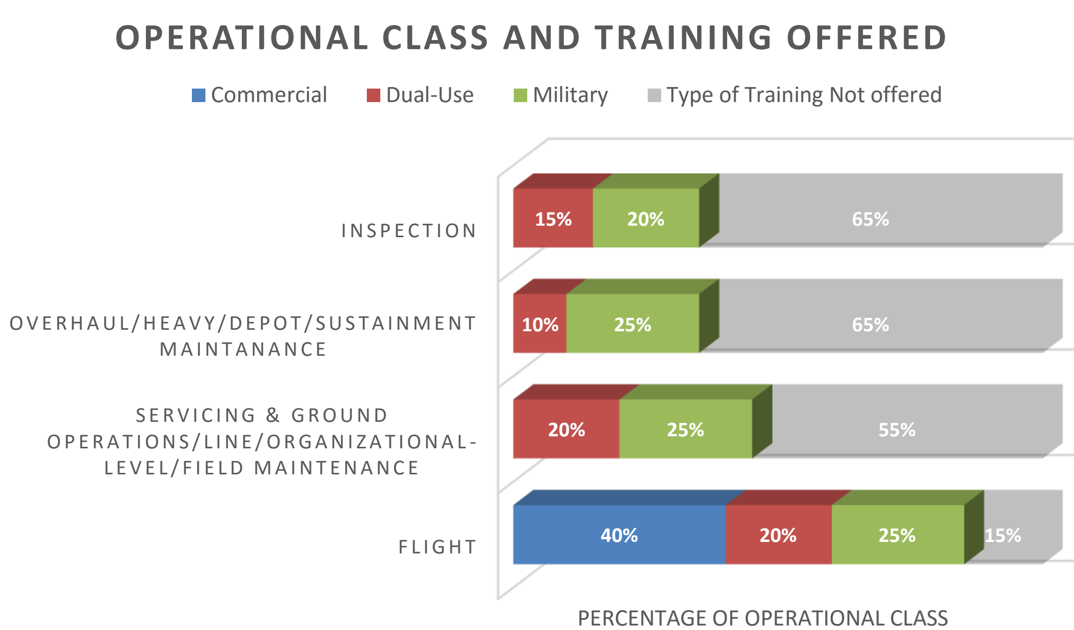


*Figure 10. Operational Class and Training Offered*

### 3.3.1 Training Program Discussion

Training offered within a program is based upon specific requirements for operating or maintaining an aircraft; persons operating or maintaining need to have demonstrated achievement of knowledge, skill, and attitudes within a subject area to a defined performance level. A strong correlation exists between the complexity of the design, construction, and operation of an aircraft and the knowledge and skill required to operate and maintain that system. Technical publications are generated to include tasks and instructions to ensure the safe and effective operation of the UAS and correspond to the complexity of the aircraft, ground control system, and the launch and recovery equipment. Training is used to tie all of this together into a package that will enable a pilot and maintainer to perform their duties. The lack of training programs available for maintenance of aircraft within Risk Classes 1 and 2 is likely driven by the lack of complex technical data and skills required to repair the aircraft. Aircraft with relatively simple design and construction have minimal requirements for repair processes and technician skill. It should be noted, however, that there are exceptions to this general rule. The Risk Class 2 aircraft represented in the surveys are Dual-use Operational Class and have more complex technical documentation necessary to support the air vehicle and its support systems. The aircraft's design, construction, and associated systems are of a level of complexity that facilitates the need for skilled maintainers and operators. For example, Insitu generates a qualifications manual that specifically outlines the skill requirements for both maintenance technicians and the operators (pilots) that are conveyed through internal training.

In contrast to formal training programs, less sophisticated aircraft, primarily sUAS found within Risk Classes 1 and 2, often utilize less conventional and informal training programs. These training programs are often based upon a small amount of formal content that is provided by the OEM, and then supplemented with information that is generated from within a community of operators and maintainers that communicate online. There are advantages and disadvantages to having a community of users sharing information online for small UAS. In an environment that is not regulated and does not have defined FARs or standards to follow, technical data does not have to be approved by the OEM nor does the training that is publically offered. This allows OEMs to focus on technology development and newer designs without developing the infrastructure and expertise necessary to create and deploy learning content. On the other hand, OEMs have less control of aircraft configuration and the quality of parts and materials used to repair the aircraft. To address this, an increasing number of sUAS manufacturers are providing online technical solutions for software updates, configuration management, maintenance logs, mission logs, and training. All of these online resources help to limit the OEM liability and may exclude aircraft repairs from warranty eligibility if the prescribed OEM support system is not utilized by the operator.

Larger more complex aircraft that fall within the higher risk categories (Risk Classes 3-6), require maintenance training that differs greatly from that of aircraft found in risk categories 1 and 2. These aircraft are generally larger, and more complex in terms of design, construction, systems, and mission requirements. As a result, more attention to maintenance is required to ensure continued safety and airworthiness. The General Atomics Gray Eagle, Risk Class 4, represents one of the larger, more complex UAS considered for this study. Per the OEM, this aircraft was designed and constructed to be treated as if it were a manned aircraft, and this philosophy extends to maintenance and associated training as well. As such, the OEM offers training across all training categories to a high level of required proficiency, particularly for their field technicians. General Atomics trains field technicians for both Avionics and Maintenance roles. Specialized training is offered for tasks including maintenance, inspection, and operations for the aircraft and ground support equipment. The GCS for the aircraft is supported by Textron Systems who have a different maintenance and training program that is separate from that of the aircraft. Specialists are trained in each system as one person cannot have competency in all systems of this complex aircraft. This training methodology aligns with its maintenance process and is compatible with existing manned military aircraft support systems. Similarly, larger aircraft operated in Risk Class 6 such as the Global Hawk, manufactured by Northrop Grumman, follow philosophies and methodologies in sustainment and training posture as Risk Class 4 aircraft. Discussions with persons who maintain and support this program indicate that this aircraft is supported in a manner no different than transport and fighter category military aircraft. In some cases, these operations are considered more complex as the system is highly mobile, operates from austere environments, and has additional complexity in its command and control system that require high skill sets in both its operators and its maintainers. To support the development of these skills, the training programs offered by Northrop Grumman, or by the third-parties contracted to develop and deliver the training, align with those associated with manned aircraft.

The following are key observations made from the UAS training programs data:

- Larger and more complex UAS aircraft, Risk Class 3 and greater, and those operated by the military, are more likely to have training for maintenance technicians.
    - Operation of these aircraft present greater hazards and risk levels. Due to the increased severity and/or probability of hazards, as well as the criticality of missions, there is a higher level of maintenance, inspection, and servicing of the aircraft. Safety-critical systems must be maintained to ensure an adequate level of safety.
    - The military usually has internal capability to perform maintenance on their aircraft due to mission deployments to austere and high threat environments. Therefore training military personnel as technicians for field maintenance is necessary.
    - These aircraft have a higher acquisition and operational cost compared to UAS in Risk Class 1 and 2. Long lifecycles and stable designs necessitate a robust, long-term sustainment posture that includes maintenance training.
- Maintenance, record-keeping, and training standards for Military and Dual-use UAS aircraft are consistent with those of manned aircraft utilized in both military and civilian operations.
- For Commercial UAS operations (primarily Risk Class 1 and 2 aircraft), the relatively simple design and construction of sUAS does not justify a traditionally robust maintenance training program that requires instructional design techniques to achieve an established level of quality and effectiveness. Also, because most of the components on these aircraft are “remove-and-replace”, the assembly instructions are often all that is necessary to affect repair of an inoperable or damaged component.

## 4 SUMMARY

The following findings have been summarized to derive the key observations of this preliminary analysis of UAS Maintenance data.

1. **Small and low-cost UAS (Risk Classes 1 and 2) maintenance practices differ greatly from manned aircraft, unlike aircraft in Risk Classes 3 through 6 which have practices more similar to manned aircraft.**
    a. The data reflects that small UAS (Risk Classes 1 and 2) have fewer technical documents published and a less extensive maintenance program due to their lack of complexity and simple maintenance required that generally involves remove and replace of components.
    b. Any instructions associated with flight, inspections, maintenance, repairs, and assembly are often found in a single document, the Owner's/Operator's Manuals, and can usually be accessed online.
    c. Small commercial aircraft are usually sent back to the OEM for repair if the operator cannot repair the aircraft in the field.
    d. There are few if any requirements for keeping sUAS maintenance records. However, there is a growing trend to utilize support portals online for customer access to technical data, configuration control, firmware, logbook entries, and service instructions.
    e. Training provided is primarily flight operator training. This is also the most likely cause for loss of the aircraft and potential liability for the OEM.

2. **UAS aircraft operated by the military (Risk Classes 3 through 6) reflect military standards and processes for maintenance, record-keeping and training.**
    a. These systems have maintenance programs that closely match those of type certificated aircraft and are consistent with requirements found for continued airworthiness.
    b. Military and Dual-use aircraft have the most complete library of technical documentation. This includes sUAS within the respective categories.
    c. Most aircraft are serviced and repaired in the field or at an operator's base. If this cannot be done in the field using approved technical data, then it is disassembled, crated, and sent to the OEM for repairs.
    d. Record keeping requirements were standardized and included robust processes for in-service difficulty reporting and communication methods no different than that are established for manned aircraft. OEM and operator relationships were interdependent to ensure the safe and effective operation of the aircraft.
    e. A variety of training was available for maintenance technicians and was delivered in a manner and quality consistent with manned aircraft systems.

## 5 RECOMMENDATIONS

The following recommendations can be made based upon information gathered from this research. These recommendations are aimed at establishing a baseline for UAS maintenance and associated training such that the levels of maintenance, training, and rigor are appropriate to the aircraft and the level of risk associated with the operation of that unmanned aircraft. This section is split into three sub-sections covering maintenance data and documentation, reporting and record requirements, and training programs.

### 5.1 MAINTENANCE DATA & DOCUMENTATION

- Create a new Advisory Circular that complements the existing AC 43.13 "Acceptable Methods, Techniques, and Practices" Series. A new AC similar to AC 43.13-3A and -3B is recommended to create "Acceptable Methods, Techniques, and Practices for UAS Alterations," and "Acceptable Methods, Techniques, and Practices for UAS Inspection and Repairs." This would be constructive within UAS Risk Classes 1-3 or non-defense applications in which maintenance practices and documentation are limited. This should include such topics as small aircraft weight and balance techniques, electro-magnetic interference (EMI) and impact to command and control systems, launcher maintenance practices, electric and small motor maintenance and inspection best practices, and similar topics.
- Solutions to defining standards and criteria for the maintenance and repair of UAS aircraft and supporting systems, including associated published technical documentation, should be scalable and flexible based upon the complexity of the aircraft's design and construction. This corresponds to the Risk Class assignment which is based on the level of kinetic energy produced (as previously discussed).
- Include technical documentation standards consistent with ASTM 2909-14 "Standard Practice for Maintenance and Continued Airworthiness of Small Unmanned Aircraft Systems" for UAS within Risk Classes 1 and 2, and utilize consensus standards for technical documentation for Risk Class 3 found within ASTM documents F2295 "Practices for Continued Operational Safety Monitoring of a Light Sport Aircraft", F2483 "Practice for Maintenance and the Development of Maintenance Manuals for Light Sport Aircraft", and F2746 "Specifications for Pilot's Operating Handbook (POH) for Light Sport Airplane."
- For larger UAS that are designed to military and civilian certification standards, technical documentation standards should be robust and consistent with manned aircraft standards similar in content and structure found in ILS-Spec S1000D, or ATA Spec 100 guidelines.
- Maintenance practices and standards for the repair and inspection of aircraft should follow the aforementioned recommendation for technical manuals based on Risk Class of the aircraft. The complexity of the maintenance performed on the aircraft follows the complexity and content of the technical documentation provided for the aircraft and its supporting systems. Further investigation will follow in Task 4 "Develop Maintenance Technician Training Certification Requirements" of the overall A.5 research plan.

- As with manned aircraft, allow OEMs to determine repairs that are approved to be performed in the field and those that must be either returned to the OEM or an approved service center for the repair.
- To align with recommendation above, definition of major/minor repairs should be determined by the OEM. Definitions should be straight forward and not subject to interpretation by maintainers or by industry. Minor repairs can be performed in the field while major repairs are to be performed by the OEM, an approved repair station qualified to do the work, or by authorized personnel following approved technical data provided by the OEM.
- Initial recommendations do not include certification standards for maintainers at this time, but it is the focus of Task 4 to "Develop Maintenance Technician Training Certification Requirements." However, previously discussed recommendations with respect to maintenance practices and technical documentation and the data thus far collected will facilitate determination of appropriate certification levels to be obtained by UAS maintenance technicians and of concomitant requisite certification standards.

## 5.2 REPORTING & RECORD REQUIREMENTS

- Service Difficulty reporting, similar to recommendations given above, should follow a standard consistent with the Risk Class of the aircraft, and thus, will follow the complexity of aircraft design and construction. A method by which OEMs are required to effectively support products in the field to ensure continued safe operations is the foundation of any sustainment program. This should not be abridged, but should follow a sensible and scalable solution that is practical and effective for the associated Risk Class of the aircraft.
  - Risk Classes 1 and 2 – Follow guidelines outlined in ASTM F2909-14 "Standard Practice for Maintenance and Continued Airworthiness of Small Unmanned Aircraft Systems."
  - Risk Class 3 – Follow guidelines outlined in ASTM documents F2295 "Practices for Continued Operational Safety Monitoring of a Light Sport Aircraft."
  - Risk Classes 4 through 6 – Develop effective instructions for continued airworthiness appropriate for UAS using FAA Order 8110.54A, "Instructions for Continued Airworthiness Responsibilities, Requirements, and Content" and draft Advisory Circular AC 20-ICA as guidelines. Instructions drafted should be appropriate for manned military and civil fixed-wing and rotorcraft aircraft designs. Specific guidelines for instructions for continued airworthiness can be found in or modeled after FAR 23.1529 and FAR 27.1529
- For UAS that will be governed by FARs and not used for recreational purposes, a maintenance and inspection logbook entry should be required consistent with FAR 43.9 and 43.11 standards and is appropriate to UAS operations. Additional elements should be included in the entries and details will be included in future research reports. Examples of additional topical requirements may include platform/GCS configuration status and changes, firmware and software updates to the GCS and platform, basic field and OEM repairs, launchers, recovery elements, battery installation, etc. Due to the nature of UAS, changes to the propulsion pack, GCS, batteries, structural components, and payload will be frequent. Standards and requirements for

record entries should reflect this reality and be flexible in nature to take advantage of today's online technologies that ease this burden.

## 5.3 TRAINING PROGRAMS

- Recommendations will be drafted after further investigation and completion of key tasks within the A.5 research that covers this topic, including Task 3 "Review of UAS Maintenance Training Practices" and Task 4 "Develop Maintenance Technician Training Certification Requirements."
- A review of training standards for maintenance technicians that are currently published will form the foundation of this investigation. This will include the baseline requirements found in Appendices A, B, C, and D of FAR Part 147 Aircraft Maintenance Technician Schools, and newly defined UAS Maintenance Technician Training Standards found in the NCATT publication Unmanned Aircraft Systems (UAS) Maintenance Standard. The content of these documents will be compared to A.5 research data, and a gap analysis will be performed.

# 6 REFERENCES


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2. ASTM F2483-12, Standard Practice for Maintenance and the Development of Maintenance Manuals for Light Sport Aircraft, ASTM International, West Conshohocken, PA, 2012, www.astm.org.
3. ASTM F2746-14, Standard Specification for Pilot's Operating Handbook (POH) for Light Sport Airplane, ASTM International, West Conshohocken, PA, 2014,www.astm.org.
4. ASTM F2909-14, Standard Practice for Maintenance and Continued Airworthiness of Small Unmanned Aircraft Systems (sUAS), ASTM International, West Conshohocken, PA, 2014, www.astm.org
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8. FAA, initiated by ACE-100, Design Standards and Assumptions for Type Design Approval Under 14 CFR 21.17(b) of Fixed Wing Unmanned Aircraft Systems (UAS), Draft AC 21.17b, unpublished.
9. ILS Spec Council (Integrated Logistics Support) S1000D – International specification for technical publications using a common source database, available from www.s1000d.org The S1000D website.
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15. United States Government, "Title 14 Code of Federal Regulations" 14CFR 27.1529. September, 1980.
16. United States Government, "Title 14 Code of Federal Regulations" 14CFR 43.9. January, 2012.
17. United States Government, "Title 14 Code of Federal Regulations" 14CFR 43.11. August, 2006.
18. United States Government, "Title 14 Code of Federal Regulations" 14CFR 147, Appendix A, B, C, D. June, 1992.

## APPENDIX 1: LIST OF SURVEYED UAS MANUFACTURES AND AIRCRAFT

| Aircraft Model | Aircraft Manufacturer | Weight (lbs) | Airspeed (Vc) (kts) | Risk Class | Operational Class |
|---|---|---|---|---|---|
| Aero-M | 3DRobotics | 6.8 | 39 | 1 | Commercial |
| Iris | 3DRobotics | 2.8 | 31 | 1 | Commercial |
| Phantom 3 | DJI | 2.8 | 31 | 1 | Commercial |
| Raven | Aerovironment | 4.2 | 44 | 1 | Dual-Use |
| Solo | 3DRobotics | 3.9 | 48 | 1 | Commercial |
| eBee* | SenseFly | 1.5 | 49 | 1 | Commercial |
| Sky Ranger* | Aeryon Labs | 6.6 | 27 | 1 | Dual-Use |
| Aerosonde Mk 4.7 | AAI/Textron Systems | 55 | 60 | 2 | Dual-Use |
| Inspire 1 | DJI | 6.5 | 43 | 2 | Commercial |
| Matrice 100 | DJI | 7.5 | 43 | 2 | Commercial |
| Penguin B | UAV Factory | 47.3 | 43 | 2 | Commercial |
| Puma AE | Aerovironment | 13.5 | 45 | 2 | Dual-Use |
| S1000 Spreading Wings | DJI | 25.25 | 31 | 2 | Commercial |
| S900 Spreading Wings | DJI | 18.1 | 31 | 2 | Commercial |
| X8-M | 3DRobotics | 7.7 | 58 | 2 | Commercial |
| Scan Eagle* | Insitu | 48.5 | 60 | 2 | Dual-Use |
| Blackjack | Insitu | 135 | 60 | 2 | Military |
| Camcopter S-100 | Schiebel | 440 | 55 | 3 | Dual-Use |
| Shadow M2 "RQ-7B" | AAI/Textron Systems | 375 | 89.5 | 3 | Dual-Use |
| Fire Scout "MQ-8B" | Northrup Grumman | 3150 | 85 | 4 | Dual-Use |
| Gray Eagle | General Atomics | 3600 | 167 | 4 | Military |
| Predator B "Reaper" | General Atomics | 10050 | 240 | 4 | Military |
| Predator XP | General Atomics | 2550 | 120 | 4 | Military |
| Global Hawk "WAS" | Northrup Grumman | 32250 | 310 | 6 | Military |
| Predator C Avenger | General Atomics | 18200 | 350 | 6 | Military |

*** Manufacture’s surveys not included in data graphs & charts at time of writing. Information included in analysis and discussion.**

## APPENDIX 2: L1 AND L2 SURVEY CONTENT

*DATA SOURCE TECHNICAL INFORMATION*

| **Aircraft Specifications & Class (Task 1c)** | | |
|---|---|---|
| **Field Description** | **Selectable Content** | **Notes** |
| Source of Data | OEM, Publication, Government Document or Operating Organization | Type of source used to collect data on aircraft specifications and class. |
| Manufacturer | Dependent on UAS | |
| Model | Dependent on UAS | |
| Aircraft Configuration | Fixed Wing, Multi-Rotor, Rotary Wing – Helo or VTOL - other | |
| Empty Weight (lbs) | Dependent on UAS | Weight of the aircraft without fuel or payload. |
| Max Takeoff Weight (lbs) | Dependent on UAS | Maximum weight at takeoff for safe operation of UAS. |
| Max Speed (kts) | Dependent on UAS | Maximum horizontal speed the UAS can reach |
| Kinetic Energy (ft-lbs) | Dependent on UAS | Measure of kinetic energy UAS has at maximum speed and maximum takeoff weight<br>K = m*v^2 |
| Risk Class | Class 1, Class 2, Class 3, Class 4 | Class 1 ≤ 529 ft-lbs<br>Class 2 ≥ 530 ft-lbs ≤ 24999 ft-lbs<br>Class 3 ≥ 25000 ft-lbs ≤ 799999 ft-lbs<br>Class 4 ≥ 800000 ft-lbs ≤ 5999999 ft-lbs<br>Class 5 ≥ 6000000 ft-lbs ≤ 49999999 ft-lbs<br>Class 6 ≥50000000 ft-lbs |
| Operational Class | Defense/Homeland Security,<br>Civil Support (non-commercial),<br>Commercial,<br>Dual Use (combined Commercial and Defense/civil support | OEM's intended market for UAS<br>Non-defense/HS includes all commercial and law enforcement |
| Propulsion System | Electric, Reciprocating, Hybrid or Gas Turbine | Type of powerplant used to propel UAS. |
| Data Source URL | Dependent on UAS | Link to source of aircraft specification and class data used. |

**Maintenance Data & Documentation**

| Maintenance Data & Documentation (Task 1d, 3a, 3c) | | | | |
|---|---|---|---|---|
| **Level 1 Survey** | | | **Level 2 Survey** | |
| **Field Description** | **Selectable Content** | **Notes** | | |
| Maintenance Program Information Available? | Yes or No | | What are the recommended and/or required maintenance schedules for aircraft (intervals)? | Open |
| | | | What type of scheduled and unscheduled maintenance procedures are provided for the aircraft? | Open |
| | | | Is there guidance that outlines the classification of field versus depot/factory level maintenance tasks?<br>Any given definitions for major repairs and alternations?<br>Are their technician qualification and training specific to major repairs and alterations? | Yes or No Describe<br>Open<br>Yes or No |
| | | | What maintenance items are included in operational checklists (pre/post flight)? | Open |
| | | | Are there Pass/Fail criteria for inspection items within maintenance tasks? | Yes or No |
| | | | What maintenance practices or tasks are performed for non-flying equipment (i.e. ground control stations, antennas, datalink hardware, etc.) | Open |
| | | | What are the software and firmware maintenance and updating practices? | Open |

| | | | | |
|---|---|---|---|---|
| Available Maintenance Documents | Illustrated Parts Catalogs (IPC), Aircraft Maintenance Manual (AMM), Engine Maintenance Manual (EMM), Component Maintenance Manual (CMM), Fault Isolation Manual (FIM), Service Letters (Instructions, et al) (SL), Service Bulletins (SB), Engineering Orders (or similar) (EO), Flight Manual (FM), Owner's Manual (OM) and/or other documents | Document(s) available that are related to maintenance of the UAS. | Are troubleshooting procedures available for both hardware (airframe/propulsion) and software (Aircraft electronics/sensors/payload)?<br><br>What are the common T-shoot tasks performed? (ID airframe/propulsion/software) | Yes or No<br><br>Open |
| Media Delivery Method | Paper, CD, Online (OEM), Online (third-party), Electronic File (pdf, word, etc…) | Type of media maintenance documents are available on. | | |
| Maintenance Data Quality Level | 1, 2, 3 or 4 | 1) Consistent with type certificated aircraft<br>2) Consistent with military standards<br>3) Instructions published, limited scope & detail<br>4) No instructions provided | | |
| Willing to provide access to UAS technicians (Task 3c) | Yes or No | | | |
| Mx Notes | Dependent on UAS | | | |

**Reporting & Records Requirements**

| Reporting & Records Requirements (Task 1d, 3a, 3c) | | | | |
|---|---|---|---|---|
| Level 1 Survey | | | Level 2 Survey | |
| Field Description | Selectable Content | Notes | Question | Content |
| Maintenance Records Used (Task 3a) | Yes or No | | How are maintenance and inspection tasks recorded? | Open |
| | | | How are in-service difficulty reports documented and processed? | Open |
| | | | What are the Manufacturer's methods for resolving reported difficulties and issuing safety directives? (How are they communicated to the technician to ensure appropriate information and tasks are communicated?) | Open |
| | | | How is aircraft/sensor/payload configuration managed? | Open |

**Training Programs**

| Training Programs (Task 4a) | | | | |
|---|---|---|---|---|
| **Level 1 Survey** | | | **Level 2 Survey** | |
| **Field Description** | **Selectable Content** | **Notes** | **Question** | **Content** |
| Training Programs Offered | Flight, Servicing and Ground Operations, Line Maintenance, Organizational-level Maintenance, Intermediate-level Maintenance, Depot-level Maintenance, Overhaul/Heavy Maintenance, Inspection | Type(s) of maintenance training program(s) available for UAS. | Are manufacture/factory/operator training courses available for technicians?<br>What type of courses do they take? | Open |
| | | | What are the maintenance technician qualification and training requirements?<br>Are specialists required?<br>What are they? | Open |
| Training Delivery Method | Classroom, Practical, CD, Online (OEM), Online (third party) or Electronic File | Means through which maintenance training is delivered. | | |
| Host | OEM, Operator (2nd party), 3rd Party, Commercial or other | Source of provided maintenance training | | |
| Location | OEM Facilities, third party facilities or Customer Site | Location maintenance training is held. | | |
| Training Notes | Dependent on UAS | | | |

## APPENDIX 3: DEFINITION OF TERMS

| Term | Abbreviation | Definition |
|---|---|---|
| Unmanned Aircraft System | UAS | Includes all equipment necessary to conduct an aerial operation with an aerial vehicle that is not controlled by a pilot on-board the aircraft. This includes the air vehicle, ground control station, software, launcher and recovery system. |
| Illustrated Parts Catalog | IPC | Document that lists the parts, and associated part numbers, used in the construction of a component, assembly or system using graphical illustration usually in an exploded-parts view. |
| Aircraft Maintenance Manual | AMM | Technical document listing manufacturer approved tasks associated with the maintenance, repair and inspection of an aircraft. |
| Engine Maintenance Manual | EMM | Technical document listing manufacturer approved tasks associated with the maintenance, repair and inspection of an aircraft's propulsion system. |
| Component Maintenance Manual | CMM | Technical document listing manufacturer approved tasks associated with the maintenance, repair and inspection of a specific component installed on an aircraft. These tasks are usually performed by the component's manufacturer and are usually tasks not authorized to be performed by the operator. |
| Fault Isolation Manual | FIM | Technical document used as a trouble-shooting guide to identify the root cause and solution to a particular aircraft or system fault. |
| Service Directives | SD | Guidance provided by the manufacture to the operator related to issues related to the aircraft that could impact safe operation or continued airworthiness. Certificated aircraft manufacturers use service bulletins and service letters. In this instance, those methods of communication have been combined. |
| Engineering Orders | EO | A form of technical communication that is usually internal to the manufacturer that involves specific engineering guidance or requirements related to a part, component, or system design or manufacture. |
| Flight Manual | FM | Technical instructions provided by the manufacturer for the safe and effective flight of the aircraft. Can include aircraft performance and flight limitations. |
| Owner/Operator Manual | OM | Manufacturer's written and illustrated set of instructions associated with the entire UAS. This includes, but is not limited to: aircraft assembly, installation of components, flight, operation, autopilot, firmware updates, ground control station operation, software, and launcher and recovery systems. Some minor maintenance and troubleshooting instructions can be included. |
| Ground Control Station | GCS | Includes all systems and devices associated with the operation, flight, command and control, navigation, and configuration of the aircraft to conduct its intended task or mission. The GCS is used as the human-in-loop interface with the aircraft during its flight. |

# APPENDIX 4: SAMPLE OF LEVEL 1 DATA TABLE

| Aircraft Specifications & Class | | | | | Maintenance Data & Documentation (Level 1) | | | Training Programs (Task 4) (Level 1) |
|---|---|---|---|---|---|---|---|---|
| **Model** | **OEM** | **Max TO Weight (lbs)** | **Risk Class (Vc)** | **Operational Class (Application)** | **Maint Documentation Available** | **Mx Data Quality/Level** | **Maintenance Records Used (Task 3a)** | **Training Programs Offered** |
| Aero-M | 3DRobotics | 6.8 | 1 | Commercial | OM | 3 | Yes | Flight |
| X8-M | 3DRobotics | 7.7 | 2 | Commercial | OM | 3 | Yes | Flight |
| Iris | 3DRobotics | 2.8 | 1 | Commercial | OM | 3 | | Flight |
| Solo | 3DRobotics | 3.9 | 1 | Commercial | OM, AMM | 3 | | Flight |
| Puma AE | Aerovironment | 13.5 | 2 | Dual Use | IPC, AMM, EMM, CMM, FIM, SL, SB, EO, FM | 2 | Yes | Flight, Servicing & ground operations/Line/Organizational-level/Field Maintenance, Inspection |
| Raven | Aerovironment | 4.2 | 1 | Dual Use | IPC, AMM, EMM, CMM, FIM, SL, SB, EO, FM | 2 | Yes | Flight, Servicing & ground operations/Line/Organizational-level/Field Maintenance, Inspection |
| SkyRanger | Aeryon Labs Inc. | 6.6 | 1 | Dual Use | SD, OM | 2 | Yes | Flight, Inspection |
| ScanEagle | Boeing/Insitu | 48.5 | 2 | Dual Use | IPC, AMM, EMM,FIM SD, FM | 2 | Yes | Flight, Servicing & Ground Operations/Line/Organizational-Level/Field Maintenance, Inspection |
| Blackjack | Boeing/Insitu | 135 | 2 | Defense/Homeland Security | IPC, AMM, EMM,FIM SD, FM | 2 | Yes | Flight, Servicing & Ground Operations/Line/Organizational-Level/Field Maintenance, Inspection |
| Matrice 100 | DJI | 7.5 | 2 | Commercial | OM | 3 | | Flight |
| Phantom 3 | DJI | 2.8 | 1 | Commercial | OM | 3 | | Flight |
| S900 Spreading Wings | DJI | 18.1 | 2 | Commercial | OM | 3 | | Flight |
| Inspire 1 | DJI | 6.5 | 2 | Commercial | OM | 3 | Yes | Flight |
| S1000 Spreading Wings | DJI | 25.25 | 2 | Commercial | OM | 3 | Yes | Flight |
| Predator XP | General Atomics | 2550 | 4 | Military | IPC, AMM, EMM, CMM, FIM, SL, SB, EO, FM, Integrated Electronics Technical Manual | 2 | Yes | Flight, Servicing & ground operations/Line/Organizational-level/Field Maintenance, Overhaul/Heavy/Depot/Sustainment Maintanance, Inspection, Avionics and Composites |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Gray Eagle | General Atomics | 3600 | 4 | Military | IPC, AMM, EMM, CMM, FIM, SL, SB, EO, FM | 2 | Yes | Flight, Servicing & ground operations/Line/Organizational-level/Field Maintenance, Inspection, Ground Station, automated landing system, site surveys, portable electric power requirements |
| Predator B "Reaper" | General Atomics | 1050 | 4 | Military | IPC, AMM, EMM, CMM, FIM, SL, SB, EO, FM, Integrated Electronics Technical Manual | 2 | Yes | Flight, Servicing & ground operations/Line/Organizational-level/Field Maintenance, Overhaul/Heavy/Depot/Sustainment Maintanance, Inspection, Avionics and Composites |
| Predator C Avenger | General Atomics | 18200 | 6 | Military | IPC, AMM, EMM, CMM, FIM, SL, SB, EO, FM, Integrated Electronics Technical Manual | 2 | Yes | Flight, Servicing & ground operations/Line/Organizational-level/Field Maintenance, Overhaul/Heavy/Depot/Sustainment Maintanance, Inspection, Avionics and Composites |
| Fire Scout "MQ-8B" | Northrup Grumman | 3150 | 4 | Dual Use | IPC, AMM, EMM, FIM, SL, SB, FM | 2 | Yes | Flight, Servicing & ground operations/Line/Organizational-level/Field Maintenance |
| Global Hawk "WAS" | Northrup Grumman | 32250 | 6 | Military | IPC, AMM, EMM, FIM, SL, SB, FM | 2 | Yes | Flight, Servicing & ground operations/Line/Organizational-level/Field Maintenance |
| Camcopter S-100 | Schiebel | 440 | 3 | Dual Use | IPC, AMM, EMM, CMM, FIM, SL, SB, FM, Spectral Approval Guide, Ships Oerations Manual, Payload Integration Manual | 1 | Yes | Flight, Servicing & ground operations/Line/Organizational-level/Field Maintenance, Overhaul/Heavy/Depot/Sustainment Maintanance, IFR Flight, Intelligent Surveillance, Sensor, Ground Station |
| EBEE | Sensefly | 1.5 | 1 | Commercial | IPC, AMM, FM, OM | 3 | Yes | Flight, Servicing & Ground Operations/Line/Organizational-Level/Field Maintenance, Inspection |
| Aerosonde Mk 4.7 | Textron Systems/AAI | 55 | 2 | Dual Use | AMM, EMM | 3 | Yes | |
| Shadow M2 "RQ-7B" | Textron Systems/AAI | 375 | 3 | Dual Use | IPC, AMM, EMM, CMM, FIM, SL, SB, EO, FM | 2 | Yes | Flight, Servicing & ground operations/Line/Organizational-level/Field Maintenance, Inspection, Ground Station, automated landing system, site surveys, portable electric power requirements, launching mechanism |
| Penguin B | UAV Factory | 47.3 | 2 | Commercial | AMM, EMM | 3 | Yes | |

## APPENDIX 5: SAMPLE OF LEVEL 2 DATA TABLE

| Aircraft and Classification | | | | Maintenance Data & Documentation (Level 2 Surveys) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **OEM** | **Model** | **Risk Class (Vc)** | **Operational Class (Application)** | **1. What are the recommended and/or required maintenance schedules for aircraft (intervals)?** | **2. What type of scheduled and unscheduled maintenance procedures are provided for the aircraft?** | **3. Is there guidance that outlines the classification of field versus depot/factory level maintenance tasks? YES NO Please describe:** | **3a. Any given definitions for major repairs and alterations?** | **4. What maintenance items are included in operational checklists (pre/post flight)?** | **5. Are there Pass/Fail criteria for inspection items within maintenance tasks?** |
| Aeryon Labs Inc. | SkyRanger | 1 | Dual Use | None. Basic Preflight and cndition inspection. | Preflight and Postflight | No. If cannot be repaired by operator through User's Guide must be returned to OEM. | No | Basic visual. Props, body, landing gear. | Yes |
| Boeing/ Insitu | ScanEagle | 2 | Dual Use | Aircraft and component level based on time, cycles and calender dates if stored. | Mostly for aircraft.Quite a few. | Yes, if in AMM it is field level. | Yes, all composite damage is cnsidered major. | Standard aircraft walkaround, payload instructions, servo control chanel with GCS | Yes |
| Boeing/ Insitu | Blackjack | 2 | Dual Use | Aircraft and component level based on time, cycles and calender dates if stored. | Mostly for aircraft.Quite a few. | Yes, if in AMM it is field level. | Yes, all composite damage is cnsidered major. | Standard aircraft walkaround, payload instructions, servo control chanel with GCS | Yes |
| General Atomics | Gray Eagle | 4 | Military | Yes, required mx schedules based on cycles, flight hours, landings, calendar time. Depends on system. Defined by manufacture. Similar to TC aircraft. | Yes, have maint. Procedures for scheduled and unscheduled.<br>- Scheduled based on defined intervals, incl visual inspections, replacement of life limited components. Similar to manned acft. Added systems incl. redundant and b/u sys + battery checks and replacement. Found in IETM.<br>- Unscheduled, found in IETM, incl. T-shoot manual w/i different section of IETM. | YES. Defined by given maintainers access to approved data.<br>- Field Maint/Flight Line Maint (operator)- approved tasks listed in IETM<br>- Field Svc (OEM Reps) - access to additional OEM manuals (electronic)<br>- OEM Maint - Maint cannot be performed in field returned to mfg.<br>- Limitations defined by available technical documentation to user, tooling and skills. | Not specifically defined as within FAA, but could be if it were necessary. Repair level determined on a case by case basis.<br>- If repair/task in IETM, soldier level<br>- if OEM involved, could progress to major repair repair. | Each item has specific items to check and are extensive in DTM (Digital Technical Manual)<br>- Command & Control units<br>- GCS<br>- Aircraft<br>Visual inspections to airframe and powerplant similar to manned acft.<br>- Use Army published inspection work cards (electronic or paper) found on DTM (ruggadized PC) | |
| Sensefly | EBEE | 1 | Commercial | 100 hour servicing at OEM or distributer | Preflight, config checks, prop repair, wing repair, foam repair | Yes, if in OM owner can do | no | Basic aircraft inspection, flight control functionality, GCS operations check | Yes |

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| Aircraft and Classification | | | | Maintenance Data & Documentation (Level 2 Surveys) | | | | |
|---|---|---|---|---|---|---|---|---|
| **OEM** | **Model** | **Risk Class (Vc)** | **Operational Class (Application)** | **6. What maintenance practices or tasks are performed for non-flying equipment (i.e. ground control stations, antennas, datalink hardware, etc.)** | **7. Are troubleshooting procedures available for both hardware (airframe/propulsion) and software (Aircraft electronics/sensors/payload)? YES NO** | **7a. What are the common T-shoot tasks performed? (ID airframe/propulsion /software)** | **8. What are the software and firmware maintenance and updating practices?** | **9. How is aircraft/sensor/payload configuration managed?** |
| Aeryon Labs Inc. | SkyRanger | 1 | Dual Use | Basic functional check of GCS | No | N/A | Online and through GCS | By GCS or through web based interface |
| Boeing/ Insitu | ScanEagle | 2 | Dual Use | Have detailed maintenance manual for non-flying equiment like GCS. | Yes | Basic systems on aircraft and C2 link. | Sensor calibrations and full control of firmware version. | Documented in logbook. Available configuration depends on the customer i.e. DOD vs civil |
| Boeing/ Insitu | Blackjack | 2 | Dual Use | Have detailed maintenance manual for non-flying equiment like GCS. | Yes | Basic systems on aircraft and C2 link. | Sensor calibrations and full control of firmware version. | Documented in logbook. Available configuration depends on the customer i.e. DOD vs civil |
| General Atomics | Gray Eagle | 4 | Military | Similar to IETM for acft, but separate section for specific equipment.<br>- Includes setup procedures (for deployment)<br>- Mobility is key, shipped to locations where needed frequently.<br>- Manned acft has fixed infrastructure for all ops.<br>- Unmanned must take its operational infrastructure w/ unit)<br>- Must accomodate specific Nav Lanes for its ops. | YES. | Avionics:<br>- Data link issues most frequent<br>- Operator error, EQ failure, environmental (buildings, terrain)<br>- EMI not an issue with these acft due to engineering and design<br>- GPS units, location, NAV<br>Airframe/Engine:<br>- Typical engine problems like manned (recip engine)<br>- Vibration (camera 'sees' high vibs)<br>- Propeller balance<br>- Leaks<br>- Temps out of range | - Performed as issues arise to patch, tested by OEM extensively first<br>- Data loader download to acft (no wireless)<br>- All systems are electrically operated and controlled, therefore All systems are integrated and in communication in the control s/w<br>- Before download, check current version on acft, then select version needed, download as required<br>- Some components may require separate connector and download independently.<br>- ex. INS/GPS vice flight control system (integrated) | - Performed by on-board s/w<br>- Can also do manual s/w version checks<br>- Logbook contains current s/w versions<br>- will contain some controlled components s/n, p/n, etc. |
| Sensefly | EBEE | 1 | Commercial | Vehicle and GCS firmware compatiblity, GCS synced to MySensefly.com for updates. | Yes | Not identified | GCS and vehicle syned to website | Through GCS and website |

| Aircraft Specifications & Class | | | | Reporting & Record Requirements (Level 2) | | |
|---|---|---|---|---|---|---|
| **OEM** | **Model** | **Risk Class (Vc)** | **Operational Class (Application)** | **10. How are maintenance and inspection tasks recorded?** | **11. What are the Manufacturer's methods for resolving reported difficulties and issuing safety directives? (How are they communicated to the technician to ensure appropriate information and tasks are communicated?)** | **12. How are in-service difficulty reports documented and processed?** |
| Aeryon Labs Inc. | SkyRanger | 1 | Dual Use | Manually through operator logs and through website. | Through support networks, service bulletns and online. | Published bulletins |
| Boeing/Insitu | ScanEagle | 2 | Dual Use | Logbook | Service Bulletins and advisories through email then confirms compliance with login. | See 11 |
| Boeing/Insitu | Blackjack | 2 | Dual Use | Logbook | Service Bulletins and advisories through email then confirms compliance with login. | See 11 |
| General Atomics | Gray Eagle | 4 | Military | - UAS-I, Unmanned Aircraft Systems Initiative (eLogbook)<br>- Logbook can be both paper and electronic<br>- Equipment R2 use removal tags, new units have serviceable tag attached (like manned acft) | - Use alert and service bulletins published by the OEM.<br>- Can be sent via email for immediate notification<br>- Available in the Tech Ref library<br>- US Army has separate reporting method | - Depends on issue:<br>- Low level - Logbook<br>- High level - logbook + speak to engineering<br>- Field discrepency reports completed by FSR as issue tracking method. Completed for any anomaly or inop LRU. |
| Sensefly | EBEE | 1 | Commercial | Logbooks - may go digital in the future. Flight logging. | Through letters, email and MySensefly.com | Documented hitorically on website. |

| Aircraft Specifications & Class | | | | Training Programs (Task 4) (Level 2) | | | | |
|---|---|---|---|---|---|---|---|---|
| **OEM** | **Model** | **Risk Class (Vc)** | **Operational Class (Application)** | **3b. Are their technician qualification and training specific to major repairs and alterations?** | **13. What are the maintenance technician qualification and training requirements?** | **13a. Are specialists required? What are they?** | **14. Are manufacture/factory/operator training courses available for technicians?** | **14a. What type of courses do they take?** |
| Aeryon Labs Inc. | SkyRanger | 1 | Dual Use | no | none | no | no | none |
| Boeing/Insitu | ScanEagle | 2 | Dual Use | OEM - Yes | | Pilot or Maintainer - outlined in qualifications manual | Yes | |
| Boeing/Insitu | Blackjack | 2 | Dual Use | OEM - Yes | | Pilot or Maintainer - outlined in qualifications manual | Yes | |
| General Atomics | Gray Eagle | 4 | Military | YES, generated by the OEM specific to specialty or function of the Field Technician | See GA-ASI Survey (L1) | Yes.<br>Avionics:<br>- NCATT UAS or AET certificate w/ endorsements<br>Aircraft Maint:<br>- A&P Mechanic<br>UV is too complex for one person to have required competencies across all systems. Best to have specialization due to complexity and competency loading required. | YES. See GA-ASI Survey (L1) | See GA-ASI Survey (L1)<br>- Avionics and Mechanics take platform specific courses. |
| Sensefly | EBEE | 1 | Commercial | N/A | N/A | N/A | N/A | N/A |