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

Task 8: Final Report

20 July 2017

Final Report

NOTICE

Legal Disclaimer: The FAA has sponsored this project through the Center of Excellence for Unmanned Aircraft Systems. However, the agency neither endorses nor rejects the findings of this research. The presentation of this information is in the interest of invoking technical comment on the results and conclusions of the research.

Technical Report Documentation Page

Title: A.5 UAS Maintenance, Modification, Repair, Inspection, Training, and Certification Considerations – Task 8: Final Report

Report Date: 8 June 2017

Performing Organizations: Kansas State University (KSU) Polytechnic Campus, Northland Community Technical College (NCTC), Embry Riddle Aeronautical University (ERAU), and Montana State University (MSU)

Authors: Charles Nick, Caleb Scott, Zackary Nicklin, John Robbins, Richard Stansbury, Doug Cairns

Performing Organization and Address:

Kansas State University
Applied Aviation Research Center
2310 Centennial Rd., Salina, KS 67401
Salina, KS 67401

Embry Riddle Aeronautical University
600 S. Clyde Morris Blvd
Daytona Beach, FL 32114

Northland Community Technical College
13892 Airport Drive
Thief River Falls, MN 56701

Montana State University
211 Montana Hall
Bozeman, MT 59717

Sponsoring Agency Name and Address:

U.S. Department of Transportation
Federal Aviation Administration
Washington, DC 20591

TABLE OF CONTENTS

*The Appendices are available separately as standalone reports.

LIST OF FIGURES

Figure Page

LIST OF TABLES

Table Page

LIST OF ACRONYMS

A&P	Airframe and Powerplant
AC	Advisory Circular
ACE-100	FAA Small Airplane Directorate
AET	Aircraft Electronics Technician
AFS-80	FAA Unmanned Aircraft Systems (UAS) Integration Office
AIM	Aeronautical Information Manual
ASI	Aviation Safety Inspector
ASIAS	Aviation Safety Information Analysis and Sharing
ASRS	Aviation Safety Reporting System
ASTM	American Society for Testing and Materials
ASW-100	FAA Rotorcraft Directorate
ATC	Air Traffic Control
AUVSI	Association for Unmanned Vehicle Systems International
BVLOS	Beyond Visual Line of Sight
CFR	Code of Federal Regulations
COA	Certificate of Waiver or Authorization
CS	Control Station
DACUM	Development of a Curriculum
EASA	European Aviation Safety Agency
EPO	Expanded Polyolefin
EPP	Expanded Polypropylene
ERAU	Embry-Riddle Aeronautical University
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FMEA	Failure Mode Effects & Analysis
FOD	Foreign Object Debris
FOE	Foreign Object Elimination
FRP	Fiber-Reinforced Polymer
FTA	Fault Tree Analysis
GCS	Ground Control Station
GROL	General Radiotelephone Operator's License
GSE	Ground Support Equipment
KSA	Knowledge Skills and Abilities
KSU	Kansas State University
M&R	Maintenance & Repair
MPP	Maintenance Procedural Profile
MR	Maintenance Repair
MRP	Maintenance Record Profile
MSU	Montana State University
NAS	National Airspace System
NCATT	National Center for Aerospace and Transportation Technologies

NCTC	Northland Community and Technical College
NMAC	Near Mid Air Collision
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
R&R	Remove & Replace
RTA	Road and Transport Authority
SC1	Skill Class 1
SC2	Skill Class 2
SC3	Skill Class 3
SOW	Statement of Work
sUA	Small Unmanned Aircraft
sUAS	Small Unmanned Aircraft System
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System

EXECUTIVE SUMMARY

The Unmanned Aircraft System (UAS) industry continues to enjoy rapid growth toward full and seamless airspace integration creating the need for this research project, which is to assist the Federal Aviation Administration (FAA) to safely integrate this new technology into the National Airspace System (NAS). Kansas State University (KSU), Embry-Riddle Aeronautical (ERAU), Montana State University (MSU), and Northland Community Technical College (NCTC) conducted a two-year research project to identify the requirements and considerations for UAS maintenance, modification, repair, inspection, training, and technician certification by building upon the existing body of knowledge for sustaining UAS. The research team collected and consolidated current UAS practices from industry and developed recommended requirements to ensure that risks of maintenance-induced failures are minimized.

This final report summarizes all research activities: (1) performing a gap analysis between the current regulatory and operational states, (2) updating a prototype FAA UAS maintenance and repair database, (3) developing recommended technician certification requirements, (4) conducting air traffic simulations to understand the effects of maintenance-induced failures (with operational impact analysis), (5) providing process recommendations for the FAA and commercial repair stations as they integrate this technology into their training and operational environments, and finally, (6) making recommendations for UAS maintenance-related accident reporting requirements.

The research team conducted a gap analysis comparing the current state of the UAS industry with the three most relevant FAA regulations (14 Code of Federal Regulations [CFRs] Parts 43, 65, and 147). To accomplish this gap analysis, four in-depth analyses were conducted to identify the maintenance technician skills required for unique UAS considerations: non-metallic materials, communication links, control stations and support equipment, software and autopilots. The in-depth analyses identified 29 UAS-specific skills which need to be accounted for in future regulations. These skills were segmented by a 3-tier skill classification developed for scalability of the recommended requirements. The 3-tier skill classifications are proposed so that maintenance training is scaled based on skills required to perform required tasks which vary depending on system complexity, rather than risk classification which is based on operational risk. Ultimately, recommended requirements were proposed to bridge the gaps in the 14 CFR Parts 43, 65, and 147.

It is also recommended that all 29 UAS skills be included in the FAA Aviation Safety Inspector's (ASI) familiarization training using the same 3-tier skill classification methodology. Recommendations are also proposed for 14 CFR Part 145 (repair stations) to add new UAS technician ratings (§ 145.59) as well as segregation requirements for UAS parts and materials.

For research activities aimed at updating the Maintenance & Repair (M&R) database, it became apparent that vehicle and system reliability information is not publicly available; most organizations utilize a logbook system containing daily flight data as well as incident information. The recommendations for UAS accidents/incident reporting requirements analyzed manned and unmanned accident databases and recommended that the Aviation Safety Information Analysis and Sharing (ASIAS) program be expanded to serve as the centralized repository for UAS information as well.

In Air Traffic Control (ATC) simulations, 42 scenarios of maintenance-induced failure simulations were conducted which identified that incidents over populated areas occurred 14% of the time. This highlights an urgent need for UAS maintenance technician certification to ensure safe operations in the national airspace (NAS). The research team recommended the creation of indicators for the UAS operator to detect and resolve operational failures. Emergency situation best practices were also proposed for ATC personnel recommending UAS contingency flight plans to be filed before flight.

This research project set a foundation for top-level requirements for maintenance technicians, training institutions, repair stations, and aviation safety inspectors, but follow-on work is needed to build upon this foundation. Follow-on work should address the following: (1) continued acquisition of reliability data through updates to the M&R database and incident/accident forms, (2) improvements to UAS industry standards using scalable requirements with the 3-tier skill classification system and better define Part 147 recommendations, (3) detailed repair analysis on the popular foams and other non-traditional materials used for construction of small UAS (sUAS), (4) a better understanding of UAS manufacturing reliability and process for parts and, (5) developing more complex simulations for maintenance-induced failures.

1. Scope

Table 1 shows the relationship of this report to other tasks in the ASSURE A.5 project: UAS Maintenance, Modification, Repair, Inspection, Training, and Certification Considerations. This report, *Task 8: Final Report*, summarizes the efforts for the entire ASSURE A.5 project.

Table 1 – A.5 Work Breakdown Structure

Task	Description	Team
Task 1	Review of Existing Maintenance Programs and Data	KSU, ERAU
Task 2	Update Maintenance and Repair Prototype Database	KSU
Task 3	Review of Maintenance Technician Training	NCTC
Task 4	Develop Maintenance Technician Training Certification Requirements	KSU
Task 5	Conduct Simulations Focused on UAS-ATC Procedures	ERAU
Task 6	Support UAS Certification Efforts, ASI training and Repair Station Criteria	KSU, ERAU
Task 7	Examine Requirements for Maintenance-Related Accident Reporting	ERAU
Task 8	**Final Report**	**KSU**

2. Introduction

The purpose of the A.5 research project is to identify the maintenance, modification, repair, inspection, training, and certification considerations that are necessary to ensure continued airworthiness of Unmanned Aircraft Systems (UAS). The project began in Task 1 by assessing the current state in the industry of UAS maintenance practices with a literature review of UAS documents and surveys of operators and manufacturers. This was followed by surveys of maintenance technicians performed in Task 3 and finally a gap analysis with in-depth analyses for special UAS considerations to provide UAS maintenance technician certification recommendations in Task 4.

Some tasks were directly associated to one another providing input and output dependencies, while other tasks, like Task 2, Task 5 and Task 7, were largely independent tasks containing their own conclusions. The primary goal of Task 2 was to add more information to the FAA's Maintenance & Repair (M&R) Prototype Database. The goal of Task 5 was to simulate ATC procedures for handling UAS maintenance-induced failures. The goal of Task 7 was to provide recommendations for accident/incident reporting recommendations.

All deliverables for the A.5 project are summarized and included in this culmination report. Table 2 provides a summary of all deliverables associated with each task and Appendix.

Table 2 – Tasks and Referenced Documents

Task	Documents & Deliverables	Appendix	Type
Task 1	Review of Existing UAS Maintenance Data	A	Report
	Draft Technical Report of UAS Maintenance Data Preliminary Analysis	B	Report
Task 2	Dashboard for Maintenance Procedural and Record Profiles	C	
	Update Maintenance & Repair Prototype Database	D	Report
	*UAS Maintenance Procedural Profile		Excel File
	*UAS Maintenance Record Profile		Excel File
Task 3	Survey Results and Technical Review of UAS Maintenance Technician Training Standards	E	Report
Task 4	Draft Technical Report of UAS Maintenance Technician Training Criteria and Draft Certification Requirements	F	Report
Task 5	Conduct Simulations Focused on UAS-ATC Procedures: Preliminary Report	G	PowerPoint
Task 6	Draft Technical Report of UAS Repair Station Criteria	H	Report
Task 7	Examine Requirements for Maintenance Related Accident Reporting	I	Report

*The two Excel files comprise a database that is summarized in a "Dashboard." The Excel files are attached to this PDF portfolio.

The key components of this research included: 1) review existing data available for maintaining UAS of all sizes, 2) compare existing maintenance data for UAS with the type of data available for manned aircraft, 3) determine if a delineation between different types/sizes of UAS is needed to establish varying thresholds of maintenance rigor, 4) identify best practices for maintaining various classes of UAS within the context of their operational environment, 5) compile the current training materials and qualifications required for various UAS platforms, and 6) recommend training and certification requirements for UAS maintenance technicians and repair stations across the spectrum of all UAS classes.

The primary research questions answered through this research are:

1. What is the current state of UAS maintenance practices and training throughout the industry?
2. How does the current state of UAS maintenance practices and training compare to manned aviation practices?
3. What are the elements that comprise UAS maintenance for all types/sizes of UAS?
4. What are the unique elements of UAS maintenance that differ from manned aircraft maintenance and what is their implication on training and certification?
5. What are the unique considerations for non-metallic material structures of UAS?
6. Is there a need to delineate between different risk classes of UAS when determining maintenance and training requirements?
7. What are the consequences of maintenance-induced failures in UAS?
8. What standards exist, or need to be developed, for determining requirements and capabilities of entities that modify and/or repair UAS?

When the A.5 project began in September 2015, the current FAA regulations for UAS only included the 333-exemption process. Shortly thereafter on June 21, 2016, Part 107 was released to help segment initial UAS commercial operations. This project took into consideration the new Part 107 requirements for UAS in order to help further define scalable requirements useful for the FAA's implementation of UAS in the National Airspace System (NAS).

All of these research tasks were built upon prior research to develop solid, justifiable recommendations to the FAA on how UAS should be maintained to support the FAA's roadmap to integrate UAS into the NAS. The results of this project will inform the Federal rulemaking process in this area.

Each of the following sections provide summaries of the task deliverables identified in Table 2.

3. Task 1: Review of Existing Maintenance Programs and Data

Table 3 – Task 1 Work Breakdown Structure

Task 1	**Review of Existing Maintenance Programs and Data**	**Contributors**
Task 1a	Perform literature review of relevant publications, standards, and regulatory requirements for manned and unmanned aircraft maintenance.	ERAU
Task 1b	Review of M&R prototype database for relevant data to be collected	KSU
Task 1c	Identification of UAS manufacturers and operators in each category/class of UAS with existing maintenance programs	KSU
Task 1d	Collection of maintenance program information from manufacturers	KSU
Deliverable 1	*Review of Existing UAS Maintenance Data*	KSU, ERAU
Task 1e	Analysis of UAS maintenance data	KSU
Deliverable 2	*Draft Technical Report of UAS Maintenance Data Preliminary Analysis*	KSU

The first task completed for the A.5 research project was to review existing Unmanned Aircraft System (UAS) maintenance program and data. The initial findings revealed a lack of knowledge and industry wide understanding of continued airworthiness of UAS maintenance practices. Maintenance practices varied from operator to original equipment manufacturer (OEM), the level of maintenance procedures and corresponding manuals varied greatly, and the skill set required to perform maintenance also varied for all parties interviewed.

The information captured in this task from many UAS types, sizes and operational environments provided a clear path forward for the rest of the tasks in this project. Preliminary data collected included maintenance practices and technical documentation, reporting requirements, maintenance records and existing UAS maintenance technician training. Two oral surveys were performed with twenty-five UAS industry participants. Information was also captured from the Association for Unmanned Vehicle Systems International (AUVSI) database identifying 54 different Unmanned Aircraft (UA) applicable to this study.

Due to the early timing of this task, the initial categorization of UA's were divided per the six risk classes as defined by the unpublished FAA Advisory Circular (AC) designated "AC20-xx-xx", which addressed 14 CFR § 21.17(b). Regardless of the initial classification used, the goal was successful identification of UA's across the entire spectrum of size, weight and operational use of the UAS industry.

The surveys and interviews with military and commercial UAS operators resulted in a wide range of information covering all types/sizes of UAS, including information on currently existing maintenance-training programs. The following generalizations are key takeaways from the Task 1 report related to maintenance technician training:

- Maintenance training is rare for commercial operations. Commercial operations typically employ small UAS for which operational training is the primary training provided.
- While military and dual use UAS tend to have independent operational and maintenance manuals, commercial operators traditionally rely on a single manual that contains both operational and maintenance data.
- In the evaluation of technical documents used during maintenance, military and dual-use operators had a more complete set of manuals in comparison to the commercial operators, whose documentation consisted primarily of Owner/Operator Manuals.
- All respondents surveyed, including both military and commercial, utilized maintenance records.
- Military operations are associated with specialists trained in the maintenance of specific systems. This training can include inspections, servicing and overhaul. Commercial operators, typically, only receive flight training.

Associated Deliverable: Appendix A: Review of Existing UAS Maintenance Data Appendix B: Draft Technical Report of UAS Maintenance Data Preliminary Analysis

4. Task 2: Update Maintenance and Repair Prototype Database

Table 4 – Task 2 Work Breakdown Structure

Task 2	**Update Maintenance and Repair Prototype Database**	**Contributors**
Task 2a	Update existing M&R database with newly collected information from Task 1	KSU
Task 2b	Develop new analytical tools for the M&R database to extract information	KSU
Deliverable	*Dashboard for Maintenance Procedural and Record Profiles* *Updates Maintenance & Repair Prototype Database*	KSU

The primary focus of A.5 Task 2 involved updating and populating the Maintenance and Repair (M&R) Prototype Database, which was provided to researchers at Kansas State University (KSU) by the Federal Aviation Administration (FAA). The M&R Prototype Database was generated in 2013 as a result of the FAA's desire to collect Original Equipment Manufacturers (OEM) technical maintenance and inspection practices as well as in-service difficulty reporting in an effort to be alerted to trends that may require FAA communication and action. The purpose and function of the database was to provide incident and accident reporting information similar to existing databases created for Type Certificated (manned) aircraft. The intent was to have the M&R database populated on a voluntary basis by OEM and operators to build a technical library of standard maintenance practices, inspection intervals, and failure records for UAS systems.

Upon delivery to KSU, the M&R Prototype Database was converted from an Oracle database to an Excel spreadsheet to more easily capture information. This split the database into two separate documents: the UAS Maintenance Record Profile and the UAS Maintenance Procedural Profile. The UAS Maintenance Record Profile was designed to capture maintenance actions and operational failures logged by the participants. The UAS Maintenance Procedural Profile was designed to capture maintenance manual information to help identify existing maintenance procedures including intervals, corrective actions and more.

As of 7/13/17, over 110 UAS operators and manufacturers were contacted to request manuals and logbook data. Three operators have provided logbook data and maintenance manuals for 13 different UAS. The Maintenance Record Profile currently contains 157 entries, which contains sufficient data to allow for statistics to be drawn from the spreadsheet. A few statistics include:

- ~95% of maintenance actions were unscheduled.
- ~71% of failures did not result in an aircraft crashing.
- ~54% of maintenance actions were repairs.
- The UAS with the most failures was the 3DRobotics Aero.
- The most common type of failure was related to the autopilot.
- Most entries were from small UAS (sUAS), or UAs weighing 55 lbs. or less.

Associated Deliverables:
Appendix C: Dashboard for Maintenance Procedural and Record Profiles
Appendix D: Update Maintenance & Repair Prototype Database
UAS Maintenance Procedural Profile – MR (attached to pdf)
UAS Maintenance Record Profile – MR (attached to pdf)

5. Task 3: Review of Maintenance Technician Training

Table 5 – Task 3 Work Breakdown Structure

Task 3	**Review of Maintenance Technician Training**	**Contributors**
Task 3a	Review UAS industry standards and best practices for maintenance practices and record requirements of UAS	NCTC
Task 3b	Review training requirements for maintenance technicians from data collected	NCTC
Task 3c	Survey of UAS maintenance technicians to identify trends in significant challenges	NCTC
Deliverable 1	*Results of UAS maintenance technician survey (combined with Deliverable 2)*	NCTC
Task 3d	Analysis of training program review with significant findings	NCTC
Deliverable 2	*Survey Results and Technical Review of UAS Maintenance Technician Training Standards*	KSU, NCTC

The purpose of Task 3 was to define the current state of maintenance technician training standards and requirements in the UAS industry today. Unlike the manned aviation maintenance industry, the growing UAS industry currently lacks regulation to define a training curriculum for maintenance technicians, such as the strict controls through Part 147 that govern the training process for manned maintenance technicians. Currently only Unmanned Aircraft (UA) weighing 55 lbs. or less are approved for routine commercial operations in the United States under Part 107 representing Small Unmanned Aircraft Systems (sUAS).

This research administered a written survey to key UAS industry personnel and a literature review of existing standards. Some key findings include identifying four maintenance specialties for larger UAS including: Mechanic, Avionics, Data Link and Control Station (CS) and the three most reported existing certificates were the Federal Communications Commission (FCC) General Radiotelephone Operator's License (GROL), National Center for Aerospace and Transportation Technologies (NCATT) Aircraft Electronics Technician (AET) and CompTIA's Security + Certificate. Surveys with UAS maintenance technicians and hiring managers elicited the following industry challenges:

(1) A need for an exclusive electronics and avionics centered program separate from an Aircraft and Powerplant (A&P) program.
(2) A lack in basic networking, computer maintenance and associated troubleshooting content.
(3) A lack of formal maintenance training programs from manufacturers.

Three primary standards were identified in this research applicable to UAS:

(1) American Society for Testing and Materials (ASTM) F2909-14 Standard Practice for Maintenance and Continued Airworthiness of Small Unmanned Aircraft Systems (sUAS) [1]
(2) The National Center for Aerospace and Transportation Technologies' (NCATT) Standard Unmanned Aerial Systems (UAS) Maintenance Technician Certification [2]

(3) The Development of a Curriculum (DACUM) Research Chart for UAS Maintenance Technicians [3]

The ASTM F2909-14 standard provides a detailed list of tasks that can be performed for typical preflight inspections, periodic inspections, rules for repairs and alterations, as well as best practices for maintaining maintenance records. Although the standard is currently being revised, it will be a strong addition to the Preflight Inspection Items list as identified in Airworthiness Circular (AC) 107-2 Section 7.3.4.

The NCATT UAS Maintenance Technician Certification defines a broad and general skill set for UAS, but can be improved by implementing scaled requirements to account for the significant variation in maintenance skills required for small UAS compared to larger UAS. Initially, the FAA's unpublished risk classification, which utilizes six separate classifications based on kinetic energy, was used to delineate between UAS classes. This taxonomy was not well suited to categorizing maintenance and training because kinetic energy and/or unmanned aircraft performance is not directly related to the skills required to maintain an unmanned aircraft or the other components of an unmanned system. Instead, to assist with the development of scalable requirements, the results in this report are presented using a 3-tiered classification system referred to as skill classes. The skill classification taxonomy defined organizes the full spectrum of UAS by skills required to maintain and repair UAS according to both equipage and complexity.

The DACUM document provides a bullet point list of general knowledge and skills, future trends and concerns, worker behaviors, acronyms, related certifications, tools, equipment, supplies and materials. The purpose of the DACUM is to guide schools that are seeking to build the curriculum for a degree in UAS maintenance. The DACUM lists UAS tasks for 12 separate duties including the following:

A. Comply with UAS Health and Safety Protocols
B. Comply with Foreign Object Elimination (FOE, aka Foreign Object Debris (FOD)) Policies and Procedures
C. Comply with UAS Maintenance Documentation
D. Perform UAS Ground Control Station (GCS) Maintenance
E. Maintain UAS Datalinks
F. Perform UA Maintenance
G. Manage UAS Ground Support Equipment (GSE, aka support equipment)
H. Execute UA Flight Operations
I. Manage UAS Parts
J. Perform UAS Administrative Functions

Associated Deliverable: Appendix E: Survey Results and Technical Review of UAS Maintenance Technician Training Standards

6. Task 4: Develop Maintenance Technician Training Certification Requirements

Table 6 – Task 4 Work Breakdown Structure

Task 4	**Develop Maintenance Technician Training Certification Requirements**	**Contributors**
Task 4a	Review manned maintenance technician regulations, standards, and best practices	NCTC
Task 4b	Gap analysis of manned versus unmanned maintenance technician tasks	KSU, ERAU, MSU, NCTC
Task 4c	In-depth analysis of areas that require special considerations	KSU, ERAU, MSU, NCTC
Task 4d	Develop [technician] certification (Part 65) and training requirements (Part 147)	KSU, ERAU, MSU, NCTC
Deliverable	*Draft Technical Report of UAS Maintenance Technician Training Criteria and Draft Certification Requirements*	KSU, ERAU, MSU, NCTC

The goal of Task 4 was to create a list of recommendations for UAS maintenance technician training certification requirements. This task received inputs from Task 1 and Task 3 outcomes. Over 20 government, industry and academic sources were considered along with 50 additional sources identifying the primary specifications and standards from Task 3 that are currently leading the UAS industry requirements with respect to maintenance.

Six primary elements for UAS were identified for this research: Unmanned Aircraft (UA), Command and Control Element (includes autopilot and control station), launch and recovery, communication data link, human element, and payload. These elements corresponded to the four in-depth analyses performed for this task: (1) the structures used on the UA (non-metallic materials), (2) the autopilot, (3) the control station and support equipment, and (4) the communication link and software, which is integrated throughout most of the UAS elements.

The first in-depth analysis researched non-metallic material structures. The result was material evaluations and recommendations for the maintenance and repair of non-metallic materials commonly used in UAS. Multiple classes of unmanned aircraft are accounted for and grouped by size, structural materials, and potential effects on public safety in the event of a system failure. This information may be used to identify and mitigate risk factors associated with the integration of unmanned aircraft systems into the national airspace.

The materials and fabrication techniques used for the structural components of a UAS are the result of a balance between cost, desired flight characteristics, and expected load requirements. This leads to the widespread use of lightweight non-metallic materials, such as thermosetting fiber-reinforced polymer (FRP) composite systems and semi-structural injection molded thermoplastics. Due to their high strength-to-weight ratio, FRPs are often used in larger UAS classes, while thermoplastics are common in smaller unmanned systems.

Non-metallic materials are used in most of the primary structures of UAS including fixed wing, rotorcraft, and lighter-than-air UAS. Consequently, the maintenance and repair of these materials are introduced and discussed in the context of operational safety with respect to specific UAS classifications. The effectiveness of certain repair techniques was investigated. When possible, these procedures were compared to the relevant standards currently established by the FAA for manned aircraft.

The first in-depth analysis also discusses some of the issues involved when making the decision whether to repair or replace a part, as well as how this decision relates to continued maintenance of the UAS, and to personnel training requirements. Examples of field repairs of non-metallic materials not common to certified aircraft are provided. Inspection methods used for the larger UAS classes are recommended to mirror the current standards used for manned aircraft, while low-cost techniques such as visual and tap testing are reasonable for small UAS (sUAS).

This analysis concludes with suggestions for the further development of best practices for the maintenance and repair of non-metallic materials in unmanned aircraft, including the sourcing of materials, the limitations of repair techniques, risk analysis, and testing criteria.

The second in-depth analysis researched Control Stations (CS) and Support Equipment. Control Stations were found to vary in size, complexity and capability though many commonalities were identified. Most CS include an interface for the operator to interpret information and imagery as well as a means for the operator to send commands and control inputs to the air vehicle. Though some closely resemble the radio boxes used by model aircraft hobbyists, others more closely resemble a desktop computer workstation. Despite these differences, most control stations are primarily designed around integrated circuitry and consumer electronic devices with the ability to network with devices locally or beyond. This sets control stations well apart from the integrated cockpits found in modern manned aircraft.

Similarly, support equipment used for launch and recovery on some UAS sets UAS apart from manned aircraft. Manned aircraft, excluding Naval carrier aircraft, rarely use any kind of launch or recovery equipment for their primary means of takeoff and landing. UAS, however, are different as 18.8% of UAS are designed to utilize launch equipment and 11.1% are designed to utilize recovery equipment. These pieces of equipment are, often, relatively simple but have tight tolerances in order to function correctly.

In order to maintain CSs and support equipment, a Part 65 certified mechanic would need to learn skills beyond their current knowledge of electrical systems and basic electronics. Current aviation mechanics require training in computer networks, microcomputers, mobile devices, software, CS operation and testing. Training is also required to get mechanics up to speed on launch and recovery equipment. Though Part 65 mechanics have experience with pneumatic and hydraulic power systems, they do not have experience inspecting, maintaining or testing launch and recovery equipment for UAS. Therefore, they also need training on how to inspect and test launch and recovery equipment including testing methods that do not include a live aircraft.

The third in-depth analysis researched communication links for UAS. The primary integrated system of the UAS is the communication link, which allows the operator and CS to be physically separate from the aircraft during flight. This component of an unmanned system allows control inputs and commands to be sent to the aircraft, data and imagery to be sent to the ground, and voice communications to be sent and received between air traffic control, the operator and other air traffic. Though many systems strictly operate within radio line of sight, other systems use a relay onboard another aircraft, a tower or a satellite, to extend the range of the aircraft to any point on the globe. This makes communication links flight critical as operator control and situational awareness depend on the reliability of communication links.

Communication link systems are very similar to the radio systems onboard manned aircraft in terms of components. Radio systems on both manned and unmanned aircraft utilize digital and analog transmitting and receiver devices, amplifiers in certain cases and antennas are often similar as well. However, unmanned systems designed for satellite relay systems or long-range radio line of sight use highly directional antennas, which require antenna-tracking equipment on the ground and, in the case of satellites, relay links in the aircraft as well. This creates lower tolerances in some relay systems that can only operate if the antenna is pointed accurately at the target.

Even though much of a Part 65 mechanic's current training in radio equipment is adequate for maintaining some UAS communication links, additional training for unique aspects of communication links is still required. A&P mechanics need training in maintenance; inspection and testing of satellite communication links and antenna trackers as well as knowledge of radio systems consistent with an aviation industry accepted certification such as a Federal Communications Commission (FCC) issued General Radiotelephone Operator License (GROL).

The fourth in-depth analysis researched UAS autopilot and software technologies, which are highly variable with regard to complexity, capability, and price. Recommendations were made to suggest pre/post flight inspections of UAS autopilot and software suites on the basis of commonality, which were key factors in determining maintainer and technician requirements. The results of the analysis suggest maintainer requirements may necessitate a broader understanding of computing technologies, however, line maintenance or service is limited with most software and autopilot systems at this time. The expansion of technology and certification requirements will require enhanced knowledge, skills, and abilities (KSA) as detailed by the sub-report found within Appendix F.

A 3-tier skill classification for training was developed in order to implement a scalable UAS maintenance technician-training requirement. This approach was a direct answer to an A.5 research question regarding the potential relevance of establishing risk classifications to help aggregate UAS into a classification schema. Refer to Table 7 for a short list of UA examples used to help determine the assumptions for the 3-tier skill classification.

Table 7 – Skill Classification: Vehicle Examples

Vehicle Examples		
Skill Class 1 (SC1)	**Skill Class 2 (SC2)**	**Skill Class 3 (SC3)**
DJI Phantom DJI S1000 Yuneec H920 Yuneec Typhoon H 3DR Aero-M	Penguin B MQ-19 Aerosonde RQ-7 Shadow Northrop Grumman R-Bat Bat 12 & Bat 14	RQ-4 MQ-1 & MQ-9 K-MAX Ehang 184 Northrop Grumman Firebird

A gap analysis was performed comparing current regulations (Part 43, Part 65, Part 147 and European Aviation Safety Agency [EASA] Part 66) to known UAS maintenance procedures as identified in Task 1 and the in-depth analyses reports. It was discovered that small UAS (sUAS) have very little, if any, maintenance guidance and typically only reference one document combining both operations and maintenance data, while larger UAS traditionally have an established technical manual and a maintenance program similar to manned aviation.

The final list of skill recommendations for UAS maintenance technician certification was created from the Part 147 gap analysis and the skills recommended from the in-depth analysis reports for each of the three skill classes. There are a total of 29 UAS recommended skills demonstrating variability across all skill classes. Part 147 was used to create the final list because of the maintenance skill requirements for manned aviation mechanics contained in its appendices. The results are provided in Figure 1 below.

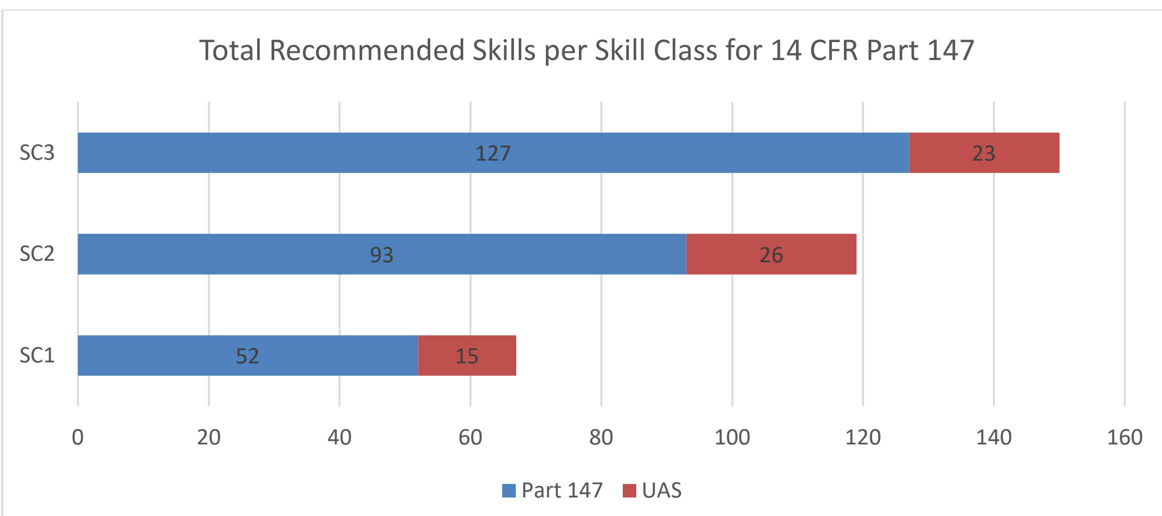

Figure 1 – Total Recommended Skills per Skill Class for CFR Part 147

Associated Deliverable:
Appendix F: Draft Technical Report of UAS Maintenance Technician Training Criteria and Draft Certification Requirements

7. Task 5: Conduct Simulations Focused on UAS-ATC Procedures

Table 8 – Task 5 Work Breakdown Structure

Task 5	**Conduct Simulations(s) Focused on UAS-ATC Procedures**	**Contributors**
Task 5a	Review of UAS accident/incident databases (Certificate of Authority reports, Aviation Safety Reporting System (ASRS), Department of Defense, etc.) for UAS maintenance-induced failures and their consequences	ERAU
Task 5b	High-level FMEA analysis for UAS to identify failure modes and effects caused by maintenance induced failures.	ERAU
Task 5c	Development of simulation protocols for maintenance-induced failures that would impact UAS operations in controlled airspace	ERAU
Task 5d	Development of simulation scenarios	ERAU
Task 5e	Execution of simulation scenarios	ERAU
Task 5f	Analysis of simulation scenario results	ERAU
Deliverable	*Conduct Simulations Focused on UAS-ATC Procedures: Preliminary Report*	ERAU

The goal of A.5 Task 5, "Conduct Simulations Focused on UAS-ATC Procedures," was to determine the impact of maintenance-induced failures on safe operations within the National Airspace System (NAS) through incident/accident data analysis, failure mode and effects analysis (FMEA), modeling and simulation, and a gap analysis of existing ATC and manned procedures.

The research team addressed the following research questions: (1) What is the consequence to flight safety resulting from maintenance-induced failures? (2) What is the consequence to air traffic control from maintenance-induced failures? (3) What is the consequence to other aviation stakeholders from maintenance-induced failures? (4) What is the consequence of maintenance induced failures on UAS-ATC procedures? (5) What additional lessons learned regarding UAS maintenance, failure reporting, risk-analysis, etc. are gained from this research task?

The first task investigated incident/accident data provided by the FAA from 333 exemption operations, Certificate of Waiver or Authorization (COA) operations, and the United States Air Force. To focus only on cases attributed to equipment failure, the team filtered the data set to exclude ambiguous reports or those attributed to pilot error. The Task 5 deliverable found in Appendix G summarizes the results by aircraft type, failure type, and impact type.

The second task examined the causes of UAS failures through two analysis techniques, FMEA and fault tree analysis (FTA). Two unmanned aircraft (platform only) were examined, including the Aerosonde and the DJI Inspire. The Task 5 deliverable found in Appendix G discusses the process and the resulting analysis.

The simulation protocols, environment, and scenarios were developed as part of the third and fourth tasks. The X-Plane 10 software provided a simulation environment where evaluators could trigger aircraft failures. The simulation used a UAV Factory Penguin-like UAS model with typical fixed-wing UAS flight characteristics. The World Traffic 2.0 plug-in for X-Plane generated simulated aircraft. The team also developed a software tool to log simulation data and allow the evaluator to trigger the failures remotely. The Task 5 report summarizes the technical environment, the selected failure modes for the simulation, the metrics and methodologies for the experiment, and the mission scenarios.

For the fifth task, the team performed the simulation experiments. The Task 5 report presents the results of the simulation runs and pre- and post-flight surveys for 42 failure-mode scenarios.

The sixth task examined the results of all the prior tasks to determine the impact of maintenance-induced failures on the NAS (questions 1 and 2), impact to other stakeholders (question 3), impact to existing manned and ATC procedures (FAA JO 7110.65W ATC procedures, Aeronautical Information Manual (AIM), and Title 14 Code of Federal Regulations Part 91) toward the handling of UAS maintenance-induced failures (question 4), and finally any additional lessons learned (question 5). The results of this analysis are as follows.

Question 1: What are the consequences to flight safety resulting from maintenance-induced failures?

- Task 5d's experiments ended in a crash for 21% and forced landing for 14% of the scenarios.
- The pilots failed to identify the failure 31% of the time highlighting the need for indicators to assist the pilot in detecting, identifying, and resolving failures.
- Failures during approach/arrival resulted in the fewest incidents/accidents.
- Failures away from airports (i.e. during mission) resulted in the most forced landings.

Question 2: What are the consequences to air traffic control from maintenance-induced failures?

- Well-clear violations occurred in 31% of the scenarios, and near mid air collision (NMAC) in 4% of the scenarios.
- No clear correlation between incursions and failure type, but most occurred during arrival / approach when encountering aircraft taxiing, taking off, or climbing out.
- ATC must be aware of contingency flight plans, loiter points, etc. to ensure other traffic remains well-clear.

Question 3: What are the consequences to other aviation stakeholders from maintenance-induced failures?

- Forced landing or a ground-impact in a populated area occurred in 14% of the scenarios, and in a remote / low population area in 12% of the scenarios.
- Since video link was the primary means of navigation for our simulation, video link failures resulted in the greatest cause of ground incursions in populated areas.

- Consideration of the impact to people on the ground should impact the prioritization of UAS maintenance for continued airworthiness

Question 4: What are the consequences of maintenance induced failures on UAS-ATC procedures?

- From the Task 5f analysis of existing policy and procedures, the following recommendations were made to improve the handling of UAS in-flight emergencies:
    - Priority for UAS emergencies must be defined relative to other air traffic priorities.
    - Terminology such as "distress" and "urgency" must be defined for UAS emergencies.
    - Develop ATC airspace procedures for UAS emergencies under pilot or contingency management control.
    - Identify the recommended information needed by controllers to respond to a request for emergency assistance.
    - Develop best practices for utilizing ATC services to assist UAS emergencies
    - Best practices should be informed by an assessment of pilot workload under a distress or urgency-type emergency scenario to account for pilot workload and the impact of latency on ATC instructions.
    - Consider alternative communication modalities between UAS pilot and ATC.
    - Develop UAS-specific guidance for UAS off-airport forced landing and ditching.
    - UAS-specific training for air traffic controllers is recommended.

Question 5: What additional lessons learned regarding UAS maintenance, failure reporting, risk-analysis, etc. were gained from this research task?

- Recommendations for incident/accident reporting were shared with the A.5 Task 7 team.
- Manufacture reliability data are needed to better understand likelihood of failures.
- For future work, a more robust simulation environment must be developed to support more complex simulation of maintenance-induced failures, live-and-constructive ATC simulations, control station alerts/indicators, etc.

Associated Deliverable: Appendix G: Conduct Simulations Focused on UAS-ATC Procedures: Preliminary Report

8. Task 6: Support UAS Certification Efforts, ASI Training and Repair Station Criteria

Table 9 – Task 6 Work Breakdown Structure

Task 6	**Support UAS Certification Efforts and ASI Training; Develop Repair Station Criteria**	**Contributors**
Task 6a	Review findings with appropriate FAA organizations (ACE-100, ASW-100, AFS-80, etc.) to assess impact to ongoing FAA certification activities	KSU
Task 6b	Development of ASI familiarization training recommendation for UAS maintenance	ERAU
Task 6c	Review applicability of 14 CFR 145 (Repair Stations) to UAS maintenance	KSU, NCTC
Task 6d	Develop criteria for repair stations to maintain UAS	KSU, NCTC
	Recommendations for ASI training (merged into Repair Station report)	ERAU
Deliverable 1	*Draft Technical Report of UAS Repair Station Criteria*	KSU, NCTC

The research for Task 6 had two primary goals: develop recommendations for Aviation Safety Inspector (ASI) Familiarization training and develop criteria for UAS repair stations. Both objectives used the gap analysis information and 3-tier skill classification proposed in Task 4 to draw conclusions along with phone interviews. Multiple oral interviews with FAA ASIs, manned repair stations and UAS repair stations were conducted.

For the first goal of creating recommendations for ASI familiarization training, current ASI training requirements for manned aviation were reviewed to include responsibilities and descriptions of each sub-category of ASI. Unmanned aviation maintenance standards were further reviewed to define pre-flight inspection items and benefits of recordkeeping, followed by recommendations for UAS ASI familiarization training. A literature review and discussion with current ASI's indicated UAS topics ASIs were unfamiliar with. Assumedly, the agency will hire ASI's that have a high level of familiarization with UAS technologies as they gain more influence on the aviation industry. However, current ASI's must be exposed to professional development through On-The-Job training and continuous development training utilizing Web-based/interactive Video Training, on-site facilitation, and out-of-agency training. Due to the current role of an FAA ASI, it is recommended that the content of their training include all 29 additional UAS recommended skills as defined in the Task 4 report recommendations based on Part 147.

For the second goal of developing criteria for UAS repair stations, Part 145 - Repair Station regulations were reviewed in conjunction with two key interviews: one interview with a Part 145 certified manned aviation repair station that is beginning to service UAS and one interview with an unmanned aviation repair station that is affiliated with a Part 145 avionics repair station.

Using data from the gap analysis and industry practices acquired through surveys in Task 4, Part 145 was analyzed for applicability to UAS in each of the three skill classes. The majority of Part 145 was found to be applicable to UAS as of June 23, 2017. Current UAS repair stations also have identified this applicability and are following Part 145 criteria as closely as possible when maintaining UAS. Most of the discrepancies in Part 145 are related to external references to CFRs that are currently insufficient for UAS, such as Part 65 and Part 43. A lack of references to both UAS regulations and terminology related to UAS articles, such as control stations and support equipment, was identified and will need to be added.

Additionally, survey data of UAS repair station operators revealed that uncertified UAS maintenance and articles were being separated from certified manned aircraft maintenance and articles. This practice is not necessary in manned aviation since certified part requirements already exist. Currently. Part 145 does not require repair stations to segregate these operations and would need to be updated to create a process for a separation of uncertified parts and certified parts to maintain the current level of safety for manned aviation. One option identified is to add a line to § 145.103 (a)(2) requiring that repair stations have adequate housing to segregate certified maintenance from uncertified maintenance.

The Part 145 area most focused on was § 145.59 Ratings, which drive the criteria and requirements for Part 145. Most ratings were found to have applicability to UAS, though some only had partial applicability or none at all. Those with partial applicability would simply need updating to reflect aspects of UAS they do not encompass.

There were a few unique UAS articles that were not covered by any current rating and require additional ratings to be added to Part 145. These included control stations, autopilots and small reciprocating engines (less than 50 horsepower). Current repair stations will likely need additional equipment and training of personnel to effectively maintain consumer mobile devices and microcomputers used in control stations, as well as the computer networks found in many control stations. Similarly, repair stations would need maintenance terminals and other equipment specific to autopilot systems in order to maintain them. Personnel will require additional training on these tools and on practices related to UAS autopilot maintenance.

Survey participants noted that additional equipment to interface with autopilots was required and personnel required training from manufacturers to maintain the control station and heavily software driven portions of UAS. While most Powerplant rated repair stations will be able to maintain small reciprocating engines making less than 50 horsepower, these engines are often more similar to those found in lawn equipment and small motorcycles. These types of engines typically contain components designed to be removed and replaced (R&R) instead of overhauled and their design is much simpler requiring less personnel training and fewer specialized tools.

Associated Deliverable: Appendix H: Draft Technical Report of UAS Repair Station Criteria

9. Task 7: Examine Requirements for Maintenance-Related Accident Reporting

Table 10 – Task 7 Work Breakdown Structure

Task 7	**Examine Requirements for Maintenance-related Accident Reporting**	**Contributors**
Task 7a	Review current requirements for data collection and reporting of UAS accidents/incidents versus manned requirements	ERAU
Task 7b	Assess effectiveness of current reporting requirements to capture maintenance-induced failures	ERAU
Task 7c	Develop recommendations for reporting maintenance-related accidents	ERAU
Deliverable	*Examine Requirements for Maintenance Related Accident Reporting*	ERAU

The goal of Task 7 was to evaluate current manned maintenance related accident reporting and make recommendations to improve current Unmanned Aircraft Systems (UAS) incident and accident reporting. A detailed analysis of data collection techniques in place for both manned aircraft and UAS yielded a better understanding of how current reporting tools may be modified to better capture incident and accident data in sufficient detail within a timely manner.

For work conducted in the first two tasks, emphasis was placed on the Maintenance and Repair Database (M&R), Certificate of Waiver or Authorization (COA), and Part 107 sUAS (Small Unmanned Aircraft System) accident reporting questionnaire. It was discovered that a total of 0.7% of the operators who filed a 333 exemption and experienced an incident or an accident used the online COA form. Fixed-wing operators (representing only 13% of the 333 exemption operators) filed 69% of those reports, while multi-rotor operators (representing roughly 80% of the total exemptions) filed 18% of the COA reports for their incidents. It is doubtful that multi-rotor aircraft are having fewer incidents, so it is recommended the FAA provide an educational outreach to the UAS community focusing on multi-rotor unmanned aircraft (UA).

The third task provided the recommendations for reporting maintenance-related accidents. A detailed analysis was conducted to define what information is currently being collected by aviation incident and accident reporting tools, then recommendations were made for the inclusion of reporting fields that better fill the gaps in UAS data collection. Results were listed for both sUAS and those unmanned aircraft that will be classified outside of the sUAS classification. UAS telemetry and component condition monitoring was also included to reference the importance of systems health monitoring onboard the aircraft.

Further review was conducted to understand the effectiveness of incident and accident reporting tools that have traditionally been used for manned aircraft by both the FAA and National Transportation Safety Board (NTSB). It was discovered that the Aviation Safety Information Analysis and Sharing (ASIAS) program is a repository for approximately 185 data and information sources from 89 members. Compared to the other FAA tools being used, the ASIAS sharing program demonstrated the strongest potential to provide a UAS incident data collection repository and future reliability and maintainability reporting.

The first recommendation: to consolidate incident and accident reporting; can be achieved by enhancing the current reporting tools to allow the data collected in the sUAS accident-reporting questionnaire, M&R database, and 333 COA to be entered into the centralized ASIAS repository. The second recommendation: to provide an educational outreach; may be achieved through the creation and dissemination of educational and guidance materials that provide stakeholders with a heightened perception of why their participation is a conduit for providing constructive feedback and possible solutions to industry related issues.

Associated Deliverable:
Appendix I: Examine Requirements for Maintenance Related Accident Reporting

10. Future Considerations for UAS Maintenance

It was discovered that most UAS operations today focus on carrying small payloads performing complex functions using sensors recording or transmitting data to a control station (CS), but tomorrow's focus for UAS leans towards carrying much more. Autonomous taxis like the Air Mule created by Urban Aeronautics Cormorant created a revolutionary new design prone for carrying injured personnel from the battlefield or passengers around a city [4]. The 10-year flying car project, the Terrafugia, was recently purchased by Zhejiang Geely, the current owner of Volvo, Lotus and Proton, prompting questions about their possible use in UAS [5]. Even the large taxi conglomerate Uber has invested in the UAS industry by hosting their first UAS conference, *Uber Elevate*, in 2017 in hopes of leading the discussions in this growing industry related to carrying passengers [6].

New UAS designs that carry humans are already here and one of the vehicles that sparked the conversation was the Ehang 184 and its partnership in Dubai [7]. HE Mattar Al Tayer commented for the Dubai's Road and Transport Authority (RTA) saying, “This project supports Dubai's government's direction to become the smartest city in the world.” Ehang representatives also explained that the 184 number stand for one passenger, eight propellers, and four arms equipping the vehicle to fly approximately 100 kilometers per hour with a maximum flight of 30 minutes. This platform is coupled with an easy-to-use navigation panel for passengers to simply touch on the map where they want to go providing a unique taxi experience.

Carrying human payloads is only one of the many growing trends for UAS; carrying freight is another primary growth industry. Amazon started their quest for delivering packages with UAS three years ago, recently adding another patent demonstrating a beehive logistics center for trucks and UA's to dock [8] while Chinese manufacturer JD.com plans to build a heavy lift UA with 1-ton lift capabilities [9]. The UPS company is testing a modified delivery truck to autonomously deliver a package with one UA after the driver presses a few buttons to help save mileage for their trucks [10]. Mercedes-Benz Vans created a drive-by wire concept delivery vehicle called the Vision Van using two Matternet UA's capable of carrying 4.4 lbs. up to 12 miles [11]. And Wal-Mart is even looking to implement UA's to handle in-store logistics delivery to shorten the buying experience allowing customers to acquire an item without walking around the whole store [12]. Meanwhile, a much more simple design created by Zipline and funded by ex-Microsoft magnate Paul Allen demonstrates cargo delivery using a fixed wing platform carrying 3.5 lbs. approximately 75 miles round trip, which is launched and retrieved from a control station created from large cargo shipping containers [13].

Carrying human passengers and delivery of cargo will both require maintenance requirements for UAS. Maintenance is a primary requirement for certification of manned aircraft due to its main function to reduce risk during operations by ensuring that no hidden failures exist. Creating a maintenance plan for all elements of UAS is needed to effectively identify and remove hidden failures. This is important for future FAA planning, especially when considering certification for higher risk operations over people or beyond visual line of sight (BVLOS).

11. Conclusion

This conclusion provides a summary of high-level answers to all eight of the research questions within scope of the research requirement. Some questions focused on identifying the current state of UAS maintenance practices, understanding the key elements of UAS and how they compare to manned aviation. Other questions were more specific and only applied to individual tasks. The following paragraphs outline the answers to the research questions and final conclusions.

1. **What is the current state of UAS maintenance practices and training throughout the industry?**
2. **How does the current state of UAS maintenance practices and training compare to manned aviation practices?**

   An in-depth understanding of the current state of UAS maintenance practices and training was compared to manned aviation Part 147 with the gap analysis as defined in Task 4. The gap analysis compared several manned aviation standards to the new 3-tier skill classification methodology, but Part 147 was used to create the final list because of the maintenance skill requirements for manned aviation mechanics contained in its appendices. A total of 29 UAS recommended skills were defined. These skills are suggested as a baseline for ASI familiarization training and additions to Part 147, potentially adding a new UAS appendix that can be scaled with UAS operations as other CFRs are updated.

3. **What are the elements that comprise UAS maintenance for all types/sizes of UAS?**

   Six primary elements for UAS were identified for this research: Unmanned Aircraft (UA), Command and Control Element (includes autopilot and control station), launch and recovery, communication data link, human element, and payload. These elements corresponded to the four in-depth analyses performed for this task: (1) the structures used on the UA (non-metallic materials), (2) the autopilot, (3) the control station and support equipment, and (4) the communication link and software, which is integrated throughout most of the UAS elements.

4. **What are the unique elements of UAS maintenance that differ from manned aircraft maintenance and what is their implication on training and certification?**

   The primary unique element of UAS maintenance that differs from manned aircraft maintenance as related to training and certification is that UAS is a system comprised of multiple components. Each component requires a condition for safe operation and additional training for system specific knowledge necessary to troubleshoot and repair. From simple two-component systems comprised of only a UA and a CS, to complex systems that integrate a UA with multiple CS, radar stations, launch and retrieval platforms and more, it is imperative to identify the proper maintenance for each of the six UAS elements to maintain nominal operations. The six key elements are listed in Section 6 - Task 4: Develop Maintenance Technician Training Certification Requirements

5. **What are the unique considerations for non-metallic material structures of UAS?**

   Non-metallic structures for UA contain some unique considerations while many remain the same as currently defined in manned aviation. For UAs that require repairs for composite structures, repairs are completed in the same fashion as currently defined in manned aviation. Thermoplastics have many existing methods for repair, such as fusion and resistance welding. However, removal and replacement of damaged parts is favored over repair for all UAS. The emphasis on removal and replacement is due to ease of performing the task and avoidance of expensive equipment and checks required to validate that the repair was sufficient. Foam construction is common in small UA (sUA) and often represents the entire structure in order to save weight.

6. Is there a need to delineate between different risk classes of UAS when determining maintenance and training requirements?

There is no need to delineate between UAS classes by risk when determining maintenance-training requirements since these classes are based on a combination of probability and impact effect, whereas maintenance training is based on specific skills required to perform a task. It is possible to delineate risk after a system has been designed and tested, but not before [14] as designs can vary with system complexity to add redundancy and/or backup systems in order to reduce risk. However, this is an unknown variable if risk is solely based off weight and performance indicators like speed. The current lack of standardized failure data in the UAS industry illustrates a missing component to effectively determine risk; leading to the potential that any risk class definitions based on probabilities are highly speculative.

7. What are the consequences of maintenance-induced failures in UAS?

Task 5 researched consequences of maintenance-induced failures using four scenarios: Flight Safety, ATC, Aviation Stakeholders and UAS-ATC. Flight Safety simulations demonstrated that the pilots failed to identify the failure 31% of the time highlighting the need for indicators to assist the pilot in detecting, identifying and resolving failures. Also failures during the approach/arrive had the fewest incidents, while failures during the mission resulted in the most forced landings.

For ATC related maintenance-induced failures it was concluded that ATC must be aware of the UAS contingency flight plans, loiter plans, etc. to ensure that all traffic remains clear during operations. For aviation stakeholders, incidents over populated areas occurred 14% in the scenarios while only occurring 12% in the low population areas demonstrating a high prioritization to require UAS maintenance certification ensuring continued airworthiness. Finally for UAS-ATC failures it was discovered that requirements should be created to define best practices for emergency situations and proper protocol both on and off-airport scenarios.

8. What standards exist, or need to be developed, for determining requirements and capabilities of entities that modify and/or repair UAS?

The manned standard Part 145 for Repair Stations could easily be modified to include requirements and capabilities to effectively modify and/or repair UAS. Task 6 uncovered the following recommendations to modify Part 145: include new UAS related definitions, add new UAS ratings in §145.59, update existing ratings in §145.59 to include UAS technology, update all reference regulations to include UAS definitions and limitations when applicable and add a new section defining segregation requirements in a repair station for UAS parts and materials from certified components.

Future Considerations

The future trends for UAS maintenance identified new complex plans for freight operations and increasing uses for human payloads. Freight operations range from complex infrastructures for sUAS from companies like Amazon and UPS to heavy lift capabilities in China. Although UAS has the ability to reduce risk for the operators by removing the human element inside of the UA, risk to Operations Over People will still require a basic maintenance plan as discovered in the ATC simulations in this report. Creating a maintenance plan for all key elements of the UAS to effectively identify and remove hidden failures is the next important step for future FAA planning when considering certification for risky operations like Operations Over People or Beyond Visual Line of Sight (BVLOS) operations.

Using the FAA benchmark of Part 107 as the first segmentation of UAS into the National Airspace System (NAS), operators are provided direction, but the OEMs are not. It is recommended to provide the 14 CFR Part 20 equivalent for UAS OEMs with an initial focus on manufacturing vehicles that can be certified for specific operational requirements, however basic. Coupled with the 3-tier skill classification, the UAS certification methodology proposed in this report outlines the basic items related to UA and UAS design to assist in identifying additions to Part 20.

Combining the 3-tier methodology with the current manned aircraft certification standards applicable to the UAS industry as defined in the gap analysis enables the FAA to more easily modify existing regulations as needed. This framework provides a scalable road map to address the gap of missing maintenance skill requirements by creating regulations for the least risky certifications first (e.g. license SC1 for sUAS) facilitating the FAA to safely introduce UAS into the NAS for varying UA types operations.

Finally, the following are recommendations for future work related to this project to fulfill gaps still remaining:

- Add more information to the M&R database while monitoring the use of the COA online form and the Part 107 incident/accident form to better understand user behavior. Updating the online forms and simultaneously effectively managing the required data for the database are recommended since they are so closely related.
- Review the NCATT and DACUM with the 3-tier skill classification system to better define Part 147 skill recommendations as defined by industry specifications.
- Perform a detailed analysis of repair methods for the popular types of foams being used for sUAS structure today, including Expanded Polypropylene (EPP) and Expanded Polyolefin (EPO).
- Research manufacture reliability data to better understand likelihood of UA failures; this includes understanding UAS manufacturing processes related to parts.
- Develop a more robust simulation environment to support more complex simulations of maintenance-induced failures

12. Bibliography

[1] ASTM International. (2015, October) ASTM F2909-14, Standard Practice for Maintenance and Continued Airworthiness of Small Un-manned Aircraft Systems (sUAS).

[2] NCATT. (2012) Unmanned Aircraft System (UAS) Maintenance Standard, National Center for Aerospace and Transportation Technologies. Document.

[3] Northland Community Technical College, Space Tec. (2016, June) DACUM Research Chart for UAS Maintenance Technicians. [Online]. http://www.northlandcollege.edu/aerospace/dronetech/UASMxDACUM.pdf

[4] Kelsey D. Atherton. (2016, November) Robot flying taxi takes its first autonomous flight. [Online]. http://www.popsci.com/robot-flying-taxi-cormorant-takes-its-first-autonomous-flight

[5] Celine Ge. (2017, June) South China Morning Post. [Online]. http://www.scmp.com/business/companies/article/2100239/will-us-flying-car-designer-take-chinas-geely-skies

[6] Richard Whittle. (2017, April) New York Post. [Online]. http://nypost.com/2017/04/01/soon-youll-be-able-to-go-to-work-in-a-flying-taxi/

[7] Sophie Morlin-Yron. (2017, March) CNN. [Online]. http://www.cnn.com/2017/03/17/tech/ehang-passenger-drone-dubai/index.html

[8] Kaya Yurieff. (2017, June) CNN Tech. [Online]. http://money.cnn.com/2017/06/23/technology/amazon-drone-beehives/index.html

[9] JD.com. (2017, May) JD.com. [Online]. http://corporate.jd.com/whatIsNewDetail?contentCode=E3I3F%2BT6JxPhAIQEWmUQGw%3D%3D&pagePath=null

[10] CNBC. (2017, February) CNBC. [Online]. http://www.cnbc.com/2017/02/25/ups-tests-drone-deliveries-via-high-tech-truck.html

[11] Lora Kolodny. (2016, September) Tech Crunch. [Online]. https://techcrunch.com/2016/09/07/mercedes-benz-and-matternet-unveil-vans-that-launch-delivery-drones/

[12] Anmol Sachdeva. (2017, March) The Tech Portal. [Online]. https://thetechportal.com/2017/03/18/walmart-patent-drones-simplify-purchase/

[13] Marco della Cava. (2016, April) USA Today. [Online]. https://www.usatoday.com/story/tech/news/2016/04/04/drone-plane-startup-nabs-funds-paul-allen-jerry-yang/82536598/

[14] Neil B. Bloom, *Reliability Centered Maintenance*, 1st ed., Kenneth McCombs, Ed. New York, New York: The McGraw-Hill Companies, 2006.

Appendix A: Review of Existing UAS Maintenance Data

Appendix B: Draft Technical Report of UAS Maintenance Data Preliminary Analysis

Appendix C: Dashboard for Maintenance Procedural and Record Profiles

Appendix D: Update Maintenance & Repair Prototype Database

Appendix E: Survey Results and Technical Review of UAS Maintenance Technician Training Standards

Appendix F: Draft Technical Report of UAS Maintenance Technician Training Criteria and Draft Certification Requirements

Appendix G: Conduct Simulations Focused on UAS-ATC Procedures: Preliminary Report

The FAA's Center of Excellence for UAS Research
ASSURE
Alliance for System Safety of UAS through Research Excellence

Appendix H: Draft Technical Report UAS Repair Station Criteria

Appendix I: Examine Requirements for Maintenance Related Accident Reporting