Airworthiness Assurance and Component Tracking of Small Unmanned Aerial Systems

Mr. Kristoffer Borgen, Purdue University

currently works as a Graduate teaching assistant in the Aviation Technology department at Purdue University. Received a BS in 2018 in Aerospace Engineering Technology from Purdue University and is currently working on a Masters in Aviation and Aerospace Management. Currently a teaching laboratory sections in statics and unmanned aerial systems (UAS).

Mr. William Theodore Weldon, Purdue University

PhD student at Purdue University studying UAS operations.

Dr. Brian Kozak, Purdue Polytechnic Institute

Dr. Brian J. Kozak is a faculty member in the School of Aviation and Transportation Technology at Purdue University where he teaches in the Unmanned Aerial Systems and Aeronautical Engineering Technology majors. He also teaches at the graduate level. Dr. Kozak developed new courses on aeronautical statics, autonomous vehicle operations, and drone operations in outdoor flight environments. He is currently collaborating with industry partners to teach skills that are required for a new generation of aviation graduates.

Dr. Kozak earned his B.S. in Applied Physics, B.S. in Interdisciplinary Science, M.S. in Aviation and Aerospace Management, and Ph.D. in Technology from Purdue University in West Lafayette, Indiana. He has strong personal interests in aviation where he enjoys piloting aircraft and building a composite airplane. Dr. Kozak holds FAA private pilot, airframe and powerplant, and remote pilot certificates

Ms. Tracy L. Yother, Purdue Polytechnic Institute

Tracy L. Yother is a PhD student in Career and Technical Education in the College of Education at Purdue University, West Lafayette, Indiana. Ms. Yother currently teaches the undergraduate Powerplant Systems course in the Aeronautical Engineering Technology (AET) program. She possesses a B.S. and M.S. in Aviation Technology. She also holds an airframe and powerplant certificate.

Ms. Yother has 18 years' experience in the aerospace and defense industry working for companies such as Boeing, McDonnell Douglas, and Pratt and Whitney. She has held positions in product support, customer support, and program management.

Work in Progress: Tracking airworthiness in unmanned aerial systems through logbook entries

Abstract

With the rising prominence of small Unmanned Aerial Systems (sUAS), there is an increasing need to maintain safety. Current Federal Aviation Administration (FAA) regulations require that each sUAS undergo a simple visual and operational preflight check. There is no detailed airworthiness assurance or tracking requirement as required for certificated aircraft. However, as the number of commercial sUAS increases, this requirement for detailed airworthiness assurance and component tracking may change. In order to familiarize students in an Unmanned Aerial Systems major with this possible change, a junior level course was structured around tracking sUAS in a way which mirrored certified aircraft. The course focused on integration on an off the shelf autopilot into a four pound 3d printed quadcopter. Student in groups of two were required to fly ten missions in outdoor, real world conditions. At the start of class, students within the class, created a course specific preflight checklist. Before each flight, there students were required to follow this checklist. Also, each component on the quadcopter had its own individual serial number recorded in a logbook. In the event of a hard landing or flight anomaly that required the replacement of a component, the student group has to file several pieces of paperwork which were recorded in the quadcopter's specific logbook. First, a flight incident report with weather conditions, operators, and description of the event was included. Then an FAA form 337 was filled out. Finally, the serial number of the components removed and the serial number of the new components were recorded. With this focus on airworthiness assurance and part tracking, students within the course are better prepared for future changes in sUAS regulations.

Introduction

Small unmanned aerial systems (sUAS) are currently the fastest growing aspect of aviation and current Federal Aviation Administration (FAA) regulations are slow to adapt this change. One of the biggest challenges in UAS is airworthiness assurance. Currently, under 14 CFR Part 107, a commercial operator needs to inspect the vehicle for airworthiness before flight. However, airworthiness is not currently defined within UAS. This is a challenge of unmanned aircraft systems (UAS) because there is no human on board the vehicle, and many of these practices are ignored.

Current airworthiness certification practices for civilian aircraft are defined in 14 CFR Part 21. These practices are defined for manned aircraft, and are mainly concerned with the safety of the aircraft occupants with the safety of those on the ground secondary [1]. These practices have evolved over the life of aviation, and the adherence to these practices has increased the safety of aviation for those inside and outside of the aircraft.

US military handbook, MIL-HDBK-516C, defines the airworthiness certification criteria for military aircraft. This handbook specifically states that the contents apply to both manned and unmanned aircraft. This safety equivocation is a good start to widespread standardization of UAS airworthiness certification standards.

Airworthiness Assurance in Manned Aircraft

Initial airworthiness certification standards are accompanied with standards to assure continued airworthiness throughout an aircraft's life. One way this is achieved is through periodic maintenance and inspection procedures [1]. Proper maintenance of aircraft includes more than just using the right tool or the right replacement parts, it also includes the proper documentation. Proper documentation allows operators to track repairs, alterations and calibrations. This in depth understanding of an aircraft's history is instrumental in/for/during maintenance activities.

The FAA describes required maintenance and maintenance documentation in Advisory Circular 14 CFR Part 43. Maintenance is the "inspection, overhaul, repair, preservation, and the replacement of parts, but excludes preventive maintenance" [2]. Preventive maintenance is "simple or minor preservation operations and the replacement of small standard parts not involving complex assembly operations" [2]. Preventative maintenance or maintenance activities accomplished during the 100-hour, annual, progressive, and other required or approved inspections require additional information to be maintained.

Documentation for maintenance performed on aircraft, engine, propeller, appliance, or component must include, at a minimum, a description of the work performed, the date of the completion of the work, name of the person who performed the work, and assuming satisfactory work, the signature, certificate number, and certificate type of the person approving the work [3]. The information required is listed below [4]:

- Records that must include
    - A description (or reference to data acceptable to the Administrator) of the work performed; and
    - The date of completion of the work performed; and
    - The signature, and certificate number of the person approving the aircraft for return to service.
- Records containing the following information:
    - The total time in service of the airframe, each engine, each propeller, and each rotor.
    - The current status of life-limited parts of each airframe, engine, propeller, rotor, and appliance.
    - The time since last overhaul of all items installed on the aircraft which are required to be overhauled on a specified time basis.

- The current inspection status of the aircraft, including the time since the last inspection required by the inspection program under which the aircraft and its appliances are maintained.
- The current status of applicable airworthiness directives (AD) and safety directives including, for each, the method of compliance, the AD or safety directive number and revision date. If the AD or safety directive involves recurring action, the time and date when the next action is required.
- Copies of the forms prescribed by §43.9(d) of this chapter for each major alteration to the airframe and currently installed engines, rotors, propellers, and appliances.

Records are defined by the FAA as:

> "any writing, drawing, map, recording, tape, film, photograph or other documentary material by which information is preserved or conveyed in any format, including, but not limited to, paper, microfilm, identification plates, stamped marks, bar codes or electronic format, and can either be separate from, attached to or inscribed on any product, part, appliance or material" [5].

In addition to creating them, the records must also be maintained for the life of the aircraft and transferred with any sale of the aircraft [4], because any time, the FAA may request access to the records for inspection. Airworthiness is defined as "aircraft conforms to its type design and is in a condition for safe operation" [5]. These records allow operators to easily understand the current configuration of the aircraft and the maintenance history of the aircraft, and are part of what makes the aircraft airworthy.

Parts and components used on aircraft are certified by the FAA to be considered airworthy through the use of Title 14 CFR part 21 of the United States federal regulations which gives approval for parts manufacturing. Title 14 CFR 21 provides users with a detailed description of materials, manufacturing location and, at times, the individual who manufactured the part. An example of this is an aircraft part that was constructed of Aluminum 2024-T4 from a known company that has been certified while in contrast, many sUAS parts have limited markings and can lack part and serial numbers. This lack of traceable part information can severely hamper the capability of operators to ensure that replacement parts are of the same quality as the initial parts. Electronic speed controllers (ESCs), the components responsible for translating controlling the power output of the motors, provide a good example of this problem. Two different ESC brands may be rated the same, but could vary widely in their in-flight performance. This discrepancy between parts can impact the performance of the aircraft but, under current regulations, does not affect the airworthiness of the aircraft. Adapting current Title 14 CFR part 21 regulations to the sUAS would require a test flight of the aircraft when a component has been replaced that could affect flight characteristics. Applying these regulations to unmanned aircraft is meant to simulate the current regulatory environment of manned commercial aviation, and foster a culture of safety and professionalism [6]. By requiring students to fill out additional forms regarding sUAS incidents it is giving them an advantage of being better prepared if additional legislation regarding sUAS is published. By using the checklists that the students create it can help mitigate part failure. Through the initial creation of the checklists students will begin to generate a general understanding of how the vehicle in theory is supposed to operate. The checklist will show the students what the vehicle is supposed to do and is expected to do. Running through the checklist will help students that have had limited experiences with them such as the non-pilot major students gain more familiarity with how checklists should be designed and run through [7]

Incident reports in manned aviation in the United States are filled when there has been loss of life of someone other than the pilot or damage exceeding a value of 25,000 USD [8]. Current sUAS regulations require "damage of over 500 USD to property other than the drone itself or if injury or death has occurred due to a collision with a person or causing injury" during commercial operations to be reported [8]. The reporting for this class goes more in-depth than what the current FAA requires by using the current weather information for the flight, who was operating at the time of the incident, and a description of the event. When reporting the accident in the class the students are required to provide a description of the weather during the time of the crash. The damage requirement for the sUAS to be reported is damage that is more substantial than a broken propeller or landing gear. These two parts are used as the baseline since they have been found to be the two most often damaged parts if an accident was to occur. Requiring weather reports to be reviewed before flight helps students better understand the operating limits of the vehicles as well as their personal operating limitations (Improving pilots' risk assessment skills in low-flying operations: The role of feedback and experience). This training aspect introduces students to some of the documentation that may be required for when incidents happen regarding sUAS. In addition to the paperwork that explains what happened during the crash there is also paperwork that is required when the sUAS is being repaired.

A FAA Form 337 is filled out when a major repair or alteration has been performed on an aircraft. This form notifies the FAA of the changes to the aircraft and furthers the aircrafts logbook details. While the authors do not send a copy of this documentation to the FAA, a copy is kept with the aircraft logbook and is also submitted to the instructor for record keeping. Current sUAS regulations do not require the creation of this documentation, which can allow damage to go unknown or unreported. Latent damage can become worse in subsequent flights and cause unexpected failures at seemingly random times. Requiring this form allows students to ensure that their vehicles are repaired adequately and are airworthy, regardless of who the last user was. These forms also create an operational/repair history and can help diagnose future or endemic problems in an aircraft design or operation.

The current approach to most sUAS maintenance after a crash is to fix the issue resulting directly in or from the crash so the vehicle can be flown again as quickly as possible [9]. While this provides minimal down time for the vehicle the information concerning the crash is often not recorded, and is not reported to any centralized body. This impedes data driven approaches to determining systemic flaws in a vehicle or operator and prevents creating maintenance schedules for airframes. Scheduled maintenance operations have increased safety in manned aviation, and have been developed over time using historical data on part wear, accidents, and incidents. Parts for manned aircraft are meticulously tracked and regulated to ensure that each individual part will stand up to the stresses of flight operations, and each part is supported by a system of redundancies to ensure that the aircraft can better withstand a part failure. sUAS components by comparison do not have the benefit of either of these quality assurances, and this can be seen in a higher accident rate for sUASs [10]. Many parts for sUAS do not come with operating guidelines, tolerances, or technical spec sheets and some lack serial numbers making it difficult or impossible to ensure the same level of airworthiness after an accident [11].

Class Exercise

During course development for a junior level course in autonomous sUAS operations airworthiness regulations for manned aircraft were introduced to the curriculum. Airframe components were manufactured in class using a Taz 6 3D printer, and quality assurance performed by lab TA’s visually inspecting components as they were produced. Standardization between the electrical components, ESCs, and motors on the aircraft was accomplished by using components from a series of kits. While these electrical components could not be verified airworthy through visual inspections, to the same degree as the airframe components, we decided that their identical nature would allow us to begin creating a maintenance history for them, and begin the airworthiness determination process. Creating a maintenance history for the aircraft and components was begun by assigning serial numbers to the aircraft and components.

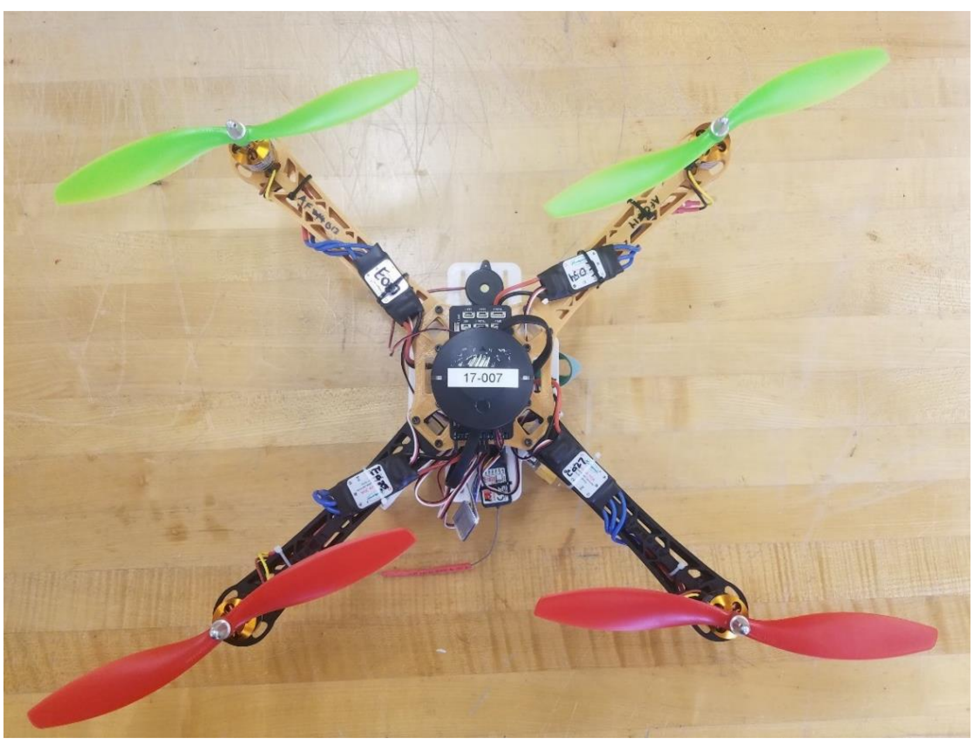

Figure 1. 3D Printed Quadcopter

After assigning serial numbers to aircraft/components maintenance documentation practices were implemented. These practices include; maintenance logbooks, using FAA documentation for airframe repairs, and electronic maintenance tracking sheets. These practices are established procedures in manned aviation, and were applied as a way to equivocate the importance of maintaining sUAS to the importance of maintaining manned aircraft. The electronic maintenance tracking sheets were developed through an instructor's past experiences in maintenance tracking operations in the airline industry, causing this to mirror airline practices.

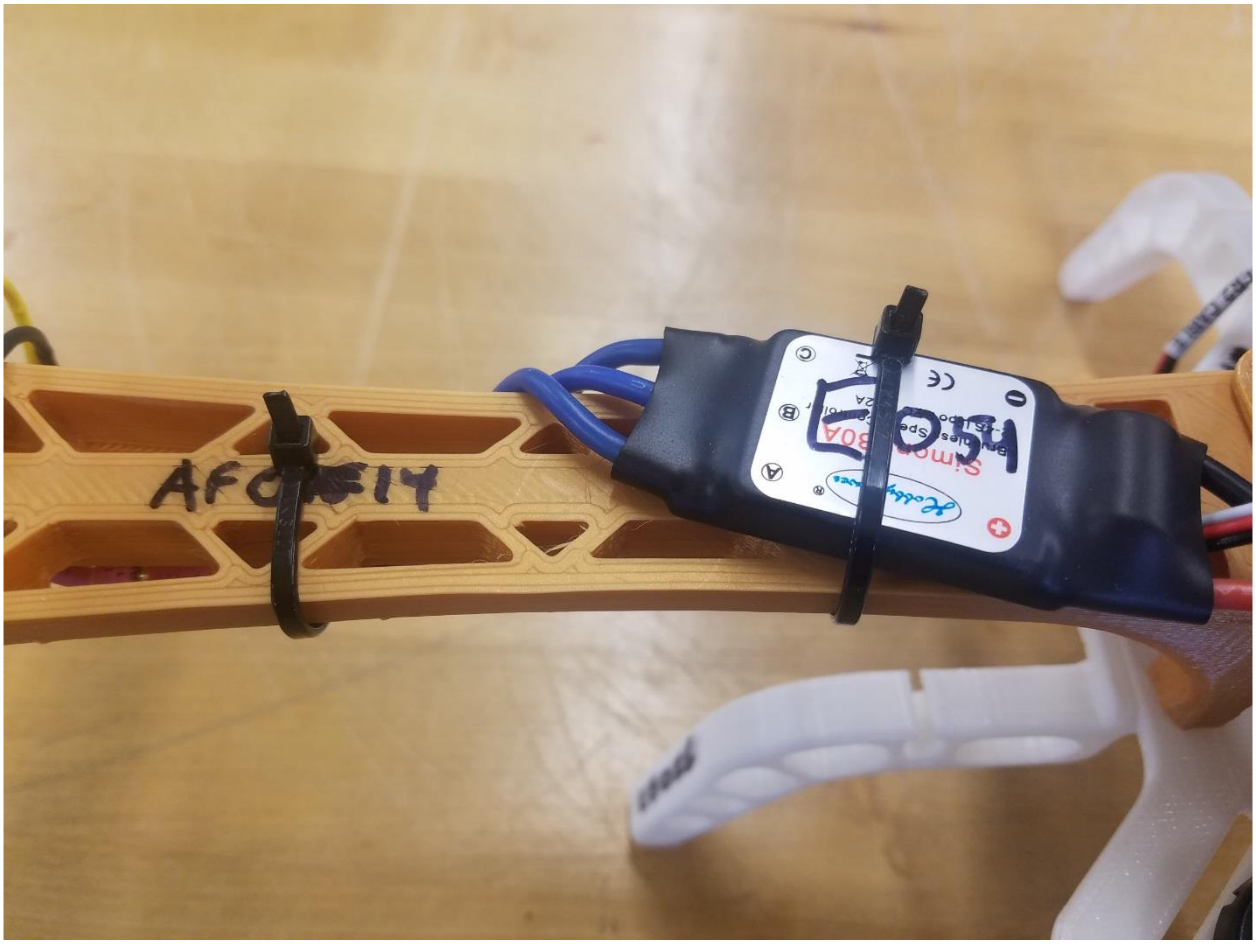

Figure 2. Component Labeling

Before any flight operations students must present the maintenance documentation for the aircraft to an instructor, and the instructor will determine if the aircraft is airworthy. In order to be determined as airworthy the condition of the aircraft must match the conditions listed in the maintenance documentation. Students must also present instructors with a weather briefing prior to any operations and have a checklist for the aircraft. Once all of these conditions have been met the students are allowed to operate their vehicle. If an aircraft is damaged during operation, with the exception of propeller or landing gear damage, the students must fill out an incident report and a form 337 for the repairs completed. Incident reports, attached in Appendix A, require an incident report number, provided by the instructor, and a description of the vehicle used during the incident, a written description of the event, and pictures taken of the damage. The details given in this report allow instructors to determine if similar accidents are occurring during operations, and if certain parts are breaking more frequently than others. These documents are stored as a hard copy with the aircraft logbook, and as a soft copy on a shared drive. Landing gear and propeller damage do not require this tracking due to their frequent failures. The frequent failures of landing gear are due to their design; the landing gear is designed to fail as a way to absorb the impact force from a hard landing.

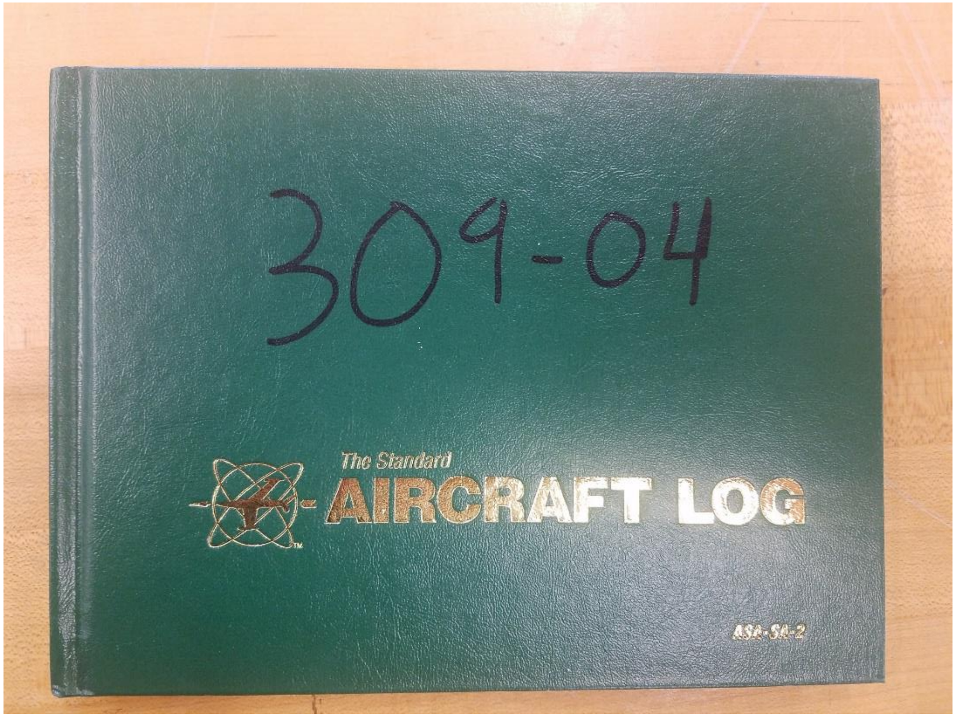

Figure 3. Quadcopter Logbook

Table 1. *Digital logbook*

Manufacture Date	8/16/2018								
Manufacturer	[redacted]								
Part Name	Part serial #	Date Part Added	Hour part added	Who added part	Date Part Removed	Hour part removed	Reason for removal	Who removed the part	Incident report number
Arm 1	AF013	8/16/2018	0	[redacted]					
Arm 2	AF014	8/16/2018	0	[redacted]					
Arm 3	AB013	8/16/2018	0	[redacted]					
Arm 4	AB014	8/16/2018	0	[redacted]					
Top Plate	TP007	8/16/2018	0	[redacted]					
Bottom Plate	BP007	8/16/2018	0	[redacted]					
Landing Gear 1	LG025	8/16/2018	0	[redacted]					
Landing Gear 2	LG026	8/16/2018	0	[redacted]					
Landing Gear 3	LG027	8/16/2018	0	[redacted]					
Landing Gear 4	LG028	8/16/2018	0	[redacted]					
Motor 1	M025	8/16/2018	0	[redacted]					
Motor 2	M026	8/16/2018	0	[redacted]					
Motor 3	M027	8/16/2018	0	[redacted]					
Motor 4	M028	8/16/2018	0	[redacted]					
ESC 1	E025	8/16/2018	0	[redacted]					
ESC 2	E026	8/16/2018	0	[redacted]					
ESC 3	E027	8/16/2018	0	[redacted]					
ESC 4	E028	8/16/2018	0	[redacted]					
RC Reciever		8/16/2018	0	[redacted]					

Conclusion

This paper is currently a work in progress with pre and post student surveys being administered during the Spring 2019 semester. These surveys are blinded seven point Likert scales allowing students to rate both knowledge and comfort with topics related to aircraft airworthiness, maintenance tracking, and preflight checks. There are eleven students in the course and all of them had completed the pre course surveys. The final surveys will be administrated in early May with results expected by early June.

Also, there needs to be significant improvement to the current regulatory parts and vehicle tracking to ensure the safety of others when operating a drone. Through the increase of use of educational materials regarding airworthiness of drones it can begin to demonstrate an industry need for better airworthiness assurance of vehicles. The materials being used to address this include creating frames and keeping serial numbers of the parts that are being used on the quadcopter. Similar to current aviation the crashes are documented with the logbooks and various reports to help identify the cause of the crash.

Future Works

Future works for this project include expanding this into a journal article regarding more detailed sUAS tracking and logbook entry requirements. Modifying the class may be necessary to achieve a more streamlined approach to the tracking and logbook aspects of sUAS. In addition to just using the educational aspect of tracking by pushing it for an industrial standard to be used for the airworthiness certification for airframe and propulsion methods on sUAS. Overall there is a large undertaking of increasing the literature regarding airworthiness certification for sUAS as the sector continues to grow.

List of References

[1] De Florio, F. (2016). Airworthiness: An introduction to aircraft certification and operations. Butterworth-Heinemann.

[2] Federal Aviation Administration, 14 CFR Part 1, 'Definitions and abbreviations', 2018. [Online] Available: https://www.ecfr.gov/cgi-bin/text-idx?SID=9949eb4dc104f421574d2d48b16ba677&mc=true&node=se14.1.1_11&rgn=div8

[3] Federal Aviation Administration, 14 CFR Part 43, 'Maintenance, preventive maintenance, rebuilding, and alteration', 2018.[Online] Available: https://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title14/14cfr43_main_02.tpl

[4] Federal Aviation Administration, 14 CFR Part 91, 'General operating and flight rules', 2018. [Online] Available: https://www.ecfr.gov/cgi-bin/text-idx?SID=9949eb4dc104f421574d2d48b16ba677&mc=true&node=pt14.2.91&rgn=div5#se14.2.91_1417

[5] Federal Aviation Administration, 14 CFR Part 3, 'General requirements', 2018. [Online] Available: https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&SID=aa8fea6ef04319b68102c105dd9437f2&ty=HTML&h=L&mc=true&n=pt14.1.3&r=PART

[6] Amaya, N., Rovira, M. D., del Cerro, S., Grillo, M., Nomen, R., & Sempere, J. (2019). Distributed Safety Management as a tool for creating a safety culture in university students and future professionals. Journal of Loss Prevention in the Process Industries, 57, 114-119. Retrieved from http://www.sciencedirect.com/science/article/pii/S0950423018300962. doi:https://doi.org/10.1016/j.jlp.2018.08.014

[7] Brigette, H., & Peter, P. (2006). The checklist—a tool for error management and performance improvement. *Journal of Critical Care*, 231-235.

[8] Federal Aviation Administration. (2018, December 20). Electronic Code of Federal Regulations. Washington DC, United States. Available: https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&SID=aa8fea6ef04319b68102c105dd9437f2&ty=HTML&h=L&mc=true&n=pt14.1.3&r=PART

[9] Mrusek, B. M., Kiernan, K. W., & Clark, P. J. (2018). UAS Maintenance: A Critical Component in Maintaining Airworthiness. *International Journal of Aviation, Aeronautics, and Aerospace*, *5*(5), 2.

[10] Hobbs, A., Cardoza, C., & Null, C. (2016). Human factors of remotely piloted aircraft systems: Lessons from incident reports. Paper presented at the *Conference of the Australian and New Zealand Societies of Air Safety Investigators*, Brisbane, Australia.

[11] Clothier, R. A., Palmer, J. L., Walker, R. A., & Fulton, N. L. (2010). Definition of airworthiness categories for civil Unmanned Aircraft Systems (UAS). *In Proceedings of The 27th International Congress of the Aeronautical Sciences.* Nice: QUT ePrints.

Appendix A

Incident Report Number	
Vehicle Serial #	
Operator	
Visual Observer	
Date	
Flight Hours	
Parts Damaged	

Description of event

Images of damage