Interdisciplinary Systems Engineering and Aeronautics Science Effort to Enhance sUAS Training Program for Undergraduate Students

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***Abstract*— This paper describes an initial effort to integrate knowledge gained during a research project funded by the Florida Department of Transportation (FDOT) into an undergraduate small unmanned aerial systems (sUAS) training program at Florida Institute of Technology. The paper discusses the approach that was adopted to develop a preliminary sUAS flight operations program. More specifically, it describes performance-based tests via flight modules, and results from experiments to understand factors affecting flight training durations. The expertise of faculty and graduate students in areas of science and engineering such as aeronautics, civil, industrial, and systems engineering were used to develop the flight training program for the research project. The paper also provides preliminary ideas to effectively integrate the knowledge gained from the FDOT research project into the sUAS undergraduate program.**

***Index Terms*—Small unmanned aerial systems, Systems engineering undergraduate education, Bridge inspections, Flight training.**

I. Introduction

Advanced technologies related to small unmanned aerial systems (sUAS) have rapidly increased during recent years. The FAA estimates seven million sUAS in the skies by the year 2020, with around 500 thousand strictly for commercial purposes only [1]. Near future expectations are that sUAS will be integrated into the operational culture of many organizations, resulting in lower operational costs and positive impacts to society's quality of life. For example, researchers have investigated the potential for using sUAS during bridge inspections. Some of the benefits from utilizing sUAS as tools during bridge inspections include reduced costs, reduced lane closures, increased safety levels for inspectors, and access to real-time video data on the ground, among others. Similar benefits can be expected from the use of sUAS in other areas such as agriculture, disaster management, traffic operations, and surveying. As a result of sUAS advances and their potential impact to society, it is crucial to develop educational programs capable of preparing future generations to understand, conduct, and manage safe sUAS operations.

The Department of Systems Engineering at Florida Institute of Technology (Florida Tech), Melbourne, Florida, was awarded a research grant from the Florida Department of Transportation (FDOT) to understand the use of sUAS for bridge and high mast luminaire (HML) inspections [2]. One of the objectives of this research study was to gain an understanding of expected training times for someone to acquire necessary skills to safely operate an sUAS during inspections. With this in mind, the research team developed a preliminary sUAS training program for individuals with different technical backgrounds. The idea was to collect data on a preliminary set of parameters (e.g., trainee prior experience operating any type of sUAV or similar remote controlled systems) and determine if any correlation exists between the input parameters and the total time that it takes to successfully complete the flight training program.

Florida Tech recently started an academic undergraduate sUAS training program –within the College of Aeronautics— that covers topic areas such as FAA regulations, sUAS power systems, basic flight aerodynamics, and flight training. All of these topic areas had to be carefully addressed in the FDOT research project by faculty and graduate students to ensure successful project completion. It can be safely assumed that integrating the knowledge gained during the FDOT research project into the undergraduate sUAS training program could significantly help to develop students into active learners by gaining necessary knowledge to solve some of the problems that were encountered in the project. This type of project-based learning approach has been praised in the academic literature to provide key benefits such as improved skill development and overall knowledge compilation (e.g., [3], [4]).

This paper describes a preliminary work-in-progress effort to initiate the integration of knowledge gained during the FDOT research project into the undergraduate sUAS training program. The paper discusses the approach that was adopted to develop a preliminary flight operations program for the FDOT-funded research project. More specifically, it describes performance-based tests via flight modules, and results from experiments to understand factors affecting flight training durations. The expertise of faculty and graduate students in areas of science and engineering such as aeronautics, civil, industrial, and systems engineering were used to develop the flight training program for the FDOT research project. The paper also provides preliminary ideas to effectively integrate the gained

This work was supported in part by the Florida Department of Transportation under grant BDV28 977-02.

knowledge from the FDOT project into the sUAS undergraduate program. Similar to the work presented in [5], the work presented in this paper is expected to motivate students to pursue careers in science and engineering that involve the fascinating topic of sUAS.

II. Preliminary sUAS Operation Training for FDOT Research Project

A preliminary sUAS training program was developed as a requirement for the FDOT research project. The objective of this program was to gain insights on expected training times to acquire skills to safely operate an sUAS during the inspection of bridge and HML structures. Figure 1a shows the type of sUAS used for the training program. This sUAS is a bare-bones aerial system equipped with only a GPS component that continuously corrects altitude and coordinate positioning, resulting in more stable flights with an accuracy of up to a 2ft radius. This sUAS, while extremely limited as a tool to conduct bridge and HML inspections, proved to be very effective to train individuals on flight maneuvers that are expected to be required to successfully conduct visual inspections. Individuals with varying skill levels, spreading from novice to experienced levels, benefitted from using this simple sUAS during training. Figure 1b shows an advanced-level sUAS developed by the research team for more specialized inspections. Although this paper only covers a preliminary training program using a basic-level sUAS, the next stage would be to train inspectors with more complex systems such as the one in Figure 1b.

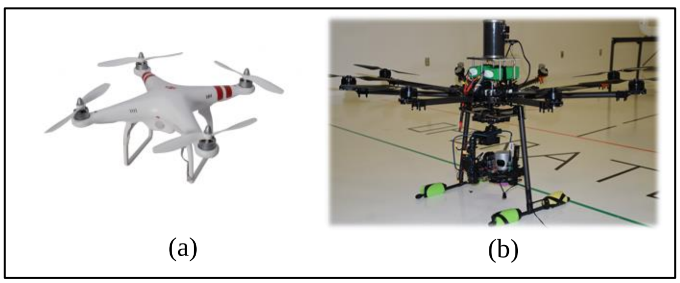

Fig. 1. (a) Basic UAS (b) Advanced UAS

A total of 10 people participated in the initial training task, which included four FDOT bridge inspectors. The trainees were individually briefed on the training regimen on a one-on-one basis. The regimen consisted of four introductory phases, each with internal modules designed to incrementally introduce complexity through different levels of sUAS maneuvers. Each module ended with performance-based tests that trainees were required to perform. Furthermore, each phase required a trainee to conduct a final objective-based flight test, which was designed to mimic either a portion of a bridge or HML inspection. The modules were accompanied by a visual module supplement such as the one shown in Figure 2. Visual module supplements were designed to further reinforce flight plans and procedures, and were reviewed before each flight. A total of 10 training flight guides and visual module supplements were developed.

The training was designed to accommodate different styles of learning by incorporating the following:

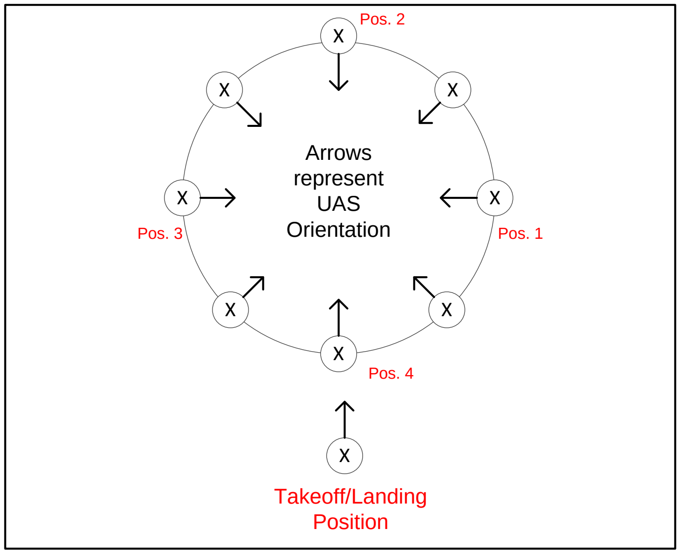

Fig. 2. Example of a Visual Module Supplement

- A set of written instructions that a trainee could review
- A one-on-one trainee-trainer open lecture where questions could be individually addressed
- A visual trainer flight demonstration of the module at hand
- A verbal instructional segment where the trainer guided the trainee
- Hands-on performance based tests that a trainee repeated until a satisfactory level of comfort was obtained.

Satisfactory levels of comfort were gauged by how well a trainee was able to operate the training sUAS while conducting various maneuverability activities around pre-defined bounded flight areas (see Figure 3a). These areas were marked with wooden stakes of different heights, as depicted in Figure 3b.

From the one-on-one training sessions, time data were captured throughout the entire training process. Time data consisted of explanation of tasks, trainer demonstration, trainer-trainee talk-through, and the time it took the trainee to complete test demonstrations. These capture data were used to estimate the time that it would take to train an individual to operate and maneuver a basic sUAS.

III. Factors Affecting Training Times

Given the current limited number of trainees, the data captured were graphed using a simple technique called *box plots*. This non-parametric technique is a convenient way to graphically depict groups of numerical data through quartiles, and does not make any assumptions regarding underlying statistical distributions. The idea was to determine if any correlation existed between key trainee identifiers and the total training time to successfully complete the program. These key trainee identifiers (i.e., independent variables) were: level of higher education, age, and prior sUAS flight experience. Results from these analyses provide a simple way to estimate training duration based on these three parameters.

Fig. 3. (a) Training Areas (b) Wooden Stakes Marking Target Points and Boundaries

Figure 4a shows the box plot generated based on trainees' level of education. The term "Technical Trainee" was used to identify those that possessed higher education levels (i.e., past an Associate college degree); otherwise, "Non-Technical Trainee" was used. An Associate college degree was arbitrarily chosen as a threshold between levels due to its commonality in present times. Figure 4a can be read by grouped participants along the x-axis and duration in minutes required to train those individuals along the y-axis. In the instance of missing data due to differing reasons, video data from training sessions were analyzed to determine the missing time. Similarly, Figures 4b and 4c show estimated operator training times required based on "Age" and "Prior UAV Experience", respectively.

There were other factors considered during the training exercises. These factors included electronic gaming experience, wind conditions, temperature, and willingness to learn. Electronic gaming experience was linked to age; therefore, it was considered redundant. Wind conditions varied from 5-15mph during training sessions, and did not have a significant effect on training time. This result can be explained by the relatively small difference of only 10mph between low and high average wind speeds. Moreover, this result can be explained by the fact that the maximum wind speeds were 15mph, which was proven to be an adequate wind condition for sUAS flights via controlled indoor experiments using industrial fans. Temperature had no significant effect on training duration; however, it is recommended that training in extreme heat for an excess of two hours should be broken into segments to avoid personal or equipment fatigue. All of the trainees showed a complete willingness to learn how to fly sUAS systems; therefore, this particular parameter was not used as it had no variation among trainees.

Accounting for the 75th percentile of the group, the results provide evidence regarding total training times for trainees using an entry-level copter with dedicated fight stabilization software. The maximum amount of training time recorded slightly exceeded 3hrs. That is, the results provide evidence to suggest that training an inspector on basic skills to operate an sUAS for HML inspections should not exceed 3.5hrs. This total duration time does not account for any specific testing requirement that may be imposed by the FAA in their new set of regulations, which is currently an undergoing process. Other significant preliminary results regarding training times include:

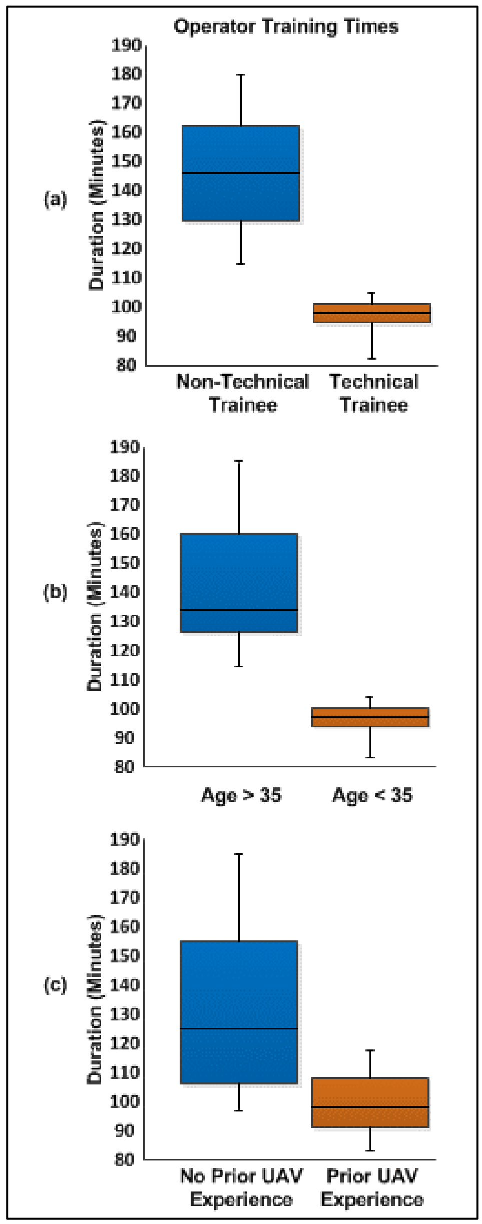

Fig. 4. Operator Training Time Required Based on (a) Education (b) Age and (c) Prior UAV Experience

- It took an average of 2.75 hours to successfully complete the basic objective-based sUAS flight training for those fitting the criterion of no prior UAS experience, over the age of 35, or those considered "Non-Technical Trainees".
- It took an average of 1.75 hours to successfully complete the basic objective-based sUAS flight training for those fitting the criterion of "Technical Trainee", or under the age of 35, or who have had prior UAS experience.

IV. Overview of Florida Tech's sUAS Program

Florida Tech provides a unique sUAS program for undergraduate students. The program equip students in key sUAS areas, including sUAS foundations, regulations, subsystems, flight operations, and flight training. Table 1 presents the general components of the sUAS program and some of the topics related to each component.

Table 1. sUAS Program Components and Related Topics

Category	Course_ID	Example of Related Topics
Foundations	F_1	Introduction to sUAS
	F_2	sUAS Applications
	F_3	Introduction to Aviation
	F_4	Aeronautics
	F_5	sUAS history
Regulations	R_1	FAA Regulations
	R_2	National Airspace Systems (NAS) regulations
Subsystems	S_1	Electronics
	S_2	Sensors
	S_3	Software and Controls
	S_4	Aerial Platforms
Operations and Flight Training	OF_1	Simulation Software
	OF_2	Flight Training in Indoor Lab Facility

The research team hypothesizes that knowledge gained from the FDOT research project would result in a significant positive impact to the effectiveness of the undergraduate sUAS training program. In the Foundations category, general aspects of sUAS types and applications can be presented to students in courses F_1 and F_2, with emphasis on transportation-related applications like bridge inspections. In the Regulations category, FAA and NAS regulations regarding sUAS integration into airspace could be clearly explained in courses R_1 and R_2 using specific highway and railroad bridges as targets. All of the courses in the Subsystems category could benefit from explaining the subsystems integrated into the sUAS engineered for the FDOT research project as prototype for bridge inspections. Similarly, teaching sUAS operations and conducting flight training could be accomplished by focusing on the different types of bridges used as targets during the FDOT research project. The visual module supplements developed for the FDOT project (e.g., Figure 2) could be used in the undergraduate program to conduct flight training, and collect further data to develop in-depth statistical analyses to gain more knowledge regarding the factors that affect training times.

V. Conclusion

This paper described an effort to initiate the integration of knowledge gained during an FDOT research project into the undergraduate sUAS training program at Florida Tech. Flight modules to conduct performance-based tests are described, as well as preliminary results from experiments to understand factors affecting flight training durations. Near future research activities include collecting more data on the factors affecting training times, updating the undergraduate courses with knowledge gained from the FDOT research project, and develop pilot cases to understand the effect of the updated material in students' learning.

VI. Acknowledgment

This work was supported in part by the Florida Department of Transportation under grant BDV28 977-02. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Florida Department of Transportation or the U.S. Department of Transportation.

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