Development and Delivery of a Multidisciplinary Online Course on Unmanned Aircraft Design

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Abstract

The design of unmanned aircraft systems is a multidisciplinary activity across a variety of subsystems both onboard the unmanned aircraft and its ground-based infrastructure. Within the UAS domain, the airworthiness of the designed system must be addressed through across the engineering and product lifecycles. This paper discusses a new course at Embry-Riddle Aeronautical University (ERAU), UAS 501: Introduction to Unmanned Aircraft Design. The course was delivered to ERAU students as part of the Master of Science in Unmanned and Autonomous Systems Engineering program and to a cohort-based ERAU Certificate of Study in Airworthiness Engineering program in partnership with Northrop Grumman Corporation. The paper will address the curriculum, its delivery, and the insights gained in educating a mixed-cohort of traditional and non-traditional students from a variety of engineering academic and professional backgrounds through both synchronous and asynchronous distance delivery.

Keywords

Multi-disciplinary, mixed-cohort, distance delivery, unmanned aircraft systems, systems engineering

Introduction

Unmanned and autonomous systems such as unmanned aircraft systems (UAS) are a rising multidisciplinary niche within engineering. The prevalence of these technologies is rising with a greater demand for their utilization in applications where they must interact around (or over) people or other vehicles. For instance, UAS applications and current R&D are increasingly pushing toward operation over people and integration within non-segregated airspace beyond the visual line of sight of the operator. Within the UAS domain, the airworthiness of the designed system must be addressed throughout the engineering and product lifecycles.

At Embry-Riddle Aeronautical University (ERAU), a new course was launched in fall 2017, UAS 501: Introduction to Unmanned Aircraft Design[1]. The course introduces systems engineering and airworthiness concepts for UAS through a survey of UAS systems, their subsystems including airframe, propulsion, control station, avionics, communication, detect-and-avoid (i.e. collision avoidance), etc. For each system, key design criteria, design and analysis methodologies, and certification standards must be considered. With a lack of current UAS regulation, the course addresses tailoring existing manned certification criteria and regulation toward UAS.

UAS 501's initial offering in fall 2017 supports two academic programs at ERAU. The course was initially planned as an introductory course within the Master of Science in Unmanned and Autonomous Systems Engineering (MSUASE) program's Systems Engineering Area of Concentration[2]. The MS in Unmanned and Autonomous Systems Engineering (MSUASE) program was launched in 2013 with the systems engineering area of concentration added in 2016. In 2017, ERAU partnered with the Northrop Grumman Corporation (NGC) to offer a new graduate Certificate of Study in Airworthiness Engineering (CSAE)[3], which was to be offered online through blended synchronous and asynchronous delivery to a geographically distributed cohort of working professionals. The author proposed to merge both student cohorts in order to provide a single online course offering.

This paper discusses the curriculum development of the new UAS 501 course and how it was tailored for synchronous and asynchronous delivery for a multi-disciplinary cohort comprised of both traditional and non-traditional students. The course curricula and pedagogy will be discussed. Feedback through student surveys and lessons learned will be presented. The paper will conclude with recommendations on how the course will be refined for future offerings.

Background

UAS 501: Introduction to Unmanned Aircraft Design was proposed as a graduate-level introductory survey course addressing a variety of unmanned systems topics for the ERAU Daytona Beach Campus's MSUASE program under its Systems Engineering area of concentration. The courses' first offering was planned for the fall 2017 term. In early 2017, the course was also selected for inclusion in a new partnership program with the NGC under a new Certificate of Study in Airworthiness Engineering program. This section provides a brief background on each of these programs and the role that the UAS 501 course plays within each of the respective programs.

The MSUASE program started in Fall 2013. It initially offered two areas of concentration, a technical concentration and an Unmanned Aircraft Systems (UAS) area of concentration. The curriculum of the initial areas of concentration supported air, ground, sea, and space unmanned and autonomous systems. The UAS area of concentration replaced the set of possible technical electives in the program with a set of aerospace engineering courses focused upon guidance, navigation, and control. After three years, the program's enrollment had remained particularly small due to competition between other ERAU programs and the program's niche focus.

In 2016, a new area of concentration in Systems Engineering was introduced, which blended systems engineering courses with technical courses related to unmanned and autonomous systems. The program's goal was to produce systems-thinking engineers ready to support the systems engineering challenges of unmanned aircraft system design, development, and test. Within the program, UAS 501 was introduced into the curriculum to provide students within the Systems Engineering track, or those in other tracks seeking a technical elective with a holistic understanding of UAS by exploring each of their major sub-systems including: airframe, propulsion, avionics, detect-and-avoid, communication systems, payloads, control station, and various ground elements.

In addition to supporting the MSUASE program, the UAS 501 course was selected for the new Certificate of Study in Airworthiness Engineering developed under a partnership with NGC. Under that program, the students were required to complete a course in system safety and certification (SYS 505: System Safety and Certification), airworthiness engineering (AWE 510: Aircraft Airworthiness Engineering Principles), an aviation course addressing aircraft systems and their airworthiness/certification considerations, and finally a capstone course with design project (AWE 510: Aircraft Airworthiness Capstone Project). UAS 501 was selected to provide the aviation course addressing aircraft systems and their airworthiness considerations. The inclusion of UAS 501 was made based upon the planned approach of surveying each major UAS sub-system, and only required a minor modification to the planned curriculum to more explicitly address the airworthiness considerations for each system.

To address the needs of both the ERAU and NGC student cohorts, the first offering of UAS 501 during fall 2017 featured a blended cohort of students. The ERAU cohort was comprised of eight students including two MSUASE students; two PhD in Electrical Engineering and Computer Science students, one at Daytona Beach and one remote; one MS in Software Engineering student; and one computer engineering student from the ERAU Prescott, AZ campus. The NGC student cohort was comprised of seven students including two employees from Melbourne, FL, one employee from St. Augustine, FL, one employee from Rockville, IL, and three employees from San Diego, CA.

In a later section, the paper will discuss the approach for teaching both cohorts through a blend of distance delivery and face-to-face lecturing, and the overall course curriculum to address the needs of both cohorts.

Related Work

In the context of the Certificate of Study in Airworthiness Engineering, one of the goals was to provide a more project and application drive curricula to the students. While each course is taught standalone, the integration of content between courses is highly relevant. In Mourtos et al.[4], the topic of integrated curriculum for a sequence of aerospace engineering courses toward solving multidisciplinary problems is discussed. Within the article, it discusses key advantages of integrated curricula including "increased communication among the faculty who design and teach these courses, helps them understand better the connections between each other's discipline." [4]

The course offered shares similarities between other aircraft design courses, but tailored to UAS. In a paper by Stocking, 2006[5], a master's level aircraft design course is presented. Like the approach within this paper, the authors utilize group projects to provide context toward the learning. Its curriculum in the areas of aircraft airframe design is comparable, but tailored toward students with a deeper aerospace engineering background. It included optional topics like avionics system design and aircraft powerplant installation5, which were non-optional topics when addressing UAS design.

The offering of a course online through synchronous delivery or asynchronous delivery is not unique to ERAU or other higher-learning institutions. A variety of papers address the topic of distance learning. For example, synchronous distance delivery is addressed in 2001 paper by Pullen[6]. A comparison of asynchronous vs. synchronous delivery can be found in an article by Midkiff and DaSilva[7]. In Adgas et al.[8], a survey and statistical analysis addressing the efficacy of distance learning is presented. In its study, it found the two primary indicators of value assessment for a distance learning course is communication requirements and logistic simplicity[8]. Aspects of logistic simplicity includes accessibility to resources (e.g. library, reading materials, etc.), personal attention, timely communication regarding questions or other issues, etc. With regard to communication, major areas of impact include the communication efficiency through the learning management system, email communication efficiency, and ability to communicate with peers[8]. The authors also indicated the accessibility of the LMS from their workplace as being a large contributor to negative feedback during the survey[8].

Finally, the offering of a unmanned aircraft design course is not unique. Several short courses and academic programs address the topics covered within UAS 501 to some degree. Short courses in unmanned aircraft design are provided by Applied Technology Institute[9] and the University of Kansas[10]. Examples of academic degree programs addressing unmanned aircraft design through one or multiple courses including the University of South Hampton's MS in Unmanned Aircraft System Design[11] and Purdue University's BS in Unmanned Aerial Systems[12], and ERAU Worldwide Campus's MS in Unmanned Systems[13].

Course Curriculum

This section provides an overview of the curriculum of the UAS 501 course. Where appropriate, the paper will discuss how aspects of the course was tailored to meet the mixed-cohort requirements of the course's offering.

Textbook and Reading Materials

For this course, an extensive search for a suitable textbook was performed. The final textbook addressed most of the requisite course topics, but did not capture them in their entirety. The textbook selected was *Designing Unmanned Aircraft Systems: A Comprehensive Approach, Second Edition by Jay Gundlach*[14]. The textbook is written as primarily a reference and makes some broad assumptions about the reader's background in aviation, which will be discussed later in this paper under lessons learned.

To address outcomes related to airworthiness and certification, existing standards, guidance materials, and handbooks from military and civilian sources from the United States, NATO, and other international sources were selected. United States Military Handbook 516C[15] (MIL-HDBK-516c), "Airworthiness Certification Criteria," addresses airworthiness issues for manned aircraft and some UAS requirements. Within the context of the course, MIL-HDBK-516c provided the students with insight regarding what aspects of the system must be assessed for manned systems, and how these requirements can be applied through tailoring toward UAS. Two NATO Allied Engineering Publications (AEPs) were used to address control station requirements and interoperability. NATO AEP 4671[17], "Unmanned Aircraft Systems Airworthiness Requirements," provided a mapping of civilian airworthiness standards toward the certification of UAS for NATO allied. NATO AEP 84[17], "Standard Interface of the Unmanned Control System (UCS) Unmanned Aerial Vehicle (UAV) Interoperability," was used to address communication and control station interoperability standards. To provide a broader civilian context, existing manned certification standards, advisory circulars, and other regulatory guidance materials were presented to the students as found under Title 14 of the Code of Federal Regulations (14 CFR)[18], materials found at the FAA's Regulatory and Guidance Library[19], and the Aeronautical Information Manual (AIM)[20]**.** Finally, proposed minimum operational performance standards (MOPS) developed by RTCA, Inc. that are approved by the FAA were reviewed included within the curriculum including RTCA Document (DO)-362[21] "Command and Control (C2) Data Link Minimum Operational Performance Standards (MOPS) (Terrestrial)" DO-365[22] "Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems", and DO-366[23] "Minimum Operational Performance Standards (MOPS) for Air-to-Air Radar for Traffic Surveillance." These standards provided great context to the topics of communication and detect-and-avoid, but produced challenges as discussed under lessons learned with availability to the students.

Course Topics and Learning Outcomes

The course was divided into 11 topics. This subsection provides an overview of each topic and the associated learning outcomes.

Topic #1: Introduction to UAS and System Architecture: The first lecture topic addresses the concept of an unmanned aircraft as a system of systems. A survey of current UAS and their applications provides high-level context to the various types of UAS in the marketplace and their suitability across a variety of applications. The students are introduced to the major sub-systems of the UAS. The definition of system and system-of-systems is discussed. A high-level overview of the regulatory considerations of UAS is also presented. The learning outcomes for this topic area as follows:

1.1 Students shall be able to identify common unmanned aircraft systems.
1.2 Students shall be able to identify common UAS applications

1.3 Students shall be able to define system vs. system of systems.
1.4 Students shall be able to explain how a UAS is a system of systems.
1.5 Students shall be able to identify the role of each major UAS sub-system.

Topic #2: Airframes: The airframes learning modules address both fixed-wing and rotorcraft airframe characteristics. The students are introduced to the categorization approaches for UAS utilized by the Department of Defense and the FAA. A survey of UAS airframe types is presented with examples through images and videos. The students are given a review of aerodynamics and flight physics. Airframe design considerations and analysis is presented including planform (wing and tail surface) configuration, weight, lift, drag, performance vs. altitude and velocity, etc. Airworthiness considerations of UAS airframe design are reviewed from both civil and military standards. The learning outcomes for this topic area as follows:
2.1 Students shall be able to identify common UAS airframe types and their key design / performance tradeoffs,
2.2 Students shall be able to classify a UAS by its airframe type,
2.3 Students shall be able to discuss role/impact of key UAS design parameters for fixed wing UAS,
2.4 Students shall be able to discuss role/impact of key UAS design parameters for single and multi-rotor UAS, and
2.5 Students shall be able to identify and discuss the implications of civil and military airframe design standards and their impact on UAS design.

Topic #3: Propulsion: The propulsion unit builds upon the flight physics discussion from the airframe topic with a focus upon thrust, weight, and vehicle endurance. A notional framework of UAS propulsion is presented based upon energy storage, energy transformation, UAS power plants, UAS end-effectors (e.g. propellers), and throttle controls. Analysis techniques for propulsion system design were discussed. The learning outcomes for this topic area as follows:
3.1 Students shall be able to compare various types of energy storage devices (batteries, fuel cells, fossil fuels, etc.),
3.2 Students shall be able to discuss mechanisms for UAS energy transformation from stored energy to work, heat, or electrical current,
3.3 Students shall be able to discuss common types of UAS fixed-wing and rotorcraft powerplants,
3.4 Students shall be able to compare types of UAS prolusion effectors (e.g. propellers),
3.5 Students shall be able to discuss various control effectors for controlling the UAS propulsion, and
3.6 Students shall be able to identify and discuss the implications of civil and military propulsion design standards and their impact on UAS design

Topic #4: Avionics: The avionics topic addresses the electronic systems onboard the UAS. It includes a discussion of avionic sensors, computers, data busses, etc. Certification considerations for the certification of onboard equipment/avionics was addressed. Additionally, the certification of flight software was discussed. The learning outcomes for this topic area as follows:
4.1 Students shall be able to define avionics and provide examples of UAS avionic equipment,
4.2 Students shall be able to discuss UAS avionics design considerations,
4.3 Students shall be able to discuss UAS flight software, and
4.4 Students shall be able to identify and discuss the implication of civil and military avionics standards on UAS avionics hardware and software.

Topic #5: UAS Control and Automation: The control and automation unit addresses the topic of UAS flight control surfaces, flight control systems, and automation of UAS operations. Levels of automation provided a key basis for the discussion as the type of controls supported by the control system are dependent upon the level of automation and the role of the pilot-in-command during the UAS mission. A basic overview of traditional control systems, sensor data fusion, and path planning algorithms provided specific context to the controls discussion. The learning outcomes for this topic area as follows:

5.1 Students shall be able to identify the levels of autonomation for UAS and the function allocation between pilot and control system implied by each,
5.2 Students shall be able to discuss UAS contingency operations and characteristics of their implementation, and
5.3 Students shall be able to discuss certification of UAS flight control software and considerations for non-deterministic software elements.

Topic #6: Detect-and-avoid: The detect-and-avoid lecture addresses the sensor technologies to support detection of potential collisions, and the algorithms and/or user interfaced requirements to avoid the collision. The formal definitions of collision avoidance based upon research from the Sense-and-Avoid Research Panel (SARP)[24] and its adaptation by the FAA and RTCA into DO-365[22] is presented. Current detect-and-avoid standards from RTCA were reviewed and discussed. The learning outcomes for this topic area as follows:

6.1 Students shall be able to discuss the definition of well-clear, near mid-air collision, etc. and how they vary between sources,
6.2 Students shall be able to identify, compare, and contrast ground-based DAA systems,
6.3 Students shall be able to identify compare, and contrast airborne DAA systems,
6.4 Students shall be able to discuss avoidance approaches applicable to UAS, and
6.5 Students shall be able to identify and discuss civil and military DAA requirements for UAS.

Topic #7: UAS Communications: The communication lecture addressed both radio frequency (RF) line-of-sight (LOS) and beyond RF LOS (BLOS) communication considerations for UAS. The communications physical layer is discussed including encoding, modulation, and propagation. An overview of antennas and rudimentary antenna analysis allows students the opportunity to compare communication performance across several sensor types. A lengthy discussion on UAS communication link budgets connect mission, flight, and airframe characteristics to the requirements of the UAS communication system(s). The learning outcomes for this topic area as follows:

7.1 Students shall be able to define key elements of a UAS communication system (RF LOS and RF BLOS),
7.2 Students shall be able to understand and apply basic RF engineering physics to UAS communication design considerations,
7.3 Students shall be able to implement a link budget for a UAS given communication system characteristics,
7.4 Students shall be able to select an antenna based upon mission requirements and aircraft characteristics, and
7.5 Students shall be able to discuss cybersecurity concerns and mitigations for UAS communication system.

Topic #8: Launch-and-Recovery: The launch and recovery topic addresses approaches, technologies, and the associated physics for conventional launch and recovery, vertical takeoff and landing, and numerous unconventional launch and recovery methods (catapult, rail, net, etc.). These systems are discussed in the context of their applicability toward different mission considerations such as runway independence, ship-based missions, etc. Some manned regulations/standards related to landing gear, parachutes, and arresting cables were reviewed to provide a regulatory baseline for conventional and unconventional launch and recovery standards. The learning outcomes for this topic area as follows:

8.1 Students shall be able to identify common UAS launch mechanisms (conventional, rail, rocket, air, hand, etc.),
8.2 Students shall be able to identify common UAS recovery mechanisms,

8.3 Students shall be able to discuss the mission and aircraft considerations impacting launch mechanism selection, and
8.4 Students shall be able to discuss the mission and aircraft considerations impacting recovery mechanism selection.

Topic #9: Control Station: The UAS control station is responsible for housing the primary and/or secondary command and control elements of a UAS during its mission. The lecture introduced types of control stations and their elements. Next, human factors considerations including information requirements, ergonomics, work environment, etc. are discussed. Finally, international standards from NATO for control station requirements and control station interoperability are discussed. The learning outcomes for this topic area as follows:
9.1 Students shall be able to identify major elements of a UAS control station,
9.2 Students shall be able to discuss human factors considerations of UAS CS design, and
9.3 Students shall be able to identify and discuss current civil and military control station requirements.

Topic #10: Payloads: To this point in the course, all topics addressed the unmanned aircraft's requirements, but largely ignored mission element considerations. This lecture addresses the common types of payloads, their design tradeoffs, and their integration considerations. Analysis of the impact of sensors on the system's onboard computing and data links is further analyzed. The learning outcomes for this topic area as follows:
10.1 Students shall be able to identify and describe common UAS payloads and their design tradeoffs,
10.2 Students shall be able to discuss considerations of size, weight, and power for payloads, and
10.3 Students shall be able to discuss computational and data link requirements to accommodate common payloads.

Topic #11: System Integration: Wrapping up the course, the final lecture reviews the topics covered previously in the context of system design and integration. Analysis techniques are presented to derive system requirements, mission requirements, system test plans, etc. The lecture then addresses the verification and validation methodologies to assess the performance of the integrated system. The learning outcomes for this topic area as follows:
11.1 Students shall be able to discuss system integration analysis considerations for UAS,
11.2 Students shall be able to identify hardware/software integration aspects of UAS systems integration,
11.3 Students shall be able to discuss of mission specific systems integration considerations, and
11.4 Students shall be able to discuss processes for validation and verification of integrated UAS system.

Student Assessment
To assess student performance in the course, graded artifacts are collected from the students throughout the semester. Online quizzes are given after every other lecture addressing both previous lectures. The quiz format is comprised of multiple choice, true false, and matching questions based upon content within the reading and lecture, and several short answer calculation problems applying engineering analysis to relevant story problems addressing the learning outcomes.

Two month-long projects, called "mini-projects," are given during the term. The first addressed airframe design and propulsion. Students were given a UAS mission and asked to follow procedures to derive an airframe design including, but not limited to weight, planform (wing) design, and its aerodynamic characteristics, and propulsion design including thrust requirements analysis, engine/motor selection, propeller selection, fuel selection, and a high-level integration plan. The project deliverable was a written design document.

The second mini-project addresses avionics, automation, detect-and-avoid, and communication considerations. Given a new UAS mission and unmanned aircraft characteristics, the students were asked to derive requirements for the system's onboard avionics. Next, the students needed to determine based upon the mission concept which flight/mission tasks must be handled manually vs. through automation. The detect-and-avoid requirements are derived based upon the proposed automation. Finally, a line-of-sight communication link budget is developed based upon specifications derived from RTCA DO-362's communication requirements.

Finally, an end-of-course final examination will assess overall student knowledge utilizing a combination of short answer calculation, multiple choice, matching, and true/false questions. The exam is given open book/open note. The problems focus primarily on course concepts addressing the learning outcomes as well as their application to particular UAS requirements.

Course Delivery

The course delivery was unique for the author, and based upon the articulated instructional agreement between ERAU and NGC for the CSAE program. ERAU students were required to follow this schedule despite some misalignment with the academic calendar's scheduled breaks.

Table 1: UAS 501 Fall 2017 Schedule

Activity	Topic	Class Day
Class 1	Topic #1: Introduction / System Architecture	8/25
Online 1	Topic #2: Airframes	9/1
Online 2	Topic #3: Propulsion	9/15
Class 2	Topic #4: UAS Avionics	9/22
Online 3	Topic #5: UAS Control and Automation	9/29
Class 3	Topic #6: Detect-and-Avoid	10/6
Online 4		10/13
Class 4	Topic #7: UAS Communications	10/20
Online 5		10/27
Class 5	Topic #8: Launch and Recovery	11/3
Online 6	Topic #9: Ground Control Stations	11/10
Class 6	Topic #10: Payloads	12/1
Online 7	Topic #11: System Integration	12/8
Final	Comprehensive Final	12/15

The course was divided into 13 three-hour lecture sessions and a 1-hour final as shown in Table 1. Of the 13 lecture sessions, six lectures are delivered through a blending of face-to-face and synchronous online delivery. For the remaining seven lectures, asynchronous distance delivery of lecture instruction was used. The course alternated between modalities every other week.

Face-to-Face and Synchronous Distance Delivery
For six sessions, the course was taught with a blending of face-to-face and synchronous online delivery. The author used a classroom designed for online distance delivery to teach the lectures. Four ERAU Daytona Beach students participated in the face-to-face delivery. The remaining 11 students participated in the lectures through synchronous distance delivery using Skype for Business[25].The lecture slides, audio, and webcam video of the instructor and the board were streamed live and recorded. Two-way communication was enabled through the inclusion of a speakerphone allowing remote participants to ask questions when desired. The NGC students participated at ERAU-Worldwide satellite campuses located near their workplace. The two remote ERAU students participated on their personal computer.
The distance delivery classroom provided a large flat-screen display at the back of the classroom to display each of the student participants' webcam feeds providing for a closer analog to a face-to-face teaching environment. Lecture slides and the recording of each lecture were posted online through the Canvas learning management system (LMS)[26].

Asynchronous Distance Delivery
Asynchronous distance delivery for the alternative seven lectures was achieved through several tools and the Canvas LMS. Each online learning module was built in Canvas including narrated presentations and assigned reading. Lectures were built and narrated using Microsoft Powerpoint 2016[27]. Using Powerpoint's "Record Presentation" feature, audio is recorded for each slide, which will play whenever the user transitions to the next slide. This feature also records any use of the virtual laser pointer, or any other markup on the slide. Each lecture was comprised of three-to-four units, which were their own standalone Powerpoint presentation. Online reading with instructions are posted on Canvas. Instructions were provided to direct the student regarding which sections of the textbook, standard, etc. should be read. Reading instructions also direct whether or not the reading is required or optional.

Communication
Communication was facilitated through multiple modalities. First, an email distribution list was generated to ensure communication between the instructor and the students. The distribution list was used in place of the Canvas LMS announcement and messaging services because NGC employees were restricted access to the website. Email was a more reliable mechanism for timely input. For assignments, a discussion board was created. Students would pose questions in the forum, and the instructor provided feedback. Face-to-face office hours were provided to Daytona Beach students. Northrop Grumman employees were also invited to weekly online office hours via Skype for Business on Wednesday evenings from 9:00 – 10:00pm. ERAU students were not permitted to attend the online office hours at the request of NGC due to some issues with NGC employees under restricting security clearances. However, the sessions were recorded and posted on the Canvas LMS page available to all students.

Course Assessment and Lessons Learned:

Standard End-of-Term Survey

The ERAU standard end-of-course survey was performed on both student cohorts. The assessment results are summarized in the table below. These results, shown in Table 2, are organized to show the results from the ERAU cohort, the NGC cohort, and the ensemble cohort.

UAS 501 Tailored Student Survey

In addition to the standard end-of-course survey questions, 10 additional survey questions were distributed to the students via an online to address the specific to this course.

The following survey questions were asked of the students using a Likert scale of (1-Strongly Disagree to 4-Strongly Agree).

- Q1. The online learning modules were well-organized, and the instructions for use were clear.
- Q2. Face-to-face and/or online communications enabled me to seek out assistance and communicate with my peers.
- Q3. The face-to-face lectures facilitated my learning of the course topics.
- Q4. The online recorded lectures provided a suitable learning experience.
- Q5. The course provided an adequate survey of the UAS sub-systems.
- Q6. The course provided an adequate understanding of the airworthiness considerations for UAS.
- Q7. Mini-project #1 aided my understanding of UAS airframe design, aerodynamics, and propulsion requirements and design.
- Q8. Mini-project #2 aided my understanding of UAS avionics, automation, detect-and-avoid, and communication system requirements and design.
- Q9. The course's online quizzes were well-designed to assess my knowledge of the UAS sub-systems that each covered.
- Q10. Overall, I have a better understanding of unmanned aircraft system requirements, design, airworthiness, and certification.

The online survey received a response rate of 6 out of 15 students. Of this, they self-reported two students from the NGC cohort, two from the ERAU MSUASE program, and two other ERAU students. The results of the second, more targeted survey can be found in Table 3.

Table 2: End-of-Term Survey Question Results

Relevant Survey Questions	Average Score	
	NGC (N=3)	**ERAU (N=4)**
I achieved the learning outcomes for this course.	3.33	3.5
The instructor taught the course content in a manner that made it understandable.	3.67	3.25
The instructor showed expertise in the subject matter.	3.67	3.5
The instructor's materials enhanced my understanding of the course content.	3	3.75
The instructor showed enthusiasm for teaching.	3.67	3.25
The instructor kept the class engaged.	3.33	3.25
The instructor was available for consultation during office hours or by appointment.	3.67	3.75
The instructor was well-prepared for class.	3.67	3.75
The instructor provided clear instructions for completing class assignments.	3.67	3.5
The instructor assessed my work according to clearly communicated criteria.	3.67	3.5
I am satisfied with the instruction in this course.	3.67	3.25

Table 3: Targeted Survey Question Results

Course-Specific Questions	Average Score (N=6)
Q1. The online learning modules were well-organized, and the instructions for use were clear.	3.83
Q2. Face-to-face and/or online communications enabled me to seek out assistance and communicate with my peers.	3.33
Q3. The face-to-face lectures facilitated my learning of the course topics.	3.50
Q4. The online recorded lectures provided a suitable learning experience.	3.33
Q5. The course provided an adequate survey of the UAS sub-systems.	3.83
Q6. The course provided an adequate understanding of the airworthiness considerations for UAS.	3.67
Q7. Mini-project #1 aided my understanding of UAS airframe design, aerodynamics, and propulsion requirements and design.	3.50
Q8. Mini-project #2 aided my understanding of UAS avionics, automation, detect-and-avoid, and communication system requirements and design.	3.67
Q9. The course's online quizzes were well-designed to assess my knowledge of the UAS sub-systems that each covered.	3.67
Q10. Overall, I have a better understanding of unmanned aircraft system requirements, design, airworthiness, and certification.	3.67

A free-form question was asked regarding the most helpful resources for the course, the responses were as follows:

- The organization of the course material greatly facilitated learning the course content, as well as the consideration given to the various backgrounds of the students in the class. It was obvious that the professor spent a lot of time preparing the course material, and the organized and logical manner in which it was presented helped me learn the course content.
- The projects were very practical and kept me engaged.
- The sheer volume of material and the spread over the semester was particularly helpful.
- The online content and an extra resources.
- Face-to-face was really good because if you had questions you can get an answer right away. I also liked the concept of adding voice audio on the online lectures. I think that was an incredible help specially when the audio provides the extra content that you don't get from reading the slider (e.g. examples to which concepts apply to).

A free-form question was asked regarding the least helpful resources for the course, the responses were as follows:

- Honestly, there are no elements in the course that I would say least helped me learn the content. I found each element of the course useful in the learning process.
- Voice recorded power point slides were very hard to use
- Some of the additional reading took focus off the core course materials.
- The way the mini projects were organised (sic) did little to help me gain significantly more than I would have gotten if spread throughout the semester a lot more with emphasis on more deliverables over time.
- The lectures were somewhat dull and just very long which couldn't be helped but it was rough

- Sometimes equations were not very clear as to how to use them or what is the output to be used for as it relates to the overall picture of solving a problem. Its easy to get lost with so many equations.

Lessons Learned

The offering of UAS 501 provided numerous lessons learned regarding the teaching of the course material, synchronous online instruction, asynchronous instruction, mixed cohort-based education, and other general lessons learned. The lessons learned are summarized in Table 4.

Table 4: UAS 501 Lessons Learned

Consideration	Lessons Learned

Course Topics and Materials	• Textbook provided a suitable survey of UAS systems, but some assumptions regarding reader background had to be acknowledged and addressed.
	  o e.g. airframe design and analysis chapters assumed a background in aerodynamics, structures, materials, and basic aircraft design.
	  o Addressed by providing guidance to students regarding outside references, and remediating where necessary.
	  o Some sections were substituted with other readings.
	  o Lack of units on equations in the textbook resulted in some students struggling with calculations (i.e. values in the wrong units).
	• Access to some digital resources was problematic due to copyright restrictions and limits by the publisher of inclusion in online library resources.
	  o e.g. RTCA standards only available in hardcopy at library.
	  o ERAU distance students could not utilize course reserve copies of these materials.
	  o Pre-print/draft versions of these documents were used under fair-use.

Communication	• Online office hours were consistently attended by a subset of NGC students, but were recorded and shared. Allowed for an opportunity to deep dive into topics discussed in class, and to address current events in the UAS community.
Synchronous Instruction	• Network bandwidth limitations impacted the ability to stream online videos during synchronous instruction resulting in lag for some, but not all distance learners. • Video display of distance learner webcams facilitated classroom instruction by creating a stronger sense of connectedness. • Difficult to design active learning activities into online distance instruction. Some students reported the lectures seemed long an dull.
Asynchronous Instruction	• Preparation of online lecture materials resulted in a significant increase in workload for the instructor. At least 3-5 hours of time must be allocated to support lecture recording for each 3-hour learning module. • Lack of real-time feedback to the instructor emphasized the importance of utilizing online quizzes for both grading and assessment of success in teaching learning outcomes. • Some NGC students experienced issues with remotely accessing course materials due to their workplace computer's restrictions.

Mixed-Cohort Education	• Limitations by the program restricted mixing of the two cohorts.
	  o NGC employees with security clearances wished to avoid interaction with ERAU student cohort due to inclusion of international students.
	  o Project teams could not mix between cohorts.
	  o Resulted in exclusion of ERAU students from online office hours.

	• CSAE's cohort-based instructional approach and course sequence provided better context for topics that overlapped such as airframe design, airworthiness analysis techniques, etc. o Discussion during synchronous allowed these students to discuss some of these connections adding broader benefit to the overall class.

Conclusions

The initial offering of UAS 501 was successful. Despite some issues as addressed through the lessons learned, the initial feedback has shown that the students enjoyed the course material, were accepting of many of the initial technology challenges, and demonstrated through assessment an understanding of the course materials.
For future offerings, only minor changes are anticipated to the courses curriculum. Issues related to technology, resource availability, and communication will be addressed in the interim between the fall 2017 offering and the anticipated summer or fall 2018 offering. Given the initial success of the collaboration between NGC and ERAU, the course will be offered to a mixed-cohort for the foreseeable future with employees from other aviation industry companies being added to the cohort. Finally, ERAU's Daytona Beach campus is partnering with ERAU's Worldwide campus to begin offering the MSUASE program online leveraging the online course development from the first offering of UAS 501 as content in support of the program's initial offering of the Systems Engineering Track.

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