UAS Aerospace Projects as a Catalyst for Interdisciplinary Engineering

Dr. Michael C. Hatfield, University of Alaska, Fairbanks

Michael C. Hatfield is an assistant professor in the Department of Electrical and Computer Engineering at the University of Alaska Fairbanks, and Associate Director for Science & Education, Alaska Center for Unmanned Aircraft Systems Integration. He earned a B.S. in electrical engineering from Ohio Northern University; an M.S. in electrical engineering from California State University Fresno, and a Ph.D. in Electrical/Aeronautical Engineering from the University of Alaska Fairbanks.

Dr. Denise Thorsen, University of Alaska, Fairbanks

Denise Thorsen received her B.S. (1985), M.S. (1991) and Ph.D. (1996) degrees in electrical and computer engineering from the University of Illinois at Urbana-Champaign. She is currently a Professor in Electrical and Computer Engineering at the University of Alaska Fairbanks

UAS Aerospace Projects as a Catalyst for Interdisciplinary Engineering

Introduction.
Aerospace projects provide a unique opportunity for students to gain valuable experience in interdisciplinary engineering by blending considerations from the fields of mechanical, electrical, computer engineering/science, and other disciplines to the solution of a complex problem. Unfortunately, most colleges often do not possess an organic aerospace engineering program or other formal means of implementing interdisciplinary engineering at the program level. However, even singular aerospace projects undertaken by students within particular engineering disciplines can provide an alternative means to promote the principles of interdisciplinary engineering and gain experience with the systems engineering design process (SEDP).

Traditional aerospace projects have predominantly focused on the design, construction, and flight operations associated with small satellites and rockets. While these have and continue to enjoy much support over the years, such efforts also generally require a relatively expensive and long-term infrastructure system necessary for the development of complex systems, ensure student safety, and span gaps of time between infrequent launch opportunities. However, in recent years, the rise in popularity of Unmanned Aircraft Systems (UAS) represents another avenue for conducting useful interdisciplinary engineering projects within a greatly compressed timeframe and limited resources.

This paper outlines efforts undertaken by students at the UAF to conduct aerospace projects via existing design courses in mechanical, electrical, and computer engineering/science. Specifically, the paper focuses on interdisciplinary skills gained by students that might not normally have an opportunity to learn these at this stage in their education with the programs on hand. This includes experience with UAS vehicle design, construction, and flight experience, as well as team dynamics and exposure to the SEDP.

Motivation.
The desire for educational programs within the field of aerospace engineering continues to be popular. This is both due to the increasing availability of technology and job opportunities within the aerospace engineering career field. According to the Department of Labor's Bureau of Labor Statistics (April 2018), "*Employment of aerospace engineers is projected to grow 6 percent from 2016 to 2026, about as fast as the average for all occupations.*" Rationale for this growth is attributed to several factors, including the increased use of cubesats, aircraft aerodynamic efficiency and noise reduction efforts, as well as the explosion in the field of UAS [1]. In addition to these are the potential for the aerospace workforce to suffer reductions of current personnel as a result of retirements over the next decade [2], [3], [4]. As a result of these factors, aerospace engineering remains a strong area of interest for many students today [6].

Need for Interdisciplinary/Systems Engineering Training. According to the Office of Science and Technology Policy (OSTP) National Science and Technology Council (NSTC) Committee on STEM Education's Charting a Course for Success: America's Strategy for STEM Education, December 2018 [16], the goal of interdisciplinary education should be to "*Engage Students where Disciplines Converge. This pathway seeks to make STEM learning more meaningful and inspiring to students by focusing on complex real-world problems and challenges that require initiative and* *creativity. It promotes innovation and entrepreneurship by engaging learners in transdisciplinary activities such as project-based learning, science fairs, robotics clubs, invention challenges, or gaming workshops that require participants to identify and solve problems using knowledge and methods from across disciplines. It seeks to help students challenged in mathematics – frequently a barrier to STEM careers – by using innovative, tailored instructional methods. Another objective is teaching learners to tackle problems using multiple disciplines; for example, learning data science by combining basic mathematics, statistics, and computer science to study a societal problem. Such activities help to create a STEM-literate population and prepare Americans for the rapidly evolving workplace.*"

According to the National Science Teachers Association (NSTA Position Statement, Aerospace Education, March 2008) Elements of Quality Aerospace Education Programs [15]. A high-quality aerospace education program and curricula should include the following features:

- *Foster observation, investigation, and creative thinking;*
- *Provide opportunities to connect science educators and their students with the broader aerospace science and technology community;*
- *Provide students with interdisciplinary, multicultural, and multi-perspective viewpoints to demonstrate how aerospace exploration and research transcends national boundaries;*
- *Address economic, historical, ethical, and social perspectives;*
- *Use appropriate technologies such as modeling, simulation, and distance learning to enhance aerospace education learning experiences and investigations;*
- *Present a balance of aeronautics, space exploration, and robotics by offering a relevant context for learning and integrating STEM core content knowledge.*

UAF has attempted to incorporate as many of these concepts into our fledgling aerospace courses, aerospace minor, and design team experiences as possible. This is accomplished through the use of student teams to investigate research topics, individual student-led course material presentations and discussions, and small team hands-on design/build/fly UAS activities. These courses and activities are described in the following sections.

Design Team/SEDP Experience. Courses centered around design team activities provide important opportunities to instill career competencies and broad skill sets needed in industry, including: (1) Leadership and Teamwork. This includes the mentoring, training, and development of workers who can work together effectively as a team to accomplish a specific set of tasks within the team's charter. (2) Management. This includes functions of coordinating work, timelines, de-conflicting resources, and securing financial support. (3) Communication. Students participating in design team activities gain much practical experience in the application of various communications skills which are directly relevant to the workplace. This includes formal/informal communications, group/interpersonal communications, written/oral communications, and various media and mechanisms for accomplishing this (written reports, briefing slides, photographs, videos, web sites, social media, email). (4) Student Ownership.

Beyond the skills mentioned above, students also benefit through taking personal ownership of their own educations, career training, and broad life goals. Through these activities, students are better equipped to develop and hone highly-desired traits such as independence, self-reliance, critical thinking, goal-setting, the ability to function effectively in small teams.

Aerospace Projects as a Traditional Means to Teach Interdisciplinary Engineering.
Aerospace engineering projects have long been used as a means of teaching interdisciplinary/systems engineering. Aerospace projects are, by their very nature, interdisciplinary, including elements of astronautical and/or aeronautical engineering, mechanical engineering, electrical engineering, computer engineering, computer science, and often other disciplines (eg, physics, management). Universities with aerospace programs or offering elements of aerospace engineering use design projects in several capacities, including senior capstone undergraduate courses, graduate courses and individual projects, and student-led design teams. One well known example of this the American Institute of Aeronautics and Astronautics (AIAA) Design, Build, Fly (DBF) team competitions.

For example, the US Air Force Academy (USAFA) possessed hands-on student satellite and rocketry programs beginning in the mid-1990's (one author was a founding member of these efforts). The satellite program has been a robust multidisciplinary effort, involving cadets from the astronautical engineering major, as well as those from mechanical engineering, electrical engineering, computer engineering, space physics, and management majors. These satellite programs could span 1-2 academic years, with cadet teams of roughly 20-40 participating for up to 2 years (junior and senior years). Cadets receive formal course credit and participate in all phases of the systems engineering design process, from requirements analysis, through preliminary design and critical design, to developmental test and operational flight test. Specialty knowledge is required in the areas of space environment, mechanical structures, electrical power, communications, computers, navigation/guidance, thermal, and others.

Beyond the technical engineering aspects, cadets also gain valuable experience in the regulatory environment, often participating in USAF/DoD Space Experiments Review Board (SERB) process to gain approval and find a ride for their satellite. Finally, given the right timing and circumstances, cadets may even participate in the launch of a satellite and see it operate. (Cadets in the space operations major also participate in the operational mission control of these assets.)

The USAFA rocketry program has also been another successful vehicle for teaching interdisciplinary engineering, over the years constructing several single-stage rockets (solid, liquid, and hybrid motors). These rockets were typically designed and built over a 1-year span (sometimes longer) by a team of about 8-12 astronautical engineers, at times augmented by cadets from other academic disciplines. Upon completion, these rockets were generally launched at nearby Ft Carson Army range. As with the satellite program, cadets receive formal course credit and step through the SEDP/systems acquisition process, led by a team of instructors.

Figure 1: USAFA satellite in construction (left); USAFA rocket launcher supporting 1-semester course (left/center) and rocket program (right) (circa 2002)

In addition to the multi-semester course supporting larger rockets, the USAFA's rocketry program offered a 1-semester course in which cadets designed, built, and flew smaller rockets and payloads. In this, cadets would form small teams of 3-4 for each project. They would step through an abbreviated SEDP process and gain approval for each phase and test critical elements of the rocket design (eg, recovery system and payload) prior to accomplishing the full rocket/payload launch. Launches for this course were generally accomplished right on the USAFA grounds away from the populated areas.

Aerospace Support Projects. While the satellite and rocketry efforts discussed above generally require a higher level of existing university infrastructure and longer term commitment, much may be accomplished with lower levels of support or students having less formal aerospace engineering background. Beyond the case of UAS projects to be discussed later, aerospace support projects can also provide an excellent opportunity to teach interdisciplinary engineering.

As an example, the mobile rocket launcher pictured above was the result of a USAFA capstone course, which (then) was a graduate requirement for all senior cadets, regardless of academic major. In this particular course, for which one author was the instructor, cadets were tasked with designing and building a portable rocket launch rail capable of being transported and erected rapidly to support launches of both the small rockets (at USAFA) and large rockets (Ft Carson). The 18 cadets of various backgrounds enjoyed the challenge and decided to propose a much more aggressive solution. While the instructor initially had serious reservations about the scope of the effort, the team worked hard to convinced him of the design and of their motivation and capabilities, ultimately winning him over.

The end result was a 26' x 8' mobile trailer, all hand built from the axels up, using square steel tubing and diamond plated decking. The 18' launch rail assembly was hydraulically actuated using a 12V DC motor and sported a removable stainless steel rail. The cadets were able to accomplish everything needed to construct the trailer in a single semester, short of the electrical trailer light/brake wiring, titling/registration, and painting of the vehicle (which occurred the following semester). The trailer was completed in 2002 and had seen many years of use.

Aerospace/UAS Projects Today.

With the technological explosion seen over the past 10-20 years, and subsequent miniaturization of capable electronics, many universities now offer aerospace design programs involving nano-satellites, rockets, and UAS. One such nanosat program is offered at UAF, where students from multidisciplinary backgrounds undertake a multi-semester program culminating in the construction of a nanosat. In addition, UAF is currently working to reinstitute a rocketry program and academic courses. These efforts will be discussed in future papers.

UAF has harnessed the recent rise in popularity of UAS to create several opportunities to teach interdisciplinary/systems engineering. These have taken the form of UAS-based undergraduate and graduate courses, as well as student-led design teams (eg, AIAA DBF). Academic courses may feature the construction and flight of a UAS as the central focus, or may include a lesser hands-on experience as an amplifying facet to reinforce interdisciplinary and systems engineering principles learned in the course.

EE656, *Aerospace Systems Engineering*. This course is offered at UAF during fall semester of odd-numbered years. Students form a mock company to solve an aerospace engineering need. During the past 2 offerings (2015, 2017), the teams have been tasked with designing, building, and flying a multirotor and/or fixed-wing UAS to satisfy some real-world requirement for an intended user. Students are led through the standard SEDP/system acquisition process, learning to: (1) critically examine and refine system requirements; (2) perform functional analysis leading to alternative potential system architectures; (3) provide a preliminary design of the selected alternative, to include functional synthesis and interface description; (4) provide a detailed design for configuration items to be bought, built, or coded; (5) accomplish approved work and acquisition of components; (6) iterative test and combination of lower level components to higher level configuration items; (7) bench test of overall item prior to flight test; and (8) final system level performance test and operational test.

In addition to these technical tasks, students also gain valuable experience in organizational leadership and management tasks, to include: (1) establish a company organizational structure to accomplish the task; (2) establish an in-depth schedule suitable to meet the overall schedule requirements; (3) establish means of communication between team members and the instructor needed to accomplish design reviews and reports, project construction, and flight test events; (4) establish a means for resolving personnel conflicts and unforeseen project difficulties which may arise; (5) communicate their results effectively with a range of audiences.

In the inaugural offering of the course (fall 2015), students were tasked with designing, building, and flying a S900 hexacopter supporting specified payloads, functions, and flight performance requirements. The team also had to provide lightweight, weather-resistant modifications to the frame allowing the S900 to operate in inclement weather (precipitation). In addition, largely due to the unexpected popularity of the course, the team was also tasked with a second project of providing subsystems which would allow old university-owned Lockheed Martin Stalker UAS to fly. A major part of this effort was focused on inexpensive design and construction techniques of foam core, composite skin (fiberglass or Kevlar) airframe components. The first of these, a vertical stabilizer, is shown in the pictures below.

The 2015 EE656 team consisted of a mixture of 16 students, predominantly undergraduates (though this was offered as a graduate course) from mechanical and electrical engineering. Students formed multidisciplinary teams, guided by the instructor, to tackle the various project challenges. These teams were formed by seeding each with students possessing core academic strengths and life experiences appropriate to the specific task, augmented by students of other backgrounds. As gaining interdisciplinary experience for each student is a goal for the course, all teams and tasks are carefully chosen to ensure this blending of experience occurs.

For example, wing design and construction for the Stalker components was led by a mechanical engineering student with experience in constructing model gliders. That team was augmented by students having electrical engineering and computer science experience, to guide the design and manufacturing processes with respect to routing of electrical wiring and use of 3D printed components. As another example, the communications and power teams were led by electrical and computer engineers, augmented by mechanical engineering students to advise in issues such as structural strength, vibrations, and weight and balance.

The team was successful in both projects. The S900 was adopted by UAF’s Alaska Center for Unmanned Aircraft Systems Integration (ACUASI) and has been subsequently used in several operations, including grants sponsored by NASA and the FAA for safely integrating UAS into the National Airspace System (NAS). In addition, a few dedicated students also continued work on the Stalker project, constructing prototype wings and fuselage on their own in subsequent semesters and ultimately flying their own fixed-wing UAS made utilizing these processes.

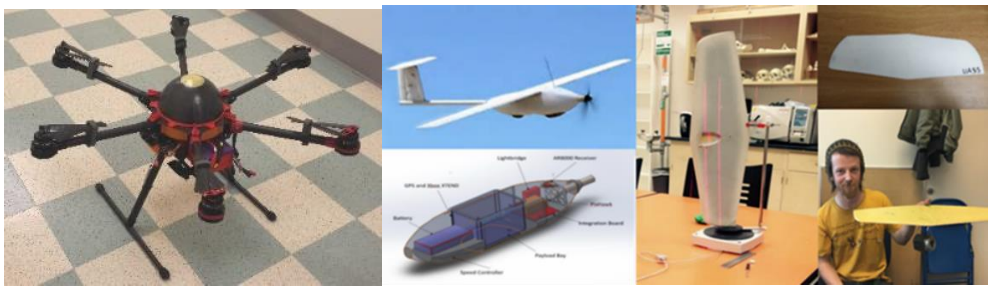

Figure 2: UAS projects from EE656, fall 2015. S900 (left); components of Stalker (middle/right)

Due to the resounding success of the previous section, this course was offered again in fall 2017. Also, as the concept of providing aerospace courses collaboratively via videolink was proven successful (see EE693 discussion below), this course was selected for a joint offering with UAF and UAA. During this semester, the team consisted of 10 undergraduate and graduate students from both campuses (6 from UAF, 4 from UAA), with academic majors in mechanical engineering, electrical engineering, and computer engineering.

This time, the class was tasked with designing, building, and flying 2 different multirotor UAS – an S1000 octocopter to be constructed at the UAF campus, and an S900 hexacopter at the UAA campus. Beyond the requirements specified for the fall 2015 offering, this section was tasked with providing a payload delivery system, as well as a wireless data networking system to support emergency responders in the field (wildlands firefighters working in areas without cell coverage).

Note that the overall team was completely integrated, with roles and responsibilities spread seamlessly across the 2 campuses. The team participated in all design, briefing, construction, and flight test preparation as a single entity. Videolink and computer tools proved adequate to the task, and the students all seemed to take to this virtual collaboration quite naturally. However, each team location was provided their own set of hardware, so that each would receive the benefit of the full design, build, fly experience. The 2 groups shared both design file information and shipped components to the other location as needed to support the overall team effort. A couple examples of this include: (1) The UAA team led the development of payload delivery systems for both the S900 and S1000. They built both (different sizes) and shipped the S1000 subsystem to UAF. (2) UAF possessed a larger 3D printer and would frequently make components for the UAA team and ship these back to them.

The team was again successful in meeting the requirements of the course, both with regard to the end UAS products, but also with their SEDP deliverables along the way. Below is a picture of the UAS at their respective field test locations. As before, the UAS developed in this course were adopted for use by UAF’s ACUASI for flight research activities supporting the FAA/NASA, as well as wide variety of other arctic research and public service missions in ACUASI’s charter.

Figure 3: UAS projects from EE656, fall 2017. S1000 built at UAF (upper left); S900 built at UAA (lower left); students participating in test flight of S1000 UAS.

EE693, *UAS Systems Design*. This course is offered at UAF during fall semester of even-numbered years. In this course, students are led through a structured investigation of UAS subsystems, including: vehicle airframe, propulsion systems, power, data communications, computer, navigation/guidance/attitude control, ground stations, launch and recovery systems, and various payloads. Students learn about UAS performance capabilities and how these may be affected by the choices made for individual subsystems and tradeoffs between these to optimize some specific capability. In addition to the traditional lectures on the above materials, students directly participate in their learning by: (1) Leading a lecture/focused class discussion on a selected subsystem. (2) Teams of 2 students perform an in-depth investigation on a selected UAS and provide a series of briefings and written reports to the class on their findings. (3) Students participate in an intensive, 2-week long UAS design, build, fly workshop to gain valuable hands-on experience, reinforcing the academic lessons of the classroom.

UAF/UAA Blended Courses. This course has been offered, quite successfully, to our sister campus at UAA since the fall 2016 semester. This was done in order to share the experience with as many interested students as possible, while keeping university overhead and expenses to a minimum. In this, the 2 groups of students are blended into a single virtual classroom, with students utilizing meeting in a single classroom at each of their respective campuses. Television monitors are arranged in a manner to provide as much direct interaction between all students as possible. Design teams investigating their specific UAS may be comprised of a student from each campus, though most groups decide to work with someone from their own campus for convenience or social purposes. Each campus is provided with sets of UAS hardware, as appropriate for that campus' participation, to allow teams of 3-4 students to build and fly their own UAS.

In the 2016 offering, students built smaller RC-quality quadcopters and hexacopters, based upon the number of students at each location. The UAA section included 6 undergraduate students from mechanical engineering, electrical/computer engineering, and from geomatics. The UAF section included 13 students (roughly equal blend of graduate/undergraduate), predominantly from mechanical engineering and electrical/computer engineering. All 4 UAS completed by their design teams successfully flew. UAS investigated in the course included: Raytheon Coyote, Scaled Composites Proteus, UrbanAero Air Mule, General Atomics Global Hawk, Airbus Zephyr, DJI Phantom 4, Arcturus Jump 15/20, General Atomics Altair, MLB V-BAT, and Trimble UX5/ZX5.

Figure 4: EE693 UAS workshops at UAA (left) and UAF (middle/right), fall 2016

In the fall 2018 section, students were provided higher quality quadcopters at each campus. These were selected as likely platforms to provide support the UAF's ACUASI in selected mission sets requiring smaller UAS. The UAA section included 4 students (equal mix of undergraduate/graduate) from mechanical engineering, computer science, and geomatics. The UAF section included 7 students (roughly equal mix of undergraduate/graduate) from mechanical engineering, electrical/computer engineering, and computer science. All 3 UAS completed by their design teams successfully flew and are expected to be used in future UAF research and academic activities. UAS investigated in the course included: Altair Mariner, ACUASI DJI S1000, Northrop Grumman Fire Scout, Aurora Flight Sciences Odysseus, Insitu ScanEagle, and Bell Eagle Eye.

Figure 5: EE693 UAS workshops at UAA (lower left) and UAF (upper left/right), fall 2018

Student Feedback.

As evidenced by student feedback and in enrollment, these courses have proven quite popular with both graduate and undergraduate students. While the electrical engineering courses (EE656 and EE693) are listed as graduate courses, these have also been well attended by undergraduate students, even though they have had to pay higher fees associated with graduate classes. Students from these courses found them, in general, to be very interesting, informative, and beneficial to their education and prospective career paths. What's more, they highly recommend these courses to other students. Specific comments on these courses are provided in Appendix 1.

Benefits to UAF Activities.

Academics. These newly established courses have benefitted UAF's engineering program, continuing to garner interest continued interest, both with current students progressing through the program, as well as with prospective students. UAF's admissions office and the engineering college's recruiting specialists frequently mention the popularity of aerospace courses, the aerospace engineering minor, and design teams as being a leading attractor mentioned by potential students. The authors are also often sought out by the engineering college and university to take part in campus recruiting events, open house activities, and STEM outreach events. It has also been the personal experience of multiple authors that students and families attending these events are highly (often, predominantly) interested in the aerospace opportunities offered at the school.

Within the University of Alaska (UA) engineering program, aerospace courses and design activities continue to be sought after by students. These courses provide an interdisciplinary/ systems engineering experience and an opportunity to work on exciting aerospace/UAS projects. As a result, demand for these courses continues to be high for engineering and technical students, both at the parent campus (UAF), as well as providing a consistent level of participation from its sister campus (UAA). Both campus engineering deans have held the joint aerospace courses up as shining examples for future UAF/UAA cooperative efforts. It is expected that these opportunities will grow to include additional courses involving both further interdisciplinary aerospace engineering (eg, rocketry) and mission applications (eg, UAS course focused on the selection of appropriate vehicle/sensor sets and data analysis tools to perform a given mission).

Research. Because of the academic opportunities being presented to students in aerospace engineering, there has been a rise in graduate student participation in these and in individual graduate research projects, both by students at UAF and in newly formed opportunities for UAA students to participate in these. One author, who has recently come to the university, has already worked with several students interested in aerospace activities for their graduate projects – these as at least a partial result of their participation in a recent aerospace course. This author has served on master's degree committees for multiple students within the academic department (electrical/computer engineering), as well as joint master's committees within UAF (mechanical engineering and geophysics students) and is now working on an inter-campus PhD committee for a geomatics student from UAA. All of these had taken aerospace courses at UAF within the rise of the program over the past few years.

At the undergraduate level, student participation in aerospace courses and design team activities has also resulted in increased support of research efforts by various university affiliated agencies, including: the Undergraduate Research and Scholarly Activity (URSA), Alaska Space Grant Program (ASGP), and the College of Engineering and Mines (CEM). These agencies have generously sponsored the AIAA team's activities over the past 4 years of its existence, and beyond this, has led to a number of follow-on aerospace/UAS-related research activities at the undergraduate level. This research has included work in the areas of: (1) Lithium Polymer (LiPo) batteries and the effect of cold weather on their operation. (2) Structural optimization of 3D printed UAS components for decreased weight and increased strength. (3) Design of lightweight, inexpensive fixed-wing UAS for training and mission operations. (4) Design of the counter-rotating dual propeller multirotor UAS for heavy lift mentioned earlier in this paper.

Student Interest in Aerospace-Related Opportunities.
The increase of aerospace-related courses and opportunities at UAF and resulting interest by current and prospective students has (not surprisingly) also been reflected in increased participation in the AIAA student chapter, the aerospace minor, and other aerospace-related courses. These, in turn, generate a higher target population and more awareness of and interest in all of the above. For a small school such as UAF, this impact has been significant.

Career options. Beyond the university realm, students participating in aerospace courses and activities have had good success in transitioning directly into an aerospace job, whether in space systems or in aeronautics. UAF has a strong record of supplying its graduates to NASA, the FAA, and major aerospace companies (eg, Lockheed-Martin, Northrop Grumman, Boeing and its subsidiaries). Likewise, this history and UAF's support of student-led design programs has also drawn interest from the aerospace industry for future collaboration. Companies see these activities as being particularly relevant on resumes.

Future Efforts.
With the great success in the courses and design team activities to date, UAF is next planning on extending these opportunities to other venues.

UAS Operations. UAF intends to extend its existing UAS investigation and UAS design courses to include a course where these assets are utilized to accomplish a realistic arctic research or public service mission. Students will examine the operational and data requirements of a mission need statement and pair these against existing UAS and sensor assets, then make a case for which UAS/sensor pair/data analysis product would best accomplish the mission. After overseeing the integration of the sensor onto the UAS, students will perform a practice mission to determine the quality of their initial data product. They will then make corrections to their UAS/senor suite and/or data analysis methodology to obtain an appropriate data set for the mission. The results of the semester effort will be presented in the end of course briefing to interested faculty/students, with details provided in a final report.

Rocketry. UAF plans to offer a rocketry course in the near future (anticipated within the next 1-2 years). This will include a 1-semester course where teams of 3-4 students prove the safety and viability of their design prior to test. Upon successful demonstration of their recovery systems, students will be able to integrate their payloads and gather data from their flights. The results of the semester effort will be presented in the end of course briefing to interested faculty/students, with details provided in a final report. (In addition, UAF intends to eventually revitalize its old Student Rocket Program (SRP), where a group of under/graduate students will design and fly single-stage-to-orbit rocket over the course of 2-4 semesters.)

Summary.
This paper has provided examples of how aerospace-based courses can provide valuable interdisciplinary/systems engineering experience to young engineers who might not normally have this opportunity until later in their careers. While the authors also possess experience in the design, construction and deployment of satellites and rockets, this paper has primarily focused on how recent advances in technology have enabled the use of UAS design projects to efficiently fulfill this educational role. It is believed that these courses will not only continue to provide a steady stream of 'job-ready' engineers for the aerospace industry and other sectors in need of systems engineers, but that these opportunities will also continue to attract talented and motivated students to our programs.

Appendix 1: Student Feedback.

***EE656, Aerospace Systems Engineering*.**

Fall 2017. The following are student responses from the most recent (fall 2017) offering of this course. The makeup of this course consisted of graduate and undergraduate students from electrical, mechanical, computer engineering/science, and geomatics from 2 geographically separated campus locations, communicating on a daily basis via videolink and electronic media. Note that these students, almost universally, had a positive experience with the course.

1. Would you recommend this course to someone else?
    - *I must say best course for the EE grad student if someone really wants some actual experience.*
    - *I wish it was available to students in UAF every year in Fall Semester at least.*
2. Comments on difficulty of course:
    - *It was nice to see how the material that is learned in undergrad doesn't always translate perfectly into the real world: nothing comes out perfect so compromises have to be made. This was the difficult part for me, having the objects be perfect on the computer but having to make modifications because the 3D printer isn't perfect.*
    - *As expected for a graduate level course this class proved to be a fun and difficult challenge which I would recommend to other students in the future. The course walked our group through the acquisitions process as a real world company would have to and provided valuable experience for me and the other students.*
    - *The course was challenging, it had somewhat of a fast pace during the start of the course and then leveled off as we figured out how everything worked.*
    - *I think this class takes the cake for giving me the most sleep deprivation in college. Because of the nature of the assignments, there was no well–defined line that marked the completion of each assignment. Sure—a document might meet the requirements in the grading rubric, but there's pretty much always more that can be done to improve formatting, organization, and content within the document. When I aimed high, this class devoured many hours.*
    - *The instructor gives proper and specific direction through the semester which makes the course comfortable.*
    - *While work itself was routine, the major challenge of the course is group effort and organization. But Fair and enjoyable. The difficulty depended on the rest of the classmates and how engaged they were.*
3. Comments on academic preparedness
    - *While there were certain areas in the course that I knew little about the benefit of working on a multidisciplinary team meant that there were certain areas where I was better equipped to do the work and somewhere another student was better equipped. Overall though I felt prepared for this class.*
    - *Academically I was very prepared. I think this course hit hard on soft skills that are not easily obtained or perfected through courses at a university. What helped people to be prepared to take the course was life experience of working at a real job or a lot of experience working in groups.*
    - *Nothing too out there or difficult, but certainly required self–motivation.*

- *I only got as far as I did due to my ME design courses and my previous years part of High School Robotics.*

4. What aspects of this course contributed most to your learning?
    - *The real world application and the hands–on activities we had to do.*
    - *Working with the group was great, I learned a lot through interdisciplinary work.*
    - *In my opinion the hands on nature of the course, working with the UAS's systems. Another unique feature of the course was working in a team with multiple degree backgrounds and experiences that the other students, something that not many other classes offer. One other aspect of the course that aided with the learning process was how the Systems Engineering Design Process was presented in a step by step manner and all expectations were laid out for what we were delivering.*
    - *The course being a giant group project was an excellent learning experience. The fact that everything was not handed to us and we had to figure out things on our own helped the class resemble something that we will actually experience after graduating.*
    - *The introduction to the engineering process was very good. I feel like this is an area where engineering programs tend to be deficient. This class helped encourage skills that will be very relevant to engineering jobs.*
        - *Proper direction from the instructor.*
        - *a vast area to work with a UAV.*
        - *How to maintain lots of deadline having a perfect schedule and direction from the instructor.*
        - *Helped to build confidence to work in my future career.*
        - *Finally, and most importantly gave me space to work independently while with a team.*
    - *The focus on group work and emulation of corporate structure gave this course a relatively novel environment.*
    - *The hands on aspect when working on the drone. I have a more engaging learning experience when the project I am working on is right in front of me and the results are immediate.*
5. What aspects of this course could be improved?
    - *Make it so other majors like business can take it to really have a company like structure going on.*
    - *It went pretty smooth, but having a better understanding of how many classes we'd have to ourselves would have helped.*
    - *One of the aspects that could be improved is if it is done between the UAA and UAF campuses again (which I recommend doing as it's a good experience to have) would be to have a professor or graduate student on UAA end who would be in contact with the main instructor and could assist if needed.*
    - *It would be helpful to know that the group that is in the class has more control of when we did or didn't have to meet for class so we would be able to work on upcoming documents. Being able to fly the UAV of any UAV would be a nice bonus for the course also.*
    - *As for the video conferencing, improvements in the sound equipment would be beneficial.*
    - *This course is just perfect for a grad student where a student can implement his learning and specialties.*

- *Ensuring each student has a technical role within the project will enhance overall awareness of the project's motivations and goals. Alternatively, periodic structure shuffling could achieve the same effect, though additional overhead may become burdensome.*
- *Have all needed tools available, had a UAA based assistant for immediate help, and wished I could ask for funding earlier if needed.*

6. How might this course benefit you (eg, personally, academically, professionally, etc)?
    - *I now understand the systems design process, and have a much better understanding of how contracting works.*
    - *This course provides an in depth process for the Systems Engineering Design process and with hands on experience in an emerging area of work and study. Along with this it provided a real life situation in which we as a class were providing a product that would be used in real life.*
    - *(Student Response)*
        - *Personally; This course helped me improve my people skills a lot. Most group projects that I have completed in the world of academics have been really short and not a lot of involvement is required. This course required constant communication with every group member and everybody had to be very involved.*
        - *Academically; I had the opportunity to figure out how to model something when I was not given every detail about what it was, I had to figure out what type of material properties to use or what material I was going to assume it was. Also had the opportunity to make decisions on how to design something from scratch and see it come to life via 3d printer.*
        - *Professionally; I think this course was very close to a real–world situation that an engineer would face. I have gained experience creating several types of documents that I will most likely end up creating in the future. I have made similar ones in previous courses, however they were about a made up generic situation and not realistic. In this class, everything was treated as it was a real thing and not made up.*
    - *This helped reinforce my knowledge of the engineering process. It also helped build my skills as a leader and a team player.*
    - *This course will help in my professional life.*
        - *Personally: How to work and share thoughts and views while working in a company.*
        - *Academically: Valuable experience to work with a UAV, A proper place to implement educational ideas.*
        - *Professionally: Helps to build confidence for my upcoming career.*
    - *The emulation of a corporation is a great stepping stone on the way to transitioning to a professional environment.*
    - *Improved by asking for parts/funding, long distance teamwork, small–group communications, and experience with professional drone work.*
7. Do you have additional comments about this course or the instructor(s)?
    - *Loved it! The professor understood the process very well.*
    - *Our professor did a great job in providing a fun yet challenging course with real life situation and the process to go about completing our task in a well thought out and efficient manner.*

- *Great course, I hope that more like this are offered in the future.*
- *Excellent class! It wasn't always fun, but I'm glad now that I took it.*
- *The course was the best course I have taken during my MS degree. The instructor is the one of the most helpful, inspiring, friendly professor in the ECE department. The course also provides all the instrument a student needs to work with.*
- *I honestly wish I had flown the main drone, or a smaller drone, to gain the experience.*

Fall 2015. Student responses are also available from the previous (fall 2015) offering of this course. This section consisted of graduate and undergraduate electrical and mechanical engineers from a single campus. Note that this section seemed to be dominated by issues of interpersonal strife between various members. The author has seen this type of behavior exhibited in similar design courses in other settings. While the tension apparently affected some students negatively, most members still had an overall positive experience.

EE693, UAS Systems Design.
Fall 2016. The following are student responses from a recent (fall 2016) offering of this course. The makeup of this course consisted of graduate and undergraduate students from electrical, mechanical, computer engineering/science, and geomatics from 2 geographically separated campus locations, communicating on a daily basis via videolink and electronic media. Note that these students, almost universally, had a positive experience with the course.

1. Comments on course difficulty:
    - *Most of the HWs were easy to do. But some questions were really hard to answer as they were conceptual questions. I liked those HWs better.*
    - *The lectures were easy to understand. The project was little bit tough to complete within the time, but it was really fun. I enjoyed a lot.*
2. Comments on academic preparedness:
    - *I was comfortable because I had some knowledge related to Aerodynamics.*
3. What aspects of this course contributed most to your learning?
    - *Researching about a selective UAV to find out details.*
    - *Course content, Presentation, Workshop*
    - *Participating in a UAV build workshop was great!*
    - *Lectures and student discussion topics.*
    - *I have learned different types of UAV that are interesting. Most interesting things is to integrate devices to build small uav and fly.*
    - *I became familiar with various types of UAs like Global Hawk, Altair, DJI etc. Also, I learned a lot practically about the structures as well as Mission Planner and Autopilot, when a project was given. Also, giving several presentations in the class, prepare me a lot for future presentation. His guidelines for presentations were excellent.*
    - *(Student response)*
        - *UAS Workshop: Hands on experience gave a good understanding of the systems.*
        - *Project: Some of the concepts I learned exploring the aircraft subsystems gave me an insight into the real-world implementation of systems design.*
        - *Assignments: I improved my writing ability through the assignments*
        - *Discussions: It gave me a chance to explore my area of interest from different subsystems.*

4. What aspects of this course could be improved?
   - *It would have been better if we had a couple more days more to finish building the UAV and testing it. I thought that review 3 for most of the groups had nothing new. So maybe if we could just have 2 reviews instead of 3, we could have 3 more days for UAV workshop.*
   - *Time for the workshop can be increased for the better understanding of the practical complicities.*
   - *More first-hand geeky knowledge! Anecdotes of the professor's first hand experiences with the phenomena related to uav systems is cool.*
   - *More systems engineering design process focus. I think that it is a great area to work on for this course. Also, one or two more days could be added to the build and fly section. Other than that I think it is good the way it is.*
   - *Add more facilities in practical activities.*
   - *Doing homework is good for the exam but the number of HW should reduce as it always kept us busy. Students should give some more time for the project so that we can go trough every step more deeply when we do the project.*
   - *Project: I think it will be interesting to have a bit more hands on project.*
5. How might this course benefit you (eg, personally, academically, professionally, etc)?
   - *I learned a lot about UAV, which was a completely new topic for me. Experience of actually building a UAV was helpful too.*
   - *Improve my personal knowledge and also helps me academically and professionally.*
   - *Gave me some great experiences in briefings.*
   - *Interesting subject and is relevant to the field of EE.*
   - *Academically*
   - *I really benefited because of giving 4 presentations. Also, his guidelines for presentation help me a lot when I prepared other courses presentation. I think it will be helpful in my professional life also. Also, I had no idea about UAV. But, I right now I have a good knowledge about it.*
   - *Learned about different subsystems*
6. Do you have additional comments about this course or the instructor(s)?
   - *Professor's presentation is very engaging and his knowledge in practical orientated. That helps a student not only theoretically but also practically.*
   - *Thanks for the learning experience, it would be great to have some guest speakers with first hand experience in the field of UAV operation.*
   - *He always motivates the students. His teaching style is good. His attitude seems to me always positive and helpful.*
   - *Within few days, he becomes one of my favorite teacher.*

Fall 2018. Unfortunately, the university changed its student feedback mechanism this past semester and it appears to dramatically impacted the number of students responding to the survey. In addition, student comments are available from an earlier section (fall 2014). All the aforementioned comments, plus other supplemental surveys from some courses, are available upon request.

Appendix 2: Abbreviated Syllabi for Aerospace Courses.

EE 693, UAS Systems Design

Meeting	Date	Chapter	Topic
1		1	L1: Course Admin; Overview
2		1	L2: History of UAVs
3		2,15	L3: Current Missions
4			L4: Research at UAF
5			A1: Visit ACUASI
6			P1: Project Discussion
7		2	L5: Classes of UAVs & Missions
8		2	L6: HALE/MALE UAVs
9		2	L7: µUAVs
10			L8: UAV Systems
11		4,19	L9: UAV Systems Trades
12		5	L10: Basic Aerodynamics
13		9	L11: Static & Dynamic Performance
14		10	L12: Controls & Autopilots
15			P2: Project Work
16		8	L13: Propulsion Systems
17		7	L14: Loads & Structures
18-20			P3-5: Project Review 1
21			L15: Electrical Systems
22			E1: Exam 1 (Midterm)
23		16,17,18,19	L16: Mission Planning Considerations
24		16,17,19	L17: Flight Planning, Data Collection
25		17	L18: Ground Control Systems
26		13	L19: Communications, Data Links
27		4,14,15	L20: Payloads
28		11,12	L21: Launch & Recovery Systems
29-32			P6-8: Project Review 2
32-36			A2-6: UAS Workshop
37			L22: ACUASI UAS, Sensors & Missions
38			P9: Project Work
39-41			P10-12: Project Briefings & Reports
42			L23: Course Wrap-up
Final Exam			E2: Final Exam (date/time)

43 Class Meetings = 23 Lectures + 2 Exams + 12 Project Days + 6 Activity Days

EE 656, Aerospace Systems Engineering

Meeting	Date	Topic	Assignments/Notes
1		Course Admin, Statement of Work (SoW) SEDP Process: Overview, SRR Preparation	
2		Company Organization, ACUASI Assets	
3		Systems Requirements Review (SRR) SEDP Process: Proposal Preparation	
4		SEDP Process: ASR Preparation	
6		Alternative Systems Review (ASR)	
7		Technical Interchange Meeting (TIM-1) SEDP Process: PDR Preparation	
10		TIM-2	
11			Proposal Due
13		TIM-3 SEDP Process: EAP/FMEA Preparation	
15			EAP/Draft FMEA Due
16		TIM-4 SEDP Process: CDR Preparation	Contract Due
17		Preliminary Design Review (PDR)	RTM Due
18			
19		TIM-5	
22		TIM-6	
23		Critical Design Review (CDR)	Draft User’s Manual Due
25		TIM-7	
28		TIM-8	
29			Test Plan Due
31		TIM-9	Final FMEA Due
34		TIM-10	
36		TIM-11	
37		Test Readiness Review (TRR)	
39		TIM-12	
40		Performance Acceptance Demonstration (PAD)	
41			Final User’s Manual
42		TIM-13	Final Briefing Slides & Written Report Due
43		Course Critiques	
Final		Final Briefing	

Appendix 3: Acronyms.

ACUASI	Alaska Center for Unmanned Aircraft Systems Integration
AIA	Aerospace Industries Association
AIAA	American Institute of Aeronautics and Astronautics
ASGP	Alaska Space Grant Program
ASR	Alternative Systems Review
DBF	Design, Build, Fly
DoD	Department of Defense
DoL	Department of Labor
CDR	Critical Design Review
CEM	College of Engineering and Mines (UAF)
EAP	Engineering Analysis Package
FAA	Federal Aviation Administration
FMEA	Failure Mode Effects Analysis
FRR	Flight Readiness Review
LiPo	Lithium Polymer
NAS	National Academy of Sciences
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NSTA	National Science Teachers Association
NSTC	National Science and Technology Council
OSTP	Office of Science and Technology Policy
PAD	Prototype Acceptance Demonstration
PDR	Preliminary Design Review
RTM	Requirements Traceability Matrix
SEDP	Systems Engineering Design Process
SERB	Space Experiments Review Board
SoW	Statement of Work
SRP	Student Rocket Program
SRR	System Requirements Review
STEM	Science, Technology, Engineering, and Mathematics
TIM	Technical Interchange Meeting
TRR	Test Readiness Review
UA	University of Alaska
UAA	University of Alaska Anchorage
UAF	University of Alaska Fairbanks
UAS	Unmanned Aircraft System
URSA	Undergraduate Research and Scholarly Activity
USAF	United States Air Force
USAFA	United States Air Force Academy

Appendix 3: References.

1. Bureau of Labor Statistics, 13 Apr 18, https://www.bls.gov/ooh/architecture-and-engineering/aerospace-engineers.htm#tab-6

2. Why Isn't America Producing the Number of Engineers the Market Needs?, Trevor English, 30 Nov 16, http://shortsleeveandtieclub.com/why-isnt-america-producing-the-number-of-engineers-the-market-needs/

3. Essays, UK. (November 2013). Boeing And The Aging Workforce. Retrieved from https://www.ukessays.com/essays/business/boeing-and-the-aging-workforce-business-essay.php?vref=1

4. https://www.newsmax.com/Finance/Economy/Aerospace-Aviation-Aging-Workforce/2014/03/13/id/559474/

5. https://www.denverpost.com/2016/06/05/aging-aerospace-workforce-seeks-young-talent-in-aurora/

6. https://www.topuniversities.com/student-info/careers-advice/top-five-demand-engineering-jobs-future, May 2016.

7. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine 2007. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, DC: The National Academies Press. https://doi.org/10.17226/11463

8. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. Rising Above the Gathering Storm, Revisited. Rapidly Approaching Category 5. National Academies Web site, www.nationalacademies.org

9. 2018 Workforce Report and Data, Aviation Week Network Executive Summary
A&D Shifts Focus to Reskilling, Recruiting, Reshaping Workforce
www.aviationweek.com/workforcereport

10. 2017 Facts & Figures, US Aerospace & Defense, Aerospace Industries Association www.aia-aerospace.org

11. Unmanned Aircraft Systems: Perceptions & Potential, Aerospace Industries Association www.aia-aerospace.org

12. Unmanned Aircraft Systems: Evolution and Opportunity, Regulatory Adaptation in a New Era of Flight, Aerospace Industries, Association. www.aia-aerospace.org

13. The Defining Workforce Challenge in U.S. Aerospace & Defense: STEM Education, Training, Recruitment & Retention, Aerospace Industries Association, www.aia-aerospace.org

14. Keeping Pace with Innovation – Update on the Safe Integration of Unmanned Aircraft Systems into the Airspace, Testimony by Chairman Roy Blunt, Aviation Operations, Safety and Security Subcommittee, US Senate Committee on Commerce, Science, & Transportation, May 8, 2018.

15. National Science Teachers Association NSTA Position Statement, Aerospace Education, March 2008

16. Charting a Course for Success: America's Strategy for STEM Education, A Report by the Committee on STEM Education of the National Science & Technology Council, December 2018. http://www.whitehouse.gov/ostp/nstc

17. Prepared Statement of Brian Wynne, President and CEO, Association for Unmanned Vehicle Systems International to the US Senate Committee on Commerce, Science & Transportation Subcommittee on Aviation Operations, Safety and Security "Keeping Pace with Innovation – Update on the Safe Integration of Unmanned Aircraft Systems into the Airspace," May 8, 2018.

18. Statement of Earl Lawrence, Director of the Federal Aviation Administration's Unmanned Aircraft Systems Integration Office to the US Senate Committee on Commerce, Science & Transportation Subcommittee on Aviation Operations, Safety and Security "Keeping Pace with Innovation – Update on the Safe Integration of Unmanned Aircraft Systems into the Airspace," May 8, 2018.

19. https://www.asme.org/career-education-retired/articles/certification/certified-systems-engineers-are-in-high-demand, September 2012

20. https://study.com/directory/category/Engineering/Systems_Engineering.html

21. https://www.payscale.com/research/US/Job=Senior_Systems_Engineer/Salary

22. https://www.acq.osd.mil/se/index.html