Motivating Students with an Unmanned Aerial System (UAS) Airmanship and Research Program

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1. Introduction

UAS operations have proven to be a key asset to the warfighter over the past decade and their use is expected to increase in the future. The Air Force needs an ever increasing number of our graduates to serve as RPA (Remotely Piloted Aircraft) pilots, and for graduates in general, to understand how UAS systems support combat operations. To help students understand the capabilities and limitations of UAS systems and to help motivate them toward the RPA career field, we have developed a comprehensive UAS program ranging from training RPA pilots to performing research and development for new UAS systems. This paper will highlight both the RPA Airmanship training program and the UAS research program at the U.S. Air Force Academy (USAFA), and assess how this comprehensive approach is preparing future RPA leaders. As an example of a cadet senior capstone design project, we discuss the Joint Cooperative Unmanned Systems Initiative (JCUSI), which was a joint project in autonomous systems between Cadet and Midshipmen from USAFA, USMA (U.S. Military Academy), and USNA (U.S. Naval Academy). We present assessment results demonstrating the project's success in helping the students understand the capabilities and limitations of RPAs in the operational environment. In addition, we also motivate cadets through field trips to operational sites like Creech AFB and overseas UAV laboratories, and assessment of these activities are presented.

2. Demand for RPA Pilots

The demand for RPA capabilities has steadily grown over the last 15 years, prompting the creation of the RPA pilot career field in 2009. The Air Force recently increased RPA pilot production to meet demand, doubling USAFA's quota for RPA pilots and requiring a concerted effort to inform, educate, and motivate officer candidates for a career as an RPA pilot. The RPA pilot career field is very similar to the manned pilot career field, with similar pay and progression opportunities. However, RPA pilot training is half as long and costs much less than manned pilot training. Undergraduate RPA Training (URT) is a 6-month program that consists of RPA Flying Training (RFT) at Pueblo, CO, learning basic aviation skills in a manned aircraft and RPA Instrument Qualification (RIQ) and RPA Fundamentals Course (RFC) at Randolph AFB. The current annual capacity is expected to grow significantly in 2017. URT graduates incur a 6-year ADSC compared to 10-years for UPT graduates. Following URT, RPA Pilots proceed to Holloman AFB, NM or Beale AFB, CA for MQ-1/9 or RQ-4 training, respectively. After receiving 2-6 months of specific aircraft training, pilots proceed to their operational base for mission qualification training and to begin operational flying.

By their junior year at the Academy, cadets that are medically qualified must decide between a traditional pilot career and the new RPA career field. To help motivate cadets toward the RPA career field, we have developed a comprehensive RPA/UAS program.

3. Airmanship Program

The RPA Airmanship program's mission is to build future combat Airpower leadership for the USAF leveraging UAS technology to create a realistic integrated air warfare training environment. This environment includes an open-architecture Air Operations Center (AOC) controlling operations of various UAS platforms. The AOC serves as an Airpower Battlelab providing cadets academic knowledge, experiential learning and operational familiarization related to the Air Force's air combat mission. The AOC controls a wide range of UAS activities, to include RPA familiarization training, RPA support of military training, and UAS-related research.

Figure 1. Student launching the RQ-11B Raven (left) and the Air Operations Center (right)

The primary RPA is the RQ-11B Raven. The RQ-11B uses a two-person crew, one Vehicle Operator (VO) and one Mission Operator (MO). The system consists of the Air Vehicle (AV) and the portable Ground Control Station (GCS). The Raven is our basic training platform.

We offer four airmanship courses. These are fully cadet led, officer/contractor mentored programs. Cadets experience the operational world from research to combat effect, while supporting various educational and military training activities. In the *Introduction to UAS/RPA Operations Course*, students learn basic RPA flight operations, concepts of operations, basic TTPs (tactics, techniques and procedures), and are introduced to AOC operations. Next is the *Small UAS Operator Upgrade Course,* in which the students learn various applications of RPAs, dynamic AOC TTPs, and use of armed ISR in a joint environment. Some cadets are then selected to go to Hurlburt Field's *MQ-11 Initial Qualification Training (IQT) course*, in which they achieve full, operational-level qualifications in the Raven in a summer program. Finally, we offer the *Flight Test Upgrade Course,* where cadets learn how to properly conduct UAS flight tests.

UAS Command and control is provided from the AOC. The AOC is in constant contact with the 306th Supervisor of Flying (SOF) and is the single POC for all USAFA UAS flight activities, to include research. USAFA has been granted flight approval authority for Group 1 UAS (under 20 lbs) and can fly both Group 1 and Group 2 UAS in our dedicated airspace shown in Figure 2. The Academy has been flying small UAS since 2003 and has well-developed UAS procedures

and operations. The Academy ensures intelligence-oversight over our UAS operations, and each mission must have an approved Proper Use Memorandum (PUM).
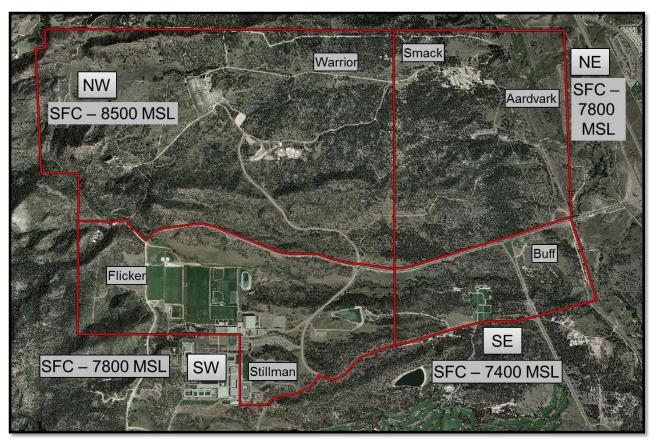

Figure 2. USAFA UAS/RPA Airspace

4. Research Program

UAS serve as an excellent platform for students across various disciplines to conduct meaningful research supporting the warfighter. Research is performed by students through their capstone design courses and independent study. In addition, our UAS Center has full-time researchers who mentor the student research, as well as perform their own programs, providing continuity for the overall UAS research enterprise. UAS Research is self-sustaining, funded by various commercial and DoD customers, such as AFOSR, AFRL, OSD/RRTO, AFSOC, NRL, MITRE, Boeing, and many others. UAS platforms include both custom designed and COTS systems and fixed-wing and multi-rotor aircraft. UAS Research is performed across several academic departments at the academy, ranging from Aeronautics, Electrical & Computer, Mechanical Engineering, Computer Science, Physics, Meteorology, Behavioral Science, Law, Biology, and Military Studies.

Figure 3. Cadets prepare to launch 3 Hauler UAVs for an autonomous mission. The aircraft are manually controlled for take-off and landing, and are switched to autonomous mode once they arrive to the search area.

4.1 Electrical and Computer Engineering Projects

The Department of Electrical and Computer Engineering began conducting autonomous, multi-UAV research in 2005, flying our first mission with one mission operator controlling 4 UAVs in 2006. This and other successful autonomous multi-UAV demonstrations led to the establishment of the Academy Center for Unmanned Aircraft Systems Research (ACUASR) in 2009.

ACUASR's Core competencies include collaborative autonomy, heterogeneous sensor fusion, and wireless communication networks. Current research at the center includes collaborative autonomous algorithms, GPS-Denied Navigation, Counter-UAS, and Sense and Avoid Exploitation. These topics present cadets with major challenges that are impacting current UAS operations. An example cadet capstone projects is the JCUSI (Joint Cooperative Unmanned Systems Initiative) in which USAFA, USMA, and USNA Cadets/Midshipmen worked together to design autonomous vehicles to protect a harbor from an intruding boat. In Spring 2015, USAFA hosted our cadet capstone team and 5 other university teams to participate in a Red Team / Blue team Counter-UAS demo. The red teams attempted to use multi-rotor UAS to conduct an ISR mission over the Blue team whose task were to detect, track, and negate the Red Team from completing their mission. Figure 4 shows some jamming experiments attempting to negate these small multi-rotor UAS. This year Boeing is sponsoring an academy challenge whereby USAFA, USNA, and USMA cadet capstone teams compete to design a futuristic autonomous micro-UAS swarm for tactical reconnaissance. Most of our capstone teams are multi-disciplinary. This year's team has 3 Aeronautical Engineers, 2 Electrical Engineers, 3 Computer Engineers, and 3 Systems Engineers.
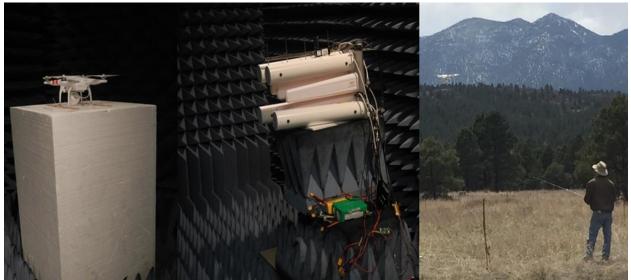
Figure 4. A Counter-UAS jamming experiment in the Department of Electrical and Computer Engineering's Anechoic chamber (Left), which was followed by experiments jamming a tethered UAS in flight (Right).

4.2 Aeronautics Projects

The Department of Aeronautical Engineering's core competencies include the ability to design/build/fly custom airframes, methodical flight testing, wind tunnel testing, computational fluid dynamics (CFD) research, and quiet propeller research. Recent efforts have shown ability to design, build and fly prototypes within 8 months of receipt of design requirements. They have developed and tested instrumentation to collect sufficient sensor information to characterize vehicle performance. Aeronautics' current research includes quiet propeller design, tube-launch UAVs, and parachute development. Their recent design of deployable sensing gliders won a 2015 DARPA Service Academy Challenge Competition.

4.3 Mechanical Engineering Projects

The Department of Mechanical Engineering's core competencies include disruptive innovation, cadet-driven research, and warfighter-focused mechanical systems. Current research includes UAS net-recovery system for recovery at sea, mobile ISR platforms, low energy SUAS for ISR applications, and enhanced unattended ground sensors.

4.4 Physics

The Department of Physics core competencies include development of instruments for autonomous navigation and tactical weather forecasting. Physics' current research includes GPS-denied navigation, detecting radioactive sources, and augmenting/validating meteorological models for using UAS combined with other sensors for tactical weather forecasting. Figure 5 illustrates methods created to display data from weather sensors in 3D from a UAS flight.
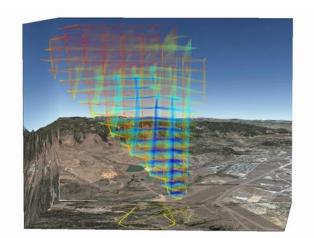
Figure 5. Developing methods for 3D display of data from weather sensors for UAVs.

4.5 Behavioral Science

The Department of Behavioral Science's core competencies include human factors design, situational awareness, and human decision making under stress. Current research includes leader decision-making in complex sociocultural environments, and RPA ground control station interface design and testing.

4.6 Biology

The Department of Biology's core competencies include forest and wildlife habitat and monitoring. Recently Biology teamed several engineering departments to develop methods for mapping the spread of Pine Beetle and Ipis Beetle damage to the forest using UAS with multi-spectral cameras. The Biology Department is beginning preliminary research with ACUASR on a proposed project by Wildlife Solutions, Inc, to leverage our past UAS autonomy research to develop a UAS system to monitor and track wildlife and protect wildlife from poachers as illustrated in Figure 6. The first stage of the project will begin with developing a UAS system to counting deer to be used during the yearly deer census at USAFA.

Figure 6. Wildlife Protection Scenario.

5.   Example Assessment of Cadet Research Project: JCUSI

As section 4 highlighted, our students are involved in a wide range of research involving UAS systems, which not only serve as good engineering and science projects, but also teach the students about the capabilities and limitations of UAS systems as well as more general concepts such as sensor fusion and command and control. In this section, we discuss an example capstone project in more detail, called the Joint Cooperative Unmanned Systems Initiative (JCUSI). We present assessment results demonstrating the project's success in helping the students understand the capabilities and limitations of UAS in the operational environment.

5.1 Purpose of Project

JCUSI is a research project composed of teams from three service academies (USAFA, USMA, USNA) to explore a cooperative control scenario involving multiple unmanned aerial vehicles (UAVs), unmanned surface vehicles (USVs), and unmanned ground vehicles (UGVs). Each team designed the UxVs their respective institution specialized in. In addition, one team designed the combined command center (CCC). These unmanned systems (UxVs) had to cooperatively and autonomously protect a harbor from intruding boats. The scenario begins with two UAVs searching the harbor entrance attempting to identify and track any incoming boats. To simplify the task, the intruding boat has a unique signature (bright orange color). Upon detecting the intruding boat, the UAV notifies its ground station, which in turn sends the detected target coordinates to the combined command center, which tasks a USV to intercept the intruding boats. The other UAV continues to search for other possible intruding boats, while the first UAV continually tracks the detected intruding boat and sends the location information to the USV via the UAV ground station and the combined command station. When the USV intercepts the intruding boat, it notifies the combined command center, which informs the UAVs, and then

escorts the boat to the shore. At this point, the UAVs must detect and track another target, a human departing the boat with a unique signature (bright orange color, but smaller size). The UAVs loiter above the boat waiting to detect and track the human target leaving the boat. When the UAVs detect the human target, they notify their ground station that sends a message to the combined command center, which then tasks the UGVs to intercept the human. The scenario ends when the UGVs intercept the intruder and notify the combined command center.

Figure 7. The UAV, USV, and UGV used in JCUSI.

5.2 Results

Figure 7 shows the three unmanned vehicles used in JCUSI and Figure 8 are photos from the final demonstration. In the final demonstration, each team was able to get their UxVs to work, but did not meet all the technical requirements. The UAV was able to detect, track, and relay tracking information of the target boat to the UAV ground station. The UAV autonomously detected the candidate target and a man-in-the-loop made the final decision to confirm the target at the UAV ground station. The USV was capable of autonomous navigation, but due to a mechanical failure was unable to intercept and escort the intruder boat autonomously. The USV's sensors were able to identify the target. The smaller size and glare of the human's signature prevented auto-detection by the UAVs, so a man-in-the-loop at the UAV ground station had to provide the human target location to the UGVs. The UGVs then successfully autonomously intercepted the ground target. The biggest technical issue was a failure to complete the final integration of the overall command center (CCC) with each team's ground control station, requiring a man-in-the-loop to relay target and status information during the

demonstration. The students learned the lesson that they cannot just focus on getting their UxV system working, but have to worry about the details of interfacing with the other systems and not taking the interfaces for granted.
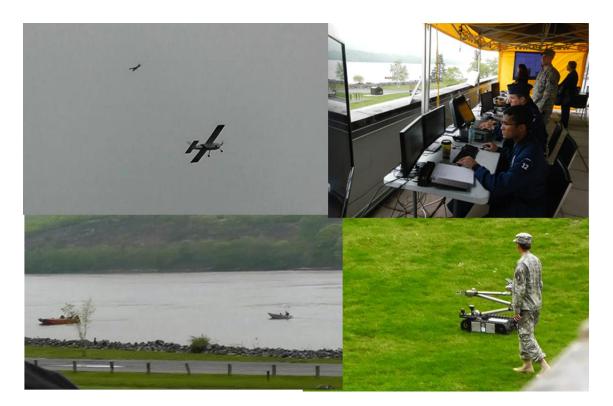

Figure 8. JCUSI demonstration day, showing two UAVs searching for the boat (upper left), Combined Command Center (upper-right), Autonomous USV intercepting the red intruder boat (lower-left), and the UGV heading to intercept the intruder (lower-right)

5.3 Assessment

In addition to the normal course assessment tools used in our two-semester capstone engineering design course (e.g., grades from the program reviews), we also had the cadets take a 38-question survey at the beginning and the end of their participation in the project to measure their perceptions of their knowledge, skills, and attitudes as they pertain to the four project learning outcomes:

Objective 1: Understand the Capabilities and Limitations of Unmanned Systems
Objective 2: Identify Operational Opportunities for Unmanned System Solutions
Objective 3: Develop and Articulate Unmanned System Requirements and Specifications
Objective 4: Function as Part of a Multi-institute, Geographically Dispersed Team.

Figure 9 presents the results for the 38-question surveys which directly measured the students' perceptions of their attainment of the desired project outcomes. Appendix A contains the survey

questions. All of students on the team took both surveys and each answered all the questions. The chart shows the average response to each question at the beginning of the project and at the end. The questions are grouped by project objective with the first objective's 14 questions the first group on the left.

Of note in Figure 9 is that the students' average responses for each objective are markedly higher at the end of the project. The largest improvement was for Objective 1-'understand unmanned systems capabilities and limitations' where their average response changed from slightly above "Disagree" to between "Agree" and "Strongly Agree."
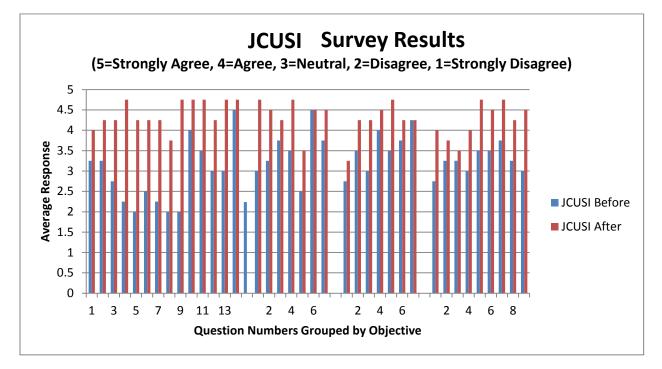

Figure 9. Students' Perceptions of their Attainment of the JCUSI Project Objectives [2]

Beyond the survey, the cadets demonstrated the lessons learned from the JCUSI project in subsequent interviews and performance in graduate school. The JCUSI project was briefed to members of the Intelligence Community visiting the Air Force Academy. As a result, the USAFA cadets were invited to interview for the opportunity to be sponsored for Master's Degrees with follow-on assignments to the National Reconnaissance Office (NRO). Two of the cadets accepted the offer and were selected for the program. The selection committee indicated that the cadets were selected over other senior ranking commissioned officers specifically because of their demonstrated understanding of UAS systems gained from the JCUSI project and their ability to articulate key command and control and operational issues associated with unmanned systems.

6.   Other methods to motivate UAS

6.1 Operational Site Visit to Creech Trip

To help cadets understand the operational importance of UAS, we take cadets involved with the UAS research program on an orientation trip to an unmanned systems operational site (Creech AFB) to view training operations and interact with pilots and operators flying operational RPA missions. The impact of the trip was assessed with a survey given before and after the trip. Figure 10 displays the results and Appendix B lists the specific questions. Questions 13-16 were added for the survey after the students returned to measure specific desired learning outcomes. Of interest in these results is that the students had high expectations for the trip (Question 2) and the trip met their expectations. The students achieved the learning outcomes as the average responses ranged from "Strongly Agree" to "Somewhat Agree" after the trip except for Question 6 "I would rate my desire to become a UAS operator as". The students seemed more interested in designing UAS than being the user/operator of a UAS. Many of the students were already selected for regular pilot training, so while they gained an appreciation and respect for UAS operations, their passion was still to be a manned aircraft pilot.
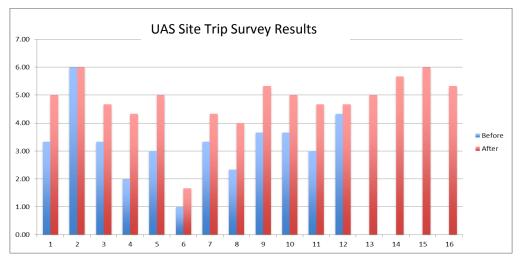

Figure 10. Results of the Unmanned Systems Operational Site Trip Survey [2]

6.2 Technical Cultural Immersion Trips

Our International Programs Office offers various study abroad opportunities, including a 10-day cultural immersion trip offered during the summer between the junior and senior year. Even though these trips are short in duration, they offer a high-impact, motivational event in the student's educational experience. We identified students that would be on the same senior capstone project teams and planned a cultural immersion trip that would be technically related to their UAS capstone project. This had three benefits: (1) developing cultural awareness; (2) learning technical information which would aid in their UAS capstone project; and (3) a team-building experience for the capstone team. We tried two different formats for the trips. The first format was to visit one foreign college for the duration of the trip and participate in a week-long workshop related to their capstone project. The other format was to visit several college and

industry laboratories related to their capstone project, each for just a half day, spread across two countries. For the first format, we participated in a week-long workshop in micro-UAVs at the Institut Supérieur de l'Aéronautique et de l'Espace (ISAE), in Toulouse, France. We were lodged in the university dorms and had many opportunities to visit cultural sites and other engineering sites, such as the European Space Agency and Airbus in the Toulouse area. For the other format, we visited Robot laboratories in Japan and Korea, and visited many cultural sites along the way. For both trips, the students were required to keep a journal and make a "photo-book" trip report. The cadets were highly motivated by these trips, and has helped recruit more cadets toward our UAS research projects.

7. Conclusion

The UAS/RPA enterprise at the US Air Force is continuing to grow each year, and the US Air Force Academy will need to graduate more cadets motivated and prepared for a career developing and/or flying RPAs. Likewise, all our graduates will need to know the capabilities and limitations RPAs bring to the combat mission. To address this training and educational challenge, we have stood up a comprehensive program, ranging from a series of airmanship courses to teach cadets to be RPA pilots, to a mature research program, allowing cadets from many different majors to contribute to UAS research in our multi-disciplinary capstone courses. Our preliminary assessments indicate these programs are motivating the cadets.

References

[1] A. Suplisson, C. Tidgewell, T. Hyer, G. York, D. Zoldi, invited panel session at the "UAV Operations and Research at USAFA" 2015 Rocky Mountain AUVSI Annual Symposium, on November 10, 2015.

[2] G. York, E. G. Royer, D. Harold, and D. D. Jensen, "Assessment of a Multi-University Unmanned Systems Capstone Design Project," *Proceedings of the 2013 American Society for Engineering Educators (ASEE) Annual Conference and Exposition,* Atlanta, Georgia, June 2013.

Appendix A. JCUSI Student Survey

Objective 1: Understand the Capabilities and Limitations of Unmanned Systems
1. I can describe how common sensors in unmanned systems are typically used and the advantages and disadvantages they offer.
2. From working on this project, I have a clearer understanding of the capabilities and limitations of air, ground, and marine vehicles.
3. I understand the typical signal processing that an unmanned system must perform.
4. I know how to integrate control system design concepts into an unmanned system design.
5. I can articulate the levels of autonomy and required key aspects of the autonomy algorithms
6. I can perform platform and sensor selection using objective criteria.
7. I know how to develop the requirements necessary to interface different platforms and subsystems.
8. I can plan for the necessary logistical requirements involved in testing and operating an autonomous system.
9. I have the general skills necessary to debug and troubleshoot an unmanned system in the field.
10 I have an appreciation of the challenges faced by field operators of unmanned systems.
11. I understand the level of robustness and redundancy required of fielded unmanned systems.
12. I understand the capability gap between prototypes and systems that are ready to be deployed and fielded.
13. I have a better appreciation for the challenges in developing robust and fully autonomous solutions.
14. I understand why unmanned systems are important to DoD.
Objective 2: Identify Operational Opportunities for Unmanned System Solutions
1. I know many of the capabilities and limitations of unmanned systems and can determine the best role for them in the operational force.
2. I can list many of the challenges unmanned systems face in the operational force.
3. I can identify tasks that can be potentially automated or replaced by an unmanned system.
4. I can identify the level of autonomy required for a particular task and can determine the potential role of a human operator.
5. I can estimate the time required to develop a system and the probability of success of an approach.
6. I believe that autonomous systems have the potential to enhance military operations
7. I feel that defense industrial partners and government laboratories are equal partners in developing solutions for unmanned systems.
Objective 3: Develop and Articulate Unmanned System Requirements and Specifications
1. I have knowledge about the current state-of-the-art commercially available unmanned systems.
2. I understand how operational needs can translate to the technical requirements of a system.
3. I can use a formal engineering design process to generate the specifications and performance measures from high level requirements.
4. I can separate the desired functionality from a specific design solution.
5. I understand the importance of possessing both technical and operational skills to generate a requirement.
6. I appreciate the need for testable or demonstrable requirements.
7. I understand that vendors and non-military personnel often use a different terminology and have a different culture than the military.
Objective 4: Function as Part of a Multi-institute, Geographically Dispersed Team.
1. I better understand the terminology used by other teams/communities.
2. I better understand the culture and expectations of the other teams/communities.
3. I can coordinate meetings and teleconferences across time zones and can lead and contribute to these meetings using language familiar to all teams/communities.
4. I can produce documentation readable by the other teams/communities.

5. I can clarify expectations to the other teams/communities.
6. I can manage deadlines across time zones.
7. I am able to develop visual aids to communicate concepts to those not physically present
8. I feel a more team-oriented cooperative spirit across the teams.
9. I have a better appreciation for the problems, constraints and solutions that the different teams encounter.

Appendix B. JCUSI Student Survey for Unmanned System's Operational Site Visit

1	I would rate my understanding of UAS operations as
2	This trip will aid my understanding of UAS operations better than if we spent this lesson in the classroom
3	I would rate my understanding of the system engineering requirements for designing, testing, and maintaining UAS systems as
4	I would rate my understanding of the maintenance and logistics requirements for UAS systems as
5	I would rate my understanding of the global nature of the operational US UAS systems as:
6	I would rate my desire to become a UAS operator as
7	I would rate my desire to become an engineer working on UAS systems as
8	I would rate my understanding of the coordination required between UAS operators and soldiers on the ground as
9	I would rate my understanding of the need for joint (Army, Navy, and Air Force) operations using unmanned systems as
10	I would rate my understanding of the roll of unmanned systems in military operations
11	I would rate my understanding of possible future UAS military operations as
12	I would rate my preparation to become an engineer as
13	I have greater knowledge about the capabilities and limitations of current UAS systems
14	I have a better understanding of how operational needs can be met by the technical capabilities in current UAS
15	I have a better understanding of how autonomous systems can enhance military operations
16	I have a better appreciation of the challenges faced by field operators of unmanned systems

NOTES: The 'before the trip' survey questions were preceded by "Before going on this trip," and the 'after the trip' questions by "After going on this trip,". Questions 13-16 were added for the 'after' survey to measure specific desired learning outcomes.