Augmenting a space mission design course with high-altitude balloon projects

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Experiential learning is a vital component of the space mission design course offered through the Department of Space Studies at the University of North Dakota. This course incorporates project-based learning through high-altitude balloon, satellite ground station, and small satellite team projects. In this educational setting, students gain hands-on experience with spacecraft engineering and operations principles. Four high-altitude balloon projects were utilized during the Spring 2011 Semester of this course. These team projects included one which focused on a superpressure balloon mission concept, a second which involved a biological payload, a third that involved an imaging payload, and a fourth that focused on launch and recovery operations. These four team projects, along with other team projects, spanned the range of systems engineering design steps leading up to the launch of a typical space mission. Each team project culminated in a mission concept review, preliminary design review, critical design review, flight readiness review, or an operational readiness review. As a result, students received practical exposure to the major phases of space mission design through project-based learning experiences.

I. Introduction

THE Department of Space Studies at the University of North Dakota (UND) offers graduate studies that lead to a Master of Science (M.S.) degree, along with undergraduate studies that support an undergraduate minor in Space Studies. A unique element of this academic program is its interdisciplinary nature. Students gain breadth and depth in the various space-related disciplines, including science, engineering, policy, law, management, business, and history. Students come from a wide variety of academic backgrounds, both technical and non-technical, which produces a rich learning environment whereby each student contributes according to their strengths and receives instruction in other areas through interactions with faculty and their peers. Students exit these degrees with a well rounded understanding of space that serves them in their current and future careers. The Department of Space Studies has a strong M.S. distance program that allows students in industry and the military to continue along their career trajectory while pursuing an advanced degree.

Among the engineering courses taught within the Department of Space Studies is Space Studies 405 - Space Mission Design (SpSt 405). This course can be applied to either an undergraduate or M.S. degree, and as such, includes a number of on-campus undergraduate students, and on-campus and distance M.S. students. The objective of this course is to foster an understanding of the space mission design process, including knowledge of payloads and subsystems and the interaction of major mission elements. Included in this course are a number of team projects that account for roughly one-third of the student effort. These team projects are made up of a series of successive engineering design projects assigned throughout the second-half of the semester, after the students have acquired a sufficient level of theoretical understanding of the space mission design process within the first-half of the semester. Since many of the students that take courses within the Department of Space Studies come from a non-technical academic background, it is crucial they gain some understanding of spacecraft engineering principles before engaging in the team project component of this course.

During the summer of 2010, the first author of this paper (R. F.) was awarded a grant through the North Dakota Space Grant Consortium Summer Faculty Fellowship to modify the content of and incorporate more experiential learning into two Space Studies engineering courses that were to be taught during the 2010-2011 Academic Year, an introductory course in orbital mechanics and SpSt 405 - Space Mission Design. The author had the opportunity to teach SpSt 405 once before during the Spring 2009 Semester. As with previous offerings of SpSt 405, he based the

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content of this course on the material contained in Space Mission Analysis and Design[1] (SMAD). While he has found this book to be an excellent reference, it was not very effective as a textbook for this introductory-level course. The author decided to retain and expand upon the high-level space mission analysis and design process as outlined in SMAD, but simplify the content pertaining to spacecraft subsystems in this course. Introductory-level spacecraft subsystem material from Understanding Space: An Introduction to Astronautics[2] was expanded upon, and incorporated into SpSt 405. Furthermore, he incorporated class projects into SpSt 405 that gave the students an opportunity to participate in "near-space" missions from end-to-end. By necessity, the payloads and subsystems for these missions needed to be very simple to ensure completion of this project over the time span of one-half semester. The class as a whole was able to gain exposure to many aspects of a typical space mission through these scaled-back near-space missions.

Subsequent sections of this paper provide an overview of how SpSt 405 was augmented with high-altitude balloon projects in order to provide students with practical exposure to the major phases of the space mission design process. The *Background* section of the paper highlights pre-existing projects and activities at UND that relate to the high-altitude balloon team projects in SpSt 405, in particular the ARTEMIS project that is directly related to the SpSt 405 Imaging Payload team project. This SpSt 405 team project is highlighted and discussed in detail for illustration purposes in the *High-Altitude Balloon Team Projects* section, and the remaining high-altitude balloon and SpSt 405 team projects are summarized. The *Conclusion* section discusses student feedback regarding the use of the high-altitude balloon projects in this course, and provides direction for future work.

II. Background

There are a number of prominent aerospace engineering projects being conducted in the Department of Space Studies and the School of Engineering and Mines at UND. Examples of such projects include space suit development[3] and unmanned aerial system (UAS) development[4] within these entities at UND. There are also a number of projects that the authors (R.F. and J.N.) have mentored involving UAS projects, high-altitude balloon (HAB) projects, sounding rocket payload development, and small satellite development[5]. This section focuses on one such project that is directly related to the SpSt 405 Imaging Payload which is highlighted in the subsequent section, along with online conferencing software that has been, and will continue to be used in high-altitude balloon projects.

A collaborative effort between the UND Departments of Electrical Engineering and Space Studies has resulted in an advanced imaging system, the Airborne Real-Time Embedded Mosaicking Imaging System (ARTEMIS)[5] for UAS. The ARTEMIS payload takes video as input, registers individual video frames at a sub-pixel level, and stitches them together, forming a mosaic image[6] of the region of interest (ref. Fig. 1). The powerful computing capabilities of the ARTEMIS computer may allow for super-resolution[7] in regions of overlap of the final image, whereby this image's resolution is better than that of the individual frames of which it is composed. It is planned that this payload will be further developed to fly on high-altitude balloon platforms.

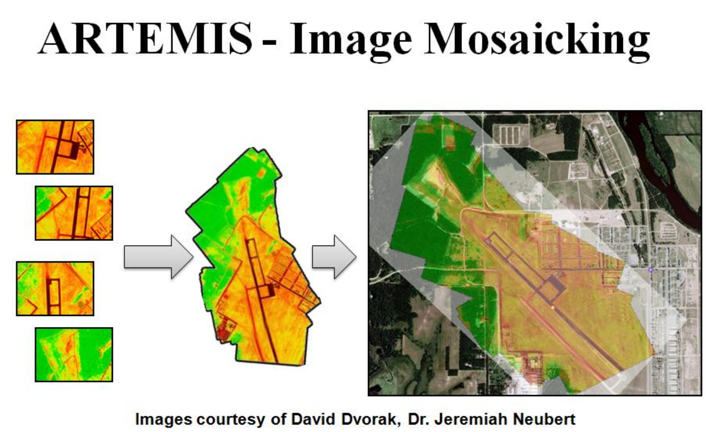

Figure 1 - The ARTEMIS imaging system combines separate video frames and outputs a single image of a region of interest.

As mentioned in the *Introduction* section, the Department of Space Studies at UND supports a sizable distance education program. Increasing numbers of distance students within this department are becoming involved in aerospace development projects. Furthermore, the UND School of Engineering & Mines has a large undergraduate distance education program, and some of these students are beginning to be attracted to these same efforts. These distance students, in addition to collaborators that are not local, can interact through online conferencing software on a regular basis. This approach has been utilized by the author (R.F.) to facilitate communications between student engineering teams over the past three years. Adobe Connect Pro® online conferencing software was used during the engineering design process for the 2008 UND HASP Project, the 2009 UND RockSat Project, and numerous spacecraft engineering courses in the UND Department of Space Studies. For instance, the preliminary design review for the 2008 UND HASP Project was

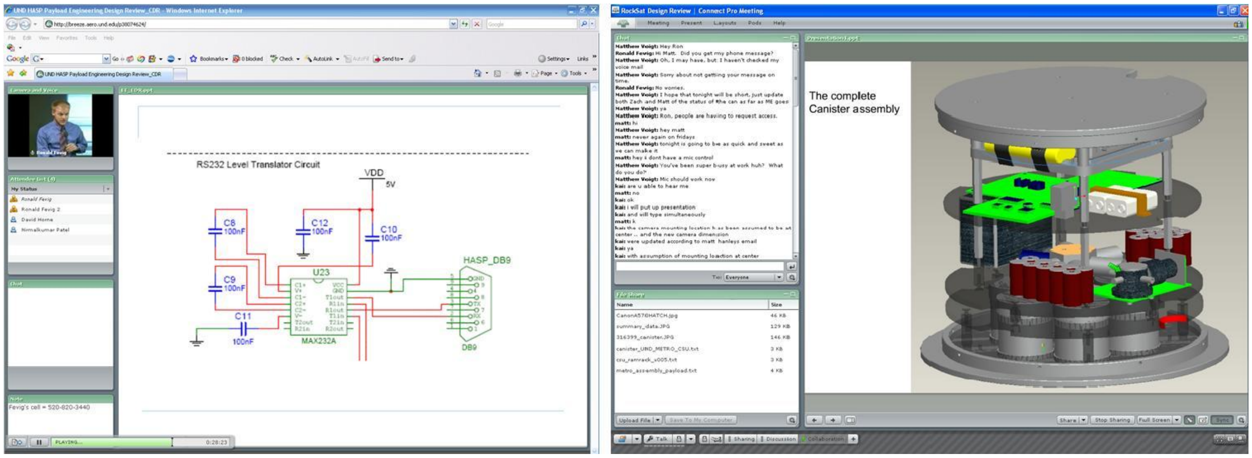

Figure 2 - Screen shots of Adobe Connect Pro® online conferencing software sessions that were used to coordinate the efforts of engineering design teams at the University of North Dakota. On the left, an undergraduate electrical engineering student during a preliminary design review answered a question posed by the ozone sensor designer in Florida for the payload that was built for HASP 2008. On the right, UND students coordinated with their Colorado-based canister partners on the payload that was built for RockSat 2009.

conducted in this online environment in order to allow the ozone sensor designer in Florida to interact with UND student engineering teams in North Dakota (Fig. 2). For the 2009 UND RockSat Project, the UND student team was provided with one-half the volume and mass allowed for a full payload canister through the RockSat Program. The other half of the canister was assigned to two separate teams of students in Colorado, each of which had their own separate payload. Again, Adobe Connect Pro® online conferencing software was used to coordinate the design efforts of these geographically dispersed teams, and integrate the three payloads that were to be contained in the RockSat payload canister (Fig. 2). As mentioned above, it is planned that such "virtual engineering teams" will be used to coordinate the efforts of students and collaborators for future aerospace development projects, including high-altitude balloon collaborative efforts.

III. High-Altitude Balloon Team Projects

Student grades for SpSt 405 were based on two written examinations, the team projects, and class participation. It should be noted that students taking the course for graduate credit were expected to serve as either a project team lead, or serve on two separate teams, while students taking the course for undergraduate credit were only expected to participate on a single team. The team project(s), mid-term examination, and final examination each accounted for thirty percent of the final grade for each student, while the remaining ten percent of the final grade was determined by the author's (R.F.) assessment of each student's level of participation in the course, and peer assessments for the contributions made by the student within their respective project team(s).

Each team project culminated in either a mission concept review (MCR), preliminary design review (PDR), critical design review (CDR), flight readiness review (FRR), or an operational readiness review (ORR). The team project component of the course was broken down into several assignments in order to guide the teams to their desired goal. It consisted of four deliverables:

1. Team member biographical sketches,
2. Team status report,
3. Initial design review, and
4. Final design review.

So that students could get to know one another, which is oftentimes problematic in courses that blend on-campus and distance students, team member biographical sketches were posted on the class website. Before team assignments were chosen, the instructor for the course (R.F.) provided a thorough introduction to each of the team projects, and outlined the current state of development and goals for the semester for each project. After students voted on, and were assigned to their respective team(s), each team was required to deliver a status report for the current state of their project and the direction for that project throughout the remainder of the semester. This step essentially echoed the information delivered by the instructor about each project and ensured each team understood the subsequent deliverables that were expected. The next deliverable was an initial design review whereby the teams delivered an in-class PowerPoint® presentation which served as an outline for the final design review that was to be delivered at the end of the semester. For both the initial and final design reviews, Adobe Connect Pro® online conferencing software allowed distance students to deliver presentations in the classroom. The final design review was an MCR, PDR, CDR, FRR, or an ORR, depending on the state of development of each team project at the end of the semester.

As mentioned above, one team project, the Imaging Payload, was selected to illustrate the type of work done by each SpSt 405 student team. The remainder of this section will focus on that team's work, followed by a brief discussion of the other team projects.

A. Imaging Payload

The primary goal for the SpSt 405 Imaging Payload team was to build a payload capable of acquiring video from a high-altitude balloon. This video could then be used to test ARTEMIS software. A Sony video camera for this purpose had already been procured, and it was this team's responsibility to design the remainder of a system which could accomplish this task. From the team's mission statement and mission objectives, and following a couple design iterations, the following set of requirements and constraints were derived:

Requirements:

- *Provide control for Sony DCRSX40 Handy-Cam with 60x zoom during the mission.*
- *The controller shall vary the camera zoom to specific increments at timed intervals during the flight.*
- *The controller settings shall be field programmable via computer.*
- *The controller shall function in the pressure and temperature environment of the flight envelope, or within any controlled payload environment.*
- *The controller shall function under any physical forces caused by the launch and flight.*

Constraints:

- *Camera system does not take inputs from controller, so servo system is only option for control of zoom.*
- *STAMP Controller system will have to be calibrated as the zoom is variable in speed.*
- *Camera zoom is recessed.*
- *Needs to be tight seating for servo to better control the zoom.*
- *Pre-flight and flight program should be made. The preflight would step rapidly through the iterations (5 sec delay), allowing for verification before launch. The preflight program could also be used for calibration and testing. The flight program would have longer delays based on actual flight parameters.*

During the design process, the SpSt 405 Imaging Team performed a number of duties that are required for such a near-space mission. Optical specifications of the video camera were used to determine the field-of-view and theoretical resolution at various altitudes and levels of (zoom) magnification. Simple thermal modeling was attempted to estimate the internal temperature of the payload. The parts list was developed with an eye toward mass and power constraints. Simple mechanical drawings were produced to show the layout of the hardware components. Software for the microcontroller was developed which controlled the level of magnification for the video camera. A rudimentary engineering prototype was built to test, in particular, the coupling between the servo and zoom control switch for the video camera. Finally, a flight model was built, fully tested, and now awaits launch.

The final deliverable for SpSt 405 Imaging Team was an FRR. This team convinced the instructor for the course (R.F.) and their student peers in SpSt 405 that they had satisfied the following success criteria[8]:

"*1. The flight vehicle is ready for flight.*
2. The hardware is deemed acceptably safe for flight.
3. Flight and ground software elements are ready to support flight and flight operations.
4. Interfaces are checked and found to be functional.
5. Open items and waivers have been examined and found to be acceptable.
6. The flight and recovery environmental factors are within constraints.
7. All open safety and mission risk items have been addressed."

B. Other Team Projects

In total, there were six team projects in SpSt 405. Each of these teams concluded their work at a certain level of engineering design. The six teams along with the design review delivered at the end of the semester are as follows:

HAB Biological Payload – CDR,
HAB Imaging Payload – MCR,
HAB Launch and Tracking Operations – ORR,
Superpressure Balloon Mission Architecture – MCR,
Satellite Ground Station – PDR, and
Small Satellite Mission Architecture – MCR.

The Biological Payload team designed a low-pressure greenhouse that can be flown on a high-altitude balloon in order to address some of the design considerations for a lunar or Martian greenhouse. The Imaging Payload was discussed in detail above. The Launch and Tracking Operations team worked on high-altitude balloon launch and payload recovery operations. The Superpressure Balloon Mission Architecture team considered mission concepts and associated mission architectures for a long-duration superpressure balloon mission to sample ozone and other gases in the stratosphere. The Satellite Ground Station team worked on a preliminary design for an amateur satellite class ground station to operate in the 2m and 70cm amateur radio bands. Finally, the Small Satellite Mission Architecture team considered mission concepts and associated mission architectures for a small demonstration satellite which would flight test hardware intended for an interplanetary mission to a near-Earth asteroid.

IV. Conclusion

So far the only independent assessment tool for the Spring 2011 Semester of SpSt 405 is the student evaluations collected at the end of the course. This course received very high marks in all categories of the students' evaluation, including those having to do with the connection of assignments to course goals and the connection of course content to real world situations. Students also indicated in their written comments that these real world team projects promoted learning.

Some concluding remarks about this course and directions for future work are as follows:

1. Through the use of high-altitude balloon mission, payload, and operational projects, students receive practical exposure to the major phases of space mission design through project-based learning experiences. Such projects provide a low-cost, short-timeline solution to otherwise costly and lengthy spacecraft development projects.
2. SpSt 405 provides students with an initial exposure to student-driven high-altitude balloon mission design. This is an incremental step toward a self-sustaining student-led high-altitude balloon program at the University of North Dakota.
3. The authors invite collaboration with those who have an academic background in education to formulate a course assessment plan that tests the effectiveness of this type of project-based learning in a space mission design course. While anecdotal evidence exists to support the hypothesis that high-altitude balloon projects provide students with invaluable exposure to the major phases of the space mission design process, it would be appropriate to test this hypothesis using educational research methods.
4. The authors invite collaborative efforts involving virtual design teams for payload development efforts and coordinated launches.

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