The North Dakota Space Robotics Program: Teaching Spacecraft Development Skills to Students Statewide with High Altitude Ballooning

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Abstract

The University of North Dakota is serving as the lead institution in a statewide effort to develop student spacecraft engineering skills. This effort, which is part of the North Dakota Space Robotics Program (NDSRP), provides students the ability to participate in the design, development and fabrication of a small satellite analog that is launched by a high altitude balloon. The first iteration of the NDSRP Near-Spacecraft Project is generating a functional prototype of a remote sensing payload, which will perform onboard image processing. This project included undergraduate and graduate students from two institutions and five different academic departments. The students involved learned and applied skills related to teamwork, project management and interdisciplinary communication. They also participated in an industry-analog distributed work environment.

I. Introduction

Preparing students to enter the modern workforce requires more than simply providing instruction regarding relevant facts, theory and techniques. Employers desire their prospective employees to know how to work effectively. This includes possessing at least rudimentary time management skills, teamwork experience, problem-solving abilities and the ability to self-start on solution implementation. While classroom (and course lab) exercises can provide some level of preparation for this, a larger-scale, long-duration project provides a suitable level of preparation.

For students seeking to enter the aerospace field, this project must perform the double duty of building the aforementioned skills while also providing students the opportunity to be involved in an end-to-end systems engineering process. Through this, students see how the various engineering and related disciplines interconnect to produce a successful result. Students gain an appreciation for and learn the vernacular for these related fields, which they will likely be required to work closely with in the workforce.

II. Background

The University of North Dakota (UND) has had an ongoing high altitude ballooning (HAB) program for nearly fourteen years. This program has launched numerous student, faculty and staff payloads to the stratosphere to perform communications, life sciences, engineering and various other experiments. Many of these HAB flights were launched for the purpose of advancing student learning [1]. UND also has a legacy of space engineering; perhaps the best example of this is the International Space Station Agricultural Camera (ISSAC) which is currently on-orbit aboard the ISS.

The advent of small satellite form factors and the availability of associated lower-cost launch services provides an opportunity for universities such as UND to get involved in the construction of independent spacecraft. For a budget under $100,000, it may soon be possible to develop and deploy a small spacecraft to orbit [2].

An independent small spacecraft, while not requiring the budget or schedule of a flagship-style mission, involves participants in all areas of spacecraft design, development, integration and testing. In fact, the small size should cause the spacecraft's developers to push the boundaries of what is possible: they must solve problems using a much more limited resource set than would be available for a larger mission. The innovations produced [e.g., 3, 4, 5] to meet the constraints posed by this small form factor may be applicable to and, thus, able to enhance future large spacecraft missions.

III. NDSRP Program Overview

The North Dakota Space Robotics Program was started in 2011 with a stated goal of developing small satellite capabilities at the University of North Dakota. This is a multi-faceted challenge, as it requires the development of flight heritage (which is required to secure funding and resources for future missions), institutional knowledge, and a

pipeline of trained students to work on the future programs. Problematically, this also presents a chicken-or-egg type scenario, as having trained students and flight heritage are required to attain mission resources and resources are required to build the flight heritage and trained student worker base.

The utilization of a HAB payload for the initial NDSRP mission provided a solution to this conundrum. The HAB payload relaxed several requirements. It removed the need to comply with the extensive set of integration, primary payload protection, range safety and other requirements that would be required for an orbital launch. The ability to retrieve the payload and perform another launch, if required, also reduced risk and allows a greater level of freedom in terms of maximizing student involvement. While relaxing these few requirements, the HAB payload would also be designed in a way that was to mirror a small satellite as closely as possible. The HAB flight, thus, would advance the technology readiness level (TRL) of the technologies required for the space mission. TRL 3, for example, can be satisfied through the development of a "proof of concept"; TRL 5 requires operation in a "relevant environment" [6]. The utilization of HABs is, thus, well suited to advancing a prospective small satellite mission through the early TRL levels while minimizing costs.

In the longer term, the payload elements of the initial HAB mission will be refined and a one-unit (10 cm x 10 cm x 11 cm, 1.33 kg) CubeSat will be built. This will benefit from the lessons learned, hardware performance analysis, and software development work performed during the creation of the HAB precursor.

IV. Involvement of High Altitude Ballooning in the NDSRP

The NDSRP Near-Space Project (NSP) incorporates a high-resolution visible light camera, a global positioning system (GPS) receiver, and an inertial measurement (IMU) module. This hardware is used to collect image data that will be tagged with the attitude and location of the near-spacecraft at the time. This will be utilized to test the utility of mosaicking and super-resolution software for use onboard a CubeSat and ascertain the value of the GPS and IMU data for increasing mosaicking speed.

The near-space environment will test critical aspects of the prospective spacecraft. The high altitude allows the extrapolation of orbital performance (the HAB will rise to approximately 30-35 kilometers in altitude while the target orbit for the satellite is between 300 and 400 kilometers) for the visual light camera. Performance can be characterized during ascent, at the peak (burst) altitude and during descent. The various levels of jostling movement of the payload (due to the impact of wind, particularly at lower altitudes) allow the performance of the payload and software to be characterized under various levels of stability. This information is integral in the selection of attitude determination and control system (ADCS) components for the orbital craft.

The payload will also be exposed to significant random vibration (again due to the jostling caused by the wind), a sizable impact force (on landing) and near vacuum. The aforementioned will provide significant information about the durability and operating performance characteristics of these components, under conditions not unlike those that will be encountered by an orbital craft. While these are not exact tests, enough analogy exists to make the data highly relevant. This information will shape the design of the thermal, structural and other subsystems of the orbital craft.

V. Educational Benefits from NDSRP

Bloom's Taxonomy provides a framework to evaluate the utility of the NDSRP NSP for educational purposes. This framework consists of six levels: remembering, understanding, applying, analyzing, evaluating and creating [7]. Each of the aforementioned levels builds on those below it and thus is considered to be of higher-value [7]. The NSP engaged students at all levels of the hierarchy.

a. Remembering

The lowest taxonomy level deals with rote recall of factual information [7]. During the NSP, students learned information about spacecraft systems engineering, spacecraft subsystems, project management, engineering techniques and technical aspects of other disciplines. The retention of this information was aided and demonstrated through its application throughout the NSP project.

b. Understanding

The second level of the taxonomy requires students to demonstrate an understanding of the material that they have learned [7]. The NSP aided understanding via interaction with actual hardware and software systems. Unlike with

lecture-style learning; hardware provides immediate feedback (via not functioning as desired) if a concept is not understood.

c. Applying

The application of material, the third taxonomy level, involves utilizing the knowledge that has been learned to solve a problem different than the context that the material was presented in [7]. During the NSP, students learned concepts and principals via oral presentations from the principal investigator and student program director and from various written sources. This material was then applied to the problem of designing and fabricating the spacecraft.

d. Analyzing

The fourth taxonomy level, analysis, requires students to identify the correct application of the knowledge gained [7]. The NSP required students to analyze system requirements and determine the most effective way to fulfill these requirements. Thus, analysis was performed using information that was newly acquired during the NSP (e.g., space-specific engineering principles and knowledge of space subsystems) and pre-existed (e.g., how to make an electric circuit to perform a given role in a system).

e. Evaluating

The evaluation level requires students to make judgments and/or justify decisions based on the knowledge that has been acquired [7]. The NSP provided students with ample opportunities to do both. Students were required to develop architecture elements, choose courses of action and present and defend the decisions that had been made.

f. Creating

The highest level of the taxonomy, creating, utilizes the acquired knowledge to formulate a new outcome [7]. The NSP, fundamentally, was an exercise in creating. While limited requirements and constraints existed from program goals and the commitments that had been made as part of the process of securing funding, how these were satisfied (as well as the definition of additional requirements) were developed as part of the NSP process. It is expected that, even with the exact same starting point, a different team would have produced a somewhat different result. While future NSPs will likely have different goals, the same mission could be reused and demonstrate this principle.

VI. Research Benefits from NDSRP

The value of student involvement in research is dramatically increased when that research is based on an actual need [8]. Research tasks that are designed specifically for students may lack the rigor and rigidness of real research. In the worst case, this may result in requirements being changed to match the product that is produced. Students, under these circumstances, are not presented with as much of a challenge, nor are there significant rewards (emotional or otherwise) for completing a task that has been refined so that one can't possibly fail to finish it.

The NDSRP and the NSP mission are based on real research-driven needs. The NDSRP seeks to develop the capability to perform space-engineering research at UND and to support space science missions for UND and other researchers. The launch of the mission by high altitude balloon provides a real succeed-or-fail outcome. If critical elements are neglected or components fail, desired data or imagery will fail to be obtained. Unanticipated system and/or integration issues need to be detected and resolved. Subsequent to the initial flight, failure analysis may need to be performed and corrective action taken.

A laboratory exercise (which might attempt to simulate the various conditions, separately, through a battery of tests) would not present these complex failure scenarios and the opportunity to analyze and resolve them. However, with this real-world project there is no guarantee that the system will work, even if no issues are present (e.g., an unrelated even such as a balloon envelope puncture could result in mission failure). Nor is there any guarantee that all system issues will be able to be resolved in the time available. Like all real research, failure is a very real possibility. Because of this, of course, success is valued much more highly.

VII. Lessons Learned

From the perspective of organizing, relying on, and leading the student teams, there are a few key lessons that will inform future activities. These relate to student involvement risk, setting expectations and requiring results.

a. Student Involvement Risk

The utilization of students as part of a development or research project carries with it significant risks. These risks fall into several categories including turnover, inexperience, scheduling issues and knowledge retention issues [9].

Turnover has to be expected on student projects. Students will, of course, leave the university at the end of their degree program. Other students may commit to participation but back out (with or without notice) if they discover that they are overcommitted (or even just identify a more desirable alternate commitment). Unlike a commercial environment, little can be done to mitigate this risk and an educator certainly doesn't want to pressure a student to continue participating in something that may hurt their overall academic performance.

Inexperience is all but a given for student involvement in research. While exceptions are possible (and certainly the reentry of students from the workforce makes this more likely than it has been historically), students are generally participating in something for the purpose of developing and demonstrating a new skill. It is thus important that time is taken to informally teach what is desired (both from a technical as well as management/behavioral perspective).

Scheduling issues are also all but inevitable. Project demands and deadlines will invariably conflict with deadlines for coursework, exams and other academic constraints. It is thus important to raise this issue early and to identify these interactions. It is also important to set expectations of what level of interaction will be expected from students – even during heavy demand periods.

Requiring results would seem to be problematic from a student activity – particularly when some or all participants are volunteers. However, this is not unreasonable for two reasons. First, the results are what are expected in exchange for providing the opportunity to be involved. The time of the paid faculty and staff that is being spent to support and guide student activities is valuable. If students don't do their part and perform, this time is effectively wasted. Second, the student experience is enhanced by requiring results. There are virtually no projects in industry where time can be expended and nothing produced (obviously, some projects will assume a risk of failure – however, a documented failure is productive). By requiring results, the project is better aligned with industry norms and thus does a better job at preparing students.

b. Setting Expectations

Setting expectations is the key to achieving results. The previous section described a litany of issues that can befall a project with student involvement. While techniques exist [e.g., 9] to manage this risk, it can be reduced by simply getting everyone on the same page from the outset. Most students have a genuine desire to perform. They know that they will need the support of faculty letters of recommendation and strong grades to achieve their future goals. However, they – in many cases – don't know exactly what they are getting into when they express an interest in participating in an activity.

At the outset, it is thus desirable to describe what levels of commitment are possible (e.g., roles for those that want to be highly involved or less involved) and what will be expected. While scheduling allowances should be made for known high-demand periods (e.g., finals weeks, etc.) the minimum required participation for these periods (e.g., attending a single regular meeting, etc.) should be conveyed. Additionally, guidelines should be given as to what to do if a student feels that they are overcommitted. It is much better to deal with this through a discussion before a student quits with no notice and handover or, worse, suffers severe academic consequences.

c. Requiring Results

The goal of a real research project is to produce results and part of gaining the benefit from participating in such a project is understanding that performance is a requirement. Thus, it should be understood by all participants that certain outcomes (both at a group and individual level) are expected and that failure to meet them will let down the group (and those that may depend on the group's work). Each individual should also understand if he or she is underperforming, this may result in being moved to a reduced project role or even, should underperformance continue, exclusion.

Criteria for expected performance should be established and feedback should be provided regularly. The same mechanisms that would be used with employees are suitable to this process. Moreover, incorporating this style of assessment allows students to experience and understand how they will be assessed in a future work environment, but with much less presently at stake.

Requiring results, thus, ensures that project outcomes are met. It also benefits the students through the creation of a more realistic environment – and the creation of a product that they can be proud of their involvement with!

VIII. Future Work

The NDSRP and first NSP mission are currently ongoing. A design failure with a critical PCB was detected during testing at the end of the Spring 2012 semester which has required the team to identify a work around that involves the replacement of several components. These components didn't arrive until after students had left for the summer. Given this, our planned May 2012 launch has been delayed. We anticipate that this launch will now occur in mid-to-late September. Efforts will then turn to analyzing the data from the HAB flight and the development of the orbital satellite, based on this data and analysis.

IX. Conclusion

The North Dakota Space Robotics Program is utilizing high altitude balloons to prepare for the development of small spacecraft and to train the students that are required to successful undertake such a mission. The initial NSP mission has demonstrated the valuable learning outcomes that can be produced from industry analog working environments, which incorporate real-world research scenarios. It has also demonstrated the heightened level of risk that comes from involving a significant student population – particularly volunteers. Those involved have dealt with unexpected situations and been forced to apply ad-hoc problem solving strategies. The ongoing effort has and will continue to deliver significant research results as well as produce the desired student learning outcomes.

Acknowledgements

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