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INTERPLANETARY HITCHHIKING TO SUPPORT SMALL SPACECRAFT MISSIONS BEYOND EARTH ORBIT

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The development of small spacecraft in educational institutions has traditionally been hampered by the high costs and integration complexities of launches. NASA’s Educational Launch of Nanosatellites program (ELaNa), kick started the concept of hitchhiking for free on a rocket launch to low-Earth or geostationary orbit. An ELaNa launch is typically provided by grouping multiple educational nanosatellites together in a rocket that is already carrying a larger and more expensive primary payload. In essence, providing the nanosats with a free hitchhike to space. The program promotes research and education by giving participants first-hand experience in spacecraft design and development.

Although the ELaNa program has created unprecedented opportunities for student engagement in spacecraft design, it is limited in scope to low-Earth and geostationary orbits. Given the success of the program, it is time to consider the next leap in educational launches, namely that of interplanetary launches.

A number of key considerations exist regarding the desirability of this proposed enhancement. In order to be effective in both their interplanetary science mission and in providing the desired educational benefits, the spacecraft must be able to (1) perform virtually their entire mission autonomously, (2) operate in the deep space radiation environment, and (3) communicate data products back to Earth.

As the primary craft may be able to be utilized as a relay for communication (though this is by no means certain), this paper will consider the benefits and challenges of the proposed change, from a programmatic perspective and the ability for spacecraft operating software to provide the requisite level of autonomous control. Work on the development of the operating software for the OpenOrbiter spacecraft is assessed, to this end, and the difference between current capabilities and required capabilities is presented. The consideration of ways of surviving the radiation environment is left as a topic for future study.

I. INTRODUCTION

The development of small spacecraft in educational institutions has traditionally been hampered by the high costs and integration complexities of launches [1]. NASA’s Educational Launch of Nanosatellites program (ELaNa) [2], kick started the concept of hitchhiking for free on a rocket launch to low-earth or geostationary orbit. An ELaNa launch is typically provided by grouping multiple educational nanosatellites together in a rocket that is already carrying a larger and more expensive primary payload. In essence, providing them with a free hitchhike to space. The program promotes research and education, while simultaneously giving participants first-hand experience in spacecraft design and development.

While CubeSats [3, 4] have been utilized as technology demonstrators for missions in low-Earth orbit and have provided both scientific and cost breakthroughs, they have not yet been seen beyond these orbits, where arguably, they could have the same critical impact, both in terms of science and cost reductions as. This would also provide first-hand experience in more complicated space mission development to students.

With space missions and space technology becoming increasingly complex, it is of tremendous value to society that students are able to prepare adequately for the demanding jobs in the fields that support and develop these missions. While an electrical engineering student gets to tinker with real projects close to his or her interests in most fields, that same electrical engineer rarely gets the opportunity to tinker with spacecraft that will carry out missions in a Martian orbit or the outer reaches of the solar system.

By adding launches that go beyond Earth orbit to the ELaNa program, educational institutions will be able to afford such missions by securing a free hitchhiking ride and students can gain vital experience in developing complex space missions. Recent changes to the CubeSat standard [5] have already paved the way for deep space missions.
missions by incorporating propulsion system design and safety requirements.

Because interplanetary missions are fewer and further between than regular satellite launches, ELaNa will likely have to be more constrained in granting launches, which puts more pressure on the institutions to design spacecraft that can provide meaningful value to society.

Another constraint to consider is the limited communications between ground operators and small satellites in Earth orbiting missions. This would prove to be a vital area of concern due to the potential for a much more limited communications link for ground controllers to manually operate the satellite and adjust scheduling priorities. In order to overcome this in both regards, a robust scheduling system needs to be in place onboard the satellite.

This paper explores the benefits and some potential missions for an ELaNa program that encompasses interplanetary missions, it considers the need for greater autonomy and compares and contrasts current operating software capabilities with the requirements for deep space operations.

II. OPEN ORBITER SPACECRAFT & OPEN FRAMEWORK

The Open Prototype for Educational NanoSats (OPEN) [6] is an initiative launched at the University of North Dakota, as a service to the nation and the world. The OPEN team is working to design a spacecraft, a set of implementation instructions and a testing plan for a 1-U CubeSat (which can be extrapolated to a 2-U or 3-U form factor CubeSat with limited modifications) [7]. These instructions and plans will be made publically available to facilitate the low-cost implementation of CubeSat programs worldwide. The goal is to allow spacecraft fabrication with a parts budget of approximately $5,000 [8]. This is designed to make the implementation of small satellite programs achievable from the teaching funds available at many institutions. By targeting teaching funds (instead of requiring research funding), programs can focus on maximizing student learning and allow for greater student leadership opportunities (as the goal of the funding is not technical achievement, and risk is reduced. The goal of OPEN is not to compete with commercial vendors, but instead to create a pipeline of institutions with the basic demonstrated capabilities required successfully obtaining funding for small satellite work (and thus, prospectively, becoming customers of the various vendors). OPEN, by providing these publically-available design documents, also lends itself to use by those that wish to modify subsystems for research or other purposes. The OpenOrbiter initiative is a student-directed, student-run program which is working to develop and implement a spacecraft based upon the OPEN concept.

III. SPACECRAFT OPERATIONS

A common issue impairing the development of small spacecraft is cost. Even when purchasing a kit, the cost of getting a small satellite into orbit can be over $150,000 [8]. One approach to resolving this is forming a conglomeration of multiple institutions. There are several benefits to this approach. First, it reduces the cost for each participant. With two institutions, the cost for each is halved and could be further reduced, if more consortium members are recruited. Another benefit is the technological capabilities that each institution brings to the table. A college that, for example, specializes in engineering but lacks a computer science department (or where the department opts to not participate) could join with another school with this capability. Perhaps the largest benefit of collaboration is the availability of numerous ground stations. The limited amount of time the satellite is in range of a ground station is perhaps the largest impairment of task assignment and data retrieval. With multiple stations this bottleneck is greatly reduced. Not only does this reduce bandwidth constraints, it also facilitates data sharing. This may allow several projects to use the same data for achieving a common goal or synergistic goals.

When sharing a single spacecraft, scheduling and conflict resolution between prospectively conflicting parties must be considered. This can be handled in several ways. These include first in, first out job scheduling, task prioritization determined by the location and path of the craft, or providing time on pro-rata basis to each institution.

The proposed system [9, 10] allows each of the participating institutions to pull data from and send tasks to the spacecraft from any participating ground station. System resources are managed onboard the satellite. This approach allows the spacecraft to send data down in a near-optimal manner. All of the data collected and manipulated is stored in the cloud so that all parties involved have access. Additionally, this allows the ability to send information to the ground in segments. A transmission may start with a connection to one ground station and be interrupted when the connection is lost. However, once the satellite is in range of the next participating ground station, it continues sending data, starting from the segment it left off at during the last transmission.

If this approach were to be used on a deep space mission, very few things would need to be changed. The biggest concern here would likely still be the communication to/from ground control. One possible way around this would be to use the launching vehicles primary payload (a full size satellite) as a relay. This approach would likely reduce the constraints caused by limited communication windows and low bandwidth.
capabilities of the CubeSat. However, the availability of this relay and the amount of bandwidth available may be severely limited, as the primary user will be the larger craft. It is thus vital that the operating software have a sufficient level of autonomous scheduling capability so as not to bog down the relay system with unneeded or excessive communications.

Another area that would need to be addressed is if the relay satellite is unable to process the requests of the CubeSat. Again, this is where a robust scheduling system would be able to re-prioritize and continue its data collection tasks as necessary and re-attempt a downlink via the relay at a later time. One possible benefit of using the relay satellite is that the CubeSat would be able to send any data to that system whenever it would be in range. This could allow a store and forward approach to operations where the limited storage capacity of onboard systems would likely no longer be an issue as the CubeSat would be able to use the storage capabilities of the larger satellite (which would likely have a much larger storage capacity).

Physical and capability differences between spacecraft sizes, capabilities and physical configurations will create difference in power generation capabilities, power storage levels and radio and antenna gain capabilities. This will necessitate changes to the decisions made by the operating software. To accommodate this, variables within the operating software can be changed. A configuration system has been put in place in order to facilitate changing numerous system variables. Everything (from onboard temperature thresholds and critical limits for low power to adjusting the resolution or filter on an onboard camera) can also be customized while the system is in orbit. An additional feature of this part of the system is that these configurations can be stored as separate files and accessed as needed to change variables on the fly.

This type of customization is also available, although on a more restricted basis, for many other features that can be directed by ground controllers should the need arise. Once a task has been downlinked (whether to the relay or to ground station) and a confirmation received, all data pertaining to that task is generally removed from the system. However, the operating software may retain applicable data for use of other scheduled tasks. For example, if a single photo or collection of photos is requested of one particular area of interest, this data would be saved if these images could also be used in a larger mosaic photo of a wider geographic area. The system would simply have to look at the GPS coordinates and determine if this data has the potential of being reused for other tasks.

Another feature deletes data for tasks that fall out of their window of interest; this, again, would be if the area of interest is out of range within the time period or the time period itself lapses. These functions help ensure storage shortages are an unlikely occurrence. This system, while allowing configuration changes from ground control, (as previously mentioned) is a fully autonomous system. By using this approach, the system dictates its own schedule and allows for a continuous schedule to be run and the task schedule to be rechecked as needed, even while not in communication with the ground controllers. The task scheduling is based off a heuristic approach as discussed in prior work [9] as other approaches were qualitatively assessed to be too time/power consuming.

By using this heuristic approach, the system is able to base its decisions of task priority off numerous variables. In particular the system looks at the time to task, ground controller assigned priority, the window of interest, and the effect on other scheduled tasks. Time to task is a variable that will increase as the time at which a task needs to be completed approaches. While there are a multitude of possible payloads for CubeSats, OpenOrbiters tasks revolve around taking pictures. With the speed at which the satellite is moving, there may only be milliseconds to perform this task. The ground controller based priority is a fixed priority between zero and five with zero being of vital importance and five indicating the lowest level of importance. This variable is seen as a constant onboard as it will likely not be changed. The window of interest is a variable that will gradually increase in size until it reaches a critical number. This pertains to the amount of time the task has left in its window of interest (i.e. how close it is to the latest possible time of completion). The slow incrementing of this number begins at the moment the task becomes available (that is the earliest start time) and continues until a predetermined percentage of this time is left. This time left variable is also included in the configuration system, as different payload systems may have different scales for this. In the case of OpenOrbiter, this number is set presently to 90%, at which time it will reach the maximum value of importance for this metric and will remain there until completed or until the window expires.

The effect on other tasks is a metric designed to limit detrimental effects on other scheduled tasks. Things considered here include how much time and power the task will take. The goal of this metric is to determine if running a particular task will causes others to be unable to be performed. If so, the windows would again be considered in order to see if this task can run, with less conflict, at a later time. Together, all of these metrics then determine a final decision making metric value for each task and the operating software will then use a high to low priority approach to run these tasks. This task scheduler is being implemented in the operating software of the OpenOrbiter flow as shown in Figure 1. The operating software is tasked with scheduling all of the systems and sensors onboard the
space craft as shown in Figure 2.

![Operating software flow chart](image)

**Figure 1 Operating software flow chart [7].**
IV. PROSPECTIVE INTERPLANETARY MISSION

Previous work [11] has provided an overview of the Open Prototype for Educational NanoSats (OPEN) and its prospective use in interplanetary missions. OPEN is a framework to facilitate the low-cost creation of CubeSat-class spacecraft via using publically available (provided by the OPEN project) designs, software, fabrication instructions and test plans. The base OPEN configuration is designed to be able to be produced with a parts budget of under $5,000 [8]. Despite this low cost, it is a very robust spacecraft (with capabilities meeting or exceeding many of the vendor-kit solutions which cost eight-or-more times this amount).

Two approaches for using the OPEN designs in the context of an interplanetary mission are relevant. Under the first, a 6-U variant of the OPEN design is used. This approach utilizes the OPEN subsystems and structural configuration in a conjoined configuration. The second includes the use of 1-U, 2-U and 3-U OPEN-derived CubeSats as part of a ‘hitchhiker’ style mission.

V. ANALYSIS AND DISCUSSION

The development of a deep space hitchhiking program, based on the ELaNA concept, would serve to benefit not only educational institutions but the world as a whole. For example, on top of the three satellites currently orbiting Mars, this program would enable a multitude of lower cost specialized satellites to be deployed to conduct further research on specialized topics. A less populated orbit field would also be a great destination for the propulsion systems onboard these smaller spacecraft as there would be far less chance that a collision could occur. At this early stage of deep space exploration, a chance collision of this sort would likely be far less expensive than a situation such as this unfolding on an Earth orbit. Once these processes are matured, they could then be mirrored for other planets as well as meteors and asteroids. The potential benefits here are significant.

Figure 2 Comprehensive Architecture Diagram [9].
VI. CONCLUSIONS AND FUTURE WORK

With the success of CubeSat missions in Earth-orbit and with the help of the OPEN program discussed herein, it is time to start looking ahead to the next phase of creating interplanetary affordable educational opportunities. The international space community is pushing ahead with deep space travel, and the transition/expansion of the ELaNa program would be an excellent addition to include in this new endeavor.

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REFERENCES

2. Skrobot, G.; Coelho, R. In In ELaNa—Educational Launch of Nanosatellite: Providing Routine RideShare Opportunities; Proc. SmallSat Conference; 2012;