Undergraduate Thesis Prospectus

Design and Construction of an Amateur Radio CubeSat

(technical research project in Aerospace Engineering)

The Right Rocket for the Job: Small Launch Providers Target Small Satellites

(STS research project)

by

Gabriel Norris

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technical project collaborators:
MAE 4690/4700 Spacecraft Design Team

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

signed: ______________________________ date: ______________

approved: ______________________________ date: ______________
Peter Norton, Department of Engineering and Society

approved: ______________________________ date: ______________
Christopher Goyne, Department of Aerospace Engineering

General Research Problem: Small Satellites in Low Earth Orbit

How can we efficiently and reliably put scientific and communications equipment into orbit?

The development of radio telecommunications transformed human communication. The line-of-sight propagation of most radio signals, however, kept the technology from enabling truly global communication for some time. By 1927, it was possible to bounce high-energy radio waves off the ionosphere, which enabled transcontinental radiotelephony, but at a very high cost and with poor signal quality. In October 1945, Arthur C. Clarke published an article proposing the concept of a satellite constellation for the purpose of relaying signals around the world, a full twelve years before the launch of Sputnik 1 (Clarke, 1945). In 1958, Clarke's vision came to pass with the launch of the first communications satellite SCORE, which broadcast a Christmas greeting from President Eisenhower to the entire world (Martin, 2007).

Now over 2,000 satellites orbit the Earth and the world is more interconnected than ever. To continue to improve global coverage and data transfer rates, many believe the future lies in large constellations of small satellites (Khan, 2015). Beyond this application, small satellites are excellent sources of data for climate science and astronomy.

Design and Construction of an Amateur Radio CubeSat

What is the most reliable and economic cubesat design that enables communication between the global amateur radio community?

On April 17th, 2019, the University of Virginia department of Aerospace engineering launched its first satellite, named Libertas, to low Earth orbit (LEO) as a secondary payload onboard the Northrop-Grumman Antares rocket (Samarrai, 2019). Our ground station has not yet been able to make contact with the satellite, as of November, 2019. While the project proved an excellent educational opportunity for several years of UVA students, without radio contact the spacecraft was not able to fulfill its operational objectives. In order to improve our satellite connectivity, educate students, and promote global interest in space exploration, the UVA department of Aerospace Engineering decided to build a communications satellite that anyone with a radio can use to communicate. The MAE 4690/4700 Spacecraft Design class, taught by Professor Chris Goyne, will undertake this challenge and design a small satellite to facilitate ground communication among the amateur radio community and improve the University of Virginia's communication with spacecraft in LEO.

Because of the partial mission failure of Libertas, we have chosen to prioritize spacecraft reliability above all else. Therefore, we are performing an extensive review of similar projects, to ensure all components of the design are flight-proven and commercial off-the-shelf (COTS). We are also aiming to keep project budget below $65,000, the total cost of Libertas. This will only be possible if we launch with the NASA CubeSat Launch Initiative (CSLI), which will pay for space on a launch provider and handle orbital deployment from the International Space Station (ISS). Launching through the CSLI is an excellent cost-saving measure, but it does require strict adherence to the CubeSat Design Specifications laid out by NASA and California Polytechnic State University (Cal Poly, 2014).

At the time of writing, a number of mission architectures are being considered, but they all involve a 1U cubesat – meaning the whole assembly must fit within a 10 cm cube and weigh less than 1.33 kg – with a deployable antenna receiving and transmitting on amateur frequencies. We are also considering the inclusion of a camera and experimental radio that could broadcast live images from orbit. In my role as the team's communications lead, I am currently comparing various transmitters and antennae, while others on the team research components of their subsystems. Once all the COTS parts are selected, they will be virtually assembled in CAD and tested through stress and thermal simulations. Then, we will begin the process of component procurement and assembly in a clean room. Finally, the spacecraft will undergo an extensive battery of tests, both to ensure that it is up to the stresses of launch and deployment and to ensure radio connectivity with the UVA ground station.

By the time we deliver the final product to NASA, we will have designed and built a reliable communications satellite for 0.02% of the price of a typical communications satellite. When it is in orbit, any amateur radio enthusiast around the world should be able to send and receive messages anywhere on Earth using our satellite.

The Right Rocket for the Job: Small Launch Providers Target Small Satellites

How are private companies racing to fill the "Smallsat" launch provider niche?

The UVA Aerospace Engineering department has one satellite in orbit and plans to launch two more within the next three years. Our sudden interest is representative of the vastly increased launch cadence by a variety of groups around the world. This is facilitated by the reduced cost and relative ease of assembly conferred by cubesats, which collectively make up 70% of satellites launched today (Halt and Wieger, 2019). Start-ups, countries, and universities that, just ten years ago, would have been incapable of any kind of space mission are now launching several. Since 2012, 663 cubesats have been manufactured by private companies, nearly 300 by governments or militaries, and 371 by academic institutions. Yearly satellite launches have increased six-fold in this time (Halt and Wieger, 2019). This marked increase in customers underscores a sociotechnical problem in the rocketry industry: most rockets are fairly large and cater primarily to large satellites.

When smallsat manufacturers finish their project, they must purchase space on an orbital rocket. The three current leaders in the launch provider industry – the United Launch Alliance, Northrop-Grumman, and SpaceX – all require smallsats to fly as secondary payloads, or to group together into rideshares. This results in fewer opportunities to fly and far less control over the launch date or orbit. The leading launch companies are all focused on developing even larger rockets for emerging markets such as Moon and Mars missions, but they are neglecting the economic vacuum that already exists with respect to the high volume of small payload delivery.

Several startups have seized upon this mistake by the corporate giants. Rocket Lab, Firefly Aerospace, Vector Launch, and Relativity Space are among the companies attempting to fill this new niche by developing rockets which deliver only about 1,000 kg to LEO per launch. Of these, Rocket Lab's Electron is the only option currently on the market; the company has already launched 40 satellites and is now expanding to a second launch site in the United States (Rocket Lab, 2019). Firefly, Vector, and Relativity all claim they will be ready to begin operations by the end of 2020 (Machi, 2019).

While it may seem straightforward to simply scale existing rocket technology down to launch smallsats, there are a great deal of technical innovations left to make this industry as profitable, if not more so, than the existing options. To keep up with the large demand, smaller rockets must either be produced at a higher rate or recovered and reused. For example, Relativity Space has opened a factory in Missouri theoretically capable of 3d-printing an entire rocket in 60 days (Howell, 2019) and Rocket Lab has announced plans to begin catching their rockets with a helicopter as they fall back to Earth (Rocket Lab, 2019).

Even the cheapest of the small rocket designs will always cost more per pound than their heavy-lift competitors. However, just as the demand for taxis remains substantial even though buses are much cheaper, the demand for small rockets will exist even with their higher price for the very same reason: customers desire control over their schedule and destination. As more of our infrastructure moves to space, small-lift launch vehicles will be a profitable and lasting part of the aerospace sector.

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