1U Amateur Radio CubeSat

(Technical Paper)

CubeSats and the Standardization of the Space Industry

(STS Paper)

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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

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Cecil, 1U Amateur Radio CubeSat

MAE 4690: Spacecraft Design I
Fall 2019

Team Members: Sean Bergmann, Henry Blalock, David Broome, Joshua Choe, Nathaniel Craft, Eva Femia, Ari Goldman, Martin Keuchkerian, Joseff Medina, Gabriel Norris, Jack Shea, Isabella Todaro, Zach Wilson, Monica Wuhrer, Andrew Oxford

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Introduction

The primary objective of this mission is to build and operate a satellite system that is able to reliably communicate with both the UVA ground station and other amateur ground stations around the world. This will be accomplished at a low cost and with low risk of failure. To allow for data sharing and collaboration, the satellite will be designed to function within the bounds of an amateur radio license. This project will provide experience in both spacecraft design and project management to the students of the University of Virginia. The development of this CubeSat is crucial in promoting interest in space-exploration and real world technical skills in Virginia's next generation of engineers.

Science/Technology Investigation and Implementation

The mission objectives, listed below, for the 1U Amateur Radio CubeSat project are primarily educational in nature: UVA students will gain firsthand experience designing, building, and operating a satellite as part of a team. The team has chosen to take on an experimental amateur radio as part of the mission's payload, in addition to the primary radio that will receive commands for the CubeSat and transmit the images captured by the camera. The mission, if successful, will be considered a "technology demonstration" that will help demonstrate the legitimacy of space mission engineering here at UVA. The project team will design the CubeSat so that the mission objectives can be completed with a low risk of failure, to ensure a high probability of successful communication with the satellite.

Primary Objectives:

- High-probability of reliable communication on amateur radio frequencies
- Achievable with a budget similar to or less than previous similar projects
- Develop UVA engineering students' hands-on skills designing, building, and operating satellites
- Able to be used by the UVA ground station and others with amateur radios

Secondary Objectives:

- Promote space-exploration interest and the development of real world technical skills in Virginia's next generation of engineers

Mission Implementation

After evaluating four different mission architectures and concepts, we decided on an implementation that best meets the primary and secondary objectives. The baseline concept for this mission is a 1U CubeSat with both an experimental radio and a camera, primarily controlled from the UVA ground station. It will also be accessible by amateur radio users.

Mission Architecture

Mission Concept

This mission will carry a camera and two radios, with the goal of allowing UVA to communicate with a satellite in Low Earth Orbit (LEO). The primary radio is meant to establish two-way communication with the UVA ground station. A secondary experimental radio will be included to appeal to and communicate with the Amateur Radio Community. After the primary radio is successful in communicating with the ground station, data from the satellite will be opened to the Amateur Radio Community where it will act as a repeater and transmit ground images from a camera on demand.

Subject

There are two subjects of this mission, the radio communications and images from the camera. The radios will establish communication with the UVA ground station and the Amateur Radio Community. Similarly, the camera will capture images that can be received by ground stations on Earth.

Payload

The payload for this CubeSat will include a primary radio, a secondary experimental radio, and a camera. The camera will be used to take photographs of the Earth on command. The primary radio will be responsible for the satellite command and control as well as transmitting the images taken by the camera. The secondary radio will also be capable of command and control as a backup, but will not be capable of transmitting photographs. The radios and camera are discussed further in the Instrumentation section of this proposal.

Spacecraft Bus

______The three main components of the spacecraft bus are the power system, attitude determination and control system, and thermal control system. The power system will consist of solar panels and a battery, both of which must be capable of operating the satellite’s mission functions for the duration of its flight. The Attitude Determination and Control System (ADACS) will be a Passive Magnetic Stabilization system. The thermal control system will ensure that the internal components are able to operate properly in the extreme conditions of LEO. All three of these systems are discussed further in the Spacecraft Bus section of this proposal.

Launch System

The mission will launch through NASA’s CubeSat Launch Initiative (CSLI). This program provides an opportunity for educational and research CubeSats to be launched as secondary payloads on larger launches. It is likely that a resupply mission to the International Space Station (ISS) will be able to transport the CubeSat to the ISS and allow for its deployment from there.

Orbit

The CubeSat will orbit in LEO with the same orbital parameters as the ISS, due to the exclusion of propulsion equipment from its design. Thus, it will remain roughly in the same orbit as the ISS after deployment. Such an orbit will be characterized by an eccentricity of approximately 0.0006, an altitude of approximately 400 km, and a 51° inclination.

Ground System

The UVA ground station will be used as the primary method of communication with the satellite while in orbit. This station will have the ability to communicate with both the primary and secondary radios. In the event that making contact with the CubeSat is difficult, additional amateur radio ground stations will be used to aid in troubleshooting.

Two circularly polarized yagi antenna from M2, a FG2MCP14 12.34dB gain antenna and a FG436CP30 15.5dB gain antenna, are used at the ground station.

Command, Control, and Communications

Commands to the spacecraft will be handled by the primary radio, with the secondary radio acting as a backup. The majority of control of the spacecraft will go only through the ground station at UVA; however, because the spacecraft uses amateur radio frequencies, the option is also available to have other ground stations around the world send commands if needed for troubleshooting issues or if commands need to be sent to the satellite on short notice. The secondary radio can also be used to transmit health information for the satellite.

The primary radio will also be used to request and transmit images from the onboard camera, where as the secondary radio will be used for voice forwarding. Requests for images and the voice forwarding capabilities of the spacecraft will be available to anyone with an amateur radio with sufficient capabilities.

Concept of Operations

The various aspects of the mission architecture, as stated in the previous sections, all work in concert to complete the mission at hand. The primary radio allows the UVA ground station to communicate with the satellite, a primary objective of the mission. Following this, the payload of a secondary radio and a camera extend the CubeSat's utility so that it may fulfill the mission objective of interacting with the amateur radio community and the public at large. The secondary radio also lends itself towards meeting the goal of a low risk mission, as it provides a redundant layer of communications between ground control and the satellite. Upon initial deployment, the UVA ground station will be the sole communicator with the CubeSat. Once communications and control have been successfully established, and onboard systems have proven functional, the satellite will be made available to the amateur radio community. At this point the UVA ground station and the amateur radio community may both send and receive transmissions and images from the satellite for the remainder of the CubeSat's lifetime. Thus, UVA engineering students will be successful in designing and operating a satellite, the project will be a point of inspiration for other Virginia aerospace engineering students, and interaction with CubeSat will be established within the bounds of an amateur radio license.

Instruments

The primary payload included on the satellite will be a pair of radios. One of these will be used to provide primary control of the spacecraft and image downloading, the other will be used to provide voice forwarding for the amateur radio community and backup control of the spacecraft. To improve the reliability of the spacecraft, the primary radio will be a commercially available one with flight heritage in LEO and extensive documentation. The secondary radio will come from the Radio Amature Satellite Corporation (AMSAT), from their Fox Project, and has flown on several missions before. It does not have the data capacity to support image transfer, but it will allow voice forwarding and telemetry, and can be used to send commands to the spacecraft if needed. Both radios will operate on amateur radio frequencies. This will decrease the regulatory complexities that need to be addressed and will give us additional options for ground stations if needed to be able to communicate with the satellite regardless of where it is in its orbit.

At least one camera will be included on the satellite to allow images of Earth to be taken from it. The camera will be controlled through the on-board computer, which will take commands from the ground telling it when to capture an image. This will allow multiple requests to use the camera to be coordinated automatically and for metadata to be attached to the images. As the design progresses, an additional, sky-facing camera may be added to the design to allow members of the community to observe the sky from space.

The flight computer that will coordinate the onboard activities of the spacecraft (including operation of the camera and radios) is a critical system for the spacecraft to function, and as such, it is vital that it not fail; however, it is a component that is very sensitive to the harsh environment of space. To help ensure that it does not fail, an off-the-shelf computer will be used that has flown on at least one mission to LEO or beyond before, for at least one year. A few possibilities for the motherboard are Pumpkin boards, Arduino, Raspberry Pi, or custom boards running on a C/C++ system. An OS software such as Real Time or Salvo will be used in conjunction.

Onboard GPS navigation will most likely include a Skyfox unit and antennae, and a magnet/hysteresis material ADACS. Power systems will be supported by ClydeSpace or EnduroSat solar panels, ClydeSpace batteries and EPS. These brands were used in prior UVA projects, providing perceived reliability. However, additional research into the current CubeSat component market will be completed to validate the previously mentioned brands, according to what suits the specific needs of the mission.

Spacecraft Bus

The four main components of the spacecraft bus are the frame, power system, attitude determination and control system (ADACS), and thermal control system. The CubeSat frame is the exterior skeleton of the satellite to which all other components will be secured. Although the material and design of the frame can vary, the 1U requirement will keep the dimensions constant at 10 cm per side. The material and rib design must be strong enough to withstand the loads placed on the CubeSat during launch on a commercial rocket. Further, the material must be able to resist damage from the temperature fluctuations that the satellite will experience in orbit. These fluctuations are caused by the presence or absence of sunlight, and the heat generated by other components of the spacecraft such as the battery. The frame must also contain fixture points to accommodate both internal components like the GPS and external components like solar panels.

The main power source for the CubeSat will be solar panels. Therefore, it is necessary that the selected solar panels have an area and efficiency that is capable of generating sufficient power to support all mission functions while also charging the satellite's battery. This battery must have a capacity large enough to hold power for the CubeSat to function through the entire duration of an eclipse. Additionally, the battery must have a lifespan long enough so that its effective capacity does not fall below the critical value for the duration of the mission. These conditions on the battery will ensure continuous operations of the primary radio, experimental radio, camera, and other mission functions until natural deorbit.

The CubeSat must be oriented so that the camera and radio antenna will always be pointed at the ground, allowing people to communicate with it from the Earth. The ADACS will be a Passive Magnetic Stabilization system. This system consists of four magnets placed at four corners of one edge of the CubeSat. These magnets will allow the satellite to always be aligned with the Earth's magnetic field, and will most likely be placed on the edge of the satellite that has the camera. One drawback to this type of system is that pictures of the Earth will only be able to be taken when the satellite is over the northern hemisphere. Hysteresis rods will also be placed in the CubeSat to add damping and avoid oscillation due to the push and pull of the Earth's magnetic field. In addition to the Passive Magnetic Stabilization system, the solar panels on the CubeSat will also include sun sensors, which will allow the operators of the satellite to determine the attitude of the satellite based on the rays of sunlight hitting it.

The orbit of the satellite is out of the control of the operators, and will depend on where and how it is launched. The CubeSat will be launched from the ISS, so it will have a very similar orbit as the space station. The altitude of this orbit is approximately 400 km, and the orbit shape is slightly eccentric (almost circular). These orbital elements are subject to change later in the lifetime of the CubeSat, because atmospheric drag will decrease its altitude and increase its speed.

The team expects the CubeSat to experience external temperatures ranging from -120^{o}C and 120^{o}C (Finckenor & de Groh, 2015) while it is in Low Earth Orbit. The internal components of the spacecraft, such as the motherboard, camera, battery, primary radio, and experimental radio, will require a much less extreme interior temperature in order to operate properly for the entire duration of the CubeSat's lifespan. The team will select and program a thermal control system that can maintain a safe internal temperature range, thus ensuring the proper function of each interior component of the CubeSat.

Purchasing, Building, and Testing

The CubeSat components will primarily consist of commercial off-the-shelf parts purchased from third-party vendors. These components will then be assembled by the 1U Amateur CubeSat team at the University of Virginia. Major satellite components such as the PC/104 boards that will be used to integrate the primary communications radio, secondary experimental radio, and GPS will be preferably bought from a vendor to reduce risk. On the other hand, the software will be written by the UVA undergraduate team. Further, the satellite will be assembled and integrated at UVA after all the individual components have been purchased, or built if needed.

In house testing of individual components and subsystems will be conducted in order to ensure on board hardware is functional and reliable. Other various testing will be performed on the final assembly as specified by the launch provider. Namely, random vibration, thermal vacuum bakeout, and shock tests will be performed with levels of test loads correlating to those imparted by the launch vehicle used. Visual inspection and testing will be performed on the fully assembled spacecraft as well. These tests, apart from visual inspection, will be performed by out-of-house organizations that are equipped with the equipment to complete these tests. A portion of the budget will be set aside to perform out-of-house testing if grants or partnerships cannot be obtained with the companies performing said tests.

Mission Status

At the time of this proposal, the satellite has completed steps one through twelve of the space mission engineering process. In other words, a multitude of alternatives have been proposed and through performance assessments and systems trades a baseline concept and architecture has been chosen.The mission utility that the chosen baseline concept would provide has been deemed adequate on how well it would adhere to the mission objectives. In addition, requirements and constraints have been further defined and quantified on a subsystem level. As the baseline is further explored and the team gains experience on the system's components, requirements and constraints will be edited and added as needed.

The mission is now ready to move into the concept design phase and component exploration. The designing efforts are expected to begin on the spring of the 2020 year.

Planned Future Activity

Technical Plans

With the alternative mission concepts evaluation review complete, it is now possible to move on to research and development of the chosen concept on a more detailed and quantitative level. Ultimately, a Preliminary Design Review (PDR) is to be produced from said research by the end of Spring semester. A baseline mission mission concept and architecture will be outlined in the PDR. All team members will contribute detailed technical information towards an updated risk assessment analysis, cost analysis, subsystem functional requirements, and program schedule. This information will be incorporated into the PDR in order to demonstrate the CubeSat's continued adherence to the original mission's objectives, minimization of risk, and design viability. With the completion of the PDR, it will be possible to move on to the next steps necessary to produce a Critical Design Review. However, the critical design review itself may or may not be completed within the semester.

Team Personnel, Roles, and Responsibilities

The proposed team will consist of fourth year undergraduate students at the University of Virginia, majoring in aerospace and/or mechanical engineering. In addition to the student teams, there will be a faculty mentor supervising the mission and staff advisor providing technical expertise. The students will be separated into a management team and functional subsystem teams including communications; software and avionics; attitude determination and control systems; structures and integrations; and power, thermal, and environment. Table 1 below breaks down the different teams, team members and their specific roles. The mission is expected to take longer than one year, past the graduation date of current team members, so new members will fill the positions described below starting in August 2020. Current efforts are being made to introduce third year students into project by offering courses that would count as a technical elective, in order to ease their transition

While the management team will focus on tasks such as budgeting, scheduling, purchasing and legal procedures with the FCC, the functional subsystem teams will work in conjunction with one another to find solutions that meet their specific subsystems requirements while also integrating smoothly with the system at large.

Table 1: Teams, Members and Roles

Functional Team	Members	Role
Program Management	Jack Shea Joseff Medina	Manage project's budget & funding, timeline & schedule, radio frequency

	Martin Keuchkerian	licence acquisitions, purchasing and risk & mitigation
Communications	Gabe Norris	Develop the on- and off-board radios to be used. Develop the communications architecture to be used.
Software and Avionics	Joshua Choe Andrew Oxford Monica Wuhrer	Develop the on-board flight control system hardware and software. Ensure all digital systems on the spacecraft integrate with each other. Develop the camera payload.
Power, Thermal, and Environment	Eva Femia Ari Goldman Isabella Todaro	Develop the power generation, storage, and distribution systems for the spacecraft. Ensure the spacecraft is able to function in the environmental extremes of LEO.
Attitude Determination and Control System (ADACS), and Orbits	Sean Bergmann Henry Blalock	Develop the systems that the spacecraft will use to determine and control where it is facing. Determine the spacecraft's orbit and assess influences on it.
Structures and Integration	David Broome Nathaniel Craft Zach Wilson	Develop the mechanical structure of the spacecraft. Integrate the hardware on the spacecraft into its structure.

Table 2: Faculty and Staff Supporting the Mission

Name	Title	Role
Chris Goyne	Associate Professor of Mechanical and Aerospace Engineering Department	Instructor for University of Virginia spacecraft design course and mentor to University of Virginia student teams.
Mike McPherson	Amateur Radio Community member.	Provide an overview of and insight into the HAM community and what they want from a satellite.

Management Approach

As described above, team members will be split up into five subsystem teams and one management team. Subsystem teams will work in conjunction with one another to ensure the chosen solution not only meets the subsystem specific requirements but also integrates well with the other subsystems solutions and adequately accomplishes the mission goals. The program management team will oversee all technical and programmatic aspects of the project as well as work closely with the subsystem team to ensure execution within proposed mission cost and schedule.

The team will have two scheduled meetings every week during the spring semester during spacecraft design class time. Additional meeting times, especially subsystem specific team meetings, will be scheduled at the beginning of the weeks if needed. During the scheduled meetings, the team will work alongside the faculty mentor. Meetings with the staff advisor will be scheduled as needed by individual teams.

Team communications outside of the schedule meeting times will be handled through the Groupme app and email. Document storage and cross-team collaboration work will be done using google drive and its applications such as google docs, slides and sheets. Communications with other experts, officials and/or representatives in organizations such as the Virginia Space Grant Consortium (VSGC), NASA and the FCC will be handled primarily by the Management team and the faculty advisor.

Risk Management and Mitigation

Table 3: Risk Management and Mitigation

Risk	Type	Risk Level	Margin or Reserve	Mitigation Approach
Total Cost Over Run	Programmatic	Medium	None	The mission objective calls for a budget similar to previous 1U satellite developed by UVa so the team will use their proposed budget and total mission cost to create the Cecil’s budget
Schedule and Program Timeline	Programmatic	High	No sponsor has been acquired yet so timeline can be adjusted indefinitely	As experience is acquired by team members, a new timeline will be proposed before project is pitched to vendor
Funding	Programmatic	Low	More than one vendor option	Funding will be seeked out from multiple sources. The project will be pitched primarily to NASA and VSGC, but other options such as the USAF will be explored.

Part Availability	Technical	Low	Multiple vendors have similar parts	Parts will be chosen according to how well they meet the mission objectives and requirements, their cost and availability
Personnel Turnover	Technical	Low	Faculty mentor and Staff advisor can provide their expertise and experience through the mission	Offer accredited courses to third year engineering students for them to come to class and get introduced to the system before fourth year

Schedule

Table 4: Schedule

Phase	End Defined By	Expected Duration	Tentative Deadline
Concept Exploration	Confirmation of preliminary technical requirements	1 month	November, 2019
Detailed Design and Development	Formal requirements release	1 year	November, 2020
Production	Ship to Launch Provider	1 year	November, 2021
Launch	Lift-off and orbital insertion (ISS deployment takes time)	6 month	April, 2022
On-Orbit Check-Out	Start of Operations	1 week	April, 2022
Operations	Spacecraft Failure	1 year	April, 2023
Disposal	Re-entry		April, 2023

Cost Estimation

The cost estimation shown in Table 5 is limited to the expected construction costs of the amateur radio CubeSat. This estimation is based on the budget of the UVA Libertas project and the average cost of commercial off the shelf components.

Table 5: Construction Cost Estimation

Construction expense	Expected cost
Solar Panels	$13,830
Cubesat Structure w/ FCPU	$7,500
Power storage and management	$3,833
Radio and Antenna	$12,300
Attitude determination and control	$4,200
Instrumentation	$7,995
Miscellaneous electrical components	$1,000
Miscellaneous mechanical components	$1,200
Shipping expenses	$1,000

Total Expected Construction Costs	$52,858

Conclusion

The 1U Amateur Radio CubeSat project will provide current and future Spacecraft Design students with valuable experience in satellite design and project management, through the design and construction of a satellite that can communicate, reliably, with UVA's ground station and with amateur radio enthusiasts. The CubeSat's payload will be a primary radio, for command and image transmission purposes; an experimental amateur radio, so that other amateur radio ground stations around the world can communicate with the satellite; and a camera, to take pictures of Earth. Deployment of the spacecraft will be from the ISS, and is tentatively scheduled for April 2022. Operation of the CubeSat will stay within the constraints of an amateur radio license. The current project team intends to reach the Preliminary Design Review phase of design by the end of the spring semester, and will move into the Critical Design Review phase if enough time remains in the semester. The design work to be completed in the next six months will hold success probability of the mission paramount and will assure that the fulfillment of the mission objectives can be attained at a low cost, approximately $65,000. Next academic year, a new project team will continue the work of the current project team.

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CubeSats and the Standardization of the Space Industry

The primary purpose of this thesis is to discuss how CubeSats are key to bringing society closer to the standardization of the space industry. Social construction of technology (SCOT) will be used to discuss the social factors that affect standardization. CubeSats are a type of research spacecraft called nanosatellites. They are built to standard dimensions (Units or “U”) of 10 cm x 10 cm x 10 cm (Loff, 2015). A CubeSat can be 1U, 2U, 3U, or 6U in size and typically weigh less than 1.33 kg per U (Loff, 2015). The first six CubeSats were launched in June 2003, from Russia’s Plesetsk launch site (Howell, 2018). Originally, only a few CubeSats were launched and most that were deployed originated from universities or research groups. However, in 2013 the commercial sector began to launch CubeSats and the number of launches started to number in the dozens. As of mid-2018, more than 2,100 CubeSats and nanosatellites have been launched (Howell, 2018). Historically, satellites have been composed mainly of custom-designed parts since each satellite has a unique mission and design. The custom parts are a significant factor in the high cost of satellites. However, the fixed body dimensions of CubeSats allow for highly modular designs. Entire CubeSat subsystems are available as “commercial off the shelf” products from a number of suppliers and can be stacked together as desired to meet the needs of the mission (Technology CubeSats, n.d). Thus, CubeSats can be designed and built at the fraction of the cost of a regular satellite.

Standardization of the space industry is vital because it allows for manufacturing costs of satellites to drop. Building a traditional satellite can cost several tens to hundreds of millions of dollars. A large part of the cost originates from the design of the parts. Since it is nearly impossible to do maintenance on a satellite once it has been launched, all technology onboard must be extremely reliable. To define the reliability of a technology, technology readiness levels

(TRL) are used as a measurement system. There are nine different technology readiness levels, with TRL 1 being the lowest and TRL 9 being the highest. A TLR 1 technology is one where scientific research into the technology is just beginning. When a fully functional prototype or representational model has been created, the technology rises to TRL 6 (Mai, 2017). TRL 7 technology requires that the working model or prototype be demonstrated in a space environment (Mai, 2017). A technology is moved to TRL 8 once it has become "flight qualified" and is ready for implementation into an already existing technology or technology system (Mai 2017). Finally, only when a technology has been "flight proven" during a successful mission, can be called TRL 9. Most technologies that are in satellites are usually at least TRL 6. Having parts achieve high TRL levels is an extremely long and costly process which plays into the high cost associated with the development of a satellite. By having standardized parts be used in a satellite, the cost involved in the development and TRL certification is completely avoided. This allows for lower development costs related to satellite development. With lower satellite development expenses, smaller organizations can feasibly begin development of their own satellites. More accessible satellite technology enables more people to work on satellites, which in allows for more innovation to occur. Another benefit of lower satellite development cost is that an increased number of satellites can be launched. An increased number of satellite missions means that satellites can conduct additional research and provide more satellite services such as telecommunication.

The STS factors that drive the standardization of the space industry are primarily economic. Satellites are incredibly costly to design and manufacture, often costing several tens of millions of dollars (Patel, 2010). The high development cost is in large part due to the custom designed parts required to create a satellite. Therefore, there is interest in the use of standardized parts as they can help bring the costs of satellite development down. Standardization of the space industry has economic implications. Widespread use of standardized parts can create a positive feedback loop of reduced part prices and an increased number of satellites. Standardized parts reduce the costs of satellites and enables more satellites to be constructed which consequentially reduce the costs of standardized parts as they can be mass produced for cheaper.

The relevant STS theory for this topic is the social construction of technology (SCOT). SCOT is a constructivist theory of technological innovation inspired by the sociology of scientific knowledge (SSK), and in particular by SSK's principle of symmetry (Social construction of technology (SCOT), n.d.). SCOT holds that successful innovation cannot be explained by assuming that they "work" better than failed innovations; the analyst must undercover the social context that promotes (or fails to promote) a given innovation (Social construction of technology (SCOT), n.d.). There are three basic principles of SCOT, interpretive flexibility, relevant social groups, and stabilization. Interpretive flexibility is the idea that there is no "one best way" to create a new technological artifact; rather, each participating group has its own, unique view of how the artifact should be made, based on its interpretation of the problem that the artifact is supposed to solve (Social construction of technology (SCOT), n.d.). Relevant social groups are groups of people that consist of "all members of a certain social group [who] share the same set of meanings, attached to a specific artifact" (Social construction of technology (SCOT), n.d.). Finally, stabilization occurs, it can come in two forms rhetorical closure, which is when social groups see the problem as being solved and they will begin to talk about the problem being solved, or the problem is redefined (Social construction of technology (SCOT), n.d.). For the standardization of the space industry, the two main social groups involved are CubeSat manufacturers and other satellite manufacturers. CubeSat manufactures want keep the price of

CubeSat missions low through the use of standardized parts. Other satellite manufactures need to have parts that are specific to their satellites, which means they will be designing and using their own custom parts. Stabilization will occur if standardized parts are widely used throughout the space industry or if standardized satellite parts become no longer relevant or used.

The thesis will start by identifying the relevant social groups in the standardization of the space industry. The motivations of the CubeSat manufacturers and other satellite manufacturers will be explored. It will analyze the arguments for and against standardized parts in the space industry and the reasons the relevant social groups have for supporting their viewpoints. In particular, the economic factors and technical merits will be evaluated. After the discussion of relevant social groups, the thesis will explain what role CubeSats play in space industry. This section will consider the advantages and disadvantages CubeSats have over traditional satellites. It will also go in-depth into how CubeSats are instrumental to the standardization of parts in the space industry. The thesis will then attempt to determine the effect standardized parts have made in other industries, for example the automotive industry, and draw parallels between them and the space industry. The effects of standardized parts on price, accessibility, and innovation will be the primary focus of this part of the thesis. To gather additional information for the thesis, research will be done on satellite development and the economics surrounding it in order to thoroughly investigate the economic factors that the relevant social groups must consider. Additional research will also be done into CubeSats and the groups that support and create parts for them to identify additional motivations that the social group may have. Finally, research will be done into the histories of other relevant industries to determine the effect that standardization had on them in order to draw parallels with the space industry.

Satellites play an essential in our everyday lives, from telecommunications, to weather and data collection. Standardization of the space industry can play a role in making satellites easier to develop so that they can meet the needs of society. The aim of this thesis is to show how standardization can lead to cheaper, more accessible, and more innovative satellites that can be used for the benefit of society.

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