Prospectus

Design of a 3U CubeSat to Measure Nitrogen Dioxide
(Technical Topic)

Geopolitics of Mars Exploration
(STS Topic)

By

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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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Introduction

On October 4th, 1957, mankind's access to space burst open with the launch of Sputnik. Sputnik, a small 23-inch diameter sphere, represented the beginning of a new, disruptive industry (Sputnik). In addition to igniting the space race of the 1960s, humanity's newfound access to space has had profound implications on the everyday lives of people around the world. Whether it be TV or GPS, the over X number of satellites in orbit provide a wide range of applications. Additionally, satellites offer a special capability for scientific research. Orbiting spacecraft can offer invaluable insight into the global behavior of the earth's weather and climate (Dunbar).

The overarching problem that motivates the technical project is the study of air pollution in the atmosphere. Specifically, the technical project seeks to study nitrogen dioxide levels over cities around the world with scientific instruments from an orbiting spacecraft. According the World Health Organization, these high nitrogen dioxide levels are linked to reduced lung function growth (2018). Additionally, NO2 levels have been linked to wheezing bronchitis in children, as NO2 reduces lung function and is referred to as a deep lung irritant (Pershagen, Rylander, Norberg, Eriksson, and Nordvall, 1995). Constructing an accurate model of NO2 levels throughout the atmosphere will help further our understanding of the characteristics and behavior of NO2 levels. Studying nitrogen dioxide levels from space has several advantages. An orbiting spacecraft can cover wide areas of the earth's atmosphere at once, allowing for the development of a large-scale, global model of the atmosphere. Additionally, an orbiting spacecraft can identify pollution levels throughout different levels of the atmosphere. Because NO2 is chemically reactive, the levels of the gas can vary widely throughout the atmosphere. Thus, measuring these levels with a spacecraft can "resolve spatial gradient at sub-kilometer scales, representing an order of magnitude higher spatial resolution that current space-based instruments" (ibid). The data acquired by the spacecraft will help to improve our understanding of the behavior and chemistry of the pollutant. In the technical project, a preliminary design review and critical design review will be conceived for a 3-unit (3U) spacecraft to study the levels of nitrogen dioxide from low-earth orbit.

As humanity continues to capitalize on the capabilities offered by earth-orbiting satellites, deep space exploration lies on the horizon, with preliminary plans for a manned Mars mission in the 2030s (Foust). Should mankind establish permanent bases or colonies on a celestial body, such as Mars or the Moon, several questions arise regarding the role of governments, corporations, and international organizations to regulate or control such endeavors. The STS portion of the paper will focus on the implications of these plans, with specific focus on the geopolitics of space exploration and the geopolitical actors who will make decisions regarding ethical questions surrounding space exploration.

Technical Dimension

The technical project involves designing a 3-unit (3U) spacecraft, with a unit referring to a cube with dimensions of 10 cm x 10 cm x 10cm (Loff, 2015). The design of the spacecraft will be managed by six functional teams: program management, communications, software and avionics, power, thermal and environment, attitude determination and control system (ADACS), and structures and integration. As a member of the structures and integration team, the technical description of the project will focus on the design of the spacecraft bus (infrastructure of the spacecraft) and integrating the scientific instruments into the spacecraft. This will involve significant mechanical design, utilizing computer aided design (CAD) software to model different parts of the spacecraft. Additionally, numerical simulation will be needed to test the structural integrity of the craft, as it will need to withstand the acceleration and vibrational forces during the launch vehicle's ascent to low-earth orbit. The layout and design of the spacecraft is show in figures X and Y.

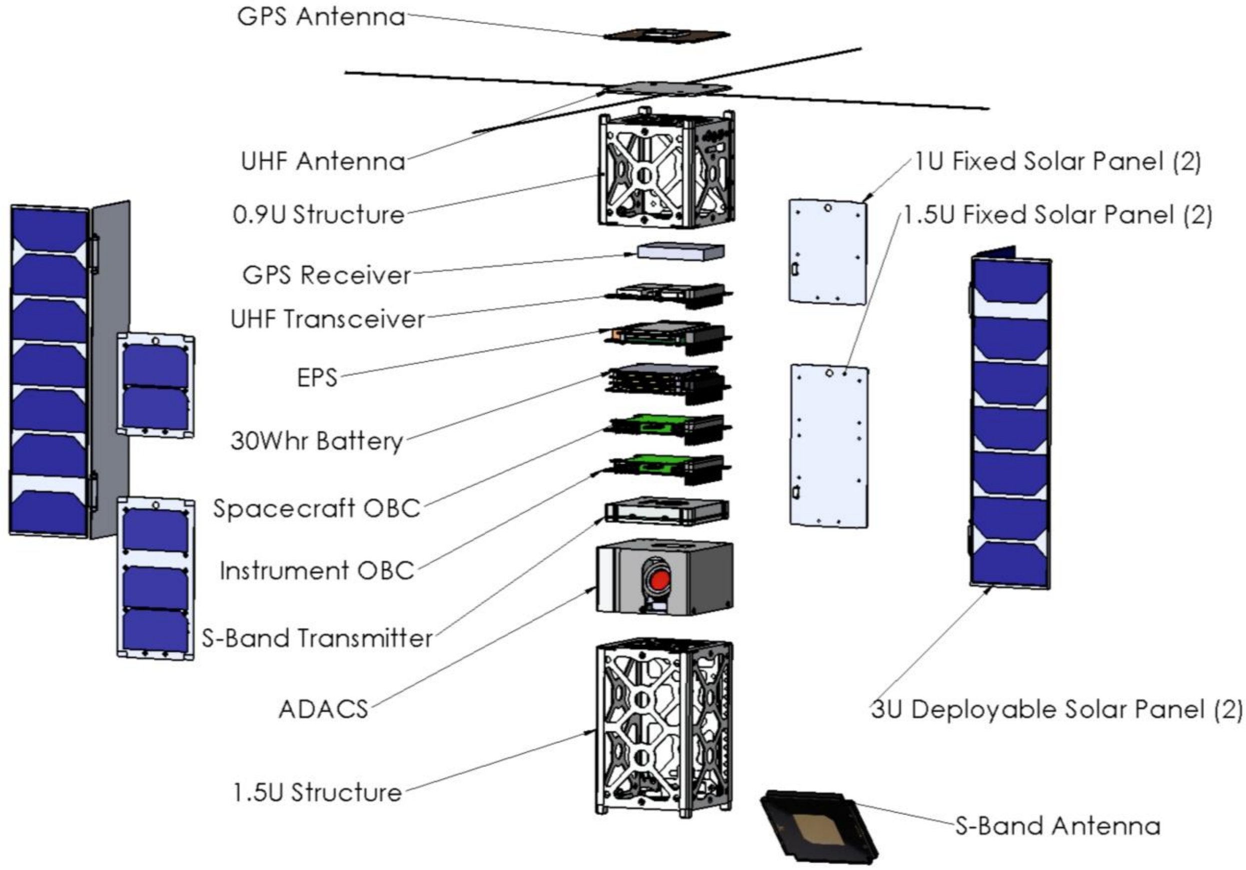

Figure 1: Exploded view of system assembly. Source: Agam

The baseline mission architecture sets a plan to carry a high-resolution small-slit spectrograph aboard a 3U spacecraft bus. From low-earth orbit, the spectrograph will collect data as it passes over target areas and/or cities. When collecting data, the spacecraft will conduct a slewing maneuver (i.e. maintain orientation with target location). When not collecting data, the spacecraft will turn to face the sun in order to maximize the solar energy on the solar panels. The spacecraft will communicate and transmit data to the team via the University of

Virginia ground station, for which the infrastructure already exists from previous CubeSat projects.

The structures and integration team has established several objectives for the project. Regarding the objectives, the spacecraft first needs to survive the space environment. During orbit, the spacecraft will endure significant thermal fluctuation as it passes in and out of the Earth's shadow every 90 minutes or so (Loff). Consequently, proper materials need to be chosen to minimize thermal expansion and thermal stress on the spacecraft.

Another objective for the team is to design the solar panel arrangement for the spacecraft. The spacecraft will receive its power via solar energy, and will require several solar panels to collect energy from the sun. Because the spacecraft will spend half of its time in the earth's shadow, the panels also need to produce enough energy to charge the battery sufficiently to power the spacecraft during time in the dark. The spacecraft only has two free sides, as the other two sides need to be kept open for the star tracker sensor in the ADACAS system. Consequently, the team will likely need to design deployable solar panels that will extend out away from the spacecraft. This design will include the panel configuration, geometry both when deployed and not deployed, deployment mechanism, and support/attachment for the panel.

Another key objective is the integration of the spectrograph and optical hardware into the spacecraft. The spectrograph has several optical components (lens/mirrors), as shown in figure U, which all need to fit within the spacecraft bus. Preliminary plans propose integrating all of the optical hardware into a single structure that can be slid into the spacecraft. The team would need to design individual attachments for each component, as well as struts and/or support brackets to secure the components firmly to the spacecraft. In order to demonstrate the design of the spectrograph integration, another objective for the team is to deliver a 3D printed model of the spectrograph along with the preliminary design review.

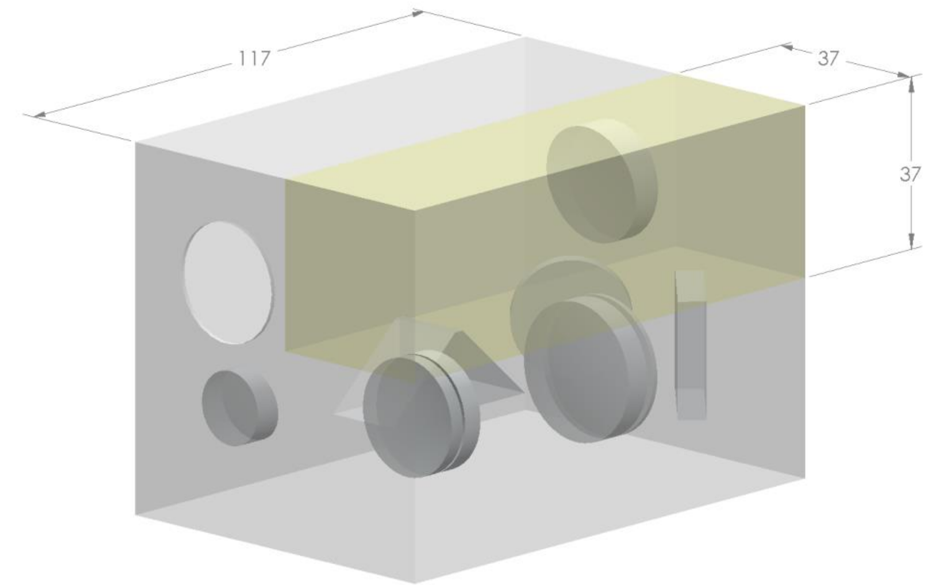

Figure 2: Proposed spectrograph optical components layout. Potentially available volume has been highlighted in yellow. All displayed dimensions are in mm. Source: Agam

The requirements in Table X present the constraints for the project, accounting for launch conditions, deployment of the spacecraft, and the environment of low-earth orbit. The spacecraft is to be deployed by the NanoRacks CubeSat Deployer on the ISS, so consequently the size and shape of the satellite are constrained as to fit into the deployer (Loff, 2015). The harsh conditions of space require special attention to temperature fluctuations, constraining the material choices and design of the spacecraft. The spacecraft needs to survive in orbit for a minimum of one year in order to collect sufficient data, so the spacecraft will be designed to endure at least a year of cyclical thermal stress, a year of corrosion, and a year of residual stress on the spacecraft.   In addition, the spacecraft's structure must be able to survive all parts of the mission, including launch and deployment of the spacecraft. The launch of the spacecraft aboard the launch vehicle will place significant vibrational loads on the spacecraft, and as a result the spacecraft will need to be designed to survive a random vibration test on the ground prior to launch, in order to unsure the spacecraft structure will maintain intact and functional after launch. (Agam)

Table 1: Structures subsystem design requirements Source: Agam

ID	Requirement	Specification	Verification Method
C1.SI.1	Mass	4.8 kg maximum	Weighing
C1.SI.2	Volume	Maximum volume of 12x12x34.05 cm^3 (10x10cm^2 for rails, 12x12cm^2 for faces)	Measurements
C1.SI.3	Center of Mass	Located within 2 cm of the geometric center (of x and y plane axis) +/- 6cm from the z plane of center of mass	CAD model Verification/ Hand Calculations
F3.SI.1	Life Span	1 year orbital minimum	Simulations/ Calculations
F4.SI.1	Temperature	-40C to 65C	Testing
F4.SI.2	Launch Loads/Accel	7G X / 4G Y and Z	CAD Model Simulations
F4.SI.3	Vibration	Random Vibration Test	Testing
F5.SI.1	Outgassing Limits	Maximum material loss cannot exceed 1% as specified in SP-R-0022A	Obtaining materials from verified sources
F5.SI.2	Independent Deployables	Does not rely on external parts (i.e., launcher, other CubeSats) to be contained	In-house testing when possible
F5.SI.3	Inhibit Switches	Three independent switches	In-house testing

F5.SI.4	Satellite Power-On Wait Time	30 mins	In-house testing of code/satellite

STS Topic

According to Jim Bridenstine, the current NASA Administrator, NASA is planning to send humans to Mars in the 2030s (Foust). Additionally, private companies like SpaceX have proposed plans to visit Mars as soon as 2028 (Wall). These timelines are aggressive, and given historical delays associated with spaceflight, it will likely take much longer to achieve. Nonetheless, exploration of Mars by humans appears to be on the horizon. When people think of the challenges of Martian exploration, most think of the technological hurdles, such as surviving the long journey, radiation shielding, landing on Mars, and sustaining long-term life support systems. While big challenges, distinctly challenging questions also surround the geopolitics of a Mars mission.

The primary framework that governs the politics of outer space is the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, commonly referred to as the Outer Space Treaty of 1967. The main provisions in the treaty is that is bans the placement of nuclear weapons in space, and it limits the use of the moon and other celestial bodies for exclusively peaceful purposes. In addition, the treaty states that astronauts as the "envoys of mankind", and that all parties of the treaty shall offer assistance in the event of an accident or emergency. If an astronaut makes a landing on the territory of another State Party, that state shall return the astronaut promptly and safely to their home state (1967). The Outer Space Treaty is the most significant existing legal framework regarding the role of government in outer space. But would the treaty be of any use for a Martian colony? How could such a treaty be enforced?

For example, the physical logistics of Mars itself pose major hurdles for governance on Mars. The average distance between the Earth and Mars is a whopping 225 kilometers. At this distance, it would take approximately 9 months to travel to Mars (How Far is it to Mars?). As a result, a Martian colony would have tremendous autonomy. Mars is so far that even communication between Earth and Mars would be affected. Delay times could reach up to 24 minutes, rendering real-time monitoring and control over Mars difficult.

To address these concerns, The STS framework of Responsible Innovation can be used. In their article, Richard Owen, David Maynard, Trevor Maynard, and Michael Depledge articulate the idea behind Responsible Innovation. Rapid innovation in the 21st century has been so rapid that society has struggled to keep up with the consequences of these changes. The framework of Responsible Innovation advocates for greater foresight in innovation. The article introduces the idea of "horizon scanning", which is an approach for "identifying emerging issues, such as innovations, associated impacts, risks and benefits… and then synthesizing this through knowledge management" (pg. 6903). Mars exploration has not begun yet. However, it certainly is on the horizon. According to the framework of Responsible Innovation, now is the time to address the consequences of a potential Mars mission, rather than wait until the arrival of the actual missions. Researchers and analysts on space exploration cannot predict the future implications of Mars exploration. But by paying attention to the horizon, they can anticipate events, circumstances, and future contingencies.

Additionally, the STS framework of Actor Network Theory (ANT) can be used to describe the network of governments, corporations, independent organizations, and individuals that would influence the geopolitics of a Mars mission. ANT can be used to describe nonhuman artifacts, such as the spaceship, habitation module, and physical base itself on Mars. Further, ANT can provide insight into the infrastructure of the actor-network for a Martian colony (Latour). For example, ANT can help describe the network of organizations that make decisions regarding planetary protection. Planetary protection is the principle that describes the concern for biological contamination of both celestial bodies and back contamination of Earth (through sample return missions). One actor, the Committee on Space Research (COSPAR), was delegated by the UN to define planetary protection guidelines for space agencies, these bodies are unable to address these concerns alone. COSPAR is mostly made up of scientists, and as a result is not equipped to take into consideration the concerns of the broader society (Arnould and Debus). Another actor of course would be NASA, which conducts research on planetary protection on behalf of the United States. Additionally, an independent organization, The International Committee Against Mars Sample Return, influences decisions on planetary protection by petitioning against the return of samples from Mars to Earth (International Committee Against Sending Mars Samples Directly to Earth). This is just one example of a network of geopolitical entities and its relationship with non-human artifacts (i.e. the Mars sample return).

Research Question and Methods

The STS research paper will address the following question: What are the geopolitical considerations that need to be taken into account for potential Mars colonialization? To evaluate this question, a case study of space movies will be conducted to offer foresight into the potential political structures of space colonies. Space movies, while mostly fictional, can have great influence over cultural attitudes and perceptions regarding space exploration. Movies, with the privilege of creative license, have the ability to explore futuristic ideas and scenarios. Movies also get to explore the human and political aspects of space exploration. Take the premise of The Martian, for example. How does the NASA respond when an astronaut is found stranded on Mars? How does the US government cooperate with other international entities to formulate a rescue mission? Answering questions like these provide insight into how situations like this could play out in the real world.

Additionally, this question will be analyzed through a historical analysis of colonialism of the New World in the X century. Space colonialism and 14th century colonialism in the New World couldn't be more different on a technological level. On a socio-political level, however, there are stark similarities. New World colonies faced similar logistical issues that a potential Martian colony would face. A typical voyage across the Atlantic typically took six weeks, but could take as long as three months under difficult sea conditions (Atlantic Ocean). While not quite as long as a journey to Mars, the voyage presents the same logistical challenges of control and authority over the New World colonies. How did the European nations regulate the colonies? How did the European nations respond to conflicts and unrest in the colonies? Answering these questions in a historical analysis would provide critical insight into the geopolitical tendencies of political entities when attempting to govern a distant and isolated world.

Timeline and Expected Outcomes

For the technical project, a preliminary design review is expected to be delivered by the end of the first semester (December 2019), and a critical design review is expected to be delivered by the end of the second semester (May 2020). Additionally, a 3D printed model of the spectrograph is expected to be delivered by the end of the first semester. Regarding the outcomes of the technical project, it is anticipated that material choices, solar panel configuration, and spectrograph integration will all be proposed in both the preliminary and critical design review. For the STS research paper, it is anticipated that evidence gathering will take place between January and February of 2020, data analysis will take place during March of 2020, and that a final paper will be delivered mid-April of 2020. With the delivery of the final paper, it is anticipated that a comprehensive model for the geopolitical implications of a Mars mission will be established.

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