**COMMUNICATIONS SYSTEM IN THE HYPERSONIC REENTRY DEPLOYABLE GLIDER EXPERIMENT (HEDGE)**

**THE ENVIRONMENTAL EFFECTS CAUSED BY CONTINUED SPACE EXPLORATION**

A Thesis Prospectus
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Bachelor of Science in Aerospace Engineering

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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Space exploration has been an expanding field of technology around the world since the 1950s. Starting with the space race to send a human beyond our atmosphere, followed by the landing on the moon, it can be seen that there is a rapid desire to learn more about what is beyond our Earth. Along with the urge to explore, space can be seen as a large open area to undergo testing that is not feasible on our Earth. Hypersonic technology is emerging, and space seems like a viable location for testing. Recently in 2021, China successfully demonstrated an object reaching hypersonic speeds while returning to orbit. The U.S. found their development alarming as China's technology is more advanced than the Pentagon. (Sevastopulo, 2021). The development of hypersonic technology in other countries has led the U.S. to fund a multitude of hypersonic tests (Bugos, 2022).

Along with these hypersonic space tests, there are still other space exploration missions, all which can cause harm in the present and down the line. Various space missions have failed, resulting in the explosion or destruction of the spacecraft. Whether "a rocket self-destructs because it thinks it is going too fast" or the trajectory is off by just a little causing it to disintegrate in Mars orbit, space debris can form (Mehta, 2021). Along with the production of space debris, emission created to launch these missions outweighs the pros as the mission was never completed.

The technical research is focused on developing a communications system for a spacecraft that will experience hypersonic flight. This is tightly coupled with the STS research which focuses on the harmful environmental effects of space exploration. For the technical research, we will begin by reviewing the conceptual design review completed by last years' class and refining their communications system plans and by the end of the semester we will have a final selection. For the Spring semester, testing will be conducted on our chosen communication system which will lead to a final design review for the overall hypersonic spacecraft mission. For the STS research, I will finish this semester by polishing up my prospectus. Next semester will consist of writing an executive summary and completing my final STS research paper.

## COMMUNICATIONS SYSTEM IN THE HYPERSONIC REENTRY DEPLOYABLE GLIDER EXPERIMENT (HEDGE)

As hypersonic technology is novel, testing and collecting data on their performance and environmental parameters are key factors to their successful integration into the civilian and defense industries. However, since these parameters need to be collected at hypersonic speeds and within a similar flight environment, the difficulty and cost of these tests are substantially high. Under the guidance of Chris Goyne of the Department of Mechanical and Aerospace at the University of Virginia, fellow team members Hussain Asaad, Aidan Case, Lauren Murphy and I will be developing the communications system for the Hypersonic ReEntry Deployable Glider Experiment (HEDGE) which will take the form of a CubeSat. CubeSats are nanosatellites that have a specific standard for dimensions of 10 cm x 10 cm x 10cm (NASA, 2018). The CubeSat design for this project is a 3U which is a 10 cm x 10 cm x 30 cm rectangular prism. Previous students under Chris Goyne have developed a basic design for the HEDGE. This design has the back 1U section designated for the electronic subsystems while the front 2U section will convert to a canonical leading edge with square-circle transitions.

## COMPLICATIONS IN COMMUNICATIONS

For the HEDGE project, our objectives as a communications team is to find a radio system that can integrate into the CubeSat platform, perform cooperatively with the other systems on the CubeSat, stay within all budgetary constraints, and successfully transmit hypersonic data. This includes four distinct parts that must be decided upon: the CubeSat transceiver, the CubeSat antenna, the relay satellite, and the ground station. However, many concerns arise when selecting the components. The primary complication is the formation of a plasma cloud around the CubeSat which is caused by shock waves heating the surrounding air to the point where the gas ionizes. As shown below in Figure 1, this cloud reflects radio waves which creates blackouts in communications, where nothing can be received or transmitted (Rybac, 1970, p.24). Other than the plasma cloud, we need to ensure that our design caters to "impairments and losses such as noise, atmospheric attenuations, and Doppler shifts" (Bomani, 2021).

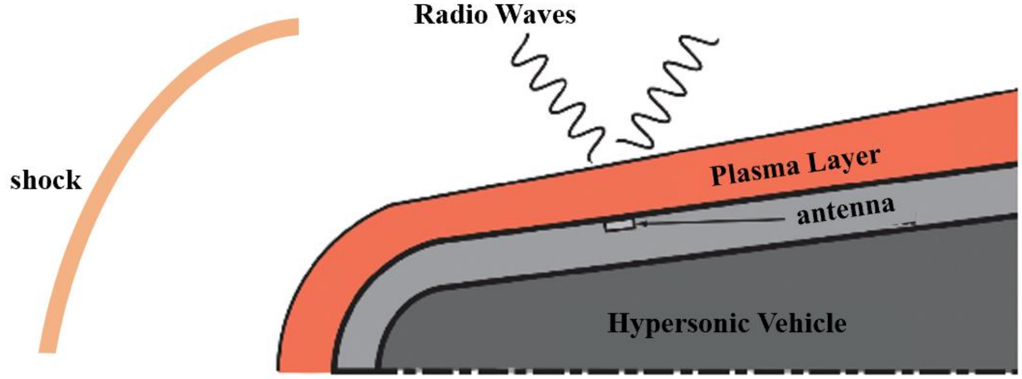


Figure 1: Visual representation of a plasma layer. Radio waves are being deflected from the plasma layer surrounding a vehicle moving at hypersonic speeds (Kim, 2011).

## PLAN OF ACTION FOR IMPLEMENTING THE COMMUNICATION SYSTEM

To ensure that a successful communication system is implemented into HEDGE, the system selection process will be broken down into three phases: research, testing, and prototyping. For the research phase, we will review the previous class's radio and antenna selections and see if they are viable for the mission. Further research will be conducted on the previous CubeSat missions' communication systems. It will be imperative to look into systems that have operated in a similar environment that our spacecraft will be operating in. Next, we will test our chosen CubeSat radio and antenna using the University of Virginia's CubeSat Simulator. The CubeSat Simulator will allow us to see if our chosen components can successfully collect data and transmit them to a nearby computer. If possible, we will have the CubeSat undergo various conditions and analyze how it affected the transmission of data. The next phase of testing will be connecting our radio to an Iridium relay satellite. Figure 2 illustrates how Iridium relay satellites will be used to relay the data from our CubeSat to an Iridium ground station then to our University's ground station and vice versa. For the last phase of our design process, we will begin preliminary prototyping. This involves implementing our chosen radio and antenna into the 1U section of the HEDGE CubeSat. Given design parameters and the other subsystem space requirements, we will get an initial look at how the radio will fit into the overall mission design.

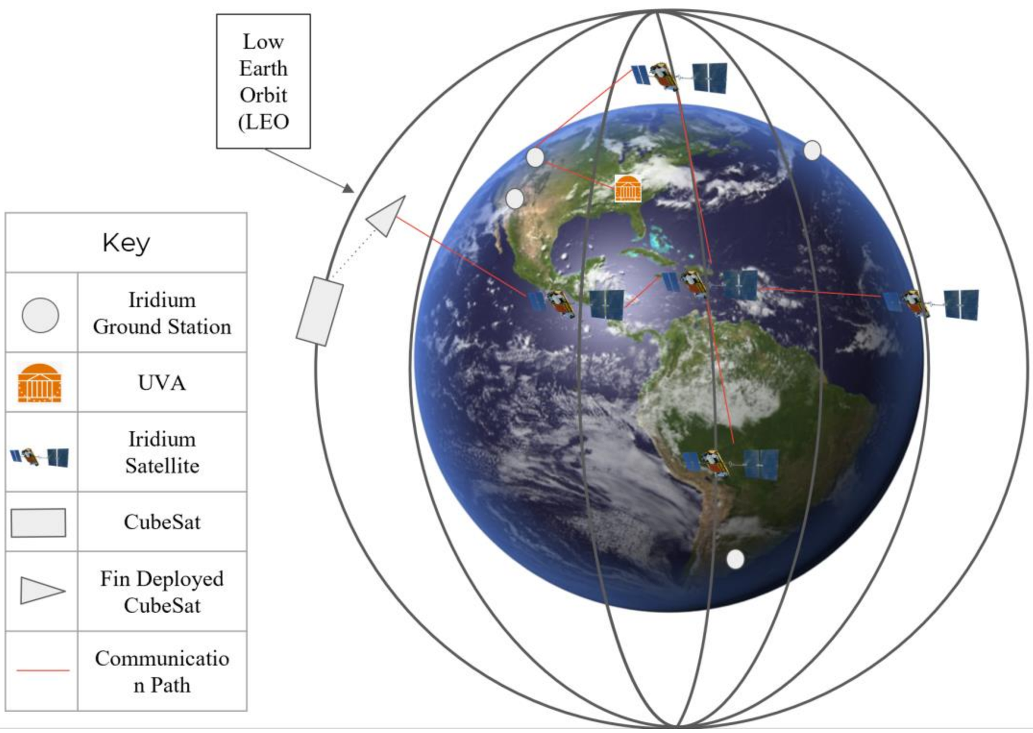

Figure 2: Depiction of expected satellite communications. Illustrates how commands will be sent from UVA to an Iridium ground station, then relay between Iridium satellites before it reaches our CubeSat. This process is then reversible with data sent from the CubeSat. (Castro, 2021)

There is $4,000 available to use for this stage of developing HEDGE. Part of that budget will be allocated to the communications team to buy commercial off-the-shelf (COTS) radios and antennas. If there is enough funding, multiple combinations of radios and antennas will be purchased in order to test for the best possible combination for our mission. As mentioned above, we have the CubeSat Simulator as a resource for our project development. We will also rely on Mike McPherson as the main point of contact for suggestions on implementing our communications system. Mike McPherson works in the CubeSat Lab here at the University of Virginia and has an amateur radio license, which will allow us to further test the communication system we design.

By the end of the fall semester, we as the communications team will work alongside the other functional teams to create a spacecraft preliminary design review paper. The functional teams include project management, communications, software and avionics, power, thermal and environment, attitude determination and control system (ADACS) and orbits, and structures and integration. A preliminary design review (PDR) is a "technical assessment that establishes the allocated baseline of a system to ensure a system is operationally effective" (Acqnotes, 2021, p.1). After prototyping and testing various radios and antennas, a critical design review (CDR) will be created together with the other functional teams by the end of the Spring semester. A CDR is a "multi-disciplined technical review to ensure that a system can proceed into fabrication, demonstration, and test and can meet stated performance requirements within cost, schedule, and risk" (Acqnotes, 2022, p.1). By this stage, we will have a finalized structure for our communications system and which radio, antenna, relay satellite, and ground station will be used. All aspects will have been thoroughly tested as described above, and the system will be ready for full integration into a HEDGE CubeSat. The Spring semester will also end with the functional teams collectively drafting up a proposal to industry for funding.

## THE ENVIRONMENTAL EFFECTS CAUSED BY CONTINUED SPACE EXPLORATION

Space exploration continuously is getting more and more popular around the world. There have been many benefits to space exploration over the past fifty years. The International Space Exploration Coordination Group (2013) connects space exploration to the economic progress of space-faring nations (p. 5). They say that the advances in science and technology that come along with space exploration furthers industrial capabilities which leads to a stimulation of industries. Although there are great benefits to space exploration, harmful consequences come along with it too.

### THE SPACE DEBRIS ISSUE

According to NASA (2021), there are approximately 23,000 pieces of debris the size of a softball or larger orbiting Earth at up to 17,500 mph. There are then about 500 thousand pieces around the size of a marble followed by approximately 100 million pieces of debris that is only .04 inches. (NASA, 2021). Although the softball sized debris can do considerable damage to spacecraft and satellites, the smaller debris can also cause issues as “even tiny paint flecks can damage a spacecraft when traveling at these velocities” (NASA, 2021, p.2). Figure 3 below provides a visual representation of the space debris orbiting the Earth as tracked by NASA. Each dot represents space debris that is the size of a softball orbiting the Earth.

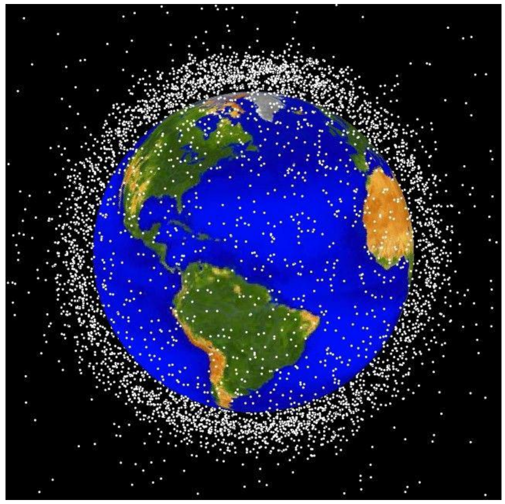

Figure 3: Space debris in orbit about Earth. This figure is a computer-generated image based on NASA’s tracking of large space debris (NASA, 2021).

These millions of pieces of space debris orbiting the Earth, as shown above in Figure 3, will only cause more debris to build up. In a report, Shenyan Chen (2011) explains the long-term effects of the space debris problem. Since orbital debris can last up to ten years, there is room for a substantial amount of collisions (p.545). Eventually, this can lead to what Chen thinks as one of the most important issues where collisions between objects are so frequent that they produce additional debris faster than atmospheric drag removes it (Chen, 2011, p. 550).

**RESULTED POLLUNTATNS FROM ROCKETS AND SPACE TOURISM**

In addition to space debris orbiting the Earth, the pollution in the atmosphere caused by launching these spacecraft needs to be looked at. Ryan, Marais, Balhatchet and Eastham (2022) emphasize in their article how the atmospheric effects due to the space industry is not something to ignore as this industry is one of the world’s fastest growing (p. 1). Recently, there has been a surge in re-entering debris as well as reusable components re-entering which form nitrogen oxides from reentry heating. Chlorine is also released from solid fuels used in the reusable rockets which all contribute to the stratospheric $O_3$ depletion. (Ryan, Marais, Balhatchet & Eastham, 2022, p. 1). Ozone depletion increases the ultraviolet radiation that reaches the earth which poses various health risks such as skin cancer and genetic and immune system damage (Wuebbles, 2022).

The increased popularity of space tourism also poses a great concern as it will increase the amount of black carbon produced. According to Ryan, Marais, Balhatchet and Eastham (2022), black carbon soot is “almost five hundred times more efficient at warming the atmosphere than all other sources of soot combined” (p. 1). The graph shown below in Figure 4 is a representation of the posing dangers of space tourism. Radiative forcing is the change in energy flux within the atmosphere and is a main factor for climate change (Chandler, 2010).

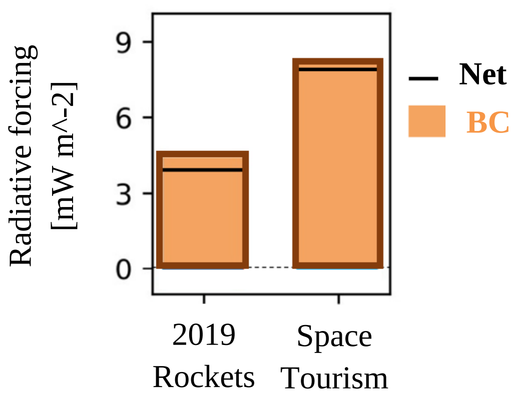


Figure 4: Comparing radiative forcing from rockets and space tourism. Compares the amount of radiative forcing is caused by black carbon (BC), ozone and methane ($O_3$and $CH_4$), and polar stratospheric clouds (PSCs) between a decade of rockets and 3 years of space tourism (Ryan, Marais, Balhatchet & Eastham, 2022).

In the graph, the right column representing space tourism is only based on 3 years of space tourism activity compared to a decade of emission effects of regular rockets ending in 2019. Within only 3 years of space tourism activity, there is almost double the amount black carbon emissions (shown in orange) which emphasizes how urgent it is to figure out regulations for these new space exploration technologies.

## CURRENT REGULATIONS

Currently, there are treaties and regulations in place to combat space debris and the deteriorating ozone layer. First there is the Inter-Agency Space Debris Coordination Committee (IADC) and their space debris mitigation guidelines. The IADC is an international governmental forum for the worldwide coordination of activities related to man-made and natural debris in space. Agencies involved include ASI (Agenzia Spaziale Italiana), CNES (Centre National d'Etudes Spatiales), CNSA (China National Space Administration), CSA (Canadian Space Agency), DLR (German Aerospace Center), ESA (European Space Agency), ISRO (Indian Space Research Organization), JAXA (Japan Aerospace Exploration Agency), KARI (Korea Aerospace Research Institute), NASA (National Aeronautics and Space Administration), ROSCOSMOS (State Space Corporation), SSAU (State Space Agency of Ukraine), and the UK Space Agency (Inter-Agency Space Debris Coordination Committee, 2019). This handbook created by the Inter-Agency Space Debris Coordination Committee (2020) states that a feasible Space Debris Mitigation Plan be established and documented for each program and project which must include the following:

1. A management plan addressing space debris mitigation activities
2. A plan for the assessment and mitigation of risks related to space debris, including applicable standards
3. The measures minimizing the hazard related to malfunctions that have a potential for generating space debris

4. A plan for disposal of the spacecraft and/or orbital stages at end of mission
5. Justification of choice and selection when several possibilities exist
6. Compliance matrix addressing the recommendations of these Guidelines. (p. 9)

These set of general guidelines will help minimize the amount of space debris that result from space exploration missions. The IDAC handbook adds mitigation measures to minimize break-up of the spacecraft starting from launch, through the operation phase, and ending with the post-mission phase to further ensure that as little space debris is produced as possible (Inter-Agency Space Debris Coordination Committee, 2020). In Ryan, Marais, Balhatchet and Eastham's (2022) research article, they mention the Montreal Protocol (p. 1). The Montreal Protocol is an agreement that regulates the production and consumption of ozone depleting substances (ODS). This protocol was adopted in 1987 and is the only UN treaty ever that has been ratified by all 198 UN member states (United Nations Environment Programme, 2022).

Although there are these regulations in place, space debris is still a large problem that may only get worse with an increased space exploration. There is also no doubt that global warming is an issue that is not going away, and the emissions from these space missions are not aiding to solving that issue.

## ANALYZING THE DESIGN PROCESS

In order to minimize the harmful environmental effects from space exploration, a Social Construction of Technology (SCOT) (Pinch and Bijker, 1987) model like that one shown in Figure 5 could be adopted.

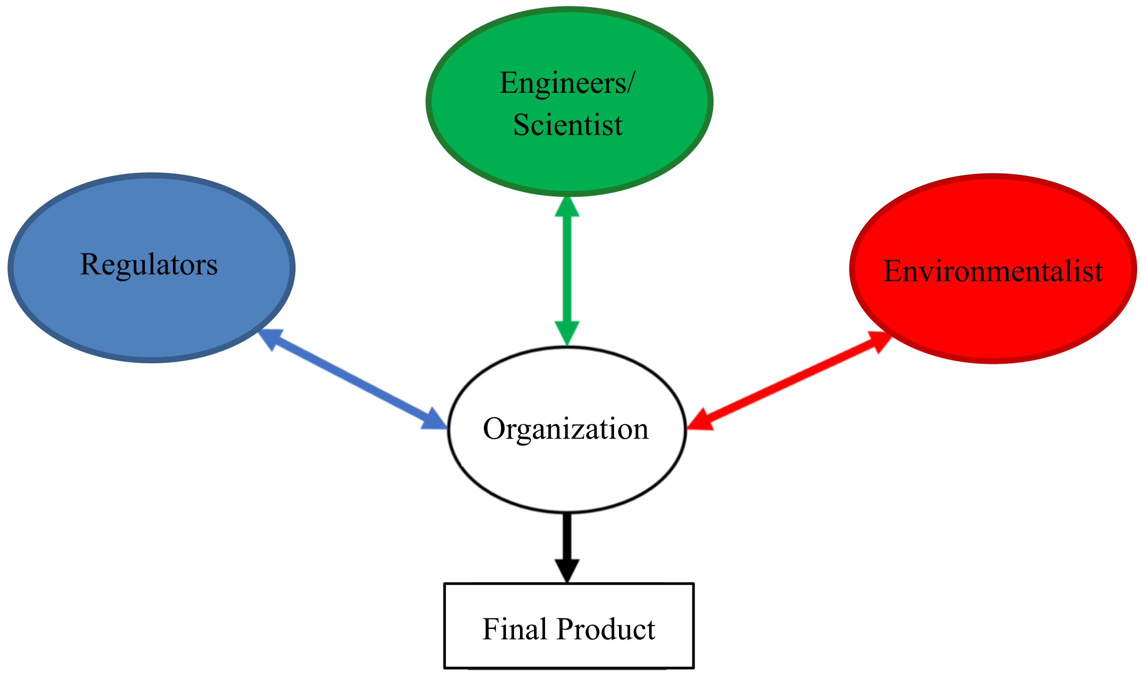


Figure 5: SCOT model for integrating a space exploration product. Three groups, regulators, engineers/scientists, and environmentalists share ideas back and forth with an organization to implement correct guidelines for space exploration technology (adapted by Kaiya Saunders from Pinch & Bijker, 1987).

For this model, an organization, for example SpaceX, would voice their ideas for a product to the other groups. The regulators would then provide them with the guidelines they need to follow in order to minimize the amount of space debris formed. The engineers/scientist will be responsible for designing the spacecraft with the right materials and making sure to test the product sufficiently so there are no accidents in space that can lead to an increased amount of space debris. Then environmentalists can add their input as to what fuel type would be most beneficial to the atmosphere. Throughout the whole design process there will be a back and forth between these three groups and the organization until a final product is produced that meets all the requirements necessary to minimize the environmental harm the space mission will cause. For the STS research, I plan to investigate the production process of space related companies and compare their process to the process described in the SCOT model. By comparing design processes, I can identify if companies take into account environmental effects of their products.

Whether the purpose is to collect useful information such as the HEDGE mission, or simply for entertainment such as space tourism, space exploration has deteriorating effects on the environment. The STS research project will be outlining how current regulations are put into play to reduce the harmful effects resulting from space exploration, presented in the form of a scholarly article. I hope to explore the relationship these regulations have in the design phase for space exploration missions.

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