2023-2024 Undergraduate Spacecraft Design

Orbital Debris; Problems, Solutions, and Impacts on the Design and Implementation of Spacecraft.

A Research Prospectus

STS 4500

Presented to The Faculty of the School of Engineering and Applied Science

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Bachelor of Science in Aerospace Engineering

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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.

Advisors:

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Introduction:

As technology surrounding space has improved over the last seventy years, modern life has also become more reliant on systems situated in space. Satellite internet, imagine, and GPS among many other technologies in space have become intertwined in everyday life, so much so that a disruption of these systems would be devastating, bordering on catastrophic to the modern world. A major problem that is beginning to be posed to all of these space-based systems is the obstruction of their launching and continued deployment, in this case due to an ever increasing number of orbital debris. Orbital debris can take many forms, but typically the form of most relevance today are orbital debris left behind by space launches; many from leftover pieces of launch vessels, collisions of spacecraft with current space debris, or the deterioration and misuse of active spacecraft. These space debris are currently proving to be a manageable problem, with only simple mapping technology required to move spacecraft out of collision courses in time. Many experts predict however, that this will very soon be an inadequate solution as the number of debris and conversely the frequency of collision courses increase. This change in the number of space debris will make it almost impossible to track with current technology and at the very least will demand a development in this field to continue to operate spacecraft at their current capacity. Unfortunately, this problem is not expected to follow a linear increase in magnitude, due to the fact that as spacecraft collide with space debris and are destroyed, orders of magnitude more space debris are created from the collision than initially collided. This sequence dictates that, akin to the mechanisms of nuclear reactions, a critical mass of spacecraft and space debris can be reached such that a chain reaction begins, rendering the atmosphere inhospitable to the likes of modern day satellites, with millions of debris creating a blanket through which no satellite can operate.

My STS research paper will examine the social impacts of the development of the space debris problem, specifically the regulation and social pressure surrounding the development and deployment of satellites, and anti space debris technology. My technical paper focuses on the design project undertaken in my capstone project, the creation of a sounding rocket to comply with competition rules for the 2024 IREC scholastic sounding rocket competition. The design of this rocket is a project that has been undertaken by a large group of students, and as a result the development of the project is compartmentalized. My focus in this project has been the design of the body of the sounding rocket, and as a result my discussion of this project will mainly focus on this aspect of the rocket, with lighter discussion on the other components of the design. These two topics are inherently connected, as the design of sounding rockets, and the payloads that they carry with them, can dictate the amount of debris left in the atmosphere, if any, and how the amount of these debris can be mitigated. Though the rocket being designed in this capstone project only aims to reach an altitude of 5000 feet, many of the same design principles are applied for a rocket that would reach a height at which space debris would become a problem.

Technical Topic:

The design of a sounding rocket is a multifaceted and long process, and in this section I will do my best to give an overview of most aspects of its creation for my capstone project. Our capstone has split its members into three main groups, structures, propulsion, and mechatronics. All of these groups are then split into subgroups which have an even more refined scope than their overall team. The structures team has four distinct subgroups; body, fins, nosecone, and couplers. The body team, the team in which I am most involved, is concerned with the creation of the body tube, orientation of weight within the body tube, and attachment of the nose cone and fins to the body tube. The main aspects that need to be taken into consideration for the body tube are the shapes and materials chosen. To choose the material, you generally want to minimize the weight while still maintaining the baseline strength needed to maintain structural integrity during flight. Using this set of criteria, our group decided to either use carbon fiber or fiberglass composites to create the body tube, eventually choosing fiberglass due to cost considerations. For the shape of the body tube, the main aspects that need to be managed are room in the body tube, to ensure that you can fit all required systems, and maintaining a reasonable stability margin, a measure of the tendency of the rocket to oscillate under perturbations. The stability margin can also be changed with different design considerations in the nose cone and fins, so we decided on a diameter of ~15cm, just slightly larger than the size required to house the payload. For the nose cone and fin design, the considerations are quite similar; minimize mass and flow disruption while maximizing stability. To this end, the nose cone team has decided on an ogive shaped cone with a height of roughly three to four diameters. The fins team has decided on a standard design, of four tapered fins roughly with a height going from two to one and a half diameters along the taper. The couplers team focuses on the integration of all other parts of the design into the rocket, ensuring their stability and maintaining the strength of the rocket at the junctions that must be created for drogue chute and parachute separations. To accomplish this, structural rings and bulkheads have been designed for use at regions of lessened stability. The mechatronics and propulsion teams' roles are self explanatory. The propulsion team has focused on the design of an engine housing as well as the formula and procedure for creation of a solid rocket propellant. The engine housing will be made with an aluminum alloy, while the propellant will be a version of 'cherry limeade', a propellant formula first designed by a MIT rocket team. The mechatronics team has focused on the integration of various flight systems required for correct deployment of the payload, mainly parachute deployment, communication with ground systems, and the parachutes themselves. The system chosen consists of a drogue chute and parachute combination, with the drogue chute launching first to control the speed enough for the parachute to be safely launched alongside the payload. Overall, the designs for these various systems have been finished, but the prototyping phase has still not been conducted, so most of these systems are subject to change.

STS Topic:

As humanity's reliance on technology in space grows, the problem of a calamity involving space debris grows alongside it. More spacecraft in space provides more opportunities for collisions that create space debris, thus perpetuating the problem, possibly leading to a chain reaction given enough time. This process would leave humanity with an atmosphere uninhabitable to most of the technology that we rely on today, including GPS, satellite internet, and satellite imaging. In my research I will aim to determine the extent to which this issue will develop in the coming years, and the degree to which I think solutions need to be created and implemented, both technologically and legislatively.

To reach this end, my research will analyze papers first that project the degree to which the situation in space will become critical. For example, a number of papers attempt to quantify the extent of the growth of the space debris problem given the current rate of satellite launches and usage of countermeasures. Using this information I will attempt to inform a decision on the level of urgency with which this issue needs to be approached, and the recommended courses of action. One of the main avenues that, through my preliminary research, I think will lead to viable solutions are regulations concerning the launch of satellites and the lifetime control (ensuring that all satellites protocols and capabilities to enter a graveyard orbit, causing them to not create orbital debris as they reach the end of their life cycle). Another solution that I have researched is the usage of varied technologies to remove space debris from the atmosphere, either by destroying them directly or removing them into lower atmospheres where they will burn up due to friction.

After conducting further research on these facets of control space debris, I plan to determine the actions and urgency to which such actions should be taken to mitigate risk. I also plan to examine economic projections on the matter in order to determine the extent to which these solutions should be carried out and the resulting economic changes that will follow. Overall, evidence for these pillars of my STS topic will be gathered from papers and statistical analysis concerning space debris and the economy of space technology, but there will also be some aspects of my analysis collected from technical documentation concerning current operations for satellites and space debris.

Conclusion:

In conclusion, I plan to discuss two main topics in my research; my technical topic, the design and creation of a sounding rocket, and my STS topic, the analysis of the growing space debris problem, and recommendations of courses of actions using prior and ongoing research. My technical research will aim to provide a detailed analysis of the process through which my capstone team has created a rocket, as well as the aspects of its construction and design that are relevant to my STS topic, specifically concerning debris creation, and avenues through which I think this problem can be mitigated in our project. My STS research will, as stated earlier, provide an overarching analysis of the current body of research in the field of orbital debris and reach a conclusion on the severity of the problem as well as recommended solutions and the urgency with which they should be applied.