ADACS and Orbits for HEDGE Project
(Technical Paper)

Space Debris: A Wicked Problem
(STS Paper)

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Mechanical Engineering

By
Sean Jones

November 4, 2022

Technical Team Members:

Joseph Beasley
Grant Duemmel
Avery Goldberg
Sean Jones
Lucas Talbert

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

Chris P. Goyne, Department of Mechanical and Aerospace Engineering

Bryn E. Seabrook, PhD, Department of Engineering and Society

Introduction

Could you dodge a bullet? If 215,000 bullets constantly shot past your window every hour would you go outside? Currently 215,000 lethal pieces of space debris orbit our planet, at speeds ten times faster than that of a bullet (Gregerson, 2022). Space debris is often caused due to accidental satellite collisions but the greatest increase in debris can be attributed to intentional anti-satellite weapons testing from the U.S., China, and Russia (Fleck, 2022). As a result space junk has become the newest form of pollution and is suffocating space exploration, research, and commerce. In my research project I will aim to study the current effects of space debris on our orbits, the potential for growth and damage to the orbital environment, while focusing on the continuation of space as a domain through both a civilian and military lens. Sitting 50 km below the orbiting space debris, a new era of research and development is occurring, the creation and testing of hypersonic vehicles and weaponry. These vehicles operate within dense atmospheric conditions at speeds greater than Mach 5. Giving the missile type a strategic advantage in conflict due to a combination of maneuverability, speed, and unique flight path making it exponentially difficult to detect and defend against (Brockman, 2022). HEDGE is an undergraduate project, aimed to design and deploy a hypersonic glider vehicle for re-entry from extreme low earth orbit. The project is a proof of concept for an in-expensive testing method to collect data and contribute to the development and understanding of hypersonic behaviors on various materials. Space warfare and hypersonic weapons are at the forefront of increasing tension among nations, and explosively expanding in technological capability. Looking ahead, satellite detection may be a key contributor to the defense against hypersonic vehicles (Sayler, 2022) but the future of space operations will be hindered with increasingly inhabitable conditions.

Technical Topic

ADACS and Orbits for HEDGE

Importance of ADACS and Orbits

Hypersonic flight occurs when vehicle speed exceeds five times the speed of sound. While hypersonics can have many applications, limitations in the capacity to research them is a growing problem. Aerospace Engineering students at the University of Virginia are developing a mission to solve the limitation problem: Hypersonic ReEntry Deployable Glider Experiment (HEDGE). With this mission, a CubeSat will travel in a launch vehicle to ELEO altitude and then be ejected. It will then deploy fins to transform into a hypersonic vehicle. Upon reentry, after about a one-week lifetime, data will be collected and transmitted, then the craft will burn up in the atmosphere. In order to ensure the project meets the mission objectives, the class is divided into six subsystems to work on specific requirements: Program Management, Communications, Software & Avionics, Power/Thermal/Environment, ADACS, and Structures and Integration.

ADACS, or Attitude Determination and Control System, is a system of components used to determine, adjust, and maintain the position of a craft in orbit. The knowledge and control of the craft throughout its flight allows for manipulation of mission parameters, such as launch windows, flight times, orbital maneuvers, sensor orientation, and reentry zones. Attitude can be controlled both passively through components such as spin stabilizers or fins, and actively with parts such as thrusters or magnetic torquers (NASA, 2021). The ADACS subsystem will determine what type of attitude control systems best fit our mission's goals, parameters, and budget.

Objective of HEDGE Project and ADACS

Prior to flight, the objective of the ADACS team is predicting and modeling the expected orbital path, planning for any potential disruptive forces that would alter the position of the craft. Upon launch, our team's objective moves to real time attitude determination and adjustment to attain spacecraft stability. ADACS is employed to ensure the vehicle enters the atmosphere at an optimal attitude for velocity optimization, according to the structure's aerodynamic abilities, and successful data collection. In addition, the ADACS team will aim to provide reliable and consistent ADACS information so that the remaining subsystem teams can plan and achieve their objectives with appropriate positional data.

Approach to ADACS

Our team's approach to ADACS and Orbits is rooted in stability dynamics and pressure sensors. Collaborating with the Structures and Integration subteam, the ADACS team will ensure that the CubeSat's center of pressure is behind its center of gravity. Ensuring stability requiring knowledge of the components that will be included in the CubeSat and their integration and how the stability dynamics will change once the fins are deployed. A main concern for ADACS is tumbling of the CubeSat after its ejection from the launch vehicle. To solve the stability problem, the ADACS sub team will use previously collected CubeSat data to make predictions about HEDGE's tumbling rate when ejected. With historical data, the team will begin to draw conclusions about what would be necessary to slow the tumbling and stabilize the CubeSat. Some potential solutions include a passive attitude control system like a magnet that would use the Earth's magnetic field to stabilize the vehicle, an active attitude control system that could be detached from the CubeSat, or using the aerodynamic stability of the CubeSat to simply self-correct. Making the decision of which method of stabilization to use will require data collection and testing. Measuring pressure is a main goal for HEDGE's data collection. The ADACS team plans to make use of measuring pressure goal by implementing a flush air data system (FADS) for attitude determination. FADS is a method of attitude determination commonly used in aircraft that "makes use of surface pressure measurements from the nose cap of the vehicle for deriving air data parameters such as angle of attack, angle of sideslip, Mach number, etc." (Mohan et al., 2018). Figure 1 shows a graphic of how the pressure sensors with FADS would lead to the air data parameter determination.

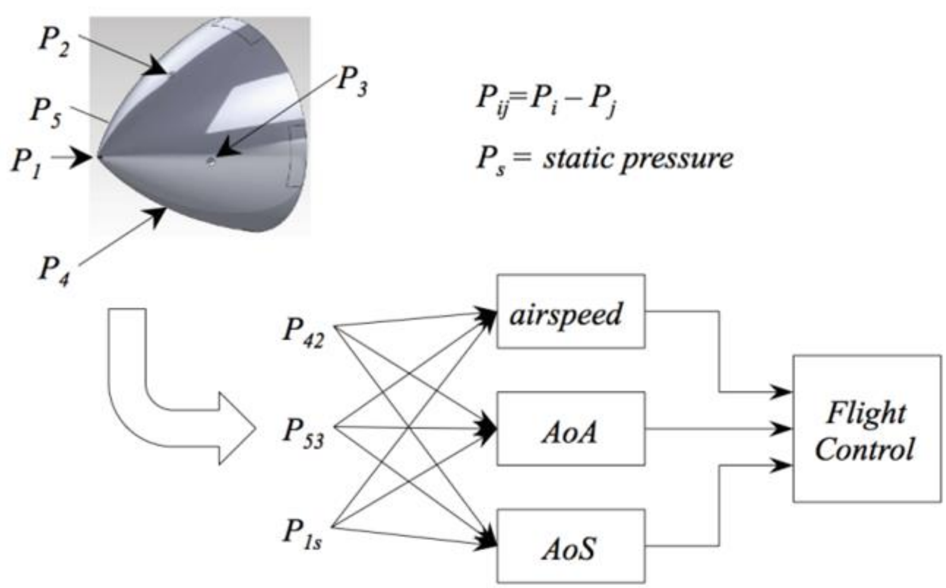

Figure 1: Flush Air Data Sensing System (Langelaan & Quindlen, 2013, p. 7)

Working with the Power, Thermal, and Environment subsystem, our team will determine whether collecting the necessary pressure measurements for the experiment would be possible using a FADS applicable system. Typically, FADS are used at lower altitudes than that of HEDGE at the point of data collection due to the decrease in pressure allowing noise to have a more significant effect on readings (Mohan et al., 2018). When the vehicle is in the lower-atmosphere portion of its re-entry, noise should not be a concern and FADS should be applicable. During the orbital and upper-atmosphere portions of reentry, HEDGE could use a celestial body sensor, likely a sun sensor due to weight and size constraints, for attitude determination. A sun sensor could measure the amount of sunlight absorbed on the spacecraft and determine its orientation relative to the sun (Gaebler, 2007). Another option would be to use magnetometers to measure the magnetic field of the Earth and determine the attitude (NASA, 2018). Based on the requirements for our attitude determination and pressure sensing, the team will choose how many pressure sensors to implement on the surface of the nose. The number of air parameters which must be derived relates to the number of sensors required (Mohan et al., 2018). Another consideration will be the tubing and type of sensors chosen, factors to be discussed with the Structures and Integration team and the Power, Thermal, and Environment team. Finally, our team plans to work with the Communications and Avionics and Software teams in planning how the pressure sensors will collect data and route it to our transmitting device.

Anticipated Outcomes for ADACS

The anticipated outcomes of the ADACS functional team are to find a predetermined orbit with a variable launch point via STK software, determine what specific hardware should be used for attitude and orbit determination, and prepare a critical design review (CDR) to submit for proposal. The predetermined orbit should be applied based on which launch vehicle the team uses and where the CubeSat is released in relation to the Earth. Currently, the launch site is undetermined, therefore orbit determination will have to use all known variables and make an estimation of the orbit that can be easily changed and used for a specific launch site. The specific hardware that will be used for the ADACS subsystem will depend on the team's budget, volumetric constraints, and the effectiveness of the hardware in the reentry environment. The CDR of the subsystem will be accomplished when the hardware is determined and tested on the spacecraft. The culmination of research and ADACS development along with all other subsystems will result in a critical design review and a technical paper in the form of a proposal to industry.

STS Topic

A simple bolt no larger than a quarter flying at 18,000 mph can leave critical life-threatening damage on the ISS or cripple home internet connection within seconds. Space debris is characterized as any man-made object that is no longer functioning or in use (O'Callaghan, 2019). The debris can range from something as small as a chip of paint or as large as a dead satellite. Much like a pandemic spreading across a nation, space debris can multiply with each piece carrying the capability to destroy and chip away at satellites in orbit to create increasingly more and more inert objects. The general misconception is that space junk is un-intentional, in some cases that is true, astronauts lose tools or rocket boosters explode but recently intentional military incidents can be attributed for the most significant spikes to the pollution population. Notoriously in 2007 China tested an anti-satellite ballistic missile striking down a decommissioned weather satellite. The test proved successful destroying the satellite into 3,000 pieces of debris large enough to be tracked and remain in orbit for decades (Weeden, 2010). In 2021 Russia performed a similar test creating 1,500 pieces of debris, both tests are suspected to have created hundreds of thousands smaller un-trackable pieces (Panda, 2021).

Now that the capability is present space has become a hostile domain with ample military and strategic targets, with tensions rising amongst nations it is not out of the realm to be facing looming attacks on GPS, missile detection, or communication satellites (Sonenshine, 2022). An imbalance has occurred as mutual assured destruction like that of nuclear war is not yet present in space. Motivating nations to exceed one another to gain control over all entities in space first and subsequently gain control over the ground components, as satellites are critically integrated into our day-to-day life (CSA, 2018). In attempts to prove superiority these tests have been conducted but at the risk of furthering pollution and the odds of retaliation. The orbital environment is paying the heaviest price which will be burdened onto the shoulders of future generations to navigate. In the end militaries will always act in the interest of the nation's security, and commercial entities will continue sending more missions into orbit (Boley, 2021), both creating tempting targets and increasing potential for collisions weather or not war were to break out. The inherent problem has now become one of sustainability and continued preservation of our orbits, a wicked problem.

Thomas Seager a professor in the school of sustainable Engineering at ASU defines wicked problem theory as an unsolvable ever-changing problem that has no clear timeline or direct solution (Seager, 2012). The problems exist with no precise answer only decisions can be made that can better or worsen the current status quo. Often environmental problems such as global climate change are characterized as wicked problems. Nuclear weapons due to the political influence and surrounding implications have led humanity past a point of no return, with no solution in sight to de-escalation due to its known presence and impact. Wicked problem theory receives criticism for its paradoxical approach and reliance of vague definitions to approach the problem. Catrien Termeer a public administrator at Wageningen University criticizes the theory in multiple facets. The first being that the approach has led to very little policy change as it essentially proposes no solutions that policy makers could act on, secondly little wins do exist within these complex problems, such as a direct extraction of one piece of space debris, contradicting the claim for no solutions, and finally that it forces extreme polarization when it comes to any policy enactment by either overestimating the issue or "paralyzing" any progress at all (Termeer, 2019). Despite its criticism, the theory helps frame complex issues across multiple stakeholders to highlight underlying problems to explain the visible symptoms and can help further other approaches when it comes down to policy.

Research Question and Methods

STS Research Question: How will the orbital environment be sustained into the future, when nations can receive a strategic advantage at the expense of increasing space debris, and what long term affects will the increase in debris cause to space operations and subsequently day to day life?

I will use wicked problem theory to analyze the relationships and unseen tensions between war faring nations involved in space, to provide information on the current impact of space junk, it's trajectory for growth, and frame the consequences if satellites are struck down and for the future of space as a human domain. In order to understand and articulate the current tensions and relationships between nations I will use case studies combined with wicked-problem framing as my two methods. Gathering information on past events through the lens of various nations to understand each perspective and how they relate or differ with one another to cause the unrest and continuing pollution. Keywords to conduct the research will include: Anti-satellite, space conflict, space junk, commercial satellite defense, sustainability in space, and mega-constellations. The collection of data will be used to inform and create policy going forward to slowdown and stop the production of space debris, in addition to drive funding for new technological efforts to collect space debris currently orbiting out planet.

In conclusion, HEDGE will serve as a contribution towards hypersonic research, acting as a proof of concept for in-expensive testing using orbital re-entry. In addition to providing a potential for valuable data collection on hypersonic behaviors and an official design review for proposal to industry buyers. Space debris will be analyzed as a product and consequence of the evolution of space as an international conflicting domain for military, social, and economic operations. Focusing on the sustainability of our orbits and future practice to propose possible solutions in both policy and technological efforts to de-pollute and maintain clear skies.

Resources

Boley, A. C., & Byers, M. (2021, May 20). *Satellite mega-constellations create risks in low Earth orbit, the atmosphere and on Earth*. Nature News. Retrieved November 4, 2022, from https://www.nature.com/articles/s41598-021-89909-7

Brockmann, K., & Schiller, M. (2022, February 4). *A matter of speed? understanding hypersonic missile systems*. SIPRI. Retrieved November 3, 2022, from https://www.sipri.org/commentary/topical-backgrounder/2022/matter-speed-understanding-hypersonic-missile-systems

Canadian Space Agency. (2018, February 8). *10 ways that satellites helped you today*. Canadian Space Agency. Retrieved November 4, 2022, from https://www.asc-csa.gc.ca/eng/satellites/everyday-lives/10-ways-that-satellites-helped.asp

Fleck, A., & Richter, F. (2022, September 22). *Infographic: Who's responsible for space junk?* Statista Infographics. Retrieved November 4, 2022, from https://www.statista.com/chart/28309/countries-creating-the-most-space-debris/

Gaebler, J. (2007). Coarse sun sensing for attitude determination of a CubeSat. University of Florida. https://ufdc.ufl.edu/AA00062245/00001/pdf

Gregersen, E. (2022, January 31). space debris. Encyclopedia Britannica https://www.britannica.com/technology/space-debris

Langelaan, J. W., Quindlen, J. F. (2013). Flush Air Data Sensing for Soaring-Capable UAVs. *American Institute of Aeronautics and Astronautics*.

https://www.aero.psu.edu/avia/pubs/QuiLan13.pdf

Mohan, N. & Jayakumar, M. & Sivamurugan, T. & Finitha, K.C. & Vidya, S.B. & Dhoaya, Jayanta & Remesh, Nayana & Mohan, Prasath & Krishna, Shashi & Sidhique, Aisha. (2018). Flush Air Data Sensing System. *Current Science*. 114. 68-73. 10.18520/cs/v114/i01/68-73.

NASA. (2021). 5.0 Guidance, navigation, and control. *NASA*. https://www.nasa.gov/smallsat-institute/sst-soa/guidance-navigation-and-control

NASA. (2018, September 4). Magnetometer (MAG). *NASA*. https://solarsystem.nasa.gov/missions/cassini/mission/spacecraft/cassini-orbiter/magnetometer/

O'Callaghan, J. (2019). *What is space junk and why is it a problem?* Natural History Museum. Retrieved November 4, 2022, from https://www.nhm.ac.uk/discover/what-is-space-junk-and-why-is-it-a-problem.html

Panda, A. (2021, November 17). *The dangerous fallout of Russia's anti-satellite missile test*. Carnegie Endowment for International Peace. Retrieved November 4, 2022, from https://carnegieendowment.org/2021/11/17/dangerous-fallout-of-russia-s-anti-satellite-missile-test-pub-85804

Sayler, K. M. (2022, October 3). *Hypersonic missile defense: Issues for Congress*. Retrieved November 4, 2022, from https://sgp.fas.org/crs/weapons/IF11623.pdf

Seager, T., Selinger, E., & Wiek, A. (2012). Sustainable Engineering Science for Resolving Wicked Problems. Journal of Agricultural and Environmental Ethics, 25(4), 467–484. https://doi.org/10.1007/s10806-011-9342-2

Sonenshine, T. D. (2022, August 2). *US-Russia tensions take orbit*. The Hill. Retrieved November 4, 2022, from https://thehill.com/opinion/international/3582689-america-and-russia-are-in-a-dangerous-space-and-not-alone/

Termeer, C. J., Dewulf, A., & Biesbroek, R. (2019). A critical assessment of the wicked problem concept: Relevance and usefulness for Policy Science and Practice. *Policy and Society*, *38*(2), 167–179. https://doi.org/10.1080/14494035.2019.1617971

Weeden, B. (2010). *SWF releases updated fact sheets on anti-satellite testing, rendezvous and proximity operations, and the X-37B.* SWF Releases Updated Fact Sheets on Anti-Satellite Testing, Rendezvous and Proximity Operations, and the X-37B | Secure World. Retrieved November 4, 2022, from https://swfound.org/news/all-news/2021/04/swf-releases-updated-fact-sheets-on-anti-satellite-testing-rendezvous-and-proximity-operations-and-the-x-37b