Undergraduate Thesis Prospectus

HEDGE: Hypersonic ReEntry Deployable Glider Experiment

(technical research project in Mechanical and Aerospace Engineering)

Norway's Remarkable Adoption of Electric Vehicles

(sociotechnical research project)

by

Desmond DeVille

November 1, 2021

technical project collaborators:

Emma Jensen
James Parker Johnson
Samantha Castro
Jashianette Fournier Jaiman
Cristina Rodriguez
Ryan Jansen
Michael Fogarty
Adam Obedin
Josh Willoughby
Jonathan Cummins
Eva Paleo
Brendan Angelotti
Maggie Che
Nicholas Lu

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.

Desmond DeVille

Technical advisor: Christopher P. Goyne, Department of Mechanical and Aerospace Engineering

STS advisor: Peter Norton, Department of Engineering and Society

General Research Problem

How can innovation in transportation systems be promoted?

Governments have long promoted innovation in transportation systems. For example, beginning in 1850, U.S. federal land grants subsidized railroad development. In the 20^{th} century, the early development of the jet aircraft required federal military contracts, and spaceflight was entirely paid for by public funds. In the 21^{st} century, the adoption of electric vehicles and the development of hypersonic systems also depend on government support. Vehicle emissions account for 29% of total U.S. greenhouse gas emissions (EPA, n.d.); reducing emissions is the primary way to combat climate change. Substitution of electric vehicles (EVs), and particularly battery electric vehicles (BEVs), for combustion-engine vehicles can markedly reduce the total CO2 emissions attributable to road transport. Financial incentives, changing social norms, and regulations have been used to promote the adoption of BEVs and deter consumption of fossil fuels. Countries that have succeeded in adopting EVs can serve as valuable examples to other countries seeking to promote EV adoption. Among these examples, Norway is the leader. Government policy helped Norway become the first country in the world in which sales of new EVs exceed sales of new combustion-engine vehicles. In other countries, development of hypersonic systems also requires government effort. The United States, Russia and China are seeking to develop weapons capable of hypersonic speeds (Mach 5: ~3840 mph at sea level; Stone, 2020). Development of hypersonic systems requires testing, but for hypersonic systems, earthbound testbeds are extremely difficult and expensive to build and operate. Yet tests in low earth orbit could yield valuable results at much less cost.

Hypersonic Flight Glider Experiment using a CubeSat Platform[1]

What is the feasibility of engineering CubeSats for spacefaring experiments involving sustained hypersonic glider flight?

Problem Statement[2]

Hypersonic flight occurs at speeds exceeding five times the speed of sound and is an expanding research field in the aerospace industry with military and civil applications. Military applications include hypersonic missiles, both offensive and defensive, and high-speed aircraft. Civil applications include access to space and commercial air travel. A CubeSat is a small satellite flown in low earth orbit that is well suited for undergraduate education. As CubeSats orbit Earth, they fly at hypersonic speeds and re-enter the atmosphere in around five to seven days if launched into Extreme Low Earth Orbit (ELEO) (Panwar & Kennewell, 1999). Once objects re-enter the atmosphere, they can prolong hypersonic flight if measures are taken to reduce drag.

This technical project will assess the capability of a CubeSat to house a hypersonic glider flight experiment. These experiments are difficult to replicate in wind tunnels and expensive to achieve on rockets and aircrafts. By using a CubeSat, university students may be able to conduct these experiments at a lower cost, and with greater accessibility. The following discusses a mission proposal for a hypersonic glider CubeSat and outlines the significance, objectives, approach, resources available, and anticipated outcomes for the mission.

---

[1]This technical portion of the Prospectus was co-written with the other members of my capstone group in MAE 4690. The final draft of this technical portion was submitted to Professor Christopher Goyne on October 27. This section is a direct copy of that submission.

[2]Professor Christopher Goyne specified the outline for this portion of the Prospectus. The italicized text in this section denotes a change in subsection.

Significance of the Problem

Some current United States Weapons systems being developed include the Air-Launched Rapid Response Weapon (ARRW), Intermediate Range Conventional Prompt Strike (IRCPS), Long-Range Hypersonic Weapon (LRHW) and unmanned hypersonic aircraft. However, conducting these large scale projects is expensive and time consuming (Bentle, 2021). By conducting this research experiment on a hypersonic glider utilizing a CubeSat, data collection will be cheaper, faster, and more accessible. Having undergraduate students conduct the research experiment will provide them with the knowledge base to directly enter the hypersonics workforce. Additionally, further understanding of hypersonic flight may lead to advancements in commercial aircraft and spacecraft. Hypersonic aircraft would greatly decrease travel time, while hypersonic spacecraft would provide greater accessibility to space travel. Flight data collected from CubeSat research will provide hypersonics researchers and professionals with information to help advance hypersonic flight, ultimately making it more accessible to the world.

Objective of the Research Work

As previously described, the aim of this research work is to perform a hypersonic experiment using a test article deployed from a CubeSat in Extreme Low Earth Orbit (ELEO). As can be seen in Table 1, this goal has been discretized into three primary objectives, which are motivated by a combination of technical and educational considerations. These have been further subdivided into supporting objectives intended to facilitate the completion of these larger goals. Upon project completion, the fulfillment of these objectives will be used to gauge mission success.

Table 1. Labeled Research Objectives

O1	**Demonstrate the feasibility of CubeSats as a platform for hypersonic glider flight research.**
1.1	Design a CubeSat-based system that can survive the environment of launch and insertion into extreme low earth orbit (ELEO)
1.2	Deploy gliding hypersonic test article from the system
1.3	Maintain stable flight at hypersonic speed for maximum possible duration
1.4	Collect/transmit mission data from test article during hypersonic flight
1.5	Prevent any large fragments from reaching Earth's surface
O2	**Show that undergraduate students can conduct hypersonic glider flight experiments at lower cost and with greater accessibility.**
2.1	Minimize cost by using commercially sourced components and a student workforce
2.2	Deploy a successful experiment designed by undergraduate researchers
O3	**Provide an opportunity for undergraduates to gain hands-on experience and generate interest in the spaceflight industry.**

Approach to the Problem

The process of planning for and designing the hypersonic glider space mission will be completed within the Mechanical and Aerospace Engineering department's Spacecraft Design course advised by Professor Christopher P. Goyne at the University of Virginia (UVA) over the course of the next two years. The students in this course are divided into two groups of fifteen members. This document is the prospectus of one of these teams, which is tasked with designing a hypersonic glider using the CubeSat platform. Each team is subdivided into five functional teams: Communications; Software and Analysis; Power, Thermal, and Environment; Attitude Determination and Control System (ADACS) and Orbits; and Structures and Integration. These component teams are all together led by one project manager.

Table 2. Brief Timeline

Phase		End Defined By	Duration
Concept Exploration		Finalized Prospectus End of Semester Presentation	Fall 2021
Detailed Development	Risk Reduction/Technology Development	Initial Design Proposal Submission	Spring 2022
	Detailed Design	Finalized Design Proposal Grant Proposals Submitted	Fall 2022
Production and Deployment	Production	Final CubeSat Testing Ship to Launch Site	Spring 2023
	Launch	Lift-Off and Arrival in VLEO	Summer 2023
	On-Orbit Check-Out and Transfer to Operational Orbit	Start of operations	~ 1 week of orbit
Operations and Support	Operations and Disposal	Re-entry	~ 1 week

Over the course of the fall and spring semesters of the first year, the class will go through conceptual and preliminary design. Each phase will be concluded with a design review. The design will be finalized in the fall of the second year, after which system manufacturing and integration will occur, followed by subsystem testing. The anticipated mission launch date is the Summer of 2023. The flight during the mission will be monitored, and after the mission is concluded, there will be post-flight analysis of the data collected. This timeline is summarized in Table 2.

It is anticipated that this CubeSat system will be launched onboard a Northrop Grumman (NG) Antares rocket and deployed from its second stage into Extreme Low-Earth Orbit (ELEO).

Technical solutions will be developed by the subsystem teams to meet functional and technical constraints and requirements developed during the Space Mission Engineering Process.

Available Resources

For the design and construction of the project, the team is provided with resources such as industry experts, sponsors, and available facilities. Team advisor, Chris Goyne, alongside additional faculty support from University of Virginia provides invaluable knowledge and guidance to the team during the conceptual design of the project. The Federal Communications Commission (FCC) will also be consulted for additional guidance on requirements and regulations on communication with the CubeSat. Two key sponsors for the team include the National Aeronautics and Space Administration (NASA) for funding of the fabrication and testing of the team design as well as providing the launch site, Wallops Flight Facility, and Northrop Grumman for providing the Antares launch vehicle (Clark, 2021). The launch profile will be dependent upon Antares concept of operations as shown in Figure 1. The profile is important to consider as the CubeSat is attached to the NG Antares Rocket. Lift off, separation, frame deployment, and reentry into orbit are its main stages. As shown in the figure, around nine minutes after lift off the CubeSat will be released into orbit for five to seven days after which it will reenter the atmosphere.

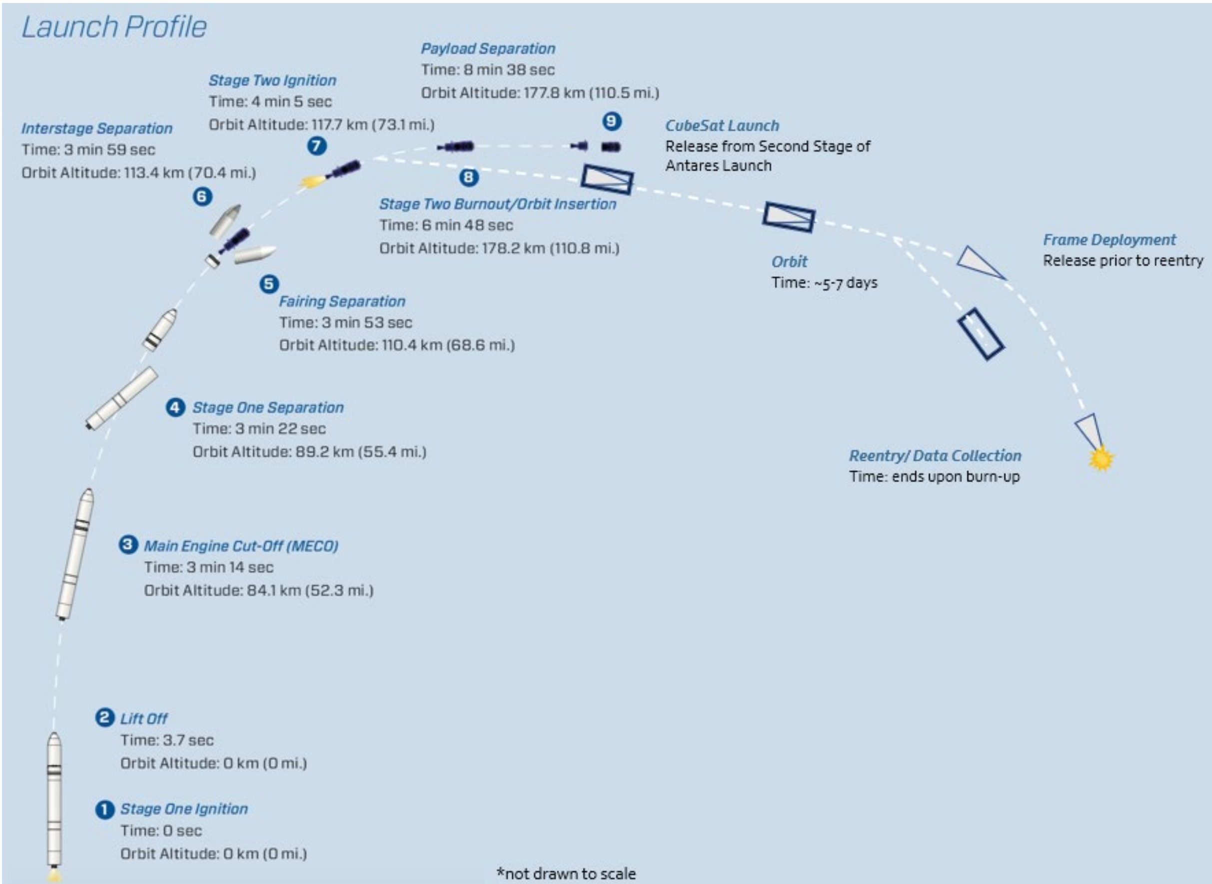

Figure 1. Diagram of Concept of Operations for CubeSat Launch to Reentry (Adapted from Clark, 2021)

Additional resources provided by the University of Virginia include lab spaces and testing equipment in the School of Engineering as well as student experimental facilities providing mechanical manufacturing capabilities and machinery for construction of future prototypes. Available labs include Lacy Hall, the mechanical engineering building basement, and the Architecture School Fabrication Lab. Group project grant funding from the University of Virginia is under consideration for additional funding of the project.

Anticipated Outcomes

Secured government funding and sponsors (UVA, NASA, etc.) will enable the construction of a CubeSat which utilizes the Space Mission Engineering (SME) process to satisfy mission objectives. By demonstrating the feasibility of CubeSats as a platform for hypersonic glider flight, this project will introduce a new method for conducting low-cost hypersonics research in conditions unachievable on the ground. The project will rely on several mission-critical events occurring: the successful deployment of the CubeSat and hypersonic glider, the stability of the glider during flight, and data being relayed during reentry. Ideally, the data will show a longer time in orbit than a typical CubeSat design due to the decreased drag on the test article with stable hypersonic flight conditions. The collected flight data will be transmitted to partner organizations.

Drafting for the funding proposal, designing the CubeSat and deployable glider, and working with government organizations will result in an optimal learning environment for all undergraduate students involved. Such an environment, which requires substantial writing, design, and communication skills will lead to increased knowledge and improved abilities of participating students. Professional relationships will be established with University of Virginia faculty and government organizations for future collaboration. Additionally, through demonstrating undergraduate students' capabilities of conducting these experiments, it is hoped that prospective students take ongoing interest in future aerospace research.

Type of Technical Paper

The final paper will be a mission proposal to the project coordinators, Professor Goyne and the University of Virginia detailing our plan for a hypersonic glider vehicle experiment using a CubeSat for submission to NASA and the DoD for funding.

Conclusion

Through this project, the turbulent conditions of hypersonic flight will be captured at a low cost providing important and limited information to the aerospace industry. Within this industry, the captured data has considerable implications for military and commercial aircraft and spacecraft. The team will finish the Concept Exploration phase of the project this semester and continue with the Detailed Development phase next semester. The project team is well-prepared, knowledgeable, and enthusiastic for the design process and continued application of space engineering principles.

Norway's Remarkable Adoption of Electric Vehicles

Since the 1990s, how has the Norwegian Parliament driven Norway's wide-scale adoption of EVs?

Overview

The methods enabling our current lifestyle are putting it and the planet in jeopardy. Vehicle emissions comprise 29% of total greenhouse gas emissions in the U.S. (EPA, n.d.) and to discontinue our carbonization of the atmosphere, a major step is switching to electric vehicles (EVs). Norway is leading the push towards a fully electric automobile market. Although it is one of the world's leading exporters of oil per capita (EIA, n.d.), new EV sales in Norway now account for about 54% of all vehicle sales (Norsk elbilforening. 2021). In Norway, the parliament and the Ministry of Climate and Environment promoted the proliferation of charging stations; tax incentives ensured that EVs became cheaper than gasoline cars (Bellona, 2015; Lewis, 2018). Publicity stunts by popstars helped too.

Prior Research

Researchers have investigated Norway's EV success. Ingeborgrud and Ryghaug (2019) contend that "…there are practical as well as symbolic dimensions that are important for BEV adoption." Through interviews and polls conducted in 2013 and 2015, Ingebrogrud and Ryghaug found that the top reasons for buying an EV included practical advantages (low operating costs, free toll roads and competitive pricing) and symbolic advantages (the environmental benefits). The practical advantages were due to Norway's policy innovations.

Noel et al. (2018) found that while many EV drivers in Norway reported little or no range anxiety (Ryghaug& Toftaker, 2014), range is important to rural drivers. One driver said: "Running out of gas is almost impossible. And running out of electricity is actual possible" (Noel, et. al, 2018).

Burs, et. al (2020) classified BEV owners as "Utilitarian Savers" seeking to save money on fuel, taxes, or tolls; "Performance Seekers" seeking driving pleasure or exhilaration; and "Green Technologists" who purchase EVs for their environmental benefit.

Orlov & Kallbekken (2019) sought correlations between consumers' attitudes about energy efficiency and their chosen vehicle type. Though they found no significant correlation, they concluded that a "willingness to take a change on new technologies to reduce energy consumption could significantly increase the likelihood of owning an EV" (Orlov & Kallbekken, 2019).

Comparatively evaluating incentives, Bjerkan et al. (2016) found that financial incentives such as purchase taxes were the most important overall. Nevertheless, for drivers facing city traffic or tolls, especially in Oslo and Trondheim, incentives such as bus lane access and toll exemptions were decisive. Drivers' priorities varied by income: "When purchase costs of a BEV and an ICEV are similar, low-income groups might more than other groups favor the alternative which also reduces use costs." (Bjerkan et al., 2016).

Participants

Participants include Norway's EV drivers (Haugneland & Kvisle, 2015), who directly contribute to EV adoption. Internal Combustion Engine (ICE) car drivers (Egbue & Long, 2012) are presumably still deterred by range anxiety, cost, or other factors.

The Energy Administration in Norway, a coalition of five government ministries, is responsible for the national energy grid, which is 98% renewable energy (MPE, 2016). Norway's Oil and Gas Industry, a component of the Energy Administration, supports further development of fossil fuels (MPE, 2021). This presents Norway's dilemma: the funds that support vehicle electrification come from oil exports. Norway's Minister of Petroleum and Energy from 2020 to 2021 claimed: "Retaining expertise and technologies in the oil and gas sector is … vital for the development of new industries and technologies" (MPE, 2021). The Energy Administration also includes the Ministry of Climate and Environment, which is responsible for "ensuring integrated governmental and environmental policies" (MCE, n.d.).

The Norwegian Electric Vehicle Association (Norsk elbilforening: NEVA) is a trade association representing BEV interest groups. On Twitter, NEVA stated: "Electric car[s] should be for everyone, but we are not quite there yet" (NEVA, 2021). The Bellona Foundation is an international environmental NGO based in Norway. It has stated: "Pollution knows no borders, thus Bellona is working with and against anyone and everyone relevant to our work" (Bellona, n.d.). The Norway Automobile Federation (Norges Automobil-Forbund: NAF), an association of Norwegian drivers, represents drivers' interests and provides services to drivers (NAF, n.d.).

References

Bellona (2015, March). Electric Vehicles: The Norwegian Experience. https://bellona.org/assets/sites/4/BellonaBrief_EV-Norwegian-Success-Story.pdf.

Bellona (n.d.). The Bellona Foundation. https://bellona.org/.

Bentle, R. (2021, September). *Strategy at Mach 5: Hypersonic Weapons in Chinese Military Strategy*. Air University: https://www.airuniversity.af.edu/Wild-Blue-Yonder/Article-Display/Article/2771133/strategy-at-mach-5-hypersonic-weapons-in-chinese-military-strategy/.

Bjerkan, K. Y., Nørbech, T. E., & Nordtømme, M. A. E. (2016). Incentives for promoting Battery Electric Vehicle (BEV) adoption in Norway. *Transportation Research Part D: Transport and Environment*, *43*, 169–180.

Burs, L., Roemer, E., Worm, S., & Masini, A. (2020). Are They All Equal? Uncovering Adopter Groups of Battery Electric Vehicles. *Sustainability*, *12*(7).

Cal Poly. (n.d.). *CubeSat Design Specification Rev. 13*. 42. https://static1.squarespace.com/static/5418c831e4b0fa4ecac1bacd/t/56e9b62337013b6c063a655a/1458157095454/cds_rev13_final2.pdf.

Clark, S. (2021, February 20). *Antares launch timeline on the NG-15 mission*. Spaceflight Now. https://spaceflightnow.com/2021/02/20/antares-launch-timeline-on-the-ng-15-mission/.

Egbue, O., & Long, S. (2012). Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. *Energy Policy*, *48*, 717–729.

EIA (n.d.). U.S. Energy Information Administration. Independent Statistics and Analysis. International. https://www.eia.gov/international/overview/country/NOR.

EPA (n.d.). U.S. Environmental Protection Agency. Sources of Greenhouse Gas Emissions. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

Haugneland, P, & Kvisle, H.H. (2015, April 10). Norwegian electric car user experiences. *International Journal of Automotive Technology and Management 15(*2): 194-221.

Ingeborgrud, L., & Ryghaug, M. (2019). The role of practical, cognitive and symbolic factors in the successful implementation of battery electric vehicles in Norway. *Transportation Research Part A: Policy and Practice*, *130*, 507–516.

Lewis, M. (2018, Dec. 19). Norway sees boom in electric cars, fueled by the Government. AP News. https://apnews.com/article/business-technology-europe-china-climate-7fdc039fee6c4c62bdc76054972a2e03.

MCE (n.d.). Ministry of Climate and Environment. About the Ministry. https://www.regjeringen.no/en/dep/kld/about-the-ministry/id673/.

MPE (2016, May 11). Ministry of Petroleum and Energy. The Energy Administration in Norway. https://www.regjeringen.no/en/topics/energy/renewable-energy/the-energy-administration-in-norway/id2340332/.

MPE (2021, June 11). Ministry of Petroleum and Energy. Government publishes White Paper on long term value creation from Norway's energy resources (press release). https://www.regjeringen.no/en/aktuelt/regjeringen-legger-frem-stortingsmelding-om-verdiskaping-fra-norske-energiressurser/id2860271/.

NAF (n.d.). Norges Automobil-Forbund. https://www.naf.no/.

NEVA (2021, April 14). Norsk elbilforening. (2021, April 14). Elbil skal være for alle … . Twitter.

NEVA (2021, Sep. 16). Norsk elbilforening. Norwegian EV policy. https://elbil.no/english/norwegian-ev-policy/.

NEVA (2021, Sep. 16). Norsk elbilforening. The Norwegian Electric Vehicle Association. https://elbil.no/english/about-norwegian-ev-association/.

Noel, L., de Rubens, G. Z., Sovacool, B. K., & Kester, J. (2019). Fear and loathing of electric vehicles: The reactionary rhetoric of range anxiety. *Energy Research & Social Science*, *48*, 96–107.

Orlov, A., & Kallbekken, S. (2019). The impact of consumer attitudes towards energy efficiency on car choice: Survey results from Norway. *Journal of Cleaner Production*, *214*, 816–822.

Panwar, R., & Kennewell, J. (1999). *Satellite Orbital Decay Calculations*. Australian Government: Bureau of Meteorology. https://www.sws.bom.gov.au/Category/Educational/Space%20Weather/Space%20Weather%20Effects/guide-to-space-radiation.pdf.

Ryghaug, M., & Toftaker, M. (2014). A Transformative Practice? Meaning, Competence, and Material Aspects of Driving Electric Cars in Norway. *Nature and Culture*, *9*, 146–163.

Stone, R. (2020, Jan. 8). "National pride is at stake": Russia, China, United States race to build hypersonic weapons. *Science*.