Undergraduate Thesis Prospectus

Safe, Simple, and Efficient Rocket Motor: Designing an Efficient Hybrid Rocket Motor

(technical research project in Aerospace Engineering)

The Struggle Over the Future of Nuclear Energy in Virginia

(sociotechnical research project)

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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General Research Problem

How can the energy efficiency of human activity safely be improved?

The need for increased energy efficiency is evident in the increasing energy demand described in a statement from the International Energy Agency (IEA), warning that "world electricity consumption is forecast to increase at a much higher pace in 2024, with growth set to reach 4% – the highest rate the world has seen since 2007, barring the exceptional rebounds in 2010 after the financial crisis and in 2021 following the Covid-19 pandemic demand collapse" (IEA, 2024). These increases are also reflected in the fact that "energy-related greenhouse gas emissions also reached a record high [in 2023], exceeding 40 GtCO2 for the very first time" (Energy Institute, 2024). According to the Intergovernmental Panel on Climate Change (IPCC), this trend must be flipped by "striking different balances between lowering energy and resource intensity, rate of decarbonization, and the reliance on carbon dioxide removal" (IPCC, 2024) to limit severe global warming.

Designing a thrust-optimized hybrid rocket motor

How can the safety of rocket motors be increased without sacrificing efficiency or increasing complexity?

Through this mechanical and aerospace engineering capstone project, with technical guidance from Dr. Chloe Dedic and Dr. Daniel Quinn, the team will design a hybrid rocket motor with the goal of building and static testing it. One important and unique aspect of this project is that it involves combustible materials making student safety a central focus of the whole process. Developing safe and efficient rocket motors is essential even if space exploration is not. Many technologies that society depends on including GPS, weather forecasting, and communications are made possible by the ability to transport objects into space. Rocket motor failures are extremely costly exemplified by an event in 2016 in Cape Canerval, when "a Falcon 9 rocket and its $200 million AMOS 6 satellite payload were destroyed during a propellant loading and hot fire test " (NASA, 2018). Space launch failures occur frequently with 41.3% of small satellite launches failing between 2000 and 2016 (Jacklin, 2019). Efforts should be made to reduce the likelihood of these costly failures.

Currently, most commercial rocket motors are powered by solid or liquid propellant. Solid rocket motors are relatively simple and reliable in the absence of defects. They are powered by the combustion of a solid fuel grain composed of fuel and oxidizer mixed. Once combustion begins, it cannot be stopped or controlled, and it has a relatively low specific impulse: the relationship of propellant mass to impulse. Safety risks are high given that on top of the lack of control, "the presence of cracks and voids in the propellant will cause excessive combustion at the crack and void locations, resulting in local over temperature at these locations and can cause catastrophic failure" (Deswandri, 2023). Liquid propellant motors have a much higher specific impulse and can be stopped and restarted. They are powered by the combustion of both liquid fuel and oxidizer as they are injected into the combustion chamber. Complex plumbing systems introduce the propellants at high pressures and in specific ratios into the combustion chamber. These complex assemblies represent many modes of failure and high cost. These risks and shortcomings leave the door open for improvements.

Hybrid propellant motors balance benefits from solid and liquid motors without suffering from the same safety risks by having a solid fuel grain and liquid oxidizer. While developing a hybrid rocket fuel David L. Dean observed standard propellants and found solid propellants produce ~263 sec and liquids produce ~304 sec while hybrids produce ~299 sec of specific impulse (1995). Hybrid motors produce nearly the specific impulse of liquid motors while eliminating the complex plumbing system required by the liquid fuel. While producing a greater specific impulse than solid motors, they can also be controlled via the mass flow rate of the liquid oxidizer. The capstone team will seek to maximize combustion efficiency by using methods enabled by new additive manufacturing of ceramics. These methods will allow the manufacture and testing of geometrically complex injectors and fuel grains to fine-tune the interaction between fuel and oxidizer. Success in this project will validate novel testing methods and provide efficiency improvements. These improvements will aim to increase the viability of hybrid rocket motors for space launches.

The Struggle over the Future of Nuclear Energy in Virginia

How have policymakers, energy companies, and environmentalists competed over the extent nuclear energy is developed and used in Virginia?

Divergent interests, environmental values, and perceptions of public safety divide social groups' positions on nuclear power, and can turn allies into adversaries. Some environmentalists favor it as an alternative to fossil fuels global warming, but others consider nuclear power an environmental hazard. Virginia has faced this complex nuclear issue head-on since, as Rassenfoss explains, "the United States' largest uranium deposit [was discovered] in Coles Hill, Virginia in the 1970s" (2020). In 1982 Virginia's General Assembly voted to institute a moratorium on uranium mining in the state, substantially on environmental grounds. Within the same decade, however, in "1972 – Surry [Nuclear] Power Station is Commissioned in Surry County, Virginia" (VNEC, 2024). Fifty years later in 2022, nuclear power supplied 31% of

Virginia's total in-state electricity generation (U.S. EIA, 2024). Plans have been made to increase this percentage even more (Virginia Energy, 2024). However, many citizens are uncomfortable with the government and energy companies making these plans without their input. How has nuclear energy steadily increased in use despite opposing opinions and public uncertainty?

Researchers have investigated this situation in Virginia and elsewhere. In their research of Southwest Virginia residents' position on nuclear energy developments, Gurley (2023) observed that "the residents of coal country who have borne those environmental and social burdens for decades are now faced with another extractive scheme" and are not happy about it. The citizens express sentiments consistent with the social concept titled "not in my backyard syndrome" (NIMBY) making the research of Uji, A (2021), on how NIMBY syndrome affects support for nuclear power in Japan, relevant. Surprisingly, they found that even though "Nuclear energy is often portrayed as a victim of the NIMBY syndrome… low-income people actually support restarting nuclear reactors when they live in proximity to a nuclear plant" when local economic and health benefits are highlighted and contrasted against coal plants. Schmid (2018) performed research "on the role of scientific authority, and of institutional inertia, for dealing with the fundamental challenges posed by the Chernobyl accident and the disintegration of the Soviet Union." He found that people's tendency toward the NIMBY syndrome can be reversed if "nuclear energy fits the mold of a socially transformative technology."

Influential participants exist in the state government, the energy industry, environmental groups, citizen groups, and academia. Given the $3.9 billion (EIA, 2012) spent by Dominion Energy, Virginia's primary energy provider, to build the North Anna Nuclear Power Plant, this issue requires substantial financial participation from utility providers. Voicing their stance that, not surprisingly, supports this colossal investment, Dominion Energy states on their website "Nuclear energy is by far America's largest source of clean, emission-free electricity" (Dominion Energy, 2024). Helpful insight is gained by observing responses to Dominion's effort, over the fourteen years from 2003 to 2017, to acquire a license to build a third unit at Lake Anna and their subsequent hold on the project (U.S.NRC, 2024). The executive director of the Chesapeake Climate Action Network and a critic of nuclear power plant development, Mike Tidwell said "Dominion is clearly realizing its bet on more nuclear in Virginia was a colossal mistake and waste of ratepayer subsidies" (Pierobon, 2017). The Virginia Chapter of the Sierra Club has voiced safety concerns for the project. Their nuclear issues chair, Erica Gray, pointed out that "this reactor would be built on an existing fault line… Additionally, it is a new reactor design that has never been built and operated commercially" (SCVC, 2024). This concern led to the formation of a new alliance, named "Not on our Fault Line" echoing the NIMBY idea, devoted to opposing the construction of the third unit (SCVC, 2024).

As momentum lessened for projects on the scale of the North Anna Unit 3, attention has turned to small modular reactors (SMRs). Governor Youngkin's office and the general assembly have participated in this shift by creating "the Virginia Power Innovation fund and the Virginia Innovative Nuclear Hub to support the efforts to bring SMRs to the Commonwealth" (Virginia Energy, 2024). Governor Youngkin also stated that he would focus on "embracing an all-of-the-above energy plan that includes natural gas, nuclear, renewables and the exploration of emerging sources to satisfy the growing needs of Commonwealth residents and businesses" (Governor of Virginia, 2022). In their plan, the Office of the Governor says it "supports funding to initiate the goal of deploying a commercial SMR in Southwest Virginia within ten years" (2022).

Several citizen groups in Southwest Virginia do not share the same level of enthusiasm as the Governor. The president of Southern Appalachian Mountain Stewards, responded to the plan by saying "If those living in our communities are excluded from decision-making about our future, how can we be expected to trust and accept the choices foisted upon us from Richmond and beyond?" (Radmacher, 2022). The president of the Clinch Coalition, Sharon Fisher, voiced her frustration that "[The governor] came, announced it, and said we're doing it" without engaging at all with those it would affect (Gurley, 2023). Well-funded powers like the Virginia Nuclear Energy Consortium which "was created to represent stakeholders invested in the development of nuclear energy" (VNEC, 2024), pose stiff opposition to small groups like the Clinch Coalition. This consortium includes members Dominion Energy, Holtec International, Newport News Shipbuilding, the University of Virginia, and others with the shared goal of promoting nuclear energy. This issue continues to develop and has far-reaching implications for the future of Virginia and relations between its citizens and government.

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