AIAA 2022-2023 UNDERGRADUATE HYBRID ELECTRIC REGIONAL TURBOPROP

A DISCUSSION ON ENGINEERING ETHICS ON RENEWABLE ENERGY-BASED TECHNOLOGIES

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 Aerospace Engineering

By
Eun Soo Park
Fall 2022

Technical Team Members

James Caputo, Darius Espinoza, Jannik Gräbner, Ryan Grant, Ryan Keller, Kangyi Peng, Alexander Poley, Alex Wang

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
Jesse Quinlan, Department of Mechanical and Aerospace Engineering
Kent Wayland, Department of Engineering and Society

Prospectus Introduction

Aircraft design consists of a multidisciplinary optimization problem. The weight, propulsion system, specific fuel consumption and sizing are priority considerations regardless of the aircraft's purpose. The consideration of materials and stress analyses cannot be ignored with respect to the economic and physical cost in designing an aircraft purposed for mass-production and implementation. The aircraft, then, transforms into a network of branching systems with either technical or socio-economic factors.

The standard role and expectation from engineers are the development of technology that improves some function of society. The technologies developed by engineers conform to this standard of belief, be it for the advancement of the society's militaristic, technical, or economic prowess. The societal benefits received then rebound into shaping the future directive of the produced technology. It is entirely possible that the technologies demanded by societal institutions are flawed or are contradictory in nature; in the case of the hybrid-electric turboprop aircraft, the technical concept is rooted in the ideals of "green renewables" that have been demonstrably proven their ineffectiveness in replacing or even replicating the energy densities of conventional sources, and in most cases, directly contradicting the ideologies behind their creation. Technologies that are contradictory to their intended purpose such as the hybrid-electric turboprop bring for the following question: how does the ethical responsibilities and obligations of the engineer change in the face of a technology that fails to complete its socio-technical objective?

Throughout this semester, a course on engineering ethics is being taken alongside the progression of the academic research study, which will help stimulate the conflict of this ethical dilemma that is faced by many scientists and engineers daily and is now being faced personally a hybrid-electric aircraft. Further investigation into this complex problem can provide insight to all sides of the argument and help understand how this large system impacts the way engineers view their ethics, as well as their role in society in the face of self-destructive technologies.

Technical Introduction

Can a commercial, regional-distanced turbo-propeller aircraft be designed with a hybrid-electric drive or power system?

The technical problem is structured around the design of a regional turboprop operating on a hybrid-electric powertrain or propulsion system and serves as an academic research study. A turboprop, or turbo-propeller aircraft is defined as an aircraft reliant on a turbine engine driving a propeller shaft. Aircraft designed around the turboprop specialize on fuel consumption efficiency and observes most use in regional airlines and short-ranged flying specifications.

Propeller-based propulsion systems are heavily limited by the lack of thrust provided with respect to modern propulsion systems. Designing an aircraft with such a system must optimize for either payload capacity or design range. For the academic project, the American Institute of Aeronautics and Astronautics (AIAA) released a Request for Proposal (RFP), requesting for a specialized turboprop design on a hybrid-electric basis on either propulsion or powertrain system, constrained to further specification requirements. The RFP takes the form of a general engineering design competition. The author, along with 8 other undergraduate students, will work throughout the school year to submit a final design proposal to the AIAA for review. The cumulative aircraft design, by the minimum requirements raised by the RFP must be capable of transporting 50 passengers and 3 crew at a design range of 1000 nautical miles. A 20% block fuel reduction must be attained for short-range mission design – within the range of 400 nautical miles and reserve mission analyses at a target speed within 276-350 knots. Additionally, the aircraft must meet one-engine inoperative, climb gradient, and flight quality certification under 14 CFR Part 25. Most importantly, the aircraft must be designed with technologies with an intended entry-of-service (EIS) of 2035. To simplify, the aircraft must fly 20% more efficiently than currently existing turboprop aircraft, must run on some renewable energy system – batteries, generators, et cetera – and be economically and technologically comparable to conventional fuel-powered aircraft on a 1000 nautical mile design range.

The first and foremost assessment of the submitted design adheres to the Technology Readiness Level (TRL) defined by the NASA institute; the TRL of any given technology serves as a rudimentary assessment of its technical maturity and readiness to be supplied to the market or industry. Common thresholds of the TRL refer to the conceptual, preliminary, trial, and revision phases of the design. The conceptual phases of the design correspond with a TRL of 1-2. TRLs 2-4 are occupied by the conceptual derivations and mathematical modeling of the design concept to verify technical consistency with known theory, and TRLs 5-7 represent the application of theoretical modeling into practical design. TRLs 8-9 correspond to the final revisions and “completion” of the technology, suggesting little adverse economic effect or technological failure; NASA has defined the EIS qualifications of their RFPs to be at the TRL 7 stage at minimum. That is, the aircraft design consolidated by the RFP must have a projected research and development timeline that assumes at least a TRL 7 by the year 2035. Technological trends of materials and technologies related to the materials and energy development sectors determine the concept to TRL 7-9 as an approximate period of 7-10 years; as such, the turboprop design must rely on technologies available almost exclusively before the 2027, especially for power-train subcomponents including the battery and transmission cables.

There is no finalized, TRL-9 classification-based hybrid-electric turboprop is in existence that could be utilized as reference material. Currently existing, gas-powered turboprops such as the ATR-42-

600 and the DHC-8-Q300 can be utilized for reference of their aerodynamic design and aeroelastic properties to shorten the initial iterative design process. The pre-preliminary, conceptual design configurations have been completed at this stage including concept down-selects, trade studies, and concept ideation of possible turboprop configurations. Initially selected aircraft configurations are then to be analyzed comparatively with respect to a reasonable mission sizing configured for commercial air transport. Geometric and aerodynamic analyses will be conducted via the use of computational software including the Flight Optimization System (FLOPS) to optimize the wing structure, propulsion arrangement and weight sizing. By the end of the academic year, the completed design should be an outline for a fully functioning and capable aircraft and will be submitted to the AIAA competition to be reviewed and judged against other submissions.

Conceptual STS Framework and Literature Review

What are the ethical problems faced by engineers working on technological systems contradictory to their purpose? Who is to take responsibility?

Engineers in the United States adhere to the codes of conduct and guiding protocols defined within the Society of Professional Engineers (NSPE) Code of Ethics. Among are the core tenets of honesty, impartiality, fairness, equity, and dedication to the protection of the public health, safety, and welfare. Engineers must not only perform under a standard of professional behavior that requires adherence to the highest principles of ethical conduct (National Society of Professional Engineers, 2019), but also make known to their employers or clients of any deceptive elements or practices made known to their notice. Extensions to the notion of engineering ethics have been raised by several researchers; namely, Stephen Undger's argument in his book titled *Controlling Technology: Ethics and the Responsible Engineer,* argues for the expansion of engineers' responsibility to not just the development and implementation of technology but in addition the outcome of the use of technology itself (Unger, 1994).

Technological systems are deeply integrated into societal systems and contribute a significant role in the agencies of socio-political actors. They are then subsequently bound by a mutual technical and social purpose or obligation to fulfill by their implementation by society. The obligations binding technological systems brings for the question – what happens when the socio-technical obligations of the system are not fulfilled, cannot be fulfilled? Who and to what extent assumes responsibility for the failure? And of the engineer?

There are multiple possibilities in which a technological system can fail to support or uphold its socio-technical obligations. The technology could be lacking in development and maturity, or perhaps a mishandling of its implementation. The strife of politics and social activisms can introduce interference and deter proper handling of the technological system, or more importantly, the technology itself is fundamentally incapable of delivering upon the societal obligations imposed upon its design. An easy-to-spot example is the renewable energy system.

The renewable energy system was initially proposed to be the modernized, sophisticated alternative to the traditional combustible fuel technological system. No longer would the world be shackled by the infamous environmental disasters caused by the direct conversion of combustible fuels into usable energy nor the pollutions incurred by accidental or intended disasters by malignant parties. The new system was proposed to capitalize upon natural geographic processes – wind, solar, hydro currents and geothermal flux – without incurring environmental harm, silently benefiting from natural processes. The system would be environmentally friendly and yet produce comparable energy yield to that of combustible fuels.

The technology itself is not yet mature, the technical evaluation of the renewable energy concept has produced critics voicing disappointing conclusions regarding its prospects. Solar panels, one of the lauded technological derivatives of the new system, has a fundamental flaw in its operation. State-of-the-art solar panels are configured with a maximum conversion efficiency of 20%, of which the total conversion efficiency is reduced to 18% over the first 24 hours of sunlight exposure; the active region of solar cells containing the boron-doped silicon cells and oxygen degrade significantly during the first few hours of operation at ambient temperatures (Vaqueiro-Contreras et al., 2019). Wind turbines suffer from the limitations of sustainability in which they suffer from leading edge erosion, of which exposure to the elements whilst operating at a high speed (minimum of 150 kph) erodes at the turbine blades. These microplastic particulates and possibly toxic compounds are exposed to the wind; turbine blade erosion can release carcinogenic and allergenic substances including isocyanates, Bisphenol A, and glass epoxy particulates. Bisphenol A found in common epoxies used in wind turbines, amounts to approximately 13-15% of the total weight of a turbine rotor blade of which one kilo of Bisphenol A is enough to pollute 10 billion liters of water (Solberg et al., 2021).

It is impossible for solar panels and wind turbines to maintain permanent operation. The sun cannot shine at solar panels for the entire 24 hours of the day, and changes in sunlight angles can incur in losses of conversion efficiency. Likewise, sufficient and consistent wind can only be sourced from certain areas of the world. The power density between solar and combustible fuels can vary as much as 1000 times, requiring 40-50 times more space than coal and 90-100 times more space than gas for solar power to bring comparable yields (van Zalk et al., 2018). Wind turbines need to be placed as far upstream as possible to reach optimal turbine speeds. The technical limitations of the renewable energy system extend beyond the benefits of energy yields. A technological review of this system and its derivatives in its current state can only be disappointing.

Many institutions of the media, social activists, and government however have insisted upon the destructive effects of hydrocarbons and combustible fuels on the environment and that widespread adoption of renewable energy infrastructures as necessary choices of action. At the same time, they have not called for reduced energy demands from industry and the economy. There have been numerous calls within the United States alone to "replace all hydrocarbons and non-renewable energies by 2030" – the proposed Green New Deal (United States House of Representatives, 2019). Policymakers have called for nearly unmitigated expansion of renewable technologies, including the recent renewable energy target set by China to attain 1200 GW of total wind and solar capacity by 2030 (Renewables, 2021). The calls by activists, policymakers, and media have demanded for the upscaling of renewable energy and supplementary technologies to contest with hydrocarbons in the short-term, ignoring the technical inefficiencies and detriments of the proposed system.

The system of renewable energy in its current form cannot sustain the rapid expansion demanded by societal, political and economic institutions. Crude oil, for example, can be refined into a satisfactory jet fuel and supports the entirety of the modern aviation industry, both commercial and military. The refining process of this material additionally supplements a vast array of industries. With a small but significant proportion diverted to be refined into gasolines and fuels compatible with transportation uses, the majority of the petroleum serves as distillates or feedstocks for making specialized chemicals. Ink, solvents, bicycle tires, dresses, boats, nail polish, fishing lures, perfumes, polishing agents, refrigerants, multi-purpose tape, insulators – most if not all modern technological developments and products introduced into the domestic and global economies find their roots in petroleum (Pascual, 2010). The technical implications of unrefined or refined oil aside, the technology itself supports many aspects of every modern society; the raw economic and military influence, cultural development, and most important in the exchange of nations, geopolitics.

The technology of fuel completes its socio-technical obligations; it has greater energy yield than its predecessors of coal and simple biofuels. The requirement of supply is not a question as despite decades of exponential growth of fuel extraction, the world has consumed roughly only 5% of known recoverable fuel sources (Brandt & Farrell, 2006). It has supplied the vast economic and cultural needs through the byproduct technologies, and has reinforced the military and political influences of many nations. A similar conclusion cannot be stated regarding the current state of renewable energy. Could the infrastructure of solar, wind, hydropower, and geothermal stations sustain the energy demands of a modernizing world and fuel further technological growth? The average solar panel produces 170 to 350 watts per hour in a single day. The average car, when converted to an electric power-train system, directly consumes 346 watt-hours *per mile.* What of aircraft, which requires power generation of several orders of magnitude greater than that of a single car? Or the power drawn by municipal electrical grids?

Therein lies the ethical dilemma. The engineer and technical staff working on renewable energy systems and derivatives cannot possibly be unaware of the detriments of the proposed system. The technology of the current renewable energy system simply cannot sustain the upscaling schemes s suggested by societal and governmental institutions or its proposed technical obligations. The technology consumes more than it yields – its current state is contradictory to its purpose and requires extensive technological breakthroughs to mature and become a socio-technical system capable of fulfilling its societal and economic obligations. Those who are involved in the proliferation of the renewable energy system's technological derivatives should consider whether their work is truly beneficial to society. More particularly, the responsibility associated with technological systems in such contradictory states as the current renewable energy system.

Research Method and Timeline

Investigating the socio-technical problem at hand first requires the structuring of the ethical problem into a philosophical inquiry. The interactions of the engineer and society are to be assessed as actor and actant relations. A general set of thresholds must be defined for which a technological system becomes “contradictory” or self-destructive. The renewable energy system will be explored by the abovementioned guidelines; the NPSE and other general codes of engineering ethics will be applied to the case of the renewable energy system to produce a judgement whether the engineer’s involvement on the proliferation of said technological system complies to the ethics prescribed. These will then be collated into answering the question regarding the responsibilities of engineers in such situations mentioned above.

Evidence required for resolving the socio-technical question will be acquired in the form of comprehensive, academic reports of renewable energy systems on their energy yield, environmental output, and materials needed to consolidate conventional renewable-energy-based technologies currently circulating in the industry. The reports will be compared with that of hydrocarbons and conventional fuels to determine a threshold of the “level of contradiction” of the renewable energy system. These will be utilized as case studies to outline a generalized concept of “contradictory socio-technical systems”.

A practical socio-technological aspect will be provided in the form of interviews with engineers in fields of either renewable energy technologies or its derivatives will be conducted to provide either alternate or supplementary perspectives. They will primarily be asked questions regarding the ethical dilemmas experienced on their job as engineers and their beliefs on the nature engineering ethics in the development of such technologies. The interviews are expected to be completed and compiled by March. The interviews are to be consolidated and utilized to form a philosophical inquiry regarding engineering responsibility with respect to socio-technical systems and the NSPE with STS thesis scheduled for completion in May.

The expected timeline of the technical project will be concentrated around the spring semester. Tentative conceptual aircraft designs will be assessed through computational tools including FLOPS, finite-element solvers, and aerodynamic calculation software; this process will be repeated numerous times to iterate onto an optimized aircraft configuration, expected to complete near March. The design choices and their causes, discussions, and reasoning will be consolidated and documented into a comprehensive report to be submitted to the AIAA in May.

Conclusion

The design process of the hybrid-electric turboprop involves the design and implementation founded on a contradictory renewable energy system not yet scalable to meet the design needs of large-scale aircraft-based transportation systems. The technical project will attempt to complete such a design, whereas the STS project attempts to consolidate the ethical dilemma of engineers that become involved in design projects such as the above. Technologies being developed must consider the socio-technical impacts that result due to their proliferation and use, but society must consider whether they are truly ready to request for certain technologies to be developed.

Bibliography

Farrell, A. E., & Brandt, A. R. (2006). Risks of the oil transition. *Environmental Research Letters*, *1*(1), 014004. https://doi.org/10.1088/1748-9326/1/1/014004

National Society of Professional Engineers. (2019). NSPE Code of Ethics for Engineers.

Pascual, C., & Elkind, J. (2010). *Energy Security*. Brookings Institution Press.

Renewables 2021. (2021). In *Market Report Series: Renewables*. OECD. https://doi.org/10.1787/6dcd2e15-en

Solberg, A., Rimereit, B.-E., & Weinbach, J. E. (2021). Leading edge erosion and pollution from wind turbine blades 5th. Edition - English. https://doi.org/doi:10.13140/RG.2.2.33339.34080

Text - H.Res.109 - 116th Congress (2019-2020): Recognizing the duty of the Federal Government to create a Green New Deal. (2019, February 12). https://www.congress.gov/bill/116th-congress/house-resolution/109/text

Unger, S. H. (1994). Controlling technology: Ethics and the responsible engineer (Second ed.). New York, NY: Wiley & Sons.

van Zalk, J., & Behrens, P. (2018). The spatial extent of renewable and non-renewable power generation: A review and meta-analysis of power densities and their application in the U.S. *Energy Policy*, *123*, 83–91. https://doi.org/10.1016/j.enpol.2018.08.023

Vaqueiro-Contreras, M., Markevich, V. P., Coutinho, J., Santos, P., Crowe, I. F., Halsall, M. P., Hawkins, I., Lastovskii, S. B., Murin, L. I., & Peaker, A. R. (2019). Identification of the mechanism responsible for the boron oxygen light induced degradation in silicon photovoltaic cells. *Journal of Applied Physics*, *125*(18), 185704. https://doi.org/10.1063/1.5091759