Design of a Hybrid-Electric, Turboprop-Powered Regional Airliner
(Technical Topic)

Discussing the Future of Internal Combustion in Modern Transportation
(STS Topic)

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Introduction

My technical project is designing a hybrid-electric regional turboprop aircraft for smaller regional airlines capable of carrying 50 passengers over a distance of 1000 nautical miles. This project happens to tie into a matter of great interest for me and my passion for automobiles. Aviation and other modes of automated transport will likely be the essence of my career in the future and I am interested in looking towards the future of this industry so that I may be a part of the exciting innovations that may occur within it during my lifetime. While the rather academic pursuit I've just mentioned is a prudent professional choice, it is even more driven by my passion for automobiles and aviation. With new emissions in the automotive and aviation sectors imperiling the future of internal combustion, I wanted to investigate the thoughts of pundits in industry and academia alike on the matter.

For my capstone, the work is essentially focused on improving the sustainability of air travel. While there are other tangible benefits associated with hybrid-electric aircraft, this Request for Proposal (RFP) from the American Institute of Aeronautics and Astronautics (AIAA) comes at a time when emissions and sustainability in the next decade are a paramount focus in environmental and engineering research. The specific aircraft that my group is designing is vital to connecting small, remote cities with metropolitan areas in the United States and abroad; it is often the fastest and safest mode of transport for denizens of these cities – in India, these aircraft are the most reliable mode of transport for younger individuals looking to study at a university outside their own small home towns, which may not have the same academic resources. (Das et al, 2022). As such, developing a technology to improve the sustainability and lower the cost of these aircraft is crucial to maintaining their presence in the areas that need them. Emissions are especially an important concern in the aviation industry, as its emissions have increased exponentially in the past 60 years with no sign of slowing down without significant change. Additionally, aircraft uniquely affect the air in our atmosphere as they deposit soot directly into our clouds, lowering the pH of the water vapor within them, which leads to more acidic rain that can damage crops and wildlife (Grewe et al., 2021). In order to achieve this, significant changes need to be made to current aircraft architectures as well as the industry as a whole. Battery technology will need to be made lighter and more energy dense, electrical systems for the aircraft will need to be developed, and the Federal Aviation Administration (FAA) will need to create new regulations around these aircraft.

I will further aim to develop an understanding of the current opinions on the internal combustion and its future in common modes of transport, such as aircraft and automobiles. Internal combustion has been the backbone of society for the last 250 years. Its inception sprang the world into the Industrial Revolution, gave man the ability to traverse great distances faster and more reliably than its equine predecessors, and even enabled us to take to the skies and beyond. That being said, with a new focus on carbon emissions and sustainability, the future of internal combustion is in jeopardy. The most potent question now is: how will engineers reconcile modern needs currently satisfied by internal combustion with a burgeoning concern for its effect on the environment?

Technical Topic

This aircraft design project is guided by this year’s AIAA RFP. There are two teams of nine students here at UVA working on the project. I am a co-lead for my team, so my job is to coordinate with my other team lead and organize our design efforts with the rest of our team as well as provide support in area that my team may need. I am responsible for a broad knowledge of every project taking place within my team as well as guiding research efforts to achieve the goals of the RFP. This project is new for this year, and as such my team and I will be designing our aircraft essentially from the ground up.

The concept of hybrid aircraft is not something entirely novel, but real development in the field is only just beginning. The main problem with hybrid technology in these aircraft is that planes have to be as light as possible in order to fly over long distances. Batteries are extremely heavy, with industrial-grade devices weighing in anywhere between 22 and 75 kilograms per kilowatt-hour. Additionally, batteries are 24 times less energy dense than jet fuel. As such, researchers have sought to forgo batteries by employing so-called turboelectric powertrains, which essentially use the aircraft's combustion-powered turbines as generators and send the resultant electricity to other electrically powered propulsors, effectively reducing the required power output of the combustion engines and thereby reducing both fuel consumption and carbon emissions. Most research in the field is focused on developing new sizing methodologies (physical displacement of the aircraft, their engines, their wings, etc.), feasibility studies of different prototype models, and preliminary performance analyses of concept designs.

The first step in this project is gaining a thorough understanding of the current state of the hybrid-electric aircraft sector as well as the requirements set by the RFP. From there, our next step is to divide into groups and gain a deeper understanding of specific components of hybrid aircraft (e.g. turboprop engines distributed electric propulsion). Next, we will draft conceptual designs and pitch them to the group. With all nine concepts presented, our group will internally select three designs to investigate further. Part of this investigation will include trade studies as well as discussion of the feasibility of these designs to help filter down to one design, which our group will develop into our final design. The final design will be tested using various available softwares and ultimately result in a complete three-dimensional model of our design, which we will present to the AIAA.

This project, while certainly motivated by the requirements of my capstone course as well as the competition in which we are participating, represents a much more significant stage in my engineering education. The reason I chose aerospace engineering was because, as a child, I always was fascinated by the great machines in the industry, aviatic and otherwise, that enabled humans to cover great distances safely, quickly, and comfortably; but as I got older I decided that I wanted to actually be a part of the brilliant invention and innovation required to create these machines rather than just a spectator. While the many courses focused on theory and mathematics are interesting, I often feel that I'm losing sight of the real world of engineering when doing homework for my classes. This project enables me to actually work at the cutting edge of a new wave of sustainable engineering, which I believe to be crucial to the survival of the brilliant machines that I grew up loving.

STS Topic

With the past 20 years seeing major development in electric vehicles and hybrid powertrains coupled with increasing scrutiny of carbon emissions and their effect on the environment, engineers and environmentalists alike have begun to question the need for internal combustion. The major problem with this is that there is currently no equal machinery capable of doing what the internal combustion engine (ICE) does. The main argument for internal combustion over electric power is established infrastructure. ICE's are widely available through mass production, inexpensive to operate, easy to diagnose and repair, and relatively easy to power given the ubiquity of fuel. In terms of arguments against ICE's, their main drawback is their obvious adverse effects on the environment. Currently in the aviation industry there are ongoing efforts to make use of more sustainable fuels for aircraft, which may be a promising way for aircraft as they exist today to continue to operate while further development is made in the sphere of hybrid-electric aircraft (Kocal et al., 2020). Additionally, researchers around the world are developing models for assessing the benefits of possible hybrid architectures for aircraft engines, going as far as developing new sizing models for these hypothetical aircraft to prove that they can feasibly be manufactured and deployed as passenger aircraft (Jimenez et al., 2022). Conversely, electric power, while being inexpensive and producing no emissions through its use, is not widely available yet. Also, the argument can be made that electric power in vehicles is often just as bad as internal combustion because the power for these electrical systems comes largely from power plants, which use internal combustion or even nuclear power. Of course, countries like Norway generate electricity from hydroelectric plants (energifaktanorge.no), but few places have access to the kind of tidal power required to make a genuine difference to their power grid. The difficulty with electric power is mainly a question of origin and availability. Another option for fuel that serves as a theoretical alternative for hydrocarbon-based power is hydrogen combustion, but research in this area is ongoing and not entirely promising (Williams et al., 2002).

With this topic, it would be easier to list the groups not affected by my question than those that would be. Combustion power is present in every facet of modern life insofar as it has become an integral part of the infrastructure of every global superpower. Indeed the ubiquity of internal combustion is what fascinated me as a child – despite the immensely complicated mechanisms within engines in cars, generators, and airplanes, their existence and crucial importance has always been a foregone conclusion. My own family works in multiple areas of the aviation industry, so I'm naturally inclined to not only respect it but also admire it; however, increasing scrutiny of the broader effect of these engines on the environment and the very people that benefit from using them has caused me to wonder if there is really a way to move forward without compromising either the efficacy of modern power generation or the natural human concern for the natural world in which we live.

The main STS framework I will be using to analyze my topic will be technological momentum (Hughes et al., 1989). To me, this framework is the obvious choice, as internal combustion has existed for centuries, become ingrained in every facet of our lives, and been the main source of power for transportation since its inception. As Hughes mentions in his work, large technological systems attracted attention from finance, regulatory, and government bodies soon after their inception. With so many industries being directly or indirectly affected by aviation and modern transport, it is safe to say that internal combustion powers the modern world to its core in finances government, travel, trade, and even defense. Currently, the aviation industry alone employs nearly 30 million people globally (aviationbenefits.org) and accounts for nearly $175 billion in global market share (Salas, 2022). It is undeniable that aviation plays a major role in global function today; however, this is merely one example of an industry that is fundamentally reliant on internal combustion. What is truly astonishing is that aviation, ground transport, and shipping are only three examples of industries that are fundamentally reliant on internal combustion, with countless more just like them. If the internal combustion engine were to cease to exist tomorrow, it is no exaggeration to say that the world as we know it would collapse. This is all to say that the internal combustion's formidable momentum comes from the fact that so many facets of modern life are rooted in its use. That being said, with global warming rates more than doubling in the last century, the modern world may face different environmental threats as a result of sustaining combustion power (Dahlman, 2022). Indeed, environmental concerns may be one way to reveal that internal combustion is not an “autonomous” technological behemoth, and will likely need continuous and careful upkeep in order to maintain its momentum and make the ICE agreeable to increasingly strict environmental regulations.

The topic I have chosen is broad and, in many ways, almost doesn’t make sense. Internal combustion has become synonymous with automotive and aviatic travel and no extensible alternatives had been developed until the 21st century. As such, even bearing in mind the adverse environmental effects caused by the use of internal combustion, how could society even begin to move away from it? I believe that this generation is in the nascent stages of a technological revolution that will seek to answer that question and I am excited to play a part in that through my analysis of this topic.

Research Question and Methods

As a future aerospace engineer as well as an automotive fanatic, the question of how engineerings will be able to adapt the ICE to modern requirements for reduced emissions and increased efficiency will likely define the futures of both my career and my passion. The answer, I suspect, will take many decades of incredibly hard work by many brilliant engineers to fully materialize. Although the solution to this problem is clearly far from simple I would like to start my own work towards it through this STS research.

In terms of my approach to this topic, I intend for my main source of information to come from interviews with experts in the areas of aviation, combustion power, and alternative fuels. I currently have four individuals in mind for my interviews: Kurt Prestegard, a Norwegian aerospace engineer (and my grandfather) who I believe will have a unique and highly refined perspective on the matter of electric power and its place in aviation; Keith Williams, a professor of electrical engineering at the University of Virginia who has done extensive research and published works on the feasibility and scalability of hydrogen power; Jesse Quinlan, a professor of aerospace engineering at the University of Virginia and a systems analysis team lead at NASA, who is the director of my technical project and is uniquely qualified to discuss the state-of-the-art regarding hybrid-electric propulsion; and Dana Elzey, a professor emeritus of materials science at the University of Virginia and an automotive expert and collector. While these four gentelemen only make up my initial list of interviews, I believe each of them will provide extremely valuable information regarding my STS topic and I look forward to discussing it in depth with them. I hope to further my interview work with a more diverse pool of people later on and picking out those from whom I would find valuable answers is an ongoing process.

Additionally, as amember of the AIAA, I have access to many articles and conferences focused on the future of sustainable aviation; I intend to attend a handful of these conferences in the Spring, either in person or remotely, in order to get a better understanding of where the industry is today with its development in the field. I would also like to keep myself across the latest articles in aviation magazines that the AIAA publishes to try to find interesting and unique information regarding sustainable aviation straight from engineers who are currently working in the field.

Conclusion

My technical project, once complete, will result in a complete design of a hybrid-electric regional turboprop aircraft that could feasibly be used as a replacement for the current avaikable aircraft. Whether or not this design will be built and fly in the future, which is realistically unlikely, the aggregation of knowledge, engineering, design savvy, and new concepts will provide the industry and the members of my group with an improved arsenal of techniques for use in the future, as well as a deep level of understanding of many facets of modern aviation. My STS topic, on the other hand, will enable me to investigate further into the changing tides of combustion power and to better understand the driving forces behind moving to electric power as well as the industry's goals for alternative power sources and their feasibility in different sectors in the future. Serendipitously, my two topics happen to bolster one another, and I think that my continued work with my technical team will help to answer some of my questions about my STS topic, and vice versa.

References

Employment. Aviation. (n.d.). Retrieved December 9, 2022, from https://aviationbenefits.org/economic-growth/supporting-employment/

Das, A. K., Kumar Bardhan, A., & Fageda, X. (2022). What is driving the passenger demand on new regional air routes in India: A study using the Gravity Model. *Case Studies on Transport Policy*, *10*(1), 637-646. doi:10.1016/j.cstp.2022.01.024

Dahlman, R. L. A. N. D. L. A. (n.d.). *Climate change: Global temperature*. NOAA Climate.gov. Retrieved December 9, 2022, from https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

Electricity production. Energifakta Norge. (2021, May 11). Retrieved October 27, 2022, from https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon/

Grewe, V., Gangoli Rao, A., Grönstedt, T., Xisto, C., Linke, F., Melkert, J., . . . Dahlmann, K. (2021, June 22). Evaluating the climate impact of aviation emission scenarios towards the Paris Agreement including Covid-19 Effects. Retrieved October 17, 2022, from https://www.nature.com/articles/s41467-021-24091-y

Hughes, T. (1989) The Evolution of Large Technological Systems. In: Bijker, W.E., Hughes, T.P. E Pinch, T.J. The Social Construction of Technological Systems. New Directions in the Sociology and History of Technology. (pp. 51-82) Massachusetts: MIT Press

Jimenez, D., Valencia, E., Herrera, A., Cando, E., & Pozo, M. (2022, January 25). Evaluation of series and Parallel Hybrid Propulsion Systems for UAV's implementing distributed propulsion architectures. Retrieved October 16, 2022, from https://www.mdpi.com/2226-4310/9/2/63/htm

Salas, E. B. (2022, July 27). *U.S. domestic market share of Leading Airlines*. Statista. Retrieved December 9, 2022, from https://www.statista.com/statistics/250577/domestic-market-share-of-leading-us-airlines/

Sustainable aviation fuel: Review of technical pathways report. (n.d.). Retrieved October 17, 2022, from https://www.energy.gov/eere/bioenergy/downloads/sustainable-aviation-fuel-review-technical-pathways-report

Williams, K. A., Pradhan, B. K., Eklund, P. C., Kostov, M. K., & Cole, M. W. (2002). Raman spectroscopic investigation of H2, HD, and D2 physisorption on ropes of single-walled, carbon nanotubes. *Physical review letters*, *88*(16), 165502. https://doi.org/10.1103/PhysRevLett.88.165502