American Institute of Aeronautics and Astronautics: Aerial Firefighting Aircraft Design Competition
(Technical Paper)

The Conflict of Increased Reliance on Aviation and Environmental Initiatives
(STS Paper)

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By
Brendan Whalen

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Technical Team Members:
Spencer Barnes, Jamie Graham,
Haley Knowles, Kevin Moccia,
Joe Orrico, Kobi Vance,
Grace Vidlak & Jackson Wray

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 and Mechanical and Aerospace Engineering

Bryn Seabrook, Department of Engineering and Society

Introduction

Since its origin a little over a century ago, the aviation industry has grown rapidly to the point where aerial firefighting is now a viable platform for combating the rise in prevalence and intensity of wildfires (Weiss & Amir, 2021). In 2019, wildfires burned large swathes of land from Siberia to the Amazon, and a shifting narrative toward the global impact and effort to combat these fires emerged (Andela et al., 2017). Spurred by this threat, innovation in the form of novel aerial firefighting aircraft has become a priority for countries with the economic resources and technologies to support such systems. The proposed technical project described in this prospectus aims to compete in the 2022 American Institute of Aeronautics and Astronautics (AIAA) Team Aircraft Design Competition to design and evaluate a responsive aerial firefighting aircraft (AIAA, 2021).

Beyond the novel use of airplanes for fighting wildfires, they are increasingly used in conventional applications to transport passengers and billions of dollars worth of cargo annually. Citizens in industrialized countries have come to expect quick shipping of goods purchased online and international militaries maintain fleets of thousands of advanced attack and cargo aircraft in a strategy of air supremacy. In a cultural climate that is shifting to emphasize environmental impacts, airplanes emit harmful chemicals high in the atmosphere with impacts that have not been thoroughly investigated and airports are among the greatest sources of localized air pollution (Friedl, 1999). The research described in the STS Topic section of this prospectus will include issues related to the future of sustainable aviation due to increasing environmental impact as a result of continued growth and reliance on the industry.

Designing an Aerial Firefighting Aircraft

Continued changes to the planet's climate have resulted in an increase in the number and intensity of wildfires posing ever greater threats to life and property. Researchers at NASA Goddard's Space Flight Center have predicted increases in future wildfire activity in the next 50-100 years as a result of rising global temperatures, extreme weather events, and regional drying. Historically, major aerial firefighting platforms consist of modified military or commercial airframes with internal or external equipment integrated into the original designs and structures, such as variants of the Lockheed Martin C-130 Hercules and Boeing's 747 aircraft (AIAA, 2021). A purpose-built large size firefighting aircraft would allow the responsible organizations, domestically and abroad, the ability to fight wildfires more efficiently from the standpoint of both performance and cost. The AIAA has issued a request for proposal (RFP) of a responsive aerial firefighting aircraft and the technical project will encompass the design and evaluation of a firefighting aircraft that aims to compete in the 2022 AIAA Undergraduate Team Aircraft Design Competition held in May (AIAA, 2021).

Aircraft design requires a thorough understanding and evaluation of the customer requirements, which have been detailed by the AIAA RFP. Notable requirements include the ability to carry at least 4,000 gallons of retardant payload dispersible in multiple drops of at least 2,000 gallons. The design is also required to be ready for entry into service by the year 2030, limiting the incorporated technologies to those available by that time (AIAA, 2021). The density of fire retardant creates substantial structural loads on key parts of the airframe that are exacerbated by extreme maneuvers. The design must not only meet the AIAA requirements, but must also comply with any specifications, standards, and regulations put forth by the governing bodies in the area of operation. The design of a new aircraft is a large undertaking that requires a team effort and engineering expertise in various disciplines. The technical project will be completed alongside a team of undergraduate aerospace engineering students under the direction and support of Professor Jesse Quinlan of the Mechanical and Aerospace Engineering Department. The project team members working alongside the author are Spencer Barnes, Jamie Graham, Haley Knowles, Kevin Moccia, Joe Orrico, Kobi Vance, Grace Vidlak, and Jackson Wray.

The aircraft design process begins with a set of requirements and an initial configuration and culminates with a viable product design ready for manufacture. Owing to the multitude of competing requirements shown in Table 1, there is never a perfect solution in the design of a new aircraft (Nicolai & Carichner, 2010). However, there are best practices and ways to optimize the process and end result to ensure an effective solution.

Table 1

Summary of General Competing Requirements in Aircraft Design

Category	Competing Requirements
Technical	Performance (speed, endurance, range, capacity, etc.)
Economic	Development, acquisition, operation, and life cycle costs
Political	Regulations, public policy, payback, and risk
Schedule	Test scheduling and entry into service date
Environmental	Energy source, noise, and pollutant emissions

In designing a responsive aerial firefighting aircraft, the team will follow the general aircraft design process divided into the three phases of conceptual, preliminary, and detailed design (Nicolai & Carichner, 2010). Much of the effort will be concentrated on the conceptual design phase, in which the feasibility of meeting the requirements with a credible aircraft design culminates in the general size and configuration of the aircraft including the inboard profile and major subsystems. The conceptual design phase will start with a brainstorming session in which the team identifies various possible aircraft concepts. Design trade studies pertaining to the categories of mission, design, and technology will be conducted around the three most promising concepts using preliminary estimates of aerodynamics and weights to converge on the specific characteristics of the wing and general body configuration. Moving on to the preliminary design phase, refined weight estimates will be made and the performance analysis will be conducted with more detail and vigor than in the conceptual phase. The best configuration in terms of cost and performance will be selected and fine tuned. In the final detailed design phase, the aircraft configuration will be solidified and detailed structural design will be completed that includes shop drawings and interior layout of equipment to be passed on to the production team. All aspects of the aircraft life-cycle will be meticulously investigated including eventual end-of-life-cycle disposal costs.

It is worth emphasizing that the design process is highly iterative, and steps are repeated until a design that best satisfies the many requirements can be converged upon. Various design and analysis tools will be used along the way, including OpenVSP and NASA's Flight Optimization Software (FLOPS) for initial configuration and sizing as well as computational fluid dynamics (CFD) software for analyzing aerodynamic performance in the preliminary phase. Additionally, computer scripts will be internally developed to perform rigorous calculations such as estimating the takeoff gross weight (TOGW), which does not follow the traditional methods employed in design textbooks due to the novel application of the aircraft. At project completion, a technical proposal including all relevant aspects and features of the final proposed design configuration as well as documentation of the pertinent analysis and studies supporting the design choices will be submitted to the AIAA competition.

The Issue of Sustainable Aviation

The aviation sector, encompassing private, commercial and military aircraft, is the fastest growing source of greenhouse gas emissions worldwide (Payán-Sánchez et al., 2019). In the United States, the EPA estimates that commercial aviation accounts for 12 percent of total transportation emissions as well as three percent of the nation's total greenhouse gas production. At the projected growth rate, it is estimated that these emissions may triple by the year 2050 (Overton, 2019). The growth of the aviation sector and related increase in emissions comes at a time when Earth scientists are warning society at large of the dangers of climate change and policy makers are taking notice of the need for increased regulation of industry (Brewer, 2007). Despite the advances in development and perception of renewable technologies in several industries, the aviation industry has not seen the same rapid progress and enthusiasm for attaining change. The environmental impact of airplane engines and design has gone relatively unchecked in favor of safety and performance objectives for decades of development (Holzman, 1997).

Despite the best efforts of the global aviation community, advances in technology such as new materials and propulsion systems over the next 30 years will not deliver significant reductions in environmental impacts, leading to a sustainable aviation conundrum (Agarwal, 2009). In this case, humanity simply moves more slowly toward global warming, thus necessitating the continued technological advancement and search for alternative fuel sources, but also an assessment of increased reliance on the industry for fast transport of people and goods. Given that the success of limiting pollutant emissions requires acceptance by the citizens at large, behavioral measures requiring citizens' active involvement are equally important as technological advancements (Maione et al., 2020). Aircraft design exists in a larger social context that goes beyond physical design characteristics and incorporates public policy, societal reliance, and supporting infrastructure. The industry lies at the intersection of the competing interests of safety, international commerce, performance and environmental impact, which makes the subject a case study of the complex interactions between society and technology. This leads to the proposed research question "How is the aviation industry evolving in response to continued growth that counteracts increased efforts of environmental sustainability?" to learn more about how and why the industry will encompass the changing social emphasis placed on environmental impact.

In answering the proposed research question, the wicked problem framework from the study of Science, Technology and Society (STS) will be utilized to gain a better understanding of the context within which the aviation sector operates and the relevance of sustainability to the industry. The general issue of sustainability is classified as an extremely ill-defined or wicked problem as it encompasses conflicting worldviews, it is dynamic, has unclear objectives, and it is vitally important for the generational survival of the human race (Brønn & Brønn, 2018). The term wicked problem was first used by design theorists Rittel and Weber in 1973 in order to draw attention to the challenges and complexities of addressing planning and social policy problems (Rittel & Webber, 1973). Sustainability as it pertains to the aviation industry confronts societal and policy actors as well as long existing institutional regimes and corporations. In the technical fields, the wicked problem framework suggests that advancing sustainable engineering science requires a shift in orientation away from reductionism and intellectual specialization towards integrative approaches to science, education, and technology (Seagar et al., 2011). Framing sustainability as a wicked problem and the challenges this poses will be used to enable a broader perspective that represents a shift in the mental modes of individual consumers, the organizations responsible for their commercialization, and the policy actors regulating the industry (Blok et al., 2016). The framework will be used to assess the need, or lack thereof, for radical change in the design and operations of future aircraft and provide suggestions for achieving this change.

The wicked problem framework is not to be used without acknowledging the various critiques specific to its usage. At a fundamental level, certain authors argue that the basis of the framework has been insufficiently examined and that the policy sciences already had a better conceptualization of large-scale public problems (Turnbull & Hoppe, 2018). Additionally, when used in policy practice the framing of problems as wicked tends to provoke paralysis or an overestimation of what policy can do to solve these issues (Termeer et al., 2019). Thus, questions emerge as to whether the framing of problems as wicked offers any new insights on how to tackle the issue at hand or if it simply redefines the issue as more complex than previously thought. Stemming from the rhetorical appeal of the concept, the term wicked has been used in different ways and in various contexts, often stretching the concept beyond its original intention and even to the point of alleviating responsibility for policy failures (Peters, 2017). While acknowledging these critiques of the wicked problem framework, the issue of sustainability is nonetheless important and complex and the framework enables an accounting for the long acting time frame, multitude of stakeholders, and differing normative ethics with regards to sustainability issues.

The question “How is the aviation industry evolving in response to continued growth that counteracts increased efforts of environmental sustainability?” is best answered through the use of various research methods. First, the environmental impact of the aviation sector will be analyzed through reviewing scientific research studies on emissions and climate change to establish the issue of sustainability as one that is important and urgent. Second, technological advancements in the industry will be reviewed from existing aircraft design specifications and future technologies will be analyzed in the form of patents, proposals and scientific research to illustrate the limitations of a technological fix approach to the issue of sustainability. Due to the limitations of publicly available information on proprietary systems and operations of privately owned commercial aviation corporations, a handful of interviews will be conducted with experts in the public domain of the field such as designers at NASA and university aerospace engineering professors. This review of technological advancements will be paired with a policy analysis of the many government agencies responsible for regulating the aviation industry and how these policies have changed over time from the first flights to the future of aviation. Finally, public sentiment and reliance on air transport will be analyzed using published survey findings and the method of discourse analysis. Through researching the various stakeholders, from the initial designers and engineers to the regulating bodies and individual consumers, a holistic perspective of sustainable aviation may be garnered and the future of the aviation sector will be assessed.

Conclusion

The two projects detailed in this prospectus deal with the opportunities and issues of increasingly applied aviation from an engineering and social viewpoint. In the technical project, a novel firefighting aircraft will be designed and evaluated to help battle the increasingly prevalent and dangerous wildfire threat across the globe. The purpose-built aircraft will increase effectiveness and lower the barriers to entry for the organizations tasked with mitigating the wildfire threat. The conflicting requirements of performance and environmental impact will necessarily be addressed. The STS Topic will investigate the issue of sustainability in the aviation industry from a more holistic perspective. Answering the proposed research question will provide a thorough assessment of the role of various stakeholders as the aviation industry comes to terms with emphasis on environmental impacts and the need for sustainability. While aviation is relied upon at ever growing rates across the globe and for various purposes, it is pertinent to understand the environmental impact of this growth and to take necessary steps to mitigate any potentially harmful consequences.

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