American Institute of Aeronautics and Astronautics: Aerial Firefighting Design Competition

(Technical Paper)

Can Planes Go Green?: Using the Multi-Level Perspective to Determine the Commercial Aviation Industry's Progress Towards Sustainability

(STS Paper)

A Thesis Prospectus Submitted to the

Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree

Bachelor of Science, School of Engineering

Jackson Wray

Fall, 2021

Technical Project Team Members

Spencer Barnes
James Graham
Haley Knowles
Kevin Moccia
Joe Orrico
Kobi Vance
Grace Vidlak
Brendan Whalen

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

Signature JWray Date 5/10/2022

Jackson Wray

Approved ______________________________ Date __________

Jesse Quinlan, Department of Aerospace Engineering

Approved ______________________________ Date __________

Peter Norton, Associate Professor of STS, Department of Engineering and Society

Prospectus

General Research Problem

How are the effects of accelerated carbon emissions being countered in the United States?

The global climate is drastically changing around us. People have known of climate change since the late 1800s, and it was officially named a national issue in 1988 (Brulle, 2018). Despite national recognition, there has been limited reduction in carbon emissions and the effects of climate change are starting to impact societies worldwide. According to the NOAA (Lindsey, 2021), carbon dioxide emissions have grown exponentially since 1850 (Fig. 1).

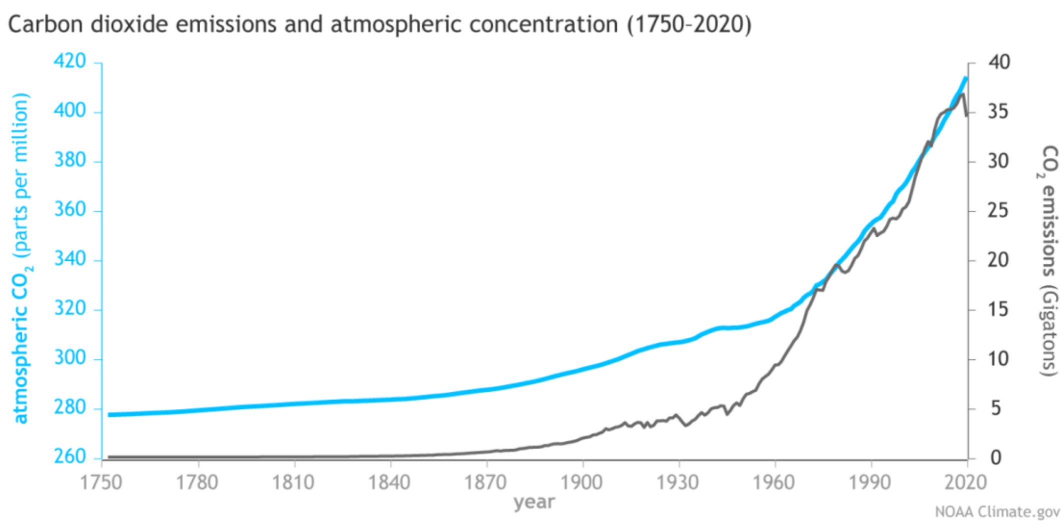

Figure 1. Carbon dioxide emissions and atmospheric concentration since the industrial revolution (NOAA, 2021)

As CO_2 and other greenhouse gasses are released into the atmosphere, more thermal infrared energy is captured by the molecules in the atmosphere increasing the average temperature of the planet. According to Huang (2016), the impact of increased carbon emissions is likely to expand drylands 23 percent by 2100, when they may account for 56 percent of global land area. Increased desertification of land area reduces the amount of livable land and yearly crop yield. Global warming has increased economic and insured losses by over 61 billion USD due to extreme weather patterns since the 1950s (McBean, 2002). As desertification and extreme weather conditions increase worldwide, it is clear that carbon emissions reductions are desperately required to slow the rate of climate change. Since the early 2000s, the U.S. Congress and federal regulatory agencies have taken only limited regulatory steps to cut emissions (CCES, 2021).

Conceptual Design of a Responsive Aerial Firefighting Aircraft

How can fixed-wing aircraft be designed for fighting wildfires?

As the planet's climate continues to change, the damage done by wildfires increases steadily, posing larger threats to life and property both within the United States and abroad. This trend is expected to continue as temperatures rise, weather events become more extreme, and regional drying continues. Modern technology enables more effective aerial wildfire responses to fill the increased demand.

Planes have been used to fight wildfires for over a century, but they are generally repurposed commercial or retrofitted military aircraft. Companies are paying high prices to improve aerial firefighting's effectiveness by designing planes around aerial firefighting's constraints. The American Institute of Aeronautics and Astronautics (AIAA) is challenging students to develop conceptual aircraft designed for next-generation aerial firefighting given a thorough set of constraints outlined in a request for proposal (RFP) document from the AIAA shown in Table 1. The conceptual design will be a large airtanker or water scooper plane to be ready for entry into service in 2030. Lockheed Martin's modified airtanker C-130 Hercules and Viking Air's "super-scooper" CL-415 currently lead the way in effective aerial firefighting.

Request for Proposal Constraints

Description	Requirement	Objective
Entry Into Service (EIS)	2030 Use existing engine(s) or one that is EIS by 2028	N/A
Fire Retardant Capacity	4000-gal capacity Multi-drop capable 2000-gal minimum per drop Fire retardant reload ≥ 500 gal/min Retardant density ≥ 9 lbs./gal	8000-gal capacity
Payload Drop	Drop Speed ≤ 150 kts Drop Altitude ≤ 300 ft	Drop Speed ≤ 125 kts
Design Radius (Full Payload)	200 nmi	400 nmi
Design Ferry Range (No Payload)	2000 nmi	3000 nmi
Dash Speed (After Payload Drop)	300 kts	400 kts

Takeoff Requirements at 5000 ft MSL, 35°F	Balanced Field Length ≤ 8000 ft	Balanced Field Length ≤ 5000 ft
Certifications	VFR and IFR flight with an autopilot system Flight capable in known icing conditions Meets FAA 14 CFR Part 25 certification rules	Enable autonomous operations

Table 1. Requirements and objectives for the design challenge (author; data from AIAA, 2021)

In designing a market-competitive aerial firefighting aircraft, the team will follow the complex aircraft design process divided into the three phases of conceptual, preliminary, and detailed design. All of the effort in this study will be concentrated on the conceptual design phase, in which the feasibility of each design objective is used to create the general size and configuration of the aircraft. This phase starts with a brainstorming session where the team identifies various possible aircraft concepts. Trade studies pertaining to the mission, design, and technology, are then conducted around the three most promising configurations using preliminary estimates of aerodynamics and weights (calculated in MATLAB) to converge on the specific characteristics of the wing and general body configuration. It is important to note that the design process is highly iterative, so many of the estimates and trade studies will be revisited and improved upon. Various design and analysis tools will be used, 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. Once the conceptual design study has been completed, the next steps would be the preliminary and final detailed design phases. In the preliminary design phase, the best configuration in terms of cost and performance from the conceptual phase will be fine-tuned through wind tunnel parametric testing. In the final detailed design phase, the aircraft configuration and comprehensive structural design will be finalized. This phase includes producing detailed technical drawings of the mechanisms, joints, fittings, and attachments, as well as finalizing the interior layout and location of avionics systems.

This challenge will be completed under the guidance of technical advisor Jesse Quinlan from the Mechanical and Aerospace Engineering Department alongside the following students: Spencer Barnes, James Graham, Haley Knowles, Kevin Moccia, Joe Orrico, Kobi Vance, Grace Vidlak, and Brendan Whalen. At the end of the project, the conceptual design will be presented to the AIAA.

How Commercial Aviation Businesses were Compelled to Issue Emissions Reduction Targets

How have consumers, shareholders, and climate advocates pressured the commercial aviation sector into committing to emissions reductions goal?

The EPA estimates that global wildfires are growing in intensity and frequency displacing millions worldwide (2021). Alan Buis (2019) of NASA's Jet Propulsion Laboratory warns that in some parts of the world, average temperature increases have surpassed 1.5°C since pre-industrial times, and this trend is projected to continue. Researchers have studied rising temperatures' contribution to extreme weather patterns, aridity, and wildfires (Liu et. al 2009). Citizens' Climate Lobby (CCL, 2021) pressures governments to impose economy-wide carbon fees and dividends. In a recent press release about proposed climate measures in a budget reconciliation bill, CCL stated: "volunteers continue to contact the President, Senators, and representatives about this crucial policy" (CCL, 2021) ahead of the 26th annual Conference of

Parties (COP26). Grassroots advocacies of increasing size have committed to boycotting traveling by plane (Irfan, 2019). Boeing (2020) pledged a 50 percent reduction of carbon emissions by 2050 relative to 2005 levels. Boeing was responding to pressure from shareholders and climate advocacies. Other enterprises the commercial aviation sector have also been compelled to set carbon emissions targets.

Wynes (2021) contends that public pressure on politicians affects "internal party negotiations about climate and energy policy" (p. 15). Researchers have also investigated the environmental effects of a carbon tax on airlines. For example, Hofer (2009) found that a carbon tax of 2 percent could reduce U.S. airlines' carbon emissions from domestic flights by 5 billion pounds per year. According to Brueckner and Zhang (2010), airline emissions taxes tend to "raise fares, reduce flight frequency, increase load factors, and raise aircraft fuel efficiency" (p. 970).

Government agencies warn that due to the climate emergency, people must prepare for: "fire-related threats ... especially as more people live in and around forests, grasslands, and other natural areas" (EPA, 2021). Climate advocacies, some airline passengers, and some shareholders pressure airlines, aircraft manufacturers, and the flying public to reduce their carbon footprint. Swedish activists introduced the term *flygskam* (flight shame) to deter travelers from flying. In 2018 Greta Thunberg and a Swedish group called We Stay on the Ground began a movement to boycott commercial flights. The group wrote Flight Free 2020, a pledge publicizing refusal to fly. According to Maja Rosén, the founder of We Stay on the Ground: "That's really the most powerful way to make people change their minds" (Irfan, 2019). Swedish and German airports have reported a decline in travelers, attributing it to the "Greta effect" (Krauss and Chokshi, 2021). Flight Free USA and Flight Free UK are continuations of the pledge worldwide to choose greener alternatives to flight further pressuring airlines to reduce emissions or lose business.

Choice architecture has been used against the commercial aviation industry but has also been used by them. Virgin Atlantic applied choice architecture in an effort to coax its pilots to conserve fuel and thereby reduce carbon emissions (Mooney, 2016). The company implemented unique choice architecture to gently nudge their pilots towards a low emission operating technique. Pilots saved 6,828 metric tons of fuel that would have emitted 21,507 tons of carbon dioxide. According to Mooney (2016), “the vast majority” of the reductions was “simply from the captains in the control group knowing that Virgin Atlantic was studying their behavior” (Mooney, 2016). Virgin claims it has achieved 20 percent fleet-wide emissions reductions over the last decade; it has also pledged to achieve net-zero emissions by 2050 (Clarkson, 2021). The favorable publicity that Virgin’s efforts have attracted has subjected other airlines to competitive pressure. Virgin is also the founding member of Sustainable Aviation, and it belongs to the Clean Skies for Tomorrow coalition. It asserts that “aviation is a truly global industry, and we can’t tackle this on our own” (Clarkson, 2021).

References

AIAA (2021). American Institute of Aeronautics and Astronautics. Request for proposal - responsive aerial fire fighting aircraft.

Boeing (2020). Boeing: environment. https://www.boeing.com/principles/environment/index.page

Brueckner, J. K., & Zhang Anming, A. (2010). Airline emission charges: effects on airfares, service quality, and aircraft design. *Transportation Research Part B: Methodological*, *44*(8–9), 960–971. Science Direct

Brulle R (2018). 30 years ago global warming became front-page news – and both republicans and democrats took it seriously. The Conversation. http://theconversation.com/30-years-ago-global-warming-became-front-page-news-and-both-republicans-and-democrats-took-it-seriously-97658

Buis, A. (2019) A degree of concern: why global temperatures matter. Climate change: vital signs of the planet, part 2. NASA.

CCES (2021, Jan. 11). Center for Climate and Energy Solutions. Congress climate history.

CCL (2021). Citizens' Climate Lobby. Values of citizens' climate lobby.

Chokshi, N. & Krauss, C. (2021, May 28). A Big Climate Problem With Few Easy Solutions: Planes. *New York Times.*

Clarkson, N. (2021, Oct. 11). Virgin Atlantic sets ambitious carbon targets to achieve net zero by 2050.Hofer, C., Dresner, M. E., & Windle, R. J. (2010). The environmental effects of airline carbon emissions taxation in the US. *Transportation Research Part D: Transport and Environment*, *15*(1), 37–45. Science Direct

EPA (2021). U.S. Environmental Protection Agency. Climate change indicators: wildfires.

Huang, J., Yu, H., Guan, X., Wang, G., & Guo, R. (2016). Accelerated dryland expansion under climate change. *Nature Climate Change*, *6*(2), 166–171. https://doi.org/10.1038/nclimate2837

Irfan, Umair. "Air travel is a huge contributor to climate change. A new global movement wants you to be ashamed to fly." *Vox*, Vox, 25 July 2019, https://www.vox.com/the-highlight/2019/7/25/8881364/greta-thunberg-climate-change-flying-airline.

Lindsey, R. (2020, Aug. 14). Climate change: atmospheric carbon dioxide. NOAA.

Liu, Y., Stanturf, J., & Goodrick, S. (2010). Trends in global wildfire potential in a changing climate. *Forest Ecology and Management*, *259*(4), 685–697. Science Direct

McBean, G. (2004). Climate change and extreme weather: A basis for action. *Natural Hazards*, *31*(1), 177–190. https://doi.org/10.1023/B:NHAZ.0000020259.58716.0d

Mooney, C. (2016). Virgin Atlantic just used behavioral science to 'nudge' its pilots into using less fuel. It worked. *Washington Post*, 2020. https://www.washingtonpost.com/news/energy-environment/wp/2016/06/22/virgin-atlantic-just-used-behavioral-science-to-nudge-its-pilots-into-saving-lots-of-fuel/?noredirect=on&utm_term=.60e9d92aa361

Wynes, S., Kotcher, J., & Donner, S. D. (2021). Can citizen pressure influence politicians' communication about climate change? Results from a field experiment. *Climatic Change, 168*(1–2), 6. Science Direct