Undergraduate Thesis Prospectus

Lake, Wind, and Fire: Design of a Large Firefighting Air Tanker

(technical research project in Aerospace Engineering)

The Fire Fighting Foam Fight: The Controversy over Toxic Fire Retardants

(sociotechnical research project)

by

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November 1, 2021

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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 firefighting efforts best mitigate threats to the environment?

Rising global temperatures and other climate changes are projected to be a major source of increased fire rates, and consequently fire risk (Gao et al., 2021). In addition to climate change, human activity is a major factor, with ignition due to human activity dwarfing ignition by lightning, and playing a major role in increasing the costs associated with fires (Balch et al., 2017). These increases in incidence and impact make firefighting advancement essential – however, these advances must be afforded caution, as they may have effects of their own (Ross et al., 2018).

Lake, Wind, and Fire: Design of a Large Firefighting Air Tanker

How can a clean-sheet large air tanker optimize firefighting effectiveness and sustainability?

This technical research problem is a part of an 8-person AIAA competition entry under Prof. Jesse Quinlan, a team project with Andreas Damm, Matteo Harris, Aaron Huynh, Del Irving, Christopher Kwon, Jason Le, and Andrew Wheatley; our team leader is Del Irving. The objective of this capstone is to design a large/very large air tanker (LAT/VLAT); key performance parameters are a 4,000+ gal. capacity and entry into service within 10 years (AIAA, 2021). A key optional requirement is autonomous operation and its impact on the airframe; this has significant effects on complexity, initial cost, 10-year window, potential firefighting approaches, total service life, safety requirements, and other conditions (AIAA, 2021).

Past these "hard" requirements, minimizing costs and maximizing durability and maintainability are key "soft" requirements – these stand as significant departures from current firefighting aircraft, generally retired transport aircraft retrofitted with firefighting equipment, leading to exceptionally low costs but significant issues with structural durability and parts availability (George, 1988; Hall et al., 2002). Durability specifically is a major concern in aerial firefighting; the stresses and strains associated with water bombing have resulted in loads exceeding even ultimate loads, which are loads aircraft are only expected to “survive” for 3 seconds – unsurprisingly this has resulted in a poor safety record (George, 1988; Hall et al., 2002). A clean-sheet design would address this deficiency well, but would struggle to address cost concerns – significant reductions in operating cost, both in cost per flight hour and maintenance, would be needed to make up for the vast difference in flyaway cost between conversion of a used aircraft and a new aircraft.

These aircraft previously discussed in a broad sense represent the current “state of the art” – a motley assortment of converted former transport aircraft, with carrying capacities generally c. 3000-11000 gal. – one representative example is the MD-87, a converted passenger aircraft of the DC-9 family with a retardant capacity c. 3500 gallons (Kliment et al., 2021). Other representative aircraft include other converted passenger craft (e.g. BAe 146, DC-10) and former military aircraft (e.g. C-130, P3); of these aircraft the vast majority are permanent conversions but certain aircraft (of those listed the C-130) feature roll-on/roll-off temporary firefighting equipment (Hall et al., 2002; Kliment et al., 2021).

To meet design challenge demands, several aircraft modeling software are to be used; their role will be to first determine appropriate aircraft weighting and sizing, and then to model flight and load characteristics. Outside modeling requirements, the majority of the work to be done is conceptual and oriented around integration of novel and proven concepts into a comprehensive final design, though some of this process may also involve modeling software.

Two core metrics may be used to assess end-of-project success. The first is straightforward; it is the development of an aircraft design to meet the requirements and optimize for as many objectives as possible, as specified in the AIAA requirements. Secondly, our objective is to create an AIAA challenge submission that best captures the aircraft design and provides a strong and substantial supporting analysis to reflect the capabilities of the aircraft.

The Fire Fighting Foam Fight: The Controversy over Toxic Fire Retardants

How have interest groups competed to shape policy regarding the use of aqueous film-forming foams in firefighting?

Aqueous film forming foams (AFFFs) are a series of materials originally designed in the 1960s to improve firefighting efforts (Caban-Martinez et al., 2019). However, key components for firefighting effectiveness, PFAS chemicals, pose health and environment risks (Clean Water Action, 2020; Henderson et al., 2020). These chemicals are particularly dangerous as they are not removed by conventional treatment, an issue exacerbated by the high cost of most treatments and the slow pace of regulation – regulations are only now moving through legislatures, several state laws banning PFAS in firefighting foam and by order of Congress permitting PFAS-free foams at civilian airports (Henderson et al., 2020; Reisch, 2019).

The relatively recent development of regulatory action stands in stark contrast to the state of knowledge within the industry regarding the toxicity of PFAS products and byproducts, with knowledge of potential risks uncovered in litigation but otherwise hidden by chemical companies for decades under the shield of trade secrecy (Richter et al., 2021; Wickham & Shriver, 2021). Policy considerations of the era, such as the grandfathering in of those substances in the 1976 Toxic Substance Control Act and weak data review, in addition to what has been referred to as "selective ignorance," have allowed PFAS to remain broadly unregulated: with minimal research on hazards due to its grandfathering in, research into PFAS is perversely disincentivized (Richter et al., 2021). Richter et al. continue by discussing corporate responses to initial scrutiny: corporate interest groups have framed substitution of one chemical with another – here long-chain with short-chain PFAS – as a science-backed approach, with the new chemicals once again undefined to regulatory agencies, continuing the "selective ignorance" previously discussed. Between the lack of data and complexity of contamination, corporations are further able to "muddy the waters" on the potential hazards of chemicals, and can be combined with a "coerced ignorance," where state agencies are limited in their ability to process and provide information, and may go so far as self-censorship due to concerns about the local economic impact of an informed public (Wickham & Shriver, 2021). Wickham & Shriver go on to discuss the shift towards private industrial funding of scientific research, which has further limited information on potential contamination and toxicity, with research into the topic underfunded by budget-limited state agencies and generally opposed by corporate interests. These efforts by the chemical industry, which produce PFAS for a wide range of applications, have forestalled discussion of the hazards of AFFF.

Groups like the Green Science Policy Institute and affiliate site PFAS Central act opposite this "coerced ignorance" by providing what they deem "current and curated information" about PFAS risks, including legislative action and peer-reviewed articles, evidence which spreads public awareness and which environmental groups such as Clean Water Action use to lobby for legislative change to phase out PFAS use (Lindeman, 2017; PFAS Central, n.d.). On a more local level, groups such as Merrimack Citizens for Clean Water (MCFCW) have organized to highlight local PFAS contamination and hazards (Panikkar et al., 2019). While in this instance the PFAS source was an upstream chemical plant rather than firefighting foam, the effort, which saw 600-odd people answering a citizen-initiated survey on demographics, exposure, and health conditions, highlighted increased health concerns among groups with more exposure to PFAS, highlighting the plight of those living in areas with heavy AFFF runoff (Panikkar et al., 2019). Also at this downstream level, the American Water Works Association (AWWA) Journal emphasizes a proactive approach to alerting consumers to potential PFAS risks in water supply, both allowing initial risk mitigation by consumers and establishing trust in case future measures are required (Henderson et al., 2020). A panel discussion published in the same journal featuring water utility leaders indicates rising awareness of the PFAS threat, with several panel heads expressing awareness of the issue and mentioning proactive testing measures, again with a focus on keeping communities involved and building trust and understanding (Hughes et al., 2020).

Expert panels and symposiums on the topic, such as that commissioned by the International Pollutants Elimination Network (IPEN), have suggested replacement as a key step toward mitigation, here a switch from fluorinated AFFF to fluorine-free firefighting foams (3F) (IPEN, 2018). This has seen significant adoption, with PFAS-free foams now permitted at civilian airports and PFAS bans in some states, as discussed previously (Reisch, 2019).

Groups opposed to AFFF replacement generally cite its effectiveness to justify seeking alternative mitigation methods - the Fire Fighting Foam Coalition, a trade association representing manufacturers of AFFF and 3F, wrote a direct response to the IPEN study criticizing its methodology and noting stringent military requirements still met only by AFFF – the group suggests minimizing the AFFF volume released and focusing on treating runoff while focusing on improving alternatives instead (Fire Fighting Foam Coalition, 2019). This coalition press release interestingly emphasized that the majority of the manufacturers it represented produced both AFFF and 3F foam, downplaying potential profit motive and thus emphasizing the performance differences (Fire Fighting Foam Coalition, 2019). The runoff treatment mentioned has been described an emergent field with great potential, but also significant limitations and not-yet-matured technology (Ross et al., 2018). The DoD likewise maintains that commercially available alternative firefighting foams do not meet their requirements, but exercises remediation efforts, researches alternatives, and limits use to mitigate the effect where possible (Ross et al., 2018; Vergun, 2020). Efforts outlined in the previous sentence have begun to take effect, and transparency regarding AFFF locations has increased; however, American bases in Japan continue to face issues with a lack of transparency – due to longstanding military agreements, military tendencies toward confidentiality, and limited Japanese water safety regulations, increased PFAS levels have gone largely unaddressed or denied by the U.S. military, stoking local resentment and damaging civic health and bilateral relations – a stark contrast to domestic efforts (Mitchell, 2020).

Firefighters themselves, as represented by the International Fire Chiefs Association and a survey sample of Florida firefighters, mitigate personal PFAS dangers through safety bulletins and best handling procedures, though individual understanding of PFAS risks remains limited and AFFF replacement occurs at a branch level (Caban-Martinez et al., 2019; International Fire Chiefs Association, n.d.).

Ultimately, while PFAS has remained in use, the frame under which its use is debated has shifted significantly – no longer is the potential harm a question of major contention; the core point of contention today is what the best way to mitigate that harm is.

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