Ablation Rates of Si-C Matrix Composites from Steam Jet Exposure
(Technical Topic)

Consumers' Visions for Sustainable Aviation Futures and Their Influence on Practices in the Airline Industry
(STS Topic)

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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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Introduction

The efficiency of an aircraft engine can be increased primarily by two methods: 1) increasing the maximum temperature it can burn at, and 2) decreasing the weight of the engine itself. Traditionally, jet engine manufacturers have used nickel-based superalloys that can withstand fairly high temperatures for extended periods of times, but new ceramic-based materials have been gaining traction as a higher temperature, more durable alternative. The Achilles' heel of these ceramics is that they deteriorate fairly quickly in the presence of water vapor; a common byproduct of combustion reactions. My technical thesis project focuses on a particular ceramic composite and coating material developed by the project's sponsor, and aims to measure the rate at which it deteriorates when exposed to a high temperature steam jet. Decreasing operational costs is clearly the main incentive for aircraft manufacturers to create more efficient turbines, but over the last two decades many companies have begun to adopt more sustainable business practices at their own expense. Alongside my technical research, I will be exploring how consumers are able to nudge airline companies towards environmentally friendly practices, as well as how consumers develop new notions of what sustainable air travel could look like.

Technical Topic

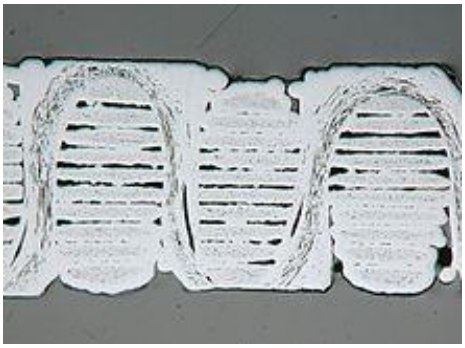

Figure 1 - SEM image of a woven ceramic matrix composite

The particular ceramic material that is being tested is a ceramic matrix composite (CMC) composed of silicon carbide. A CMC is essentially made by laying out a grid-like matrix of ceramic material, and "weaving" through it long strands of ceramic fibers, similarly to a carbon fiber. Figure 1 depicts a typical woven ceramic composite as imaged by a scanning electron microscope. By creating a braid of ceramic strands and layering many of these braids on top of one another, a composite material is produced that has high temperature resistance and low thermal expansion, the hallmark of most ceramics, but can also stand up to high stresses, is low density, and is incredibly resistant to crack propagation – one of the major downfalls of traditional ceramics (Golden, 2017). Additionally, when heated above ~1000 C, the silicon carbide forms a solid silicon oxide (SiO_2) "shell" that encompasses the inner matrix. The SiO_2 shell grows slowly, but is enough to completely protect it from oxidation in dry environments, making silicon carbide ideal for high temperature, non-combustive applications. In jet turbines, though, where combustion abounds, a considerable amount of water is produced. This deteriorates the protective SiO_2 layer more quickly than it can regenerate, causing oxidation and volatilization to occur in the silicon carbide. This effect can lead to erosion rates of up to 1 μm/hour (dos Santos et al., 2011), a considerable amount for blades with lifetimes of up to 10,000 hours.

To combat this erosion, many CMCs are protected by what is called an environmental barrier coating. These coatings are on the order of ~1 mm to ~100 μm, and are composed of complex oxides that are more resistant to water vapor than the SiO_2 that naturally forms on the

silicon carbide composite. Environmental barrier coatings were developed to parallel thermal barrier coatings, which are applied to traditional nickel-based superalloy turbine blades to insulate them from the inlet temperatures that surpass nickel's melting point. While the primary function of environmental barrier coatings is to prevent oxidation of the CMC, they have the added benefit of insulating the ceramic material and preventing repeated thermal expansion and contraction, which can cause microscopic crack formation called thermal fatigue. Silicon carbide CMCs are very common and have been the subject of numerous studies, and thus is not the main focus of this project. Instead, it is the novel environmental barrier coating, developed by Rolls Royce, that we are interested in testing.

Some studies have been done on deterioration rates of different EBCs at high temperatures, but, as dos Santos et al. point out, many laboratory setups neglect the high velocity of the incoming water vapor in a turbine environment. Our project design surmounts this shortcoming by rapidly heating water vapor through a 1 mm inner diameter alumina tube, causing it to expand quickly and achieve a velocity of ~100 m/s and temperature of ~1400 C, accurately mimicking a turbine environment. This steam jet will then be shot from a distance of ~2 mm at the silicon carbide test sample, which is treated with the novel environmental barrier coating, over the course of many weeks in increments of up to 8 hours at a time. Periodically, the test sample will be removed and its surface will be scanned to get an accurate measurement of the rate of surface ablation under accurate turbine conditions. At this time, water vapor is the only substance being used to wear down the test sample, but there are plans to incorporate other chemical species that are found in turbine environments in future iterations.

STS Topic

Since the turn of the 21st century, there has been a surge in public demand for companies operating on a global scale to adopt sustainable practices and alleviate the wounds they inflict on the earth. In recent years, as the scourge of humanity has grown more vicious and its repercussions more apparent, consumers have taken it upon themselves to blacklist companies that implement environmentally harmful practices and push for regulations that promote sustainability. Alongside this growth in consumers' awareness, academia has turned its attention to evaluating and quantifying the degree to which sustainable practices are being implemented in industry (Hussain & Hussain, 2015). Corporate social responsibility (CSR) has emerged as the leading lens through which a company's environmentally conscious actions can be analyzed, though also used to evaluate other social issues, such as racial and gender equality. Many CSR models exist for evaluating a company's sustainability, distinguished primarily by the hierarchal format they use (Geva, 2008).

In this research, no singular CSR model will be used, but instead the wealth of existing CSR research will be drawn upon to understand how companies in the aviation industry are pushed towards sustainable practices. The consumer side of aviation will also be analyzed using a STIR model (Richter et al., 2017) to understand how consumers form notions of what sustainable air travel could look like, how they act, or fail to act, on their support for eco-friendly aviation, and how technological myths can counteract progress by instilling a sense of stagnation.

Airlines' Sustainability Practices

Common sustainability efforts put in place by airlines can be largely divided into accomplishing one of the following goals: decreasing the engine's emissions, and decreasing the

company's overall waste. For the former, current leaders in green aviation make efforts to research green fuels and biofuel blends, limit their atmospheric and noise pollution, and optimize their takeoff and landing techniques. The latter goal of decreasing waste is accomplished in ways similar to most major corporations (sourcing organically produced meals and using compostable cutlery, promoting recycling of single-use items and using recycled materials for chairs, etc.) and therefore the specifics of these smaller scale changes will not be explored.

It's important to note, though, that cups and chairs are far easier to brand as "green" than a 10,000-pound engine, and thus these items generally become the focus of an airline's eco advertising campaign. Similarly, the eco-friendly consumers more readily associate these practices with other "green" brands they've chosen, and can feel comfortable knowing they've chosen the right company to fly with when their cup says it will be fully composted in 90 days. Beyond this, many subconscious effects of green brands work to make airline passengers feel drawn to certain companies, and airlines incorporate these designs as a result. Hwang and Choi's 2017 study of Korean consumers found that "psychological benefits of green brands (i.e. warm glow, self-expressive benefits and nature experiences) help to enhance the overall image of an environmentally friendly airline," and that these benefits make the consumer more likely to use that airline. Clearly, sustainable practices by airlines attract consumers, but this may lead to companies branding themselves as environmentally conscious, and tugging on said psychological reactions, without actually working to abate their emissions.

Biofuel has long been touted as the key to unlocking green aviation, with the most recent figures reported by NASA boasting reductions in particle emissions by "as much as 50 to 70 percent" when using a 50% blend of biofuel (Elliott, 2017). All aviation companies have felt the intense pressure to commit to sustainability measures, and many of the major players (United, Jet

Blue, Virgin, Lufthansa, Boeing and Airbus being the most notable) have joined the Sustainable Aviation Fuel User Group as a result. The group was formed in 2008 and works to advance biofuel research and expedite its widespread use. In 2012, only 15% of industry demand was represented, but an increase in consumer pressure in recent years has increased this number to 33% of commercial aviation fuel demand (SAFUG, 2020). Consumers know that airlines won't cover the cost of using biofuels entirely, though, and are willing to cover up to a 13% markup in price if the plane uses a substantial amount of biofuel (Rains et al., 2017). Both actively and through subconscious attraction, consumers have pushed airlines towards sustainability.

Consumers' Attitudes Towards Green Aviation

For many consumers, the term "green aviation" is an oxymoron, a pie-in-the-sky idea that cannot be attained with our current technology. Younger consumers especially, who use terms like flygskam (Swedish for "flight shaming") and hope for international railways rather than green airplanes, may hold the belief that a sustainable future can only be achieved by putting an end to commercial aviation. While it's certainly true that high-speed rail offers a feasible alternative to domestic flight, the as of yet unparalleled speed of airplanes and their ease in surmounting geographic obstacles makes it essentially impossible for aviation to cease as a means of commercial transportation. Regardless, green aviation is an entirely feasible concept, but uncertainty and misinformation plague the public's hopes for a greener future.

The previously referenced NASA study boasting emissions reductions of up to 70% and consistent improvements in turbine efficiency decade after decade proves that a sustainable future with aviation is well within reach. As Gegg et al. underline in their 2014 study of constraints on the biofuel industry, many airlines face uncertainty about future regulations they will need to meet, and if a reliable supply of biofuel will exist if they make a commitment.

Similarly, though consumers are willing to pay more for sustainable flights (Rains et al., 2017), they are uncertain as to how sustainable biofuel is, and its overall safety as a fuel source (Filimonau et al., 2017). Also, while many environmental efforts are made by consumers in other areas of consumption, travel is often viewed as an exception, like a vacation that doesn't fall victim to one's standard discretions on spending and luxury. Some consumers even fail to link air travel to pollution altogether (Hares et al. 2010). Lastly, some consumers report a sense of stagnation, as new innovations seem to make major headlines and then disappear in a cyclical fashion (Peeters et al., 2016). My research aims to expand on how consumers codify their sustainable behaviors, how they perceive sustainability efforts by airlines, and how they distinguish between efforts done to lure customers versus truly eco-conscious developments. Also, ways to combat misinformation will be explored.

Next Steps

- This semester:
    - Nail down a key research pertaining to aviation sociotechnical futures
    - Decide if the focus should shift more to consumers notions of airlines, sustainable practices etc. and less on why airlines try to act sustainably
- Early Spring
    - Work out a cohesive overview of consumers' attitude towards sustainable aviation
        - Include a brief history of green aviation's evolution
- Late Spring
    - Propose methods for educating the public on real, concrete developments in green aviation and debunking common myths

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