Thesis Project Portfolio

AIAA 2022-2023 Undergraduate Hybrid-Electric Regional Turboprop Aircraft Design

(Technical Report)

Assessment of the Environmental Effects of Wind Turbines and BPA Emissions

(STS Research Paper)

An Undergraduate Thesis

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Executive Summary

The drive for recent technological developments has been centered around the concept of "sustainability", with particular emphasis on the environmental sustainability of technological systems and their implementations. The global aviation industry has the notorious reputation of consuming an annual average of 73 billion gallons of aviation fuel with a peak of 98 billion in 2019, accompanied with fossil fuel consumption marking a record high 136,018 terawatt-hours in the year of 2021. In the industries of aviation transportation and energy generation, two technological systems have observed remarkable focus with regards to sustainable development: the hybrid-electric regional turboprop and the wind turbine. While not strictly new technological systems, they are proposed alternatives that have received increasing attention and acclaim in recent years, but little scrutiny – an interaction that may result in disastrous consequences.

As part of their continuing initiative to reduce aviation fuel consumption, the American Institute of Aeronautics and Astronautics presented a design challenge to design a hybrid-electric turbo-propeller aircraft for regional commercial purposes. The challenge outlines a series of requirements and objectives defined for the aircraft beyond standard certifications for regional applications, namely: comparable design ranges and flight speeds to conventional, gas-powered turbo-propeller aircraft, a minimum 20% fuel consumption reduction for short range trips of 500 nautical miles, and utilize technology that could be certified in 2034, with an entry-of-service of 2035 set for all components of the aircraft. To begin the design process, the team of nine undergraduate students researched advantageous aerodynamic structural features for conventional, top-wing turbo-propeller aircraft designs as well as state-of-the-art developments in aviation electric propulsion schemes, energy systems, propeller designs, as well as general developments in aviation. Subsequently, initial CAD designs and CFD meshes were developed, analyzed via weight estimation and high-fidelity vorticity simulators, then refined and optimized for the constraints determined for a conceptual

hybrid-electric aircraft. The final design was then selected and optimized via an assortment of aircraft design and analysis software to effectively fulfill the design requirements.

As alternative energy storage systems, be it battery systems, fuel cells, or environmentally friendly "sustainable air fuels" were unable to adequately meet the technological deadlines, a turbo-electric configuration was chosen to satisfy the hybrid-electric requirement for the final design; thrust and energy generation was sourced from the gas turbine, with electricity diverted to the electric motors as an improvement to the specific fuel consumption of the propulsion configuration. The aircraft was then aerodynamically optimized for this configuration with technological systems with high probability of a 2035 entry of service, of which a technical report will be compiled and submitted to the American Institute of Aeronautics and Astronautics for final review and ranking.

The challenges encountered by the hybrid-electric design can be projected onto the wind turbine. The technology, over the recent decades, has been proposed as the environmentally friendly power generation alternative to hydrocarbon fuel systems, with comparable scalable power yield. This claim can be sourced from major regions of the globe regardless of political, social, or economic interests. Yet, interrogating this claim yields a disappointing answer. Wind turbines face numerous limitations in their operating range. The power output of wind turbines is only significant in the range of 12-60 km/h and must be stopped at wind speeds of 88 km/h to avoid severe damage. To maintain power output corresponding to an increasing demand, the enlarged wind turbines are constructed from epoxies and thermoset polymers due to the sheer weight and strength requirements. These epoxies have a composition fraction of 30-37% Bisphenol A, a chemical notorious for its detrimental health effects, and is released into the environment when the wind turbine blades experience severe erosion along the leading edge with regards to environmental conditions.

The safe limit of BPA emissions in water is defined as 0.1 ppm by the WHO. The conventional 2 MW wind turbine blade is estimated to contain 1.56-2.52 kilograms of pure BPA along the leading edge. Cross-matching the annual production of a standard 500 MW coal power plant requires a maximum of 450 2 MW wind turbines in ideal operation and a minimum land area of 225 square kilometers. The potential BPA emissions produced by wind turbines become astronomical when considered alongside the electrification of conventional hydrocarbon systems. While designed to operate for 20 years, photographic evidence of onshore and offshore wind turbines depicts exposure of the turbine blade core matrix material within 2-5 years operation without protective coating, or after 10 years with coating materials, well before the defined threshold. Further breakthroughs in materials are necessary before considering the widespread implementation of wind turbines.