Mission Profile Performance Analysis of an On-Ground Serial Hybrid-Electric Drivetrain for Aircraft Propulsion

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I. Introduction and Background Information

Currently, aviation contributes 2.4% of the overall greenhouse gas emissions worldwide [1]. However, the industry has been identified as the fastest-growing source of greenhouse gas emissions, despite significant efficiency gains and the implementation of emissions reduction technologies over the past 60 years. This prompted regulatory bodies worldwide to pass stringent regulations. For example, the Government of Canada has pledged as of April 2021 to reduce emissions by 40–45% compared to 2005 levels by 2030 [2]. New aviation technologies are needed for this goal to be achieved.

The ideal solution to eliminate aviation-based emissions would be fully electric aircraft. However, the current level of battery technology is simply insufficient. Currently, batteries have approximately 50 times lower specific energy than liquid hydrocarbon fuels [3]. Thus, the batteries involved in these fully electric aircraft are large and heavy, and it is difficult for them to produce the required energy. It is proposed that hybrid-electric aircraft are developed as a compromise of the two conflicting areas of pollution reduction and aircraft required power.

II. Project Overview

Hybrid electric propulsion involves using both traditional fossil fuels and electric power to operate an aircraft. The overall goal is to reduce fuel burn, emissions, and noise. Since hybrid-electric propulsion is at an early stage of development and implementation in the aviation industry, its performance must be thoroughly evaluated and improved to ensure its success.

In this work, a full-scale theory-based aircraft flight-performance model that determines the power requirements of a sample aircraft during various mission profiles is combined with a fully implemented serial hybrid-electric drivetrain installed in an on-ground research facility. The combination of the aerodynamics and power management models with the on-ground drivetrain system enables performance evaluation of the drivetrain, which has future potential to be implemented in a real aircraft. The performance evaluation compares the power required of the aerodynamics model to the power output recorded using the drivetrain system under identical operating conditions.

III. Aerodynamic Model

The aerodynamic model is based on the dimensions and weight distribution of a Pipistrel Virus 912, which has a similar power output to the hybrid-electric drivetrain ground-test stand. The power requirements of each flight segment of a given mission profile are calculated using the known L/D vs. velocity curve of the reference aircraft and general aerodynamic equations. First, the power requirements for the reference aircraft operating using a traditional internal combustion engine are calculated. The calculations are then repeated for the reference aircraft operating using a hybrid-electric powerplant. This allows not only for a confirmation of the power output of the physical hybrid-electric drivetrain system, but also for performance, emissions, and power output comparisons between a traditionally powered aircraft and a hybrid-electric powered one of the same size.

The power requirement calculations of the hybrid-electric aircraft case require the associated drag to be calculated. An accompanying weight analysis that ensures all components are accounted for and are within the maximum takeoff weight is completed. The weight analysis determines the allowable mass of the batteries and associated components since most components found on the traditional internal combustion engine-powered aircraft are still needed on the hybrid system, such as the aircraft’s external structure, the instrumentation, the crew, and the engine itself. The main differences in the hybrid-electric configuration are the addition of the battery system and a decrease in fuel volume since the batteries provided a portion of the power. The goal is to maximize the proportion of power provided by the batteries (known as the degree of hybridization) so that the system may use as little amount of fuel as possible, thus reducing overall emissions. The degree of hybridization depends on the level of battery technology used, specifically its battery energy density.

IV. On-Ground Serial Hybrid-Electric Drivetrain

The on-ground serial hybrid-electric drivetrain can deliver more than 60 kW of mechanical power at the shaft of the electric propulsion motor. The power comes from two sources: electric battery power and traditional hydrocarbon fuels. As a series hybrid system, the internal combustion engine is used to power an electric generator. Power from the electrical generator and the battery emulator are combined at a DC bus before being converted into mechanical power at the motor shaft. The system is equipped with sensors and instrumentation that measure real-time electrical power generation and consumption, mechanical power generation, and other operational variables such as the temperature of the components and cooling fluid temperature.

V. Mission Profile Performance Analysis

The performance analysis of the on-ground system is accomplished using the following methodology:

1. A mission profile is defined and input into the aerodynamics model.
2. The power, motor speed, and motor torque requirements of each flight segment are determined.
3. These requirements are then used as inputs to the on-ground system.
4. The system is operated to satisfy the requirements of the mission profile.
5. The actual operational parameters of the drivetrain are recorded in the data acquisition system.
6. The data is analyzed, and the methodology can be repeated for other desired mission profiles that highlight other essential performance parameters.

Since the drivetrain is an on-ground system, the performance of hybrid-electric propulsion systems can be tested and perfected because system parameters and flight profiles can be easily modified for an individual test cycle without the need to consider airworthiness constraints. This enables the evaluation of the drivetrain under specific flight mission requirements, mission optimization, and improvement of the aerodynamics model. Furthermore, the installed system enables the change of the behaviour and performance of the DC power supply to the bus from the electric power source, i.e., batteries. This allows for range and power output predictions of aircraft powered with batteries that have capabilities that are not currently on the market.

VI. Expected Results

The expected outcome of the comparison between the baseline internal combustion engine-powered aircraft model and the hybrid-electric drivetrain setup is that a substantial reduction in pollutant emissions is achieved while maintaining performance and range. Although the hybrid electric test stand is an on-ground one, the hybrid-electric aircraft aerodynamics model will allow us to apply results obtained from the hybrid-electric drivetrain setup to real aircraft.

Detailed system description and results obtained from preliminary experiments will be presented, highlighting the system's capabilities operating through more complex missions and using different degrees of hybridization. The potential for performance gains via power management optimization will be investigated.

The results presented will highlight prospects of hybrid-electric propulsion performance and range capabilities compared to current aircraft of a similar power output capability. The data, analysis, and conclusions drawn from the proposed experimental procedure will be influential in the future of hybrid-electric propulsion. They will provide results showcasing successful techniques and operational parameters that can be used to design systems intended for flight. This will help Canada reach its emissions reduction goal by 2030 and continue to be a world leader in aviation technologies.

VII. References

[1] J. Overton, "Fact Sheet: The Growth in Greenhouse Gas Emissions from Commercial Aviation - Part 1 of a Series on Airlines and Climate Change," *Environmental and Energy Study Institute*, 2019. .

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