UAM Hybrid Power System

Final Report – Team 9

MECH 460: Team Project, Conceive and Design

Department of Mechanical and Materials Engineering

Queen's University

Following the professional engineering practice, we bear the burden of proof for original work. We have read the Policy on Academic Integrity posted on the Faculty of Engineering and Applied Science web site engineering.queensu.ca/policy/Honesty and confirm that this work is in accordance with the policy.

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Based on the information provided to me by the Team, they have satisfactorily completed both the technical work and the deliverables for their project.

______________________________ Date: Dec 6, 2021

Professor Kim

Executive Summary

Urban populations are quickly outgrowing existing intracity transportation infrastructure. To meet intracity travel demands, new technology must be developed to alleviate congested ground transportation. Urban Air Mobility (UAM) vehicles are increasingly becoming popular in the aviation industry, due to their small form factor and suitability for short intracity flights and utilization of the relatively empty airspace above cities. UAM vehicles take advantage of vertical takeoff and landing (VTOL) strategy. The Structural and Multidisciplinary System Design (SMSD) team at Queen's University has been working on a UAM vehicle and has requested the design of a hybrid power system. The vehicle must have VTOL capabilities and the ability to complete a 150 km trip while travelling at least 110 km/h, with a desired power system weight of 700 kg or less. The hybrid power system to be developed for the UAM vehicle will consist of a gas turbogenerator, batteries, AC electric motors, and propellers.

To determine an accurate estimate of the power requirements needed for a 150 km trip, a mission simulation was created in Python. The mission simulation is based upon first principles, utilizing free body diagrams and power equations to determine the power output required during the entire trip. This simulation segmented the flight into 3 main sections: vertical takeoff, horizontal cruise, and vertical landing. By defining velocity profiles from assumed vehicle top speeds and vehicle accelerations, the forces and thus power requirements at each timestep in the flight simulation were determined. To find the forces acting on the aircraft, the software package OpenVSP was used to determine lift and drag coefficients. It was determined that a cruise speed of 264 km/h would generate a lift force equal to gravity, allowing the VTOL propellers to be completely turned off during cruise. Based on this cruise speed, the trip can be completed in just under 38 minutes. The simulation output resulted in a peak power for the VTOL motors of 560 kW, a peak power for the forward motors of 107 kW, and a total power consumption of 94.3 kWh. There are 8 VTOL motors and 2 forward motors. Using the simulation outputs, potential designs were suggested that utilize 350 kW, 250 kW and 150 kW turbogenerators, respectively. The turbogenerator operates at a constant power output to maximize efficiency, and the lithium-ion batteries cover fluctuations in power output. The resulting degrees of hybridization, power system weight, and battery power consumption for each initial design option are summarized in Table 6.

After presenting these findings to the client, the 250 kW turbogenerator design was chosen. The final design includes three different power strategies that can be implemented on the same aircraft. The first option had the turbogenerator on for the entire flight and fully recharged the batteries during the 33-minute cruise. The second design does not consider recharging and leaves the turbogenerator on for the entire flight. The final power strategy option would turn the turbogenerator off for the cruise phase of flight to reduce emission and utilize surplus battery capacity. The results of these three power strategies are summarized in Table 10. These power strategy options highlight the tradeoffs between downtime, degree of hybridization, and fuel consumption. The location of refueling stations, trip demand, and the life cycle of vehicle components must be considered when choosing a strategy, which is why the three options were presented to allow the client greater flexibility. Although three options are being presented, the option being recommended has a degree of hybridization (defined as battery energy/[battery + fuel energy]) of 17.8%, a power system mass of 683 kg and requires less than 14 minutes of downtime between flights for charging and refueling.

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