University of Victoria | Graduate Studies

Notice of the Final Oral Examination
for the Degree of Master of Applied Science

of

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BSc (University of Victoria, 2016)

"Evaluation of Hybrid-Electric Propulsion Systems for Unmanned Aerial Vehicles"

Department of Mechanical Engineering

Thursday, December 19, 2019
2:00 P.M.
Engineering Office Wing
Room 430

Supervisory Committee:
Dr. Afzal Suleman, Department of Mechanical Engineering, University of Victoria (Supervisor)
Dr. Curran Crawford, Department of Mechanical Engineering, UVic (Member)

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Dr. Helen Kurki, Department of Anthropology, UVic

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Abstract

The future of aviation technology is transitioning to cleaner, more efficient and higher endurance aircraft solutions. As fully electric propulsion systems still fall short of the operational requirements of modern day aircraft, there is increasing pressure and demand for the aviation industry to explore alternatives to fossil fuel driven propulsion systems. The primary focus of this research is to experimentally evaluate hybrid propulsion systems (HEPS) for Unmanned Aerial Vehicles (UAV) which combine multiple power sources to improve performance. HEPS offer several potential benefits over more conventional propulsion systems such as a smaller environmental impact, lower fuel consumption, higher endurance and novel configurations through distributed propulsion. Advanced operating modes are also possible with HEPS, increasing the vehicle's versatility and redundancy in case of power source failure.

The primary objective of the research is to combine all of the components of a small-scale HEPS together in a modular test bench for evaluation. The test bench uses components sized for a small-scale UAV including a 2.34*k*W two-stroke 35*cc* engine and a 1.65*k*W brushless DC motor together with an ESC capable of regenerative braking. Individual components were first tested to characterize performance, and then all components were assembled together in a parallel configuration to observe system-level performance. The parallel HEPS is capable of functioning in the four required operating modes: EM Only, ICE Only, Dash Mode (combined EM and ICE power) as well as Regen Mode where the onboard batteries get recharged. Further, the test bench was implemented with a supervisory controller to optimize system performance and run each component in the most efficient region to achieve torque requirements programmed into mission profiles. The logic based controller operates with the ideal operating line (IOL) concept and is implemented with a custom LabView GUI.

The system is able to run on electric power or ICE power interchangeably without making any modifications to the transmission as the one-way bearing assembly engages for whichever power source is rotating at the highest speed. The most impressive of these sets of tests is the Dash mode testing where the output torque of the propeller is supplied from both the EM and ICE. Working in tandem, it was proved that the EM was drawing 19.9*A* of current which corresponds to an estimated 0.57*Nm* additional torque to the propeller. Finally, the regenerative braking mode was proven to be operational, capable of recharging the battery

systems at 13*A*. All of these operating modes attest to the flexibility and convenience of having a hybrid-electric propulsion system.

The results collected from the test bench were validated against the models created in the aircraft simulation framework. This framework was created in MATLAB to simulate the performance of a small UAV and compare the performance by swapping in various propulsion systems. The purpose of the framework is to make direct comparisons of HEPS performance for parallel and series architectures against conventional electric and gasoline configuration UAVs, and explore the trade-offs. Each aircraft variable in the framework was modelled parametrically so that parameter sweeps could be run to observe the impact on the aircraft's performance. Finally, rather than comparing propulsion systems in steady-state, complex mission profiles were created that simulate real life applications for UAVs. With these experiments, it was possible to observe which propulsion configurations were best suited for each mission type, and provide engineers with information about the trade-offs or advantages of integrating hybrid-electric propulsion into UAV design.

In the Pipeline Inspection mission, the exact payload capacities of each aircraft configuration could be observed in the fuel burn versus $C_{L,cruise}$ parameter sweep exercise. It was observed that the parallel HEPS configuration has an average of 3.52*kg* lower payload capacity for the 35*kg* aircraft (17.6%), but has a fuel consumption reduction of up to 26.1% compared to the gasoline aircraft configuration. In the LIDAR Data collection mission, the electric configuration could be suitable for collection ranges below 100*km* but suffers low LIDAR collection times. However, at 100*km* LIDAR collection range, the series HEPS has an endurance of 16hr and the parallel configuration has an endurance of 19*hr*. In the Interceptor mission, at 32*kg* TOW, the parallel HEPS configuration has an endurance/TOW of 1.3[*hr/kg*] compared to 1.15[*hr/kg*] for the gasoline aircraft. This result yields a 13% increase in endurance from 36.8*hr* for gasoline to 41.6*hr* for the parallel HEPS. Finally, in the Communications Relay mission, the gasoline configuration is recommended for all TOW above 28*kg* as it has the highest loiter endurance.