Integration and Power Management of Turbo-Electric Propulsion for Multirotor UAV

Rannock Thomas & Dr. Kurt Rouser

Abstract / Objective

This research aims to develop and study the feasibility of a novel hybrid turbo-electric propulsion system for a multirotor unmanned aerial vehicle (UAV). This project includes the physical integration of a turbo-electric power system onto a dodecacopter. As well as the development and testing of a power controls system capable of throttling the gas microturbine and conditioning the electrical power output to meet the multirotor's constant voltage and transient current requirement.

Figure 1: X-Fold Dodecacopter outfitted with turbo-electric power system.

System Theory Overview

- A gas turbine converts energy-dense hydrocarbon fuels into mechanical work at a rate regulated by an active throttle controller.
- An electrical generator then converts mechanical work into electrical power to supply the aircraft.
- Electrical power generation is regulated by a "VESC" motor controller and supplied to both a small flight battery and to power the multirotor.
- The battery charge level and aircraft power demand is sent as feedback to the throttle controller and VESC control loops.

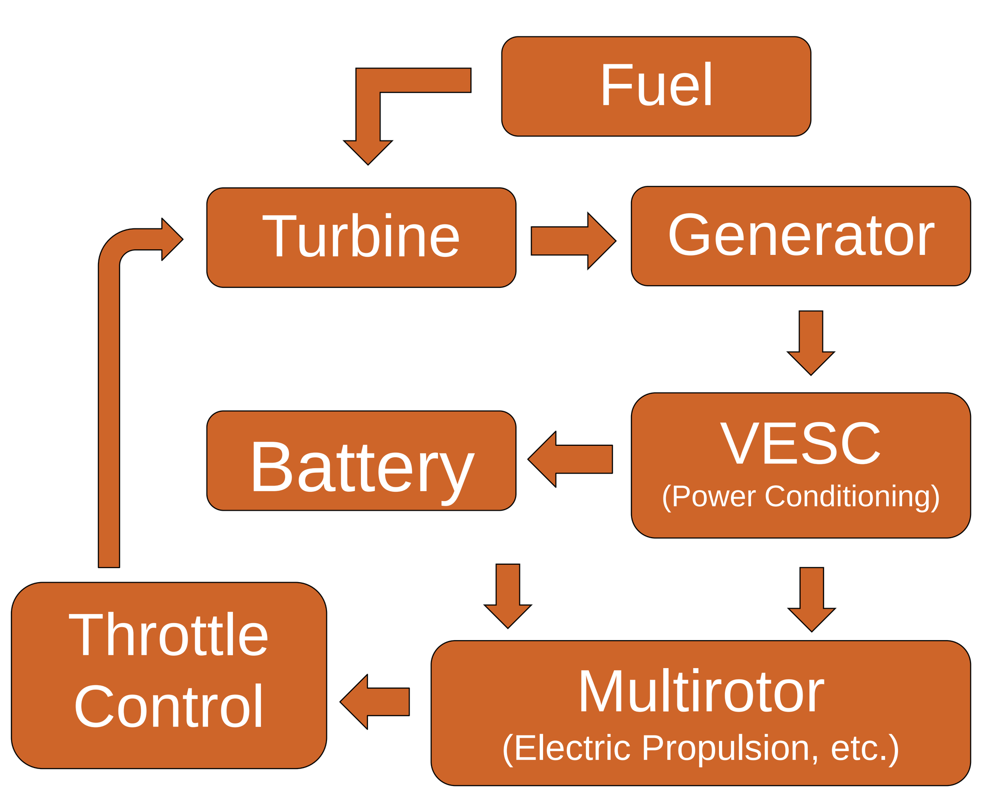

Figure 2: Block diagram outlining the system operational architecture.

Methodology

Electrical Power Regulation

- A Bi-Directional AC-DC converter "VESC" is used to regulate power generation and boost the output voltage with high frequency modulation of the generator coils.

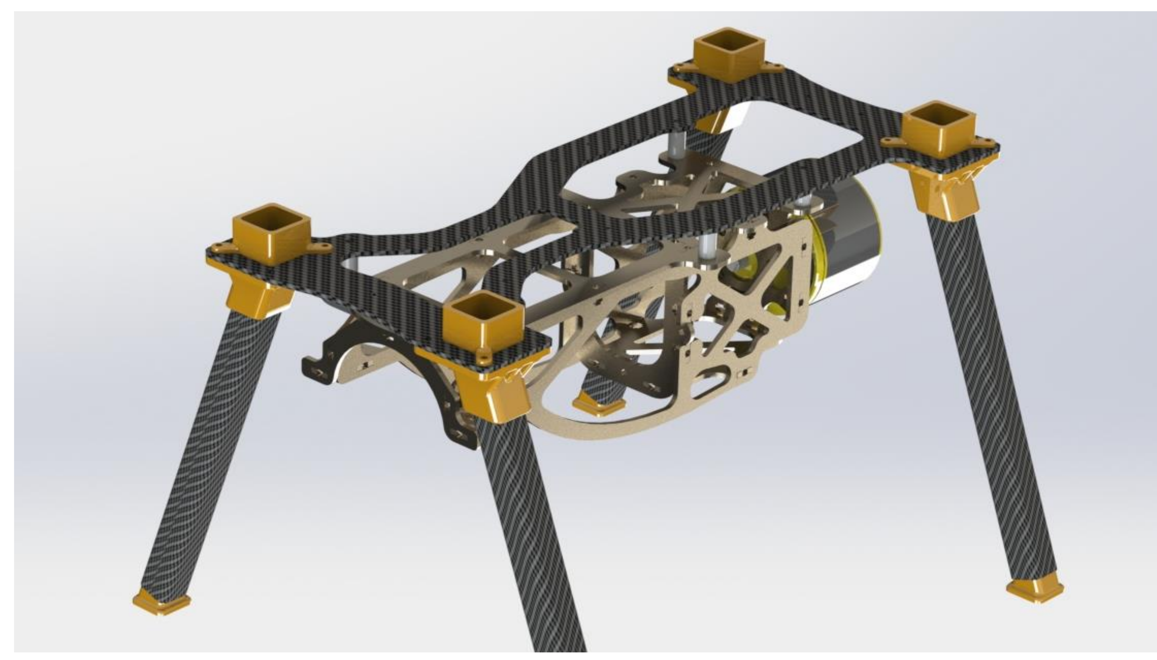

Figure 3: CAD rendering of the turbo-electric frame and redesigned landing gear assembly to mount the power system to the multirotor.

Active Throttle Controller

- A low-cost proportional-integral-derivative throttle controller was developed to maintain turbine shaft speed and generator voltage.

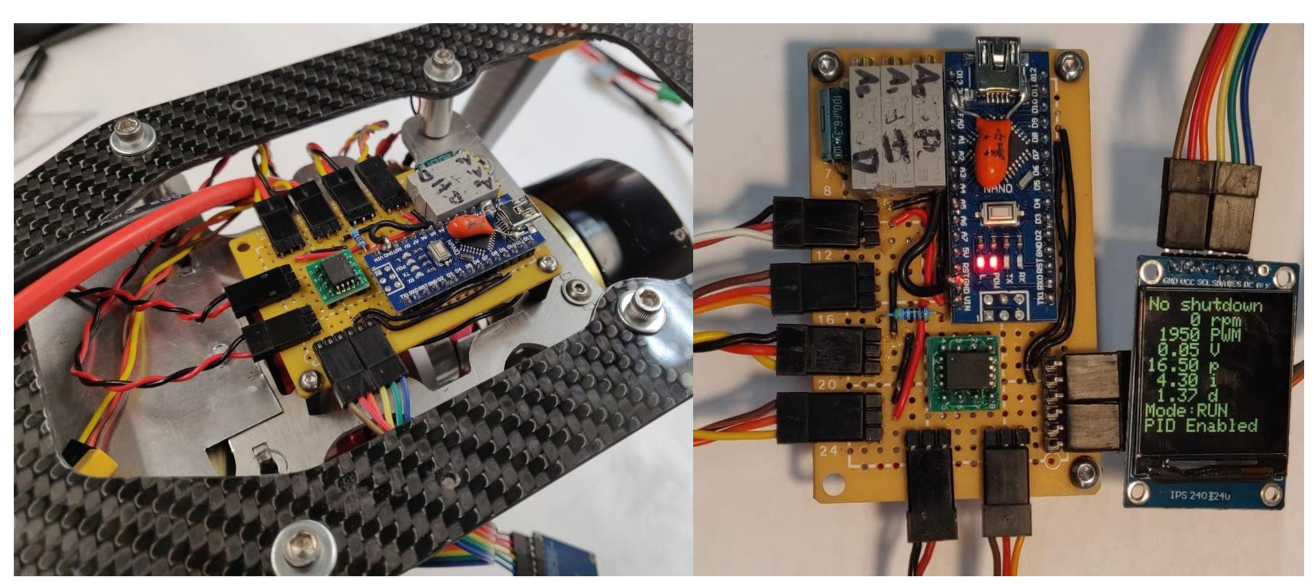

Figure 4: Active throttle controller installed on turbo-electric system (left) and on test bench (right).

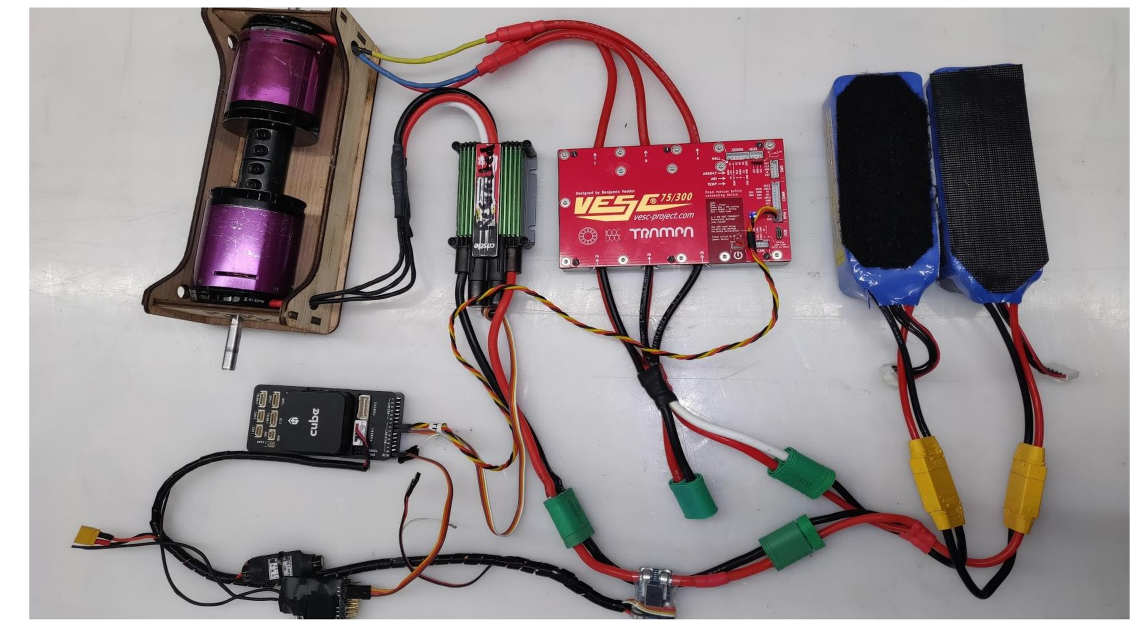

Figure 5: Experimental apparatus for VESC testing, utilizing a motor/generator pair, LiPo batteries, a BLDC motor driver, and a Pixhawk for logging power data.

Physical Integration

- A lightweight frame of aluminum and carbon fiber was design and built to couple the turbine and generator as well and mount the unit to the multirotor.

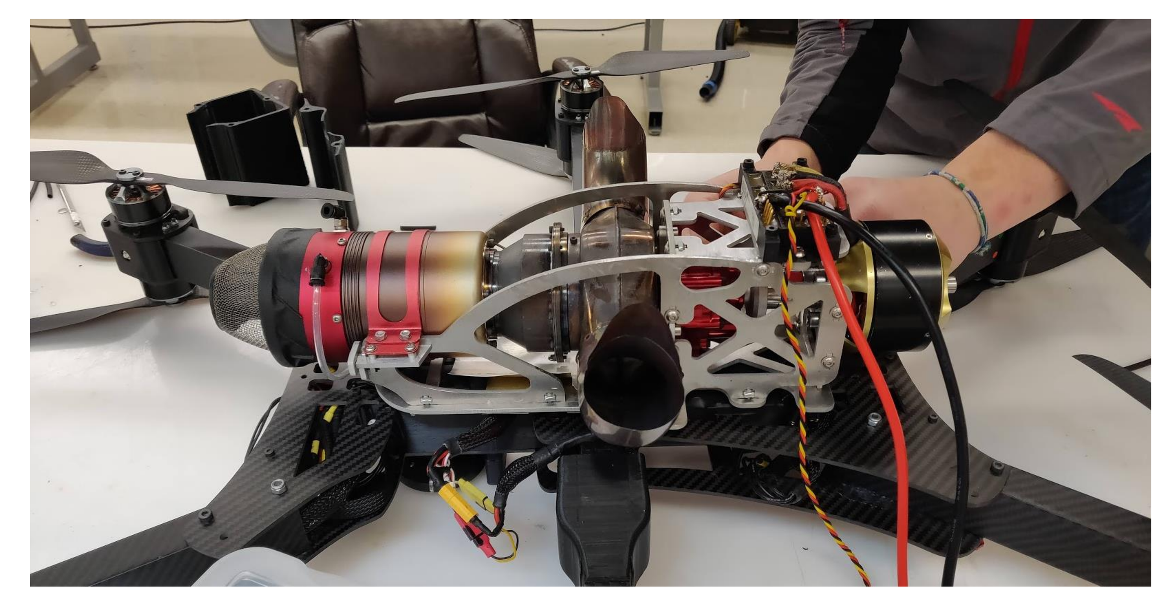

Figure 6: Test fitment of system during the physical integration process.

Voltage and Current Measurement

- Mauch power modules installed on the turbo-electric unit and the multirotor provide experimental power data and provide feedback for the control system.

Results

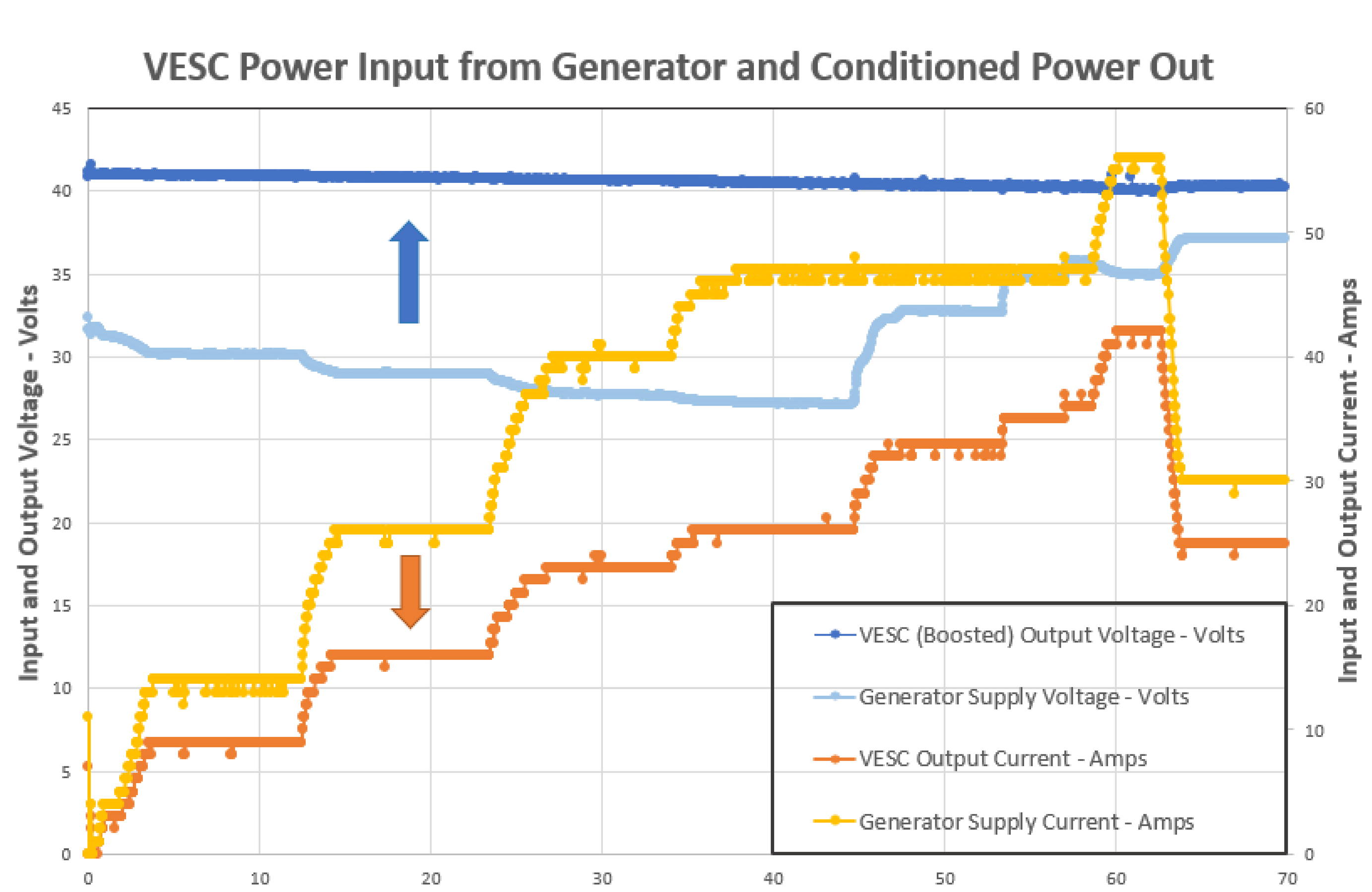

Figure 7: Comparison of generated voltage and current with the regulated power out of the VESC, note the constant voltage output as the VESC efficiently boosts the voltage in exchange for current flow.

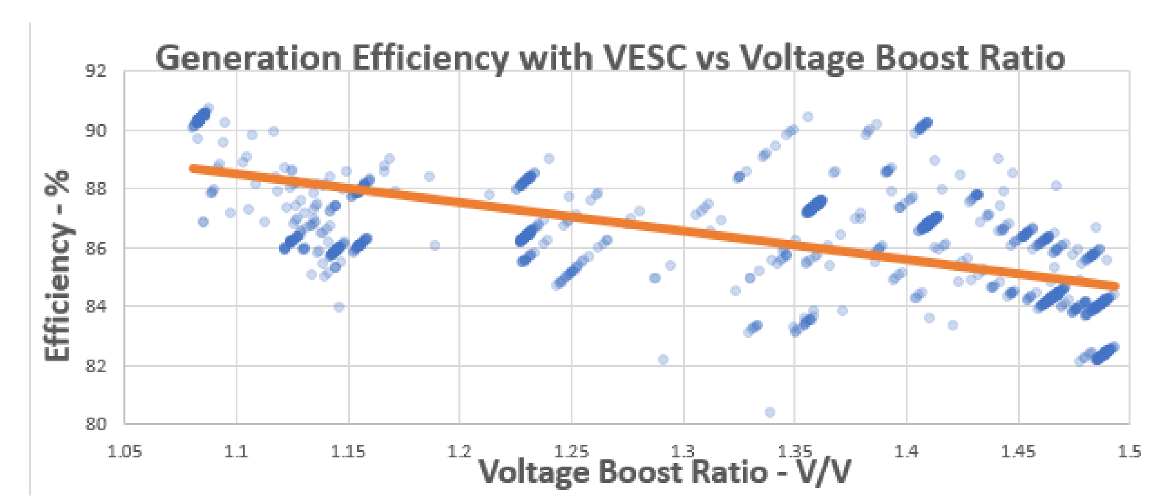

Figure 8: Overall generation efficiency for test setup (figure) 5 plotted against boost ratio

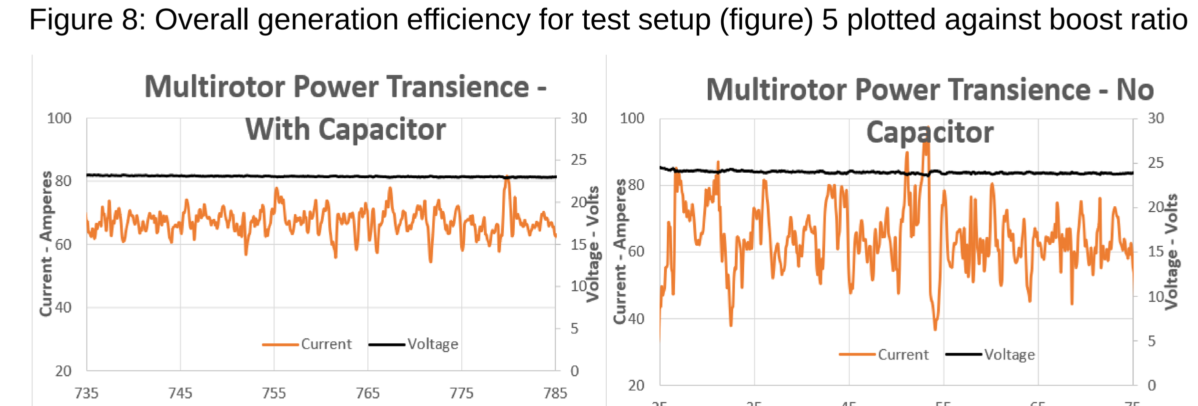

Figure 9 & 10: Plots comparing the fluctuations in the multirotor power demand during equivalent flight conditions with and without the addition of a capacitor.

Discussion

Multirotor Integration

- The weight of this experiment turbo electric system ended up at the maximum take off weight leaving no additional payload capacity.
- The addition of a capacitor on the multirotor's power bus was successful in halving the apparent current fluctuations, which reduced the require response rate of the generator system.

VESC Power Regulation

- Rectifying and regulating the generator 3-phase AC output to a constant DC voltage proved very effective using the VESC with regenerative braking.
- This system has proven to provide increased efficiency over a silicon-diode rectifier.
- VESC based active rectification allows for multiple output voltages from the same generator assembly, increasing system adaptability.
- An expected downwards conversion efficiency trend was observed with increasing voltage boost ratio, however the actual power conversion efficiency should be higher than indicted by the overall generation efficiency plot.

Future Work

- Characterization of combined system transient response and generation efficiency. As well as steady state performance across the throttle range.
- Further tuning of the active throttle controller and expansion of control features.
- Static ground test of multirotor with turbo-electric power.
- Flight testing of the turbo-electric multirotor!

Acknowledgements

A special thanks to Lew Wentz Foundation for providing funding for this research. Thanks to Dr. Kurt Rouser, Dr. Jamey Jacob, and the Unmanned Systems Research Institute for providing the guidance and resources that made this project possible. Finally, thanks to Kyle VanDeventer and Jay Welke for their assistance throughout the design and integration process.