EXPERIMENTAL EVALUATION OF TRANSIENT AND STEADY-STATE CHARACTERISTICS OF A 180KW TURBOELECTRIC-AIRCRAFT TESTRIG

By

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Abstract:

This thesis presents the experimental results of a turboelectric-aircraft power system operating under two electrical configurations. Hybrid turboelectric power systems enable increased versitility over their singularly hydrocarbon fuel or electrically based counterparts through the combination of their advantages: energy density in the case of combustion power systems, and power density in that of electrical systems. However, much of the research pertaining to such hybrid systems has been analytical, leaving a need for implementation and experimentation to characterize operating performance. The testrig assembled to undertake this work is comprised of a Cessna-172 airframe, a modified 180kW PBS-TP100 turboprop, and the components necessary to create two electrical configurations. The first of these configurations involved the use of a low system voltage, battery augmentation, and an inductive load in the form of electic motors; whereas the second configuration used a high system voltage, a variable-resistive load, and electrical power sourced exclusively from a turbine-driven generator. Custom electronics were fabricated to aid in the control of the variable-resistive load as well as for protection of the battery. The objective of the studies conducted on this system have been to evaluate the transient and steady-state performance of turboelectric aircraft under various engine and electrical load conditions. Configuration one was tested by varying electrical throttle at maximum engine throttle, whereas configuration two was tested through repeated variation in electrical load under four fixed engine throttle points. Engine operation data was acquired from every test including output shaft torque, speed of the free and gas turbines, and combustion gas temperature, while voltage, current, and power data was recorded at different locations within the electrical systems. Tests conducted on the first configuration showed 17kW of peak electrical power: 4kW from the generator and 13kW from the battery; while 142kW of mechanical power was transfered from the turboprop. Test two demonstrated consistent waveforms accross all four turbine throttle points, with peak power output reaching 11.5kW from the generator, and XXXXkW from the engine. Observations from these tests highlight the importance of capacitance to hybrid powertrains, the forces induced on turbine engines by electric load, and functional safety considerations in the design and operation of hybrid systems. This thesis provides insight into practical implementation of turboelectric power systems for future electrified aircraft.

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2.1 Turbine Engines

A cursory understanding of turbine engines is necessarry to contextualize this work, as their improved power to weight ratio and performance at altitude when compared to piston engines make them an ideal choice for use in hybrid electric aircraft. The following is a description of how a general jet engine with a single inlet and exhuast functions. This description corresponds to the station numbering found in 1 and is applicable to the subcategories of turbine engines discuessed later.

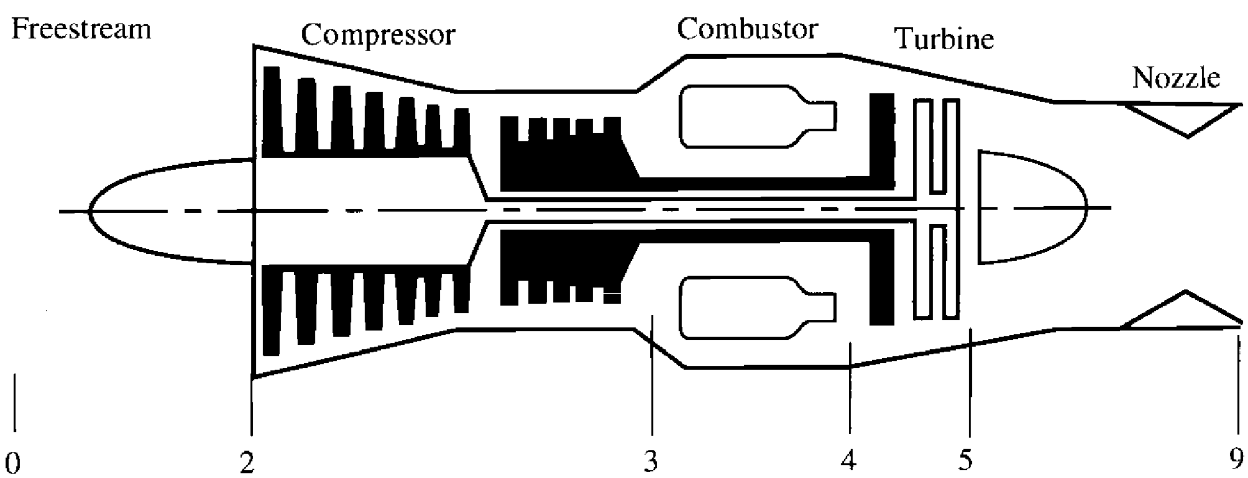

Figure 1: Ideal Turbojet with station numbering

The Inlet is the first section of the gas turbine engine, denoted by station numbers 0-2, and its operation and design are described in terms of the efficiency of the compression process, the external drag of the inlet, and the mass flow into the inlet. [6] Inlet design is most heavily influenced by whether the air entering it is subsonic or supersonic. Subsonic inlet design is simple, and typically involves selecting an operating velocity at which air compression is most efficient at the expense of performance at other velocities. Supersonic inlets must take the shockwaves endemic to supersonic flow into account for optimal performace. This is accomplished by adjusting inlet geometry to reduce flow velocity while adding as little weight to the system as possible. Variable inlet geometry will allow for increased efficiency accross many velocities.

Compressors, denoted by station numbers 2-3, increase the pressure of the flow obtained by the inlet such that the combustion and exhaust processes can be conducted more efficiently. Increasing the pressure of an initial volume of air results in the reduction of its volume, allowing for the combustion of the air/fuel mixture to occur within a smaller volume than it would otherwise. Turbine engines most commonly employ centrifugal or axial compressors. Figure 1 appropriately depicts an axial compressor in the makeup of the common turbine engine by virtue of their superiority. However, centrifugal compressors find use in smaller, less expensive engines due to their simple design. Centrifugal compressors are comprised of an impeller, which serves to increase flow velocity through rotation; a diffuser, which decreases the velocity of the flow thereby increasing its pressure; and a manifold which directs the compressed air into the combustor. Axial compressors are made of a series of stator vanes and rotor blades that are concentric to the axis of rotation. Each set of these stators and rotors is referred to as a stage. "The flow path in an axial compressor decreases in cross-sectional area in the direction of flow." [**?**] Each stage of the compressor results in an increase in air density. Thus, multiple stages are used in the design of high compression ratio turbine engines. Many turbines, including that which is depicted in figure 1, are equiped with dual axial compressors. Dual axial compressors allow for a more uniform loading of compressor stages, as well as for improved flexibility in the balancing between the initial and later stages.

Gas turbine engines fall into four categories: turbofan, turboprop, and turboshaft, and turbojet. Turbojets make use of a propelling nozzle to create thrust by allowing the heated exhaust created by a gas turbine to expand. [8]

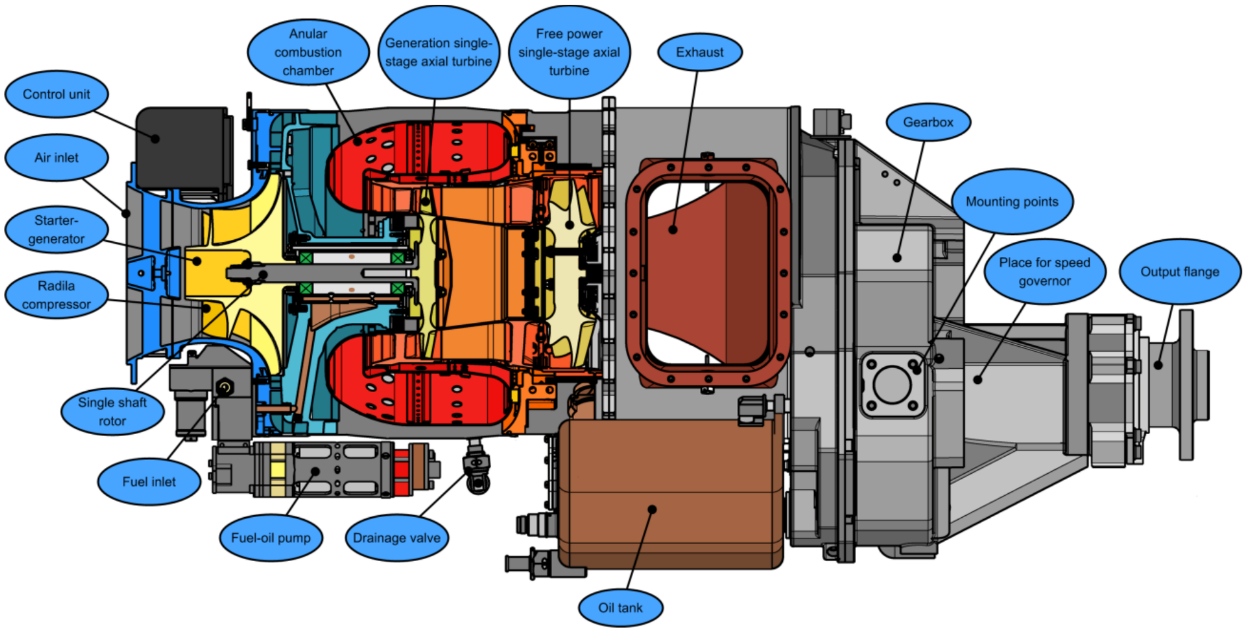

Figure 2: PBS TP100 Cutaway

2.2 Generator Theory

2.3 Battery Theory

2.4 Turboelectric Theory

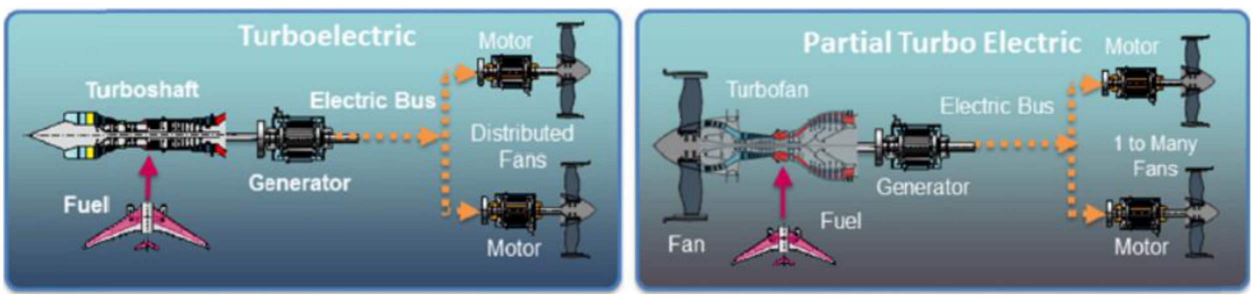

Figure 3: Turboelectric Architectures

2.5 Previous Work

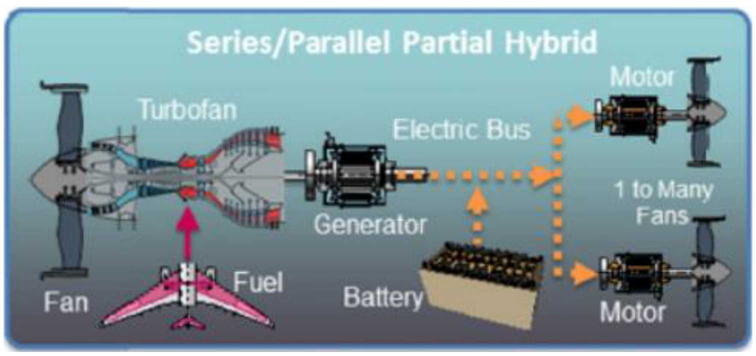

Figure 4: Parallel Turboelectric Design

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3.3.1 Data Acquisition

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REFERENCES

[1] PBS Aerospace, *Basic technical information turboprop engine tp100*, April 2015.

[2] Cheryl L. Bowman, Ty V. Marien, and James L. Felder, *Turbo- and hybrid-electrified aircraft propulsion for commercial transport*, 2018.

[3] Johnathan Burgess, Timothy Runnels, Joshua Johnsen, Joshua Drake, and Kurt Rouser, *Experimental comparison of direct and active throttle control of a 7 kw turboelectric power system for unmanned aircraft*, Applied Sciences **11** (2021), no. 22.

[4] Ralph Jansen, *Overview of nasa electrified aircraft propulsion activities*, NASA Glenn Research Center, 2017.

[5] Joshua Johnsen, Joshua Melvin, Joshua Drake, Muwanika Jdiobe, and Kurt Rouser, *Experimental evaluation of an electric powertrain designed for a 180-kw turboelectric aircraft ground test rig*, Journal of Engineering for Gas Turbines and Power **146** (2024).

[6] Jack Mattingly and Hans von Obain, *Elements of propulsion: Gas turbines and rockets 2nd edition*, AIAA, 2016.

[7] Joshua Melvin, *Integration and evaluation of a 180-kw turboprop engine with a turboelectric ground test rig*, Master's thesis, OKLAHOMA STATE UNIVERSITY, May 2021.

[8] NASA, *Turbojet engine*, NASA Glenn Research Center, 2017.

[9] Manuel Rendón, Carlos Sánchez, Josselyn Gallo Muñoz, and Alexandre Anzai, *Aircraft hybrid-electric propulsion: Development trends, challenges and opportunities (https://rdcu.be/cmg4u)*, Sba Controle & Automação Sociedade Brasileira de Automatica (2021).

APPENDICES

Title of Appendix (Not Numbered)

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