

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

By

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STEADY-STATE CHARACTERISTICS OF A 180KW
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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 versatility 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 electric 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 transferred from the turboprop. Test two demonstrated consistent waveforms across 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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CHAPTER I

INTRODUCTION

CHAPTER II

BACKGROUND

2.1 Turbine Engines

A cursory understanding of turbine engines is necessary 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 exhaust functions. This description corresponds to the station numbering found in 1 and is applicable to the subcategories of turbine engines discussed later.

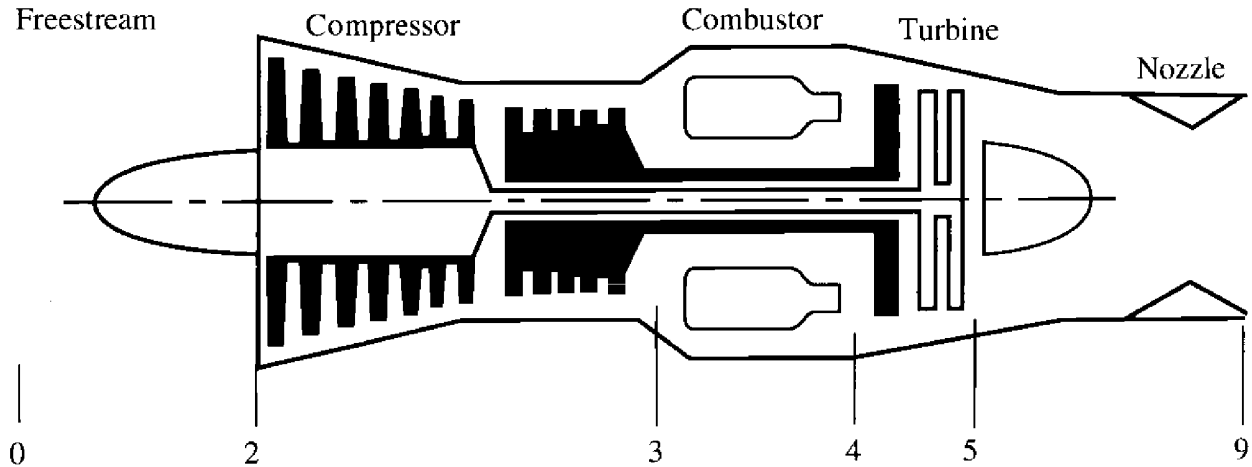


Figure 1: Ideal Turbojet with station numbering

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. [?] 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 performance. 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 across 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 equipped 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. [?]

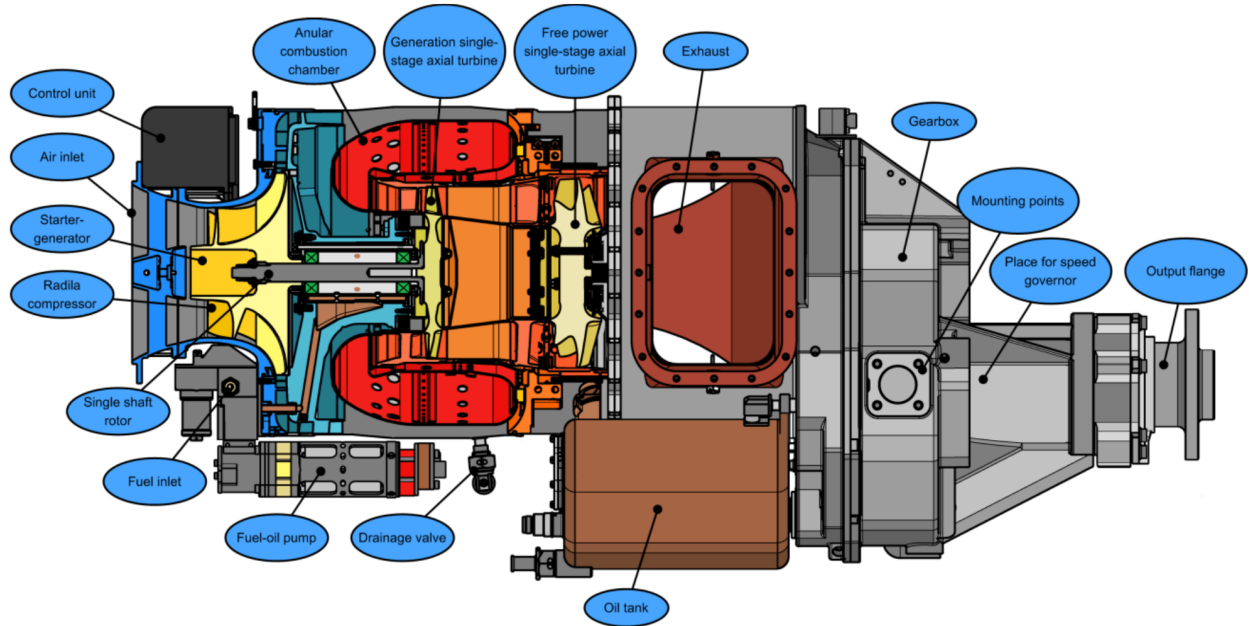


Figure 2: PBS TP100 Cutaway

2.2 Generator Theory

2.3 Battery Theory

2.4 Turboelectric Theory

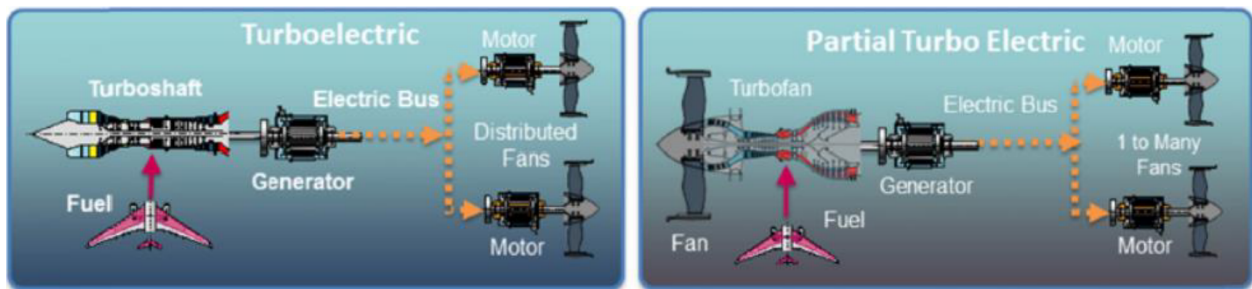


Figure 3: Turboelectric Architectures

2.5 Previous Work

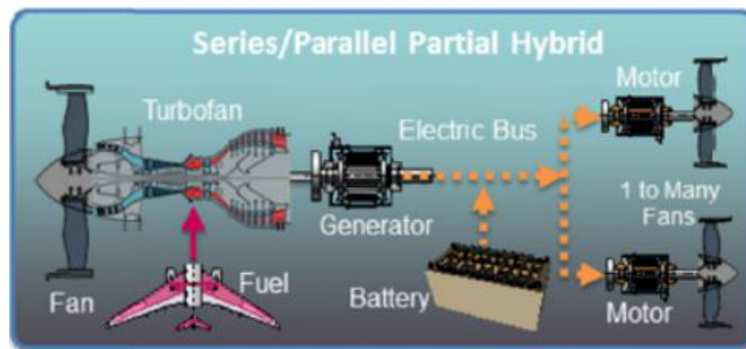


Figure 4: Parallel Turboelectric Design

CHAPTER III

METHODOLOGY

3.1 General Aircraft System

3.2 Configuration One

3.2.1 Data Acquisition

3.2.2 Experimental Procedure

3.3 Configuration Two

3.3.1 Data Acquisition

3.3.2 Experimental Procedure

CHAPTER IV

RESULTS

4.1 Configuration One

4.2 Configuration Two

CHAPTER V

CONCLUSION, RECOMMENDATIONS, AND FUTURE WORK

APPENDICES

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