

Design of Hybridization and Distributed Propulsion for a Regional Turbo-Prop Aircraft

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Abstract— The present work aims at studying the possibility of a distributed propulsion for an ATR-72 Regional Aircraft. Considering the demand a Regional Aircraft is experiencing, its continuous growth and keeping in mind the economic and environmental factors associated with it, the initial part of the project highlights the role of Hybrid and All-Electric Propulsion technology for future aircrafts. A Hybrid Electric Aircraft produces energy by making use of an on board gas-turbine that drives a generator that produces electricity. This electricity is then distributed within the airframe by means of cables to the inverters or the motor controllers that drive the motors. These motors convert the electric energy into kinetic energy by means of a propeller. Since, the series hybrid architecture allows us to have distributed propulsion, we chose this configuration. Simple models have been adopted and designed for the power chain. The validation of these models has been restricted to the literature considering the vast scope of variables involved in their design. These models have been designed in the form of small subsets, so that they can be integrated into future projects for design and optimization under MDAO framework. The gas turbine model for a turboprop engine was generated in order to obtain the shaft power as a function of altitude and velocity which is required for the series hybrid electric model. The models are tested and have been found to give favourable results with respect to the limited literature acquired over the course of our research. They have been tested for 2, 4, 6 and 8 propeller configurations with a Lithium Oxygen battery, having energy capacity of 1000 Wh/Kg. It has been observed that maximum fuel savings are obtained for 4 propellers. Further tests and modifications could be necessary for the practical application of these models. Designers can optimize the power distribution based on individual requirements using these models. The project can now be extended to a feasibility study for lateral control with asymmetric thrust settings and minimized tail design.

Keywords— Series Hybrid Electric Aircraft (SHEA), Distributed Propulsion, Gas Turbine Model.

I. INTRODUCTION

The aviation industry is currently responsible to about 12% of CO₂ emissions in the transportation segment [1]. Sustainability has become an important factor for the transportation sector. The challenges of future commercial aviation requires a multi-disciplinary effort that focuses on: fuel consumption, safety and reliability, noise, future aircraft propulsion and airframe design. The automotive industry is witnessing an increase in trend towards electric vehicles over the last decade. Electrical propulsion system application in commercial aircrafts will be able to reduce carbon emissions only if new technologies attain the specific power, weight, and reliability required for a successful commercial fleet. From the existing studies we find that, the all-electric systems use batteries and fuel cells as the only source of propulsion power. There are certain systems which are proposed to use fuel-cells for power requirement.

Turboelectric propulsion research is one of the four high-priority approaches identified for developing advanced propulsion and energy system technologies that could be introduced into service during the next 10 to 30 years to reduce CO₂ emissions [2].

The following are the 6 different configurations which are considered:

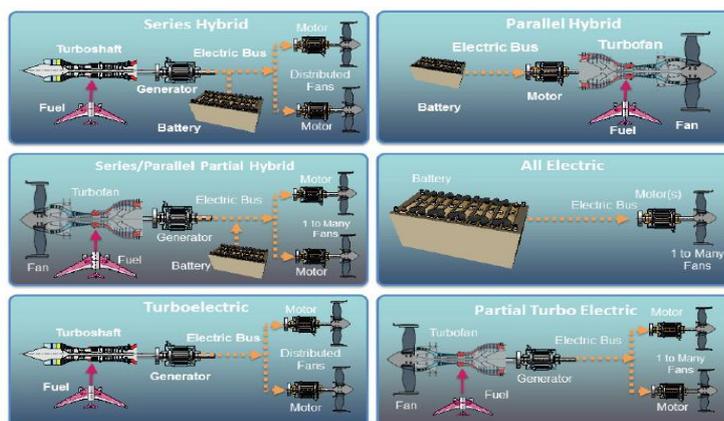


Figure 1.1: Different Electric Architecture Configurations [2]

The hybrid systems use gas turbine engines for propulsion and to charge batteries, the batteries also provide energy for propulsion during one or more phases of flight. As shown in Figure 1.1, with a parallel hybrid system, a battery-powered motor and a turbine engine are both mounted on a shaft that drives a fan, so that either or both can provide propulsion at any given time.

With a series hybrid system, only the electric motors are mechanically connected to the fans; the gas turbine is used to drive an electrical generator, the output of which drives the motors and/or charges the batteries. Series hybrid systems are compatible with distributed propulsion concepts, which use multiple relatively small motors and fans. The series/parallel partial hybrid system has one or more fans that can be driven directly by a gas turbine as well as other fans that are driven exclusively by electrical motors. These motors can be powered by a battery or by a turbine-driven generator.

Since, the series hybrid architecture allows us to have distributed propulsion, we would choose this configuration. The propeller units will be decided and integrated with the architecture based on the aerodynamic and structural design constraints. This model would be designed and optimized using an MDAO framework.

II. MODELLING

The baseline aircraft considered for modelling is an ATR 72 regional aircraft. This aircraft gives room to a maximum of 70 passengers and can carry a maximum payload of 7,500 kg [3]. The most important feature of the aircraft with respect to this research is the fact that there are two PW 127M turboprop engines with propellers present.

- **Series Hybrid Electric Model (SHEA)**

A HEA produces energy by making use of an on-board gas-turbine that drives a generator that produces electricity. This electricity is then distributed within the airframe by means of cables to the inverters (i.e. motor controllers) that drive the motors. These motors convert the electric energy into kinetic energy by means of a propeller. In order to visualise the systems used within a typical HEA Figure 2.1 is created.

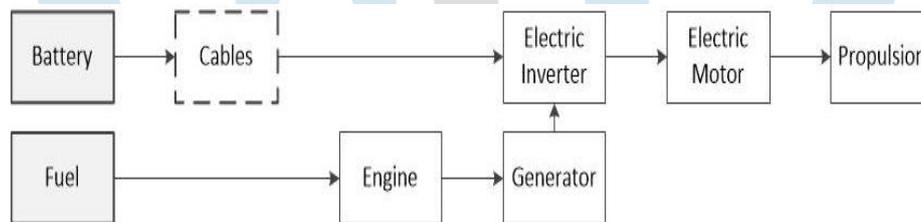


Figure 2.1: Chosen Series Hybrid Electric Model (SHEA)

The following models were obtained from the literature survey [4] and modified which helped in developing the overall model.

1. Propeller Model.
2. Battery Model.
3. Motor Model.
4. Inverter.
5. Cables.
6. Residual Thrust.
7. Lift/Drag Model.
8. Fuel Consumption Model.

III. RESULTS

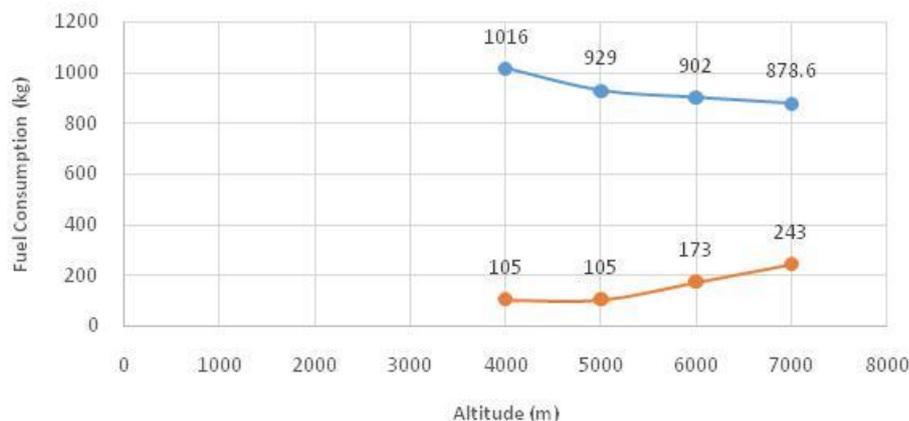


Figure 2.2: Fuel consumption comparison between Hybrid model and Baseline model for various altitudes for a chosen battery density (Lithium Oxygen)

Energy density is an important parameter for consideration when it comes to hybridisation. Hence, fuel consumptions for the current propulsion system of ATR 72 and the Series Hybrid Electric model (SHEA) were compared for different cell types. Figure 2.2 shows the comparison for Lithium Oxygen battery. It's been observed that with specific energy of 350 Wh/kg or greater, we see a Positive fuel save and there is a gradual increase with increase in Specific Energy of the battery. After a certain point, with battery of Specific Energy greater than 1000 Wh/kg, the fuel save remains stagnant. This is due to the Profile mission and Energy distribution between fuel and battery among different profile segments adopted within the model.

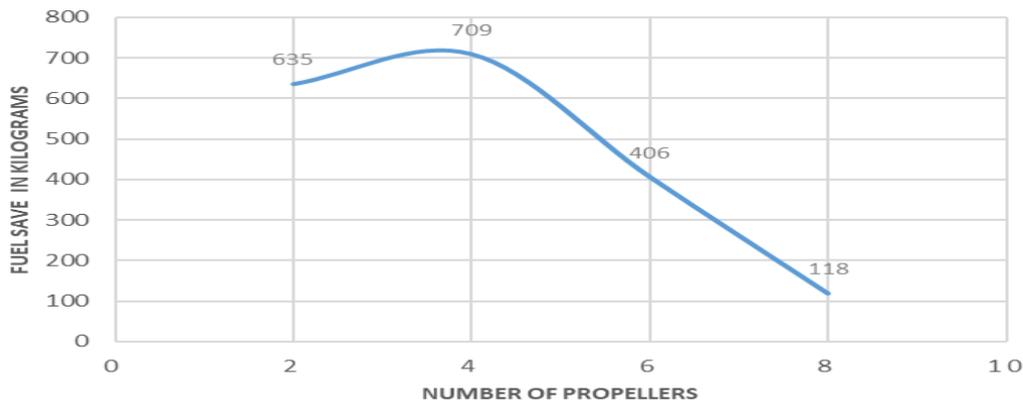


Figure 2.3: Fuel save with change in number of propellers for Lithium Oxygen Battery

With distributed propulsion, there is a large decrease in efficiency involved with the distribution of power over multiple propellers. But since there is a reduction in the differential power requirement from the engine and the battery, the fuel save increases with increase in number of propellers from 2 to 4 as shown in figure 2.3. But with further increase in propellers, the weight increase overdoes the reduction in power and hence fuel save starts to reduce.

IV. CONCLUSION

It can be observed that the efficiency of all components decreases as the power per component decreases. Especially, the propeller and the inverter experience a significant decrease in operating efficiency, while the total mass of the system increases. These two trends lead to the conclusion that, while distributed propulsion does allow for design conditions with the possibility of lateral control and tail less configurations, the overall model does not show great improvement for an increase in efficiency of the propulsive systems. This is in accordance with the previous research performed on this topic for the current available technologies.

The models are tested and have been found to give favourable results with respect to the literature acquired over the course of our research. They have been tested for 2, 4, 6 and 8 propeller configurations under various parameter variation. It has been observed that maximum fuel savings are obtained for 4 propellers, indicating the feasibility of distributed propulsion.

Further tests and modifications could be necessary for the practical application of these models. Designers can optimize the power distribution based on individual requirements using these models. The project can now be extended to a feasibility study for lateral control with asymmetric thrust settings and minimized tail design.

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