A General Approach to the Conceptual Design of All-Electric and Hybrid-Electric Aircraft

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Electric powertrains are currently considered as promising means to improve aviation sustainability, starting with light and General Aviation aircraft and with the ambition to provide solutions for commuter and even regional future air transportation.

This work describes a general procedure for the preliminary sizing of propeller-driven electric airplanes. The overall approach makes use of typical sizing and performance evaluation procedures, with specific provisions for electrically-driven aircraft, including appropriate energy management strategies. Indeed, both all-electric (AE) and serial hybrid-electric (HE) solutions can be considered, where the latter include thermal engines (either reciprocating or gas-turbine generators) for battery charge. These are included by simulating their thermodynamic cycle during each phase of flight in which they are active. Batteries are considered through their specific energy, specific power and weight. Power and energy needs are set through mission requirements, leading to the sizing of electric motors and batteries (for AE and HE), as well as generator and fuel system (for HE only).

The proposed sizing procedure is strongly coupled with a thorough performance analysis, in which the flight mission is simulated by quasi-steady time integration. This delivers the time histories of several relevant parameters, such as distance travelled, altitude, airspeed, motor and generator power, battery state of charge (SOC), fuel level, and cumulative required energy. An iterative procedure is applied to meet design requirements in terms of total distance achieved, final battery SOC, and fuel remaining. A preliminary validation was carried out considering several existing airplanes, including conventional aircraft recovered as degenerate cases of HE ones.

The design of an 8-seat commuter was investigated, considering both AE and HE architectures (Figure 1). They both share the same airframe and make use of Li-S batteries. The AE version provides a 300 km range, with a total battery mass of 550 kg and a 10% residual battery SOC at landing. In contrast, the HE version provides a range of 600 km, with 350 kg of batteries and 125 kg of fuel. Given the time-integration approach to performance verification, a study of different charging techniques for HE solutions can be carried out. Figure 2 shows the case of “cyclic charge” strategy, in which battery SOC is brought up to a given level as soon as it sinks below a pre-defined threshold, in contrast to the “steady charging” strategy where the battery state of charge is kept constant. A comparison between different charging techniques is provided and critically assessed.

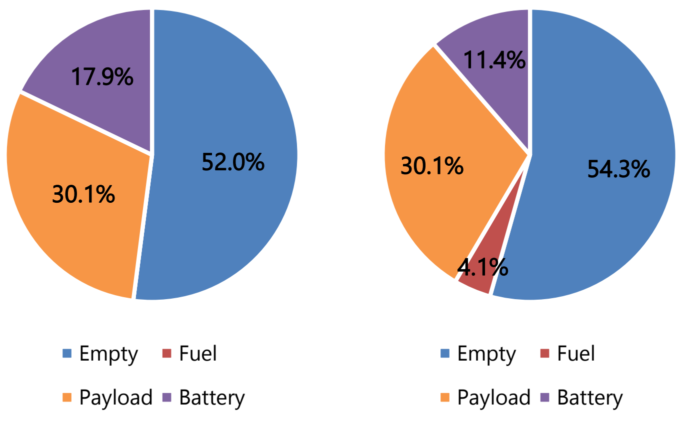

Figure 1. Weight breakdown comparison for all-electric (left) and hybrid-electric (right) 9-seat commuter design solutions.

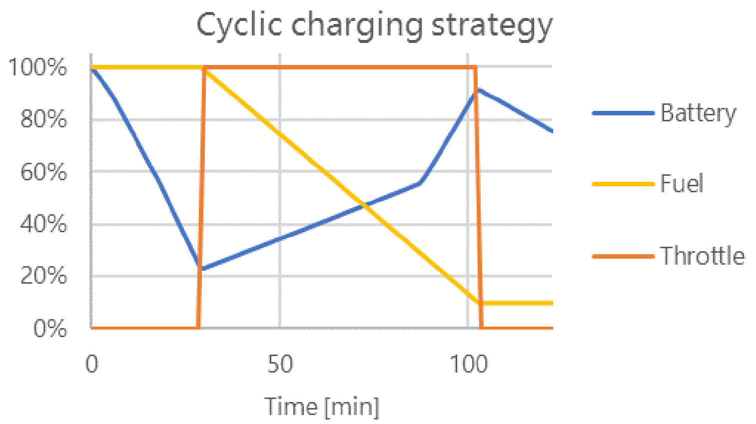

Figure 2. Time evolution of battery state of charge, fuel quantity, and generator throttle for the “cyclic charge” strategy.