Chance constrained business case of a three-engines hybrid aircraft

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1 Abstract

Coupling thermodynamic and electric engines encounters some success, at least commercially speaking, in powering ground vehicles. Would it be possible to transpose the principle of hybrid propulsion to aircraft? If there is no real doubt about the technical feasibility, the economic interest is not obvious. The main reason is the high penalty cost of each extra kilogram carried by the aircraft linked to the poor energy density of currently available accumulators. Most probably, a few technological breakthroughs in the field of electrical energy storage, generation and conversion will be necessary to make the electrical commercial transport aircraft a reality.

In this study, we are interested in the required values of technical characteristics of airborne electrical devices to make it economically viable, taking into account the uncertainty of all simulations and predictions. More precisely, we look for the minimum values of accumulators' energy & power density and engine power density that would ensure the same cash operating cost as a conventional non-hybrid configuration whatever the prediction errors that could cloud the computation results. Of course, both hybrid and conventional configurations are designed according to the same set of operational requirements.

To give a chance to hybrid-powered-aircraft, we also worked on the general arrangement of this aircraft. To avoid internal hybridization of the engine (when the electrical engine provides its mechanical power to the fan shaft of a turbofan), we selected a configuration that mixes classical turbofans and an electrically powered turbofan (fan only powered by an electrical engine) associated to a limited amount of accumulators.

In order to make the comparison as relevant as possible, both hybrid and conventional configurations have been designed within the same software environment based on semi-empirical models and simple performance simulators. Thermodynamic engine model has been selected as the simplest real turbofan simulator that could take account of the most important internal thermodynamic behaviors, e.g. SFC bucket. The electrical engine model does not assume the use of superconductivity. The uncertainty brought by each design and simulation module has been assessed individually, according to its predictive performance versus existing database. This uncertainty has been propagated through the overall design processes up to the final decision criteria. One of the original points of this study relies on the analytical propagation of uncertainty by the way of moments instead of using Monte-Carlo methods.

Common design parameters for conventional configurations are classically the wing area and a driver of the engine size. For the hybrid aircraft, we added the stored electrical energy and the installed electrical propulsive power. The result of the optimization is complemented by sensitivity studies on technological parameters, uncertainty parameters and some prospective design options. The results of the studies show that, even if the current technology of electricity storage and conversion is not mature enough to make electrical air transport economically competitive, a good integration of this technology can make the over-cost quite small in a near future and provide some interesting improvement in air transport operations.