POLITECNICO MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

Executive Summary of the Thesis

Environmental benefits introducing hybrid propulsion on 70 and 19-seat aircraft

Laurea Magistrale in Aeronautical Engineering - Ingegneria Aeronautica

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Academic year: 2020-2021

1. Introduction

Environmental sustainability is the big challenge that the aeronautical industry has to face: with the current technology, it is not yet possible to design regional aircraft with a hybrid-electric (HE) propulsive configuration, without significant penalties in performance, compared to conventionally-powered competitors. In this work, scenarios for expected technology maturity in 2035 and 2050 are analysed, to assess the benefits arising from the hybridization of commuter (19 passengers) and large regional turboprops (70 passengers).

2. Fuel budget and emissions

The analysed propulsive configuration consists in a serial thermal hybrid-electric (THE) configuration, in which the power needed to perform the flight comes from batteries or a power generation system (PGS) based on an internal combustion engine (ICE), according to a specific power management strategy We consider retrofitting with propulsive configuration on the ATR72-600, for the 70 passenger aircraft class, and on the Dornier DO228, for the 19 passenger aircraft class; in addition, a clean sheet design solution for a 19-seat HE aircraft is considered. The used methodology allowing the retrofits and clean sheet initial design is HYPERION [3], which allows to perform the preliminary sizing of HE aircraft following a two-step approach, consisting of an initial estimation of the design masses, corrected with the result of a time marching mission simulation.

An aircraft can be a marvelous piece of engineering, but it must also be able to fulfill the needs of the airlines, that choose a specific model referring to its capabilities and operational costs. For this reason, the assessment of the considered HE aircraft is performed by deploying it on existing airline networks.

The retrofit of the HE technology introduces complexity and extra weight on board the aircraft, limiting the design range or payload. Networks with shorter flights have a less stringent limitation on payload. Besides, the initial battery charge only covers a part of the total energy needed for the flight: for shorter flights, the energy degree of hybridization (defined as the ratio between the battery energy and total energy onboard) is higher, maximising the positive impact of the new technlogy. For these reasons, out of the many operators of the ATR72 or equivalent in Europe, the networks of Binter (Spain) and Olympic Air (Greece) have been selected for the creation of the network scenario. Concerning 19-seat aircraft, Silver Air (Italy) and TwinJet (France) are selected, as they are two of the most prominent airlines operating commuter aircraft.

2.1. R70THE

Looking closely at the retrofit of the ATR72-600, called R70THE, two versions have been designed, to precisely address the needs of Binter and Olympic Air: the obtained aircraft have a design range of 300 km and 600 km respectively. This differentiation, necessary to limit as much as possible the restriction on the maximum payload, shows how the choice of the design range affects the available payload, given the constraint on the MTOW due to the retrofit strategy. The fuel needed by the retrofits to perform a mission of a given length comes as output from HYPERION, whereas for the ATR72-600, it has been modeled considering performance data presented in the aircraft Flight Crew Operating Manual (FCOM) [1], dividing the flight into taxi, climb, cruise and descent, and creating a FL schedule depending od the route length. Figure 1 shows the quantity of fuel needed to perform the routes of Olympic Air's network, by the ATR72 and by the retrofits with 2035 and 2050 envisaged technology standards.

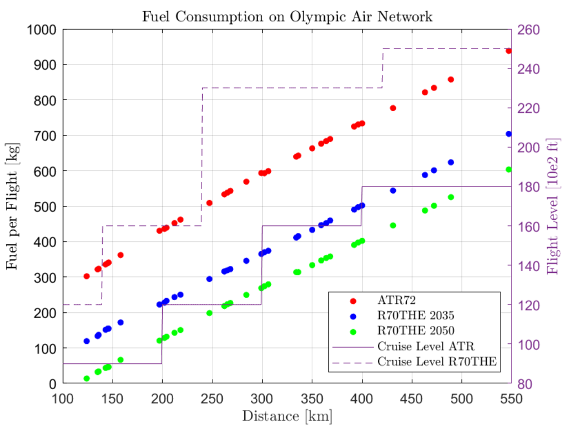

Figure 1: Fuel per flight length for the ATR72 and retrofits on Olympic Air's network.

The frequencies of each route of the considered networks have been recorded for the last week of July 2021, allowing to precisely obtain the weekly fuel budget necessary to operate the network. This result has been extended to a full year of operations, introducing a seasonal corrective factor, based on the monthly movements at the airlines' bases. The obtained yearly fuel budgets are presented in Table 1.

Example of Table

Airline	Baseline	2035	2050
	[t]	[t]	[t]
Olympic	447.1	176.5	110.4
Binter	528.3	271.7	139.2

Table 1: Yearly fuel budgets of Olympic Air and Binter.

As mentioned, the hybridization imposes a limitation on the design point of the aircraft: the retrofits for 2050 are able to carry a payload comparable to that of the baseline aircraft, but in 2035 the aircraft is limited to 57 passengers on Olympic's network and to 63 on Binter's. An evaluation of the fuel and cost (fuel, electricity and crew wages) per passenger still shows that the retrofits are convenient, with only the longest routes showing a marginally higher cost than that of the original ATR72. Last, it is necessary to evaluate the greenhouse gases emissions linked to the exploitation of the presented aircraft. The used model considers emissions of CO_2, NO_x, SO_x and CO proportional to the amount of burnt fuel. For NO_x and CO coefficients specific for the considered engine technology are introduced. This shows how the hybridization allows a reduction of about 50% in 2035 and of 70% compared to current levels.

2.2. R19THE and C19THE

The aircraft considered as baseline for the 19-seat analysis is the Dornier DO228, but the selected operators have a fleet composed of Let 410 (Silver Air) and Beechcraft 1900D (TwinJet). The Let 410 has a design point comparable to that of the DO228, but the Beechcraft is more capable, making the retrofit strategy not suitable, as many routes would have to be discarded and the remaining would be operated carrying a limited payload. For this reason, a clean sheet design has been assessed, aiming to develop an aircraft capable of operating the selected networks and four 250-km hops without refueling/recharging at intermediate stops. The obtained aircraft is designed to satisfy the CS23 Commuter category limitations. Table 2 shows the obtained weekly fuel budgets, not expanded to a full year, as such modeling is hard for these carriers that account for a minimal amount of movements at the airports they operate at.

Aircraft	Silver Air	TwinJet
	Weekly fuel	[t]
Baseline	5.2	19.9
R19THE 2035*	3.0	10.1
C19THE 2035	2.1	16.2
R19THE 2050*	2.1	8.6
C19THE 2050	1.0	12.7

* Considering only routes up to 396 km.

Table 2: Weekly fuel budget of the baseline, retrofits and clean sheet designs.

The clean sheet designs are capable of delivering a remarkable reduction of the fuel budget and consequent emissions compared to the baseline, both in 2035 and 2050, also because of a lower cruise speed that limits the power needed in that phase. The low figures for R19THE for TwinJet are due to the fact that the majority of the routes are past the design range of 396 km.

3. Ground operations

The sizing and fuel budget considering only the portion of flight spanning from take off to landing are accurate, but the obtained aircraft need to be assessed even for their ground operations. The possibility of getting the energy either from the batteries or the PGS allows to choose what is the best: performing the taxi powered by batteries is optimal, as the emissions at airport level are zeroed. The batteries are sized to start at a level of charge of 85% and never go below 25% to preserve life, therefore the taxi out will cause the aircraft to take off with a lower level of charge and the taxi in will delay the PGS switch off, so that the aircraft lands with enough battery energy to allow taxiing to the gate without going below 25% level of charge. The battery energy used for taxiing is replaced by fuel burnt once the aircraft reaches the hybrid transition altitude (above which the PGS can be turned on). The amount of energy needed for the taxi phase depends on the taxi in/out average duration, function of the airport size, and on the battery discharge rate. The average taxi times are evaluated thanks to the database presented by the European Environment Agency (EEA) [4] for mega hubs (more than 40M annual passengers), medium airporst (4-10M annual passengers), regional airports (less than 100k annual passengers) adn for the specific networks of Binter and Olympic Air. The battery discharge rate is computed considering ICAO's LTO (Landing and Take Off) Cycle modelling, that considers that taxi needs 7% of the installed power, compared to the power needed for take off and climb, and the corresponding battery discharge rate, available from HYPERION's simulations. The altitude profile, battery, PGS and tank level of an average mission are shown in Figure 2. The bat-

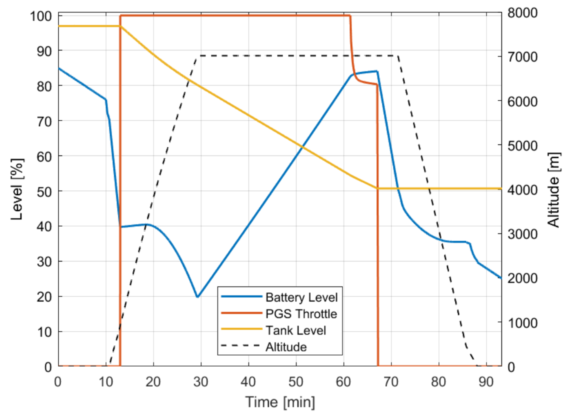

Figure 2: Levels and mission profile, R70THE 2035.

tery level obtained for take off for all considered aircraft allows to climb at least to 3000 ft; considering that the descent is already powered by batteries only because of the implemented power management strategy, it is possible to state that the designed aircraft are able to perform a zero-emission LTO cycle, limiting the impact on the area surrounding airports.

The introduction of batteries adds a task to the turnaround process: starting from the energy capacity of the installed batteries and from the expected recharging capabilities, it is possible to assess the impact on operations. Specifically, considering a recharger power up to 500 kW in 2035 and 1000 kW in 2050 and the fact that the batteries only have to be recharged 60%, from 25% to 85%, the R70THE can be recharged in 23 minutes (2035)/28 minutes (2050) and

R19THE/C19THE in 20 minutes, which does not increase the turn around time.

4. Noise

Together with greenhouse gases emissions, the noise emitted by aircraft is an environmental issue. Its modeling for a novel configuration can only be done by bundling together the noise emitted by the different components. A similar approach was followed in [2], a study that has been used to validate the constructed model. Specifically, the wing, propellers, landing gears, flaps and electric motors noise emissions have been computed referring to semi empirical models that had been previously developed. These models take as input flight mechanics parameters, available from HYPERION, and configuration (take off flaps, landing flaps and landing gears for approach). The developed model has been used to evaluate the noise level at ICAO's noise reference points, 2 km before touchdown for approach and 6.5 km from brake release for take off. The obtained values,

Aircraft	Take off	Approach
ATR72-600	79.2 dB	92.3 dB
R70THE	77.6 dB	89.4 dB
DO228	79.4 dB	-
R19THE	78.3 dB	82.4 dB

Table 3: Noise levels.

compared to the certified values for the baseline aircraft are shown in Table 3. The improvement is marginal, because the loudest component, the propeller, has not been changed with the retrofit.

Besides, noise trajectories have also been obtained, to assess how every component evolves as a function of the elevation angle: the example for the approach of R70THE is shown in Figure 3. This figure is obtained modeling the elevation angle, directly linked to the horizontal distance from the aircraft. In this analysis, the aircraft is fixed at the reference location. From this, it is possible to assess the noise exposure on the ground.

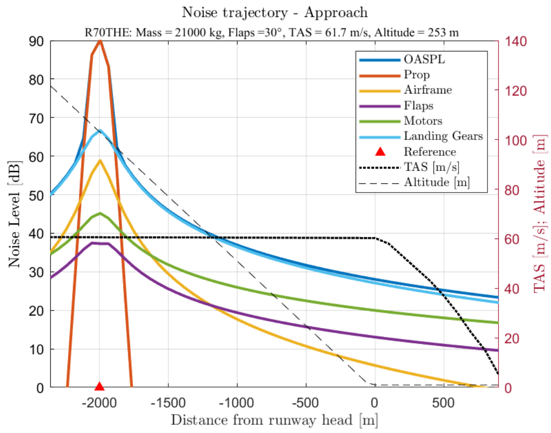

Figure 3: Noise trajectory at approach, R70THE 2035.

5. Conclusion

This work allows appreciating how the future introduction of a HE propulsive configuration may improve the environmental sustainability of aircraft operations on regional networks. Specifically, the foreseen reduction of fuel budget and consequent emissions is considerable, with no noteworthy impact on operational costs that would be cascaded down to the passengers. The propulsive configuration allows to perform complete LTO cycles, powered by batteries only, thus considerably reducing local emissions (gases, particulate and noise) at airports. For what concerns noise, the peak level remains very close to the original level, as the propellers have not been optimised, but given the fact that its effect is only audible for elevation angles close to 90°, the overall exposure is reduced.

References

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