Propulsion System Optimisation Approach for Hybrid/Electric Aircraft

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Abstract

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Propulsion System Optimisation Approach for Hybrid/Electric Aircraft Peter Malkin (1), Meletios Pagonis (2) 1: Cranfield University, Building 52, Cranfield University, Bedfordshire, MK43 0AL, p.malkin@cranfield.ac.uk 2: Cranfield University, m.pagonis@cranfield.ac.uk Abstract This paper describes the possible approaches for the propulsion system of a hybrid/electric aircraft. Such an electric concept is being considered in both the marine and aviation industries due to the economic (i.e. reduced fuel burn) and environmental (i.e. less emissions and noise) benefits that it offers. The hybrid/electric propulsion system is characterised by the design freedom it permits on the whole aircraft system. Prime movers are no longer limited by the fans and vice versa, while the presence of an advanced energy storage system facilitates the addressing of the dynamic requirements of the whole system. Thus, significant efficiency gains across the cycle, quiet taxing and landing, and savings on the maintenance costs should be possible using a novel flexible electric power system. Introduction The aerospace industry has lately started looking on different “unconventional” approaches regarding the propulsion system of next aircraft generations. This was driven by the very ambitious goals that important institutions such as NASA [1] and ACARE [2] have set for future civil aircraft, aiming on fuel burn reductions of 60%, 80% less NOx emissions and noise levels decreased by 65% compared to the 2000s standards. It was therefore clear that innovative solutions will be necessary to satisfy these targets. Hybrid/electric aircraft is considered one of the most promising solutions and it involves a distributed propulsion (DP) system, advanced energy storage systems and possibly a fully superconducting network that will reduce the weight of the whole system which in the initial studies was considered the main obstacle of this concept [3]. This novel approach frees the propulsion system from many restrictions that conventional configurations were facing. More importantly it allows the system components to be designed in a more efficient way. The latter is the main
reason for some of the benefits derived from this hybrid/electric approach. Hybrid/Electric Distributed Propulsion In this concept electric power generated by gas turbines alternators (GTAs) and/or energy storage devices is distributed to a number of electrically driven fans. It has also been proposed that a Blended Wing Body (BWB) could be the most beneficial airframe for this approach. BWB will enable the effect of Boundary Layer Ingestion (BLI) which will potentially reduce the drag of this configuration. An example of such an aircraft can be seen in figure 1. Another characteristic of this approach is that gas turbines and fans are no longer limited to each other. The electric system of this aircraft allows the optimal design of both components maximising the overall power generation efficiency. Moreover, the existence of an advanced energy storage system offers further benefits to the whole propulsion system operation cycle and some of them will be described on this paper. Fig. 1: An example of a BWB/DP Aircraft Hybrid/Electric Ship Propulsion The marine industry could be considered as a good reference to aerospace due to the similarities between a ship's and an aircraft’s propulsion system. Figure 2 demonstrates a relatively conventional and a more complex hybrid type ship propulsion system. It is clear that the second system is far more complex with more components which in theory could affect negatively both the cost and the efficiency of the whole system. However, the market for hybrid ships is currently close to $3B and is anticipated to double in the next five years [4]. The main benefit of these hybrid ship propulsion systems is derived from their advanced operating cycles. The variable loads and the frequent starts and stops could be handled easier and most importantly a lot more efficiently in these hybrid configurations. For this reason hybrid approaches are preferred in sections like cruise ships, naval vessels, work-ships, tugs, ferries etc. Fig. 2: Comparison between a conventional (top) and a hybrid type (bottom) ship propulsion system Aircraft Asymmetric Operating Cycle As it is well known aircraft consists of five main flight cycles: taxi, take-off, cruise, descent, and landing. Therefore, unlike cars and ships an airplane’s mission is not characterised by its several stops and starts. This at first sight may seem to eliminate any benefits a hybrid propulsion system may offer. However, in a commercial aircraft the power required during cruise is only a fraction (around 20%) of the maximum capability of the gas-turbines. This becomes even worse if we take into consideration the safety case of one engine out during take-off which normally sizes these machines. All the aforementioned mention a rather “asymmetric” operating cycle that makes the design of the numerous components of the propulsion system really challenging. Some of these obstacles could be overcome by the use of energy storage systems as well as by designing a flexible electric power system. Energy Storage Energy storage in a hybrid system offers several advantages and creates by all means a more flexible system [5]. However, it is the authors’ opinion that a fully electric aircraft where batteries will provide all the necessary power demand throughout the whole mission is not a viable choice even for the 2050 timeframe. Such a battery bank will be too heavy for an airborne application. On the other hand, in the proposed approach energy storage devices will be used for relatively short periods of time mainly in order to cope with the dynamic requirements of the flight mission. Furthermore, instead of having just batteries, a mixture of different energy storage techniques might prove beneficial. Supercapacitors and Superconducting Magnetic Energy Storage (SMES) could be considered as alternative options. Energy storage technologies are improving rapidly and it is expected to improve even more the next few years. However, the design optimisation process of the energy storage system could become really complex and several factors must be taken into consideration simultaneously. Moreover, the additional weight of this system is an issue that is nevertheless believed to be countered by the numerous benefits that such a system offers. Flexible Electric Power System Figure 3 demonstrates the idea of a flexible integrated electric power system. In this novel approach our power system is illustrated by a main power bus bar that is supplied by several prime movers such as gas-turbine alternators (GTAs) and energy storage. The latter could provide instantaneous power or even large amount of power but for a short period of time. The GTAs might be either of different sizes or identical and the merits of both options need to be explored. Fig. 3: A flexible Integrated Electric Power System This approach basically removes some of the constraints that conventional propulsion configurations have. The prime movers can now be optimised closer to their optimal design point, while the dynamics of this system can be managed easier. The asymmetric thrust is also reduced significantly improving the capabilities of the airframe design. Conclusions Future trends in aviation dictate innovative solutions regarding the propulsion system of the next aircraft generations. One such approach is the hybrid/electric distributed propulsion aircraft where many studies have shown promising results. One of the main benefits of this design approach is the wide range of options that it creates in the design process of the aircraft. The majority of the components can now be designed on their optimal design point while the dynamics of this system can be controlled easily with the presence of systems like the energy storage which however still need to improve significantly. Benefits could include significant efficiency savings across the cycle and further benefits including quiet taxiing and landing for example and savings on maintenance costs should be possible. These would be in addition to propulsive efficiency gains of future aircraft. References 1 S.W. Ashcraft et al, “Review of Propulsion Technologies for N+3 Subsonic Vehicle Concepts”, NASA/TM-2011-217239, October 2011. 2 W.R. Graham et al, “The potential of future aircraft technology for noise and pollutant emissions reduction”, Transport Policy Special Issue Aviation and the Environment, July 2014. 3 P. 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