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Transportation Research Procedia 65 (2022) 44–51

Transportation Research Procedia

www.elsevier.com/locate/procedia

11th International Conference on Air Transport – INAIR 2022, Returning to the Skies

Availability of en-route alternate aerodromes as potential limitation in flight planning for hybrid-electric regional aircraft

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Abstract

To reduce carbon emissions, hybrid-electric aircraft could replace conventional turboprop aircraft on regional operations. Because of the limited energy density provided by batteries and requirements concerning reserves for operations under instrument flight rules (IFR), a range extender will be required to achieve commercially relevant ranges. In a serial hybrid concept with electric motors driving propellers, a gas turbine in combination with a generator would provide sufficient electricity for longer ranges, on top of the energy stored in the batteries. It is advantageous that the initial flight stages of missions beyond the battery-electric range are operated with the range extender, with battery power reserved for the final part of the mission. If the gas turbine fails, full battery power will remain available to return to the origin airport, to reach the planned destination or to divert to a suitable en-route alternate airport. Therefore, in cases of longer missions, flight planning must consider the availability of alternate en-route airports within the remaining battery-electric range of the aircraft. This paper examines whether the requirement to reach an alternate airport within the remaining battery electric range in case of a failure of the gas turbine / generator is a major constraint on hybrid-electric aircraft operations. For this purpose, actual airport pairs operated by larger regional turboprop aircraft (ATR42/72 and Dash 8-400) as listed in global flight schedules for the year 2019 are analyzed. The authors find that only a small fraction of routes is constrained by the availability of en-route alternate airports, but this result depends on the battery-electric range, for which a sensitivity analysis has been conducted. Minimizing operational constraints can be an important factor for the acceptance and market uptake of new aircraft concepts.

Keywords: Hybrid-electric aircraft; flight planning; en-route alternate airports

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10.1016/j.trpro.2022.11.006

1. Introduction

Hybrid-electric aircraft are one possibility to reduce carbon emissions of aviation, at least in the class of commuter and regional aircraft. Currently, various research and development projects are conducted in order to assess the viability of design and operation of such aircraft concepts (e.g. Pornet and Isikveren, 2015 and Atanasov et al., 2019). Hoelzen et al. (2018) describe the different strategies to use battery-electric power, such as peak power shaving or the maximization of battery power utilization. Geiß and Strohmayer (2020) have analyzed the problem of en-route diversion distance of hybrid-electric and electric aircraft and provided probability distributions for the distances to emergency airports for Europe and the USA.

In this paper, we focus on the question how flight planning could be constrained on missions exceeding the battery-electric range. We assume a serial hybrid aircraft concept to be comparable to the ATR42/72 or De Havilland Dash 8-400 in terms of range, speed or payload. Figure 1 depicts a simplified schematic of the energy concept of such a serial hybrid-electric aircraft.

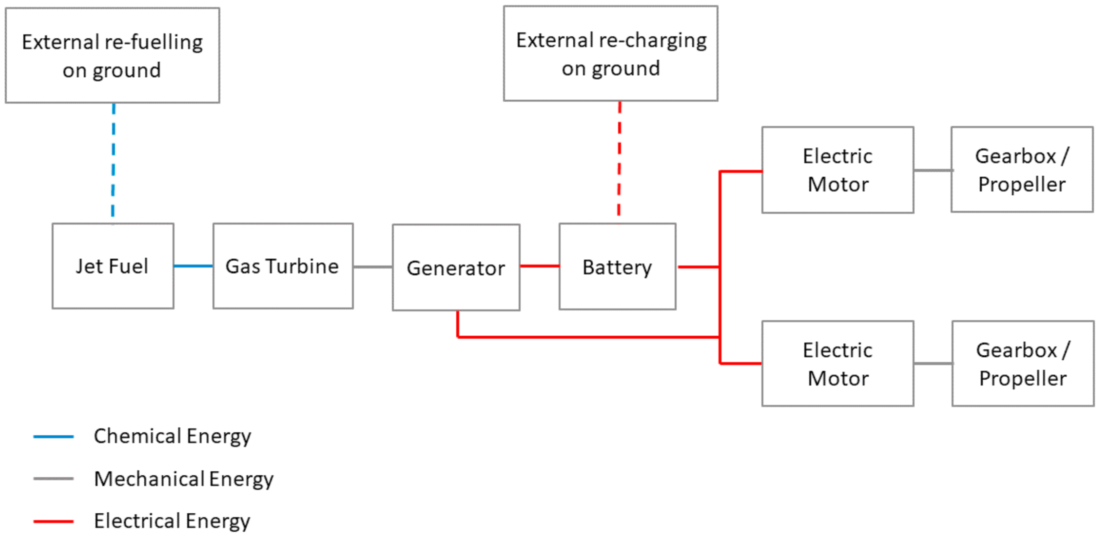

Fig. 1. Schematic energy concept of a serial hybrid-electric regional aircraft with gas turbine/generator as range extender

Propulsion is generated by propellers driven by electric motors, sized to provide power for all flight stages, including take-off/cruise and go-around flight phases. The concept would also allow for distributed propulsion with multiple small electric engines/propellers, improving aerodynamic characteristics, such as short field performance for takeoff.

Batteries can be charged on ground, preferably with electricity from renewable sources. In this case, on missions within the battery-electric range, the aircraft can operate without any direct CO_2 or local emissions. However, due to the low energy density of batteries, it is estimated that the full electric range is limited and highly dependent on the assumed energy density. At least for the class of 19-seater commuter aircraft, Atanasov et al. (2019) have shown that a full-electric range of 200NM is possible with conventional structural and aerodynamic design and an energy density of 230Wh/kg, which resembles the current state-of-the-art. Hence, it is not unrealistic that on a longer time-scale, the same can be achieved for larger regional aircraft, as the performance of batteries will improve over time and better materials and aerodynamic concepts are applied. Nevertheless, to be as realistic as possible in the scope of the analysis, a sensitivity analysis is conducted, also considering only 100NM full electric range (pessimistic case) and 300NM (optimistic case).

It must be noted that no official regulations on reserves or potential en-route alternate airports for flight planning of hybrid-electric aircraft are in place currently. For the analysis conducted in this paper the authors have drawn some analogies with existing regulations for single- and twin-engine turboprop/turbofan aircraft (e.g. those outlined in EASA's AMC1 CAT.OP.MPA.150, EASA, 2022). It assumed that regulations for hybrid-electric aircraft will be conceived which will maintain the same level of flight safety as today with conventional aircraft. The risk assessment of flight operations with hybrid-electric aircraft will have to take the peculiarities of this propulsion system into account.

For longer missions, electricity will be generated by a single jet-fuel powered gas turbine driving a generator to provide electricity for the electric motors and/or for re-charging the battery in cruise flight. This setup creates specific issues concerning flight safety: In case of a failure of the gas turbine/generator combination, aircraft range is limited to the remaining charging level of the batteries. While the in-flight shutdown of modern turboprop engines is an extremely rare occasion, precautions have to be taken for such an event. Pratt & Whitney reports an in-flight shutdown rate of its PT6A turboprop engine, very commonly found in various versions on a wide range of commuter and regional aircraft, of one per 333,333 flight hours (Gerzanics, 2004).

With only one gas turbine, as compared to two engines on larger turboprop aircraft, the safety implications of such a concept are as follows: First, an en-route alternate airport shall be available at all times during cruise flight within the remaining battery-electric range of the aircraft. Second, this implies to conserve battery power for the final flight stage, which in turn also creates advantages that the aircraft weight is constantly declining when fuel is consumed at the initial phase of flight.

Based on the global flight schedules of larger turboprop aircraft (ATR42/72 and De Havilland Dash 8-400) in the year 2019, it is analyzed whether flight planning for hybrid-electric aircraft is constrained by the availability of en-route alternate airports.

The structure of this paper is as follows: After this introduction, the authors provide a brief overview on the current regulatory background concerning the maximum distance to alternate airports in flight planning. This is followed by a section on problem definition and methodology. Then the results are presented, including a sensitivity analysis to show how the availability of en-route alternate airports varies with the battery-electric range of aircraft. The paper concludes with a discussion of the results and an outlook for further research.

2. Regulatory background

As pointed out in the previous section, regulations on required reserves and en-route alternate airports do not yet exist. In order to define reasonable assumptions, some analogies for potential hybrid-electric aircraft regulations are drawn based on existing regulations for single- and twin-engine turboprop/turbofan aircraft. For twin-engine aircraft, flight planning regulations require that an en-route alternate airport must be reachable within 60 minutes of flying time (ICAO, 2018). The flying time to an en-route alternate airport can be extended to more than 180 minutes under Extended Diversion Time Operations (EDTO), as outlined in ICAO Annex 6, Part 1, Chapter 4.7 and Attachment C (ICAO, 2018). The ICAO standards and recommended procedures are transposed into European law by EASA's Acceptable Means of Compliance for Extended Range Operation with Two-Engine Aeroplanes (ETOPS, EASA, 2021a). These regulations are not only applicable for long-range, transoceanic flight operations, but also for regional aircraft in remote regions of the world, such as the Pacific. In these regions, commuter and regional aircraft operate on commercial routes where no alternate airfield is available within 60 minutes of flight time with one engine inoperative. For this purpose, the ATR72 as a very popular regional turboprop aircraft has been certified as early as in the year 1995 for 120 minutes ETOPS operation (EASA, 2021b).

With the use of single turbine engine aircraft (SET, such as the Cessna Caravan/Grand Caravan or the Pilatus PC-12) in commercial air transport operations (CAT), regulations on flight planning and the consideration of suitable landing sites in case of inflight engine failures have come into force. Only in 2017, such aircraft have been approved to conduct commercial air transport operations under instrument meteorological conditions or at night (CAT SET Ops in IMC or at night, EASA, 2017). Flight planning requires that the maximum cumulative time span an aircraft cannot reach a landing site for each flight must not exceed 15 minutes, unless specifically approved by authorities (BAZL, 2018). For flight planning purposes, glide circles are drawn around each landing site. From within these circles, the aircraft can reach the landing site safely without engine power from the maximum en-route altitude and under prevailing wind conditions. The maximum gliding distance for a Cessna Grand Caravan from 15,000 ft above ground is in the order of 30 NM (Cessna, 2008, including the addition of a 0.5 % safety margin in the glide). This corresponds to the maximum distance to an alternate airport to be used for flight planning purposes under the CAT SET Ops in IMC.

Regulations for aircraft with alternative propulsion technologies are still in its infancy. When developing certification and operational standards for these aircraft, the key focus should be laid on maintaining the same level of safety as with conventional aircraft and propulsion systems. This poses a challenge for regulators, aircraft manufacturers and operators, when these aircraft have strongly diverging characteristics, e.g. concerning the reliability of systems or maximum range.

3. Problem Definition and Methodology

The regulatory framework for aircraft with hybrid-electric propulsion systems is not yet developed. We assume that it will be required that the maximum distance to an alternate airport equals the remaining battery-electric range of the aircraft, so that the aircraft can land safely in case of a failure of the range extender (gas turbine / generator combination). This assumption is in analogy to the regulations for the operation of single turbine aircraft at night or in instrument meteorological conditions, which also require to have an available en-route alternate airport to be reached within gliding distance of the aircraft in case the single turbine engine fails. Figure 2 depicts an exemplary mission over 1000 NM with a hybrid-electric aircraft with battery-electric range of 300 NM. After takeoff, electrical power for propulsion is provided by the range extender, in order to conserve battery power for any unforeseen events and to reduce aircraft weight through fuel consumption. In the example, the range extender (gas turbine/generator combination) fails after 400 NM. The aircraft can now safely operate to an en-route alternate airport, which is located within the battery-electric range (assumed to be 300 NM in this case).

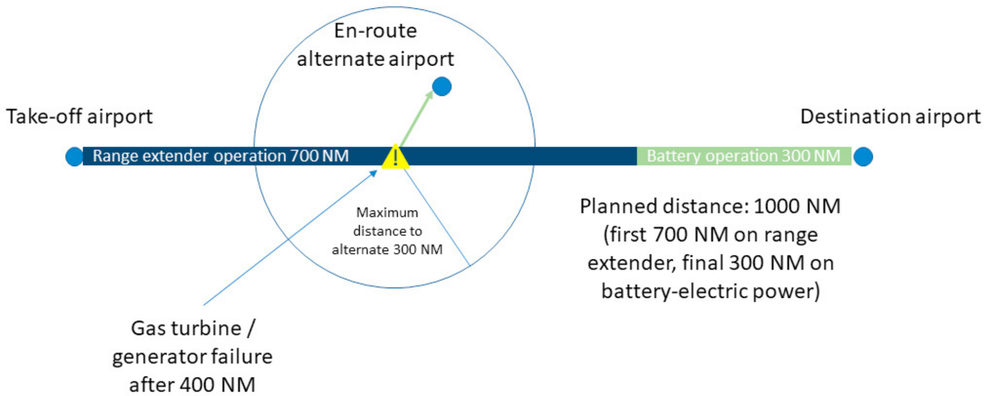

Fig. 2. Exemplary mission over 1000 NM with serial hybrid-electric aircraft and a gas turbine/generator failure after 400 NM

This operational concept requires the availability of an en-route alternate airport within the remaining battery-electric range. The key question is therefore, whether such a constraint in flight planning restricts the operation of a hybrid-electric aircraft. To test the constraint on en-route alternate airports for flight planning, we use global ATR42/72 and Dash 8 aircraft schedules for 2019 provided by Sabre Market Intelligence. The dataset includes 9,926 airport pairs with a total of 3.2 million flights, which represents current operational patterns of turboprop aircraft around the world. The data set on airports comes from ourairports.com. Eligible en-route alternate aerodromes are chosen based on runway length and runway surface. Aerodromes with a runway length of at least 1200 m and a paved surface are considered as potential alternate landing sites. The data quality of ourairports.com is limited with regards to the equipage of airports with any visual or electronic landing aids as well as opening hours. Such information would help to define the usability under inclement weather conditions or at night, which is highly relevant with regards to suitability as en-route alternate aerodrome in flight planning. This shortcoming could be overcome in further research applying a more reliable, commercial aerodrome data base. For the time being, the analysis of the data set provided by ourairports.com results in a total of 8,188 aerodromes globally designated as potential en-route alternate aerodromes.

We assume a remaining battery-electric range of 100, 200 and 300 nautical miles (NM) to potential en-route alternate airports to test the sensitivity of the availability of alternate landing sites in relation to the electric range. It is assumed that the battery systems of hybrid-electric aircraft will be sized to achieve these ranges, once in cruise flight, without additional on-board electric energy generation. With the operational concept of burning fuel in the initial stages of the flight and using electrical power stored in the battery system at a later flight stage, an improved level of flight safety is achieved, assuming that the failure rate of the electrical system (battery, power electronics, electric motor) is lower than that of the gas turbine/generator combination. The remaining electric energy is available to reach an en-route alternate airport.

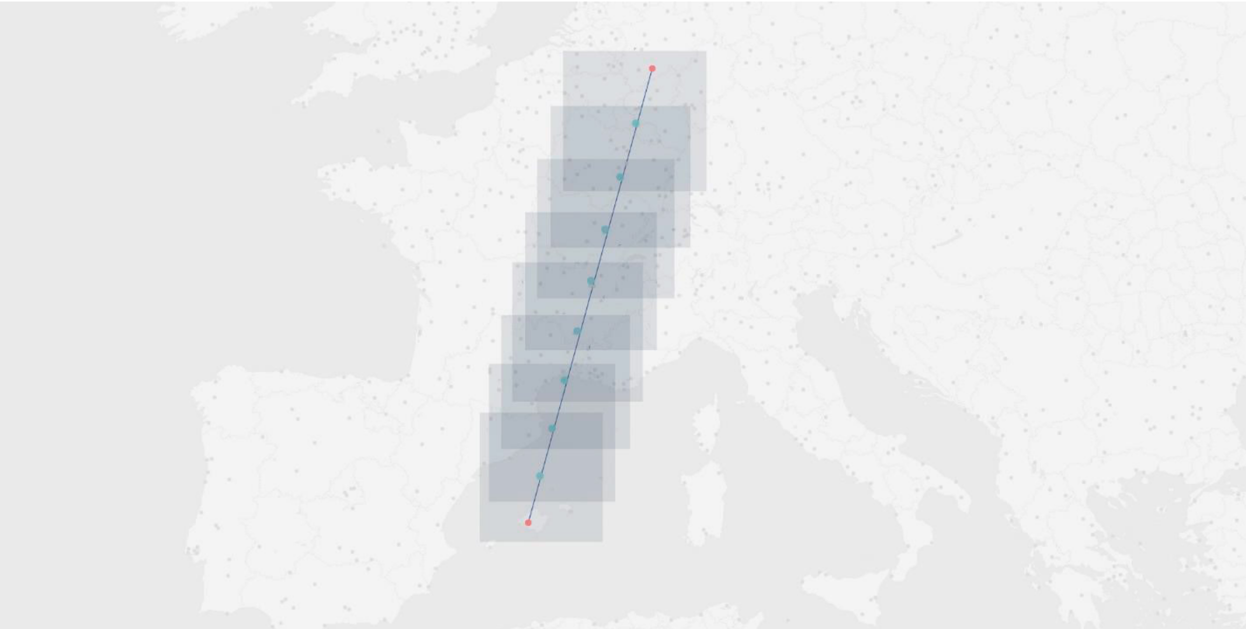

Fig. 3. Graphical representation of the search algorithm for a flight from Cologne to Palma de Mallorca

As a first step, the great circle distance is calculated for each airport pair. If the distance is less than twice the respective (remaining) battery range, the flight needs no further checking. In this case, after a failure of the gas turbine or generator at any point during the mission, the aircraft can use the battery to either return to the departure airport or continue the flight to the planned destination. In the next step, search points are generated along the flight path, which are located at a distance corresponding to the remaining battery-electric range. For each search point, we draw a virtual rectangle with the search point in the center. The distance from the center to the east, west, north and south is the respective remaining range. A virtual rectangle - instead of a circle - is drawn to simplify our database queries. The longitude value from the east and west points and the latitude value of the north and south point of the virtual rectangle is used to build up database queries for potential alternate airports. As we use a rectangle instead of a circle, the distance from the center to the corners exceeds the remaining range. Therefore, in the next step, we re-check the exact distance from the search point to all alternate airports in the results. If the distance is higher, the airport is not considered as an alternate for this search point. Figure 3 shows an example flight from Cologne (CGN) to Palma de Mallorca (PMI). The blue dots represent the search points with a search range of 100 NM and the corresponding rectangle. The gray dots on the map represent all possible alternate airports, including those in the corners where the remaining battery range would be exceeded.

4. Results

Table 1 shows the calculation results of affected connections and flights in different world areas.

Table 1. Number of affected connections and flights in different world areas.

Region	Number of airport pairs / 100 NM constraint	Number of flights / 100 NM constraint	Number of airport pairs / 200 NM constraint	Number of flights / 200 NM constraint	Number of airport pairs / 300 NM constraint	Number of flights / 300 NM constraint	Total number of airport pairs	Total number of flights
NORTH AMERICA	238	19,339	6	290	0	0	1,289	562,141
EASTERN EUROPE	226	15,034	26	456	2	6	565	125,326
WESTERN EUROPE	104	9,997	8	740	0	0	2,269	705,978
PACIFIC	103	10,180	14	1,484	2	10	300	174,384
CENTRAL AFRICA	89	3,485	0	0	0	0	191	14,122
EAST AFRICA	78	13,705	0	0	0	0	408	127,390
CENTRAL ASIA	72	5,544	0	0	0	0	85	8,892
NORTH AFRICA	41	2,926	0	0	0	0	208	38,597
ASIA SUB-CONT.	34	8,027	0	0	0	0	999	301,576
AUSTRALIA	32	5,616	0	0	0	0	365	125,445
SOUTHEAST ASIA	32	9,798	0	0	0	0	1475	499,281
CARIBBEAN	28	4,082	0	0	0	0	271	83,633
WEST AFRICA	17	352	0	0	0	0	197	28,414
SOUTHERN AFRICA	16	1,757	0	0	0	0	83	16,307
FAR EAST ASIA	7	278	0	0	0	0	241	174,408
SOUTH AMERICA	7	1,981	0	0	0	0	744	179,793
GULF	4	1,405	0	0	0	0	25	7,144
CENTRAL AMERICA	0	0	0	0	0	0	37	6,272
MIDDLE EAST	0	0	0	0	0	0	174	29,345
SUM	1,128	113,506	54	2,970	4	16	9,926	3,208,448

It turns out that with a battery-electric range of 300 NM, only four airport pairs globally would be constrained for the operation of hybrid-electric aircraft, as no alternate airports would be available. With 200 NM battery-electric range, the number of affected airport pairs would increase to 54 and with 100 NM battery-electric range, 1,128 airport pairs would be affected. This is still only a fraction of the total of almost 9,926 airport pairs served by ATR42/72 and Dash 8. Interestingly, the rate of affected airport pairs (11.4 %) is considerably higher than the rate of affected flights (3.5 %). Out of this we conclude that flights in remote regions are operated at a much lower intensity of daily/weekly flight frequencies.

Affected routes are (mostly) located in remote regions, for instance Alaska, northern Canada, Greenland or the Pacific. As an example, Figure 4 shows the constrained airport pairs in North America if a 200 NM battery-electric range is assumed. As can be seen, the constrained routes are on services to remote communities. Services in more densely populated areas, as for instance in the center of North America or Europe are typically not affected by a constraint on the availability of en-route alternate airports.

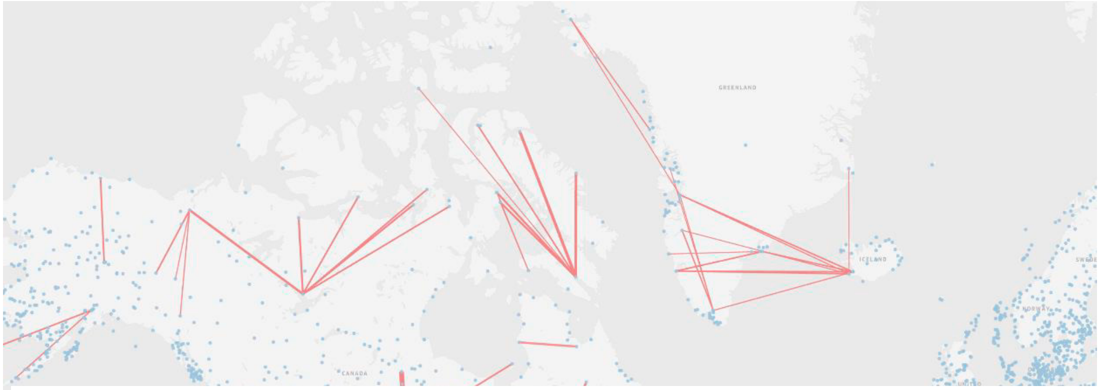

Fig. 4. Constrained airport pairs in North America with 200 NM battery-electric range

5. Conclusion

In this paper, the authors analyzed the impacts of the availability of en-route alternate airports on flight planning for hybrid-electric regional aircraft. Different hybrid-electric aircraft concepts exist, some of which are expected to feature only a very short pure electric range with energy stored on-board, in case the range extender (combination of gas turbine/generator) fails. For the concept of a serial hybrid-electric regional aircraft it could be shown that almost all airport pairs commercially relevant for regional aircraft can be served without constraints. This result holds even for a case where the hybrid-electric aircraft is assumed to feature only a range of 100 NM on the energy stored on-board in the batteries.

On a global scale, for 11.4 % of airport pairs and 3.5 % of the flights of turboprop aircraft operating the flight schedule of the year 2019, no alternate en-route airports would be available within 100 NM of a great circle distance-based flight path. On a regional level, in North America only 3.4 % and in Western Europe only 1.4 % of the flights would be constrained by the non-availability of suitable alternate airports. With 84.7 % of the airport pairs (72 out of 85) and 62.4 % of the flights (5,544 out of 8,892), the highest impact is in the region Central Asia, which is more sparsely populated and less airports are available.

The analysis shows how sensitive the results are with respect to battery electric range. If the hybrid-electric aircraft is equipped with batteries allowing for an electric range of 200 NM instead of 100 NM, the global number of constrained airport pairs declines to 1.81 % and with respect to flights to 0.09 %.

Therefore, it can be concluded that the majority of turboprop aircraft is operated on short routes and in regions, where sufficient alternate airports are available. Hence, we hypothesize that under strict safety-related regulations for hybrid-electric aircraft, flight operations would only be constrained for very rare cases of operations in remote regions. As it can be expected that the energy density of batteries will increase over time and with it the battery-electric range of hybrid-electric aircraft, the operational flexibility of this new aircraft type is likely to increase further. Therefore, constraints in flight planning associated with the availability of en-route alternate airports will most probably decrease over time. For the time being, conventional aircraft could be operated further on any of the constrained airport pairs.

Generally, it can be concluded that the availability of potential alternate airports should not pose a significant obstacle for the introduction of hybrid-electric regional aircraft. In the vast majority of cases, it is likely that airlines will be able to operate the same route profiles as today with conventional aircraft.

References

Airbus, 2003. CRYOPLANE – Liquid Hydrogen Fuelled Aircraft – System Analysis, Final Technical Report. https://www.fzt.haw-hamburg.de/pers/Scholz/dglr/hh/text_2004_02_26_Cryoplane.pdf

Airbus, 2020. Airbus reveals new zero-emission concept aircraft, 21st September 2020, https://www.airbus.com/en/newsroom/press-releases/2020-09-airbus-reveals-new-zero-emission-concept-aircraft

Atanasov, G., van Wensveen, J., Peter, F., Zill, T., 2019. Electric Commuter Transport Concept Enabled by Combustion Engine Range Extender. German Aerospace Congress (DLRK) 2019, Darmstadt.

BAZL, 2018. FOCA Guidance Material / Information, FOCA GM/INFO Commercial Air Transport with Single Engine Turbine Aeroplane in IMC or at Night, https://www.bazl.admin.ch/dam/bazl/de/dokumente/Fachleute/flugoperationen/gm-info/GM_INFO_CAT_SET_IMC.pdf.download.pdf/FOCA_GM_INFO_CAT_SET_IMC_Final_Version_Iss1_Rev2.pdf

Cessna, 2008. Information Manual Grand Caravan, Model 208B G1000, https://caravannation.com/208BG1000POH.pdf

EASA, 2017. New Regulation for CAT SET-IMC has been adopted, https://www.easa.europa.eu/newsroom-and-events/news/new-regulation-cat-set-imc-has-been-adopted

EASA, 2021a. Acceptable Means of Compliance for Airworthiness of Products, Parts and Appliances (AMC-20, Amendment 20), Subpart A – General, AMC 20-6 Extended Range Operation with Two-Engine Aeroplanes ETOPS Certification and Operation, https://www.easa.europa.eu/document-library/easy-access-rules/online-publications/easy-access-rules-acceptable-means?page=8

EASA, 2021b. Type-Certificate Data Sheet No. EASA.A.084 for ATR 42 and ATR 72, https://www.easa.europa.eu/sites/default/files/dfu/TCDS%20ATR_EASA%20A%20084%20Iss%2009_1.Feb%2021%20corrected%20per%2010.Feb%20%5Bmarked%5D.pdf

EASA, 2022. Easy Access Rules for Air Operations ANNEX IV (Part-CAT), Subpart B: Operating Procedures, https://www.easa.europa.eu/downloads/20342/en

Geiß, I., Strohmayer, A., 2020. Operational Energy and Power Reserves for Hybrid-Electric and Electric Aircraft, German Aerospace Congress (DLRK) 2020, https://www.dglr.de/publikationen/2021/530149.pdf

Gerzanics, M., 2004. FLIGHT TEST: Pilatus PC-12 - Power of one, https://www.flightglobal.com/flight-test-pilatus-pc-12-power-of-one/56828.article

Hoelzen J., Liu Y., Bensmann B., Winnefeld C., Elham A., Friedrichs J., Hanke-Rauschenbach R., 2018. Conceptual Design of Operation Strategies for Hybrid Electric Aircraft. Energies. 2018; 11(1):217. https://doi.org/10.3390/en11010217

ICAO, 2018. Annex 6 to the Convention on International Civil Aviation, Operation of Aircraft, Part I – International Commercial Air Transport – Aeroplanes, 11th Edition, July 2018.

Pornet, C., Isikveren, A.T., 2015. Conceptual design of hybrid-electric transport aircraft. Progress in Aerospace Sciences, Volume 79, November 2015, Pages 114-135, https://doi.org/10.1016/j.paerosci.2015.09.002