



Conceptual Feasibility Study of Integration of Aircraft With New Propulsion Technologies in Current Airline Flight Schedules

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Given the increasing importance of sustainability in the aviation industry, the integration of aircraft with new propulsion technologies that produce fewer, or no emissions is essential. The aim of this paper is to analyze the feasibility of the integration of aircraft with new propulsion technologies in current network planning of flights. We present a methodology to select suitable routes based on the performance of the two selected aircraft (Airbus zero emissions (ZEROe) turboprop hydrogen aircraft as well as a Wright Spirit electric aircraft). The network of a major German airline is used as a case study. Possible routes are selected, and new route network flight plans are generated to fulfill the passenger (PAX) demand. New propulsion technologies create additional complexities from an airline and airport perspective, which are listed and then categorized in 4 areas regarding the selected aircraft types. The results show that aircraft with new propulsion technologies can be integrated into existing route network Flight planning, but new complexities will arise and must be considered from an airline as well as airport perspective to guarantee smooth operations. This paper focuses as a proof of concept on strategical planning of different flights and not the planning of one specific single flight.

Keywords: airline operation, route network flight plan, new propulsion technologies, sustainable aviation, turnaround process

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INTRODUCTION

Sustainability is one of the most crucial discussions in aviation today. Reducing flight emissions to the lowest possible or at best to zero emissions is of biggest concern to the industry and public. With the fact that aviation currently accounts for 3.8%–4% of total EU greenhouse gas (GHG) emissions and up to 2% of the CO₂ world emissions attributed to the aviation industry, this is experiencing a faster growth rate in recent decades compared to rail, road, or shipping [1]. The aviation industry is perhaps the second largest emission generator in the transport industry, right after the road transport with 12%–14% of the total emissions from the transport industry [1–3].

The quest to lower the emissions coming from the aviation industry has led to various emission reduction plans and climate roadmaps. Such roadmaps include the European Green Deal, which seeks to achieve carbon neutrality by 2050. This goal covers the vision to lower transport emissions up to 90% in comparison to 1990 with an intermediate GHG emissions reduction target of at least 55% by 2030 [1]. Another such roadmap specifically for the aviation industry is the International Air Transport Association (IATA) Fly Net Zero Plan, which came with a commitment by IATA member

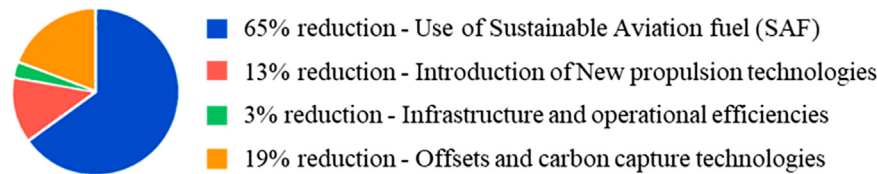


FIGURE 1 | Share of each emission reduction pathways [4].

airlines to achieve net-zero carbon emission operations by 2050. The IATA strategy roadmap seeks to achieve net-zero through various emission reduction pathways, as shown in **Figure 1** [4]:

The introduction of new technology such as electric, hydrogen and hybrid-electric flying promise heavy reductions on emission generated from fleets. Electric aircraft typically have range limitations due to the battery weight and energy density but however have the potential of 49%–88% reduction in carbon dioxide equivalents (CO₂e) relative to fossil-fueled aircraft including the battery production emissions [5, 6]. Hydrogen aircraft will offer a much better range in comparison to electric aircraft and better emission reduction, with an adoption rate of up to 40%, they can offer up to 6%–12% of passenger aviation's CO₂e emissions reduction [7]. Various new aircraft concepts for electric and hydrogen flying are discussed further in the background section of this paper (Chapter 2).

The introduction of various new technologies to existing airport operations will bring some new complexities such as infrastructure development, policy and regulations, personnel training and operational changes (particularly in terms of turnaround processes). The German “Luftfahrtforschungsprogramm” (LuFo) project OpAL is focused and assesses the operational impact of the introduction of new propulsion technology on the aviation environment. This paper addresses some identified expected complexities that will arise during the integration of new aircraft propulsions into the current Network Flight plan.

An overview of current research into the operational impact of new technologies is presented in the background section of this paper. We also introduce a methodology to explore the feasibility of integrating aircraft with new propulsion technologies into existing airline fleets and networks. The methodology aims to demonstrate the potential viability of new aircraft to meet the operational demands of flight routes while identifying key complexities that could arise for airlines and airports.

BACKGROUND AND RELATED WORK

The goal of this work is to assess new complexities that might arise from integrating new propulsion aircraft concepts into existing airline networks. The integration of new propulsion aircraft is expected to contribute immensely to the net-zero goals in the aviation industry. However, this process is anticipated to lead to a disruptive effect on the existing

aviation ecosystem and requires additional changes to the operational processes [8–11].

Previous works have assessed the impact of new propulsion aircraft from a technological feasibility and characteristic integration perspectives ([12, 13]), while others have investigated the infrastructural, regulations and certification changes that could be associated with the migration of alternative aircraft propulsion [14].

Babuder et al. [15] carried out an impact assessment of new technologies on the existing aviation ecosystem, focusing on the changes associated with airline operations, airport operations, and airside airport infrastructures from a commercial aviation perspective. The study identified considerable impacts on the airline operations during the introduction of both electric and hydrogen aircraft to commercial aviation. This study is based on an interview data collection with 22 experts [15] from the industry (Airport Operation, Airline operation & Airport Infrastructure) without real modelling on the extent of this effect on network planning and turnaround process.

NASA has been researching hydrogen aircraft since 1954 [16], testing it in a use case for rocket engines before flying it on a Wright J65 engine aircraft. Boeing also converted a two-seat Diamond DA20 to fuel cell technology and conducted a test flight in 2008 [17]. While most subjects concerning hydrogen aircraft have been related to structural and technological efficiency, recent research has since switched to commercial level flights operation, and numerous cooperative ventures have tested the operability and performance on various application cases, ATI Flyzero [18] is one such initiative that evaluated numerous hydrogen flight concepts in the UK and has since developed a technological roadmap for their inclusion into the UK fly space.

Marc Prewitz et al. [19], Dries Verstraete [20] provides an insight into the structural complexity that could influence Hydrogen flight operation, such as adjustment in wing dimensions, storage and range flexibility. Hoelzen et al. [21] assessed the infrastructural requirement for green hydrogen flight operations and cost implications using a direct cost modelling approach to compare operational cost of hydrogen powered aircraft with kerosene powered aircraft. This study underscored the importance of more re-search study in the complexities that could arise during airline operation and network integration of Hydrogen flights.

Several published research publications have investigated various aspects of electric aviation integration. Athina et al. [22] conducted a feasibility study on long-haul electric flights

TABLE 1 | Characteristics of the selected aircraft concepts [34, 35].

Property	Airbus ZEROe turboprop	Wright spirit
Propulsion	hybrid-hydrogen	all-electric
Range (km)	1825	500
Capacity (PAX)	100	
Cruising Speed (kts)	330	270

and suggested a methodology for evaluating low geophysical complexity flight routes for electric flight introductions. A flow-based evaluation of the effects a fully electric aircraft concept would have on air traffic in Europe was also conducted by Bekir Yildiz et al. [23]. The study comes to the conclusion that, in comparison to current conventional flights, fully electric aircraft models have slower speeds and longer charging times as complexity that affect throughput and schedule matching.

To quantify the effects of the integration of new propulsion technologies to existing airline operation, we have selected a number of aircraft concepts based on proposed range performance and PAX capacity in relation to existing conventional aircraft on different routes.

At the moment, there are various aircraft propulsion concepts currently in development both for electric and hydrogen aircraft concepts. Universal Hydrogen is working on converting existing conventional aircraft to hydrogen propelled aircraft [24]. Other concepts in development are the Airbus ZEROe concepts [25] or ZeroAvia aircraft [26].

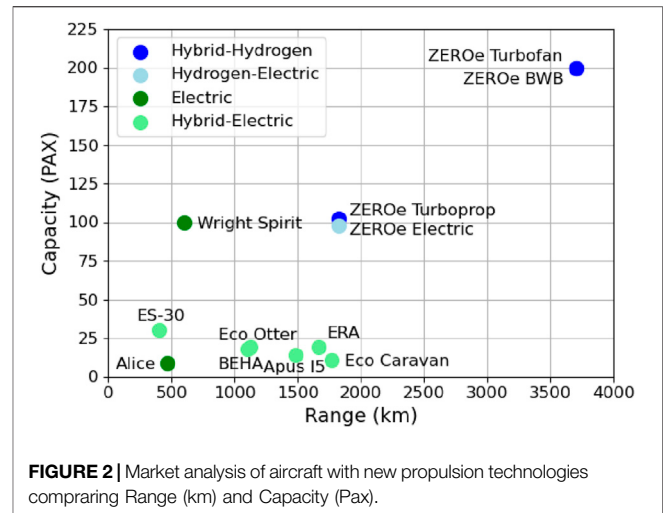
Electric concepts are also in development with few test flights for regional aviation, Pipistrel [27], Lilium [28], Wisk [29] and Volocopter have different 4-seater models for UAM [30]. In contrast to that, Wright Spirit (Wright Electrics [31]) and Alice (Eviation Aircraft [32]) are larger electric concepts for regional mobility. Hybrid-electric concepts such as Apus i5 [33] and Heart Aerospace ES-30 [34] promise more range capacities than all-electric concepts.

For our study, we identified a few of the new propulsion concepts within very close proximity to existing conventional aircraft. We have selected the Airbus zeroe turboprop and the wright spirit aircrafts with characteristics reflected in **Table 1**. We model the selected aircraft on the current network, to assess their operational impact.

RESEARCH QUESTIONS AND OBJECTIVE

Based on the findings in the literature, precise research questions for this paper were defined:

- How can aircraft with new propulsion technologies be integrated in current Network Flight planning of airlines?
- Can they achieve the operational requirements needed (e.g., range and PAX) on current routes?
- What new complexities will arise with the integration of new propulsion technologies to an airline fleet?
- In which areas do airlines and airports need to prepare for the expected increase in complexity?



The overall goal of this paper is to explore the feasibility of the integration of aircraft with new propulsion technologies into existing fleets and flight schedules and the associated challenges that come along with it. This paper focuses more on strategical planning of different flights and not the planning of one specific single flight.

ROUTE SELECTION AND NETWORK FLIGHT PLAN DEVELOPMENT

If an airline decides to integrate aircraft with new propulsion systems into their existing fleet and network, different parameters have to be evaluated to identify suitable aircraft as well as possible routes that can be covered. A hypothetical airline has been selected as an example to show our developed integration approach. The airline's fleet and network is composed of a balanced mix of aircraft types operated on various routes from regional to long-haul flights based on the network of a major German airline.

The first decision is the choice of which aircraft should be integrated in the current fleet. Therefore, different parameters can be evaluated, as the new aircraft shall also align with the overall strategy of the airline. One possible approach to reach this alignment is comparing the new possible aircraft with the current fleet composition in that segment. Hence, a market analysis has been carried out to identify the best fitting aircraft for the airline network. The result of this analysis is shown in **Figure 2**.

When comparing these aircraft to the current airline fleet in this range-segment (Airbus A319/A320 or Bombardier CRJ900), only the four Airbus ZEROe aircraft as well as the Wright Spirit offer a suitable capacity that aligns with the needs of the airline. For the further approach, the integration of an Airbus ZEROe Turboprop as well as a Wright Spirit will be considered as these aircraft also utilize different propulsion systems. The Airbus uses hybrid-hydrogen propulsion consisting of hydrogen combustion

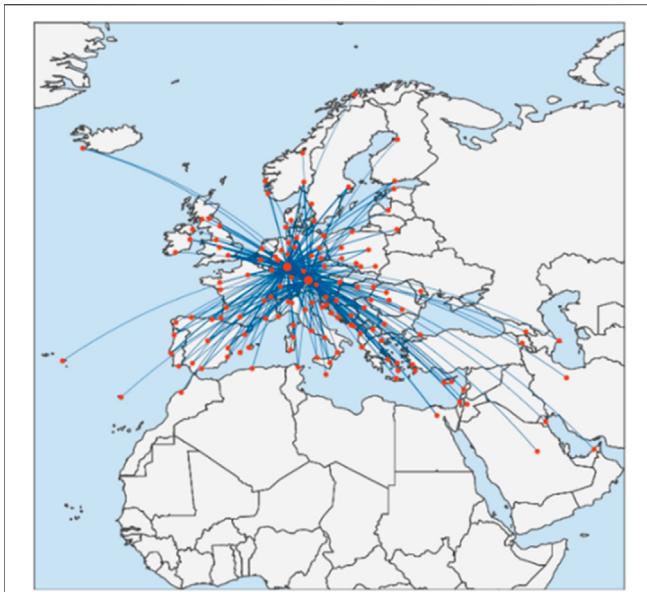


FIGURE 3 | Major German airline route network.

and a hydrogen fuel cell while Write Electrics decided to design an all-electric aircraft.

Now that the aircraft are selected, the current route network can be evaluated to identify possible routes for these aircraft. Hence, a list of all current routes as a first output can be drawn. This list includes the main characteristics of each route such as the distance between the origin and destination or the actual customer demand in a specific period to be considered. The required data for such a list has been collected manually by deriving all available flights from the airline in an exemplary week in June 2024. Therefore, Flight Connections [36] was used to identify all airline destinations that week and further the number of flights to each destination and aircraft type used for each flight. The choice of this monthly data does not yet account for seasonal variability, which does influence airline schedules. However, the goal of this study is with emphasis on range dependent feasibility which can be adapted to any other seasonal schedule. To determine the demand, it was assumed that the used aircraft was chosen to match the market demand well and that there is no undersupply of flights. Hence, the demand was determined by deriving the seats for each aircraft from the airline's website. The sum of seats on each aircraft used on that route then represents the expected current demand. This research leads to the network shown in **Figure 3**.

Also connected to the network evaluation is the overall network structure. In our selected airline, a hub-and-spoke network is operated. Hence, a different filter can be applied than for a network that follows the point-to-point structure. As the hubs offer a good location for new technologies due to its high traffic volume and basis of many airlines, they can be used as bases for the new infrastructure. Thus, routes that cover a distance of about half the range of the new aircraft are an interesting consideration for integration as a flight from and back to the hub can be operated. Applying this filter to the

previously introduced airline network leads to the routes as shown in **Figure 4**.

In the next step, additional filters can be applied shown in **Figure 5**. At first, the regular connections can be filtered. This step aims to find routes where the new technology can be used daily. A route that is more of an exception in the flight schedule is not appropriate to integrate a new technology, since it would limit the hours of use and therefore reduce the economic efficiency. Hence, not only the seasonal but also the weekly availability of routes must be checked. The exact definition of a regular route will vary from airline to airline depending on their current flight schedule. For this example, a route is considered regular, if the connection is offered at least 6 days a week. Our analysis has been performed based on a proof of concept on introducing new propulsion technology to existing flight schedules, therefore we picked daily route offerings identified in a single month of June 2024 as a basis. We are aware of seasonal flight changes, however since the focus of our study is on validating the integration possibility of new propulsion technology to today's flight schedules, seasonal changes is of no direct influence on our study.

The next step would be the limitation of operated flights per day (flights/day) with a factor k_{flights} . Therefore, a comparison to the current situation is useful to identify routes where the demand matches the capacity of the new aircraft. To identify the required flights per day with the new aircraft, the current demand has to be divided by the capacity of the aircraft and then scaled to the period of 1 day. That value is then rounded to the next integer to consider the days with maximum flights. This filter aims to prevent too large aircraft on routes with low demand and the same the other way around. For this example, a k_{flights} -factor of 2 is used leading to the bounds as shown in **Equation 1**:

$$\frac{1}{k_{\text{flights}}} * \text{flights/day}_{\text{current}} \leq \text{flights/day}_{\text{new}} \leq k_{\text{flights}} * \text{flights/day}_{\text{current}} \quad (1)$$

Lastly, the operating time (OT) has to be considered. Even though the k_{flights} already restrict the flights per day operated by the new aircraft, it has to be ensured that these flights are still feasible in the given time. To calculate the time required by the aircraft to operate the route, the new flights per day have to be multiplied by the required block time on the selected route. The block time is calculated as the sum of flight time, turnaround time (TAT) and taxi time (TT). The flight time is calculated by dividing the distance between the airports by the cruise speed of the aircraft.

This assumption will lead to a reduced accuracy of result as the speed is normally not constant over the whole flight. To also be able to compensate for unexpected events or delays, a reserve factor (R) shall be used to reduce the available operating time of the airline. This leads to the following calculation in **Equation 2**:

$$OT_{\text{aircraft}} = 2 * \frac{\text{flights}}{\text{day}_{\text{new, peak}}} * \left(TAT + \frac{\text{distance}}{\text{speed}} + TT \right) < OT_{\text{airline}} * R_{\text{base}} \quad (2)$$

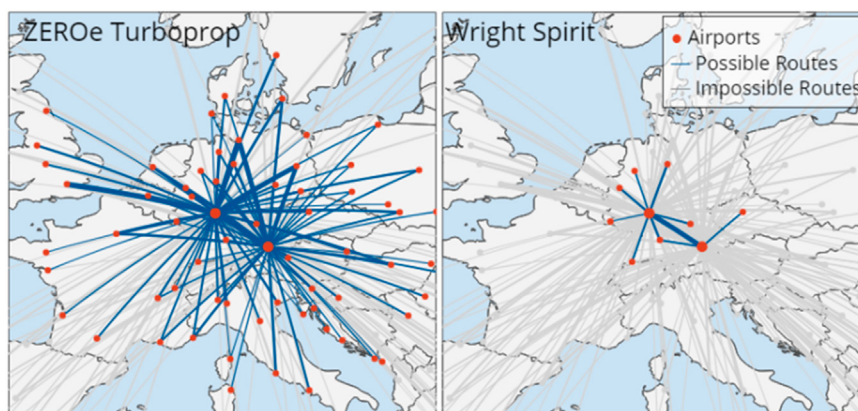


FIGURE 4 | Filtered airline route network showing possible and impossible routes for the various selected aircrafts.

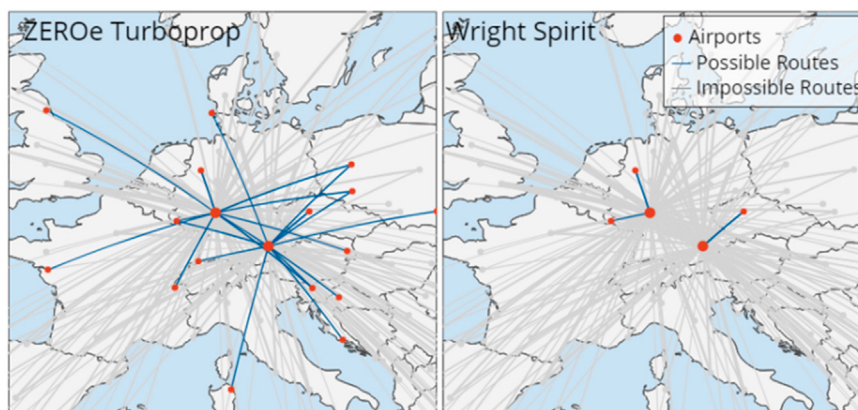


FIGURE 5 | New generated filtered Possible routes for the two selected aircraft.

The Reserve factor accounts for an ideal operational scenario, signifying the boundary conditions of how many possible flights are operational for an airline in absence of disruptive scenarios such as diversion, sick crew and maintenance unavailability. A simplistic approach is currently adopted to account for the absence of real regulatory measurement for future propulsion aircrafts.

For our selected airline, the following values will be used for further calculations:

The estimated TATs are based on different assumptions. The Airbus ZEROe requires hydrogen refueling. Postma-Kurlanc et. Al [10]. have performed a case study of different aircraft types and their refueling times. One of these aircraft has similar characteristics as the Airbus in this example. Hence, a conservative scenario (4 inch pipe diameter and $5 \text{ m}^3/\text{s}$ flow rate) was used to estimate the required time to refuel the Airbus. This leads to a refueling time of about 20 min which is 5 min longer than currently for an aircraft of the same size with a conventional propulsion system. Additionally, fewer tasks can be fulfilled simultaneously, leading to an extension of about 15 min–20 min compared to the current TAT of 35 min–45 min [10, 35].

TABLE 2 | Assumed values for the calculation of the operating time of an aircraft on a specific route [34, 35].

Property	Airbus ZEROe turboprop	Wright spirit
Turnaround time (TAT)	Full: 60 min, Short: 40 min	40 min
Taxi time (TT)	30 min	
Operating time (OT)	16 h	
Base Reserve factor (R) 10% flight time	0.9	

For the electric aircraft, manufacturers of aircraft in the same market segment estimate charging times of about 30 min under optimal conditions. However, due to process restrictions and for a more conservative approach, the full TAT was set to 40 min [32, 34]. Assumed values for the operating time estimation is summarized in **Table 2**.

However, those values are still based on various assumptions and may change in the future due to real life complexities such as

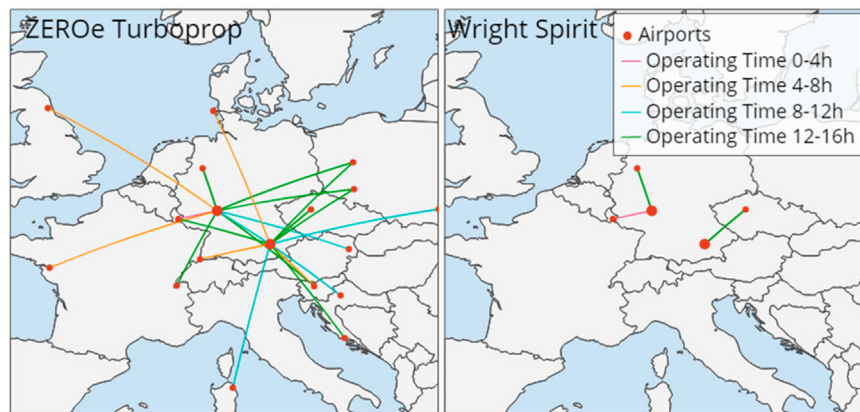


FIGURE 6 | Possible routes and their corresponding operating times.

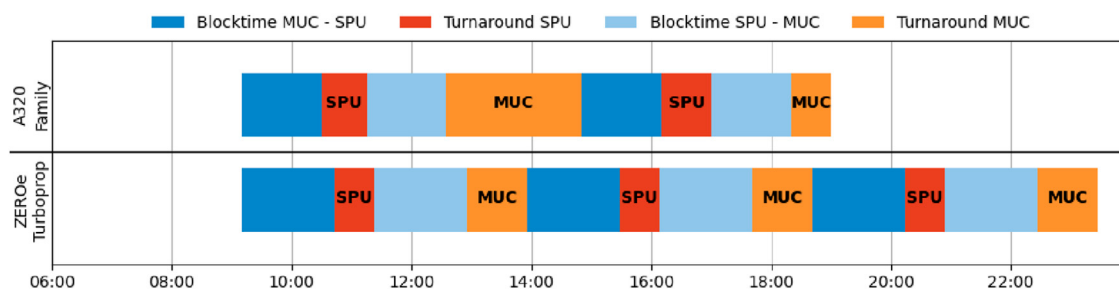


FIGURE 7 | Current and new Route network Flight plan on the route MUC-SPU using an Airbus ZEROe Turboprop.

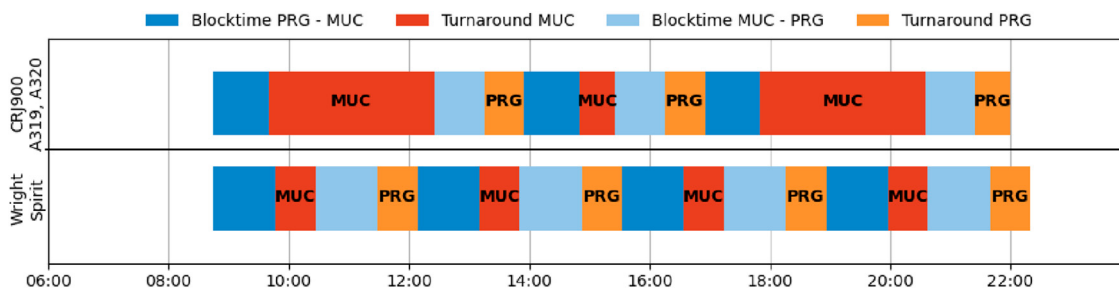


FIGURE 8 | Current and new Route network Flight plan on the route MUC-PRG using a Wright Spirit.

Ramp congestion, Refueling flow rate & pump size, Charging Capacity and other ground handling activities. Route selections have been made with operational range feasibility as main criteria rather than the infrastructural access in airports such as Energy and Hydrogen availability.

As a result of the previous steps, the following routes have been filtered for the selected aircraft:

In combination with the calculated operating time per aircraft-route-pair, **Figure 6** arises. This shows the required time to operate the new aircraft on a specific route while maintaining the same PAX demand. Therefore, the operating times are

clustered in four blocks each represented by a different color. Routes colored in pink require the least time while green ones require up to 16 h a day.

If the airline now wants to build a network Flight plan using the new aircraft, it can be done as usual by arranging the required number of flights per day with their calculated block and turnaround times. Additionally, information on the demand over the day is required to find an efficient schedule. For our scenario, the routes with the highest OT for each aircraft will be used. This leads to the route Munich-Split (MUC-SPU) for the Airbus ZEROe Turboprop and Munich-Prague (MUC-PRG) for

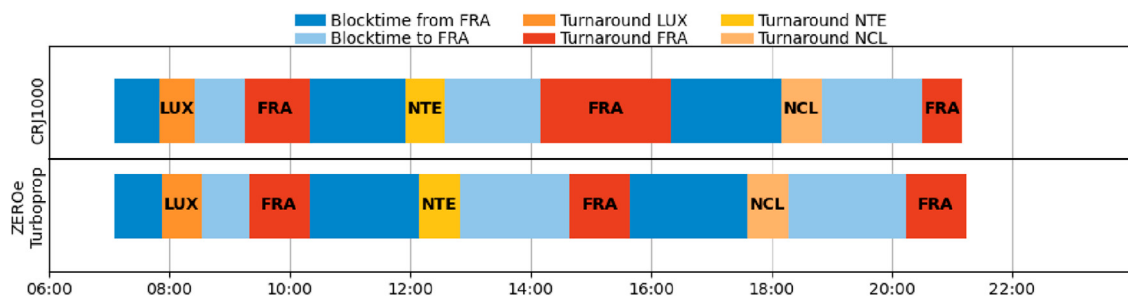


FIGURE 9 | Current and new Route network Flight plan on the multi destination route FRA-LUX, FRA-NTE and FRA-NCL using an Airbus ZEROe Turboprop.

the Wright Spirit. The matching of the demand is then carried out by comparing the new network Flight plan to the current schedule.

The resulting route Network Flight plan for the selected pairs are shown in **Figures 7, 8**.

Both route Flight plan are already quite close to the current ones. However, due to the additional flights needed to cover the passenger demand, it cannot be fully ensured that the demand at a specific time of the day can be met. Hence another integration strategy can be interesting to solve this issue: operating multiple routes. This is a well-established scenario in the analyzed airline network to increase aircraft utilization and efficiency. To showcase an example closer to actual operations, the operation of a new aircraft on multiple routes has been considered. An exemplary Route network Flight plan was generated using the Airbus ZEROe Turboprop on the routes from Frankfurt (FRA) to Luxembourg City (LUX), Nantes (NTE) and Newcastle (NCL). Therefore, both operating times and locations had to match. The operating time of these three connections sums up 14.2 h, which is still feasible and as all return to the same hub, they are connectable. The updated Route network Flight plan is given in **Figure 9**.

Regardless of the exact scenario, all flight schedules show that the new aircraft are highly competitive on the selected routes. Almost no difference between the current and new aircraft can be seen in terms of a single flight schedule. This is based on the advantage of short-range flights. As the current aircraft often are not able to reach their maximum cruising altitude and speed during short-range flights, the new aircraft can keep up with them, even though having a lower maximum cruising altitude and speed.

However, the estimated flight times for the new aircraft still relies on simplifications leading to errors. Nevertheless, the block and turnaround times are especially close to the current state which also enables a partial integration to the selected routes next to the current aircraft without any special disruptions.

NEW COMPLEXITIES AND PROPOSED ACTIONS LIFE SCIENCE IDENTIFIERS

The analysis in Chapter 4 proves that based on the required PAX demand and current routes it is possible to replace conventional

aircraft with hydrogen or battery propelled aircraft. But with these new propulsion technologies there arise new complexities from an airport and airline perspective. However, the introduction of new propulsion technologies comes with different complexities that can have direct consequences on the flight scheduling and turnaround process for both airlines and airports. Based on a workshop session conducted in the LuFo project OpAL comprising of experts across Aircraft manufacturing, Engine manufacturing, Airport & Airlines operation and Airport infrastructure, the following complexities were identified as potential influences on the schedule and operational turnaround.

A closer look shows, that also the new route Flight plan described from Chapter 4 will result in some of the new complexities stated in **Table 3**.

The selected aircraft in the previous example uses hydrogen and electric propulsion. By excluding the complexities related to sustainable aviation fuel (SAF) four main areas of new complexities can be identified:

- Turnaround Process
- Maintenance
- Flight Planning
- Cost & General

The following sections summarize the complexities for each of these areas.

Turnaround Process

During the turnaround process the new propulsion technologies will have an impact on the allocation of parking positions or gate allocations, since now it needs to be guaranteed that the airport can provide the required fuel (hydrogen or electric energy) at that specific location. In general, new dependencies and requirements, e.g., regarding safety, could lead to changes in the overall tasks and order of tasks during the turnaround process.

Maintenance

With the implementation of new propulsion technologies, the maintenance procedures and processes will need to be adapted. New training requirements, certification processes and job safety rules for maintenance staff as well as new training for flight and ground staff on these new technologies are needed. The

TABLE 3 | New complexities due to the integration of aircraft with new propulsion technologies.

No.	New complexity
1	Handling more than one fuel type during turnaround process - gate and parking position allocation - for airports with hybrid propellant
2	New training requirements, certification processes and job safety rules for maintenance staff
3	New technologies, parts and tools to be maintained by maintenance staff
4	Considering fuel type and charging requirements in minimum equipment list (MEL) during Route network Flight planning - availability on selected routes and alternate airports
5	Considering changed aircraft performance (cruising speed and range) due to new technologies during Route network Flight planning
6	Considering noise and emission restrictions in Route network Flight planning
7	New training for flight/ground staff on handling new propulsion technologies
8	Changes in turnaround process (new task order or requirements)
9	Changes in cost structure
10	More aircraft types can lead to less exchangeable aircraft and crew
11	Route planning to avoid areas of adverse weather (e.g., temperature, wind)
12	New Route network Flight planning considering charging/refueling route
13	New Route network Flight planning considering battery capacity, state of health, fuel cell
14	Increased complexity in data requirements in new airspaces (e.g., very low level airspaces)
15	Fleet and network planning uncertainty as result of unknown future range and MTOW developments
16	Exploration of more diverse stakeholders for operations
17	Increased network complexity due to a higher integration of small electric aircraft in multimodal transport
18	Establishing additional and new supply chains for an increased diversity of spare parts
19	Less homogenous market for supplies, fueling and equipment
20	Infrastructural availability such as Charging stations, Hydrogen Availability

maintenance task will require new technologies, parts and tools that still need to be developed or manufactured. Therefore the introduction of new supply chains for the increased diversity of spare parts is essential.

Flight Planning

The task of flight planning is heavily affected by the new propulsion technologies. Reduced or changed performance of the aircraft regarding range and capacity has an immediate impact on the selected routes and the schedule in which it is operating on. Selected destinations as well as the alternate airports must be able to provide the fuel type, and the equipment needed to handle these aircraft with new propulsion technologies. The availability of high-speed charging and hydrogen refueling capabilities will be a new requirement during the allocation of specific aircraft to a route to be operated. Especially for the electric propulsion it will be essential to track the state of health of the battery at all times, since it is directly linked to the range of the aircraft. The effect of weather (very cold or very hot temperatures) can affect the range of the battery. Fleet and flight planning must be prepared to handle uncertainty during the calculation of future range and maximum take-off weight (MTOW).

The cruising speed and flight altitude can also vary from conventional kerosene propelled aircraft and influence the route selection. This could limit the ability to avoid areas of adverse weather and as a result reduce the available route the aircraft can be operated on. On the other hand, the lower emissions (noise and carbon dioxide) of the new propulsion technologies could enable new routes, since more and more noise emission restrictions for conventional propelled aircraft are being implemented.

A more diverse fleet will result in a higher variety of training for flight staff and make the crew or aircraft less exchangeable in a disruption event, when the airline would like to use a reserve aircraft or a reserve crew.

Cost & General

All changes from the previous three areas will impact on the cost structure from an operational perspective. These changes must be represented in the prices of seats or cargo for each specific flight and route. Overall, more diverse stakeholders will be handling the operation, which leads to a less homogenous market for supplies, fueling and equipment.

These identified complexities could lead to longer than assumed turnaround times (see Chapter 4) and therefore affect the flight schedule by inducing delays. The sooner these complexities are consciously addressed, the easier the integration of aircraft with new propulsion technologies will be.

RESULTS SUMMARY

We have described a methodology for integrating aircraft with new propulsion technologies into an existing airline flight network, as demonstrated by a case study with a major German airline that uses the Airbus ZE-ROe Turboprop and Wright Spirit on specific routes that meet range and passenger demand requirements. Our study proposes that to replace conventional aircraft, the flight network will require modification in the scheduling and operation. Adding additional flights during normal operation hours to meet capacity demands will ensure full-day coverage of existing flight schedules, and having the appropriate infrastructure will

TABLE 4 | Sensitivity analysis on available routes with variable range.

Property	Range (km)				
	–20%	–10%	Current	+10%	+20%
ZeroE Turboprop	14	18	20	20	23
Wright Spirit	1	3	3	5	5

TABLE 5 | Sensitivity analysis on available routes with variable capacity.

Property	Capacity (seats)				
	–20%	–10%	Current	+10%	+20%
ZeroE Turboprop	9	15	20	23	29
Wright Spirit	1	2	3	3	6

boost turnaround times and process to match existing conventional flight operations.

Our result also delves more into the operational challenges that will be created by these new technologies, focusing on turnaround processes, maintenance, flight planning, and cost management, and underlining the importance of airlines and airports implementing mitigation techniques to reduce their impact. Overall, the integration of such aircraft with existing networks is deemed feasible with proper planning and adjustments.

CONCLUSION AND OUTLOOK

This study provides insights into the feasibility of integrating new propulsions into existing airline networks and fleets. Utilizing a developed methodology to model the integration of hydrogen and electric aircraft concepts on a range of routes, we present possible complexities that could arise for airlines and airports during this process.

The proposed methodology indicates good potential for new propulsion technology to be successfully integrated on existing airline flight routes and provide an integration pathway for airlines. However, it is important for airlines and airports to understand and be prepared for the complexities that could arise as a result of these new network flight plans, which include and are not limited to operational complexities in the turn-around process, maintenance, flight planning, and associated costs during integration with existing flight networks.

The proposed methodology examines the possibility of new propulsion aircraft on selected routes based on the operational time and demand matching; this methodology can be further extended to account for additional factors such as crew training, deployment, and availability of maintenance personnel for airlines. In addition, an adapted method could be developed to identify suitable new aircraft to replace the current fleet, considering factors such as age and emissions.

A thorough understanding of various airline business strategies and the possible implications on the planning

TABLE 6 | Sensitivity analysis on available routes with variable TAT.

Property	TAT (min)				
	–20%	–10%	Current	+10%	+20%
ZeroE Turboprop	22	20	20	15	13
Wright Spirit	5	3	3	3	2

parameters is necessary to tailor the methodology to individual airline planning procedures. The incorporation of an airport database to account for destinations with infrastructural capability will further aid the robustness of this approach for airline network planning.

However, it needs to be stated that this is only the beginning of new propulsion technologies in aviation and the promised performance characteristics may change as they approach market maturity. A sensitivity analysis regarding the promised Range (**Table 4**), PAX capacity (**Table 5**) and TAT (**Table 6**) shows that even a change as low as plus/minus 10% already has some impact on the available routes for the ZeroE Turboprop as well as the Wright Spirit aircraft.

Table 6 also shows that the assumed TAT of the new aircraft could be 20% higher and there would still be routes available for the aircraft to be operated on. On the other hand, a reduction of TAT by 10% does not enable the operation on additional routes. Only a reduction by 20% allows operation on additional routes.

Due to the lack of genuine performance data for take-off and descent speeds, our Block time estimate was made using an assumption of cruising speed, which reflects the ideal flight trajectory of the new propulsion. Block time is highly reliant on variable circumstances, such as parking gate position, runway length, seasonality and time, weather, and traffic patterns, resulting in critical variances in operational block time of both conventional and new propulsion flights.

The results show that the performance values promised by the manufacturers tend to represent a minimum requirement from an airline's perspective. It is therefore necessary to repeat this type of analysis as soon as real performance data on market-ready aircraft with new types of propulsion is available.

Electric and hydrogen-powered aircraft is expected to vastly reduce aviation emissions, with electric models potentially eliminating roughly 3.7 million tonnes of CO₂ annually by 2050 and hydrogen propulsion delivering up to 94% lifecycle emissions reduction [37, 38]. Both technologies significantly reduce noise pollution compared to traditional aircraft, allowing for more flexible airport operations and increased community acceptance. This quantitatively acknowledges the vast importance of integrating new propulsion systems to the current flight operation towards decarbonizing the aviation industry.

Airline operations are fundamentally passenger-centric, and the introduction of new propulsion aircraft could prompt airlines

to adopt more flexible flight schedules to accommodate evolving passenger needs, particularly given the typical lower seating capacities of these aircraft compared to conventional models. However, the potential effects of such scheduling flexibility on passenger demand remain uncertain and warrant further investigation from a human factor's perspective.

Despite significant initial infrastructure investments needed globally in order to achieve the vision of new propulsion flights by 2050, long-term operational reductions in fuel and maintenance costs along with Technological growth will provide better economic viability of new propulsion aircrafts as observed in the automotive industry.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

The manuscript was written by AA, JL, and ID with PH and TF as supervisor. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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