EVALUATION OF THE MARKET POTENTIAL AND TECHNICAL REQUIREMENTS FOR THIN-HAUL AIR TRANSPORT

A. Paul[1], W. Grimme[2], G. Atanasov[3], J. van Wensveen[1], F. Peter[1]

[1]Bauhaus Luftfahrt e.V., Willy-Messerschmitt-Straße 1, 82024 Taufkirchen, Germany

[2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Flughafenwesen und Luftverkehr

[3]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Systemarchitekturen in der Luftfahrt

Abstract

The future mobility landscape faces several challenges including increasing congestion, meeting emission reduction goals, and reducing overall travel time from door to door. The current transport market, including the aviation sector, needs different concepts that provide feasible solutions. This paper therefore considers the re-introduction of small regional aircraft with up to 19 passengers, and the potential benefits these may yield for both travellers and companies offering these services.

The market for these particular aircraft types, including the Dornier Do228 or Beechcraft 1900, was at its peak in the 1990s, and respective services focused on very thin-haul routes for both passengers and freight as well as military applications. The paper discusses developments that potentially contributed to the decline of these particular aircraft. These may include the entry of low cost carriers on many routes, making it more affordable for a high share of travellers to use air transport, and thus turning thin-haul demand routes into ones with potentially high seating capacities. Furthermore, alternative transport modes such as high-speed rail may have imposed increasing competition on regional flights, offering faster and less expensive travel options for passengers.

Today, however, the specific characteristics of 19-seater aircraft fit well into the required rethinking of the current transport system – short take-off and landing capabilities, or the use of airports with minimum infrastructure requirements. The paper evaluates and outlines the required technical features of these particular aircraft required for a successful future market dissemination. Taking these characteristics into consideration, the research in this paper discusses future fields of applications and respective business models. These include the introduction of on-demand services for both passengers and freight, focusing on commuter services, for example, in order to realize significant reductions by offering direct point-to-point connections.

Additional benefits resulting from the (re-)introduction of these specific aircraft services are also generated for remote rural regions, making it more attractive locations for companies by ensuring high connectivity to urban agglomerations, and alleviating some of the capacity shortages at larger airports by offering more point-to-point connections on thin-haul routes.

doi:10.25967/490206

1. INTRODUCTION AND OBJECTIVES

The future mobility landscape faces several challenges including increasing congestion, meeting emission reduction goals, or reducing overall travel time from door to door. In Europe, the Flightpath 2050, for example, postulates that 90 per cent of passengers shall be able to conduct their door-to-door journey within four hours, including an air segment. Figure 1 shows the current status of door-to-door travel times, for both business and family travellers, with a European-wide mean door-to-door travel time of more than five and a half hours (DATASET2050).

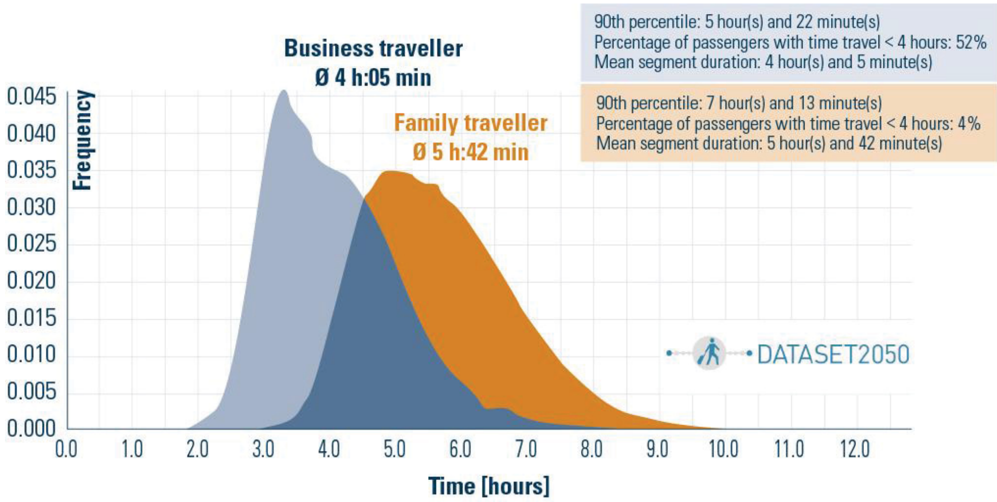

Figure 1: Meeting Flightpath 2050 objective from door-to-door within 4 hours (source: DATASET2050)

In terms of reducing emissions caused by the air transport sector, the Flightpath 2050 goals also state that “in 2050 technologies and procedures available allow a 75% reduction in CO_2 emissions per passenger kilometre and a 90% reduction in NO_x emissions” (European Union, 2011, p. 15). Finding an air transport solution that enables the reduction of emissions is therefore a necessary way forward.

The current transport market, including the aviation sector, needs different concepts that provide feasible solutions for these challenges. This paper therefore considers the potential of electric small regional aircraft with range extender with up to 19 seats, and the possible benefits these may yield for both travellers and firms offering these services.

The first part of this paper (Section 2) focuses on the historical market development of 19-seater aircraft, and potential reasons why this particular market segment declined over time. The second part of the paper (Section 3) gives a qualitative outlook on the potential new application areas of an electric aircraft with a combustion engine range extender within this category, considering feasible areas of future operation. Section 4 concludes the paper and gives an outlook on further required research.

2. HISTORIC MARKET DEVELOPMENT

Despite their versatile use in passenger and cargo transport, as well as specialized applications such as parachuting and sight-seeing flights, the market for 19-seater aircraft has not followed the general growth trend in aviation over the last decades. In scheduled commercial aviation, 19-seaters have been displaced to a large extent on routes with growing demand for larger aircraft, as operating costs per available seat kilometre are relatively high compared to larger aircraft (see Section 2.3).

This section outlines the development of 19-seater aircraft both on a global as well as regional scale, starting with an overview of the number of aircraft in service, and including an outline of the different application areas in which these aircraft are used (Section 2.1). The more detailed analysis of regional use of these aircraft (Section 2.2) shows the number of movements and the respective development across different regions, and outlines those factors that potentially had an influence of the decline of this particular aircraft segment (Section 2.3).

2.1. Aircraft fleet development

From 1980 onwards the fleet of those aircraft within the category of 19-seater increased steeply, peaked in the mid-1990s, and then saw a steady decline in the number of aircraft being operated on the market. The following Figure 2 shows the development of the active fleet of 19-seater aircraft, used for civil purposes. After having peaked with 3,239 aircraft in 1996, the number of aircraft in service has declined to a global total of 2,272 in 2018. Also the market for new 19-seater aircraft for civil applications is rather small, with only 18 aircraft delivered in 2018. Only three types remain in production: the Dornier/RUAG Do228NG, the Viking Air DHC-6 Twin Otter and the LET-410UVP. Textron Aviation Inc. also announced the introduction of the Cessna SkyCourier with an entry into service in 2020 (Textron Aviation, 2018).

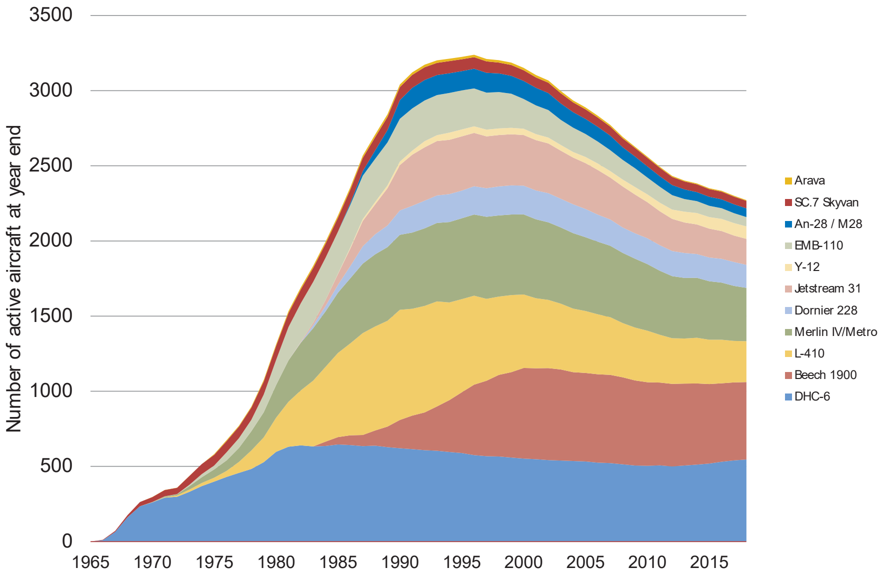

Figure 2: Global civil 19-seater aircraft fleet (source: own depiction, based on Cirium Fleets Analyzer)

Historically, 19-seater aircraft have been applied in different areas. Figure 3 shows the distribution of uses for the 19-seater aircraft. About two thirds of the civil 19-seaters currently active globally are used for passenger transport. 14 per cent of the aircraft are used for cargo transport. A notable special use for this class of aircraft is parachuting, with 7 per cent of the global fleet. A rather small share of 4 per cent of the active aircraft are dedicated for business aviation or air taxi uses, mostly in remote areas, e.g. by the mining or oil and gas industry. Another 8 per cent of the fleet have other purposes, e.g. training school aircraft, flying hospitals, or aircraft used for research.

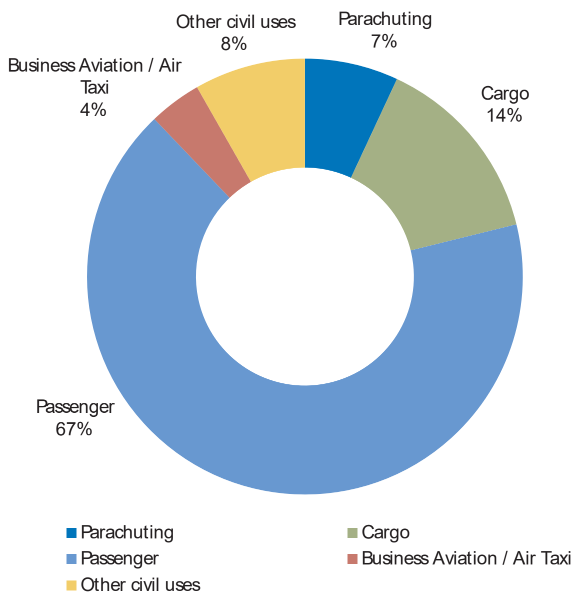

Figure 3: Share of civil uses of 19-seater aircraft (source: own depiction, based on Cirium Fleets Analyzer)

2.2. Regional development and application

The more detailed, regional analysis gives an initial insight into possible geographical characteristics and regional specifics that fostered the rise or decline of these specific aircraft types and associated services. In this regard, the U.S. market has always been the market with the highest number of movements of 19-seater aircraft (see Figure 4), with Latin America and Oceania also having a high number of movements.

The analysis of airport pairs which are being served by 19-seater aircraft with scheduled services between the years 2000 and 2018 shows that the number of these declined from more than 3,500 in the year 2000 to about 1,000 in 2018. Out of the initial airport pairs in 2000, only about 400 are still being served by 19-seater aircraft in 2018.

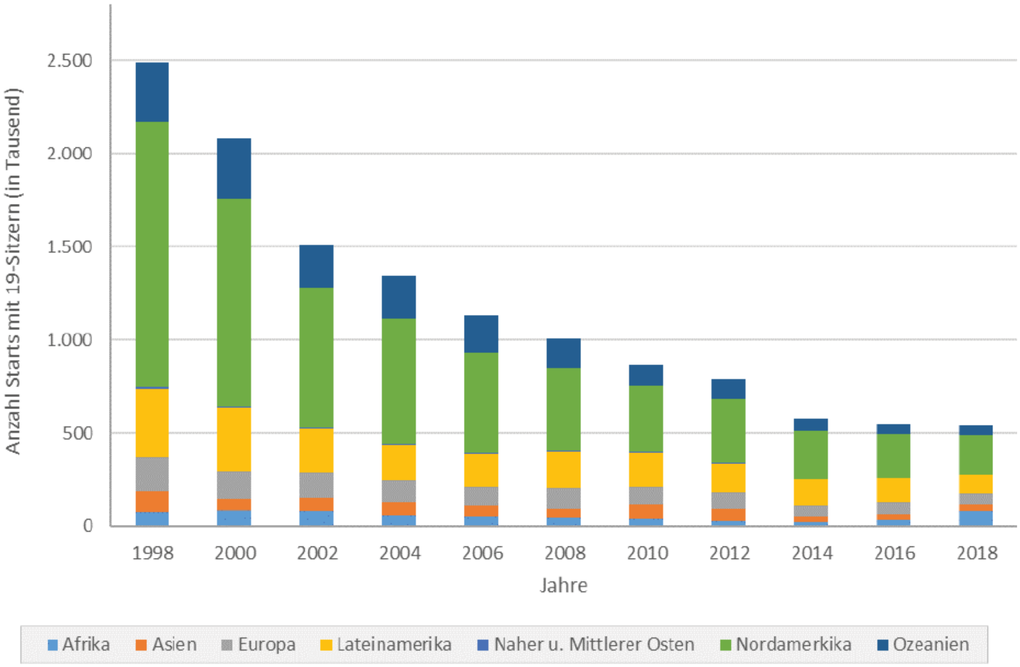

Figure 4: Number of departures per region and year (source: Middel, 2019)

The analysis also reveals that more than 50 per cent of the 3,500 airport pairs are not being served at all in 2018. Another 30 per cent of these airport pairs are still connected but by flights with aircraft larger than 19 seats. In this regional analysis, a particular focus is placed on both the North American and European markets.

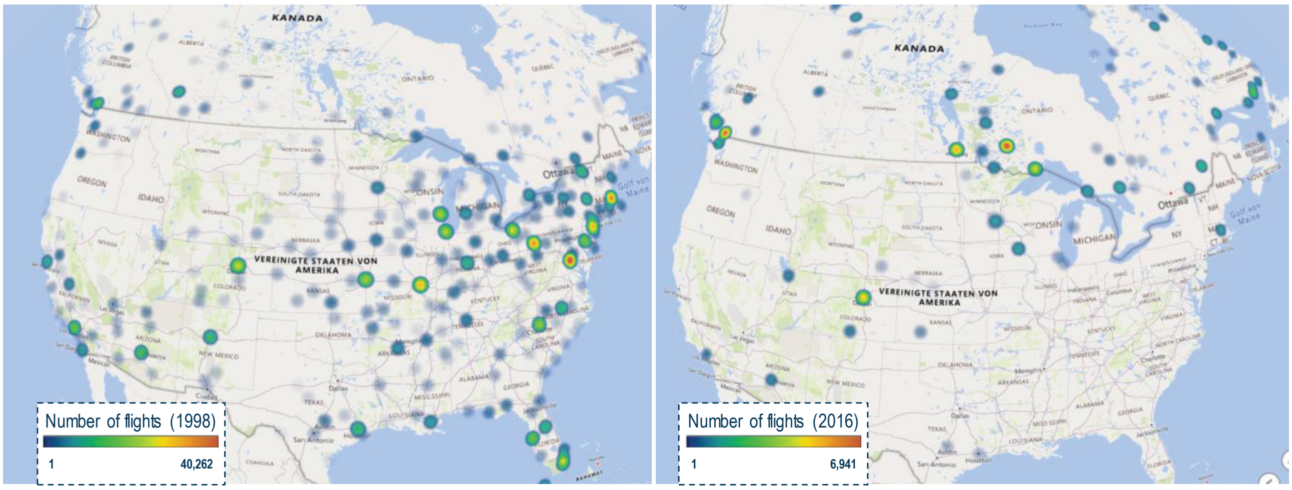

Figure 5: Airport pairs served by 19-seater aircraft (1998 vs. 2000) (source: own depiction, based on OAG data)

From Figure 5, it can be seen that especially the U.S. market experienced a closure of many high-density routes between 1998 and 2018. The European market, with a high number of low density routes, i.e.

less than 250 flights per airport pair per year, saw a steep decline on overall movements of 19-seater aircraft (Middel, 2019). The next section therefore focuses on aspects that had a potential influence on the decrease in 19-seater aircraft movements.

2.3. Factors influencing the decline of regional aircraft

Several developments are assumed to have contributed to the decline of these small regional aircraft. One is the cost structure associated with 19-seater aircraft compared to larger ones, as can be seen in Table 1. Compared to regional jets or narrow-body aircraft, the total cost per block hour for a turboprop aircraft with less than 20 seats is twice as high as those for a regional jet with more than 60 seats. Furthermore, compared to other aircraft categories, types with less than 20 seats have a high share of fixed costs, with about 30 per cent of total costs. Considering that 19-seater aircraft can only transport a low number of passengers and are mainly employed within ranges up to 400 kilometres (see Figure 9), the unit aircraft operating cost (cost per available seat kilometre) are significantly higher than for other aircraft. This represent a disadvantage towards the operation of other aircraft categories, and may have contributed to the decline in 19-seater aircraft operations.

Table 1: Average operating and fixed costs in (US$) per block hour for different aircraft categories (source: FAA, 2016)

Aircraft cetegory	Total variable costs	Total fixed costs	Total costs	Block hours
WB >300 seats	**13,500**	**1,092**	**14,592**	191,834
WB <300 seats	**8,236**	**867**	**9,103**	2,006,089
NB >160 seats	**5,014**	**627**	**5,641**	2,392,889
NB <160 seats	**3,833**	**557**	**4,390**	8,975,434
RJ >60 seats	**1,080**	**344**	**1,424**	2,156,423
RJ <60 seats	**993**	**247**	**1,240**	2,598,953
TP >60 seats	**1,165**	**447**	**1,612**	218,193
TP 20-60 seats	**818**	**382**	**1,200**	112,295
TP <20 seats	**293**	**727**	**1,020**	95,571

In addition to that, following aviation market liberalisation, the business model of the low cost carrier gained increasing market share from the mid-1990s, and especially from 2000 onwards. The widespread introduction of this business model led to the opening of new routes, and provided reasonably cheap fares for passengers, thus inducing new demand on different routes.

Givoni and Rietveld (2009) also show that the presence of a low cost carrier on a route leads to an increase in the number of seats offered per flight, i.e. an increase in aircraft size. This development is confirmed by Pai (2007) who empirically tested for the effect of low cost carrier presence on a particular route on aircraft size and frequency offered. The findings reveal that both aircraft size and frequency increase.

Another development impacting the demand for very short-haul air transport, which is often operated by small regional aircraft like the 19-seater category, is the increasing supply of high-speed rail options, especially in Europe. Figure 6 shows the door-to-door journey times for both rail and air transport across various distance segments. In particular, for the segment in which 19-seater aircraft are mainly operating, rail options exhibit time savings for passengers compared to air transport.

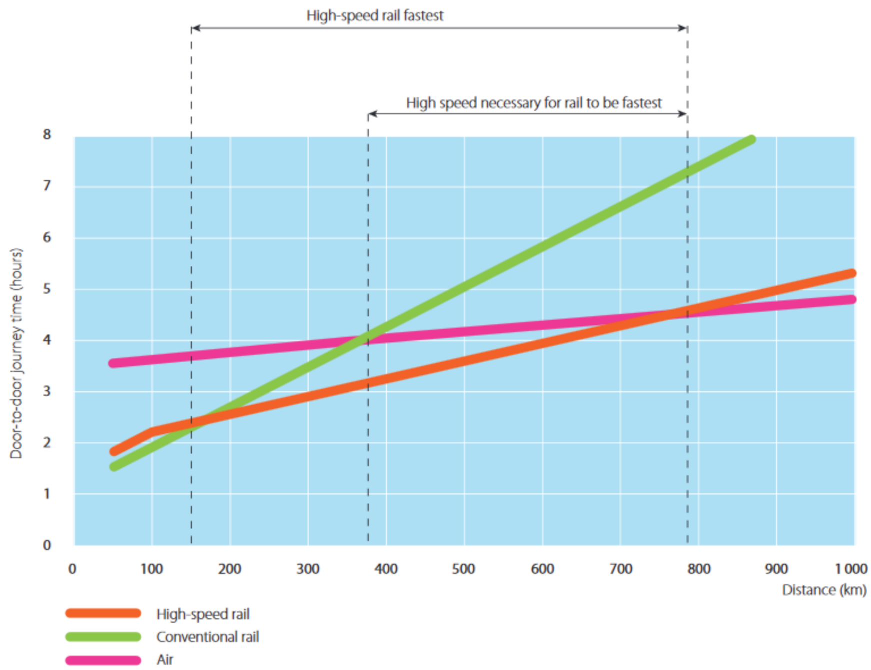

Figure 6: Journey times vs. distance for rail and air transport (source: Directorate-General for Mobility and Transport, 2010)

High-speed rail even offers time savings for passengers up to almost 800 kilometres. These potential journey time savings by using other modes in combination with the high operating costs for a 19-seater aircraft may also have contributed to the cease of operations on many routes.

Also contributing to the cease or replacement of 19-seater aircraft operations is the increase in air transport demand, accompanied by an increase in capacity shortages at large airports globally. Airlines have been replacing smaller aircraft in order to increase the number of passengers transported per flight instead of increasing frequencies (Berster et al., 2015; Eurocontrol, 2018).

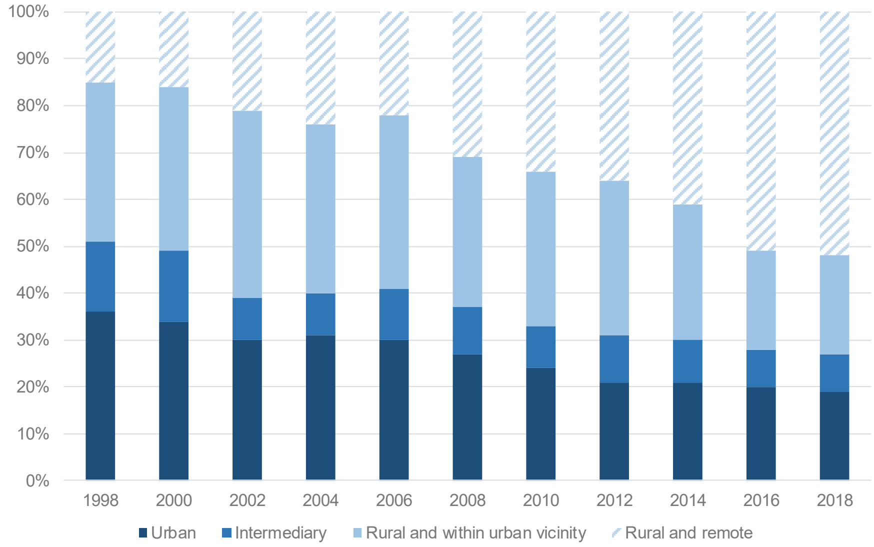

Figure 7: Development of departures of 19-seater aircraft according to regional categories (source: Middel, 2019)

Taking the North American market as an example again, Figure 7 shows that there has been a shift towards more rural operations of 19-seater aircraft, with only 15 per cent of departures in rural regions in 1998 and 53 per cent in 2018. Pai (2007) also finds, using data for the North American market, that if one of the airports on a particular route is a hub airport this is associated with larger aircraft and higher frequencies.

Givoni and Rietveld (2009), however, find the opposing effect with airlines using smaller aircraft and higher frequencies at hub airports. The latter include data on routes within Europe, the US and Asia which may account for some of the difference in results. The regional analysis by Middel (2019) supports the results of Givoni and Rietveld, by taking a look exclusively on the European market. When taking the same regional categories as depicted in Figure 7, only 27 per cent of departures of 19-seater aircraft are from rural areas, and about 40 per cent are from urban areas.

Considering the distinct geographical and regional characteristics of Europe and North America, the added value of using smaller aircraft to connect peripheral regions may be much higher on the North American market than in Europe.

This section outlined some of the factors that potentially contributed to the decline of 19-seater aircraft operations in the past. However, as highlighted in the introduction, there are developments and high-level goals within the mobility and aviation sector that provide new feasible market applications of fully or hybrid electric 19-seater aircraft. These are outlined in the following section.

3. FUTURE MARKET POTENTIAL

This section focuses on the qualitative outline of potential business case applications of thin-haul operations with 19-seater aircraft (Section 3.2), considering the technical capabilities of an electric aircraft with a combustion engine range extender (Section 3.1).

3.1. Aircraft technical specifications

The technical capabilities of an electric 19-seater aircraft with a range extender in terms of range and payload are a key determinant of potential business case applications of these aircraft in the future. Figure 8 shows the payload-range diagram for this particular aircraft (see Atanasov et al., 2019).

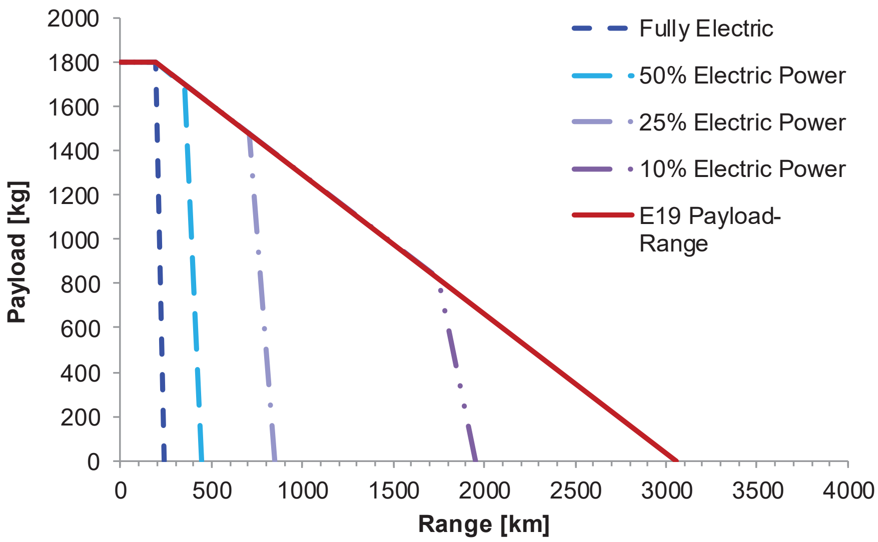

Figure 8: Payload-range diagram for fully-electric 19-seater aircraft (source: Atanasov et al., 2019)

With fully electric operations, i.e. not using the range extender, the 19-seater aircraft has a range of about 190 kilometres with maximum payload. Using only 50 per cent electric power increases the range to 445 kilometres. The technical specifications are further detailed in Atanasov et al. (2019). For the business case analysis in the following section, the range of an aircraft operating fully electric are assumed in order to assess the market coverage.

3.2. Business case analysis

The business case of an electric aircraft with a range extender will depend on various factors and characteristics. One key characteristic of any aircraft is range. While range does not play a major role in some specific aircraft applications (e.g. skydiving), for most it is a decisive factor on fleet decision making by the respective operators.

The following figure shows the distance distribution of 19-seater aircraft used in scheduled passenger transport. In 2018, 56 per cent of flights had a distance of less than 200 kilometres and 83 per cent of flights had a distance of less than 350 kilometres.

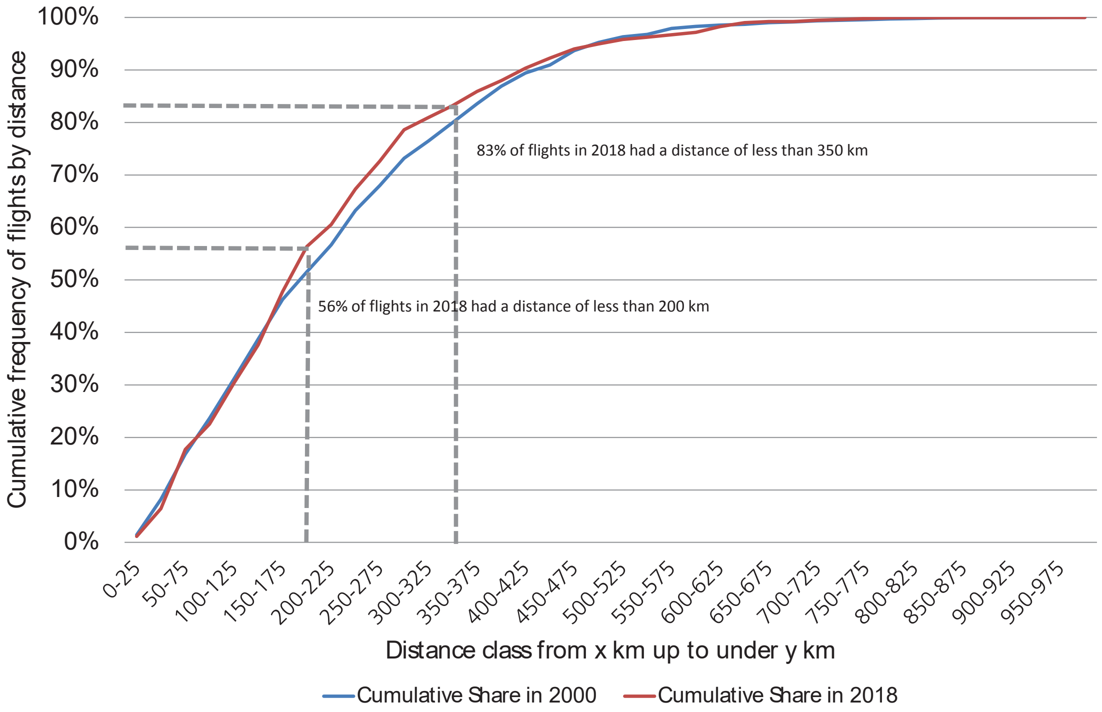

Figure 9: Cumulative share of scheduled passenger flights with 19-seater aircraft by distance 2000/2018 (source: own depiction, based on Sabre Market Intelligence)

This analysis shows that despite the limited range of the electric aircraft with a range extender, as outlined in Section 3.1, for a reasonable number of missions conventional aircraft could be replaced by this aircraft. However, two aspects should be investigated further in this regard. First, even when a majority of missions is below 200 kilometres, operators might need additional range capability for the flexibility to fly longer missions. As the majority of 19-seater aircraft operators possesses less than five aircraft, it is less likely that the operators will keep different sub-fleets for shorter and longer missions. Second, when aircraft are operated in remote regions, it must be guaranteed that the necessary infrastructure for recharging and/or changing battery packs is available.

In addition to conventional business cases (such as scheduled commercial passenger services, on-demand freight services or special applications like parachuting or sightseeing flights), the authors have investigated the possibility to use electric aircraft in innovative business concepts. One application in this area could be an on-demand air taxi system, which could operate on city pairs where travel times with existing ground transport modes are relatively long. Even in Germany, such an air taxi system could create travel time savings as the following case study shows. Germany is taken as an example due to detailed data availability.

The case study has included the following assumptions:

- All 240 German airports and airfields with a runway length of more than 800 metres could be used.
- Electric aircraft can operate over distances of up to 200 km, with a cruise speed of 360 km/h and an additional 20 minutes for taxi-out, take-off, landing and taxi-in – at distances of more than 200 km, intermediate stops for a change of battery packs are also calculated by adding 20 minutes to the total flight time.
- Car travel times for comparison are calculated using the HERE API.
- 15 minutes are added for airport process times for both curb to gate at the departure airport and gate to curb at the arrival airport.
- It was assumed that the air taxi service can capture 5 per cent of the current origin-destination passenger demand, as derived from the origin-destination passenger demand matrix from the German transport master planning (Intraplan et al., 2014) based

on NUTS-3 regions (districts and independent cities).

Based on these assumptions and data, Table 2 shows the five origin-destination NUTS-3 region pairs with the highest total travel time saving as compared to car travel.

Table 2: Travel time savings of air taxi service (own calculations)

Origin	Destination	Number of travellers in 2010 in each direction	Distance (great circle, in km)	Shortest travel time by car	Travel time electric air taxi	Travel time savings electric air taxi	Potential benefit (travel time savings at 5% market share)
Bremen	Berlin	370,456	321 km	234 min	168 min	66 min	409,354 h
Dresden	Hamburg	158,094	377 km	273 min	190 min	83 min	217,511 h
Bielefeld	Berlin	218,057	335 km	225 min	174 min	51 min	186,014 h
Kiel	Berlin	173,119	297 km	217 min	160 min	57 min	164,030 h
Mannheim	Munich	216,944	268 km	198 min	158 min	40 min	140,832 h

From the case study, it can be concluded that travel time savings between German cities can be significant. We see the highest benefits on city pairs between medium sized cities (250,000 – 500,000 inhabitants) to the biggest cities (1 – 3.5 million inhabitants) at distances of 250 to 400 km, as these city pairs offer a substantial travel demand and individual travel time benefit compared to car travel.

However, from a business case perspective, monetized travel time savings must exceed differences in travel costs so that a successful business model can be established. Here, one could be sceptical, as electric propulsion alone will be less likely to reduce costs far below costs encountered today with conventional aircraft. The high costs per available seat kilometre (as outlined in Section 2.3) could be an explanation why an air taxi service has not yet been established on the routes shown above. Hence, it is reasonable to assume that the passengers' willingness to pay and the achievable costs per ticket diverge strongly, making it difficult for an operator to set up a viable business model.

3.3. Environmental impact

In the current public debate, air transport has come under strong pressure, as it is considered as the most energy-intensive mode, resulting in relatively high CO_2 emissions per passenger kilometre. It can be expected that future policy measures will increase the price of CO_2 emissions beyond current levels (25 €/t in the European Emission Trading System, EU-ETS), e.g. through carbon taxation or a more stringent emission trading scheme. The de-carbonisation of air transport is challenging, with power-to-liquid fuels as a viable strategy for medium- and long-haul flights. For short-haul flights with relatively small aircraft, the direct use of electricity for propulsion, in combination with a range extender using hydro-carbon fuels is possible.

The system-wide impacts of a replacement of conventional 19-seater aircraft with hybrid electric 19-seaters are shown in Figure 10. The hypothetical replacement is conducted for all scheduled passenger flights with 19-seater aircraft in 2018. The total CO_2 reduction potential is 45.2 per cent if the current CO_2 intensity for electricity generation in Germany (0.486 kg CO_2 per kWh in 2017 as shown in Umweltbundesamt, 2019) and a 15 per cent efficiency loss in charging the aircraft batteries are assumed. CO_2 reduction potential increases to 73.3 per cent, when it is assumed that all electricity can be generated from renewable, carbon neutral sources.

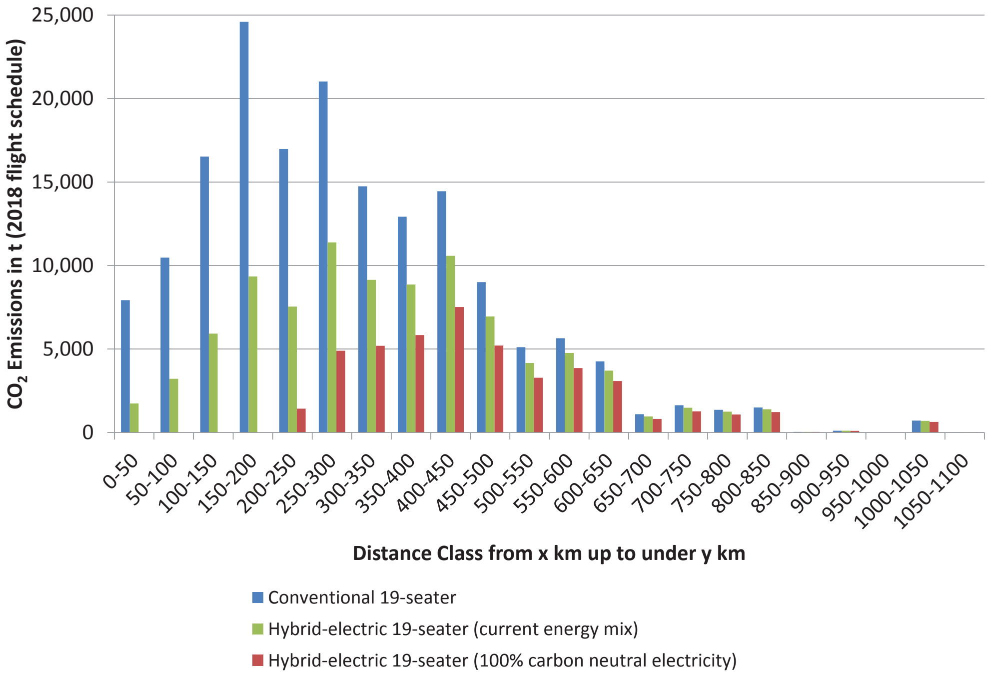

Figure 10: Emissions reduction potential of 19-seater aircraft replacement with an electric aircraft with range extender (source: own depiction)

The relatively high CO_2 reduction potential can be accomplished as the majority of flights would be operated under full electric propulsion with a distance of less than 200 kilometres. For longer flights, at least up to 200 kilometres can be flown under electric propulsion, with the remainder of the flight distance being covered by the range extender.

4. CONCLUSION AND OUTLOOK

The analysis in this paper outlined both the historical development of 19-seater aircraft as well as those factors that contributed to the decline of 19-seater aircraft, including the cost structure of these aircraft, the increasing market penetration of low cost carriers, competition from (high-speed) rail services, and capacity-constraint induced choice of larger aircraft.

Considering future challenges such as the introduction of a more seamless passenger journey as well as the reduction of emissions from air transport, an electric 19-seater aircraft with a range extender may provide a feasible solution to address these challenges. Assuming a range of an electric 19-seater aircraft of about 190 kilometres, more than 50 per cent of today’s movements can already be covered. Furthermore, the potential for new innovative business models has been highlighted concerning the introduction of an on-demand air taxi service. This can provide significant time savings for passengers on the German mobility market, for example. As highlighted, in order for a business application to be feasible the operational costs per available seat kilometre have to be on a competitive level. Further work should therefore focus on the analysis of operational costs.

In addition to the potential time savings, the analysis in this paper showed that the introduction of an electric 19-seater aircraft with range extender on the market segments which are already operated today can lead to a significant reduction in emissions, considering fully electric operations. This finding provides the basis for further research of the application potential of electric operations of 19-seater aircraft.

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