ECONOMIC FEASIBILITY STUDY OF A HYBRID-ELECTRIC 19-PASSENGER COMMUTER AIRCRAFT

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Abstract

The development of new aircraft configurations with hybrid-electric propulsion reflects the high demand for sustainable aviation and for reduced travel times. The CleanSky 2 project ELICA (ELectric Innovative Commuter Aircraft) aims to propose a concept design of a 19-passenger commuter aircraft which uses hybrid-electric propulsion. This paper investigates whether such an aircraft could be economically feasible from an operator's perspective. A new aircraft design involves certain risks in terms of market success, especially when new technologies such as hybridisation shall be included. Therefore, the operations and the impact of hybridisation of the aircraft are thoroughly analysed from an economical point of view.

Starting with a brief overview of historic usage of 19-passenger aircraft, new market opportunities which are opening up are explored next. These consist of Regional Air Mobility (RAM), which promises highly reduced door-to-door travel times and thin-haul air cargo, which is aided by the rise of e-commerce and the steady growth of general air cargo demand. Additionally, favourable regulations can provide significant competitive advantage. Next, the direct operating costs (DOC) are examined in greater detail in the business case of the aircraft, relying on benchmark values or expert assessments for the single cost positions. Moreover, sensitivities of the business case are analysed, which range from average mission distance, across the average load factor over to fuel consumption.

It can be shown that a hybrid-electric 19-passenger aircraft can be operated profitably with a profit margin of above 10 %. All assumptions are made conservatively as the aircraft uses future technology implying that greater profit is possible, if technology improves faster than currently expected or beneficial regulation is implemented. With regard to the impact of the Covid-19 pandemic, a solid tool to assess the economic feasibility of technology is even more valuable. The assessment however was conducted without taking the impact of a global health crisis on the travel industry into account. The prognosed numbers might occur delayed, at least until travel recovers to prepandemic levels.

1. INTRODUCTION & OBJECTIVES

As the world is rapidly changing, the aviation industry is experiencing what some experts call an electric aviation revolution [1]. Excluding the impact of the COVID-19 pandemic, air traffic is expected to double within the next 20 years [2]. Therefore CO_2-emissions are required to drop significantly to achieve carbon-neutral growth [3]. Electric propulsion technology provides one possible solution for this challenge. The first CS-LSA certification of an electric trainer aircraft with two seats [4] demonstrates the potential of electric propulsion. The transition of this technology to larger aircraft remains the main challenge. Besides technological challenges, also economic boundary conditions need to be considered, as the market success of a new aircraft cannot rely on (potential) government support but needs to be both ecologically and economically sustainable.

The objective of this paper is therefore to understand whether a 19-passenger commuter aircraft in a hybrid-electric configuration called ELICA is economically viable or whether a positive business case can be calculated. ELICA is limited to 19-passengers as this is the defined limit of the CS-23 certification category and has long been established as a class of aircraft. The goal of this paper is therefore to assess the market potential of a more ecological design of 19-passenger aircraft. First new market opportunities for ELICA are introduced in the form of RAM and thin-haul air cargo. In the following different cost positions for aircraft are investigated and discussed. Additionally, potential revenues are estimated and a profit margin is calculated. Lastly a sensitivity analysis is carried out to determine how ELICA's profit margin is impacted by minor changes of important parameters.

2. NEW MARKET OPPORTUNITIES

The market for 19-passenger commuter aircraft saw immense growth in the 1980s with the number of aircraft in service tripling within 10 years. This peaked in 1996 at 3,239 aircraft but by 2018 the number of aircraft in service had declined by 30 % compared to the high point. The most operated aircraft in this segment today are the Beechcraft 1900 and Viking Air DHC-6 Twin Otter. Only the DHC-6, Dornier Do 228 and LET410 remain in production, although once a total of eleven 19-passenger aircraft were in production at the same time. [5]

Nonetheless new market opportunities emerge for the proposed aircraft in two areas. The first new market opportunity is RAM and uses existing airfield-infrastructure to reduce door-to-door travel times by enabling point-to-point traffic. The other new market thin-haul air cargo is created by the rise of e-commerce amongst others. Textron Aircraft is currently developing the Cessna 408 Sky Courier specifically to the requirements of FedEx [6] which is the first entirely new 19-passenger-class aircraft in many decades and supports the focus of this paper. The new

doi:10.25967/530307

market opportunities are further explored in the following sections.

2.1. Regional Air Mobility

The goals of 'Flightpath 2050' by the European commission state that '90 % of travellers within Europe are able to complete their journey, door-to-door within 4 hours' [7]. Different scholars agree that this will lead to a sharp increase in the demand for commuter aircraft due to a more individual air transport within Europe [8]. SUN ET AL. compare different modes of transport (car, train, CS-25 aircraft and air taxi services) across different distances within Europe and are able to show that air taxi service in the RAM segment like those with the characteristics of ELICA are the preferred mode of transport for distances between 100 and 500 km regarding door-to-door travel time, as shown in FIG 1 [9].

To evaluate existing infrastructure in Germany, data from the accessibility model of the German Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) was used which shows how fast a federal motorway access, train station with long-distance service or large airport can be reached [10]. It can be derived that large parts of Germany are not well connected with legacy modes of long-distance transport. The same holds true for all larger EU countries. Using flight plan data for Germany, it is apparent that existing airport infrastructure is not fully exploited as only a small fraction of connections theoretically possible are offered. Probable explanations for this phenomenon are capacity constraints at major airports and the need to load entire large CS-25 aircraft for which there is not enough demand.

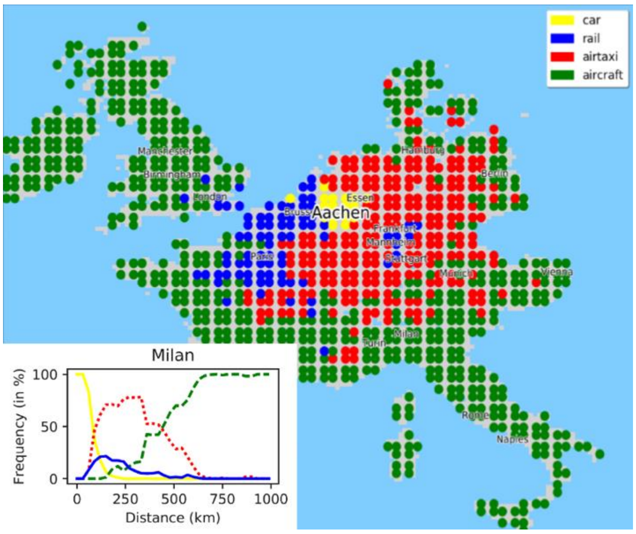

FIG 1: Preferred transport mode for trips originating from Aachen, Germany and Milan, Italy over travel distance [9]

The goals of Flightpath 2050 can therefore only be accomplished by domestic air travel that uses thin-haul RAM services. In 2019, 75 % of German domestic air travel went through one of the five largest domestic airports [11]. However more than 350 airports and airfields exist in Germany and are ready to be used. These airports are distanced less than 20 km from 80 % of German population [12]. It can be stated that a comparably dense network of small airfields exists in most other European countries and also across the rest of the world in countries like the United States or Australia [13].

Under the condition that aircraft with STOL (short take-off and landing) capabilities are introduced into the market and can be operated with reasonable costs, a large market potential for RAM can be assumed. Exemplary, German start-up e.SAT introduces the price range of a first class train ticket for RAM services [14].

2.2. Thin-haul air cargo

The total air cargo volume itself has increased significantly in the last years and accelerated growth is expected within the next two decades – not reflecting potential long-term effects created by the COVID-19 pandemic. BOEING expects a Compound Annual Growth Rate (CAGR) of 4 % within the next 20 years. Apart from the growth of the global economy, e-commerce drives the demand for air cargo. Amazon is setting new standards by making extremely fast delivery times and large product choice the new norm. Air transport is used to support this development. Additionally international express cargo has increased its market share from 4.1 % in 1992 to 19 % in 2017. [15]

BOEING expects 2,430 cargo aircraft to be delivered in the next 20 years to both replace old aircraft and to answer growing demand. The total number of cargo aircraft is set to rise by 60 % within that time frame. More importantly the number of aircraft with a Maximum Take-Off Mass (MTOM) below 45 t will increase by 69 % into which thin-haul air cargo and ELICA can be grouped. [15]

Amazon is not only setting new standards for customer expectations but also becoming a major player in air cargo itself with its Amazon Air subsidiary. Having started operations in 2016, Amazon Air is planning to operate 70 aircraft by 2021 [16]. In the US every second Amazon package was at least in part transported by air in 2019 up from only 10 % in 2017 [17]. Amazon is also starting to base aircraft in Europe and – according to expert information – looking to introduce smaller aircraft types like ATR 72 (7-8 t payload) or Saab 340 (4.4 t) into its fleet. Due to capacity constraints at airports during night-time, Amazon is taking the atypical approach of operating during day-time rather than night-time like UPS or FedEx leading to an improved utilization of cargo airports.

The case for a 19-passenger commuter aircraft in a thin-haul cargo role is supported by Textron Aircraft's development of the Cessna 408 SkyCourier specifically for FedEx. This aircraft is being developed with both a cargo version and a passenger version. FedEx has ordered 50 aircraft so far and holds options for another 50. The aircraft will be used to replace its aging fleet of Cessna 208 Caravan aircraft, which will double the aircraft payload volume [18]. This shows that a 19-passenger aircraft is just in the right spot for thin-haul cargo operations, having enough payload capacity for effective cargo operations but not too much to have runway constraints at small airports.

Overall, it is clear that air cargo will continue to grow, particularly to support e-commerce and express freight. In a move to shorten delivery times, smaller aircraft are used as enabling vehicles for thin-haul air cargo. A 19-passenger commuter aircraft is strongly supported by these circumstances.

2.3. Regulative upside potential

Regulation naturally has a great impact on aviation and ELICA has great potential to create regulative upside potential, by emitting very little CO_2 and noise. Low emissions can lead to a competitive advantage in the form of lower landing costs or CO_2-penalties. With governments around the world bringing laws into place that aim to penalise CO_2-emissions, a low emissions aircraft will keep penalties to a minimum. In the European Emission Trading Systems (EU-ETS) a ton of CO_2-emissions is priced around 25 € today [19]. As laid out in section 4.2.1 of this paper, it is assumed that ELICA could save between 172 and 196 kg of CO_2 per mission, which would translate into savings of 4.30 to 4.89 € per mission. By expert opinion the price of CO_2 is certain to significantly rise in the future, implying increased savings.

Another key factor, for the previously mentioned market opportunities to work successfully, is noise emission. With an increase in the number of flights from infrequently used airports opposition by residents can be predicted to rise. The opposition to large commercial airports is well known, but in the US even an airport only used for General Aviation is set to be closed due to noise concerns, amongst other reasons [20]. Consequently, as noise pollution, which has a direct impact on people's health [21], could prevent the operation of future aircraft, it also presents the opportunity of lowered landing costs and a competitive advantage. Landing costs at most airports around the world consider the level of noise created by an aircraft. It is therefore of great importance that ELICA delivers its propulsion low-noise [22].

2.4. Summary

In summary, ELICA can directly approach two promising market segments. Further development projects support these findings: Project Fresson in Scotland by Loganair aims to electrify a Britten-Norman Islander aircraft [23] and Project Zero by Widerøe airline in Norway is setting the groundwork for a zero-emissions aircraft by 2035 [24]. These are just two of many examples of aircraft around the world that have started campaigns to significantly reduce their CO_2-emissions and plan to employ more environmentally friendly aircraft.

3. METHODOLOGY

The business case of the aircraft is split into considering initial technical assumptions about the operations of the aircraft, an investigation of the different costs associated and finally the results that, together with the expected revenue, allow to calculate the total expenditure and profits.

All calculations are done in a conservative manner to achieve a robust and reliable picture of future operations of ELICA. For any costs incurred, which differentiate by location, like landing, air-traffic fees or social benefits, the appropriate fee for a German operator of ELICA is used.

Cost of aircraft operation can be generally split into DOC and Indirect Operating Costs (IOC). While the DOC are directly related to the operation of a specific aircraft like fuel cost, the IOC are overhead costs for the airline like marketing, which cannot be associated with a single aircraft but with a fleet operator. To assess the economics of the aircraft from an operator's perspective only the DOC are therefore relevant as the IOC are unrelated to it. Following the approach of Kreimeier the DOC are further split into Variable Direct Operating Costs (VDOC) and Fixed Direct Operating Costs (FDOC) [12].

The VDOC are any DOC that are solely incurred if operations take place. Due to that, they are calculated either per flight hour or mission, depending on their nature. For example, fuel is burnt at a constant rate, but landing fees arise once for every mission of the aircraft, independent of flight duration. FDOC however arise independent of an aircraft taking-off or not, like staff cost as a fixed annual salary is paid.

To calculate the profit, all different costs are aggregated with potential revenue. The revenue is far less complex to determine than the operational costs, as solely the ticket sale is used as reference.

4. BUSINESS CASE

The operations of any aircraft are highly complex and influenced by many different assumptions. This section sets out to summarise operations of ELICA and their financial implications. Assumptions about availability and utilisation of the aircraft are discussed first. Subsequently the costs of operations are explored in great detail before being combined with revenue to calculate the potential profit of operations.

4.1. Availability and utilisation

Certain assumptions are made when calculating the DOC and these should be outlined for better understanding. This chapter discusses assumptions, which concern the average availability and utilisation rate of the proposed aircraft. Other assumptions about general aircraft characteristics are introduced in other chapters when appropriate. Most regional airfields operate according to the average day length, which is 12 hours and 9 minutes long in Central Europe [25]. The average operating day (OD) is therefore fixed at 10 hours. By expert judgement two thirds of the available work hours will be used for missions per OD. The other third is used for planned downtime, mission preparation and debriefing.

TAB 1: Average mission distance

Do 228NG; Hofmann et al. [8]	740 km
RAM reference aircraft	370 km
Hybrid 19-seater; Grimme et al. [5]	200 km
Average mission distance	**435 km**

To calculate the average mission distance, the average across three different standard types of mission are used which are 'long-distance' thin-haul air service, business travel within RAM and 'island hopping' as shown in TAB 1. The value for the average distance for RAM was generated in a transport simulation. The final average mission distance is 435 km. Furthermore, the average cruise speed is defined at 375 kph [26]. These two values set the reference mission of the proposed aircraft.

To set the load factor of the aircraft, in other words the share of booked seats per average mission, actual utilisation data of another 19-passenger aircraft (Dornier Do 228) was used. Data is available for the operation by US-airline VisionAir, which reported a utilisation rate per aircraft of 74 % and taxiing time per mission of 0.15 hours between 2010 and 2015. Data available for the operations by VisionAir is reported in

TAB 2. The German Aerospace Center (DLR) has reported that the average utilisation rate of the 30 largest airlines worldwide was 80 % in 2014 [27]. Moreover KREIMEIER has assumed a utilisation rate of 80 % for an air taxi study [12]. After consideration of all different factors, the load factor was set at 75 % and 0.5 hours per mission to be needed for ground handling (taxiing, entry and exit of payload, etc.).

TAB 2: KPIs derived from US-airline Vision Air (yearly average, 2010-2015) [28], [29]

Available seat miles per aircraft	851,153
Revenue passenger miles per aircraft	634,153
Load factor	74 %
Taxiing per aircraft per mission	0.15 h

Although VisionAir had reported 100 % of missions to be revenue missions, the share was set at 75 % to consider non-revenue positioning flights. The average operational day of the aircraft comprises of 5.3 hours spent in direct passenger service and 4.7 flight hours per OD. It is assumed that operations occur daily, Monday through Friday, and both half of Saturday (morning) and Sunday (afternoon), as the focus of ELICA is on business travel. The aircraft will spend 5 % in down time to go through scheduled and unscheduled maintenance. All assumptions are gathered in TAB 3.

TAB 3: Assumptions regarding utilisation

Hours of work per OD	10 h
Mission share per OD	67 %
Avg. mission distance	**435 km**
Avg. cruise speed	**375 kph**
Ground handling per mission	0.50 h
Avg. mission duration	**1.66 h**
# missions per OD	4.02
Share of revenue missions	75 %
# revenue missions per OD	**3.01**
Avg. load factor	75 %
PAX/revenue mission	**14.25**
# PAX per OD	42.92
OD per week	6
Uptime aircraft	95 %
OD p.a.	296.4
Flight hours per OD	4.66 h
Flight hours p.a.	**1,381 h**
Revenue flight hours p.a.	1,036 h
PAX p.a.	12,722
Revenue Passenger Kilometers p.a.	**5,534,065**

4.2. Variable Direct Operating Cost

4.2.1. VDOC per flight hour

The main cost that occurs on a per flight hour basis is energy cost. A mission energy calculation is conducted to calculate the required fossil (JET-A1) and electric energy consumption. The mission energy for a given flight time is obtained with a given split between fossil and electric energy.

The calculation is conducted using the airplane flight manual (AFM) [30] of an aircraft comparable with ELICA with regard to capacity and design mission. The British Aerospace (BAe) Jetstream 32 was put into service in 1988. It is a commuter aircraft with a two-pilot cockpit, 19 passenger seats, low wing, cruciform tail and retractable landing gear. Being equipped with an improved version of the Honeywell TPE331 engine and a pressurised cabin, the aircraft is a good comparison, especially as detailed data for the mission energy consumption is available. In Chapter 14 titled ‘flight planning’ of its AFM, detailed manufacturer data on aircraft performance is available.

Using the sector fuel table from the AFM, the necessary fuel amount can be calculated as a function of the most relevant mission parameters. 60 lb or 10 minutes total of additional fuel and time for pre take-off and post landing taxi are added. Although additional tables for diversion and reserve fuel are provided, these are not relevant to the mission energy calculation. Different cruise pressure altitudes are studied to evaluate whether advantages regarding fuel consumption can be gained. The different altitudes are Flight Level (FL) 210 or 21,100 ft pressure altitude and FL110 or 11,000 ft to consider flight in a typical altitude for an aircraft with an unpressurized cabin. Flying at higher altitudes has both positive and negative effects. To name a few examples, above FL110 a pressurised cabin is required, leading to a higher aircraft weight and the aircraft takes longer to ascend to the final cruise altitude. On the contrary, drag reduces at higher altitudes due to the reduced air density, which reduces fuel burn directly.

To account for technological improvement since the first flight of the aircraft in 1988, the fuel consumption was lowered by 5 %. This leads to a block fuel of 364.12 kg at FL210 and 414.11 kg FL110. As more time is spent climbing and descending and engine output is lower at higher altitudes, cruise flight at FL210 results in a longer sector flight time plus taxi of 82.5 minutes compared to 79 minutes at FL110. Taking the density and specific energy of JET A-1 into account, a total amount of fossil fuel energy required can be calculated.

The specific fuel consumption (SFC) of the turboprop engine considers the energy delivered to the propeller shaft and losses in the conversion of fossil fuel to rotational energy. It can be converted into the overall efficiency. The overall efficiency is 26 % for the TPE331-12UHR engine, which is installed and results in 1,146.78 kWh provided to the propeller shaft at FL210 and 1,295.24 kWh at FL110.

ELICA is initially set to provide 15 % of the mission energy by an electric powertrain, an assumption set by the project consortium. Consequently, the electric powertrain must provide 172.02 kWh and 194.29 kWh respectively. The efficiency of the electric powertrain is considered to determine the energy provided by batteries. With an efficiency of 90 %, this leads to 191.13 kWh and 215.87 kWh. Due to the use of electric energy, the amount of fuel is reduced to a fuel flow of 277.89 l/h and 330.04 l/h as opposed to 326.93 l/h and 388.29 l/h without its use. Furthermore 172.05 kg and 195.67 kg of CO_2 are saved thanks to hybridisation, at 3.15 CO_2 per kg of Jet A-1 being saved. Although this approach only enables a first order of magnitude estimation of the required energy, it is considered sufficient for the scope of this paper.

In subsequent calculations an unpressurised cabin is assumed to require an hourly fuel flow of 325 litres. As ELICA operates in Commercial Air Transport (CAT), it is exempted from energy taxes [31] and a net price of JET A-1 of 0.95 €/litre is used [32]. Since it is unclear how much electric energy is needed for take-off, climb and cruise, its cost is considered at a later stage in the mission cost.

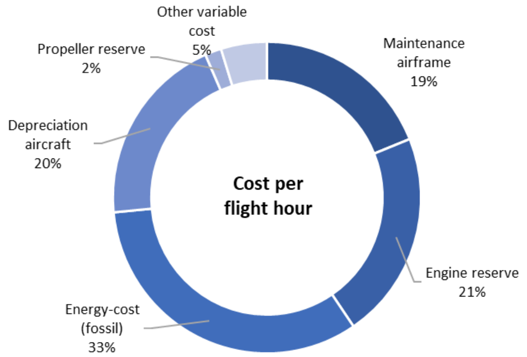

FIG 2: Cost distribution per flight hour

The VDOC per flight hour are additionally highly influenced by the reserves for the engines and maintenance. Realistic values can be used from the Operations Planning Guide of the Business & Commercial Aviation magazine that publishes the according values for a wide range of aircraft [33]. The Cessna Grand Caravan, DHC-6-400, King Air 350ER and Swearingen Merlin IVC are used as reference aircraft and differences between them are taken into account (e.g. single vs. dual engine). From this, a maintenance reserve of 176 € is derived. To account for the reduced complexities of the electric powertrain, the engine reserve is reduced by 7.5 % and set to 202 €. Additionally, the propeller reserve is defined to be 16 € according to benchmark values.

Taking example from comparable existing 19-passenger commuter aircraft, the net-price of the aircraft is specified to be 6 million €. Using a linear depreciation period of 21 years according to German tax law [34] and a residual value of 10 %, a depreciation cost of 186 € per flight hour is calculated. To account for inaccuracies, ‘other costs’ were assumed to be 5 % of the calculated cost (applied to VDOC per mission and FDOC as well). The cost distribution per flight hour is depicted in FIG 2 with a total cost of 933 € per flight hour or 2.49 € per flight km.

4.2.2. VDOC per mission

Not all cost positions occur on a per flight hour basis, but on a per mission basis as well. These are mainly airport and air traffic fees. Airport fees were analysed using the online appearance for eight airports across Europe, as they are a substantial part of operating cost and presented in

TAB 4.

The fees are split into a base fee per mission and a fee per passenger. Since a model that would make major handling fees comparable would be too complex, as their systems of calculation vary greatly, these are not taken into account.

TAB 4: Airport fees across Europe

Airport (IATA Code)	**Yearly PAX (last year reported)**	**Base fee [€]**	**Passenger fee [€]**
TRS	772,517	28.80	12.94
RNS	856,791	48.22	5.98
FMO	986,260	75.00	8.65
INN	1,119,347	17.51	30.11
AHO	1,365,129	15.48	9.21
AAL	1,462,507	45.00	13.50
MPL	1,879,963	5.80	5.39
BRE	2,308,338	10.90	8.95
Average	**1,343,857**	**30.84**	**11.84**

To calculate the final airport fee, a load factor of 75 % is used and it is assumed that the flight is intra-European. Therefore, no fees for passport checks are added. This leads to average airport fees excluding handling cost of 199.56 € for the reference mission of the proposed aircraft.

Aircraft operators are also charged air traffic fees. They are paid to the respective air traffic organisation to guarantee that the airspace is safe. The air traffic fees are split into two parts: The first for approach and departure services also called terminal charges and the second for en-route services. Terminal charges are paid to the national air navigation services while en-route charges are paid to the Central Route Charges Office (CRCO) of EUROCONTROL in a single payment per flight. The individual countries then receive the appropriate revenue. This charge not only includes the cost incurred by German air traffic control DFS, but the costs of EUROCONTROL as well and the aeronautical meteorological service.

The terminal charge is a function of the MTOM in metric tons and a unit rate published every year in the relevant publications [35], [36]. The unit rate is 126.29 € in Germany in 2020. The en-route charge likewise also takes the MTOM into account, but in addition the distance flown in km as well and a different unit rate. Although exerted at a European level, the en-route unit charge differentiates for every European country too and is published by EUROCONTROL

[35], [37]. The terminal charge is 36.89 € high for an MTOM of 8,618 kg and the en-route charges amount to 132.31 € which leads to a total of 169.20 € per mission.

Furthermore, the depreciation of the battery is part of the VDOC per mission. If the maximum state of charge is 80 % and 215 kWh of electrical energy is required per mission 269 kWh need to be installed. The lifetime of the battery pack is defined to be 800 cycles, the cost of per kWh are 250 € at battery level and a residual value of 33 %, according to desk research and expert assessment. This leads to a depreciation of 56 € per mission.

At this point in time, it is not clear whether electrical power will be delivered as an electrical boost during take-off or continuously. Therefore, the cost of energy consumption and battery depreciation is part of the mission cost.

TAB 5: Cost assumptions for VDOC and relevant KPIs

ELICA net price	6,000,000 €
Depreciation period	21 years
JET-A1 consumption per flight hour	325 l/h
Net price JET-A1 for CAT	0.95 €/l
Electrical energy consumption per mission	215 kWh/mission
Net price per kWh	0.22 €/kWh
Maintenance reserve per flight hour	176.00 €/h
Engine reserve per flight hour	201.65 €/h
Propeller reserve per flight hour	16.00 €/h
Other variable costs per flight hour	45.00 €/h
VDOC per flight hour	**932.53 €/h**
VDOC per flight km	**2.49 €/km**
Passenger fees per mission	168.72 €/mission
Air traffic fees per mission	169.20 €/mission
Battery depreciation per mission	56.27 €/mission
Other mission costs	23.00 €/mission
VDOC per revenue mission	**495.11 €/mission**
VDOC per empty mission	**309.14 €/mission**

Overall, the cost per mission (including electrical energy and other mission cost) result to 495 € per revenue mission and 309 € per positioning mission (no passengers on board). In TAB 5 all major cost assumptions for the VDOC are gathered and other relevant KPIs.

4.3. Fixed Direct Operating Cost

The FDOC are mainly comprised of staff costs, which can be divided into salaries, social benefits and training cost. Annual salaries are set to 80,000 € for the chief pilot and 35,000 € for the co-pilot and based on expert judgement. To cover German social benefits, these are multiplied with a factor of 1.21. The training cost are defined to be 16,500 € p.a. in line with the Operations Planning Guide [33]. Assuming 1,650 work hours p.a., 1.8 crews are to be hired that sum up to total staff cost of 279,604 €.

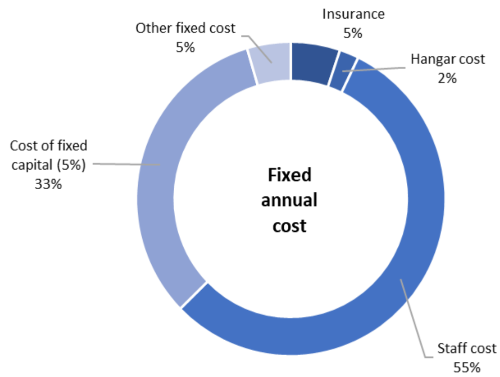

FIG 3: Breakdown of annual FDOC

TAB 6: Assumptions for annual FDOC

Chief pilot salary (gross, employee)	80,000 € p.a.
Co-pilot salary (gross, employee)	35,000 € p.a.
Employer factor for social benefits	1.21
Cost for training p.a.	16,500 € p.a.
Work hours p.a.	1,650 h p.a.
Staff cost p.a.	**279,604 € p.a.**
Insurance cost p.a.	26,000 € p.a.
Hangar cost p.a.	10,200 € p.a.
Cost of fixed capital (5 %) p.a.	165,000 € p.a.
Other fixed costs p.a.	24,000 € p.a.
Fixed cost p.a.	**504,804 € p.a.**

The Operation Planning Handbook is used to estimate additional FDOC. Insurance cost is estimated at 26,000 € p.a. and hangar cost at 10,200 € p.a., according to benchmark values. Moreover, the cost of fixed capital is priced with 5 % resulting in 165,000 € p.a. To account for additional FDOC not included, 5 % of the total annual FDOC is added as other costs. Overall, this leads to an annual FDOC of 504,804 €. The discussed costs are broken down in FIG 3 and listed in TAB 6.

4.4. Summary: Total expenditure, revenues, and profits

The operator's business case is summarised in

TAB 7 with all major cost groups. To account for general administration and management, 10 % overhead cost is added, resulting in 2.6 million € of total expenditure p.a. The average price range for a German first-class train ticket was researched to be in the range of between 0.45 and 0.60 € per Revenue Passenger Kilometre (RPK). As a result, the revenue per RPK is specified at 0.53 € which leads to annual revenues per aircraft of 2.9 million € and a profit of 10.7 % or 313,000 €. Analysis of historic flight prices across various airline website's of flights operated by 19-passenger aircraft (not including fees as calculated) identified a price per flight minute of 2.49 € [38]–[45] - the proposed aircraft achieves a price per revenue passenger minute of 2.31 € resulting in a one-way ticket net-price of 230.55 € for a trip length of 435 km.

TAB 7: Aircraft total expenditure, revenue and profits

Fixed cost p.a.	504,804 € p.a.
Variable cost p.a.	1,821,681 € p.a.
Overhead cost (10 %) p.a.	293,305 € p.a.
Total expenditure p.a.	**2,619,791 € p.a.**
Revenue per RPK	**0.53 €**
Net ticket price per PAX (one way)	230.55 €
Revenue per aircraft p.a.	2,933,054 € p.a.
Profit per aircraft p.a.	**313,264 € p.a.**

Merely rough estimates are available for hourly charter rates of 19-passenger aircraft that can be found on broker websites which collect and present these for potential customers, meaning that all additional costs are included. The charter rates vary substantially depending on both the aircraft type and region of operation. Having gathered several different charter rates, the average hourly charter rate of a 19-passenger aircraft is calculated to be 1,832 €. An overview of different aircraft types is presented in **Fehler! Ungültiger Eigenverweis auf Textmarke.**.

TAB 8: Average hourly charter rates for different aircraft

Aircraft	Average hourly charter rate [€]
Beechcraft 1900	2,178
Viking Air DHC-6-300 Twin Otter	1,487
Dornier Do 228	1,168
Embraer EMB-110	2,271
Fairchild Swearingen Metroliner	1,606
LET410	1,287
Average	**1,832**

A utilisation rate of 75 % rather than 100 % is used due to no fixed route services resulting in a potential charter cost (net and wet) of 1,745 € per hour for ELICA. Hence, charter operations of ELICA can be considered as economically feasible.

5. INFLUENCING FACTORS BUSINESS CASE

When analysing the cost of operations, it is apparent that they are driven by energy cost, fees, staff, overhead expenditure, depreciation and reserves for maintenance and engines.

It was analysed how profit is affected by technological changes. A sensitivity analysis was executed to strengthen the business case and to find room for future improvement. Of all the cost positions, 58 % of these can be influenced by design choices meaning that there is a large design range to optimise ELICA's economics.

The most influential factor is energy cost, which in turn is influenced by the fuel burn rate of the engines and overall efficiency of the powertrain. Next, the depreciation is mainly controlled by two factors. While the aircraft net price and successively the production cost can be influenced by design, the depreciation period is legally set and cannot be influenced. The aircraft net price determines the cost of fixed capital as well.

Further cost drivers, which are directly related to the design, are the reserves for engines (maintenance and overhaul) and likewise general maintenance. The more accessible maintenance-intensive parts and the longer the maintenance intervals of systems and components are, the lower the associated costs. Lastly, the propeller reserve should also be taken into account as the degradation of this component leads to sharp efficiency losses or a strong increase in fuel consumption.

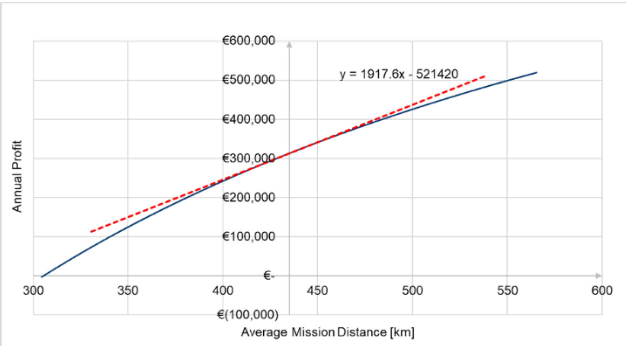

FIG 4: Sensitivity analysis for the average mission distance

After investigating which factors influence the cost of operation, it is important to understand how a change in one of these factors changes the profit of aircraft operations. That way, assumptions made, when setting up the business case, can be tested to determine any possible weaknesses. Such a sensitivity analysis is performed for the mission distance and speed, load factor or utilisation rate, the ELICA net price, its fuel consumption and maintenance reserve. The selection is such that all important cost groups are examined. Results for part of the factors are directly coupled to factors of secondary nature with the maintenance reserves and cost position, which are measured per flight hour being one of these couples.

The sensitivity analysis of the impact of a change in the average mission distance and the maintenance reserve are shown in FIG 4 and FIG 5. In summary, the reference mission distance and speed greatly impact profit. If the former is reduced from 435 km to 350 km, profit is halved. The latter creates losses if reduced below 300 kph. On the other hand, an increased load factor from 75 % to 80 % would double profit. A direct linear influence is established for fuel consumption and maintenance reserves as a 1 % improvement raises profit by 1 %. The net price of ELICA is of second order of magnitude and yearly profit would increase by 7,000 € for every 100,000 € reduction.

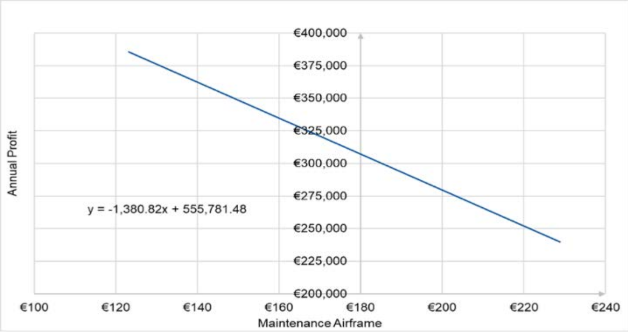

FIG 5: Sensitivity analysis for maintenance reserve

6. CONLUSION & OUTLOOK

This paper analyses whether a 19-passenger aircraft that uses hybrid-electric propulsion can be economically operated. This investigation is carried out as it is a prerequisite for long-term success of 19-seater aircraft as part of the regional air mobility market.

Two new market segments with high potential are introduced. RAM encompasses flights of mission distances between 100 and 500 km and enables significantly shorter travel times by utilising a pre-existing dense network of airports and airfields. Thin-haul air traffic provides a stepping-stone for widespread adaption and ELICA can exploit the CAGR of 4 % of air cargo within the next 20 years.

After compiling all different cost items which are relevant to the aircraft's operation and potential revenue, a profit margin of 10.7 % is achieved, which leaves a large design space. Using the sensitivity analysis, it is clear what areas of the aircraft should be optimised first.

Development of the Cessna 408 SkyCourier and the prospect of RAM and thin-haul air cargo show that the air transport market is ready for an electro-hybrid 19-passenger aircraft. Additionally, the aircraft can generate profit. Therefore, development should continue.

In future work, the impact of changes in the reference mission distance and speed should be examined in greater detail and assumptions for ELICA's utilisation rate should be challenged.

7. ACKNOWLEGDEMENTS

The presented studies have been partly financed by the project ELICA (ELectric Innovative Commuter Aircraft), funded by the European Commission within the research program Clean Sky 2 (CS2 GA No. 864551).

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