CONCEPTUAL STUDIES OF A TRANSPORT AIRCRAFT OPERATING OUT OF INNER-CITY AIRPORTS

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Abstract

An inner-city airport concept is proposed as a result of an interdisciplinary group design project at Bauhaus Luftfahrt, as a novel approach towards the realization of the Advisory Council for Aviation Research and Innovation in Europe (ACARE) goals of a four hour door-to-door travel. Accelerated airport and terminal processing times are seen as key enablers for the idea. Therefore existing infrastructure is used that provide the required space and connectivity. A holistic concept is conceived for application in urban regions to relieve congested hub airports from direct passengers and aircraft movements and achieve faster travel times. The paper summarizes the key requirements and constraints that are driving the design, such as the airport layout and facilities.

Due to space limitations in width and length, possible aircraft concepts have to deal with short runways and need to gain acceptance of the surrounding population. This leads to an aircraft design, which is strongly coupled to the airport infrastructure and forces the requirement of a very low noise design with Short Takeoff and Landing (STOL) capabilities. A concept for an Entry-Into-Service year 2040 is proposed, that fulfils these requirements and leads to a significant reduction in fuel burn per passenger and nautical mile, for a 1500 nautical mile design range with 54 passengers, compared to a year 2000 reference. New airframe and propulsion technologies were analysed and implemented to help achieving the desired specifications. The low noise design, required for acceptance among the population in urban areas, leads to an investigation of different noise reduction technologies for airframe and propulsion systems and their interaction. Off design analysis and cabin design optimization has been conducted to ensure a wide utilization spectrum and a quick turnaround time.

1. INTRODUCTION AND MOTIVATION

In an interdisciplinary group design project at Bauhaus Luftfahrt and in collaboration with the Glasgow School of Art, a well-matched airport and aircraft concept, “CentAirStation” and “CityBird,” has been developed. The motivation to conduct this project is the European Commission’s Flight Path 2050 [1] document with its goal that 90% of travellers should be able to reach a destination within Europe in four hours from door-to-door. A seamless intermodal connection for travel is intended.

Today´s traffic grows mostly via large airports. According to Ref. [2] in Europe, there are 25 busy airports and more than 225 smaller airports with lower connectivity. From these airports, direct flights are often precluded. Interconnections and extended travel times are the result. A second problem visible in today´s operation, are long airport access times and the time spent within the airport for check-in and security. The concept targets both of these problems.

To achieve short travel times, an inner-city airport (Figure 1, overleaf) was conceived located above pre-existent traffic nodal points, such as train main stations, ensuring best possible infrastructural connection and seamless travel.

With a holistic approach the manifold implications of the four hour door-to-door requirement were identified and taken into account aiming for a 2040 timeframe for potential Entry-into-Service. Preliminary investigations conducted in Ref. [3], ensure operational and infrastructural significance of the concept, leading to the top level requirements described in Chapter 2.

In Chapter 3 the aircraft concept is described in conjunction with [4], outlining the airport concept. Besides the general appearance of the aircraft concept, the cabin concept is introduced in detail in section 3.1. Furthermore, the following sections are dedicated to the several challenges that need to be considered to ensure feasibility of the idea. The main challenge is the acceptance of the concept by the urban population. As aircraft noise is an often discussed topic, leading already to restricted operating times at airports, a special focus, detailed in section 3.2, is necessary to ensure public acceptance. Another challenge of inner-city operation is a restricted space for the airport. This results in the necessity for a Short Takeoff and Landing (STOL) capability of the concept explained in section 3.3.

In Chapter 4, the operation is described, starting with the turnaround process in section 4.1. A passenger flow simulation was conducted to investigate different concepts of cabin and door arrangements in section 4.2.

Considering all aspects, safety has to be ensured throughout operation, with appropriate measures in place. These measures are outlined in section 4.3.

Achieving the time limit and adhering to all requirements and challenges, the concept´s performance is evaluated in Chapter 5 as a result of all implications and benchmarked against a year 2000 reference and the Strategic Research and Innovation Agenda (SRIA)-Goals [5].

2. TOP LEVEL REQUIREMENTS

Starting with the motivation of a four hour door-to-door travel, requirements were derived using a top down approach. The maximum travel time is thereby a function of aircraft mission speed schedule (mainly cruise speed), airport access times and processing times, and the design range of the aircraft. Certain access times lead to locations with specific transport connection capabilities and population densities. This sets limits to the available space in populated areas. The 90% criterion defines the capacity of the airport in terms of passengers per year and for the aircraft a corresponding payload. The noise requirement is defined by the aforementioned acceptance issue in urban regions and was decided to be an interpolation of the Flightpath 2050 [1] goals for the year 2040. To account for the possibly higher limits in populated areas, the Chapter 4 [6] (active since 2006) limits were used as the baseline instead of the Chapter 3 [6] limits active in the year 2000.

To this end, possible airport locations have been investigated in the city centres of the 30 biggest cities in each Europe, Asia and the United States in Ref [4]. Other continents than Europe were taken into consideration to obtain a wide utilization spectrum for the concept and avoid tailoring it solely for one region. As a result, the airport dimensions were defined as a minimum of 640 m (2100 ft) in length and 90 m (295 ft) in width and consist of at least four levels:

(1) A rail level, where passengers arrive or enter the building.

(2) A public level with both fully accessible facilities and security processes for air travellers.

(3) The apron level with 15 gate positions for ground handling of CityBirds.

(4) The runway level on the roof for takeoff and landing.

An impression of the airport layout, showing the four levels, can be obtained from Figure 1.

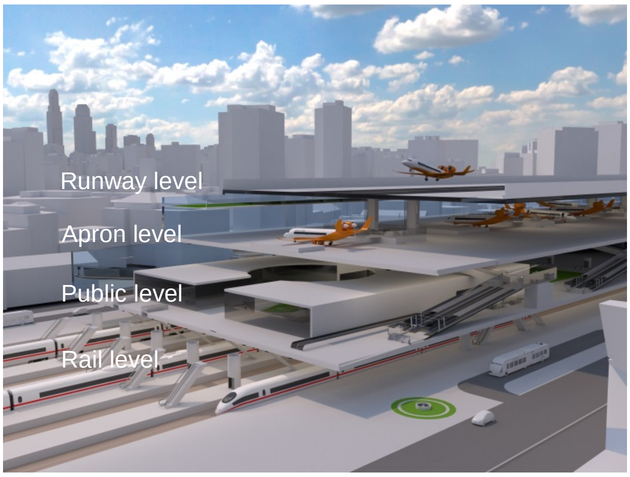

Figure 1: Impression of the airport concept showing the different levels

The definition of all requirements is laid out in more detail in [4] and [7]. The top level requirements of the aircraft concept can be summed up as:

- The vehicle must accommodate 60 passengers in a single class arrangement
- Maximum range not less 1,500 NM at a load factor of 90 % (54 PAX)
- Takeoff Field Length (TOFL) and Landing Field Length (LFL) less than or equal to 640 m (2,100 ft) at ISA+10K and a pressure altitude of 2,000 ft at Maximum Takeoff Weight (MTOW)
- Cruise speed of not less than M0.6 on design range
- Time to climb to cruise altitude of no more than 25 minutes
- Cruise altitude higher than 31,000 ft to permit operational flexibility and overfly weather
- Maximum dimensions driven by airport apron space constraints of 28 m (92 ft) wingspan and 24 m (79 ft) length
- Noise reduction by 52% compared to the ICAO Chapter 4 (239 EPNdB)
- Certification rules according CS-25 and FAR 25 transport category
- Turnaround time of 15 minutes
- The vehicle must operate at conventional airports with no negative impact on processes and capacity and only minor infrastructural requirements
- Reduction of CO_2 by 55% compared to the year 2000 interpolated from the Flightpath 2050 [1] and SRIA [5] goals resulting from propulsion and airframe improvements

The requirements described herein lead to the concept described in the following section.

3. CONCEPT DESCRIPTION

The resulting aircraft concept features a dragon configuration with a low unswept, high aspect ratio wing and a short tricycle landing gear. The engines are aft-mounted on the upper fuselage surrounded by a U-tail.

The wingspan is 28 m with a length of 24 m, taking full advantage of the available space set in the top level requirements. Two doors per side enable a quick access to the cabin, described in section 3.1. The aircraft furthermore adheres to the requirements for low noise (section 3.2) and STOL (section 3.3) capabilities. Figure 2 depicts the aircraft concept.

Figure 2: Illustration of the aircraft concept

The key to increase performance of the aircraft was due to the application of new technologies. Using the specific air range metric, the aircraft structural weight, the aerodynamics and the propulsion efficiency were targeted for improvement.

The aircraft weight was significantly reduced through the application of carbon fibre reinforced plastics. Besides the benefits normally coming with a reduced weight, the wingspan limit also implies a certain aspect ratio, considering a fixed wing loading. A foldable wingtip would be a solution, but adds weight and complexity, and was therefore not deemed necessary in this case, since an aspect ratio of 13.3 was obtained. Furthermore a prior analysis indicated that the low wing loading reduces the effect of induced drag over the whole mission. Further weight reductions resulted from the application of a fly-by-light system and the reduction in furnishing weight through improved seat concepts such as [8], [9]. The weights are depicted in Table 1.

Parameter	**Value**
Operating Empty Weight	12,350 kg
Maximum Takeoff Weight	20,600 kg
Maximum Landing Weight (MLW)	19,160 kg
Maximum Zero Fuel Weight	18,550 kg
Maximum Payload	6,120 kg

Table 1: Overview of weights

Improved aerodynamics result from the implementation of a high aspect ratio wing. A drag reduction coating on the fuselage decreases the friction coefficient and, thereby, reduceds profile drag. The use of plasma actuators that increase CL_{max} (see section 3.3.) enable a higher wing loading, which reduces profile drag.

To decrease specific fuel consumption (SFC) considerably, a Composite Cycle Engine [10] concept was chosen. It utilizes a piston section, which is comprised of piston engines driving piston compressors. This allows to obtain a higher peak pressure ratio than in a turbofan. A ultra-high bypass ratio of 37 is achieved in that way with a fan diameter of 1.52 m (5 ft). The configuration results in an increase in engine mass by around 440 kg compared to a year 2040 reference turbofan, but yields an SFC advantage of 17.4% [7].

3.1. Aircraft Cabin Configuration

The aircraft is equipped with four passenger doors (type B) which are larger compared to contemporary regional aircraft. The cabin layout is designed for 60 passengers in a four-abreast arrangement with a 29.5-inch seat pitch (0.75 m), as depicted in Figure 3.

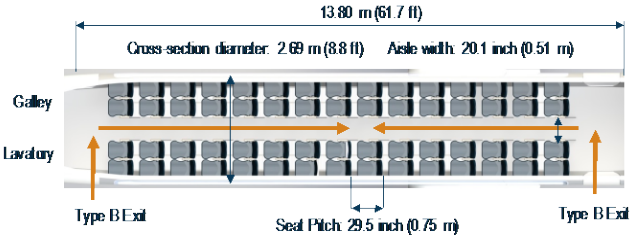

Figure 3: Standard 60 passenger cabin configuration with galley and lavatory in the forward cabin [7]

A circular cross-section with an outer diameter of 2.69 m (8.8 ft) and lower floor position improves the passenger flying experience with a cabin height of 1.97 m (77.6 inch). The replacement of overhead-bins with small racks for jackets provides a spacious interior perception comparable with larger narrow-body aircraft. The required storage volume is provided below the cabin floor accessible through a hatch. The underfloor stowage is designed to house IATA standard sized luggage [7]. The under-seat luggage stowing is realized through a foldable seat concept where the seat pan is pivot-mounted. This allows passengers to step into the row, if the aisle seat is not yet occupied, and to stow their luggage below the cabin floor and in the overhead bins without blocking the aisle. In the case of seat interferences with occupied aisle seats, these passengers can stand up while remaining within the row, reducing the duration of aisle interferences [11].

3.2. Noise

The growing awareness of aircraft noise in the vicinity of airports has already made an impact on commercial aviation. In Germany 14 out of 22 (64%) [12] of the larger airports have night curfews in place. Furthermore, within the concept the reduced lateral distance between the runway and the population in city centres, compared to conventional airports increases noise perception. These considerations make noise one of the main drivers of the proposed concept.

In an effort to reduce sound emissions, several measures were taken. These can be separated into two different approaches. The first approach provides operational measures to lower the noise footprint the aircraft leaves on the ground by adjusting procedures or flight paths. The second approach targets the aircraft source noise, using low noise technologies and a configuration that is beneficial for a low noise emission.

On the operational side it was decided to apply a night curfew leading to a 16-hour operation per day. Studies concerning haul capacity for top level requirement definition took this aspect into account. A further benefit of the concept is that other transport aircraft with similar payload characteristics are not capable of taking off or landing in the proposed inner-city airport. Therefore only concepts particularly designed for the inner-city airport are conducting the operation. A distribution of aircraft, operating on the airport, over wide ranges in MTOW and aircraft age and, therefore, resulting higher noise emissions are not present, keeping the average noise emission significantly lower than on conventional airports.

3.2.1. Operational Noise Abatement Procedures

Operational noise abatement procedures (NAP) are one element of the International Civil Aviation Organization´s (ICAO) Balanced Approach of Aircraft Noise Management [13]. Generally, operational NAPs allow a reduction of ground noise without the necessity to change the aircraft's characteristics. However, much of the potential of operational NAPs is not used nowadays, due to different reasons, e.g. capacity constraints at airports, current ATM/ATC standards, or due to cost-saving priority of aircraft operators. In the future, the CityBird may use all of the potential operational NAP benefits in noise reduction.

Operational NAPs exist both for departure procedures as well as for approach procedures. In this study, noise abatement approach procedures are investigated and compared. Today, approach procedures at airports usually include level step segments in order to ease the control of approaching air traffic, especially during traffic peak times. During the final approach, current navigation technology, namely Instrument Landing Systems (ILS), hinder a variation of glide slope angles, which is usually set to a fixed angle of 3.0°. Increased glide path angles are already flown today, e.g. at London City Airport [14].

In this study, firstly, a standard level approach is regarded having a level step segment at an altitude of 4000 ft of 8 NM length and a final approach at a glide slope angle of 3.0° (see Figure 4). Secondly, a Continuous Descent Operation (CDO) is presented, having no step segment letting the aircraft continuously descend at a glide slope angle of 3.0°. Thirdly, a steeper CDO at a significantly increased glide slope angle of 5.5° is modeled. In Figure 4, the altitude of the three procedures is plotted along the distance to the runway threshold.

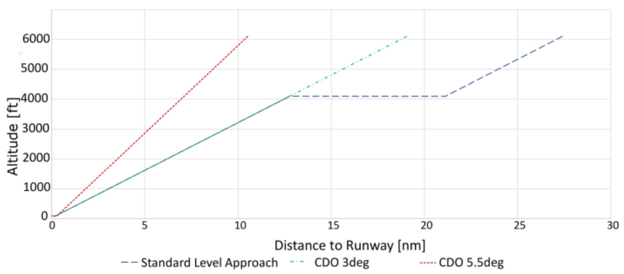

Figure 4: Altitude profiles for three modelled approach procedures – Standard Level approach (in blue), a 3.0° CDO (in green), and a 5.5° CDO (in red).

3.2.1.1. Modelling Approach

The three approach procedures are modelled using FAA's Aviation Environment Design Tool (AEDT). As absolute noise levels of the CityBird were not available at the time of calculation, the CityBird was modelled using an Embraer 145. In order to compare different operational procedures for the same aircraft type, absolute noise levels are not needed; relative noise levels are sufficient. Calculated noise values are thus presented in relation to a reference noise level L_{ref}. A single aircraft movement was modeled for each of the three procedures. Noise was calculated on the ground (altitude 0 ft) at observer points along an observer grid with a grid size of 50x50 m. Noise at the observer points was evaluated using the maximum, A-weighed sound pressure level L_{Amax}.

3.2.1.2. Results of operational measures

Calculated noise contours for the three operational procedures can be found in Figure 5. The top contour represents the 5.5° glide slope CDO, the middle contour the 3.0° glide slope CDO, the low contour the standard level approach.

As expected, the standard level approach shows the largest noise contour areas while the 5.5° CDO has the smallest noise contours. Yet, the calculated results show that contour sizes vary strongly between the three procedures. Regarding the L_{ref}-40dB area, for instance, the 3.0° CDO contour only makes up of 72% compared to the contour of the standard level approach. The 5.5° CDO area represents only 34% compared to the corresponding contour of the standard level approach. These numbers prove the high noise reduction potential for noise abatement approach procedures. Noise contour areas for the 3.0° CDO and the standard level approach are almost similar as the last approximately 12 NM show identical altitude profiles for both procedures (see Figure 4). On the contrary, the 5.5° CDO shows strong reductions in noise contour area throughout all calculated noise contour areas. A 5.5° CDO thus allows to significantly mitigate aircraft noise also for regions in the close vicinity of an airport.

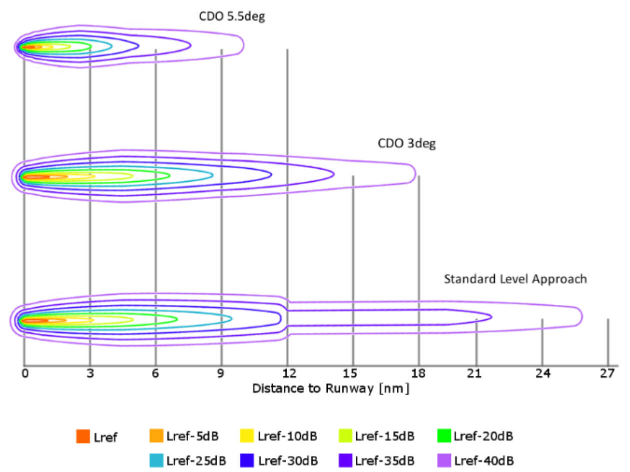

Figure 5: Contour sizes (L_{Amax}) for the three modelled approach procedures.

3.2.2. Source noise

The source noise was treated with two different methods. First, the configuration of the aircraft was designed to minimize noise. Low speed characteristics, required for STOL, also benefit the noise emissions. As described in [15], lowering the speed also decreases noise emission, according to the following equation.

$$\Delta L = 55 \cdot log_{10} \left(\frac{V_{new}}{V_{ref}}\right) \quad (1)$$

A reduction of speed by 20% decreases the noise emission by 6 dB. Detailed description of the low speed characteristics can be found in section 3.3. The low wing configuration with aft mounted engines enables a short landing gear, which is besides the engine and high lift system, one of the main contributors to aircraft noise. Noise emission of the landing gear is amongst others dependent on gear length [15], therefore the short strut length reduces the landing gear source noise. The major benefit from a specially designed configuration comes through engine noise shielding [16], [17]. To perform this, the engines were aft mounted and shielded towards the side and the bottom with a U-tail configuration.

The second approach to lower source noise was by implementing low noise technologies to the main noise contributors. The aforementioned landing gear can be upgraded with landing gear fairings, lowering the sound intensity over the whole frequency spectrum and shifting it towards less annoying frequencies [18].

Engine noise treatments consist of the application of chevrons and advanced acoustic liners, such as over-the-rotor foam-metal liners [19] and soft vanes [20]. Furthermore, the engine itself features a very high bypass ratio, resulting in lower noise emission and a shift of source noise from the exhaust to the fan.

The high-lift noise is lowered via a sealed Krueger flap at the leading edge and a plain flap system for the trailing edge. This eliminates most of the noise creating mechanisms. However, the maximum lift coefficient, even with plasma actuators, might not be sufficient. A continuous mold link flap would be beneficial by creating a slot and still cancelling out the side edge vortices of the flap [21].

3.2.2.1. Source noise modelling

The noise source modelling is based on the semi-empiric source models and methodology described in [15]. The overall noise emissions of an aircraft are composed by aerodynamic noise and engine noise.

Regarding aerodynamic noise, source models for the clean wing, flaps, slats and the landing gears have been implemented. The engine noise consists of fan emissions and jet emissions as the predominant noise sources. The noise source models split the sound pressure level (SPL) into a maximum of five individual terms:

- a normalized reference level L_{norm},
- the spectral shape function $\Delta L_{spec}(Str)$,
- a velocity dependent term ΔL_{vel},
- a geometry dependent term ΔL_{geo} and
- a directivity term ΔL_{dir},

where Str is the Strouhal number. L_{norm} is an empirical reference level of the noise source. The spectral function, $\Delta L_{spec}(Str)$, represents the characteristics of the emissions over the considered frequency range. For the calculation of the Effective Perceived Noise the term is calculated for 1/3 octave bands from 50 to 10000 Hz. Figure 6 shows the main landing gear noise emissions of the "Citybird" in this frequency range during approach. The directivity term, ΔL_{dir}, includes the emission characteristics of the noise source regarding direction. Dependent on the source, the term is a function of the longitudal emission angle α^* and/or the lateral emission angle β^*. The velocity dependent term, ΔL_{vel}, and the geometry term, ΔL_{geo}, are determined for the current operating conditions and source geometry.

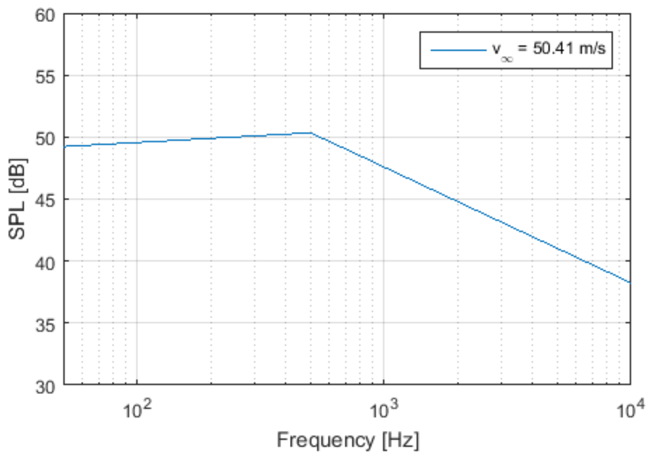

Figure 6: Noise emissions in the range of 50Hz to 10000Hz of the "Citybird" main landing gear during approach.

The SPL of a noise source at a specific frequency is calculated as

(2) $$L(Str) = L_{norm} + \Delta L_{spec}(Str) + \Delta L_{vel} + \Delta L_{geo} + \Delta L_{dir}$$

Finally, to determine the overall sound pressure level of a component the SPL emission spectrum for a given frequency range is summated.

To calculate perceived noise level of an observer in relative position and distance to the aircraft, the noise emissions of all considered components are summed up on a reference sphere with a radius, $r = 1m$. For atmospheric attenuation, a model of the American Institute of Physics described in [22] is implemented.

The propagation effects due to airframe noise shielding are not included on model level. Instead, the noise reduction through shielding and other technologies are included by adding constant correction terms provided through literature review.

The implemented methods were validated against the presented results of [15] and calibrated with an existing model of an Airbus A320-200. The predicted noise emissions were compared to the certified noise levels at the ICAO certification points published by the EASA [23] and deviated in a range of $\pm 5\ EPNdB$. Subsequently, appropriate calibration additions/deductions were applied.

3.2.2.2. Results

The source noise model (including the effects of applied technologies) was used on the aircraft concept and resulted in a calculated Effective Perceived Noise Level (EPNL) for all three ICAO noise certification points. These are:

- Lateral 82.5 EPNdB
- Flyover 70.3 EPNdB
- Approach 80.1 EPNdB

This sums up to a cumulative EPNL of 232.9 EPNdB which leaves a cumulative noise margin of 6.1 EPNdB to the noise target of 239 EPNdB. Since the ICAO certification standard is based on a three degree glide slope, the results are suitable for comparison and the noise goals defined in [1] and [5]. The actual perceived noise is still lowered due to the 5.5° CDO described in 3.2.1.2. From Figure 5 it is visible that for most of the approach path the difference between a 5.5° CDO and a 3° standard approach is roughly 15 dB which translates to a 2.83 times less psychoacoustic loudness for a receiver on the ground. All these aspects contribute to a very low noise signature of the aircraft operation. However, it has to be mentioned that unfavourable effects are present as well. Reflection of noise at building or general urban infrastructure can increase the perceived noise levels. A statement on the magnitude is very difficult, since it is dependent on flight path, directional noise emission pattern and the geometry and material properties of the urban surroundings.

3.3. Short Takeoff and Landing

As seen in section 2, the required runway length is 640 m (2100 ft). Compared to other aircraft in this MTOW-class a TOFL of about 1100 m (3609 ft) in average is common. To lower the TOFL and LFL, several measures were taken.

For the takeoff, the acceleration phase is supported by a ground based Electromagnetic Aircraft Launch System (EMALS) to achieve the requirement of a low TOFL. This enables a shorter ground run and an engine sizing that is not driven solely by the takeoff case. Since, the runway is already around 40 meters above the ground, the screen height was reduced to 3 m (9.8 ft). With these measures the TOFL amounts to 532 m, which relates to a safety factor of 1.2. Atmospheric conditions were set to ISA+10K and 2000 ft pressure altitude.

For the landing scenario a low approach speed is desirable. In order to achieve this, the aircraft has an unswept wing. Due to aft engine position, the wing has uninterrupted leading and trailing edge high lift devices. An aileron droop in landing configuration supports low speed capabilities. As an additional enhancement, plasma actuators are in use, operating during low speed phases in takeoff and landing and adding a lift enhancement of up to 20% [24] due to avoiding flow separation at high angles of attack. Furthermore, the wing loading of 350 kg/m² is lower than a cruise optimum would suggest, supporting low speed performance at the cost of cruise efficiency. These measures lead to a comparably low approach speed of 102 kts at MLW. The increased approach angle also reduces the required length from screen height to touchdown. The LFL amounts to 553 m, resulting in a safety factor of 1.16.

4. OPERATION

The airport infrastructure has been tailored to maximize use of available space and ensure quick curb to gate times, as well as ensuring satisfactory safety standards. The arrival procedures form landing to access of the train station level is guaranteed in 10 minutes. Departing passengers will only need 15 minutes from entering the building until taking their dedicated seat in the aircraft during boarding [4].

4.1. Turnaround

After the aircraft lands on the runway, it taxis to one of the elevators at the end of the runway and shuts down both engines. Taxi robots connect with the aircraft and take over the taxi process. After changing to the apron level, the taxi robots move the aircraft laterally to an available gate where the turnaround is performed. Each of the gates can be operated independently [4].

The turnaround time is targeted to be below 15 minutes which demands for a fast passenger boarding and disembarking with simultaneous refuelling process. A parallel passenger egress and ingress is allowed using displaceable boarding bridges which can either dock from the left or right hand side. Passengers can drop their oversized luggage directly at the aircraft which is then stowed in the bulk hold. This however, is an exception case and not the standard for every passenger. Waste water and potable water is stored in exchangeable trolleys which will be substituted during the cabin service. The ground power plug and fuel connector are actuated via an automated connector attached to a sub-surface supply [7].

After the aircraft is ready for departure, the taxi robots proceed with the pushback and move the aircraft to one of the elevators, which lift it up to the runway level. Then, the aircraft is manoeuvred to its takeoff position and connected with the EMALS.

4.2. Passenger Process Simulation

In order to determine passenger process times, the two-dimensional agent-based passenger flow simulation framework PAXelerate[1] [25], [26] is applied.

In total, 18 studies were performed, covering combinations of 80% and 100% load factor (LF) and three hand luggage (HL) variations. The results are compared to a reference case (RC) featuring 60 seats in a one-class four-abreast single-aisle layout with conventional seats and overhead bins. The passengers have randomly assigned seats and use the forward left door to enter the cabin. In total three HL cases are investigated, a best case scenario with no luggage, one case with a usual distribution and one bulky HL scenario (see Table 2).

Study	**Hand luggage distribution [%]**			
	N	S	M	B
No HL	100	0	0	0
Usual HL	50	10	30	10
Bulky HL	10	30	40	20

[1] The PAXelerate source code and any accompanying materials are available under the terms of the Eclipse Public License (EPL) v1.0. Further information can be obtained from http://www.paxelerate.com.

Table 2: Luggage distribution parameter variations (N: no, S: small, M: medium and B: big hand luggage.)

Monto Carlo experiments are conducted in order to gain insight into the performance of the cabin layouts. The passenger anthropometrics and properties are distributed among the agents using probability functions before each simulation run. The number of required runs is estimated with the approach by Byrne [27], but at least 20 simulation runs are performed for each study. The average coefficient of variation (CV) for the investigated case studies accounts for 0.056. The CV as a measure of variability is defined as the ratio of standard deviation and median.

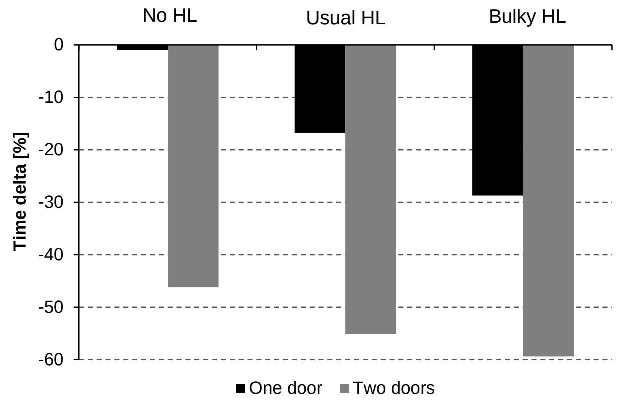

Figure 7: Comparison of the CityBird cabin layout with the reference case.

The CityBird cabin layout yields up to 29% reduced boarding times in comparison with the RC using one door in the case of bulky HL, as depicted in Figure 7. In the RC with bulky HL, passengers need an average of 05:03 minutes to board the aircraft compared to 02:03 minutes using two doors in the investigated CityBird layout. The benefit decreases with a reduction of carried HL and is not present when passengers have no HL. Since all seat pans are designed foldable, bulky items can be stowed in the underfloor storage without causing aisle interferences and an empty aisle seat allows passengers to stow smaller items in the overhead rack. Furthermore, seat interferences are shorter. If two doors are used for passenger boarding, a time reduction of up to 59% could identified for the bulky HL case. In the case of no HL, the advantage still accounts for 45%. A similar trend all investigated cases can be identified with a LF of 80%.

Feeding these findings into to the turnaround assessment enables a fulfilment of the targeted 15 minutes goal. Passenger processes and cabin service constitute the critical path with a total time of 11 minutes when using two doors.

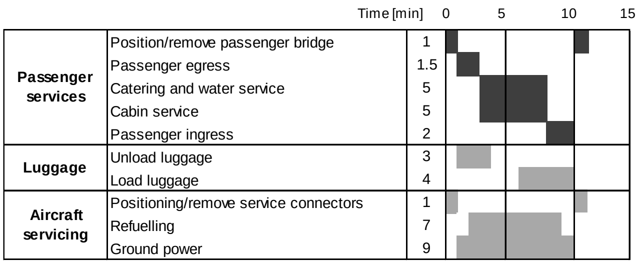

Figure 8: Turnaround Gantt chart for 60 passengers and two doors.

4.3. Safety

The operation out of city centres under STOL conditions requires special consideration regarding safety. Accidents in crowded city centres have potentially greater consequences than on conventional airports. Therefore several safety measures were implemented in the airport and the aircraft concept. An overview of the runway measures is depicted in Figure 9.

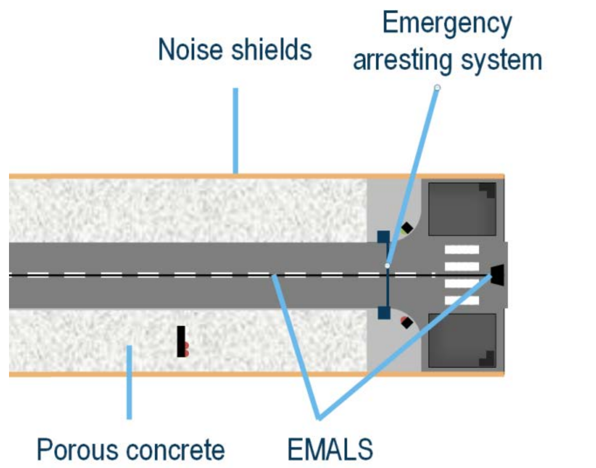

Figure 9: Overview of safety measures on runway

The highest priority is to avoid that aircraft overrun the runway or fall off the side of the building. On the ground side, the airport has a porous concrete [28] on both sides of the runway that is capable of decelerating the aircraft quickly with a deceleration of 0.6 – 1.1 g [28]. Behind the concrete, on the very side of the building, noise barriers are erected, that could be reinforced to withstand impacts of aircraft with low kinetic energy. In case of an overrun, a cable system proposed by [28] was adopted. A cable perpendicular to and embedded in the runway can quickly be lifted. The cable is caught and arrested on the main landing gear strut forcefully bringing the aircraft to a stop. A damage of the aircraft is tolerated. The system is installed on both sides of the runway 75 m from the runway end. With an average deceleration of 1.2 g an aircraft with an arresting system entry speed of 81 knots can be brought to a full stop. This corresponds to 79% of the MLW V_{ref}. During normal operation, the aircraft speed when passing over the arresting system is not higher than 52 knots at MLW, when making full use of the margin provided by the safety factor.

For the takeoff, the nose wheel is connected to the EMALS. Considering failures during takeoff, the accelerating stop distance can become a critical issue on a short runway with no stopway. To achieve a feasible balanced field length, the EMALS system can be used to decelerate the aircraft in addition to the normal braking system. For the rejected takeoff case, the braking force cannot be introduced via the nose gear, since this leads to instabilities. Therefore, a second rod has to be connected to a second piston within the EMALS that is located aft of the aircraft´s centre of gravity. The actuation in case of a deceleration follows the same principle as during the acceleration phase. A rotation actuated mechanism is used to disconnect the aft rod during the takeoff. A rejected takeoff can also be executed with normal braking of the aircraft, but not leaving any margin. An arresting system at the end of the runway can also be employed if necessary.

5. CONCEPT BENCHMARKING

Considering the constraints, the concept has to cope with, the following performance results were achieved.

As seen in Section 3.2, the noise targets were achieved by a margin of 6.1 EPNdB. This ensures that one of the main drivers of the concept, the public acceptance, was reached with a satisfactory result.

The size constraint of the airport led to a demanding requirement for STOL. The results in Section 3.3 show that an operation is feasible. However, the safety factors are lower than current standards, which led to the implementation of additional safety features.

For comparison with today's state of the art technology, the concept was matched against current regional aircraft. Furthermore, a reference aircraft was set up, having the same top level requirements, except for the low noise goals. On the design mission following reductions were achieved. Reductions are based on the fuel burn per passenger and nautical mile (FPNM).

Aircraft	EIS	Reduction
ATR 72	1989	29%
Embraer E170	2004	53%
Year 2000 reference	2000	49%
FP2050 target (interpolated)	**2050**	**55%**

Table 3: Performance comparison based on fuel burn per passenger and nautical mile and Entry into Service (EIS)

It is visible that the concept is not reaching the target of a 55% reduction compared to the year 2000 reference. The ATR 72 and Embraer 170 are listed for comparison with actual current aircraft, showing the difference between slow turboprop and faster jet engine driven regional aircraft.

An off design mission analysis was conducted to evaluate the operational flexibility of the concept. An increase in fuel burn is observed, when reducing mission range. For a typical A320 mission of 500 NM an increase in FPNM of 11.3% was observed. In the off design case a further tradeoff is visible. The low wing loading, helping to achieve noise and STOL target values, calls for a higher than usual initial cruise altitude of 37.000 ft to obtain maximum specific air range. For short range missions, the negative impact on fuel burn of the climb and descent phase therefore increases. For comparison, the difference between a design and 500 NM off design mission for an A320 is only 9%.

The concepts cruise speed is M0.65, chosen to be low enough for an unswept wing with low wave drag penalty, which favours the aforementioned low speed characteristics but fast enough to obtain the overall target of four hour door-to-door travel. The chosen speed is in favour of the time requirement; an optimum cruise speed is due to the wing loading around M0.6. This would yield a decreased trip fuel of 2.5% on a 500 NM off design mission, but leads to an additional flight time of 5 minutes. For the four hour door-to-door target, the difference in cruise speed equals an additional range of 103 NM.

6. CONCLUSION

The many requirements set in this project were transposed in an aircraft concept. It was with numerous trade-offs and the application of new technologies that most of the proposed goals were met. The fuel efficiency was thereby sacrificed in a way that achieving the target of a 55% reduction could not be reached anymore. The required target values for STOL and low noise were met, satisfying the need for public acceptance. A strong focus on safety underlines the target of achieving public acceptance, recognizing it as a key enabler for the concept.

7. OUTLOOK

During the work at this project many question were not answered, that are worth researching. A hybridization of the aircraft concept could benefit efficiency and reduce CO_2 and NO_x emissions. Local flow patterns, caused by buildings and their effect on the aircraft are particularly interesting. A family concept could increase utilization and enable tailoring for specific applications.

Furthermore a detailed analysis of the four hour door-to-door goal for benchmarking is necessary. It has to take into account various considerations. Current and forecasted population densities all over Europe have to be coupled with available and forecasted transport modes, everything dependent on geographic location. This is necessary to obtain door to airport and airport to door travel times. All possible permutations between locations have to be analysed and statistically evaluated to obtain a statement of the general ability of people being able to travel within four hours.

A less detailed method with a constant door to airport time is shown in Figure 10. It uses average values obtained from data samples for the airport access time and block times, depending on different cruise speed and taxi times. The difference between today´s conventional transport mode and the proposed concept is evident. The influence of accelerated airport access and processing times is clearly visible. Although the conventional aircraft are about 17% faster, the ground time is 2.7 times higher.

Figure 10: Comparison of range for a four hour travel time using average values for door to gate times

Overall the concept study shows that creating the required acceptance to perform inner-city operation comes at certain costs. Both, the STOL requirement and the noise requirement have to be traded with fuel efficiency. Furthermore, the concept incorporates many technologies that may or may not be ready for operation in the timeframe of focus. Under consideration that even small changes in technologies can have severe impacts (e.g. Boeing 787 grounding due to battery problems [29]) the implementation of these technologies renders a certain economic risk. Furthermore, the concepts stands opposed to the trend of larger aircraft with more passengers on board, which are in favour of the FP2050 metric. In combination with increasing travellers, the airspace would experience a high increase in aircraft density. Under these considerations it is questionable, if the four hour door-to-door goal has highest priority and is worth sacrificing the reduction goals for CO_2.

Within this study only air transportation modes were considered, which seems a reasonable approach, considering possible distances between Europe's centres and the enormous cost and infrastructural effort of other proposals such as the Hyperloop One [30].

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