Deutscher Luft- und Raumfahrtkongress 2016
DocumentID: 420225

MULTI-MODAL TRANSPORT HUB CONCEPT FOR INNER-CITY AIRPORT OPERATION

M. Urban*, C. Jessberger*, R. Rothfeld*, M. Schmidt**, V. Batteiger*, K.O. Plötner*, M. Hornung*

*Bauhaus Luftfahrt e.V., Willy-Messerschmitt-Str. 1, 82024 Taufkirchen, Germany

**Munich Aerospace e.V., Willy-Messerschmitt-Str. 1, 82024 Taufkirchen, Germany

Abstract

The Advisory Council for Aviation Research and Innovation in Europe (ACARE) Strategic Research and Innovation Agenda intends maximum intra-European travel times of four hours door-to-door for 90% of passengers in 2050. However, todays' commercial air travel is affected by several time-consuming influences which results not only in an unintended extension of the actual travel time well beyond single flight time but also increases the hassles for the passengers along the journey.

In order to meet this target, Bauhaus Luftfahrt e.V. has developed an integrated transport solution during its internal Group Design Project in collaboration with Glasgow School of Arts. This transport concept consists of an inner-city airport combined with a short takeoff and landing (STOL) capable, short-range aircraft, providing capacity for up to 60 passengers. Scrum, an agile development methodology, was utilized to realize the development of both – the airport and aircraft concepts – from an initial idea within a highly constrained time scope of overall three months.

This paper presents the development of the inner-city airport concept, which overbuilds city space that is currently occupied by railway tracks and features full integration into the existing rail and air traffic systems. With 16 hours of daily operations, the inner-city airport was designed for up to 10.5 million annual passengers. The building consists of four levels including the runway level on top, the apron level, located directly below the runway, a public terminal and a rail level. The roof-top runway with a length of 640 meters – combined with an aircraft elevator system and a distributed security check concept – allows for shortened overall travel times. In addition, the potential air traffic capacity increase, by introducing inner-city airports in Europe, Asia and the United States of America, was investigated to estimate the concept's effects on existing air traffic infrastructure.

However, several key challenges were identified, hereunder the additional emissions of airport operations within city centers, arising safety implications, and the required adaptation of all required ground handling and passenger processes to the self-imposed time and space restrictions. Further, potential benefits – of the multi-modal, inner-city transport hub – were examined with regards to the travelers' and residents' interests.

1. MOTIVATION

Todays' air transport faces several challenges due to the increasing demand, i.e. capacity constraints at airports as well as congestion, delay times and environmental issues associated with aviation. The ACARE Strategic Research and Innovation Agenda contains the ambitious target for aviation in Europe to enable a travel time of four hours door-to-door for 90% of all intra-European connections [1]. Analyses on travel times reveal that the highest optimization potential results from the process times of getting to the airport, time spent for processes at the airport prior to the actual flight and after the flight at the destination airport. Furthermore, objectives in the European Commission white paper on trans-European transport network require the connection of all core network airports to the rail network and request that the majority of the medium-distance and intercity passenger transport should be provided by rail [2].

In order to meet these ambitious targets, the paper presents a concept study on an integrated transport solution, the CentAirStation concept, for inner-city airport operations with intermodal connection to the public transportation and the High-Speed Rail (HSR) infrastructure. One key driver for the concept development is the time saving potential towards a four hour door-to-door journey within Europe in 2050. Especially, in between the rail and the air transport mode, the economy of time can be improved through vertical passenger flows through the CentAirStation building. A corresponding aircraft concept, the CityBird, has been developed concurrently and in close coordination in order to meet the requirements for inner-city air transport operations [7].

A meta-analysis of eleven aviation forecasts[1] reveals that for the United States of America, Europe and Asia, average annual growth rates for air traffic of 4.7% until 2030 are expected [3]. Asia outweighs the two other regions by far with respect to the absolute frequency growth rate of 146% as well as to the growth rate of the number of average seats installed of 15% between 2012 and 2030. Europe shows moderate growth rates with respect to revenue passenger kilometers, frequency and seats installed, as well, and the United States of America maintain a strong position in the global air transport market (see table 1).

The growth in air transport is encouraged by the global expansion of the population [19, 20]. But this expansion does not proceed in an evenly distributed manner. In fact, a trend towards agglomeration in cities as well as an increasing number of cities with a population above 10 million people, so-called Mega Cities, intensifies capacity shortages and congestion at existing airports [4]. An expansion of capacity by building new airports is exceptional, especially in the United States of America and Europe where the air transport infrastructure is well established due to the level of maturity of their air transport markets [21, 22, 23].

	USA	**Europe**	**Asia Pacific**
Annual RPK growth	*+ 3.0%*	*+ 4.1%*	*+ 6.2%*
Absolute frequency growth rate from 2012 to 2030	*+ 36%*	*+ 40%*	*+ 146%*
Absolute growth rate of avg. installed seats from 2012 to 2030	*+ 5%*	*+ 7%*	*+ 15%*

Table 1: Revenue passenger kilometers, movements and seat growth forecasts [3]

To overcome these capacity constraints and to enable the ambitious target of four hour door-to-door travel not only within Europe but also on continental routes in the United States of America and Asia, the initial idea of the integration of air transport into the city center and the connection with other transport modes into a multi-modal transport node has been emerged within the CentAirStation and CityBird concept.

The next chapter 2 gives an overview of preliminary analyses and key requirements derived which set the framework of constraints for the concept development, including operational and dimensional target values. Subsequently, the major aspects of the CentAirStation concepts are described in more detail, including the overall layout (section 3.1.), passenger processes (section 3.2.1.), the aircraft characteristics (section 3.2.2.) and aircraft ground operations (section 3.2.3.). Furthermore, aspects of concept integration into existing city centers (section 3.3.1.) as well as the impact of operations on the air quality (3.3.2.) are briefly discussed and further research in these areas is pointed out. In chapter 4, the concept is assessed within a Strengths, Weaknesses, Opportunities and Threats analysis. The paper concludes with a summary of the results and an outlook on potential future work and in-depth analyses on certain aspects of the concept which have only been considered at the current development stage of the concept but are not investigated in detail. For example, the impact of noise, CO_2 and NO_x emissions as well as the economic feasibility of the concept, including strategies of how to create incentives for the initial investment, are potential topics for this.

2. KEY REQUIREMENTS

The CentAirStation concept is combined with a corresponding aircraft concept, the CityBird [4], which meets all requirements for the inner-city operation. For example, due to the available dimensions for the CentAirStation building with a minimum length of 640 meters, the CityBird needs to provide STOL capabilities and a low noise footprint. Furthermore, the CityBird concept should be capable of using the infrastructure at existing airports without any required additional adjustments.

The impact of the CentAirStation building should be kept at a minimum meaning that the building layout, especially the façade, needs to be aligned to the landscape of each city individually. Negative impacts from emissions, e.g. noise, CO_2 and NO_x, need to be limited with the target to minimize the impact on local air quality. The airport operations need to be reliable to the maximum possible extent in takeoff and landing approaches close to adjacent buildings. In summary, the following key requirements need to be complied:

1) Focus on city-to-city connections
2) Potential to add significant capacity to the existing system
3) Possible integration into existing air transportation system and infrastructure
4) Integration into city landscape with very low negative impact

Preceding investigations dealt with the availability of “brown space”, i.e. space above rail tracks or directly above rail stations in the city center. Europe, the United States of America and Asia were selected as global regions with highest air transport activities as well as most promising future prospects with regard to air transport development. The length and width of each identified “brown space” have been collected and average figures for these two dimensions have been calculated for selected cities located in one of the three global regions.

---

[1] Airbus 2012-2031, Boeing 2012-2031, ICAO Environmental 2010-2030, Marketing Group of Japan Aircraft 2011-2030, ICAO: ACI Airport Statistics 2010-2030, ICAO: FAA Forecast 2011-2030, ACI: DKMA 2011-2031, ICAO Outlook 2005-2025, Rolls Royce 2009-2028, Embraer 2012-2031, ACI Global Forecast 2007-2027.

Table 2 shows the average number of investigated cities in the three different global regions as well as the average number of potential additional inner-city airports and the minimum, maximum and average dimensions for the runway length and width. This investigation focuses on the actual potential of the construction of CentAirStation concepts in the respective city center of all considered cities across the United States of America, Europe, and Asia.

	USA	**Europe**	**Asia Pacific**
No. of investigated cities	*25*	*34*	*40*
Avg. no. of inner city airports	*3.4*	*5.8*	*3.6*
RWY length [m] min/avg/max	*580/ 1230/ 3000*	*570/ 1341/ 5300*	*600/ 980/ 3000*
RWY width [m] min/avg/max	*80/ 133/ 880*	*80/ 124/ 500*	*80/ 122/ 260*

Table 2: Availability of potential “brown spaces” for CentAirStation construction [6]

In the United States of America, for example, an average of 3.4 CentAirStation concepts can be built per city with an average runway length of 1230 meters and an average runway width of 133 meters, based on 25 investigated cities. In contrast to that, CentAirStation concepts in Asia only have an average runway length of 980 meters and according runway width of 80 meters available. In Europe, the highest number of potential “brown spaces” was identified with an average of 5.8 CentAirStations per each of the investigated 34 European cities (see table 2).

The average potential of additional capacity through the integration of CentAirStation concepts into the existing air transport system has been investigated in comparison with the cumulated city-to-city traffic in 2012 in each region (analyses based on [5]). The highest potential can be realized in Europe with an average additional capacity potential of 480% of annual passengers. In Asia, the number of annual passengers on city-to-city connections can be increased by 341% and in the United States, the average additional capacity of passengers can almost be doubled.

Furthermore, the CentAirStation and the CityBird concepts need to be integrated into the existing air transportation system and infrastructure. This requirement mostly affects the CityBird concept due to the fact that this aircraft needs to be able to be operated on conventional airports. Even if the focus will be on connections between cities within one global region, it needs to be ensured that maintenance events of the CityBirds can be processed at conventional airports. Furthermore, CityBirds need to provide the capability to divert to and land at conventional airports in case of adverse weather conditions at the destination CentAirStation or other events affecting the scheduled operations.

The integration of the CentAirStation concept into the landscape of each city center has been revised and processed by design students from the Glasgow School of Arts. The results of these attempts will be presented in the subsequent subchapter 3.3.1.

The overall time scope for the entry into service of the integrated transport concept CentAirStation and CityBird is targeted for the year 2040. Daily operations of at least 16 hours are required in order to provide additional capacity of minimum 10.5 million annual passengers at 30 movements per hour (see figure 1, analyses based on [5]). This number has been derived from an analysis on scheduled traffic between the biggest cities in the United States of America, Europe and Asia in 2012, excluding all connections from and to other destination airports, and covers almost 90% of the traffic (see figure 1: all cities below the red dashed line marking 10.5 million annual

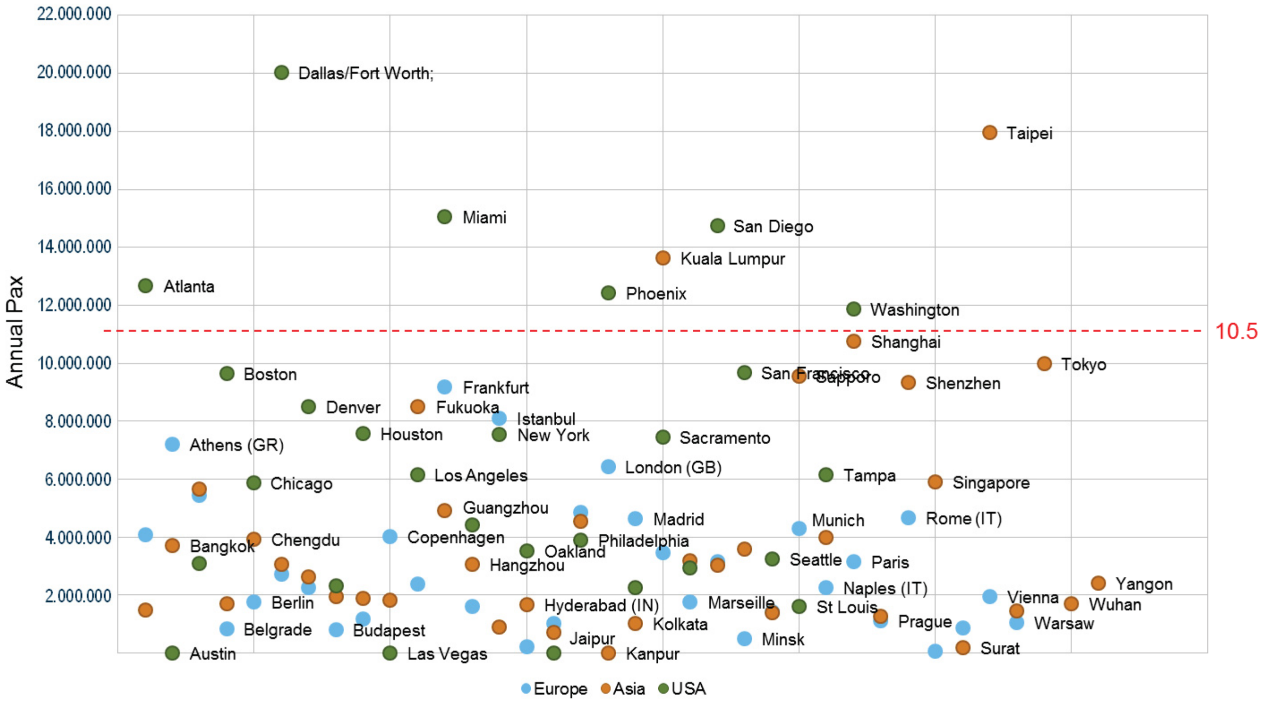


Figure 1: Scheduled city-to-city connections within Europe, Asia and USA in 2012 (based on OAG data 2012 [5])

passengers). As a minimum boundary, the remaining 10% (see figure 1: all cities above the red dashed line) could be achieved, for example, through an increase in movements per hour which is an ambitious but potential approach.

The minimum dimensions of the runway for this performance account for a width of the building of at least 90 meters (and a length of at least 640 meters). But the CentAirStation has to be operable at a lower building width of 80 meters, then with a capacity reduction of 20%. Significant for this reduction is the apron capacity and not the runway capacity with maximum of 49 potential movements per hour.

Moreover, the residents need to experience an additional value besides the improved connectivity. This does not only include a very low level of negative impacts through the CityBird operation, e.g. noise, CO_2 and NO_x emissions, but also a range of leisure activities or working space in the CentAirStation as well as an appealing appearance of the CentAirStation building itself. Safety is a mandatory requirement which needs to be ensured without any constraints. Consequently, all safety standards and requirements valid for conventional airport and aircraft operations need to be targeted by the CentAirStation and CityBird concepts as far as possible.

3. DEVELOPMENT OF THE CENTAIRSTATION CONCEPT

The CentAirStation concept consists of minimum four levels, as shown in Figure 2, the rail level, the public level, the apron level and the runway level, each measuring a height of around 10 meters. Additional levels can be included. However, the strength of the concept in order to enable significant time savings in between different transport modes is the vertical passenger flow through the building. This advantage would decrease with additional levels to some extent. Furthermore, the concept is designed to be built on rail tracks, not necessarily at train stations. The installation of platforms on the rail tracks needs to ensure a connection between the rail mode and the air mode.

3.1. CentAirStation layout

The CentAirStation concept has been designed in a way to find the compromise between inner-city space restrictions and the required space for safe aircraft operations. The minimum length, width, and height of the concept are 640 meters, 80 meters, and 40 meters respectively; which represent the minimum runway length for the CityBird to be operated safely and the minimum width for operations to be handled effectively. For presentation purposes, however, a building width of 90 meters was chosen, as the additional width allows for a more flexible and fault-tolerant apron and runway level design.

The top level of the flat-roofed building, i.e. the runway level, provides a 30 meters wide runway strip over the complete length of the building. The short runway length results from a combination of STOL aircraft technologies and the utilization of an electromagnetic aircraft launch system (EMALS) [7, 8] – built into the runway's centerline. In contrast to catapults used on, for example, aircraft carriers, the in-built catapults work two-fold: one aircraft front fixation is used for acceleration during takeoff, while another rear fixation can be used for deceleration in case of an aborted takeoff. For additional safety during landing, both ends of the runway provide safety rope, similar to the ones found on aircraft carriers, which are used to forcefully stop the aircraft in case of an emergency [7]. Finally, the runway is surrounded by strips of porous concrete in case an aircraft steers off the runway during landing, and enclosed by noise shielding barriers to deflect emitted noise.

Figure 2: CentAirStation profile with its four levels

Four elevators, two along each end of the runway, allow for the transportation of arriving and departing aircraft from the runway level to the apron level and vice versa. Each elevator requires around 15 seconds traversing the CityBird the 10 meters apron level height in order to move one aircraft from one level to another.

The apron itself is split into three main areas: the ground handling area, with 15 gate positions, and two main taxiways along both sides of the gates. Both taxiways are connected with each other just before the elevators – thus, enclosing the gate positions. This connection renders the taxiways and elevators to be used redundantly, allowing for higher fault-tolerance and increased aircraft throughput. The area between two elevators of one runway side can be used to store ground handling equipment or as an additional overnight parking position. Retractable passenger bridges, located between every second gate position, allow for aircraft boarding and disembarking. These boarding platforms also serve the purpose of connecting the apron to the subjacent public level via 16 gate-access security tunnels. The distributed security concept, with tunnels leading from the public level to the passenger gates on the above apron level, aims at reducing potential congestion and reducing overall passenger travel times. By replacing a single security area, a potential bottleneck, with multiple walk-through security tunnels, allows passengers to continuously move towards their assigned gate. Since security checks are being performed on passengers only on their way up to the gates within the security tunnels, the below-apron level remains fully accessible to the public, i.e. non-passengers. This provides the opportunity to design this level with public access in mind, resulting in a vivid marketplace with, for example, rentable working and meeting spaces, restaurants, retail and exhibition spaces, or even hotels to be located within the public level. While the security tunnels connect to public level to the apron level, numerous elevators and escalators distributed throughout the public level connect it to the subjacent rail and street level, which allows intermodal and public access to a CentAirStation (see figure 3).

Providing an interface for intermodal transport and short distances are key aspects of the CentAirStation concept. Thus, the rail level combines all common inner-city transport modes, such as trains, subways, busses, taxi, bicycling, and walking; with the above-laying possibility for air transport. Bus bays and bicycle racks line the building and provide fast and direct access to the station, regardless of a passenger's chosen transport mode. The building concept, with its multiple access points and wide, open public spaces allows passengers to, either, transfer quickly between different modes of transport or enjoy the offerings of the public level that invites passengers to linger.

3.2. Airport operations

The CentAirStation concept has to meet several target process times in order to provide the capacity of 10.5 million annual passengers with 16 hours of daily operations and an average of 30 movements per hour. The maximum capacity can be achieved through the operation of 49 movements per hour which leads to 13.7 million annual passengers on a CentAirStation with dimensions of 640 meters runway length and 90 meters width of the building. For an operation at this maximum passenger capacity figures, a minimum of nine gate positions are required at a runway occupancy time of 75 seconds, a turnaround time of 15 minutes, an expected taxi time of three minutes and a taxiway capacity for two aircraft. However, this target requires very well coordinated runway and apron processes with almost no buffer times and, thus, is an optimum operations scenario which is very difficult to achieve.

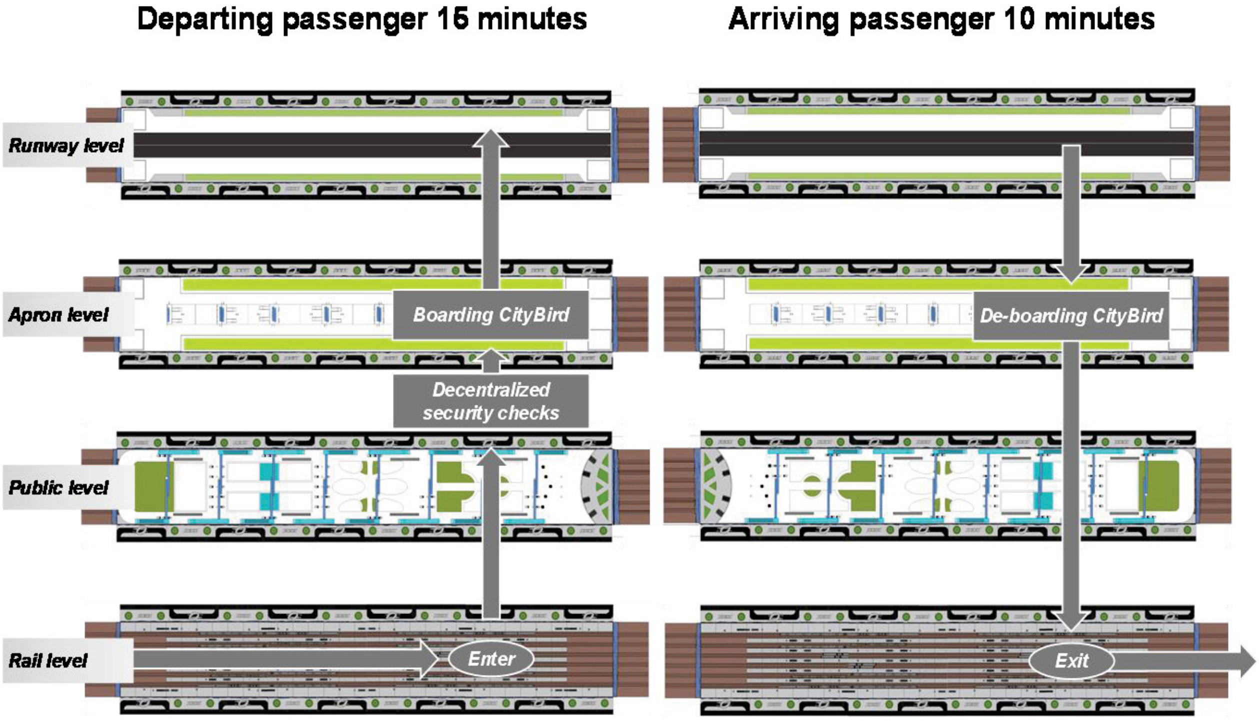


Figure 3: Passenger flows and process times through the CentAirStation building

3.2.1. Passenger processes

The concept layout provides a foundation for vertical passenger paths which are displayed in figure 3. This huge advantage enables a minimization of the passenger process times in order to meet the Flightpath 2050 targets of four hour door-to-door for 90% of all intra-European journeys in 2050 [1]. Departing passengers will need 15 minutes from entering the CentAirStation building until taking their dedicated seat in the aircraft during boarding. Arriving passengers should expect a time of 10 minutes from landing until they arrive at the rail platform or exit the building.

The security processes are integrated within the pathway of departing passengers. The connection between the public level and the gates, i.e. the security tunnels, located at the apron level, includes security checks of the passenger and his or her hand luggage. Passengers enter the security check area with a scan of a valid boarding pass. Behind that barrier, passengers place their luggage on a conveyor belt which moves alongside with the way of the passenger. Passengers and hand luggage are scanned with different technologies searching for dangerous goods, weapons or other items which are forbidden on the flight. The passengers themselves step on a second conveyor belt system with gentle gradient providing a smooth level change.

Each gate position is connected to one security tunnel at each side of the building and each security tunnel provides two security check lanes so that two passengers can be checked parallel per each security tunnel. If there are two aircraft at the gate position, one disembarking passengers and one boarding passengers, then the passenger flows need to be divided so that each of the two security tunnels connecting the apron and the public level either proceeds the departing or the arriving passengers. A parallel operation of one security tunnel, having departing passengers passing the security checks and arriving passengers which execute a level change from the gate to the public level, is not designated. This distributed security check concept has been developed in order to ensure less waiting times for the passengers. Its capacity is coordinated with the process times for departing passengers. The security tunnel system provides the sufficient passenger capacity for boarding or disembarking two CityBird aircraft parked at the gate positions in parallel.

Arriving passengers get to the public level via the security tunnels without a security check. This reduces the time required to get to the rail level or leave the CentAirStation via any other public transportation mode.

3.2.2. Aircraft

The CityBird is designed for STOL with a low-wing configuration and aft mounted engine with an entry into service (EIS) of 2040. Figure 4 provides an overview of the general aircraft dimensions. The design range is 1000 nautical miles at cruise speed of M0.65 with 60 passengers in a four-abreast seating layout. A detailed review of the aircraft specification is provided in Ref. [7, 8].

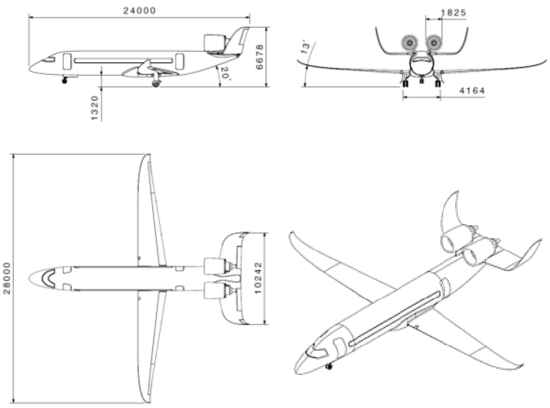


Figure 4: General aircraft dimensions

A structural weight reduction is realized through carbon fiber reinforced plastic (CFRP) resulting in a maximum takeoff weight (MTOW) of 20.6t. The overall aircraft lengths amounts to 24m and features an advanced high lift system with a wingspan of 28m. The wing is unswept with a high aspect ratio of 13.31 allowing for improved low speed performance. During the takeoff, the EMALS automatically hooks-up and launches the aircraft. The aft mounted engines shielded by the U-tail are Composite Cycle Engines (CCE), which use pistons to achieve a higher compression ratio resulting in a fuel burn reduction of about 15% and 10% reduced NO_x emission. The cabin layout features two doors per side and an innovative underfloor baggage storage concept accessible through foldable seats.

3.2.3. Aircraft Ground Operations

The airport infrastructure has been tailored to the designed aircraft to maximize use of available space and ensure quick curb to gate times. The arrival procedures form landing to access of the train station level is targeted to be completed in 10 minutes.

The Gantt-chart in figure 5 breaks down the individual process times. 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.

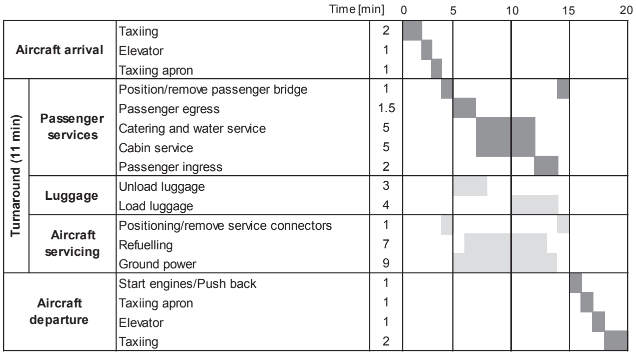


Figure 5: Gantt-chart of aircraft arrival, service and departure

Three taxi robots, which are parked on the elevator, connect with the aircraft and take over the taxi process. After changing to the apron level, the taxi robots forward the aircraft laterally to an available gate where the turnaround is performed. Each of the gates can be operated independent.

The target turnaround time is defined as 15 minutes in the aircraft top level requirements (ATLeRs) which demands for a fast passenger boarding and disembarking with simultaneous refueling process. This is enabled through an installed sprinkler system inside the apron level. The passenger procedures boarding, cabin service and disembarking constitute the critical path, as depicted in figure 5. Simulations of the passenger boarding using an agent-based approach [9] revealed lower process times which reduce the turnaround time to 11 minutes [7].

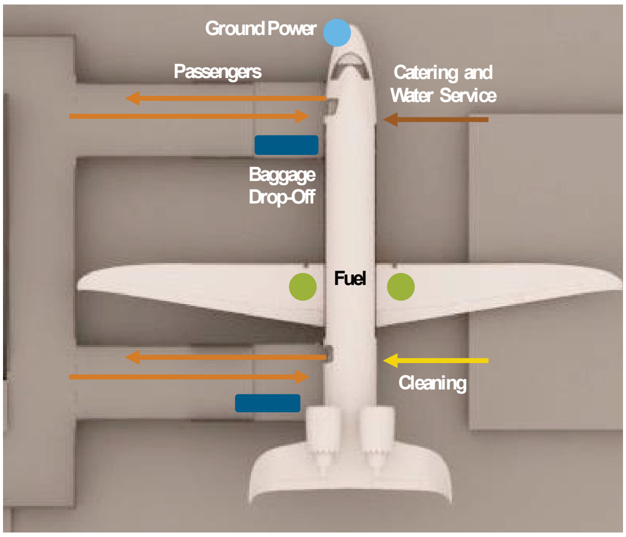


Figure 6: Ground service arrangement at inner-city airport [8]

Figure 6 illustrates the general ground service arrangement for operations at the inner-city airport. 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. Waste water and potable water is in contained in exchangeable trolleys and directly connected to lavatory and galley. The ground power plug and fuel connector are automated with a robot-arm attached to a sub-surface supply [8].

After the aircraft is ready for departure, the taxi robots proceed with the pushback and move the aircraft to one of the elevators which take it up to the runway level. Then, the aircraft is maneuvered to its takeoff position and connected with the magnetic catapult launching system. Meanwhile, the taxi robots disconnect and drive back to the elevator being ready to hook-up the next aircraft. For passengers, the time from the arrival at the airport to taking a seat in the aircraft seat lasts 15 minutes.

3.3. Integration into urban environment

The CentAirStation concept is designed as a much-frequented intermodal hub; consequently it will shape its surrounding environment and create new opportunities. From an urban planning perspective, the integration of the city airport strongly depends on the specific conditions at the particular site. During the screening of suitable sites, large urban railway areas with a minimum length of 640 meters and a minimum width of 90 meters have been identified as feasible available space for a concept construction. Such areas are located at terminal stations close to the city center for example, but also at more peripheral industrial rail yards. Frequently, large railway areas have historically evolved into inaccessible islands surrounded by a growing city. The CentAirStation and Citybird concepts can, thus, unlock profound benefits for its neighborhood if the emission impact of the airport operation is acceptable.

3.3.1. Building integration approaches

The conceptual design of the external appearance of the CentAirStation concept has been developed of a group of students from the Glasgow School of Arts. One promising approach was the integration of solar energy production on the runway level, for example by replacing the conventional runway current with solar panels, in order to produce a significant part of the energy required for the operation of the CentAirStation. In Germany, solar panels on the roof with a size of 48.000 square meters could produce 3.300 MWh per year, equivalent to the annual output of 68 KWh per square meter. Another way to ensure a good integration of the building is the architectural design of the outer façade.

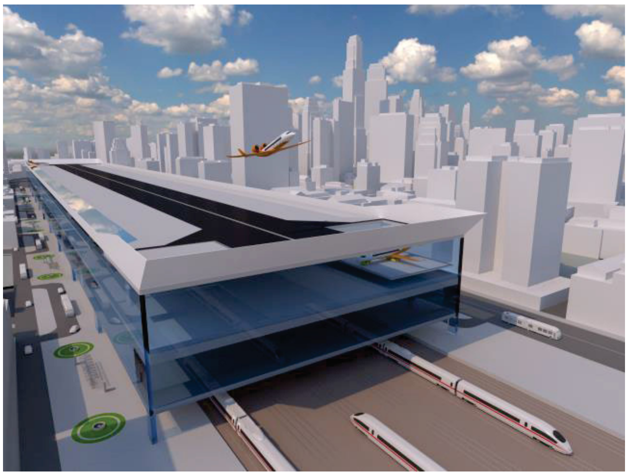


Figure 6: CentAirStation with glass façade

Figure 7 depicts a basic version of the CentAirStation façade designed with glass where the building is suffused with daylight and appears to be open and transparent for the residents and pedestrians from the outside. The students from the Glasgow School of Arts have created further futuristic ideas based on this version in order to demonstrate that the façade of the CentAirStation building can be modified in different ways without losing the required functionalities for the operational processes. Furthermore, each city has individual design possibilities in order to align the CentAirStation with the existing appearance of the city center and to maintain its unique characteristics. The results of the design studies provided by the students from the Glasgow School of Arts are not implemented in the current basic version of the CentAirStation concept.

3.3.2. Emission impact

The main emission impact of the CentAirStation and Citybird concepts consists of two distinct contributions; namely air quality emission and noise emission. Airport emissions affecting the air quality primarily result from the fuel burn in aircraft engines. The dominant contributions are particulate matter emissions and NO_x emission, which add to the background emissions in the city environment. The main impact of air quality emission is related to long-term health effects.

Noise emissions are directly linked to the immediate presence of emission sources. The instantaneous acoustic signature at a particular location is dominated by single or few noise sources, because of acoustic shielding and quickly decreasing intensity with the distance to an emitter. The human hearing is highly non-linear and the health impacts of noise are complex as they depend, e.g., on the individual perception but also on unconscious effects [10].

The World Health Organization (WHO) has issued guidelines values both for air quality [11] and for community noise in specific environments [10]; national legislation in developed countries is often tailored to meet the respective guidelines [12, 13].

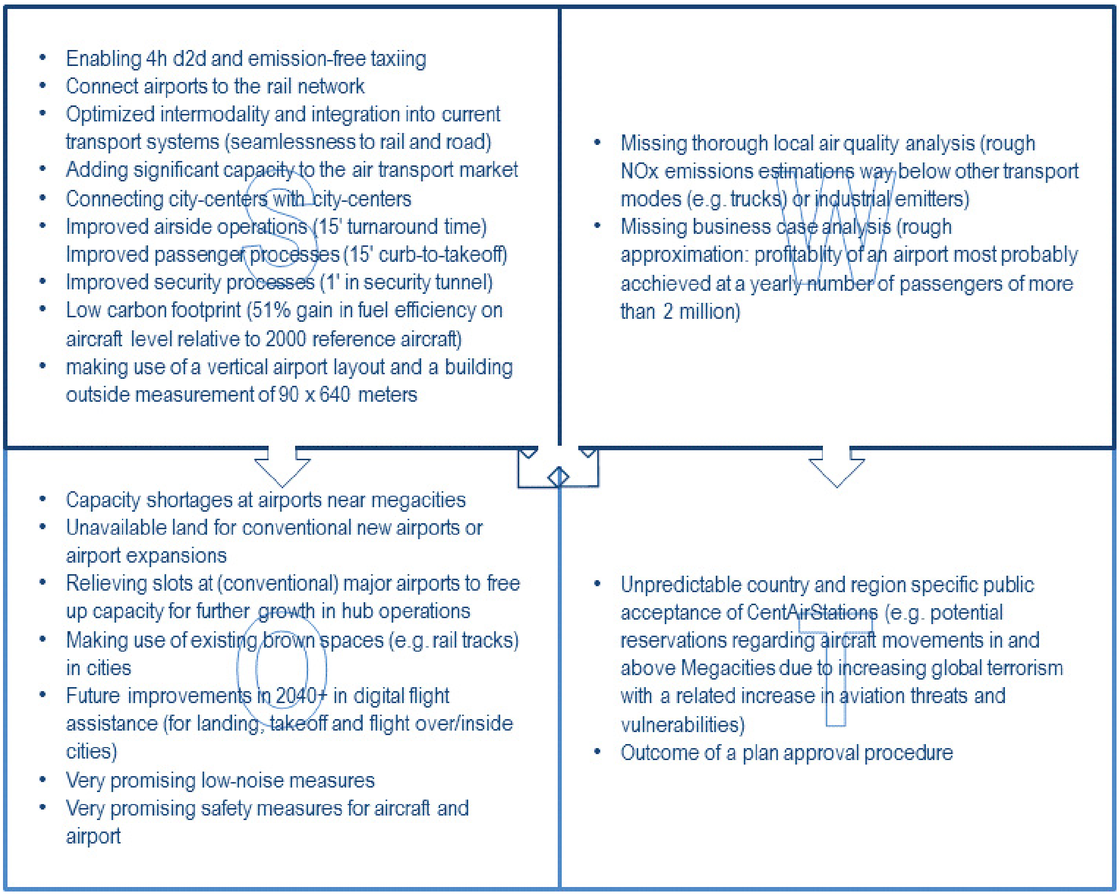
An analysis of existing urban environments has revealed complex patterns with large local variability both for air quality and noise emissions. The dominating source of emissions in cities is transportation. Hotspots of noise emissions are found at railway lines, city highways and arterial roads (intense traffic with high velocity), while air quality emissions peak at congested arterial roads and city centers.

A preliminary analysis on the noise impact of the CentAirStation operations in the city reveals that a variation in the glide path angle might reduce the noise contour of the CityBird aircraft. Consequently, a steep approach with a glide path angle of 5.5° is recommended in order to reduce the noise impact by an average of 50% (or 10dB) [7, 8]. Furthermore, it is expected that the aircraft noise is overlapping with the highway traffic noise in the city. Curved approaches along the inner-city transport arteries combined with a lower speed in the final approach could enable a further decrease of the noise impact of the CentAirStation operations in the city center. But this improvement is benchmarked with the highway traffic noise of todays' conventionally motorized trucks, cars and buses.

4. SWOT ANALYSIS

From an aerial perspective, it is important to assess the CentAirStation concept with respect to its key benefits and challenges. Thus, an analysis of Strengths, Weaknesses, Opportunities, and Threats, a SWOT analysis, has been conducted. The results of this analysis are presented in figure 7.

A major benefit and strength of a CentAirStation is that this concept is an enabler of the European Union's Flightpath 2050 target that 90% of travelers should be able to reach a destination within Europe in four hours



- Enabling 4h d2d and emission-free taxiing
- Connect airports to the rail network
- Optimized intermodality and integration into current transport systems (seamlessness to rail and road)
- Adding significant capacity to the air transport market
- Connecting city-centers with city-centers
- Improved airside operations (15' turnaround time)
  Improved passenger processes (15' curb-to-takeoff)
- Improved security processes (1' in security tunnel)
- Low carbon footprint (51% gain in fuel efficiency on aircraft level relative to 2000 reference aircraft)
- making use of a vertical airport layout and a building outside measurement of 90 x 640 meters

- Missing thorough local air quality analysis (rough NOx emissions estimations way below other transport modes (e.g. trucks) or industrial emitters)
- Missing business case analysis (rough approximation: profitablity of an airport most probably acchieved at a yearly number of passengers of more than 2 million)

- Capacity shortages at airports near megacities
- Unavailable land for conventional new airports or airport expansions
- Relieving slots at (conventional) major airports to free up capacity for further growth in hub operations
- Making use of existing brown spaces (e.g. rail tracks) in cities
- Future improvements in 2040+ in digital flight assistance (for landing, takeoff and flight over/inside cities)
- Very promising low-noise measures
- Very promising safety measures for aircraft and airport

- Unpredictable country and region specific public acceptance of CentAirStations (e.g. potential reservations regarding aircraft movements in and above Megacities due to increasing global terrorism with a related increase in aviation threats and vulnerabilities)
- Outcome of a plan approval procedure

Figure 7: Strengths, Weaknesses, Opportunities and Threats analysis of the CentAirStation concept

from door to door [14]. In this EU document another target is to achieve emission-free taxiing. With the aid of our taxi robots CityBirds are taxiing emission-free on the runway level and inside the CentAirStation, i.e. on the apron level, A Trans-European Transport Network (TEN-T) policy target for 2050 of the European Commission's White Paper says that network airports shall be connected to the rail network [15]. As all CentAirStations are built above the tracks at existing railway stations, this target is also achieved and, thus, is a clear strength of a CentAirStation. Furthermore, this advantageous location also optimizes the intermodality and the integration into existing transport systems, thus, it spurs the seamlessness of modal change from or to rail and road. Other strengths of this concept are that CentAirStations connect city-centers with city-centers and add significant capacity to the air transport market, i.e. 10.5 million passengers per year per CentAirStation. With an average of 3-6 CentAirStations per city, this concept strongly promotes to meet annual air traffic growth forecasts of >4% until 2035 and beyond. Improved airport operations represent another set of strengths of CentAirStations: airside operations meaning a turnaround time of 15 minutes are feasible. Herein, the positioning of passenger bridges and aircraft service connectors takes 1 minute. Then, cabin service lasts 5 minutes and passengers' ingress or egress within 4 minutes while the parallel fueling process of the CityBird lasts 14 minutes. Passenger processes are also improved considerably to 15 minutes from curb to takeoff: Here, passengers need 5 minutes from curb to gate, another 5 minutes for the security check and boarding, and then additional 5 minutes for taxiing inside the CityBird from the gate to the runway until takeoff (see figure 5). The security processes inside the security tunnels lasts 1 minute and is an important part of the improved passenger process. Another key element of these very quick passenger processes is the vertical airport layout with at least 4 levels (see figures 2 and 3) and a building outside measurement of only 90 x 640 meters. Besides, there are plenty of technical aircraft improvements implemented in the CityBird concept [7, 8]. The concept does not achieve the carbon footprint target, i.e. 51% gain in fuel efficiency on aircraft level relative to a reference aircraft in the year 2000, but, at least, obtains a value of 49%.

Of course, each concept has its drawbacks. The current state of the concept shows two major weaknesses as well as two clear threats: One weakness of this concept is a missing thorough local air quality analysis. Rough estimations of NO_x emissions (~500-600 kg/day) are reasonable below other transport modes, e.g. trucks and busses (~1200 kg/day [16]) or industrial emitters (~17.000 kg/day, [17]). However, these numbers need much more in-depth analyses to be reliable. The same applies for a missing business case analysis. A financial feasibility study has not yet been performed. The only preliminary approximation is that an airport is profitable most probably if its yearly number of passengers exceeds 2 million [18].

The country and region specific public acceptance of the CentAirStation concept is one of two threats as public acceptance is very difficult to measure and can be subject to temporary and significant variations. For example, potential reservations regarding aircraft movements in and above Mega Cities can emerge and manifest in the peoples' minds if global terrorism is increasing with a related increase in aviation threats and vulnerabilities. Irrespectively but also in combination of the first threat, the outcome of a plan approval procedure embodies an enormous risk and, thus, is another major threat of any CentAirStation from a political affairs perspective.

Besides these weaknesses, threats as well as promising strengths, a CentAirStation concept offers a number of opportunities: By adding significant capacity to the transport market, capacity shortages at conventional airports near megacities could be avoided on the one hand. On the other hand these potential capacity shortages at conventional airports could spur the demand for CentAirStations. Likewise, CentAirStations could relieve slots at conventional airports to free up capacity for further growth in hub operations. Available land in and near megacities for additional conventional airports or airport expansion is very limited and could become even more scarce in 2040 and beyond due to high population growth. Another opportunity of CentAirStations is that this concept can make use of existing “brown-space”, e.g. above rail tracks in cities. Moreover, future improvements in digital flight assistance for landing, takeoff and flight over/inside cities in 2040 and beyond can give the concept an additional impulse, e.g. with respect to safety issues or public acceptance. The same applies for very promising low-noise measures with the aid of engine shielding, short landing gears with fairings and use of flight corridors above rail tracks or motorways. In addition, very promising safety measures for aircraft and airport operations, e.g. emergency braking system, safety net, safety wire, porous concrete, have a beneficial impact and, thus, represent another opportunity of a CentAirStation.

5. CONCLUSION AND OUTLOOK

The paper has presented a conceptual study on an integrated air transport concept for inner-city operations, the CentAirStation concept. Together with the corresponding aircraft concept, the CityBird [7], it provides potential of additional capacities connecting two different city centers within global regions, e.g. the United States of America, Europe or Asia, and, thus help to relief congestion at conventional airports. Besides, one key requirement for the concept development was meeting the Flightpath 2050 target of four hour door-to-door travel not only within Europe but also in the other two global regions which have been analyzed. The CentAirStation concept enables potential in travel time reduction along the transport chain as the process times at the airport have been improved through vertical passenger flows.

Several aspects of the concept, which could not be analyzed more detailed, have been identified during the development. Future work could focus on these aspects, such as the potential electrification of the CityBird, an in-depth analysis of the noise impact of the aircraft and airport operations in the city center as well as an analysis on the potentials for initial investment, integration of the concept into the existing air transport system and an analysis of the costs and benefits associated with this concept. An electrification of the CityBird, for example, could be an additional option to reduce the noise emissions resulting from the air transport operations. Furthermore, the integration aspects and first concept ideas developed by the students of the Glasgow School of Arts can be further investigated, e.g. with acceptance and feasibility studies of the practicability of the ideas.

The attainment of the four hour door-to-door target could be analyzed in a detailed and quantitative comparison of existing door-to-door journeys and the according travel times with the travel times resulting from the implementation of the CentAirStation concept. Currently, the results only demonstrate certain process time reductions in curb-to-gate as well as processes at the airport.

Nevertheless, the CentAirStation concept with its according aircraft CityBird demonstrates a potential solution to overcome the challenges of air transport growth and its impact on capacity and passenger's perception of travel time, not only in Europe but for different global regions where major proportions of the daily air transport take place.

ACKNOWLEDGEMENTS

As with all design and integration efforts, this paper is a product of a collective effort. In this instance owing to nature of the problem a good measure of innovative thinking and technical excellence was exhibited by the members of the Bauhaus Luftfahrt Inter-disciplinary Design Team. The following are recognized for their most valued contribution to the CityBird and CentAirStation initial technical assessment exercise:

Julian, Bijewitz, Oliver Boegler,
Kai-Daniel Büchter, Christian Endres,
Christoph Falter, Philipp Heinemann,
Sascha Kaiser, Ingrid Kirchmann,
Ulrich Kling, Holger Kuhn,
Lukas Miltner, Oluwaferanmi Oguntona,
Annika Paul, Florian Riegel,
Arne Roth, Christoph Schinwald,
Michael Shamiyeh, Anne Stroh,
Patrick Vratny, Felix Will

References

[1] ACARE (2012): Realising Europe's vision for aviation – Strategic Research & Innovation Agenda, Vol. 2, 2012.

[2] EC White Paper TEN-T policy targets for 2050 (trans-European transport network).

[3] Schmidt, M./Plötner, K. (2013): Forecast Summary, Internal Report 2013/ 13008.

[4] UN World Urbanization Prospects – The 2009 Revision Highlights, report, available: https://www.google.de/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&cad=rja&uact=8&ved=0ahUKEwi8t4SVp9_OAhXKVxQKHa1LC_QQFgg7MAQ&url=http%3A%2F%2Fipcc-wg2.gov%2Fnjlite_download2.php%3Fid%3D10148&usg=AFQjCNE5NxBHolHsaj1otB9VMpwV0Xtx6g&bvm=bv.131286987,d.bGg

[5] Official Airline Guide (OAG) (2012): Scheduled Flight Database.

[6] Official Airline Guide (OAG) (2014): Scheduled Flight Database.

[7] Heinemann, P./Schmidt, M./Will, F./Shamiyeh, M./Jeßberger, C./Hornung, M. (2016): Conceptual Studies of a Transport Aircraft Operating out of Inner-City Airports, Deutscher Luft- und Raumfahrtkongress, Braunschweig, Germany, 2016.

[8] Heinemann, P./Schmidt, M./Will, F./Kaiser, S./Jeßberger, C./Hornung, M. (2016): Sizing and performance implications of a regional aircraft for inner-city-airport operations, READ/SCAD, September 2016.

[9] Schmidt, M., Engelmann, M., Brügge-Zobel, T., Hornung, M., and Glas, M., "PAXelerate - An Open Source Passenger Flow Simulation Framework for Advanced Aircraft Cabin Layouts," 54th AIAA Aerospace Sciences Meeting, American Institute of Aeronautics and Astronautics, San Diego, California, USA, 2016. doi:10.2514/6.2016-1284

[10] Berglund, B./Lindvall, T./Schwela, D. H. (1999): Guidelines for Community Noise, report, available: https://www.google.de/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjqgKnbkN_OAhXIPhQKHbC_ApAQFgghMAA&url=http%3A%2F%2Fwhqlibdoc.who.int%2Fhq%2F1999%2Fa68672.pdf&usg=AFQjCNHq0SRjmXAXPKGPvQC88NtlGaJJBQ&bvm=bv.131286987,bs.2,d.bGg&cad=rja

[11] WHO (2005): WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide – Global Update 2005, Summary of risk assessment, available: http://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf

[12] European Commission (2016): Environment – Air Quality Standards, update: 08/06/2016, available: http://ec.europa.eu/environment/air/quality/standards.htm

[13] Bayerisches Landesamt für Umwelt (2012): Grenz-, Richt-, Leit-, Immissionswerte, April 2012 available: http://inters.bayern.de/grenzwerte.pdf

[14] European Union (2011) "Flightpath 2050: Europe's Vision for Aviation", Luxembourg, http://ec.europa.eu/transport/modes/air/doc/flightpath2050.pdf

[15] European Commission (2011) "White Paper - Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system", COM(2011) 144 final, 28.03.2011, Brussels, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0144&from=EN.

[16] RSB-Munich (2011) "Sitzungsvorlage Nr. 08-14 / V 05724", Referat für Stadtplanung und Bauordnung, München.

[17] Umweltbundesamt (2014) „Emissionsbilanz erneuerbarer Energieträger", Umwelt Bundesamt, 29/2014.

[18] DB Research (2015) "Germany's regional airports under political and economic pressure", Deutsche Bank Research, 31.07.2015.

[19] Sessa, C./Enei, R. (2010): EU Transport GHG: Routes to 2050? – EU transport demand: Trends and drivers ISIS, paper produced as part of contract ENV.C.3/SER/2008/0053 between European Commission Directorate-General Environment and AEA Technology plc; see www.eutransportghg2050.eu

[20] Profillidis, V./Botzoris, G./Taxidis, S. (2015): A Holistic Approach of the Correlation between GDP and Air Transport through Panel Data Analysis, 7th International Congress on Transportation Research, Athens, Greece, 2015.

[21] Smyth, A./Christodoulou, G. (2011): Maturity in the Passenger Airline industry? Revisiting the Evidence and Addressing Maturity in Foreasting the Future Market for Air Travel, Working Paper, Association for European Transport and Contributors 2011.

[22] Airbus (2016): Mapping Demand: Global Market Forecast 2016-2035, available: http://www.airbus.com/company/market/global-market-forecast-2016-2035/

[23] Boeing (2016): Current Market Outlook 2016-2035, available: http://www.boeing.com/resources/boeingdotcom/commercial/about-our-market/assets/downloads/cmo_print_2016_final.pdf