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Impact of an Innovative Quiet Regional Aircraft on the Air Transportation System

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In this paper, requirements for a new aircraft designed for the regional market are presented. The design is mainly driven to fulfill the needs of the next-generation air transportation system. Today, Europe's major hubs have already reached the limit of their capacity. To facilitate the predicted growth rate of air transportation, smaller regional airports have to be integrated into the current airport network. To analyze the impact on the air transportation system, a numerical model is presented that allocates potential passengers from their place of origin to their most likely airport of choice. This passenger allocation model is used to predict future airport's growth rates and possible capacity shortages for given airport scenarios and helps to investigate the influence of the integration of new airports and a new aircraft concept into the current air transportation system. The simulation presented in this paper is based on the German airport network, but it can be easily adapted to any other national or international scenario. Requirements for an aircraft serving such smaller regional airports are directly derived from this simulation.

Nomenclature

H_{cr} = initial cruising altitude, m
M_{cr} = initial cruise Mach number
R_{design} = range of design mission, n mile
γ = glide-path angle, deg

I. Introduction

IN RECENT decades, a continuous growth of the worldwide air traffic has been observed. Figure 1 shows the evolution of the worldwide passenger kilometers since the year 1970 and an extrapolation until the year 2020. Currently, a growth of approximately 5% per year is recorded; for cargo, the growth is estimated to be 6% per year. Temporary effects such as the economic crisis may slow the growth, but a continuation of this trend is expected for the future. An extrapolation of the overall passenger kilometers to the year 2020 using today's growth rate results in a twofold increase in the current values.

Today, many major European hubs have already reached their maximum manageable passenger numbers. With this background, the challenges of coping with the growth are obvious. Goals for European aviation have been defined in a document known as Vision 2020 [1] by the Advisory Council for Aeronautics Research in Europe. Solutions for managing the predicted passenger demand are the focus in this strategic paper, allowing for the growth, but at the same time lowering the noise and emission impact from this growth. One possible approach is the extension of the current air transportation system through the integration of regional airports that are currently only used by charter service or general aviation. Figure 2 shows today's civil airports with clearance for aircraft with a maximum takeoff weight (MTOW) greater than 10 t in Germany, categorized by runway lengths. Currently, only 20% of the 80 available airports are used for scheduled commercial air transportation. The integration of regional airports into the commercial air traffic has to be well structured. The simultaneous operation of 80 possible airports in Germany would be a challenging task for air traffic control. Because of the limited runway lengths at the majority of the regional airfields, only small airplanes with low passenger capacities could be operated at those airports. This will result in a significant increase of flight movements, which is neither an economically nor an ecologically acceptable solution for next-generation air transport system. Thus, a somewhat larger short takeoff and landing (STOL) aircraft is needed that can be operated at those smaller airfields and that provides sufficient passenger accommodation. A reduction of perceived external noise by 50% is targeted in Vision 2020 [1]. Therefore, low noise emission is another design driver alongside STOL characteristics. Hence, a quiet-STOL next-generation regional aircraft is addressed in the scope of this paper.

The method presented in this paper has been developed to analyze and predict local passenger capacity shortages as well as the impact of the integration of new airports and new aircraft concepts into the current air transportation system in Germany. A passenger allocation model has been derived that assigns passengers from their place of origin to their most likely airport of choice. For this model, a robust algorithm has been chosen in order to minimize the needed input quantities. A large amount of passenger sources and airports can be captured without the need of a time-consuming model setup. The simulations presented address the impact of the integration of additional regional airports and a quiet short takeoff and landing (QSTOL) aircraft concept on the current German air transportation system only. The influence of air passengers from adjacent countries has not been included in the presented model. Internal studies showed that the influence is of secondary importance. The flux of foreign air passengers using German airports is also predicted to be higher than German air passengers using the airports of neighboring countries. The integration of adjacent countries would therefore further increase the utilization of the German air transportation system. For future research, the integration of additional European countries is targeted. The passenger allocation model has been designed so that it can easily be refitted to describe any other national or international scenario.

In addition to the major design driver and compatibility with regional airports, margins for other top-level requirements such as range and takeoff-field length (TOFL) will be defined for this next-generation regional aircraft concept. Thereby, a complete set of parameters for conceptual design has been derived within the scope of this study.

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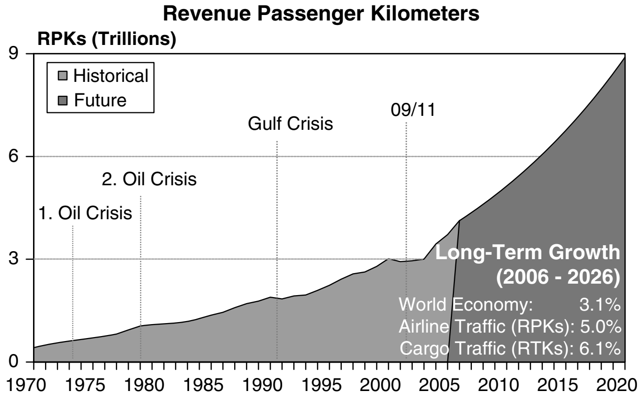

Fig. 1 Evolution of the worldwide air traffic [5,6].

II. Current German Airports and the Passenger Allocation Model

Germany, a country with a population of 82.3 million people and an area of about 357, 000 km^2, is currently served by 19 international airports [2]. These airports offer a regularly scheduled commercial airline service to various domestic and international destinations. With 52.2 million passengers per year, Frankfurt/Main is the eighth-largest airport in the world [2]. Together with London Heathrow, Amsterdam Schiphol, and Paris Charles de Gaulle, Frankfurt/Main serves as Europe's main hub. Today, Frankfurt/Main already operates at its capacity limit and cannot provide many additional slots. Thus, Germany's main carrier Lufthansa has started to relocate increasingly more of its international flights from Frankfurt to Munich. Because of this development, Munich airport recorded double-digit growth rates in recent years and is now Germany's second-largest airport, with 28.6 million passengers in 2005 [2]. However, this airport also has to serve the high local demand of the densely populated and economically strong region of Munich. The closest alternatives, Nuremberg and Stuttgart, are relatively far away (170 and 220 km). As a consequence, Munich airport is also gradually reaching its capacity limit. For both Frankfurt and Munich airports, an additional runway is planned; whether it will help to avoid the local capacity shortages at these airports in the long term is not clear. Germany's third-largest airport is Dusseldorf (15.5 million passengers in 2005 [2]), which lies only 230 km to the north of Frankfurt/Main. It mainly serves the Rhine–Ruhr metropolitan area, which has a population of about 12 million people; it is one of the world's most densely populated areas. The airport offers a few intercontinental destinations but is mainly used for European connections. The German capital city of Berlin is currently served by three airports: Tegel, Tempelhof, and Schönefeld. Following the nomenclature of the German Airport Association (ADV), these three airports will be considered as one single airport in this paper. In 2005, 17.1 million passengers departed from Berlin [2]. Aside from the international airports, about 10 smaller regional airports are serving nonscheduled services mainly for vacation and business travelers. In 2005, only 2.5% of air passengers used those smaller regional airports [2]. Thus, these airports can be neglected for the evaluation of the current air transportation system.

The aim of this paper is to derive top-level specifications for a next-generation regional aircraft from the requirements of the German air transportation system. Therefore, the current air transportation system in Germany has to be assessed. Future capacity shortages will be identified and a possible solution will be presented. To identify capacity shortages, a model had to be developed that allocates passengers from their place of origin to their most probable airport of choice. To evaluate the utilization of each airport, a method is introduced that approximates the maximum passenger capacity of an airport; cargo is neglected. Two assumptions are made: First, the average number of passenger per flight movement has to be defined. It is assumed that it equals the arithmetic mean between the passenger capacity of the smallest and the largest aircraft that can be operated on each specific airfield. Second, it is assumed that the maximum number of flight movements that are possible on each specific airfield can be scaled based on data of Frankfurt/Main. As a consequence, the time between two flight movements is defined as 7 min per number of runways. Since the operating hours for each airport are known, the maximum capacity can be calculated from the average passenger per flight movement and the minimum time between two flight movements. In Table 1 the approximated capacities and utilization of Germany's international and regional airports are shown. This approach has been validated using known data.

To model the passenger fluxes, information about the regional origin of the passengers is required. For reasons of privacy, however, this information is protected by the airlines and is not accessible. Hence, representative surveys that directly question the passengers have to be used. Such a survey is an air passenger survey from Germany in the year 2003 [3,4]. Coordinated by ADV and the DLR, German Aerospace Center, passengers at 22 airports were asked about their place of origin, the mode of access to the airport, purpose and duration of the journey, route information, and traveler information. The passengers' places of origin were assigned to specific zones in Germany that are defined as spatial planning regions (RORs). These are defined by the Federal Ministry of Housing and Transportation and are used for regional, spatial, and transport planning. These regions cannot be easily described with a mathematical model. Point sources with a corresponding set of Global Positioning System coordinates have to be used instead. Thus, the passengers have to be relocated from the RORs to representative cities that are located within the specific ROR (Fig. 3). The population of each city is used as a weighting factor for the relocation of the passengers. The use of all German cities with a population of more then 50,000 is

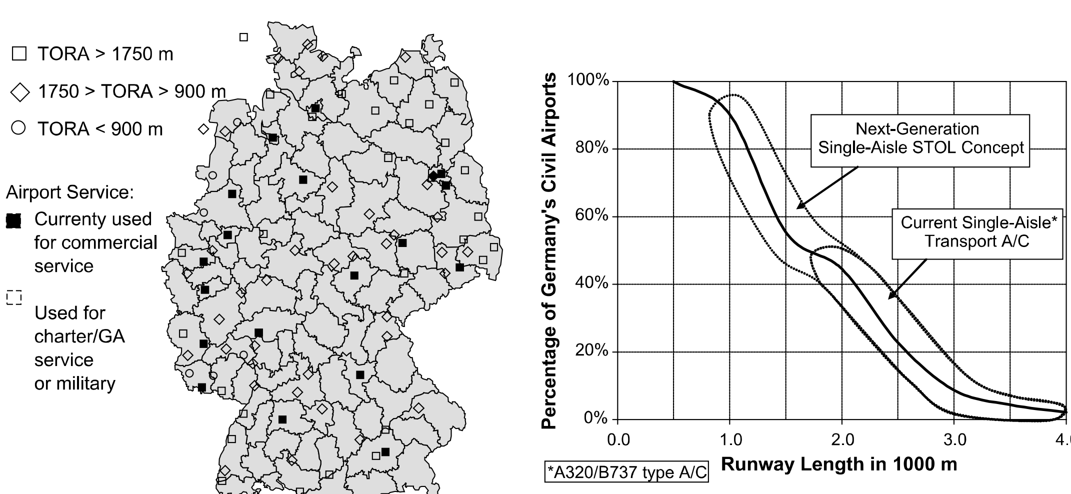

Fig. 2 Airport utilization in Germany (Jeppesen, Inc., Electronic Airport Directory, 2007); TORA is takeoff runway available and A/C is aircraft.

Table 1 Capacity and utilization of German airports

	Total PAX capacity, 10^6	Year 2005 PAX, 10^6	Utilization, %
International airports	376	165	43.9
Regional airports	99	5	5.1
Total	475	170	35.8

sufficient. A total of 203 passenger sources within Germany were identified.

To keep the allocation algorithm fast, it was assumed that the average passenger chooses his or her departing airport by only two criteria. One criterion is the accessibility of the airport. In this model, the accessibility of an airport is described by the distance between the airport and each passenger source. Thus, the model assumes that the closer an airport is located to a passenger source, the more likely that the passengers will choose this airport. Another criterion is the airport size, which is represented by the passenger numbers. The airport size is a measure for the connectivity of an airport. The larger the airport, the more destinations that can be reached with a higher frequency and a wider choice of airlines. Aside from the connectivity, the airport size also describes the attractiveness of an airport. Aspects such as preflight entertainment and gastronomy gain increasing importance.

To implement these two airport choice criteria in the passenger allocation model, two mathematical probability functions have been used [Eqs. (1) and (2)]. Function p_i only depends on the distance to the airport, and function q_j only depends on the size of the airport in the previous year (Fig. 4). Only airports used for scheduled commercial airline service were included in the air traveler surveys. Thus, the passenger numbers are only known for these airports. To integrate new airports into the network, Eq. (2) has to be segmented. The limit of 250,000 passengers was chosen empirically and equals the size of the smallest airport included in the survey. Finally, the two functions are combined into an overall probability function $w_{i,j}$ [Eq. (3)], which describes the probability of a passenger (PAX) choosing this specific airport, depending on the passenger source, the airport size, and the simulated year:

$$p_i = a_1^{(\text{distance}_i/100)} \tag{1}$$

where $0 < a_1 < 1$ and $i = \text{source}_1, \ldots, \text{source}_n$,

$$q_j = \begin{cases} \text{PAX}_{j-1}^{a_2} & \text{if } \text{PAX}_{j-1} \leq 250,000 \\ (250,000 \cdot 1.05^j)^{a_2} & \text{if } \text{PAX}_{j-1} > 250,000 \end{cases} \tag{2}$$

where $0 < a_2 < 1$ and $j = \text{year}_1, \ldots, \text{year}_n$, and

$$w_{i,j} = [(p_i \cdot q_j)^{a3} / \Sigma(p_i \cdot q_j)] \tag{3}$$

where $\Sigma w_{i,j} \equiv 1$ and $0 < a_3 < 1$.

The factors a_1 to a_3 are weighting coefficients that are used to scale the model so that the simulation results best fit the present airport utilizations, as shown in Fig. 5. The simulation results for the year 2003 are compared with the findings of the air traveler surveys. Deviations greater than 5% can only be observed for the Berlin and Dusseldorf airports. These deviations are caused by the unique locations of both cities. Both are serving a region of high demand. Whereas Dusseldorf is surrounded by other two international airports within a 50 km radius and another four airports within a 250 km radius (including Frankfurt/Main), Berlin is only surrounded by two small airports within a 250 km radius. Hence, the simulation allocates too few passengers to Dusseldorf International and too many passengers to Berlin's airports. However, Fig. 5 shows how well the presented model works and how accurately the passenger allocation for the current situation in Germany can be described with such a simplified simulation.

To simulate the passenger growth within the coming years correctly, two other constraints need to be introduced into the algorithm.

1) Each airport has a maximum passenger capacity beyond which it cannot accept any additional passengers. Therefore, the function q_j has to be set to zero if an airport's maximal capacity has been reached.

2) For accurate results, each passenger source has to be treated equally. In the simulation code, however, the passenger sources are processed one after another, starting with the lowest ROR and ending with the highest ROR. Thus, the passengers of the first processed cities would be favored in using the free capacity of the major airports. The passengers of the next cities would have to switch to minor airports that originally would not have been their first choice. To avoid such a falsification of the simulation, the passengers are allocated in 400 iteration steps per year (Fig. 6). Hence, in each iteration step, only 1/400 of the passengers of each source are allocated. The use of 400 iteration steps has shown a numerical convergence of the results. When using less steps, differences in the results can be observed. The use of more steps leads to an increase in computing time without a significant impact on the results.

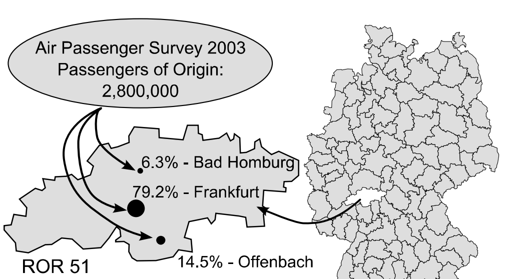

Fig. 3 Passenger allocation from an air passenger survey 2003.

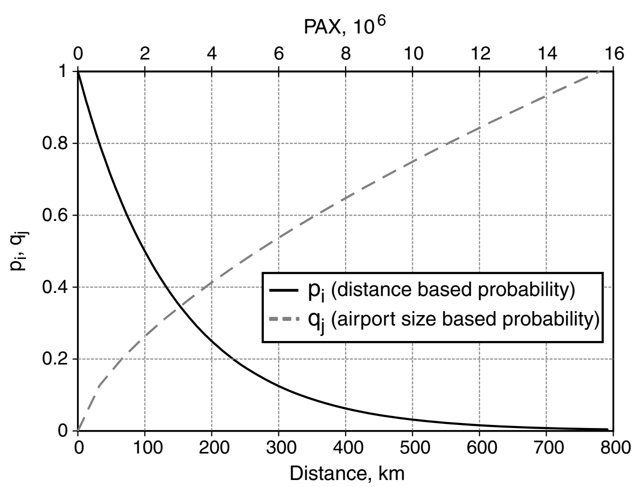

Fig. 4 Probability functions for the passenger allocation model.

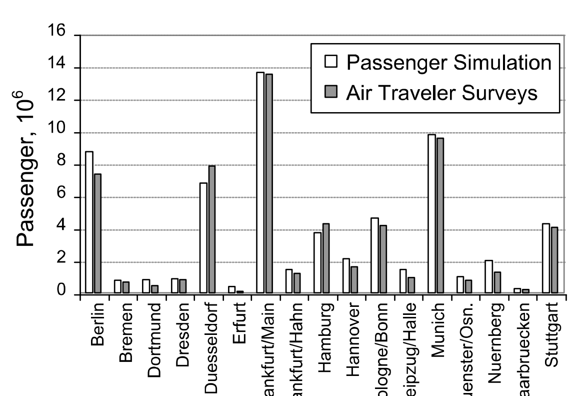

Fig. 5 Comparison of passenger allocations based on simulation with the air traveler surveys.

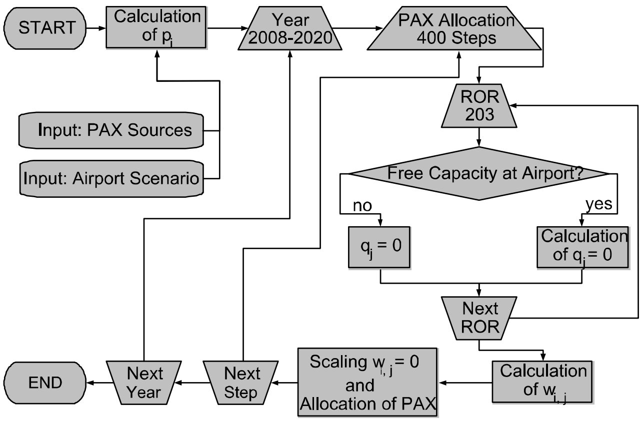

Fig. 6 Flowchart of the passenger allocation model.

A total growth in passenger air traffic of 5% per year is expected for the forthcoming years [5,6]. Hence, the source strength of each passenger source is increased by 5% after each simulated year. Local saturation effects or the disproportionate growths of single sources cannot yet be modeled with the simulation model. The same holds for the shifting of source strengths due to a redistribution of the population. The possibility of changing an airport's infrastructure, such as the integration of an additional runway during a running simulation, has not been implemented into the model yet.

The passenger allocation model described above is now used to simulate the airport utilization for the current air transportation system in Germany. The simulations have been run for the years 2008 to 2020. In the first scenario, only today's 17 international airports (as listed in Table A1) are taken into account for commercial air transportation with a typical current fleet mix. The simulation shows severe capacity shortages. Within the first four years, five airports already reached their capacity limits, including Germany's largest airports: Frankfurt/Main, Munich, and Dusseldorf. Hence, in 2012 only 70% of Germany's airports will still be capable of growth. Four years later, only 53% of the airports will have spare capacities left. With Stuttgart reaching its limit, Germany's economically strongest region, the south, is without any airport that can provide spare capacity. In 2020 only two airports, Dresden and Hamburg, will have growth capacity. All other airports will have reached their limits (Fig. 7). Hence, the current air transportation system does not provide sufficient infrastructure for the predicted growth rates. This is not only a national problem, however. Worldwide, most of the major hubs are currently operating at their maximum capacities. Thus, it is expected that the results of these simulations also account for markets other than Germany.

III. Integration of Regional Airports into the Current Air Transportation System

To meet the predicted growth rate in air traffic, new airport capacity must be created. This can either be achieved by optimizing the processes and extending the infrastructure at today's international airports or by the integration of new airports into the current network. The major airports are already working with highly optimized processes today. Therefore, an increase in capacity through operational planning is very limited. An extension of the infrastructure is rarely possible as well, due to environmental reasons. Single cases such as the enhancement of Frankfurt/Main and Munich International by an additional runway may help to stall local shortages; however, a solution of the overall problem cannot be achieved. Thus, it is unlikely that today's airports can fulfill the capacity needs of the next-generation air transport system in Germany. Because of environmental issues and costs, it is also unlikely that future capacity shortfalls will be met with the construction of entirely new airports. Only one international airport will be newly opened in the near future in Germany: Berlin Brandenburg International (BBI). Compared with Berlin's current airports, BBI is located far outside the city, which complicates the mode of access for the passenger. This opposes the concept of seamless air traffic, however. BBI is also planned for the same capacity as Berlin's airports today, so that no additional capacity is gained when it will be opened and the other three airports will be closed for commercial air traffic. In recent years, low-cost carriers such as Ryanair or Easy Jet have shown that the move to smaller regional airports in regions of high demand is a feasible solution for avoiding high charges and delays at hub airports. Airfields such as London Stansted or Frankfurt Hahn suddenly became international airports [7]. Today, carriers are strongly limited by the takeoff and landing performance of their aircraft fleet. Nevertheless, a further integration of regional airfields could be a promising approach for avoiding the predicted capacity problems.

One demand of such next-generation air transport system is the integration of regional airports, where only minor enhancements of the infrastructure are required to avoid costly licensing debates. Since

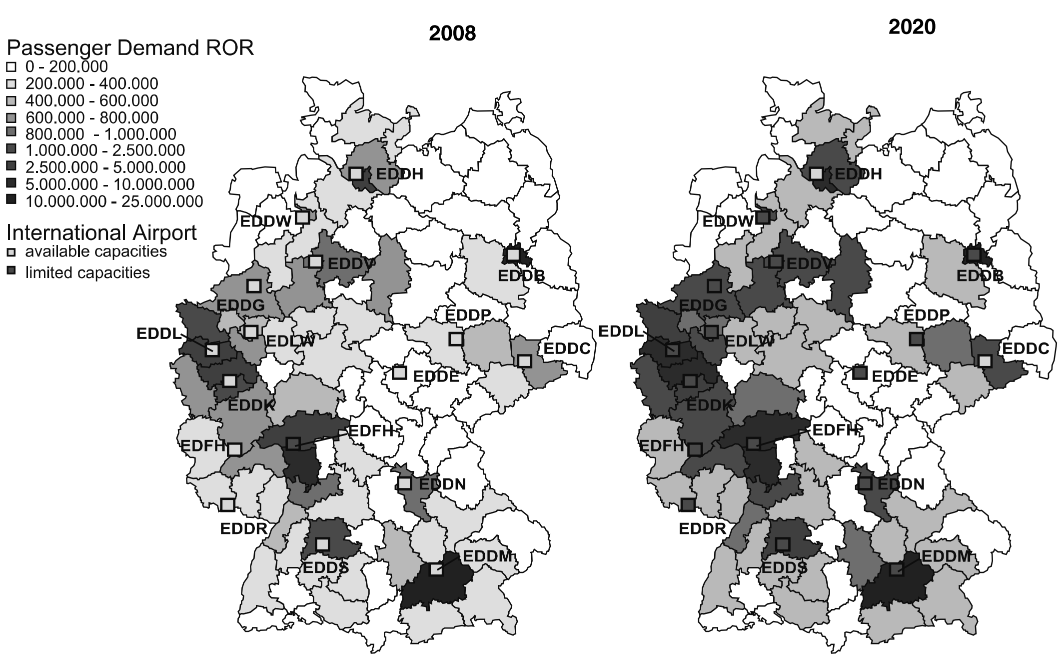

Fig. 7 Scenario 1: simulation results for the current air transportation system for years 2008 and 2020 [for International Civil Aeronautics Organization (ICAO) codes, see Table A1].

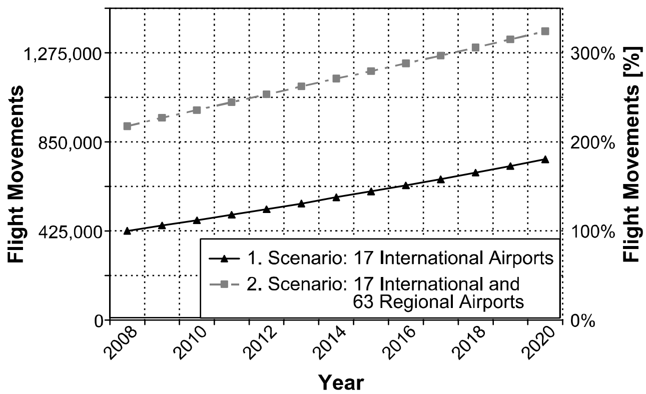

Fig. 8 Comparison of the flight movements needed.

the clearance for aircraft with an MTOW greater than 10 t is a difficult step toward commercial service for an airport, only those airports that already have such a clearance shall be evaluated within the scope of this paper (Fig. 2). This reduces the number of available regional airfields from over 250 to 63 in Germany. Figure 2 shows that a significant number of such airports are located in areas of high demand close to other major airports. Hence, in shortening the mode of access and in increasing the convenience of flight connections, such airports offer a competitive alternative to international airports for regional air traffic in the future. However, environmental issues such as noise emission will also play a crucial role at those regional airports. Therefore, with new aircraft concepts it must be ensured that the total cumulative noise exposure as well as the peak noise levels around those airports will not increase significantly. The possibility of reducing utilization at the main hubs through the integration of regional airports into the current air transport service shall be assessed with the passenger allocation model.

In the second scenario, all regional airports (as presented in Table A2) will be integrated into the air transportation system, regardless of the local demand. As a consequence, a total of 80 airports (17 international and 63 regional airports) are operated simultaneously. Since current commercial regional or single-aisle aircraft cannot be operated at many of the regional airfields, small general aviation (GA) propeller aircraft with low accommodation must be operated at most of the airfields instead. Not presented in this paper, the passenger allocation model shows that the major airports can be relieved through the integration of regional airports. In 2020, 13 out of 17 international airports will still be capable of growth. Therefore, the estimated capacity requirements in 2020 are satisfied by this scenario. However, compared with the first scenario, the necessary flight movements double (Fig. 8). The same amount of passengers are transported with aircraft with lower accommodations. Thus, the total number of flight movements increases. It also has been assumed that a total of 80 airports are operated simultaneously in such a small country as Germany ($357,024\ \mathrm{km}^2$), which is an overoptimistic scenario. Thus, this scenario shows neither an economically nor an ecologically feasible solution for the predicted capacity shortages.

In the third scenario, only those regional airports shall be integrated into the current air transportation system on which an Airbus A320 can operate without any limitations in MTOW (Table A2). This reduces the number of new airfields significantly. With the current infrastructure, only seven additional regional airports could be identified as being compatible with an A320 without any limitations on aircraft classification number (ACN). Therefore, a total of 24 airports (17 international and 7 regional airports) are considered in this scenario. The operation of today's single-aisle aircraft on the now-integrated regional airfields guarantees the same constant increase in flight movement as found for the first scenario. No significant increase in flight movements as found for the second scenario can be observed. Since these additional airports are located in regions of low demand (Fig. 9), the passenger allocation simulations show that this scenario does not provide any relief to the major airports. No significant difference can be observed when compared with the findings of the first scenario presented in Fig. 7. Thus, so far, neither of the presented scenarios can provide a feasible solution for avoiding future capacity shortages at the major airports. Therefore, a new approach is needed in which the air transport vehicle is targeted as well.

IV. Need for new Aircraft and Primary Requirements Derived from Air Transportation System

So far, it has been shown that the current air transportation system does not provide enough free capacity for the predicted air passenger growth. The integration of existing regional airports into the current system could provide sufficient additional capacity. However, today's airline fleets cannot cope with the simple infrastructure at those regional airports, and so the benefits of the integration of these airports cannot be used. As a consequence, a next-generation regional aircraft is needed. The top-level requirements will now be

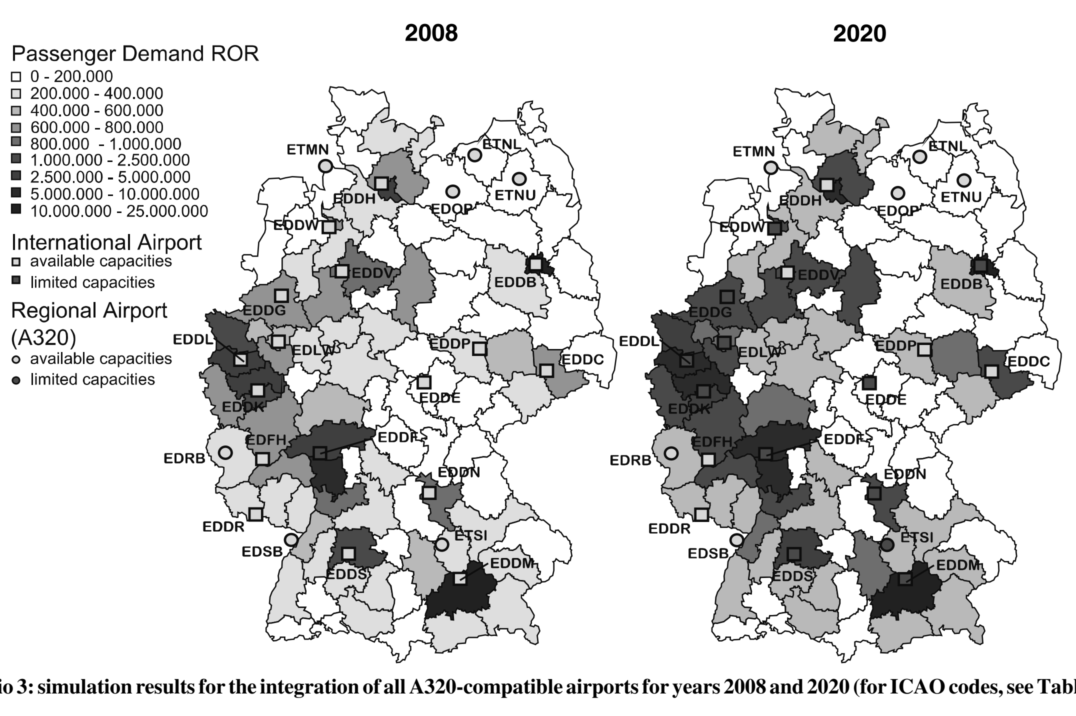

Fig. 9 Scenario 3: simulation results for the integration of all A320-compatible airports for years 2008 and 2020 (for ICAO codes, see Tables A1 and A2).

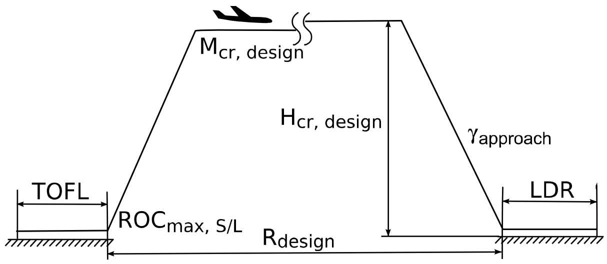

Fig. 10 Derived design mission for STOL concept.

derived directly from the needs of the air transportation system and the expected design mission of the aircraft. The typical mission profile as well as the top-level parameter are shown in Fig. 10.

Figure 11 shows that 80% of the major European cities are closer than 1000 n mile apart. Also in [5] it is stated that until 2027 an average inner-European flight will cover a distance of not more than 650 n mile. Thus, as a first requirement, a design range of 1000 n mile suffices for next-generation regional aircraft. Because of the short distances flown, the initial cruising speed is not a driving parameter. For economic flight with today's state-of-the-art technologies, an initial cruise Mach number of 0.7 to 0.75 is feasible. This allows for a vast choice of efficient propulsion technologies.

Current regional aircraft typically offer seat capacity of approximately 80 to 100 PAX. However, to cope with air traffic growth, the accommodation has to be further increased [5,6]. The current evaluation of regional aircraft already shows a similar trend: e.g., Bombardier's CRJ series [8]. The accommodation of 150 PAX for next-generation regional aircraft shall be another driving parameter. Using today's single-aisle jets, with equal accommodation as a reference, a MTOW of 75,000 kg is a realistic target.

It has been shown in Fig. 2 that approximately 97% of the relevant German regional airports have a runway length of at least 900 m. All areas of high demand are covered by those airports. Thus, a TOFL and landing distance required (LDR) of 900 m shall be directly derived as a requirement. Design studies of STOL aircraft in the past have shown that a TOFL of less than 750 m is achievable with today's technology if required. To ensure that an aircraft can be operated at a given airfield, runway length is not the only constraint. To avoid structural damage, runway strength is another important constraint factor. Each runway is classified by a pavement classification number (PCN); this mainly depends on the type and strength of the surface. Accordingly, an ACN is assigned to each aircraft. This ACN is an equivalent for the maximum load each main gear puts on the runway. The ACN not only directly depends on the landing weight of the aircraft, but also on parameters that can be easily influenced during the design, such as landing gear configuration and number of wheels per main gear. For safe operation at a given airport, the ACN shall never exceed the PCN. Most of the available regional airports have not been planned to facilitate the operation of larger commercial aircraft. Hence, the runways offer a relatively low strength. For next-generation regional aircraft, a standard tripod configuration will be applied. The targeted MTOW does not require an additional center gear. Today's standard for regional and single-aisle aircraft is a main landing gear with one pair of wheels. Experience shows that this is the best tradeoff between weight, braking performance, and space required. This configuration is not optimized for a low ACN, however. To reduce the ACN, additional wheel pairs can be mounted to the main landing gear. With the A320 bogie version [8], Airbus has shown that such a measure requires manageable effort and can even be retrofitted to an existing aircraft. Each additional pair of wheels increases the complexity of the landing gear and the space needed. Thus, a tradeoff between airport compatibility and simple landing gear design has to be found. In [9] a method is introduced by the Federal Aviation Administration (FAA) that estimates the ACN for arbitrary configurations. With the parameters presented in Table 2, the resulting ACN for different configurations of a next-generation regional aircraft has been calculated. Based on these data, the compatibility with German regional airports has been evaluated in Table 3. The compatibility with airports can be increased by 67% by adding an additional pair of wheels in the main landing gear. The configuration with three wheel pairs shows acceptable complexity in design combined with low ACN. Although the gain in airport compatibility is small for the German air transportation system, the configuration STOL.3 will be investigated further to guarantee an easy integration of the aircraft in other markets.

The driving design parameters for the next-generation regional aircraft have now been introduced (Table 4). Additional requirements regarding aircraft noise will be addressed later.

To assess the impact of the next-generation regional aircraft on the air transportation system, configuration STOL.3 and all compatible regional airports (as listed in Table A2) are integrated into the passenger allocation model (Fig. 12). As a consequence, a total of 43 airports (17 international and 26 regional airports) are operated. The fourth scenario shows a significant relief of the major airports in Germany. In 2012 only two airports will have reached their limits in capacity. Compared with the first scenario, sufficient free passenger capacity is provided in both greater Munich and the Rhine–Ruhr metropolitan area. In 2020 only 6 out of 17 international airports will have reached their capacity limit. Although the available airports in Greater Munich are crowded, Stuttgart International still offers a sufficient alternative (Fig. 12). After all, the simulation has shown that for a successful integration of additional regional airports into the air transportation network, a STOL aircraft with requirements adapted to capacity needs is essential to avoid capacity shortages at the major airports in the future. Contrary to the second considered scenario, no significant increase in flight movement compared with the first scenario (Fig. 8) can be observed when the STOL concept is integrated into the air transportation system. The limited number of additional airports as well as the unchanged number of flight movements needed show an economically feasible scenario.

V. Demand and Acceptance for Next-Generation STOL Aircraft

These positive impacts of next-generation regional aircraft on the air transportation system already imply a high demand for such an

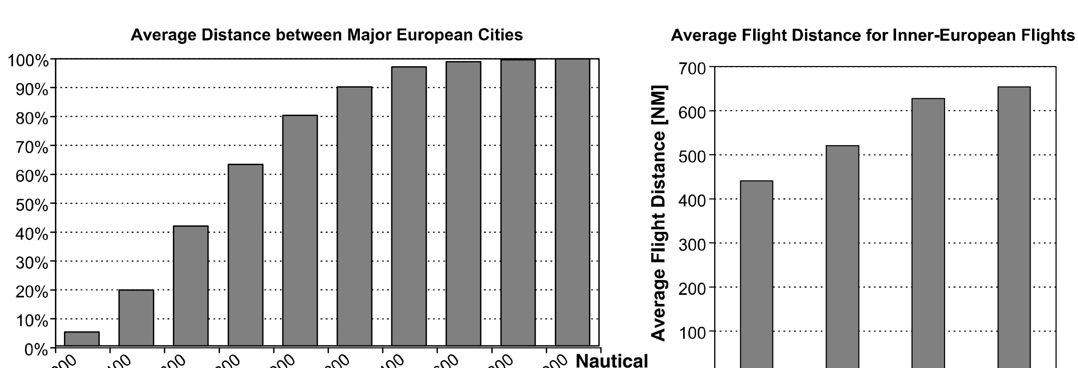

Fig. 11 Average distance between European cities and average flight distance for European flights [5].

Table 2 Parameters for ACN estimation and results on ACN [9]

Aircraft configuration[a]	No. of main-gear wheels	Runway pavement type	ACN class A	B	C	D
STOL.1	2	Rigid	44.4	47.0	49.4	51.4
STOL.1	2	Flexible	39.3	40.9	45.3	51.2
STOL.2	4	Rigid	21.9	25.8	29.9	33.7
STOL.2	4	Flexible	21.5	23.9	29.3	33.1
STOL.3	6	Rigid	14.6	17.9	22.3	26.5
STOL.3	6	Flexible	12.1	13.3	15.9	22.5
STOL.4	8	Rigid	9.9	12.2	16.2	20.6
STOL.4	8	Flexible	10.5	11.8	14.5	21.6

[a]Classical tripod configuration and MTOW = 75,000 kg. MTOW on the main -gear is 94%. Tire pressure is 1.35 kPa. A320-200 is used as the reference aircraft.

Table 3 Compatible German regional airports

STOL.1, 15 airports	STOL.2, 25 airports	STOL.3, 26 airports	STOL.4, 27 airports
Altenburg-Nobitz	as before, plus:	as before, plus:	as before, plus:
Bitburg	Allendorf/Eder	Moenchengladbach	Kassel-Calden
Braunschweig	Augsburg	——	——
Cottbus-Drewitz	Barth	——	——
Friedrichshafen	Bautzen	——	——
Ingolstadt/Manching	Heringsdorf	——	——
Karlsruhe/Baden Baden	Kiel	——	——
Lübeck	Memmingen/Allgaeu	——	——
Neubrandenburg	Niederrhein	——	——
Nordholz	Straubingen	——	——
Paderborn/Lippstadt	Zweibrucken	——	——
Rostock-Laage	——	——	——
Schwerin-Parchim	——	——	——
Siegerland	——	——	——
Westerland/Sylt	——	——	——

aircraft in the market. In the following, the demand for the German market shall be assessed. In Table 5 a prognosis for new deliveries of aircraft until 2027 are shown. The next-generation STOL aircraft targets the regional as well as the single-aisle market, with the passenger capacity as specified before. A total of 5200 new aircraft in these two categories are expected to be delivered for the European market until 2027.

In Fig. 13 the flight movements in the German air transportation system are shown, which have been derived from the simulations presented above. To assess the market share of the next-generation STOL aircraft, the percentage of its flights on the total flight movement have to be estimated. To guarantee a realistic view, an optimistic and a conservative parameter set will be used. In Table 6 the flight movements at sample airports are categorized by the number of passengers per flight. Thus, Table 6 gives an estimate of the distribution of flights by aircraft size at international and regional airports. To estimate the possible number of flight movements with next-generation STOL aircraft from the findings in Table 6, assumptions regarding the proportionate flight movements at the respective airports with this aircraft concept have to be made (Table 7). With these assumptions and the findings of Fig. 13, the number of flight movements with a next-generation STOL aircraft in the German air transportation system can be assessed, as shown in Fig. 14.

To estimate the demand for such an aircraft from the flight movements, the average flights per day have to be assessed. Data of two representative airlines are used. As a low-cost carrier, Ryanair operates with high utilization and short turnaround times on its routes. Hence, the carrier operates with a high frequency of flight movements per day. Therefore, Ryanair gives an optimistic view for the estimation. The average daily flight movements of Ryanair aircraft give the estimate of 6.6 flights per day.[‡] As conservative estimation, data from Lufthansa CityLine are used [10]. The number of daily flights for one aircraft averages to 5.2 as a conservative figure; hence, the demand of STOL aircraft can be assessed, and the results are shown in Fig. 14.

The future demand for a next-generation STOL aircraft is estimated to be 97 to 158 aircraft until 2020 for the German market only. In terms of flight movements, Germany provides the largest market share in Europe (Fig. 15). Extrapolated to the entire European market, a demand of 541 to 883 STOL aircraft is expected. Compared with the prognosis from [5], this represents 10 to 17% of the new deliveries in the regional jet and single-aisle aircraft markets. In addition to Europe, the North American and the Asia-Pacific markets show strong potential for such an aircraft concept. Assuming a market share of 15% in the regional jet and single-aisle classes, a realistic assumption of the worldwide demand for a next-generation STOL aircraft averages to a total of 3251 aircraft.

Table 4 Derived top-level requirements

Requirements	Values
PAX	150
MTOW	75,000 kg
$M_{\mathrm{cr,design}}$	0.7–0.75
R_{design}	1000 n mile
$H_{\mathrm{cr,design}}$	35,000 ft
TOFL	900 m
LDR	900 m
$\mathrm{ROC}_{\max,S/L}$	N/A[a]
$\gamma_{\mathrm{approach}F}$	N/A[a]

[a]Driven by noise requirements; not assessed in the scope of this paper.

[‡]Data available online at http://www.ryanair.com/doc/investor/present/Full_Year_Results_2007.pdf [retrieved 17 March 2008].

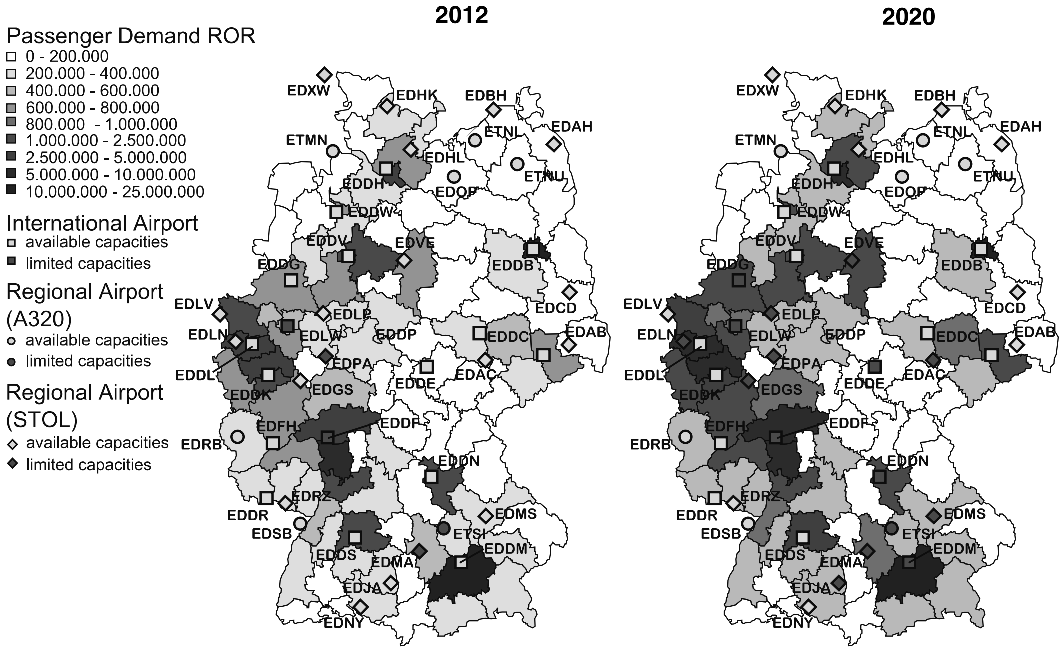

Fig. 12 Scenario 4: simulation results for the integration of next-generation regional aircraft for years 2012 and 2020 (for ICAO codes, see Tables A1 and A2).

Although a high demand for a next-generation regional aircraft is expected, the acceptance of regional airports for integration into the commercial air transportation system is not known. Therefore, a survey was conducted by the Institute of Aeronautics and Astronautics at RWTH Aachen University (ILR), which included a total of 23 German airports. The survey included mainly regional airports but also smaller international airports for which an STOL aircraft may also offer interesting perspectives. The airports have been asked for their current and future perspective on air traffic as well as on planned or necessary enhancement in infrastructure. The results on their perspective on air traffic for general aviation and commercial air traffic is shown in Fig. 16. It can be seen that the airports are currently depending on general aviation, whereas the business aviation has the strongest share. Today commercial service only plays a role at 29.4% of the surveyed airports. In the future, this perspective may change: 58.8% of the surveyed airports will focus on the commercial air traffic, whereas the general aviation will lose its strong share. Hence, the results of the ILR airport survey imply that the regional airports are interested in the integration into the commercial air traffic. It has been shown before that a next-generation regional aircraft is essential for such a development.

VI. From STOL to QSTOL

In the previous section, it has been shown that the integration of regional airports in conjunction with a next-generation regional aircraft can solve future capacity shortages. However, such a scenario is only feasible if the community noise around these airports stays

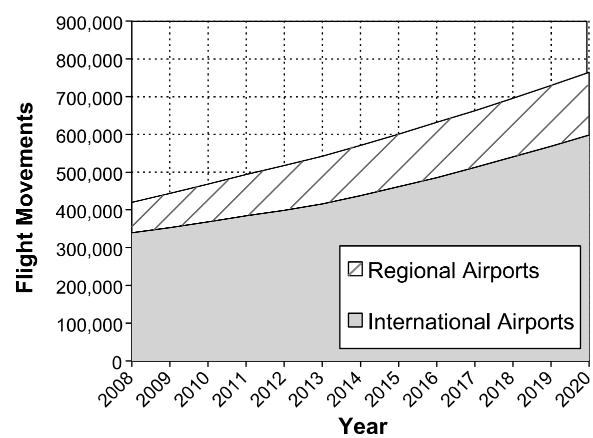

Fig. 13 Flight movements with the integration of next-generation Regional Aircraft.

within admissible limits. Most of the previously identified regional airports are situated in highly populated areas. This guarantees an easy mode of access for the potential passengers and that the regional demand is met. Both aspects are essential for a successful integration into the air transportation system. On the other hand, an increase in aircraft noise emission in those urban areas will not be tolerated by the authorities. In Vision 2020 [1], a reduction of perceived external noise by 50% is targeted for the year 2020. Therefore, noise is a major design driver for such a next-generation regional aircraft.

Table 5 Deliveries by airplane size until 2027 [5]

Region	Regional jets	Single-aisle	Twin-aisle	747 and larger	Total deliveries
Asia-Pacific	430	5,440	2,810	480	9,160
North America	1,190	6,080	1,190	90	8,550
Europe	320	4,880	1,490	210	6,900
Middle East	60	660	690	170	1,580
Latin America	110	1,340	250	——	1,700
Russia and Central Asia	340	460	130	20	950
Africa	60	300	190	10	560
World total	2,510	19,160	6,750	980	29,400

Table 6 Average flight movements per passenger capacity in 2007 (data taken from online statistics for each airport)

Airport	Flight movements with PAX capacities <75, %	75–125, %	125–175, %	175–225, %	>225, %
Regional airfields					
Karlsruhe	0	24	76	0	4
Friedrichshafen	72	0	31	0	0
Bremen	39	14	47	0	0
International airports					
Frankfurt/Main	10	11	29	0	22
Stuttgart	23	8	44	0	1
Munich	36	9	44	0	7
Amsterdam	18	8	45	0	12
Average regional airfield	37	13	51	0	1
Average international airport	22	9	46	0	10

Table 7 Estimated percentage of next-generation regional aircraft flight movement on total flight movements

PAX capacity	Regional airfield Optimistic, %	Regional airfield Conservative, %	International airport Optimistic, %	International airport Conservative, %
Less than 75 seats	50	15	50	15
75 to 125 seats	80	30	60	20
125 to 175 seats	90	70	40	20

In the scope of this paper, one example airfield will be chosen to evaluate the noise challenge for the integration into the commercial air service. For the simulation of all different airport scenarios, greater Munich was identified as the most critical region for future capacity shortages. The southern part of Germany is economically the strongest region. Thus, the growing demand for spare capacity in this region is even higher than in the rest of the country.

Munich International already works on a high utilization. Although a third runway is planned to be put into operation in 2011,[§] no significant long-term relief can be expected for this region. In the course of this development, Augsburg Airport becomes an interesting alternative for future commercial air traffic in this region. Within the last few years, the airport invested in infrastructure to favor such a development. Therefore, the authors chose to further evaluate the integration of Augsburg airport for commercial air service.

The airport is located 4 km north of the city center and directly east of a residential area. In 2006, 53,253 flight movements with a total of 143,895 passengers were recorded at Augsburg Airport.[¶] Approximately 54.6% of the total flight movements covered charter and other commercial services such as private pilot training with mainly single- and twin-engine propeller aircraft, turboprop aircraft, and business jets; 45.2% of the total flight movements covered private leisure flights with typical single-engine propeller aircraft. The remaining 0.2% of charter holiday services is neglected. Current traffic at Augsburg Airport is summarized in Table 8.

Additionally, the integration of Augsburg Airport into the commercial air transportation system with and without a next-generation regional aircraft shall be assessed. The simulation with the passenger allocation model for the year 2020 showed a total of 62,611 flight movements at Augsburg, with 1,440,000 passengers and without a QSTOL concept (Table 9, scenario 2). In this scenario, the total flight movements at this specific airport increase by 17.6%; a distinct change in fleet mix can be expected. It is assumed that the currently predominant single-engine propeller aircraft traffic is replaced by turboprop aircraft and small jets. Hence, a significant increase in noise emission has to be expected. By integrating the QSTOL concept into the passenger allocation model (scenario 4), the simulation shows a total of 33,833 flight movements at Augsburg Airport for the year 2020. The total flight movements decrease by approximately 37.8% compared with the second scenario, whereas the number of passenger nearly triples (Table 10, scenario 2). This utilization lies within the range of today's smaller international airports and still shows capacity for growth.

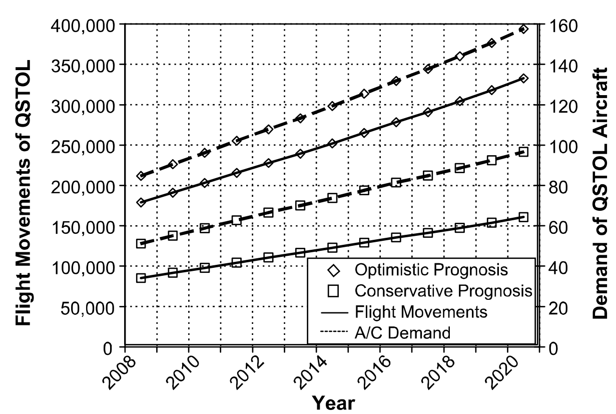

Fig. 14 Flight movements and demand for STOL aircraft in Germany.

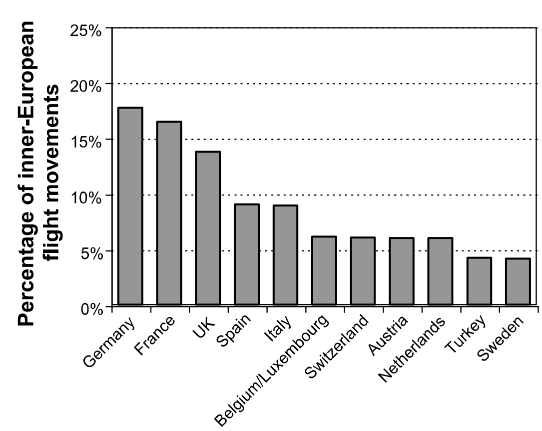

Fig. 15 Percental distribution of inner-European flights [11].

[§]Data available online from https://www.muc-ausbau.de/ [retrieved December 2008].

[¶]Data available online at http://www.adv.aero/fileadmin/pdf/statistiken/1997-2007/Statistik_2006_02.pdf [retrieved 15 October 2008].

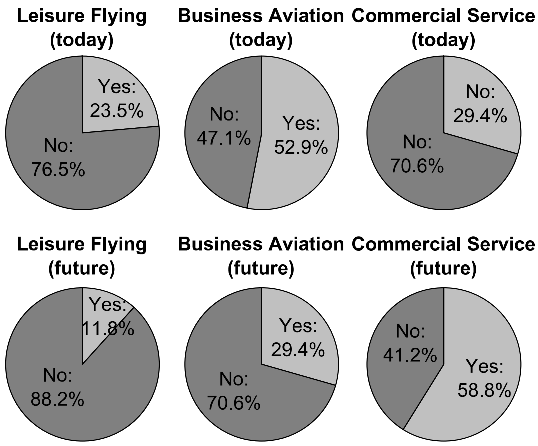

Fig. 16 Perspective on air traffic development at smaller airports.

However, to achieve the targets set in Vision 2020 [1], a noticeable decrease in aircraft noise is required. Thus, noise emission is a major design driver for next-generation regional aircraft. For the target of reduction in noise emission, a noise footprint of 55 EPNdB (effective perceived noise in decibels) within the airport borders has been suggested in [12]. Such an improvement can only be achieved by changes in aircraft configuration, e.g., engine noise shielding, and noise-optimized approach and departure procedures. Therefore, requirements regarding noise emission will have a direct influence on the design mission in terms of maximum rate of climb and descent. A detailed analysis regarding aircraft noise is beyond the scope of this paper. However, criteria on noise emissions have to be specified as requirements at the beginning of the design process to allow for a successful integration of this aircraft concept into the air transportation system. In current studies at ILR, the integrated-noise model FAA method is used to assess the noise emission of different designs at the reference airport in consideration of the different scenarios presented in this paper. Requirements on noise emission will be derived from these simulations. A future publication on this topic is planned.

VII. Extrapolation to Markets Other than Germany

Although only the German air transportation system has been evaluated with the passenger allocation model, the results can be easily adapted to different national or international scenarios. On the one hand, a robust algorithm was chosen that guarantees an easy adaption and enhancement of the implemented scenario. On the other hand, the shortfall of available slots is a common problem known to most international hub airports. In 2008 Southwest Airlines acquired 14 slots at New York's LaGuardia Airport for a $7.5 million bid [13]. The acquisition, however, was only possible through the acquisition of a bankrupted airline that held the slots. The situation is well known at other main hubs such as London Heathrow, Amsterdam Schiphol, or Frankfurt/Main. Airlines can only acquire additional or new slots through costly deals. The further enhancement of existing airports or the construction of new airports in western countries is rarely possible.

The two largest markets, North America and Europe, show a similar dense network of regional airports that are currently not used by scheduled commercial air traffic. Therefore, it seems reasonable

Table 8 Utilization at the reference regional airport of Augsburg in 2005 (see footnote ¶)

Type of service	Passengers per year	Flight movements per year		Typical aircraft mix
		Total	Relative	
Scheduled service	0	0	0.0%	——
Charter holiday service	2280	178	0.3%	Turboprop aircraft, regional/single-aisle jets
Private pilot training	N/A	23,985	45.0%	Single-engine propeller aircraft
GA charter	N/A	1545	2.9%	Single-engine and twin-engine propeller aircraft, business jets
Company service	N/A	3363	6.3%	——
Leisure flying	N/A	24,182	45.4%	Single-engine propeller aircraft
Total	143,895	53,253	100%	——

Table 9 Estimated utilization at the reference regional airport of Augsburg in 2020 without QSTOL

Type of service	Passengers per year	Flight movements per year		Typical aircraft mix
		Total	Relative	
Scheduled service	1,440,000	57,525	91.9%	Turboprop aircraft, regional jets
Charter holiday service	2280	178	0.3%	Turboprop aircraft, regional/single-aisle jets
Private pilot training	0	0	0.0%	Single-engine propeller aircraft
GA charter	N/A	1545	2.5%	Single-engine and twin-engine propeller aircraft, business jets
Company service	N/A	3363	5.4%	——
Leisure flying	0	0	0.0%	Single-engine propeller aircraft
Total	N/A	62,611	100%	——

Table 10 Estimated utilization at the reference regional airport of Augsburg in 2020 with QSTOL

Type of service	Passengers per year	Flight movements per year		Typical aircraft mix
		Total	Relative	
Scheduled service	4,060,000	33,833	86.9%	Turboprop aircraft, regional jets, QSTOL
Charter holiday service	2280	178	0.5%	Turboprop aircraft, regional/single-aisle jets
Private pilot training	0	0	0.0%	Single-engine propeller aircraft
GA charter	N/A	1545	4.0%	Single-engine and twin-engine propeller aircraft, business jets
Company service	N/A	3363	8.6%	——
Leisure flying	0	0	0.0%	Single-engine propeller aircraft
Total	N/A	38,919	100%	——

to apply the results of this paper to the North American market, although it has not been assessed in detail. Both [5,6] predict a high demand of regional and single-aisle jets for North America. The same may partly hold for the Asian market. Although many new hub airports have been constructed in the recent past [e.g., Hong Kong Chek Lap Kok (1998), Shanghai Pudong (1999), or Bangkok Suvarnabhumi (2006)], cities in rural areas need commuter service due to the lack of other means of transportation [5]. In particular, the two countries with the highest predicted potential in air traffic growth, China and India [6], may be interesting for the integration of a QSTOL concept. Because of the lack of infrastructure, both countries heavily rely on air transportation for domestic travel [5]. Although the main metropolitan areas offer the needed airport infrastructure for present short-haul aircraft, cities in rural areas still lack such airports [5,6]. Hence, further research on the applicability of the presented QSTOL concept on the air transportation system of emerging markets may show promising results.

VIII. Conclusions

The expected growth rates in air traffic can only be achieved if additional capacity will be made available at the airports in the future. Neither the optimization of the turnaround processes nor an enhancement in infrastructure at the existing international airports will provide the additional slots needed. The integration of existing regional airports into the commercial air transportation system shows a promising solution for this problem. However, the present fleet mix does not lead to a substantial relief at the major airports. For the successful integration of these airfields, a new aircraft concept is mandatory. A QSTOL aircraft is needed that provides sufficient accommodation and can deal with the short runways available. In addition to the short takeoff and landing performance, noise is another crucial design driver. Scheduled air service can only be introduced at the regional airfield if community noise does not increase. The requirement of a decrease in noise by 50% set in Vision 2020 [1] shall be met by a QSTOL concept.

A passenger allocation model has been used in this paper to quantitatively evaluate the integration of regional airports and a QSTOL concept into the German air transportation system. The simulations showed that not only could the overall capacity problems in Germany be solved, but that by selective integration of regional airfields, the local capacity shortfalls could be avoided, e.g., for greater Munich or the Rhine-Main metropolitan area.

Appendix A: ICAO Airport Codes

Table A1 ICAO code of German international airports

Airport	ICAO code	Scenario 1	2	3	4
Berlin	EDDB	X	X	X	X
Bremen	EDDW	X	X	X	X
Dortmund	EDLW	X	X	X	X
Dresden	EDDC	X	X	X	X
Düsseldorf	EDDL	X	X	X	X
Erfurt	EDDE	X	X	X	X
Frankfurt/Main	EDDF	X	X	X	X
Frankfurt/Hahn	EDFH	X	X	X	X
Hamburg	EDDH	X	X	X	X
Hannover	EDDV	X	X	X	X
Köln/Bonn	EDDK	X	X	X	X
Leipzig/Halle	EDDP	X	X	X	X
München	EDDM	X	X	X	X
Münster/Osn.	EDDG	X	X	X	X
Nürnberg	EDDN	X	X	X	X
Saarbrücken	EDDR	X	X	X	X
Stuttgart	EDDS	—	X	—	—

Table A2 ICAO code of German regional airports

Airport	ICAO code	Scenario 1	2	3	4
Aalen-Heidenheim/Elchingen	EDPA	—	X	—	—
Allendorf/Eder	EDFQ	—	X	—	X
Altenburg-Nobitz	EDAC	—	X	—	X
Augsburg	EDMA	—	X	—	X
Barth	EDBH	—	X	—	X
Bautzen	EDAB	—	X	—	X
Bayreuth	EDQH	—	X	—	—
Bitburg	EDRB	—	X	X	X
Braunschweig	EDVE	—	X	—	X
Bremerhaven	EDWB	—	X	—	—
Cottbus-Drewitz	EDCD	—	X	—	X
Egelsbach	EDFE	—	X	—	—
Eisenach-Kindel	EDGE	—	X	—	—
Emden	EDWE	—	X	—	—
Essen/Mülheim	EDLE	—	X	—	—
Finow	EDAV	—	X	—	—
Flensburg-Schäferhaus	EDXF	—	X	—	—
Freiburg-Breisgau	EDTF	—	X	—	—
Friedrichshafen	EDNY	—	X	—	X
Grossenhain	EDAK	—	X	—	—
Halle-Oppin	EDAQ	—	X	—	—
Heringsdorf	EDAH	—	X	—	X
Hof-Plauen	EDQM	—	X	—	—
Husum Schwesing	EDXJ	—	X	—	—
Ingolstadt/Manching	ETSI	—	X	X	X
Kamenz	EDCM	—	X	—	—
Karlsruhe/Baden Baden	EDSB	—	X	X	X
Kassel-Calden	EDVK	—	X	—	—
Kiel	EDHK	—	X	—	X
Koblenz-Winningen	EDRK	—	X	—	—
Lahr	EDTL	—	X	—	—
Lübeck	EDHL	—	X	—	X
Mainz/Finthen	EDFZ	—	X	—	—
Mannheim City	EDFM	—	X	—	—
Memmingen/Allgäu	EDJA	—	X	—	X
Mengen-Hohentengen	EDTM	—	X	—	—
Mönchengladbach	EDLN	—	X	—	X
Neubrandenburg	ETNU	—	X	X	X
Niederrhein	EDLV	—	X	—	X
Niederstetten	ETHN	—	X	—	—
Nordholz	ETMN	—	X	X	X
Nordhorn-Lingen	EDWN	—	X	—	—
Paderborn/Lippstadt	EDLP	—	X	—	X
Pirmasens	EDRP	—	X	—	—
Rechlin-Lärz	EDAX	—	X	—	—
Rendsburg-Schachtholm	EDXR	—	X	—	—
Rostock-Laage	ETNL	—	X	X	X
Rothenburg/Görlitz	EDBR	—	X	—	—
Saarlouis-Düren	EDRJ	—	X	—	—
Schwäbisch Hall	EDTY	—	X	—	—
Schwerin-Parchirn	EDOP	—	X	X	X
Siegerland	EDGS	—	X	—	X
Speyer/Ludwigshafen	EDRY	—	X	—	—
Spremberg-Welzow	EDCY	—	X	—	—
Stadtlohn-Vreden	EDLS	—	X	—	—
Stendal-Borstel	EDOV	—	X	—	—
Straubing	EDMS	—	X	—	X
Trier-Föhren	EDRT	—	X	—	—
Tutow	EDUW	—	X	—	—
Westerland/Sylt	EDXW	—	X	—	X
Wilhelmshaven-Mariensiel	EDWI	—	X	—	—
Worms	EDFV	—	X	—	—
Zweibrücken	EDRZ	—	X	—	X

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