Towards a Quiet Short Take-Off and Landing Transportation System: Concept Evaluation and ATM Integration

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ABSTRACT

Despite the current economic situation, a moderate to strong growth in air traffic is expected in the medium term. Even today, major airports are operating at their capacity limits. The consequences for airlines and passengers are increasing delays and longer travel times. Airport expansion seems necessary to deal with the traffic growth but is hindered by legal and environmental issues. Already, neighbouring residential areas are subject to increasing noise pollution and emissions. A promising solution to the problem might be a quiet aircraft concept that operates from short and underutilized runways.
Therefore, DLR established a multi-disciplinary process for the design and system evaluation of a new *Quiet Short Take-off and Landing* (QSTOL) transportation concept. In comparison to what has been presented in 2009, the focus of this work lies on active high lift systems, i.e. *Upper Surface Blowing* (USB). Corresponding modules within the QSTOL process are modified to incorporate the effect of the active high lift system on aircraft/engine design, aerodynamics, flight mechanics, and noise prediction. Furthermore, ground noise pollution for multiple flyover events and airport scenarios can now be evaluated. Next to common noise metrices, like the Day-Night Average Sound Level, a dosage-effect relationship is implemented to identify community response to aircraft noise. The extended process is applied to evaluate a generic airspace/airport scenario. USB operations on a third independent runway may increase the number of flight operations by around 8 % but rise community annoyance regarding aircraft noise.

INTRODUCTION

Increasing demand for air transportation along with limited capacities at major airports require radical solutions. One such solution is the integration of underutilized regional airports into the overall system. This can be achieved by *Quiet Short Take-off and Landing* (QSTOL) aircraft with high passenger capacities. These aircraft require short field lengths and at the same time allow for environmental friendly operation. Recent studies [1]–[3] have revisited this concept that has been around since the 1970s [4]. A significant capacity increase for the German air transportation system is predicted by Henke [5].

NASA has identified in 2002 that coupling noise prediction capabilities with air traffic simulation becomes inevitable to understand the impact of air traffic on local communities [6]. Definition of requirements and interfaces of such an integrated process have been presented. Initial results of another study predict a significant impact of environmental effects on communities in the vicinity of airports for the current air traffic system with conventional aircraft types [7].

The German Aerospace Center (DLR) has established its own multi-disciplinary process for the design and system evaluation of such a transportation concept. This process involves expert tools from several DLR institutions which have been harmonized in input and output format. Initial application of the process towards conventional aircraft configurations with passive high lift systems has been presented in 2009 [8].

In comparison to what has been presented by NASA [7] and by DLR [8] in 2009, the focus of this work lies on the impact of active high lift systems, i.e. *Upper Surface Blowing* (USB). Corresponding modules within the design process are modified to incorporate the effects of the active high lift system. New powered-lift aircraft are designed to operate along tailored flight paths. Ultimately these flight paths are incorporated into a generic terminal airspace scenario to study the impact on delay and community noise annoyance.

AIRCRAFT DESIGN

Four different aircraft are selected for the system evaluation, two of each equipped with active and passive high lift system. These aircraft are designed with the PrADO software developed at the Technical University of Braunschweig [9]. A conventional medium-range transport aircraft with passive high lift design is selected as the reference aircraft within this study. The design mission for the QSTOL aircraft is modified to a short-range mission of 1850 km with a reduced flight mach number of 0.7.

The two configurations with passive high lift systems have been introduced in 2009 [8]. Both configurations are

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medium-range transport aircraft and are referred to as Q1 and Q2. Advanced materials installed on-board of both aircraft allow for an increased thrust-to-weight ratio hence necessary excess thrust for short take-off operations. Overall, reducing structural and fuel weight along with the otherwise unmodified geometry results in significantly reduced wing loading hence approach speeds are reduced. The same engine as the base design is installed on-board of Q1 whereas Q2 is equipped with a geared turbofan engine.

The two configurations with active high lift systems are referred to as Q11 and Q12 (Figure 1). Both aircraft are equipped with Upper Surface Blowing with Q11 being a redesign of Boeing's technology demonstrator YC-14. On the other hand Q12 is based on the reference aircraft using an adjusted and modified YC-14 wing and high-lift design. To simulate the aerodynamics of these aircraft new active lift modules are implemented into the overall aircraft design code PrADO.

Figure 1. Aircraft configurations illustrated with PrADO, Q11 and Q12

Powered-lift Aerodynamics

The PrADO code is updated with an aero module for the prediction of Upper-Surface Blowing [10]. The module is based on two methods found in the literature, i.e. the Jet Flap Theory by Spence [11] and the Circular Streamline Theory by Keen [12]. The new module predicts the impact of the USB system on the overall aircraft design. The influence on weights, aerodynamics, and aircraft performance can be evaluated. The resulting data is stored in look-up tables for further investigation of the flight performance with dedicated tools as will be shown.

The resulting performance and design characteristics of the aircraft are summarized in Table 1.

NOISE PREDICTION

The *Parametric Aircraft Noise Analysis Module* (PANAM) is a development of the Institute of Aerodynamics and Flow Technology [13]. The software predicts ground noise impact along arbitrary 3-D flight maneuvers. PANAM was developed to enable comparative noise evaluation of different aircraft concepts as early as possible within the design process. Hence, the level of complexity of required input data is well suitable for preliminary design. Necessary input parameters for PANAM are those which specify the aircraft and engine design, flight conditions and observer locations. Output formats of PANAM include the standard noise measures. For a grid of observer locations the distribution of noise levels as received on the ground can be visualized. PANAM features the analysis of noise events in real-time. Instead of working with time integration or maximum levels only, the real-time distribution of sound pressure levels can be evaluated. The level time history SPL(t) is stored for each one observer location. Detailed evaluation of the noise footprint for each one time step as well as a quick animation of the noise footprint development versus flyover time can be performed.

The code as presented in [8] and [13] can be applied to conventional transport aircraft only. PANAM's setup allows for a straightforward integration of additional or updated noise source models reflecting the progress in modelling the physics of noise source mechanisms and their parametrical dependencies. Therefore, to predict ground noise impact of powered-lift concepts, e.g. upper surface blowing (USB) or externally blown flaps (EBF), a promising approximation has been identified in the literature.

Furthermore, the code is modified to predict time-integrated noise levels for multiple flyover events [14]. Hence it is possible to compute noise metrics such as the Day-Evening-Night Sound Level (L_{DEN}) for arbitrary combinations of aircraft, fleet mix, flight operation, and runway layout. In order to understand and predict community response to aircraft noise, a dosage-effect relationship [15] is implemented into PANAM. This relationship correlates the predicted L_{DEN} with the percentage of highly annoyed, annoyed, and little annoyed people. Applied on a given population density around an airport, this would directly result in the number of annoyed people. But it is not in the scope of the presented work to identify and implement the population density.

Powered-lift Acoustics

An approximation to predict powered-lift noise has been identified in the literature [16]. The method by Clark is applicable to upper surface blowing as well as externally blown flaps. Engine concepts with unmixed as well as internal jet mixing can be evaluated. The following limitations and restrictions have to be considered when interpreting the predicted powered-lift noise. The underlying database is comprised of static measurements only, i.e. no free field velocity is taken into account which may influence jet entrainment effects. Only little variation in engine size has been investigated with a constant relative distance between engine exhaust and flap. Overall, the design space for this prediction model is rather limited. The predicted impact of noise directivity in flight direction is very limited and therefore neglected.

The model predicts powered-lift flap noise only, i.e. noise levels are corrected for core, fan, and jet noise. Free field noise levels for arbitrary observer locations can be determined. Noise propagation effects and losses are not included hence have to be applied within the overall noise prediction.

FLIGHT OPERATIONS

The selected aircraft designs with either active or passive high lift system are evaluated concerning their individual flight operations.

Simulation Tools

To simulate and investigate different approach and departure procedures for these aircraft, a fast time simulation tool has been developed. This tool works under a Matlab/Simulink environment and is referend to as NAPSim. The complexity of required input data is well suitable for preliminary aircraft design. Engine and design parameters as well as look-up tables with aerodynamic coefficients C_A and C_W are provided as input. Furthermore, dependencies and interaction of lift and thrust are accounted for. It comprises a 3DOF mass point simulation and aerodynamic coefficients are provided as input. According to the high lift system the aerodynamic coefficients can be thrust dependent. Input for the simulation is comprised of thrust lever position, pitch and roll angle. Output data include aircraft position, velocities, accelerations, and attitude as well as a simple aircraft simulation model that can be used for further investigation [17].

To investigate the aircraft performance and safety during take-off and landing the program package MAPET is used. This program runs under Matlab/Simulink as well and was developed at the Institute of Flight Systems. MAPET is a software tool for model based aircraft performance evaluation during climb, descent, curve, and cruise flight conditions. MAPET is able to control the simple NAPSim aircraft simulation model for detailed simulation of take-off and landing phases. Due to input data limitation for the preliminary aircraft designs only longitudinal motion and no control surface effectivity is evaluated [18].

Arrival and Departure Noise Abatement Procedures

Different noise abatement procedures for approach and departure are currently in use or under investigation [19]–[22].

Departures Engines are usually operated with high thrust settings to gain speed and lift off. Therefore, engine noise remains the dominating noise source along the entire take-off procedure. The standard departure procedure of *Lufthansa German Airlines* (DLH) is the *Modified ATA Procedure* (MATA) with reduced take-off thrust (MODATA-FLEX). If the runway length does not match the take-off requirements due to aircraft weight, temperature and weather conditions, a full thrust take-off has to be performed (MATA-TOGA). Other airlines perform another procedure called ICAO-A. The difference between the two procedures is the beginning of the acceleration phase. Using the ICAO-A procedure the acceleration phase is initiated after cut back and steady climb up to 3000 ft. In comparison the MATA procedure's acceleration is initiated at much lower altitudes. Both procedures are depicted in Figure 2.

Approach Low-noise operation with conventional aircraft can be achieved by shifting certain flight segments towards the runway threshold. Descent, deceleration, and reconfiguration phases are shifted as close towards the runway threshold as possible. Obviously, the engines have to run on minimum rpm, ideally on idle until touch down.

The powered-lift aircraft uses thrust to generate lift so the pilot has to use a high thrust setting to have the ability to perform a slow approach which is a conflict to the prior statement. Therefore, the main noise source for the conventional design is the airframe noise whereas the for the USB design, engine noise and jet/flap interaction are dominating along the approach.

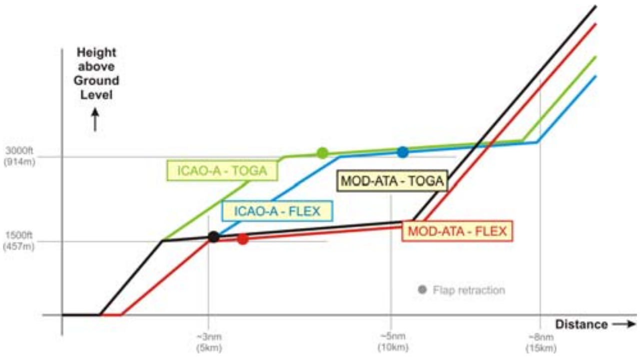

Figure 2. Departure Profiles

The investigated approach procedures are depicted in Figure 3. The most commonly used approach procedure is the *Low-Drag-Low-Power* (LDLP) procedure. The procedure begins with a first open descent with idle thrust setting until intermediate approach altitude of approx. 3000 ft. At this point deceleration and reconfiguration phases are initiated. About 9 NM before touch down the common ILS path (three degree glide slope) is intercepted. Along the glide slope the landing gear is extended and final reconfiguration initiated. At an altitude of 1000 ft the aircraft must be stabilized (flight path, speed, and thrust setting) to avoid go-around. On final approach, thrust is increased to prevent any spool-up times in case of a necessary go-around. Modifications to the LDLP in order to avoid higher thrust levels on the intermediate height result in a new procedure (OLDLP). A LDLP with steeper final approach is referred to as SLDLP. The descent angle of the final approach is limited by maximum vertical speed requirements (1000 ft/min). Another approach procedure, the Continuous-Descent-Approach (CDA) starts with a descent until the ILS glide slope is reached without the use of an intermediate height. The CDA and its variations mainly differ in the point of descent, deceleration and reconfiguration.

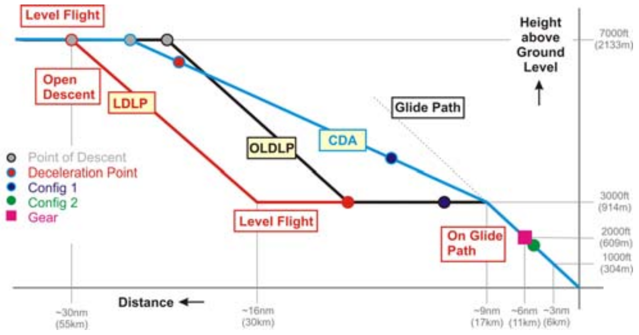

Figure 3. Approach Profiles

The main differences among all depicted approach procedures are time and fuel required, pilot's workload, ATM aspects, and noise pollution.

Simulations

The above mentioned noise abatement procedures are simulated to evaluate technical feasibility for each aircraft within the study. The procedures have been manually optimized for low-noise operation.

Departures In Figure 4 the altitude, speed, configuration setting, thrust and the noise under the flight path for the MODATA-FLEX procedure, performed by all four aircraft, is shown. The aircraft with active lift systems feature the lowest take-off speeds and therefore allow for the shortest runway lengths. Due to thrust enhanced lift, these concepts allow for steeper climb-out. At the same time they require increased thrust settings leading to higher engine noise emission. This additional engine noise emission is counteracted by the increased ground distance resulting from steeper climb angles. Therefore, noise predictions along the ground flight track indicate similar impact for the powered lift concepts compared to the conventional aircraft. Yet, the noise isocontour areas for all noise levels (Figure 5) are considerably larger compared to the conventional designs. The advanced engine design leaves the Q2 aircraft with the lowest ground track noise impact as well as with the smallest noise isocontour areas.

Figure 6 shows a comparison between the four aircraft designs regarding the fuel consumption and the time required from brake release to an altitude of 6000 ft 20 NM from the airport. The USB configurations need less time because of the higher thrust but this leads to a higher fuel consumption compared to the conventional designs.

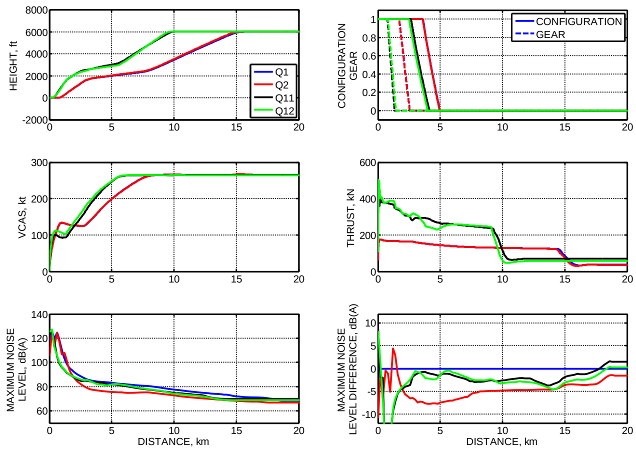

Figure 4. Flight profiles MODATA-FLEX

Approach The Low Drag Low Power approach procedure for all aircraft is shown in Figure 7. The powered-lift aircraft feature a higher initial approach speed but a significantly slower final approach speed compared to the conventional designs. The powered-lift aircraft are also capable of higher rates of deceleration, hence resulting in late reconfiguration. Because of the higher initial speed and the higher thrust requirement, the noise isocontour areas are significantly larger than those of the conventional designs (Figure 8).

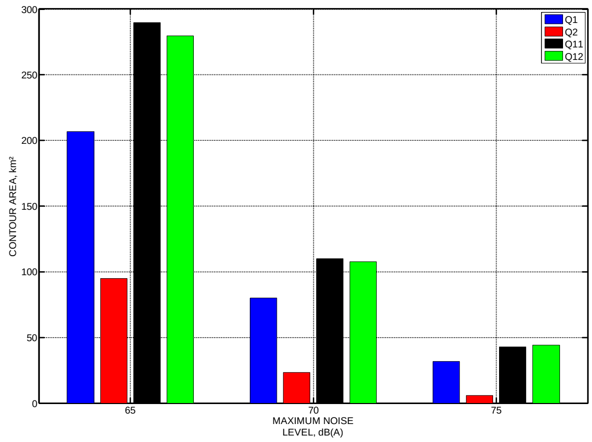

Figure 5. Noise isocontour areas MODATA-FLEX

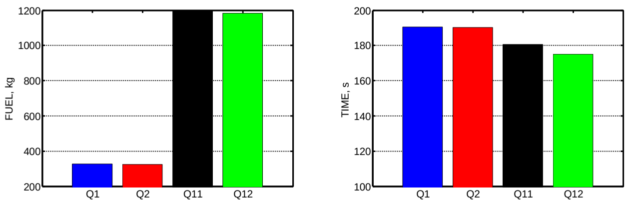

Figure 6. Time and Fuel consumption MODATA FLEX

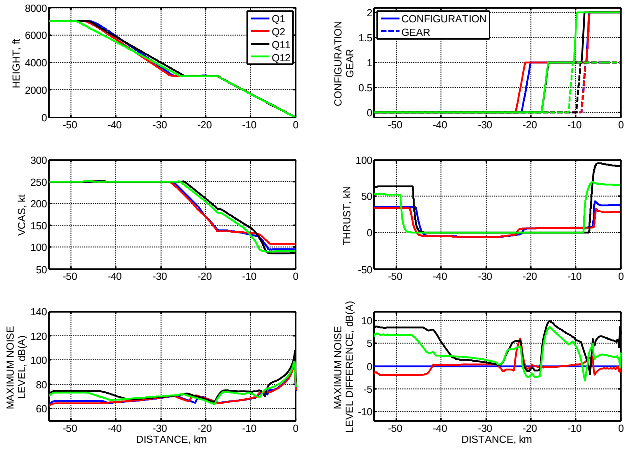

Figure 7. Flight profiles Low Drag Low Power

Again, active lift design leads to higher fuel consumption for approach procedures compared to the conventional aircraft (Figure 9) due to thrust enhanced lift in slow flight conditions.

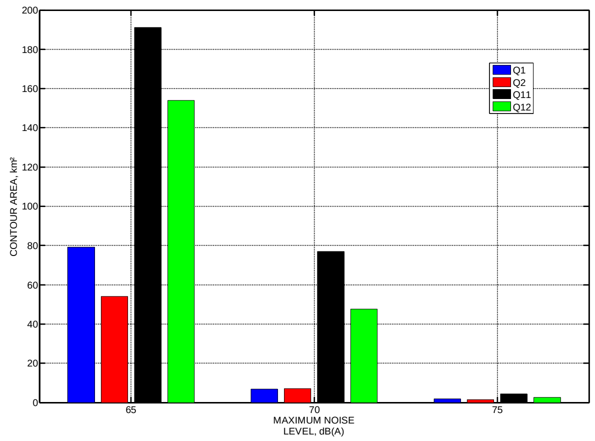

Figure 8. Noise isocontour areas Low Drag Low Power

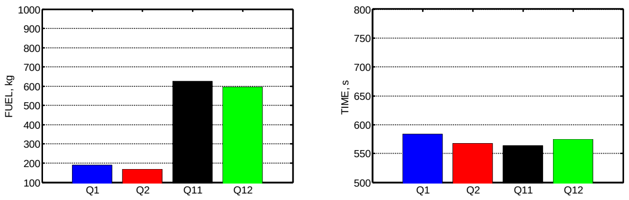

Figure 9. Time and Fuel consumption Low Drag Low Power

Engine failure Figure 10 shows a take-off with an engine failure [22] for an USB configuration (Q11). The aircraft first accelerates to V_S before it starts to rotate. At around V_2 it lifts off and the controller is set to maintain a climb with steady speed at V_2. At an altitude of 18 ft one engine fails. Because the USB configuration produces lift with the engine thrust, the stall speed rises after the failure. As shown in Figure 10 the new V_S with only one engine is close to the old V_2. The aircraft has to lower the nose to accelerate again to reach the new V_2. In real flight conditions, this could prove to be a serious problem. The conventional aircraft configurations do not face these problems since their speeds won't change during engine failure.

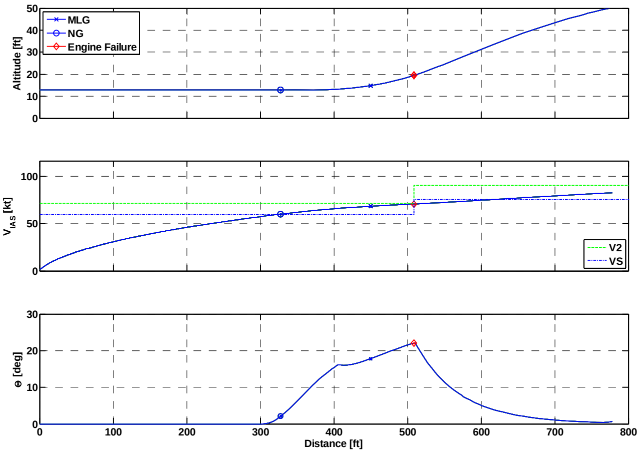

Figure 10. Take-off with engine failure (USB)

An engine failure during a landing procedure for an USB configuration is shown in Figure 11. The aircraft is already on the glide path with its approach speed when one engine fails. The approach speed for single engine operation is higher because of the missing lift from the other engine. After a reaction time of two seconds thrust is set to maximum available. The pilot uses a steeper glide path to gain speed and reach the new approach speed. Afterwards the aircraft is able to climb at a steady speed.

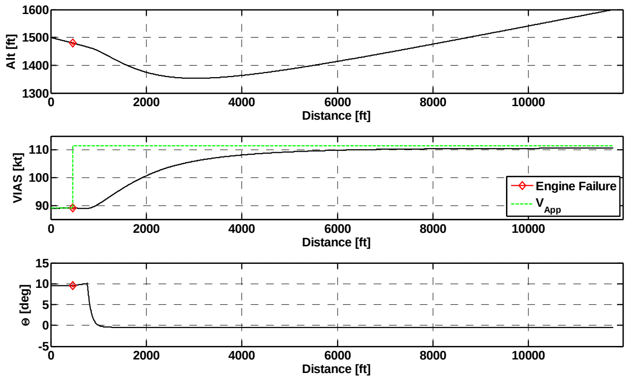

Figure 11. Landing with engine failure (USB)

In both cases the roll and lateral movement is completely neglected but for these USB configuration an engine failure would result in an asymmetrical lift contribution which would lead to a roll and lateral motion. This additional motion would make it more difficult for the pilot to recover the aircraft.

Performance data and noise certification data for each individual aircraft is summarized in Table 2 and

Table 3 respectively.

ATM INTEGRATION

Even though QSTOL aircraft are usually intended to be used from so-called STOLports, i.e. small airports close to city centers, flights to and from major airports are necessary for an effective transportation system. To evaluate the transportation concept, the integration of the aircraft into a major airport's terminal airspace is analyzed using the fast-time simulation tool SIMMOD. SIMMOD is a discrete-event airport and airspace simulation tool developed by the Federal Aviation Administration (FAA) [23]. The tool is applied by airport operators and planners, as well as by air traffic control authorities as an industry standard analysis tool for conducting simulations of future airport and airspace scenarios. Movement of individual aircraft is simulated along airspace routes, runways, taxiways and gates consisting of a node-link structure.

Selected low-noise procedures are implemented into the fast time simulation of the air traffic to study their impact on capacity and delays. The QSTOL aircraft's lower approach speeds could reduce airport capacity while the use of QSTOL aircraft specific procedures might reduce or even reverse that effect.

Simulation Scenario

The airport layout of the presented study features three runways, two of which are parallel dependent runways (26L and 26R, centerline distance 500 m). The third runway (19) intersects both parallel runways. The airport layout does not represent a specific airport but is based on a selection of several major airports (Hamburg Intl. Airport, Düsseldorf Intl. Airport). The layout was designed to be able to study both dependent parallel and intersecting runway configurations. Three different airport configurations are used for the simulations, one with intersecting runways (arrivals on 26L and departures on 19, Figure 12) and one with two dependent parallel runways (arrivals on 26R and departures on 26L) as shown in Figure 13. These scenarios are usable with all aircraft types. In both configurations, one runway is used for departures and one for arrivals. A third runway configuration consists of the use of the parallel runway system with all Q12 aircraft using intersection take-offs (19Q) from the additional intersecting runway that would otherwise be unused when traffic is operating from both parallel runways (Figure 14).

Since taxiways and aprons are not subject of the simulations, only major taxiways are modeled connecting the runway entries and exits with one accumulative gate, summarizing all the airport's parking positions in one point.

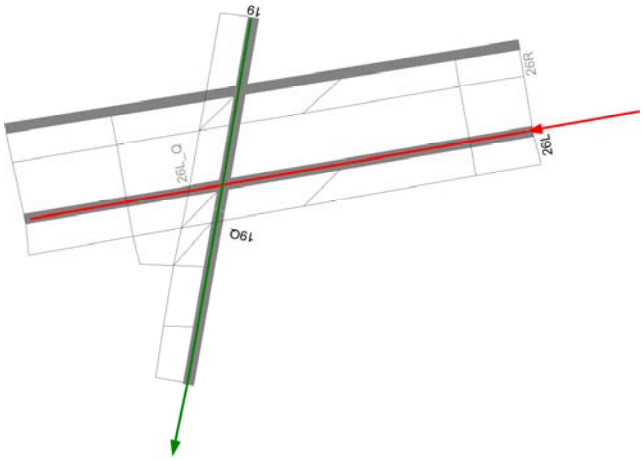

Figure 12. Airport Configuration A26L/D19

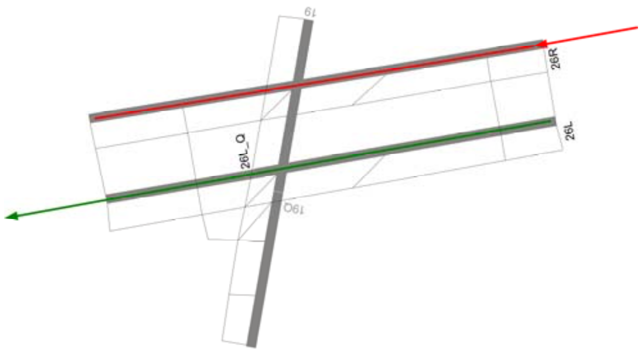

Figure 13. Airport Configuration A26R/D26L

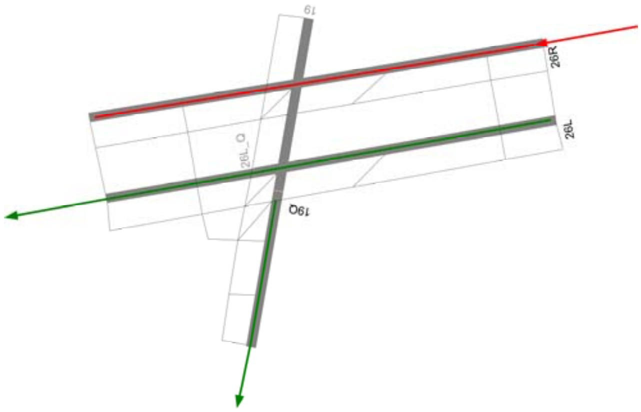

Figure 14. Airport Configuration A26R/D26L/19Q

Due to their short-field performance, powered-lift QSTOL aircraft (Q11, Q12) are able to perform intersection take-offs (26L_Q, 19Q, *take-off run available* (TORA): 900 m) which are significantly reducing *runway occupancy times* (ROT). The quieter conventional aircraft designs (Q1, Q2) are not able to perform intersection take-offs in the chosen simulation scenario since they require slightly longer TORA distances.

The approach (OLDLP and CDA) and departure profiles (MOD-ATA, ICAO-FLEX) for the different aircraft designs as well as for conventional aircraft are approximated and integrated into the simulation model.

The reference flight plan contains 719 flights (360 arrivals and 359 departures) during one simulated day (06:00-22:00) with around 10 % heavy sized aircraft, 80 % medium sized jet aircraft and 10 % smaller business jets and commuter aircraft. This fleet mix is representative for major European airports. Figure 15 shows the hourly demand (during rolling hours) in the course of the day.

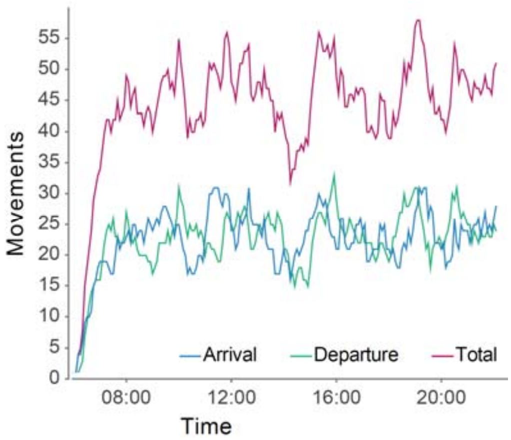

Figure 15. Demand Air Traffic Scenario

Different percentages of medium class aircraft are substituted with QSTOL aircraft to analyze the impact of the new transportation concept on capacity and delay. Both scenarios are simulated for two combinations of flight trajectories, OLDLP approach and MODATA departure profiles and CDA approach and ICAO-FLEX departure profiles, as well as for two aircraft designs (Q2 and Q12).

SIMULATION RESULTS

The airspace simulations are conducted for the three above mentioned runway configurations. Furthermore, the simulation output is used to generate noise isocontour area plots. For the scenario noise evaluation, isocontour areas of the Day-Evening-Night Sound Level L_{DEN} [dB] are selected. Furthermore, isocontour areas of highly annoyed people (percentiles) are evaluated according to [15]. In each isocontour plot, the area is highlighted where more than 33 % of the people are highly annoyed by aviation noise. For the noise evaluation the reference fleet mix is comprised of medium-class reference aircraft only due to limitations in noise source modelling of other aircraft classes. The fleet mix is modified by replacing reference flights with Q2 and Q12 flight operations.

Arrival 26L / Departure 19 Runways 26L and 19 are utilized within this scenario. All aircraft touch-down on runway 26L and take-off from runway 19 with Q12 aircraft using an intersection take-off.

The average delay slightly increases with higher numbers of both Q2 and Q12 aircraft as depicted in Figure 16 and Figure 17 due to increasing arrival delay. Departure delay decreases with Q12 operations since intersection take-offs allow for independent departures.

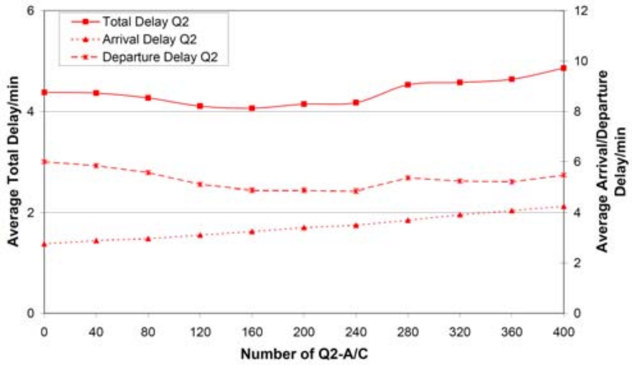

Figure 16. Average Delay A26L/D19 (Q2)

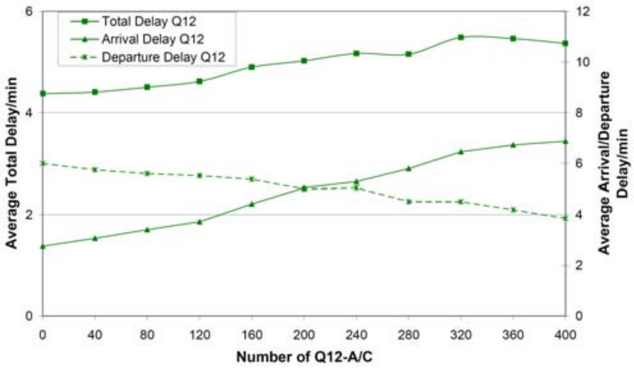

Figure 17. Average Delay A26L/D19 (Q12)

Figure 18 shows the noise contours if only reference aircraft are operated. Again, implementation of the Q2 results in noise reduction whereas the Q12 replacement increases noise pollution. Figure 19 and Figure 20 present the results for 200 arrivals and 200 departures of Q2 and Q12 aircraft respectively.

Arrival 26R/Departure 26L Runways 26R and 26L are utilized within this scenario. All aircraft touch down on runway 26R and take off from runway 26L.

Average delay does not change significantly with higher numbers of Q2 operations (Figure 21). A slight increase in arrival delay due to slightly slower approach speeds is countered by a decrease in departure delay due to shorter runway occupancy times of the Q2 aircraft.

On the other hand, higher numbers of Q12 aircraft lead to a significant rise in both arrival and departure delay (Figure 22) due to the Q12 aircraft's slower approach and departure speeds and the dependency between take-off and landing in this scenario.

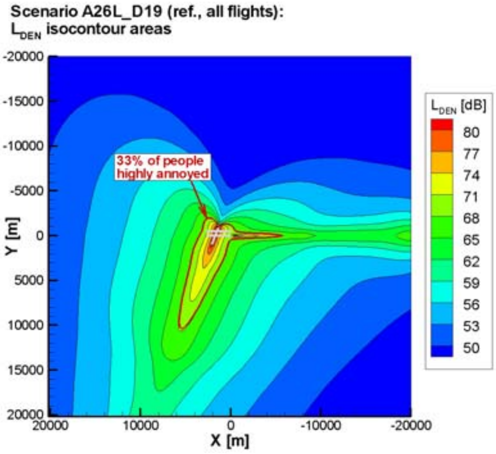

Figure 18. Isocontour Areas A26L/D19, reference scenario

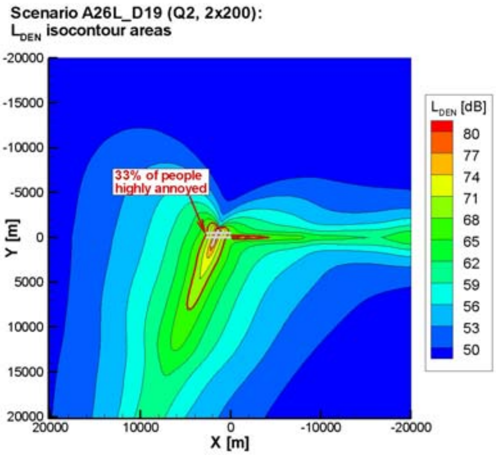

Figure 19. Isocontour Areas A26L/D19, 400 movements replaced by Q2

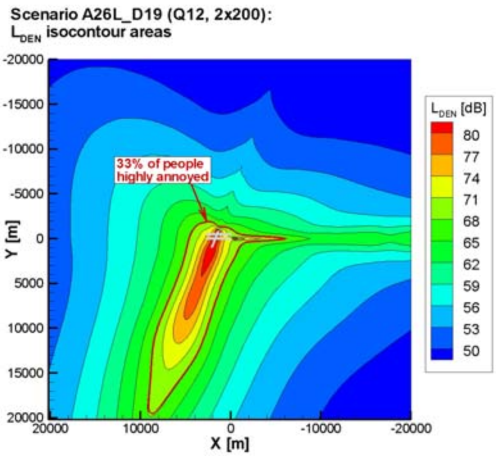

Figure 20. Isocontour Areas A26L/D19, 400 movements replaced by Q12

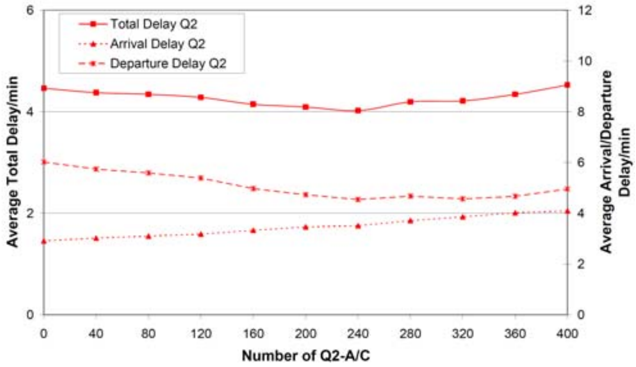

Figure 21. Average Delay A26R/D26L (Q2)

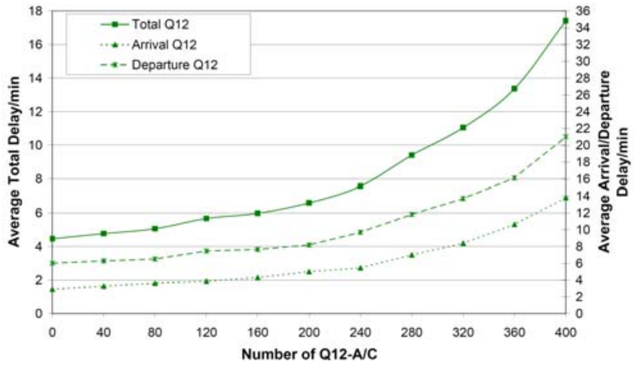

Figure 22. Average Delay A26R/D26L (Q12)

Figure 23 shows the noise isocontour areas for flight operations of the reference aircraft only. Increasing the percentile of Q2 aircraft strongly decreases the isocontour areas. Figure 24 shows the isocontour areas if 400 movements of the reference aircraft are replaced by Q2 flights. Hereby, approximately 50 % of all flights are operated with a geared turbofan engine hence significant noise reduction is achieved. Figure 25 shows a comparison of the noise isocontour areas of 719 flights of the medium-class reference aircraft versus 719 Q2 flights. Due to the low-noise characteristics of the Q2 concept, noise contours can be significantly reduced.

Replacement of reference aircraft with powered-lift designs, here Q12, increases the noise isocontour areas. The certification noise levels of the Q12 aircraft are predicted to be slightly higher than the levels of the reference aircraft, as shown in

Table 3. Nevertheless, noise isocontour areas indicate significantly higher noise pollution due to the powered-lift concept. Increasing the number of Q12 movements to 400 results in large areas of high noise levels as pictured in Figure 26.

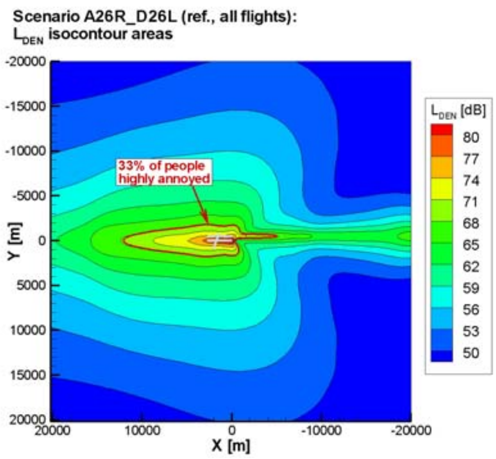

Figure 23. Isocontour Areas A26R/D26L, reference scenario

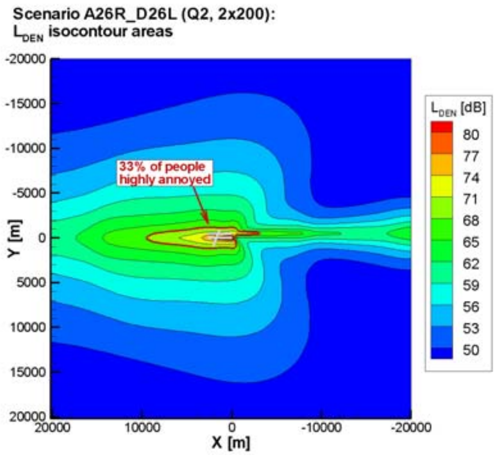

Figure 24. Isocontour Areas A26R/D26L, 400 movements replaced by Q2

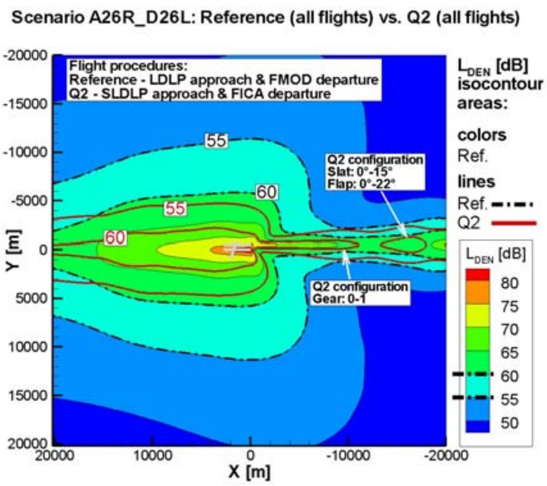

Figure 25. Isocontour Areas A26R/D26L, comparison 719 reference movements vs. 719 Q2 movements

Arrival 26R/Departure 26L and 19Q (Q12) Within this scenario, aircraft are operating on all three runways. All approaching aircraft are scheduled for touch-down on runway 26R. The reference aircraft are scheduled for departure from runway 26L and the powered-lift aircraft Q12 depart from runway 19 using an intersection take-off (19Q).

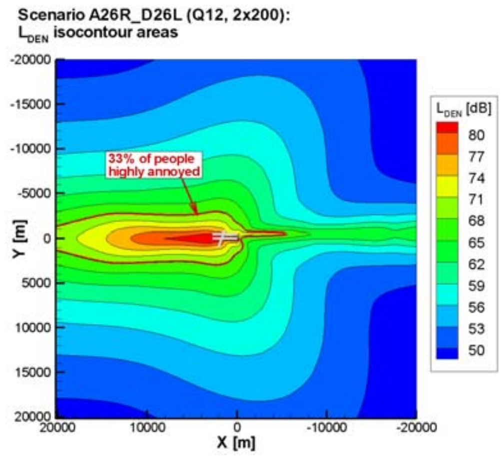

Figure 26. Isocontour Areas A26R/D26L, 400 movements replaced by Q12

As shown in Figure 27, higher numbers of Q12 movements significantly reduce average departure delay due to independent Q12 departures from runway 19 with a slightly increasing arrival delay. The effects of the slower approach speeds are countered by fewer departures from runway 26L. 400 Q12 movements lead to a reduction in average delay of nearly 40 % compared to the reference traffic mix.

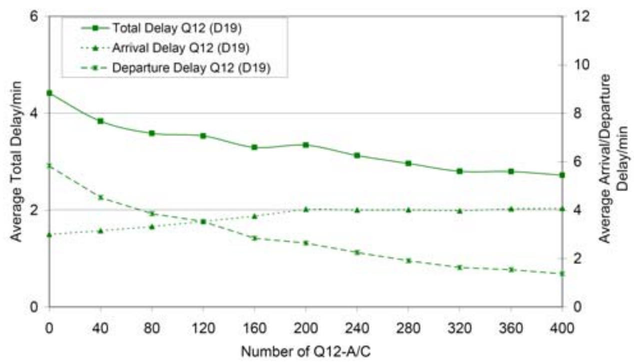

Figure 27. Average Delay A26R/D26L/D19Q (Q12)

The traffic mix of 10 % heavy, 24 % medium, 56 % Q12 and 10 % small aircraft allows for an increase in traffic of nearly 8 % or 57 movements per day before the average delay rises above the reference scenario's level. The bottleneck in this scenario is the arrival delay since all aircraft use the same runway to land.

Figure 28 shows the isocontour areas for 400 implemented Q12 flights. Due to the powered-lift system, high noise levels are perceived in larger areas around the airport. Figure 29 shows the differences between the noise isocontours for two-runway operations of conventional aircraft versus three runway operations including 400 Q12 movements. Due to flight operations of Q12 on runway 19, isocontours are relocated.

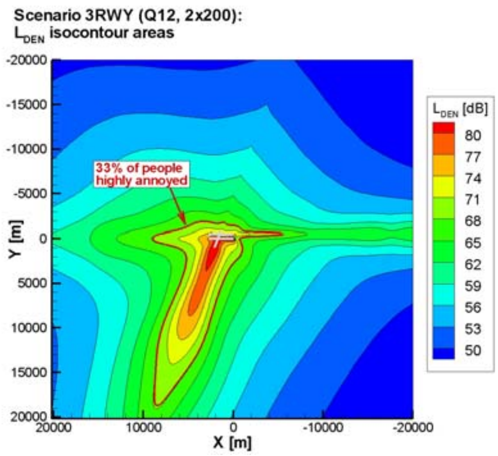

Figure 28. Isocontour Areas A26R/D26L/D19Q, 400 movements replaced by Q12 departing from runway 19_Q

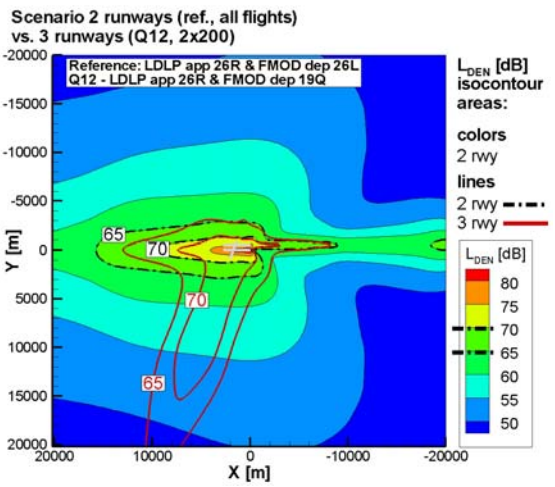

Figure 29. Isocontour Areas, comparison A26R/D26L vs. A26R/D26L/D19Q

Noise vs. Delay

For all three scenarios, noise isocontour areas are plotted versus expected delays according to the fast time simulation with FAA's SIMMOD. Figure 30 and Figure 31 show the average delay compared to the areas of 33% highly annoyed people for the different scenarios. With intersecting runways, delays for both aircraft concepts are increasing only slightly with a marginal reduction in noise for Q2 operations and a strong increase in noise pollution for Q12 operations. Q2 operations result in a similar effect on parallel runways while Q12 operations lead to significantly higher delays and larger noise isocontour areas in the case of dependent parallel runways. The use of the additional independent runway for Q12 departures can only counter the rise in delays, the larger noise isocontour areas remain a possible problem. Obviously a trade-off between noise and delays becomes inevitable.

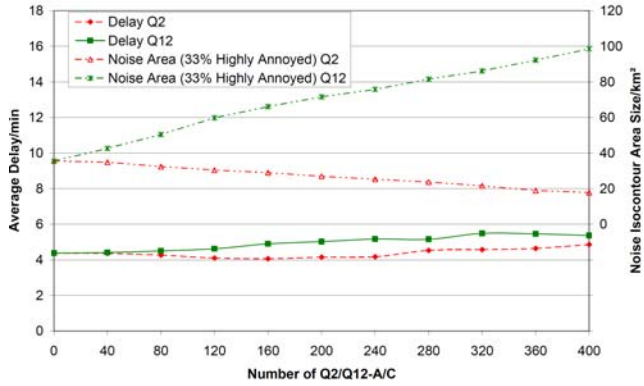

Figure 30. Average Delay vs. Noise Isocontour Size A26L/D19

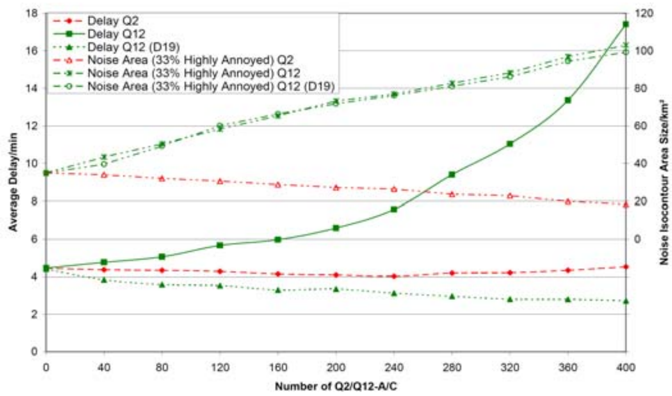

Figure 31. Average Delay vs. Noise Isocontour Size A26R/D26L and A26R/D26L/D19Q

CONCLUSIONS

The process chain for the design and evaluation of an aircraft based transportation system has been extended to include active high-lift configurations. New aircraft design modules have been developed and integrated into the existing preliminary aircraft design process. Engine design cycle tools were modified to simulate Upper-Surface Blowing. Finally, two aircraft with upper-surface blowing technology have been designed. To predict ground noise impact for these new concepts, noise source models have been implemented. Approach and departure procedures have been simulated considering thrust-lift-interaction of the active high-lift systems. Furthermore, engine failure during take-off and landing was considered using a simple model based performance evaluation. Approach and departure procedures for selected configurations were integrated in a terminal airspace simulation to analyse impact on delay.

The USB configurations require short take-off and landing field lengths due to their low-speed flight performance and are capable of steep climb-out angles.

Disadvantages of the active lift systems include special procedures to maintain safety in case of an engine failure. Furthermore, higher noise emissions and fuel consumption are unfavourable to the overall system performance. Slower approach and departure speeds compared to the conventional aircraft result in higher delays in terminal airspace unless the USB aircraft are independently operated on separate runways.

The next step towards a comprehensive transport concept evaluation is the definition of a common metric for noise and delays. Translation of the results into this metric, e.g. costs, would allow for automated optimization of the transport concept but this was not in the scope of the work presented. Furthermore, future work will include research towards more generic noise source modeling to evaluate a broader range of aircraft types and classes. Population density in the vicinity of airports will also be accounted for. This will provide a more realistic model of community response to aircraft noise.

Obviously, the main advantage of a powered-lift configuration has not been in the scope of this report. A short take-off and landing aircraft is designed for simultaneous, non-interfering flight operations. These aircraft concepts promise significant capacity increase if they are operated along new noise abatement procedures, such as spiraling approaches [24], on underutilized runways and airports. This will be in the scope of future research towards a quiet take-off and landing transportation system.

TABLES

Table 1. Aircraft Characteristics

	Q1	Q2	Q11	Q12
Fuselage length [ft]	123.4	123.4	121.4	123.4
Fuselage diameter [ft]	13.1	13.1	17.7	13.1
PAX	150	150	-	150
MTOW [kg]	56652	56869	96976	88050
MLW [kg]	54677	55462	96976	88050
max. fuel capacity [kg]	11502	9704	24476	14754
max. payload [kg]	13049	18049	28123	11396
OWE [kg]	35861	37292	54768	62028
Range [nm]	1000	1000	1818	1000
Blockfuel [kg]	5534	4625	16176	9406
total fuel [kg]	7738	6527	19485	12999
block time [hr]	2.496	2.490	4.353	2.518
L/D cruise at cruise speed	14.382	14.266	18.053	18.002
CL, cruise	0.3642	0.3668	0.6454	0.5077
CD, cruise	0.0253	0.0257	0.0358	0.0282
engine type	CFM 56 -5A4	GTF	GE CF6-50D	GE CF6-50D
number of engines	2	2	2	2
T/O thrust/engine (sea level) [lb]	26303	32000	48678	48678
SFC ref. at cruise speed, SL, ISA [lb/lbf/h]	0.590	0.483	0.787	0.860

Table 2. Aircraft Performance

	Q1	Q2	Q11	Q12
Engine static thrust [kN]	113	144	217	217
Wing loading [kg/m²]	463	465	595	604
Thrust / weight [-]	0.406	0.516	0.455	0.501
TO field length [ft]	1692	1700	522	403
APP field length [ft]	3258	3262	2539	2443
APP speed MLW [kts]	95	107	86	90
cruise speed mach	0.70	0.70	0.64	0.70
max. op. alt. [ft]	33000	33000	33000	33000

Table 3. Noise level differences [EPNdB] at the certification points wrt reference aircraft

	Q1	Q2	Q11	Q12
Approach	-3.0	-4.4	+3.5	-0.1
Community	-2.5	-7.7	-1.5	-1.7
Sideline	-1.3	-9.8	+2.7	+2.2

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