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Process Implementation for the System Evaluation of new Low-Noise STOL Transportation Concepts

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Summary

The *German Aerospace Center* (DLR) has initiated the project *Quiet Short Take-Off and Landing* (QSTOL) to set up a multidisciplinary analysis process for new low-noise STOL transportation concepts. The process chain consists of expert tools from various DLR institutes and their partners which are harmonized in input and output data. Involved disciplines are aircraft design, engine cycle modeling, flight mechanics, air traffic integration, and noise prediction. The influence of aircraft design modifications on flight performance/operational procedures, ground noise impact, and air traffic intergration can be evaluated. Obviously, these diciplines are highly correlated and need to be integrated into one multidisciplinary process. The implementation of this new process along with first applications are addressed in this paper. A conventional medium-range transport aircraft is modified for QSTOL operation. Structural modifications of the airframe and a geared turbofan engine concept are investigated. The effects of these measures on ground noise impact, field performance, and air traffic integration are discussed.

1 Introduction

According to the ACARE (*Advisory Council for Aeronautics Research in Europe*) global scenarios a moderate to strong growth in air traffic is expected. Even today a large number of major airports is operating at their capacity limit. The consequences for airlines and passengers are more delays and longer travel times. Airport expansion seems necessary to deal with the traffic growth but is hindered by legal and environmental obligations. Already, neighboring residential areas are subject to increasing noise pollution and local emissions. New transportation concepts integrating underutilized regional airports could ease the situation [1]. Promising candidates, located in close proximity to the congested airports or in areas of high population density exist in large numbers. Integrating these airports into the transportation system would allow for traffic distribution, new point-to-point connections, and could open up the capacity bottleneck. Current medium and large aircraft are yet prevented from operating at these airports due to their field length requirements and noise emissions. Therefore, new aircraft designs to fulfill the opposing requirements for low-noise operation and short field length are necessary. DLR has initiated the project QSTOL to interconnect the relevant expert tools and to establish a multi-disciplinary process for the system evaluation of these new concepts.

2 Multidisciplinary Analysis Process

The QSTOL process chain consists of tools for aircraft synthesis, engine cycle modeling, flight mechanics, noise prediction, and air traffic management. Most tools are developed by participating DLR institutes and their partners. The tool data formats have been harmonized to enable the multidisciplinary design process depicted in Fig. 4. The top level aircraft requirements comprise the input of the aircraft design process. The feasibility of each aircraft synthesis is analyzed with the *Parametric Aircraft Design and Optimization* programm (PrADO), a development of the Technical University of Braunschweig [2, 3]. Instead of using PrADO's implemented engine design modules, the engine performance deck and engine design parameters are provided by high fidelity DLR engine tools. The engine parameters are translated and fed back into the PrADO design process. The overall aircraft meeting the predefined requirements will successfully end the aircraft and engine design phase.

The aircraft's flight performance and safety obligations are then evaluated during simulated flight operations. The flight

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procedures and trajectories are tailored to the aircraft performance and optimized for short field lengths and low ground noise impact. Not meeting predefined ground noise levels or flight performance requirements will cause design modifications and new runs of the design modules become necessary. The user modified aircraft and engine design is fed back into the modules to restart the process.

Finally, identifying an aircraft concept with low ground noise impact during short take-off and landing operations will start the subsequent step in the analysis process. The concept's airspace and air traffic management integration is evaluated. The results of this study determine if further modifications to the aircraft or its flight operation become necessary. The outcome of the concept integration is fed back to the aircraft designer to ultimately influence and optimize subsequent aircraft designs. Detailed information about the applied tools is provided in the following sections.

2.1 Aircraft Design

The feasibility of each new aircraft design is analyzed with the PrADO software, a development of the Technical University of Braunschweig. Furthermore, user specified airframe design parameters and configurational aspects are optimized with PrADO whereas the engine design is held constant. The initial design for the optimization comes from the Institute of Aerodynamics and Flow Technology. The corresponding optimum engine design comes from the Institute of Propulsion Technology (see section 2.2 for more details). The engine design parameters and performance data are translated into PrADO's specific input format to analyze the overall aircraft characteristics. Engine design can be modified outside the PrADO framework upon request.

The PrADO framework is made up of individual design modules each dedicated to a certain task or discipline involved in preliminary aircraft design. The design modules run interactively until predefined design parameters reach convergence. These design parameters represent aircraft mass, thrust requirement, and field length requirement among others. Each PrADO design module offers a selection of methodologies for solving it's designated task. The selected method's level of complexity will determine the computational requirement and the accuracy of the results. Implementation of new methodologies into preexisting modules as well as integration of new design modules into the framework are possible due to PrADO's flexible setup. To evaluate promising QSTOL concepts, new modules have to be developed and integrated into the existing PrADO framework, i. e. modules to predict aircraft noise and to evaluate powered lift concepts.

To include noise evaluation into the PrADO design process a noise prediction module is under development; see section 2.4 for more details. Influence of geometry, configuration, and operation condition on noise emission are accounted for by parametric noise source definition. Noise generating effects can be identified and analyzed during simulated flight operation. Direct implementation of the noise prediction module into the PrADO framework ultimately allows for low-noise design optimization.

A first powered-lift design module was implemented into PrADO to analyze *Upper Surface Blowing* (USB). Boeing's USB technology demonstrator YC-14 [4] was redesigned and validated with existing flight data. The results of the verification are promising [5]. Powered-lift designs are not presented in this study since the analysis methods are still under development.

2.2 Engine Design

The engine design is optimized to match the aircraft's thrust requirements and engine geometry limitations. The thermodynamic aero engine synthesis is carried out using the one-dimensional performance calculation program VarCycle [6] which was developed at the DLR Institute of Propulsion Technology. VarCycle is an off-design performance simulation code based on a given design point. A more general thermodynamic description of a two spool bypass engine without detailed compressor and turbine performance mapping is used. The power equations of the high and the low pressure spool have to be fulfilled taking into account the mechanical losses. Furthermore, the pressure balance and the continuity of the mass flow are used for the iteration process. The basic assumptions this performance calculation model is based on are the following:

- Due to an adiabatic approach there is no increase in temperature modelled in the inlet. A constant loss in total pressure is set as a design variable. For supersonic operation an additional Mach number dependant loss in total pressure is assumed.
- Constant specific heat capacities are applied during compression and expansion.
- Leakage and bleed air only occurs within or behind the high-pressure compressor. In case the amount is unknown, it is assumed to compensate the amount of fuel added in the combustor.
- Generalised operating curves characterize the performance of high-pressure and low-pressure turbines (component maps), which allow for simulation of choked and unchoked conditions.
- The cooling air is extracted after the last compressor stage and is added proportionately to the annulus in the stator and the rotor of the high-pressure turbine.

- Constant combustor pressure losses, combustion efficiencies, mechanical shaft efficiencies and nozzle efficiencies are assumed.
- Compression and expansion is characterized using polytropic efficiencies. These efficiencies are defined at the engine design point. The decrease in component efficiency during off-design operation is modelled by using a correlation method assuming polynomial behavior.
- Power offtake is an option on high-pressure and low-pressure spool.

The tool is able to provide engine performance data over the relevant altitude and Mach number range. The data includes traditional performance measures such as thrust and thrust specific fuel consumption on the one hand and inputs for aeroacoustic analysis on the other hand. The data is fed back as input into PrADO.

2.3 Flight Mechanics

Aerodynamic, performance, and geometric data of each new aircraft configuration is handed over to the Institute of Flight Systems, where trajectory optimizations are conducted using flight simulations [9]. The input data is distributed in look-up tables. The tables give the lift, drag, and pitching moment coefficients as a function of angle of attack, Mach number, and configuration setting. The engine table describes thrust and pitching moment as a function of normalized power lever setting, altitude, and Mach number. This input data is then implemented into a nonlinear simulation model. Using this model, a basic performance calculation was conducted. As a first step towards quiet takeoff and approach procedures the aircraft performance limitations were identified. Flight performance is limited in terms of maximum and minimum flight path angles and/or maximum acceleration and deceleration capability related to a specific configuration of slats/flaps and gear. Noise calculation and assessment of operational feasibility have less significance at this point because only single, constant segments of the flight path can be regarded.

In the next step, optimized noise abatement procedures for STOL operation are analyzed within the constraints of safety aspects and the aircraft performance. Safety is critical and so it has to be assured at all times. Main safety aspects in the planning of noise abatement approach procedures are maximum and minimum airspeeds, maximum rates of descent, minimum altitudes, and the stabilization height. The stabilization height is the height above ground, at which an aircraft has established constant airspeed, rate of descent, and thrust setting. This is supposed be before reaching the height of 1000 ft above ground. If this is not the case, pilots must abort the approach and perform a go-around. For take-off procedures, maximum and minimum airspeeds, minimum flight path angles, and maximum possible flight path angles without decelerating were taken into account. The ground noise impact along each trajectory is predicted and evaluated according to the methods described in section 2.4.

2.4 Noise Prediction

The Institute of Aerodynamics and Flow Technology has implemented the *Parametric Aircraft Noise Analysis Module* (PANAM) into the process chain. The code was developed to introduce noise as a new constraint in preliminary aircraft design [10]. The code predicts real-time, time-integrated, and maximum noise levels for conventional aircraft configurations along arbitrary three-dimensional flight trajectories. Methods to compute noise shielding effects through advanced engine installation exist at DLR [11] but are yet to be implemented. Low CPU requirements are crucial for noise evaluation within preliminary design processes. Therefore, aircraft noise is predicted with semi-empirical, parametric methods. Only major noise sources are modelled with an componential approach, neglecting interactions between individual noise sources. The new prediction tool and its implemented models for airframe and engine noise are described in Ref. [10].

The noise source models for aerodynamic noise [10, 12] are developed by the Institute of Aerodynamics and Flow Technology. The underlying data base originates from DLR flyover noise measurements and airframe component wind tunnel testing. Modelled noise sources are wing and control surfaces, trailing and leading edge devices (slat and flap), spoiler, and landing gear. A source model for flap side edge noise is currently under development.

The parametric models of engine noise implemented in PANAM come from the Engine Acoustics Department. Two engine-related noise sources are taken into account. One noise component is the dual-stream jet exhausting from the nozzle. The fan is the other engine noise component considered in PANAM. Initial results presented in Ref. [10] indicate that fan noise is probably overpredicted with the implemented noise source model [13]. Improvements in fan noise prediction are expected with the integration of a model to account for the noise absorption due to the liners. This model will be implemented according to the method described by Moreau, Guérin, and Busse [14]. The liner model will enable investigation of the liner length influence. A long intake and bypass-duct equipped with damping material could offer indeed a feasible solution to reduce the noise contribution from the fan in a QSTOL concept.

2.5 Air Traffic Integration

At the Institute of Flight Guidance the integration of the aircraft into airport operations and the Terminal Movement Area is analyzed. Initial results regarding the first QSTOL aircraft are available. Conventional approach and departure procedures at a major hub airport are evaluated regarding the effects on capacity and delay. While the QSTOL aircraft is primarily intended for use at smaller underutilized airports, it has to be able to conduct flights to or from major airports that are operating close to or at their capacity limits without causing further delay. QSTOL-specific main input data for the simulations consist of the approach and departure trajectories and aircraft dimensions. This data is delivered by flight mechanics and preliminary aircraft design. The results of this study are fed back to the Configuration Design Group and will influence the next design iteration.

FAA's airport and airspace simulation model SIMMOD in the commercially available version Simmod PRO by ATAC is used to conduct the studies regarding concept integration. SIMMOD is a discrete-event fast-time simulation tool. At the time of an event, the times of subsequent events are calculated and the simulation clock is forwarded to the time of the next event. The basic SIMMOD-engine is available free of charge while Simmod PRO is an extended version that includes a scripting language to realistically model more complex processes at airports. In this study the scripting language is primarily used to accurately model the approach trajectories as well as the required separations. Furthermore, additional scripts to postprocess the output data were implemented since SIMMOD output consist of text-based chronological log files containing every movement step of every aircraft in the simulation.

3 Application

The first application of the new process chain is presented in the following. A conventional aircraft with under-the-wing engine installation is modified for QSTOL operations. Structural modifications and a new engine concept is evaluated. Implications of the design modifications on aircraft noise, flight performance, and air traffic integration are analyzed.

3.1 Aircraft Design

The reference aircraft for this study is a conventional medium-range transport aircraft with 150 passengers. The design mission for this aircraft is defined with a range of 4800 km, a cruise mach number of 0.78, and cruise altitudes between 8500 and 12500 m. The aircraft was designed and optimized for this mission with PrADO.

In a first step towards a QSTOL configuration the reference aircraft is modified for low-noise and short field length requirement (refered to as QSTOL-1). Assuming advanced materials for the otherwise unmodified fuselage and wing design leads to a significant reduction of Manufacturer's Weight Empty (MWE) for QSTOL-1[1]. The reference wing and high lift system design is utilzed for the configuration. Furthermore, the design mission range and cruise mach number is reduced to 1850 km and mach 0.7 respectively. Despite the reduction of structural weight, fuel mass, and range the engine design is held constant. The increased thrust-to-weight ratio provides the necessary excess thrust for short take-off operations. The required take-off field length could be reduced by 36.8 % compared to the reference. Reduced wing loading and similar aerodynamic characteristics result in lower minimum approach speeds. The lower speed along the approach flight path reduces the required landing field length by 11.2 % compared to the reference.

A second variant, QSTOL-2, is derived from QSTOL-1 by replacing the reference engine with a UHBR design, see section 3.2. The impact of the new engine on the overall aircraft performance and noise radiation is analyzed. Necessary geometry and performance input data for the new engine come from the engine design tools.

These design modifications along with operational changes result in decreased cruise performance, see Table 1. Obviously a trade-off between good cruise aerodynamics and low-noise STOL performance is unevitable.

3.2 Engine Design

The reference engine for this study is a two spool turbofan engine assuming todays technology. It is designed to provide sufficient thrust in all flight regimes of the reference aircraft. The reference engine is also installed on the QSTOL-1 aircraft. The QSTOL-1 configuration with a modified new engine design is refered to as QSTOL-2.

Besides low-noise operation the reduction of fuel consumption is a major goal in aero engine design. Therefore the fan pressure ratio has been reduced and hence the bypass ratio had to be increased continuously over the last decades. The trend to lower the fan pressure ratio for the benefit of increased propulsive efficiency leads to larger fan diameters. The engine diameter on the other hand is limited by the circumferential speed of the fan blades. Today's fans already run with a relative tip speed of Ma $\approx$ 1.4. A further increase in speed would lead to flow separation and negative aero-acoustic effects. Therefore an enlargement of the fan will lead to a reduction of the fan speed. This has negative effects on the

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[1] component weight reduction: fuselage -20 %, wing -15 %

turbine, which normally runs most efficiently at high speeds. A lower turbine speed leads to a higher number of turbine stages, increasing the number of parts, weight and size of the engine. In order to run high bypass fans and low pressure turbines (LPT) at favourable speeds it becomes necessary to separate the rotational speeds of both. One way of doing this is the introduction of a gearbox between the fan shaft and the LPT shaft.

A transmission ratio of around 3 allows the use of a compact high-speed turbine which is driving a low-speed, large-diameter fan. Besides the benefits concerning a high-speed LPT there are several other advantages. With low rotational speed, the fan will become more efficient and has - in combination with a low fan pressure ratio - a great potential for the reduction of fan-related noise. Due to a higher rotational speed and lower torque of the LPT, the diameter of the low pressure shaft can be reduced, easing its integration through the high pressure turbine and the corresponding shaft. The availability of extremely reliable and lightweight gearboxes will be crucial for the success of this concept. A risk of increased engine failure probability will not be accepted by potential customers. Integration and cooling of the gearbox pose further challenges. For medium sized engines, as regarded in this study, a mechanical loss of about one percent causes a heat output of several hundred kilowatts demanding large (and heavy) oil coolers.

In Ref. [7, 8] different future engine architectures (for entry into service around 2020) were analyzed concerning their potential fuel efficiency. The geared fan engine was shown to be a suitable concept for realisation of an ultra high bypass ratio engine cycle with a 15 % reduction in fuel consumption compared to a year 2000 engine. Furthermore, the propulsion unit powering a future QSTOL-aircraft has to provide high thrust levels for take-off along with quiet thrust generation. The geared fan concept provides high thrust excess during take-off; inherent for high bypass ratio engines [8]. The reduced fan rotational speed allows for significantly quieter engine operation. Therefore, the geared turbofan engine is the selected propulsion unit for the next design iteration (aircraft refered to as QSTOL-2). Weight and diameter of the geared turbofan engine are 2682 kg and 2.17 m respectively (reference engine weight is 2266 kg with a diameter of 1.74 m). The increase in diameter causes higher drag hence affects the flight performance. Drag is scaled linearly with the increased engine diameter adding approximately 4.6 drag counts compared to the reference configuration. The additional drag is fed back into the design process to account for the impact on overall aircraft performance.

3.3 Flight Mechanics

Flight performance is evaluated according to aircraft weight, aerodynamics, and engine performance. The configuration setting of the high lift system is segmented into four stages. Configuration settings are cruise (C), take-off (TO), landing approach (LA), and landing (LD). Furthermore, gear extension (+G) is indicated along with the configuration setting. Fig. 1 shows the lift vs. drag curves for different configuration settings at a flight mach number of 0.3.

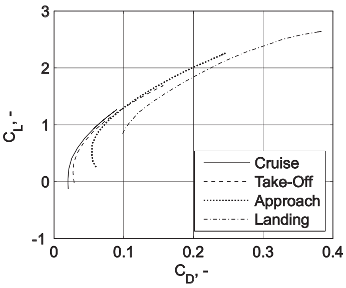

Figure 1 Lift vs. drag curves for different configurations at $M = 0.3$

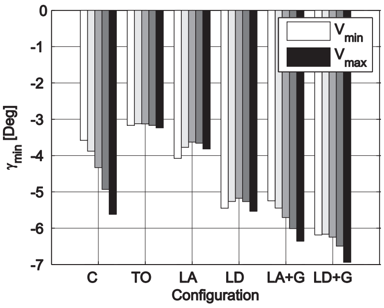

Figure 2 Minimum flight path angle with idle engines for constant airspeeds

Approach procedure performance is analyzed for all aircraft designs. As an example, Fig. 2 shows minimum flight path angles (FPA) for the reference aircraft. The miminum flight path angles are computed for different configuration settings, different airspeeds, and the engine running on idle. The reference aircraft approaches with maximum landing weight and a flight altitude of 914 m (3000 ft). The airspeed is varied from minimum to maximum allowed airspeed ($V_{min} = 1.23 \cdot V_S, V_{max} = V_{FE}$) for the current configuration in four equally-spaced steps. Obviously, steeper flights are possible with larger deflection of the high lift system and with extended gear. The cruise configuration with the lowest idle thrust setting allows for steeper flight path angles than the take-off configuration. At V_{max}, very steep flight path angles are possible because of the very high airspeed (350 kts). The configuration along the flight path is set according to the obtained results. Safety and operational constraints are derived from the overall flight performance evaluation.

Optimized noise abatement flight procedures are designed for each individual aircraft. The trajectories are based on the Modified ATA takeoff procedure and the Low Drag Low Power approach procedure [9]. These flight maneuvers represent the current approach and take-off procedures at many major airports. Furthermore, the maneuvers are implemented in Lufthansa's Standard Operating Procedures as the "noise abatement takeoff" and the "noise abatement ILS approach", respectively. The flight procedures are tailored to the current aircraft and engine design. Engine operation, configuration setting, and flight speed are optimized for low-noise operation. The resulting flight paths are shown in the upper frames of Fig. 5 and 6. The results for the Low Drag Low Power approach are depicted in Fig. 5(a) and 6(a) whereas the MATA departure is evaluated in Fig. 5(b) and 6(b).

3.4 Noise Prediction

Ground noise impact for each aircraft design is evaluated along the simulated flight procedure. Middle frames show noise level contour areas and bottom frames depict a componential breakdown of the relevant noise sources. Maximum Sound Pressure Level (max. SPL) is the selected noise metric to capture noise related effects along the trajectory. Evaluating the Effective Perceived Noise Level (EPNL) requires time integration of the noise levels hence would smear out most details [10].

The aircraft is approaching along the LDLP flight path from the left with the runway threshold at x = 0 m and y = 0 m. The flight path is identical and the thrust setting is similar for both aircraft. The reduced aircraft weight of QSTOL-1 allows for significantly lower approach speeds compared to the reference aircraft. Airframe noise sources are correlating with flow speed hence are significantly reduced as well. Overall ground noise impact is reduced while airframe is the dominating noise source with the engine running on idle (until 6 km prior touch-down). Reducing the dominating airframe noise is minizing SPL_{max} noise contour areas (Fig. 5(a), middle frame). The configuration change from LA to LD has little influence on noise generation. Gear extraction (+G) at approximately 8 km prior touch-down increases airframe noise as depicted in the lower frame of Fig. 5(a).

QSTOL-1 requires only very short take-off field length due to it's high thrust to weight ratio. This results in the early and steep climb-out of QSTOL-1 compared to the reference departure. Along the steep departure more noise is emitted close to the airport while more distant observers experience a noise reduction. Along the flight track noise isocontour areas are significantly reduced by the steep climb-out. The componential breakdown of the noise sources for QSTOL-1 and the reference aircraft are dominated by fan noise (Fig. 5(a), bottom frame). The noise components of QSTOL-1 and the reference aircraft indicate a nearly constant offset of their noise levels. This is caused by the increased ground distance of QSTOL-1. Furthermore, QSTOL-1 reaches cut-back height prior to the reference aircraft hence can earlier reduce speed and thrust. A significant noise level drop 15 km after take-off can be identified and attributed to this early speed and thrust cut-back (Fig. 5(b), middle frame). Configuration changes can be identified in the airframe noise levels (Fig. 5(a), bottom frame). The first level peak indicates the gear retraction (-G), the second reduction is caused by switching from take-off (TO) to cruise (C) configuration. Obviously the levels are insignificant compared to engine noise levels.

To further reduce ground noise impact it is necessary to decrease engine noise radiation. Therefore, a geared turbofan engine design is evaluated on QSTOL-2. The most important influence on fan noise is the fan rotational speed. With a geared fan concept the rotational speed and therefore fan noise is reduced significantly. Jet noise is dependend on the engine nozzle exit velocities. The geared fan engine provides a very high bypass ratio hence low nozzle velocities and reduced jet noise. Engine fan noise is the dominating noise source when engine thrust setting is high. Increased thrust setting becomes necessary in the final approach segment (last 7 km prior touch-down) and along most of the departure trajectory as depicted in the upper frames of Fig. 6(a) and 6(b). Therefore, with the geared fan concept overall ground noise is reduced along the complete departure maneuver and along the final approach segment. The break-down of the individual engine noise sources shows the reduced noise by the engine components during both take-off and landing.

It is demonstrated that a low-weight modification of the airframe combined with the new engine concept reduces ground noise impact significantly. Airframe noise and engine noise are reduced simultaneously to enable low-noise approach and departure operation.

3.5 Air Traffic Integration

Based on approach and departure trajectories for the reference aircraft and the QSTOL concepts, the impact of QSTOL operations on capacity and delay at a major hub airport is analyzed by means of fast-time simulation. The simulations are conducted at the Institute of Flight Guidance using the airspace and airport simulation model Simmod.

The airport used in the simulation scenario is a major hub airport based to some extent on a future stage of expansion[2] of Germany's Frankfurt/Main Airport with two runways used for arrivals (25N and 25L) and two for departures (18 and 25R) respectively. The flightplan contains 2054 movements a day with 50 % arrivals and departures each. 36 % of the aircraft belong to the wake-vortex separation group heavy and 64 % belong to the medium class. With this number of flights the airport is operating close to it's capacity limits and the impact of changes in the aircraft mix will be evident.

The approach trajectories and velocities of the reference aircraft (medium) and the QSTOL-2 aircraft are compared in Fig. 6(a). The QSTOL-2 aircraft's final approach speed is significantly lower (by about 30 %) than the approach speed of a regular aircraft of similar size. Based on the reference flight plan, different percentages of medium-class aircraft are substituted by QSTOL-2 aircraft. To compensate for systematical errors, multiple flight plans with different randomly substituted QSTOL movements are generated for each aircraft-mix. Several simulation runs are conducted for every flight plan and the mean values of the results are compared. The average delay as well as arrival and departure delay is shown in Fig. 3.

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[2] four-runway configuration

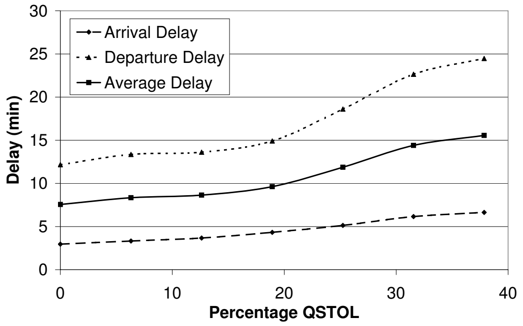

Figure 3 Impact of different QSTOL operation percentage on average delay

With a higher number of QSTOL aircraft the delay significantly increases due to the greater distance required between two aircraft with different approach speeds to assure the required separation on the whole approach path. An arriving QSTOL aircraft following a faster aircraft results in minimum separation at the beginning of the common approach path while the separation at touch down is higher than required. On the other hand, a QSTOL aircraft followed by a faster one requires a higher separation at the beginning of the common path to assure minimum separation at touch down.
The departure delay in this simulation scenario is generally higher than the arrival delay because arrivals are prioritized. Departures can only be released if there is enough spacing between two arrivals. Even though arrivals and departures are operating from different runways, the runways may not be used independently due to their close proximity. With higher arrival separations, departure delay will increase unless the gap between the two arriving aircraft allows for an additional departure flight to be released.
Possible solutions to minimize the impact on airport capacity at major airports are new approach strategies like curved approaches with late interception of the glide slope to reduce the common path of aircraft with different approach speeds. The results of this study are fed back to the Configuration Design Group and will influence the next design iteration.

4 Conclusions

It is well known, that airframe noise can be dominating along most of the approach trajectory. Modifications of individual airframe components reduce ground noise impact as long as the modified component is the dominating aircraft noise source. To fully exploit low-noise modifications of individual components the noise levels of all other noise sources of similar strength have to be reduced at the same time.
Instead of reducing the noise of individual airframe components, a more holistic approach is followed. As the noise radiation of aerodynamic noise sources is correlated with a high power of the flow velocity, a reduction of the approach speed is an efficient way to reduce overall airframe noise. Therefore, hypothetical QSTOL transport aircraft, having a reduced mass, are developed and assessed. The performance characteristics of the modified aircraft due to the reduced wing loading and increased thrust to weight ratio is then used to develop optimum takeoff and landing trajectories. The resulting aircraft are compared with a reference aircraft in terms of performance, noise impact and airport traffic integration.
In order to reduce engine noise emissions, a high bypass ratio geared turbofan engine concept is integrated into one of the configurations. This concept contributes significantly to noise reduction during take-off.
The results show that the overall ground noise impact along the take-off trajectories is significantly reduced by these measures. While this is clearly noticeable outside of the airport perimeter, slightly higher noise levels must be accepted immediately at the airport. Reduced noise emission of the geared turbofan engine leaves airframe noise as the dominant noise source along most of the approach trajectory.
As expected, the reduced operational weight of the aircraft has a strong influence on the field performance. The approach field length is reduced because of the lower approach speeds. The take-off field length is drastically shortened by the lower wing loading and the higher thrust to weight ratio of the modified aircraft.
The design modifications of this study produced aircraft having the desired QSTOL characteristics. However, as the aircraft wing area was not adapted, the cruise performance of the studied configurations is lower than that of the reference aircraft. The lower lift-to-drag ratios and reduced cruise speed increase the direct operating costs and gaseous engine emissions. Therefore a more complete optimization study is part of the ongoing activities.
When operating in the traffic pattern of a conventional large airport, the low approach speed of QSTOL aircraft may lead to higher delays. These disadvantages have to be reduced to a tolerable level within further iterations of the presented multidisciplinary process or by developing alternative airport infrastructure, e.g. usage of separate runways or taxiways for QSTOL operations.
Initial results of new PrADO modules modeling the aerodynamics of powered-lift configurations shows great potential for STOL operation with these concepts [5]. First noise prediction results of blown flap configurations show tolerable noise levels on the ground and do not rule out mild powered-lift concepts for further investigation because of possible high noise radiation. So far, the implemented noise source model for blown flaps [15] is very coarse and needs more investigation. Powered-lift concepts will therefore be in the scope of a follow-on study, which must also address the design of engines with a suitable air supply for flow control.

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Appendix

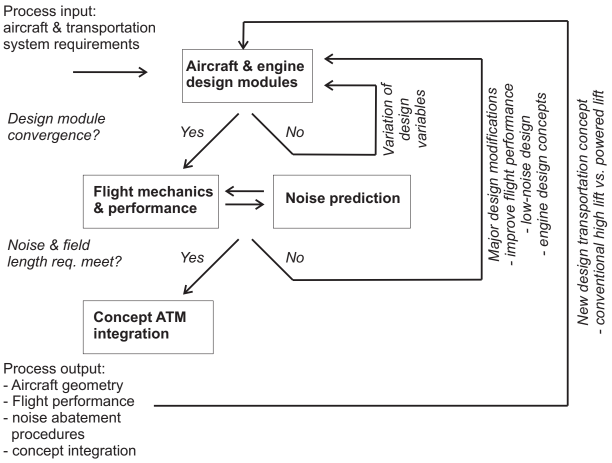

Figure 4 Process structure

QSTOL mission				reference mission
cruise altitude [m]	10000.0			10000.0
cruise mach [-]	0.7			0.78
payload [kg]	13050.0			13050.0
range [km]	1850.0			4815.0
Design	QSTOL1	QSTOL2	reference A/C	
fuselage weight [kg]	6972.8	6966.9	8701.4	8911.4
wing weight [kg]	6116.2	6145.3	7433.1	8406.8
engine weight [kg]	2170.0	2682.0	2170.0	2170.0
OEW [kg]	35861.1	37292.5	39069.5	40760.3
MTOW [kg]	56651.5	56869.1	60019.2	70568.0
max. landing weight [kg]	54676.7	55461.6	57930.1	62100.9
engine BPR [-]	6	15.9	6	6
SFC cruise [kg/N/h]	0.0601	0.0492	0.0599	0.0599
T/W [-]	0.3779	0.5167	0.3567	0.3033
max. M/S [kg/m^2]	462.8	464.6	490.4	576.5
fuel consumption [kg]	5535.5	4624.5	5640.6	14103.6
lift coefficient cruise [-]	0.36426	0.36682	0.38583	0.38583
drag coefficient cruise [-]	0.02530	0.02571	0.02581	0.02536
lift-drag-ratio cruise [-]	14.3994	14.2663	14.9485	15.2170

Table 1 Design parameters

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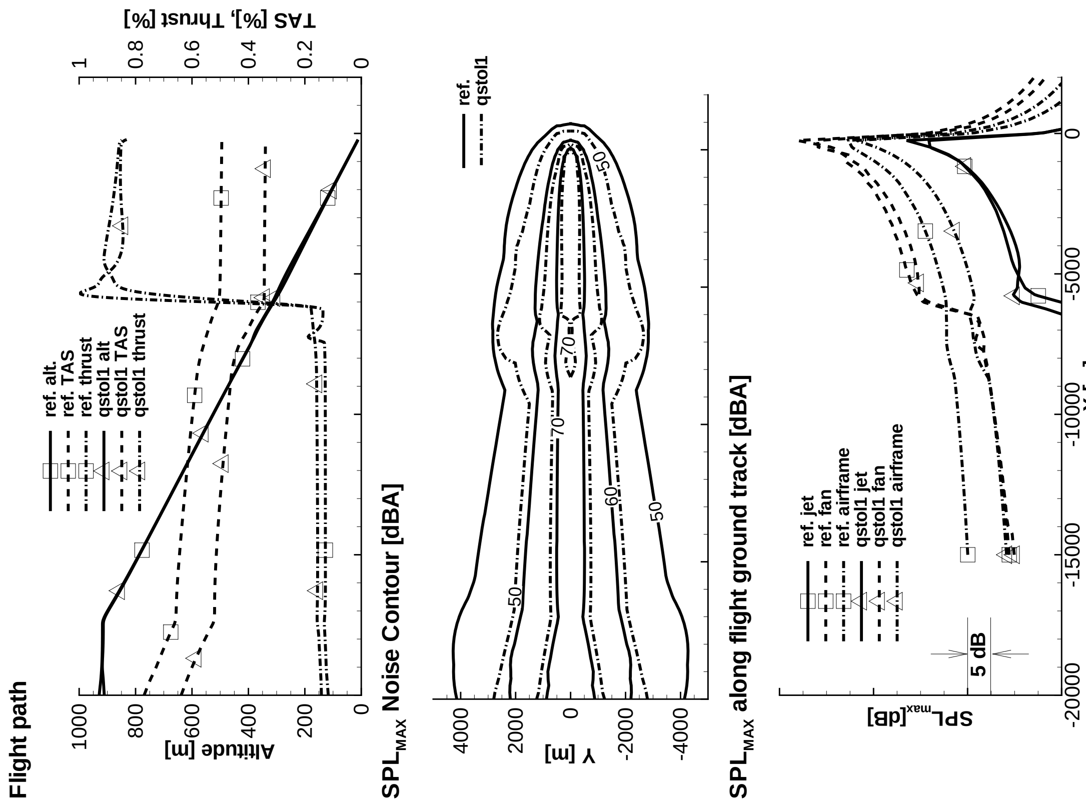
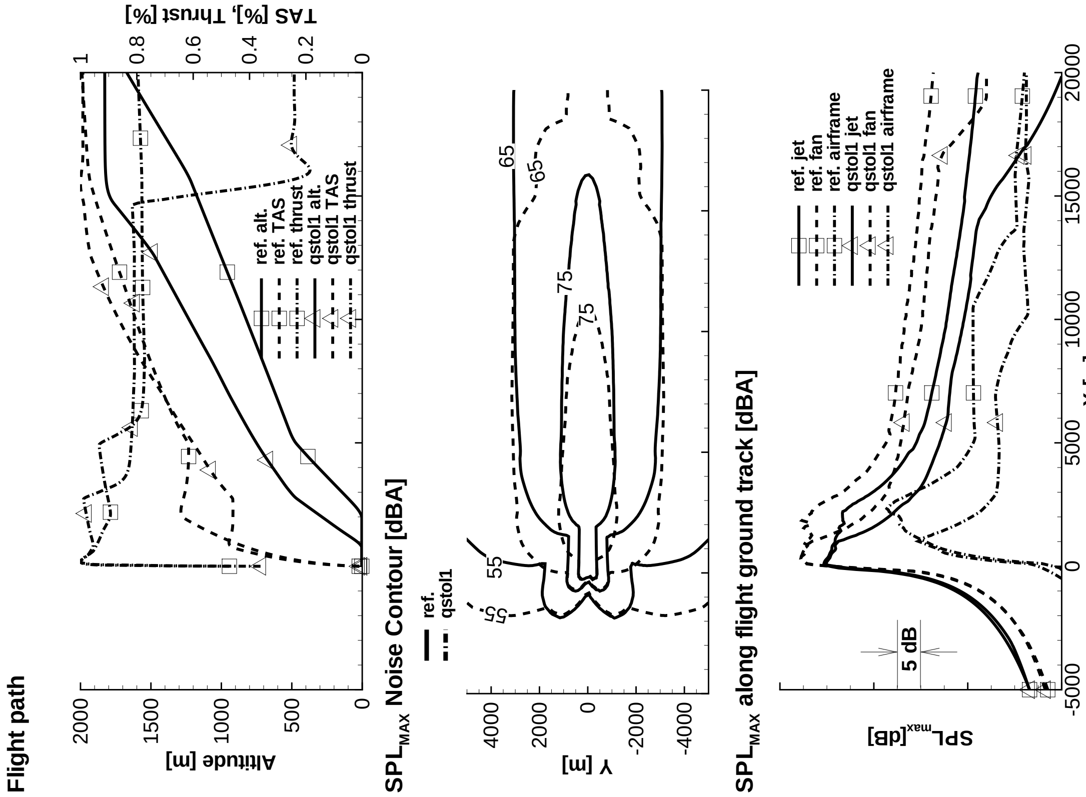
[3] Configuration Design, Institute of Aerodynamics and Flow Technology, DLR, Lilienthalplatz 7, 38108 Braunschweig

[4] Technical Acoustics, Institute of Aerodynamics and Flow Technology, DLR, Lilienthalplatz 7, 38108 Braunschweig

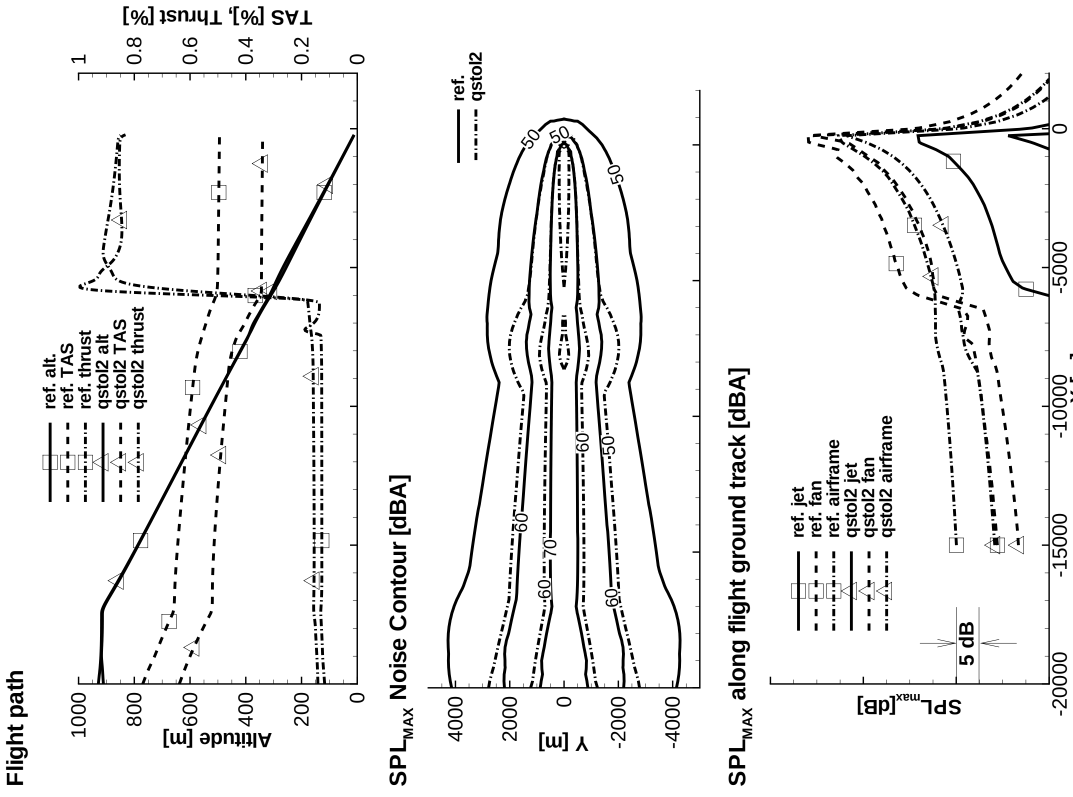


(a) Low-Drag-Low-Power approach

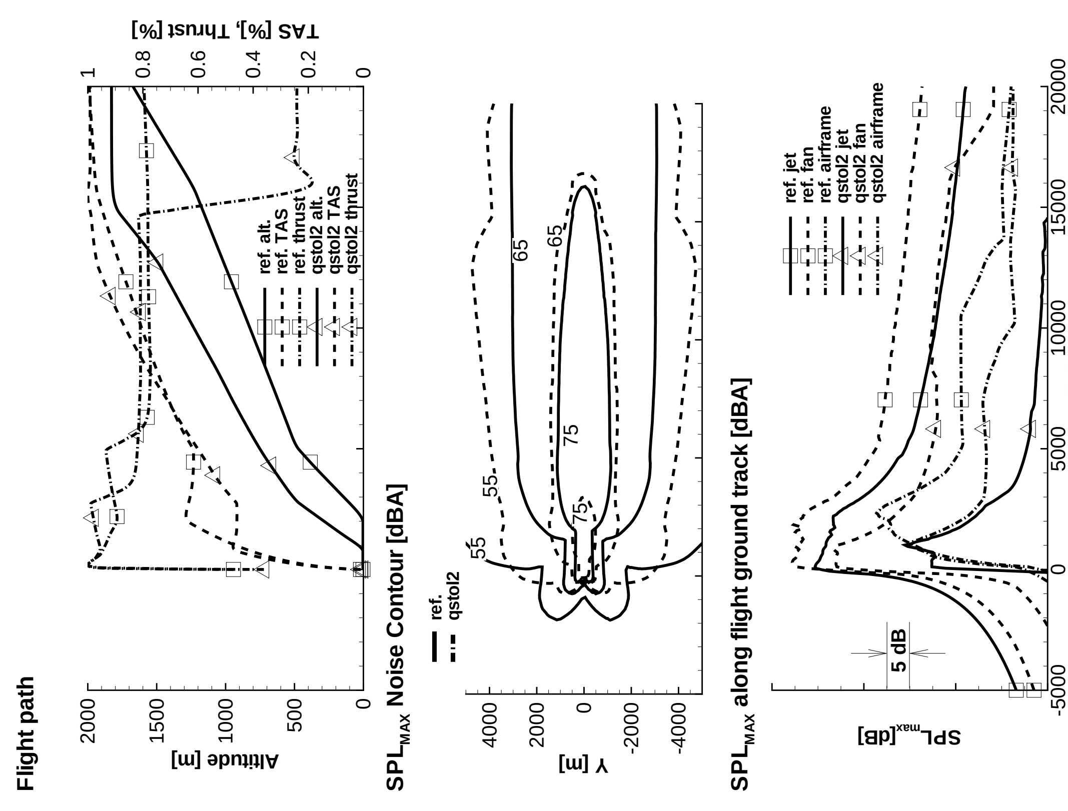


(b) Modified ATA departure

Figure 5 QSTOL-1 vs. reference aircraft



(a) Low-Drag-Low-Power approach



(b) Modified ATA departure

Figure 6 QSTOL-2 vs. reference aircraft