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Aircraft Flight Procedure Design with Respect to Noise Abatement as well as Economical and Pilot Workload Aspects

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Abstract The paper describes the design process of noise abatement procedures (NAPs) for the landing approach of commercial aircrafts with respect to safety, economy, passenger comfort and pilot workload. The methods of this process vary from basic performance calculation up to flight tests. All steps are conducted to noise calculation or simulation using different software programs. Results from related projects will be shown.

1. INTRODUCTION

Aircraft flight procedures for landing approach already have been optimized in the past. But lower engine and higher airframe noise levels of modern airliners as well as additional possibilities for aircraft guidance and control lead to the fact that existing noise abatement procedures do not exploit the full noise reduction potential.

To calculate the correct immission values the methods used have to take into account that airframe noise may be dominant, if engines are operated near idle thrust during landing approach. Furthermore safety-critical items (compliance with air law requirements and airline standard operating procedures [SOP's]) and economical items (fuel flow, flight time, engine and airframe stress) have to be regarded during the design process.

In addition pilot acceptance and a none increase in workload should be guaranteed, hence investigations of noise abatement procedures within full flight simulator studies and flight tests are necessary.

2. NOISE ABATEMENT FLIGHT PROCEDURE DESIGN PROCESS

The design process of noise abatement flight procedures usually starts with the definition of demands on noise reduction and operational feasibility. These demands are the inputs of several design loops which are different in complexity and result (Fig 1). Furthermore all loops or steps include an assessment of noise reduction and operational feasibility if possible.

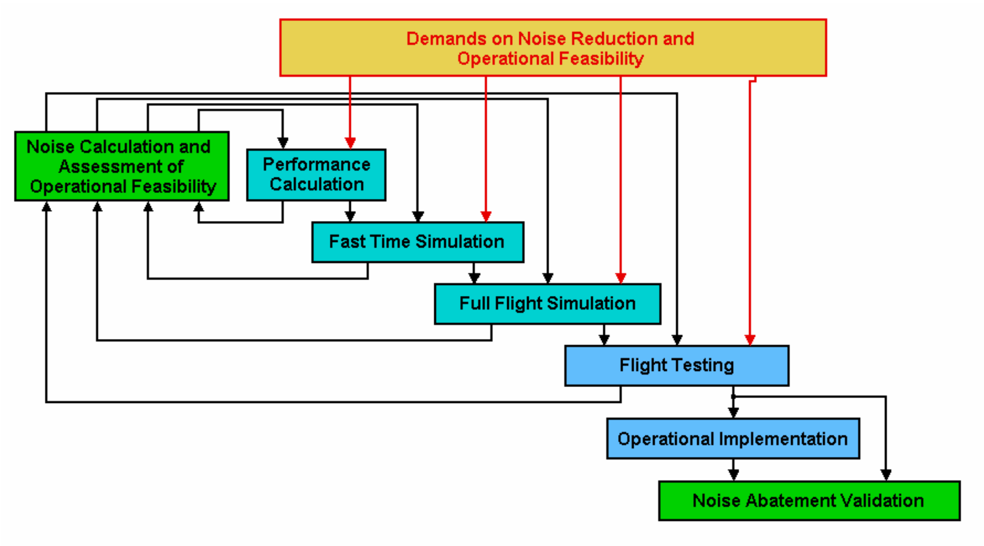

Figure 1: Loops of NAP Design Process.

The first loop is a basic performance calculation which identify the aircraft's boundaries in terms of minimum flight path angles and/or maximum deceleration capability related to a specific configuration of slats/flaps and gear. Noise calculation and assessment of operational feasibility have less significance because only single constant segments of the flight path can be regarded. The next step is to set up a fast time simulation in order to get the complete approach profile including the transition phase between the segments. In addition to a dynamic model of the aircraft, flight control algorithms are necessary to simulate the full flight path. Noise calculation can be carried out and compared with a reference procedure. But the results of feasibility and safety considerations strongly depend on the behavior of the implemented flight control laws.

Research into pilot acceptance and workload presupposes full flight simulation which is also needed to prepare flight tests. Full flight simulation provides the behavior of the total system containing the aircraft and engine dynamics, the flight management and control systems and the pilot interaction. A high level assessment of noise abatement and operational feasibility is possible. Flight testing is the last step of the NAP design process. Real weather conditions as wind changes and real traffic conditions and their influences on the procedure design could be investigated. Furthermore a noise abatement validation can be performed by noise measurements on ground.

3. DEMANDS ON NOISE REDUCTION AND OPERATIONAL FEASIBILITY

3.1 Noise Reduction

A constant noise abatement across the complete approach area can not be expected just by procedure changes. The noise impact has to be regarded along and perpendicular to the aircraft's track. Noise footprints and noise level areas resulted are another measure which has to be taken into account. A mean reduction of the sound exposure level (SEL) of about 3-5 dB could be a realistic objective.

3.2 Operational Feasibility

Safety and Pilot Workload

The approach phase is characterized by reaching the runway threshold with the target speed acquired, while maintaining a safe flight state during the whole approach. Starting from the cruise flight at high altitudes, potential as well as kinetic energy has to be reduced.

The approach and landing phase contains 59% of all commercial jet aircrafts accidents (initial approach 5%, final 7%, landing 47%) according to [1]. Particular during the configuration phase, the approach to the ground, the flare and the deceleration the workload of the crew is very high. Additional work load due to modified procedures shall be avoided.

Air Traffic Regulations

The ICAO PANS-OPS [2] provides information about the constraints for design and implementation of noise abatement approach procedures. Accordingly the aircraft has to take the final configuration at outer marker position but latest at 5 nm from threshold. Extreme sink rates should not appear during the complete approach phase. If the design of procedures is based on currently available systems and equipment (year 1982), it is not possible to require flight path angles more than standard 3° ILS glide path angle for the final approach part. However, if an implementation of new systems and equipment allows the realization of noticeable differing approaches, the procedures may and should redesigned.

Furthermore, noise abatement procedures are not permitted, if the runway is not clean and dry, the ceiling is up to 500 ft, the ground visibility is lower than 1 nm, the crosswind component including gusts amounts to more than 15 kts, the tail wind component including gusts is greater than 5 kts and if wind shear during final approach is anticipated.

Passenger Comfort

The passenger comfort is affected by vertical and horizontal accelerations as well as low pitch attitudes, but critical values are not known.

Economy

The economic feasibility of noise abatement approach procedures is not as important as the economic aspects of departure procedures. Generally noise abatement approach procedures will help to reduce fuel consumption.

To operate an airport at its full capacity the aircraft's arrival time has to be determined as accurately as possible. If new approach procedures do not allow a precise arrival time-prediction, separations have to be increased due to safety reasons and therefore airport capacity decreases. That would never be accepted by airport authorities, airlines and ATC due to economic reasons. Therefore only night- or off-peak time operations would be feasible for such procedures.

4. DESIGN METHODS AND TOOLS

4.1 Noise Calculation

Integrated Noise Model (INM)

Since 1978, the FAA has provided one of the worldwide most commonly used tools for noise assessments, the Integrated Noise Model (INM) [3]. Assessment of overall noise impact for whole airport-operation-scenarios with mixed fleets including aircraft of various types as well as calculations of single-event noise-footprints are possible.

For the design process, the latter feature is used, with the special aspect, that flight trajectories are first calculated / simulated with a simplified mass-point-model of an aircraft. Second, the attained data is transferred into the INM to calculate noise immissions on the ground.

INM contains an acoustic database of Noise vs. Power vs. Distance (NPD) values, augmented by a database of spectral characteristics. Several noise metrics are available. In this paper the A-weighted sound exposure level L_{AE} and the maximum A-weighted sound level $L_{A,max}$ are used. The INM is a so-called "segmentation model". The underlying assumption is that the NPD data represent an aircraft proceeding along a straight flight path of infinite length and parallel to the ground. For flight path segments of finite length a correction for exposure based metrics has to be applied ("noise fraction"). Additional adjustments for e.g. atmospheric absorption, lateral attenuation, and acoustic impedance or noise fraction and duration for exposure-based metrics are implemented as well.

INM does not provide the modeling of separate noise sources like engine-, airframe- and landing gear-noise. It is based on a simple 4th power dipole model of sound radiation. This means that the changes of the directional characteristics of the radiated sound due to changes in engine power and aircraft configuration are neglected.

SIMUL

This simulation procedure was introduced in 1988. It has been enhanced continuously, with the future goal to enable aircraft noise calculations in the vicinity of airports [2]. SIMUL is based on a separate modeling of engine and airframe noise sources and accounts for directional characteristics as well as for spectral information. The noise calculation is based on the estimation of the spectral noise-time-history at an observer location. Additionally, this program offers different features with respect to the modeling of sound propagation.

In the current version only noise immission calculations for the Airbus A320 aircraft can be performed, nevertheless including all features of the model. Since detailed knowledge of the aircraft noise sources is necessary, the acquisition of these data via theoretical research and flight test with acoustical measurements requires great efforts. As a first step, flight tests have been conducted in cooperation with Lufthansa German Airlines (DLH), accompanied by theoretical research and acoustical measurements in the German-Dutch-Windtunnels (DNW) carried out by the German Aerospace Center. These test activities will continue, thus providing a more extensive noise database.

Analogous to the calculations performed with the Integrated Noise Model, all trajectories used for noise calculations in SIMUL have to generate in a performance calculation or fast time simulation prior to transferring them.

4.2 Flight Path Calculation

As mentioned already before the first step of the NAP design process are performance calculations. The basic equations for the approach flight phase can be derived from the drag and lift equations of motion. Assuming that lift is equal to weight, equation (1) provides the flight path angle γ and/or the aircraft's acceleration ratio $\dot{V} / g$ due to a given thrust to weight F / W less drag to lift C_D / C_L. On idle thrust F_{idle} the aircraft performs a so-called open descent with minimum flight path angle. If the flight path angle and/or the aircraft acceleration is given, i.e. during flight on glide path, a specific thrust is required (Eq. 2).

$$\sin(\gamma) + \frac{\dot{V}}{g} = \frac{F_{idle}}{W} - \frac{C_D}{C_L} \qquad (1)$$

$$\frac{F_{req}}{W} = \frac{C_D}{C_L} + \sin(\gamma) + \frac{\dot{V}}{g} \qquad (2)$$

Using these equations flight path and appropriate noise immission could be calculated segment-wise.

5. RELATED PROJECTS

5.1 Results of Fast Time Simulation Studies

Figure 2 shows the vertical flight profile of different approach procedures. Today's standard for many major airliners is the Low Drag Low Power Approach (LDLP). This procedure starts with constant speed and level flight at an altitude assigned by Air Traffic Control (ATC). That followed a descent with thrust in flight idle position. At the intermediate approach altitude, i.e. 3000 ft above ground level (AGL), transition to level flight and deceleration to clean maneuvering speed proceeds. To maintain constant speed and altitude requires the thrust to be increased followed by an increase of noise emission. After further speed reduction the approach flap setting can be obtained. Glide path intercept from below will be performed and speed keeps nearly constant until gear extension and final flap setting decelerate the aircraft to its final approach target speed. To perform a safe final approach and landing, the aircraft has to be stabilized at 1000 ft AGL. Gear and final flap extension on glide path, just before outer marker result in low drag, leading to low thrust levels as well as low noise levels.

The main measures on approach procedures for additional noise reduction are increased height, decreased thrust and delayed configuration changes. Sometimes these measures are contradictory, e.g. an increased height means a steeper approach, which only can be performed by early extended gear and final landing flaps.

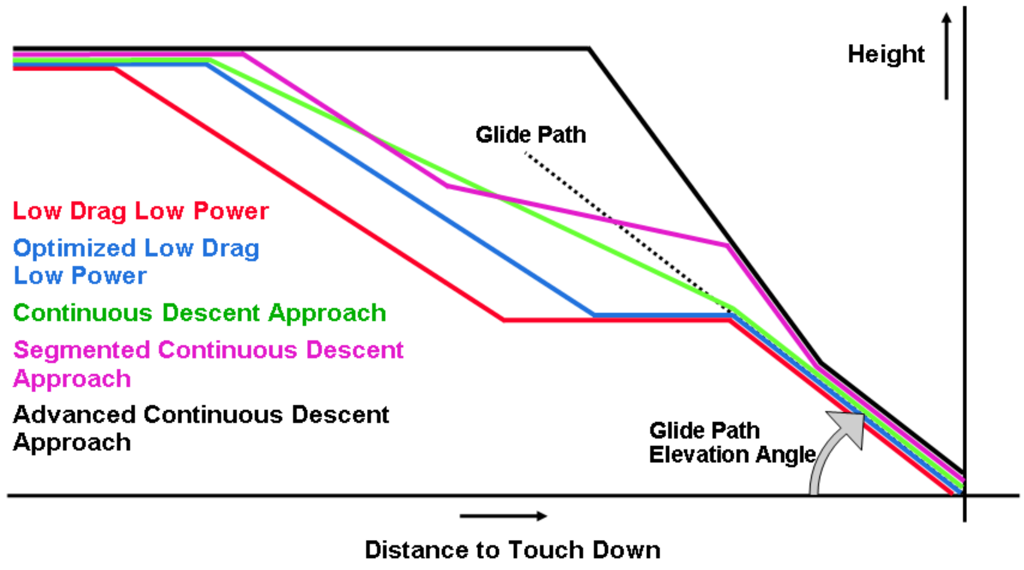

Figure 2: Approach Profiles.

Lifting the vertical flight path can be achieved by shorten the length of the intermediate approach altitude (Optimized Low Drag Low Power), avoid it totally (Continuous Descent Approach), perform a steep approach intercepting the glide path from above (Advanced Continuous Descent Approach) or perform a Segmented Continuous Descent Approach (SCDA) with multiple optimized segments [5].

The SCDA is composed of an open descent, a deceleration, a steep and a 3° final approach segment. The procedure is the most suitable for the given demands on noise level below flight path and lateral noise distribution, feasibility (using today's functionality of flight management and flight control systems), safety (maximum sink rates and compliance with the required stabilization height), passenger comfort and economic efficiency (time need and fuel consumption) (Table 1) [6].

Table 1: Advantages and Disadvantages of NAPs related to the reference LDLP
+ better than today's standard, 0 equal to today's standard, - worse than today's standard .

	Optimized LDLP	CDA	SCDA	ACDA
Noise Level below Flight Path	+	++	+++	+++
Lateral Noise Distribution	+	+	+/-	+/--
Feasibility	0	0	-	-
Safety	0	0	-	-
Passenger Comfort	0	+	-	-
Economic Efficiency	0/+	--	0/-	---

Compared with the LDLP the magnitudes of Sound Exposure Level (SEL) areas are decreased significantly. (Fig. 3) [6].

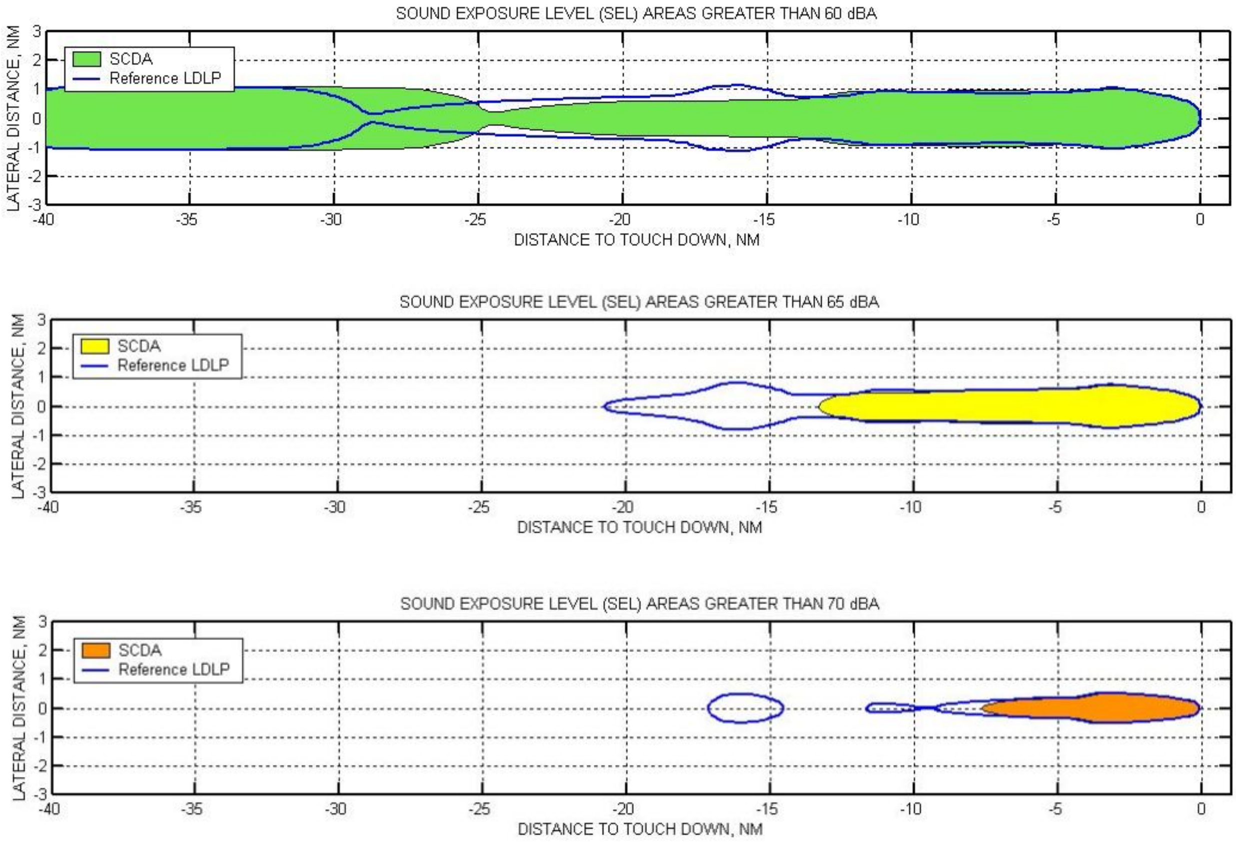

Figure 3: Noise Footprints of the SCDA compared with a LDLP Procedure.

The SCDA procedure was selected to be investigated within full flight simulator and flight test.

5.2 Results of Full Flight Simulator Studies at Lufthansa Flight Training and TU-Berlin

Due to the assessment of pilot workload 44 pilots in total (mean flight experience 11 year) were tested either on a A320-full-flight simulator (Lufthansa Flight Training) in Frankfurt or on the A330-test simulator (Centre for Flight Simulation) in Berlin [7]. They performed a LDLP landing scenario followed by three SCDA procedures. Flight simulation data as well as physiological and psychological data were recorded during all test sessions. Noise levels on ground could be calculated using the DLR noise simulation software SIMUL.

Fig. 4 shows the vertical flight paths from the SCDA procedure. Due to the fact that the point of descent often was missed and the pilot has too many actions at the beginning of the steep segment, there is a large variance of flight path deviation at 4th segment. In the most cases the actual flight paths are lower than the planned paths and therefore the glide path intercept is earlier. This produces an earlier thrust adaption and the risk of higher noise on ground.

Corrective measures could be a better indication of the point of descent to result in adequate pilot actions and a reduction of pilot workload by self-controlled slat/flap extension.

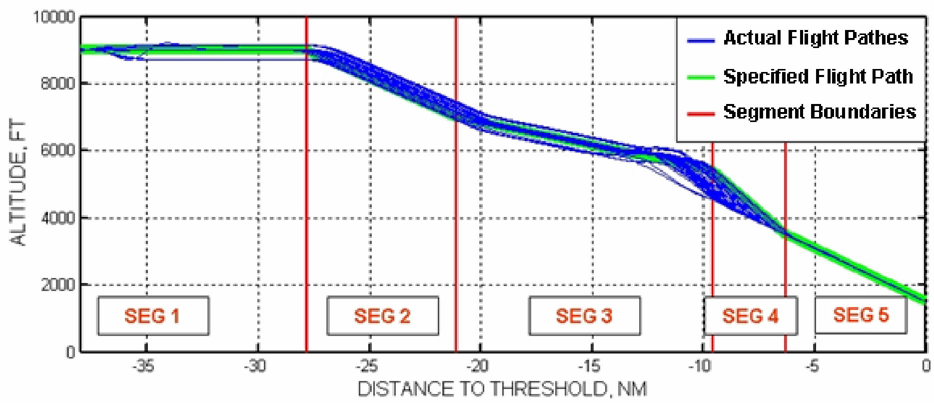

Figure 4: Vertical Flight Paths of SCDA Procedure from Full Flight Simulator Study.

The full flight simulator studies have shown that the SCDA procedure is realizable after an adequate briefing of the crew. There were no safety critical flight states during all simulator runs. Due to the fact that the noise calculation program INM does not take airframe noise into account, small differences result in calculated noise levels related to the SIMUL software. The workload was stated by the pilots as higher than by the LDLP procedure but not as critical. Medical data did not show significant differences to the standard procedure.

5.3 DLR ATTAS Flight Testing

The SCDA-Procedure was flight tested using the Advanced Technologies Testing Aircraft System (ATTAS) (Fig. 5) operated by German Aerospace Center (DLR) at Braunschweig research airport.

Figure 5: ATTAS Aircraft .

The standard ILS instrument approach procedure at Braunschweig airport (EDVE) has some local peculiarities e.g. a 3.5° glide path angle instead of a common 3° ILS glide slope and a lowered intermediate approach altitude of only 2500 ft MSL (2200 ft AGL) compared to usual values of 3000 ft AGL or even higher. Fig. 6 shows the flight test demonstration results from a LDLP-Reference-Approach followed by two SCDA-Procedures. The required tops of descent for the SCDAs were pre-estimated by using standard aviation weather forecast including wind speeds and wind directions at different flight levels. All boundary conditions as specified before were met. Single–spot noise measurements, underneath the flight path were conducted at a distance of 8 nm to the runway threshold. Noise relief of up to -8 dB $L_{A,max}$ was metered.

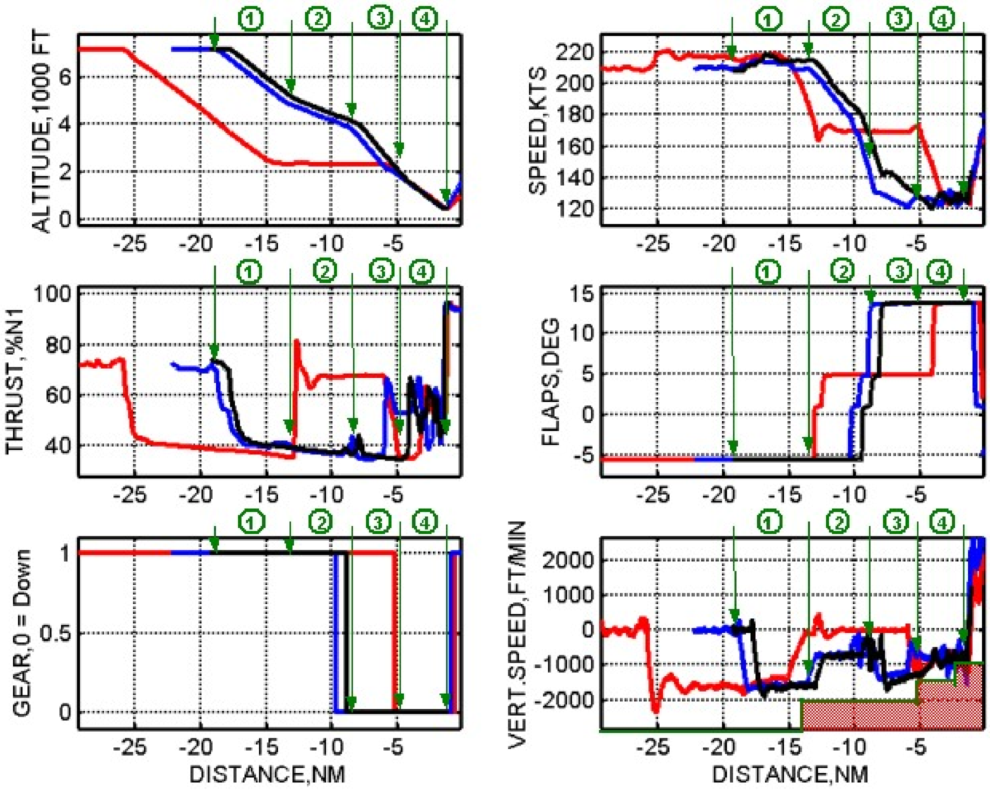

Figure 6: Flight test results containing one LDLP-Approach (red line) and two SCDA-Procedure (blue and black line) .

6. SUMMARY AND CONCLUSIONS

The design process of noise abatement flight procedures can be divided in several steps / loops of different complexity and significance. Starting with performance calculations, followed by fast time and full flight simulations, the process is closed by flight tests before an operational implementation can be performed.

For all steps demands on noise reduction and operational feasibility as safety, pilot workload, passenger comfort and economy aspects, have to be fulfilled. Design methods and tools, especially the noise calculation method, may influence the design results. Therefore it is a must, that airframe noise during landing approach, which can be dominant related to the engines noise, has to take into account.

The Segmented Continuous Descent Approach (SCDA) is the most suitable for the given demands and therefore selected to be investigated within full flight simulator and flight test. Demands on additional functionality of Flight Management and Flight Control Systems could be derived from full flight simulator studies. Flight tests with the DLR ATTAS aircraft validate the expected noise reduction.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

[1] *Statistical Summery of Commercial Jet Airplane Accidents*, Worldwide Operations 1959-2002, Airplane Safety, Boeing Commercial Airplanes, Seattle, Mai 2002

[2] *ICAO Procedures for Air Navigation Services - Aircraft Operations* - , Volume 1, Flight Procedures 4th Edition, Amnd. 11, Part V - Noise Abatement Procedures, Chapter 3

[3] *Integrated Noise Model (INM) Version 6.0 Technical Manual*, Federal Aviation Administration, Office of Environment and Energy, FAA-AEE-02-01, January 2002

[4] U. Isermann, *Berechnungen der Fluglärmimmission in der Umgebung von Verkehrsflughäfen mit Hilfe eines Simulationsverfahrens*, Dissertation, Universität Göttingen, 1988

[5] R. Koenig and R.-G. Huemer, *Noise Saving Potential of Future Approach and Departure Procedures*, 24th International Congress of Aeronautical Sciences, Yokohama, Japan, September 2004

[6] M. Maierhofer, *Untersuchung von lärmreduzierten Landeanflugverfahren in Bezug auf Lärmminderung*, Fliegbarkeit und Wirtschaftlichkeit, DLR Institut für Flugsystemtechnik Braunschweig, IB 111-205/19

[7] Ekkehart Schubert, Oliver Lehmann, Gerhard Hüttig, *Evaluation the influence of noise abatement procedures to pilot's workload by using an Airbus A330/A340 full flight simulator*, Internoise 2005, Rio de Janeiro, Brazil