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Design and evaluation of short-term realizable new noise abatement flight procedures

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ABSTRACT

Aircraft noise in the vicinity of airports and its impact to residents represents a problem that is growing according to the increasing air traffic density. Improved and completely new designed aircraft configurations are promising approaches. But they represent only long-term solutions, whereas the application of newly designed noise abatement flight procedures (NAPs) could be able to contribute to the reduction of noise immission in a near future.

The paper will describe the NAP design process and an evaluation of the results. It is based upon several studies performed in Germany during the last 6 years.

Starting from existing NAPs, new procedures were designed using performance calculations, fast time simulations, full flight simulator studies and flight tests. Assessments of noise reduction as well as assessments of safety, operational feasibility, pilot workload, passenger comfort and economic aspects were carried out.

The newly designed “Segmented Continuous Descent Approach” results in a reduction of the >50 dBA maximum noise level area of about 40% and was investigated in detail by full flight simulator research into pilot workload and flight tests including on ground noise measurements. Analysis of take-off procedures showed advantages and disadvantages of steep departure flight paths and full thrust use.

1 INTRODUCTION

Noise Abatement Procedures (NAPs) for departure and approach have already been designed in the past. Lower engine and higher airframe noise levels and additional possibilities for aircraft guidance and control lead to the fact that existing noise abatement procedures do not exploit the full noise reduction potential.

Prerequisite for any new flight procedure design is to consider safety standards, like airline standard operating procedures (SOPs), economical items, e.g. fuel flow, flight time and engine stress, air traffic management and capacity issues and legal requirements (Figure 1). Due to the need for short term solutions, extensive hard- and software changes of onboard and ground equipment should be avoided, since typical legal certifications would prolongate the entry into service of such procedures.

Tradeoffs have to be made to satisfy these opposite requirements. Steeper departure procedures indeed reduce high noise levels but increase the fuel consumption.

The achievement of noise reduction during the approach is more complicated than in the departure phase. Airframe noise may be dominant, if engines are operated near idle thrust. The main measures on flight procedures for noise reduction are increased height, decreased thrust and delayed configuration change [1].

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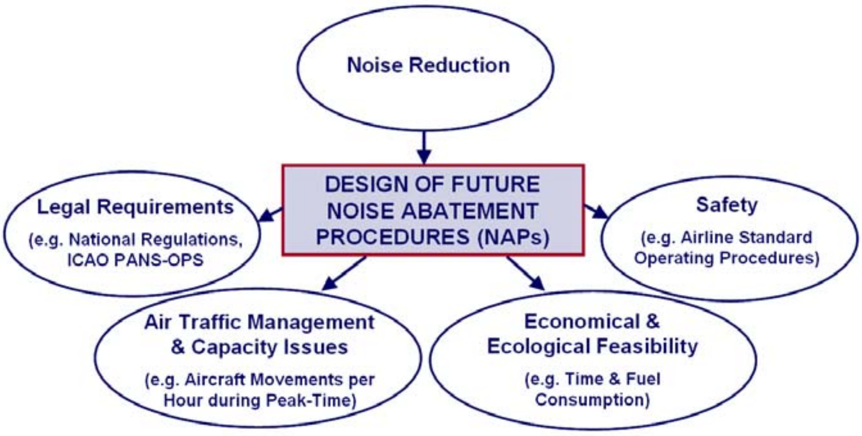

Figure 1: Demands for the design of future noise abatement procedures.

2 DESIGN PROCESS AND TOOLS

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 to several design loops which are different in complexity and result. All loops or steps include an assessment of noise reduction and operational feasibility if possible [2].

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.

For noise level calculation / simulation the SIMUL software [3] from the German Aerospace Center (DLR), which was introduced in 1988, was used. This software has been enhanced continuously. 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. In the current version only noise immission calculations for the Airbus A320 aircraft can be performed.

3 NOISE ABATEMENT FLIGHT PROCEDURES

3.1 Take-off and Departure

The standard take-off and departure procedure of Lufthansa German Airlines (DLH) is the "Modified ATA Procedure" (MODATA) in combination with reduced take-off thrust (FLX) whenever it is feasible, that means the runway length is adequate. The steady state climb after lift-off passes until 1500 ft (457m), then thrust will be reduced and aircraft nose dropped, which induces acceleration. Arriving the minimum clean configuration speed flaps will be retracted and the aircraft further accelerated until 250 kts (129 m/s), which is the speed for the steady state climb out (Figure 2).

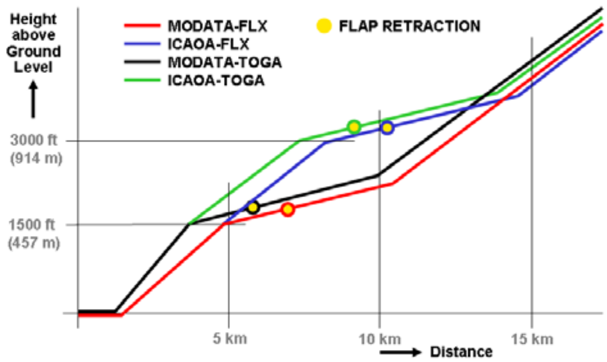

Fig 2: Different take-off and departure procedures

Alternatively there is another departure procedure in use by other airlines which differs in the beginning of the acceleration phase. After thrust cut back a steady state climb follows until 3000 ft (914 m), before the acceleration starts. This procedure is called ICAOA.

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 (TOGA). Because more thrust stands for shorter take-off run and steeper flight path angle, height is always greater than for the corresponding procedures with reduced thrust setting (FLX). Certainly, a full thrust take-off can be performed on a long runway also.

To calculate noise levels, simulations of these take-off and departure procedures were performed. Figure 3 shows results consisting of height, speed, thrust, flap deflection, gear state, total and difference noise versus the distance from break release point. Noise level means the maximum value. The comparison is made between *MODATA-FLX*, *ICAOA-FLX* and *MODATA-TOGA*. The noise level on the left side of the figure refers to the ground directly below the aircraft. It could be stated that the noise level of *ICAOA-FLX* between 5 and 14 km is up to 3dBA lower than that of *MODATA-FLX*. The *MODATA-TOGA* procedure is quieter than *MODATA-FLX* except during the take-off roll segment. But only this assessment is not sufficient.

The shape of noise level contours and the associated areas have to be regarded too. Therefore on the right side of Figure 3 noise level contours are shown to perform a more extensive assessment. Please notice that the resolution changes between the different noise levels due to a better identification.

While the areas greater than 60 and 70 dBA of *ICAOA-FLX* are larger than from *MODATA-FLX* (between 5 and 10 km and between 24 and 33 km distance), the areas greater 85 and 90 dBA are smaller (see also Figure 5). Both results have different reasons.

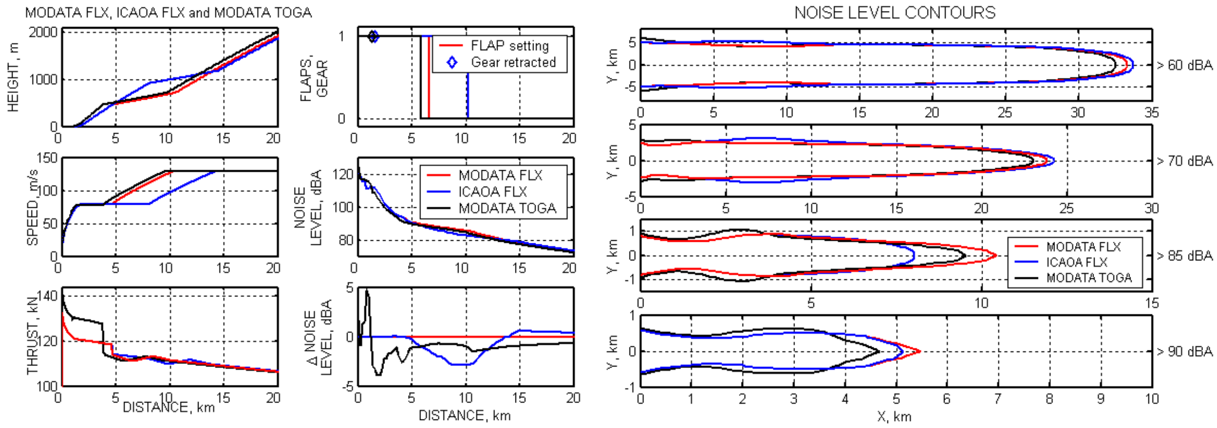

Fig 3: Simulation and noise calculation results of different take-off and departure procedures

The damping of acoustic noise depends on the distance to the source as well as to the lateral elevation angle (low angles lead to high damping). Therefore, an aircraft on a higher flight path can laterally induce an extended contour (Figure 4).

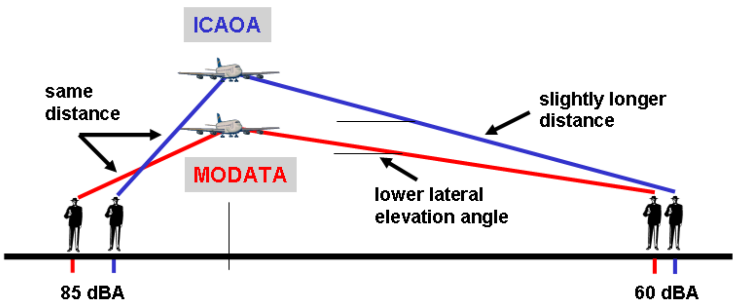

Fig 4: Effect of lateral attenuation

Figure 5 shows this effect. Two kilometers laterally of the flight path projected on ground the noise level of *ICAOA-FLX* increases compared to *MODATA-FLX*. At 9 km distance the inversion points are located of about 1 km left and right of the projected flight path (Figure 5, right / bottom diagram). The reason for the larger 60 and 70 dBA areas between 23 and 33 km distance is the lower height of *ICAOA-FLX* due to a flight path intersection shortly before the procedure acceleration segment is finished. In addition there is no effect from lateral attenuation because the elevation angles are higher than those close to the airport. Regarding contour levels greater 85 and 90 dBA *ICAOA-FLX* leads to smaller areas than *MODATA-FLX* which results from the higher flight path and no effect of lateral attenuation because the lateral elevation angles are also high regarding these levels (Figure 4).

The *MODATA-TOGA* procedure has a steeper flight path after lift off combined with a higher noise level from the engines due to a higher thrust setting. During climb the distance effect dominates the source effect and noise below the flight path is lower than from *MODATA-FLX*. But in lateral direction the same effects as described before appear.

Total noise contour areas of all 4 procedures and the differences to the *MODATA-FLX* procedure are shown in Figure 6. From noise levels greater 60 to greater 80 dBA *MODATA-FLX* has the lowest areas! For levels greater than 85 dBA there is a benefit from the *ICAOA-FLX* and *ICAOA-TOGA* procedures. The areas of *MODATA-TOGA* are always higher.

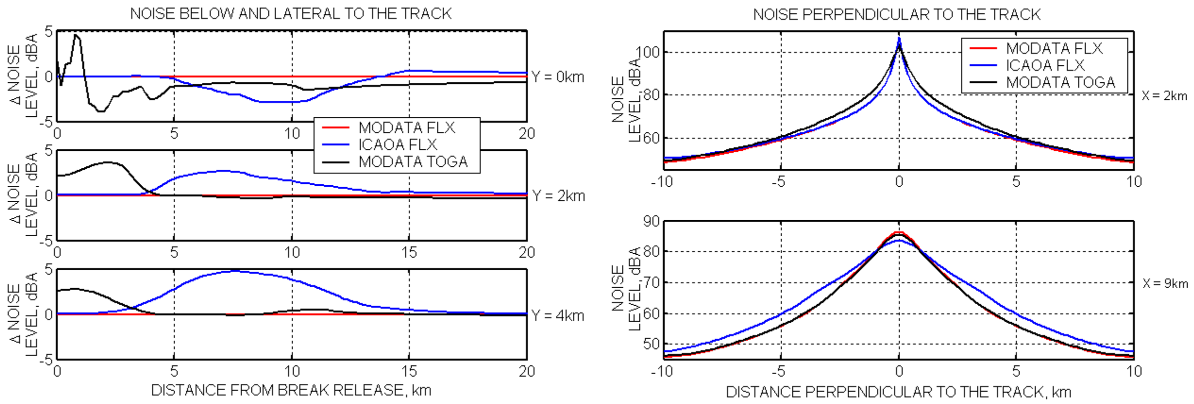

Fig 5: Noise level on ground lateral and perpendicular to the flight path

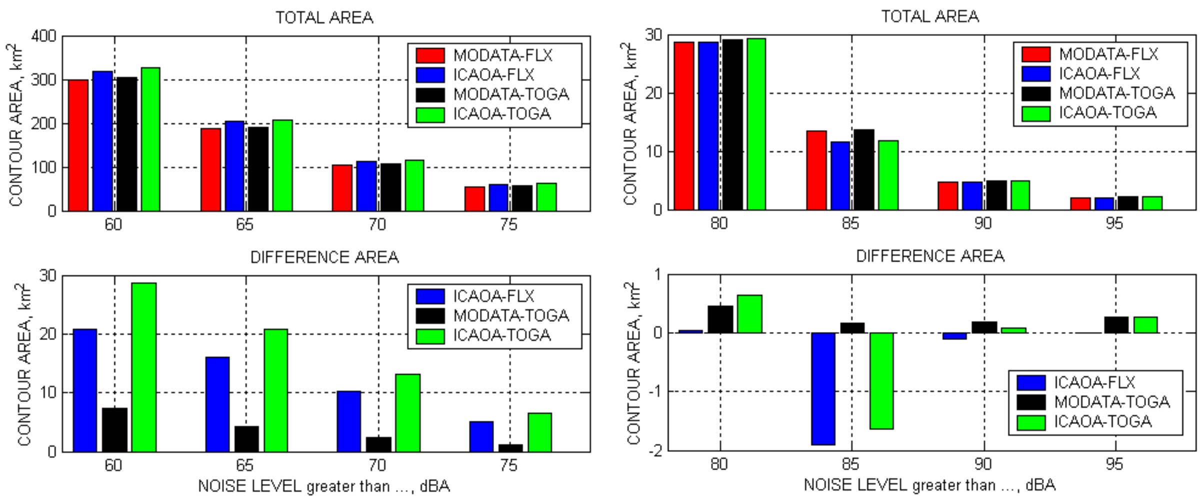

Fig 6: Noise contour areas of different take-off and departure flight procedures

Besides the noise aspects it is necessary to evaluate fuel consumption and time need too. Regarding fuel consumption the *MODATA-FLX* procedure has the lowest values, regarding time need only *MODATA-TOGA* leads to a better value. Over all it could be stated, that the *MODATA-FLX* procedure is the best one. Additional investigation looking at the parameters of *MODATA-FLX*, like thrust cut back height and acceleration magnitude, will be performed in the near future.

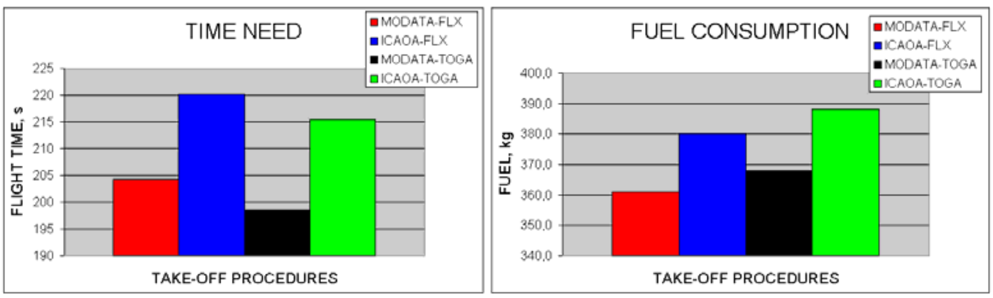

Fig 7: Time need and fuel consumption different take-off and departure flight procedures

3.2 Approach and Landing

The commonly used approach procedure is the Low-Drag-Low-Power (*LDLP*), which will be described in the following for a short / medium range Airbus aircraft. Starting from a level flight at for example 7000 ft (2133m) with a speed of 250 kts (128,6 m/s, 463 km/h) the aircraft performs a so-called “open descent”, which is characterized by idle thrust setting and constant speed (Figure 8). The airplane acts like a sailplane. Arriving at the intermediate approach altitude, typically 3000 ft (914 m), a change to level flight associated with adequate thrust adjustment takes place. To reduce speed for landing a deceleration is necessary and then lower speeds require the extension of flaps and slats to maintain lift. Therefore, at the deceleration point thrust is reduced to idle and reaching the minimum clean configuration speed the first configuration stage has to be engaged. After further deceleration the next configuration stage follows. A three degrees glide path will be intercepted from below at about 9 nm (17 km) distance from touch down. On glide path the aircraft decelerates slightly further while thrust remains in idle condition. About 2000 ft (609 m) above ground the landing gear will be extended, directly followed by configuration changes to stage 3 and 4. To maintain landing speed after it is reached, the thrust has to be adapted. At 1000 ft (539 m) at the latest the aircraft must be stabilized in flight path, speed and thrust setting. If not so, a go-around has to be performed. The *LDLP* name results from the late gear and final flap extension which means low drag at the initial part of the glide path and therefore only low power.

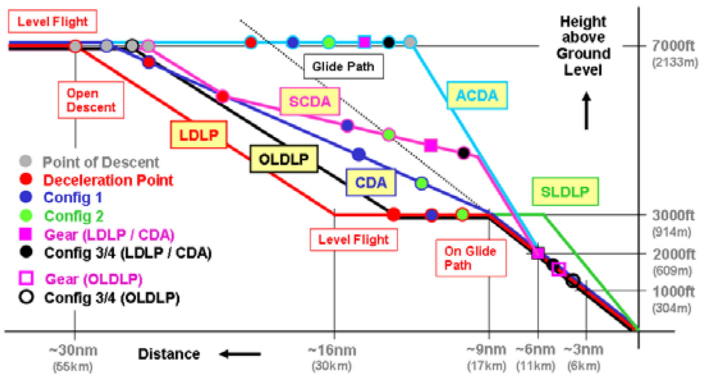

Figure 8: Different noise abatement approach flight procedures.

Now the challenge is to improve the *LDLP* with regard to noise without affecting safety and only low influences to feasibility and economy. The disadvantage of the *LDLP* is among other things the intermediate approach altitude which is often too long due to air traffic control reasons. For an optimized LDLP (*OLDLP*) the length has to be reduced to the required deceleration length. Furthermore a reduction of the gear extension height is possible without affecting the stabilization height. To avoid the intermediate approach altitude totally a Continuous Descent Approach (*CDA*) has to be performed. The *CDA* makes higher demands on air traffic control and aircraft flight guidance. During continuous descent, deceleration and aircraft configuration changes have to be initiated earlier than with *LDLP*. On glide path there are no differences between both procedures.

Figure 9 shows aircraft inputs and states as well as noise level, difference and contours for the three described procedures as a result from simulation calculations. *OLDP* and *CDA* avoid the necessary thrust adjustment by *LDLP* on intermediate approach altitude. Therefore the contour area of greater than 50 dBA shrinks clearly between 25 and 38 km distance from touch down. The islands for >55 and >60 dBA disappear completely. Due to later thrust adjustment regarding the *OLDLP* procedure all displayed contour areas become smaller in the region between 7 and 9 km distance from touch down point.

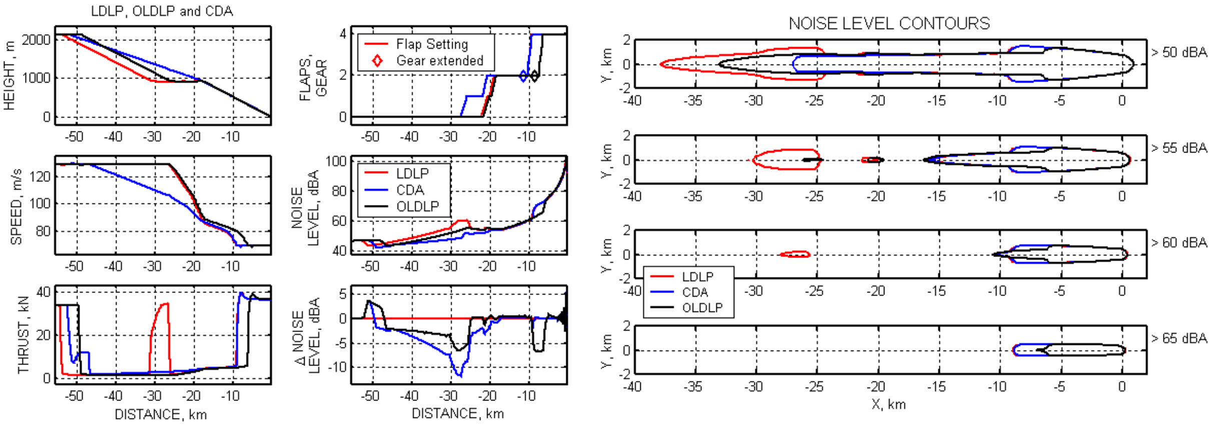

Fig 9: Comparison of LDLP, OLDLP and CDA procedures

As described before the *CDA* procedure avoids the intermediate approach altitude but differs not during the flight on glide path from *LDLP* procedure. Noise reductions at higher levels could only occur at steeper flight path angles (more height) during final approach, but then the aircraft has to be configured earlier since more drag is required. A steep final approach (more than 3° glide path angle) until touch down is not practicable in near future because equipment on ground and aircraft certification have to be changed. The appropriate solution is a steep segment up to 1500 ft (457 m) which ensures that the stabilization height of 1000 ft (305 m) is maintained. Glide path interception will take place from above with gear down and full flap setting so that aircraft stabilization comprises only the glide path capture task.

Two additional CDA procedures are designed with such steep approach segments. Figure 8 shows the Advanced-CDA procedure (*ACDA*) and the Segmented-CDA procedure (*SCDA*). For the *ACDA* the aircraft will be fully configured during the initial level flight which leads to a fast speed reduction and an early steep descent at low airspeed. The *SCDA* consists of multiple segments that are an open, a decelerated and a steep descent. The *ACDA* implies the most noise reduction regarding the >50 dBA contour. The noise reduction from *SCDA* is not so much but also significant (Figure 10).

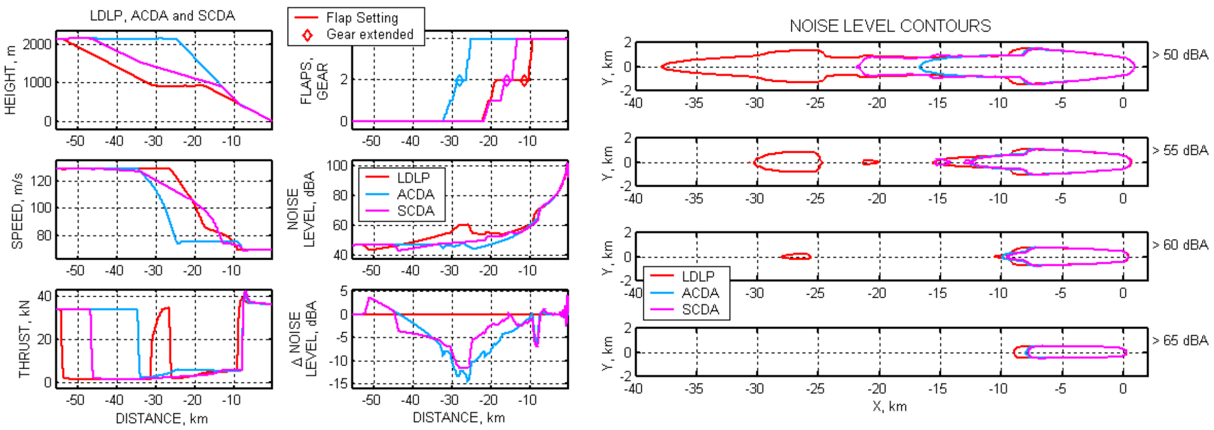

Fig 10: Comparison of LDLP, SCDA and ACDA procedures

Even if a steep approach until touch down is not feasible yet, an investigation of the amount of noise benefit makes sense. Figure 11 shows the Steep-LDLP (*SLDLP*) with a 3.8° glide path angle compared to the *LDLP* and *OLDLP*. The -3.8° flight path angle can only be achieved by earlier stage 3 flap/slat setting, which requires a change in normal flap/gear schedule. Expectedly most benefit is achieved at higher levels on glide path when thrust has been adapted. Please note that the Y-resolution of the >70 dBA noise level contour in Figure 11 is not the same as for the other levels.

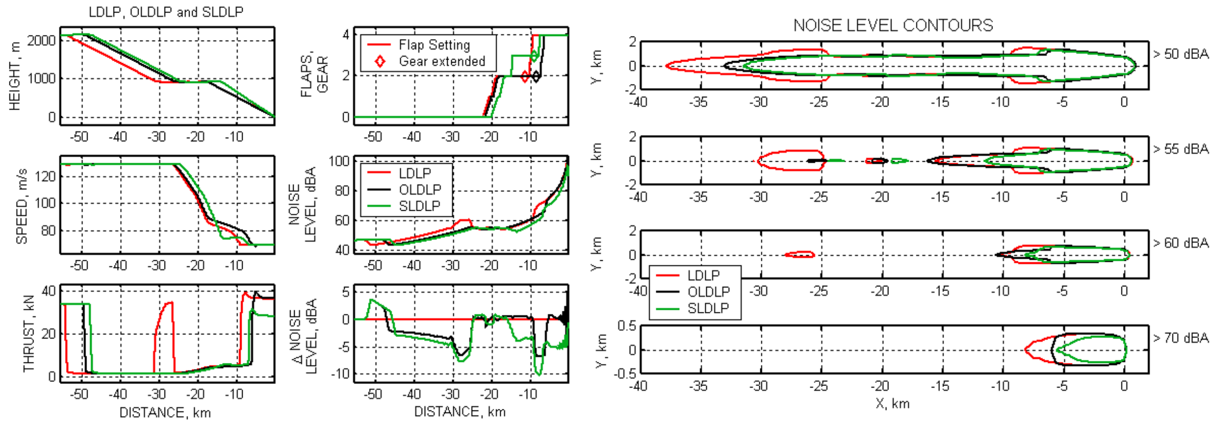

Fig 11: Comparison of LDLP, OLDLP and SLDLP procedures

Figure 12 shows the noise contour areas of all investigated approach procedures in order of the size of their >50 dBA contour. The *ACDA* followed by the *SCDA* gives the best value. For higher noise levels (>70 dBA) the *SLDLP* followed by the *OLDLP* will be the best one. As for the departure procedures time need and fuel consumption for the approach procedures have to be regarded, too. These values are worst for the *ACDA* and best for the *OLDLP* (Figure 13). Due to the fact that the *SLDLP* is not feasible today, the *SCDA* seems to be the best compromise between noise reduction and economy.

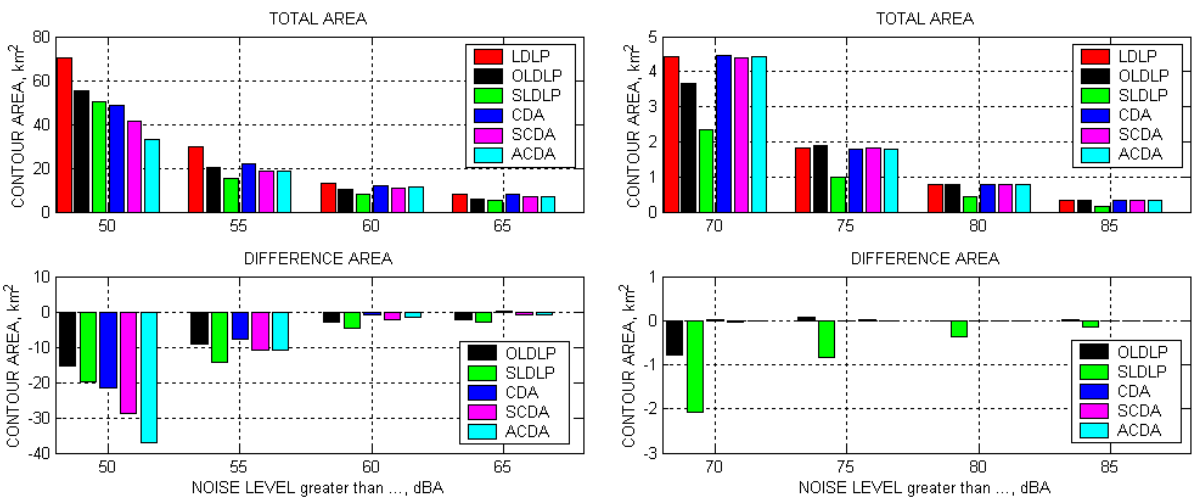

Fig 12: Total and difference noise contour areas of different noise abatement approach procedures

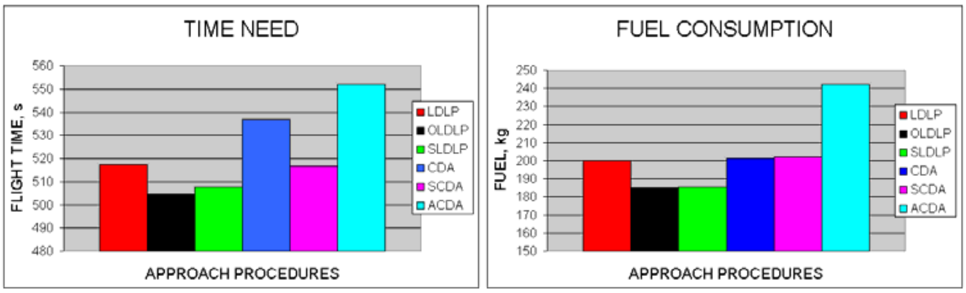

Fig 13: Time need and fuel consumption of different noise abatement approach procedures

4 FULL FLIGHT SIMULATOR INVESTIGATIONS AND FLIGHT TESTS

The SCDA procedure was selected to be investigated within full flight simulator and flight tests. Due to the assessment of pilot workload 44 pilots in total were tested either on an A320-Full- Flight-Simulator (Lufthansa Flight Training) at Frankfurt or on the A330-Test-Simulator (Center of Flight Simulation at Technical University) at Berlin [4]. All crews performed a LDLP landing scenario followed by three SCDA procedures. Flight simulation data as well as physiological data were recorded during all test sessions. Noise levels on ground were calculated using the DLR noise simulation software SIMUL.

The 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. 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].

Flight tests were performed using the Advanced Technologies Testing Aircraft System (ATTAS) operated by German Aerospace Center (DLR) at Braunschweig Research Airport. Figure 14 shows the maximum noise level from different procedures measured directly below the flight path. The maximum noise reduction about 5 dBA compared to the LDLP automatic flight of is provided by the SCDA automatic flight. CDA and SCDA on manual flight deliver the half reduction values.

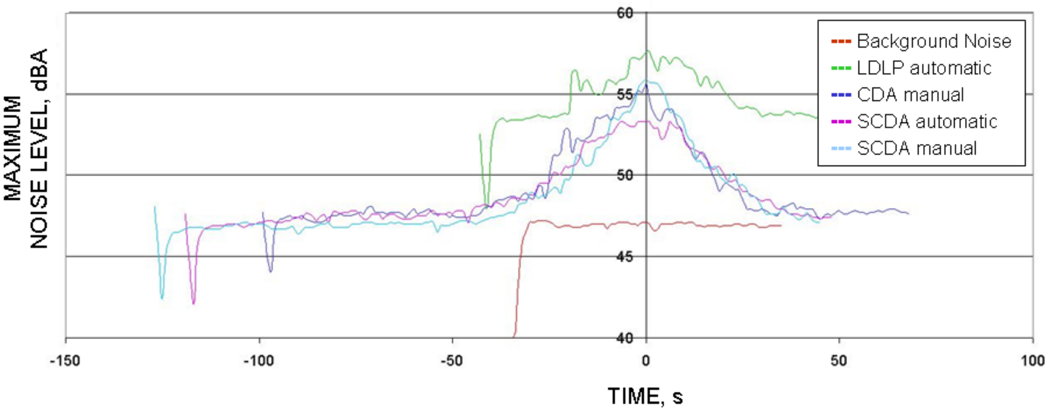

Fig 14: Flight test noise measurements of different approach procedures

5 SUMMARY AND CONCLUSIONS

Noise abatement take-off/departure - and approach procedures are investigated systematically with regard to noise levels below and perpendicular to the flight path, contour areas, flight time and fuel consumption.

Due to lateral attenuation effects the take-off/departure procedures with full thrust and/or steep climb after thrust cut back lead to larger contour areas regarding low noise levels. Only at high levels (>85 dBA) the contour areas are smaller. Therefore it can be stated that for the take-off/departure case a real noise reduction is difficult, but a redistribution possible.

For the approach case all investigated procedures lead to a real noise benefit compared to the reference LDLP. But there are procedures which are not short term realizable, like the SLDLP (steep final descent until touch down), or are not economical, like the ACDA. The best trade-off for the given demands seems to be the SCDA which is indeed difficult to perform.

6 ACKNOWLEGDEMENTS

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