On the Influences of an Increased ILS Glide Slope on Noise Impact, Fuel Consumption and Landing Approach Operation

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Abstract
This paper will show the theoretical influences of an increased glide slope to noise impact and fuel consumption and will describe the possibility or risk of procedure changes by the pilots to cope with a steeper descent. Furthermore, the development of a simulator study, the achieved results with regard to safety and operational aspects and the results of performance simulations for different aircraft types will be described. As a result glide slopes up to 3.2° could be realized without the necessity of flight procedural changes from performance and pilots view. Based on this fact the Frankfurt/Main Airport will conduct a test operation of a 3.2° ILS for noise purposes on the new north-west landing runway, which construction is in progress.

Keywords: Steep Approach, Noise Impact, Fuel Consumption, Landing Operation.

Introduction

Measures to reduce flight noise impact are on the one hand a reduction of the source noise of engines, structures, high lift devices and landing gear and on the other hand an increase of the distance to this sources. Source noise decrease can be achieved by new airplane design, but also by changes in flight procedures. More distance to the noise sources is feasible by horizontal flight path optimization and by an increase of flight height. Whereas a higher vertical flight path means a steeper landing approach which requires more drag and less thrust, both with an influence on noise, fuel consumption and operational aspects. Several studies [1, 2] have shown that steep descents could make a contribution to active noise abatement in the final approach area of an airport.

The Frankfurt/Main Airport (major international airport in Germany, the third busiest in Europe and the ninth worldwide in 2009) will increase its capacity to assure competitiveness, sustainability and to satisfy growing market demands. In line with this expansion a new runway, parallel to the existing east-west runway system, will be build. Simultaneously the airport has committed within the authorization process to keep down the impacts on humans and environment. Therefore, it is planned to lift the glide slope of the Instrument Landing System (ILS) at the new runway to 3.2° for noise purposes, which is only possible under CAT I conditions.
The German Aerospace Center (DLR), Institute of Flight Systems, Braunschweig, Germany, and the Technische Universität Berlin (TUB), Department of Aeronautics and Astronautics, Chair Flight Guidance and Air Transportation, Berlin, Germany, have conducted a Full Flight Simulator study under contract of the Fraport AG (operator of Frankfurt am Main Airport) to investigate safety, operational aspects and pilot workload for 3.0°, 3.2° and 3.5° ILS glide slopes [3]. Eight professional crews from Deutsche Lufthansa (DLH) were “flying” 176 landing approaches with different conditions on an Airbus A330/340 Full Flight Simulator. A comprehensive assessment was made using the recorded simulator data and the crew / pilot questionnaires. Flight simulator investigations for other aircraft types are not feasible due to costs and time required. Therefore, the portability of some results was ensure through additional performance calculation using fast time simulation of further Airbus and Boeing aircrafts.

**Noise and Flight Operation**

The commonly used approach procedure is the Low-Drag-Low-Power (LDLP), which implies late gear and late final flap extension resulting in low drag at the initial part of the glide path and therefore only low power. Starting from a level flight at for example 7.000 ft with a speed of 250 kt the aircraft performs a so-called “open descent”, which is characterized by idle thrust setting and constant speed (Fig. 1). The airplane behaves like a sailplane. Arriving at the intermediate approach altitude, typically 3.000 ft, a change to level flight associated with adequate thrust adjustment takes place. To reduce speed for landing, a deceleration is necessary and to maintain lift at lower speeds the extension of flaps and slats is required. Therefore, at the deceleration point thrust is reduced to idle and reaching the minimum clean configuration speed high lift devices (first configuration stage) has to be deployed. The Airbus A320 per example can engage four configuration stages while approaching which are defined by different slat and flap positions. For the first stage only slats are deployed. After further deceleration the next configuration stage follows. A three degrees glide path will be intercepted from below at about 9 nm distance from the target touchdown point. The aircraft decelerates further on glide path while thrust remains at idle condition. At about 2.000 ft above ground the landing gear will be extended, directly followed by configuration changes to stage 3 and 4. To maintain landing speed once it is reached, the thrust has to be adjusted. At 1.000 ft at the latest the aircraft must be stabilized in flight path, speed and thrust setting. If not possible for some reasons, a go-around has to be performed.

**Fig. 1: Low-Drag-Low-Power Flight Procedures [4]**
Now the question is how to improve the *LDLP*-approach with regard to noise without affecting safety and only minor influences on operational 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. A further measure is to increase the glide slope to more than 3.0° which leads to the primary effect of more distance to the ground and therefore to lower noise. Fig. 2 shows the Steep-*LDLP* (*SLDLP*) with a 3.5° glide slope angle compared to the *LDLP* and *OLDLP*. This angle can only be achieved by earlier Flap 3 setting, which means a change in normal flap/gear schedule.

Glide slope angles steeper than 3.5°, as 4.0° or 5.0°, require a gear deployment before the intercept take place (Fig. 3). The maximum reachable angle amounts to 6.0° and can be flown only with early gear down and early full landing flaps. Nevertheless, the more resulting gear and airframe noise is lower than the benefit from more height (Fig. 4). Fuel consumption and time need decreases also with the increased glide slope (Fig. 5). The limit of 1000 ft/min rate of descent is reached performing a 4.0° approach.

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**Fig. 2: Flight States, Inputs and Noise for Optimized (OLDLP) and Steep (SLDLP) Low-Drag-Low-Power Flight Procedures [4]**

**Fig. 3: LDLP with different glide slope angles**
Regarding the A320 aircraft, glide slope angles up to 3.2° do not need any procedural changes theoretically. A comparison of 3.2 and 3.0 glide slopes for Runway 25L of Frankfurt/Main Airport shows Fig. 5. The expected noise benefits will be achieved by:

- The 3.2° flight path is up to 246 ft higher and the ILS intercept is 0.7 nm closer to the airport.
- The flaps deployment before 3.2° ILS intercept may also be 0.7 nm closer to the airport.
- The gear deployment on 3.2° ILS is 0.4 nm closer to the airport, assuming that the height for "gear down" is the same.
- The required thrust increase on 3.2° to stabilize the aircraft is 0.3 nm closer to the airport.
- The required thrust on 3.2° ILS is lower.
- More space to the noise sources, later deployment of flaps and gear, later thrust adjustment and lower thrust leads on 3.2° ILS to 1-2 dB lower noise.

Full Flight Simulator Investigations

Only Full Flight Simulator Tests could give significant answers to safety and operational aspects of steeper landing approaches. Therefore, simulator trials were performed using the A330/A340 Full flight Simulator at the Zentrum für Flugsimulation, Berlin, Germany during three weeks in June 2009. The used aircraft model was a qualified model of an A330-322 preferentially applied by TU-Berlin for research purposes [5]. Using this model a comprehensive data recording and modifications of implemented software were possible. For instance, the ILS glide path angle could be set to 3.2° and 3.5°. Since no visual simulation of the projected north-west runway was available, the simulated final approaches were performed to the existing Runway 25L, which was truncated optically to 2800m. An adaption of the Precision Approach Path Indicator (PAPI) to the respective ILS glide slope assures that deviations from the required flight path can also be detected optically. The aircraft weight was
maximum landing of 179 t and the weather complied with CAT-I conditions (day, ceiling 950 ft, and visibility 8 km).

All participating pilots were male, came from German Lufthansa on a voluntary basis and all sessions were filled with complete crews. The demographical data show a uniform dissemination of the age brackets with a medium age of 43 years. The fulfilled flight hours have peaks at 4 to 6 thousand and 12 to 14 thousand which can be allocated to the groups of “first officer” and “captain” and a mean value of thousand flight hours indicates very experienced crews.

Preparing the simulator tests 3 technical sessions and 1 final session were performed. During the actual test phase 8 sessions with 4 hours test time took place. With 22 simulated approaches per session the study contained 176 trials in total:

- 64 approaches with 3.0° glide path and Flaps 3 as final configuration
- 32 approaches with 3.2° glide path and Flaps Full as final configuration
- 64 approaches with 3.2° glide path and Flaps 3 as final configuration
- 16 approaches with 3.5° glide path and Flaps Full as final configuration.

In addition to the glide path angle and the final flap setting scenarios like tail-/crosswind, engine failure/go-around and heavy gusts were analyzed. The simulator test matrix (Table 1) was a trade-off between analyzing a lot of different parameters and having enough runs for a statistic evaluation in the limited time frame.

Table 1: Simulator test matrix

<table>
<thead>
<tr>
<th>Glide Path Angle Conditions</th>
<th>3.0° Flaps 3</th>
<th>3.2° Flaps 3</th>
<th>3.2° Flaps Full</th>
<th>3.5° Flaps Full</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Tail- / Crosswind</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Engine Failure / Go-Around</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Heavy Gusts</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>4</td>
<td>8</td>
<td>2</td>
<td>22</td>
</tr>
</tbody>
</table>

A comparison of all simulator runs is shown in Fig. 7. The three approach angles 3.0, 3.2 and 3.5 could be identified clearly. Furthermore, three kinds of go-around were performed, whereof the reasons will be explained later. All runs show an individual speed management combined with a lot of thrust activities which will produce a lot of unnecessary noise. Gear and flap deployment seems to be closer to the airport if the glide slope angle increase. The overshoot of the altitude at glide path intercept resulted from the thrust controller.
Safety requirements for the landing approach are the compliance with minimum and maximum speeds, the compliance with maximum deviations from glide path and the compliance with maximum sink rates. The minimum speed is protected by thrust control. If the glide path deviation is greater than ± 0.5 dot the pilot and/or if the sink rate is more than 1000 ft/min below 1000 ft height the pilot has to initiate a go-around. Furthermore, a safe go-around has to be ensured.

The mean vertical deviations from required glide path are very small. There is no remarkable dependency on the glide slope angle. Flaps Full shows a little higher deviations. The mean values of the sink rate are not greater than 1000 ft/min. For the same final flap setting the mean values increase for steeper approaches. For Flaps Full instead of Flaps 3 and the same glide slope angle the sink rate decreases due to lower approach speed. For tailwind conditions the sink rate is in principle higher.

Besides the mean values of the sink rate the number of runs with temporarily more than 1000 ft/min are of interest. For headwind conditions and Flaps 3 the number of runs increases from 4 to 5 going from 3.0° to 3.2°, which is not statistically relevant. For tailwind conditions an increase from 5 to 14 runs occurs, which has to be regarded as critical. Furthermore, the increase from 6 to 11 runs going from 3.2° to 3.5° using Flaps Full seems to be critical.

**Fig. 7: Comparison of all simulator runs**

**Fig. 8: Glide Path Vertical Deviation**

**Fig. 9: Temporarily Sink Rate**
Go-arounds were initiated shortly after the simulated engine failure, after the synthetic call out "Go-Around, Wind-Shear Ahead" near to the threshold with one engine operating only or after a heavy crosswind gust. A dependency of the go-around initialization and realization flying the 3.2° glide slope could not be found.

To gain all noise benefits from a 3.2° glide slope Flaps 2 and gear-down initialization should be closer to the airport. Fig. 10 shows the mean distances of Flap 2 initialization, which achieve nearly the theoretical expected values. Tailwind leads independent from the glide slope elevation to an earlier Flap 2 initialization, probably because pilots expect problems reducing the speed after glide path intercept. A reason for the differences between Flaps 3 and Flaps Full for final configuration on 3.2° glide slope could not be found.

Landing gear deployment is usually at 2000 ft height. The simulator study shows for 3.0° glide slope a mean value of 2.100 ft, 100 ft more. On 3.2° and headwind conditions the gear deployment height increases somewhat, with tailwind there is a considerable increase. Apparently the pilots anticipate difficulties with speed reduction and therefore deploy the gear earlier to have a better deceleration capability. Maybe that on 3.5° these difficulties are expected for headwind conditions also, the mean gear deployment height increases to 2.320 ft. On a steeper glide path the gear-down point is closer to the runway, assumed that the height remains equal. The theoretical value for a 3.2° glide slope is about 0.4 nm and is shown as well by the simulator study (Fig. 11). For tailwind conditions the gear-down point does not move so close to the runway, because the gear down initialization height increases. For the 3.5° glide slope there is no further remarkable movement to the runway due to same reason.

As described already before on a steeper descent the gear deployment happens closer to the runway and then the distance to the outer marker becomes also shorter. Therefore and due to the steeper glide slope angle less speed reduction is feasible until reaching the outer marker location. So on 3.2° glide path and headwind conditions the speed at outer marker is 3 kt and for tailwind conditions 4 kt higher (Fig. 12). Using Flaps Full as final flap setting more speed reduction is possible. But at 1.000 ft stabilization height the target speed is reached in all runs (Fig. 13).
The flight time decreases for steeper approaches because the aircraft intercepts the glide slope later and therefore moves longer with a higher speed. A comparison between the investigated glide slope angles using the same final flap setting shows this effect in the simulator data (Fig. 14). The mean landing distance decreases if the glide slope angle increases, which is mainly caused by a shorter flare distance. Using Flaps Full the landing distance decreases as well because the landing speed becomes lower (Fig. 15). But remarkable positive influences on the runway capacity from lower flight time and shorter landing distance are not expected.

The required engine thrust, respectively the engine rpm, decreases on a steeper descent flying with constant airspeed (Fig. 16). Due to the lower thrust the fuel consumption decreases also, but only by a small amount. A higher final landing flap setting leads to a higher drag and requires a higher thrust. The associated fuel consumption increases significantly (Fig. 17).

At the end of each simulator session the pilots had to fill out a questionnaire which was subdivided into the groups:

- General questions
- Training state and experiences with steep approaches
Most pilots performed about 20 landing approaches during the last 12 months, two pilots 50 and more, one pilot only 2. The quantity of 22 landing approaches during one simulator session was nearly the same as during one year in real flight. Most pilots had less than 20 flights with steep approaches, but 4 pilots had 60 and more. The questions about acceptance contained safety, pilot workload, training time and effort and operational applicability issues. 13 of 16 pilots agreed totally with the statement that a 3.2° glide slope is just as safe as a 3.0° glide slope, 3 pilots agreed partially. For 9 of 16 pilots the final flap position 3 was as safe as the position Full. The majority of pilots negated a higher workload of a 3.2° compared to a 3.0° approach. This held also comparing Flaps 3 to Flaps Full as final flap setting. All pilots agreed with the statement that the training time and effort of a 3.2° approach is equal to a 3.0° approach, 10 of 16 pilots agreed totally. All pilots agreed with the statement that 3.2° approaches are operationally applicable, 13 of 16 pilots agreed totally.

Three landing approach segments had to be assessed by the pilots:

1. Horizontal flight until glide path intercept
2. Glide path intercept until 1000 ft stabilization height
3. 1000 ft stabilization height until stop on the runway

There were no noticeable problems or appreciable aspects for the 1. Segment. For the 2. and 3. Segment the general demands increased with increased glide slope and decreased with increased flap position, but both only by a very small amount (Fig. 18). The assessment of the speed control led to the same results (Fig. 19).

The sink rate on 3.2° glide path for segments 2 and 3 was assessed as passable by the pilots. The decision for a go-around was not at all affected by the higher glide path (14 of 16 pilots). This is also true for the go-around procedure itself.

**Portability of Simulator Test Results**

The results of the simulator study show that the Airbus A330 has no problems to reduce the speed on a 3.2° glide path and that the pilots do not change the common flight operating
procedure. Technical, time and cost reasons do not allow performing additional simulator studies with other aircraft types and crews from other airlines. Investigations by performance calculations and fast time simulations with other aircraft, consulting other airlines than German Lufthansa and searching the operations manuals can satisfy the portability of some simulator test results. The following aircraft and airlines were selected for these investigations: Airbus A330-300 (Lufthansa Passage), Airbus A320-200 (Lufthansa Passage, Air Berlin), Airbus A380-800 (Lufthansa Passage), Boeing B737-300 (Lufthansa Passage), Boeing B737-700/800 (Air Berlin), Boeing B747-400 (Lufthansa Passage), Boeing B767-300 (Condor), McDonnell Douglas MD-11F (Lufthansa Cargo), Bombardier CRJ-900 (Lufthansa CityLine), Embraer E-190 (Lufthansa CityLine) and British Aerospace BAE-146 (Lufthansa CityLine). Only the Airbus and Boeing aircraft could be investigated by fast time simulations due to availability of performance input data from the EuroControl BADA database.

Based on airspeed of 195 kt at glide path intercept the fast time simulation provides the height where the aircraft reaches 170 kt, assuming maximum deceleration. This height should be greater than 2000 ft, so that the pilot does not tend to deploy the gear sometimes earlier. The second part of the final landing approach reaches from 2000 ft until 1000 ft where the aircraft has to be established on speed, glide path and thrust. During the flight between these heights the gear deployment takes place, the final flap setting is performed and the speed is reduced to landing target speed.

All considered aircraft achieve the intended speed of 170 kt on 3.0° and 3.2° glide slope until 2000 ft height. On 3.5° glide slope the A320, A380 and B767 need a larger height difference to decelerate (Fig. 20). All aircraft could decelerate on all considered glide slopes from 170 kt to landing speed before reaching the height of 1000 ft (Fig. 21). Changes of flight operation are not necessary on 3.2° approaches because the target speed was reached on time.

The operations manuals of the considered aircraft types contain no instructions to change the approach procedure on 3.2° glide path, except for the recommendation to use maximum flap position for a glide path greater than 3.0°. Already today a lot of airports operate with glide slope angles of more than 3.0° until 4.0° due to obstacle clearance. The respective approach procedures do not differ from the standard. In principle it is the pilot’s decision, how to organize the landing approach considering safety requirements, demands of air traffic control, cost effectiveness and noise abatement. May be in future the last two items will be change in priority.

Fig. 20: Final Height (1) after Speed Reduction

Fig. 21: Final Height (2) after Speed Reduction

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Conclusion

Steeper landing approaches can lead to a significant noise and fuel reduction. Having regard to the sink rate limit of 1,000 ft/min below 1,000 ft height they can be performed only up to 4.0° glide slope angle. In addition a change of gear/flaps schedule is necessary to fly approach angles of more or equal 3.5°, which can reduce the noise benefit gained from the higher flight path.

The results of the simulator study have shown that a 3.2° glide path does not lead to any safety problems, that modifications of the approach procedure are not necessary and that the pilots did not perform any procedural changes. Operations in tailwind conditions on a 3.2° glide slope and a further increase to 3.5° may induce too high sink rates in piloted flight associated with the risk of a go-around. Based on the results from fast time simulations of multiple Airbus and Boeing aircraft, consulting other airlines and searching the operations manuals the portability of some simulator test results could be ensured.

The theoretically predicted noise benefits due to a 3.2° glide slope angle were confirmed in the full flight simulator study. However, the benefits were slightly smaller than expected. Only direct noise measurements from real flight operation will provide the final proof.

Future operation using the Ground Based Augmentation System (GBAS) will offer the potential of individual aircraft performance related glide slopes, which lead to a maximum of noise reduction and a minimum of fuel consumption.

References


