Evaluation the influence of noise abatement procedures to pilot’s workload and safety by using an Airbus A330/340 Full Flight Simulator

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Abstract Future growth of air traffic leads to higher noise emissions, even if new or modernized aircraft will improve this situation. A possible mitigation strategy is the development and validation of noise abatement procedures. However, new aircraft operating procedures will affect flight safety, aircraft performance, crew workload and pilot acceptance. Therefore, evaluation of technical aspects in particular with regard to human factors is essential. An \textit{Airbus A330/340 Full Flight Simulator} installed at the \textit{Institute of Aeronautics & Astronautics (Technische Universität Berlin, Germany)}, linked with a special experimental environment (\textit{Scientific Research Facility}), assures high quality results in these fields of research.

The evaluation of human factors based on recording of physiological parameters (\textit{Eye-tracking, Electrophysiology}), subjective measurements (e.g. questionnaires / interviews regarding fatigue, sleepiness, tension, workload and acceptance) and multi-video / audio data. In addition, specific technical parameter from the simulation process (such as flight aerodynamic/mechanical data, deviations and indications) and pilot’s interaction with the cockpit human machine interface were recorded.

To obtain highly accurate and reliable data fully rated line pilots will have to take part in any research investigation. Additionally the simulator setup and definition of accurate scenarios and exact reproduction are key features of the available experimental system. Therefore, involvement of airlines and air traffic control are required in defining realistic scenarios (\textit{Crew Coordination Concept / Standard Operation Procedures}).

Different research projects at our Institute keep focus on evaluation of new operational procedures, pilot’s workload and new or modified avionic systems. This lecture gives a detailed overview of our simulator experimental environment and presents initial results from an simulator based project related to noise abatement procedures (Partners: \textit{German Aerospace Center} (DLR) and \textit{Lufthansa German Airlines / The German Ministry of Research and Technology} supported this study).
1. INTRODUCTION

The increased number of jet flights and growing number of regional airports in association with the increased density of urbanisation, have given rise to much greater intrusion of aircraft noise on community life and hence to noise exposure. Community noise is today cited as a major problem to be solved by all transport industries (road, rail and air) particularly if current growth is to be pursued.

Besides new and quiet aircrafts (like A380 and the planned B787) with reduced engine and airframe noise, an update of existing approach and take-off procedures for short-term improvement must also be applicable to most of the existing aircrafts. Important influencing variables for new procedures are safety-critical items (compliance with air law requirements and airline standard operating procedures) and economical matters (fuel flow, flight time, engine stress). In addition, pilot acceptance and a non-increased workload should be guaranteed. Therefore, investigations of noise abatement procedures within simulator studies for evaluation of technical aspects, as well as human factors analysis are necessary.

An Airbus A330/340 Full Flight Simulator (FFS) with dedicated Scientific Research Facility (SRF) at the Institute of Aeronautics & Astronautics (Technische Universität Berlin) as experimental environment ensures high quality results in these fields of research.

2. EXPERIMENTAL ENVIRONMENT: A330/340 FULL FLIGHT SIMULATOR WITH DEDICATED SCIENTIFIC RESEARCH FACILITY

The Airbus A330/340 Full Flight Simulator, manufactured by the Canadian company CAE Electronics Ltd., located at the Institute of Aeronautics & Astronautics of the Technische Universität Berlin (TUB) is operated by Zentrum für Flugsimulation Berlin GmbH (ZFB) since 1993. The use of a FFS for research as well as airline pilot training was conceived already in 1980 [6].

The Airbus A330/340 FFS in Berlin is qualified according to JAR-STD-1A (Level DG) and the first worldwide having a dedicated Scientific Research Facility (SRF).

Figure 1: A330/340 FFS and Reference Aircraft A330 D-AERF from LTU. [7]
The Figure 1 shows an outside view of the flight compartment on motion base (left), one of the simulated aircrafts (LTU A330-322 D-AERF) and the direct view into the cockpit (right below). Visible are the original instruments and the realistic outdoor view, which is based on a 3D-computer animation. This animation is able to simulate day, night, dawn and various types of meteorological effects.

The A330/340 FFS and the SRF consists of several IBM RISC6000 workstations providing all necessary functions to develop and apply user-appropriate simulation software. The research host computer, as main part of the SRF, being identical to and independent from the training host computer, but provided with additional scientific features such as:

- **direct simulator source code access** for the complete aircraft and avionics software located on the research computer,
- **avionics software simulation** that emulates avionics computers normally installed as “hardware in the loop”, e.g. Flight Management System (FMS), Flight Guidance System (FGS) and Flight Envelope System (FES),
- **display development/ operator station computer** enabling rapid prototyping of highly dynamical graphical displays that can optional be installed into the cockpit environment,
- **re-configurable test bench** providing an interface to connect user-designed or type-unfamiliar avionics boxes into the simulation process,
- **audio, video and data recording** facility,

and will be used for software development and validation. One main advance of this approach is the separation of the training environment from the research environment [7].

To guarantee highest quality of flight simulation, original avionic components and computers are used. In addition, for the complete cockpit environment e.g. displays, flight controls, switches etc. only original components are used. On the other hand, the host computer realizes the simulation of all not available components such as the flight mechanical model, aircraft’s sensor technology, atmospheric model, engines, hydraulic and any other sub-system available in the real aircraft. For exact calibration of simulator’s behaviour and performance, flight test data from the reference aircraft are used. One of the outstanding characteristics of such a simulation is the perfect connection, communication and interaction of original aircraft avionics with simulated components. Requirements for this are an all-embracing network and the consequent management of all simulation parameter on the simulation host computer inside a so-called **Common Data Base** (CDB). The CDB consists of approx. 90,000 parameters, which can be monitored, recorded and modified on-line. The simulation host computer does not comprise other important simulation systems such as the visual system, motion and control loading system and two **Instructor Operational Stations** (IOS) in the flight compartment. Those systems are connected via the simulation network.

Closed circuit TV cameras are accomplishing video recording. Two monochrome low light cameras (back view) equipped with exchangeable lens can be installed in the cockpit to record the pilot’s and co-pilot’s actions as well as to provide a centre view. For the ESSAI project [3], an additional wide view micro camera was integrated into the front area of the flight compartment to record and observe pilot’s interactions from front view. A video scan converter is used to convert the RGB signal of one IOS to a video signal. Three Super VHS video recorders are installed off-board and can be controlled from the instructor station. Three table mounted monitors are installed in the SRF Control Room (see Figure 2).
3. NOISE ABATEMENT PROCEDURES

A first step to noise abatement can be realized with flight procedures without the need for additional equipment (or modification of existing equipment) or tools for the aircraft or Air Traffic Control (ATC). Therefore, flight procedures have been considered with:

- increased final approach altitude,
- (slightly) increased glide slope angles,
- delayed flaps and/or gear approaches,
- reduced final landing flaps settings,
- continuous descent approach.

When looking at a typical instrument approach procedure, like the Low Drag Low Power (LDLP) procedure in Figure 3, there is a horizontal flight segment to intercept the final descent gradient. This level portion of flight is usually combined with flying at a relatively high thrust setting when the aircraft is intercepting the Instrument Landing System (ILS) glide slope from below.

The Figure 3 shows the different examined approach procedures by our partner DLR Institute of Flight Systems (Brunswick, Germany) in so-called Fast Time Simulation Studies [4]. The change of an approved standard operation procedures due to lower noise emission causes an multidisciplinary design problem involving generic aspects like air law regulations (e.g. ICAO PANS-OPS [2]), airline safety, ATC capacity, cost benefit and user acceptance (pilots and air traffic controllers) and also archive airport specific conditions like general traffic flow and geographic limitations.

The special designed Segmented Continuous Descent Approach (SCDA) was selected to be investigated with simulator based studies, because of most suitable for the given demands (noise reduction, feasibility with modern flight guidance systems, safety with compliance to
required stabilization height, passenger comfort and economic efficiency) in consideration with a suggested slightly increased work-load for the pilots [5].

Figure 3: Vertical flight profile of different noise abatement approach procedures.[4]

4. SIMULATOR BASED STUDIES

4.1 Flight Test Scenarios and General Experimental Conditions

For investigations on the operability of noise optimized approach procedures, some demands were defined:

- using experienced and type rated pilots as volunteers,
- scoring a standard operation procedure (LDLP) in comparison with only one experimental scenario (SCDA) for noise abatement,
- examine physiological and psychological functions with additional instructor scoring,
- choosing odd times of the internal clock (night duty).

Figure 4 shows the two different approach procedures on so-called “flight test cards” based on performance calculation for the Airbus A330 done by DLR Institute of Flight Systems (Brunswick, Germany). The boundary conditions for both scenarios are equal: Airport EDDM Munich, Germany / Runway 08L / ILS approach system / gross weight of 164 tons and fuel freeze on / no wind and special weather effects / Clouds and Visibility O.K. (CAVOK) / daytime “Night”.

Today’s standard operating procedure for an instrument approach of major airliners like Lufthansa German Airlines is the Low Drag Low Power Approach (LDLP):

0. The procedure starts with constant speed of 250 kts and level flight in 9,000 ft Above Sea Level (ASL) with auto flight system (auto pilot / flight director / auto thrust) activated on Flight Control Unit (FCU).
1. At the Point of Descent (POD) an “Open Descent” down to 5,000 ft ASL will be performed by the crew, which results in an Idle Thrust Setting by the auto thrust system with constant speed control by the autopilot via the pitch axis.
Figure 4: Experimental Scenarios (LDLP & SCDA).
2. The next phase is an intermediate altitude hold at 5,000 ft with speed reduction to clean maneuvering speed (selected speed of 205 kts on FCU) and arming the “Approach Mode” of the of the auto flight system. To maintain constant speed and altitude the thrust has to be increased by the auto thrust system, what is followed by an increase of engine noise emission.

3. On “Glide path alive” (movement of diamond symbol on Primary Flight Display) Flaps 1 will be selected by the crew, with further speed reduction to 170 kts for next Flaps 2 setting.

4. After setting Flaps 2, the autopilot will intercept the glide path from below and fly down the aircraft with speed nearly constant at 170 kts.

5. Gear extension will be at 4,000 ft ASL with deceleration to final approach speed by pushing the speed to “Managed Speed Control” on FCU.

6. Following by next flaps setting (Flaps 3) if Gear is down locked.

7. Final flaps extension (Flaps 4) follows direct after Flaps 3 indication. Gear and final flaps extension on glide path results in low drag with low thrust level on auto thrust system as well as low noise emission.

8. The aircraft has to be stabilized in final configuration at 2,500 ft above sea level (1,000 ft on radio altimeter) due to airline standard operation procedures.

9. Finally the crew can perform a manual landing.

The **Segmented Continuous Descent Approach (SCDA)** was selected as reduced noise but non-standard approach for the simulator experiments:

0. The SCDA procedure starts with same conditions (also release point) as for the LDLP scenario.

1. The later POD at 29.1 NM to DMN DME, resulting in a 4.9 NM longer level flight than on LDLP procedure. The crew has to select a flight path angle (FPA) of -2.6° to 2,700 ft ASL (safe altitude down to outer marker to avoid aircraft level off) and select approach speed of 135 kts as target speed for the complete approach (because of auto thrust function will adjust speed via thrust before reaching next minimum configuration speed if speed is managed). The aircraft will fly down with nearly constant speed of 250 kts with thrust at idle (auto thrust speed function).

2. At 7,000 ft ASL, the crew reduces FPA to -1.0° for deceleration of the aircraft.

3. Clean speed +10 kts = 215 kts is the speed for Flaps 1 extension.

4. Next proposed speed by flight envelope function (VFE\(_{\text{NEXT}}\)) – 10 kts = 195 kts, is the speed for Flaps 2 setting by the pilots.

5. Direct after Flaps 2 extension the gear has to be extracted. The thrust of the Engine gets up to “Approach Idle” (automatic function of the Full Authority Digital Engine Control System [1]).

6. Gear down and locked has to be followed by a steep descent with -5.5° FPA select on FCU and directly flaps 3 setting by the crew.

7. After Flaps 3 extended position, final approach flaps have to been set immediately.

8. If Flaps 4 are extended the “Approach Mode” can be armed. If everything is done in time, the aircraft will fly down the steep approach with speed at 160 kts with auto thrust speed function at idle thrust. The glide slope will be captured from above by the autopilot before outer marker.

9. The aircraft has to be stabilized in final configuration at 2,500 ft above sea level (1,000 ft on radio altimeter) due to airline standard operation procedures.

10. The crew now can perform a manual landing.
4.2 Physiological and Psychological methods

For scoring, the pilot workload different physiological and psychological measures are used by the DLR-Institute of Aerospace Medicine (Cologne and Hamburg, Germany):

- **Questionnaires** on Fatigue, Sleepiness, Alertness, Tension and Workload (NASA TLX, Task Load Index) between the scenarios, De-briefing questionnaire for each crew member after the complete simulator session,
- **Examinations / Judgements** by Check-Captain during/after each scenario,
- **Physiological objective measurements**: Blood Pressure and Cortisol (Saliva) between all scenarios; Brain Waves (EEG), Eye Movement (EOG) and Heart Rate (ECG) were conducted continually.

4.3 Simulator Data Gathering

The Data Gathering Utility (DGU) is a tool to create log files of the simulation state as stored in the CDB. Up to 197 parameter were selected for recording and written in a DGU profile file. The DGU scans this profile in regular intervals (here: 5 Hz) and writes all values to be logged as specified by the profile into a binary file on the host computer.

The technical data recorded in our experiments were arranged in eight mainly groups:

- **Generic simulator data**, such as freezes, positions (e.g. latitude, longitude and height), flight mechanical and aero dynamical data.
- Flight guidance data shown on **Primary Flight Display (PFD)** with “basic-T” information, like speed, attitude, altitude and course of the aircraft.
- The **Flight Mode Annunciator (FMA)** also located on PFD shows all information about auto-flight system data (Autopilot/Autothrust).
- Complete data input on **Flight Control Unit (FCU)** for handling of auto-flight system.
- Settings on **Electronics Flight Instrumentation System (EFIS)** separated for captain and first officer.
- **Aircraft controls** such as flaps/slat handle and side stick, rudder and thrust lever inputs by the pilots.
- **Engine parameters**
- 20 special parameters for **noise calculations** such as netto thrust and aircraft surface positions.

Aim of the recorded Data is to get a nearly complete snap-shot of the pilot’s human-machine-interactions and can be used for later detailed statistical analysis and software development for the planned automation of the SCDA procedure in the software avionic system.

4.4 Simulator Test Procedure

Due to assessment of pilot workload with the two selected scenarios, 40 pilots in total were tested either on the introduced simulator in Berlin (twenty A330 volunteers from different airlines) or on an A320 FFS in Frankfurt (twenty A320 pilots provided direct from Lufthansa German Airlines). The overall pilot experience (average) was 11 years with an average of 6,080 flight hours total (3,500 flight hours on airbus type).

The volunteers received a project introduction and a technical briefing one hour before the experimental session. The pilots were equipped with electrodes for the ECG/EOG/EEG just
before entering the cockpit at exactly midnight (00:00). Both pilots, the captain and the first officer, flew one LDLP Procedure as reference first. Then one SCDA Procedure for training was flown before a short break. The duration of each Procedure was about 12 minutes, with 5 min in addition for the questionnaires, Blood Pressure and Cortisol (Saliva) measurement between all scenarios. After the short break, each crewmember flew two SCDA Procedures for examination. The session closed with a debriefing containing several questionnaires and an individual interview outside the simulator.

### 4.5 Experimental Results

The evaluation of the measurements showed no significant differences in terms of tension and workload between both approach procedures. Fatigue and Sleepiness increased significantly depending on time-on-task, but hardly on procedure. The Pilot Flying (PF) judges work load higher than the Pilot No Flying (PNF), but independent from procedure. There are no differences of blood pressure or substantial change of objective stress (depending on Cortisol and mean heart rate) between the procedures. The subjective operability and acceptance (safety) is lower for the SCDA procedure. This result based on NASA TLX and on pilots answers in the post study questionnaires.

The feedback of the pilots was collected in the post study questionnaire, with many “open questions” regarding procedure design and technical aspects on the new approach procedure SCDA:

- The pilots need **more displayed information** and handout charts for the SCDA procedure in the cockpit. A symbolism for information if the aircraft is “on profile” likes the current Glide Slope Indicator.
- More **Automation** like a “fully managed approach”, with performance and predictions calculation of the FMS to get sure the glide slope will be intercepted from above under safe conditions.
- **Changes in procedure design:** One segment less and a reduction of necessary pilot interactions before the Steep Descent.

The average rating of the instructor for all pilots was very high, this means the pilots were high experienced and the crew procedures were well coordinated.

The first evaluation of the simulator technical data was done by the DLR Institute of Flight Systems (Brunswick, Germany) with focus on operability, reliability on flight profile and noise benefit [4]. At the SCDA procedure the pilots often delayed the point of descent. Also many actions from the flight test card for flaps setting, gear and the necessary change of the FPA to go down the steep descent gave a great variation of flight profiles within this segment of the SCDA. Also in some cases the actual flight paths were lower than the planned and therefore the glide path intercept was earlier. This produces an earlier thrust adaptation and an increase of noise emission. Corrective arrangements could be a better indication/automatic point of descent and flap/slat gear extension for reduction of workload and a reliable flight profile.

### 5. SUMMARY AND CONCLUSIONS

The full flight simulator studies showed that the experimental SCDA procedure is feasible after an adequate briefing of the crew. There were no safety critical flight states during the simulator runs. The workload was subjective stated by the pilots as higher than the standard
LDLP procedure depending on missing automation but not as critical. Objective physiological data did not show significant differences between the procedures.

There was a demand by the pilots for additional functions of the existing Flight Management System due to desirable Automation of the SCDA procedure. For a medium-term improvement of noise abatement procedures, the software of the existing FMS and affected systems like Electronic Flight Instrument System (EFIS) displays and also flight guidance and engine control has to be modified.

The avionics software simulation of the Scientific Research Facility as part of the A330 FFS in Berlin offers the capabilities to implement and present such features to the pilots:

- new **displayed information** like an information if the aircraft is “on profile” on the Primary Flight Display,
- **performance and predictions calculation** by additional functions of the FMS to make sure the glide slope will be intercepted from above under safe conditions,
- automated flap/slat and gear setting to achieve a “**fully managed approach**” and guarantee a precise timing.

The demands of the pilots, combined with airline operational aspects have to be the basic principle for implementation and approval. New simulator-based studies can be reasonable to realise an intuitive an easy to handle human-machine interface and check manageability and acceptance by experienced pilots in their typical working environment.

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