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ERAS- Evaluation of realistic approach scenarios for minimal noise - preliminary findings

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Abstract

During approach to an airport aircraft as noise sources change along the approach paths they travel. Extension of slats, flaps and landing gear will affect aerodynamic noise and as a consequence of increased drag also engine noise will be affected. In the ERAS-project the overall possibilities at an airport to reduce noise by implementing operational procedures for arriving aircraft is evaluated. As a first step a number of aircraft types were selected and the operational descriptions in the Aircraft Noise and Performance database (ANP), maintained by Eurocontrol were compared to the operational descriptions in the aircrafts' operating manuals (FCOM). One aircraft type where discrepancies was found between the ANP and the FCOM and where flight data from real flights were available was selected for further analysis. Flight data recorder data from 1 357 flights were analyzed in order to find operational possibilities and limitations. Based on the outcome from actual flights and the FCOM, twelve operationally feasible approach scenarios were developed in which noise and fuel calculations were performed for the developed scenarios. The results suggest that there exists possibilities for airports to reduce both noise and CO_2 emissions by implementing operational recommendations for landing aircraft.

Keywords: aircraft noise, airport noise, aircraft operations

1. Introduction

Aircraft noise in the proximity of an airport is in many cases a disturbance for nearby residents. The noise can either be a source of minor irritation, or it can be the cause of somatic illnesses [1] that will lead to costs at an overall societal level and also to personal inconveniences for the affected persons. Minimization of noise is therefore generally accepted to be fruitful both at an individual level and for the whole society and as a consequence legislation may be required. On June 25th 2002, the European Parliament adopted a directive on the assessment and management of environmental noise [2]. As a result, the European Commission has developed Common NOise aSSessment methOdS (CNOSSOS-EU) for environmental noise [3]. For the calculation of aircraft noise, the 4th edition of document 29, from the European Civil Aviation Conference (ECAC Doc 29) is therefore used. ECAC Doc 29 is in its turn supported by a database, the Aircraft Noise and Performance database (ANP) [4], which is maintained by Eurocontrol. The ANP database describes both noise levels and how each specific aircraft type is expected to be operated during take off, approach and landing. In ECAC Doc 29 however, it is stated that *"Users should examine the applicability of ANP database default 'procedural steps' to the airport under consideration. These data are generic and in some cases may not realistically represent flight operations at your airport"* [5]. A statement that makes it plausible to further investigate how aircraft are actually operated into airports under different circumstances.

The way a given aircraft is operated into a given landing runway is heavily dependent on how the individual pilot flying the aircraft is handling the aircraft on its way to the landing. A pilot performing an approach into a runway must adhere to several regulatory based restrictions. The approach path to fly is designed according to a regulatory framework [6] based on annexes published by the United

Nations specialized agency the International Civil Aviation Organization (ICAO) and as implemented in the country of operations [7]. The pilot must also operate according to the individual airline's standard operating procedures (SOP), which is based both on requirements in the ICAO annexes, the aircraft flight manual (AFM) from the airframe manufacturer and the legislation in the country of where the aircraft operator is registered.

In practice, all these regulations will sum up to that the aircraft should not be operated faster than 250 knots (kts) of indicated airspeed (IAS) below an altitude of 10 000 feet (ft) and that the aircraft shall be established in landing configuration at the correct speed, the correct rate of descent and along the intended flightpath at a height of 1 000 feet above the landing runway threshold, the latter height to be reduced to 500 feet if the pilot have the landing runway in sight at 1 000 ft [8] [9].

Also affecting the operation of the aircraft is the intervention of air traffic control (ATC) in order to sequence traffic using radar vectors, speed control and segments of level flight, which is necessary at large airports with a lot of departing and arriving traffic and also based on regulatory framework from ICAO [10].

The most common approach type at major airports is the instrument landing system approach (ILS), where the aircraft is guided horizontally by the localizer signals (LOC) and vertically by the glide slope signals (GS). The standard ILS glide slope angle is 3.0° although variation may occur. To reach the desired landing speed the pilot needs to slow the aircraft down by a combination of level flight segments, increased drag and thrust reduction. When the aircraft is flown along the ILS glide slope, increased drag is primarily created by extension of trailing edge flaps and the landing gear.

From earlier research [11] it was noted that before the approach is executed the pilot creates a mental model of the approach he/she is going to fly. This mental model is created to be within the operating limitations of the SOP for the given airline and aircraft type. Since the SOP varies between airlines and the pilot have a certain degree of freedom of when to extend slats, flaps and landing gear as long as it is done within the SOP, there will be a distribution of different operational behaviors when it comes to extension of slats, flaps and landing gear, and the use of engine thrust. The same earlier research also noted that the mental model is adjusted during the execution of the approach and that the mental model itself can differ from how the pilot actually executes the approach. Since the extension of slats, flaps and landing gear creates drag, both aerodynamic noise as well as engine noise can be expected since thrust requirements are affected and thus influencing the characteristics of the aircraft as a noise source [12] [13]. So even during similar pre-existing conditions, such as weather and aircraft mass, the resulting environmental noise footprint and fuel consumption will differ between various approaches, even when conducted by the same pilot.

The aim of the research covered in this paper is to address if noise can be reduced or minimized with the implementation of operationally viable approach procedures for one specific aircraft type, the Airbus A321-251N (A321Neo).

2. Method

2.1 Review of FCOMs, Comparison with ANP and selection of aircraft type

FCOMs and when possible also Flight Crew Training Manuals (FCTM) for Boeing aircraft, or Flight Crew Techniques Manuals (also FCTM) for Airbus aircraft were collected and the approach procedures were analyzed for seven different aircraft types; the Airbus A320 [14] [15], A330 [16], A340 [17], A350 [18] [19], Boeing 737 [20] [21], Boeing 777 [22] [23] and the Boeing 787 [24]. In this context a wider definition of an aircraft type was used so that sub-versions like the A318/A319/A320/A321 series of aircraft was considered as one aircraft type since this is the practical definition normally used within the FCOM structure itself.

Within the ANP however aircraft types are more specifically defined so that the A320 and A321 is not considered as the same aircraft type. In the ANP there are also distinctions between different versions of one specific aircraft type for example depending on engine type. When the comparison between the FCOM operational procedures and the ANP was performed, considerations were taken to all versions of any specific aircraft type.

In order to have a common reference for an approach to evaluate, a standard 3.0° ILS approach with glide slope interception from level flight at 3 000 ft above ground was defined to be the reference. That operational behavior is also consistent with the operational description in the ANP database. Based on differences between the descriptions in the FCOMs and the ANP database, the points of selection of trailing edge flap extension and landing gear extension was used as the references in order to select the aircraft type to analyze further.

2.2 Review of operational behavior

For the selected aircraft type FDR-data was available from 1 389 flights. All data was handled in an IBM SPSS database and a confidentiality agreement with the airline selected was signed in order to be able to use the data. The average, maximum and minimum extension heights and distances before landing for each slat, flap and landing gear extension was noted. The pilots' use of thrust and speed brake were also evaluated.

2.3 Development of approach scenarios

Four standard ILS approach scenarios possible to fly with the selected aircraft type were designed based on the outcome of the operational behavior analysis. One scenario was designed to be in line with the operational description in the FCOM, defined as approach scenario #1 (FCOM), one as close as possible to the average scenario flown as achieved from the FDR-data, defined as approach scenario #2 (Data average), a high speed as scenario #3 (High speed) and one as a low speed scenario defined as approach scenario #4 (Low speed). Each approach scenario was then slightly modified in order to be evaluated also for glide slopes at 2.5° and at 3.5°. These approach scenarios were numbered as approach scenario #n+4 for the 2.5° scenarios and as approach scenario #n+8 for the 3.5° scenarios, where n = the number for the 3.0° glide slope scenario. All in all twelve scenarios were developed.

In order to prepare for the next phase of the project where all scenarios will be flown in full flight simulators and to facilitate the use of the noise calculation software, the scenarios were implemented as approaches into Stockholm-Arlanda Airport runway 01L at an initial height of 3 000 ft.

2.4 Noise calculations

Noise as the A-weighted maximum noise on the ground (L_{Amax}) was calculated with the aircraft manufacturers Performance Engineer's Programs (PEP) for all approach scenarios for the A321Neo with a landing weight of 73 t. The ICAO standard atmospheric model [25] was used, noise lateral attenuation according to the ICAO SAE AIR 5662 model and the ICAO SAE ARP 866A model for atmospheric damping was used. The model also used a microphone height of 1.2 m above ground. The resolution of the resulting noise grid was selected to be 200 m. Only L_{Amax} levels at or above 40 dB(A) were used in the further analysis.

Approach scenario #2 (Data average) was defined to be used as a reference scenario and the difference between that scenario and the others were calculated.

3. Results

3.1 Evaluation of FCOMs and ANP

The operational behavior as described in the FCOMs and the ANP is summarized in Table 1 below.

Table 1 – Description of operational behavior in the ANP and the FCOM.

A/C type and document	**Point for initial flap/slat setting**	**Height for intermediate flap setting [ft]**	**Height for reduced landing flap setting [ft]**	**Height for landing flap setting [ft]**	**Height for landing gear extension [ft]**
A320 FCOM	Earlier than at 2 000 ft	2 000 ft	Approx. 1 550 ft*	Approx. 1 450 ft*	Approx. 1 800 ft*

A/C type and document	Point for initial flap/slat setting	Height for intermediate flap setting [ft]	Height for reduced landing flap setting [ft]	Height for landing flap setting [ft]	Height for landing gear extension [ft]
A320 ANP	No info in ANP	No info in ANP	No info in ANP	1 819 - 2 003 depending on version.	1 819 - 2 003 depending on version of a/c.
A330 FCOM	Earlier than 2 500 ft height	2 500	Approx. 2 000	Approx. 1 800*	Approx. 2 200*
A330 ANP	No info in ANP	No info in ANP	No info in ANP	1938 - 2144	1938 - 2144
A340 FCOM	Earlier than at 2 500 ft	2 500	Approx. 2 000*	Approx. 1 800*	Approx. 2 200*
A340 ANP	No info in ANP	No info in ANP	No info in ANP	1 650 - 1 976 depending on version	1 650 - 1 976 depending on version
A350 FCOM	Calculated by the FMGS system	Calculated by the FMGS system	Calculated by the FMGS system	Calculated by the FMGS system	Calculated by the FMGS system
A350 ANP	1 950 m - 8 311 m before GS intercept depending on version.	2 709	2 494	2 180	2 709
B737 FCOM	> 2 Nm before GS intercept	Approx. 2 Nm before GS intercept	GS Intercept	GS Intercept	Approx. 2 Nm before GS intercept
B737 ANP	4 678 ft height	GS intercept/ 1 500 depending on version.	1 500	1 000 - 2 817 depending on version	Not described
B777 FCOM	> 2 Nm before GS intercept	Approx. 2 Nm before GS intercept	GS Intercept	GS Intercept	Approx. 2 Nm before GS intercept
B777 ANP	N/A	N/A	N/A	2 700 or N/A depending on version	N/A
B787 FCOM/FCTM	> 2 Nm before GS intercept	Approx. 2 Nm before GS intercept	GS Intercept	GS Intercept	Approx. 2 Nm before GS intercept
B787 ANP	No info in ANP	No info in ANP	No info in ANP	2 725	No info in ANP

**Height is dependent on extension time of previous selections.*

Since there were large discrepancies, or lack of information between the operational behavior described in the FCOMs and the ANP for all aircraft types, the aircraft type to investigate further was based on the best availability of data from flight data recorders (FDR-data) from actual flights. Based on that the A321Neo was selected.

3.2 Operational behavior from actual flights

FDR-data from 1 389 flights into three different runways using ILS-approaches was available whereof 32 flights were excluded, either due to lack of continuous data or the flight not being stabilized at the point where the glide slope should have been intercepted. Hence 1 357 flights were used for further analysis. The distances and heights for selection of slats, flaps and landing gear is found in Table 2 below. It should be noted that the A321 flap 1 position is equal to extension of leading edge slats only.

Table 2 – Average distances or height for configuration changes.

	Distance to THR for selection of slats, flaps or landing gear. [km]				**Height for selection of slats, flaps or landing gear. [ft]**			
	Flap 1 (F1)	**Flap 2 (F2)**	**Landing gear (LG)**	**Landing flap (F3)**	**Flap 1 (F1)**	**Flap 2 (F2)**	**Landing gear (LG)**	**Landing flap (F3)**
max	70,4	48,7	21,9	17,4	11 113	8 976	3 824	3 049
average	25,4	16,2	10,0	7,5	3 928	2 806	1 757	1 331
min	9,7	7,0	5,4	3,3	1 719	1 254	979	625

3.3 Approach scenarios

Twelve different approach scenarios described in Table 3 below were developed and tested for flyability in the PEP. The twelve scenarios were defined to start at a ground track distance of 44 500 meters (m) from the landing runway threshold, at an initial height of 3 000 ft above the landing runway threshold. They were to be simulated to be flown in still air, at standard atmosphere, with the initial state of the aircraft being in level flight, all systems functioning normally, flaps, slats and landing gear retracted, air conditioning systems in normal position, wing and engine anti icing systems de-activated, and at an indicated airspeed of 230 kts. None of the approach scenarios included landing with full flaps since less than 2 % of the landings in the FDR-material from actual flights used full flaps for landing.

Table 3 – Average distances or height for configuration changes.

Scenario #	**GS angle [deg]**	**F1 selection distance to THR [m]**	**F2 selection distance to THR [m]**	**Landing gear extension height [ft]**	**Landing flap selection height [ft]**
1 (FCOM)	3.0	23 000	20 870	2 000	1 763
2 (Data average)	3.0	25 400	18 500	1 757	1 354
3 (High speed)	3.0	20 500	18 378	2 000	1 300
4 (Low speed)	3.0	44 500	19 500	1 700	1 300
5 (FCOM)	2.5	26 200	24 073	2 000	1 800
6 (Data average)	2.5	25 400	21 500	1 757	1 330
7 (High speed)	2.5	24 000	21 877	2 000	1 400
8 (Low speed)	2.5	44 500	21 500	1 600	1 200
9 (FCOM)	3.5	20 500	18 368	2 000	1 400
10 (Data average)	3.5	25 400	17 500	1 800	1 516
11 (High speed)	3.5	18 700	16 578	2 300	1 300
12 (Low speed)	3.5	44 500	17 500	1 700	1 300

3.4 Noise results

The L_{Amax} levels for the four approach scenarios calculated on a 3.0° glideslope are presented in Figures 1 - 4 below. For the scenarios calculated on 2.5° and 3.5° glideslopes the results are similar although the geographical points where initial flap setting (F1) and intermediate flap setting (F2) are selected will be positioned further away from the runway threshold for the 2.5° scenarios and closer to the runway threshold for the 3.5° scenarios. This can be seen by comparing Fig. 5 and Fig. 6 with Fig. 1, where all three figures represents an approach performed in accordance with the FCOM but on approaches with different glide slope angles.

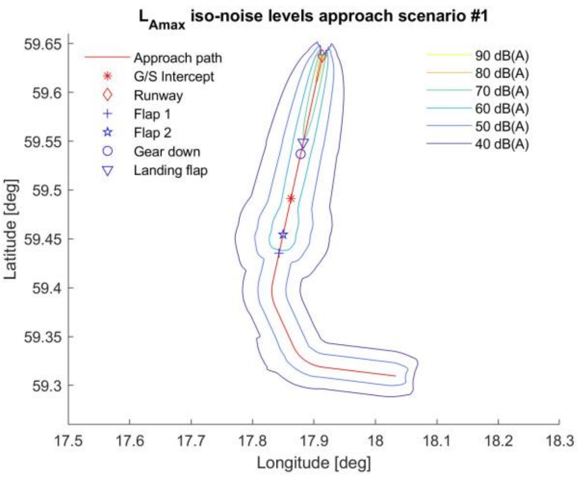

Figure 1 – On ground noise levels for approach scenario #1 (FCOM).

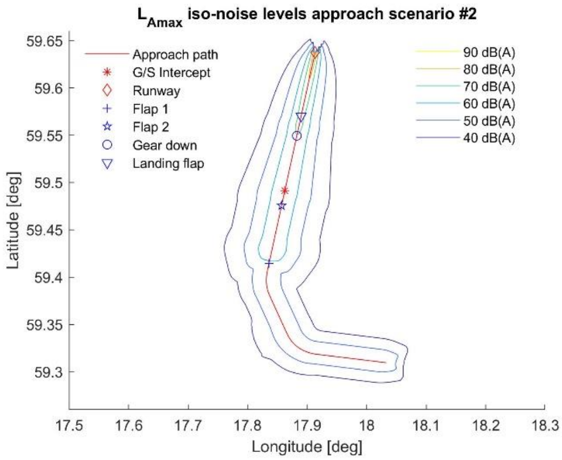

Figure 2 – On ground noise levels for approach scenario #2 (Data average).

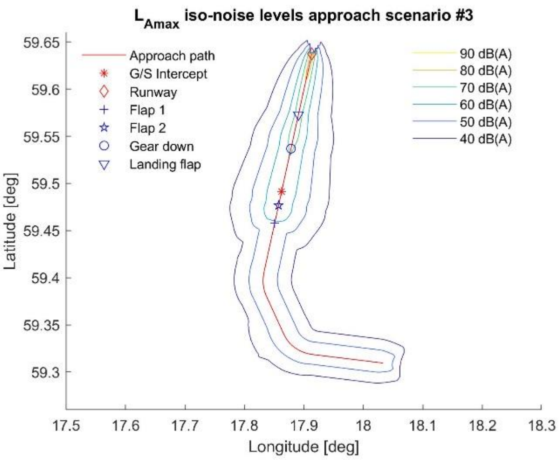

Figure 3 – On ground noise levels for approach scenario #3 (High speed).

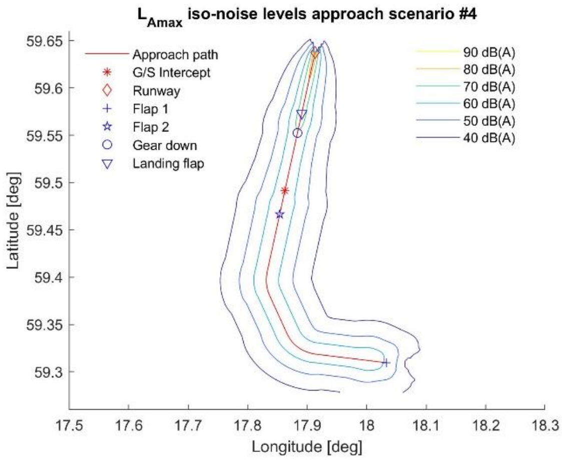

Figure 4 – On ground noise levels for approach scenario #4 (Low speed).

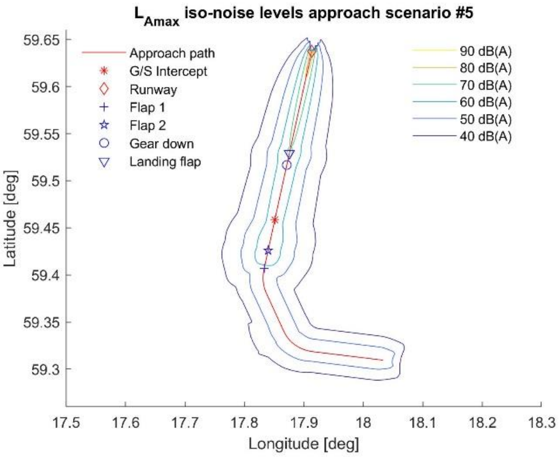

Figure 5 – On ground noise levels for approach scenario #5 (FCOM 2.5°).

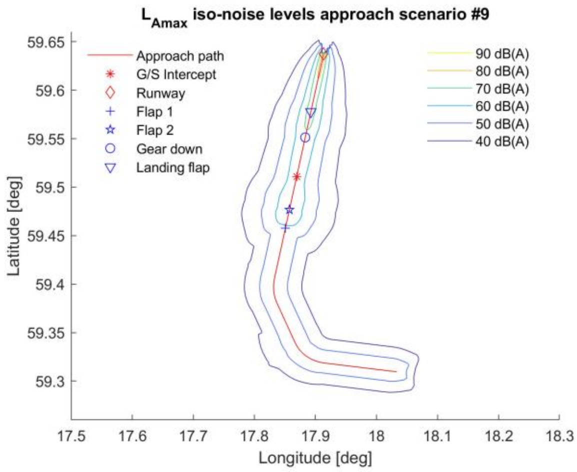

Figure 6 – On ground noise levels for approach scenario #9 (FCOM 3.5°).

The results from the comparison between the reference scenario and the other scenarios are depicted in Figures 7, 8 and 9 below.

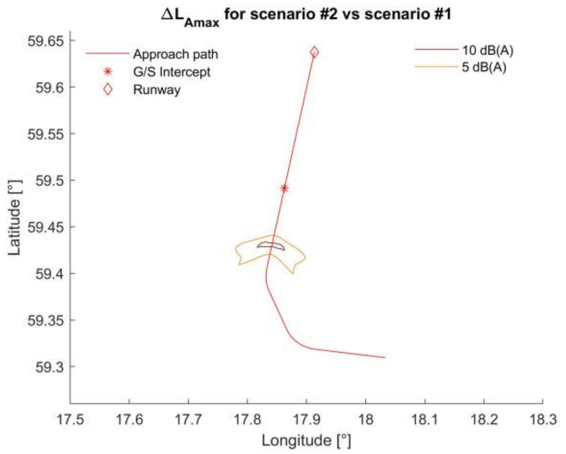

Figure 7 – Difference in L_{Amax} levels for scenario #2 (Data average) versus scenario #1 (FCOM). The area where scenario #2 (Data average) has an L_{Amax} 10 dB greater than scenario #1 (FCOM) covers a ground area of 1.1 km^2 in an area where L_{Amax} is 50 – 60 dB. The 5 dB area is 14 km^2 in an area where L_{Amax} is 40 – 60 dB.

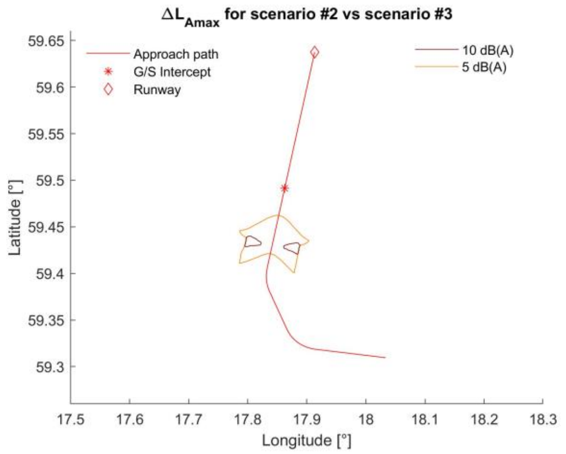

Figure 8 – Difference in L_{Amax} levels for scenario #2 (Data average) versus scenario #3 (High speed). The area where scenario #2 (Data average) has an L_{Amax} 10 dB greater than scenario #3 (High speed) covers a ground area of 2.6 km^2 in an area where L_{Amax} is 40 – 50 dB. The 5 dB area is 25 km^2 in an area where L_{Amax} is 40 – 60 dB.

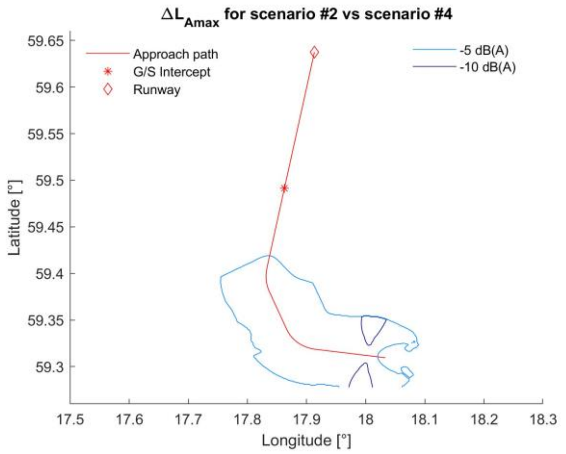

Figure 9 – Difference in L_{Amax} levels for scenario #2 (Data average) versus scenario #4 (Low speed). The area where scenario #2 (Data average) has an L_{Amax} 10 dB lower than scenario #4 (Low speed) covers a ground area of 10 km^2 in an area where L_{Amax} is 40 – 50 dB. The 5 dB area is 160 km^2 in an area where L_{Amax} is 40 – 50 dB.

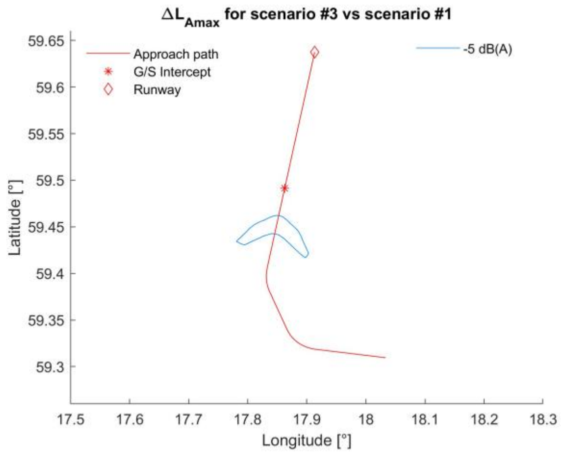

Figure 10 – Difference in L_{Amax} levels for scenario #3 (High speed) versus scenario #1 (FCOM). The area where scenario #3 (High speed) has an L_{Amax} 5 dB lower than scenario #1 (FCOM) covers a ground area of 13 km^2 in an area where L_{Amax} is 50 – 60 dB.

If it can be assumed that a noise efficient scenario is a scenario where high L_{Amax} levels are experienced over an as small area as possible then the result of the comparison of different approach scenarios revealed that the most noise efficient scenario is approach scenario #3 (High speed), where extension of any drag increasing devices is delayed as long as possible. That scenario is better than scenario #1 (FCOM), see Fig. 10 above, where the extension of slats, flaps and landing gear is performed as described in the aircraft's operations manual. Those two scenarios are both more noise efficient than the scenario derived from FDR-data from actual flights. The low speed scenario contains an extension of the leading edge slats early in the scenario, which is enough to create additional noise leading to that scenario being the least noise efficient alternative. The areas where the noise differences described above occurs are up to 3.5 km perpendicular out from the approach path's projection on the ground.

3.5 Fuel and CO_2 results

For the twelve scenarios the calculated fuel requirement as calculated by PEP is listed in Table 4 below. For the CO_2 it is assumed that each kg of fuel will result in an emission of 3.15 kg of CO_2 [26].

Table 4 – Result of time and fuel calculations for the 12 approach scenarios.

Approach scenario #	**Glide slope angle [°]**	**Fuel used [kg]**	**CO_2 emitted [kg]**	**Time used [s]**
1 (FCOM)	3.0°	204	643	456
2 (Data average)	3.0°	192	605	435
3 (High speed)	3.0°	185	583	422
4 (Low speed)	3.0°	221	696	469
5 (FCOM)	2.5°	219	677	470
6 (Data average)	2.5°	202	655	443
7 (High speed)	2.5°	202	636	440
8 (Low speed)	2.5°	227	715	471
9 (FCOM)	3.5°	189	592	442
10 (Data average)	3.5°	188	602	435
11 (High speed)	3.5°	178	561	414
12 (Low speed)	3.5°	214	674	461

In addition to the aggregated fuel calculations for the approach scenarios the specific range was calculated for the aircraft in different slats, flaps and landing gear configurations in level flight at 3 000 ft. The result is listed in Table 5 below.

Table 5 – Specific range for the selected aircraft type in different configurations in level flight at a weight of 73 tons.

Configuration	**Speed IAS [kts]**	**Fuel flow [kg/hour]**	**Specific range [m/kg]**
Clean	250	2 186	221
Clean	220 (Green Dot Speed)*	2 041	208

Configuration	**Speed IAS [kts]**	**Fuel flow [kg/hour]**	**Specific range [m/kg]**
Flap 1, gear up	228 (V_{fe}-10)**	2 475	178
Flap 1, gear up	199 (S-Speed)***	2 313	166
Flap 2, gear up	205 (V_{fe}-10)**	2 591	153
Flap 2, gear up	154 (F-Speed)****	2 367	126
Flap 2, gear down	205 (V_{fe}-10)**	3 284	121
Flap 2, gear down	154 (F-Speed)****	2 794	107
Flap 3, gear down	185 (V_{fe}-10)**	3 322	108
Flap 3, gear down	147 (V_{app})*****	2 917	98
Flap Full, gear down	176 (V_{fe}-10)**	4 134	82
Flap Full, gear down	136 (V_{app})******	3 213	82

**Green Dot Speed is the recommended lowest speed in clean configuration.*
***V_{fe} is the highest speed allowed for a specific flap setting*
****S-speed is the recommended lowest speed with Flap 1 set.*
*****F-speed is the recommended lowest speed with Flap 2 set.*
******V_{app} is the approach speed for the given configuration.*

3.6 Flight operational appropriateness

All approach scenarios developed were tested for operational appropriateness by calculations in PEP. All scenarios could be operated within the normal flight envelope. Neither use of excessive thrust nor speed brake was found necessary. The aircraft was calculated to comply with the stabilized approach concept and thus following the correct flight path, in landing configuration, with the correct speed and attitude at a height of 1 000 ft above the landing runway threshold.

For the comparison between different glide slope angles it was noted that in order to be able to reduce speed the use of the 2.5° glide slope angle required an earlier extension of the two initial flap settings F1 and F2. For approach scenario #11 (High speed, 3.5°) where the glide slope angle was 3.5° and speed was maintained high as long as possible, the landing gear had to be extended at a height of 2 300 ft, see Table 5, in order to achieve an appropriate speed reduction. A number of different high speed scenarios were tested and the speed could in all cases be reduced by the extension of the landing gear. Since the early extension and increased drag was performed in order to reduce speed the fuel consumption was not affected since thrust was kept in idle in all cases.

4. Discussion

Based on the result of the comparison between how approaches are performed between the FCOMs, the ANP and, for the selected aircraft type, real operations it is obvious that the ANP is not a good source for detailed information regarding aircraft operations. Some countries have ECAC Doc 29 and consequently the ANP as the primary source regarding for noise calculations [27] and it might be that the results are accurate enough at an aggregated level, but when it comes to evaluation of different specific approach scenarios where for example different speeds are assessed, then there are many limitations in the ANP.

When it comes to speed it is normal that noise from aircraft increases when the airspeed of the aircraft increases [28], and hence a reduction of noise could be expected from the low speed scenario. But it can also be expected that there is an increase in noise levels if devices such as slats or flaps are extended due to increased drag of the devices. Whether an increase of noise in the latter case is due to increased aerodynamic noise or due to increased engine noise due to increased thrust requirement, caused by increased drag, is not always easy to determine for an observer on the ground. But, for residents living beneath or close to runway approach areas the assumption of the ERAS-project is that it is of no or very small importance to them personally, or to the society at a general level, what the source of the noise is, i.e. aerodynamic noise or engine noise. In the scenarios evaluated, increased noise due to slat extension is experienced in all scenarios. This is especially noticeable in scenario #4 (Low speed), where the speed reduction of 17 m/s (from 230 kts to 198 kts) is performed early in the procedure, but the increased drag from the extension of the leading edge slats outweighs the reduction of drag from the speed reduction, causing a need for an increased engine thrust and the noise on ground will increase. Since the extension of leading edge slats is performed before the interception of the glide slope it could be tempting to claim that there is no correlation between the extension of initial flap settings and the final glide slope angle. But it must be noted that an increased glide slope angle will move the point where the complete sequence of extension of slats, flaps and landing gear needs to be initiated, closer to the landing runway threshold, thus allowing for a later speed reduction.

Corresponding results are achieved also for the extension of the landing gear. When the gear is extended a considerable amount of thrust might be required to counteract the drag of the landing gear. Both aerodynamic noise and engine noise will then increase and subsequently it is preferable for on ground noise if the extension of the landing gear can be performed as close as possible to the landing runway threshold. This is however not valid if an early gear extension is used in order to reduce speed as in the high speed scenario. Then only the aerodynamic noise must be considered.

A similar pattern is experienced for fuel. The further away from the runway threshold any extension of slats, flaps or landing gear has to be performed in a scenario, the larger amount of fuel is used for that approach scenario. And consequently a larger amount of CO_2 is emitted. There are two reasons for this fact which can be deducted from Table 5. Not only do extended devices increase the drag, they also call for a reduced speed due to the structural limitations of the slats, flaps and landing gear, and since the amount of fuel that is used only for keeping a turbofan engine with an overall efficiency of 30 – 50% [29] running, the total time to execute the approach will then also be a factor to consider.

5. Conclusions

5.1 Conclusions

Based on the findings in Table 1 that there are lack of information in the ANP, or discrepancies between the ANP and the FCOMs in the description of how different aircraft should be operated, it can be concluded that for a number of aircraft types the ANP is not a suitable tool in order to perform detailed analysis of different approach scenarios. For the A321 Neo specifically the lack of information regarding initial and intermediate flap settings in the ANP leads to the conclusion that other sources of information must be used. Neither does the FCOM give a precise description of actual operations, so the conclusion is that FDR-data is the preferred source if detailed approach scenarios analysis should be performed for a specific airport or runway.

It can also be concluded that it is preferable if the speed during the approach for aircraft of this type can be allowed to be as high as possible for as long as possible during the approach. Lower speed will call for the extension of slats and flaps which will increase drag and have a negative impact on the overall noise. Lower speed will also extend the overall time for the approach which will have a negative impact on fuel efficiency and emission of CO_2. Extension of leading edge slats will for this aircraft type lead to levels of increased L_{Amax} from 5 to 10 dB(A) directly below and up to 3.5 km perpendicular to the approach path.

One further conclusion is that even if the scenario described in the FCOM is more noise efficient than the scenario developed according to actual operations, the actual operations scenario is still more fuel efficient than the FCOM scenario, primarily due to the higher speeds used during actual operations.

It can finally be concluded that excessive speed experienced after interception of the glide slope can be reduced by extension of the landing gear. Aerodynamic noise will, for the A321Neo, increase slightly at that point due to the increased drag but neither engine noise nor fuel efficiency or CO_2 emissions will be affected since the engines will not be used to counteract the increased drag.

5.2 Further research within the ERAS project

The continued work within the ERAS project will extend the research to cover more aircraft types and to verify if the conclusions regarding the A321Neo can be generalized for all or most aircraft types. Continued development of approach scenarios will also focus on the definition of relevant speed intervals during different phases of the approach in order to minimize noise and CO_2 emissions.

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