Proposals for mitigation of pollutant emissions from aircraft at Lisbon Airport

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Resumo: A aviação tem impacto nas alterações climáticas e na qualidade do ar local, particularmente próximo dos aeroportos (CAA, 2007). Desta forma, os aeroportos têm sido desafiados a melhorar o seu conhecimento sobre as suas emissões, sua contribuição para a poluição local e planejar ações de mitigação (Fleuti, 2001). Neste trabalho são sugeridas propostas mitigadoras para as emissões poluentes das aeronaves no aeroporto de Lisboa. A proposta 1 sugere que se desligue pelo menos um dos reatores durante a rolagem nos *taxiways*. Na proposta 2, pretende-se que as aeronaves sejam rebocadas pelo *push-back* até à cabeceira da pista de descolagem no *taxi out* e da pista até ao stand no *taxi in.* Na proposta 3 pretende-se uma redução do tempo de rolagem de cerca de 20%, propondo-se um terminal remoto, junto à pista 03 – 21, capaz de estacionar 75% das aeronaves do aeroporto. Por último, a proposta 4 sugere um sistema inovador de reboque de aeronaves, do stand até à pista de descolagem. A principal vantagem de todas as propostas é a diminuição da quantidade de gases e partículas poluentes emitidos, embora estas alterem os procedimentos operacionais do aeroporto, provocando impactos ao nível do seu desempenho e segurança.

Palavras-chave: aeroporto de Lisboa, emissões poluentes, medidas de mitigação, qualidade do ar.

Abstract: The aviation sector has impact on climate change as well as in local air quality, especially near airports (CAA, 2007). Therefore, airports are challenged to deploy mitigation plans and to reduce their carbon footprint (Fleuti, 2001). This work puts forward mitigation proposals for aircraft emissions at Lisbon airport. Proposal 1 suggests that aircrafts shuts-off at least one of the engines during taxiing phase, whereas in proposal 2 the aircrafts are carried by the push-back to/from the runway in the taxi out/in. In Proposal 3 a new terminal is proposed closer the runway 03-21 which may reduce up the taxiing time by 20%. Finally, in proposal 4, an innovative automatic system for aircraft taxiing is proposed. The main advantage of all the proposals is the smallest amount of fuel consumed and minor amount of gaseous and particulate pollutants. However, these proposals change the airport operational procedures, resulting into impacts on performance and safety.

Keywords: Lisbon airport, pollutant emissions, mitigation measures, air quality.

1. INTRODUCTION

In recent years a large growth in air transportation has been reported providing benefits to the economy and prosperity for the societies. This growth has contributed to Globalization. However, aviation has also been responsible for an adverse environmental impact imposing costs to the society and to the economy (Eurocontrol, 2008; Janić, 2008).

At the local and national levels, a greater attention has been given to airports as they are sometimes the most responsible for air pollution. Consequently, their challenge is to improve knowledge on their induced emissions and its contribution to local pollution and also plan mitigation actions (Fleuti, 2001).

The inclusion of aviation sector in the European Union ETS (Emission Trading Scheme) is an essential element which demonstrates the commitment of the European Union (EU) in the reduction of 20% of CO_2 emissions by 2020, comparing to the emissions in 1990 (reference year). The inclusion of the aviation sector into ETS in EU will result in a better approach from an economic and environmental point of view (Macário *et al*., 2007).

Although there are many different pollutants sources at an airport (see section 2), the aim of this work is to put forward proposals to mitigate aircraft pollutant emissions at the Lisbon airport. These proposals require quantifying the emissions from aircraft landing and takeoff (LTO) cycle and suggesting ways to reduce these emissions. The proposed emission reductions presented in this work concern the following pollutants: hydrocarbons (HC), Carbon monoxide (CO), Nitrogen oxides (NO_X), Carbon dioxide (CO_2), Sulfur dioxide (SO_2) and particulate matter (PM).

Section 2 discusses the sources of emissions at an airport and describes the methodology applied in this study to evaluate the aircrafts' emissions. In Section 3 it is proposed and analyzed four mitigation measures to be deployed in the airport of Lisbon to curb the aircraft emissions in taxiing operations. At last, in Section 4 it is presented the main conclusions of this work.

2. EMISSIONS

According to the European Commission (2001), an impact or effect is any change in the physical, natural or cultural environment due to a project development.

There are several types of environmental impacts in airports. The main impacts resulting from its activity are: Noise Pollution; Degradation of Air Quality; Intensive Resource Consumption; Degradation of Water Resources Quality; Contamination of Soils and Aquifers (ANA, 2007b).

According to the Civil Aviation Authority of United Kingdom (CAA), the main effects of aviation are in the: climate change; local air quality (particularly around the airport because it can damage human health); noise levels

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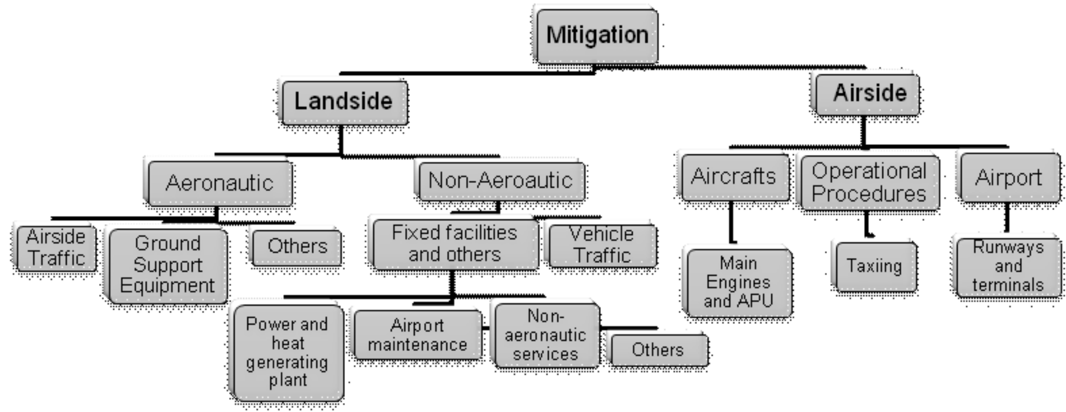

Figure 1. Sources of pollutants at the airports

near airports and under flight routes; energy use; waste and water. There are also environmental impacts due to travel to and from the airport (CAA, 2007). There are a variety of air pollutants, gaseous and particulate matter due to airport activities that have an environment and health impact on the people living nearer the airport. The most relevant pollutants to be considered in the airport emission inventory are: SO_2; Ozone (O_3); Volatile Organic Compounds (VOC's), including HC; $PM_{2.5}$ and PM_{10}; NOX, including Nitrogen dioxide (NO_2) and Nitrogen oxide (NO); CO, CO_2, Benzene, Toluene and Xylenes (BTX) (ICAO, 2007).

CO_2 is more regarded as a global concern rather than strictly local, though local inventories can be part of global inventories when required.

Xylenes are considered hazardous air pollutants (HAPs) and others that are not mentioned in this work.

There are a large variety of emission sources in the airports. In this context, ICAO suggests to group the emission into four different categories: i) Emissions from aircraft; ii) Sources of road traffic; iii) Emissions from ground handling and iv) Emission related to the infrastructure activities and fixed sources (ICAO, 2007).

The Figure 1 shows the various emissions sources presented at an airport. To reduce the emissions from the ground vehicles (landside), a considerable amount of research and projects have been developed and multiple direct and indirect measures have been proposed. For the land side, the direct measures include the utilization of alternative fuels (Clean Energy, 2009), compressed air (Air France, 2009), fuel cell (Fontela *et al*., 2007), electricity or renewable energy sources; while indirect measures include carpooling (Correia and Viegas, 2005), taxi sharing, or incentives to use public transport or planting trees to offset emissions.

For the airside, alternatives include blended wing-body aircraft; ground effect vehicle (GEV) (Chapman, 2007); prototype solar plane[1]; alternative fuels, including liquid hydrogen (Janić, 2008); Prosene and hydrated alcohol (Simões and Schaeffer, 2005); the change of operational procedures, in particular, reducing use of the engines during aircraft taxiing; the use of cleaner engines for aircraft taxiing; aircraft towed by push-backs; or redesign the airport involving tilted runways, vertical terminals (Vindnaes, 2008) or remote terminals.

In this work, the annual emissions from aircraft were estimated for the following gases and particles: HC; CO; NO_X; CO_2; SO_2 and PM.

The amounts of HC, CO and NO_X emissions from the aircraft were estimated using the following equation (ICAO, 2007; Kesgin, 2006):

$$E_{i,m} = \sum_a \sum_e n_a l_{a,e} F_{a,e,m} E_{e,m,i} t_{m,a} \quad (1)$$

where,

- $E_{i,m}$: annual emission of pollutant $\underline{i}$ for operational mode $\underline{m}$ (g/year);
- n_a: number of engines of the type aircraft $\underline{a}$;
- $l_{a,e}$: number of annual LTO cycles for type of aircraft $\underline{a}$ with engine type $\underline{e}$;
- $F_{a,e,m}$: fuel consumption factor for aircraft type $\underline{a}$ with engine type $\underline{e}$ in mode $\underline{m}$ (kg/s);
- $E_{e,m,i}$: emission factor for engine type $\underline{e}$, operational mode $\underline{m}$ and pollutant $\underline{i}$ (g/kg); e
- $t_{m,a}$: time in operational mode $\underline{m}$ for aircraft type $\underline{a}$ (s).

The landing and takeoff cycle (LTO) is defined by ICAO consisting in four operating modes (Figure 2): Approach, Taxi, Take-Off and Climb Out, with average times of 4 minutes, 26 minutes, 0.7 minutes and 2.2 minutes, respectively (ICAO, 2007).

The emissions calculation of SO_2 and CO_2 only depend on the fuel consumed by aircraft type. It is known that 1 kg of jet A1 fuel produces 3156 grams of CO_2 (Rachner, 1998; Janić, 2007) and SO_2 is about 0.10% of fuel consumption (ICAO, 2007).

Emissions of PM are calculated by the methodology FOA3.0 recommended by ICAO (Wayson *et al*., 2009). In this methodology, component nonvolatile and volatile of PM can be independently quantified, as the following general form:

$$EI_{vols} = \sum \left(\text{Sulfates} + \text{Fuel Organics} + \text{Lubrification Oil Organics}\right) \quad (2)$$

$$EI_{nvols} = \text{Related with Smoke Number (SN)} \quad (3)$$

where,

- EI_{vols}: volatile PM component; e
- EI_{nvols}: nonvolatile PM component.

[1] <http://www.swissinfo.ch/por/capa/Pioneiro_Bertrand_Piccard_apresenta_aviaosolar.html?siteSect=105&sid=10885991&cKey=1246052306000&ty=st>

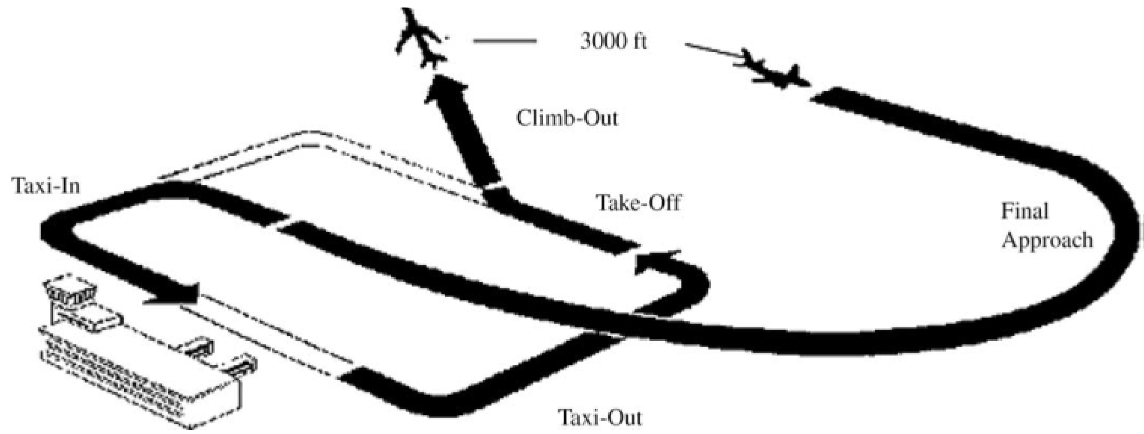

Figure 2. LTO cycle (Source: Kesgin, 2006)

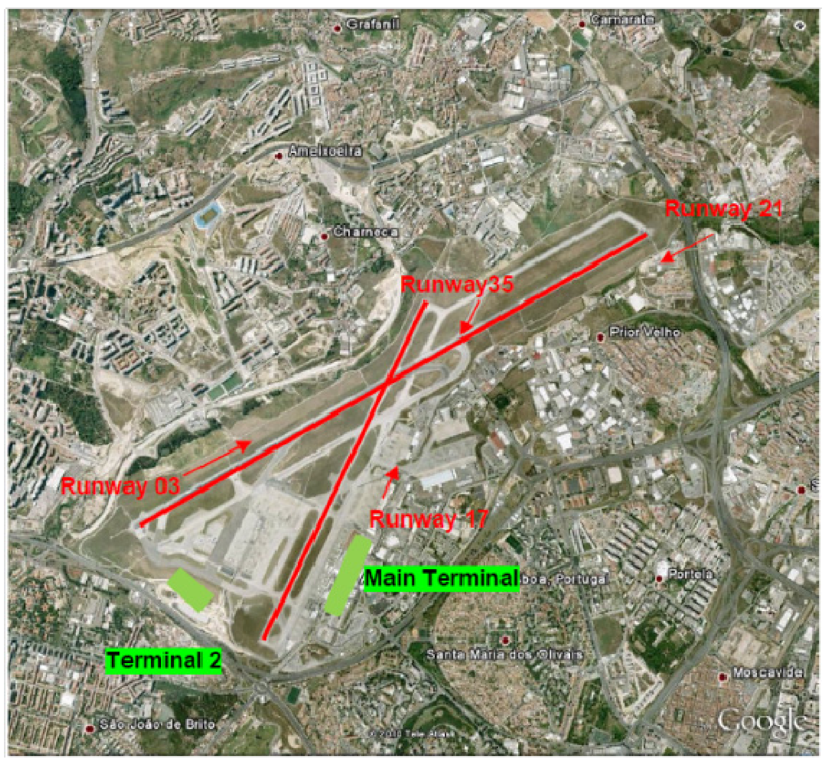

Figure 3. Lisbon Airport (Google Earth image)

Total PM emissions index (EI) is the addition of the two components (Wayson *et al*., 2009). The calculation of total amount of PM emission is the application of equation (1), where $E_{e,m,i}$ is calculated by methodology FOA3.0.

3. APPLICATION TO LISBON AIRPORT

3.1. Framework

Lisbon airport, located at Portela de Sacavém between Lisbon and Loures, in northwest of Lisbon city center is surrounded by residential and commercial areas. The airport has a total area of 495 hectares, with two terminals and two runways: 03-21 (3805x45m) and 17-35 (2400x45m) – see Figure 3.

3.2. Reference Case (Current Emissions)

Current emissions from aircraft types were estimated to the airport of Lisbon through the equation (1). The most recent data available was found on to the year 2007. It was assumed a similar distribution for the following year. The ICAO Database was used to identify the type of engines for each aircraft (Table 1).

The first parameter of the equation (1) concerns the number of engines of each aircraft type (Table1), while the second parameter refers to the number of LTO cycles. The estimated total number of LTO cycles in 2008, at Lisbon airport, was half the total number of movements (Table 2). The third parameter required for the application of equation (1) is the fuel consumption factor for each type of engine in different aircraft operational mode. These factors as well as emission factors for HC, CO and NO_X emissions were found in the ICAO Engine Emissions data-bank (CAA, 2009).

The last parameter gives the time consumed by the aircraft in each operating mode. The time used for the differ-

Table 1. Engine types in ICAO (Source: ICAO, 2007, p. 50)

		ICAO	
Aircrafts	***Number of engines***	*Engine UID*	*Engine type (ICAO)*
A320	2	1CM008	CFM56-5A1 (TF)
A319	2	4CM036	CFM56-5A5 (TF)
E145	2	6AL007	AE3007A1 (TF)
A321	2	3CM025	CFM56-5B3/P(TF)
F100	2	1RR021	TA Mk650-15 (MTF)
A310	2	1GE016	CF6-80C2A2 (TF)
B752	2	3RR028	RB211-535E4 (TF)
A332	2	3RR030	Trent 772B-60 (TF)
B738	2	3CM033	CFM56-7B26 (TF)
CRJ2	2	1GE035	CF34-3A1 (TF)
B737	2	3CM031	CFM56-7B22 (TF)
A343	4	2CM015	CFM56-5C4 (TF)
B733	2	1CM004	CFM56-3B-1 (TF)
MD88	2	1PW018	JT8D-217C (MTF)

Table 2. Number of movements at Lisbon airport (Source: ANA, 2007[a], 2008[a], 2008b)

Aircraft	***Movements 2008***
A320	37.927
A319	34.511
E145	8.874
A321	7.981
F100	7.654
A310	7.265
B752	4.447
B190	4.133
A332	2.836
B738	2.663
CRJ2	2.647
B737	2.478
A343	2.267
B733	2.241
MD88	2.088
Others	14.758
Total	*144.771*

Table 3. Total emissions and fuel consumption of the reference case (2008)

	Total emissions (ton/year)						***Fuel Consumption***
LTO cycle phase	*HC*	*CO*	*NO_X*	*CO_2*	*SO_2*	*PM*	***(ton/year)***
Take-Off (T-O)	1,16	6,34	216,86	24,45	7,75	51,55	7.746,47
Climb-Out (C-O)	1,92	13,73	363,90	52,85	16,75	110,51	16.746,37
Approach (AP)	2,47	26,77	91,31	32,51	10,30	67,15	10.300,84
Sub-Total	5,55	46,85	672,07	109,81	34,80	229,21	34.793,68
Taxi (Idle)	43,34	350,29	58,05	45,03	14,27	92,71	14.267,31
Total	48,89	397,13	730,11	154,84	49,06	321,93	49.060,98

ent phases of the LTO cycle were 50 seconds to take-off, 4 minutes to approach, 2.2 minutes to climb out and a 16 minutes to taxi in average time, corresponding to 4 minutes for taxi in and 12 minutes for taxi out. The time used for taxi (idle) is the sum of taxi in and taxi out. This data was confirmed by controllers of control tower at Lisbon airport, from NAV Portugal. The results of the application of equation (1) are presented in the Table 3.

3.3. Mitigation Proposals

The aim of this work is to suggest proposals for mitigating emissions from aircraft at Lisbon airport. Four proposals were chosen from several solutions related to aircraft emissions mitigation:

- Proposal 1: Aircraft taxiing with only one engine;
- Proposal 2: Push-back takes aircraft until/from runway;
- Proposal 3: New terminal near the runway; e
- Proposal 4: Automatic system for aircraft taxiing.

In the Proposal 1, the aircraft uses only one engine in the case of having only two (or two engines in case of aircraft with four jet engines like A340, for example) in taxi phase. The taxiing speed achieved by aircrafts is the same with only one engine compared with two engines. However, it will be needed a greater power to start moving the aircraft. The

Table 4. Total emissions and fuel consumption of the proposal 1

LTO cycle phase	Total emissions (ton/year) HC	CO	NO_X	CO_2	SO_2	PM	Fuel Consumption (ton/year)
Sub-total (T-O; C-O; AP)	5,55	46,85	672,07	109,81	34,80	229,21	34.793,68
Taxi (Idle)	21,67	175,14	9,02	22,51	7,13	46,35	7.133,65
Total	27,22	221,99	681,09	132,32	41,93	275,57	41.927,33

Table 5. Total emissions and fuel consumption of the proposals 2 and 4

LTO cycle phase	Total emissions (ton/year) HC	CO	NO_X	CO_2	SO_2	PM	Fuel Consumption (ton/year)
Sub-total (T-O; C-O; AP)	5,55	46,85	672,07	109,81	34,80	229,21	34.793,68
Taxi (Idle)	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Total	5,55	46,85	672,07	109,81	34,80	229,21	34.793,68

Table 6. Total emissions and fuel consumption of the proposal 3

LTO cycle phase	Total emissions (ton/year) HC	CO	NO_X	CO_2	SO_2	PM	Fuel Consumption (ton/year)
Sub-total (T-O; C-O; AP)	5,55	46,85	672,07	109,81	34,80	229,21	34.793,68
Taxi (Idle)	34,67	280,23	46,44	36,02	11,41	74,17	11.413,84
Total	40,22	327,08	718,51	145.830,93	46,21	303,38	46.207,52

results of the application of this proposal are presented in Table 4.

In the Proposal 2, the aircraft is towed and carried by the push-back between the stands and the runway in the taxi phase. Therefore, the aircraft taxiing occur with all engines shuttered down. Average speed of aircraft during taxiing is 8 m/s (Winther *et al*., 2006) and the maximum speed of a push-back is 30 km/h (information obtained by Ground Force Portugal) corresponding to 8.3 m/s which increases 4.2% of taxi time. The results are presented below, in Table 5. It was not measured the consumption of the push-backs.

The Proposal 4 suggests an innovative automatic system for towing aircrafts between stands and runway. This system is made by a fixed rail on the ground, on which an automatic towbar moves. The towbar will move the aircraft between the runway and the stands. As a result the aircrafts need only to start the engines just before takeoff and they may shut down them just after landing (see Table 5). It was not measured the consumption of the new automatic system. This system is a new idea, proposed by the author.

In the Proposal 3 a new terminal near the main runway is foreseen, which will reduce the distances of taxiing and the taxi time by around 20%. This new terminal will receive 75% of the total aircrafts, while the remaining 25% will continue to use the current terminal. The results of the application of this proposal are presented in Table 6.

The comparison between the above-mentioned proposals and the reference case are provided below.

3.3.1. Comparison of proposals

Assuming that the aircraft engines perform according to the ICAO database (CAA, 2009), the biggest reductions are in emissions of HC and CO obtained by proposals 2 and 4, reducing almost 90% (Figure 3 and 4). The largest reductions of CO_2 emissions are also obtained with proposal 2 and 4 (Figure 6).

Regarding fuel consumption, the largest reductions are again achieved by proposal 2 and 4, leading to a reduction of almost 30%, followed by proposal 1 with a reduction in fuel consumption of about 15%, and finally proposal 3 with a smaller reduction of 6% (Figure 5 and 6).

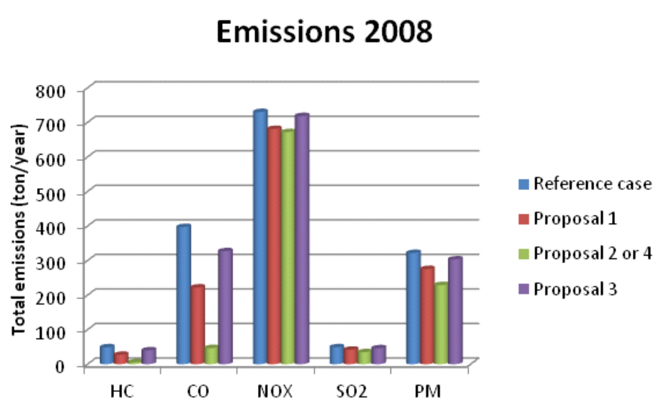

Figure 3. Pollutant emission results of the case reference and the suggested proposals

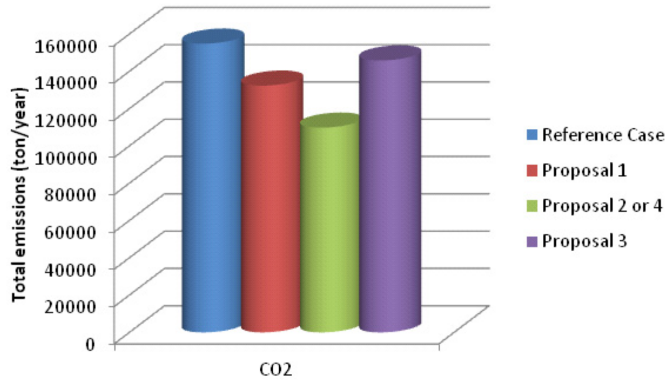

Figure 4. Pollutant emission results of the case reference and of suggested proposals

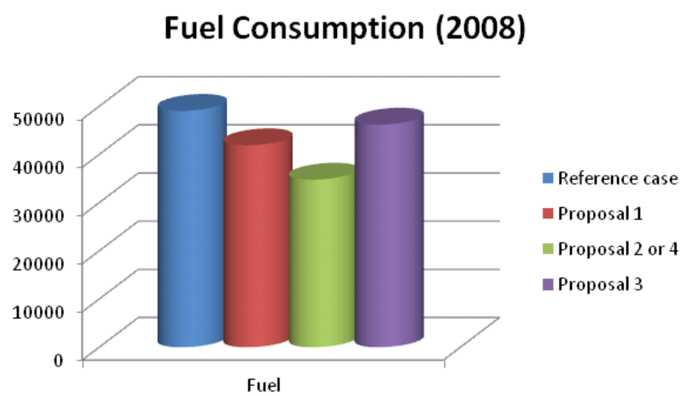

Figure 5. Fuel consumed in the reference case, applying the suggested proposals

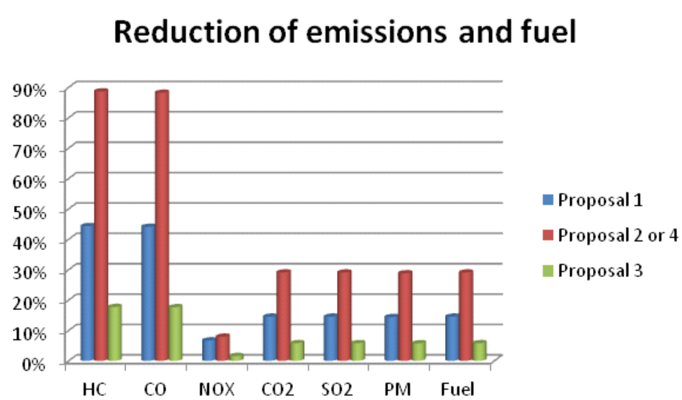

Figure 6. Reduction in polluting emissions and in fuel by applying the suggested proposals

3.3.2. Critical Analysis

Bearing in mind the objective of this work, the main advantage of all previous proposals is the minor amount of fuel consumed and consequently smaller amount of gaseous and particulate pollutants emitted during taxiing. However, the proposals suggested in this study change the airport operational procedures may bring some impacts on the performance or safety of the operations, which are briefly discussed in Table 7.

Regarding proposal 1, the power required to taxiing depends on the weight of the aircraft, and therefore the use of only half of the engines may lead to worse performance on taxiing in situations of heavier aircrafts. The aircraft achieve the same speed with two engines or with just one; however the situation where only one engine is used needs a greater power to start the engine at the beginning in order to reach the same speed that all the engines would.

The use of push-backs to tow the aircraft from stand to runway in taxi out, and from runway to stand in taxi in (proposal 2), requires a greater quantity of available push-backs needed at Lisbon airport. The wear of these vehicles will be higher, since they will be used for longer times and larger routes. However, the most negative impact of this proposal is the increase in taxiing time, around 4%, which at peak times may represent loss of capacity and efficiency at the airport. Another important impact to consider is the safety for ground handling at the airport.

Table 7. Critical analysis of four proposals

Proposal 1	***Proposal 2***	***Proposal 3***	***Proposal 4***
Impact on the aircraft performance	Greater quantity of available push-backs needed at Lisbon airport	Does not imply the inactivation of either of the two existing terminals	Further technical development and research for future implementation
Worse performance on taxiing in situations of heavier aircrafts	The wear of these vehicles will be higher, since they will be used for longer times and larger routes	The new terminal have not to be a very complex infrastructure	Monitoring all routes between stands and runway
The aircraft achieve the same speed with two engines or with just one	Increase in taxiing time, around 4%	The airport capacity in number of stands is identical (75% of the aircraft parking corresponds to the new terminal and 25% to the main terminal)	Part of the airport airside may be unavailable due to the infrastructure construction
The situation where only one engine is used, needs a greater power to start the engine	Impact in ground handling safety (increase the probability of accidents)	Investment will be necessary for the implementation of this new terminal (economic feasibility study)	Investment costs

The suggested proposal 3, where a new remote terminal is added, does not imply the inactivation of either of the two existing terminals neither represent a very complex infrastructure. In fact, it could serve as a central or intermediate station for passengers connecting to the two existing terminals. This connection can be made through moving walkways, air bridges or other less polluting systems than passenger buses powered by fossil fuels. Furthermore, investment will be necessary for the implementation of this new terminal, which implies an economic feasibility study assessing the decision of implementing this proposal.

The proposal 4 is a new idea which requires further technical development and research for future implementation and it will involve monitoring all routes between stands and runway in order to detect problems and proceed quickly. Other disadvantages of this new system are that part of the airport airside may be unavailable due to the infrastructure construction and the investment costs are considerable.

In this work, it was not take into account the warm up period of the engines (normally 2 minutes) in all the proposals. In the proposal 2 and 4, it was not measured the consumption of the push-backs and the new automatic system, but this consumption will be certainly lower than in the current case.

In spite of the eventual operational impacts, the proposals result in lower environmental impacts compared to the reference case. These proposals will be more practicable as soon as political commitment and environmental protection becomes an essential value to society.

4. CONCLUSIONS

In this paper four proposals for reducing the emissions of aircrafts (HC; CO; NO_X; CO_2; SO_2 and PM) while at the airport are proposed and analyzed for the airport of Lisbon. The proposals are:

- Proposal 1: Aircraft taxiing with only one engine;
- Proposal 2: Push-back takes aircraft until/from runway;
- Proposal 3: New terminal near the runway; e
- Proposal 4: Automatic system for aircraft taxiing.

The best results were found in the proposal 2 and 4, with the biggest reductions in emissions and also in fuel consumption.

This work also revealed that airside mitigation options are very important, allowing reductions in emissions of major gaseous and particulate matter, in some cases very significant reductions of around 80 and 90%, especially emissions of HC and CO by applying proposal 2 and 4. In both proposals, the reductions in emissions of CO_2, SO_2 and PM were approximately 29%. The smallest decrease was 8% observed in NO_X emissions.

The second best proposal in terms of reducing emissions was proposal 1. This resulted in emission reductions of HC and CO around 44% and 48% depending on the engine used in calculation. Emission reductions of CO_2, SO_2 and PM were in the order of 13-15%, while emission reductions of NO_X were 3-4%.

Finally, the proposal less advantageous for emissions reduction was proposal 3, with reductions around 17% and 18% in HC and CO, 5-6% in CO_2, SO_2 and PM emissions, and only 1-2 % in NO_X emissions.

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