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EVALUATION OF WORLDWIDE NOISE AND POLLUTANT EMISSION COSTS FOR INTEGRATION INTO DIRECT OPERATING COST METHODS

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Abstract

This paper analyzes the current Pollutant and Noise (PN) emission costs due to airport charges and CO_2 costs due to the Emissions Trading Scheme (ETS) of the European Union. Based on this analysis, equations for a realistic prediction of PN fees of future aircraft are proposed allowing the consideration of these PN fees in the calculation of Direct Operating Costs (DOC) and consequently their integration into the objective function for aircraft design optimization. Firstly, the PN Emission Fees (PNEF) per flight and passenger (PAX) for 36 commonly used aircraft, at the 50 busiest airports in the world in 2010 (in terms of their number of PAX per year) are analyzed. The PNEF are then weighted against the total number of PAX worldwide. The weighted average of the PNEF of these 50 airports is assumed to represent the average PNEF of all airports in the world. Secondly, the Costs due to the ETS (CETS) of the European Union per flight and PAX starting in 2012 are analyzed. Amongst others, the method is able to consider the current and future European share of worldwide aircraft movements as well as variable emission certificate prices, for several assumptions for the worldwide growth of CO_2 emissions of aircraft. Finally PNEF and CETS are included into the Direct Operation Cost (DOC) method of the Association of European Airlines (AEA) from 1989 although any DOC method could be selected. The analysis of an Airbus A320-211 with the AEA DOC-method shows that noise emission fees account for about 0,20 %, pollutant emission fees for 0,02 % and CETS for 0,12 % of the DOC showing that these costs are low compared to other DOC elements. Current PNEF therefore have little influence on the overall economics of aircraft which explains why the economic motivation for more silent or less pollutive aircraft stays low. The economic motivation could be increased by a considerable rise of the PNEF, a higher number of airports charging for PN emissions or the introduction of a worldwide ETS. The proposed method for inclusion of PNEF and CETS in DOC methods is universal and enables to forecast charges until about 2020. It remains however necessary to repeatedly observe the current charges in order to represent them correctly in extended DOC methods also in years to come.

1. INTRODUCTION

Within the last years, PN emissions of aircraft gained more and more attention. This happened because of the increasing awareness of negative environmental impacts of Pollutant Emissions (PE) and because an increasing number of people is bothered by aircraft noise. As a result more and more airports introduce PNEF [1] and the EU started an ETS.

This paper evaluates the worldwide PNEF at airports as well as the CETS. Also, it is shown how these costs can be integrated into the DOC method of the Association of European Airlines (AEA) of 1989 ([2], [3]) so that they can be considered within aircraft design.

Please note that the actual costs amongst others depend on current exchange rates, jet-fuel and emission certificate prices. The presented cost calculations are based on the following USD exchange rates from February 29, 2012

$$1\ \mathrm{EUR} = 1{,}3461\ \mathrm{USD}$$

$$1\ \mathrm{JPY} = 0{,}012425\ \mathrm{USD}$$

$$1\ \mathrm{GBP} = 1{,}5929\ \mathrm{USD}$$

and a jet fuel price of 1,055 USD/kg [4] also from February 29, 2012. A price of 10 € per EC has been assumed which is about the average EC price of the German EC auctions between January 2011 and July 2012 [5].

The outline of the paper is as follows. Section 2 presents methodologies and the results for the calculation of PNEF at airports. Section 3 describes a methodology and the results for the calculation of CETS. Section 4 presents the integration of PNEF and CETS into the AEA DOC method while Section 5 concludes the paper.

2. POLLUTANT AND NOISE EMISSION FEES AT AIRPORTS

2.1. Methodology for the Consideration of Noise Emission Fees at Airports

The increasing awareness regarding Noise Emissions (NE) makes the noise characteristics of an aircraft an important aspect of the design process. Not only because the noise levels have to meet the requirements of the International Civil Aviation

Organization (ICAO) for certification but also because more and more airports introduce noise limitations and charges (FIG. 1). This section describes a methodology extending the AEA DOC method by including Noise Emission Fees (NEF) in the DOC calculation.

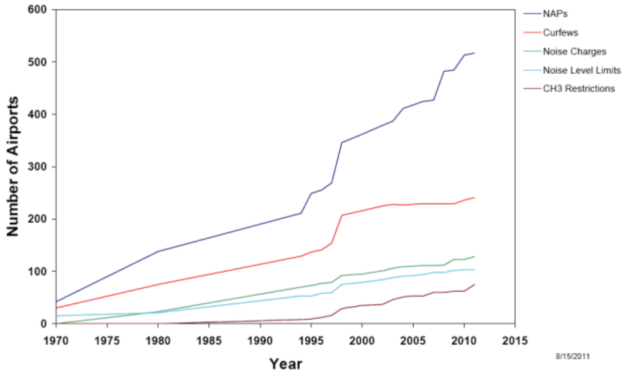

FIG. 1 Growth in airport noise charges [1]

For certification, the aircraft noise is measured at three different points (approach, sideline, flyover) as shown in FIG. 2. Depending on Maximum Take-Off Mass (MTOM) and the noise certification chapter, maximum noise levels are defined at all three measuring points. The difference between the actual measured aircraft noise at a certain measuring point and the noise limit at that point is called margin Δn_i. The sum of the margins at all three measuring points is called cumulative margin $\sum(\Delta n_i)$. The lowest difference between the noise limit and the actual noise level at one of the three measuring points is called lowest individual margin $\min(\Delta n_i)$. Many airports use $\sum(\Delta n_i)$, $\min(\Delta n_i)$ and the MTOM to classify the aircraft into different noise categories. These noise categories are then related to NEF. Nevertheless the challenge in calculating the NEF of an aircraft is that each airport has a slightly different charging system.

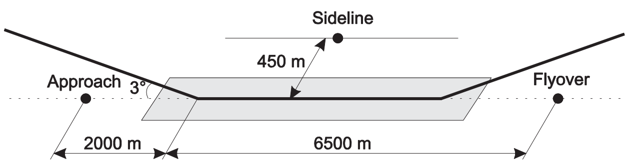

FIG. 2 Chapter 3 noise measuring points for certification

In 2011, 10 of the 50 busiest airports in the world charged for noise [1]. Some of these airports have different charges for the day and night period. As most passenger aircraft take-off and land during the day period and as this period lasts for about three-quarters of the day, the night charges have not been considered in this paper.

Some of the airports have no separation between landing fee and noise fee. In these cases, the fee of the lowest achievable noise category is assumed to be the basic landing fee. All additional fees are considered as NEF.

The official noise characteristics of many aircraft can be found in the ICAO Noise Certification Database [7]. In this database, the noise characteristics of an aircraft type are listed depending on the aircraft version, its MTOM, Maximum Landing Mass (MLM) and its engine which means that for a single aircraft type, for example an A320, many different noise characteristics are listed. For a single aircraft version, for example an Airbus A320-211, each different combination of engine, MTOM and MLM has its own noise characteristic in the database.

In order to calculate average NEF, despite the different charging systems, the proposed method analyzed the noise charges of 36 commonly used aircraft types at the 50 busiest airports in the world in 2010 [13]. These airports handled 44,56 % of the total number of PAX. The noise charges of these airports $c_{n,a}$ were weighted by their percentage of the total number of PAX worldwide p_a. The weighted average of the noise charges c_n of these 50 airports is assumed to represent the average noise charge of all airports in the world.

c_n is calculated by the following equation:

$$c_n = \frac{\sum(p_a \cdot c_{n,a})}{\sum p_a} \qquad (1)$$

For each aircraft type, one specific combination of aircraft version, MTOM and engine was chosen. The calculated charges refer to these specific combinations and are listed in TAB. 4. Based on these results, the following formula has been developed. It can be used to estimate c_n for new aircraft:

$$c_n = 13{,}934 \cdot \frac{m_{MTO}}{2000(2+\sum(\Delta n_i)+min(\Delta n_i))} \qquad (2)$$

This equation has a Pearson product-moment correlation coefficient (PCC) of 0.53. According to [8], this can be evaluated as a moderate correlation.

In order to provide a methodology with the ability to calculate future noise charges, the yearly inflation and the increasing number of airports with noise charges has to be considered. This number is steadily increasing since 1970 (FIG. 1) and is expected to further increase in the next years. Of the 651 airports listed in the database of [1], 128 airports have been charging for noise in 2011. Assuming that the linear increase continues in the same way as in the last 41 years (FIG. 1), the future number of airports with NEF $n_{a,NEF}$ can be calculated with the following linear equation:

$$n_{a,NEF} = 128 + \frac{128}{41} \cdot (n_y - 2011) \qquad (3)$$

where n_y is the year for which the number of airports with NEF is calculated. Dividing this number by the current number of airports with noise charges leads to the parameter $k_{a,n}$ which is the factor of the number of airports with noise charges related to the year 2011:

$$k_{a,n} = \frac{n_{a,NEF}}{128} \qquad (4)$$

[16] suggests to multiply cost elements related to a certain year with an inflation factor k_{inf} to adapt them to the price level of the current year:

$$k_{inf} = (1 + p_{INF})^{n_y - n_m} \qquad (5)$$

where

p_{inf}	Yearly inflation
n_y	Year for which the DOC are calculated
n_m	Year when the method was created

[18] compares C_{FEE} calculated using the AEA method with the real C_{FEE} at airports. It is shown that a yearly inflation of 2 % leads to a good accordance of the real and the calculated C_{FEE}. For the presented DOC calculation, p_{INF} is therefore set to 2 %. n_m is set to 2011, because the proposed method has been created in that year.

Multiplying $k_{a,n}$ by k_{inf} and the average noise charges per flight in 2011 c_n leads to the total average noise charges per flight $c_{n,f}$ in a certain year in the future:

$$c_{n,f} = k_{a,n} \cdot k_{inf} \cdot c_n \quad (6)$$

Combining Equations (2) … (6) leads to an equation for the calculation of $c_{n,f}$ that can be integrated into the AEA DOC-method (described in Section 4.1):

$$c_{n,f} = \left(1 + \frac{n_y - 2011}{41}\right) \cdot \frac{m_{MTO} \cdot (1 + p_{INF})^{n_y - 2011}}{143{,}5 \cdot (2 + \sum(\Delta n_i) + min(\Delta n_i))} \quad (7)$$

2.2. Resulting Noise Emission Fees at Airports

The noise charges mainly depend on MTOM (FIG. 3), $\sum(\Delta n_i)$ (FIG. 4) and $\min(\Delta n_i)$ (FIG. 5.). A higher MTOM tends to result in higher noise charges. The higher $\sum(\Delta n_i)$ and the higher $\min(\Delta n_i)$, the lower the noise charges.

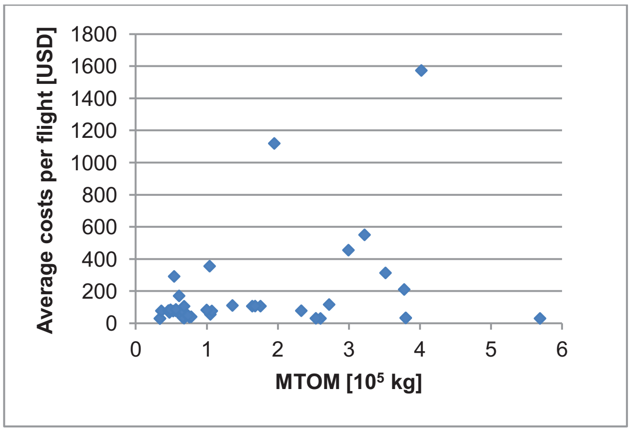

FIG. 3 Noise charges per flight plotted against MTOM (based on NEF from [20] … [29])

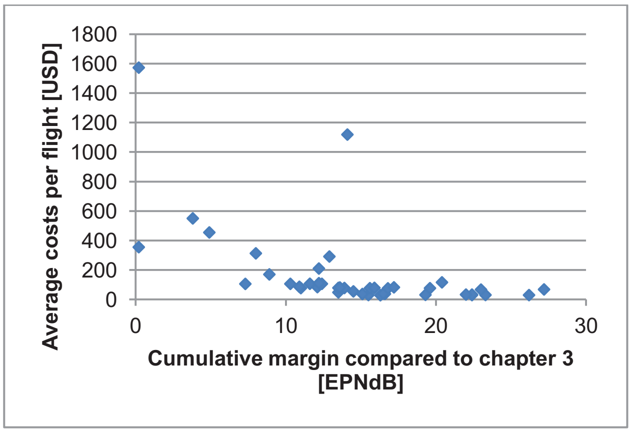

FIG. 4 Noise charges per flight plotted against $\sum(\Delta n_i)$ (based on NEF from [20] … [29])

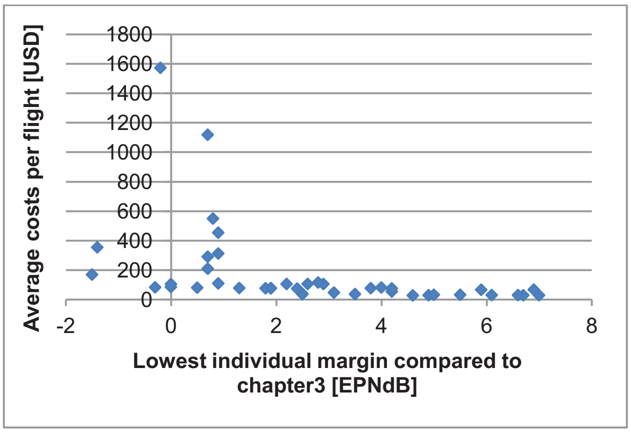

FIG. 5 Noise charges per flight plotted against $\min(\Delta n_i)$ (based on NEF from [20] … [29])

The NEF of a certain aircraft vary greatly between different airports because each airport has its own noise charging system. FIG. 12 shows the comparison of the NEF of three airports. Note that the x-axis has a logarithmic scale.

The results of the calculation of c_n are shown in TAB. 4. The mean charges in 2011 due to NE are 99 € per flight. The main reason for the low value is that in 2011 only 10 of the 50 biggest airports charged for NE. FIG. 11 shows the NEF of the considered aircraft per flight and PAX and compares them to the pollutant emission fees at airports. Obviously NEF are higher than pollutant emission fees.

2.3. Methodology for the Consideration of Pollutant Emission Fees at Airports

The method used to calculate Pollutant Emission Fees (PEF) is very similar to the method used to calculate NEF. For the proposed method, the PEF of 36 commonly used aircraft at the 50 busiest airports in the world in 2010 were analyzed. As mentioned before, these airports handled 44,56 % of the total number of PAX. The PEF of these airports $c_{p,a}$ were weighted by their percentage of the total number of PAX worldwide p_a. The weighted average of the PEF c_p of these 50 airports is assumed to represent the average PEF of all airports in the world.

c_p is calculated by the following equation:

$$c_p = \frac{\sum(p_a \cdot c_{p,a})}{\sum p_a} \quad (8)$$

The results for c_p of the considered aircraft are listed in TAB. 4.

In 2011, 4 of the 50 busiest airports in the world charged for PE [1]. The PEF at these 4 airports depend on the amount of NO_x emissions during the ICAO LTO-Cycle. 2 of these airports also include the amount of HC emissions during the ICAO LTO-Cycle into their PEF. The emission characteristics used for this method are taken from the ICAO Aircraft Engine Emissions Databank [14].

If the Aircraft Engine Emission Databank contains more than one value for a certain engine type, the highest value was chosen (the same procedure is used by the considered airports).

The amount of NO_x ($e_{NOx,LTO}$) and HC ($e_{HC,LTO}$) emissions during the LTO-Cycle and the number of engines n_e were then used to find equations that can be used for the calculation of PEF during the design of new aircraft. This was done with the help of the software tool Eureqa that can be used to detect equations for hidden mathematical relationships [15].

The equations found by Eureqa are:

1) For aircraft with HC emissions during the LTO-Cycle < 19,6 g:

$$c_p = 7{,}12 \cdot 10^{-4} \cdot e_{NOx,LTO} \cdot n_e \quad (9)$$

with a PCC of 1. According to [8], this can be evaluated as a direct or indirect linear correlation.

2) For aircraft with HC emissions during the LTO-Cycle > 19,6 g:

$$c_p = 2{,}12 \cdot 10^{-5} \cdot e_{NOx,LTO} \cdot e_{HC,LTO} \cdot n_e \quad (10)$$

with a PCC of 0.99. According to [8], this can be evaluated as a direct or indirect linear correlation.

Equations (9) and (10) can be used to predict the average aircraft PEF in 2011. In order to provide a methodology with the ability to calculate future PEF, the yearly inflation and the increasing number of airports with PEF has to be considered.

Dividing the future number of airports with PEF $n_{a,pc}$ (which can be found in [1]) by the current number leads to the parameter $k_{a,p}$ which is the factor of the number of airports with emission charges related to those in the year 2011:

$$k_{a,p} = \frac{n_{a,pc}}{25} \quad (11)$$

The yearly inflation can be considered by the parameter k_{inf} that has already been introduced in section 2.1.

Multiplying $k_{a,p}$ by k_{inf} and c_p leads to the total average PEF per flight $c_{p,f}$ taking account of inflation and the further increasing number of airports with PEF:

$$c_{p,f} = k_{a,p} \cdot k_{inf} \cdot c_p \quad (12)$$

Combining Equations (9) … (12) leads to two equations for the calculation of $c_{p,f}$ that can be integrated into the AEA DOC-method (described in Section 4.1):

1) For aircraft with HC emissions during the LTO-Cycle < 19,6 g:

$$c_{p,f} = 7{,}12 \cdot 10^{-4} \cdot \frac{n_{a,pc} \cdot e_{NOx,LTO} \cdot n_e}{25} \cdot (1 + p_{INF})^{n_y - 2011} \quad (13)$$

2) For aircraft with HC emissions during the LTO-Cycle > 19,6 g:

$$c_{p,f} = 2{,}12 \cdot 10^{-5} \cdot \frac{n_{a,pc} \cdot e_{NOx,LTO} \cdot e_{HC,LTO} \cdot n_e}{25} \cdot (1 + p_{INF})^{n_y - 2011} \quad (14)$$

2.4. Resulting Pollutant Emission Fees at Airports

The average airport PEF of the analyzed airports and aircraft in 2011 are shown in FIG. 6. The mean charges in 2011 due to PE are 15 € per flight. The main reason for the low value is that in 2011 only 4 of the 50 biggest airports charged for PE.

Obviously these PEF are low compared to other DOC components. Reducing the PE of an aircraft will therefore lead to minimal DOC reductions. As long as these reductions are low, the financial incentive to reduce PE will stay low.

The results of the calculation of c_p are shown in TAB. 4. FIG. 11 shows the PEF of the considered aircraft per flight and PAX and compares them to the NEF.

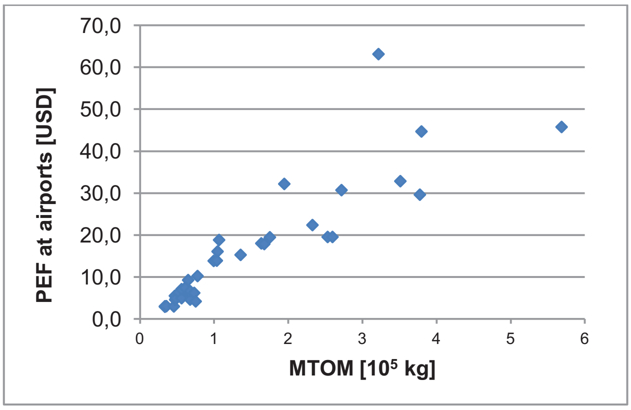

FIG. 6 Average airport PEF per flight for different aircraft (based on PEF from [21], [22], [24], [26])

3. CO_2 FEES DUE TO THE EMISSION TRADING SCHEME OF THE EUROPEAN UNION

In 2003 the European Parliament decided to launch the European Trading Scheme which came into effect on January 1, 2005. Beginning in 2012, aircraft operators taking off or landing in the European Union (EU) will be integrated into this scheme and will have to pay for their CO_2 emissions. The functioning of the ETS for aircraft operators is described in the following paragraphs.

In the years 2004 … 2006, the EU identified the emissions of all affected aircraft operators. The average value of the CO_2 emissions per year was 221,4 Mt CO_2. After that the EU defined CO_2 reduction targets for the future. The emission target of 2012 is 214,8 Mt CO_2 which represents a 3 % reduction compared to the baseline of 2004 … 2006. The target of the years 2013 … 2020 is 210,4 Mt CO_2 representing a 5 % reduction.

FIG. 1 shows the CO_2 emissions of aviation in the EU in 2012 … 2020 as expected by [9]. The green line indicates the average emissions in the years 2004 … 2006 while the grey line indicates the emission targets in 2012 … 2020.

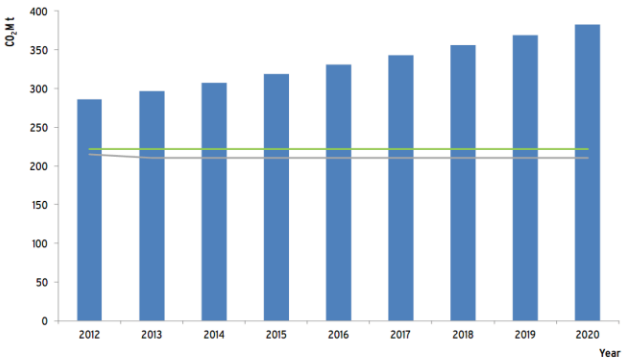

FIG. 7 Expected CO_2 emissions of aviation in the EU within the next years [9]

Beginning in 2012, the EU will distribute and auction emission permits (so called Emission Certificates (EC)) to the aircraft operators. Aircraft operators can also buy emission permits from each other or other participants of the ETS. Each certificate allows them to emit 1 t of CO_2 within the current year. The certificates only cover the previously defined emission targets. If the ECs of an aircraft operator do not cover its emissions, the operator has to pay a fine. This fine was 40 € per t CO_2 in 2005 … 2007 and 100 € per t CO2 since 2008. [10]

For the calculation of CETS, it is assumed that the aircraft operators can cover their CO_2 emissions with ECs, so that no fines have to be paid.

In 2012, 85 % of the certificates will be distributed for free and 15 % will be auctioned. In 2013 … 2020, 82 % will be distributed for free, 15 % will be sold by auction and 3 % will be held in reserve. [10]

A detailed description of the EU ETS can be found in [10].

The consideration of the ETS costs in the DOC is described in the following section.

3.1. Methodology for the Consideration of Fees due to the Emission Trading Scheme of the EU

In a first step, the CO_2 emissions per flight are calculated. The ETS assumes an emission of 3,15 kg CO_2 per kg Jet A or Jet A-1 fuel burned [17]. The CO_2 emissions (in tons) of one flight $e_{CO2,f}$ can then be calculated by

$$e_{CO2,f} = \frac{m_{F,f} \cdot 3{,}15\ \text{kg}}{1000} \qquad (15)$$

where $m_{F,f}$ is the fuel burned during one flight.

If other fuels would be used, the emission factors would obviously be different. For example natural gas would have an emission factor of 2,69 kg CO_2 per kg natural gas burned [17] or hydrogen would have an emission factor of 0.

Obviously CETS are proportional to the fuel burned during one flight. Consequently CETS can be considered as a kind of complex kerosene tax.

A certain percentage of the ECs will be free of charge for the aircraft operators ($p_{CO2,free}$). This effect can be considered by

$$c_{t,CO2} = \left(1 - p_{CO2,free}\right) \cdot c_{t,CO2,m} \qquad (16)$$

where $c_{t,CO2,m}$ are the average costs per EC traded on the market and $c_{t,CO2}$ are the actual average costs per EC for an aircraft operator.

The CO_2 emissions caused by aircraft are steadily increasing. The DLR predicts a 2 … 3 % increase of CO_2 emissions by aircraft each year [6]. The presented fees are calculated assuming a yearly increase of the CO_2 emissions of 2,5 %. Taking account of the increasing emissions, $p_{CO2,free}$ can be calculated by

$$p_{CO2,free} = \frac{p_{CO2,free,p}}{p_{CO2,fut}} \qquad (17)$$

where $p_{CO2,free,p}$ is the predefined percentage of free ECs in a certain year (85 % of the emission target in 2012, 82 % of the emission target from 2013) and $p_{CO2,fut}$ is the percentage of future CO_2 emissions compared to 2005 which is calculated by

$$p_{CO2,fut} = 100 + 2{,}5 \cdot (n_y - 2005) \qquad (18)$$

where n_y is the year for which the emission costs are calculated. 2005 has been chosen as the base year for this equation because the EU ETS identified the CO_2 emissions of aircraft operators in the years 2004 … 2006 which afterwards served as a baseline for the definition of the emission targets.

ETS is limited to aircraft taking off and landing in Europe. The percentage of aircraft movements in Europe compared to worldwide aircraft movements in a certain year is

$$p_{mov,EU} = \frac{n_{mov,EU}}{n_{mov}} \qquad (19)$$

Assuming an average worldwide Revenue Passenger Kilometer (RPK) growth of 4,8 % and an average RPK growth of 4,0 % in Europe in 2011 … 2030 [11], the future number of aircraft movements in the world (n_{mov}) and in Europe ($n_{mov,EU}$) can be calculated in a simplistic way

$$n_{mov} = n_{mov,2010} + \frac{4{,}8}{100} \cdot n_{mov,2010} \cdot (n_y - 2010) \qquad (20)$$

and

$$n_{mov,EU} = n_{mov,EU,2010} + \frac{4{,}0}{100} \cdot n_{mov,EU,2010} \cdot (n_y - 2010) \qquad (21)$$

$n_{mov,2010}$ and $n_{mov,EU,2010}$ can be found in [12] and are listed in TAB. 1.

TAB. 1 Aircraft movements in 2010 [12]

Region	Aircraft movements in 2010
Europe	17596411
World	64418742

Finally the average CETS per flight can be calculated by

$$c_{ETS,f} = c_{t,CO2} \cdot p_{mov,EU} \cdot e_{CO2,f} \qquad (22)$$

Combining Equations (15) … (22) leads to an equation for the calculation of $c_{ETS,f}$ that can be integrated into the AEA DOC-method (described in Section 4.1):

$$c_{ETS,f} = \frac{3{,}15 \cdot 10^{-3} \cdot m_{F,f} \cdot c_{t,CO2,m} \cdot (17{,}6 + 0{,}7 \cdot (n_y - 2010)) \cdot \left(1 - \frac{p_{CO2,free,p}}{100 + 2{,}5 \cdot (n_y - 2005)}\right)}{64{,}4 + 3{,}1 \cdot (n_y - 2010)} \qquad (23)$$

3.2. Resulting Fees due to the Emission Trading Scheme of the EU

The red bars in FIG. 8 show average fees per flight and PAX due to the EU ETS in 2012, assuming a load factor of 75 %, a flight with the maximum range at maximum PAX payload and a 2,5 % growth of the CO_2 emissions caused by the aviation industry per year since 2005. Additionally it is assumed that the aircraft is operated worldwide which means that only 26,9 % of the aircraft movements include take-offs or landings in Europe (calculated using Equation (19)). The blue bars in FIG. 8 show the CETS per flight and PAX assuming that the aircraft is solely operated in Europe so that each flight incurs CETS.

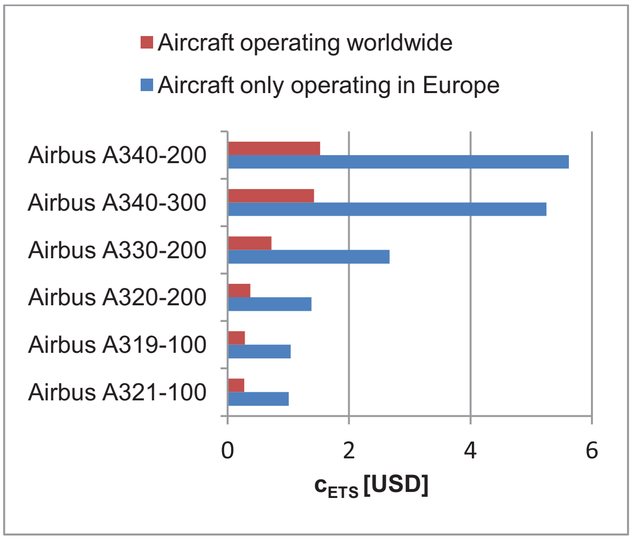

FIG. 8 Average fees per flight and PAX due to the EU ETS in 2012

FIG. 9 shows the development of the average CETS of an A320-211 operated worldwide (the key parameters are listed in TAB. 3) assuming that there will be no changes to the EU ETS and that it stays restricted to Europe until 2020. It can be seen that the CETS increase from 32 USD per flight in 2012 to 52 USD per flight in 2020 even though the share of aircraft movements in Europe will slightly decrease within the next years. This is because of the chosen inflation factor and the increasing CO_2 emissions of the aircraft industry causing that the actual percentage of free ECs decreases. The increase of CETS from 2012 to 2013 is slightly steeper because the share of free ECs will be reduced from 85 % to 82 % in 2013.

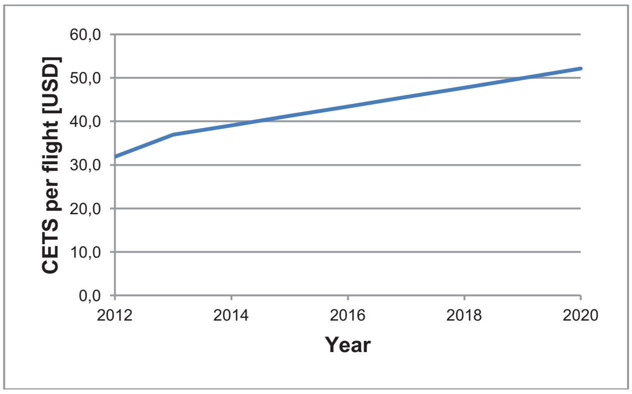

FIG. 9 Development of the CETS of an A320-211

4. INTEGRATION OF POLLUTANT AND NOISE EMISSION FEES INTO DOC METHODS

4.1. Methodology for the Integration into the AEA DOC-method

As already mentioned, the cost calculations presented in Sections 2.1, 2.3 and 3.1 could be integrated into any DOC method. In the following paragraphs, the integration into the AEA DOC method from 1989 is exemplarily described. This method calculates the DOC using the following equation:

$$C_{DOC} = C_{DEP} + C_{INT} + C_{INS} + C_F + C_M + C_C + C_{FEE} \quad (24)$$

where

C_{DEP} Depreciation cost
C_{INT} Interest cost
C_{INS} Insurance cost
C_F Fuel cost
C_M Maintenance cost
C_C Crew cost
C_{FEE} Fees and charges cost

C_{FEE} is calculated as follows:

$$C_{FEE} = C_{FEE,LD} + C_{FEE,NAV} + C_{FEE,GND} \quad (25)$$

where

$C_{FEE,LD}$ Landing fees
$C_{FEE,NAV}$ Navigation fees
$C_{FEE,GND}$ Ground handling fees

The commonly used DOC methods have been created many years ago which means that recently upcoming PNEF usually are not included. To take account of the influence of the fees due to the ETS $C_{FEE,ETS}$, the C_{FEE} calculation of the AEA-method has to be extended in the following way:

$$C_{FEE} = C_{FEE,LD} + C_{FEE,NAV} + C_{FEE,GND} + C_{FEE,ETS} \quad (26)$$

$C_{FEE,LD}$ is calculated as follows:

$$C_{FEE,LD} = k_{LD} \cdot m_{MTO} \cdot n_{f,y} \quad (27)$$

NEF and PEF at airports are part of $C_{FEE,LD}$. Therefore the previous equation for $C_{FEE,LD}$ has to be replaced by the following equation to include PNEF at airports:

$$C_{FEE,LD} = k_{LD} \cdot m_{MTO} \cdot n_{f,y} + C_{FEE,NE} + C_{FEE,PE} \quad (28)$$

where

$C_{FEE,NE}$ total noise emission fees per year
$C_{FEE,PE}$ total pollutant emission fees per year

TAB. 2 lists values for the parameter k_{LD}.

The AEA method calculates the DOC per year. Therefore the end results of Sections 2.1, 2.3 and 3.1 have to be multiplied by the number of flights per year $n_{f,y}$ to get the total fees per year:

$$C_{FEE,NE} = c_{n,f} \cdot n_{f,y} \quad (29)$$

$$C_{FEE,PE} = c_{p,f} \cdot n_{f,y} \quad (30)$$

$$C_{FEE,ETS} = c_{ETS,f} \cdot n_{f,y} \quad (31)$$

According to [16], $n_{f,y}$ is:

$$n_{f,y} = \frac{t_f}{U_{a,f}} \quad (32)$$

with the flight time t_f and the annual utilization:

$$U_{a,f} = t_f \frac{k_{U1}}{t_f + k_{U2}} \quad (33)$$

TAB. 2 lists values for the parameters k_{U1} and k_{U2}.

TAB. 2 Parameters for the calculation of $C_{FEE,LD}$ and $U_{a,f}$ from [2] and [3]

AEA DOC-method	k_{LD}	k_{U1}	k_{U2}
Short-medium range aircraft	0,0078	3750	0,75
Long range aircraft	0,0059	4800	0,42

4.2. Results of the Integration into the AEA DOC-method

FIG. 10 shows the results of the integration of pollutant and noise emission fees into the DOC-method of the AEA.

The DOC are calculated for an A320-211 with CFM56-5A1 engines. TAB. 3 lists the chosen key parameters for the DOC calculation of that aircraft.

TAB. 3 Key parameters of the chosen A320-211

Parameter	Value
Maximum take-off mass [kg]	73500
Maximum landing mass [kg]	64500
Payload mass [kg]	19256
Operating empty mass [kg]	41244
Mission fuel mass [kg]	9827
Range [NM]	1510
PAX [-]	180
Glide ratio [-]	17,6
SFC [kg/N/s]	1,59E-05

Even though NEF and PEF at airports are included in the landing fees in Section 4.1, they are listed separately in FIG. 10 to visualize their percentages.

In 2012, the investigated A320-211 has average NEF of 0,29 USD per flight and PAX. The average PEF are only 0,035 USD per flight and PAX and the CETS are 0,17 USD per PAX for a flight with a range of 1510 NM. In this case, NEF account for about 0,20 %, PEF for 0,02 % and CETS for 0,12 % of the DOC showing that these costs are low compared to other DOC elements.

NEF do not yet play an important role in the DOC. Nevertheless, the increasing awareness regarding noise will lead to further increasing noise costs in the future.

Much more important for aircraft manufacturers is meeting the requirements of the ICAO noise chapters for certification and making sure that an aircraft will meet future noise requirements during its entire operational life.

PEF and CETS also do not yet play an important role in the DOC. The main reason for the low PEF is the low number of airports charging for PEF. Only if that number increases in the future, the influence of PEF will grow. The main reasons for the low CETS are that the ETS is restricted to Europe and that the current EC price is relatively low. The introduction of a worldwide ETS or higher EC prices could lead to higher CETS in the future.

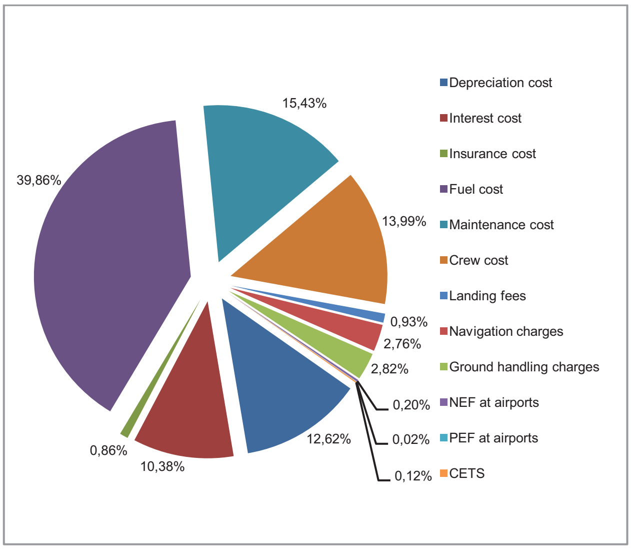

FIG. 10 Direct Operating Costs of an A320-211 calculated with the AEA DOC-method for short and medium range aircraft [2]

5. SUMMARY AND CONLUSION

This paper evaluates pollutant and noise emission fees (PNEF) at airports as well as CO_2 emission Costs due to the Emission Trading Scheme (CETS) of the European Union. It is shown how these fees can be included in the Direct Operating Cost (DOC) method of the Association of European Airlines of 1989 although the method could also be integrated into any other DOC method.

Taking the example of an Airbus A320-211 the average Noise Emission Fees (NEF) in 2012 are 0,29 USD per flight and PAX. The average airport Pollutant Emission Fees (PEF) are 0,035 USD per flight and PAX and the CETS are 0,17 USD per PAX for a flight with a range of 1510 NM. In this case, NEF fees account for about 0,20 %, PEF for 0,02 % and CETS for 0,12 % of the DOC showing that these costs are low compared to other DOC elements.

In 2011 only 10 of the considered 50 airports charged for noise emissions, and only 4 of which charged for pollutant emissions. Further, the emission trading scheme only accounts for aircraft taking-off and/or landing in Europe, which in itself only accounts for 26,9 % of the worldwide aircraft movements in 2012, which goes some way towards explaining these low fees.

The results show that current NEF have little influence on the overall economics of aircraft, which explains why the economic motivation for more silent aircraft stays low. However the increasing ICAO noise requirements have led to the development of more silent aircraft over the last decades. Current PEF and CETS also have low influence on the aircraft economics. If governing bodies want to encourage the aviation industry to reduce their pollutant and noise emissions, it is clear that current measures are not sufficient.

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NOMENCLATURE

Symbols

C_C	Crew cost
C_{DEP}	Depreciation cost
C_{DOC}	Direct operating costs
$c_{ETS,f}$	ETS costs per flight
C_F	Fuel cost
C_{FEE}	Fees and charges cost
$C_{FEE,ETS}$	ETS costs per year
$C_{FEE,GND}$	Ground handling fees
$C_{FEE,LD}$	Landing fees
$C_{FEE,NAV}$	Navigation fees
$C_{FEE,NE}$	total noise emission fees per year
$C_{FEE,PE}$	total pollutant emission fees per year
C_{INS}	Insurance cost
C_{INT}	Interest cost
C_M	Maintenance cost
c_n	weighted average of noise emission charges
$c_{n,a}$	airport noise charges
$c_{n,f}$	total average noise charges per flight
c_p	weighted average of pollutant emission charges
$c_{p,f}$	total average pollutant emission charges per flight
$c_{t,CO2,m}$	average costs per EC traded on the market
$e_{CO2,f}$	CO_2 emissions during one flight (in tons)
$e_{HC,LTO}$	HC emissions during the LTO cycle
$e_{NOx,LTO}$	NO_x emissions during the LTO cycle
$k_{a,n}$	factor of the number of airports with noise charges related to those in the year 2011
$k_{a,p}$	factor of the number of airports with emission charges related to those in the year 2011
k_{inf}	inflation factor
k_{U1}	parameter for the calculation of $n_{f,y}$
k_{U2}	parameter for the calculation of $n_{f,y}$
$m_{F,f}$	fuel burned during one flight
m_{MTO}	maximum take-off mass
$\min(\Delta n_i)$	lowest individual noise margin at one of the three measuring points
$n_{a,NEF}$	number of airports with noise charges
$n_{a,pc}$	number of airports with pollutant emission charges
n_e	number of engines of one specific aircraft
$n_{f,y}$	number of flights per year
n_{mov}	number of aircraft movements in the world in a certain year
$n_{mov,EU}$	number of aircraft movements in Europe in a certain year
n_y	year for which charges, … are calculated
p_a	percentage of the total number of PAX in the world of an airport
$p_{CO2,free}$	percentage of CO_2 emissions certificates that is free of charge
$p_{CO2,free,p}$	predefined percentage of free CO_2 ECs
$p_{CO2,fut}$	percentage of future CO_2 emissions compared to 2005
p_{inf}	inflation rate for fees and charges
$p_{mov,EU}$	percentage of aircraft movements in Europe compared to worldwide aircraft movements
t_f	flight time
$U_{a,f}$	annual utilization
Δn_i	noise margin
$\sum(\Delta n_i)$	cumulative noise margin at all three measuring points

Abbreviations

AEA	Association of European Airlines
CETS	Costs due to the ETS of the EU per flight and PAX
CN	airport noise emission charges
DOC	Direct Operating Costs
EC	Emission Certificate
ETS	Emission Trading Scheme
EU	European Union
ICAO	International Civil Aviation Organization
LTO	Landing and Take-Off
MLM	Maximum Landing Mass
MTOM	Maximum Take-Off Mass
NE	Noise Emissions
NEF	Noise Emission Fees
PAX	Passenger
PCC	Pearson product-moment correlation coefficient
PE	Pollutant Emissions
PEF	Pollutant Emission Fees
PN	Pollutant and Noise
PNEF	Pollutant and Noise emission Fees
RPK	Revenue Passenger Kilometer

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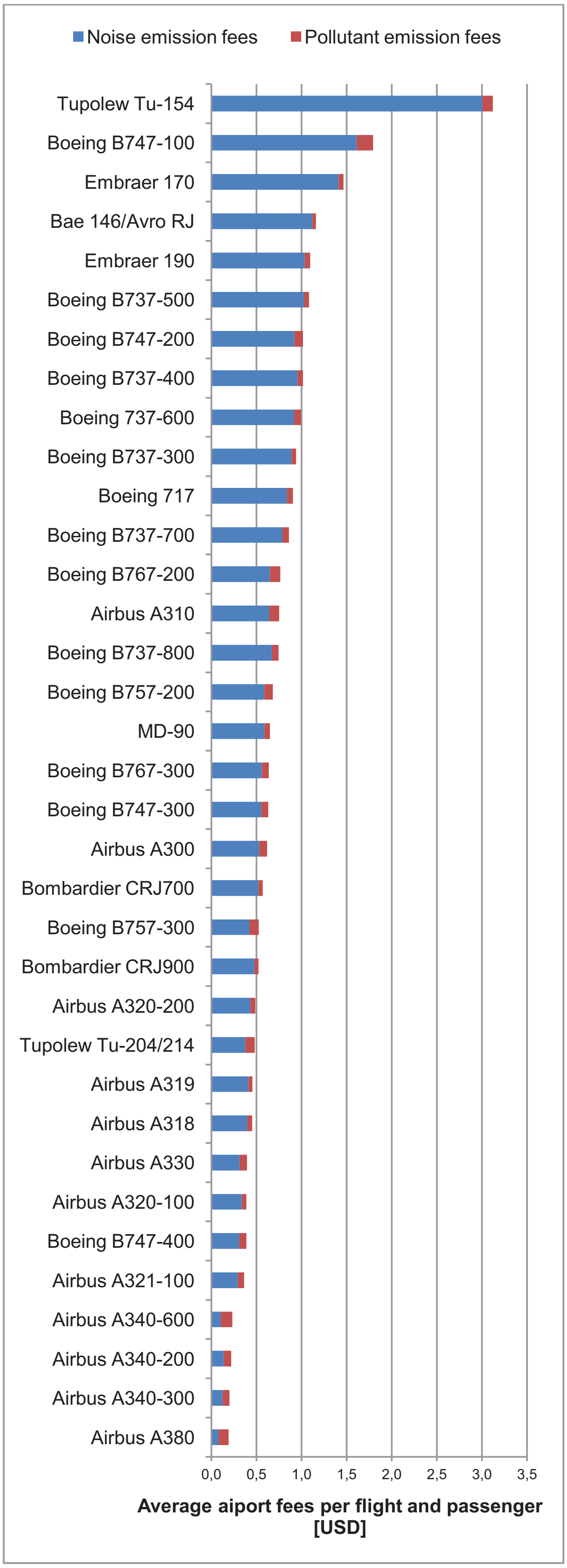

FIG. 11 Average PNEF per flight and PAX in 2011 (based on PNEF from [20] … [29])

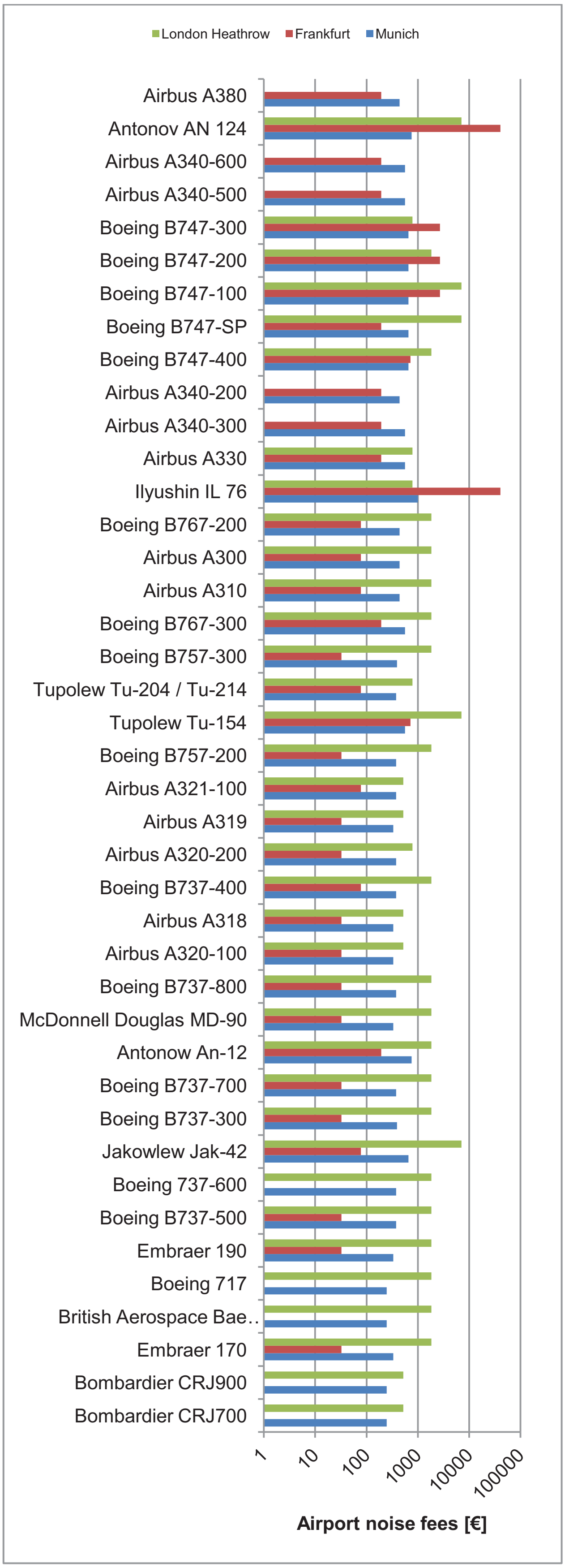

FIG. 12 Comparison of the NEF of three airports in 2011 (based on NEF from [21], [24] and [26])

TAB. 4 Worldwide average PNEF of the considered aircraft in 2011 (based on PNEF from [20] … [29])

Aircraft	Worldwide average NEF c_n USD	Worldwide average PEF c_p USD
Airbus A340-300	31,4	18,8
Airbus A300	105,6	17,2
Airbus A310	105,0	17,3
Airbus A318	31,8	4,5
Airbus A319	38,3	4,1
Airbus A320-100	37,6	6,0
Airbus A320-200	48,4	6,0
Airbus A321-100	40,5	9,9
Airbus A330	77,9	21,5
Airbus A340-200	30,8	18,8
Airbus A340-600	34,2	43,0
Airbus A380	30,8	44,0
Bae 146/Avro RJ	78,2	2,9
Boeing 717	66,0	5,3
Boeing 737-600	74,4	6,1
Boeing B737-300	85,3	4,8
Boeing B737-400	104,2	6,4
Boeing B737-500	82,9	4,8
Boeing B737-700	75,5	6,8
Boeing B737-800	80,5	8,9
Boeing B747-100	533,2	60,4
Boeing B747-200	304,9	31,6
Boeing B747-300	206,5	28,5
Boeing B747-400	115,1	29,6
Boeing B757-200	81,4	13,3
Boeing B757-300	75,7	18,1
Boeing B767-200	105,1	18,7
Boeing B767-300	109,5	14,7
Bombardier CRJ700	29,2	2,8
Bombardier CRJ900	30,5	2,9
Embraer 170	76,1	3,0
Embraer 190	77,6	4,4
MD-90	66,9	7,2
Tupolew Tu-154	345,5	13,3
Tupolew Tu-204/214	55,1	15,5