ENVIRONMENTAL IMPACT OF AIR TRAFFIC FLOW MANAGEMENT DELAYS

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1 Abstract

The regulation of European air traffic, as currently done by the CFMU and the regional ATFCM cells, essentially consists in delaying on the ground all flights that may encounter congestion at some stage of their trip. This preventive strategy is based on the assumption that avoiding en-route traffic overload contributes to safety and that ground delays should, in theory, be cheaper than their en-route equivalent from the airspace users' viewpoint. This study aims at performing a comparative environmental analysis of ground and en-route delays, along with assessing the corresponding costs.

2 Introduction

Air traffic in Europe is regulated by the CFMU (Central Flow Management Unit), which holds the functions of centralising declared capacities by all European air traffic control centres and declared flight plans by all airspace users operating under Instrument Flight Rules.

By confronting ‘supply of capacity’ and ‘demand for capacity’, the CFMU is able to: strategically and tactically estimate the European air traffic system planed and actual utilisation; ensure smooth operations; avoid controller workload above desired levels; and ensure a fair treatment of airspace users in their access to capacity.

The regulation of air traffic mainly relies on a ground delay principle. The CFMU allocates departure slots by delaying on the ground the flights that might encounter traffic overloads at some stage of the trip. This can be seen as a preventive action, based on the idea that avoiding en-route traffic overload is a safety factor, and that for airspace users, a ground delay should in theory be more economical than an en-route delay.

However, ground delay regulations generate congestion at the departure airport; they also prevent the use of en-route or arrival capacity that would appear to be available in reality although not forecasted at the time of the slot allocation. Depending on the aircraft type, the delay duration, the airline operational organisation and the strategic importance of the delayed flight, it is not obvious that ground delays are always more efficient than en-route delays or vice versa.

One way to approach these issues would be to study delays (airborne and ground) before and after the CFMU creation. However, the CFMU started its operations in March 1996 and replaced a situation where traffic flow management existed but was not centralised. Five flow management cells were operating in Europe: Paris (established in 1973), Frankfurt, London, Roma, and Madrid. Inferring from delay statistics the impact of CFMU regulation is thus not possible, as pre-CFMU times do not mean absence of flow regulation by ground delays. Furthermore, traffic and control centre capacities grew at different speeds over time, and delay statistics, although influenced by regulation strategies, primarily depend on demand / capacity patterns.

3 Background and Objectives

The present study aims at conducting an environmental and economic assessment of both the ground delay practices and airborne delays alternatives. It is, to our knowledge, the first attempt of an environmental analysis of ground delays. As an exploratory research field, the scope of investigations is deliberately focussed on a reduced traffic sample as modelling the environmental cost for all European traffic would be premature, and too detailed for an initial exercise. The following objectives were pursued:

- To obtain orders of magnitudes of environmental costs of different delay strategies (ground vs. airborne) based on simplified but representative traffic samples;
- To assess impacts on local and global emissions;
- To consider only delays resulting from ATFM (Air Traffic Flow Management) regulation.

The study thus does not cover the investigation of the cost of delays that are not related to an environmental impact (crew cost, maintenance, reactionary delays, passengers delay cost, etc.), nor the other environmental aspects of local pollution and global emissions of aircraft such as noise, soil and water pollution, contrails.

4 Definition of Scenarios

The study examines two scenarios: a ground delay scheme, based on the observed current situation, and an airborne delay scheme.

4.1 *Ground delays*

The scenario of environmental impact under a ground delay scheme has to consider the aircraft operating mode when delayed on the ground. The following possibilities can be used:

- Engines ON while stationary or taxiing ;
- Auxiliary power unit (APU) ON ;
- Ground Power Unit (GPU) ON.

The issue when setting assumptions on the operating mode of an aircraft delayed on the ground is that the situation depends on aircraft, airports, and delay duration. Indeed, being delayed ‘on the ground’ can result in extra time at the gate, where GPU or APU can be used, or in extra time off-gate (stationary or taxi) where the main aircraft engines are used.

A study [Ref 1.] relying on detailed investigations, direct airline interviews and data collection, and used as the reference by the Performance Review Commission for costing ATFM delays in Europe [Ref 2.] has proposed the following assumptions and repartition keys to allocate ground ATFM delays into different operating modes.

Table 1: Allocation of ground delay per operating mode

Operating mode	Proportion of time spent
At gate with GPU only	81%
At gate with APU only	9%
Off-gate stationary ground or active taxi out	10%

In absence of contradictory evidence, and for consistency with the PRR (Performance Review Reports) framework, the same assumptions are used in this study. The only difference is that the taxi-out and stationary distinction is not applied as the environmental model used (ALAQS) uses the same fuel and emissions values for both modes.

4.2 *Airborne delays*

The alternative scenario (airborne delay scheme) is also subject to different options. If airspace users were attributed an arrival slot instead of a departure slot (arrival can be arriving at final destination or arriving in the sector generating an ATFM regulation), airspace users would apply one of the three following options:

- Holding stacks ;
- Rerouting ;
- Speed control.

The feasibility of each option depends on the delay duration, and on the location of the regulation causing delay in the flight path. The following assumptions are studied:

Table 2: Allocation of airborne delays per option

	Location of the regulation	
	En-route (50% of CFMU statistics)	**Arrival airport** (50% of CFMU statistics)
Holding stack	0%	100%
Rerouting	100%	Not possible

4.3 *Fleet sample and delay times*

According to [Ref 2.] the most congested airports in the EUROCONTROL area are Frankfurt, London Heathrow, Zurich, Paris CDG, Wien, Roma Fiumicino, München, Amsterdam, Barcelona, Brussels Zaventem, Madrid, Praha, Iraklion, Villafranca, Alicante, and Dublin. This group alone generates 80% of European airport delays.

The fleet sample selection was based on the observed fleet of the main airlines operating at these airports. It does not reflect precisely the whole fleet exposed to en-route delays (this would require the extraction of the information from CFMU data), however, it is assumed that the resulting selection is wide enough to be representative of the fleet suffering en-route congestion, and not only airport delays.

The analysis of airline data revealed it is relevant to focus the environmental impact analysis on the following subset of 16 aircraft types, namely: A319-100, A320-200, A321-100, A330-200, A340-300, ATR42-300, ATR72-200, B737-300, B737-500, B757-200, B747-400, B767, B777-200, CRJ100/200, MD82, Avro RJ85.

The above list includes the main aircraft types and represents the diversity of the fleet in operation. This fleet sample should allow the analysis of different environmental characteristics while keeping a small and workable sample size, flexible enough to run alternative scenarios.

Any of the above aircraft can be subject to ATFM regulation of variable duration. It could be derived from CFMU statistics that particular aircraft types are actually suffering longer delays than others depending on the types of routes they operate. However, focusing the analysis at such a level of detail would allow for a precise ex-post assessment, but would not reflect what the situation could be in the future.

Actually, in the hypothetic case where the CFMU would not allocate ground regulations but airborne regulations, it is not sure that the delay duration per aircraft type would have the same distribution as today. It is therefore difficult to infer from observations a precise delay duration distribution pattern. The 2004 distribution is shown for illustration purposes. The current study will model environmental impacts of ground and airborne delays of any duration for all aircraft types.

As stated in [Ref 1.], there were 8.9 million flights in 2004 in the EUROCONTROL area among which 8.5% (i.e. 756,500 flights) were delayed by at least 5 minutes because of ATFM regulations. The repartition of delays per delay duration is presented in Table 3.

Table 3: 2004 delay distribution – EUROCONTROL area

Delay duration [minutes]	% total traffic	Number of flights
0 – 4	91.4	Not considered delayed
5 – 15	4.6	409,400
16 – 30	2.7	240,300
31 – 60	1.0	89,000
> 60	0.2	17,800

We infer from Table 3 that any delayed aircraft is subject to probability of delay duration as shown in Table 4 below (this assumption allows the estimation of the 2004 total delay of 14.9 million minutes):

Table 4: Assumed probability of delay duration

Delay duration [min]	Probability [%]
10	54%
23	32%
45	12%
70	2%

5 Fuel Burn and Emission Assessment

Fuel burn and emissions are calculated using the EUROCONTROL Airport Local Air Quality Studies (ALAQS) tool for ground delays and Advanced Emission Model (AEM) tool for airborne delays. The aircraft/engines association relies on JP Airline-Fleets ([Ref 6.])

5.1 *Ground delays*

Environmental impacts of ground delays are computed using the ALAQS database [Ref 2.], [Ref 3.], [Ref 4.]. The database groups specific aircraft into categories and then allocates fuel and emissions values per category. The list of aircraft selected for the study has the following correspondence with ALAQS categories:

- TURBOPROP - includes the ATR42 and ATR 72 ;
- JET REGIONAL - includes the Avro RJ85, CRJ100, and CRJ200 ;
- JET SMALL - includes the A319, A320, A321, B737-300, B737-500, B757-200 and MD82 ;

- JET MEDIUM - includes the A330 and B767 ;
- JET LARGE - includes the A340, B747, and B777.

For each aircraft category ALAQS provides fuel consumption and NO_x/CO/HC emission rates in kg/min of Auxiliary Power Units (APU), Ground Power Units (GPU) and engines in idle mode – referring to the operating modes in

Table 1. Figures were obtained from [Ref 2.] and [Ref 3.]

Based on the operating mode allocation in

Table 1 and the annual figure of 14.9 million minutes of ATFM delay in 2004, the annual fuel burn and emissions related to ground delay only were derived and presented in Table 5 hereunder.

Table 5: Annual impact of ground delay

	% in flight movements	Fuel [tonnes/year]	NOx [tonnes/year]	HC [tonnes/year]	CO [tonnes/year]
JET SMALL	57%	15 465	197	41	399
JET MEDIUM	4%	1 637	16	7	37
JET LARGE	3%	2 049	17	9	57
JET REGIONAL	13%	2 560	41	13	87
TURBOPROP	23%	3 886	70	27	96
All	*100%*	*25 597*	*342*	*98*	*676*

It should be noted that CO_2, H_2O and SO_x emissions are directly proportional to fuel burn.

5.2 Airborne delays

Environmental impacts of airborne delays are computed based on:

- BADA3.6 (Base of Aircraft Data) [Ref 8.]. BADA is an aircraft performance database being maintained and developed by the EUROCONTROL Experimental Centre. Although BADA's main application is trajectory simulation and prediction within ATM, the database holds fuel flow information for 295 different aircraft types.
- ICAO Engine Exhaust Emissions Data Bank [Ref 6.]. This databank holds results from engine tests. Fuel flow and emission indices for NOx, CO and HC at ground level can be extracted from this databank.
- Boeing Method 2 – EUROCONTROL Modified is applied to adapt ground level emission indices to higher altitudes.

All aircraft types in the study’s fleet are covered by BADA3.6; the most common engine was identified for each of them.

5.2.1 Holding stacks

After reviewing the organisation of airborne holding stacks at the main airports covered by the study (Amsterdam, London, Paris and Zurich), the following assumptions were considered as a reasonable description of the “average” situation, keeping in mind that each airport is specific and that even at a given airport, procedures in holding will vary in accordance with the runway in use, the meteorological conditions, etc.

- The holding stack design is typically based on an oval shape with a lateral leg of 1 minute flight duration, a 180 degrees turn, another 1 minute flight leg, and another 180 degrees turn. The total time for a turnaround is thus assumed to be 4 minutes.
- The exit point of the holding stack (ending the delay) is assumed at FL70.
- The entry point in the stack depends on the traffic already in the queue, knowing that there is a 1000 feet vertical separation between queuing aircraft. One could imagine that for less than 10 minutes delay, the entry point is around FL90, for a 20 minutes delay, FL120, and for a one hour delay, FL220. However differences in fuel consumption between holding stacks starting at FL80 or at FL120, or FL180, are insignificant, and the impact on our results would be negligible. The assumed average altitude for holding stack was set arbitrarily to FL80, ending at FL70.

- The aircraft speed (IAS) in the holding stack is assumed to be 230 kt, knowing that the maximum speed in a TMA (Terminal Manoeuvring Area) is generally 250 kt.

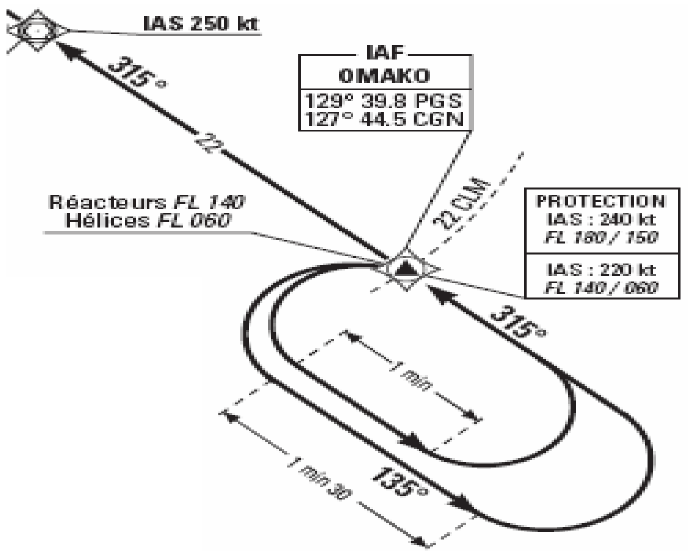

Figure 1: Example of a holding stack – extracted from Paris CDG AIP

Stack fuel consumption and NO_x/CO/HC emission rates (kg/min) were derived for each aircraft by averaging FL80 cruise rates (weighted at 75%) and 230 knots TAS (True Air Speed) descent rates, corresponding to about 1000 feet per minute descent rate (weighted at 25%). Complete holding turnaround is assumed 3 minutes at stabilised level and 1 minute for descending 1000 feet lower.

5.2.2 *Flight rerouting*

The flight rerouting alternative is established based on the assumption that congested sectors are all located in the upper airspace, where aircraft are at standard cruise altitudes. A more precise evaluation of the alternative would require identifying the average altitudes of actual congested sectors. This would probably identify situations were the congested area is an approach sector which is not possible to avoid. Some congested sectors could also appear to be in the ascending phase, where the fuel consumption is higher than in the cruise phase, but it could also be in the descending phase where the consumption is lower. As an initial feasibility study, we consider that setting the assumption at the cruise level will be enough to establish orders of magnitude.

Avoiding a 10 minute ground regulation through a rerouting manoeuvre may not translate into an extra 10 minutes of flight duration. Provided there is just one congested sector the extra flight duration will just be the extra time to fly around the congested sector. However, it is reasonable to assume that for long ATFM delays, there might be a combination of several congested points.

Real sectors are complex polygons, and modelling them in the scope of this study would require too many details to be adjusted with regard to the aim of the study. Computing the extra distance needed to avoid a congested sector is therefore based on the following simplified assumptions:

- Sectors are squares of 100 kilometres side ;
- Aircraft transit sectors completely, and take about 9 minutes to do so ;
- On average, the closest detour route from the sector entry point is 50 kilometres (half of the average transit distance).

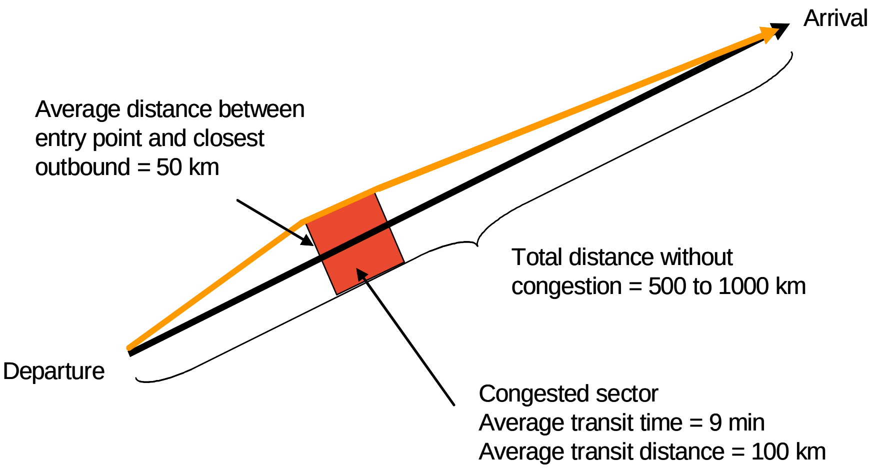

Figure 2: Illustration of rerouting assumptions

Based on the above assumptions, the extra flight time for avoiding an average congested sector, would be very limited, 1 to 3 minutes only, depending on the congested sector location.

We assume that in case of long ground delays (45 and 70 minutes), there is more than one congested sector to avoid. In the case of 45 minute delays, we assume that 2 sectors have to be avoided leading to 2-6 minutes airborne delay, and 70 minute delays would correspond to 3 congested sectors, and 3 to 9 minutes airborne delay. Because rerouting may generate congestions in adjacent sectors, a ripple effect may have to be added. This aspect is beyond the scope of the current study, and would need further investigation for a more detailed impact assessment.

Table 6: Estimated equivalence between ground delays and rerouting duration

Ground delay duration [min]	Rerouting duration [min]
10	2
23	3
45	4
70	6

Rerouting fuel consumption and emission rates are then derived for each aircraft type.

Given the delay duration probabilities (Table 4) and the rerouting time assumptions (Table 6), it is estimated that avoiding 14.9 million minutes of ground delays with flight rerouting would generate 2 million minutes rerouting time. Airborne holding delays would have the same duration as ground delays.

Furthermore, the management of airborne delays would be very dependant on local practices and cannot be generalized. Our main assumption was that a "standard" airborne delay would be equally shared between holdings and flight rerouting.

In absence of ground regulation, airborne delay during 2004 would correspond to 8.5 million minutes[1]. The resulting annual impact of airborne delay is presented in Table 7.

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[1] Assumption: 14.9 millions minutes of ATFM delay in 2004 are equivalent to 7.5 million minutes spent in holding stacks plus 1 million minutes of rerouting (see Table 4 and Table 6).

Table 7: Annual impact of airborne delay

	% in flight movements	Fuel [tonnes/year]	NOx [tonnes/year]	HC [tonnes/year]	CO [tonnes/year]
JET SMALL	57%	95 260	714	25	550
JET MEDIUM	4%	13 981	125	2	42
JET LARGE	3%	13 516	126	3	87
JET REGIONAL	13%	13 761	93	2	51
TURBOPROP	23%	11 911	29	153	1 363
All	*100%*	*148 429*	*1 087*	*185*	*2 093*

5.3 *Comparison of the ground and airborne scenario*

The following table presents the yearly difference between airborne and ground delay fuel burn and emissions (‘airborne’ minus ‘ground’).

Table 8: Annual difference between airborne and ground delays

	% in flight movements	Fuel [tonnes/year]	NOx [tonnes/year]	HC [tonnes/year]	CO [tonnes/year]
JET SMALL	57%	79 089	512	-17	146
JET MEDIUM	4%	11 230	98	-5	2
JET LARGE	3%	13 134	125	-6	40
JET REGIONAL	13%	11 687	55	-11	-33
TURBOPROP	23%	7 980	-41	125	1 262
All	*100%*	*123 120*	*748*	*87*	*1 417*

The amount of fuel burn due to airborne delays would be far more important than with ground delays, although some ground delays could be compensated by fairly short rerouting. The net annual benefit of ground delays strategies compared to airborne strategies reaches about 120,000 tonnes of fuel. Globally, there is also a net benefit for all studied emissions. However, the impact per pollutant depends on aircraft type:

- With the exception of turboprops, NO_x emissions due to airborne delay are higher than ground delays' emissions. Higher NO_x emission rates for airborne aircraft are the result of a higher-temperature combustion compared to ground idling, due to engines running near to top speed.
- Conclusions for HC and CO are less obvious. Indeed HC emissions generated by ground delays generally exceed airborne emissions while the best option regarding CO depends on the aircraft category. High HC and CO emissions for ground delays were predictable since they are highest at low engine power setting, and especially during idle. Airport and/or airline strategies concerning APU, GPU or engine use at ground are essential to monitor the amount of HC and CO emitted, and eventually could help reduce these emissions below airborne level. VOC (Volatile Organic Compounds) and TOG (Total Organic Gases) follow HC evolution since their definitions include most of the same gases.

Finally, looking at total emission figures in a 'ground versus airborne' assessment is necessary but not sufficient. The environmental effects of most aircraft emissions strongly depend on the flight altitude, and whether aircraft fly in the troposphere or stratosphere. The effect on the atmosphere can be markedly different from the effects of the same emissions at ground level. Moreover, emissions at low altitude have a direct impact on populations living around airports, while emissions at altitude influence climate. This aspect would need further trade-off investigation.

6 Cost Assessment

The above fuel burn and emission amounts are finally converted into monetary terms using statistics of jet kerosene cost, and results from a previous study on aviation emission costs [Ref 8.]. Additional emission cost information was derived from the 2002 report by CE Delft on external costs of aviation [Ref 9.], and from the EU Emission Allowances (EUA) market [Ref 10.]. The objective is to quantify the financial benefit of delaying aircraft on the ground compared to delaying them en-route.

6.1 *Fuel unit cost*

2005 monthly statistics on the spot price of jet kerosene were obtained from the February 2006 issue of Airline Business and converted from US$ to EUR on a monthly basis. Two “into plane” surcharge values were added separately (one low, one high), yielding the two curves for the unit cost of “into plane” jet kerosene (in €/tonne) hereunder:

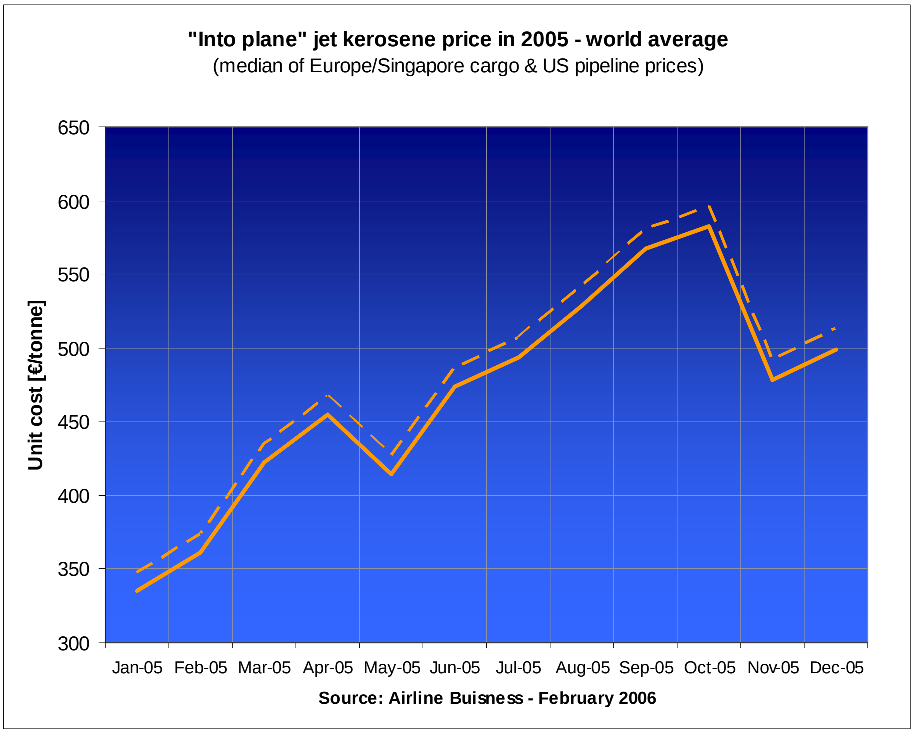

Figure 3: 2005 “into plane” jet kerosene price – low/high surcharge

From the above curves, three cost values (low, base and high) were derived for fuel, respectively 335 €/tonne, 482 €/tonne and 596 €/tonne. These values correspond to the minimum, median and maximum values of 2005 “into plane” jet kerosene price.

The total fuel cost of each studied scenario is computed using these economic values.

6.2 *Emissions unit cost*

For each pollutant, a low, base and high unit cost was derived from a literature review. The unit costs of CO_2, NO_x, SO_x, HC and CO were taken from a study on aviation emission costs [Ref 8.], while H_2O prices were taken from the 2002 CE Delft report [Ref 9.].

Table 9: Emissions unit costs (€/tonne) – Low, Base, High

Unit Costs (€/tonne)	Low	Base	High
CO2	11	37	65
H2O	2.8	8.3	14
NOx	4,460	6,414	10,693
SOx	2,110	6,094	11,133
HC	2,569	5,543	8,518
CO	104	142	205

It was initially attempted to obtain different unit costs for ground emissions on one hand and airborne emissions on the other hand. Indeed, the impact of a given pollutant on the environment depends on the altitude at which it has been emitted.

Such information could only be partially obtained, therefore a single value was used in the scope of this study. As far as NO_x is concerned, the level of uncertainty for both local and global costs is such that average values are finally not very different. Furthermore, the cost of ground emissions is highly dependent on the population density around the airport – which is an unknown parameter in the present study. Later in this section it will be discussed which pollutants should actually be taken into account in the ground scenario, and which ones should be considered in the airborne scenario.

In addition to the above literature review, recent statistics of CO_2 prices on the EU Emission Allowances (EUA) market were collected. The corresponding evolution of CO_2 price along 2004 and 2005 is represented hereunder:

Figure 4: CO_2 prices on EUA market [Ref 11.]

The above graph shows CO_2 values that are comparable to those in Table 9. However, it tends to show as well that the high value in Table 9 may be overestimated when assessing the cost of ground-emitted CO_2 [2].

6.3 Comparison of ground and airborne delays environmental costs

From the emission amounts in Table 5 and Table 7, and the unit costs in previous sections, environmental costs of ground and airborne delays were calculated.

When taking all fuel use and pollutants into account, the yearly environmental cost of ground delay has low, base and high values of about 10 M€, 20 M€ and 25 M€ respectively[3]. The base cost distribution among fuel and emissions is represented in the pie chart hereafter:

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[2] This assumes that the market cost of CO_2 credits equals the cost impact on the environment. This is debatable, as this market cost only reflects how much companies are willing to pay to avoid reducing CO_2.

[3] The environmental cost of ATFM delays in 2004 estimated here (about 20 M€) is not comparable with values published by the Performance Review Commission (800 M€, [Ref 11.]), as the PRC includes fuel, maintenance, crew costs, reactionary delays, strategic and tactical buffers, etc. In our study we only looked at fuel and emissions costs.

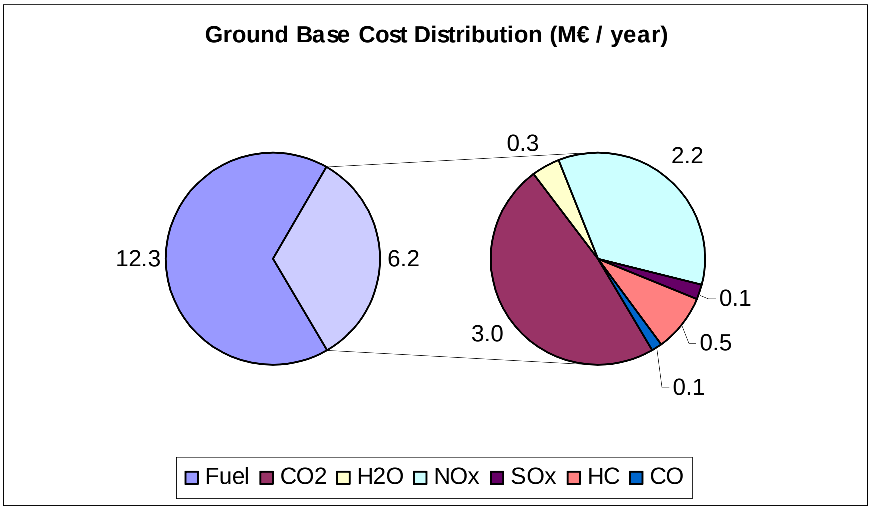

Figure 5: Ground Base Cost Distribution (M€ / year)

It can be argued that the effect of ground-emitted H_2O is null, and therefore the associated cost should be ignored. However, Figure 5 shows that ignoring H_2O hardly affects the overall ground cost and distribution. The environmental cost of ground delay could be further reduced if low, base and high CO_2 prices correlated with the recent values on the EUA.

When taking all fuel use and pollutants into account, the yearly cost of airborne delay has low, base and high values of 60 M€, 100 M€ and 135 M€ respectively. The base cost distribution among fuel and emissions is represented in the pie chart hereafter:

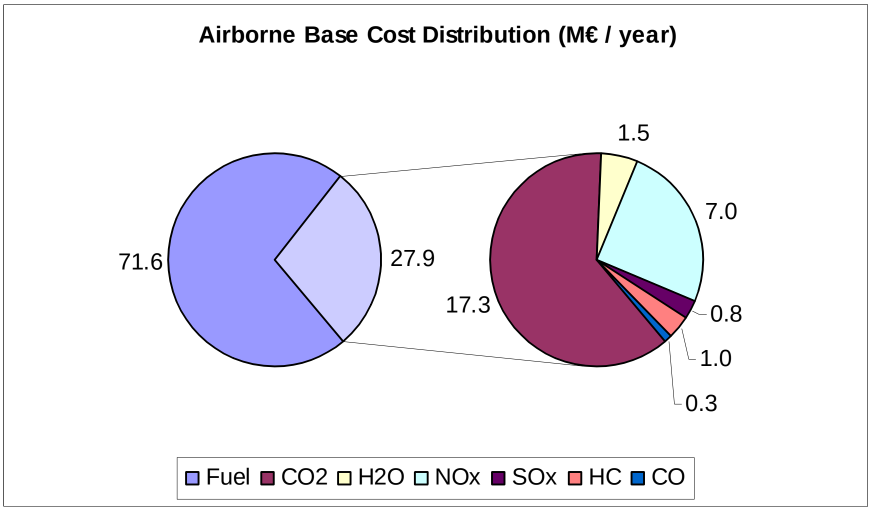

Figure 6: Airborne Base Cost Distribution (M€ / year)

It can be argued that the effects of SO_x, HC and CO are negligible when they are emitted at higher altitudes. However, Figure 6 confirms that ignoring SO_x, HC and CO hardly affects the overall airborne cost and distribution.

Fuel use and NO_x clearly represent the vast majority of costs for both the ground and airborne delay scenarios.

From the above results, a net benefit of ground delays over airborne delays is observed. The low, base and high annual benefit reach respectively 50 M€, 80 M€ and 110 M€.

6.3.1 *Sources of benefit*

The distribution of the overall financial benefit among fuel burn and the miscellaneous pollutants is represented in the bar chart hereunder for the three low, base and high scenarios:

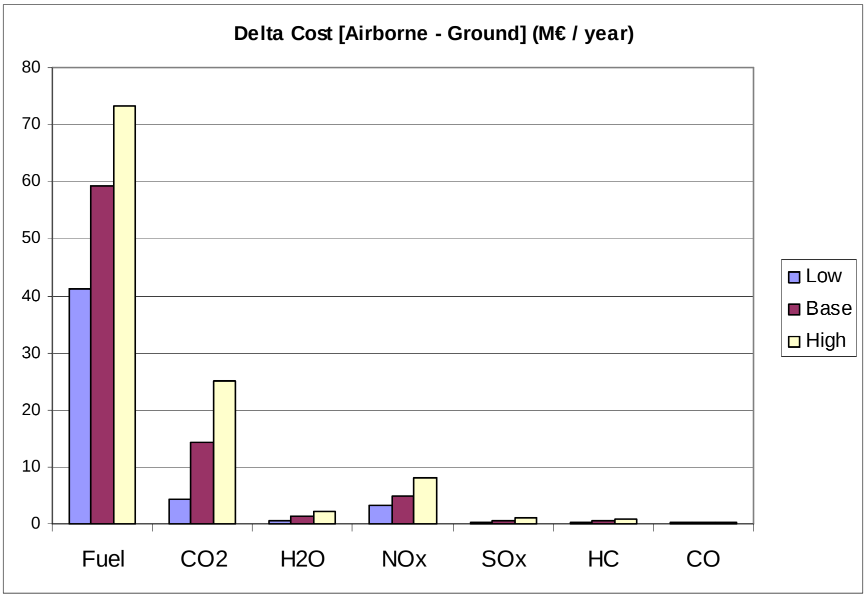

Figure 7: Financial benefit of ground delay vs. airborne delay by pollutant

The above graph confirms that the major benefit is obtained from the reduction in fuel burn direct cost (73% of the overall benefit in the base scenario), which reaches up to 73 M€ yearly savings for airlines. The relative cost reduction between ground and airborne delays is represented by pollutant type in the following figure:

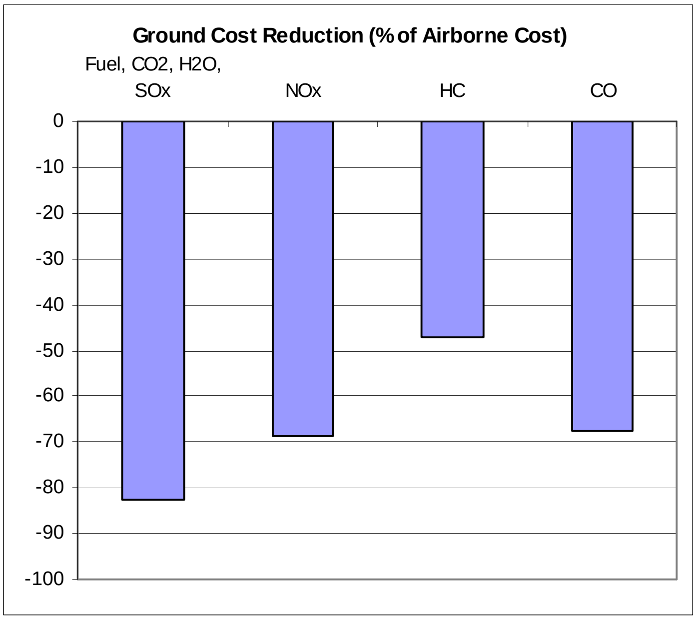

Figure 8: Relative cost reduction of ground delay vs. airborne delay by pollutant

Figure 8 shows that the maximum relative gain between the airborne and ground delay scenarios is also obtained for fuel (83% reduction) in terms of both the emitted mass and its cost. The same figure applies to CO_2, H_2O and SO_x as their masses are proportional to the fuel burn mass.

6.3.2 *Sensitivity analysis*

When:

- H_2O is ignored in ground emissions,
- SO_x, HC, CO are ignored in airborne emissions,
- and the cost of ground-emitted CO_2 is updated to the EUA market prices (low/base/high vales of 10/20/30 €/tonne – see Figure 4),

the resulting financial benefit remains very similar: 50 M€, 80 M€ and 110 M€ for low, base, high estimations respectively.

6.4 *Synthesis of environmental costs*

The financial assessment of the ground delay benefits compared to airborne delay shows a gain of around 80 M€ per year when the base unit costs are used for fuel and emissions.

From these 80 M€, around 60 M€ are related to the reduction in fuel consumption – which represents a direct benefit for airlines, while the remaining 20 M€ stand for the indirect cost of emissions, essentially CO_2 and NO_x (14 M€ and 5 M€ respectively).

Confidence in these cost estimations should be fairly high, as the most uncertain unit values are for the pollutant which are the most negligible.

7 Conclusion

This study is the first attempt at quantifying environmental impacts of delays in the EUROCONTROL area. Initial estimates show that the impact of ground delays is highly dependent on the power source used during the delay. They show as well that the impact of ground delays is less than for airborne delays, both for fuel consumption and emissions.

For all aircraft types GPU are more efficient than APU, and both are far more efficient than aircraft engines in idle mode. A weighting of the different operating modes showed that the fuel consumption during a 1 minute ground delay is between 1 kg to 4 kg, depending on aircraft types.

In absence of ground regulation the 14.9 million minutes ground delays would translate into both:

- 7.5 million minutes spent in holding stacks (around FL100) where aircraft consumption is between 10 and 100 kg/min.
- 1 million minutes of rerouting manoeuvres in order to avoid congested sectors, where aircraft consumption is between 10 and 160 kg/min.

There is a direct environmental benefit of applying ground delays rather than airborne delay. The total airborne delay fuel consumption is estimated to be about 6 times higher than with ground delay. Non-linear emissions (e.g. NO_x, HC and CO) are about 3 times higher with airborne delay compared to ground delays.

Based on the annual figure of 14.9 millions minutes of ATFM delay:

- the environmental cost (fuel and emissions) of the “ground delay scenario” was estimated at 20 M€.
- the environmental cost (fuel and emissions) of the “airborne delay scenario” would reach 100 M€.

The environmental benefit of the ATFM ground delay actions therefore amounts to 80 M€ for the EUROCONTROL area (including 60 M€ fuel cost savings and 20 M€ emissions cost savings).

8 References

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9 Biographies of the Authors

Sandrine Carlier (ENVISA) is an Aircraft Emission Modelling Expert. She has a masters-degree in Aeronautics and Space and has proven experience in the design and execution of Global Aviation Emission Studies (GAES). She successfully completed several aviation emissions studies in support of major operational concept projects including EUR RVSM Implementation, Free Route Airspace, Mediterranean Free Flight , and the 8.33 kHz Vertical Expansion Programme.

Ivan de Lépinay (ENVISA) holds a Diploma in Civil Engineering and a Postgraduate in Applied Acoustics. He has been recently involved in aviation noise impact studies for the EEC's Society, Environment and Economy (SEE) Research Area (e.g. ENHANCE, SOURDINE, CDA trials). In parallel, he has gained experience in aircraft emission modelling through his involvement in the GAES-INVENT 2002 ECAC emission inventory and CAEP Goals Assessment. He has also conducted several tradeoffs studies, notably for the environmental impact assessment of the latest EUROCONTROL CDA trials.

Jean-Claude Hustache graduated in Air Transport Economics in 1996. He has been working extensively in the field of air navigation economics, contributing to numerous projects for the EUROCONTROL Experimental Centre (capacity planning, environmental impact assessment), for the Performance Review Unit (benchmarking, flight efficiency, information disclosure), and for the Association of European Airlines (leading the SESAR task on the Air Transport Value Chain). He has been recently commissioned to advise and support several European ANSPs in the economic and financial aspects of their Functional Airspace Blocks initiatives (F-CH FAB, FAB Europe Central).

Frank Jelinek (EUROCONTROL-EEC) is an aviation engineer working at the EUROCONTROL Experimental Centre (EEC) with in-depth practical experience in the domains of aircraft performance, ATC/ATM modelling and Fast-Time Simulation. Since 2001 he is the responsible project manager for global aviation emission studies (GAES) and has defined the concepts & architecture of the related tools, such as AEM, TEA, Contrail & TBEC etc. Before joining EUROCONTROL in 1994 he worked in the aviation and airport related software industry Lufthansa (LIS) & ABB (former CCS).